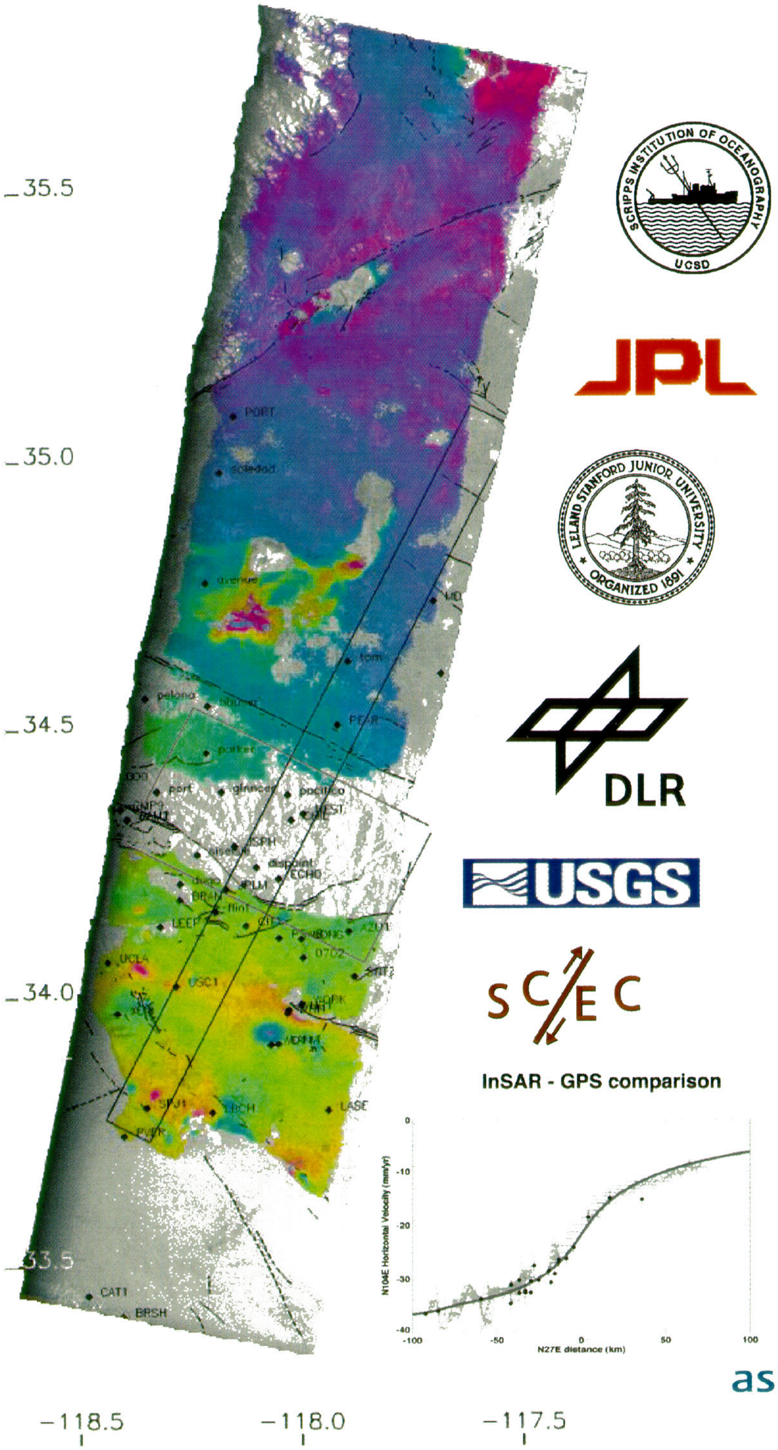
A Proposal in Response to NASA AO-01-OES-01
Earth System Science Pathfinder (ESSP) Missions

EARTH CHANGE AND HAZARD OBSERVATORY



InSAR - GPS comparison

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Earth System Science Pathfinder (ESSP) AO
Section B - Investigation Summary Form I

AO 01-OES-01 ESSP Announcement of Opportunity	Proposal No. __________ *NASA Use Only*

Principal Investigator

Professor of Geophysics	**Jean-Bernard**		**Minster**
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Institute of Geophysics and Planetary Physics

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Proposal Title
Earth Change and Hazard Observatory

Science/Application Research Supported
☐ Earth System Variability and Trends
☒ Primary Forcings of the Earth System
☒ Earth System Responses and Feedback Processes
☒ Other (Specify) _____Natural Hazards____
(As listed in NASA's Earth Science Research Strategy for 2000-2010 (Appendix A))

Scientific Theme, Application Research or Commercial Development topic: _____Scientific Theme_________

Abstract (Limit 150 words)

The Earth Change and Hazard Observatory (ECHO) is an L-band interferometric radar mission addressing two of NASA's Earth Science Enterprise research priorities: transformations of the Earth's surface, and variability of the Earth's ice cover and its impact on sea level. ECHO's primary scientific goals are to

- *Understand and model strain changes leading to and following major earthquakes*
- *Characterize three-dimensional magma movements to predict volcanic eruptions*
- *Assess the impact of ice sheet and glacier system dynamics on sea-level rise*

Unlike other sensors, ECHO will build time series of three-dimensional surface displacements of Earth's tectonically active areas and cryosphere with mm accuracy. The ECHO team will quantify processes such as strain accumulation along fault systems and magma migration, and will estimate the variability of ice discharge and its impact on sea level. Innovations in orbit control and ground system design result in efficient, timely data distribution and usage.

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Earth System Science Pathfinder (ESSP) AO Form
Section B - Investigation Summary Form II

AO 01-OES-01 ESSP Announcement of Opportunity	Proposal No. __________ *NASA Use Only*

Principal Investigator

Professor of Geophysics **Jean-Bernard** **Minster**

Title *First Name* *Middle Name* *Last Name*

Proposal Title
Earth Change and Hazard Observatory

Mission Mode [**X**] Complete Mission	Cost (real year dollars) NASA ESE Cost $125.0M NASA Mission Cost $174.8M Total Mission Life Cycle Cost $288.2M
Anticipated Launch Vehicle: **DNEPR provided by the German Aerospace Center (DLR)**	Anticipated Launch Date: **October 2006**

Anticipated Instrument Carrier (if applicable):
Astrium GmbH Flexbus

Press Release Abstract (50 words)

The Earth Change and Hazard Observatory (ECHO), an unprecedented, dedicated interferometric radar mission, focuses on two of NASA's research priorities (1) the relation between earthquake and volcano hazards and minute surface deformations, and (2) the relation between sea level and climate change and changes in polar ice sheets and glaciers.

Co-Investigator(s)

Name	Institution	Responsibility	Funded	E-Mail
Paul Rosen	JPL	Space segment	Yes	par@parsar.jpl.nasa.gov
Howard Zebker	Stanford	Ground segment	Yes	zebker@stanford.edu
Tom Jordan	USC	SCEC liaison	Yes	tjordan@usc.edu
Ian Joughin	JPL	Ice sheet objectives	Yes	ian@radar-sci.jpl.nasa.gov
Eric Rignot	JPL	Ice sheet objectives	Yes	eric@adelie.jpl.nasa.gov
Gilles Peltzer	UCLA	Active tectonics	Yes	gilles@altyn.ess.ucla.edu
Paul Segall	Stanford	Crustal deformation	Yes	segall@pangea.stanford.edu
David Sandwell	SIO	Model corrections	Yes	sandwell@radar.ucsd.edu
Mark Simons	CalTech	Crustal modeling	Yes	simons@gps.caltech.edu
Wayne Thatcher	USGS	Volcanic objectives	Yes	thatcher@usgs.gov
Maria Zuber	MIT	SoCal natural lab	Yes	zuber@mit.edu

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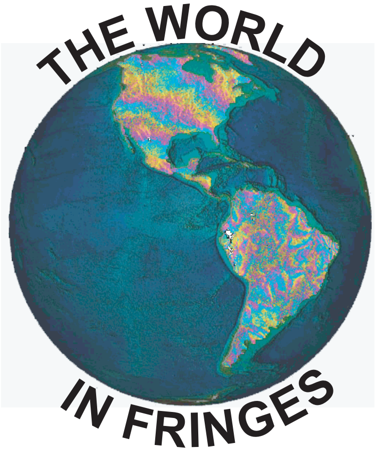


ECHO

JPL
SCEC
Ball Aerospace & Technologies Corp.
VEXCEL
Image Information Engineering
DLR
astrium
USGS

Earth Change and Hazard Observatory

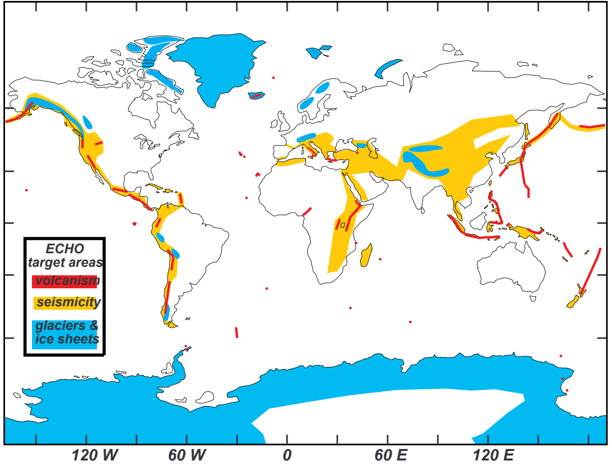
Mission Statement:
The Earth Change and Hazard Observatory is a dedicated L-band interferometric radar mission addressing two of the NASA Earth Science Enterprise strategic research priorities:

- ***i) transformations of the Earth's surface and their predictability, and***
- ***ii) variability of the Earth's ice cover and its relation to sea level and climate change.***

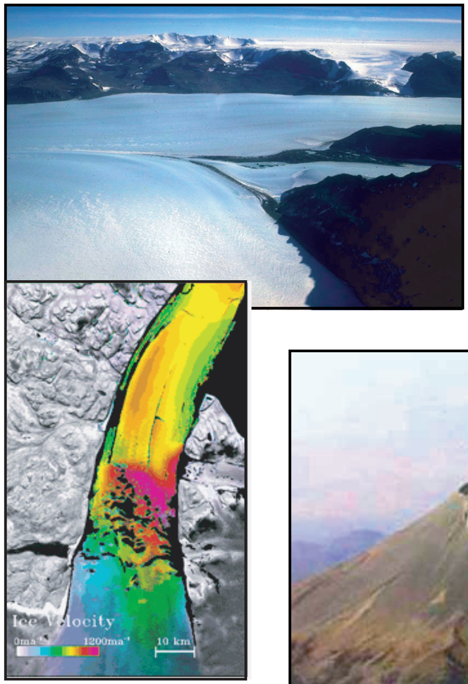
ECHO also contributes to the goals of the multi-agency EarthScope initiative.

Jean-Bernard Minster, SIO, PI
Howard A. Zebker, Stanford, Deputy PI
Paul A. Rosen, JPL, Deputy PI

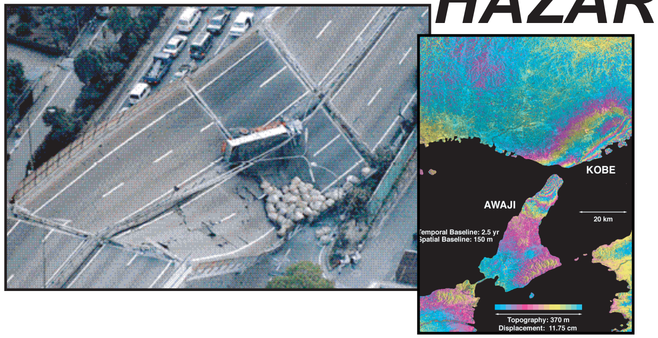
Primary ECHO Science Targets



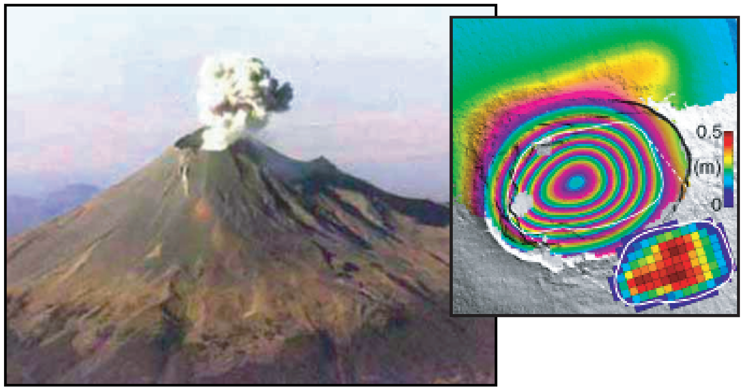
ICE



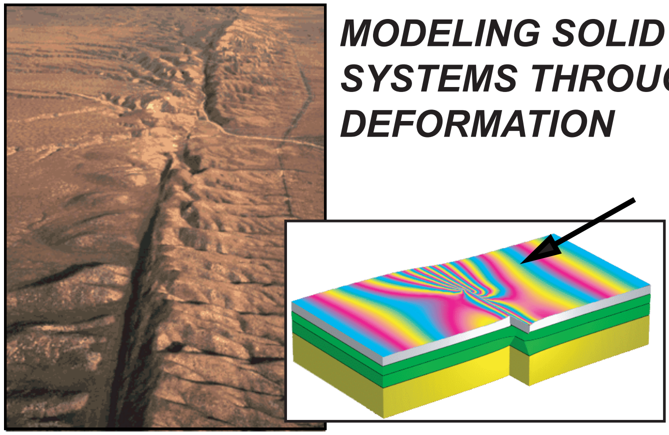
HAZARDS

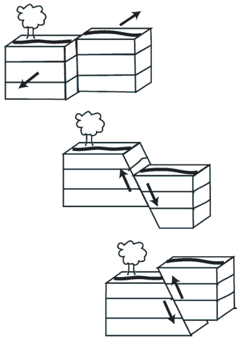


VOLCANOES



MODELING SOLID EARTH SYSTEMS THROUGH CRUSTAL DEFORMATION

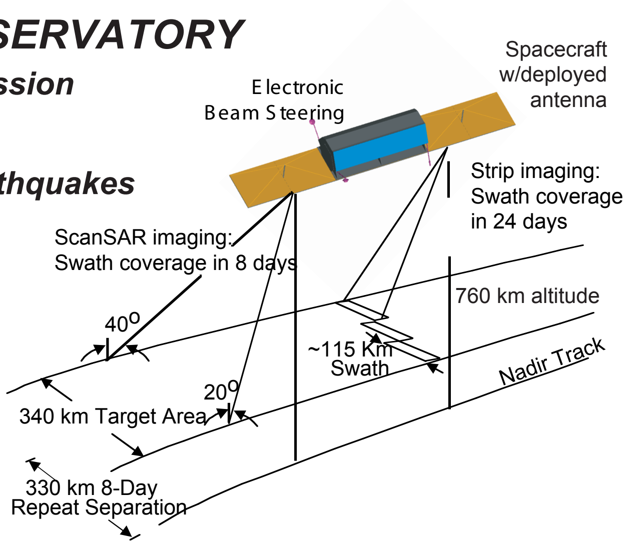




EARTHQUAKES

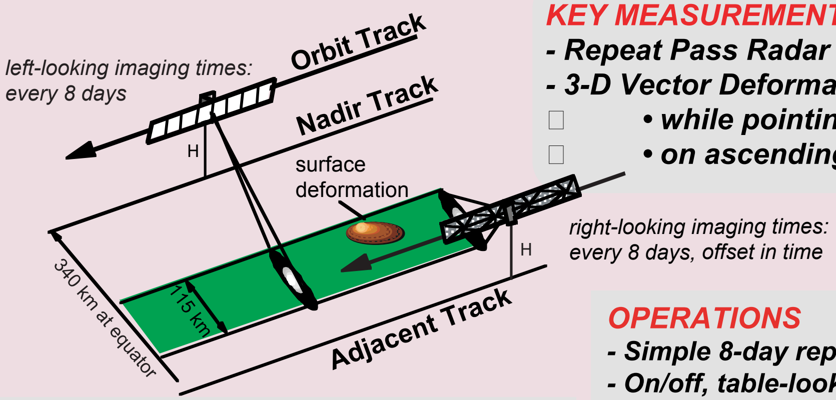
ECHO - EARTH CHANGE AND HAZARD OBSERVATORY

L-band Radar Repeat Pass Interferometry Mission



Primary Scientific Objectives:

- Understand strain changes in the Earth's crust leading to and following major earthquakes
- Characterize magma movements to predict volcanic eruptions
- Assess the impact of ice sheet and glacier system dynamics on sea-level rise



KEY MEASUREMENT TECHNOLOGY

- Repeat Pass Radar Interferometry
- 3-D Vector Deformation by observing:
  - ***while pointing to the left and right***
  - ***on ascending and descending orbits***

MISSION REQUIREMENTS

- 5 year baseline, 3 year minimum
- 7 minutes of data per orbit baseline,
6 min/orbit minimum

SPACECRAFT REQUIREMENTS

- Pointing	***0.05° 3-sigma yaw/pitch***
	0.5° 3-sigma roll
- Maneuvers	***Left/right pointing at 0.1°/sec***
- Downlink	***300 Mbps X-band***
- Storage	***256 Gbits onboard***

SPACECRAFT CHARACTERISTICS

- Bus	***Astrium TerraSAR X with deployment structure***
- Mass	***1533 kg wet, 1361 kg dry w/ contingency***
- Power	***673 W Avail., 574 W Bus+Radar (orbit avg.) w/c***

NAVIGATION AND ORBIT

- Orbit	***Sun synchronous 6am/6pm***
- Altitude	***760 km***
- Inclination	***98.5°***
- Control	***250 m diameter orbital tube***
- Knowledge	***< 10 cm using GPS ground analysis***

LAUNCH VEHICLE

- DNEPR	***Oct 2006 (1700 kg to 400 km)***
- Launch Margin	***11%***

OPERATIONS

- Simple 8-day repetitive mission cycle
- On/off, table-lookup commanding
- One high-latitude receiving station
- Distributed processing software

EDUCATION AND PUBLIC OUTREACH

- Leveraging of Southern California
Earthquake Center EPO
- Coordination with established JPL
Radar EPO

INSTRUMENT

- Single mode L-band (24 cm-wavelength)
- Dual carrier operations for ionospheric correction
- Strip mapping for 8 day target repeat
- ScanSAR mapping for 8 day global repeat

- Mass	***569 kg w/ contingency***
- Power	***198 W (orbit avg.) w/ contingency***
- Antenna	***13.8 m x 2 m L-band active array***
- Structure	***AEC-Able deployable frame***
- Resolution	***7 m x 25 m ground single look***
- Accuracy	***5 mm range displacement at 8 looks***

COST ($RYM) AND SCHEDULE

Start Ph 2 ▲ ***MCR*** ▲ ***CDR*** ▲ ***Phase 3/4*** ***Launch*** ▲ ***Phase 5*** ▲ ***End***

FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	Total	
0.20	17.97	46.05	51.34	42.96	12.49	3.99	-	-	-	175.00	*NASA Cost*
0.11	8.18	19.16	14.42	2.44	2.59	3.46	6.64	6.56	6.18	69.73	*NSF Contribution*
-	-	-	3.94	3.94	3.12	3.12	3.12	3.12	3.12	23.45	*USGS Contribution*
-	-	-	-	10.00	2.00	2.00	2.00	2.00	2.00	20.00	*DLR Contribution*
0.31	26.15	65.21	69.70	59.33	20.20	12.57	11.75	11.68	11.29	288.18	*TMLCC*

- Scientists from Scripps, Stanford, JPL, Caltech, USGS, MIT, USC, UCLA, Germany
- JPL Project Management, Development, Radar Electronics, MOS
- DLR Launch Vehicle, MOS
- Astrium Spacecraft - Ball Antenna - Vexcel Ground Segment
- SCEC Science and EPO Management

The ECHO Team

D. TABLE OF CONTENTS

AO Table K-3. Compliance Table

#	Sect.	Table	Requirement	Included	Page(s)
1	A		Cover Page	Included	N/A
2	B		Investigation Summary (Forms I and II)	Included	N/A
3	C		Fact Sheet	Included	N/A
4	D		Table of Contents	Included	D-1 to D-6
5	E		Endorsement Summary	Included	E-1
6	F		Science/Applications Investigation	Section F.1	F-1 to F-8
7	F		Baseline and Minimum Science/Applications Missions	Sections F.2.3-F.2.4	F-9
8	F		Sensitivity Analysis	Section F.1.9	F-8
9	F	L-2a	Instrumentation Technical Maturity Matrix	Table F1-2, Foldout 1.	F-13
10	F	L-3	Science Traceability Matrix	Table F1-1, Foldout 1.	F-13
11	F	K-4	Instrument Information Table	Table F2-1.	F-14
12	G		Technical Implementation	Section G	N/A
13	G	K-7	Launch Services Table	Table G-7.	G-34
14	G		Data Systems	Section G.8.1 to G.8.4	G-41 to G-47
15	G	L-4	Mission Traceability Matrix	Table G-2	G-4
16	G	K-5a,b	Mission Design Table	Table G-1	G-2
17	G	L-2b	Spacecraft Technical Maturity Matrix	Table G-6	G-26 to G-27
18	G	K-6	Spacecraft Characteristics Table	Table G-4	G-21, G-22
19	G		Manufacturing, Integration and Test Strategy	Section G.6	G-34 to G-36
20	G	K-8	Mission Operations, Ground and Data Systems Table	Table G-8	G-37
21	G		Plans to Resolve Open Technical Implementation Issues	Section G.9.	G-50
22	H		Management Processes and Plans	Section H.1	H-1 to H-6
23	H		Work Breakdown Structure	Section H.3.1, Section M	H-10 to H-13, Vol. II
24	H		Principal Investigator	Sections H.3, H.3.5	H-9, 10, 12, 16 to 17
25	H		Project Manager	Sections H.3, H.3.5	H-10, 12, 17
26	H		Co-Investigators	Section H.3.5	H-18
27	H		Mission Schedule	Section H.2, Figure H-1	H-6 to H-9
28	H		Mission Reviews	Section H.1.8, Table H-2	H-5, 6, 8, 9
29	H		Risk Management Plan	Section H.4	H-19 to 22
30	H		Mission Assurance and Safety	Section H.5	H-22 to 24
31	H	L-5	Mission Assurance Compatibility Table	Tables H-8 and H-9	H-24
32	H		Facilities and Equipment	Section H.6	H-24 to 25
33	H		Plans to Resolve Open Management Issues	Section H.7	H-25

AO Table K-3. Continued

#	Sect.	Table	Requirement	Included	Page(s)
34	L		Preliminary Mission Definition and Requirements Agreement Appendix	Section L.4	L.4-1 to -10
35	L		Draft Incentive Plan Appendix	Section L.5	L.5-1 to -2
36	L		Relevant Experience and Past Performance Appendix	Section L.6	L.6-1 to -28
37	L		Draft International Agreements Appendix	Section L.7	L.7-1 to -3
38	L		Contractual Requirements Appendix	Section L.9	L.9-1
39	I		Cost and Cost Estimating Methodology Summary	Section I	I-1 to I-3
40	I		NASA Mission Cost in Real Year Dollars	Section I, first paragraph	I-1
41	I		Contributions	Table I-1, Section I.4	I-2 to I-3
42	I	K-9	Total Mission Life Cycle Cost Phasing in Real Year Dollars	Table I-1	I-2
43	I		Plans to Resolve Open Cost Issues	Section I.7, Section M	I-3
44	J		Education	Section J	J-1 to J-10
45	K		Small, Small Disadvantaged, and Women/Veteran-owned Small Businesses and Minority Institutions	Section K.1	K-1 to K-2
46	K		Commercialization	Sections K.2 and K.3	K-2 to K-5
47	K		Plans to Resolve Open Other Opportunity Issues	Section K.4	K-5
48	L		Resumes	Section L.1	L.1
49	L		Letters of Endorsement	Section L.10	L.10
50	L		Civil Rights Certification	One letter regarding Certifications (from Steve Prioa, Contract Management Office, JPL) was included, Section L.3	L.3-1 to –2
51	L		Certification Regarding Lobbying		
52	L		Verification Regarding Debarment, Suspension, and Other Responsibility Matters Primary covered Transactions		
53	L		Statement of Work	Section L.2	L.2.1 to 8
54	L		Acronyms List	Section L.12	L.12.1 to 8
55	L		Reference List	Section L.11	L.11-1 to -2
56	M	L-6, 7, 8, 9	Cost and cost Estimating Details	L-6: Table M-3	Section M
				L-7: Table M-4	Section M
				L-8: Table M-5	Section M
				L-9: Table M-17	Section M
57	M		Summary of Elements of Cost	M.1, M.4 – M.5	Section M
58			Electronic Version of Proposal		N/A
59			Site Visit Location	JPL, Building 300. (Section H.8)	H-25

E. ENDORSEMENT SUMMARY

1. Principal Investigator and Deputies

   The PI and his deputies form a core consortium team for managing the mission, with the PI solely responsible for the mission, but assisted by the DPIs. The team members and authorizing officials of their institutions have endorsed the Step 2 proposal.

   a. Bernard Minster, Principal Investigator, Scripps Institution of Oceanography
   b. Charles Kennel, Director, Scripps Institution of Oceanography
   c. Paul Rosen, Deputy Principal Investigator, Jet Propulsion Laboratory (JPL)
   d. Charles Elachi, Director, JPL
   e. Howard Zebker, Deputy Principal Investigator, Stanford University
   f. Franklin M. Orr, Dean, School of Earth Sciences, Stanford University

2. Science Team Co-Investigators

   Science team members will receive funds from the ECHO project to perform critical algorithm development, calibration and validation of science data, and education and public outreach. Each co-Investigator and an authorizing official of their institution have endorsed the Step 2 proposal.

   a. David Sandwell, Scripps Institution of Oceanography
   b. Paul Segall, Stanford University
   c. Ian Joughin, JPL
   d. Eric Rignot, JPL
   e. Tom Jordan, Southern California Earthquake Center
   f. Gilles Peltzer, University of California at Los Angeles (UCLA)
   g. Mark Simons, California Institute of Technology
   h. Wayne Thatcher, US Geological Survey (USGS)
   i. Maria Zuber, Massachusetts Institute of Technology (MIT)

3. Industry Partners—Astrium GmbH, Ball Corporation and Vexcel Corporation

   Industry partners will receive funds from the ECHO project to build parts of the space segment and ground segment. A technical representative and an authorizing official of their institution have endorsed the Step 2 proposal.

   a. Bernhard Doll, Proposal Manager, Astrium GmbH
   b. M. Strodl, Vice President, Commercial, Astrium GmbH
   c. Thomas Kampe, Proposal Manager, Ball Aerospace & Technologies Corp.
   d. G.J. Chodil, Vice President, Ball Aerospace & Technologies Corp.
   e. David Cohen, Senior Engineer, Vexcel Corporation
   f. John C. Curlander, President and CEO, Vexcel Corporation

4. Agency Partners—US Geological Survey and National Science Foundation

   a. The ECHO Project will receive in-kind funding from the US Geological Survey through the contribution of the long-term archive and curation of ECHO data.
   b. The ECHO Proposal relies on substantial funding from the National Science Foundation. The Step 2 proposal is being submitted jointly to NASA and NSF. Upon favorable review by NSF, a mechanism for commitment will be established.

5. International Partner - German Aerospace Center

   a. The ECHO project relies on a contributed launch vehicle and mission operations from the German Aerospace Center (DLR). The definition of the commitment will be the subject of an MOU between NASA and DLR.

F. SCIENCE INVESTIGATION

The **Earth Change and Hazard Observatory** (ECHO) mission consists of a satellite Interferometric Synthetic Aperture Radar (InSAR), capable of measuring surface motions ranging from millimeters per year during strain accumulation between earthquakes to several meters per day on ice-streams. ECHO will address the following overarching science questions:

- How does strain accumulate along faults and plate boundaries, and how is it released during the earthquake cycle?
- What are the spatial and temporal deformation patterns of volcanoes worldwide, and how can these data help predict eruptions?
- What is the rate and variability of ice discharge, and what is its relation to sea level rise and climate change?

These questions address two of the five key research priorities of the NASA *Earth Science Enterprise* (ESE) *Research Strategy for 2000-2010:* Primary Forcings of the Earth System, and Earth System Responses and Feedback Processes. Specifically, ECHO is designed to characterize, understand, and model: *i) "How is the Earth's surface being transformed, and how can this information be used to predict future changes?"* and *ii) "How is global sea level affected by climate change*?" ECHO achieves these diverse goals through a single measurement—mm-level surface deformation at resolutions of tens of meters with worldwide accessibility.

ECHO's unique scientific potential stems from its ability to measure detailed deformation over wide areas. During the past two decades, space geodetic techniques, in particular GPS, have proven a powerful way to study deformation of the Earth's surface, leading to major advances in quantitative modeling capability. These measurements, however, require much field work and will always lack spatial continuity, which leads to aliasing and consequent ambiguity in interpretation. Hence, the first interferometric radar maps of the co-seismic displacement of the 1992 Landers earthquake [*Massonnet et al*., 1993*; Zebker et al.,* 1994] were arguably the most exciting recent development in earthquake science.

Global, comprehensive, and finely detailed measurements of deformation make it possible to discover and analyze motions of the Earth's crust that simply pass unnoticed today. In particular, because ECHO will generate *time-series* of displacement maps, it will be a unique tool to detect slow (weeks to years) transient deformations that have only been inferred or observed occasionally in isolated seismic (e.g., *Dragert et al*., 2001), volcanic (e.g., *Wicks et al.*, 2001) or glacial areas (e.g., *Joughin et al*., 1996). This exciting new possibility will open a domain of spatial and temporal scales heretofore inaccessible to Earth scientists except by serendipity.

Because no mission dedicated to this purpose exists, spaceborne interferometry remains primarily a demonstration tool. International systems planned for launch, including ENVISAT, ALOS, and RADARSAT 2, are not optimized for interferometry and are not likely to provide data significantly better than the ERS and RADARSAT systems. Data availability, quality, and temporal and spatial coverage continue to be major concerns of scientists using these sensors.

The science community has endorsed the need for a mission like ECHO through the EarthScope inititiative. EarthScope is a major collaborative solid Earth science initiative sponsored by the National Science Foundation (NSF), NASA, and the US Geological Survey (USGS). EarthScope will lead to an unprecedented deployment of instruments and observatories that will greatly increase our knowledge and understanding of the structure, evolution, and dynamics of the North American continent. Collectively, ECHO and other EarthScope facilities will generate a synoptic time-series of images of the continent to provide an integrative framework for research on earthquakes, magmatic systems, regional tectonics, and associated hazards.

The science questions addressed by ECHO have a strong societal benefit. A significant fraction of the Earth's population lives in or near areas likely to experience earthquakes, volcanic eruptions, or the consequences of sea level change. Better understanding of these hazards through ECHO-related studies can help mitigate the consequences, potentially saving lives and reducing economic impact.

ECHO will achieve its objectives through a long-duration InSAR mission. A 5-year mission allows sufficient time to observe the slow rates of inter-seismic deformation along faults. A tightly controlled orbit guarantees that all measurement pairs will be interferometrically viable. An L-band radar (λ=24 cm) will overcome temporal decorrelation problems in regions of appreciable ground cover, which plague C-band systems, opening large areas of the Earth to geodetic study. In addition, ECHO will resolve and correct dispersive ionospheric delays by using two sub-bands separated by 70 MHz. Unlike existing radar systems, ECHO will image from either side, providing the multiple view angles necessary to obtain 3D vector displacement maps.

The ECHO science team consists of world leaders in radar interferometry and the analysis and modeling of deformation of the solid Earth and cryosphere. ECHO will use a novel distributed processing scheme whereby science investigators are provided with SAR data and the software tools necessary to generate the calibrated maps of surface displacement needed to meet the science objectives. The science team will calibrate and validate ECHO data, and will ensure that ECHO products and software are suitable for the science objectives.

F.1 SCIENCE OBJECTIVES AND JUSTIFICATION

ECHO will bring a fundamentally new data type to the study of changes of the Earth's surface: time series of spatially continuous, vector maps of surface change associated with earthquakes, volcanoes, ice sheets, and glaciers. As with many new observational capabilities, ECHO will undoubtedly lead to major new discoveries, in addition to the contributions described below. The principal geographic focus areas include regions of active tectonics and regions of glaciation, or approximately 10% of the area of the Earth.

F.1.1 Seismic Hazards

NASA's ESE Research Strategy identifies surface deformation as the primary measurement needed to begin answering the question "*How is the Earth's surface being transformed and how can such information be used to predict future changes?*" ECHO will provide deformation measurements to address the following earthquake science objectives:

1. Detect and map inter-seismic and potentially pre-seismic transient strains, which remain elusive and raise a major challenge to our understanding of the earthquake cycle.
2. Derive models of faulting and crustal rheology from vector co- and post-seismic displacement maps, complementing conventional seismological and geodetic measurements.
3. Assimilate vector maps of surface deformations through various stages of the earthquake cycle in large-scale numerical simulations of interacting fault systems, currently a "data-poor" discipline.

Spatially continuous maps of vector surface displacement provide critical bounds on models of co-seismic fault rupture. By itself, InSAR provides maps of surface faulting complexity and constrains its extent at depth. In elastic models of the lithosphere, geodetic data can constrain the spatial distribution of slip on a fault plane (e.g., *Melbourne et al.,* 1997). When combined with seismic data, these models can estimate the temporal evolution of slip during an earthquake (e.g., *Chen et al.,* 2001). Such models permit us to estimate the distribution of co-seismic stress drop, to calculate ground acceleration, and to infer the characteristics of strain release in the shallow crust. Well-constrained co-seismic models of recent events also can be compared with inferences of earthquake magnitudes from geological field observations, providing a long-needed calibration of paleo-seismological inferences of historic earthquakes (e.g., *Rockwell et al.,* 2000).

Besides providing an understanding of co-seismic processes, accurate models of the co-seismic "kick" are required as input, along with post-seismic geodetic data, to constrain models of the post-seismic response of the crust [*Deng et al.,* 1998; *Pollitz et al.,* 2000]. Such post-seismic models (Fig. F-1) help constrain the rheological behavior of the lithosphere, thus providing clues to the long-term structural evolution of the tectonic plates and their boundaries.

Mapping slow Earth deformation poses the greatest scientific challenge for ECHO. This deformation includes the inter-7seismic strain accumulation leading up to earthquakes, as well as transient post-seismic strain relaxation following earthquakes. Such signals are subtle, with mm-sized displacements and long spatial wavelengths that are vulnerable to systematic measurement errors. These signals have only been detected with InSAR in limited regions

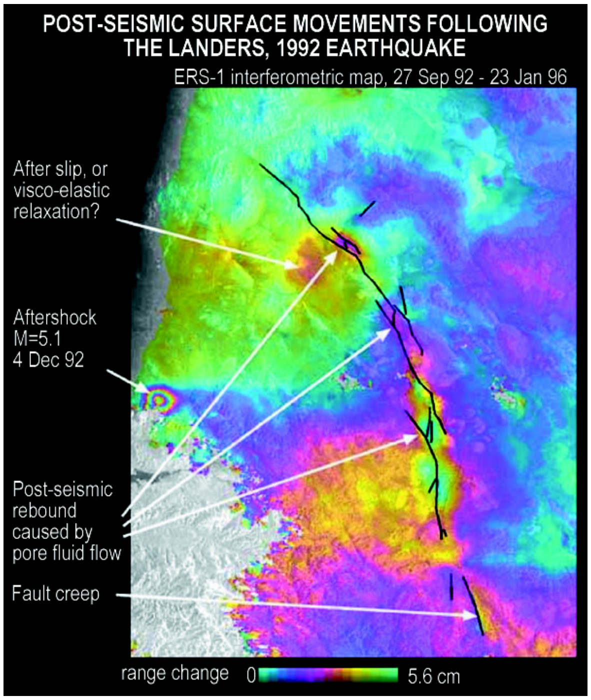


Figure F-1. This ERS-1 interferogram illustrates deformation signatures of several post-seismic processes after the 1992 Landers earthquake in California that were not observed in conventional geodetic data [*Peltzer et al.*, 1996]. Visible are the poro-elastic rebound in the fault stepovers, the effect of visco-elastic relaxation in the deeper crust, fault creep, and the effect of an aftershock. ECHO will make such observations routinely.

and under ideal conditions [*Peltzer et al.,* 2001]. Accumulation and release of strain in the Earth's crust is a first order indicator of future seismic hazard. Post-seismic fault creep and flow of the lower crust are crucial to the time-dependent stress transfer to neighboring faults. Stress diffusion has long been thought to cause earthquake clustering and the propagation of major seismic events along fault zones. For the first time, InSAR provides the means to map crustal strain with full spatial continuity. ECHO therefore has unprecedented potential to identify otherwise unknown areas of strain accumulation and fault interaction.

Current models of deformation are severely limited in detail, mostly due to imperfect knowledge of the boundary conditions. With GPS, at most a few hundred point measurements ever will be available in any region. ECHO will transform the field from "data poor" to "data rich," making possible study of earthquakes in extraordinary detail. We will effectively carry out a "stress analysis of the Earth," similar to that used by civil and mechanical engineers to study materials and structures. These ECHO-derived data will be the most important constraint on generalized earthquake models that simulate the dynamics of interacting fault systems.

The danger posed by blind thrusts in the Los Angeles (LA) basin provides an illustration of the potential contribution of InSAR-generated maps of surface deformation. The Southern California Integrated GPS Network (SCIGN), a 250-station, continuous-GPS network to monitor crustal deformation across the basin, provides time series of strain accumulation. Nevertheless, with a nominal station spacing of 10-15 km, there remain serious gaps. InSAR mapping shows that about half of the SCIGN sites in the LA basin are contaminated by spurious seasonal and long-term motion due to groundwater pumping [*Bawden et al.,* 2001]. These deformation features, ranging from a few km to tens of km, could be identified only through the continuous mapping capabilities of InSAR. Pinpointing their effects will permit SCIGN to better achieve the goals for which it was designed. Likewise, and over much wider regions, ECHO will provide a quantitative means of interpolating the displacement field between GPS sites [e.g., EarthScope Plate Boundary Observatory (PBO)]. Conversely, GPS provides valuable "tie" points in the calculation of interferograms.

Finally, ECHO may prove invaluable for disaster response following earthquakes. Northridge and Kobe results show that urban areas maintain interferometric correlation except where there has been extensive damage. Thus, interferometric decorrelation could help map the extent of destruction. Wide-scale damage maps would be most valuable for the largest events—say a great earthquake on the Cascadia subduction zone or the Wasatch front—or for earthquakes in inaccessible areas such as Caucasus, Tien Shan, or Tibet.

F.1.2 Volcanology

ECHO's volcanic hazard objectives flow from the same NASA ESE crustal deformation science priority just described under seismic hazards. Here science objectives specifically relate to improving our understanding of the volcanic cycle and to developing a predictive capability. ECHO's volcanology objectives are to collect deformation data in order to:

1. Derive models of magma migration from the spatial and temporal extent of deformation preceding and accompanying eruptions.
2. Quantify pressure changes at depth resulting from magma intrusion beneath many of the world's ~600 active volcanoes.
3. Analyze the spatial extent of new material deposited during an eruption, an important diagnostic of the eruption process.

Deformation data are the primary observables in understanding magma movement within volcanoes. Although uplift from the ascent of magma into the shallow crust has been observed prior to some eruptions, particularly on basaltic shield volcanoes, the spatio-temporal character of such transient deformation is poorly known. Little is known about deformation on most of the world's volcanoes because only a small fraction is monitored. ECHO's global access capability will permit study of many volcano types in different environments. InSAR has already been used at Mt. Etna to investigate the balance between lava production and volume change of the volcanic edifice during an eruption [*Massonnet et al.,* 1995; *Lanari et al*., 1998], and in the Galapagos Islands (Fig. F-2) to map dike intrusions [*Jonsson et al*., 2001] and magma chamber volume changes [*Amelung et al.*, 2000]. Detection and modeling of such transients could provide warning of impending eruptions, reducing loss of life and mitigating property damage.

Significant hazards are posed by active calderas that have been the source of large eruptions. For example, the Long Valley caldera has experienced several sequences of moderate earthquakes (M6) in the past two decades. The caldera itself has experienced ground uplift of 800 mm since 1979 [*Battaglia et al.*, 1999; *Langbein et al.,* 1993], probably as the result of the injection of 0.1 km^3 of magma beneath the caldera [*Langbein et al.,* 1993]. In view of such volcanic hazards, it is essential to complement ground-based geodetic data with InSAR deformation maps [*Thatcher and Massonnet,* 1997; *Simons et al.*, 2000].

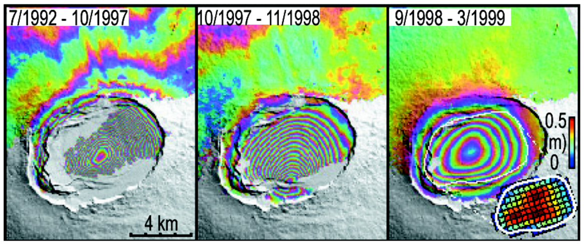


Figure F-2. Monitoring of volcanic regions can reveal unexpected phenomena, such as this series of interferograms from Sierra Negra on the Galapagos island of Isabela [*Amelung et al*., 2000]. For most of the 1990's, inflation due to magma chamber growth dominated, but in the 1997-98 period a "trap-door" faulting episode shifted the deformation towards the caldera rim. The high resolution of InSAR also led to a solution for a map of change in the magma distribution.

ECHO also will provide unique observations of active surface processes on volcanic edifices. SIR-C yielded maps of active lava flow evolution on Kilauea volcano from the daily area of surface decorrelation over a 4-day period [*Zebker et al.,* 1996]. ECHO will monitor the growth of potentially unstable lava domes (e.g., Soufriere Hills, Montserrat, West Indies and Mt. Unzen, Japan). Collapse of such domes can lead to devastating pyroclastic flows. The remobilization of ash deposits to form lethal mud flows (lahars) could also be detected via decorrelation maps. Field observations of lava flows are difficult, often dangerous, and rarely permit an entire flow field to be studied simultaneously. The all-weather surface imaging capability afforded by ECHO will advance our understanding of these.

F.1.3 Ice Sheets and Glaciers

The impact of sea level change on coastal populations is of great societal importance. Glaciers are currently experiencing a global retreat, contributing to sea-level change. Potentially larger contributions from Greenland and Antarctica are less well known (*Report of Working Group I of the IPCC, 2001*). In response, NASA's ESE Research Strategy identifies two fundamental questions related to ice sheets and glaciers*: i) What changes are occurring in the mass of the Earth's ice cover? and ii) How is global sea level affected by climate change?*

The primary measurements identified by the *NASA ESE Strategy* to address these questions are ice-sheet velocity (InSAR) and precise topography (altimetry). ECHO data will help

1. Determine ice velocity and discharge by ice streams and glaciers worldwide and quantify their contributions to sea-level rise.
2. Characterize the temporal variability in ice flow well enough to separate short-term fluctuations from long-term change.

3. Provide critical data to determine the fundamental forcings and feedbacks on ice stream and glacier flow to improve the predictive capabilities of ice-sheet models.

Ice sheets and glaciers can be driven out of balance either directly by climate through precipitation/melt change or by dynamic instability caused by a change in ice flow, which may or may not be climate related. The ICESat and GRACE missions will allow measurement of ice sheet thickening/thinning rates and mass change. ECHO will provide critical data for the complementary measurement of surface velocity, and hence ice discharge [*Rignot et al.,* 1997], needed to relate observations of ice volume change to ice dynamics (e.g., *Joughin et al.,* 1999). In particular, ECHO data will permit distinguishing the thinning caused by ice flow from that caused by accumulation and melt on both ice sheets and temperate glaciers.

Traditionally, ice sheets have been assumed to evolve slowly with dynamic response times of the order of centuries to millennia [*Paterson*, 1994]. Recent InSAR analyses challenge this model. Although only a small fraction of the world's ice streams and glaciers have been sampled interferometrically, examples of short-term (days to decades) change are abundant. In Greenland, observations of velocity change include a mini-surge [*Joughin et al.*, 1996], and a post-surge stagnation front [*Mohr et al.*, 1998]. Decadal-scale acceleration and deceleration have been observed in West Antarctica (Figs. F-3 and F-4). InSAR also has been used to detect the migration of glacier grounding lines [*Rignot,* 1998], which is a sensitive indicator of thickness change. These observations of temporal variation have been too sparse to ascertain whether they constitute normal ice-sheet variability or indicate long-term change. Thus, ECHO will frequently (as often as every 8 days) monitor outlet glaciers in order to characterize and understand their short-term temporal variability. Comparison with ERS/RADARSAT data will facilitate detection of decadal-scale change.

The controls on fast ice flow are still the subject of active investigation and debate [*Alley and Bindschadler, Eds.,* 2000]. Understanding of ice flow dynamics has been limited by a lack of data. The velocity data provided by ECHO will be used to validate existing models and to motivate the development of new ones. In conjunction with ice sheet models, ECHO data will provide a powerful means to investigate controls on glacier flow. For example, inversion of an ice stream model constrained by InSAR data was used to determine the location of a weak till bed in northeast Greenland [*Joughin et al.,* 2001]. Incorporation of this type of knowledge into full ice sheet models will greatly improve predictions of ice-sheet evolution.

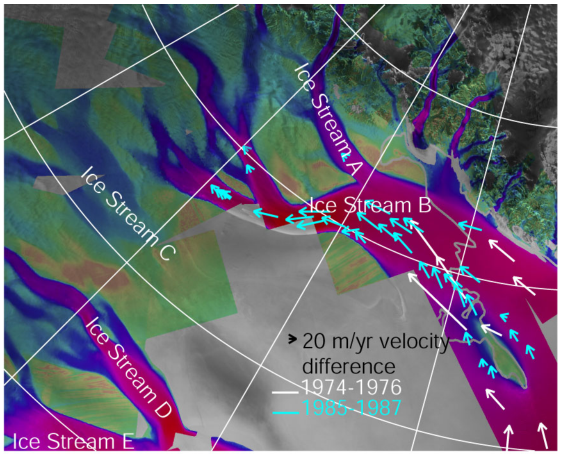


Figure F-3. Velocity change (vectors) on Ice Stream B between field measurements (1970's-1980's) and RADARSAT InSAR (1997; color coded). Deceleration rates of 5.5 m yr-2 were detected, suggesting Ice Stream B could stagnate in 80 years, as did neighboring Ice Stream C 150 years ago [*Joughin and Tulaczyk*, 2002].

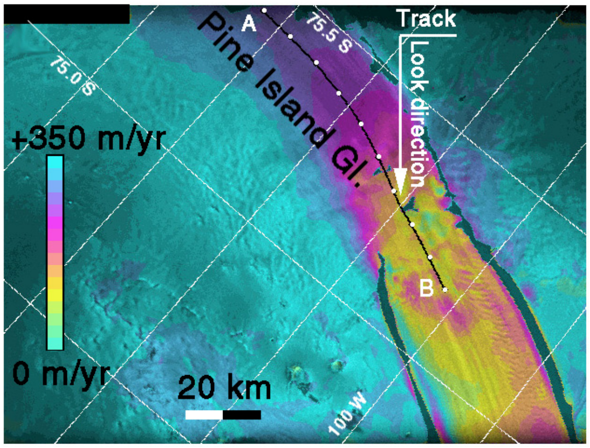


Figure F-4. This InSAR velocity difference indicates a 10% increase in velocity from 1996 to 2000 on Pine Island Glacier [*Rignot et al.,* 2001], which produces the largest ice discharge from West Antarctica. Additional data show an 18% increase from 1992 to 2000. This is the strongest evidence for ongoing thinning in this sector of West Antarctica.

F.1.4 Application Science

ECHO data will be useful for studying other geophysical phenomena of strong scientific value and societal benefit. One example (Fig. F-5) is the study and management of groundwater aquifer systems [*Hoffman et al.,* 2001*; Amelung et al.,* 1999]. Although withdrawal of water from subsurface aquifers represents only a small term in the global water cycle, the limited nature of this resource directly determines the habitability of many arid areas. ECHO observations will lead to better models and improved management of this important resource. Other examples include landslides, floods, oil extraction, and coastal erosion.

F.1.5 Underlying Physics of the Measurements

InSAR measures surface deformation through repeated observations of an area from one or more vantage points over time. The phase of a complex radar image incorporates the intrinsic phase scattering characteristics of the imaged surface and the propagation delay, which is proportional to the distance from the radar to the surface. The phase difference between two SAR images acquired at different times from nearly identical locations measures the changes in path lengths from the surface to the sensor. A map of this difference (an interferogram) includes both topography parallax and surface deformation that occurred in the time interval. The surface displacement field is isolated by removing the topographic component through other InSAR observations [*Gabriel et al.,* 1989] or independent elevation data [*Massonnet et al.,* 1994]. The relative positions of the surface scatterers within a resolution element may change over time (e.g., vegetation growth), adding temporal decorrelation noise. Other effects limiting the measurement accuracy include baseline-dependent geometric decorrelation, atmospheric and ionospheric refractive variability, and errors in the topography used in data reduction. Unlike existing systems, ECHO mission characteristics minimize these sources of error.

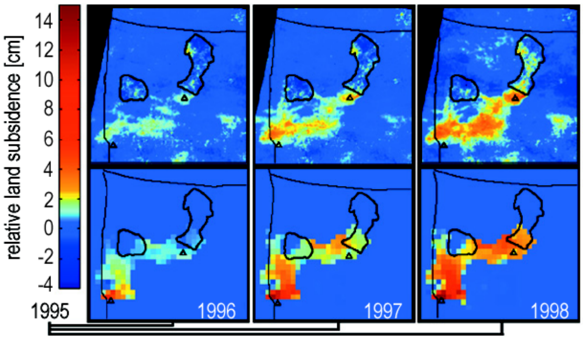


Figure F-5. Comparison of measured (InSAR) and modeled subsidence from groundwater removal in the Antelope Valley, California [*Hoffmann et al.*, 2001].

F.1.6 Mission Characteristics

ECHO will meet its science objectives with a low-cost SAR system aboard a single dedicated spacecraft (S/C). A 5-year mission is required to meet all these objectives. The L-band SAR uses two sub-bands with 70-MHz separation to permit ionospheric corrections similar to the L1/L2 GPS approach. While the instrument is based on existing technology, it represents a major leap forward in measurement capability. ECHO is optimized specifically to overcome the many limitations of existing systems (see Table F-1). Instrument and mission design elements for achieving the science objectives are

- L-band minimizes temporal decorrelation.
- No complications arise from competing science objectives or other instruments.
- Two sub-bands separated by 70 MHz allow correction of ionospheric effects.
- Onboard GPS for cm-level orbit and baseline knowledge improves calibration.
- Orbit maintenance within a 250-m tube guarantees that every scene is interferometrically viable.
- The S/C right/left roll capability allows the fixed-mount radar antenna to point to either side of the orbit plane, permitting vector displacement measurements and full coverage of polar regions.
- Frequent coverage for target areas allows averaging to reduce artifacts from atmospheric and other noise sources.
- Electronic beam steering minimizes S/C interactions for acquisition, and allows greater flexibility in science planning via wide-swath ScanSAR operations.

The mission is resilient with respect to degradation of these characteristics. Orbit control within a 250-m tube is a new capability; several LightSAR studies have indicated that such control is achievable. Even if orbit control were only comparable to ERS, the critical baseline (maximum baseline) scales with wavelength so that ECHO performance at L-band would be better by a factor of four than at C-band.

F.1.7 Relation to Past, Present, and Planned Missions

A dedicated InSAR mission measuring crustal deformation is needed to achieve significant increases in our ability to understand and perhaps forecast Earth surface change. Many InSAR applications have been demonstrated. Although impressive, existing InSAR systems are limited in scope and precision (Table F-1). ECHO will be a major advance over existing and planned systems.

ECHO will offer shorter repeat intervals to resolve fine space-time details of major events, and to provide practical response times to natural disasters. Short repeat times allow multiple acquisitions to eliminate (by averaging) noise caused by atmospheric propagation variations that limit current systems to cm or poorer accuracy in regions of even moderate humidity [*Massonnet et al.,* 1994*; Goldstein* 1995; *Zebker et al.,* 1997].

L-band avoids much of the temporal decorrelation that plagues C-band systems over vegetation [*Zebker et al.,* 1996] and temperate ice [*Rignot et al.,* 1996]. Using two sub-bands allows correction for ionospheric variations. Also, an experimental pass-to-pass ScanSAR synchronization mode will allow InSAR comparison of 340-km swaths (three times the nominal swath width) and could triple coverage on selected acquisitions, in area or in frequency.

RADARSAT has been used in a campaign mode to map Antarctica [*Jezek*, 1999], but the extent and accuracy are limited by the satellite's 24-day repeat cycle. ECHO will provide the first complete continuous monitoring of ice sheets and glaciers needed to study changes in ice mass and the related impact on sea level.

Restricted data availability limits the usefulness of the current generation of radar satellites. ECHO data will be freely provided to the scientific community via online access within 24 hours of downlink and tape delivery.

F.1.8 Relation to Existing Techniques

Tectonic plate motion and localized crustal deformation are measured by a variety of tools, including continuous GPS [*Bock et al.,* 1997]. In spite of their exceptional accuracy, these widely spaced measurements can spatially alias the geophysical signals of interest. In contrast, InSAR provides nearly spatially continuous maps of surface deformation, as illustrated by Figure F-1, showing post-seismic deformation following the 1992 Landers M7.6 earthquake. Only InSAR can generate this type of map.

InSAR and GPS are complementary in that GPS affords superior temporal resolution and long-term (decadal) stability, but InSAR provides strain maps at spatial densities several orders of

Table F-1: ECHO characteristics overcome many limitations of existing and planned SARs.

Sensor Characteristic	ALOS	ERS/ENVISAT	RADARSAT 1/2	ECHO
Prime Mission	Multipurpose	Multipurpose	Multipurpose	Dedicated InSAR
Repeat Period	44 days	35 days	24 days	8 days
Coverage	Few repeat pass areas	Limited/Global; limited repeat passes.	Few repeat pass areas.	Global; frequent collection over seismic/volcanic/ice
Orbit control	Moderate	Moderate	Poor/unknown	Excellent (all data good for interferometry)
Left/Right Imaging for Vector Measurement	No	No	Limited/Yes	Yes
Atmospheric	Poor	Poor	Poor	Good (can average multiple repeats)
Ionospheric	Poor	Good	Good	Very good (dual sub-band correction)
Temporal correlation	Good (L band)	Poor (C band)	Poor (C band)	Good (L band)
Data availability	Limited access	Moderate	Costly	Excellent
Wide-swath for greater coverage	ScanSAR but not for InSAR	ScanSAR but not for InSAR	ScanSAR but not for InSAR	InSAR-capable ScanSAR 340-km swath.

magnitude finer. Long-baseline strain- and tiltmeters, while exquisitely precise, are onerous to install and maintain, thus very few exist. ECHO will map sub-mm-level displacement, enabling worldwide deformation studies. ECHO will regularly collect data for the many areas that remain uninstrumented (e.g., Fig. F-2).

InSAR also allows mapping of faster processes, such as rapid ice flow [*Goldstein et al.,* 1993]. InSAR is the only way to map velocity over the featureless areas that comprise the majority of the ice sheets. Glacier motion is vastly undersampled by *in situ* measurements (GPS) and optical imagery can only provide velocity estimates in crevassed areas (feature tracking).

F.1.9 Sensitivity Analysis

ECHO will vastly improve sampling of the deforming part of the Earth's surface. InSAR data from existing sensors hint at the power of these observations, but application has been limited to those areas where conditions are ideal. In addition to the description below, further sensitivity considerations are described in Sections F.1.1–F.1.3

For most fault systems, there is no ground infrastructure to monitor deformation. Even on heavily instrumented faults, measurements are too sparse for many applications. ECHO will allow estimation of strain accumulation on a worldwide distribution of locked faults. Even a minimum mission with accuracy reduced to 4 mm yr^{-1} would still provide an adequate sampling along fast-slipping faults and a globally distributed data set of slip distribution far more complete than existing ones.

ECHO acquisitions will provide concurrent observations of over 600 volcanoes, which is impractical with ground-based measurements. In many cases, ground-based instruments are not deployed until an eruption is imminent. Accuracies of 5-10 mm will allow detection of subtle motion leading up to eruptions. A reduction in sampling frequency to 2 months would impact our ability to model basaltic volcanoes that evolve rapidly, but should have less impact for silicious volcanoes formed by more viscous magmas. It would also result in longer delays in detecting potential eruptions.

ECHO will provide the first comprehensive mapping of ice sheet velocity with which to estimate ice discharge and determine controls on fast flow. Although RADARSAT has collected InSAR data for ice velocity, accuracies on fast moving glaciers are limited to ~5 m yr^{-1} with 1-5 km resolution [*Joughin et al*., 1999]. ECHO will improve accuracy to 1 m yr^{-1} at 100-m resolution. Limited InSAR data already have revealed a surprising degree of temporal variability in ice flow. ECHO will provide the frequent sampling needed to characterize the short-term variability of glaciers.

F.2 MEASUREMENT OBJECTIVES AND NATURE OF INVESTIGATION

The ECHO mission consists of an L-band SAR interferometer optimized to collect the surface deformation data necessary to meet the science objectives described above.

F.2.1 Mission Overview

ECHO will fulfill the science objectives with a low-cost, SAR, launched on a contributed Russian Dnepr rocket. Because it is dedicated to, and configured for, repeat-track InSAR, ECHO will provide breakthrough performance for crustal deformation and ice motion science.

The S/C will fly a 5-year mission on a tightly constrained, 8-day exact-repeat Sun-synchronous polar orbit, at an 760-km altitude. The ground separation between orbit tracks is roughly 340 km at the equator. With three radar swaths averaging 115-km wide and steerable over a 340-km range, any point on the Earth can be imaged every 8 days. Complete coverage of any broad area requires 24 days (three 8-day repeats). An experimental ScanSAR mode yields a 340-km swath, allowing full coverage every 8 days. A more detailed description of the mission characteristics is included in Section F.1.6

F.2.2 Measurement Requirements

The ECHO measurement requirements are summarized in Foldout (F/O) Table F1-1. Many objectives require vector deformation measurements; hence observations from at least three different directions are needed. The most stringent resolution requirement is 35 m with 4 radar looks for characterizing fault geometries after earthquakes.

Characterizing inter-seismic strain accumulation is one of the highest priority goals; it is the one that drives accuracy requirements. The baseline-mission single-component accuracy requirement of 2 mm yr^{-1} over spatial scales of a few hundred km for inter-seismic objectives allows confident estimation of strain accumulation on locked faults with long-term slip-rates of 10-20 mm yr^{-1}. This also allows detection and limited measurement for the large fraction of faults that have substantially lower slip-rates. This requirement allows estimation of average strain rates of order 10^{-7} yr^{-1}. This stringent requirement will be achieved by averaging multiple observations (Fig. F-7). A 5-year mission is required to observe sufficient deformation in order to achieve the desired accuracy and to provide a sufficient sampling of earthquakes and other seismic events.

The baseline mission must cover the principal volcanic regions of the Earth (including arc volcanism, shield volcanoes, and calderas) at least monthly. Two components of displacement must be recorded with 5- to10-mm accuracy over distance scales of 25-50 km, as these are the scales of precursory inflation. This requirement is met with a single observation (Fig. F-6) so that multiple observations can be used to build time series of volcanic activity.

The ECHO ice sheet objectives require an accuracy of 1 m yr^{-1} over scales of 200 km and greater. This accuracy is needed to resolve small changes in velocity (e.g., 2.4 m yr^{-2} deceleration at the UpB camp, Antarctica), and for studies using inverse techniques to infer basal controls on fast flow. This requirement translates into a displacement accuracy of 11 mm over 8 days. Averaging of multiple observations (1-4) and/or longer intervals (> 8 day) can provide this accuracy. Coverage must ensure at least two full mappings (with multiple repeats) of ice sheet velocity in Greenland and Antarctica. Frequent acquisitions are required to monitor roughly 60 glaciers and ice streams for change.

F.2.3 Baseline Mission

The baseline 5-year mission meeting the above requirements has the characteristics listed in Section F.1.6. The L-band mission will enable inter-seismic studies globally. In the baseline mission, science data will be acquired at an average rate of 7 min/orbit. These data will be provided to users, along with the software necessary to process them to calibrated displacement maps.

F.2.4 Minimum Mission

Characterization of co-seismic and post-seismic portions of the crustal strain budget on several major plate boundaries is a minimum requirement. Global accessibility would still be required to sample a sufficient number of events. Measurement of inter-seismic deformation throughout a single plate boundary zone is also a minimum requirement.

Binary observation of the full set of ~600 active volcanoes is a minimum objective. A minimum subset of ice sheet objectives is a single ice sheet mapping and frequent sampling of ~40 glaciers.

F.2.5 Calibration/Validation Measurements

The ECHO *in situ* calibration and validation strategy will be based on the concept of *"natural laboratories"* which we define as geological targets of scientific interest, for which considerable ground truth is available (e.g., geodetic networks). Radar calibration (common range and phase delays) will require ground-based corner reflectors in the California's Mojave Desert and Alaska. Further details are given in Section F.4.10. Also, individual investigators may improve the accuracy of their baseline estimates using measurements that they acquire in the field.

F.2.6 Descopes Options

ECHO relies on a single simple instrument. Removal of the ScanSAR timing vernier would disable ScanSAR to ScanSAR operations, but save ~$1M if implemented before CDR. Removal of this experimental cabability would have no impact on the baseline mission. An additional $1M could be saved before PDR by removing the phase shifters for ScanSAR and electronic steering so that S/C roll would be needed to steer the beam. This does not compromise the baseline objectives, but loss of beam agility would add cost and complexity to the instrument tasking.

Replacing the Blackjack GPS receiver and associated Precision Orbit Determination (POD) activity with a commercial single-frequency GPS receiver is a descope that would save up to $5M if implemented at or before PDR. Orbits better than 1 m could be achieved with a cheaper commercial receiver. This accuracy is sufficient for navigation, but science analysis would rely more heavily on ground control for InSAR baseline estimation, making it more labor intensive and reducing the overall rate of science return.

Another descope that trades cost against science return, involves reducing the data volume by 15–25% so that it is possible to use only a single ground station, thus reducing the archive and distribution load to save roughly $3–5M. All of these reductions in hardware occur during Phase

3/4. In addition, the regional on-line archive concept could be scaled back, delaying delivery of data to the users by up to several months. This would save about $10M in hardware procurement, maintenance and operations. This could impact the science return in the timeframe of the mission, but would preserve the historical integrity of the data since all data will be stored at the EDC.

F.3 INSTRUMENTATION

The SAR instrument consists of a radar electronics package and a deployable active antenna. F/O Figure F1-1 shows the instrument block diagram. F/O Table F2-1 lists the instrument characteristics.

F.3.1 Instrument Overview and Functional Description

F.3.1.1 Radar Instrument Electronics. The radar electronics perform the transmit waveform generation to excite the antenna, and perform the receive echo downconversion and digitization. The radar instrument electronics will be built at the JPL, drawing on expertise in L-band radar design with heritage from the SeaSat and SIR programs. Developments in space-qualified electronics, and standardization of many of the hardware components allow for a capable and reliable low-cost radar. The instrument RF, digital, and mixed signal hardware, including the reference oscillator, digital chirp generator, up- and down-conversion mixers, filters, RF switches and amplifiers, analog-to-digital converter, high-rate data handling circuitry, and radar control and timing, will be housed in a shielded enclosure. The radar electronics will be *fully redundant*, allowing recovery from any single-point failure. The radar electronics mass will be ~69 kg (includes 30% contingency). The antenna control interface and power distribution electronics, to be built at Ball, will be housed separately as discussed below.

The radar will transmit and receive a single linear polarization (HH) in two frequency sub-bands (split-spectrum) separated to take advantage of the 80-MHz L-band frequency allocation. Subharmonic sampling will be used to combine the two sub-bands into a minimum-rate data stream using the least amount of hardware. Radar control will be accomplished using a simple table consisting of On/Off (GPS) times, and corresponding radar set-up and pointing parameters.

F.3.1.2 Radar Antenna. Ball will provide the phased-array antenna and deployment structure. Ball will procure the deployment structure, which is a deep-truss structure similar to the successful Seasat structure, from AEC-Able. AEC-Able is building a similar deployment structure for the RADARSAT 2 SAR antenna. The panel radiating element design is taken from SIR-C and therefore has minimal risk. The 13.8-m-by-2.0-m L-band antenna is made up of six 2.296-m-by-2.0-m panels. The two center panels are kinematically mounted to a fixed adapter truss that is mounted to the S/C. Deployable antenna “wings” on either side position the remaining four panels for radar operation. Transmit/Receive (T/R) modules distributed on each antenna panel maximize performance and reliability. This architecture minimizes the impact of an amplifier or DC/DC converter failure and eliminates the criticality of a bulky, expensive low-loss, high-power RF manifold. The antenna mass, including the deployment structure and T/R modules, is 477 kg (includes 30% contingency for the antenna and 20% for the deployment sturcture).

Ball will also supply the antenna Control and Power Distribution Unit (CPDU), which provides a well-defined electrical interface to the radar electronics and S/C. The CPDU receives its antenna commands and timing signals from the Radar Control and Timing Unit (RCTU) for distribution to the antenna panels. It receives and distributes antenna power from the S/C and collects and serializes engineering telemetry from the panels for delivery to the S/C telemetry processor. The CPDU mass, including CPDU-to-panel cabling, is estimated to be 23 kg (inludes 30% contingeny).

F.3.2 Instrument Design Rationale

The ECHO radar instrument is designed to meet the science and environmental requirements, while minimizing technical risk and cost. The design is based on a proven approach having only one operational data acquisition mode, which is one of 23 radar modes (not counting experimental modes) from the 1994 SIR-C missions. The L-band operating frequency is optimal for the science.

The ECHO radar antenna follows from a successful series of L-band and C-band antennas supplied by Ball for JPL radar projects, including SIR-C and SRTM. The design of the radar electronics for ECHO is based on the use of lightweight, compact components recently developed under NASA/JPL's Advanced Radar Technology Program (ARTP).

The JPL and Ball instrument design team has avoided duplication of functionality wherever possible. One example is the S/C On-Board Computer (OBC), which controls all the high-level operations, such as turn-on/turn-off of the radar. Instrument telemetry is routed as analog or discrete digital inputs to the S/C's telemetry processor, eliminating the need for telemetry sub-processors in the radar electronics. Critical calibration data are embedded in the radar high-rate science data in real-time during data acquisition.

Simplicity of design and implementation is also achieved with block redundancy (primary and redundant subsystems) for the radar, antenna-control, and power-distribution electronics. In the event of a failure, the redundant subsystem is switched in by powering it up and powering down the primary subsystem. This approach avoids the need for an elaborate primary/redundant switching network. Graceful degradation in the antenna RF electronics is inherent in the distributed system, which allows several T/R modules to fail without significant impact on the overall radar performance. With the exception of the data window position, no "hot" changes are permitted during a datatake, simplifying the radar operation.

Several features of the S/C bus that help simplify the design of the radar instrument are summarized in F/O Table F2-2.

F.3.3 Radar Requirements and Relation to the Science Objectives

Functional requirements for the ECHO S/C and instrument are summarized in F/O Table F1-1. The key science requirements driving the mission/instrument design are the measurement of surface change with accuracy of 2 mm yr^{-1}. These requirements impose functional requirements that drive the radar design: global access; high interferometric coherence; pixel-level geolocation; split-spectrum ionospheric corrections; and a 5-year mission lifetime.

The global access requirement drives the selection of a polar orbit. With these orbit parameters, the radar must allow data collection over all areas on the Earth's land surface. Instrument pointing will be achieved by a combination of precise S/C roll maneuvers to provide right-of-track or left-of-track pointing at a fixed angle from nadir, plus electronic beam steering to either scan rapidly across three beams (ScanSAR), or remain fixed at a single beam. The radar must achieve good performance (resolution, signal-to-noise, ambiguity level) over the range of incidence angles (swaths) encompassed by the three beams. To meet the ECHO science objectives, an 8-day repeat was chosen, resulting in a 340-km targetable ground-track separation at the equator. To best achieve global access in the shortest possible time, the radar swath width is maximized, constrained by antenna size and mass, data rate and signal-to-noise ratio (SNR). The nominal swath is 115 km. ECHO's three electronically steered beams ensure full global access.

The requirements for high coherence and measurement of long-term surface change drive the selection of L-band for ECHO. The requirements on deformation accuracy drive the selection of the radar resolution and thus the bandwidth. The need for ionospheric corrections leads to a split spectrum mode of operation for the radar.

The requirement for pixel-level geolocation drives the selection of one-second GPS time-ticks to control the on-off configuration of the radar. This control is handled by the S/C OBC, which has direct input from the S/C GPS receivers. The radar electronics handle the precise sub-second timing (e.g., the transmit inter-pulse period, the data window position, and the ScanSAR burst timing). Untracked errors in any of these parameters could affect the pixel location accuracy. The radar calibration telemetry includes a parameter to track the radar's reference Stable Local Oscillator (StaLO) frequency as a function of GPS time, allowing correction of radar timing drift errors in ground data processing.

The ECHO mission is designed to meet the requirement for high coherence through orbit and attitude control and careful attention to interferometric issues in the radar design. The three main sources of decorrelation are baseline, temporal, and thermal noise.

Baseline decorrelation results from imaging at different positions, with longer baselines yielding greater decorrelation. Baseline decorrelation also depends on the intrinsic spatial resolution. With the ECHO baseline controlled to within a 250-m tube, the 15-MHz range bandwidth meets the accuracy and spatial resolution requirements.

Temporal decorrelation is caused by wavelength-scale changes in the relative positions of sub-pixel scatterers. Longer wavelengths allow greater change before significant temporal decorrelation takes place. Comparative studies with C-band (5.6 cm wavelength) and L-band (24-cm wavelength) indicate that L-band maintains stronger correlation, particularly in vegetated areas [*Rosen et al.*, 1996]. The nominal 8-day repeat orbit also reduces temporal decorrelation for ice sheets and other areas that experience rapid surface change.

Thermal-noise decorrelation is directly related to the radar SNR, which depends on the backscatter (signal) from Earth's surface. The ECHO radar performance is designed to ensure millimetric accuracy over radar-dark regions.

The ECHO objective of measuring surface change over a 5-year mission places requirements on phase coherence. This is a significant departure from the 'standard' design constraints for SAR, where considerable emphasis is placed on radiometric stability to compare backscatter (i.e., σ^o) measurements. Radiometric fidelity is a lesser concern for ECHO when compared with phase fidelity. The 5-year mission also requires that redundancy must be inherent to the radar.

F.3.4 Maturity Matrix

The instrument technical maturity matrix is given in F/O Table F1-2. Elements of the ECHO radar electronics have direct heritage from SIR-C/SRTM Technology Readiness Level (TRL) 9. The NASA/JPL ARTP has focussed on reducing the mass and power consumption of these elements by a factor of ten from a SIR-C class instrument. The ARTP radar prototype is currently at TRL 7.

F.3.5 Operational Modes

The radar will nominally remain in the STANDBY state when not acquiring data. This maintains power to the StaLO in the Radio Frequency Electronics Subsystem (RFES) to assure good frequency and phase stability, and to the digital subsystem RCTU so it is always ready to receive commands. Sequences of datatake commands are generated on the ground and uploaded to the S/C OBC at daily intervals. Prior to a left-looking data take, the S/C will roll to achieve left-side pointing. Instructions to do this will be included in each uploaded datatake command. To initiate a data take, the S/C will set control signals to close relays in the radar RF Electronics and Antenna subsystems to enable operate power. A command will then be sent from the S/C OBC to the RCTU. The RCTU will parse out the appropriate control signals to the RFES and Antenna Electronics CPDU, and will begin the datatake at the next GPS pulse per second (pps) time-tick. Besides the Receiver gain setting and Caltone level setting, the radar command will include the following for each of the three antenna beams:

- Pulse Repetition Frequency (PRF)
- Elevation Steering Angle
- Data Window Duration (DWD) (# of samples)
- A series of entries for Data Window Position (DWP), with a corresponding DWP Dwell (DWPD) to indicate how long to use these positions before moving on to the next set.
- Command Pause-Before-Execution Setting, which allows for millisecond alignment of ScanSAR bursts for pass-to-pass ScanSAR interferometry.

The datatake will be executed using a fixed set of the above-listed set-up parameters, with the exception DWPs for three beams, which will sequence through up to 32 different values to accommodate the varying slant range during very long data-takes due to the Earth's oblateness. Each set of three DWPs will remain active for a duration specified in its corresponding DWPD command field. When the command's DPW/DWPD entries are all used up, the data collection will cease. The RCTU will set a status bit to reflect end-of-datatake to the S/C OBC. Power-down commands from the S/C CPU to the radar RF electronics and antenna, and a simultaneous command to the SSR to stop recording data, will end the datatake, and return the instrument to the STANDBY state.

Before the start of each data-take, the Antenna Electronics CPDU also receives a command which includes a matrix of bit values (instructions to power up each individual T/R module). The T/R module on/off settings will be maintained at the same state during any one datatake. Under normal operation, T/R modules will only be turned off (bit-value set to 0) prior to a datatake if a failure has been detected.

F.3.6 Concept Studies

Concept studies leading up to the current proposal include the 1-year TOPSAT mission design study, the 2.5-year LightSAR Phase A/B studies, the 3-year ARTP program, and the

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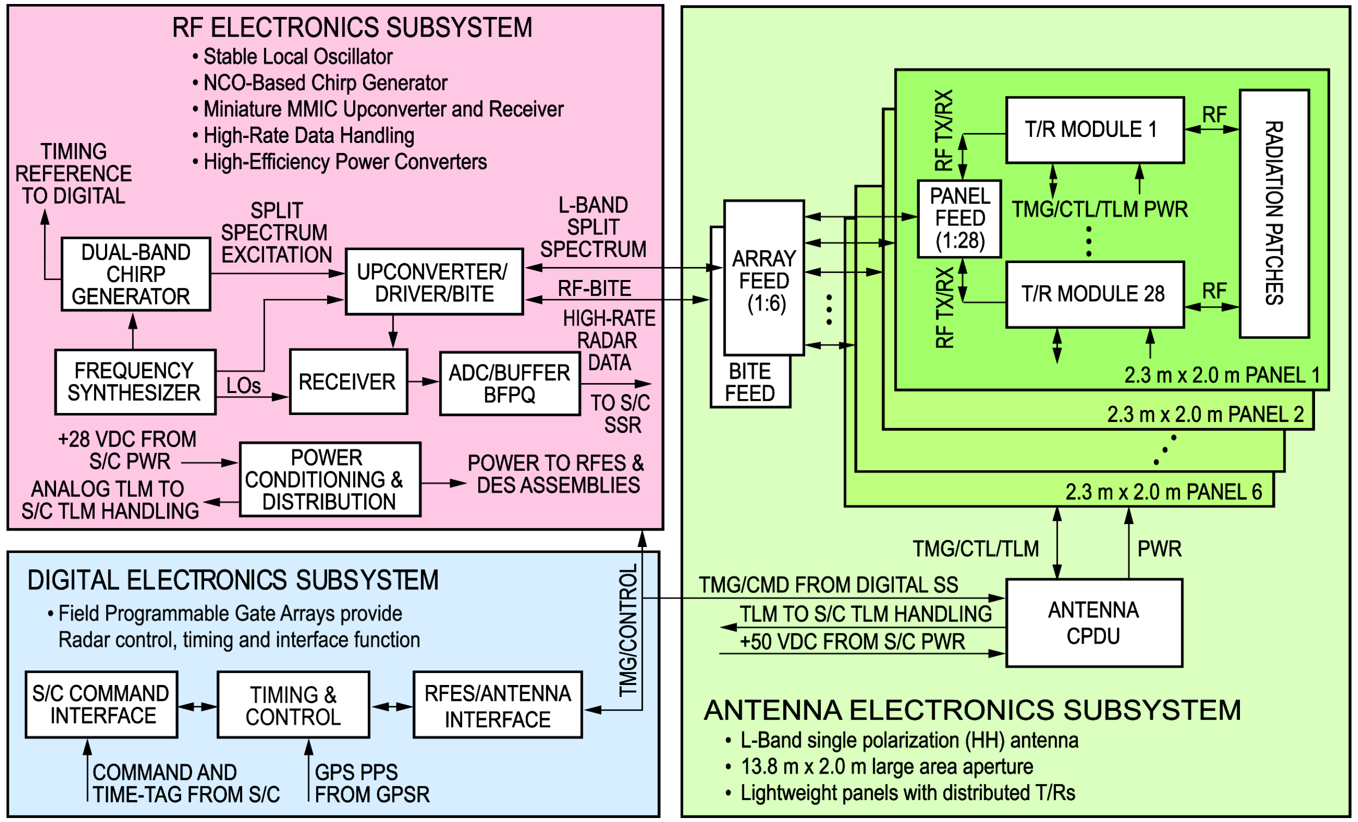

Figure F1-1. Block diagram of the ECHO Radar Instrument. The RFES, DES, and antenna CPDU are block redundant. The antenna panels degrade gracefully.

Table F1-3: System performance for ECHO beams.

Parameter	Near	Mid	Far	Requirement
Swath Width (km)	128	121	96	340 total
PRF (Hz)	1352.6	1263.1	1180.4	-
Boresight Ang (deg)	22.15	29.29	34.63	-
Min Look Ang (deg)	18.00	25.89	32.32	-
Max Look Ang (deg)	26.02	32.42	36.78	-
Range to midswath (km)	829	888	952	-
Start Coverage (km)	249	374	493	-
Stop Coverage (km)	377	495	589	-
Ground-Range Resolution (m)	20.5	15.8	13.6	35
Azimuth Resolution (m) (4-look)	27.6	29.6	31.7	35
Minimum σ^o_{NE} (dB)	-40.2	-38.2	-36.6	-24
Maximum σ^o_{NE} (dB)	-30.5	-31.8	-33.4	-24
Worst Azimuth Ambiguity (dB)	-23.7	-22.0	-20.0	-20
Worst Range Ambiguity (dB)	-38.0	-25.6	-25.6	-25
Ave. Radiated Power (W)	128.0	119.5	111.7	-
DC Power (W) †	199			††
fData Rate (Mbps)	130	144	126	<175

† Avg DC power value assuming 8.5 minutes of data collection per orbit, including 30% contingency
†† See Table G-5 for S/C capability

Table F1-1: Science Traceability Matrix (L-3).

Science Objectives	Scientific Measurement Requirements	Instrument Functional Requirements	Mission Functional Requirements
Understand strain changes leading to and following major earthquakes.	Globally distributed measurement of vector deformation rates to 2 mm yr^{-1} (single component accuracy), which implies deformation accuracy of 5-10 mm at 35-100 m resolution over a 5-year mission.	**Accuracy** • L-band Radar for high coherence. • Split-Spectrum for ionospheric correction. • Noise equivalent so better than -24 dB for radar-dark regions. **Accessibility** • 30 minutes of onboard storage for global accessibility within ground-station constraints. • Electronic beam steering in range **Calibration** • GPS for baseline knowledge and for orbit control. **Mission Duration** • High reliability for 5-year mission.	**Vector Measurement** • Ability to image left and right for vector measurements. **Accuracy & Interferometric Viability** • Orbit maintenance to repeat-tracks to within 250 m for short interferometric baselines (high coherence). • Precise orbit determination. • Instrument pointing to better than 0.05 deg. 1σ. • Frequent observations over a site to average out tropospheric and other noise sources. **Mission Duration** • Sufficient expendables for a 5-year mission duration. • High reliability S/C sufficient to enable 5-year mission duration.
Characterize three-dimensional magma movements to predict volcanic eruptions.	Globally distributed monthly measurements of deformation with 5-10 mm accuracy. Frequent measurements during eruptions.	As above with no additional drivers	As above plus **Accessibility** • 8-day repeat orbit for frequent monitoring of eruptions.
Assess the impact of ice sheet and glacier system dynamics on sea level rise and characterize temporal variability.	Ability to map vector ice motion for Greenland and Antarctica to 1 m yr^{-1} (single component accuracy). 5-year mission to study temporal variability.	As above with no additional drivers	As above plus **Accuracy & Interferometric Viability** • 8-day repeat to avoid temporal decorrelation & aliasing of fast motion. **Accessibility** • Polar orbit & left/right looking to image to both poles.

Table F1-2: Technical maturity matrix (L-2a). All elements of the ECHO radar electronics have direct heritage from SIR-C/SRTM (TRL 9).

Hardware Item	Item Description	Maturity	Maturity Rationale
StaLO/Frequency Synthesizer	Crystal oscillator & PLL frequency multipliers	TRL 7	SIR-C, ARTP
Chirp Generator	NCO-based DDS	TRL 7	SIR-C, ARTP
Upconverter/Driver	MMIC-based upconverter and SSPA	TRL 7	SIR-C, ARTP
Receiver	MMIC-based receiver	TRL 7	SIR-C, ARTP
ADC/Buffer/BFPQ/ Formatter	8-bit ADC/buffer with 8:4 BFPQ	TRL 7	SIR-C, ARTP
Radar Control & Timing	FPGA-based	TRL 7	SIR-C, ARTP
T/R Modules	MMIC-based transmit and receive amplifiers	TRL 7	SIR-C, SRTM
Antenna Panels	Microstrip phased array on honeycomb	TRL 9	SeaSat, SIR-A/B/C, SRTM
Antenna Control Electronics	Timing, serial command & telemetry bus	TRL 7	SIR-C, SRTM
Antenna Structure	Rigid, deep truss, composite tube with titanium end fitting, low CTE truss elements & thermal tape, bond joints, DOF fittings, snubber system	TRL 7	SeaSat, RadarSat-I/II
Deployment Mechanism	Pyrotechnic latch release, bearing design & lubrication, preload mechanisms, drive motor assembly, synchronization linkage, cable/spring powered elbow mechanism, outboard panel hinge latch	TRL 9	RadarSat

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Table F2-1: ECHO instrument information.

Item	Value/Summary	Units
Sensor type	SAR	N/A
Number of instruments (including redundant units and spares)	1 instrument with built-in redundancy	N/A
Number of channels	1	N/A
Size, meters x meters x meters	13.8 x 2.0 x 0.05	m^3
Mass with contingency, kg and %	569 kg (28%)	kg, %
Power with contingency (nominal, peak, duty cycle, standby), watts and %	Nominal 198 W (30%) @ 8.5% Duty Cycle Peak 1793 W (30%) Standby 50 W (30%)	W, %
Data rate with contingency, kbps and %	175 Mbps (30%) (avg. 8.5 minutes/ orbit)	Mbps, %
Mechanical, electrical, and thermal layouts	(see Figs, technical section)	N/A
Optical layout including field of view (if appropriate)	(see Figs, technical section)	N/A
Ground and on-orbit calibration scheme	Geodetic ground control	N/A
Pointing requirements (knowledge, control, and stability), degrees	Knowledge 0.05 deg Control: 0.05 deg Stability: 0.05/10 s	degrees
Command and control requirements	1 radar command per data take	N/A
Flight software architecture and thousands of lines of software code used. Include new and reuse/retest/ redesigned code., KSLOC. (Use of existing or commercial off the shelf or hybrid software shall be identified)	Instrument on/off sequencing runs on S/C control computer. ~100 lines of code	
Definition of instrument operational modes over all science phases with power and data requirements, watts and kbps	Standby, 50 W, 20 kbs Datatake, 1793 W, 175 Mbps	

Table F2-2: Spacecraft bus features that help simplify the radar design.

Spacecraft bus feature	Impact on radar design
Accurate positioning	Allows radar commands to be uploaded well in advance of data-take.
Accurate, stable pointing/ yaw steering	Removes uncertainty in antenna pointing. Simplifies radar timing and control.
Powerful CPU	Removes need for radar CPU.
Solid-state recorder (SSR)	Simplifies buffering scheme/interface for science data stream.
Telemetry handling	Removes need for an additional dedicated radar telemetry processor unit.
GPS one-second time-ticks	Provides accurate timing reference for radar system on/off configuration.

Table F2-3: Radar electronics and antenna potential problems, associated risks, and mitigation plans.

Risk Area	Explanation	Likelihood	Consequence	Mitigation Plan
RFES/DES	Unit failure	L	L	Block redundancy for each subsystem
RFES/DES	Schedule slip	M	L/M	Request for pre-phase B risk reduction phase; schedule reserve
T/R modules	T/R module components difficult to find	M	L	Evaluate part availability early to facilitate mods to SIR-C designs
T/R modules, RFES Drivers	Multipaction enabled by HPA output power	L	H	Evaluate all high-power transmission lines and junctions, modify connectors as on SIR-C
Structure	Structure development schedule lags	L	M	Monitor this major subcontract closely to uncover problems ASAP
T/R module	T/R development schedule lags	L	M	Monitor this major subcontract closely to uncover problems ASAP
Panel	Panel flatness degrades due to large panel size	L	L	Construct panel as symmetrically as practical to minimize thermal distortions
Antenna Structure	Structure does not deploy	L	H	Pre-launch test of proven deployment system, redundant pyrotechnic cutters

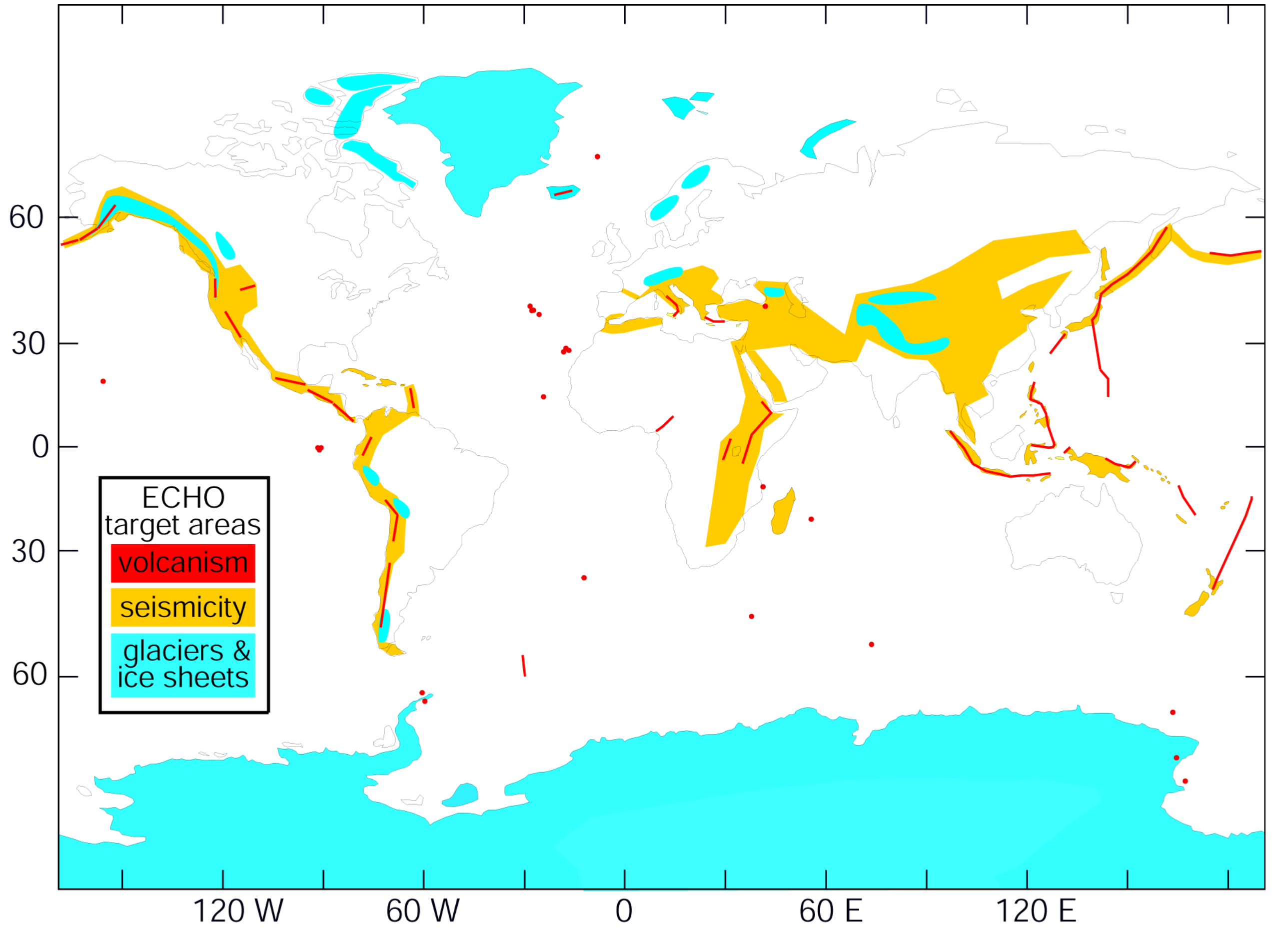


Figure F2-1. ECHO coverage areas for seismic, volcanic, and ice sheet objectives. Data for other natural hazards research can be collected worldwide.

prior study for the ECHO missions proposed to ESSP in 1996 and 1998.

F.3.7 Instrument Requirements and Performance

The performance is the same for the baseline and minimum mission.

F.3.7.1 Radar Performance. F/O Table F1-3 summarizes the overall radar performance. The bandwidth and pulse length for the split spectrum segments are fixed at 15 MHz /33.8 ms, and 7 MHz /33.8 ms, respectively. The remaining radar configuration parameters shown in the table were chosen to maximize performance within the swath constraints. The radar will have three swaths yielding a total combined swath width of 340 km, which is required for continuous coverage at the equator.

Amplitude weighting in elevation is necessary to meet the swath and ambiguity requirements. In order to minimize cost and retain simplicity, this is implemented in the antenna by using a uniformly driven aperture in amplitude for both transmit and receive, with the transmit amplitude taper achieved by using two types of HPA, and the receive taper achieved using post-LNA attenuators. This yields swaths between 104 and 141 km in width.

The maximum data rate assumed in determining the parameters for this design was 175 Mbps; the highest operational data rate used in the design was 144 Mbps, to give a 31 Mbps (21%) margin. The overlapping regions between adjacent beams are greater than 2 km, for mosaicking adjacent swaths in order to construct deformation maps over large areas.

One figure of merit for a SAR is the noise equivalent normalized backscatter (σ^o_{NE}), defined as the surface backscatter coefficient required to produce unit SNR in the radar image. SNR is then the ratio of the measured backscatter to the σ^o_{NE}, and surfaces with backscatter greater than σ^o_{NE} have a positive SNR. To meet the science requirements, the σ^o_{NE} should be lower than the minimum backscatter over the study area. Interferometric phase accuracy increases with SNR, all other noise sources being constant. Spatial averaging of the processed data can improve the InSAR phase accuracy, at the cost of degraded resolution.

The antenna dimensions and radiated power are closely linked to radar system performance, particularly SNR. An antenna 13.8-m in length and 2.0-m in height meets the requirements. The antenna is as long as possible, consistent with low fabrication costs for the antenna and deployment mechanism, while meeting science requirements. The worst case σ^o_{NE} occurs at the swath edges and is -30.5 dB.

The instantaneous dynamic range of the radar system is limited by the dynamic range of the (8-to-4 bit) Block Floating-Point Quantizer (BFPQ), which is 30 dB. An additional 8 dB (or more) of dynamic range is provided by a selection of receiver gain settings.

Other performance measures optimized in the design are the range and azimuth ambiguities. The range ambiguities meet or exceed the requirement of -25 dB for all three beams. The worst azimuth case ambiguities are -20 dB. Though acceptable, this level can be improved further by processing out the ambiguous signals at the cost of degraded azimuth resolution.

The radar PRFs for each beam position were selected by trading off the ambiguity levels while maintaining a duty cycle below 9.2% during radar operation. The design includes a choice of 16 commandable PRFs in the range of 1100–1700 Hz.

F.3.7.2 Command and Control Requirements and Performance. As mentioned previously, the S/C OBC controls the radar via a serial interface. The regular command sequence upload for ECHO will consist of a table of entries for each acquisition. The parameters required to control the radar are:

- Start Time, synchronized with the on-board GPS time to the nearest second.
- PRF, selectable from a set of 16, in the range 1100–1700 Hz. Three PRF settings, one for each beam, are required for a datatake.
- Elevation Steering Angle, selectable from a set of 10, to accommodate left and right-looking ScanSAR. Three Steering Angle settings, one for each antenna beam, are required for a ScanSAR datatake. For a fixed beam (non-ScanSAR) datatake, the three angle entries in the command are simply set equal so that the radar effectively has a single mode.
- Receiver DWP start, specified in terms of number of 256-pulse blocks of the ADC sample clock (~5 μs increments) from the signal starting the transmit event (PRF pulse). A minimum of three DWP settings, one for each antenna beam, is required for a datatake. Additional sets of DWPs may be included for

long datatakes, where the DWP must drift to accommodate altitude changes with latitude.

- DWPD Time, specified in number of ScanSAR bursts. For long datatakes requiring DWP drift, this parameter sets the duration for which each DWP is valid. Each set of three DWPs will have an accompanying DWPD Time.
- Receiver DWD, specified as a number of 128-sample block. Three DWD settings, one per beam, are required for a datatake.
- Receiver Gain, specified in 2 dB steps over a range of at least 8 dB, to accommodate the range of backscatter.
- Caltone Level, specified in 6 dB steps over a range sufficient to accommodate the receiver gain range.
- Command Pause-Before-Execution Setting, specified in ms over a range of 0 to 999 ms, to allow for millisecond alignment of ScanSAR bursts for pass-to-pass ScanSAR interferometry
- Stop Time, synchronized with the on board GPS time to the nearest second. (The actual end of data collection will precede this stop time by a fraction of a second. The datatake ends on a ScanSAR burst boundary when the DWP control table entries expire. The Stop Time then triggers the S/C OBC to return the radar instrument to the Standby state.)

In addition, the antenna CPDU also receives the following command:

- *Antenna Transmit/Receive Module Control*, commandable to activate specific T/R modules, giving the capability to turn-on/turn-off individual T/R modules.

F.3.8 Technology/Development Risks

F.3.8.1 Risk Assessment. ECHO radar design goals are reliability, system performance meeting or exceeding mission functional requirements, low cost, and low schedule risk. JPL and Ball have considered potential problem areas. F/O Table F2-3 shows risk assessments and mitigation strategies. The developmental and operational risk of the radar electronics has been greatly reduced by the small number of subassemblies, the simplicity of design, and the development team's experience with similar designs. Because of this, and in order to reduce cost, the ECHO radar development plan is to breadboard only selected items deemed necessary, to proceed directly to prototype for most assemblies, and to build the flight units following successful prototype evaluation. Many of the electronics prototype assemblies will become part of the Ground Support Equipment (GSE) used for testing the flight assemblies, thus minimizing the GSE cost. While spare parts will be purchased, and major subassemblies will be swappable, there will be no separate engineering model. Parts will be subjected to burn-in as required to reduce risk and improve reliability.

For the antenna, the majority of the risk assessments are low and, more importantly, the majority of the potential problem areas have a low likelihood of occurrence. Management's focus in the ECHO antenna development effort will be to minimize the likelihood of problems, through careful monitoring. JPL and Ball will maintain the risk matrix in F/O Table F2-3 throughout the course of the program as a management tool, reporting monthly to the team.

F.3.8.2 Risk Mitigation. The radar electronics design includes block redundancy (primary and redundant subsystems) to reduce the risk of subsystem failure. To reduce development risk, radar development includes an 8-month risk reduction phase, beginning fourth quarter 2002. The objective of this phase will be to set up a small, focused team to produce a detailed radar system design, described by the following documents:

- Radar Instrument Functional Requirements/ Functional Design
- Radar Instrument Interface Specification
- Radar Instrument Design Specification
- Software Requirements Document
- Software Design Document
- Radar Instrument Integration and Test Plan

The design of the science data acquisition command word set and the functional requirements/ functional design of the radar flight software will also be completed in this period.

The antenna and radar electronics teams will work closely during the risk reduction phase on the detailed instrument design. Work will also begin on the detailed design and procurement of the T/R modules and the antenna deployment structure, both of which are long lead items, and represent interface uncertainties.

The digital electronics are essentially off-the-shelf technology using digital logic families and components with a heritage of reliable performance in space. The majority of the digital logic will be implemented in Field-Programmable Gate Arrays (FPGAs), which are available as highly reliable rad-hard parts and are being flown in missions such as Cassini. These boards and spares will be assembled and tested in a manner similar to the RF electronics.

F.3.9 Instrument Development/ Construction Schedule

The schedule for radar instrument design, fabrication, integration and test is shown in the master schedule in Figure H-3 in the Management volume. The radar instrument schedule assumes a 12-month Phase 2 risk-reduction phase, a 9-month detailed design period (PDR to CDR), and 17-months for sensor fabrication, integration, and test. This allows 8 months for integration with the S/C and 1 month for launch vehicle integration.

Detailed design of the flight software will be completed by the middle of Phase 2. A test version of the radar flight software will be developed using a S/C I/F simulator provided by Astrium (6 months before CDR). This test version will be used during the sensor integration and test period. Final delivery of the radar flight software will be a year before launch.

F.4 ANTICIPATED SCIENCE RETURN

The ECHO mission will distribute SAR data and software needed to produce surface deformation maps for the science objectives described above. Scientists using ECHO data will be able to routinely produce 3D displacement maps associated with earthquakes, post- and inter-seismic deformation, volcanic activity, and glacier flow. Also, as part of the validation activities, the science team will produce and distribute several deformation maps as part of the *natural laboratories* validation.

F.4.1 Expected Results

ECHO-derived products promise significant advances in the areas of seismic, ice sheet, volcanic, and subsidence research. For earthquake studies, ECHO seeks to provide the first continuous series of velocity and strain-rate (spatial gradient of velocity) maps of the Earth's major tectonic zones. These data will be enormously beneficial for earthquake science and hazards studies. First, these maps will likely reveal previously unknown zones of strain accumulation. When combined with other geologic and seismic data, ECHO-derived strain-rate maps should yield substantial improvements in seismic hazard assessments. Other ECHO products will provide invaluable information on slip distribution, fault geometry at depth, and crustal rheology, resulting in significant advancements in modeling earthquake physics. Finally, ECHO-derived decorrelation maps will allow investigators to evaluate the distribution of damage following earthquakes and other natural disasters.

For volcano studies, ECHO will provide continuous deformation maps for active volcanoes, yielding unprecedented information about the transport of magma in the Earth's crust. ECHO-derived deformation maps will be inverted to determine the geometry and volume of the magma sources at depth. Because ECHO provides global coverage it will be possible to image any of the Earth's active volcanoes. Detecting changes in surface deformation patterns will help identify volcanoes likely to erupt in the near future. This will flag areas requiring additional seismic and geologic investigations for the issuance of eruption forecasts. After eruptions, ECHO will provide accurate maps of the spatial extent of newly erupted material, information important in understanding the eruptive process and in identifying the potential for future hazards (e.g., those due to lahars).

ECHO will produce velocity maps of the major outlet glaciers and ice streams in Greenland and Antarctica to aid estimation of ice sheet mass balance and associated sea level change. These data will provide much tighter constraints on the contribution of ice-sheet discharge to present-day sea-level change. ECHO will provide a time series of ice velocity data to detect and help characterize short-term fluctuations in ice velocity. The data will also be used to detect shifts in grounding line position, which are sensitive indicators of change in the ice-sheet/ice-shelf system. Finally, the data will provide a valuable new data set for determining the controls on fast flow and improving ice sheet models.

F.4.2 Relation to EarthScope

ECHO will increase NASA's role in a major solid earth science initiative, EarthScope. A collaborative NASA/NSF/USGS venture, EarthScope is a distributed, multi-purpose set of instruments and observatories that will greatly increase understanding of the structure, evolution, and dynamics of the North American continent. Interferometry is a component of this program, and ECHO will serve as the prime instrument for supplying spatially continuous crustal deformation data. EarthScope's three other components are: USArray, a continental scale seismic array to provide a coherent 3-D image of the lithosphere and deeper Earth, SAFOD (San Andreas Fault Observatory at Depth), a borehole observatory across the San Andreas Fault to directly measure physical conditions under which earthquakes occur, PBO, a fixed array of strainmeters and GPS receivers to measure plate boundary deformation at a range of temporal scales.

F.4.3 Relationship of Products to Science Objectives

The ECHO science objectives seek answers to several important Earth science questions based on analysis of high-resolution deformation measurements provided by ECHO. The mission will produce SAR data and software for generating vector deformation maps. These deformation maps are the products required to answer the questions that motivate the ECHO science objectives. A detailed mapping of the science requirements into the instrument and mission design characteristics needed to generate these products is given in the Science Traceability Matrix (F/O Table F1-1). The Science Team will demonstrate the validity of these data for meeting the science objectives. The detailed analysis of these data needed to answer the science questions will be performed during the AO specified Science Data Analysis Projects (SDAP) and under of the EarthScope initiative.

F.4.4 Science Data to Be Returned

The raw measurements acquired by ECHO are digitized, offset-video samples of radar echo returns. The project will reformat these to produce the product to be distributed, along with the precision orbit estimates, to science users. This processing includes browse SAR (~100 m resolution) images. The project will also develop and provide software to the science community for processing and calibrating these data to geolocated vector displacement maps. These displacement maps are the common products for seismic, volcanic, ice-sheet, and subsidence studies. They are used to derive discipline-specific measurements (e.g., maps of seismic strain and glacier velocity) needed to meet the science objectives.

F.4.4.1 Data Products. The basic ECHO products are SAR signal data, Doppler analysis, precision orbit state vectors, and other meta-data necessary to produce calibrated measurements of deformation using the ECHO supplied software. Many difficulties in processing SAR data stem from the inconsistent data formats. ECHO will maintain a uniform and consistent format to simplify processing.

F.4.4.2 Demonstration Science Data Products. The science team has the responsibility for ensuring that ECHO data are fully calibrated and validated. Because of the global scope of ECHO science, and because of the combinatorial explosion of possible higher level data products (e.g. multiple interferograms, stacked to mitigate tropospheric noise, and processed into deformation time series), it is not practical to implement a centralized processing of ECHO data to high-level. Instead, the science team will prepare and distribute properly verified software together with the SAR data. The validation of the data and of the processing software (including the effectiveness of the specific algorithms) will be performed based on the concept of "*natural laboratories*". The science leads for each of these laboratories are identified in Table F-2. We will select three such areas, characterized by (1) the richness of the scientific issues they pose (2) the human interest aspects and (3) the availability of readily accessible ground truth, in the form of other geophysical data that can be integrated with ECHO data. For each natural laboratory, demonstration science questions to be answered by the Science Team using ECHO data are:

Southern California plate boundary zone:

What is the geographical and temporal distribution of deformation?

Is compressional tectonics in southern California accommodated primarily by horizontal motions ("escape from LA") or by vertical motions?

What are the respective tectonic and non-tectonic (e.g. ground water) deformation signals?

Hawaiian volcanic edifice:

What are the timing and areal patterns of deformation associated with the eruptive cycle?

West Antarctica

What are the time dependent dynamics of the ice sheet, ice streams, and ice shelf?

What is the variability in ice discharge from West Antarctica?

We note that a common scientific thread is the use of repeated measurements to build a picture of vector deformation continuous in space and densely sampled in time. When assimilated into three-dimensional time-dependent physical models of the subsurface, such maps will help support significant scientific advances over past or current SAR missions. Our Cal-Val strategy is to use these geological targets to develop and validate the tools and approaches for producing higher-level data products and verify them under controlled circumstances. These higher-level data products will be made available through the distributed ECHO archive.

F.4.4.3 Data Coverage and Mission Phases. ECHO coverage will focus on the areas shown in F/O Figure F2-1 for meeting seismic, volcanic, and ice-sheet objectives. Additional data will be collected at targeted sites worldwide for subsidence studies. Following commissioning and on-orbit checkout, ECHO will collect data during a single 5-year deformation mapping phase, during which time ~250 TB of SAR data will be collected.

ECHO will image all areas of seismic interest at least four times/year from at least three different directions to allow vector measurement. This coverage yields at least 20 images from each direction over the 5-year mission for the seismic and volcanic areas shown in F/O Figure F2-1. The large number of images collected over each site is required to reduce tropospheric and other artifacts through averaging. Coverage at regular intervals ensures there will always be an up-to-date reference image for measuring co- and post-seismic deformation associated with earthquakes. Volcanoes will be imaged monthly from at least two different directions.

When seismic or volcanic activity is detected, ECHO coverage will be stepped up to provide the frequent temporal sampling necessary for monitoring such activity.

The mission will include two complete mappings of the Greenland and Antarctic Ice Sheets, separated by 3 years. Each mapping will include multiple repeats (5 to 8) to reduce noise by averaging. Roughly 60 ice streams and outlet glaciers will be monitored more frequently (as often as 8 days) to detect velocity change and grounding line migration. ECHO will also image the worldwide distribution of glaciers outside of Greenland and Antarctica several times.

The coverage will follow a stable and repetitive schedule to simplify mission planning. Earthquakes, volcanic eruptions, and other natural disasters occur spontaneously and globally and must be imaged at the first available opportunity. In response to such events, unscheduled acquisitions will interrupt routine mapping. Enough leeway will be maintained in the acquisition plan to quickly and easily reschedule any preempted acquisitions.

F.4.5 Data Processing

The ECHO project will supply users with a suite of InSAR processing software to allow them to process the data to SAR images, interferograms and geocoded and calibrated displacement maps. Current PCs and Macs can process a 100-km scene in roughly 15 minutes. This time should drop dramatically by the time of launch. The ECHO software package will allow users to process and calibrate the data without specialized SAR processing knowledge.

SAR data will be received and formatted at the receiving stations as they are acquired. Vexcel has installed similar systems for processing at various facilities around the world. The SAR signal data are the basic archived data sets. These data will be processed to higher level products by users using the ECHO software package.

In addition to algorithm development, the Science Team will provide software training and support to the science community. This model of software development and support has been successfully employed in GPS processing and SAR processing packages at JPL, Scripps, Stanford, and other institutions. A more detailed description of the user processing package is given in Section F.4.7.

F.4.6 Data Quality

Interferometric measurement errors are determined by such factors as system performance, scattering properties, vegetation, tropospheric water content, and imaging geometry. In extreme conditions (e.g., open water), measurements are not possible. For any interferometric system, there is a variety of imaging conditions, leading to a wide range of measurement accuracy. The ECHO radar is designed to meet the measurement requirements under circumstances that apply to the majority of the Earth's land surface. The following subsections describe the sources of measurement error and how they impact data quality.

F.4.6.1 Decorrelation Noise. Decorrelation between InSAR images causes phase error that is directly proportional to displacement error.

Interferometric decorrelation is caused mainly by thermal noise (i.e., system noise), baseline length, and temporal effects.

The ECHO instrument has been designed so that over a nominal range of target backscatter, baseline and thermal-noise decorrelation is kept below 4 mm at 35-m resolution with a 250-m baseline, which is below the anticipated level of tropospheric error (see Fig. F-6). Spatial averaging (e.g., more radar looks) can further reduce decorrelation noise at the expense of resolution.

Temporal decorrelation causes additional noise. The L-band radar and 8-day repeat period were selected to minimize, to the greatest extent feasible, temporal decorrelation. Further reduction in temporal decorrelation noise will be achieved by averaging data from several observations (see Fig. F-6).

F.4.6.2 Influence of Baseline Knowledge on Measurement Accuracy. Precision InSAR processing requires knowledge of the S/C orbit to within a few centimeters. ECHO will use the onboard Blackjack GPS receiver to provide precise orbital products. These products will be available for on-line distribution within 3 days of acquisition.

The radial component of the TOPEX/POSEIDON (T/P) orbits is precise to within 3 cm when determined by GPS alone [*Bertiger et al.*, 1994]. Although the other components are less well determined (about 10 cm RMS) for T/P, several factors should improve performance for ECHO. The GPS receiver technology carried by ECHO is more mature than for T/P and avoids systematic errors in P-code data in the presence of Anti-Spoofing. Bertiger et al. [1994] confirmed this improvement. This heritage indicates that the GPS data should easily determine the relative vector orbital separation ("baseline") between ECHO passes with 10 cm or better accuracy.

Baseline errors affect displacement estimates in two ways. First, baseline errors combine with topography to produce small biases, which are typically negligible [*Zebker et al.*, 1994]. Second and more significantly, errors in the baseline yield systematic phase patterns ("tilts") in the interferograms.

With ECHO baseline estimates, tilt magnitudes range from several millimeters to a few centimeters. While this accuracy is sufficient for many studies, some form of baseline refinement will be necessary to meet the measurement requirements listed in F/O Table F1-1. At least 4 to 6 control points typically are required. These points need not be "radar visible" and in most cases do not require *in situ* measurements of displacement. For example, the baseline can be estimated using points outside the deformation field of a volcano where displacement is assumed to be zero. Stationary points near the coast or estimated velocities provide adequate control for ice sheets [*Joughin et al.,* 1998b]. ECHO coverage will be selected to maximize such opportunities.

F.4.6.3 Tropospheric Errors. Studies have shown that turbulent mixing of water vapor in the troposphere produces artifacts in interferometric maps [Massonnet *et al*., 1994; Goldstein, 1995; Zebker *et al.*, 1996]. Tropospheric delay will be the dominant form of error for many ECHO measurements.

To evaluate this error, we have used GPS derived tropospheric delay estimates from a number of sites around the globe to quantify the effects of error out to length scales of 200 km. Using these data, we constructed an error model that includes the tropospheric noise, thermal and baseline decorrelation noise, and baseline estimation error. Figure F-6 shows results that reflect typical operating conditions. The colored regions indicate a range of accuracies that meet the science objectives. The upper curve shows the single observation accuracy for geophysical length scales up to 200 km. The control points used in the model are spaced at distances comparable to the geophysical scale and bound the area of interest. Consequently, the errors decrease with scale, since the baseline solution removes errors at wavelengths much above the control-point spacing.

Figure F-6 indicates that the single observation accuracy meets the requirement of 1 cm for length scales below 50-km (for volcanic studies). In cases requiring better accuracy, multiple observations will be used to reduce tropospheric error. This will yield an improvement of $N^{-1/2}$, where N is the number of independent observations. Although results illustrated in Figure F-6 only extend to 200-km length scales, extrapolation of the results indicates that the ice and interseismic requirements can be met. For interseismic studies, an average of 4 to 20 interferograms are needed, while ice requirements are met with 1 to 4 interferograms.

F.4.6.4 Ionospheric Errors. The ionosphere also introduces propagation error. Unlike tropospheric delays, which are non-dispersive, iono-

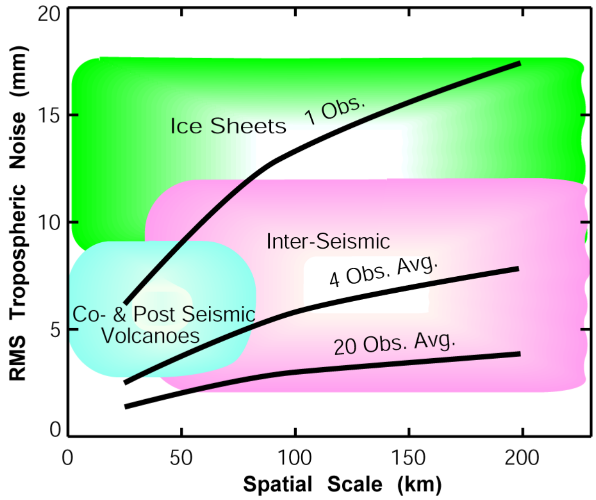


Figure F-6. Modeled error for ECHO single-component displacement estimates, including effects of tropospheric path delay, decorrelation, and baseline error. Ionospheric effects are not included, as they will be largely removed using the dual sub-band correction. Water vapor is the limiting source of error. Different curves show the effects of averaging interferograms. The horizontal axis represents the maximum scale of interest; error dependence on scale reflects the power-law nature of the troposphere. Boxes show the ranges of ECHO measurement requirements.

spheric delays are proportional to the square of the radar wavelength, and thus, are a factor of 16 worse at L-band than C-band. Past experience with L-band (SEASAT, JERS-1) shows that the ionosphere is not a dominant source of high-spatial-frequency error for interferometric studies. The uncertainty in the average excess path length, however, will likely lead to undesired "tilts" in the final deformation maps.

ECHO will use two methods for removing ionospheric affects. First, the dispersive nature of the ionosphere will be exploited to perform a two-frequency correction (two sub-bands separated by 70 MHz). Second, averaging of multiple interferograms will remove any resisdual ionospheric errors.

F.4.6.5 Relative Accuracy of Vector Components. ECHO is the first radar mission designed to make three-component vector displacement measurements. Existing systems (e.g., ERS-1/2), yield scalar maps along the radar line-of-sight. Application-specific assumptions do allow limited 3-D vector measurements with ERS-1/2 data from crossing orbits, particularly for ice sheets [*Joughin et al.*, 1996], but apply in only limited circumstances. Conversely, ECHO will provide true vector data by combining information from ascending left- and right-looking, and descending left- and right-looking passes. Figure F-7 shows how line-of-sight range displacement errors map into the relative precision in the East, North, and vertical directions.

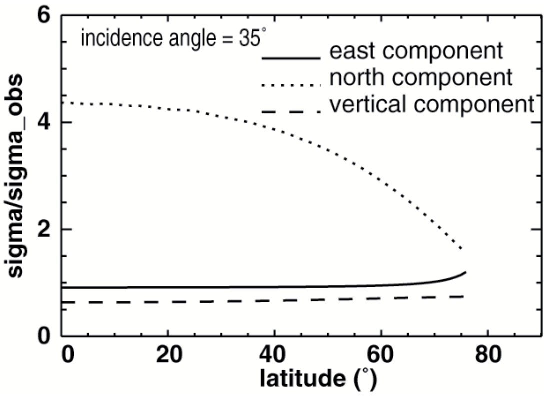


Figure F-7. Relative sensitivity of ECHO measurements in the directions east, north and vertical as a function of latitude, assuming four independent observations at mid-swath on the four line-of-sight directions of the satellite (ascending left- and right-looking, and descending left- and right-looking). For example, if the phase noise corresponds to 1 mm of range change in the four directions of observation, the associated error at low latitudes is ~3 mm in the north component and ~0.7 mm in the east and vertical components. Averaging several observations of slow deformation processes will reduce the error.

F.4.6.6 L-band Data Over Ice Sheets. ECHO's L-band wavelength is four times longer than existing C-band systems such as ERS-1/2 and RADARSAT, so that is better suited to measuring the fast motion of ice streams.

Deep penetration of L-band signals into the firn potentially could yield significant geometric decorrelation due to volume scattering interactions. L-band airborne interferometric data collected in 1995 over the Greenland Summit and other Greenland sites by the NASA/JPL TOPSAR indicate that increased L-band decorrelation over dry snow facies is not a significant concern for ECHO [*Rignot et al.*, 2001].

F.4.7 Algorithm Development and Validation

The Science Team will provide algorithms for generation of higher-level products. Vexcel will develop GUI interfaces for these programs and distribute the processing code to the science community at no cost to users. The Science Team will validate the ECHO data and the ability to generate the necessary higher-level products using the Vexcel package.

F.4.7.1 Processing Software Development. The Project-supplied algorithms and software will:

- Form images, interferograms, range displacement maps, calibrated vector displacement maps, topographic maps, and correlation maps using ancillary data;
- Geocode products using precise orbits and topographic information;
- Estimate baselines from precise orbit solutions and using image-derived methods;
- Calibrate products from corner reflector analysis and provide tools for estimating temporal phase stability; and
- Verify products with a statistical package comparing ground truth GPS to interferometrically derived displacements.

JPL and Vexcel are world-leaders in developing production-grade processors for science applications and research; Stanford, Scripps, and Caltech have developed InSAR code for reasearch. Repeat Orbit Interferometry (ROI)_PAC, developed at JPL and Caltech and used in over 30 institutions worldwide, is a research code suite designed to perform ECHO-like ROI on ERS, JERS, and RADARSAT data. All the processing functionality listed above is currently included in the ROI_PAC distribution. Calibration and verification packages for SAR data also exist at JPL but have not been distributed.

Existing software will be upgraded for the ECHO mission characteristics, including:

- Pre-processing of ECHO telemetry, signal data, and ephemeris information to standardize radar image processing.
- Upgrade of the image-formation processor to incorporate an ionospheric correction. This will include split-spectrum range processing and azimuth auto-focus processing.
- Upgrade of strip-mode processors to accommodate ECHO-radar-specific configuration changes, including gain, beam-pointing, and data window position changes.
- Upgrade of JPL SRTM-based Repeat Orbit ScanSAR Interferometric (ROSI) preprocessor and processor for ECHO data.
- Upgrade calibration tools to use specific ECHO ancillary products and ground-truth data sets to generate
- Upgrade verification tools for ECHO specific data and meta-data.

F.4.7.2 Software Validation. The science user processing software will be validated and quality-checked prior to launch using simulated data as well as existing ERS and JERS data. Post-launch software validation will be included implicitly in the effort to validate the measurements against ground truth collected within natural laboratories (Section F.4.10).

F.4.8 Analysis Approach

Other than calibration and validation, data analysis will be the responsibility of scientific investigators. The first step common to all disciplines is the generation of range displacement maps (interferograms) in as many as four viewing directions obtainable with ECHO. Data and software will be provided to investigators, allowing them to produce calibrated radar line-of-sight displacement maps and vector displacement maps. This approach is consistent with the current InSAR processing methodology, in which SAR signal data is the preferred product requested by users. This approach also allows users to incorporate any site-specific data (e.g., GPS data) they may have into the processing.

F.4.9 Data Archiving and Distribution

ECHO will provide free and open distribution of ECHO data in a manner consistent with NASA and U.S. Government data policy. The ECHO ground system will distribute data to the science community in two ways: Internet access, and requests to the long-term archive.

Data will be received at 2 ground stations. From there, the data will be moved to a network of several online servers with Internet-2 connections to provide users with online access within 24 hours from reception. Data will be kept online on this server network for at least 1 year from reception when demand is expected to be high. All ECHO data also will be available online throughout the mission at the San Diego Supercomputing Center (SDSC/NPACI). In addition, the data will be permanently archived at the USGS EROS data center (EDC) (meeting AO App. 6 requirements) from where users can request tape delivery of the data. DPI Zebkev will be responsible for the delivery of the ECHO SAR data products.

F.4.9.1 Data Formats. All low-level SAR products will be archived in CEOS format. Images and maps will use EOS-HDF format for compatibility with EOSDIS.

F.4.10 Data Validation and Calibration

The Science Team will use dense GPS networks (e.g., SCIGN and EarthScope) for validation. The Science Team will determine the various calibration parameters (e.g., instrument delays). In addition, consistent with the current state of the art, displacement maps will be individually calibrated (e.g., InSAR baseline solution) by users using the ECHO processing software.

The Science Team will fully calibrate, validate, and evaluate the ECHO data products. Calibration and quality assessment of mission products by Science Team members includes: (1) calibration of the radar instrument, (2) validation of the processing software, (3) evaluation of the GPS orbit determinations, (4) validation of interferometric measurements, and (5) periodic checks to assess the performance and stability of the instrument.

F.4.10.1 Calibration of the Radar. Precise geolocation of the data requires that slant-range pixel spacing and slant range to the first sample be known to approximately the 0.2-pixel level. Several factors that determine the geolocation accuracy, including knowledge of the position of the radar antenna phase center, the time delay to the first range sample, and the time interval between samples. There are also additional delays internal to the radar.

Most of these delays will be measured as part of the pre-launch sensor calibration and testing activities, and on-orbit drift will be monitored with the Built-In Test Equipment (BITE). In orbit, the radar will be calibrated using precisely located corner reflectors to determine unknown delays and the antenna phase centers. These corner reflectors are located on the Rosamond Dry Lake in the Mojave Desert. This test site has been used for many years as a calibration site for NASA's TOPSAR and for the SIR-C/X-SAR. These reflectors will be supplemented with existing reflectors in Delta Junction, Alaska. The result of the pre- and post-launch calibration activities will be a file containing calibration data for distribution with the processing software

F.4.10.2 Orbit and Baseline Evaluation. ECHO orbit knowledge will be evaluated by following the procedure used for the T/P orbit quality assessment. Specifically, the quality of the ECHO orbit quality will be determined by comparing overlapping sections of adjacent, 30-hour orbit arcs centered at noon UTC [*Bertiger et al*., 1995].

Baseline accuracy will be assessed over an area of known topography where the baseline can be determined using ground control.

F.4.10.3 Measurement Validation. The ultimate products that will be derived from the ECHO data are maps of surface displacement vectors. The quality of these products will be assessed through comparisons with *in situ* displacement estimates. These validation data will be acquired using conventional geodetic techniques, such as the GPS at sites representing various environmental and surface conditions. The prime objective of these validation experiments is to assess the precision of the ECHO displacement maps and assess impacts of system noise, and atmospheric and ionospheric artifacts.

At lower latitudes, measurement validation will rely on existing, continuously operating GPS arrays in the Western U.S. and Japan. In addition to the current South California Integrated Network (SCIGN), the EarthScope PBO will deploy several hundred more permanent GPS monuments along the West Coast of North America. These arrays will provide vector displacement comparisons over a wide range of station spacings. This will facilitate the assessment of both short- and long- wavelength errors. The Japanese GPS network currently contains over 1000 stations.

Kilauea volcano, Hawaii, is probably the world's best-monitored volcano, including a 15-station permanent GPS array. Kilauea experiences tremendous gradients in atmospheric moisture, and will be an excellent place for validating algorithms for removing atmospheric delay artifacts.

Validation and evaluation of glacier and ice-sheet data will rely on existing GPS measurements of ice velocity. These measurements are primarily those acquired during the Siple Coast Project in West Antarctica [*Whillans and Van der Veen*, 1987]; and those measured every ~30 km at the 2000-m contour line of Greenland by NASA's Polar Research Program.

As part of the validation activities, the Science Team will produce several higher level products over areas of high scientific priority. These products will be used to confirm the ability to produce displacement maps for the relevant disciplines over broad geographic areas. A summary of these products is given in Section F.4.4.2.

F.4.10.4 Radar Performance and Stability Evaluation. Radar performance will be evaluated with a tool that allows semi-automated analysis of data collected over corner reflector sites. This tool will perform tests to evaluate the statistics and signal quality of the data. Throughout the mission, phase stability will be assessed by checking long strips of data collected over regions with little or fixed surface deformation (e.g., Antarctic Plateau).

F.4.10.5 Schedule for Calibration and Validation Activities. Post-launch calibration activities will begin once the radar begins collecting data. These activities will be completed over a 3-month commissioning period. Once the instrument is calibrated, data will be released to the science community along with the calibration data and report.

The validation and evaluation experiments will occur during the first year. A full year is needed to obtain enough data to fully quantify errors due to tropospheric and ionospheric delays. The Science Team will generate an interim validation report after the first 3 months. A complete validation report will be issued at the end of the first year.

Radar performance evaluation will occur weekly during the commissioning period. For the rest of the first year, quality checks will be performed monthly. Performance will be evaluated every 3 months for the rest of the mission. Radar housekeeping telemetry and receive-only noise data samples will be screened as acquired to monitor instrument health

F.5 SCIENCE TEAM

The ECHO Science Team consists of a multi-institutional, multi-national, consortium of both academic and Government scientists. Collectively, team members bring the proper balance of expertise in InSAR, and Earth science analysis and modeling to the mission. Responsibility for meeting ESSP program objectives of providing calibrated and validated data lies with the PI, supported by the team. The team role also includes development and support of the InSAR processing software and support of education and public outreach efforts. In addition to the individual roles described below, team members' responsibilities are organized by focus areas in Table F-2. Curriculum vitae are provided in Appendix L.1.

In addition to the team members listed here, DLR will assign and fund additional German science team members, whose research will focus on the complementarity of ECHO and TerraSAR-X.

BERNARD MINSTER, Professor of Geophysics, SIO, PI: Fully responsible for all aspects of the mission and for the science team management. Establishes and operates a *Science Data Acquisition Planning Facility* on the UCSD campus and works with the Science Team to establish acquisition priorities with input from the broader scientific community. Participates in Southern California Cal/Val experiments. Acts as a liaison to EarthScope and to the commercial and application SAR communities.

PAUL ROSEN, Radar Scientist, JPL, Deputy PI: Ensures that S/C and instrumentation are configured to meet science objectives. Coordinates the development and dissemination of algorithms for interferometric SAR processing. Conducts radiometric and geometric calibration of the radar instrument using ground corner reflectors.

HOWARD ZEBKER, Professor of Electrical Engineering and Geophysics, Stanford, Deputy PI: Responsible for overall ground system architecture and validation algorithms definition and development. Responsible for assuring the quality of the SAR data distributed during the mission. Conducts Cal/Val experiments.

Table F-2: Science team focus groups. (Leads shown in italics)

Data Product definition & Availability	Seismic Objectives	Volcano Objectives	Ice Sheet Objectives	Orbit Control & Knowledge	InSAR algorithms & calibration	Education & Outreach
Zebker	*Jordan*	*Segall*	*Joughin*	*Sandwell*	*Rosen*	*Minster*
Sandwell	Peltzer	Thatcher	Rignot	Zuber	Zebker	Sandwell
Rosen	Simons	Simons	Minster	Segall	Simons	Jordan
Joughin	Minster	Zebker	Sandwell	Jordan	Joughin	Rignot
Peltzer	Segall	Zuber	Zuber	Rosen	Rignot	Thatcher

TOM JORDAN, Professor of Geophysics, USC, and Director of SCEC, Co-I: Ensures a heavily leveraged and ECHO-tailored education and outreach program with SCEC. Defines and promotes the role of ECHO data in integrative science activities. Communicates ECHO achievements to the National Academies, and ensures coordination with EarthScope .

IAN JOUGHIN, Glaciologist, JPL, Co-I: Specifies mission science requirements for glacier and ice sheets. Conducts Cal/Val experiments under the West Antarctic natural laboratory.

GILLES PELTZER, Professor of Geophysics, UCLA, Co-I: Conducts Cal/Val experiments under the Southern California natural laboratory. Specifies science requirements for earthquake studies. Investigates the effects of atmospheric delay on the recovery of large-scale deformation patterns.

ERIC RIGNOT, Glaciologist, JPL, Co-I: Conducts Cal/Val experiments as part of the West Antarctic natural laboratory, focusing on Pine Island and Thwaites Glaciers.

PAUL SEGALL, Professor of Geophysics, Stanford, Co-I: Coordinates the validation of ECHO-derived estimates of crustal deformation within natural laboratories in California and Hawaii.

DAVID SANDWELL, SIO, Co-I: Assembles ancillary data needed for first-order corrections to interferograms, with a focus on tropospheric effects. Validates the use of these corrections. Conducts calibration of InSAR and ancillary data using the dense GPS array in Southern California.

MARK SIMONS, Assistant Professor of Geophysics, Caltech, Co-I: Conducts Cal/Val experiments using modeling and continuous GPS. Coordinates data acquisition of volcanic events during the mission.

WAYNE Thatcher, Senior Research Scientist, USGS, Menlo Park, Co-I: Acts as liaison to the USGS and EDC. Develops an ECHO database for several volcanic sites distributed worldwide, analyzed at least once per month.

MARIA ZUBER, Professor of Geophysics, MIT, Co-I: Develops techniques to merge the small-scale deformation patterns derived from ECHO InSAR with the more accurate point-wise displacement measurements from the Southern California natural laboratory.

F.5.1 Team Activities

In addition to the above, team activities are targeted towards the following deliverables for the instrument calibration effort:

- ECHO instrument and navigation system requirements derived from measurement requirements.
- Design of the calibration plan, including GPS measurement and deployment of corner reflectors or other ground-based instruments
- Development, testing, validation, and delivery of the user InSAR processing software package.
- Derivation of calibration parameters including: time offset to first sample, inter-sample spacing, and along-track latency between the actual time of a pulse relative to the annotation time.

The PI will convene 3–4 science team meetings per year, depending on the mission phase. Prior to launch, meetings will focus on setting mission requirements and processing code development. After launch, team meetings will focus on Cal/Val activities. The PI will also convene and chair at least one science workshop per year to secure input from the scientific community concerning the mission and coverage priorities. Guests from the commercial and applica-tions communities will be invited to attend these workshops. The PI will appoint key discipline scientists from outside the core team to chair working groups on the ECHO science themes.

F.6 PLANS TO RESOLVE OPEN SCIENCE ISSUES

There are currently no open science issues to be resolved.

G. TECHNICAL IMPLEMENTATION

ECHO will be the first civilian SAR mission dedicated to a single measurement objective: vector deformation of Earth’s land surface. The deformation measurements for seismic, volcanic, ice sheet, and subsidence objectives will be made using repeat-pass Interferometric SAR (InSAR) data.

The radar electronics will be built at JPL and the SAR antenna at Ball. They will be integrated and tested at JPL and then will be shipped to Germany for integration with the Astrium built spacecraft (S/C) bus. Following I&T, the observatory will be sent to Baikonur Space Center in Kazakhstan where it will launch aboard a DLR contributed Dnepr launch vehicle. With overall coordination provided by JPL, DLR GSOC will be responsible for command and control of the observatory. The science data will be downlinked at the Alaska SAR Facility (ASF) and the University of Miami, FL.

G.1 Mission Design

The ECHO observatory will fly in a highly constrained, 8-day, exact-repeat, sun-synchronous polar orbit, at an altitude of 760 km. The ground separation between orbit tracks is 340 km at the equator (see Fig. G-1 and Table G-1). The radar has 3 steerable beams with an average swath width of 115 km. These beams are electronically steerable over a 340-km targetable range, so that it is possible to image any point on the Earth every 8 days. Complete coverage of any broad area is possible every 24 days (three 8-day repeats). The baseline science objectives call for a 5-year mission. The radar includes the capability for repeat-pass ScanSAR interferometry.

The instrument is designed so that the S/C bus can roll to image from either side for vector measurement and to image to extreme northern and southern latitudes. In the nominal flight attitude, the antenna boresight is pointed 30 deg from nadir to the right of the orbit plane, which keeps the sun on the solar panels. For left side imaging, the S/C executes a 60-deg-roll maneuver in 5 minutes to point the antenna to the opposite side (Fig. G-2).

The science objectives require an average of 7 minutes of data per orbit. The instrument and ground system with margin are designed for an average of 8.5 minutes per orbit evenly divided between left- and right-side imaging. Figure G-2 shows a typical sequence of data takes over a single orbit, including the roll maneuvers for left side imaging. Figure G-3 shows coverage for a typical 8-day period and demonstrates the variability in instrument usage and number of acquisitions per orbit. The mission is designed to accommodate up to 20 minutes on a single orbit.

Data will be downlinked to ground stations in Fairbanks and Miami. The bus has a large (256 Gb) onboard Solid-State Recorder (SSR) to allow the data to be downlinked to these stations (see Figure G-3). Following reception,

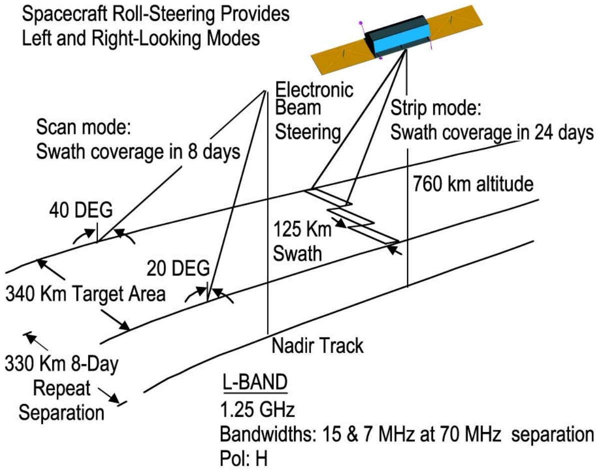


Figure G-1. Scenario illustrating the unique features of the mission. The nadir track separation is roughly 340 km at the equator. The antenna can electronically point to any of 3 standard strip mapping beams, or time-share all the beams in ScanSAR mode. The S/C can image to the right or left side of the orbit track. Mission planning consists of deciding which of the observation possibilities are spent in a given beam looking to a given side.

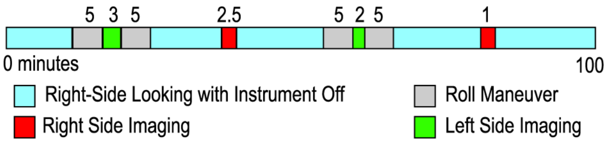


Figure G-2. Typical sequence of data collections for a single 100-minute orbit. Data take lengths are specified in minutes. Although this example shows 8.5 minutes of data collection, the number of minutes acquired per orbit may vary significantly as shown in Figure G-3.

Table G-1: Mission Design Table (K-5).

Parameter	Value, units	Contingency, units
Orbit Apogee Altitude, km	747 km	N/A
Orbit Perigee Altitude, km	760 km	N/A
Orbit Inclination, deg	98.46 deg	N/A
Orbit Node Time of Day for Sun Synchronous Orbits, hh:mm	0600 ascending node	N/A
Parking Orbit Apogee Altitude, km (if applicable)	N/A	N/A
Parking Orbit Perigee Altitude, km (if applicable)	N/A	N/A
Parking Orbit Inclination, deg (if applicable)	N/A	N/A
Launch Date(s), mm/dd/yy	10/01/06	N/A
Mission Lifetime, days	1825 days	N/A
Maximum Eclipse Period, minutes	18 minutes	N/A
Mass weighted reuse percentage of payload and S/C subsystem components, %.	Payload: 50% S/C: 66%	N/A
Mass weighted redundancy of payload and S/C subsystem components, %.	Payload: 100% S/C: 100% (excl. structure)	N/A
S/C Dry Bus Mass and contingency by Subsystem, kg and %	1333 kg w/contingency (see Table G-5)	23%
S/C Propellant Mass and contingency, kg and %	204 kg w/contingency	10%
Launch Vehicle Margin, kg and %	162 kg	11%
S/C Bus Power and contingency by Subsystem, watts and %	566 W w/contingency (see Table G-5)	23%
S/C Power Margin, watts and %	107 W (EOL)	19%

data will be transferred via fast Internet to a distributed online archive. The data will also be archived at EROS Data Center (EDC) and the San Diego Supercomputing Center (SDSC). *Data will be available online to the science community within 24 hours from reception at the ground station.*

G.1.1 Mission Design Drivers

Mission drivers are listed in the Mission Traceability Matrix Table G-2. ECHO's mission design and technical capabilities are focused on InSAR measurements, leading to a simple and cost-effective implementation. The primary factors driving the mission design are

- Polar orbit to allow ice measurements;
- Rapid repeat for noise reduction, ice motion, and transient observations;
- Tight orbit control for InSAR viability;
- Left/right, ascending/descending observations for vector measurements;
- Two L-band sub-bands for ionospheric corrections; and
- Electronic steering for pointing agility that simplifies mission planning.

G.1.2 Spacecraft

The ECHO S/C will be built by Astrium from its AstroBus line of satellite buses. AstroBus is the successor to FlexBus and follows the same design principles as the CHAMP and GRACE programs. CHAMP is a German satellite launched in July 2000 and is still operating successfully. GRACE is a US/German ESSP mission consisting of two FlexBus S/C that will launch in spring 2002.

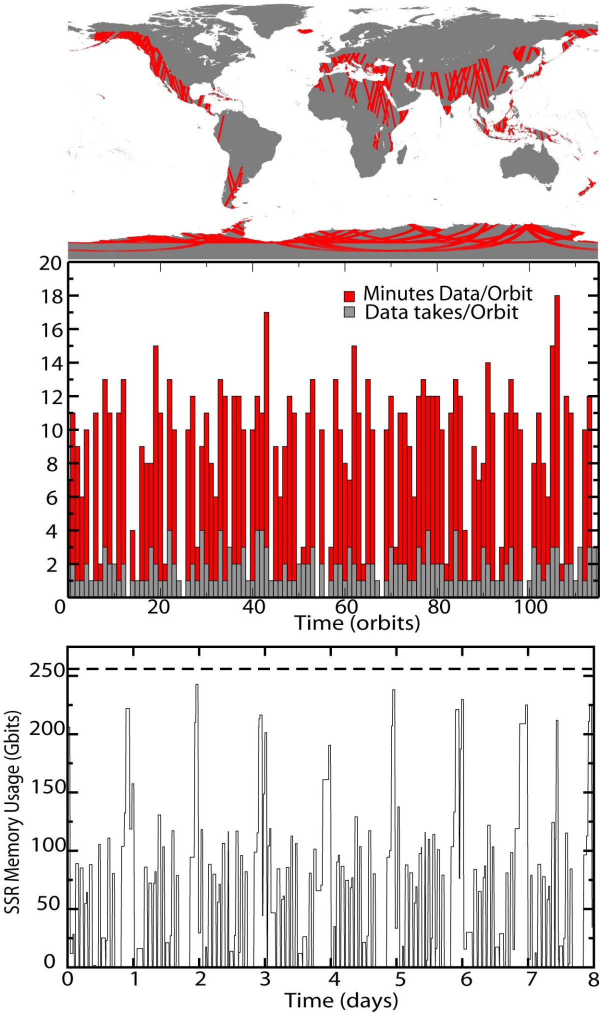


Figure G-3. (top) Typical 8-day data collection scenario during the ECHO mission for an average of 8.5 minutes per orbit. (middle) Related plot showing corresponding minutes of science data per orbit and data takes per orbit. (bottom) Plot showing amount of data resident in the solid-state recorder over the 8-day cycle. Dashed line shows the maximum capacity of the SSR.

An X-band SAR satellite called TerraSAR-X, which will launch 18 months prior to ECHO, is the first AstroBus build. TerraSAR-X is a private-public partnership between the German Space Agency (DLR) and Astrium GmbH.

Both the ECHO and TerraSAR-X S/C will be practically identical in terms of electrical architecture and the main structural features. Structural adaptations will be made to accommodate the ECHO deployable SAR antenna and a different arrangement of the propulsion module.

G.1.3 Instrument Accommodation

ECHO's L-Band antenna is designed around a fixed center frame that rigidly mounts to the S/C bus. The fixed center frame helps to maintain the rigidity and ensures flatness of the antenna panel system. Two 2-panel, deployable antenna sections mount to either side of the fixed frame and attach to the frame with moment-free fittings and standard flight-proven release mechanisms in the stowed condition. In the deployed configuration the antenna has an unobstructed view of the Earth. It can operate in either a right- or left-facing, (sun- or shadow-facing) orientation. The associated antenna Control and Power Distribution Unit (CPDU) mounts to the S/C bus' thermally-controlled electronics mounting structure, as does the radar electronics package.

The radar electronics receives and processes high rate data directly from the antenna and interfaces with the SSR, which multiplexes the high rate data with essential radar telemetry and science GPS data and passes it to the X-Band communication system. The radar electronics also has a power interface to the S/C Power Control and Distribution Unit (PCDU), a digital serial interface with the S/C On-Board Computer (OBC) for commands and low rate engineering telemetry, and discrete interfaces for analog and temperature telemetry. Figures G-13 and F/O Figure G2-3 illustrate the ECHO payload data pathways.

G.1.4 Launch Vehicle and Services

ECHO will launch on a DLR contributed Russian Dnepr vehicle, which is the same as that which will be used by the similarly configured TerraSAR-X. The launch preparation and lift-off will take place at the Baikonur Space Center in Kazakhstan. ECHO will be injected into a 400 km circular orbit and will propel itself to 760 km using the S/C mono-propellant system. Section G.5.1 describes the Dnepr flight record.

G.1.5 Ground Data System

ECHO uses a novel approach to ground operations rooted in a unique data, downlink, processing, and access policy. Data will be received at Fairbanks and Miami. Once received data will immediately be processed to level 1 format and transferred to a distributed online archive to provide users with access to the data within 24 hours of reception. The distributed online archive consists of 5 Internet-II connected sites to ensure rapid retrieval. The project will supply users with software for the generation of higher-

Table G-2: Mission Traceability Matrix (L-4).

Science Measurement Requirement	Mission Requirement	Instrument Requirement	Spacecraft Requirement	Ground System Requirement	Operations Requirement
Globally distributed measurement of vector deformation rates to 2 mm yr^{-1} (single component accuracy), which implies deformation accuracy of 10 mm at 35-100 m resolution over a 5-year mission.	- 250-m repeat orbital tube - 5-year duration Global accessibility - avg. of 8.5 minutes data/ orbit	- 35 m resolution - L-Band for vegetation penetration - Split-Band for ionospheric correction - Fully redundant design - Hi Xmtr power for accuracy	- Right/Left-looking capability (vector) - 256-Gbit on-board storage - Fully redundant design for 5 yr mission. - Pitch/yaw steering repeatability (0.05deg. 1σ) - GPS for position accuracy - 300 Mbps downlink	- avg 8.5 minutes data/ orbit capture to Level 1 archive - 300 Mbps reception.	- Navigation to repeat orbit track in 250 m tube - Dynamic modeling for pointing repeatability
Ability to map vector ice motion for Greenland and Antarctica to 1 m yr^{-1} (single component accuracy). 5-year mission to study temporal variability.	As above + - 8-day exact repeat, polar orbit.	As above + High SNR in radar-dark regions of ice sheet (σ^0_{NE}< –24 dB)	- Right/Left-looking capability (polar access)	As above	As above
Globally distributed monthly measurements of deformation with 5-10 mm accuracy. Frequent measurement during eruptions.	As above	As above	As above	As above	As above

level products. A web-based catalog will provide support for search and data transfer of the level-1 products and all ancillary data. This will be the primary means to access data within a period of 1 year from reception.

All mission data will be maintained in a long-term online archive at SDSC and at the permanent archive at EDC. These will be the primary distribution sites for retrieving data sets where it has been more than a year from reception.

ECHO will encourage peer-to-peer (P2P) exchange of SAR data and products such as images and interferograms, and incorporate P2P user-developed systems into the data catalog. ECHO will coordinate these activities with the NASA Federation of Earth Science Information Partners (ESIPs).

G.1.6 Mission Operations Plan

The Mission Operations System (MOS) design for ECHO focuses on mitigating S/C risk, while maintaining maximum science return. The MOS is divided into 3 major elements consisting of Satellite Operations, Instrument tasking/ monitoring and Precision Orbit Determination (POD). JPL will provide the overall management and systems engineering.

The German Space Operations Center-DLR (GSOC) in Oberpfaffenhofen will provide the satellite operations. GSOC will utilize existing staff and infrastructure in a multi-mission environment. GSOC currently provides operations services for CHAMP and GRACE. Twelve to eighteen months prior to launch, GSOC will provide operations services for the TerraSAR-X mission, which will utilize nearly an identical S/C bus as ECHO and will have similar in size, function, and navigation requirements.

JPL will support the MOS with instrument task planning, scheduling and monitoring.

POD is critical to mission success. GSOC will process satellite GPS data at a coarse level for navigation. The POD team at JPL will provide precision science orbits based upon the on-board GPS data. Orbits will be reconstructed at JPL using tools developed for a host of modern systems, including TOPEX/Poseidon, SRTM, GRACE, IceSAT, and Jason. Processed orbit data will be maintained on the database workstation and will be available to the science community via the Internet.

G.1.7 Mission Assurance, System Engineering, and I&T

JPL mission assurance will use the JPL Design, Verification/Validation and Operations Principles for Flight Systems to develop performance assurance requirements for the flight system. Mission assurance will include a rigorous parts upscreening program. To ensure a 5-year mission, both the S/C and instrument are fully redundant.

ECHO will have a project level systems engineering team (PSET) led by the project engineer, with participation from each project element. The PSET is the single coordinating engineering team for the project, responsible for system design and requirements development.

The basic approach to I&T will be to use a parallel process of mechanical and electrical verification and instrument and S/C development. The instrument/spacecraft will be integrated at Astrium. Following integration, interface verification testing, functional testing, and S/C environmental (EMC, T/V) will be carried out prior to shipment to the launch site.

G.1.8 Orbital Debris and De-orbit

The ECHO S/C will be compliant with the NSS 1740.14 guidelines. The Russian launch vehicle should be accepted by the NASA O.D. office for use on this mission. The JSC Orbital Debris Office Software (DAS Version 1.5.3) was used to determine compliance with Guidelines 5-1, 6-1 and 7-1. Guideline 5-2 will be met by using sufficient shielding from small debris. Other applicable guidelines are met. The DAS 1.5.3 program was run for the ECHO S/C for the nominal orbit and a 5-year mission. The probability of collision during the mission life was 0.0001, which is less than the required maximum of 0.001. ECHO will also meet the stiffer new proposed Debris Standards. The ECHO S/C will perform an orbit reducing burn at the end of the mission that puts the S/C in a 760 × 580 km orbit. The ECHO S/C (BC = .01 m^2/kg) will reenter within 24 years, meeting the 25-year maximum allowed orbit lifetime. DAS burn up model indicates that only the Titanium Tank fails to burn-up giving a casualty area of 1.5 m^2, which is less than the maximum allowed of 8 m^2. The launch vehicle upper stage will also perform a reduction burn.

G.2 Instrument Implementation

The SAR flight instrument consists of a radar electronics package, and a deployable active phased array antenna. The electronics consist of a Radio Frequency Electronics Subsystem (RFES) and a Digital Electronics Subsystem Radar Control and Timing Unit (DES RCTU) provided by JPL, and an Antenna CPDU provided by Ball. The antenna includes six active phased array panels provided by Ball, and a deployable structure provided by AEC-Able.

G.2.1 Instrument Description

F/O Figure G1-1 shows the functional block diagram for the radar instrument. The RFES generates the radar excitation pulses and amplifies, filters, and upconverts them to L-Band for transmission to the antenna, then downconverts, amplifies, filters, and digitizes the received radar echoes. It then performs data compression (using Block Floating-Point Quantization), adds a frame count, a PN sequence, time tags, and calibration data to the science data stream, and directs it via a high-speed (up to 175 Mbps) data-link to the S/C’s SSR. On transmission, the antenna amplifies the RF signals at L-Band, and radiates them to illuminate the swath. On receive, the antenna collects the returned echoes, amplifies them and feeds them into the RFES. The DES RCTU generates the radar system timing and control signals based on commands from the S/C OBC.

The ECHO radar design is kept simple by using space-qualified Microwave Monolithic Integrated Circuit (MMIC) and Field Programmable Gate Array (FPGA) technology to minimize the number of parts while maintaining design flexibility. The digital subsystem integrates the radar control functions with the S/C OBC such that a separate CPU is not required for the radar. By using the S/C OBC instead of a dedicated radar control computer, significant cost, mass, and power savings are realized. A serial interface between the S/C OBC and the RCTU will provide the once-per-datatake setup parameters that the RCTU distributes to control the RF Electronics Subsystem and the Antenna CPDU. The CPDU, in turn, distributes control signals to the Phase-Shifters and Transmit/Receive (T/R) modules of the antenna subsystem.

The RF, high-rate data handling, and digital control and timing assemblies are mounted in a custom stand-alone housing (Figure G-4).

G.2.1.1 RF Electronics Subsystem. The RFES will be implemented in eight custom enclosures as shown in F/O Figure G1-2: a Frequency Synthesizer, Chirp Generator, Upconverter, Driver/Receiver Front-End, Built In Test Equipment (BITE) Monitor, Downconverter, High-Rate Data Handler, and Power Converter. This approach was chosen to provide signal isolation between subassemblies, and to provide modularity to allow parallel development and testing. A second set of these eight subassemblies, which can be switched in as a single block, provide redundancy. A ninth subassembly, the Redundancy Selector, connects the active RF signals to the Antenna. Subsystem redundancy is illustrated in F/O Figure G1-3.

Frequency Synthesizer: The Frequency Synthesizer includes the Stable Local Oscillator (StaLO), and the frequency multipliers needed for signal up and downconversion. The StaLO is the phase reference for the entire radar. There are three time scales of stability relevant for ECHO: short-term stability (over milliseconds) for phase coherence over the round-trip time of a pulse from the antenna to the ground, medium-scale stability (over minutes) for phase fidelity over a single datatake, and long term stability (over weeks and years) for forming interferograms between data sets. Over the typical time of flight (7 milliseconds) the total transmit to receive phase should not vary more than 1 degree as result of oscillator instability. The medium-scale stability is related to frequency drift over the track. The frequency sensitivity for ECHO, given an 850-km slant range, is 24 mrad/Hz of change in the carrier frequency. Analysis shows that these performance requirements are met with currently available StaLOs, which have an Allan variance as low as 10^{-13}. The long term frequency drift is accounted for by providing a copy of the StaLO signal to the DES, where its frequency is counted against the GPS receiver Pulse-Per-Second (PPS) signal. The resulting count is inserted into the high-rate data header every second for ground processing.

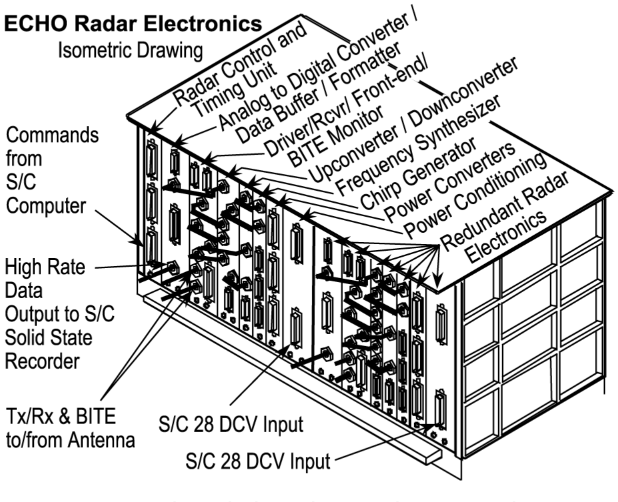


Figure G-4. Chassis housing Radar RF and DES.

Chirp Generator: The chirp generator uses a commercial off-the-shelf GaAs Numerically Controlled Oscillator (NCO) packaged for spaceborne applications. The chirped (linear frequency modulated) pulse is generated at an intermediate frequency (IF), time multiplexed with a CW calibration tone produced in the inter-pulse period between chirps. The chirp is generated in two segments, one at the low-frequency end of the 80-MHz passband, followed by another at the high-frequency end, to create the split-spectrum sub-bands. The chirp generator subassembly also creates the digital timing signals and synchronous clocks required by the other RFES subassemblies.

Upconverter: The IF chirp and caltone output from the chirp generator is mixed with the upconversion LO from the frequency synthesizer to produce the L-Band excitation signals in the upconverter. An RF switch gates out the chirp signal for routing to the driver subassembly, and the caltone is routed to the BITE subassembly. A copy of the chirp signal is also provided to the BITE subassembly to serve as a phase reference for transmit BITE processing.

Driver/Receiver Front-End: The driver/receiver front-end amplifies the transmit chirp signal from the upconverter, which is then directed through a circulator to the antenna RF feed. On receive, the circulator directs the RF return echo signals from the antenna to a limiter (for receiver protection), a bandpass pre-

Foldout G1

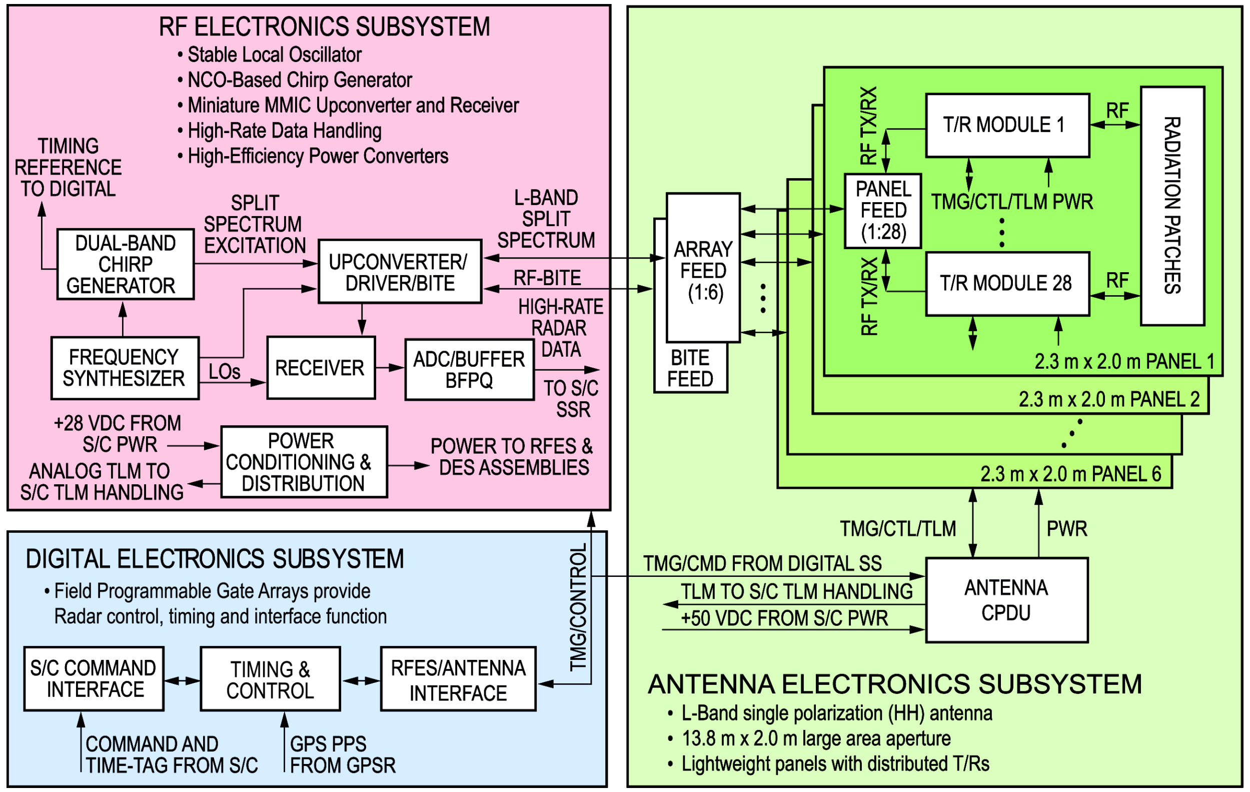


Figure G1-1. Block diagram of the ECHO Radar Instrument. The RFES, DES, and antenna CPDU are block redundant. The antenna panels degrade gracefully.

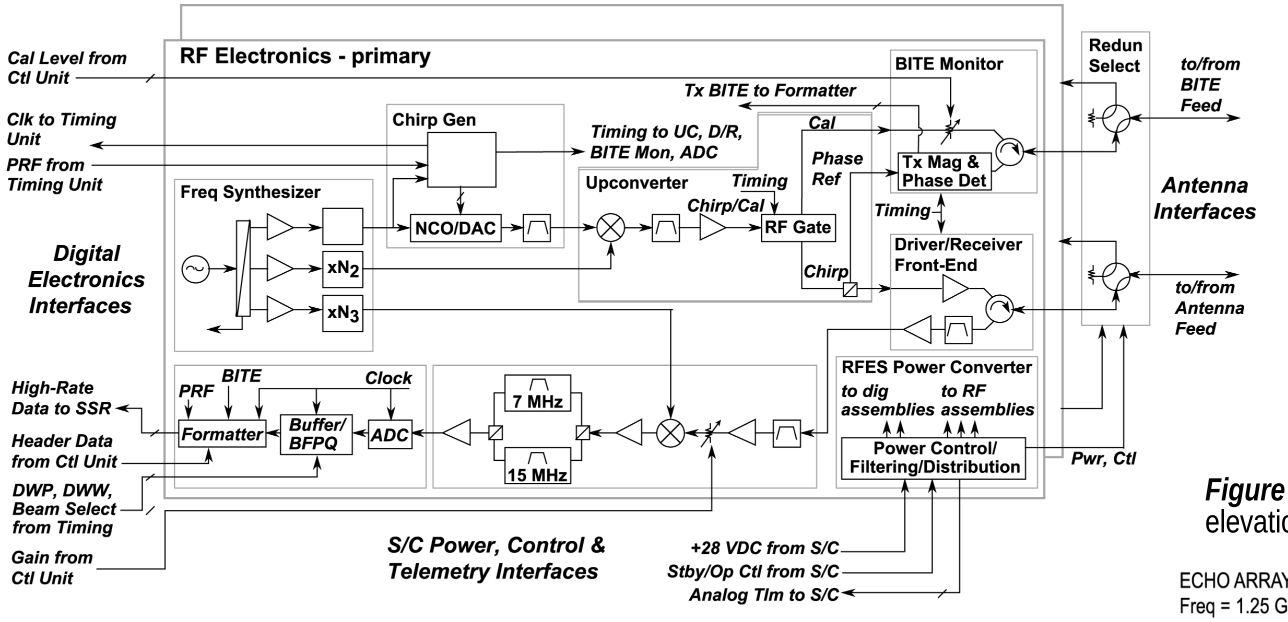


Figure G1-2. Block diagram of the Radar RF Electronics Subsystem. Gray boxes show the 8 RFES subassemblies that are replicated for the Primary and Redundant sides, and the Redundancy Selector subassembly.

Figure G1-5. ECHO Radar Antenna elevation and azimuth one way pattern.

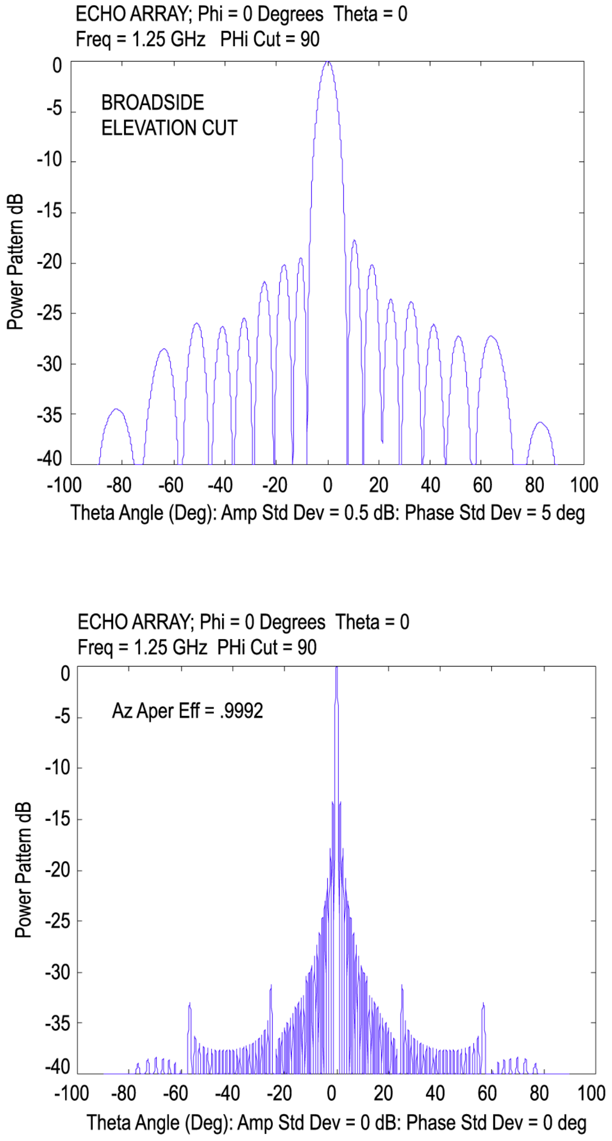
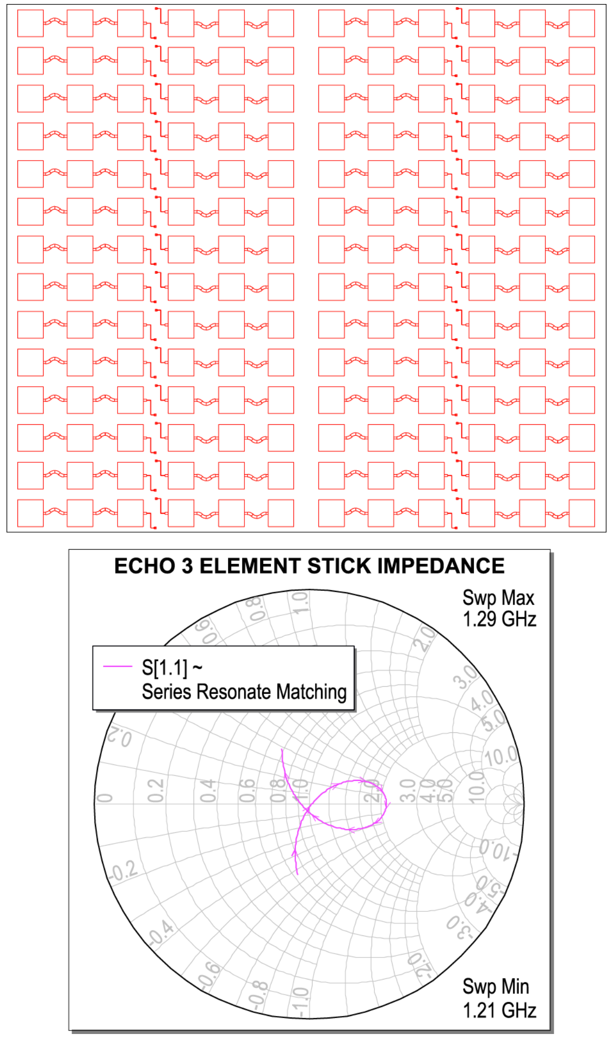


Figure G1-6. Optimized ECHO Antenna Panel is 2.296 m wide × 2.0 m high. Element Stick Input Impedance shows a good match over the radar 80 MHz passband.



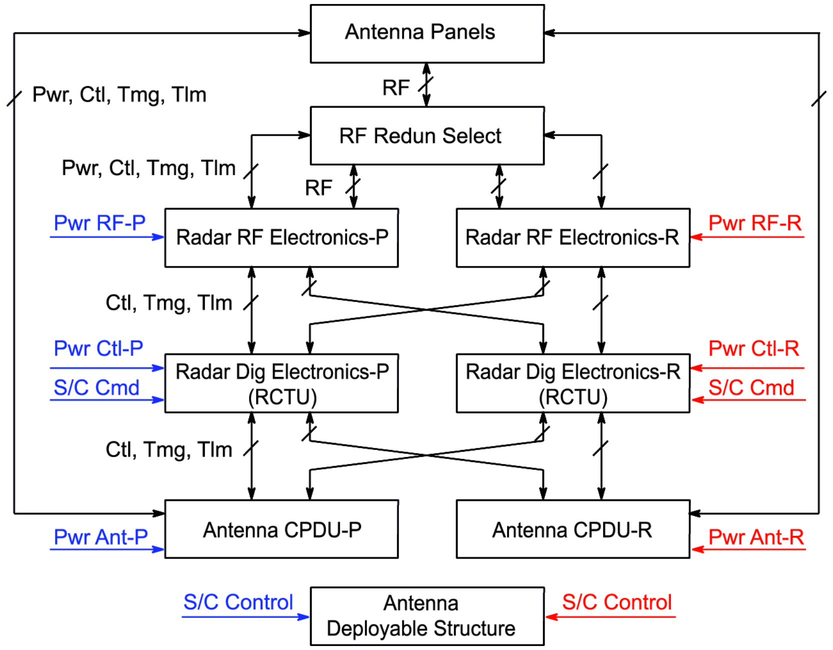


Figure G1-3. ECHO Instrument Redundancy. Redundancy cross-strapping allows for independent selection of primary or redundant RF, Control, and Antenna Interface subsystems so that multiple failures can be tolerated.

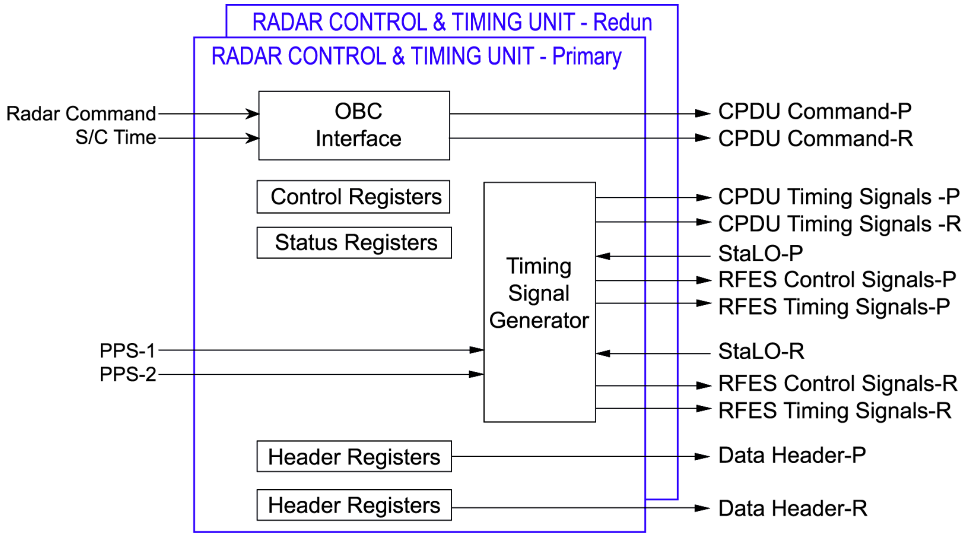


Figure G1-4. Block diagram of the DES RCTU.

selector filter, and a low-noise amplifier. The low-loss preselection filter provides out-of-band spurious rejection and a low-loss input limiter and receiver-protect switch provide sufficient isolation from transmitter leakage. The return echoes are then routed to the downconverter. To minimize cost, the driver/receiver front-end uses the same design and parts as the T/R module used on the antenna, packaged to fit in the RFES enclosure.

Downconverter: The downconverter uses a heterodyne conversion scheme from L-Band (1.2 GHz) to range offset video, with image-rejection filtering at RF and anti-aliasing filtering at video. Separate anti-aliasing filters are used for the two sub-bands of the split-spectrum to suppress the noise between the bands that would be folded in-band after sub-harmonic sampling. The design also features gain control, which is provided by RF and IF digital step attenuators. Parts count is minimized to reduce cost and improve reliability by utilizing an active MMIC downconverter, which integrates a local oscillator buffer amplifier, double-balanced mixer and IF amplifier into a single GaAs monolithic chip. The control components include integral TTL driver circuitry. The use of versatile, broadband components ensures maximum design flexibility. The MMIC L-Band receiver prototype developed under ARTP funding exhibits low noise, high dynamic range, and excellent linearity and stability. A cost-effective MMIC packaging approach has been demonstrated that will be applied to other MMIC-based hardware components in the ECHO transmit chain.

The single-channel offset-video design for the receiver back-end is chosen over the traditional two-channel In-phase/Quadrature (I/Q) design since it requires only one low-rate (55 MHz) analog-to-digital converter (ADC). This approach eliminates phase errors introduced by imbalance in the gains and phases of the I and Q channels, and DC bias errors in the ADC output. The data rate and processing for offset video data is the same as for I/Q data.

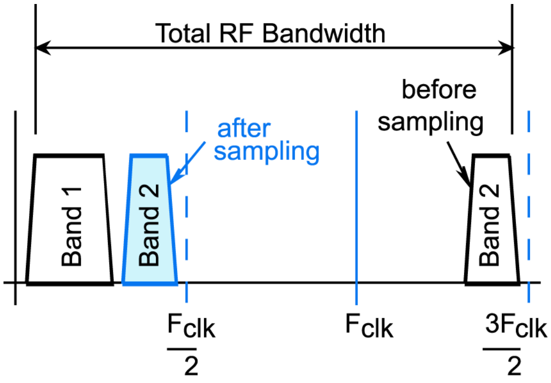


Figure G-5. Subharmonic Sampling Spectrum Reduction. Total RF Bandwidth = 80 MHz; Sampling Frequency = 55 MHz.

High-Rate Data Handler: The high-rate data handler is composed of an ADC, Data Buffer, Block Floating Point Quantizer (BFPQ), and Data Formatter. The offset-video 80MHz-bandwidth split-spectrum analog signal from the downconverter is digitized using a single 8-bit ADC operating at a 55 MHz sampling rate. The effect of sampling with this sub-Nyquist frequency is to fold the spectra of the two sub-bands such that they become contiguous in the frequency domain (Figure G-5). As a result, no storage and downlink bandwidth is wasted on the empty spectrum between bands. The digital data are then buffered using a FIFO memory and fed at a constant rate into the BFPQ. The BFPQ partitions the data into blocks of range samples and evaluates the mean-squared intensity of the data within the block. Since raw SAR data has a slowly varying dynamic range, 4 bits/sample has been demonstrated to be sufficient for InSAR, given there is little distortion for either underflow, or ADC saturation. The BFPQ optimally compresses the data to 4-bits utilizing the intensity information derived from the 8-bit ADC data. The average intensity is also sent in the data stream so that the original dynamic range of the 8-bit data can be restored. The BFPQ 2:1 reduction in data volume is critical to meeting the data storage and downlink rate limitations.

The BFPQ output is fed into the high-rate data formatter, where it is merged with a frame line header for every transmitted pulse. The frame line header will consist of a sync code; a non-rollover 11-bit frame count (maximum value equal to the maximum PRF); the ScanSAR beam select information; the Data Window Position (DWP) (provided in order track the preprogrammed DWP); and the transmit BITE data.

Every GPS one-second pulse the formatter will introduce an additional one-second header that will be inserted into the science data stream and fed into the S/C SSR. This header consists of the S/C time incremented by the S/C GPS one-second pulse; the current RCTU status; and the

StaLO drift measurement. This one-second-event header will also reset the frame counter to zero. The data stream output from the formatter is then routed to the S/C SSR.

Power Converter: The power converter filters and conditions the DC power from the S/C 28V-power supply. It includes the DC-DC converters to provide the voltages for each RFES subassembly and for the DES RCTU. Independent converters are used for the RF and digital subassemblies to provide noise immunity.

G.2.1.2 Digital Electronics Subsystem.

The DES consists of the RCTU. The RCTU receives radar commands from the S/C OBC and configures the radar electronics (PRF, DWP and duration, receiver gain and caltone level settings) and antenna control electronics (elevation beam steering angles, ScanSAR timing) for data-taking. F/O Figure G1-4 shows a block diagram of the DES. The RCTU is a single card that will be enclosed in a subchassis, and integrated with the RFES subassemblies as shown in Figure G-4. The S/C OBC controls the RCTU through a series of write-only registers. The card design leads to significant reduction in digital subsystem cost and complexity. The RCTU will drive both the primary and redundant RF Electronics and primary and redundant Antenna CPDUs.

G.2.1.3 Telemetry. Radar engineering telemetry from the RF Electronics Subsystem, including temperature and DC current and voltage measurements, will be directed in analog form to the S/C OBC. Radar engineering telemetry from the Antenna Subsystem, including panel temperatures, voltages, and currents, will be digitized, serialized, and routed from the CPDU to the S/C OBC. These engineering telemetry data will be downlinked via the S-Band narrow-band realtime link, and will also be multiplexed in to the high-rate data stream to the SSRs. Radar science and calibration data will be sent to the S/C's SSR for storage.

G.2.1.4 Antenna Electronics. The ECHO antenna electronics subsystem consists of a six-panel active phased-array antenna, and an antenna CPDU. The antenna has T/R modules, DC electronics, a six-way RF T/R feed network, and a six-way RF BITE feed network.

Parameters for the antenna subsystem are given in Table G-3. The entire radar antenna, including the antenna panels, structure, and deployment actuators, weights approximately **500 Kg** (including 30% contingency) and requires **1663 W** (including 27% contingency) of prime power when operating. The combined G/T plus EIRP margin is **1.2 dB**. A total of 168 distributed T/R modules combine to radiate 3,400 Watts of RF power. The elevation patterns have sidelobes that are less than –15 dB, and a HPBW of 6.7 degrees. The azimuth pattern has a HPBW of 0.88 degrees, and has uniform weighting. The array is designed to scan in elevation ±25 degrees without grating lobes and ±1 degree in azimuth with grating lobes less than 16 dB. F/O Figure G1-5 shows a typical elevation and azimuth one way radar pattern.

System level RF BITE will be implemented for both health check and calibration on both transmit and receive. In transmit mode, HPA power sampling and routing to the RF Electronics BITE Monitor for magnitude and phase detection, will provide an accurate transmit power level and phase of every T/R module. The receive RF BITE will use the same couplers to

Table G-3: ECHO Antenna Characteristics.

Dimensions	13.8 m x 2.0 m
Radiated Power Requirement (peak)	3400 W
Noise Temperature Requirement	800 K
G/T * EIRP Requirement	82 dBW/K
EIRP expected	72.9 dBW
G/T expected	10.3 dB/K
G/T * EIRP expected	83.2 dBW+G/T
# of panels	6
# of element rows (in elevation) per panel	14
# of element sticks in azimuth per panel	2
# of element sticks driven per T/R	1
Total number of T/R modules	168
Avg DC power when taking data	1663 W (incl. 30% contingency)
Mass	500 kg (incl. 27% contingency)

inject a calibration tone through a 6-way (array level) and 28-way (panel level) BITE feed. Each T/R has its own BITE enable line to activate each channel independently. Transmit and Receive BITE will sequence on one channel at a time, while the on-board BITE monitor and receiver sample the amplitude and phase response of that channel. The RF BITE feed manifold will have to be independently characterized in order to separate out the phase and amplitude errors from those of the radar.

The ECHO radar antenna architecture is shown in Figure G-6. The antenna interfaces mechanically to the S/C, and electrically to the radar RF Electronics (Transmit/Receive and BITE), the RCTU (timing and commands), the S/C's controller (telemetry and deployment control), and the S/C's DC power source. RF interfaces to the radar RFES are via coaxial cable. Antenna DC interfaces (power, control, and telemetry) are via multi-wire connections.

L-Band Panel Design: Each panel assembly measures 2.296 m × 2.0 m. The panel design integrates printed antenna board (PAB) and structure in a manner identical to SeaSat. The antenna portion is made of etched copper elements on a 0.50-mm face sheet with a 0.13-mm copper-clad FR-4 ground plane separated by a 12.7-mm dielectric honeycomb core. In addition, there is another 12.7-mm honeycomb core and a 0.50-mm face sheet on the other side of the ground plane. This provides additional panel strength and a thermally balanced cross-section about the ground plane. The element feed is through a feed pin into an SMA connector soldered to the ground plane. The face sheets are 0.50-mm, and the dielectric honeycomb core is HRH-10, 1/8-3.0.

Antenna Subsystem RF Design: The radiating aperture is located on the front side of each panel and the active T/R modules and beam-steering/beam-forming unit are located on the back side. The radiating element architectures, consisting of the spacings between patches in both dimensions as well as the series-feed transmission line, are similar to those used on the SIR-C apertures (Figure G-7). Each radiating element stick (6 patches) has 2 feed ports that must be excited with signals 180º apart. The 180-hybrid circuit will therefore be integrated into the T/R module. F/O Figure G1-6 shows the elements viewed from the radiation side of the panel and the input impedance over an 80 MHz bandwidth. The T/R module utilizes a class C discrete amplifier to achieve 45 Watts (at the HPA output) for the centermost eight T/R modules. The outside three channels on both the top and bottom of the panel will utilize a 25 Watt

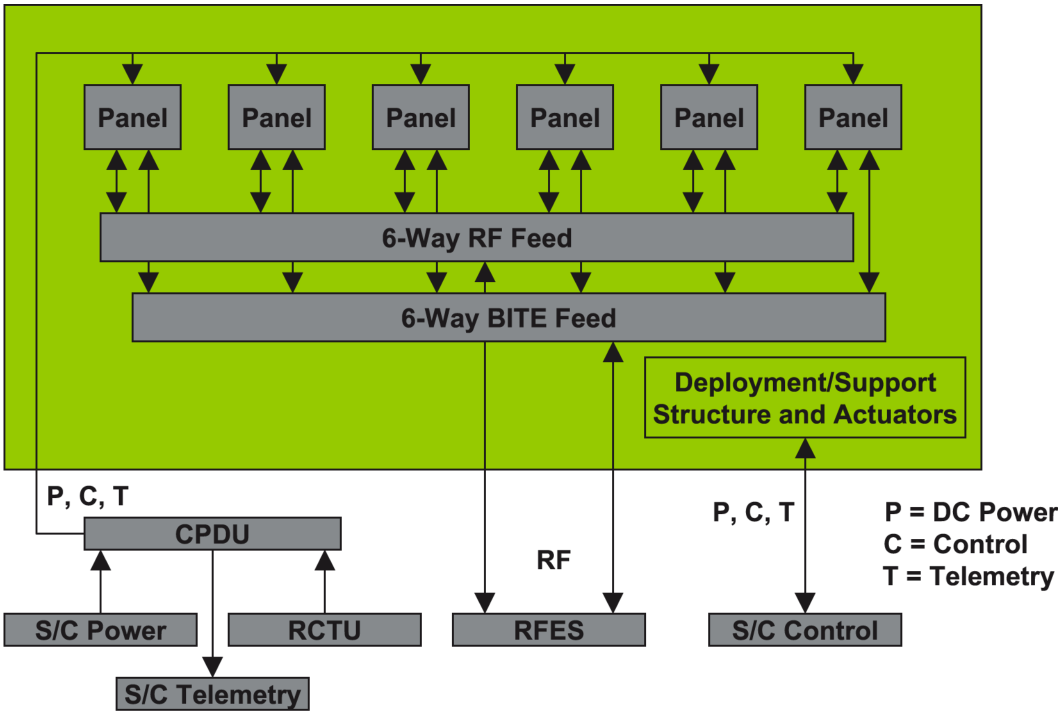


Figure G-6. Block diagram of the ECHO Antenna Subsystem.

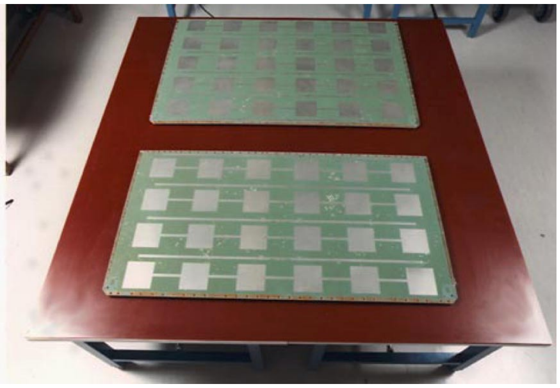


Figure G-7. SIR-C L-Band radiating elements.

part for improved efficiency and the desired 4.4 dB taper. The receive beam taper will be achieved using a variable attenuator located on the output side of the LNA. A transmit receive switch will be used in place of a circular/isolator because it can be made with less loss, better isolation, lower weight, and less real estate.

The T/R modules are connected to the Phase Shifter Control Unit (PSCU) that has fourteen 4-bit phase shifters and a 14-way combiner network as shown in Figure G-8. The phase shifters, which are downstream from the T/R modules, are common to both the transmit path and receive path. To eliminate costly phase trimming at the T/R module level, the phase alignment errors will be measured at the full panel level and the phase shifters will be utilized to phase align all the elements on transmit and receive. Since the phase alignment errors will be different on transmit and receive, the phase shifters and control logic will be implemented to allow switching the phase bits between each transmit pulse (one setting for transmit and a different setting for receive). The 4-bit phase shifter will be designed utilizing SMT SPDT switches. This solution is low cost, low DC power, and has excellent amplitude and phase performance. The 14-way panel combiner/divider is a uniform weight combiner made up of 2:1, 1.33:1, and 1:1 power dividers.

Antenna Control and Timing Electronics: Commands received by the CPDU from the RCTU are distributed independently to each PSCU in a serial bit stream via the CPDU signal/power harness. Each PSCU receives the command and can control T/R module DC power. Timing signals from the RCTU control the switching of the T/R modules between transmit and receive and control the PSCU phase shifters to sequence through the ScanSAR beams are passed via the CPDU and PSCUs. The S/C GPS receiver provides a one-second-time tick to the RCTU that is passed to the PSCUs via the CPDU to coordinate the serial transmission and reception of commands and telemetry.

DC Power: The antenna subsystem DC power originates in the S/C bus and is distributed to the panels via the CPDU. The CPDU serves as a breakout box with an input power cable interface to the S/C and output power cable interfaces, one for each antenna panel. At the panel level the PSCU accepts the input power from the CPDU and uses switched-redundant DC/DC converters to provide power for telemetry and phase shifter control. The PSCU also filters the CPDU-input power and supplies it the T/R modules via a power harness. The current-carrying requirement for this harness is minimized by utilizing storage capacitors within the T/R modules to provide the short-duration, high-

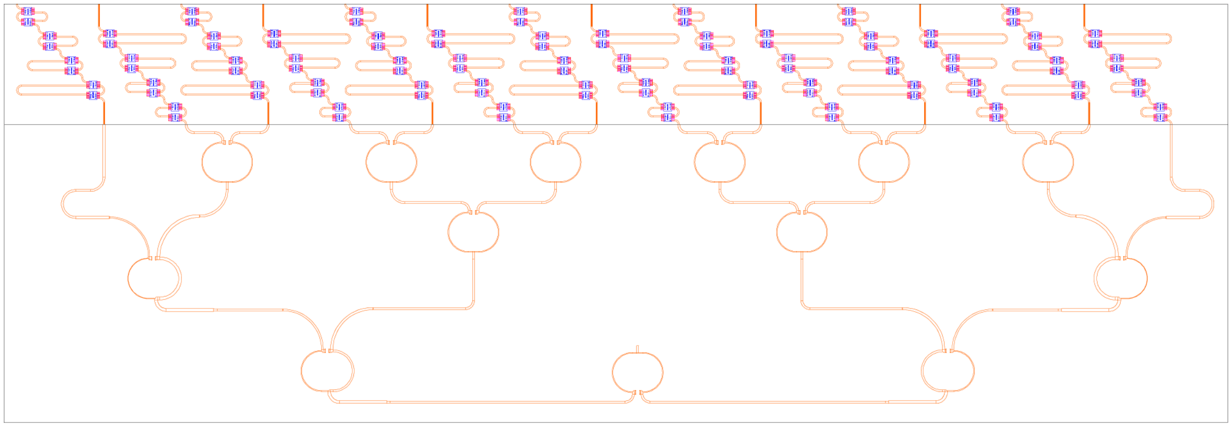


Figure G-8. Panel-Level Phase Shifter/14-Way Combiner Divider Circuit.

level current required by the high-power amplifiers (HPAs) during the transmit pulse. The T/R modules implement DC/DC converters to generate the HPA and LNA voltages necessary and provide enhanced operational reliability. In-rush current protection will prevent excessive current draw from the S/C power bus during antenna panel power-up. The CPDU will provide further in-rush current protection by sequencing the antenna panel power-up order.

Telemetry: Within each panel the PSCU independently monitors the voltage and current levels for each T/R module, digitizes these values, and formats the results for the serial PSCU telemetry output. In addition, each panel has six temperature sensors mounted externally on select T/R module housings and the back surface of the panels. The analog temperature sensor outputs are digitized and formatted into the serial PSCU telemetry output that is transmitted to the CPDU via the CPDU signal/power harness. Logic within the CPDU receives telemetry from the PSCUs and combines the result to create a radar antenna telemetry output frame. The frame is transmitted serially to the S/C OBC over a ~9-second interval.

G.2.1.5 Antenna Mechanical. The antenna mechanical subsystem consists of support structure, launch support latches, and deployment control actuators. The deployed antenna system is shown in Figure G-9. The support structure is divided into three sections: a center adapter truss and two extendable support structures (ESS). The stowed antenna interfaces to the S/C bus by a kinematic mount at the center adapter truss. Each separate ESS is attached to the center adapter truss at two hinge points and at one point, through an articulated strut, to the upper and lower S/C bus internal platforms. The (ESS) deployment rate is controlled by an electric-motor-driven actuator located on the truss corner bracket. The deployed ESS is a rigid, three-point-interface, deep truss that supports the antenna wing and maintains its flatness after deployment. This mechanical arrangement, a center truss and two ESS, allows the antenna subsystem to be pre-assembled, aligned, and tested prior to final integration into the bus. The proposed ESS is a lighter version of that used in the RADARSAT 2 antenna.

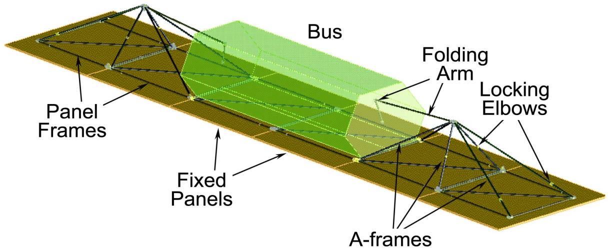


Figure G-9. ECHO S/C with deployed Radar Antenna.

Extendible Support Structure: The ESS is made up of lightweight tubular folding truss elements and associated mechanisms that deploy and position the flat radar antenna panels as shown in Figure G-16. Accurate and stable deployed position is vital to the performance of the radar system. The deployed antenna contains 6 panels in a linear array. Two deployment mechanisms, one on each end of the bus are employed to deploy 4 of the antenna panels. The two center panels are mounted to the bus on a fixed stable truss structure.

Deployment Mechanism: The key element in the approach to mitigating risk during deployment is a synchronizing linkage that directly couples rotation of the outboard panel hinge to rotation of the inboard panel hinge. This simple, robust linkage connected between the two panel hinges provides deployment torque to the outboard panel hinge and maintains absolute determinacy of the ESS’s position throughout deployment. The synchronization linkage alone positions the panels during deployment. The folding truss elements that provide depth to the deployed truss (A-frames and folding arm) do not control deployment in any way nor do they contribute significant deployment forces. These unfolding truss elements are just “along for the ride” in that they follow the controlled motion of the deploying panels into their fully deployed positions. A deployment motor actuator applies torque to the inboard panel hinge to deploy the truss. Reversing the motor stows the truss from any stage of deployment prior to lockout. Deployment is completed and is maintained by the locking out of spring powered elbow hinges in the A-frames and folding arm. The deployment sequence is illustrated in Figure G-10.

Deployment Actuator: The deployment actuator consists of a redundantly wound brushless DC motor, gearhead, and drive arm. An electronic control unit with separate redundant channels controls the motor to a constant output speed.

Truss Structure: When deployed the ESS forms a statically determinate deep truss structure. As such, on-orbit loads are carried prima-

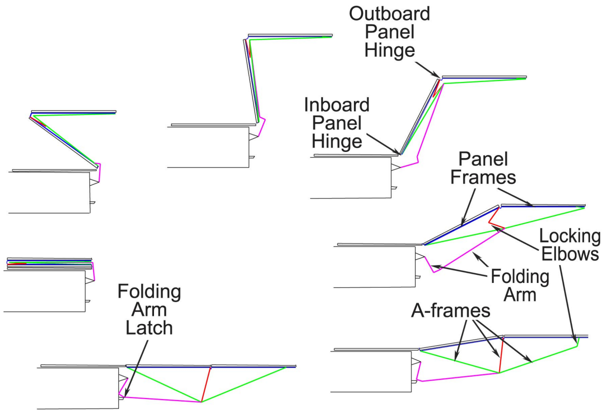


Figure G-10. ECHO Radar Antenna deployment sequence.

rily as axial loads by the truss elements thus maximizing structural efficiency. The absence of overconstraint intrinsic in a statically determinate truss is key to providing a stable support for the antenna panels. Accurate and stable deployed position is a function only of the effective length of each truss element; it is not affected by bending and torsional distortions in truss elements. Use of a statically determinate truss simplifies thermal distortion behavior which is predicted from the change in length of each truss element as a function of temperature. Tubes are covered with thermal tape of appropriate optical properties to control their temperature.

Hinge Joints: All hinge joints utilize plain bearings with fully floating hinge pins for bearing surface redundancy. Preload mechanisms are incorporated at all hinge joints active in the deployed truss to establish a repeatable deployed position by removing deadband resulting from mechanical clearances. Preload is applied between connected truss elements in the axial direction of the truss element thereby trapping the floating pin connecting them.

Kinematic Panel Mounts: Preloaded sliding friction type kinematic mounts allow for in plane differential thermal expansion between the truss structure and the panels. All kinematic mounts will allow limited travel in all three rotational degrees of freedom. Zero, one, or two translational degree of freedom mounts will be used at the four corners of each panel to accurately maintain the position each panel while allowing it to expand and contract.

Snubber System: A system of snubbers is incorporated to support long span tubes against launch loads. Snubber brackets are mounted to the panels or bus sidewalls and rubber pads contact the tubes.

Launch Restraint and Release Mechanism: The stowed antenna panels will be restrained to the bus using 8 cup/cone type stacks each released by a separation nut type release actuator.

G.2.1.6 Flight Software. Radar instrument flight software will be integrated with and will operate in the S/C OBC. Commands for data acquisition will be uploaded via the S-Band link and stored by the S/C OBC. Essential functions of the instrument flight software are:

- Queue data acquisitions by time tag;
- Parse science data acquisition commands into sub-commands for radar electronics, and S/C subsystems;
- Switch power on to primary or redundant radar and antenna electronics according to settings in sub-commands;
- Write telemetry, GPS, and attitude control data to the SSR immediately prior to and after each science data acquisition;
- Monitor instrument and S/C telemetry for hazardous states and take the appropriate steps to secure proper instrument and S/C operations;
- Provide time synchronization functions between the S/C and radar instrument.

Only a single data acquisition command is required per science data take, reducing the complexity of the OBC software.

G.2.2 Instrument Margins

Instrument performance margins are summarized in Table F/O F1-3. The instrument radiated power is driven by the requirement for a σ^0_{NE} of better than –24 dB. The worst case instrument performance of –30.5 dB provides a margin of 6.5 dB, which exceeds the *JPL Radar Design Principles* of >5 dB margin.The other key instrument margin is the data rate. The S/C can handle data rates up to 2260 Mbps. An allocation of 175 Mbps was assigned that is consistent with the mission design and SSR size. The average data rate for the 3 beams is 133 Mbps, so the margin for telemetry overhead (e.g., headers) is 30%.

G.2.3 Margins Driving Cost

None of the instrument margins mentioned above are major cost drivers. The lifetime reliability margin drove the redundancy requirement and cost of the instrument. The use of screened parts over the space grade parts also drove the margin to choose redundancy over a single-string design. Cross-strapping of the radar instrument hardware elements increases the design margin over a single-string design while maintaining cost

G.2.4 Items to be Developed

No significant development is required for the radar electronics or antenna assemblies. All designs draw on hardware heritage from previously flown missions.

G.2.5 Design Heritage from Existing Instruments

A key example of the design heritage of ECHO is the selection of just one of the operational modes demonstrated with SIR-C. The design draws on other lessons learned and hardware heritage from previous missions, combined with hardware designs for certain elements from ARTP. Development thus far has focused on advanced, but production-oriented, L-Band radar demonstration modules, such as the receiver described previously. Some components have been tested in flight aboard the NASA JPL DC-8 airborne radar test bed. These designs represent an order of magnitude reduction in power and mass over hardware in earlier spaceborne radars. Using this miniaturization technology, a radar receiver can be built with all dimensions smaller than 17 cm.

Figure G-11 shows an RCTU developed under ARTP, which will be the type of technology used for ECHO. Figure G-11 also shows the reduction in size of a block-adaptive floating-point quantizer from a full circuit board with 80 components to a miniaturized chip-based architecture. Prototypes of these designs exist and will be available at the start of ECHO Phase 2 for test and evaluation, and potentially direct integration. A single chip implementation of the SIR-C BFPQ has achieved a 40:1 reduction in power consumption for that unit with no loss in throughput and will serve as the basis of the ECHO BFPQ. Finally, Figure G-11 also shows an ADC board without parts installed that was developed for JPL's ARTP. The ADC, BFPQ, and data formatter for ECHO will reside together on a single card.

The ECHO antenna subsystem, including the deployment/support structure and the SAR antenna, is a highly mature design by virtue of the heritage from which its major components are drawn. The deployment/support structure and actuators have strong heritage from SeaSat (Figure G-12) and RADARSAT-2, and the antenna design draws heavily from SIR-C.

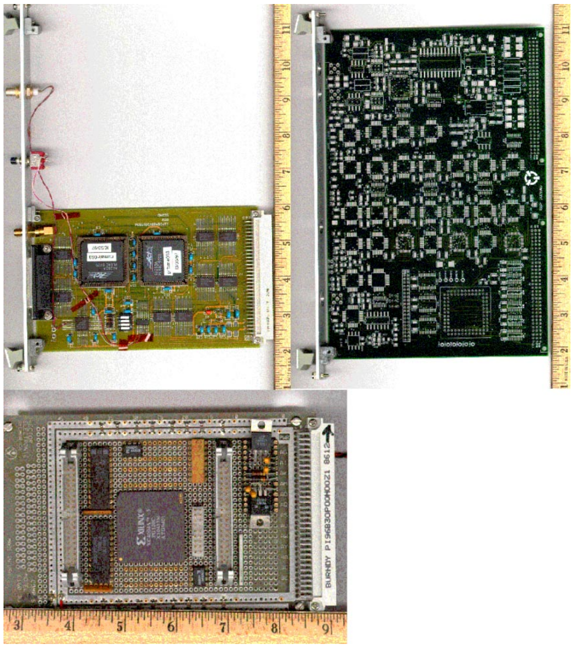


Figure G-11. Breadboard units developed under ARTP. Top left - RCTU. Top right - ADC buffer board layout. Bottom - BFPQ board. Scale in inches.

Figure G-12. SeaSat antenna and structure in deployed state with thermal blanketing.

G.2.6 Steps for Space Qualification

Space qualification of the components and higher level assemblies will be performed to ensure proper radar and S/C operations. These steps will include everything necessary from parts screening and testing to subsystem redundancy so as to provide a low-cost, high-reliability instrument design. These space qualification steps will be in accordance to applicable JPL S/C design practices.

G.2.7 Cost Saving Innovative Features

Innovative design approaches provide ECHO cost savings. For example, the use of the S/C OBC to perform the various radar command and telemetry monitoring tasks simplifies the radar digital subsystem significantly. The flight software to command and control the radar is kept simple and merely parses the command frame to the RCTU for distribution to the radar and antenna electronics prior to a data take. At the data take end the OBC performs a shutdown sequence to conserve power. The flight software never performs any real-time calculations or timing operations relative to the radar instrument, instead operating in the second to second environment. This reduction in hardware and software complexity reduces both test time and risk, resulting in a significant cost savings.

G.2.8 Instrument Calibration

Phase instabilities are not a significant problem for existing radars (e.g., ERS), which have no special interferometric requirements. To achieve even better performance, ECHO will use a rigorous calibration scheme to mitigate any system-dependent phase errors.

The radar calibration approach is similar to that used for SIR-C in InSAR mode. Before launch, the amplitude characteristics and pathlengths through the radar electronics will be calibrated as a function of temperature. The transmit-and-receive phase of the antenna panels plus RF feed will also be calibrated versus temperature. From these measurements, a model of phase and amplitude versus temperature for the radar will be developed. The model will generate system calibration files, which will be used to remove system-dependent phase errors during processing. This file will also contain system-dependent radiometric calibration parameters. This model and the resulting calibration files will be validated during the commissioning phase and updated as necessary using data collected over ground calibration sites.

To facilitate calibration of the science data, temperature measurements for the antenna and radar electronics, made throughout each data take, will be incorporated into the radar data trailer. A calibration tone, routed sequentially to each T/R LNA through the BITE feed will be embedded in the radar data stream to allow monitoring of the radar receive gain and phase. The transmit signal amplitude and phase for each T/R HPA will be monitored in the BITE Monitor subassembly of the RFES, and inserted into the radar data headers. Samples of receive-only noise data will also be collected at the start of each datatake. Short data takes, designated as instrument health checks, will be carried out as needed and analyzed on the ground.

G.2.9 Operational/Control Considerations

The operation and control of the radar instrument is straight forward and has been kept simple to allow for ease of test and integration. All digital interfaces are based on a standard RS-422 transmitter and receiver pair, and the analog interfaces use flight proven designs.

The radar operates in a simple fashion. There are no unknowns in the timing or in the data being collected. All timing is synchronous and data is collected in fixed block sizes. Neither the S/C OBC or the radar digital hardware checks command parameters; this is accomplished on the ground during the command generation process. The S/C OBC will not perform any sub-second real time command operations. The OBC will not perform any radar data processing or intervene with the RCTU during the data take, outside of collecting and storing of payload telemetry.

The S/C OBC shall configure RCTU by writing to a series of RCTU control registers. The OBC will determine RCTU status by reading RCTU status registers. The configured RCTU will provide control and timing to the RFES and antenna CPDU. All RCTU timing signals will be generated from the RFES StaLO clock.

The radar high-rate science data is written directly to the S/C SSR. During the down link opportunities the data is read out of the SSR at a high rate and received at ground stations.

G.3 Instrument Interface and Payload Integration

G.3.1 Instrument/Spacecraft Interface

ECHO utilizes the AstroBus configuration that was designed for TerraSAR-X. Since this configuration was designed specifically for a SAR instrument only minor payload interface modifications are needed.

G.3.1.1 Instrument/Spacecraft Electrical Interface. The instrument/spacecraft electrical interfaces are as simple as possible to accommodate the following functions: transfer of power, command, timing synchronization, engineering telemetry, and high-rate science data.

A graphical description of the ECHO payload data pathways is shown in Figures G-13 and F/O Figure G2-3.

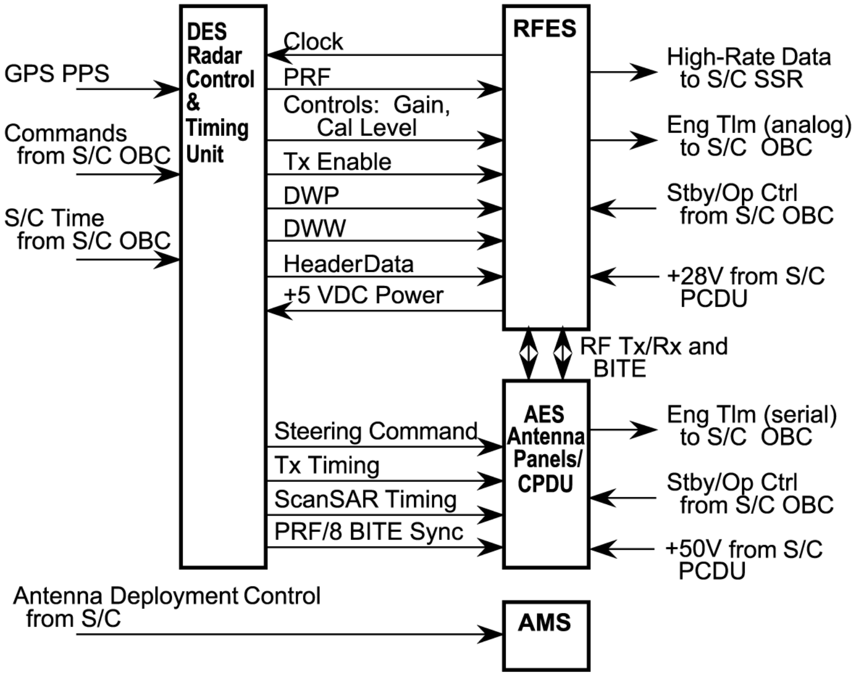
Power: Unregulated 50 V DC power is provided by the S/C PCDU to the antenna electronics via the instrument's Antenna CPDU. Regulated 28 V DC power is provided to all instrument electronics and the antenna deployment electronics. The PCDU power interface supports both primary and redundant instrument units.

Timing Synchronization: The S/C OBC provides a GPS-based PPS time pulse to the RCTU, which is used by the RCTU to initiate command execution, and generate one-second headers. The S/C OBC also provides a serial S/C time tag signal to the RCTU for inclusion in the science data headers.

Command: Commands to operate the radar instrument are transmitted from the S/C OBC to the instrument RCTU in form of RS422 UART serial signals. The OBC performs all command sequencing, and issues the radar command immediately before the PPS time tick on which a datatake execution commences. Only one command is required per radar datatake. All sub-second level radar control (e.g. ScanSAR timing), and all radar parameter setting variation required within a datatake (e.g. Data Window Drift to track terrain altitude), are controlled by the RCTU. The S/C also provides discrete standby/operate commands from the OBC to the Radar Electronics and antenna CPDU to turn on operate power prior to a datatake, and to turn off operate power following a datatake.

Engineering Telemetry: The Radar Electronics Subsystem outputs analog signals to the interface section of the OBC for monitoring voltages, currents, and temperatures. The OBC will convert these analog signals to digital,

Radar Subsystem Interface Diagram



DES: Radar Digital Electronics Subsystem, located in Radar Electronics enclosure
RFES: Radar RF Electronics Subsystem, located in Radar Electronics enclosure
AES: Radar Antenna Electronics Subsystem consisting of Antenna Panels and Control & Power Distribution Unit (CPDU)
AMS: Radar Antenna Mechanical Subsystem deployable antenna structure
S/C SSR: Spacecraft Solid State Recorder
S/C OBC: Spacecraft On-Board Computer
S/C PCDU: Spacecraft Power Control and Distribution Unit
GPS PPS One Pulse Per Second timing reference from GPS
PRF: Pulse Repetition Frequency timing signal
DWP: Data Window Position timing signal
DWW: Data Window Width control signal

Figure G-13. Block diagram of ECHO Instrument/Spacecraft Interfaces.

store them during non-contact periods with the ground, and embed them into the telemetry data stream both real time and recorded. The antenna telemetry is digitized and serialized in the CPDU, and provided to the OBC via an RS422 UART serial connection. The CPDU telemetry is folded into the instrument telemetry gathered by the OBC.

Environmental Sensitivities: Due to the similar frequencies of operation, the GPS receiver will be "blanked" during transmission of L-Band radar pulses.

High-Rate Science Data: The radar high-rate science data, with its embedded range-line headers and one-second headers, is written to the S/C solid state data recorder via a high-speed link (Giga-Link) interface.

G.3.1.2 Instrument/Spacecraft Mechanical Structural Interface. The accommodation of the L-Band antenna is the main driver for the ECHO mechanical configuration (Figure F/O G2-4). The antenna panels and support structure subassembly are attached to the bus primary structure at the +Z side (tilted 5 degrees with respect to the longitudinal axis). The satellite primary structure provides a rigid interface support construction (e.g., CFRP sandwich panel) on which the support structure center adapter truss is mounted. In addition, there are two pillow blocks mounted to the top and bottom satellite bus internal platforms. These pillow blocks are the rotating fulcrums for the extendable support structure articulated struts. A slot is provided at the bottom platform for articulated strut clearance.

The requirements for the antenna alignment and pointing stability are moderate (Table G-2). Nevertheless, the use of a distortion-insensitive structure material together with the accommodation of the star tracker on the antenna support (upper part of the S/C) guarantees a high alignment quality throughout the mission. The boresight of the star tracker is such that it is not impacted by stray light from the sun or the Earth in either right or left looking mode.

G.3.1.3 Instrument/Spacecraft Thermal Interface. The S/C provides thermal control for the radar electronics boxes (thermally controlled mounting surface, thermistor controlled heaters, radiators etc.). The *JPL Design Principles* requires that the "Bus electronics shall be designed for –35 to +70°C or allowable flight temperature limits extended by –15°C and +20°C whichever is greater." The S/C thermal control design will keep the electronics boxes within an operating range of –15 to +45°C (allowing 5°C margin for design analysis).

The individual antenna panels (6 total) utilize passive thermal control based on multi-layer insulation blankets (MLI) on the back (electronics) side of the panel and white paint on the front (aperture) side. There are no moving parts or active heaters. The extendable support structures implementing the two antenna wings will have insulation sleeves at some of their struts. When the antenna is deployed, the main thermal sources across the antenna assembly structure-to-S/C interface are those generated by the 28 T/R modules on the back side of each of the two panels mounted to the center adapter truss.

G.3.2 Instrument/Spacecraft Integration and Test

The basic idea of the I&T flow proposed (Figure F/O G2-1) is to allow a parallel process of mechanical and electrical verification, as well as a parallel process of instrument and S/C development ending with as late as possible delivery of the instrument flight model hardware to Europe.

The lead for structural verification will be on the S/C side. The structural interface between the instrument and the S/C bus needs a combined mathematical model for qualification and verification. Inputs to allow running NASTRAN computations, and physical test models, (one thermal equivalent for thermal qualification, and one flight model for acceptance) are needed for the radar antenna including all necessary secondary elements. In addition to the software model, a physical structural antenna model for qualification testing with the S/C is under consideration, and is currently included as a risk item (low to moderate risk). Mass dummies of all electronic boxes will be utilized for the qualification of the primary structure. Qualification and acceptance of the electronics boxes will be performed at the box level, performing hard mounted shaker tests based on input levels derived from the mathematical model and the structural qualification test results.

Electrical and functional integration of all elements will be done in a first step with a flat sat test set up utilizing engineering models. The output of this phase concentrates on basic verification of interfaces, data base contents and test procedure contents. When the flight model

Foldout G2

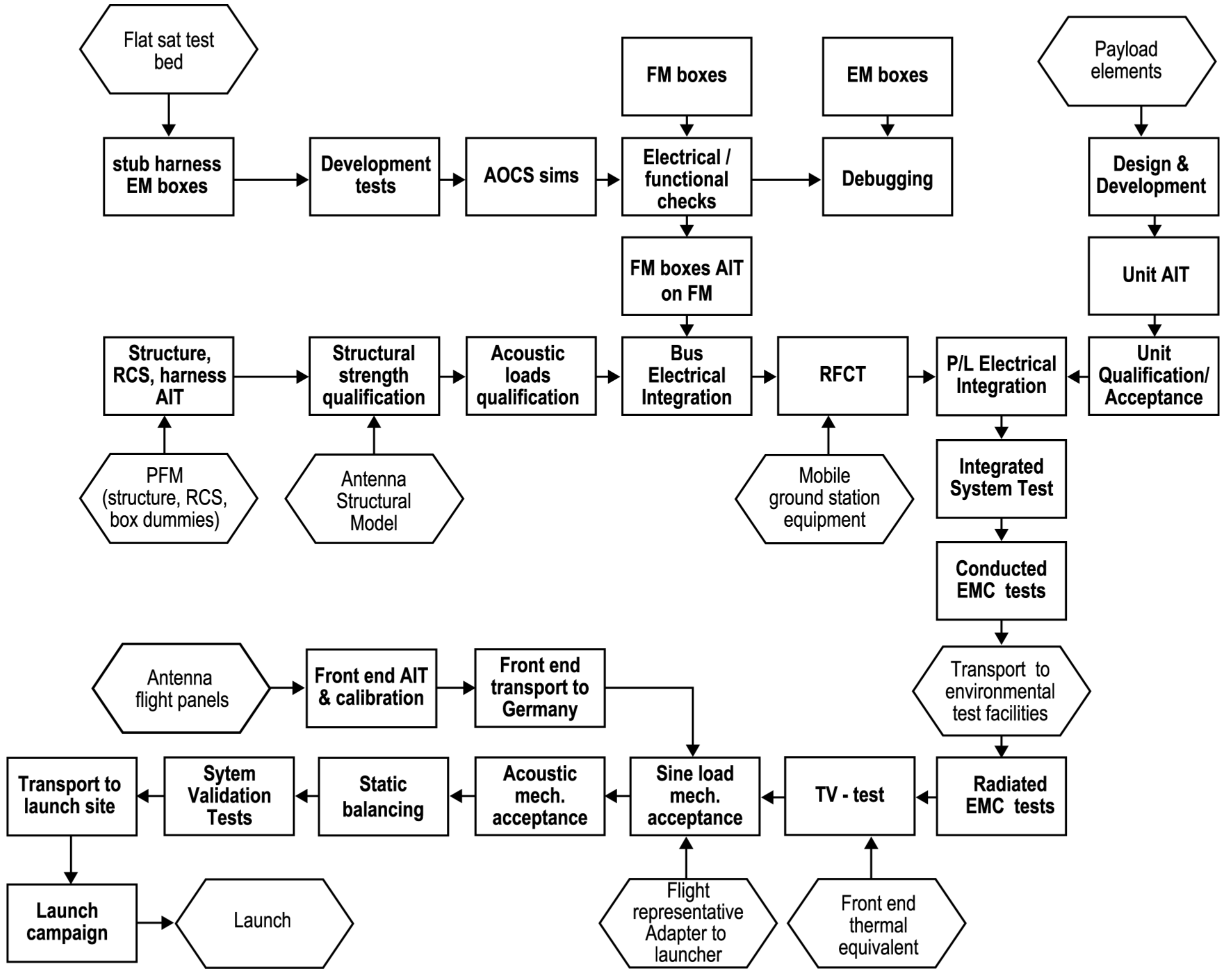


Figure G2-1. Spacecraft Integration and Test Flow.

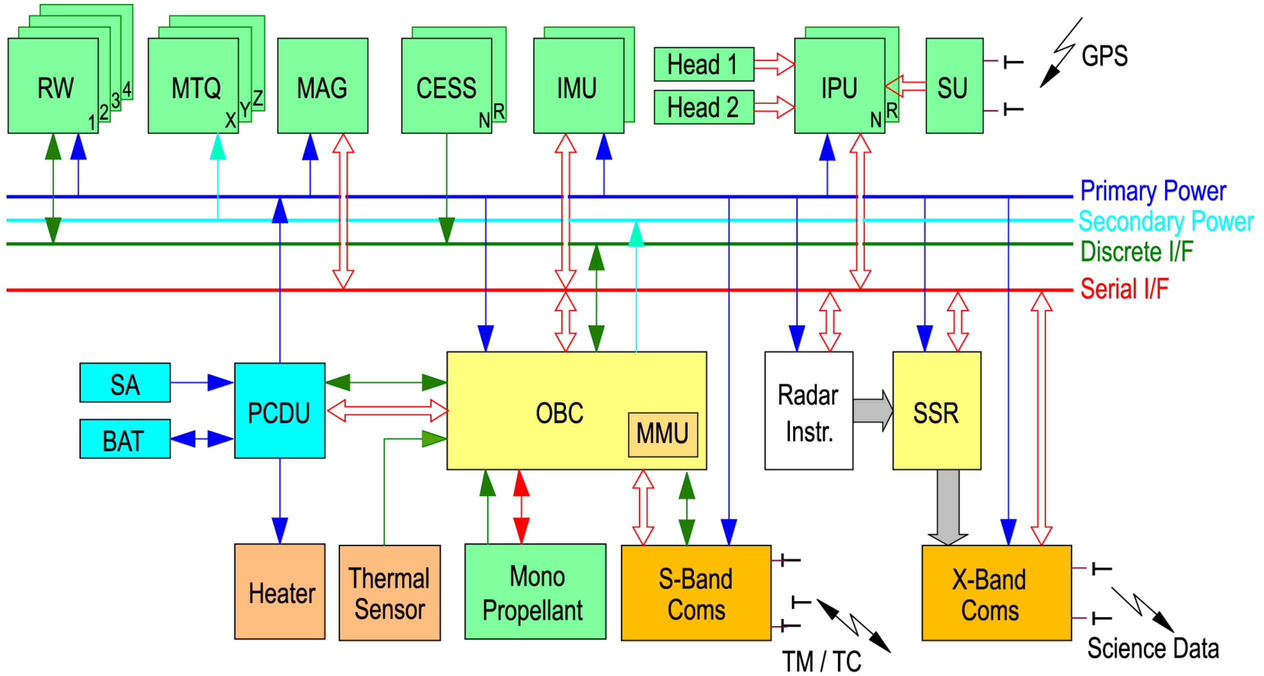


Figure G2-3. Spacecraft Block Diagram.

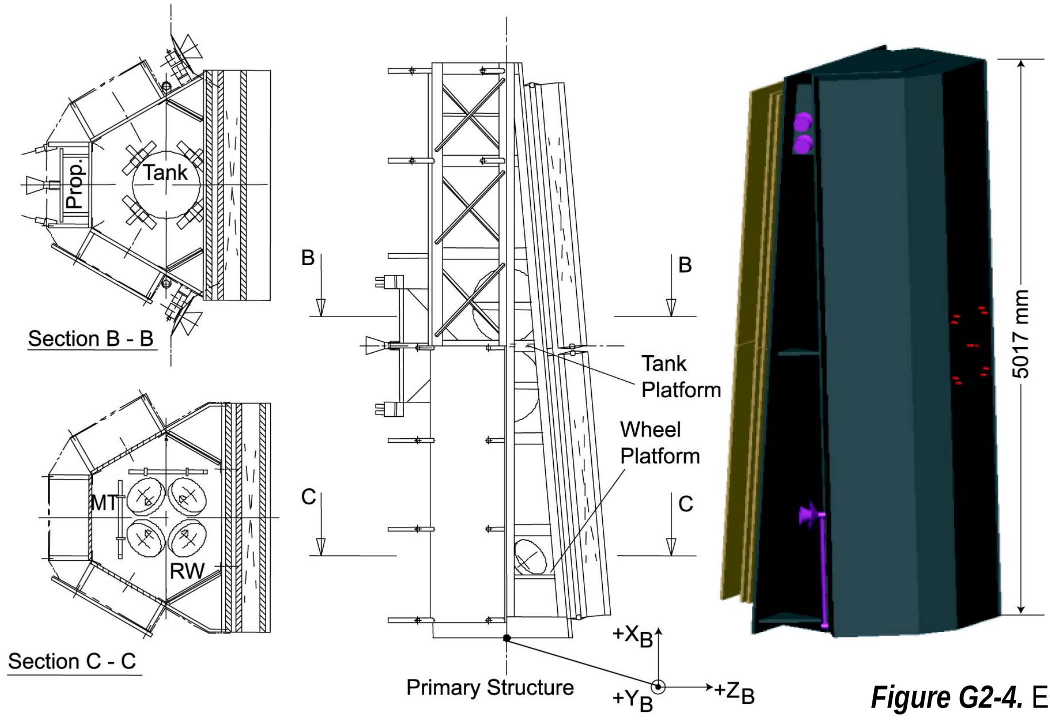


Figure G2-4. ECHO S/C structure.

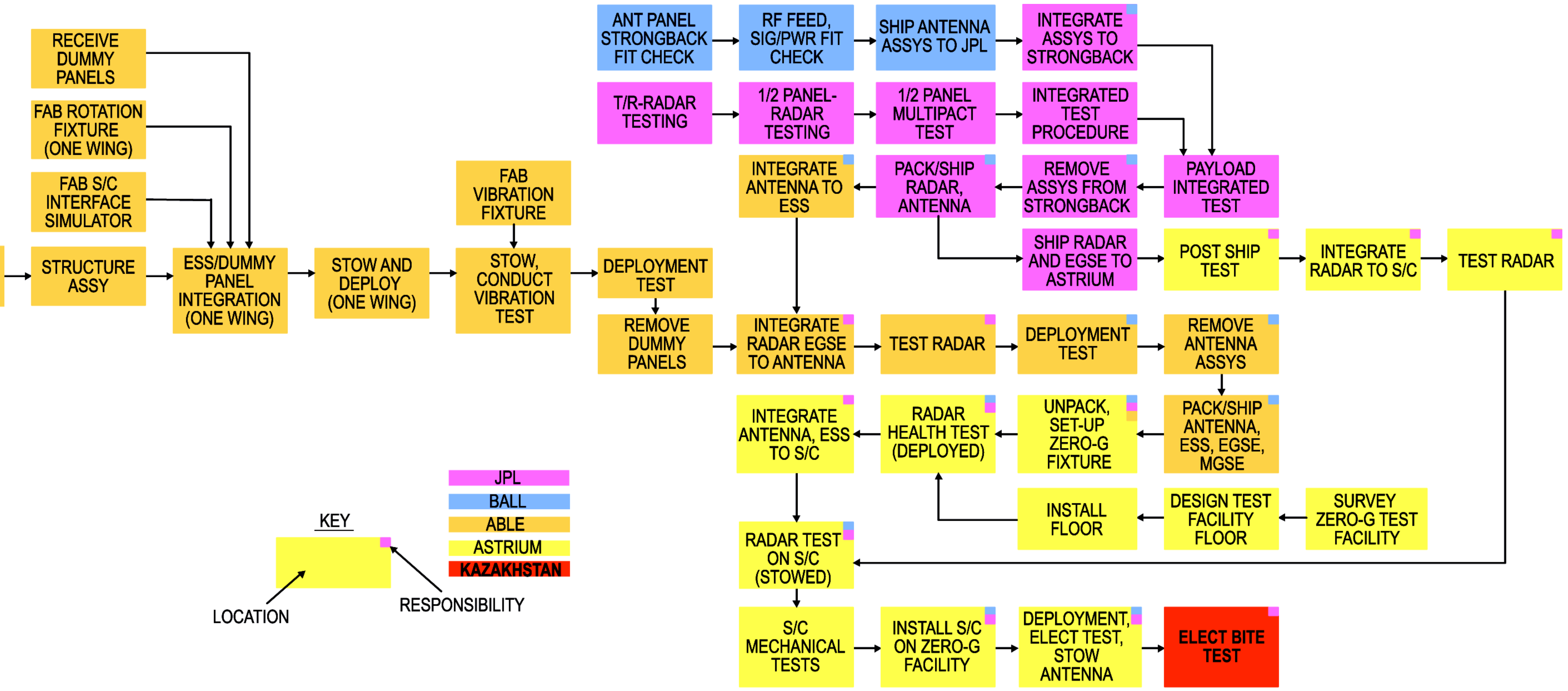


Figure G2-2. Radar Payload Integration and Test Flow boxes are delivered, their system compatibility will be verified on the test bed before integration onto the flight model S/C. The harness of the test bed will be a stub version of the flight harness.

For the thermal qualification at the system level, a thermal equivalent of a deployed antenna will be installed.

Deployment tests of the antenna will be performed after environmental testing in Europe. Final mechanical acceptance testing at the system level will be done with the complete system in launch configuration.

G.3.3 Payload Testing

The flow for the I&T of the Radar Instrument components that are developed at JPL, Ball, and AEC-Able, and the steps to be performed at Astrium for integrating the payload with the S/C are summarized in F/O Figure G2-2.

The Radar Electronics developed at JPL will undergo subassembly level functional and performance verification testing at ambient temperature and pressure, and thermal testing for design verification as required for thermally sensitive subassemblies. The integrated Radar Electronics assembly will undergo vibration, EMI/EMC, and thermal/vacuum (T/V) qualification testing prior to integration with the Ball-provided antenna electronics.

In order to most efficiently simulate interfaces during development testing, and to mitigate risk of interface incompatibility when the flight units are integrated, JPL will provide an RCTU simulator for use at Ball during CPDU/panel testing. Ball will provide JPL with a CPDU prototype, engineering model unit (EMU) T/R modules (one center-mounted-type maximum-power T/R, and one edge-mounted-type minimum-power T/R), and a quarter-panel (7 sticks high by one stick wide) integrated aperture with T/R modules, phase-shifters, panel feed, and PSCU. In addition to functional and performance verification testing with JPL electronics, this quarter panel will undergo vacuum testing for multipactor breakdown at JPL’s antenna test facility.

JPL will also provide an RCTU simulator to Astrium, and Astrium will provide a simulator for their OBC to JPL for development testing and software verification.

Mass models of the electronics boxes will also be provided to Astrium for their S/C structural qualification.

Ball will fabricate and test an engineering model unit (EMU) antenna panel that includes T/R modules environmentally-qualified at the module level. The EMU panel will undergo RF-performance and electrical-interface testing as well as thermal characterization, multipaction (at JPL), vibration, and EMI/EMC testing. The flight antenna panels, RF and DC feed networks, and CPDU will undergo similar testing, with the exception of multipaction, to verify payload and environmental compatibility.

At Ball, a strongback will be constructed to simulate the deployed antenna structure. The antenna panels will be installed on the strongback for cabling layout, and cabling fit-check. The panels and cabling will then be removed from the dummy structure, and the structure will be disassembled for shipment to JPL.

At JPL’s Spacecraft Assembly Facility (SAF), the strongback will be re-erected, and panels and cabling will be re-installed for functional and performance verification testing with the JPL Radar Electronics. A microwave absorber wall (from SIR-C and SRTM testing) will be erected to allow for full antenna transmit RF performance characterization testing.

Meanwhile, the flight deployable antenna structure development and test will be conducted in parallel at AEC-Able. The flight actuators, hinge-line components, and kinematic mounts will be T/V tested using simulated loads. The full structure, with dummy panels installed to represent the stiffness, mass, thermal distortion, and interface properties of the flight panels, will undergo thermal, vibration, and deployment repeatability qualification testing.

When the mechanical structure at Able is ready, and the electrical testing at SAF is complete, the flight panels and cabling will be disassembled from the strongback, and shipped to Able for integration with the flight structure. The flight electronics boxes will be shipped to Astrium at this point, and EGSE will be used to verify the electrical functionality for pre- and post-deployment tests at Able. When the mechanical testing of the flight structure integrated with the flight panels and cabling at Able is complete, the integrated antenna will be shipped to Astrium as a unit.

This payload I&T flow yields cost savings by not having to construct any support fixtures for deployment testing at JPL. Risk is reduced, and schedule saved, by not having to ship the flight structure from Able to JPL, and not having to handle the flight structure at all at JPL.

When the Radar Electronics and Antenna CPDU assemblies arrive at Astrium, they will undergo post-ship functional verification prior to installation on the S/C bus. Following installation, interface verification testing, functional testing, and S/C environmental testing (EMC, T/V) will be carried out. T/V testing will be done with a simulator to represent the deployed antenna optical properties, and thermal dissipation.

The integrated antenna assembly shipped from Able will also undergo post-ship, pre-installation deployment verification at Astrium. Following S/C T/V, the antenna will be integrated with the S/C, and vibration and acoustic mechanical acceptance testing will be conducted with the antenna in the stowed configuration. A final deployment test will follow. Final RF and signal flow verification will be done with the antenna in the deployed position. The antenna will then be stowed for shipment to the launch facility.

G.4 Spacecraft

G.4.1 Spacecraft Design Approach

The fully-redundant S/C follows the Astrium AstroBus concept, which is designed to achieve tailor-made solutions for space missions at competitive prices and in a wide range of applications by maximizing the recurring effort in engineering and hardware of the core bus and focussing on an optimized implementation of the payload and specific mission aspects. AstroBus is the upgraded successor of the Dornier Satellitensystem FlexBus S/C series used for CHAMP (DLR, Germany) and GRACE (JPL/NASA). The AstroBus S/C uses a basic electrical architecture characterized by

- A backbone consisting of a set of fixed core elements that is used for all missions, e.g. S-Band RF equipment, On-Board Computer (OBC), Power Control & Distribution Unit (PCDU), heaters and thermistors, frame software,
- Elements selected in accordance with the respective mission/system performance requirements from a pool of existing, recurring hardware: batteries, Altitude and Orbit Control (AOC) sensors/actuators, OBC external solid state recorders, high rate encoders and transmitters, high rate antennas, software library,
- Tailored elements for each mission: payload (if not customer furnished), solar array, mechanical/thermal configuration and structure, specific application control software.

The ECHO S/C electrical architecture is centered around the OBC for Command and Data Handling and the PCDU for the control and distribution of electrical power (Figure F/O G2-3). In general, the bus and instrument equipment are connected to the OBC via standard discrete and serial command and housekeeping lines. All interfaces are either known and tested in the CHAMP and GRACE programs or, as in case of the reaction wheels and magnetometer, will be tested in the preceding TerraSAR-X program. Thus the architecture, the corresponding ground test equipment, and validation environment are well known and tested and the ties with the selected suppliers are well established.

While the basic electrical architecture features a high degree of heritage from former Astrium programs, the mechanical and thermal configuration of the S/C is tailored to the ECHO requirements. Due to the similarities in the ECHO and TerraSAR-X missions, however, a significant commonality is achieved for the mechanical/thermal design, as well.

G.4.1.1 Spacecraft Requirements. The ECHO S/C requirements are listed in the Mission Traceability Matrix (Table G-2).

G.4.2 Spacecraft Description

G.4.2.1 Spacecraft Characteristics and Performance. The AstroBus core S/C meets or exceeds the ECHO mission requirements. The S/C performance and characteristics are summarized in Table G-4. Table G-5 provides a mass and power summary.

G.4.2.2 Configuration and Structure. The ECHO S/C configuration (F/O Fig. G2-4) is mainly driven by the accommodation of the folded L-Band SAR antenna inside the Dnepr-1 launch vehicle fairing. The antenna consists of a mid section (2 panels) fixed to the satellite bus and two double deployable panels. In stowed condition the dimensions of the stack are 4660 × 2000 × 350 mm. It is mounted onto the +Z side of the asymmetrical hexagon central bus structure, which is tilted by 5° to accommodate the antenna inside the conical section of the launcher fairing.

Table G-4: Spacecraft Characteristics Table (Part 1) (K-6)

Spacecraft bus	Value/ Summary, units
Structure	
Structures material (Aluminum, Aluminum w/ Composite face, Exotic, Composite)	Carbon Fiber Reinforced Plastic framework (CFRP), with Aluminum w/ composite face panels
Number of articulated structures (not including solar arrays)	0
Number of deployed structures (not including solar arrays)	4
Thermal Control	
Type of thermal control used (passive, heaters, semi-active, active / cryocooler)	passive, heaters
Propulsion	
Estimated delta-V budget, m/s	293 m/s
Propulsion type(s) (mono propellant, bi-prop, dual-mode, solar electric, etc.) and associated propellant(s)/oxidizer(s)	monopropellant
Propellant mixture ratio (if bi-prop)	N/A
Propulsion type (none, cold gas, mono, biprop, ion)	mono
Number of thrusters and tanks	8 1-N thrusters, 1 22-N thruster, 2 tanks
Specific impulse of each propulsion mode, seconds	225 sec (22-N), 210 sec (1-N)
Attitude Control	
Control method (3-axis, spinner, gravity gradient, etc.). For spin stabilized S/C provide spin rate and axis in terms of S/C body coordinate frame.	3-axis
Control reference (solar, inertial, Earth-nadir, Earth-limb, etc.)	inertial
Attitude control capability, degrees	0.011 deg 1–σ
Attitude knowledge limit, degrees	0.003 deg 1–σ
Agility requirements (maneuvers, scanning, etc.)	Nominal 0.2°/sec (0.5°/sec possible) 60° Roll within 5 min (Data Take) 30° Roll/90° Pitch within 21 min (Orbit Maintenance)
Articulation (1- or 2 -axis solar arrays, antennas, gimbals, etc.)	Solar arrays are body mounted
Attitude knowledge processing (e.g., real-time versus post-processing, spaceborne versus ground)	real-time, spaceborne

For overall balance reasons, all radar and bus units are arranged in three compartments located opposite to the SAR front end.

1. The +Y-Z compartment houses the mass memory and all X-Band down link units close to the base point of the corresponding booms. The SAR unit compartment is closed by removable GaAs solar array panels with a combined area of 4.8 m². In nominal earth orientation the SAR antenna boresight points 30° off nadir towards the shadow side of the orbit. Due to the hexagonal cross section of the configuration, the sun illuminates the solar cell area more or less perpendicular, depending on the actual seasonal sun declination.

Table G-4: Spacecraft Characteristics Table (Part 2) (K-6)

Spacecraft bus	Value/ Summary, units
Sensor and actuator information (precision/errors, torque, momentum storage capabilities, etc.)	star trackers (2). coarse earth/sun sensors (6 heads) 3-axis magnetometers (2) IMU (2) Internally Redundant Blackjack GPS reaction wheels (4): 0.18 Nm, 20 Nm/s torque rods w/ redundant windings (3): 70 Am**2, IMU (2) thrusters (8): 1 N thrusters(1): 22 N
Command & Data Handling	
S/C housekeeping data rate, kbps	Uplink: 4 kbps Downlink: 32 kbps/1 Mbps selectable
Data storage unit type and capacity, name and Mbits	Housekeeping DSU: 8 Gbits Science SSR: 256 Gbits
Maximum storage record rate, kbps	2260 Mbps (SSR)
Maximum storage playback rate, kbps	300 Mbps (SSR)
Power	
Definition of each S/C subsystem operational mode over all science phases. Provide power demand in watts for each operational mode.	Standby: 339 W Standby + X-band: 461 W Science: 1679 Science + X-band: 1801 W Safe: 250 W Values are CBE
Type of array structure (rigid, flexible, body mounted, deployed, articulated)	Rigid, body mounted
Solar array axes of rotation (vector projected in S/C coordinates)	N/A
Array size, meters x meters	1 m x 4.8 m
Solar cell type (Si, GaAs, Multi-junction GaAs, MJ GaAs with concentrators)	Triple junction GaAs
Solar cell efficiency, %	26%
Expected power generation at Beginning of Life (BOL) and End of Life (EOL), watts	1130 W (BOL) 1056 W (EOL)
On-orbit average power consumption, watts	461 W + 104 W contingency
Worst case sun incidence angle to solar panels during science mission, degrees	Nominal Attitude: 31.5 Alt. Side Imaging: 0 deg
Battery type (NiCd, LiH, NiCd, Li-ion)	NiH2 CPV
Battery storage capacity, amp-hours	75 A-hr
Worst case battery Depth of Discharge (DOD), %	20%
S/C bus voltage, volts	50 V unregulated, 28 V regulated

Table G-5: Spacecraft Mass and Power Summary. See Section G.4.9 for rationale. Current best estimates and contingency are book-kept separately as shown. Totals include contingency.

		Power Watts	
	Mass Kg	Orbit Avg	Peak
Payload	**446**	**152**	**1379**
L-Band Antenna	286	109	1279
Antenna dep. struct.	107	N/A	
Electronics	53	43	100
Bus	**637**	**309**	
Structures	294	N/A	
Downlink booms (3)	16	N/A	
Power & Dist.	131	72	
C&DH	20	25	
Telecomm	10	9	
X-band Downlink	16	21	134
SSR	30	50	
Thermal Cont	30	50	
Attitude and Orbit Control	91	82	
Propellant	**186**	**N/A**	
Contingency	**269**	**104**	
Payload	123 (28%)	43 (30%)	
Bus	127 (20%)	61 (20%)	
Propellant	19 (10%)	N/A	
Total Dry	**1333**	**N/A**	
Total	**1538**	**566**	
Available Power	**N/A**	**673 (EOL)**	
LV Capacity	**1700**	**N/A**	
Margin	**162**	**107**	
Margin %	**11%**	**19% (EOL)**	

2. In the opposite -Y-Z compartment all bus units (data and power handling, telemetry & telecommand etc.) are accommodated.
3. The –Z compartment is reserved for the L-Band SAR electronics. The thrusters for orbit raise and attitude & orbit control are located between these units.

Each compartment consists of a sandwich mounting panel with the boxes facing outwards. These panels are bolted onto the central structure. The compartments are closed by thermal tents, which are put up by light-weight support brackets and belts in-between. This open structure concept guarantees easy integration and late access to all boxes, harness and connectors throughout the complete AIV process until the final integration on the launcher.

The tank and all associated units of the monopropellant system are concentrated on a common propulsion plate. This module is placed in the middle of the central structure close to the satellite CoG. This position minimizes the satellite deviation moments by lifting the overall satellite CoG close to the antenna center and supports the orbit raise maneuver with minimum offset torques.

A sandwich platform is located at the bottom of the S/C for the mounting of the four reaction wheels and two of the three magnetorquers.

Two X-Band down link booms and their antennas are attached to the satellite exterior. Their deployment is such that one antenna always looks towards nadir in either left or right imaging mode. Furthermore, a helix S-Band antenna is supported by a boom to give free field of view to Earth even in the stowed SAR configuration.

A pair of star trackers are located close to the antenna to guarantee alignment. They are located at the tip of the satellite to avoid the thruster plume. Their boresights are chosen to avoid sun and earth albedo input into the baffles and are separated by 90° in the orbit plane to give best possible performance around all axes.

A set of redundant GPS antennas and two patch S-Band antennas are located on opposite sides of the S/C to provide hemispherical S-Band coverage. For GPS coverage, the view to space is always sufficient even in sun looking mode. The six coarse earth- and sun sensor heads are also mounted on orthogonal brackets giving a free field of view, as required.

The structure main load path from the launcher interface is provided by the central asymmetrical hexagonal CFRP framework construction with six identical carbon fibre 120°-L-profiles of about 4 mm thickness. These profiles are connected to each other by cross stringers or the equipment panels of the unit compartments. Contour stability of the hexagon is given by internal stiffener platforms. The interface brackets of the heavy antenna stack are located close to these platforms.

This structure constitutes a stiff and distortion stable backbone for the attachment of the tilted SAR antenna and allows the attachment of the sandwich panels for the accommodation of units. Each of the panels have the same material composition (2 × 0.6 mm CFRP face sheet and 28.8 mm Al core). The three solar panels are also a carbon fibre light weight construction, which is supported by thin sheer plates to form a stiffened box.

Stiffness: The Dnepr-1 launcher necessitates a first natural frequency of above 10 Hz in lateral direction. Nevertheless, to be compatible with other launch vehicles, the structure dimension is aimed for a frequency of > 15 Hz.

Strength: The maximum quasi-static launch loads for the Dnepr-1 are 8.2 g in axial direction and up to ± 1.1 g in lateral direction. To cope with worst case transport loads the actual design loads will be of 9.0/3.0 g.

G.4.2.3 Electrical Power Subsystem (EPS). The electrical power subsystem is based on the direct energy transfer principle, resulting in an unregulated bus of 38 V to 50 V. It consists of a solar array, a PCDU and a rechargeable NiH2 battery. In the sun phase the solar arrays deliver power to the main bus and provide all excess power to charge the battery until it is fully charged. The battery provides main bus power during eclipse and during sun phase periods when the power demand of bus and instrument exceeds the solar array capability.

The **solar array** is constructed from GaAs technology triple junction cells, accommodated on a body mounted panel with an area of 4.8 m^2 resulting in an end of life power capability of 1056 W under direct equinox solar illumination. With a reference operational mix with

- 75% operation time in nominal attitude,
- 5% operation time in 60° roll attitude,
- 20% operation time in transient between the two orientations,

and under worst case orbit conditions (18 min eclipse), the available orbit average power is 673 W. Each string provides a blocking diode to protect the power bus against string internal short-circuits, each cell itself is equipped with a by-pass diode to cope open-circuit failures.

The **Power Control and Distribution Unit** (PCDU) safely controls the charging of the battery and delivery of electrical power to the bus and instrument units on protected switchable output lines. This unit is designed for autonomous operation of the power system in orbit and, in particular, is designed to recover from a complete power down failure as soon as sun light strikes the solar array.

During periods of solar illumination all excess currents are delivered to the NiH2 battery until the NiH2 reaches the end-of-charge voltage. After that the charge current is regulated to trickle charge current. Charge control is executed in the regulator stages of the PCDU, consisting of 12 sequential shunt stages, established as parallel switchable solar string close-circuit (shunt) lines. During trickle charge mode, a certain number of shunt stages are on or off and 1 stage is pulse-width modulated so that the battery is charged with the required trickle charge current.

Power to the instrument and bus electronic units are distributed as regulated 28 V ± 10 % on latch current limit (LCL) protected output lines. Heater power is distributed on LCL protected lines from the 50 V bus to individual heaters controlled by the PCDU internal interface control logic in accordance with command patterns received from the OBC in 1 sec intervals. Power to the radar antenna will be provided as unregulated 50 V on two switchable and protected output lines.

The PCDU communicates with the OBC on redundant, cross-coupled series lines to receive command patterns for the bus/instrument units and the heaters and to transmit the necessary housekeeping data to allow the on-board FDIR and ground crew to assess the status of the EPS.

The **battery** is identical to TerraSAR-X and consists of 32 NiH2 cells providing an end of charge voltage of 51.2 V. The capacity of the battery is rated to > 75 Ah for the high TerraSAR-X discharge currents during instrument imaging and exceeds the ECHO requirements. Moreover, the battery cells are qualified for the high number of ECHO radar operation cycles when battery power is required to supplement the solar array (100,000 cycles up to 10% DoD and 5000 cycles up to 20% DoD).

G.4.2.4 Command and Data Handling (C&DH). The C&DH functions are embedded within the OBC. Functions performed by the OBC are

- Receive the telecommand (TC) data stream from the S-band receivers
- Decode high priority commands (HPCs) from the TC data stream using hardware logic and issue associated commands directly to the on-board users, i.e. by-passing the OBC software,
- Decode nominal bus commands using the OBC software and issue associated commands to the on-board recipients via the respective output command channels,
- Decode, intermediately store and transmit in a time-tagged manner instrument command sequences,
- Acquire, time-stamp and send orbit and attitude data received from the GPS and star trackers to the SSR for X-band transmission,
- Acquire, time-stamp, format and intermediately store (during non-contact-to-ground periods) housekeeping data (including GPS raw data) necessary for system operation, resource management and transmission to ground,
- Transmit stored and real-time telemetry data via S-band during ground contact periods,
- Provide computing and memory resources for the application software to autonomously operate the S/C during periods without ground contact, in particular for the AOC software and the command sequencing of the instrument.

During **telecommand decoding** the addressed of the two hot redundant telecommand modules within the OBC selects the ‘active’ receiver by evaluation of the sub-carrier lock status and accepts the telecommand data at a constant rate of 4 kbps. The consistency of the data is checked and acknowledged with the release of a respective command link control word into the down-link telemetry data stream. High priority commands are extracted from the data stream and executed using the 16 HPC channels of the decoder. The nominal data stream is forwarded to the OBC for further processing.

The **processor module** consists of an ERC32 processor and the necessary interface and memory to provide 15 MIPS. The capacity of the processor memory (6 MByte RAM, 128 kByte PROM, 2 MByte EEPROM) is sized to comply with the requirements of a nominal and initial acquisition mode autonomous operations, especially the needs of the AOC and the intermedi-

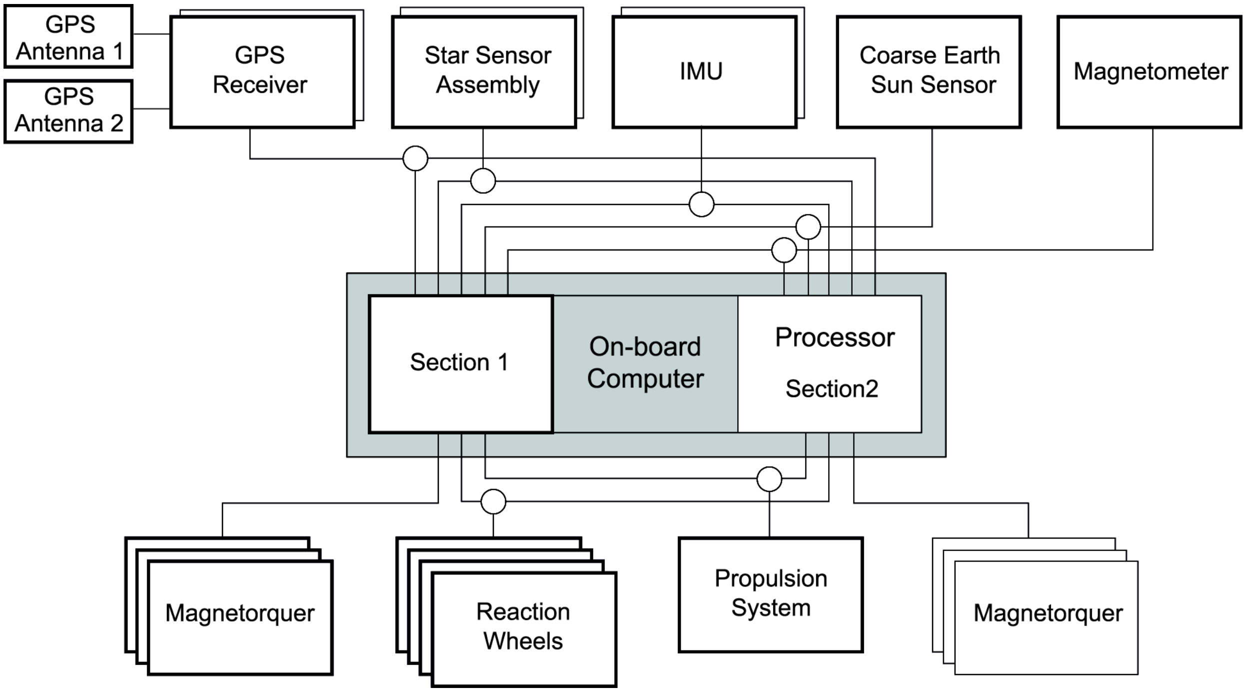


Figure G-14. ADCS Schematic.

Table G-6: Spacecraft Technical Maturity Matrix (L-2b)

Name of Heritage Hardware	Item Description	Maturity Level	Rationale for Maturity Assessment
Structure	- Structural support for the bus and instrument units	7	- Mission specific - No new materials
X-Band Boom	- Provision of field-of-view for the X-band antennas	7	- CHAMP instrument boom heritage - Reduced tube length
S-Band Boom	- For field-of-view of the S-band helix antenna	9	- GRACE S-Band/Globalstar Magnetometer Boom Heritage - Extended tube length
Thermal Hardware	Heaters, thermistors, MLI, radiator	9	- Off-the-shelf equipment
On-Board Computer	- TC Decoding - Processing / SW - TM Data Storage - TM Encoding - System Reconfiguration	8	- CHAMP / GRACE heritage - New processor: ERC 32 instead of 1750 - TerraSAR-X qualification
Solid State Data Recorder	- Instrument Data Storage - Encoding, Encryption, Framing	7	- Partly new development (Input I/F and Memory Module) - TerraSAR-X qualification
Solar Array	3J GaAs technology	8	- Cells off-the-shelf - Panel tailored to S/C - TerraSAR-X qualification
Battery	NiH2	9	- Cells off-the-shelf - Battery tailored to S/C - TerraSAR-X qualification
Power Control & Distribution Unit	- Solar Array Control - Battery Charge Control - Bus Voltage Control - Power Distribution - Ordnance	9	- Heritage (flight proven) design on module level (CHAMP / GRACE / OFFEC) - Adaptation to S/C needs - TerraSAR-X qualification
S-Band Coms Electronics	- Receiver - Transmitter - RF Interconnect Circuitry	9	- CHAMP / GRACE Heritage
S-Band Coms Antennas	- 1 x Rx/Tx Quadrifilar Helix - 1 x Rx Patch Antenna - 1 x Tx Patch Antenna	9	- CHAMP / GRACE Heritage
X-Band Modulator	- QPSK Modulation	9	- METOP heritage - Adaptation to higher data rate
X-Band TWTA	- Travelling Wave Tube Assembly	9	- METOP heritage - Adaptation to higher output power
X-Band Antenna	- Shaped Beam Antenna	7	- New Development - TerraSAR-X qualification
Propulsion System	- Mono-propellant/Pressurant Tank - Filter, Fill/Vent Gauge, Latch Valve - 1 N Thruster - 22 N Thruster	7	- Components off-the-shelf - Similar architecture as TerraSAR-X - Additional 22 N thruster branch

Table G-6: Spacecraft Technical Maturity Matrix (L-2b) (cont'd.)

Reaction Wheels	- Attitude Actuator	9	- Off-the-shelf equipment - Adaptation to higher torque levels
Magnetorquer	- Wheels Unloading	9	- Off-the-shelf equipment
Magnetometer	- Rate Measurement	9	- Off-the-shelf equipment
Star Tracker	- Attitude Sensor	9	- CHAMP / GRACE Heritage
GPS Receiver	- Orbit Position Sensor	9 80% 8 20%	- GRACE Heritage - New Oscillator - Deletion of K/Ka band ranging channels
Inertial Measurement Unit	- Rate Measurement	9	- Off-the-shelf equipment
Coarse Earth & Sun Sensor	- Safe Mode Attitude Sensor	9	- CHAMP / GRACE Heritage
Laser Range Reflector	- Orbit Position Sensor	9	- Off-the-shelf equipment

ate storage of time tagged instrument command sequences. The processor is operated by a 20 MHz internal clock with a stability of better than 5E-05.

Two hot redundant **mass memory** units are implemented within the OBC to store housekeeping data meant for S-band downlink. The 8 Gbit memory in combination with a 1 Mbps downlink allows for an intense screening of the S/C subsystem functions by the ground crew.

The **telemetry module** encodes the real-time and stored telemetry data in accordance with the ESA PSS-04-106, Packet Telemetry Standard. Each encoder has two virtual channels, with the higher priority channel reserved for the real-time data transmission. The transfer frame length is 1115 octets or 8920 bits. The data are pseudo-randomized according ESA PSS-04-103 in order to ensure the required symbol transition density. The output data interface to the transmitter in NRZ-L, the data rate selectable (32 kbps/1 Mbps).

The OBC provides command and data acquisition access to the core S/C and the instrument electronics via interface channels located within the interface unit (IFU). Each of the redundant IFUs provides Mil Std 1553 B and UART RS 422 serial interfaces, analogue and bi-level discrete input and output interfaces, as well as timing lines in accordance with the needs of the bus and instrument users.

The **solid state recorder** (SSR) is the central storage element (288/256 Gbit at BOL/EOL) for SAR data (digitized echo data) captured during data takes and associated attitude/GPS data. It features all the necessary elements to control the data flow, file management, data formatting, encryption and encoding for transmission to ground. The SSR can accept up to 2.2 Gbps of science data on two G-link input lines from the instrument as well as position and attitude data via the MilStd 1553 interface from the OBC.

During ground contact periods, the SSR data are routed to the X-band communication system at a rate of 300 Mbps, equally split on I and Q channels. The output data will be encrypted, CCSDS framed with Reed Solomon encoding applied to the transfer frames.

The SSR can simultaneously accept input data from the sensor and deliver stored data to the X-band communication system, including a quasi-realtime downlink. The files to be downlinked are selectable including the ability to organize scenes into one file.

The SSR is commanded and controlled by the OBC via the S/C Mil Std 1553 bus.

Data corruption management is handled on different levels. A Real-time Single Symbol Error Correction by use of a Reed Solomon Code is capable of correcting single SDRAM device failures per Word Group, such that the loss of one complete SDRAM device can be corrected in real-time (back-ground scrubbing). Additional protection is implemented against memory device destruction by radiation induced single event latch-up using latch-up overcurrent sensing and supply voltage switch-off on memory module partition level.

G.4.2.5 Attitude Determination And Control Subsystem (ADCS). The Attitude/Orbit Determination and Control Subsystem (ADCS) is designed for the ECHO and TerraSAR-X orbits. The following classical functions are implemented: initial rate damping, Earth acquisition, safe mode in Earth orientation with yaw control, orbit correction maneuvers, and mission specific normal mode operations.

Adequate FDIR capabilities and standard as well as advanced functions for autonomous operation are included. The normal mode will provide two typical states of operation (see Fig. G-2):

- Normal SAR Operation in nominal Earth pointing attitude,
- Temporary roll to sun-side looking SAR operation.

The roll maneuver sequence will be performed with a high degree of AOC autonomy. Only a few basic telecommands are required in order to provide comfortable AOC and S/C handling qualities.

The AOC operations follow the AstroBus concept. Upon initialization (boot-up) of the OBC application software, the AOC software starts with the Acquisition and Safe Mode (ASM) using the CESS and gyro information as sensors and the propulsion thrusters as actuators. The ASM ensures safe conditions for the S/C for a time period only limited by the fuel consumption (< 0.2 m/s per day). In steady state conditions of the safe mode, upon ground command, the magnetorquers are used in addition to the thruster control to reduce the fuel consumption. Upon ground telecommand transition into normal mode (NOM) will occur. Nominal mode attitude control will be performed with the reaction wheel, using the magnetorquers for wheel momentum control. This mode is maintained during the mission life time, interrupted only for temporary slews to sun-side looking SAR operation and for the orbit maintenance maneuvers in Orbit Control mode (OCM). The slew to sun-side-looking (around roll axis) will be performed with the reaction wheels only, the rate limited to < 0.3 deg/sec, in order not to risk star sensor performance degradation or even lock-off. The slews for OCM will be performed using the control thrusters as actuators and will be limited to < 0.3 deg/sec. The interruptions for OCM and sun-side looking operations will be commanded from ground.

The ADCS is designed to be fully functional after start-up of the OBC in an operational state without the need to load data from the ground. It constitutes a major portion of the autonomy implementation of the overall S/C. In case of severe failures, the AOC supports the autonomous transition of the S/C into the safe mode.

G.4.2.6 GPS Receiver. An integrated GPS/Star Camera instrument will be supplied by JPL's Tracking Systems and Applications Section. This receiver will have strong inheritance with the BlackJack GPS receivers used on the Astrium-built CHAMP and GRACE S/C. All of the receiver assemblies will consist of either dual-string components or will be internally redundant. It will provide real-time estimates of position, time, and inertial attitude to the OBC and a real-time GPS time epoch signal to the OBC and radar instrument. It will also provide GPS radiometric observables to the flight recorder, to be used for precise post-processed orbit determination. The GPS receiver will operate in a single mode in which all of its functionalities are simultaneously exercised. Receiver operation will be "blanked" during L-band radar transmit events.

G.4.2.7 Communications Subsystem. The S-Band system receives RF signals from the ground stations of Weilheim (15 m) and Svalbard (11 m), and delivers the demodulated digital command data stream to the OBC. It also receives a digital command data stream from the OBC and transmits it as an RF signal to the same ground stations.

The S-Band communication system consists of two transmitters, two receivers, an RF distribution unit and three antennas. The antenna system consists of one combined receive/transmit quadrifilar helix antenna, mounted on a short boom to point toward nadir during nominal flight orientation. The zenith side accommodates one transmit and one receive patch antenna. While the two receivers are running in permanent hot redundancy, one of the two transmitters is switched on by the OBC well in advance of an expected ground station fly-over.

RF signals from the ground stations are received by both receive antennas, superposed in a combiner/splitter and routed to the two receivers. Due to the nominal and contingency orientation of the S/C, the nadir antenna gets preference and the signals from the zenith antenna is attenuated such that the overlapping region for signals received on both antennas are on the zenith side. The first receiver to achieve subcarrier lock is selected by the OBC telecommand decoder as the "active" receiver.

The active transmitter sends the generated RF signal to the nadir antenna for transmission to ground. Before launch the coax transfer switch (CTS) will be commanded to a position so that the nominal transmitter is connected to the nadir antenna. If the nominal transmitter fails, the redundant one will be activated and the coax switch position altered respectively. The transmitter can operate with two output power levels, 20 dBm and 29 dBm depending on the selected data rate (32 kbps/1 Mbps). Uplink and downlink margins are included in Table G-8.

The **X-Band communication system** is used to transmit science data to the Fairbanks and Miami ground stations. The transmitter is designed for 300 Mbps and is directly connected to the SSR via LVDS data interface, but is completely controlled by the OBC. The data transmission will be executed via shaped beam antennas (68° half-cone) in order to fulfill the link margin and PFD requirements.

The X-Band communication system consists of two identical transmit chains (QPSK modulator, TWTA, plus RF isolators), one of which is switched to one of the two antennas. The second channel serves as cold spare.

The QPSK-modulator internally generates the X-band carrier, which is hard-key QPSK modulated by the input data. The resulting RF signal is amplified by a TWTA and filtered by a channel filter (bandpass and lowpass). For a better matching of the TWTA two RF isolators (coax isolator and WG circulator) are implemented.

A WG-switch connects the active chain to the filter and the antenna, that is earth pointing for the actual flight orientation. The filter rejects unwanted out of band signals up to the fifth harmonic (5*fc) of the RF signal.

The antenna transmits the RF signal toward Earth. The antenna characteristics yield a nearly constant power flux density at the Earth's surface for elevation angles > 5°.

G.4.2.8 Propulsion Subsystem. The ECHO propulsion system design (Figure G-15) performs the following tasks:

- initial orbit correction (rate damping),
- orbit raising from 400 km to 760 km altitude,
- orbit maintenance and attitude control for the 5-year mission,
- de-orbiting to 580 km altitude.

The ECHO propulsion system is a N_2H_4 based mono-propellant system pressurized with He and operated in blow-down mode (pressure range of 5–24 bar). The system is arranged in three branches, one for the orbit raise maneuver to the mission orbit (burst thrust points through the S/C center of gravity) and two branches of 4 × 1 N, each. These branches provide full capabilities for attitude control and orbit maintenance maneuvers. The two branches are operated in cold redundancy. During orbit raising the 1-N thrusters are used for attitude control in off-modulation mode. In detail, the system consists of the following equipment:

- **Two Propellant Tanks** with a combined capacity of 226 kg
- One **22-N** and eight **1-N Thrusters**
- Three Latching Valves
- One **Fill/Drain Valve** (for propellant and pressurant, off-the-shelf equipment)
- One **Pressure Transducer** with an accuracy of better than 0.5 %
- **Filters** (off-the-shelf equipment)

The thrusters are equipped with two solenoid valves in series to avoid open failures. Both solenoid valves are activated at the same time by a single switch. The cat-bed heaters will typically be switched on 20 minutes before thruster actuation.

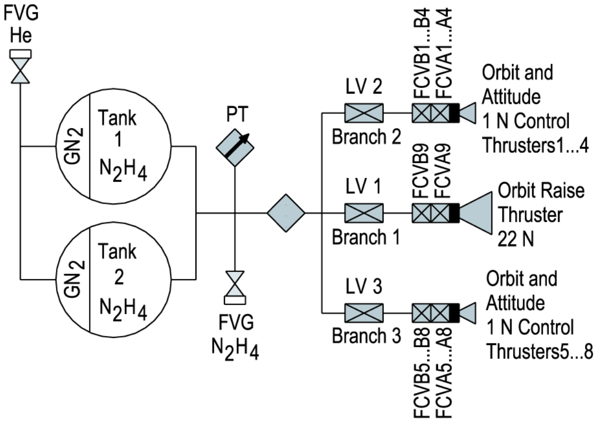


Figure G-15. Block diagram of the ECHO S/C propulsion system.

During pre-launch and before launcher separation, the latching valves will be closed to avoid contamination in case of unwanted thruster actuation (e.g. by premature boot-up of the OBC). After separation, the two latching valves in branch 2 and 3 will open and hot redundant thruster operation will be performed. In case of leakage, the related latching valve will be closed and the system will operate with one branch only.

For orbit raising, the latch valve of branch 1 will be opened and the single 22-N thruster will provide the delta-v to achieve the mission orbit. Any disturbance torque during this operation will be controlled by branch 2 and 3. After orbit raising branch 1 latch valve will be closed.

All propulsion equipment is arranged on a single platform, the propulsion module, which is accommodated close to the satellite COG. This layout facilitates the AIV process, since the propulsion system can be verified off-line without interaction with the satellite. This arrangement allows for attitude control around all axes using individual thrusters or thruster pairs and orbit control by using all 4 thrusters in off-modulation mode.

G.4.2.9 Thermal Control Subsystem. The S/C thermal control subsystem mainly relies on state-of-the art passive thermal control hardware (MLI, radiators) assisted by an actively controlled heater system. It is a single-failure tolerant design to keep all units within their thermal limits during launch, early orbit phase, nominal operation and in safe mode. These requirement are met by:

- Thermal insulation of the satellites to space wherever possible, except unavoidable heat leakage areas, as the launcher I/Fs, thrusters, sensors, S-Band and GPS antennas etc.
- Dedicated thermal radiators are planned for heat rejection. Final flight temperature level trimming will be performed by adjustment of the surface area and/or the surface properties of the inside face of radiators.
- An electrical heater system consisting of independently controllable heater lines is included for cold orbit design load cases. The redundancy is given by the relatively high number of heater circuits rather than by a redundant chain.
- Each heater line is closed-loop controlled by its own temperature sensor via the OBC. The lines are simply switched on/off if the actual temperature is lower/higher respectively than the desired temperature. Each heater line's temperature set point is adjustable by ground command with a pre-defined on-board default value.

The S/C offers three main compartments for unit accommodation as briefly outlined before. For the accommodation of the internal units the following aspects have been accounted for:

- The changes of the external thermal environment of the S/C external surfaces are defined by the seasons and S/C attitude relative to the sun and earth.
- For heat rejection the -Y side is the most efficient and stable one. The -Y surface receives no sun, albedo and earth IR radiation.
- The units' dissipation is distributed via conduction on the equipment panel and radiated directly and via the equipment panel to the inner surface of the foil SSM radiator on the -Y side, which transfers the heat via radiation to space.
- The internal boxes are low emissive if their dissipation is < 5 W, or else they are painted. High dissipating boxes are flat mounted to the equipment panel with interface filler in between.
- The RCS components are mounted around the mono-propellant tank on a dedicated panel in the middle of the central structure.

SSM foil radiators are foreseen on the -Z side and the ± X sides of the +Y+Z compartment and on the -Y side of the -Y-Z compartment. The foil radiators are built of a single foil. The outer foil surface is a completely second surface mirror (SSM), the inner surface is partly untreated VDA, and partly black painted. The size and location of the black painted patterns is determined such that the units remain well within their temperature limits and that the temperature controlled units require nearly no heater power in the worst hot case. The SSM foils are attached to the secondary structure with stand-offs and clip washers.

G.4.2.10 Launch Vehicle Interface. The accommodation of the ECHO inside the Dnepr-1 payload envelope is shown in Figure G-16. To fit inside this fairing a cylindrical extension of 2200 mm is needed, which is inserted in the lower part of the Dnepr-1 outer fairing shell. This is the same fairing extension that will be used for TerraSAR-X, which will be launched 18 months prior to ECHO.

The ECHO S/C is attached to the launch vehicle by means of six pyro-devices on a circular diameter of 1360 mm. The position of the launcher interface is close to the six longitudinal edge profiles, which build the backbone of the structure.

The separation system used on Dnepr-1 has no spring pushers, since the S/C separation is done by removing the upper stage by means of the upper stage motor throttled-back. The separation boost will be such that separation will occur in under 2 seconds.

Switches mounted on the adapter are used to verify the S/C separation. A dedicated mechanism is used to disconnect umbilical connectors for electrical links, which is activated prior to the operation of payload separation.

Pyro devices, separation switches and umbilical mechanism have undergone all necessary ground and flight testing and are highly reliable.

No satellite telemetry is required before and during launch. The ECHO instrument and S/C bus will be switched off, except for the bus power conditioning function. Thus, the electrical interface between launcher and S/C is limited to the supply of electrical power for battery charging during launch preparation. For this purpose one of the three available 50-pin umbilical connectors will be used.

G.4.3 Flight Software

G.4.3.1 Description. The ECHO OBC flight software is based on the flight software that is under development for TerraSar-X. The TerraSar-X flight software development uses the heritage from other Astrium programs (such as GRACE). Under TerraSAR-X, this software is being ported from a 1750 to an ERC 32 CPU with a different operating system (commercially available OS like VxWorks or RTEMS). Compatibility will be maintained with the ESA/ESOC generated Packet Utilization Standard.

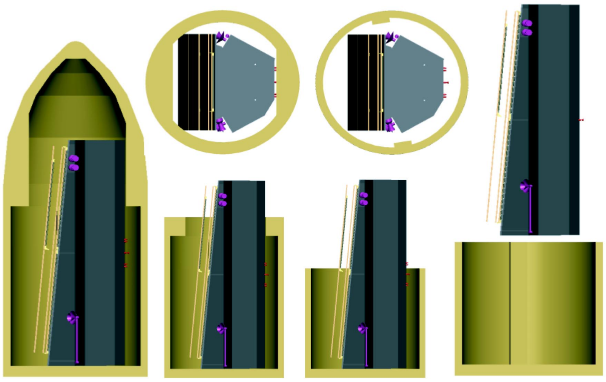


Figure G-16. ECHO S/C in Dnepr-1 payload envelope.

The software system comprises

- The bootstrap software (located in PROM), which provides the minimum software needed to boot the processor
- A set of low level drivers (driver library) to allow the application software to communicate with OBC internal and external components via standard buses and/or dedicated interfaces
- The operating system that provides the basic functions for task scheduling and control, low level communication processes, error messaging and error handling
- The application software

The application software represents the highest level of the onboard software system. It is functionally organized in object oriented packets, the upper level of them being identified and seen from operations point of view as Application Packet ID (APID). The typical software cycle has a duration of 1 sec, for some specific functions within the AOCS packet (like attitude determination, control and actuator control). A 4 Hz software cycle is possible, if necessary.

The functional blocks “TC handling” and “TM handling” represent the interfaces to the Ground. These two blocks mainly use standard services as specified in the Payload Utilization Standard.

The “System Control” is the highest hierarchy level within the application software. Beside the standard functions (local command interpreter, HK/TM handling, HK database), which are part of all functional blocks, it provides for overall system control (event and action service, S/C mode control), the system FDIR, and for the control of the system start-up sequence and initialization.

“S/C Bus Control” provides for all generic bus functions (except AOC and Payload Management).

“Attitude and Orbit Control” covers all functions necessary to perform attitude and orbit control, including sensor data acquisition and consistency checks, attitude and orbit determination filters, mode dependent controller, actuator control, as well as the AOCS local FDIR and mode handling. All AOCS states and transitions are reported via the standard TM service to the System Control, but only in case of system relevant failure cases/events the System Control will initiate actions on S/C level (such as OBC reconfiguration or transition to Satellite Safe Mode).

“Payload Management” provides all functional services necessary for the payload operation.

G.4.3.2 Development. The software development will be performed according to the Astrium standard, a tailored version from ESA standard ECSS-E-40A. This includes documentation approach, version control, hierarchical test steps and reviews.

A high-level software requirements document will be established by the system team, describing the relevant interfaces, a prescribed functional decomposition, the functional and implementation requirements and constraints.

A detailed software requirements document will be established and subjected to peer review. Based on this detailed requirements document, the software design will be performed and verified.

Verification on software level will be performed within the Software development environment and on the Software Validation Facility (SVF). The intention is to use an Astrium standard SVF with a target processor.

The formally deliverable software versions are:

- Version V0: used for flatsat integration testing and Realtime Testbed Integration testing
- Version V1: used for System IST and for RTB verification testing
- Version V2: final flight version (after successful system IST)
- Version V3: after in-flight commissioning.

Intermediate deliveries are possible, as required to fix failures during the test phases.

G.4.3.3 Validation. Software validation is performed in 4 major steps, where some of the steps are parallel for AOC (software) and application software:

Step 1: AOCS: Dynamic performance simulation within simulation environment SW: Development Testing within Development Environment

Step 2: AOCS and SW: open loop testing with SVF

Step 3: AOCS and SW (with emphasis on AOCS): AOC closed loop testing with Realtime Testbed (dynamic simulation environment, RT frontend-stimulation and OBC breadboard)

Step 4: AOCS and SW (with emphasis on SW): 4a): flatsat testing (electrical interfaces and data flow) 4b): Integrated System Test.

G.4.4 S/C Heritage and Technical Maturity

The ECHO S/C bus will make the utmost use of the heritage and the experience gained at Astrium GmbH for the design, development and testing of CHAMP (in orbit) and GRACE (Spring 2002), and the predecessor earth observation program TerraSAR-X.

Table G-6 shows the S/C technical maturity matrix. The use of items with strong heritage leads to a bus design with a high level of technical maturity.

G.4.5 New Developments Needed

All S/C bus equipment is either off-the-shelf, has accumulated flight heritage or will be qualified in the context of the TerraSAR-X program. Therefore, no new development is necessary in the context of the ECHO program.

G.4.6 Space-Flight Qualification Plan

By the time ECHO launches, all S/C components will be flight-proven through the previous flights of at least two FlexBus (CHAMP and GRACE) and one AstroBus (TerraSAR-X) S/C. The ECHO configuration will undergo a full S/C verification program. Since the ECHO S/C design incorporates only moderate changes to the TerraSAR-X design, no dedicated qualification hardware is planned. The ECHO S/C will be tested to protoflight levels.

G.4.7 Logistics Support

The S/C bus will be manufactured and integrated on the Astrium site in Friedrichshafen, and the system level tests will be performed on the IABG site near Munich. Astrium will provide the containers and vehicles necessary to safely carry the integrated S/C flight hardware and test equipment between the two sites. All containers are equipped with environmental load sensors (mechanical loads, temperature, humidity) for logging purposes.

Astrium will organize the transport of the integrated S/C from Germany to the launch site in Baikonur, Kazakhstan. Transport will be by aircraft and train and, where necessary, by helicopter. Again, during all transport, the environmental loads will be logged.

The ground test equipment used for S/C integration and test will be available as an extract at the launch site to perform a final check-out and to service the S/C during launch preparation and, to a limited extent, on the launch pad.

During the I&T phase in Germany, offices with up-to-date communication links will be made available to involved NASA, JPL and Ball staff and, to be agreed on a case-by-case basis, by NASA/JPL assigned support contractors in Friedrichshafen and at IABG in Munich.

G.4.8 Design Features to Reduce Cost

Cost reduction for the ECHO core S/C concentrates on linking its development to the flight heritage of the successful Astrium FlexBus core S/C series and on combining the development with the TerraSAR-X program in terms of technical implementation and team staffing.

As outlined in Section G.1.2 the AstroBus core S/C that is used for ECHO is a direct successor of the FlexBus series including technology adaptations as the upgrade of the OBC system. With the same design principles applied and all major data and electrical interfaces nearly identical, a significant portion in the procurement and development phase will be recurring from the CHAMP and GRACE programs.

Except for the primary structure, the mechanical/thermal interfaces to the instrument and the additional thruster branch for initial orbit lift, Astrium intends to build the ECHO core S/C identical to the TerraSAR-X core S/C. As a result, TerraSAR-X specifications are implemented as an envelope of the requirements from both programs such that TerraSAR-X with its head start serves as a “qualification” program to ECHO and the majority (in cost) of the units will be supplied as recurring units of TerraSAR-X.

A shared team approach is envisaged in a way that the technical work for ECHO will be performed by the same staff that performs the work on TerraSAR-X slightly ahead in time. The same design principles applied to both S/C allows an efficient use of staff and tools.

G.4.9 Key Performance Margins and Rationale

Mass and power margins are shown in Table G-5. The mass margin is dictated by the mass allocation for the contributed Dnepr-1 launch. There are several factors that mitigate the 11% margin. The instrument and antenna have a robust contingency of 30% and the antenna deployment structure has 20% (RADARSAT-2 heritage). Many elements of the S/C have been through Phase B for TerraSAR-X and so the S/C carries a healthy 20% mass contingency. The combined margin and contingencies are consistent with the *JPL Design Principles*. In addition, the mission could fly with a 512-km orbit and still achieve the baseline science. This would save 49 kg of propellant, and yield a larger margin. This change can occur past CDR as it does not affect the radar hardware, only the selectable parameters (e.g., PRF, DWP).

The combined power contingency and margin are consistent with the requirements of the *JPL Design Principles*. In addition, the S/C could accommodate an increase in the solar array by 20% at the cost of the additional solar cells and labor to provide additional margin. The CPU (970%), and memory margins (250%) exceed the margins required by the *JPL Design Principles.*

G.4.10 Phase 2 Development

Phase 2 activities for the satellite bus will focus on the refinement of the requirements and technical implementation concepts as described in this proposal including a first round of analyses in the area of thermal, structural and power. Phase 2 will end with the release of an agreed satellite specification accompanied by procurement specifications for the bus units.

A first issue of the satellite design and interface document will be released.

G.4.10.1 Schedule for Spacecraft Development. The schedule for design modifications, assembly and test is shown on the master program schedule in Figure H-1 of the Management Section.

G.5 Launch Services

G.5.1 Launch Vehicle

ECHO will be launched on a DLR contributed Russian/Ukraine Dnepr-1 rocket with characteristics listed in Table G-7. This contribution includes launch support services. The launcher is derived from the Intercontinental Ballistic Missile SS-18. The heritage of this system comprises 157 successful launches (97%) since 1975 in ICBM configuration and two successful launches in April 1999 and September 2000

Table G-7: Required Launch Services (K-7).

Launch Vehicle: Dnepr	Value, units
Launch Vehicle Performance	1700 kg
Shroud Volume	cylinder 2400 mm dia., 3540 mm long, conical section 3170 mm long
Launch Site	Baikonur
Injection Inclination Error	± .04 deg
Injection Line of Nodes Error	± 0.05 deg
Injection Altitude Error	± 4 km

in a satellite transport configuration implementing an upgrade in payload fairing and on-board electronics.

The Dnepr is a robust rocket system with three stages of liquid propellant and an overall mass of 210 tons.

After payload integration, the launcher will be stored in an underground silo. It will be propelled from the silo by hot gas pressure after which the first stage ignites about 25 m above ground. After second stage burn-out and fairing jettison the initial injection orbit is reached using the third stage.

The separation of the payload from the third stage is executed by a so called “drag scheme” separation strategy, in which this third stage turns by 180°, followed by the three-axis stabilized release of the satellite. In this position the upper stage is accelerated in flight direction, leaving the payload behind and the upper stage will execute a destructive re-entry.

The actual payload lift capability with the modified fairing into the initial injection orbit of 400 km altitude and 98.5° inclination is 1700 kg. ECHO will use the same fairing (see *ECHO Launcher Specification* in Appendix 11) as will be used by TerraSAR-X 18 months before the ECHO launch.

G.5.2 Range of Acceptable Launch Options

Due to the low price and programmatical reasons (close co-operation with the German DLR as the launcher provider similar to the GRACE program) the actual layout of ECHO is adapted to the Russian/Ukraine vehicle Dnepr-1.

Nevertheless, the satellite/antenna configuration (dimensions), structural design (strength and stiffness) and required resources (wet launch mass) is compatible with the full range of medium size launcher systems. The required payload diameter is > 2700 mm, which is the case for the US Delta or Atlas and the Russian Soyuz or Zenith.

G.5.3 Orbit Parameters

Orbit parameters are delineated in Table G-1. To realize ECHO’s required local time without excessive fuel consumption, launch window duration must be minimized. Launch windows exist every day of the year. ECHO’s Δv budget accounts for 3-σ dispersions from the Dnepr.

G.5.4 Launch Option Margins

The mass margin for ECHO is given in Table G-6. Figure G-16 shows the S/C and stowed instrument in the payload envelope.

G.6 Manufacturing Integration and Test

G.6.1 Manufacturing Strategy

G.6.1.1 Spacecraft Manufacturing Strategy. To ensure reasonable prices, most of the S/C components/units will be procured in an open competition process. All potential suppliers need to accept an audit conducted by a combined Astrium/JPL/NASA team prior to the start of the tender process if considered necessary. Only audited or well known suppliers will be invited to make offers.

Once the supplier is selected, the S/C development and manufacturing process will be controlled by peer reviews conducted by combined Astrium/JPL/NASA review teams. The final procurement of components will be performed after successful completion of all tests on unit and system level. The selected suppliers will be shadowed by members of the prime system engineering team.

The system engineering responsibilities (e.g., thermal, mechanical analysis or AOCS system design and analysis) will be performed by Astrium. To the maximum extent, possible unit specifications will be identical to the precursor program TerraSAR-X. As a result, TerraSAR-X will serve as a “qualification model” for many of the ECHO S/C component suppliers.

Spacecraft assembly and integration will be performed at Astrium under full control of the system engineering team. Environmental test facilities for system level tests will be the same as those for CHAMP, GRACE and TerraSAR-X. A site survey was performed by JPL/NASA prior to GRACE testing.

G.6.1.2 Radar Electronics Manufacturing Strategy. The radar electronics will be manufactured in accordance with JPL procedures and processes established for SRTM and the SIR Series.

G.6.1.3 Antenna Manufacturing Strategy. Ball will take a low-risk, system-engineering approach to the manufacture of the antenna subsystem, including the use of qualified subcontractors with expertise in specialized areas. This approach, proven to be successful on SRTM, not only distributes the risk but also takes advantage of the best capabilities available in the industry. For antenna fabrication and assembly, Ball's internal processes are flight-proven and ISO-9000 certified.

G.6.2 Fabrication Processes and Procedures

G.6.2.1 Spacecraft. ECHO's manufacturing, integration and test approach is based on standard Astrium processes accepted by NASA (X-SAR, SRTM, GRACE), ESA (Cluster, XMM, Ulysses, etc.) and DLR (Rosat, CHAMP) as well as the experience and successful record of Astrium GmbH in producing and delivering flight systems for science and Earth observation missions.

G.6.2.2 Radar Electronics. The radar electronics assembly will be a custom design both mechanically and electrically. The design will draw on previous flight experience, and fabrication, assembly, and testing will be carried out in accordance with JPL practices and procedures. Electrical and mechanical interfaces to the S/C and interfaces between the RFES and CPDU will be defined and controlled by interface control documents (ICD). The interfaces will be kept simple and frozen at a early stage of design to avoid costly redesigns later on. All subsystems will be tested electrically and mechanically as required in various environments including thermal vacuum. All levels of fabrication and test will be monitored by JPL quality assurance (QA), and all tests fully documented and witnessed by QA and system engineering whenever necessary or required.

G.6.2.3 Antenna. The antenna subsystem consists of an active phased-array antenna, an antenna deployment structure, and the antenna CPDU. All will technically be unique designs but will be significantly based on previous flight successes. No component of the antenna subsystem requires a fabrication process or procedure not previously proven for space application by the organizations involved. All component designs will be driven by specifications and interface control documents (ICDs) that will ensure the required performance and compatibility. All appropriate aspects of performance, including environmental compliance, will be verified. Quality assurance will monitor the details of the fabrication and test program and will certify the steps followed and the measurements made.

G.6.3 Production Personnel

The production teams at JPL, Ball, AEC-Able and Astrium will include a production manager, material specialist, mechanical production engineer, and electrical production engineer. All program work is authorized by work orders that are issued for individual tasks identified in the project work breakdown structure (WBS).

G.6.4 Use of New Technologies/ Materials

There are no new materials or technologies required to implement the ECHO radar or S/C. The antenna panel laminate is very similar to those used on SeaSat and SRTM. The T/R modules use amplifiers and DC/DC converters very similar to those used on SIR-C and a current Navy satellite communication program at Ball. The antenna CPDU will be a much-simplified descendent of the CPDU on SRTM, and the antenna deployment structure utilizes the same materials and technologies currently being implemented by AEC-Able for RADARSAT-2 (CDR was Jan. 2002).

G.6.5 Test and Verification Program

The plan for ECHO flight system-level testing includes an initial full-up systems performance test, environmental exposure (thermal vac, vibration, pyro shock, acoustic) with smaller scale functional, and a final post environmental system performance test that includes radiated compatibility tests (see also Section G.3). Pre- and post-environment deployment tests are planned for the SAR antenna. Following the post-environmental tests, the S/C will be in its final configuration for shipment to the launch site. At this time final mass properties will be evaluated. At the launch site a set of S/C functional tests will be performed to verify that the S/C was not affected by the shipping process. Once on-orbit, a complete set of tests will be performed within the first 30 days of the mission. These tests will characterize the performance of the S/C and establish the operational routine for the remainder of the mission.

G.6.6 Facilities, Techniques and Processes

For the I&T of the ECHO core S/C as well as the overall observatory, Astrium facilities in Friedrichshafen and supplementary installations of the Industrie- and Anlagenbau GmbH (IABG) in Munich will be utilized. Access to the in-house facilities in Friedrichshafen is granted and a priority partnership relation assures the timely utilization of IABG facilities.

The I&T facilities in Friedrichshafen are located in close vicinity to the engineering and manufacturing buildings. The facilities comprise standard and high-bay clean rooms of class 100,000 up to class 100, preparation and check-out rooms as well as work shops to support observatory level assembly, I&T. For subsystem and unit level assembly I&T, thermal balance/thermal vacuum test facilities, temperature test facilities, clean rooms, vibration & shock test facilities as well as shielded and anechoic chambers are at the project's disposal.

The IABG facility complex comprises clean rooms ranging from class 100,000 to class 100 as well as observatory level test installations as thermal vacuum chambers with and without simulated sun illumination, shielded anechoic chamber, vibration/shock test facilities, mass property determination complex and reverberation (acoustic) chamber.

The facilities of Astrium and IABG are sized in dimension and performance to meet the needs of the ECHO S/C program.

Techniques and processes for ECHO I&T follow well established and proven Astrium standards. Maximum benefit will be taken from the fact that the TerraSAR-X I&T program will occur prior to the ECHO activities using the same facilities, nearly identical procedures and the same I&T staff.

No new facilities are required for the ECHO integrated antenna/deployment structure. Ball is a full-service space hardware firm with well over 1 million square feet of design, manufacturing, integration and environmental test facilities. AEC-Able is also a world-renowned deployment structure contractor with relevant experience including the SRTM extendable mast and the RadarSat-2 antenna extendable support structure. Ball, AEC-Able, and JPL have in place all necessary development, integration, and test facilities to build and qualify the ECHO integrated antenna/deployment structure and integrated Radar Instrument.

G.6.7 Schedule for Manufacturing, Integration and Test

The schedule for manufacturing, integration and test of the instrument and S/C is shown on the master program schedule in Figure H-1 of the Management Section.

G.6.8 End Items

Astrium GmbH will provide a fully tested and integrated S/C, on orbit command control and communications software, ground segment command, control and communication software, documentation on how to operate the S/C, and mission operations support.

JPL will provide one flight model (primary and redundant) radar electronics. No prototype or qualification hardware will be provided. No hardware or software for post launch ground support will be provided.

Ball will provide a fully-tested and integrated active phased-array antenna and deployment structure flight model, a single antenna panel used for qualification, and support for payload and S/C integration. Ball will provide the antenna deployment structure via subcontract with AEC-Able.

G.7 Mission Operations

The ECHO MOS will be implemented in a multi-mission environment at the GSOC in Oberpfaffenhofen, Germany with a limited set of functions being performed at JPL. GSOC, a section of DLR, is one of the major space MO centers in Europe with experience in operating over 30 satellite missions. Recent or planned missions include CHAMP, BIRD (IR-remote sensing), GRACE, EUTELSAT HB6 (commercial), DIVA (astronomy) and TerraSAR-X. GSOC has a close cooperation with NASA/JPL (GRACE mission) along with ASTRIUM (S/C manufacturer) to provide a seamless transition between development and operations. The primary functions of the MOS are shown in Table G-8.

G.7.1 Mission Operations Management

The MOS team consists of a partnership between JPL, SIO, GSOC and ASTRIUM. JPL will provide overall operations coordination, MOS support for instrument monitoring, and instrument task planning and validation. GSOC

Table G-8: Mission Operations and Ground Data Systems Table. Link budget (LB) values assume a mask with 5-deg. elevation.

Down link Information	Value, units
Number of Data Dumps per Day	engineering: 2 science: 10-14
Downlink Frequency Band, GHz	engineering: S-band science: X-band
Telemetry Data Rate(s), bps	engineering: 32 kbps, 1 Mbps science: 300 Mbps
S/C Transmitting Antenna Type(s) and Gain(s), name and DBi	S-band nadir: quadrifilar helix ant., max/LB gain 2/–1 dBi S-band zenith: patch antenna, max/LB gain 7/0 dBi X-band left and right: shaped beam antenna, LB 3 dBi
Spacecraft transmitter peak power, watts.	engineering: 7 W science: 75 W
Ground Station Selection(s), name	S-band: Weilheim X-band: Fairbanks, Miami
Geographic locations of Ground Station(s) if not existing within STDN net-work, latitude & longitude	Weilheim (N47 deg, 52 min, E11 deg, 5 min)
Downlink Receiving Antenna Gain, DBi	Weilheim G=47.8 dBi, G/T=27.8 dB/K
Bit Error Rate	engineering: 10**-6 science: 10**-6
Downlink Modulation Format (e.g., PCM/PM/Bi-Ù, PCM/PSK/PM, BPSK, QPSK, etc.), name	engineering: BPSK (PM for incoherent ranging) science: QPSK
Error Detecting-Correcting Coding (e.g., convolutional, Reed-Solomon, concatenated, etc.), name	engineering: none science: Reed Solomon
Transmitting Power Amplifier Output, watts	engineering: 29 dBm (ca. 800 mW) science: 30 W

Uplink Information	Value, units
Number of Uplinks per Day	1
Uplink Frequency Band, GHz	S-band
Telecommand Data Rate, bps	4 kbps
S/C Receiving Antenna Type(s) and Gain(s), name and DBi	nadir: quadrifilor helix ant., max/LB gain (2/0 dBi) zenith: patch ant., max/LB gain 7/0 dBi

will provide the majority of the MOS support services with technical support from ASTRIUM for S/C engineering analysis and anomaly resolution. The SIO team will provide data acquisition planning services in coordination with JPL. The MOS team will be lead by the ECHO mission operations manager at JPL in coordination with the GSOC mission operations manager. The ECHO MOS manager is responsible for the overall coordination and execution of mission operations during all phases of the mission. The GSOC MOS manager is responsible for coordinating and executing all mission operations functions performed by GSOC and ASTRIUM. ECHO mission operations consist of four parts: science acquisition planning, mission planning and scheduling, S/C operations, and POD.

G.7.1.1 Science Acquisition Planning. The Science Acquisition-Planning Group (SAPG), based at SIO, is responsible for high-level planning of data acquisitions. This group will primarily consist of science team members and a full time acquisition planner who approve user requests for acquisitions, assemble priorities for acquisitions, and resolve conflicts. This high-level acquisition plan will be passed on to the mission planning team at JPL. All non-immediate requests for acquisition will be approved by the SAPG at regular meetings. A subset of the group, which includes the PI, will be on call to approve high-priority requests for coverage of significant events. Requests can be executed within 12 hours if necessary. The SAPG will utilize the same mission-planning tool used by the mission planning team to ensure consistency and provide flexibility for changes.

G.7.1.2 Mission Planning/Scheduling. The mission planning/scheduling (MPS) team, at JPL, is responsible for planning and validation of science acquisition requests provided by the SAPG with other S/C operations activities. This process is based upon time allocation, ground station availability, and S/C capability. This process yields multiple products such as a detailed task plan of instrument activities, and a X-band ground-station scheduling plan. The validation of the task plan will be based upon S/C constraints and models provided by GSOC/ASTRIUM. The task plan consists of an online document that is used by the operations team as a guide for instrument operations and is also used by the ECHO user community to monitor S/C activities. This plan also includes instrument on/off times, look angle, and left/right pointing based upon the SAPG inputs. The task plan provides the GSOC parametric inputs for conversion into S/C commands based upon predefined commands blocks. This standardization will increase efficiency for instrument tasking and reduce operational risk.

G.7.1.3 Spacecraft Operations. The S/C operations team at GSOC is responsible for maintaining the health and safety of the S/C. This task includes functions such as command handling, telemetry processing, engineering and trend analysis, anomaly resolution, navigation and maneuver design. A lead engineer on this team will coordinate all daily activities for mission operations. ASTRIUM will also support the team for engineering support and anomaly resolution.

G.7.1.4 Precision Orbit Determination (POD). The JPL POD team is responsible for providing precision orbit solutions for science data processing. Orbit solutions will be based primarily on the S/C GPS receiver data. The ground laser ranging data will also be utilized for validation purposes and to supplement the GPS data if necessary. The software tools producing the orbit solutions will be developed and maintained by JPL. These software tools incorporate heritage from previous and planned flight missions such as Topex/Poseidon, CHAMP and Jason-1. Software operations services during mission operations will be provided by Raytheon with JPL providing management and systems engineering support. Orbit solutions will be provided to the user community via an file server on a daily basis through links from the GDS catalog (see Section G.8). Ground automation procedures and standardization of processes will reduce workload and operational risk.

G.7.2 Operational Phase

The operational phase is divided into three parts; pre-launch, operations prior to data acquisition, and operations for data acquisition. The pre-launch portion consists of preparations and testing of the MOS prior to launch. The operations prior to data acquisition consists of functions that are performed prior to instrument turn-on such as orbit acquisition, on-orbit system checkout, and deployments. The final portion relates to normal mission operations for science data acquisition. An overview of the mission operations structure and data flow is show in Figure G-17.

G.7.2.1 Operations Prior to Launch. The complete MOS system is targeted for delivery 4 months prior to launch. After delivery, the system will undergo final testing for critical functions such as S/C commanding, telemetry processing and ground station interfacing. The testing will be conducted in conjunction with the S/C bus testing such that the ground system can interface with the actual S/C and ground stations. Other MOS team activities consist of creating operations procedures, personnel training, design of command blocks, design of automation scripts, generation of contingency

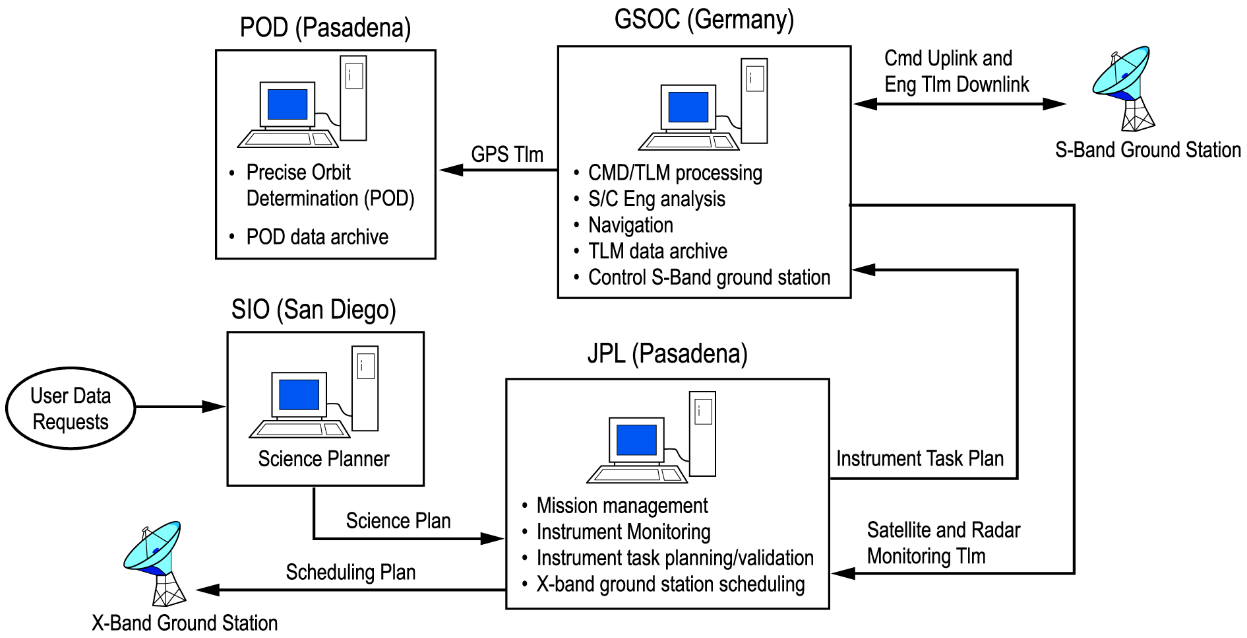


Figure G-17. ECHO mission operations structure and data flow.

plans, design of expected maneuvers, and development of engineering analysis tools.

G.7.2.2 Operations Prior to Science Data Acquisition. During the first two weeks after launch, the MOS team will work to place the S/C into its final orbit, deploy the antenna, and evaluate the performance of the S/C bus and its subsystems. During this phase, S/C and radar engineering personnel will augment the MOS team at the mission control center. To ensure S/C health and safety, contact with the S/C will be maintained at least once per orbit.

G.7.2.3 Maneuver to Obtain Final Orbit. After separation from the launch vehicle, the S/C will autonomously stabilize to a sun-pointed, power-positive attitude. Within the next 2 days, the MOS team will perform an initial checkout of the S/C subsystem performance and perform a series of orbit maneuvers to attain the final orbit. After every orbit maneuver, the GPS data will be used to assess maneuver performance and provide input for the design of the next maneuver. Utilizing existing software tools, the MOS team will design the next maneuver and produce a set of S/C commands.

G.7.2.4 On-Board Checkout. After ECHO reaches the desired sun-synchronous 8-day repeat orbit, the radar antenna will be deployed. A more thorough checkout of the S/C will be performed. After the radar is powered up and calibrated, and S/C operation is deemed to be nominal, the operations staff will be reduced in preparation for normal mission operations.

G.7.2.5 Operations for Data Acquisition.

During the data collection phase, the satellite will be operated from the GSOC mission control center. Mission planning will generate a weekly sequence of events that corresponds to a set of a stored S/C commands and ground station scheduling data. Stored commands will be uplinked to the satellite during one of the daily contacts. During these contacts, commands for real-time operations will also be sent, and recorded engineering data will be played back. Real-time and recorded data will be alarm checked, processed and archived. These data are then available for engineering analysis of S/C performance and generation of GPS engineering and science data products. Normal staffing for the center will consist of 3 to 4 persons with off-hours support from additional personnel as needed. The ground system will be automated such that off-hours contacts with ECHO can be managed based upon pre-existing command and verification scripts. If any parameters are found to be in an alarm state an operator will be notified.

G.7.3 Operational Constraints

Tables G-2 and G-8 provides details regarding constraints, viewing, and pointing requirements.

G.7.4 Ground Support Requirements

The ECHO mission operations utilize modern communications methods for both S/C communications and information distribution. The primary communications link between the mission center and the S/C will be via an existing closed/secure network. This network provides secure, redundant, and reliable service that supports industry standard protocols and interfaces such as TCP/IP. Mission critical functions for operations are isolated behind a firewall computer that limits external access and protects against unauthorized access. Some mission operations products are available to the public via (mirrored GND System Data Server, ftp) the MOS data server, which is external to the firewall. To add flexibility and provide for low-cost operations, all mission control functions are available remotely using a "smart-card" device for password security.

Contact with the satellite to monitor S/C health and safety will be scheduled to occur at least two times per day. Additional contacts will be scheduled during critical mission activities such as maneuvers or anomaly resolution. In the event of a contingency or emergency operations, the GSFC provides tracking services at the next available viewing opportunity. This service will be provided upon request by the ECHO mission manager and does require an additional usage fee.

G.7.5 Special Equipment or Skills Required of Ground Personnel

The ECHO mission is designed for low-cost mission operations, which will be achieved by utilizing modern technology and increased productivity. ECHO operations workstations will incorporate technology that allows for multi-mission operations, thus allowing reduced capital expenditures. To operate the S/C with this advanced technology requires additional skills for the operations staff, who must be generalists able to assume interchangeable roles. Personnel must possess skills in the areas of S/C systems engineering, ground system operations, and technical team management.

G.7.6 Telemetry Acquisition and Processing

Spacecraft engineering data is acquired onboard and stored locally in RAM, separate from the science-data SSR. During each S-Band contact, real-time telemetry will be captured and stored engineering data will be played back. Retrieval and analysis of engineering data occur on a routine basis to monitor S/C performance. Non-real time data will be especially important during anomaly isolation and recovery.

The GPS data will be captured by both the onboard processor (for orbit propagation purposes) and by the telemetry processor (for downlink as part of the normal engineering telemetry).

Refer to Section G.8 for information regarding the acquisition of science data.

G.7.7 Ground Meta-Data Processing

The GPS data will be downlinked, processed, and packaged for delivery to the appropriate users. Archived data will reside on the ECHO data server for retrieval by the user community. These data will then be available within 3 days. The capability to process raw GPS telemetry and generate coarse ECHO orbits for navigation purposes will be available at the GSOC control center.

G.7.8 Telemetry Archiving

Engineering data will be processed in a real-time or playback mode by the mission control center software at GSOC. These data will then be archived for future processing and analysis as required. In addition, some of the engineering data will be further processed for performing routine trend analysis and S/C calibration. These products will also be archived separately. Downlinked GPS data will be archived in a raw form but will be formatted to conform to existing file structures and standards.

Refer to Section G.8 for information regarding science data processing and archival.

G.7.9 Schedule for Data Distribution

The GPS orbit data will be placed on an open Internet server within 3 days of data receipt.

Refer to Section G.8 for information regarding science data processing.

G.7.10 Software Development

All elements of the MOS software have strong heritage from other missions. Software development for the S/C operations at GSOC will rely largely on existing GSOC capability and development under the German TerraSAR-X, which will precede ECHO by 18 months. ECHO mission planning software will be developed at JPL and mainly will consist of modifications to the SRTM planning tool. Precision orbit determination will be performed using software developed for other missions (e.g., Jason).

G.7.11 Features that Enable Low-Risk Operations

The primary mission operations for ECHO is a contributed (no-cost) service provided by DLR-GSOC based upon the utilization of the current operational capability supporting similar missions. The ECHO operations methodology takes advantage of heritage, standardization, and new technologies to provide a substantial increase in efficiency and productivity while reducing operational risk. Following are some of the specific areas that are affected:

- Multi-Mission operations: Utilize experienced staff requiring minimal retraining. Use of virtual operations team consisting of personnel that are time-shared among multiple projects. Sharing of existing facilities reduces overhead costs.
- Partnership with S/C contractor (ASTRIUM) provides strong program commitment, good interfaces, and operations flexibility.
- Use of heritage data for MOS configuration (TerraSAR-X) and standard ground station facilities and interfaces.
- Use of an automated ground system for telemetry processing, archiving, and other housekeeping functions.

G.7.12 Mission Operations Facilities

The GSOC of DLR, located at Oberpfaffenhofen near Munich, has been responsible for the preparation and execution of approximately 20 national and international, co-operative space flight projects. Besides the space flight operations facilities and its own remote site for satellite ground stations (Bodenstation) at Weilheim/Lichtenau, GSOC comprises a technology oriented section for simulations of in-orbit servicing and operations (In-orbit Operations Technology facility). GSOC—controls and monitors scientific satellites, communication satellites and manned space-flights, taking responsibility for mission preparation, ground segment development, S/C communications with earth stations and relay satellites, satellite tracking and orbit control, communication satellite positioning and operations, control, telecommanding and monitoring of satellite onboard systems and experiments, acquisition, processing and presentation of S/C data, payload coordination and control center functions.

To fulfill the space flight control center functions the following operations facilities and infrastructure installations are available at GSOC:

Control rooms: For accommodation of the flight operations personnel the following fully equipped control rooms are available: Four control rooms at 160 m² each with a total of 60 standard consoles. Three User rooms with a total of 130 m² for 11 workstations and supporting equipment. The access-controlled control rooms are separated from the other areas in the basement of the GSOC.

Data Processing System: The multi-mission data processing system comprises: communications frontend for data acceptance, distribution and storage, central data processing for telemetry data processing and storage, display system, command system, mission planning system, interfaces for electrical ground support equipment (EGSE), and interfaces to H/W, S/W and hybrid simulators.

Voice Intercommunication System (VIS) and Video System: This system serves internal control room communication, external and air to ground communications.

Office Communications System (OCS): This system forms the backbone of the GSOC electronic documentation and information system.

Ground System Control Room: For operating the above ground systems a control room (ca 100 m²) is equipped for easy control and monitoring of the various components on the same floor. These ground systems mentioned above are accommodated on an entirely separate floor (ca 1000 m²) in order to facilitate their operation and maintenance. This floor can also be access controlled.

G.8 Ground and Data Systems

ECHO will use a novel approach to ground operations rooted in a unique data, downlink, processing, and access policy. Figure G-18 shows an overview of the ECHO GDS and shows its relation to the MOS. Data from the ECHO SSR will be downlinked to two ground stations (ASF, U. Miami). The data will be immediately processed to L1 format at these stations. SAR signal data are often referred to as L0 data. The L1 designation used here is consistent with the EOS Data Gateway (EDG) catalog. Following L1-processing the data will be sent via high-speed Internet-II connections to the Network Transfer Subsystem (NTS) at Stanford University. The NTS will log the data as they are received in the data catalog and distribute archival copies of the data to the distributed archive system over high-speed Internet connections. The distributed archive is comprised (Fig. G-18) of 5 online short-term archives, a full online mission archive (SDSC), and a permanent archive at the Eros Data Center (EDC). Users may then retrieve data either electronically from the online archives or via tape from EDC. The catalog system keeps track of the physical locations of the data so that to the user the distributed online archives appear effectively as a single archive.

The short-term archives hold the data online for a period of approximately one year from reception when demand is expected to be the highest. The use of 5 short-term archives distributes the network load allowing users rapid access to the data. Each short-term archive is sized to hold approximately 6 months of data so that collectively they can hold more than a year's worth of data when each data take is kept at two short-term archives.

All data will be archived online over the 5-year mission at the SDSC. Users will be able to access these data over the Internet through the same online catalog that serves the short-term archives. Because these data are stored on tape silos, the latency in retrieving these data will be slightly longer (e.g., a few hours). The largest demand for data should occur at the short-term archives, eliminating bottlenecks at the SDSC.

All data will be archived at the USGS EDC. This will serve as the permanent mission archive and tape distribution center.

L1 SAR data will be archived and distributed. The ECHO project will supply users with software for generation of the higher-level products needed to meet the science objectives. This distributed data processing approach reduces the computational requirements on the central data

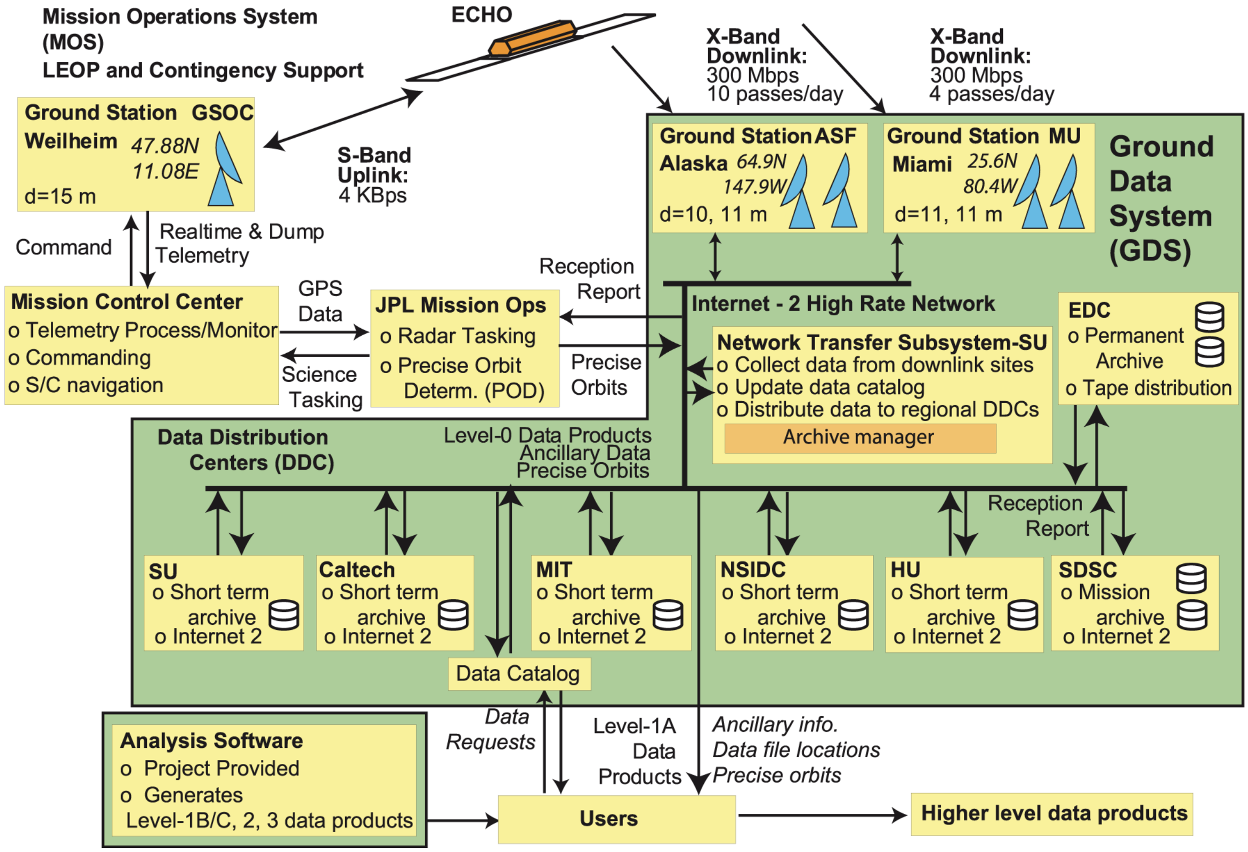


Figure G-18. Major data flow paths. Data are downlinked though the primary facility in Fairbanks, AK. A secondary site at the University of Miami receives data on passes not visible in Alaska. Data are sent to online archive and distribution centers over Internet-2, and stored at the EROS Data Center and the San Diego Supercomputer Center. Users access data online, and may submit requests for data on physical media to EDC. Data acquisitions are managed by an operations group, with the Science Team setting priorities. Command uplink is provided by DLR GSOC.

system. It also avoids the combinatoric problem of having to distribute many more combinations of scenes (interferograms) than scenes themselves. Furthermore, it eliminates the need for a complicated customer interface for the on-demand processing of a large variety of products. This enables a low cost approach while ensuring efficient and timely access to the data for the scientific user community. It is also consistent with the user preference for Level 1 products for InSAR.

G.8.1 Communications

The major communications links used for the ground data system are shown in Figure G-18. Data are transferred from the satellite to the ground station via a 300-Mbs X-band downlink. From there all communications pathways are either Internet or Internet-2.

G.8.1.1 X-Band Downlink/Ground Stations. Radar data will be recorded on the S/C SSR and then transmitted to the ground stations via an X-band downlink at 300-Mbps. These sites will be largely automated, as their purpose is limited to satellite tracking, Level 1 processing (frame synchronization, bit error correction, and quick-look processing), and delivery of data to the Internet-2 connection. This will require only minimal staffing, much of which will be shared with other missions using the downlink sites.

The primary site is located in Fairbanks, at the Alaska SAR Facility (ASF). This site is equipped with a 10-m and an 11-m dish. A second site at the University of Miami will obtain passes on orbits not visible in Alaska. The Miami site is currently under construction as part of a DOD funded effort and will include two 11-m dishes. ECHO will be in the ASF mask for 101 minutes each day and in the Miami mask for 38 minutes. The daily data volume can be downlinked in 64 minutes at 300 Mbps.

Data will be downlinked, processed to Level 1 “on the fly,” and delivered via high-speed connections to the NTS at Stanford. Data will also be copied to tape as backup at the ground stations. The data from the primary site at ASF will be routed to the NTS through the OC-12 connection at the Arctic Region Supercomputing Center. Miami, which will receive about 15% of the data, will send the data to the NTS through an existing OC-3 connection.

G.8.1.2 Network Communications. ECHO will use high-speed Internet-2 connections to move data from the ground stations to the NTS and then from the NTS to the distributed archive sites (see Fig. G-18). Data will be stored triply-redundantly (2 short-term archives and the SDSC mission archive) to ensure rapid online access.

The archive nodes coincide with ready access to the high-speed infrastructure provided by the National Science Foundation's vBNS+ (very high performance Backbone Network Service) and Abilene networks. The vBNS+ and Abilene networks are integral parts of the Internet-2 (I-2), a consortium of over 180 universities working in partnership with industry and government to develop advanced network technologies. At present, OC-48 fiber lines with a bandwidth of 2.5 Gbps interconnect major routing centers, with additional access to certain I-2 partners over OC-12 (622 Mbps) connections. Nodes in the ECHO GDS are located at participating I-2 institutions, mainly at access points to the 2.5 Gbps lines (see Fig. G-19, Table G-8).

Data initially downlinked at ASF will be sent to Stanford, where the NTS will forward copies of each satellite pass to the SDSC archive and the appropriate short-term archives. In addition, data will be directed to the permanent archive at EDC. These internal data system transfers will be routed over the 2.5 Gbps I-2 lines.

Even though the high-speed trunk lines are rated at extremely high throughput, care must be taken to ensure high-speed transfers. Modern networks are optimized for high aggregate bandwidth, but IP stack protocols limit single connections ~10 Mbps, even over the 2.5 Gbps lines. But parallel stream approaches to increase aggregate data rates are well known (see for example King, Lawrence Livermore National Laboratory report UCRL-MI-142491, Feb. 26, 2001; presented at SC2000, Dallas, TX, Nov. 4–10, 2000).

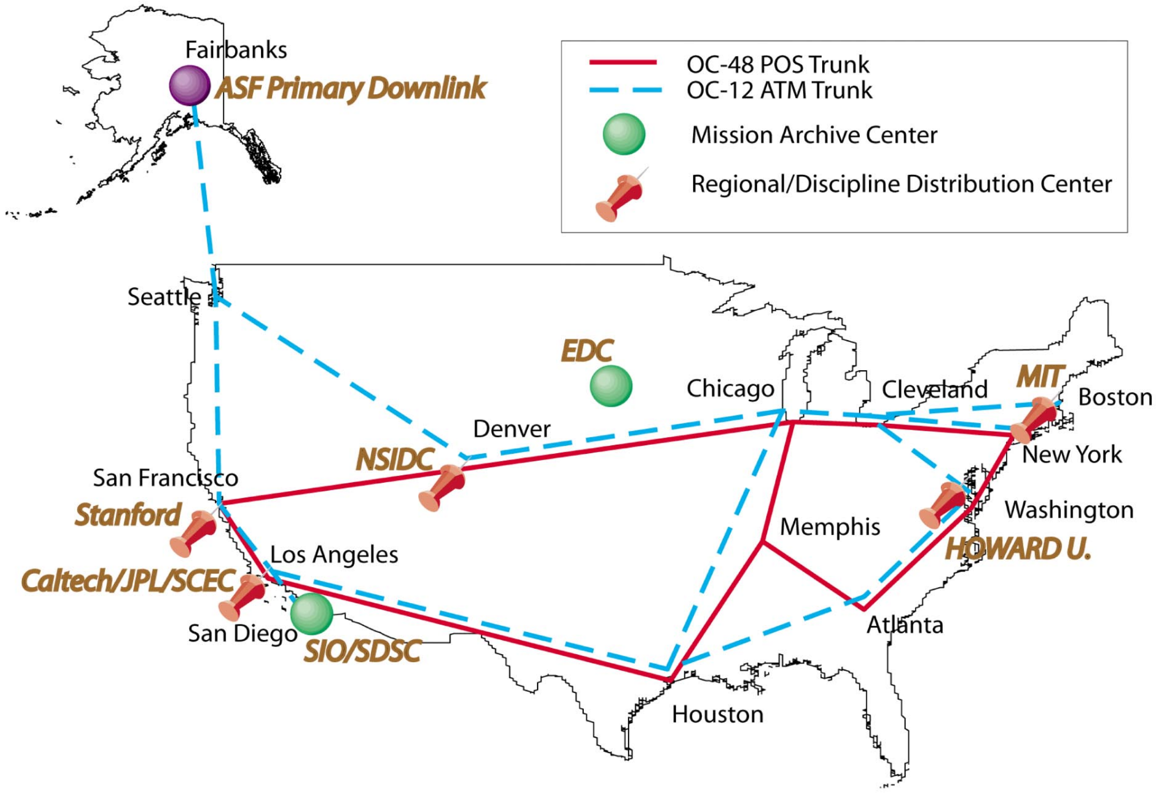
Specialized code that sends files over multiple parallel sockets to permit the high speed transfers will be required to make the system function for the large radar data volume. Table G-9 illustrates the level of the performance that can be achieved based with multiple sockets, based on preliminary experiments completed as part of a Stanford program to encourage new networking technologies.

Assuming 200 Mbps as a minimum average data rate, the transfer time for the 140 GB of daily ECHO data through the system is about 1.5 hours, which is well in excess of the mission requirements. These values apply to 2002 hardware and networks and may improve further by the time ECHO is launched in 2006.

Averaged over 24 hours, the sustained rate needed to transfer one copy of the daily data volume is 15 Mbps. Four copies of the data will be distributed from Stanford daily (2 to short-term archives, 1 to SDSC, and 1 to EDC). If two copies are sent on each of the trunk lines leading out of Stanford (Fig G-19), then ECHO will utilize 1.2% of the capacity of each line. With the high throughput described above, network transfers can be performed during off-peak times to minimize the load at peak times.

Machine Names	Connection	Rate, Mbps
Cass->Erda-gig	Gigabit-Gigabit (long-haul)	212.9
Erda-gig->Cass	Gigabit-Gigabit (long-haul)	145.7
Diode->Capacitor	Gigabit-Gigabit (local)	234.6
Ftp Cass->Erda-gig	Gigabit-Gigabit (long-haul)	9.7
Ftp Cass->Jukebox	Gigabit-100 Mb (local)	65.9
cp Cass->Cass	Internal bus	223.2

Table G-9: Sample transfer rates over Internet-2 lines. Erda is located at JPL and the other machines are at Stanford. Multi-socket, long-haul transfers from Stanford to JPL achieve >200 Mbps rates over Gigabit lines. Ftp connections between the sites are limited ~10 Mbps by network protocols. Local transfer and disk rates are also ~200 Mbps, implying that they are the limiting factors.



ECHO Archive and Distribution Center Siting on NSF vBNS Backbone

Figure G-19. ECHO GDS nodes are located primarily at access points to the highest speed (OC-48) trunk lines of the vBNS+ network, part of the Internet-2 consortium. Nodes are distributed geographically and topologically to minimize any potential bandwidth concentrations from user requests or internal data system transfers.

G.8.2 Short-Term Archive Load Analysis

The previous section described the network communications needed to populate the archives. Nominally users will rely on normal Internet connections to receive data as shown in Figure G-19 (although many may take advantage of their University's Internet-2 connection). The configuration with five regional/discipline online archives is driven by an assessment of anticipated user load and desired queuing times for download requests.

For a load analysis, the user base can be divided into three categories: i) megasite communities, ii) power users, and iii) casual users. Megasite communities are larger groups of scientists who require a large number of radar scenes. Examples of megasite communities include scientists studying the San Andreas Fault, Antarctic ice sheet, and Andes Mountains. Power users are small groups requiring many scenes to stack. Casual users require only a small number of interferograms.

To assess the load, 1 minute of radar data is assumed as a typical scene size, which corresponds to approximately 1 Gb of data. To size the system, the following is assumed as representing the user population:

1. 25 megasite communities, each requiring 4,000 scenes per year
2. 100 institutions with 5 students each needing 100 scenes per year
3. 5000 casual users each requiring 10 scenes per year

With these assumptions, the anticipated load is 200,000 scenes per year or about 550 scenes per day, which includes ample margin.

Data files are retrieved from the online archives via ftp or http protocols, which are usually limited to ~10 Mbps. Hence one scene download requires about 1000s transfer time. Over a day, a total of 550,000s is needed to transfer these data, implying that averaged 24/7 a total of 7 simultaneous connections are required. Since data requests are not evenly distributed in time, a peak rate of 70 simultaneous connections is assumed as a design maximum. Beyond this level the system degrades gracefully by providing the data but with longer access times.

Assuming a single server can accommodate 10 users at full speed (10 Mps) and applying standard queuing methods, the probabilities can be calculated that the server receives 10 and 20 requests over the 1000s required service time. If up to 10 requests are outstanding, then, no waiting is expected. If 20 are received over that time users will experience longer download times. Calculating these probabilities with an arrival rate during high-use periods of 5500 connections per day, then for a single server, a 5 server, and a 10-server system, the probabilities for any single server are

# Servers	Prob (>10 requests)	Prob (>20 requests)
1	1.0	1.0
5	0.72	0.02
10	0.06	0.000004

Thus, with a single server, most requests will be delayed. For 5 servers, while many requests may be moderately delayed during periods of high usage, only 2% fall in the near-certain delay category. With 10 servers, delays are essentially avoided completely, albeit at a cost of doubling the investment in servers. Based on this analysis, 5 online servers will be used for the ECHO short-term archive.

G.8.3 Data Distribution and Archiving

Although the ECHO archive is distributed, users will order data through a catalog system that links these archives so that it appears as a single "virtual" archive. This web-based catalog system supports search, framing, and data transfer of the Level 1 products and any necessary ancillary data. Data from both the short-term archive and mission archive at SDSC can be accessed in this manner. Data stored at the permanent EDC center will be accessed through the EOS Data Gateway and will include delivery of products on tape. Data delivered via any of these options will be denoted modified CEOS Level 1, in compressed format, and framed per user-specifications.

G.8.3.1 Short Term Archives. The distributed online short-term archive will consist of 5 sites as identified above, each capable of storing 25 TB of data, roughly the equivalent of six month's acquisitions. With a copy of each data take maintained on 2 servers, the 5 sites can collectively store more than a year's worth of data. Data access will be from the online data catalog system, with a web-based interface that permits users to locate and download data via ftp or http access. These will be based on technologies now being developed for Internet exchange of music, video and other files. These archives, which each comprise one or two racks of computers and disks, will be supplied by the project to their respective host institutions.

G.8.3.2 Online Complete Mission Archive . All ECHO data will be archived and available online throughout the mission at SDSC mission archive (Fig. G-19). The data will be stored in the SDSC/NPACI petabyte tape archive. Users will rely on this archive to obtain older data (more than a year since reception) no longer resident in the short-term archive.

G.8.3.3 Permanent Archive. The permanent archive will be located at the EDC as the USGS's contribution to the mission. Users may obtain tape delivery of data from this system. Since these data will be integrated into the DAAC system during the mission, requirements for post-mission migration (Appendix G of ESSP AO) to the DAAC are met implicitly.

G.8.3.4 Ancillary Data. Ancillary data will be available via the Data Catalog. The basic information will be precise orbits based on post-processing of the S/C GPS, global ionospheric models based on the global distribution of GPS sites in the International GPS Service (IGS), solid earth tide models, and tropospheric models based on the Fleet Numerical Meteorology and Oceanography Center (FNMOC) or other appropriate sources. These are standard corrections used for processing ocean altimeter data. The project-supplied processing software will optionally ingest these data to correct interferograms. The catalog is structured so that the ancillary data can be updated easily by setting the link to the revised data set.

G.8.3.5 Data Catalog. Users will be able to access data online from short-term and mission archives through the ECHO data catalog (Fig. G-18). As data are entered into the archive, corresponding entries and links to the data will be entered into the catalog data base. The catalog will then allow users to:

- Search the archive by geographic region, date, mode, data quality, and interferometric baseline.
- View low resolution (100 m) imagery for all archived SAR data;
- Request and receive data from the distributed archive;
- View/search planned acquisitions;
- View and download auxiliary data such as precision orbits and calibration data from the Science Team.
- Access higher-level products, from topical or regional databases associated with specific research groups.

G.8.3.6 Archive Manager. Data movement throughout the system is coordinated by Archive Manager software, which directs the NTS at Stanford to pull data from the ground stations and forward copies to the distributed archives. It also determines file storage locations, monitors server activity, rebalances file locations based on server load, and creates a file location database to be accessed by catalog.

These functions will be based on existing Vexcel Earthfinder software.

G.8.3.7 Archiving of Higher Level Products. The catalog system contains the links needed to access the Level 1 data. Implicit in the design of this system is the ability to link to other sites and products. This includes the higher-level products produced by the Science Team as part of the validation effort. In addition, the ECHO project will encourage the development of a "federation" of users. This will include providing links through the catalog system for higher-level products that members of the federation wish to share with the community. The exact inventory of products and services available will depend on the nature of the participating institutions. The ECHO project will seek to integrate these activities with the current NASA Federation of Earth Science Information Partners (ESIPs).

G.8.3.8 Heritage: WInSAR as a prototype archive and distribution system. Several members of the Science Team have been involved in the Western North America Interferometric SAR (WInSAR) consortium, a group of 25 universities and national laboratories. WInSAR was formed to allow member institutions to purchase collectively SAR data from the European Space Agency and share it for academic purposes. Online archive and distribution facilities at SIO, Caltech, Berkeley, and Stanford have been developed under WInSAR. This system has provided valuable insight into which data product types and formats best suit the needs of the science community and it will serve as a functional prototype for the ECHO distributed archive.

WInSAR delivers Level 1 SAR data exclusively, along with metadata and ancillary files (e.g., orbits solutions). Users generate interferograms from a variety of software packages, including freeware distributed by WInSAR partners. In a similar manner, ECHO will package mission data and software together as bundled Level 1 products. Regular meetings of WInSAR members suggest that this approach both meets science user's needs and remains inexpensive to implement.

Data is obtained from WInSAR through a data catalog that runs in a web browser, so that anyone may visit the archive. Searching the archive is open to all users, but ESA requires WInSAR to restrict data downloads to approved users. Data are searchable by latitude/longitude, map GUIs, or by parameters such as orbit, track, frame, or acquisition time. Once a region is selected, a list of available scenes is displayed, and the user may select from which archive the data are to be downloaded.

The data catalog for WInSAR is a fairly small ASCII file that contains searchable data fields, and http and ftp pointers to the actual products. ECHO will use a similar approach, so that the catalog simply manages the locations of the data files and not the files themselves. Because ECHO will produce much more data than is currently in the WInSAR system, the ECHO catalog will be Oracle based. But the general principles of distributing the SAR and ancillary data over the network, while linking them through a modern database, remain the cornerstones of the proposed development.

G.8.3.9 Schedule for Data Delivery to Users. Following a 3-month commissioning phase of the instrument, data will be made available online with 24 hours of reception. In the event of outages at the downlink sites, or temporary loss of Internet connectivity, data will be saved on tape and introduced to the system as soon as the errors are corrected.

G.8.4 Data Processing

G.8.4.1 Level-1 Processing. All data will be processed to level 1 at the ground stations and organized as 1-minute sections, which can be concatenated to restore the full data take. These are the products that will be stored in the archive. Vexcel will base this processor on its existing SAR L1 production processor.

When a user requests a particular scene from the archive, the user will specify via the catalog interface the extents of that scene by rubber-band selection within the browse image, ground coordinates, or time offsets from the start of the data collection. The framing subsystem will then extract the appropriate part of the data from the stored file(s), and write the frame in modified Level-1 CEOS format. This format will maintain the data in its compressed form to facilitate rapid transfer to the user.

G.8.4.2 Higher Level Product Generation.

As described above, ECHO will move away from centralized processing facilities and rely on a novel distributed processing scheme. Level 1 data will be distributed to users along with the software required for generation of SAR images through calibrated displacement maps. The software interfaces will be designed so that no special processing knowledge is required on the part of the user. Current generation personal computers are capable of processing dozens of images a day.

The project-supplied software will:

- Form images, interferograms, correlation maps, and vector displacement maps using ancillary data;
- Geocode products using precise orbits and topographic information;
- Estimate baselines—precise orbit and image derived baselines;
- Calibrate products—corner reflector analysis code, tools for estimating temporal phase stability; and
- Verify products—statistical package comparing ground truth GPS to interferometrically derived displacements.

The project-supplied processing software will be maintained and supported by the ECHO mission throughout the operations phase.

Higher-level data products are also needed by the ECHO project for assessment of performance. A more specialized set of the processing code, developed from prototype algorithms, will comprise a CAL/VAL processing system for use during the operations phase of the mission.

G.8.5 GDS Management/Personnel

The ECHO GDS is designed to maximize the use of automated operations during normal conditions, while recognizing that some human intervention is needed to solve problems and address unique user situations. Operational staffing will be largely used for data-flow planning and verification, and anomaly resolution

Managing a distributed system poses particular challenges. The ECHO approach is to integrate a combination of project management, system-wide engineers and operators, and facility-specific engineers and operators to oversee the GDS as a system.

A JPL GDS manager will oversee the development and operations phases and will be responsible for coordinating the activities of the following GDS elements:

- Ground Reception Facilities (ASF, Miami): Downlink data from satellite and process to Level 1. Stage data for transfer to the NTS. Temporary tape storage until data acknowledged by central archive.
- Network Transfer Subsystem (Stanford): Pull data from reception facilities and forward to short- and long-term archives. Populate database and verify transfers to archive centers. Manage data as needed to balance use of distributed archive. Manage routing issues and interfaces to optimize the high-speed node-to-node data transfers.
- Remote Administration and Maintenance (Vexcel): Remote, centralized administration of downlink and regional archive computer systems. Software maintenance of Level 1 processor, data catalog, and user web interface. Hardware support at ground stations and short-term archives.
- Archive and Distribution Facilities (see Fig G-19): These include the short-term archives as well as the Long-Term Archive and the Permanent Archive.

ECHO will rely largely on remote administration and maintenance for the GDS network. These staff will perform general system administration functions as well as maintain and troubleshoot hardware and software. In addition, there will be full user support for the catalog interface to the ECHO mission. Additional staff will be located at the NTS to manage data flow, and other issues related to data transfer. Operations at the downlink sites will be largely automated, but will rely on the common pool of operational staff shared with other missions utilizing the facility. At all other sites only minimal staffing will be maintained to assist the operators at the Remote Administration and Maintenance Center (e.g., replacing a failed disk in a RAID array).

G.8.6 GDS Hardware Development

The major hardware subsystems that will be developed for the ground system are:

- Upgrades to existing downlink stations for data capture
- Level 1-processing hardware at downlink sites.
- Online regional/discipline archives (5 copies).
- The network transfer computer at Stanford.

The SDSC mission archive and EDC permanent archive will use existing infrastructure and require no hardware development.

G.8.6.1 Downlink stations. At both the ASF and Miami receiving stations there are dual receiving antennas. Vexcel will upgrade the RF hardware to allow 300 Mb/s reception. Additional computing resources and hardware will be added for the L1-processing. Following reception of the data by one of the antennas, the data flow to the Data Capture Subsystem and, subsequently, frame synchronized Level 1 products are produced in accordance with project specifications. Vexcel's high speed direct-to-disk data capture system has proven reliable and is designed to enable significant operational savings in media and personnel resources by automating many tasks.

The ECHO capture and processing systems at ASF and Miami will be composed of two UNIX workstations, a tape library, and a RAID disk array. The two antennas will be connected to two cross-strapped capture systems, thus providing hot backup in case of failure. Both acquisition systems will operate simultaneously during all capture events. In the event of failure, data will be extracted from the disk array of the backup capture system.

G.8.6.2 Short-term Online Archives. Each of the five short-term archives has a transfer computer (router/firewall) to receive data over the high-speed network, to receive user data requests, and to control upload of data to the user. The servers communicate over local network connections, and appear as ftp URL's to each other and the outside world. Data requests are managed across a storage area network (SAN) that provides high-speed server access to 25TB of online storage. A diagram of the regional and archive system is shown in Fig. G-20. Vexcel will develop five identical systems. There is

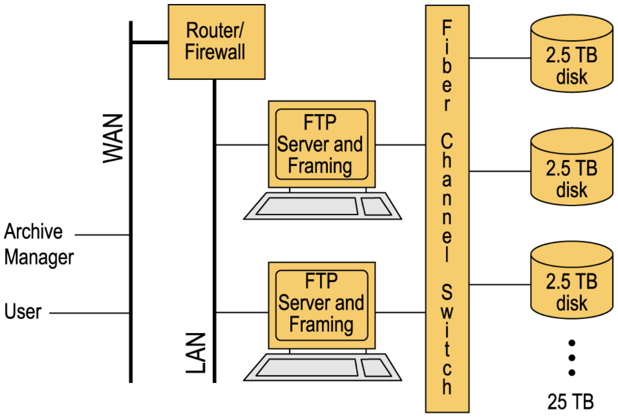


Figure G-20. Block diagram of the regional/discipline archives. One machine with multiple network interface connections accepts data from the high-speed Internet-2 transfers; the data are subsequently transferred to a 25 TB archive built from multiple RAID arrays. An additional machine coordinates user requests, serves Level 1 data, and hosts mirror copies of the ECHO database and ancillary files.

strong heritage in the development as all hardware subsystems are COTS-based.

G.8.6.3 Network Transfer System. Stanford will host the NTS, which consists of a redundant pair of computers that manage the high-rate communication with the ASF and Miami receiving stations and the distributed archive centers. This computer and its file system will house the current versions of the Oracle database file, along with the ancillary data files. This system will be developed at Stanford.

The NTC software will also be compatible with computers at each of the regional archives. While operation here will be slower, this provides a backup capability in case both systems at Stanford are temporarily down. The distributed nature of the networked system provides this extra degree of robustness, eliminating many potential single-point failures in the design.

G.8.7 Software Development.

The major software elements to developed for the ECHO GDS are:

- The Level-1 processor at the ground stations
- The data catalog and archive management software
- The network transfer system software

G.8.7.1 Level 1 Processing. Vexcel will develop the ECHO Level 1 processing that accepts raw data from the Data Capture Subsystem at the downlink station, and implements Level 1 processing "on the fly." Level 1 processing includes the following steps: satellite frame detection and bit error rate (BER) estimation, byte alignment, bit error correction, metadata extraction, and Doppler centroid estimation. As part of the processing, a quick-look processor will generate low-resolution browse images of the entire data strip that will be accessible to users through the catalog.

The ECHO Level 1 processing system will be based on an existing commercial capability—the Vexcel SKY™ processor. This system has been employed in several commercial installations around the world, and will be an integral part of the University of Miami multi-satellite downlink installation currently under construction. The major development task is modification to conform with ECHO-specific formats.

G.8.7.2 High-speed Network Transfers. Stanford will develop the network transfer system software that will receive data from the ground stations and route it to the appropriate archive elements. This includes the development of a set of high-speed file transfer codes to facilitate node-to-node communication and permit high rate transfers of the large Level 1 data sets. The principles for this system are drawn from parallel ftp and hierarchical storage interface (HSI) codes developed by the HPSS consortium led by IBM and the national energy laboratories. These codes will be modified to reflect ECHO formats, and interfaced to the Oracle database used by the Data Catalog.

G.8.7.3 Data Catalog System and Archive Manager. Vexcel will develop the Data Catalog System (DCS) that is the primary user interface with all aspects of the ECHO GDS. It provides a complete inventory of all data products available including Level 1 data, browse data, and all ancillary data such as orbit solutions. The DCS also provides access to other mission elements such as acquisition plans, acquisition status, acquisition requests, processing software, and user support. This development also includes the framing subsystem that will be used to extract a specific portion of the data take from the archive at the users request.

Vexcel will build the ECHO Catalog around a commercial Oracle database system to provide the basic catalog functionality, such as searches, sorts, and other routine tasks. Part of the development will include interface code to allow the Oracle kernel to interact with the ECHO-specific products and formats. The catalog development will also include a web-based user interface to the catalog database.

Vexcel also will produce the Archive Manager software that coordinates internal data movement and load/node balancing within the GDS.

The prototype for the ECHO system will have heritage from the multi-satellite downlink facility at the University of Miami, which will be completed several years before a similar system is needed by ECHO. The ECHO catalog will be derived from Vexcel's existing EarthFinder™ software, which provides access to Level 1 and all ancillary products. The EarthFinder catalog browser is written in Java so that it may be accessed as a standalone program or from within an Internet browser. EarthFinder provides password-protected access to the catalog system, with several user access categories, such as unprivileged users (browse only), privileged users (browse and production order), maintenance (browse, production order, and ability to add or delete data), and administrator (all privileges of maintenance but with the ability to change database organization).

G.8.8 InSAR Level 1+ Cal/Val and User Processing Packages

The Science Team will develop a prototype processing system that will generate and test the algorithms needed to generate higher-level products (e.g., interferograms, displacement maps). Vexcel will use the prototype to develop the software package that will provided to users (at not cost to them) for the generation of calibrated higher level products as described above. The user package development includes a GUI interface to simplify processing tasks so that no special knowledge of SAR processing will be required. In addition, a validation processor will be developed for the Science Team that uses interferograms from the calibration processor to produce geophysical data products and validate them using ancillary field data.

JPL will lead the calibration/prototype processor development. Stanford/Scripps will develop the validation processor. All codes will be delivered to Vexcel for development of the user software package.

All elements of the InSAR processing development have strong heritage. JPL and Caltech have developed the Repeat Orbital Interferometry Package (ROI Pac) that is in use at over 30 academic institutions. The JPL-developed Shuttle Image Radar Topography (SRTM) processor provides heritage for the interferometric ScanSAR processing. Vexcel has developed and marketed a full line of SAR and InSAR processing packages with complete support, maintenance, and documentation. The major development tasks will be adaptations of the existing core algorithms to accommodate specific characteristics of the ECHO mission, including preprocessing of ECHO-format telemetry, signal data, and ephemeris information, upgrading the image formation processor to incorporate a split-spectrum ionospheric correction, upgrading strip-mode codes to accommodate ECHO-radar-specific configuration changes, upgrading calibration tools to use ECHO ancillary products and ground truth data sets, and upgrading verification tools for ECHO specific data and metadata.

G.8.9 Use of Existing Facilities

ECHO will use the existing downlink facilities at ASF for the prime downlink. The Miami station is currently under independently funded development and will be online by the ECHO launch. The online mission archive will take advantage of existing infrastructure at SDSC. The contributed permanent archive will make use of existing facilities at EDC. Finally, the hardware for the online archives will be located in existing facilities at their respective sites.

G.9 Plans to Resolve Open Technical Implementation Issues

Phase 2 activities will focus on defining and documenting the detailed mission requirements. TerraSAR-X has already been through their Phase B, so there requirements are reasonably mature. The ECHO Phase 2 activities will strive for commonality where possible and identify areas where ECHO specific modifications are required. TerraSAR-X is currently in the process of negotiating the contract for the Dnepr launch vehicle, with an option for a second LV for ECHO. Details of these negotiations will be described at the site review.

The LightSAR phase A/B study conveyed a significant level of maturity to the ECHO instrument design. A 12-month risk reduction study will be conducted during Phase 2 to define instrument requirements and interfaces.

H. MANAGEMENT

H.1 Management Processes and Plans

Management Approach

The ECHO project is proposed as an integrated international partnership designed around the experience and proven capabilities of each team member. The Principal Investigator (PI), Jean-Bernard Minster of the Scripps Institution of Oceanography, is in charge of the investigation and is responsible to NASA for all aspects of the mission, including Education and Public Outreach. He is supported by Deputy PIs Paul Rosen (JPL, flight segment) and Howard Zebker (Stanford University, ground segment), by JPL Project Manager (PM) Kim Leschly, and by proven JPL project management, mission design, planning, systems engineering, and mission assurance processes that conform to ISO 9000, mission safety standards, and ECHO project objectives.

It is anticipated that ECHO will be the cornerstone of an international partnership between NASA, the German Aerospace Center (DLR) and the National Science Foundation (NSF), founded in an interagency memorandum of understanding. DLR will contribute the launch vehicle and mission operations, both development and flight operations themselves, on a no-exchange-of-funds basis. Subject to peer review, NASA and NSF will co-fund the remaining project elements, consistent with ESSP cost-caps and funding profile guidelines. The ECHO project is designed to furnish the geodetic imaging data component of the NSF-NASA-USGS EarthScope Initiative.

JPL will execute and manage contracts with all the team members, with the exception of the PI, who will be funded directly by NASA/NSF. JPL will provide all financial reporting to NASA. The major contracts will be with the spacecraft provider, Astrium GmbH, the antenna subsystem provider, Ball Aerospace & Technologies Corp., Civil Space Systems (Ball), and the ground system provider, Vexcel Corporation. These contracts will be designed so that incentives are provided for on-orbit performance and successful data return.

Management Processes Summary

The management processes for the ECHO Project are built on the best of the experience gained on numerous missions including the GRACE project on which JPL, NASA, Astrium, and DLR are currently partners. Management processes include:

- Establishing the project team, including formal partnerships with other NASA Centers, space agencies, industry and academia (See H.3)
- Establishing a product-oriented WBS and corresponding organization, thus defining clear decision making roles and lines of authority (See H.3)
- Project planning
- Systems engineering will lead the technical management and assessment effort
- Configuration management
- Managing information
- Managing schedule and cost, including the production of performance metrics, including earned value, and progress tracking and reporting.
- Managing risk
- Conducting reviews
- Ensuring that ITAR rules will be followed correctly but efficiently (See Appendix L-7 for the ITAR).

A critical outcome is the prudent use of cost and schedule reserves, and rational and timely application of descope options. The decision making process is outlined at the end of this section.

Astrium management processes are in full compliance with its in-house AstroBus standard ensuring the utilization of existing designs and well-developed AIT processes. These processes are adapted to ECHO project needs to satisfy management, reporting and documentation requirements of the project. Astrium is fully aware of these requirements through the GRACE project development.

Ball management processes are aligned with the JPL ECHO Project. These processes are documented in the Ball Quality Business System (QBS) conforming to ISO 9001. These processes are implemented on several contracts that Ball is currently performing with JPL.

As a small business not involved in flight hardware development, Vexcel manages its work in a manner that is commensurate with its size and project role and will work closely with JPL to establish and maintain management processes and reporting plans appropriate for the ground segment development.

H.1.1 Effective Plans

The ECHO Project has used the JPL Project Support Team, including recently enhanced planning templates, to create a planning baseline that is compliant with NPG 7120.5, ISO 9001, and with the JPL Design Principles. Management processes and plans will be documented in a detailed Project Implementation Plan (PIP) and in subordinate plans that will be completed in Phase 2. A set of preliminary Work Agreements for every cost account for Phases 2 and 3/4 have already been developed. The following plans will be prepared in Phase 2:

1. Task Plans for Phase 2 and for Phase 3/4
2. Project Plan
3. Project Implementation Plan, which may include:
   a. Project 7120.5/ISO Compliance Assessment (Matrix)
   b. Design Principles compliance assessment exceptions
   c. Risk Management Plan
   d. Review Plan
   e. Acquisition Plan
4. Mission Assurance Plan
5. Configuration Management Plan
6. Science Management Plan
7. Science Data Management Plan
8. Software Management Plan, including Algorithm Theoretical Basis Documents (ATBD)
9. Information Management Plan
10. Project document tree and Master Controlled Data List
11. MOUs and MOAs
12. Tracking Services Service Level agreements
13. Project Integrated Schedules, subsystem level
14. Mission Operations Implementation Plan

Ball in a detailed PIP will document management processes and plans. The PIP will incorporate the management processes and ECHO specific plans developed by the Ball Civil Space Systems and the Antenna & Communications Technologies (ACT) organizations. The following plans will be prepared in Phase 2:

1. Work Order Task Plans for Phase 2 and for Phase 3 and 4
2. Program Plan, in accordance with Ball QBS
3. Inclusive Program Implementation Plan
4. EEE Parts Plan
5. Quality Assurance Plan
6. Reliability Plan
7. Configuration Management Plan
8. Data Management Plan
9. Project Document Tree
10. Integrated schedule
11. Earn Value Reporting Plan

Astrium and Vexcel will develop similar plans in accordance with project needs.

H.1.2 Systems Engineering and Requirements Development

Roles

ECHO will have a project level systems engineering team (PSET) led by the project engineer, with participation from each major element of the Project (Table H-1). The PSET is the single coordinating engineering team for the project, responsible for system design and requirements development. Participation by the Project Manager, PI and DPIs ensures timely decision-making.

The PSET activities are described below.

1. Requirements Development—Develop project-level requirements (level 2). Level 2 requirements will be responsive to science objectives and level 1 requirements.

Table H-1: Project System Engineering Team Membership

Project Engineer (leader)
Spacecraft Systems Engineer (JPL)
Software System Engineer (JPL)
Mission Assurance Manager (JPL)
Instrument Engineer / PEM (JPL)
Project Manager (JPL)
Principal Investigator (SIO)
Deputy PIs (JPL and Stanford)
Mission Operations / GDS Manager (JPL)
Lead Engineers from Astrium, Ball, AEC-Able (antenna structure), and Vexcel

Level 1 and 2 requirements will be prepared in the first 3 months of the project, and will be frozen at the time of the Systems Requirements Review (SRR). The PSET allocates requirements to systems and subsystems.

2. Define system and subsystem partitions and develop interface requirements so that interface control can be maintained.
3. Identify design options and lead trade studies to improve responsiveness to requirements, improve system testability, improve system operability, or to reduce cost, schedule times, or risk
4. Develop system verification requirements. This includes deciding which of the 6 methods is to be used for verification. This activity will produce a design verification matrix (DVM)
5. Manage system technical resources. This is done by allocating resources and holding resource reserves and margins which will be adequate to accommodate the anticipated growth in resource needs that occurs in the implementation phase. Technical resource margins will be estimated and maintained consistent with JPL Design Principles
6. Perform Configuration Management (CM) and change control
7. Prepare documentation that serves to communicate and coordinate the activities of those developing the system. This documentation consists of:
    - System requirements document
    - System design documents
    - Subsystem requirements
    - Interface control documents
    - Design verification and validation requirements document
    - Design verification matrix
    - Operating constraints, flight rules and idiosyncrasies document
    - System Action Item collection, tracking, and resolution

The PSET will monitor verification and validation activities. As verification steps are completed, via analysis, test, demonstration, simulation, inspection, and/or inheritance, the Design Verification Matrix (DVM) is updated. The DVM is reviewed prior to delivery of subsystems and instruments to Integration and Test, and again before the spacecraft is shipped. All outstanding items (non-conformances, deviations, waivers, or Problem Failure Reports) will be addressed at that time.

H.1.3 Configuration Management

The ECHO Configuration Management (CM) system provides procedures and tools for configuration management of hardware, software, interfaces, and associated documentation. The JPL institutional CM system is fully compliant with the requirements of NPG 7120.5 and applies throughout the life cycle of the Project. Each organization will control their own detailed design and as-built configuration information with their own in-house CM system.

Configuration control is accomplished through a systematic method of establishing levels of change control, and classifying and monitoring changes. The project level Configuration Control Board (CCB) will conduct regularly scheduled meetings to evaluate all baseline changes. The PSE chairs the project CCB.

The JPL Product Data Management System (PDMS) will provide Project-level CM services. The PDMS provides electronic "real-time" status records on release and revision status of engineering documentation, change approvals, and implementation status. Ball maintains a similar PDMS.

The project manager is responsible for ensuring that the processes necessary to implement Configuration Management will be followed throughout the project. The PM and his system engineering team perform CCB administration including Engineering Change Request (ECR) processing, coordination of impact assessments and follow up activities, and recording of minutes and action items recording and reporting current change request status. The project assistant system engineer is the project point-of-contact with the PDMS providing for document release and control through the PDMS and reviewing and concurring with contractor/collaborator CM Plans. An archive of configuration data will be retained at JPL for the duration of the mission.

H.1.4 Information and Communications Management Plan

The objectives of ECHO Project Information and Communications System are to facilitate management, access and sharing of information within all elements of the project, while meeting applicable security, ISO, ITAR, NASA and JPL requirements.

ECHO will use a project information system that has proven to be successful on many projects. This will include an electronic Project Library, internal and external Project web sites, e-mail archive, a Configuration Management System, and Project engineering databases. These services are part of the JPL infrastructure.

The project information system will be active throughout the project lifecycle, including formulation, implementation and mission operations. At the end of the Project, all documents, drawings, design data, engineering notes, e-mail archives, web pages, and other materials in electronic format that have long-term technical, historical, and/or institutional value will be archived using the appropriate electronic storage media.

H.1.5 Schedule Management and Cost Management

Cost management (including reserve management) for the ECHO Project is the responsibility of the Project Manager (PM). Cost management will be integrated with schedule management through the Earned Value Management (EVM) system that has been used successfully by JPL on other projects. The ECHO PM Kim Leschly will identify and resolve budget problems, and will report status regularly to the NASA Sponsor. Funded schedule reserve and additional budget reserves have been incorporated into both the schedule and cost estimates of the ECHO Project.

Reserves are consistent with JPL Design Principles for reserves. The PM applies reserves to whichever system has the greatest need for risk reduction. The PM continuously monitors the remaining reserves against the time remaining in the schedule. Encumbrances against the reserves will include: A) hard liens, i.e., those that will be accepted by the teams and project management, and B) soft liens. The total value of the encumbrances of the soft liens will be reduced by a factor of probability of occurrence to yield an effective encumbrance against reserves, using the quantitative Significant Risk List tool that is used at JPL.

H.1.5.1 Cost Management. The Project Manager will control the budgeting process, including baseline budgets, actual costs, and cost liens, and administer them through a Project Resource Administrator (PRA). Each organization will use its own institutional financial management process, and will report budget status monthly to the ECHO Project PRA. The PRA will maintain the master baseline and cost record, identify and resolve budget/cost variances, and report status to the Project Manager, who in turn will report to the ESSP Program Office and the PI.

H.1.5.2 Schedule Management. Schedule management is the responsibility of the PM. A Receivable/Deliverable (Rec/Del) planning process will be used to establish and maintain a baseline of critical and minor deliveries between project elements. Each organization will use their own processes to create schedules based on their Rec/Del commitments. They will also report the arrival of receivables as soon as they occur, and will report on progress on deliverables each month to the PM. The PM will maintain a master network schedule, identify and resolve schedule problems, and will report status to the sponsor at NASA HQ.

The Project Schedule Analyst (PSA) is responsible for creating and maintaining the project level network schedule. The instrument providers, JPL and Ball, and the spacecraft provider, Astrium GmbH, will provide updates to their subsystem schedules to the JPL PSA in Microsoft Project 98 or 2000 format. Ball's schedule is particularly important to integrate seamlessly as the antenna subsystem is on the critical path. Ball will assign its own PSA in Phase 2 to develop an integrated antenna subsystem schedule that includes networked activities from the structure and antenna panel suppliers and the subsystem integrator, dovetailed to the JPL master schedule early in Phase 2. This schedule will be a key component of the Ball Earned Value Analysis system. Each deliverer's schedule will consist of tasks with milestones depicting work activities per the contract SOW. The schedule will be of a sufficient granularity so that a technically correct network flow can be created. The Receiving Party sets a Performance Measurement Baseline based on the Delivering Party's schedule submittal. This submittal will include a detailed network schedule in accordance with the standards above, and a properly phased budget. The Receiver's Baseline will serve as the Performance Measurement Baseline for both the Delivering and Receiving Parties for the purposes of Earned Value Analysis and other metrics.

Scheduling Work Products will include but will be not limited to:

1. Baselined Top Level and Detailed Working Schedules
2. Slack Analysis Table
3. Rec/Del Report
4. Milestone Count Report
5. Critical Path Analysis
6. Custom reports at Project Manager's request

H.1.5.3 Project Management Control and Support Systems. The Project's baseline scope, schedule, and budget plans will be established and captured in work agreements at JPL and in contracts with other elements of the project.

Management Tools

JPL utilizes the Resource Management System (RMS) which is fully integrated with JPL's Institutional Business System. This resource budgeting methodology uses COBRA to integrate project network schedules (MS Project) and the JPL financial system to provide the following capabilities: scheduling, cost estimating (including "what-if" scenarios), budgeting, estimate-to-complete, actual cost/obligation imports, workforce data forecasting inputs, and performance analysis which includes earned value management, reporting, and baseline control. Established accounting systems provide accumulation of actual cost for the project. The actual cost is compared with the earned value to indicate an over or under run condition. Any variance to the plan is noted as a schedule or cost deviation. Ball and Astrium have and will employ comparable management tools.

H.1.6 Unique Tools, Processes or Methods

No mission unique tools, processes or methods will be considered necessary for managing the ECHO Project. Proven methods will be employed.

H.1.7 Progress Tracking and Proposed Performance Metrics

The JPL PM is responsible for reporting integrated cost, schedule, and technical performance, as well as risk. Internal progress reporting will occur both by formal and informal means. Weekly updates of receivable/deliverable status supported by Astrium, Ball, Stanford, and Vexcel will be used at weekly tele- and video-conferences to report progress. The PM will report weekly status to the PI, and the PI will inform NASA immediately of any major problems, failures, personnel problems or any other problem that might affect the mission status.

The PM will submit monthly management reports to the sponsors and will also provide the ESSP Office with updated schedules on a quarterly basis. These reports will include performance metrics on significant accomplishments; the status of technical margins; mission risk identification, mitigation tracking and resolution; planned versus actual costs, planned versus actual schedule status, current schedule margin; planned versus actual earned value, and workforce. During the development phase, emphasis will be placed on schedule and cost metrics. After launch, the focus will shift to data acquisition performance, data quality, and data availability to the users.

The PM will also submit monthly and quarterly (533M and 533Q) financial management reports as described in NPG 9501.2C "Procedures For Contractor Reporting Of Correlated Cost And Performance Data" (23 April 1996). Mission financial management reports will be prepared according to the WBS and cost element structure contained in the mission proposal unless changes will be negotiated and approved after selection. Mission financial management reports will be provided from prime contractors as well as first-tier subcontracts that meet the reporting requirements set forth in NASA FAR Supplement Section 18-42.7201 (b) (1). Mission teams will also provide funding profiles and explain variances between projected and actual costs, as required during mission implementation. The Project will use existing management reporting systems at JPL, Ball, and Astrium to satisfy mission financial reporting requirements.

H.1.8 Reviews

The Project will utilize a rigorous review process in accordance with JPL D-10401. It will be similar to the successful CloudSat Project review process. Table H-2 describes project level reviews, their purpose, and timing. Reviews will include all of the types of reviews called for in the AO and in the NIAT report:

- Critical Milestone Reviews
- Peer Reviews, which will precede Critical Milestone Reviews, and will provide in-depth assessment of technical material (Pro-

gram and project management may attend these reviews)

- Product Integrity Reviews by the line management of the organizations performing the work of the Project. These reviews include participation in Critical Milestone Reviews and in Peer Reviews, and also include reviews at the system and subsystem level, where appropriate. These and peer reviews will be conducted consistent with the JPL Reviews Process, which incorporates the recommendations of the NIAT
- Red Team Reviews, beginning at CDR.
- Independent Reviews lead by the JPL and GSFC Systems Management Offices (SMO).

Both Astrium and Ball are quite familiar with the JPL review process through the GRACE and Cloudsat programs, respectively. Astrium and Ball are committed to supporting all formal or informal reviews identified by the ECHO Project.

The intent of the review process is to assess progress during the formulation, implementation, and operation phases of the Project. Reviews will address the adequacy of the Project definition and the understanding of the driving requirements, interfaces, capabilities, and verification methods. Reviews also will be used to demonstrate understanding of the driving technical risks and the intended means by which those risks will be mitigated. In addition, the reviews will address the adequacy of margins.

Critical Milestone reviews will include a description of the disposition of all requests for action (RFAs) from the peer reviews. The review board will be informed of the disposition of RFAs after each review.

Reviews will be consolidated where practical. For example, peer reviews and heritage reviews will be consolidated. The MDR will be held at the end of the mission formulation subprocess and will be combined with the PDR. Also, Red Team reviews will be integrated with formal reviews. An Integrated Independent Review Team (IIRT) will be comprised of experts that are fully independent of the ESSP Office and the Project and largely independent of the performing organizations. The IIRT will be led by two co-chairs; one each from the GSFC SMO and the JPL SMO, who will be responsible to the GSFC PMC and the Office of Earth Science for the conduct and reporting of the Integrated Independent Reviews.

Management Reviews

Monthly Management Reviews (MMRs) will be conducted to assess status against plans. These reviews will be held with JPL's Governing Program Management Council (GPMC) once each quarter.

Management Action Plan

The processes described above allow the PM to act on any variance in the planned mission elements. Variances in cumulative cost and schedule, flight segment mass and power, or instrument and mission performance will be dealt with according to the following set of rules, to be refined during Phase 2. Variances in the range of 0–10% are considered condition green and will be managed at the discretion of the PM. Variances in the range of 10–25% are considered condition yellow and require special consultation between the PM, the PI and the DPIs. Variances between 25–50% are considered condition orange and call for review and input from the science team, the advisory board, JPL senior management, and the ESSP office. Variances exceeding 50% are considered condition red, and call for thorough review under JPL management with reporting to the interagency steering group. In this way, we plan to react promptly and efficiently to unanticipated development difficulties.

H.2 Schedule

A project master schedule depicting all mission phases and major milestones is shown in Figure H-1. During Phase 1 (ESSP Proposal Phase), the project's architecture, system requirements, a conceptual design, a draft Project Plan and set of work agreements have been prepared. Phase 2 includes trade studies, development of a preliminary design, a refinement of requirements resulting in a SRR, a set of peer reviews, which will each incorporate heritage reviews, a PDR, and finally an MDR. The ECHO Team will start procurement of long-lead parts for electronics, instruments, and other critical items. Completion of the MDR indicates readiness to move into Phase 3, Mission Detailed Design. Completion of CDR indicates readiness to move into Phase 4, Mission Development and Launch.

Schedule Reserve

The S/C design and funds available for this schedule will be adequate with robust margins.

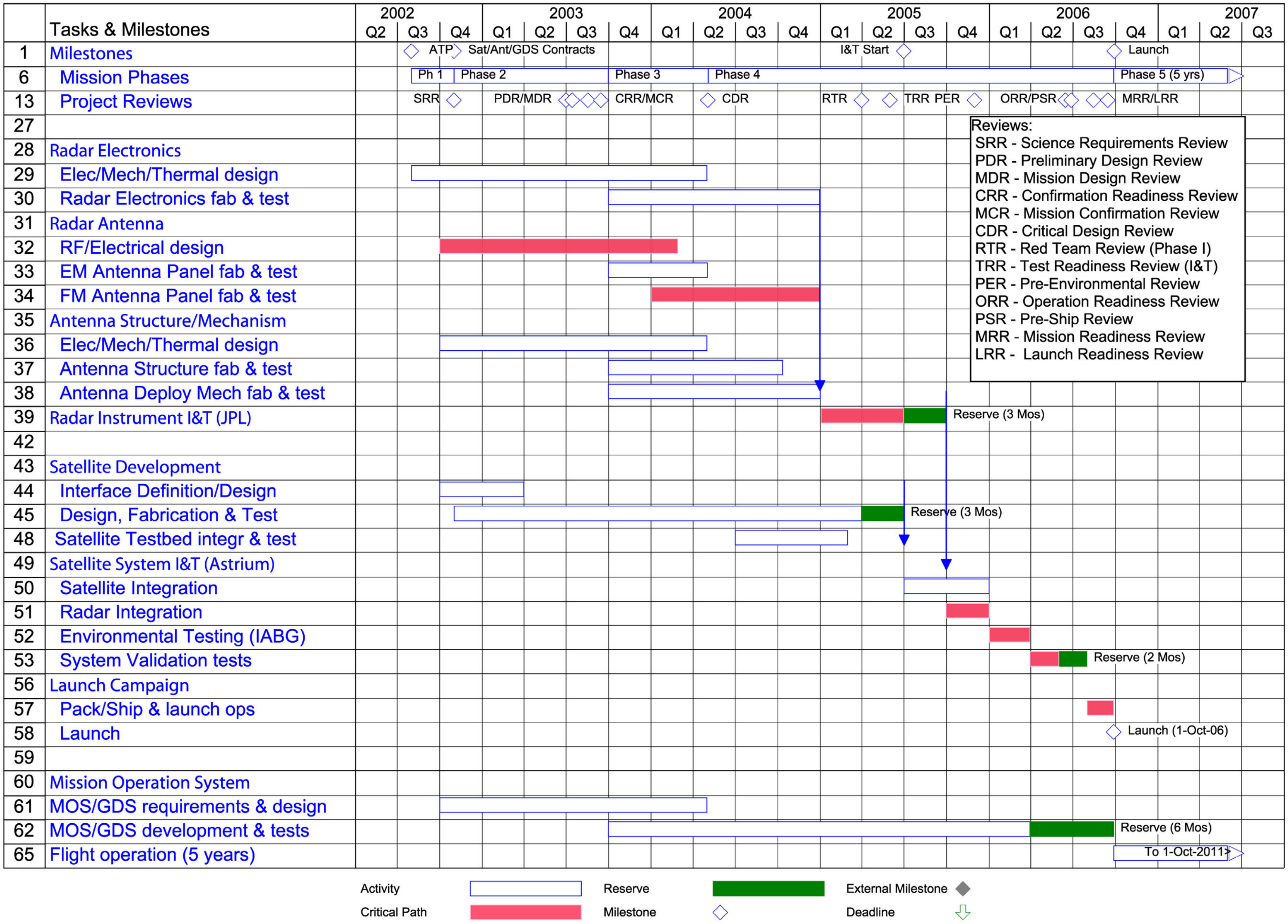


Figure H-1. ECHO Project Master Schedule

Table H-2: Reviews Summary (All dates will be based on a 08/01/2001 start)

Review	Purpose	Timing
System Requirements Review (SRR) and Software Requirements Review (SWRR)	Formally examine the agreed-to mission science, operations and technical (Level 1 and Level 2) requirements Assess Level 2 SW requirements Traceability of these requirements will be demonstrated	11/02
Informal Peer Reviews And Heritage Reviews	Provide in-depth review of the preliminary design and any inherited designs/hardware/software at the subsystem level by knowledgeable peers	For 30 days prior to PDR/ MDR
Preliminary Design Review (PDR), Mission Design Review (MDR)	PDR: • Examine preliminary designs of all mission subsystem and system components for technical feasibility with respect to the mission requirements • Assess the mission design at the subsystem and system levels • MDR: • Does the Mission, Spacecraft and Instrument Design, as presented, reflect a level of maturity that meets the mission science requirements? • Are the Management Processes used by the Mission Team sufficient to develop and operate the Mission? • Do the cost estimates, control processes and schedules indicate the mission will be ready to launch on time and within budget? • Risk assessments and compliance with JPL Design principles will also be described	PDR 7/03 MDR 8/03
Confirmation Readiness Review (CRR)	Earth Explorers Program approval for mission to proceed into Implementation	8/03
Mission Confirmation Review (MCR)	Associate Administrator, Office of Earth Science approval for the mission to proceed into Implementation	9/03
Informal Peer Reviews	Provide in-depth review of the detailed design and test planning at the subsystem level by knowledgeable peers	For 30 days prior to CDR
Critical Design Review (CDR), Software Critical Design Review (SWCDR), and Red Team Review	Assess readiness of design approaches, mission operations planning, as well as test planning for all flight systems	5/04
Informal Peer Reviews	Provide in-depth review of the readiness of each subsystem for integration and test by knowledgeable peers	For 30 days prior to PER
Pre- Environmental Review (PER), Software Test Readiness Review (SWTRR), and Red Team Review	Assess the readiness of the flight hardware, software and required environmental test facilities to begin acceptance testing Verify readiness of Ground System to support integration and testing	2/06

Table H-2: Reviews Summary (All dates will be based on a 08/01/2001 start) (Continued)

Review	Purpose	Timing
Pre-Ship/Operational Readiness Review (PSR/ ORR) and Software Acceptance Review (SWAR)	Verify that all system elements meet the requirements of the mission and are ready to proceed into final launch preparations. Verify that testing has been completed with no unacceptable open issues Validate the readiness of the flight hardware and software and ground system	
Mission Readiness Review (MRR)	Assess readiness of all mission systems to proceed with the launch campaign Assess readiness to proceed with full-up, routine operations	8/06 L – 30 to 42 days
Launch Readiness Review (LRR)	Update mission status and certify final flight readiness of all mission elements Verify that all open issues from the MRR have been resolved	9/06 L – 1 to 2 days

Schedule margin has been planned and placed at strategic points throughout the life of the project. Critical paths are represented by the black lines in Figure H-1. ECHO has allocated a minimum of 20 work days of margin for each major delivery to the project. Both the avionics and science instrument deliveries have 20 work days of schedule margin. Additional schedule margin totaling 20 work days have been provided for ATLO operations at IABG in Munich. The schedule also allows for 10 work days of margin for vehicle processing at the launch site. Note that the schedule shown in Figure H-1 shows accumulated schedule reserve at the end of the major project phases rather than spread as described above. While the project was costed with distributed reserve, the PM prefers a schedule display as shown for clarity.

Critical Path

The critical path is associated with the development and integration of the radar antenna. The transmit-receive modules for spaceborne L-band radars are mission-specific, and must be custom-assembled from standard components used in other L-band radars. Once assembled, a prototype module must be tested for transmit/receive channel isolation, feedback, and oscillation. Once tested, the modules must be produced in sufficient numbers to populate the antenna array, and integrated. These modules are therefore long-lead items that must be tested in the array in large numbers. Once the panels are individually tested, they are mounted on the deployment structure and integrated with the radar electronics. After instrument integration and testing, the radar is shipped to Astrium for integration with the spacecraft. This process defines the critical path for ECHO development.

H.3 Team Organization, Structure and Experience

The ECHO Project will be implemented by a multi-institutional team led by SIO, JPL, and Stanford. Industrial team members are Astrium GmbH, Ball, and Vexcel Corporation. Government team members are the US Geological Survey and the German Aerospace Center (DLR). The Southern California Earthquake Center (SCEC) at the University of Southern California is an academic team member. Science team members are from SIO, JPL, Stanford, Caltech, MIT, and USGS. These organizations form an integrated team where each member brings unique strengths to the project team. The team provides the optimum mix of experience and capabilities to provide NASA with a successful project, completed within the proposed cost.

Roles and Responsibilities of the Principal Investigator and Project Manager

The Principal Investigator (PI), Bernard Minster, is in charge of the ECHO investigation and maintains full authority for its scientific integrity and for the integrity of all other aspects of the mission, including EPO. The PI is assisted by two Deputy PIs, Paul Rosen and Howard Zebker, to whom he may delegate authority for execution of the project in the event he is unavailable. The PI delegates the authority for implementation of the project to the JPL Project Manager (PM), Kim Leschly. The PM will plan coordinate and monitor system design and implementation during all phases of the project. The PM is also responsible for over-all risk management. The PI will have approval authority over the Project Plan and all other project level documents, as well as any changes to those documents.

The PI contact is: Jean-Bernard Minster, Institute of Geophysics and Planetary Physics, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA, 92093-0225, Phone—(858) 534-5650 Fax—(858) 534-2902 Email: jbminster@ucsd.edu.

Project Manager contact is: Kim Leschly, MS 264-664, Jet Propulsion Laboratory, Oak Grove Drive, Pasadena, CA 91109 Phone—(818) 354-3201 Fax—(818) 354-5075.

Decision Making

The selected decision making approach will enable the ECHO Project team to respond quickly and effectively to development issues as they arise. Decision-making will occur at the lowest level possible as long as there is no effect outside the system in question. The PI will delegate his decision making authority to either DPI as appropriate in instances when he is not available. The PI will resolve all conflicts that can not be resolved by the PM, particularly conflicts that might affect the scientific return of the mission. Conflicts at the agency level will require inputs from the advisory board for consideration by the interagency steering group. The PI will be the final arbiter on all issues affecting the quality, quantity and timeliness of the science product and will be responsible to NASA for successful delivery of that product to the ECHO Data Archive System.

Termination Recommendation

The PI will be prepared to recommend mission termination if in his judgement, the successful achievement of established science/applications objectives, as defined in this proposal, is no longer likely within the committed cost and schedule reserves.

Experience

All element-level management and financial reporting is through the PM. An overview of responsibilities and relevant experience of each mission organization is provided in Table H-3. The PM will develop and administer contracts or MOUs with all the other mission organizations that reflect the commitment of each organization to mission success within the proposed cost. The PM is responsible to the PI for detailed project planning, integrating all team member's development schedules, monitoring progress, resource and reserve management, resolving problems and assuring satisfactory accomplishment of all key mission objectives. The PM is responsible for the risk management activities of the Project. Decision-making is delegated to the lowest level possible, allowing each organization to fully utilize the experience and resources available at each institution. The PI is the final project authority for all decisions.

In the event of a change in senior personnel, especially the PM, the PI will select from a list of qualified candidates from JPL.

H.3.1 Work Breakdown Structure (WBS)

The complete ECHO Project WBS dictionary is included in Section M, Cost Volume. Here we describe the WBS to level 1, and depict it by organization in Figure H-2. This is a product-oriented WBS. The implementation organization corresponds to that product-oriented WBS, thus establishing clear responsibilities for work and lines of authority. The plan for intersite delivery of WBS elements is for the instrument to be delivered to the spacecraft contractor, and for the flight system to be delivered to Baikonur for launch by Kosmotras, as described in the schedule in the previous section. The RecDel table for this project provides a matrix of major and minor deliveries between project elements.

WBS:

1. Project Management (JPL): Overall ECHO project management, including PM and PI management, spacecraft contract management, and mission assurance.
2. Mission Systems Engineering (JPL): Mission engineering that include project-wide functional requirement definition and conceptual design, systems engineering, and interface control and documentation.
3. Instruments (JPL/Ball Aerospace): Design, fabrication and test of the L-band radar electronics (JPL). Design fabrication and test of the L-band radar antenna and structure (Ball). Integration and test of the radar

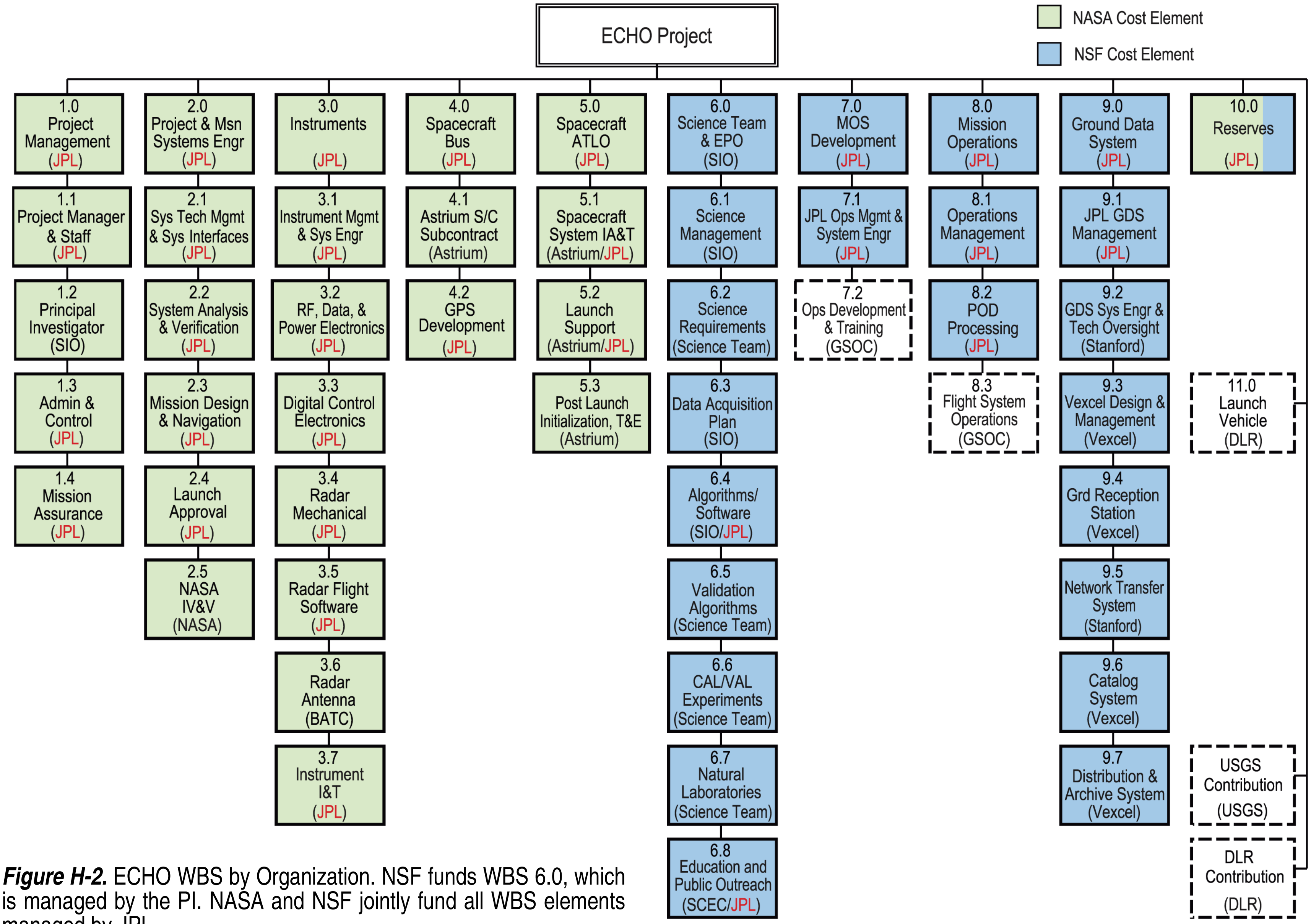


Figure H-2. ECHO WBS by Organization. NSF funds WBS 6.0, which is managed by the PI. NASA and NSF jointly fund all WBS elements managed by JPL.

Table H-3: ECHO team members and their institutions bring many decades of successful experience to the project.

Team Member	ECHO Contributions	Unique Capabilities/ Facilities/Equipment	Relevant Experience
SIO, PI	Principal Investigator, Science Team Leadership	Science, advisory committees	IceSat co-I, PI on numerous science investigations
JPL	Project management, system engineering, mission assurance, mission design, navigation, mission operations (lead), NEPA compliance, science instrument management	Project management, system engineering, mission design and navigation, multi mission operations, NASA NEPA compliance and launch approval, Deep Space Net, Earth Science instrument design, development, and operations	Voyager, Galileo, Cassini, Mars Pathfinder, Mars Global Surveyor, MCO, MPL, Mars '01 Odyssey, Deep Impact, Deep Space One, QuikScat, SRTM, WIRE, GALEX, GRACE, CloudSat, AIRS, MISR, ASTER, SIR-C, Seawinds, Jason, TOPEX-Poseidon
JPL	Project Manager	ESSP project management	GRACE DPM
JPL	Deputy PI, Spaceborne Radar Science Leadership, Algorithm Development Leadership	Co-located with PM	SRTM Algorithm Development, PEM, NASA PI, SIR-C co-I
Stanford	Deputy PI, Ground Segment Architect	Originator of Ground System concept	SIR-C PI, NASA PI, Cassini Radar Team Member
Vexcel Corp.	Ground System Development	Radar Data Reception and Processing, distributed ground station receivers	ASF Level-0 Processor, AMM-2 Mission
Astrium	Spacecraft development/ manufacturing/integration/assembly/ test; instrument integration, spacecraft-level systems engineering and product assurance, spacecraft operations	Spacecraft manufacturing, test, and assembly facilities in Friedrickshaven	CHAMP, GRACE, TerraSAR-X
DLR/ German SOC	Mission Operations (command and control)	Fully operational MOS facility, integrated with Astrium spacecraft testing methodology; Cost-saving contribution	CHAMP, GRACE
DLR/ Kosmotras	Dnepr Launch Vehicle	Cost-saving contribution	159/2 successful missile/ commercial launches
Ball Aerospace and Technologies Corp.	Radar Antenna development/ manufacturing/integration, assembly/ test	Program management, system engineering, antenna manufacturing, test, environmental test, and assembly facilities in Broomfield and Boulder, CO	SIR-C, SRTM, Seawinds, Cloudsat, Deep Impact, Mars Pathfinder
SCEC/ USC	Education and Outreach Coordination	Well-developed infrastructure for EPO at USC	SCEC-I, SCEC-II, NSF ITR programs
USGS	Permanent Archiving	EROS Data Center	SIR-C, SRTM

(JPL). Management of the Ball antenna contract (JPL).

4. Spacecraft Bus (Astrium): Design, fabrication, and test of the spacecraft.
5. Spacecraft Assembly, Test, and Launch Operations (ATLO) (Astrium): Integration and test of the radar instrument with the spacecraft in Germany. Integration with the launch vehicle. On-orbit check-out.
6. Science Team Education and Public Outreach (SIO/SCEC/JPL): Science Management, science acquisition planning (SIO). Algorithm development (JPL). Calibration and validation, science in natural laboratories (SIO/Science Team). Education and Public Outreach (SCEC/JPL)
7. MOS Development (JPL/GSOC): MOS Management, coordination of science data planning and spacecraft commanding, scheduling of ground receiving stations, spacecraft health monitoring, precision orbit processing (JPL). Development of ECHO interfaces in Germany for day-to-day operations of the spacecraft (GSOC).
8. Mission Operations (JPL/GSOC): MOS Management, coordination of operations with science team and GSOC, precise orbit determination (JPL). Day-to-day operations of the spacecraft (GSOC).
9. Ground Data System (JPL/Stanford/Vexcel): Manage the ground data system (JPL). Design, implement and test the Network Transfer system (Stanford). Design, implement and test the data capture system and level-0 processor; Design, implement and test on-line archive centers; manage contract with ASF and University of Miami for ground station services; design build and test the catalogue system for data distribution; operate and maintain the distributed archive.
10. Reserves (JPL) WBS-related reserves, plus project discretionary reserve.

H.3.2 Implementation Organization

The project organization shown in Figures H-3 and H-4 builds upon the JPL experience in successfully implementing PI-led space science missions for NASA. The PI is responsible to the project sponsors at NASA Headquarters and the NSF through the interagency steering group for the overall success of the mission. He chairs a Project Advisory Board whose other members include John Orcutt, SIO Director of IGPP; Charles Yamerone, JPL, Deputy Director for Earth Sciences; Franklin Orr, Stanford Dean of Earth Sciences; Vice President for Business Operations at Astrium; and Vice President for Civil Space Systems at Ball. The Board's responsibility is to ensure that the PI has the support he needs from their respective organizations. Each element of the implemented organization has a well defined role. The assigned people and institutions have had successful experiences commensurate with these roles.

Our organization for operations is described in Figure H-4. This organization will carry out the operations concept described in Section G. The individuals in this organization have well defined roles, and have had significant successful experience in these roles.

H.3.3 Organization Agreements

Teaming Arrangements

Teaming arrangements have been formalized with a Memorandum of Understanding between the PI, JPL, Stanford. The PI will be funded directly by the National Science Foundation (NSF), a proposed major funding partner with NASA. NSF is asked to contribute $70M toward the ECHO mission costs. The funds not contracted directly to the PI will be transferred to NASA to be used for the JPL-managed mission development. JPL manages the project under a task order executed as part of JPL's existing NASA contract. Upon selection, the responsible parties will file for export licenses, as appropriate, unless the NASA Office of External Relations (Code I) decides to formalize international agreements with the foreign partners. JPL and the PI will conduct its relationships with international partners in accord with the U.S. International Traffic in Arms Regulations (ITAR) and the U.S. Export Administration Regulations (EAR).

Upon selection by NASA and NSF, the PI will execute a contract with NSF, and JPL will execute contracts with each of the other NASA/NSF-funded team members. These contracts will provide incentives for on-cost, on-schedule delivery of flight elements for launch, on-orbit performance, and science-data return. A firm fixed price (FFP) contract similar to the FFP contract under which the GRACE spacecraft were built will be implemented with Astrium. This reflects the commitment of all team members to the return of science data at or above the minimum mission, at or below the total mission cost proposed, and on the schedule proposed. This will also allow each team member the maximum freedom to use their own successfully demonstrated processes to achieve the mission goals.

Project Agreements required with other organizations are identified in Table H-4.

Contributions

In addition to a proposed contribution from NSF, several organizations have agreed to contribute to the ECHO mission at no cost to NASA. First, the German Aerospace Center (DLR) is committed to contribute a launch on the Dnepr launch vehicle. The ECHO spacecraft requires a Delta-II class of launch vehicle, or an equivalent DLR contribution of $65M. In addition DLR will contribute mission operations for the entire 5 year lifetime, amounting to approximately $10M if costed equivalently to a JPL-operated mission. These contributions are truly mission-enabling.

The USGS is committed to permanently archive the ECHO data set. From a preliminary costing exercise at the EROS Data Center scoped to include the ECHO data into their standard archive and distribution system, this contribution is approximately $23M, another major contribution.

Operations Service Level Agreements

Spacecraft tracking will be provided by the GSOC by arrangement through DLR. The NASA-DLR MOU will contain the commitment of GSOC resources for tracking the spacecraft and mission operations. Detailed interface specifications will be handled through Astrium as part of the spacecraft contract managed by JPL, providing a streamlined flow of information.

In addition, to reduce risk, a service level agreement will be arranged with the NASA polar network to ensure maximum post-launch contact with the spacecraft.

H.3.3.1 Long-lead and Proposed Major Procurements

Major contracts and critical subcontracts

The major contracts and critical subcontracts are as follows:

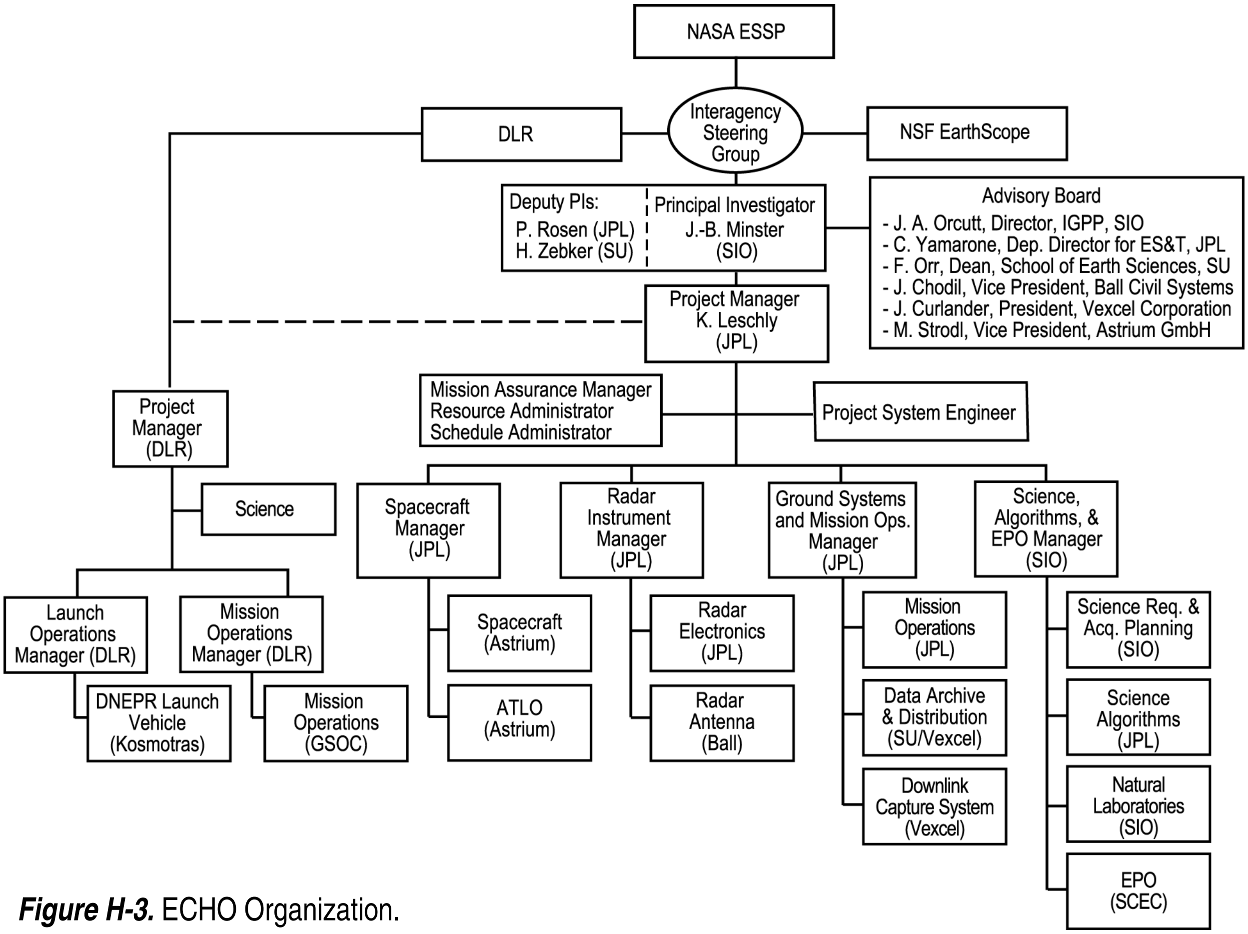


Figure H-3. ECHO Organization.

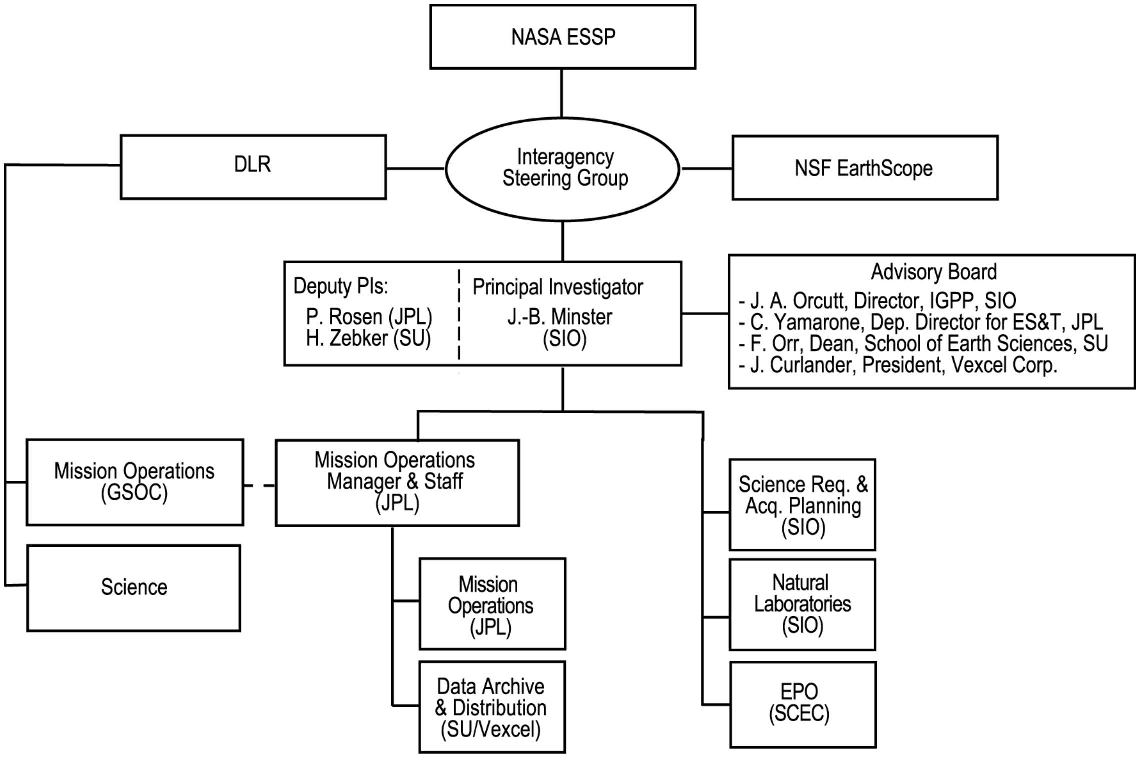


Figure H-4. ECHO Operations Organization.

1. **Spacecraft contract:** The spacecraft contract with Astrium GmbH will include design and development of the spacecraft bus, integration and test of the spacecraft and payload at the contractor's facility, environmental test at the contractor's facility, delivery of the flight system to the launch site by 2 months before launch, support of launch operations, and in orbit commissioning. The proposed award schedule will be incentive based, with payments that are milestone driven. In addition to the flight system, deliverable items will include all design documentation for the final delivery. JPL mission assurance will use the JPL Design, Verification/Validation and Operations Principles for Flight Systems to develop performance assurance requirements for the flight system.
2. **Antenna subsystem contract:** The antenna contract with Ball will include design and development of the radar panels, test of the panels at Ball facilities, documentation of interfaces and tests conducted, support of radar integration and test at JPL, support of spacecraft integration and test at Astrium, management of the antenna deployment structure subcontract, and radar antenna integration and mechanical test. Deliverable items will include all design documentation for the final delivery. The proposed award schedule will be incentive based, with payments that are milestone driven.
3. **Antenna structure subcontract:** Ball will manage the antenna structure subcontract to Able engineering. Able will design and develop the deployment mechanism at their facilities, and perform deployment tests and verification using on-orbit load conditions at their facilities. Thermal constraints will be tested for critical parts and joints. Able will support radar integration and test at Ball and spacecraft integration and test at Astrium. Deliverable items will include all design documentation for the final delivery.
4. **Network Transfer Subsystem contract:** The NTS contract with Stanford will include the design and development of a computer system that receives high-rate radar data from the ground stations, transfers them to a distributed set of archive centers and sends documentation of its transactions to a catalog system. Stanford will test the system and deliver all design and test documents to the project. Stanford will manage and maintain

Table H-4: These agreements forge the basis for our partnership with the other key organizations who will contribute to mission success.

Agreement	Purpose	Draft Document	Final Document
NASA MOU with NSF[1]	Establish funding amount and profile for ECHO project	Project Start	Project Start+30 days
NASA MOU with DLR	GSOC commitment for Telecomm & command support; sequencing tools; tracking and mission operations; Dnepr launch and launch support	Project Start	Project Start + 30 days
SLA with NASA polar network	Ensure low-risk orbit insertion and raise	Project PDR	Project PDR + 90
MOA with the NASA IV&V Facility	Software IV&V	Project PDR	Project PDR + 60 days
MOA with USGS	Commitment of permanent archive	Project PDR	Project PDR + 90 days

[1]This proposal is submitted jointly to NASA and NSF. See NSF letter in Appendix 10.

the NTS. The proposed award schedule will be incentive based, with payments that are milestone driven.

5. **Ground Data System contract:** The GDS contract with Vexcel will include design and development of the ground station data capture and level 0 processing system, web-based catalog system, and five network-based archive and distribution systems, designed to receive data from the Network Transfer Subsystem. Vexcel will integrate and test the system in concert with Stanford. Vexcel will manage the operations and maintenance of the archive and distribution centers and the capture systems. The proposed award schedule will be cost-plus-fixed-fee based, with payments that are milestone driven.
6. **Alaska SAR Facility services subcontract:** ASF will operate their receiving station to acquire ECHO data sufficiently often to meet project needs, roughly 60 minutes per day of downlink time. ASF will install the ECHO data capture system and level 0 processor, and operate the system.

Relationship and controls: JPL will manage these contract in accordance with the cost, schedule, and quality assurance controls described in Section H.1 of this proposal.

Long-lead items

All spacecraft parts can be procured with adequate schedule margin after mission confirmation, and therefore there are no long-lead spacecraft bus items.

The radar antenna L-band T/R modules and panel integration require design work and fabrication that will drive the critical path. The risk to the program is mitigated by Ball's current investment into the preliminary design of T/R module design.

The antenna structure is a 25-month build, and so is on a parallel critical path. Contract start for AEC-Able Engineering will be in April 2003. The design is based on the current RadarSAT-II ESS that recently completed CDR.

H.3.4 Experience and Commitment of Key Personnel

JPL has the most experience of any institution in managing cost capped, PI-led projects. The resumes of key personnel are provided in Appendix L-1. Each of the key individuals named is fully qualified by training and experience for their roles, as described in Table H-5, and in Appendix L-6.

Each individual is fully committed to the ECHO mission as described in the text below.

H.3.5 Specific Roles and Responsibilities of Key Project Personnel

Principal Investigator

Bernard Minster is in charge of the investigation and is responsible to NASA for all aspects of the mission, including EPO. The PI leads the Science Team. Bernard Minster's commitment

Table H-5:

Team Member	Relevant Experience
PI, Bernard Minster (SIO)	Co-I for ICESAT instrument, Science Director of SCEC, Systemwide Director of IGPP, Univ. of CA
DPI, Paul Rosen (JPL)	SRTM PEM (Algorithms), NASA PI, leader in differential interferometry
DPI, Howard Zebker (SU)	NASA Investigator and leader in field of interferometry
PM, Kim Leschly (JPL)	DPM on GRACE, PM for Oersted
PSE/PE (JPL)	Assigned by JPL prior to Project start
Inst. Mgr (JPL)	Assigned by JPL prior to Project start
SC Mgr (JPL)	Assigned by JPL prior to Project start
SC Mgr, Albert Zaglauer (Astrium)	SC Mgr on CHAMP, GRACE
MOM, Parag Vaze (JPL)	MOM on TOPEX, JASON
MAM, Michael Gross (JPL)	MAM on GRACE project
EPO Mgr, Tom Jordan (SCEC)	Director of SCEC, with key role in defining its EPO activity

to ECHO for Phases 2 through 4 is 49% and 40% for Phase 5. The PI approves the Project Plan and all other project level documents. The PI reports to NASA all changes to the plan and descope options exercised, if any, for NASA concurrence. The PM controls the expenditure of reserves except for cases where the science data is affected. In those cases the PI has final authority. The PI delegates the authority for implementation of the flight system to the PM as described below.

Deputy Principal Investigators

Paul Rosen and Howard Zebker are the ECHO deputy PIs. Dr. Rosen is cognizant in the flight system aspects of the mission, while Dr. Zebker is cognizant in the ground systems development for the project. Both DPI's are experts in algorithm development and science applications of ECHO-like data and have considerable experience working through radar flight hardware and system design issues with hardware engineers on the SIR-C and SRTM projects. Together with the PI and Project Manager, who is responsible for the management oversight of project activities during all phases, this group forms the top level managerial unit, communicating regularly, and operating in concert. In a more traditional approach the DPIs might be construed as project engineers, but for ECHO, they cover a spectrum of science and engineering activities that are unique to radar. Dr. Rosen will be committed to the project at an 80% level for Phases 2 through 4, and a 40% level in Phase 5. Dr. Zebker will be committed at the 40% level throughout the project.

Project Manager

The PM, Kim Leschly, plans, coordinates and monitors and reports on system design and implementation during all phases of the project. The PM is also primarily responsible for overall risk management. The PM is a veteran project manager, whose latest assignment was to manage the GRACE project in collaboration with Astrium GbmH. Kim Leschly's commitment is full time from the time of the proposal acceptance through commencement of routine operations in Phase 5. The PM will report monthly against the Project Plan and the EVM baseline, and reports progress to the PI in weekly meetings. Weekly status updates, monthly management and quarterly Governing Program Management Council (GPMC) reports will also be used to communicate to NASA.

Project System Engineer

The Project System Engineer/Project Engineer (PSE/PE) will be assigned at project acceptance from a large pool of highly-qualified experienced systems engineers at JPL. The PSE leads a project system engineering team that draws talent from all ECHO systems, and all essential technical disciplines (see Table H-3). The commitment is full time from the time of Phase 2 through Phase 4. The PSE will be available as needed for Phase 5. The PSE will lead and perform the activities described in Section H.1.2.

Instrument Managers

The Instrument Manager will by assigned by JPL at project start. The IM reports directly to the PM and is responsible for delivery of the flight instrument components at the time agreed to in the Project Plan at the cost that has been agreed to, meeting both performance and interface requirements. The Instrument Manager position will be a full time commitment from the time of Phase 2 through launch and check out.

Spacecraft Manager (JPL)

The JPL spacecraft manager oversees the contract with Astrium for technical compliance with project requirements and assists the project manager in engineering analysis with regard to spacecraft related issues, in particular with regard to integration of the JPL-built GPS instrument with the spacecraft. The position is a full time commitment, beginning in Phase 2 and continuing through project launch plus 30 days.

Spacecraft Manager (Astrium)

Albert Zaglauer (Astrium) is the Spacecraft Manager at Astrium. He was the spacecraft manager for CHAMP, AI&T manager for GRACE, and the project manager for the Mars HRSC. He manages the design, development, integration and test of the spacecraft, and the subsequent integration and test of the payload. Mr. Zaglauer is also responsible for spacecraft support to flight operations. The position is a full time commitment, beginning in the proposal effort and continuing through project launch plus 30 days. This position continues to support flight operations at an appropriate level throughout the end of the mission.

Ground Systems and Mission Operations Manager

The Ground Systems and Mission Operations Manager manages the design, development, integration, test and personnel training of the mission science planning and operations, and ground data systems. The bulk of flight operations development and routine operations of the spacecraft will be the responsibility of the German Spacecraft Operations Center (GSOC), services contributed at no cost to NASA through DLR. The role of the MOM in ECHO flight operations will be to coordinate science plans and inputs with required spacecraft inputs. The MOM position continues as the Mission Manager at the time of project transition to the Operations Organization shown in Figure H.3-2. Responsibilities include: science operations planning; coordination of services provided by JPL, SIO, GSOC, and Astrium with regard to flight operation of the spacecraft, and by Stanford and Vexcel with regard to the ground reception and data distribution system; coordination of day-to-day activities during operations including conducting mission critical event rehearsal training and tests; and transfer of scientific data to the PI and providing an ECHO data archive interface for science users' transfer of scientific products according to the schedule established in the Science Data Management Plan. The MOM/MM position is a full time commitment from Phase 2 through Phase 5 (Ops). The MOM will work closely with DPI Zebker from Stanford University on the development of the Network Transfer Subsystem, and the Vexcel Ground Data System Manager on the development of the remainder of the ground segment. The MOM reports to the JPL PM and maintains overall responsibility for ensuring the project processes are followed by Stanford and Vexcel, and tracks the implementation. JPL, Stanford, and Vexcel have worked successfully on similar collaborative projects, SRTM and the Antarctic Mapping Mission.

Mission Assurance Manager

Michael Gross, the ECHO Mission Assurance Manager, leads and manages safety, reliability, QA, parts, and problem failure reporting for the ECHO Project. Mr. Gross is the MAM for the GRACE mission. Mr. Gross is responsible for implementing the overarching actions of the NASA Agency Safety Initiative on the ECHO Project. The MAM is responsible for providing safety and mission assurance guidance to acquisition-related materials, including RFPs, any statement of work, source evaluation criteria, etc., for the ECHO team. The MAM is responsible for incorporating NASA and JPL Lessons Learned into ECHO in order to reduce risk, and supplying Lessons Learned from ECHO to other NASA elements. The MAM position is a full time commitment from Phase 2 through launch, and continues at an appropriate level through the end of the mission.

Co-Investigators

The Co-Investigators forming the Science Team (see F.5) are world-renowned scientists and experts in discipline areas for ECHO science. Many team members are also experts in interferometric algorithm and software development. Hence the roles of the Co-Investigators in ECHO are 1) to assist the PI in science planning, 2) produce the project software for processing radar data to science products, 3) perform calibration and validation experiments, and 4) create demonstration science in ECHO's national laboratories. The PI manages the Science Team.

Education and Public Outreach (EPO) Manager

The SCEC leads the EPO activity. Day to day management is provided by the EPO Manager, Dr. Thomas Jordan. Dr. Jordan provides the overall intellectual guidance for ECHO EPO and reports directly to the PI. The EPO Manager is responsible for development of the EPO products. This includes planning, staffing and implementing a diverse but cohesive effort that makes substantive contributions to K to 14 education, lifelong learning, and inclusion of underserved groups. This activity will engage the broad public that is interested in earthquakes and other natural hazards, particularly those interested in space-based remote sensing of hazards.

H.4 Risk Management

ECHO utilizes the JPL risk management process for continuous, proactive risk management that has been used effectively on over ten flight projects. This process includes defining mission success criteria, risk management responsibilities, and risk identification criteria. The process steps are: risk management planning; risk identification and assessment; risk mitigation where appropriate; documenting information in a significant risk list; and risk tracking.

Risk Management Responsibilities. The PI has the final project authority on all risk management decisions that might result in a descope of ECHO. The PM will make risk management decisions that do not involve a descope. The Project Systems Engineer has primary RM coordination activity project-wide, including planning, identification and assessment of risks, and formulation of mitigation approaches. Each member of the project will be responsible for identifying risks and will mitigate risks within their scope of the project.

Risk Management Planning A Risk Management Plan will be finalized during Phase 2. This plan describes a systematic approach to identification, assessment, and mitigation of all significant risks. JPL principles for design, validation, and operation of missions will be applied to ECHO. These principles incorporate the many lessons learned on management of risk of space missions. These principles include the establishment and management/release of appropriate project reserves and technical margins over the project lifecycle. ECHO is in compliance with those principles. Another important element is the establishment of an integrated baseline of requirements, schedule and cost, against which progress will be tracked, in order to determine as early as possible when project reserves will be needed. A preliminary project descope plan is discussed in Section H.4.3 of this proposal, and will be completed in Phase 2.

Risk Identification and Analysis The risk management plan assigns risk identification and assessment responsibilities to the entire project team. It establishes risk metrics and identifies the technical performance measures to be tracked (e.g., mass, power, data rate) to uncover risks throughout the ECHO Project lifecycle. The Significant Risk List (SRL) tracking system, Failure Modes and Effects Analysis (FMEA), Fault Tree Analysis (FTA), and Probabilistic Risk Assessment (PRA) will be used. Risk will be a factor considered in system trade studies and design decisions. Contractors will be involved and will contribute to project risk management.

Risk Decision Making. During Phase 2, mitigation approaches will be completed for the most significant risk items. This may include mitigation (avoidance by design or alternative implementation), contingency planning (what to do if the risk occurs), or acceptance (allocating reserves to absorb the impact if the risk occurs). The preliminary descope plan will be refined through tradeoff analyses.

Risk Tracking and Communication The project will use schedule, budget, and technical risk-tracking tools. Risk will also be tracked during testing through Problem/Failure Reports (P/FRs). Technical risks will be tracked by assessing Technical Performance Measures, including margins. Risk tracking results will be reported at monthly management reviews and at each major project review. Astrium and Ball will follow similar risk management processes coordinated with JPL, as was done on previous mission implementations.

H.4.1 Top Risk Items

ECHO's design minimizes risk building on a successful spacecraft build process, using the simplest, demonstrated mission concept (e.g., ERS interferometry observations), and employing a conservative margins management strategy. Cost risk is minimized by a firm MOU between contributing DLR and NASA with no exchange of funds for the contributed launch vehicle, a major cost savings. This arrangement cannot lead to launch vehicle cost increases. Furthermore the spacecraft contract will be firm fixed price, as it was with Astrium for GRACE, and there is low probability of significant cost growth there. The ECHO Team has thoroughly assessed the mission for risk and established the initial risk list, along with associated mitigation strategies (see Table H-6). The table shows that there are no risk elements posing a significant challenge to launch in October 2006. In the table, the baseline project strategies for minimizing risk are described along with the mitigation strategies. The cost impacts are assessed by assigning a cost for the given risk and weighting that cost by the likelihood of occurrence. The total risk cost impact is the $6.9M, well within the reserves held by the project. While the Dnepr launch vehicle fairing is new for the TerraSAR-X mission to be flown in advance of ECHO, DLR will work with Kosmotras, the LV manufacturer, and will ensure that the engineering and testing is sufficient to justify the use of this vehicle. Much of this work will be done prior to start of Phase 2 for the TerraSAR-X mission, and an updated risk assessment can be given at the proposal site visit. Attached to this proposal is the launch vehicle specification from Kosmotras identifying the technical issues, their assessment of the risks, and their proposed solutions. A final design and analysis will be presented at PDR, in time for a NASA confirmation decision at MCR. The instrument delivery schedule is on the critical path and represents a moderate risk to the project. However, the year-long Phase 2 gives ample time to refine the design and procure many of the long lead item parts, such as the T/R modules, thereby mitigating much of the risk.

H.4.2 Margins and Reserves Management Strategy

JPL has a set of design principles for the design, validation, and operations of projects. The ECHO margins according to these principles are shown in Table H-7. JPL margins are defined as *allocation—CBE* and expressed as a percentage of the *allocation*. ECHO's mass margin according to the *JPL Design Principles* definition is 25% and according to the NASA AO definition is 11% which excludes the generous contingencies used in the ECHO mission design from the margin calculation. The margins shown in Table H-7 will be the basis for the ECHO Margins Management Strategy.

H.4.3 Descope Plan

The ECHO Team has identified 5 potential descopes at a value of $20M. These can be implemented at various stages of the mission to all elements.

Descope options for ECHO Project are:

1. Eliminate electronic beam steering. This simplifies the antenna design, implementation and testing considerably. It implies loss of ScanSAR mode, but does not imply loss of baseline science.

   Latest possible decision date with no adverse schedule impact: PDR

   Cost impact: Potential savings of $1M.

   Impact on science objectives: Minimal

2. Replace JPL-built GPS receiver and associated precision orbit determination with less capable commercial unit that give real-time orbits of degraded (~1m) accuracy.

   Latest possible decision date with no adverse schedule impact: PDR

   Cost impact: Potential savings of $4M.

   Impact on science objectives: More laborious science computations; additional software development for science processor; some science users would require additional training.

3. Reduce volume of science data. By reducing the total data requirement, it is possible to limit the ground system to a single ground station, reduce the archive and distribution load by roughly 20-30%.

   Latest possible decision date with no adverse schedule impact: Phase 4

   Cost impact: Potential savings of $4M.

   Impact on science objectives: Reduced science return. Minimum mission.

4. Remove ScanSAR timing vernier. This would disable ScanSAR to ScanSAR operations

   Latest possible decision date with no adverse schedule impact: CDR

   Cost impact: Potential savings of $1M.

   Impact on science objectives: Minimum impact as mode is experimental.

5. Scale back regional on-line archives.

   Latest possible decision date with no adverse schedule impact: Phase 3/4

Table H-6: Project top-risk watch list

	Risk Element	Baseline/Mitigation Strategy	Impact/Cost	Likelihood
1	Engineering of extended launch vehicle shroud is a new development and is not delivered on time.	Baseline: Precursor development using the same identical shroud with TerraSAR-X program which is scheduled to be launched 12 months prior to ECHO. Mitigation: Apply reserve to schedule slip. Most likely cost based on 3 months of slip beyond 6 months of schedule reserve	Low $0.3M	Low
2	Antenna is not delivered on schedule	Baseline: Using heritage design with adequate project oversight and schedule reserve, and have increased development cost by $5M to minimize likelihood. Mitigation: See Entry 1 above	Low-Moderate $0.7M	Low
3	GPS redesign required due to failure of heritage receivers on CHAMP and/or GRACE results in added development costs and schedule slip	Baseline: Implementing a rigorous parts upscreening program. Additional testing is already costed. Mitigation: Apply reserve to GPS development at the level of effort used for GRACE and schedule slip of 6 months beyond project schedule reserves	Moderate $1.7M	Moderate
4	TerraSAR-X program (currently in Phase C) is delayed and/or canceled resulting in reduced inheritance	Baseline: Project is carrying 10% reserves on the fixed price S/C contract and the equivalent of 15% additional in discretionary reserves.	Low $0.1M	Very Low
5	NASA-NSF budget negotiations results in a schedule slip of 6 months	Baseline: Submit proposal to and participate in both the NASA and NSF review process in parallel Mitigation: Apply reserve to schedule slip. Most likely cost based on 6 months of slip beyond 6 months of schedule reserve.	Moderate $2.2M	Moderate
6	Antenna mass simulator needed for spacecraft qualification at Astrium	Baseline: Will study RadarSat actual load coupling compared with Nastran software model Mitigation: Apply reserves to procure mass simulator for Astrium	Low $0.4M	Moderate
7	Scope of NASA IV&V grows	Baseline: Project is carrying JPL SWQA cost consistent with a low-risk mission assurance plan plus 25% spacecraft reserves and $1.5M for NASA IV&V Mitigation: Negotiate actual IV&V costs with NASA during formulation and apply reserves if necessary.	Low $0.2M	Low
8	Delays in implementing international agreements impact the schedule	Baseline: Vigorous assessment of ITAR needs with project funds in Phase2 and early application for export/import licenses. Mitigation: See Entry 5 above.	Moderate $1.4M	Low

Cost impact: Potential savings of $10M from reduced hardware procurement,

Impact on science objectives: Reduce timely science during the mission by limiting access to the data. Overall mission sci-

Table H-7: ECHO's rigorous approach to margins management

	Proposal Actuals	PDR	CDR	Start ATLO	Ship to launch site	Launch
Mass Margin (%)	25	20	10	5	5	2
Power margin (%)	31	20	15	10	10	10
Schedule margin (mo/yr)	1	1	1	2	1 wk/mo	0
Flight S/W performance margins* (%)	>600	60	50	35	35	20
Budget reserve**(%)	26	25	20	20	10	10

**Margin on performance parameters such as CPU speed, control cycle rates, RAM, PROM, etc.*
***Unencumbered cost reserves/estimated cost-to-go, Phases 1-4*

ence would not be impacted if future funding enabled science work.

H.5 Safety and Mission Assurance

The JPL-led ECHO Safety and Mission Assurance Team will plan and implement a comprehensive Safety and Mission Assurance (SMA) program. Through consultation with Goddard's Office of Flight Assurance, the SMA team will develop a cost efficient approach to meet the intent of GSFC SMA requirements for ESSP-3 missions.

The JPL Mission Assurance Manager will lead SMA team, which will consist of JPL, Astrium and Ball engineers. The SMA program will incorporate JPL SMA Principles as applicable to the project.

The SMA program, via concurrent engineering, will be an integral part of all ECHO flight and ground hardware, software, ground support equipment (GSE) and mission operations planning, development and implementation. This SMA program will emphasize the use of quality parts and materials, and high standards of workmanship in combination with proven, in-place ISO 9001 compliant processes and procedures at JPL, Astrium, Ball, and their subcontractors and vendors.

The Project's SMA program will integrate operations assurance early into the design phase to assure functional compatibility between the flight system and mission operations. Specific details of the Project's overall SMA approach will be documented in a Mission Assurance Plan early in the Formulation Phase and be provided for Earth Explorers Program Office review. The SMA program will consist of the disciplines defined below.

System Safety. The ECHO project system safety team will coordinate and implement safety planning early in the Project's life cycle, using JPL Standard for System Safety, D-560 as a guide. The Project's safety program will be documented in a System Safety Plan, and shall apply to all work performed by the Project, including the team's suppliers and subcontractors.

All mission hazards to personnel, facilities, support equipment and the flight system will be identified and controlled during all stages of the Project's development. System safety visits and surveys will be performed at all facilities before and during operations involving flight hardware and launch activities.

Hardware Quality Assurance for the ECHO project will include activities implemented during design, fabrication, test and delivery of the flight hardware and ground support equipment. It will emphasize quality tasks and their integration with design, fabrication, and test activities. Quality requirements will be defined for the detection and correction of deficiencies or trends that may result in unsatisfactory quality of the flight hardware. JPL approved workmanship standards will be used on all Project hardware, at the team and their suppliers/subcontractors. All project hardware will be completed with a team generated Hardware Review and documented on a Hardware Review and Certification Requirement Form [HRCR], JPL Form 1023 or team equivalent.

Software Quality Assurance will provide the ECHO project software development support tailored to the mission software requirements. The SQA team member performs a software development process risk assessment, in conjunction with the project software developers, using criteria contained in JPL institutional standards and lessons learned. An output of this process is recommendations to the project pertaining to software development tasks, SQA activities and/or NASA IV&V facility support.

The resulting tailored software quality approach is documented in appropriate sections of the Project's Quality Assurance Program Plan. Software Quality Assurance acts as the focal point for project interface with the NASA IV&V center.

Electronic Parts Engineering will implement a Project parts program, in support of the hardware development process, that assures all mission reliability and performance requirements are met. The provisions of GSFC 311-INST-001 will be used as a guide in selecting and processing parts. Additional parts screening requirements such as the additional parts screening requirements will be Destructive Physical Analysis (DPA), Particle Impact Noise Detection (PIND) and x-ray will be in accordance with JPL's standard electronic parts baseline program.

The project electronic parts team will control the management, selection, application, evaluation (including derating) and acceptance of Project parts through an ECHO Parts Control Board. Criteria appropriate to the mission characteristics-mission duration, expected radiation environments, including single event effects requirements and other space environments, will be established prior to PDR.

The parts team will support parts procurement of project instruments and maintain a Project EEE parts listing for the radar electronics package and the GPS instrument. The final as-built list will be included as part of the hardware documentation package. JPL will review and approve its team member's parts lists and provide additional support as required.

The team will have access to and maintain knowledge of parts problems as reported by the GIDEP and NASA Alert Programs.

Reliability engineering participation in the project's design, development and implementation will focus on the areas of design and test and will be organized to effectively, efficiently and responsively perform tasks that enhance the expected mission lifetime. Analyses to be performed on the Project hardware include Failure Modes and Effects, fault tree, worst case and parts stress analysis. A system-level Probability Risk Assessment will be performed and made available for review. A JPL reliability engineering team member will review the team's analyses, and perform the analyses for the JPL built instruments. The hardware operating time prior to launch will be based on JPL's Design Principles, D-17868.

A documented, closed loop failure reporting system for hardware and software will be implemented by the team and maintained at the project level. It will include risk rating and thorough closure review process.

The team's environmental requirements engineering members will verify that flight hardware meets specified mission requirements through analytical investigations and environmental test planning, test oversight and reporting. Environmental assurance design requirements and testing will utilize robust margins appropriate to the mission characteristics.

Contamination Control will identify contamination requirements, schedule the performance of a contamination source and source path analysis, as well as establish and maintain a program consistent with Project mission design requirements. The spacecraft and instruments thermal and physical parts and layouts will effect the contamination control cleanliness processes.

Materials and Processes used by the Project will be reviewed for compliance to standard JPL spacecraft requirements, including outgassing, compatibility and stress corrosion cracking. Fastener selection and use will be controlled using GSFC S-313-100 as a guide. The Project will maintain an updated list of all materials/processes used on flight hardware, and include a complete as-built listing in the final hardware documentation package. The information collected and assessed here will influence the contamination control process.

Mission Operations Assurance early planning and Phase 5 support on the Project consists of several major functions, worked in coordination with the operations system engineer at GSOC. These functions include: ECHO operations team training and follow up, confirmed integration of flight operations requirement with the flight hardware and software, verification of mission and flight rules adherence, inclusion of mission operations into the risk management process. The MOA will develop a project process for operations validation assessment, develop procedures for the preparation and implementation of End-To- End Information System Test and Operations Readiness Testing, including reviews.

Risk Management team members include the safety and mission assurance staff. Safety and mission assurance will be proactive in the continuous ECHO risk management program [see details in Section H.4]. The team will also conduct or support project reviews and will also support the independent Red Team reviews. [See Table H-8 and H-9 and Section H.4 for the specific project reviews.]

H.5.1 Software IV&V

The ECHO team has performed the standard Software IV&V self-assessment of seven criticality areas. They are: requirements, maturity, safety, complexity, testability, performance and cost/schedule. Applying these criteria, the team identified the ECHO Project as a candidate for IV&V. Based on early planning information from the NASA IV&V Facility, Fairmont, West Virginia, the ECHO team has set aside $1.5M dollars to cover this risk mitigation strategy, and has added IV&V to its cost risk liens. The NASA IV&V Facility will work jointly with the Project management and quality assurance personnel in Phase 2 to plan the exact IV&V that will be performed.

H.6 Facilities and Equipment

Government furnished property, services, and facilities for the ECHO Project will be described in Memoranda of Agreement (MOAs), and costs have been included in the cost estimates in this report. Specific items that will be furnished are:

Table H-8: Mission Assurance Compatibility Table

Mission Assurance Element	Check all that apply	Applicable Plan, Document, Review or Program
1. Mission Assurance Program	X	Project Mission Assurance Plan
2.1 Quality System	X	Project Quality Assurance Plan
2.2 Standards	X	Project Quality Assurance Plan
2.3 Non-Conformance Reporting	X	Project Quality Assurance Plan
2.4 Operating Time	X	JPL Design Principles, D-17868
3. Reviews: SRR, PDR, CDR, PER, MRR, LRR	X	Project Review Plan
4.1 Parts Program	X	Project Parts Program Requirements
4.2 Materials and Processes Program	X	Project Materials & Processes Plan
4.3 Reliability Program	X	Project Reliability Plan
4.4 Software Development Program	X	Project Software Development Plan
5. Verification Program	X	Project Environmental Requirements Document
6. Contamination Control Program	X	Project Contamination Control Plan
7. Independent Mission Operations Requirements	X	Project Mission Ops Assurance Plan
8. Red Team Reviews	X	Project Review Plan
9. Continuous Risk Management	X	Project Risk Management Plan

Table H-9: Mission Assurance Compatibility Table

Mission Assurance Element	Check all that apply	Applicable Plan, Document, Review or Program
3.a Additional Reviews from Appdx H	X	Project Review Plan
Mission Design Review	X	
Confirmation Readiness Review	X	
Mission Confirmation Review	X	
Pre-Ship/Operational Readiness Review	X	
Flight Readiness Review	X	

- The NASA Software IV&V facility will provide independent verification and validation of software.
- The US Geological Survey will provide long term archive facilities and services at the EROS Data Center in Sioux Falls, South Dakota.
- JPL, Astrium, Ball and Able Engineering will furnish the major facilities, laboratory equipment, and ground-support equipment identified in Table H-10, in accordance with the schedule provided in Section H.2.
- Table H-10. Major Facilities and Equipment for the ECHO Project. Letters of Commitment appear in Appendix 10.

H.7 Plans to Resolve Open Management Issues

Open management issues include the following:

- Uncertainty about the nature of NSF's commitment to support the ECHO Project, including the exact funding mechanisms and reporting requirements. Once selected, NASA and NSF must quickly reach an interagency agreement, and funds from NASA and NSF must be available in FY 2003. The project will work within the NASA profile while NSF funds are allocated, and work with NASA and NSF to understand contracting and reporting issues.
- Make or buy decision for GPS instrument. While the proposed JPL-built GPS instrument has the benefit of heritage from the GRACE, there are assumed risks in the use of upscreened class B parts in the design. There may be some cost and risk reduction if Astrium purchases a European unit as part of their fixed price contract.
- Management of the ASF contract. It may be simpler to have the ASF contract issued directly from Goddard Space Flight Center, since GSFC presently funds most of ASF operations. This will be resolved by the time of the site visit.

Staffing Profile. While the commitment of workforce has been secured for ECHO at the management level, this is dependent on other active projects at the time of project start. The technical divisions at JPL will evaluate project needs at the time of project start, and work through Phase 2 to staff all projects adequately.

H.8 Site Visit Location

The site visit will occur at JPL, in building 300.

Table H-10: Major Facilities and Equipment for the ECHO Project. Letters of Commitment appear in Appendix L-10.

Organization	Facility	Committed to ECHO Project?	New?
Astrium	Astrium S/C assembly facility	yes	Existing
Astrium	Astrium environmental test facilities	yes	Existing
JPL	Radar Instrument assembly facility	yes	Existing
JPL	Radar antenna test facility	yes	Existing
Ball	Antenna manufacture and test facility	yes	Existing
Ball	Environmental test and integration facility	yes	Existing
AEC-Able (under Ball contract)	Large structure assembly and deployment facility	yes	Existing
ASF, U. of Miami	Downlink ground ops systems	yes	Existing
Stanford, Caltech, Howard U, Scripps, MIT	Regional Archive Facilities (to be supplied with commercially available servers and disk arrays)	yes	Existing
EDC, SDSC	ECHO science data repository	yes	Existing
GSOC	Mission Operations facility	Yes	Existing

I. COST AND COST ESTIMATING METHODOLOGY

Table I-1 presents the proposed baseline ECHO mission cost estimate in real-year dollars. The total NASA ESE Mission Cost (NEMC) is $125M, with the total NASA Mission Cost (NMC), including the NASA $50M launch credit, at $174.8M, below the NASA cap. The Total Mission Life-Cycle Cost (TMLCC), including contributed costs, is $288.2M (see Fig. I-1). Composite project reserves are substantial at 26%. The reserves are divided into a WBS-based reserve and a project discretionary reserve to use as a management tool for unforeseen problems. Total funds from contributions equal $113.4M (39% of TMLCC). Peak funding years are FY04 ($65M) and FY05 ($69.9M). Costs associated with the radar instrument, $55.4M, and spacecraft and I&T, $59.5M, are the largest individual elements.

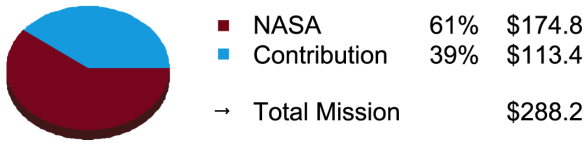


Figure I-1. Total ECHO Mission Cost Distribution by Contribution (RY$M)

The ECHO Team is submitting this proposal concurrently to the NSF to seek $70M in supplemental funds. Table I-1 and all cost analysis in this proposal assume that NASA and NSF contributions can be divided along the WBS lines. The ECHO team chose the most natural division: NASA's costs as flight segment costs and NSF costs as Science Team and ground segment costs. This profile for NSF is also the most easily programmed into future year expenditures. NASA, however, has prescribed a particular yearly funding cap that must be met. The requested NASA and NSF funds are given in the lines at the bottom of Table I-1, and clearly do not match the WBS-oriented cost breakdown. The ECHO team relies on funding coordination between NASA and NSF that can meet our TMLCC, and will work with both agencies toward that goal.

I.1 COST ESTIMATION TECHNIQUES

JPL derived cost estimates for all WBS elements using bottom-up, grassroots methods and by analogy to previous similar proposals. The results integrate cost estimates from team partners with JPL in-house cost estimates, using the JPL Project Cost Analysis Tool. Program management then audited all cost estimates to eliminate possible overlaps and/or omissions. The JPL implementing technical organizations conducted a review of the work proposed for each WBS element and signed preliminary work agreements committing their organization to the work proposed at the costs proposed. In addition, JPL management conducted thorough technical, management and cost reviews of ECHO and endorsed the proposal and its costs as reasonable and sufficient.

I.2 INDEPENDENT COST ESTIMATES (ICE):

For validation proposes, JPL independently estimated the ECHO mission costs based on mass, power, heritage, schedule, and mission architecture details. Models included a NASA instrument cost model, MO&DA cost models, and a review of Astrium buses flown to date. Aerospace Corporation was also contracted to apply the NASA/Air Force Cost Model for the instrument and spacecraft. ICE estimates ranged from $201M to $233M, excluding the launch vehicle, somewhat lower than the ECHO grassroots estimate (Table I-1) but comparable if the current ECHO science and archive scenarios are taken into account.

JPL's Advanced Projects Design Team ("Team X") performed their own independent review of the design. Team X estimated the ECHO costs to be in a range of $230M to $307M using quasi-grassroots methods. Team X also ran the Aerospace Small Satellite Cost Model V3 for the bus and produced similar cost results. The Team X evaluation of the proposal radar instrument cost agrees with the proposed costs.

Finally, JPL's Parametric Mission Cost Model (PMCM) was applied. PMCM gives total life-cycle cost by WBS element based on many pre-phase A studies done at JPL. The model matches fairly well the current best estimates of cost for the Stardust and Genesis missions, and several other recent missions. Assuming the ECHO team instrument costs, the total project cost ranged from $256M to $346M, which spans the proposed cost.

I.3 INSTRUMENT COSTS

The NASA/JPL Shuttle Imaging Radar-C perceived costs have frequently been cited as

Table I-1: Total Mission Life Cycle Cost (Thousands of Real Year Dollars), AO Table K-9 (RY$K)

Cost Element	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	Total (RY $K)
Mission Development:											
Project Mgmt / Msn Analysis / System Engr	222	4,783	6,074	5,527	5,492	570	-	-	-	-	22,668
Instrument Mgmt & System Engr	36	1,378	2,025	2,019	1,806	504	-	-	-	-	7,767
Instrument - RF, Data, & Power Electronics	14	1,163	5,806	3,084	-	-	-	-	-	-	10,066
Instrument - Digital Control Electronics	14	485	1,115	679	-	-	-	-	-	-	2,292
Instrument - Radar Mechanical	22	530	967	1,322	464	-	-	-	-	-	3,306
Instrument - Radar Flight Software	-	80	72	43	-	-	-	-	-	-	195
Instrument - Radar Antenna	-	6,720	14,388	2,569	-	-	-	-	-	-	23,678
Instr. Integration, Assembly and Test	-	366	1,942	2,695	2,905	151	-	-	-	-	8,058
Subtotal - Instruments	***85***	***10,722***	***26,314***	***12,410***	***5,176***	***655***	-	-	-	-	***55,362***
Spacecraft Bus	-	5,441	17,927	21,228	267	112	-	-	-	-	44,976
Science Team	-	-	-	-	-	-	-	-	-	-	-
Ground Data System Development	-	-	-	-	-	-	-	-	-	-	-
Education (1)	-	-	-	-	-	-	-	-	-	-	-
Mission Operations Development Activities	-	-	-	-	-	-	-	-	-	-	-
Integration, Assembly and Test	-	-	-	2,296	9,221	-	-	-	-	-	11,517
Instrument Reserves	-	715	5,961	6,852	2,884	196	-	-	-	-	16,609
Spacecraft Bus Reserves	-	365	956	2,477	1,338	22	-	-	-	-	5,158
IA&T Reserves	-	-	-	-	1,152	-	-	-	-	-	1,152
Other Reserves (2)	-	616	1,650	4,308	5,039	360	-	-	-	-	11,973
Subtotal - Reserves	-	***1,696***	***8,567***	***13,637***	***10,413***	***579***	-	-	-	-	***34,892***
Total Mission Development	**307**	**22,642**	**58,882**	**55,098**	**30,569**	**1,916**	-	-	-	-	**169,414**
Launch and Mission Operations:											
Project Mgmt / Msn Analysis / System Engr	-	-	-	-	-	394	292	249	251	287	1,474
Payload Integration to Launch Vehicle (3)	-	-	-	-	72	2,986	-	-	-	-	3,058
Mission Operations and Data Acquisition	-	-	-	-	-	-	-	-	-	-	-
Data Analysis, Archival & Dissemination	-	-	-	-	-	-	-	-	-	-	-
Launch and Mission Operations Reserves	-	-	-	-	7	579	58	50	50	57	802
Total Launch and Mission Operations	-	-	-	-	**79**	**3,959**	**350**	**299**	**302**	**345**	**5,334**
Launch Vehicle and Services	-	-	-	-	-	-	-	-	-	-	-
Total NASA Cost ($175M Cost Cap)	**307**	**22,642**	**58,882**	**55,098**	**30,648**	**5,875**	**350**	**299**	**302**	**345**	**174,747**
Contributions											
1) National Science Foundation (NSF)											
Science Team	-	1,092	1,636	2,662	3,327	2,816	2,063	1,777	1,567	1,487	18,428
Ground Data System Development	-	1,081	2,965	5,012	6,085	-	-	-	-	-	15,142
Mission Operations Development Activities	-	29	486	1,152	1,373	-	-	-	-	-	3,040
Mission Operations and Data Acquisition	-	-	-	-	97	984	987	1,021	1,057	1,092	5,239
Data Analysis, Archival & Dissemination	-	-	-	-	-	3,638	2,493	2,334	2,462	2,234	13,160
Reserves	-	329	1,049	2,008	4,399	2,133	1,564	1,204	1,174	1,111	14,972
Subtotal - NSF	-	***2,532***	***6,136***	***10,833***	***15,281***	***9,572***	***7,106***	***6,337***	***6,260***	***5,924***	***69,981***
2) U.S. Geological Survey (USGS)	-	-	-	3,936	3,936	3,116	3,116	3,116	3,116	3,116	23,453
3) DLR											
Launch Vehicle	-	-	-	-	10,000	-	-	-	-	-	10,000
Mission Operations	-	-	-	-	-	2,000	2,000	2,000	2,000	2,000	10,000
Subtotal - DLR	-	-	-	-	***10,000***	***2,000***	***2,000***	***2,000***	***2,000***	***2,000***	***20,000***
Total Contributions	-	**2,532**	**6,136**	**14,769**	**29,216**	**14,688**	**12,222**	**11,453**	**11,377**	**11,041**	**113,434**
Total Mission Cost =	**307**	**25,173**	**65,019**	**69,867**	**59,864**	**20,563**	**12,572**	**11,753**	**11,678**	**11,386**	**288,182**
Total Net Reserve % (excluding USGS and DLR costs)											**26.11**
Required Funding with Carry Forward	**307**	**26,148**	**65,206**	**69,697**	**59,333**	**20,195**	**12,569**	**11,752**	**11,680**	**11,292**	**288,182**
DLR/USGS Contributions	-	-	-	*3,936*	*13,936*	*5,116*	*5,116*	*5,116*	*5,116*	*5,116*	*43,453*
NASA/NSF Required Funding	307	26,148	65,206	65,762	45,398	15,079	7,453	6,636	6,564	6,176	244,728
Total NSF Mission Funds Requested	*107*	*8,177*	*19,159*	*14,421*	*2,441*	*2,588*	*3,459*	*6,636*	*6,564*	*6,176*	*69,728*
Total NASA Mission Funds Requested	200	17,971	46,047	51,341	42,957	12,490	3,994	-	-	-	175,000
NASA Launch Allowance for Development	-	-	*13,100*	*14,400*	*16,000*	*6,500*	-	-	-	-	*50,000*
NASA ESE Mission Funds Requested	**200**	**17,971**	**32,947**	**36,941**	**26,957**	**5,990**	**3,994**	-	-	-	**125,000**

(1) Education costs are included in Science Team

(2) Other Reserves include all Management & Engineering reserves and the budget for the SDSC/NPACI on-line archive.

(3) Payload Integration to Launch Vehicle costs included JPL Travel and Astrium Launch Support

ECHO is being proposed jointly to NASA and NSF as the InSAR component of the EarthScope initiative. Every effort was made to separate costs according to whole WBS elements assigned to both agencies, while satisfying the overall cost cap of the ESSP program, without regard to the funding profiles. Such a separation leads to substantial discrepancies with the yearly cost caps specified by the ESSP funding profile. We have added information showing the requested yearly funding levels from both NASA and NSF, which allows ECHO to satisfy the ESSP yearly funding caps (including the launch vehicle allowance). We propose to work closely with both agencies during Phase 2 of the project to generate a mutually agreeable and achievable funding plan that acknowledges the joint nature of the project. The USGS contribution is focused on long-term archiving and curation of the ECHO data, for external users of the EDC DAAC. The $10M launch vehicle provided by DLR is a nominal figure derived from Dnepr literature, and should be compared to the $65M cost of a Delta-2 US launch vehicle, which would otherwise be called for. Combined with the $10M of Mission Operations costs provided by DLR, this results in a total savings of $10M + $65M = $75M to the US participants in the project.

proof of the high cost of radar missions and evidence that recent proposed estimates are unrealistically low. The ECHO team requested that a rigorous independent cost comparison be conducted to better understand the validity of these perceptions. Details are given in the cost volume, Section M. In this comparison, SIR-C actual recorded costs were adjusted for inflation and changes in scope and complexity and compared to ECHO expected instrument costs of $72M including reserves. The range of scaled SIR-C cost for comparison is $53.6M to $80.6M. The mid-range value of $67.1M seems a reasonable metric for comparison. The ECHO instrument cost with reserve is $4.9M (7%) above the mid-range of the scaled SIR-C estimate. An appropriate scaling of cost heritage data therefore seems sufficient to justify ECHO costs.

Ball provided a grassroots estimate of $21.3M for the antenna ($15.3M) and its structure ($6M), which represents the bulk of the mass, and therefore the bulk of the cost in typical parametric estimates. Ball based its estimate on experience developing similar radar antennas for other NASA missions, e.g. SRTM, with an antenna of similar complexity for $11M. Consistency with SRTM actual costs validates the ECHO grassroots costs.

I.4 CONTRIBUTIONS

Contributions from the National Science Foundation (NSF) of $69.9M will cover aspects of mission development as needed to match the NASA funding profile.

The German Aerospace Center (DLR) is offering a substantial contribution to ECHO of approximately $20M to cover the costs of the launch vehicle and launch operations (about $10M), and mission operations (about $10M), including engineering development.

A substantial contribution from the USGS of $23M will cover the costs of permanent archive and data distribution of ECHO data at the EROS Data Center.

Letters of endorsement accompany this proposal (Appendix L.10).

I.4.1 Launch Vehicle Cost

The DLR contribution of a Dnepr launch comes at no cost to NASA. NASA allows a $50M launch credit for use in the development phase when a launch is contributed (see question/answer section of ESSP web page). ECHO applies nearly the entire $50M to development efforts. Note that a comparable US Delta II launch vehicle would cost about $65M. Thus, the launch contribution is mission enabling.

I.5 RESERVES

The ECHO estimate established prudent reserve levels based upon the assessed risk level for each WBS element, vendor recommendations, and heritage considerations. The total net reserve is a substantial 26% of total mission cost minus USGS and DLR contributions, against which reserves can not be directly applied due to the no-exchange-of-funds nature of the contributions.

I.6 RECONCILIATION WITH STEP 1 COSTS

JPL cost estimates that were presented in Step 1 for ECHO were based on a similar, but preliminary, grassroots costing exercise. The NASA Step-1 review considered the proposed costs to be unrealistically low. When the cost of an equivalent Delta-II launch (about $65M) is used in place of the DLR launch contribution, the total ECHO value is $343M, which is in accordance with NASA expectation. At a NASA cost of $175M, ECHO is a highly-leveraged mission of considerable science value. The cost increase from Step-1 to Step-2 is distributed among: 1) higher development and cost margins to reduce risk, 2) increased science demonstration activity, and 3) a lengthened schedule to ensure international coordination of I&T.

I.7 PLANS TO RESOLVE OPEN COST ISSUES

There are two open cost issues:

1. Timing and reconciliation of the NASA and NSF funding profiles, and
2. Payload security requirements at the launch site.

Section M addresses these issues and discusses the planned resolution.

I.8 CONCLUSIONS

Based on the rigorous review of grassroots costs and remarkably good agreement with independent model estimates and analogies, the ECHO team believes the proposed costs to be firm and robust, with substantial reserves to accommodate unforeseen issues.

J. EDUCATION

J.1 RATIONALE

The ECHO satellite radar interferometer will provide a new system for imaging the dynamic Earth—earthquake ruptures, the breathing of volcanoes, and the flow of ice rivers. Placed in a proper context, the ECHO "motion pictures" should excite great public interest and furnish abundant and much-needed new information for educating students at all levels about how Earth science contributes to the understanding of natural processes and the mitigation of risks associated with natural hazards.

The Education and Public Outreach (EPO) aspects of this mission will be a challenge, however, because the InSAR methodology is itself quite complex, and the sometimes violent, sometimes subtle motions the ECHO system will measure involve a combination of space and time scales that reach beyond most of human experience. Public appreciation of the mission and the successful use of InSAR products for educational or professional development purposes will therefore require the results to be presented carefully and in an appropriate context. Thus an aggressive EPO program is needed that will develop a broad yet purposeful set of activities for appropriate regions and audiences, with an emphasis in areas of high risk.

J.2 GOALS

Although the ECHO mission will collect InSAR data for much of the earth, the science mission is focused on studying the movements associated with earthquakes, volcanoes, ice sheets and glaciers to address two ESE research priorities: *Primary Forcings of the Earth System* and *Earth System Responses and Feedback Processes*. Similarly, ECHO EPO will focus on communicating the hazards and risks associated with these features of the dynamic earth, though ECHO EPO will also address another ESE priority: *Consequences of change in the Earth system for human civilization*. The public's natural interest in these consequences provides an opportunity to not only provide information, but to achieve the following goals:

1. Increase awareness and understanding of earthquakes, volcanoes, ice sheets and glaciers;
2. Develop appreciation of the use of InSAR science and technology to improve knowledge of these hazards; and
3. Promote the conscious usage of that knowledge to meet personal and societal need for risk reduction.

In addition to these overall goals, ECHO EPO activities will seek to achieve the following NASA ESE objectives (codes in parentheses will be referenced in the activities summary Table J-1).

(IE) *Informal Education Objectives:* Increase public awareness and understanding of how the Earth functions as a system and NASA's role in the development of that knowledge.

(FE) *Formal Education Objectives:* Enable the use of Earth science information and results in teaching and learning at all levels of education, via the following approaches:

(FE$_{CS}$) Curriculum Support—Develop, utilize, and disseminate science, mathematics, and technology instructional products based on the mission and results.

(FE$_{SC}$) Systemic Change—Enhance the capabilities of the broad educational community through efforts with a range of partners and/or infrastructure changes.

(FE$_{SS}$) Student Support—Provide research experiences and training for students in the sciences, mathematics, engineering, and technology.

(FE$_{TP}$) Teacher/Faculty Preparation and Enhancement—Develop programs, resources, and facilities designed to enhance knowledge and skills.

(PD) *Professional Development Objectives:* Build capacity for productive use of Earth science results, technology, and information in resolving everyday practical problems. For earthquakes and volcanoes especially, this will involve educating scientists, engineers, emergency managers, and government officials about how ECHO InSAR data can be used in hazard analysis and risk reduction.

Within the context of these goals and objectives, ECHO EPO activities will seek to communicate the following "take-home messages:"

- The earth is a dynamic planet

- InSAR is an exciting new technology for earth system education
- ECHO will provide useful information for risk reduction and emergency response
- Science and Technology are relevant both as a *process* and a *product*

Anticipated outcomes of the ECHO EPO program include the widespread use of InSAR products in K–16 science education, effective application of InSAR products related to earthquakes or volcanic eruptions for emergency response or evacuation, and familiarity among the general public with InSAR such that products do not need detailed explanation to be understood. The display of InSAR images for earthquakes, volcanoes and ice flows (by the new media and elsewhere) will be as common as Doppler radar is now for imaging weather phenomena.

J.3 AUDIENCE

A successful EPO program will require the involvement of many members of the ECHO Community and the participation of those who will benefit, as follows:

Informal Education Audiences

- General public: Nationwide, and especially people in areas at high risk due to earthquake and volcano hazards.
- Spanish speakers: By 2010, over 50% of people living in southern California will speak Spanish. Activities developed for this audience and other Spanish-speaking Americans will also have value in Latin American Countries.
- News media: Television, radio, newspaper and Internet reporters and writers nationwide.

Formal Education Audiences

- K–16 students: Educational activities will benefit students nationwide, though some will serve students specifically in areas of high risk due to earthquake and volcano hazards.
- K–16 teachers and faculty: Educational activities for educators will be offered nationwide, with emphasis on providing training and resources for educators in areas of high risk due to earthquake and volcano hazards.

Professional Development Audiences

- Earth scientists: ECHO scientists and the extended community of ECHO data users.
- Research engineers: Nationwide, especially earthquake engineering researchers.
- Practicing engineers and design professionals: EPO will target those in California.
- Risk management professionals: EPO will focus its efforts in areas of high risk due to earthquake and volcano hazards, though others will benefit through printed and web-based information.
- Public officials: EPO will provide information and services to government agencies at all levels with jurisdiction in regions at high risk due to earthquake and volcano hazards.
- Business and Industry: EPO programs for this group will focus in areas at high risk due to earthquake and volcano hazards.

These audiences each have unique learning preferences and needs for information, so activities must be tailored accordingly to be most effective. Basic knowledge of earthquakes, volcanoes, ice sheets and glaciers exists within these audiences, but InSAR and its application will be new to most all groups. While this presents a challenge there will be few if any misconceptions about InSAR that will need to be addressed.

ECHO EPO will conduct activities that benefit people across the country and even internationally (via the internet), but as mentioned will focus efforts to educate people in areas of high risk for earthquakes (California) and volcanoes (Pacific Northwest, Hawaii, Alaska, Long Valley California). Education about ice sheets and glaciers will be national in scope.

The urgent need for earthquake education and public outreach focused in California was underscored in a report released in September 2000 by the Federal Emergency Management Agency (FEMA), which estimated the earthquake loss for the nation at $4.4 billion/year. Nearly three quarters of this national risk is located in California,[1] the product of a dense

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[1] *HAZUS®99 Estimated Annualized Earthquake Losses for the United States*, Federal Emergency Management Agency Report 366, Washington, D.C., September, 2000, 32 pp (http://www.fema.gov/pdf/FEMA366.pdf).

network of active faults (high hazard) and a population of over 30 million people (high exposure). California is the sixth largest economy *in the world* and contains a number of rapidly growing urban centers with extensive infrastructures: major harbors, airports, freeways, lifelines, heavy and light industry, and all building types.

California is also the most sophisticated user community for earthquake information, and as such is the ideal region to establish InSAR as a useful technology for hazard identification and risk reduction. The application of space-based technology for the study of earthquakes in California received national attention at an event in July 2001 to unveil the Southern California Integrated GPS Network (SCIGN), a system of 250 permanent GPS receivers that are used to measure crustal deformation. The interest of the news media and the general public in the use of GPS is a possible precedent for future interest in the ECHO mission.

Volcano-themed ECHO education and public outreach will also be focused in areas of high risk: the Pacific Northwest, Long Valley, Alaska, and Hawaii. While earthquake hazard can be estimated in terms of strain accumulation and recurrence intervals, volcanoes usually show signs of pending eruption, allowing focused EPO activities in surrounding areas. InSAR provides new information about the status of volcanoes, and may have greatest benefit for volcanoes where deformation is currently not monitored well or often (East Maui Volcano, Mt. Rainier, other Cascadian volcanoes). Deformation imaged by ECHO and other signals therefore have the ability to trigger interactions with the public and public officials, to explain what the signals mean. This will include how to understand ECHO InSAR images. Such information will also allow scientists to focus research resources in these areas.

J.4 MANAGEMENT

ECHO EPO goals and objectives for these audiences will be accomplished through an aggressive program of activities (see 10.5) managed primarily by EPO programs within the Southern California Earthquake Center (SCEC) and the Jet Propulsion Laboratory (JPL), both which have considerable expertise in promulgating advanced concepts in Earth science to the public, students, and end-users of research. Managers of the ECHO EPO efforts within each organization will report to the overall mission PI (Minster) and Science Team EPO Focus Group (Minster, Sandwell, Jordan, Rignot, and Thatcher).

The SCEC Communication, Education and Outreach (CEO) program has established visibility as an international resource for both its products and for its expertise in coordinating effective dialogue and cooperative projects among multiple communities. CEO's work with public officials, for example, leads to improved mitigation strategies such as new seismic safety legislation, improved hazard maps, and realistic earthquake scenarios for engineering design and mitigation planning. SCEC Public outreach services and resources have reached millions of people– not just in California but also around the world through information provided via the Internet, national television programs, and printed products. Educational resources developed by SCEC provide educators and students with the latest information about earthquakes as well as fundamental science knowledge and understanding. Further, SCEC is a leader in a series of national partnerships that will connect ECHO EPO to many existing efforts. Relevant examples for this proposal are SCEC's partnerships with the U.S. Geological Survey (three offices of the USGS are SCEC "Core Institutions"), the Incorporated Research Institutions for Seismology (IRIS), Consortia of Universities for Research in Earthquake Engineering (CUREE), Digital Library for Earth Systems Education (DLESE), and SCEC's leadership role in the development of EarthScope and EarthScope's EPO program. SCEC CEO will function as both a producer and a broker for ECHO EPO activities, with the SCEC Associate Director for CEO providing coordination of a team of education, public outreach, and digital product specialists.

The JPL Education & Public Outreach Office (EPOO) is comprised of a dedicated team of specialists in their respective fields, who have joined together to support the NASA initiatives in formal education and general public outreach. The JPL EPO Coordinator for ECHO will work directly with the project and oversee all outreach efforts at JPL. The Earth Science Media Representative, the Earth Science writer and the Theme lead will complete the JPL ECHO EPO team and provide necessary support to the coordinator. This team will report to the project manager and the EPOO manager, and will benefit from being a part of the overall EPOO team structure that encompasses: Pre-College Programs, University/Community Colleges Programs, Minority Education Initiatives, Informal Education and the Office of Space Science (OSS) Solar System Forum. This network provides expert council to the laboratory work themes divided into: Solar System, Technology, Earth, Mars and Universe, who become the crucial bridge between the science and informing the public about the science. EPOO is a part of JPL's Office of Communications & Education, which also includes: Media Relations, Audiovisual Services, Public services and Internal Communication. The integration of the diverse talents and experience of the entire team ensures the successful continuation of JPL's goal to enrich and enlighten the general public.

SCEC and JPL will work with the Earth Science Enterprise Education Implementation Office to coordinate with educational efforts across the Enterprise and to ensure synergy between the development and delivery of learning experiences across all audiences. Similarly, SCEC and JPL will be in collaboration with the EarthScope EPO program so that ECHO EPO products and programs are well integrated within the overall EarthScope EPO effort. To ensure broad application of ECHO products, SCEC CEO will partner with the USGS Earthquake Hazards and Volcano Hazards Offices, and JPL EPOO will collaborate with appropriate glaciology and polar oceanography centers, i.e. National Ice Snow Data Center (NISDC), the Arctic & Antarctic Research Center (AARC), and Global Land Ice Monitoring from Space (GLIMS). The result of all these collaborations is that ECHO EPO will significantly leverage existing projects within established EPO programs. This will also enable most ECHO EPO activities to be sustained beyond 2011 without further NASA investment.

J.5 ACTIVITIES AND DISSEMINATION

This section describes ECHO EPO activities. Several are unique to ECHO EPO, while many significantly leverage existing SCEC, JPL, USGS and other EPO programs by integrating InSAR information into larger activities. Several of the ECHO activities disseminate outputs of other activities. Numbers and codes listed for goals and objectives refer to section 10.3. Most activities will begin in earnest in FY2006, in order to build upon materials, web sites, and partnerships developed in FY2005. Labor and expenses listed for each activity do not include overhead and inflation and are in 2002 dollars. Most of these expenses represent the incremental time and costs involved in developing the ECHO component within existing activities. Activity summary is found on **Table J.1.**

J.5.1 ECHO EPO and Science Conferences

Description: This annual two-day conference will bring together all ECHO scientists and EPO personnel, as well as potential end users, to secure the input of the scientific community concerning the priorities of the targets for the mission. The first conference will also involve additional EPO experts from across the country to address several EPO issues: What is important about ECHO/InSAR to communicate? What specific products are expected? What is the role of ECHO science team members in EPO? Future conferences will provide for coordination between EPO activities and ECHO science results. Invited guests representing the commercial community will also attend these workshops, so that the coordination between scientific and commercial data requests can be properly balanced.

Labor: 2 months preparation and conference management each year.

Expenses: Materials and facility: $7500 each year. Meals: $15000 each year. Travel: $15000 for 20 external EPO people FY05 only.

J.5.2 Mission Outreach Materials

Description: Mission-oriented outreach materials will promote awareness and appreciation of the benefits of InSAR technology and its use in the ECHO mission. These materials will supplement topic-specific EPO activities that will focus on the application of InSAR products. As is standard for NASA missions, brochures, fact sheets, folders, posters, and scale models will be produced. See the budget justification for quantities that will be produced.

Labor: JPL ECHO EPO Coordinator as needed FY06-11. Also $20,000 for design and editing of initial materials FY06.

Expenses: $40,000 for production of initial materials FY06, $8000 a year for reproduction and press kits FY07-11.

J.5.3 Main ECHO Mission Web Pages

Description: The main web page for the ECHO mission will provide information about the S/C, the launch schedule, an animated overview of radar interferometry (see 10.5.4), and connections with other NASA missions. Media resources (press releases, other materials) will be provided as they are developed. These pages will be hosted by JPL. Links to topic-specific EPO pages will be featured: InSAR products and education related to earthquakes will be hosted on SCEC's web services, InSAR information for volcanoes will be provided by the USGS Volcano Hazards Office web sites, and ice sheet and glacier InSAR information will be offered on the web pages of relevant organizations.

Labor: Oversight by JPL ECHO EPO Coordinator as needed FY05-11. Design and construction by JPL EPOO web team (as part of budget described in 10.5.4). Maintenance fee $4000 a year.

Expenses: $0

J.5.4 Web-based Animated Educational Tool

Description: This educational tool will visually explain radar interferometry and how it is used in the ECHO mission. There will be general information on how the interpretation of the mission data will be useful for various audiences. This is also a media friendly vehicle that can used to generate further interest on the scientific topics and for media coverage on the mission. The animations will also be featured in many other ECHO EPO activities, such as the main mission web pages, SCEC's Electronic Encyclopedia of Earthquakes, displays at museums, and teacher trainings (see these activities below for more description).

Labor: Oversight by JPL ECHO EPO Coordinator as needed FY05-06. JPL EPOO Web team: $35,000 FY05 (Design/ Architecture/ Interface: $10,000; Programming: $6,000; Production: $13,000; Management: $3,500 + 1 yr maintenance).

Expenses: $0

J.5.5 Media Relations

Description: The Media Relations office at JPL is separated into three groups: Media representation, TV/Imaging and the Internet. The dedicated media representative for Earth Science will work with his team members to ensure that "newsworthy" information and data will reach the general public via multi-media vehicles. The representative will write press releases and create press kits, work with the imaging/video group to create video, respond to outside news media requests, coordinate with SCEC to offer periodic science writer and reporter seminars about the ECHO mission, and maintain communication with JPL's Public Service office and NASA headquarters. By locating media operations at JPL, ECHO results can be combined with announcements from other NASA missions that study ice sheets and glaciers, volcanoes, and earthquakes.

Labor: Oversight by JPL ECHO EPO Coordinator as needed FY06-11. Science writer: 1 2/3 months FY06, 1-2 months/yr FY06-11.

Expenses: $0

J.5.6 Collaborate with Ice Sheet and Glacier Organizations

Description: There is currently little if any EPO projects in Glaciology and Polar Oceanography. This can be a unique opportunity for ECHO EPO to provide data/support to existing organizations (NISDC, AARC and GLIMS) and contribute to the development of Outreach programs. The lead will take the initiative to develop educational opportunities: (K-5) Meet a Glaciologist program; (9-12) The role of ice/ snow in General Earth Science program; and (13-16) Uses of Radar interferometry in Glaciology & Polar Oceanography. Collaboration with groups such as GLIMS will provide another image resource (via EOS instrument ASTER) to museums such as the Arctic Studies Center that want to expand and update their image library. JPL EPOO will also provide support to informal education programs such as the Arctic Studies Center, a permanent program at the National Museum of Natural History of the Smithsonian Institute, where glacial data images may be an additional educational resource. Furthermore, ECHO scientists can participate in promoting ice/snow studies in educational conferences and at local schools as guest speakers.

Labor: JPL ECHO EPO Coordinator as needed FY06-11.

Expenses: Materials & travel $3000 a year FY06-11.

J.5.7 Collaborate with USGS Volcano Hazards Office EPO Programs

Description: The Outreach activities of the USGS Volcano Hazards Program promote the value of earth science information to mitigate potential consequences of natural hazards and increase public understanding of the results of new and ongoing scientific studies. The program works to extend USGS products and services to many audiences, especially those that are likely to be affected by volcanic activity and unrest, through partnerships and specific tactics, including brochures, fact sheets, video programs, several Web sites, volcano-hazard workshops and emergency exercises, field trips, news media, educator training, exhibits and posters, and public presentations. ECHO EPO will supplement these activities with InSAR information such as deformation images for USGS printed and web materials, information developed for earth science digital libraries (10.5.9), the web-based InSAR educational tool (10.5.4), and a fact sheet describing the use of InSAR for volcano research

Labor: 1-2 months each year FY06-11.

Expenses: $2000 per year for printing and travel FY06-11. $5000 in FY07 and 08 for special fact sheet printing.

J.5.8 SCEC Webservice / InstaNET News

Description: SCEC's webservice (www.scec.org) presents the research of SCEC scientists, provides links to SCEC institutions, research facilities, and databases, and serves as a resource for earthquake information and educational products. For ECHO EPO, a section will be added that presents the aspects of the ECHO mission related to earthquakes for the all audience levels, with links to the main ECHO web pages and partner pages for volcano and ice InSAR products. In addition, the ECHO mission and results will be featured as part of the SCEC InstaNET News, a service that disseminates news, announcements, earthquake information, and in-depth coverage of earthquake research via the Internet. New articles are announced via e-mailed news "bytes" to subscribers of the free service. SCEC InstaNET will feature ECHO Updates quarterly beginning two years before launch, and then up to monthly as results are made available from the science team (based on news releases produced by the JPL EPOO team).

Labor: 1 month web page construction FY05, 1/2-1 month/year maintenance and updating FY06-11.

Expenses: $0

J.5.9 Digital Libraries

Description: Content will be developed for inclusion within the NSF-funded Digital Library for Earth System Education (DLESE), based on all ECHO results. DLESE is also part of the National Science, Mathematics, Engineering and Technology Education Digital Library (NSDL). The ECHO web-based InSAR animation (10.5.4) and other products and resources will be submitted for inclusion in the DLESE collection, with SCEC developing content based on volcano and ice sheet/glacier results with partners in those fields.

The primary effort, however, will be the inclusion of ECHO products and results within the *Electronic Encyclopedia of Earthquakes (E3),* a DLESE collaborative project between SCEC, the Consortium of Universities for Research in Earthquake Engineering (CUREE), and the Incorporated Research Institutions for Seismology (IRIS) that will synthesize a large and varied amount of earthquake data and information and provide broad access via the Internet as a collaborating partner with DLESE. *E3* will feature Earth science and engineering topics but also provide curricula useful for physics and mathematics education. The collection will support K-16 education by providing educators and students with the tools and resources for instruction and research. Like a traditional printed encyclopedia, *E3* is an entry-based collection, comprising several hundred primary topics with cross-references. *E3* provides much more than this, however: each topic has multiple levels of explanation (a simple glossary definition, a synopsis of content, and content in depth) and many links to annotated curricular resources including archived and real-time databases. SCEC will develop a set of **E3** entries related to the ECHO mission: an overview of InSAR and its application to study the dynamic earth, the JPL-developed InSAR animation, more technical information for advanced learners, an entry about the ECHO mission with ongoing updates both before and after launch, and inclusion of InSAR results in other entries. These entries will provide a resource for other EPO activities such as media relations, teacher trainings, material for science museums, and professional development.

Labor: 1-2 months/yr development FY05-06, 1/2 month/yr maintenance FY07-11.

Expenses: $0

J.5.10 Updated version of "Putting Down Roots in Earthquake Country"

Description: To answer the growing concern regarding the implications of earthquakes in southern California, in 1995 the U.S. Geological Survey and SCEC produced two million copies of this extremely popular 32-page color publication. Its message is consistent and encouraging: earthquakes are inevitable, but they are understandable, and damage and serious injury are preventable. The document was a vehicle for communicating cutting-edge research results (as of 1995) and can now be updated to include new technologies such as the use of InSAR for improving earthquake understanding, risk reduction and emergency response.

Labor: 2 months FY05. (InSAR portion development)

Expenses: $0 (printing costs will be sponsored)

J.5.11 ShakeZone Exhibit

Description: SCEC has established a partnership with the Riverside County Children's Museum and the CUREE-Caltech Woodframe Project to create an educational, family-oriented exhibit on earthquakes in their region. "ShakeZone," to be completed in fall 2001, will occupy fully half the space at "KidZone." The mission of the exhibit is to reach the local community, particularly elementary and secondary school children, with positive messages about studying the Earth and preparing for earthquakes. The exhibit will present information about science, engineering, safety and mitigation. A shake table, an interactive computer display, and wall displays will teach the visitors about the tools and techniques of earth scientists, engineers and emergency services personnel. All components of the exhibit can be replicated in other museums with science education programs.

Labor: 2 months development and production FY06. 1/2 month/yr maintenance and updating FY 07-11.

Expenses: $5000 new materials FY06, $1000 materials/yr for updated information FY07-11.

J.5.12 The George Brown Center for Innovation

Description: This science and technology center will open in 2002 and offer interactive exhibits and activities to the Inland Empire region of southern California (pop. 3.2 million) with a goal to enhance the public understanding of how science and technology impact and benefit society. The Center will feature exhibits and programs about biomedical research, the space program, agricultural research, and earth science. In addition to year-round programs for students (64% in the region are minorities), special seminars and conferences for the public with national experts will discuss science and technology issues and how science and technology benefits society. Teachers will participate in programs that focus on new innovative methods and techniques to teach science and technology. Finally, the Brown Center will encourage displays from other organizations interested in serving youth and the public. The unique combination of space program and earth science exhibits makes the Brown Center an ideal location to educate students, the public, and risk reduction professionals about the ECHO mission and its scientific results (especially relating to earthquakes).

Labor: 2 months development and production FY06. 1 month/yr maintenance and updating FY07-11.

Expenses: $5000 displays and materials FY06. $2000/yr for updating FY07-08, $1000/yr for maintenance FY09-11.

J.5.13 "The Real Meaning of Seismic Risk" Symposia

Description: The objective of this symposia series is to increase public awareness and understanding of urban seismic risk and related social and public policy issues, and is produced by SCEC in partnership with the Los Angeles City Emergency Preparedness Commission. Over 275 participants to date have attended symposiums that featured presentations on earthquake awareness, preparedness and mitigation for K-12 teachers and school administrators. Future symposia (four per year) will address other audiences such as business and industry, public safety officials, and the news media, and will provide a venue for describing the ECHO mission.

Labor: 2 months development FY06. 1 month/yr preparation and production of symposia FY07-11

Expenses: $2000 for new materials FY06, $1000 for additional copies and other materials FY07-11.

J.5.14 USGS/SCEC/IRIS Earthquake Education Workshop for Teachers

Description: A 1-day course on earthquake education conducted by USGS and SCEC, funded by IRIS. Four workshops will be held each year at facilities such as Shakezone (10.5.11), the Brown Center for Innovation (10.5.12) and at national education conferences such as the National Science Teachers Association. Information about InSAR and the ECHO mission will be included in the workshop series beginning in FY06.

Labor: 1 month development FY06, 1/2 month/yr for production of workshops (InSAR portion).

Expenses: $1000 for new materials FY06. $500 for materials FY07-11.

J.5.15 Spanish-Language Products and Programs

Description: Identify Spanish-speaking scientists within each topic area and identify methods that are most (cost) effective in reaching the speaking-speaking population. Develop Spanish-language versions of EPO activities, including an online version of Putting Down Roots in Earthquake Country (10.5.10) and displays at science museums. Identify existing Spanish community resources (people, products, news media), and develop resources for future Spanish activities. Partner with IRIS to disseminate Spanish language products and activities in Latin America, including Professional Development activities.

Labor: 1/2-1 month/yr FY05-11.

Expenses: $5000 for materials FY06, $2500/yr for additional materials FY07-11.

J.5.16 Attract Students to Earth-Science Degree Programs

Description: ECHO materials will be very useful in promoting interest in Earth science. This activity will create a guide for students/advisors to promote earth science departments at participating ECHO academic institutions; facilitate visits by ECHO scientists to high schools/ community colleges/universities to discuss careers in earth science (especially schools with large minority student populations); and participate in high school student mentor programs such as *EarthLaunch.*

Labor: 1 month for development of materials and recruitment in FY07, 1/2 month/yr for recruitment activities FY08-11 (part of larger SCEC effort).

Expenses: $2000 FY07, $1000/yr FY08-11 for promotional materials and other expenses.

J.5.17 Summer Undergraduate Research Experiences

Description: To provide hands-on experiences in the earth sciences or science outreach, provide insights into career opportunities, and interest underrepresented undergraduate students in Earth science-related careers, SCEC has sponsored 72 students (including 39 women and 16 minority students) to work alongside 50 SCEC scientists over the past 7 years. This program will be expanded to include internships for 3 students to work specifically with ECHO scientists on any ECHO project (not just earthquake studies). SCEC may support other students to work with ECHO scientists as well as part of its existing summer program. To begin the summer, the interns attend a Communication Workshop on writing and presentation skills. Mid-summer students participate in a field trip to geologic features and research locations throughout southern California, and update each other about their research projects. Finally, students present posters describing their research results at the SCEC annual meeting. During the academic year, students will be invited to SCEC workshops and other events. Students working on volcano or ice sheet/glacier studies will be supported to attend meetings in those fields.

Labor: 1 month/yr program management (ECHO component) FY07-11.

Expenses: $6000 stipend per student plus $1000 each for travel (field trip, meetings) FY07-11.

J.5.18 Include ECHO Products in General-Education Earth Science Courses

Description: A coalition of SCEC and other scientists who teach introductory earth science courses will develop a consensus-based general-education level earth science course which could result in a nationally distributed textbook and accompanying teaching materials (PowerPoint slides, exercises, demonstration materials, etc.). In addition to earth science, the will also include public policy issues related to earthquakes, volcanoes, etc. A lecture and chapter of the textbook will focus on the science of InSAR and the products of the ECHO mission.

Labor: 1 month/yr for development FY05-06 (ECHO component), 1/2 month/yr for distributing updated information FY07-11.

Expenses: $2000/yr for materials production (ECHO component) FY05-06, $1000/yr for printing and mailing of updated materials FY07-11.

J.5.19 California Post Earthquake Technical Clearinghouse

Description: SCEC provides existing connection with the Post Earthquake Technical Clearinghouse, coordinated by EERI, CDMG, OES and others, which will collect perishable post-earthquake data and facilitate dissemination of understandable information to the public sector via the media. The participants of this group will benefit from the application of near-real time InSAR data following earthquakes. The Clearinghouse will also serve as a venue for communicating InSAR results to the media and the general public.

Labor: 1 week/yr, as necessary

Expenses: $1000.yr for printed materials FY07-11.

J.5.20 Provide Programs and Products for Practicing Professionals and Interface with Engineering Researchers

Description: SCEC CEO’s workshops and short courses that present results that are relevant and immediately useful to attendees will be expanded to include presentation of ECHO results. SCEC CEO will include InSAR information as part of its “Implementation Interface” to facilitate the identification of research products that are useful to engineers.

Labor: 1 month/yr FY06-08, 1/2 month/yr FY09-11.

Expenses: $0 (covered by registration fees)

J.5.21 Activities for Risk Managers and Decision Makers

Description: Workshops, publications, and web pages specifically for risk managers and decision makers will be expanded to include ECHO information. In addition, SCEC CEO is coordinating the development and activities of the Southern California HAZUS Users Group (SoCalHUG) with FEMA, USGS, and OES. HAZUS is FEMA’s earthquake, flood and wind loss estimation software. This Users Group is an excellent audience for ECHO EPO information as they promote improved mitigation and response activities.

Labor: 1 month/yr FY06-08, 1/2 month/yr FY09-11.

Expenses: $0 (sponsored by state and local government agencies)

J.6 EVALUATION

As many of the activities in this proposal are existing projects of SCEC, USGS, and other organizations, much or the impact evaluation will be conducted as part of larger program evaluations. However, SCEC CEO and JPL EPOO will implement the following pre-assessment activities with a focus on the ECHO EPO activities during FY05.

1. Clarify priorities, goals and objectives of key stakeholders: develop logic models (flow chart from resources to outputs to outcomes).
2. Identify barriers to evaluation: existing resources and products; internal and external factors that limit implementation; likelihood that program goals and objectives will be achieved.
3. Get agreement on evaluation priorities and explore evaluation options: prioritize ECHO activities that need assessment; identify feasible performance measures/ metrics (web page visits, students and teachers reached, occurrences of ECHO results in the news, etc.); identify outcomes to evaluate as indications of the achievement of goals and objectives; consider how data would be collected and analyzed; identify how the results would be communicated and used; and develop time lines.
4. Select individuals to conduct pre- and post-release assessments (include assessment experts at ECHO institutions).

This evaluation strategy will begin in FY05 for pre-evaluation, with full implementation by FY06 when most activities will have either completed initial products or will be beginning development. At the end of each year, a summary report will be written of progress towards particular objectives and goals as indicated by performance measures.

Table J-1: ECHO Education Activities Summary

	Activity	Goals	Objectives	Timeframe	Management	Topics
1	ECHO EPO Science & Conferences	1,2,3	IE, FE(all), PD	FY 2005-11	SCEC CEO	Earthquakes, Volcanoes glaciers
2	Mission Outreach Materials	2	IE, FE_{CS}, PD, FE_{TP}	FY 2006-11	JPL EPOO	Earthquakes, Volcanoes glaciers
3	Main ECHO Mission Web Page	1,2,3	IE, FE(all), PD	FY 2005-11	JPL EPOO	Earthquakes, Volcanoes glaciers
4	Web-based animated Educational Tool	2	IE, FE_{CS}, PD, FE_{TP}	FY 2005	JPL EPOO	Earthquakes, Volcanoes glaciers
5	Media Relations	1,2,3	IE	FY2005-11	JPL EPOO	Earthquakes, Volcanoes glaciers
6	Collaborate with Ice/glacier Organizations	1,2,3	IE,FE(all), PD	FY 2005-11	JPL EPOO	Ice/Glacier
7	Collaborate with USGS Volcano Hazards Office EPO Programs	1,2,3	IE,FE(all), PD	FY 2006-11	SCEC CEO	Volcanoes
8	SCEC Webservice/ InstaNET News	1,2,3	IE,FE(all), PD	FY 2005-11	SCEC CEO	Earthquakes
9	Digital Libraries	1,2,3	FE(all), IE, PD	FY 2005-11	SCEC CEO	Earthquakes, Volcanoes glaciers
10	Updated vers. of *Putting Down Roots in* Earthquake Country	1,2,3	IE, FE_{CS}, PD, FE_{TP}	FY 2005	SCEC CEO	Earthquakes
11	ShakeZone Exhibit	1,2,3	IE, FE_{CS}, FE_{TP},FE_{SC}	FY 2006-11	SCEC CEO	Earthquakes
12	The George Brown Center for Innovation	1,2,3	IE, FE_{CS}, FE_{TP},FE_{SC}	FY 2005-11	SCEC CEO	Earthquakes, Volcanoes glaciers
13	The Real Meaning of Seismic Risk Symposia	1,2,3	IE, PD, FE_{TP}	FY 2006-11	SCEC CEO	Earthquakes
14	USGS/SCEC/IRIS Earthquake Education Workshop for Teachers	1,2,3	FE_{CS}, FE_{TP},FE_{SC}	FY 2006-11	SCEC CEO	Earthquakes
15	Spanish-Language Products & Programs	1,2,3	IE, FE_{CS}, PD, FE_{TP}	FY 2005-11	SCEC CEO	Earthquakes
16	Attract Students to Earth Science Degree Program	1,2	FE_{SS}	FY 2007-11	SCEC CEO	Earthquakes
17	Summer Undergraduate Research Experiences	1,2	FE_{SS}	FY 2007-11	SCEC CEO	Earthquakes, Volcanoes glaciers
18	Include ECHO Products in General Education Earth Science courses	1,2	IE, FE_{CS}, FE_{TP}	FY 2005-11	SCEC CEO	Earthquakes, Volcanoes glaciers
19	California Post Earthquake Technical Clearinghouse	1,2,3	PD,ID	FY 2005-11	SCEC CEO	Earthquakes
20	Professional Development	1,2,3	PD	FY 2006-11	SCEC CEO	Earthquakes
21	Activities for risk managers/ decision makers	1,2,3	PD, IE	FY 2006-11	SCEC CEO	Earthquakes volcanoes

K. OTHER OPPORTUNITIES

K.1 Small, Small Disadvantaged, Small Veteran-Owned, Small Women-Owned Businesses, and Minority Institutions

K.1.1 Goals

The ECHO project will use its best efforts to assist NASA in achieving its goals for the participation of small businesses (SBs), small disadvantaged businesses (SDBs), small women-owned businesses (SWOBs), small veteran-owned businesses (MVOBs), and historically black colleges and universities (HBCUs).

The ECHO Project goal for SBs, SDBs and SWOBs is at least 15% of total contract value.

K.1.2 Past Achievements

JPL strongly supports NASA's socioeconomic development programs, and makes an aggressive effort to assist the agency in meeting it's goals for participation of SBs, SDBs, SVOBs, SWOBs, and HBCUs. JPL has a committed SDB program, administered by the JPL Business Opportunities Office, that pursues involvement with these types of businesses and institutions.

JPL has an excellent record of performance. Over the past 5 years, JPL has exceeded the SB/SDB/SVOB/SWOB goals set by its NASA contract. JPL's recent record is shown in Table K-1.

In addition, JPL has been widely recognized for its leadership in the area of SDB participation. The long list of awards includes the Dwight D. Eisenhower Award for Excellence (R&D) in 1996. This is the Small Business Association's highest and most prestigious award, developed to recognize large prime contractors that have excelled in their use of small businesses as subcontractors. Other awards included the NASA Center Small and Small Disadvantaged Business Achievement Award (1996-2000), the CEO of the Year for JPL's Deputy Director Larry Dumas from the National Association of Small Disadvantaged Businesses (1997-1998), and the NASA New England Outreach Center Commitment to Excellence Award (2001).

Ball Aerospace is also committed to meeting or exceeding NASA's small business goals. Its Small Business Program (SBP) subcontracting efforts will be focused on maximizing opportunities to small business concerns and providing high-technology work content to the ECHO program.

Ball will aggressively solicit the participation of small business concerns by including them in our competitive subcontractor solicitation process. To facilitate this process, Ball has a database of over 1000 qualified small business suppliers to draw from, and hold high-tech small business supplier fairs to present new high-tech small businesses and their capabilities to Ball engineering groups. Ball will also continue to solicit small business concerns to meet the material needs of the ECHO program. We will continue to focus our efforts on pursuing small businesses on the ECHO program, as well as flowing that commitment down to our subcontractors.

Ball's Small Business Program received an "outstanding" rating in 2001 and has received an outstanding rating three of the past 4 years. Ball's support to NASA programs is evidenced in their 5-year averages including; 51% to small businesses; 2% to small disadvantaged busi-

Table K-1: JPL's 5-Year Record of SB/SDB/DVOB/SWOB Goal Performance

Year	Total Business	Small Business	Small Disadvantaged Business	Women-Owned Business	Socio-Economic Business*
1997	$595.1M	$213.5M (35.9%)	$86.4M (14.5%)	$36.8M (6.2%)	$119.7M (20.1%)
1998	$638.9M	$214.IM (33.5%)	$87.7M (13.7%)	$28.2M (4.4%)	$112.1 (17.6%)
1999	$673.3M	$231.7M (34.4%)	$118M (17.5%)	$25.2M (3.7%)	$161.3M (24%)
2000	$613.9M	$209.2M (34.1%)	$104.7M (17.1%)	$25.5M (4.1%)	$116.7M (19%)
2001	$732.zc5M	$257.7M (35.2%)	$136.4M (18.6%)	$36.5M (5.0%)	$153.8M (21.0%)

** Socioeconomic Business includes SDB, WOB, HBCU/MI and subcontract flow down.*

nesses, 5% to women-owned businesses and 1% to veteran-owned businesses.

K.1.3 ECHO Small Business Involvement

Vexcel Corporation is providing the ECHO Ground Data System. According to Title 13—Code of Federal Regulations (CFR)—Section 121.201, Vexcel is considered a small business (NAIC 541330). The estimated Vexcel contract value is $22.2M (before JPL procurement burden); about 13% of the ECHO Total Cost to NASA.

AEC Able, a small business specializing in deployment structures and mechanisms, is the planned subcontractor for the Radar Antenna Deployment Structure. AEC Able has been tentatively selected as a sole-source contractor, due to their perfect performance record and extensive experience with Ball and JPL on previous projects. Ball will manage the contract with AEC Able, which has a ROM cost of $6M. The final contract terms will be negotiated at the start of Phase 2.

K.1.4 Historically Black College Collaboration

The ECHO project is partnering with Howard University in Washington, DC, an Historically Black College. Howard University's department of Computer Science and Architecture will host one of the five data distribution and archive centers. Within the next year, Howard University will be connected to the Internet-2 backbone on the east coast, enabling efficient mirroring of ECHO data for the southeastern United States. The University will benefit from using the distribution center as a statistical resource for high-speed data transfer hubs. Students can use the ECHO hub as a test case for queuing theory and packet optimization projects; the University intends to assign a professor to interact with the ECHO project and advise students in this area. In addition, students at the University interested in Earth Sciences will be given an opportunity to work with Project scientists, software tools, and EPO products to generate new products and contribute to the ECHO peer-to-peer data generation process described in the technical section. Howard University does not have an Earth Sciences department, so ECHO involvement is a cost-effective way for the University to reach interested students who might otherwise find alternative disciplines to study, and a way for the project to energize a segment of students who do not typically enter into the sciences.

K.2 COMMERCIAL OPPORTUNITIES

Development of a commercial adjunct promises to provide significant benefit to the ECHO project. The ECHO team includes partners with considerable experience in data commercialization, particularly with regard to SAR applications. Ball was a founder of EarthWatch (now DigitalGlobe), a major participant in the NASA LightSAR study, and holds a NOAA License to operate a commercial SAR system. In addition to leading the LightSAR study with Ball, Vexcel Corporation has world-renowned experience in SAR processing, value-added SAR data products, and analysis of SAR data markets.

The proposed NASA-DLR ECHO partnership and ECHO project connection with Astrium GmbH opens up new and exciting commercial potentials for ECHO data. Astrium has contributed its own funds to the development of TerraSAR-X, an X-band SAR mission mostly supported by DLR to build commercial markets for these data. Astrium will be the principal commercial partner for TerraSAR-X, and part of the German interest in ECHO is the possibility of commercializing combined X-band and L-band products. Such commercialization would not compromise the open distribution and access to the L-band science data.

Once the NASA-DLR MOU is finalized, the ECHO partners, together with the appropriate government agencies, will develop a specific commercialization plan and work with the entire ECHO team to establish the data policy and framework for commercial applications. This ITAR-compliant plan will ensure that ECHO science is not compromised and that any resulting commercial applications provide direct benefit to NASA DLR, and ECHO science.

K.2.1 Commercial and Public Use of NASA Earth Science Products

NASA is partnering with industry to commercialize a wide range of applications that have evolved from NASA-funded research.

Led by the Applications Division (Code YO) of NASA's Office of Earth Science, NASA is working with multiple partners from the private and public sectors and academic institutions to apply NASA remote sensing instrument data to practical socio-economic issues and problems.

The NASA Earth Science Applications Program is focused on four theme areas of public concern. These areas provide a general framework through which ESSP missions such as ECHO can contribute to the commercial users:

- Environmental Assessment: both air and water resources, and the effect of natural and human-induced changes—such as the physical and economic impact of sea level.
- Natural Resource Management*:* nonrenewable and renewable (e.g., croplands, grazing lands, forests, and water resources).
- Community Growth and Infrastructure: land use, transportation, infrastructure, cultural and recreational resources—*Also, the impact of sea-level rise on coastal communities and the resiliency of communities to seismic hazard.*
- Disaster Management: natural disasters, such as volcanic eruptions, earthquakes, severe weather and floods, as well as ecological issues related to the health of human, plant and animal communities—*Also, earthquake risk assessment, mitigation, and response based on better understanding of strain accumulation and release.*

K.2.2 Relevance of ECHO ESSP Mission to Commercial Applications

The largest commercial opportunity to which ECHO can add value and help encourage is the risk-management industry—an integration of scientific, engineering, financial, and economic players that is continually seeking innovative technologies to manage risk and reduce losses. These efforts rely increasingly on new data, modeling and scientific understanding across broad spatial and temporal dimensions, whcih will be provided by ECHO.

Disaster losses in the U.S. are currently estimated conservatively at $50 billion annually. This figure does not include indirect losses such as short- and long-term economic and social impacts that many experts believe could more than double such a figure. Of the estimated $500 billion in disaster losses between 1975 and 1994, 80% were imposed by meteorological events and 10% were the result of earthquakes and volcanoes. Only about 17% ($85 billion) of the estimated losses were insured. Since 1989 the federal government, in presidentially declared disasters, has paid approximately $20 billion in losses. While losses from major catastrophic events are rising, the majority of hazards-related damages result from smaller events that do not qualify for federal assistance and which are not insured, leaving victims primarily responsible for the costs.

In the field of disaster management, there is a growing worldwide trend to shift disaster management, including those issues that affect environment and human health issues from reactive operations, which focus on response and recovery operations, to more proactive activities, which focus on mitigation and preparedness. Therefore, it is critical that a systems approach to understanding natural hazards in the context of long-term environmental trends be developed. This will require among other things the integration of better science, technology, and remote sensing data while upgrading (or developing) of new tools to specifically assess hazard risk and vulnerability (integrating socioeconomic factors into the analysis).

GIS-based loss estimation methodology is maturing rapidly, and it will accelerate the use of remote sensing imagery, provided information is extracted rapidly and effectively to support risk-management decisions. Remote-sensing GIS products and databases for risk assessment and loss estimation enable global business growth through more accurate portfolio management, targeted to corporate and public-sector clients seeking to reduce costs and expand market share. The convergence and witnessed recent growth of insurance with financial markets also is driving demand for improved catastrophe (cat) risk-management tools. The market for cat risk-management products and services is anticipated to grow if product and services improvements are validated, quantifiable, and accepted by (larger) clients. For example, improved data collection and computer modeling of the effects of catastrophic disasters on (re)insurance have dramatically increased understanding of individual exposures and those of the industry as a whole. Better understanding of risk allows tapping alternative sources of capital, including institutional investors and financial markets not related to the insurance industry.

The disaster-management applications Code YO theme specifically addresses the use of NASA basic and applied Earth science, data, and technology in the decision-making process. NASA is working with customers and stakeholders to understand information needs and is building partnerships among the science community, disaster managers and practitioners, government agencies, and commercial data and service providers. Example partnerships include those with FEMA, USGS, Pacific Disaster Center, the U.S. Army Corps of Engineers (USCOE), the Association of American State Geologists and the ECHO Team (as a future possibility). The focus is to balance remote-sensing technologies, Earth science, and modeling capabilities with the practical needs of those impacted by hazards—either as a direct outcome (property, casualty, or economic) or needing improved decision-making for risk management.

Consider, for instance, the subject of sea-level change. A fundamental question from NASA's ESE Research Strategy asks, 'How is global sea level affected by climate change? ECHO plans to address this question with its study of ice sheets and glaciers. Commercial relevance and economic impact of sea-level rise is presented in: *Sea…Sea-Level Rise & Global Climate Change: A Review of Impacts to U.S. Coasts*, prepared by the Pew Center on Global Climate Change (February 2000). The rapid growth of coastal areas in the last few decades has resulted in larger populations and more valuable coastal property being at risk from sea-level rise. This growth, which is expected to continue, brings with it a greater likelihood of increased property damage in coastal areas. Each week, about 8,700 new single-family homes are constructed along the U.S. coast (NOAA, 1999).

In the U.S., the dimensions of the coastal zone potentially at risk from sea-level rise are enormous. There are roughly 20,000 km of coastline and more the 32,000 km^2 of coastal wetlands (EPA, 1989). The land area of coastal counties comprises about 25% of the total land area of the U.S., while accounting for 53% of the U.S. population in 1997. Projections of growth of the coastal population suggest that by 2010 the coastal population will have grown 60% from 1960 levels. Recreational beach visits account for almost 200 million visitor days per year with an estimated annual value of over $3 billion. Based on review of the existing literature, estimates of the cumulative impacts of a 50-cm seal-level rise by 2100 on coastal property range from about $20 billion to about $150 billion.

K.3 ECHO TECHNOLOGY TRANSFER AND COMMERCIALIZATION PLANNING

ECHO project formulation and implementation activities will be conducted in compliance with NPG 7120.5B, *"NASA Program and Project Management Processes and Requirements."* The ECHO *Technology Transfer and Commercialization Plan* shall provide the framework for meeting the requirements set forth in NPG 7120.5B, "Develop Technology and Commercialization Program Plans." The Plan shall be developed with assistance from the JPL Commercial Technology Program. This Program, funded by the NASA Commercial Technology Program (Code RW), helps fulfill NASA's goal of enhancing U.S. economic competitiveness while encouraging state and local government, and the private sector to use space technologies, data, and attendant capabilities.

JPL has a heritage of working with industry, from joint technology development to transfer and commercialization, working on over 485 cost-reimbursable tasks with 160 plus commercial firms. Regularly since 1997, well over 200 new technologies were reported annually to NASA by JPL. Since 1998, Caltech has issued hundreds of royalty bearing, non-royalty-bearing, and web-based software and hardware licenses. On an annual basis, Caltech files close to 100 patents, including provisional patents, on JPL technologies and converts about 10%.

This approach will begin with an assessment of the unique characteristics of the ESSP-utilized technologies and derivative and/or supportive capabilities, the identification of potential applications and industries, due diligence market research, and finally, the generation and execution of a technology transfer and commercialization plan. The plan incorporates elements of intellectual property management and licensing that encourage private sector investment in related research, development, applications, test marketing, and commercialization:

- Identifying and/or enhancing new commercial applications of project elements within and outside of the aerospace sector;
- Identifying commercial partners for product and market concepts;
- Securing Memoranda of Agreement and/or cost reimbursable task plan agreements, partnerships or alliances leading to further collaborative R&D and technology applications and commercial opportunities;.

JPL will utilize the resources and expertise of NASA's network of National and Regional Technology Transfer Centers (RTTCs) funded by NASA Code RW.

As part of its strategic intellectual property management, the ECHO PI and PM will encourage the disclosure of new capabilities. ECHO will work with the Caltech Office of Technology Transfer towards the patenting of technologies or models and algorithms, and copyrighting software that hold the greatest commercial promise for licensing. The Bayh-Dole Act (1980) and subsequent amendments provide the basis for technology transfer practices. New technology reports, licenses, and partnerships are recognized metrics for demonstrating the advancement of earth science capabilities and of the value provided to industry through NASA activities in support of commercial opportunities.

K.4 PLANS TO RESOLVE OPEN OTHER OPPORTUNITY ISSUES

There are currently no open issues regarding other opportunities.

L.1 RESUMES

Michael A. Gross
Thomas L. Henyey
Thomas H. Jordan
Ian R. Joughin
Kim Leschly
Jean-Bernard H. Minster
Gilles Peltzer
Eric J. Rignot
Paul Alan Rosen
David T. Sandwell
Paul Segall
Mark Simons
Wayne Thatcher
Howard A. Zebker
Maria T. Zuber

MICHAEL A. GROSS

Phone: (818)393-3342

PROFESSIONAL EXPERIENCE

Senior Member of Technical Staff

GRACE Mission Assurance Manager (Acting), 2/2001 to present. Responsible for Managing all aspects of the mission assurance team including Reliability, Parts Engineering, Environmental Requirements, Safety and Materials and Processes. Job has involved considerable interaction with foreign partners, which have included Germany (Engineering Systems and Satellite), Denmark (Star Cameras), France (Accelerometer) and Russia (Launch Vehicle).

GRACE Environmental and Reliability Engineer, 1/1999 to present. Responsible for the implementation of the Environmental and Reliability Programs of the GRACE mission. Performed peer reviews of all GRACE hardware. Peer reviews have included Part Stress Analysis, FMECAs, Worst Case Analyses and Environmental Testing programs. Responsible for developing and writing the Environmental Requirements Document. Other responsibilities included trouble shooting of the electronics subsystems when problems arose.

X2000 Environmental Requirements Engineer, 6/1997 to 1/1999. Responsible for developing and writing the Environmental Requirements Document. Interfacing with vendors prior to hardware build and helping vendors meet defined requirements with cooperation during design phase. Left job prior to completion to work GRACE.

Member of JPL's EMC/EMI/Magnetics Team. Performed Radiated and Conducted Emissions and Susceptibility testing. Knowledge of Magnetic and E-Field Shielding, Grounding Schemes, Electrostatic Discharge (ESD) and triboelectric effects. Performed EMC/Magnetics work on several NASA projects including Cassini, Seawinds, MISR, AIRS and GRACE.

Education

B.S.	California State University Northridge 1996
Major:	Electrical Engineering
	Summa Cum Laude

Awards

JPL NOVA Award for Achievement, 1996
JPL NOVA Award for Achievement, 1997
JPL Group Nova Award for the Electromagnetic Compatibility Team Accomplishment for the Cassini Mission.

Selected Publications

Advanced Failure Determination Measurement Techniques in Thermal Fatigue Life Testing Of Electronic Packaging, 1997 Pan Pacific Microelectronics Symposium, Lahaina, Maui, Hawaii, By: Michael A. Gross, Andrew P. Wallace and Steven L. Cornford.

Modeling of Ideal and Real Thyristors in a Single Phase Rectifier to Compare Their Effect From the Power Quality Point of View, 1996 IEEE Power Engineering Conference, Los Angeles, California, By: Michael A. Gross, Michael Hoopes and Kirk Jones.

THOMAS L. HENYEY

Personal Information

Born: March 7, 1941; New York, NY
Marital Status: Married; one child
Current address: Department of Earth Sciences
University of Southern California
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Los Angeles, California 90089/0740

Education

A.B. Geophysics, University of California, Berkeley, 1962
Ph.D. Geophysics, California Institute of Technology, 1968

Professional Experience

Research Assistant, Caltech, 1966-1967
Teaching Assistant, Caltech, 1967-1968
Research Fellow, Caltech, 1968
Assistant Professor of Geological Sciences, University of Southern California, 1968-1974
Associate Professor of Geological Sciences, University of Southern California, 1974-1981
Sabbatical leave, U.C. Santa Barbara, Spring, 1976
Professor of Geological Sciences, University of Southern California, 1981-present
Sabbatical leave, DSIR, New Zealand, Summer/Fall, 1982
Professor of Geological Sciences and Chairman, Department of Geological Sciences, University of Southern California, 1989-1991
Professor of Geological Sciences, University of Southern California and
Executive Director, Southern California Earthquake Center, 1991-1996
Professor of Geological Sciences, University of Southern California and
Director, Southern California Earthquake Center, 1996-2002
Deputy Director, Southern California Earthquake Center, 2002-

Other Professional Activities

1. Member of American Geophysical Union.
2. Member of Seismological Society of America.
3. External Advisor to California Seismic Safety Commission Research Committee.
4. Member, External Advisory Committee for University of California's Institute for Geophysics and Planetary Physics.
5. Member, External Advisory Committee for Pacific Earthquake Engineering Center.
6. NSF Polar Programs proposal review panel, Washington DC (1997-1999)
7. NEHRP Review Panel, San Francisco (1998)
8. Member of DOSECC Board of Directors.
9. Member, TriNet Advisory Committee.
10. Founding Member, International Science Board, APEC Cooperation for Earthquake Simulation.
11. Co-organized with Jill Andrews numerous Center workshops and symposia.
12. Chair, EarthScope Working Group
13. Member, PBO Steering Committee

Biographical Sketch: Thomas H. Jordan

a. Vitae

BIRTH:	October 8, 1948, Coco Solo, Canal Zone
S.S. NUMBER:	264-92-7023
CITIZENSHIP:	U.S.A.
EDUCATION:	B.S., Geophysics, California Institute of Technology, 1969 M.S., Geophysics, California Institute of Technology, 1970 Ph.D., Geophysics and Applied Mathematics, California Institute of Technology, 1972
EMPLOYMENT:	1969-1972: Graduate Research Assistant, California Institute of Technology, Pasadena, CA; 1972-1975: Assistant Professor, Princeton University, Princeton, NJ; 1975-1977: Assistant Professor, Scripps Institution of Oceanography, University of California, San Diego, CA; 1977-1982: Associate Professor, SIO; 1982-1984: Professor, SIO; 1984-2000: Robert R. Shrock Professor of Earth and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA; 1988-1998: Department Head, Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA; 2000-present, W. M. Keck Foundation Professor of Geophysics, University of Southern California, Los Angeles, CA.
HONORS & AWARDS:	National Merit Scholar, 1965-1969; Alfred P. Sloan Fellow in Physics, 1980-1982; Fellow, American Geophysical Union, 1983; James B. Macelwane Award, American Geophysical Union, 1983; Fellow, American Academy of Arts and Sciences, 1996; Member, National Academy of Sciences, 1998; George P. Woollard Award, Geological Society of America, 1998.

b. Scientific Publications

Approximately 130, on various topics in seismology, geodynamics, tectonics, geodesy, and marine geology. Five recent examples are:

127.2000 McGuire, J. J., and T. H. Jordan, Further evidence for the compound nature of slow earthquakes: the Prince Edward Island earthquake of April 28, 1997, *J. Geophys. Res.*, 7819-7827.

128.2000 McGuire, J. J., and T. H. Jordan, Rupture dimensions of the 1998 Antarctic earthquake from low-frequency waves, *Geophys. Res. Lett.*, 2305-2308.

129.2000 Saltzer, R. L., J. B. Gaherty, and T. H. Jordan, How are vertical shear wave splitting measurements affected by variations in the orientation of azimuthal anisotropy with depth?, *Geophys. J. Int.*, **141**, 374-390.

130.2000 Zhao, L., T. H. Jordan, and C. H. Chapman, Three-dimensional Fréchet differential kernels for seismic delay times, *Geophys. J. Int.*, **141**, 558-576.

131.2000 Richardson, E., and T. H. Jordan, Seismicity in deep gold mines of South Africa: Implications for tectonic earthquakes. *Bull. Seismol. Soc. Am.*, in press.

c. Recent Collaborators (last 48 months, exclusive of students)

D. Weidner, SUNY, Stony Brook; Y. Wang, University of Chicago; Paul Silver, Carnegie Institution of Washington; David James, Carnegie Institution of Washington; Chris Chapman, Schlumberger Cambridge Laboratories; Brad Hager, MIT

Ian R. Joughin

Education

Ph.D., Electrical Engineering, 1995, University of Washington
M.S., Electrical Engineering, 1990, University of Vermont
B.S., Electrical Engineering, 1986, University of Vermont

Ph.D. Dissertation

I. R. Joughin, *Estimation of Ice Sheet Topography and Motion Using Interferometric Synthetic Aperture Radar*, University of Washington, 1995.

Research and Teaching Experience

Jet Propulsion Lab, **Polar Remote Sensing Group**, ***Post Doc***, 1995-1996, ***Staff Engineer***, 1996-2000, ***Senior Engineer***, 2000-present.

Conducted independent research into the application of differential SAR interferometry to the measurement of ice sheet motion and topography. Served as PI and Co-I of several investigations to use SAR interferometry to study the ice dynamics, mass balance, and topography of Greenland and Antarctica. Developed the prototype mosaicking algorithms that will be used to mosaic data from the Shuttle Radar Topography Mission (SRTM) to produce a near-global map of topography. Served as the lead public information officer for the SRTM mission.

Applied Physics Lab UW, Polar Science Center, *Research Assistant,* 1990-1995

Conducted pioneering research into the use of differential SAR interferometry for the estimation of surface motion and topography of ice sheets.

Green Mountain Radio Research, *Electrical Engineer,* 1986-1988

Designed and developed hardware and software for a digital receiver to collect test data sets for adaptive-noise-cancellation algorithms for through-the-earth communications.

Selected Publications

Joughin, I., M. Fahnestock, D. MacAyeal, J. Bamber, and P. Gogineni, “Observation and analysis of ice flow in the largest Greenland ice stream.” *J. Geophys. Res.*, in press.

Bamber, J.L., D.G. Vaughan, and **I. Joughin**, “Widespread complex flow in the interior of the Antarctic Ice Sheet,” *Science*, vol. 287, 2000.

Joughin, I., L. Gray, R. Bindschadler, S. Price, D. Morse, C. Hulbe, K. Mattar, and C. Werner, “Tributaries of West Antarctic ice streams revealed by RADARSAT interferometry,” *Science*, vol. 286, no. 5438, 1999.

Joughin, I., M. Fahnestock, R. Kwok, P. Gogineni, and C. Allen, “Ice flow of Humboldt, Petermann and Ryder Gletscher, northern Greenland,” *J. of Glaciology*, vol. 45, no. 150, 1999.

Joughin, I., R. Kwok, and M. Fahnestock, “Interferometric estimation of the three-dimensional ice- flow velocity vector using ascending and descending passes,” *IEEE Trans. Geosci. Rem. Sen.*, vol. 36, no.1, 1998.

Joughin, I., S. Tulaczyk, M. Fahnestock, and R. Kwok, “A mini-surge on the Ryder Glacier, Greenland, observed via satellite radar interferometry,” *Science*, vol. 274, no. 5285, 1996.

Kim Leschly
Jet Propulsion Laboratory
Pasadena, CA 91109

Role ECHO Project Manager

Education M.S. in Mechanical Engineering (1974), Danish Technical University, Denmark.

Related Work Experience

23-years JPL work experience

Current job: Deputy project manager for the ESSP GRACE Project, a cooperative project between NASA and DLR, involving foreign participation by Russia (launch), Germany (satellites and mission operations), France (accelerometer) and Denmark (star camera). The GRACE launch is planned for March 2002.

Previous project management experience at JPL includes the Mars Micromission/ Mars Surveyor Orbiter Projects (flight system manager).

Prior to this, direct system engineering and task management experience with all project phases on various JPL flight projects/experiments: Galileo, Hubble WFPC-1 and –2, SeaWinds, and several advanced technology/science flight experiments (DS1/NSTAR Diagnostics Field Measurement Package, Free-flying “Hockey-Puck” Magnetometers, STRV-2 Active Pixel Sensor Flight Experiment, and Miniature Avionics Flight Experiment for X-33.

Other project management experience

Project manager (1992-94) for the Ørsted Satellite Project, a small 60-kg Danish geomagnetic research satellite, launched by NASA as a Delta-II piggyback payload in February 1999. Ørsted is a co-operative effort between Danish research institutions, universities, and industry. Two of the Ørsted instruments were provided by NASA/JPL and CNES, respectively.

Honors and awards

NASA exceptional service award and numerous NASA group achievement awards.

Biographical Sketch for Jean-Bernard H. Minster

1. Personal data:

Nationality: US Citizen (Naturalized in 1986). Social security No.: 569-94-4513
Military Duties: Commissariat à l'Energie Atomique, Département de Physique Générale, 1975.
Address: Scripps Institution of Oceanography, University of California, San Diego
Institute of Geophysics and Planetary Physics, 0225
La Jolla, California, 92093-0225 Tel. (858) 534-5650

2. Education:

Graduate, Eng.:	Ingénieur Civil des Mines de Paris,	1969
Graduate, Eng.:	Ingénieur du Pétrole, Institut Français du Pétrole,	1969
Ph.D. (Geophysics):	California Institute of Technology,	1974
Doctorat d'Etat (physics):	Université de Paris VII,	1974

3. Professional Experience:

3.1. Recent Academic positions held

1994-present Director, systemwide, Institute of Geophysics and Planetary Physics, University of California
1989-present: Professor, Scripps Institution of Oceanography, University of California, San Diego

3.2. Recent Community & Professional Service:

2000-present Member, Conseil Scientifique, Institut de Recherches pour le Developpement (IRD)
2000-present Member, NASA Earth Systems Data Information System and Services Committee (ESDISAS)
2000-Present Chair, NRC Committee on Geophysical and Environmental Data
1999-present Science Director and Chairman, Board of Directors, Southern California Earthquake Center
1998-present: Member, UCSB Donald Bren School of Environmental Science and Management Advisory Committee
1997-present: Member, NASA ESSAAC Technology Subcommittee.

3.3. Research Interests

Structure of the Earth interior from broad-band seismic data; Imaging of Earth crust and upper mantle using seismic waves; Verification of nuclear Test Ban Treaties; Development of new space geodetic techniques and applications to crustal dynamics; Ship-board and airborne techniques for determination of the gravity field; Plate tectonics and plate deformation; Earthquake prediction, pattern recognition

3.3.1 Significant Collaborators within the last 48 months:

Duncan Agnew, Yehuda Bock, Peter Shearer, David Sandwell, Scripps Institution of Oceanopgrahy
Steven Day, San Diego State University; John McRaney, University of Southern California; John Rundle, University of Colorado, Boulder; Paul Rosen, Jet Propulsion Laboratory; Bob Schutz, University of Texas; Steve Shkoller, UC Davis

3.3.2 Thesis Advisor in the last 5 years:

Harrold Gurrola, Ph.D. 1995, Texas Tech. University; G. Eli Baker, Ph.D. 1996, Maxwell Technologies, San Diego; Heming Xu, Ph.D. 1998; Adrian Borsa, and Jeremy Bassis, Graduate Students, IGPP>

3.3.3 Posdoctoral Sponsor in the last 5 years for:

Eric Calais, CNES, France; Michelle Hofton, University of Maryland; Steve Shkoller, California Institute of Technology and Los Alamos National Laboratory; Helen Amanda Fricker, Scripps Institution of Oceanography.

4. Recent relevant Publications

Calais, E. and J.B. Minster, GPS detection of ionospheric perturbations following the January 17, 1994, Northridge earthquake, Geophys.Res. Lett. , 22, 1045-1048, 1995

Shkoller, S. and J.-B. Minster, Reduction of Dietrich-Ruina attractors to unimodal maps, *Nonlinear Processes in Geophysics*, **4**, 63-69, 1997.

Calais, E and J.-B. Minster, GPS, earthquakes, the ionosphere, and the Space Shuttle, *Physics of the Earth and Planetary Interiors*, **105**, 167-181, 1998.

Calais, E., J. B. Minster, M. A. Hofton, and M. A. H. Hedlin, Ionospheric signature of surface mine blasts from Global Positioning System measurements, *Geophys. J. Int.*, **132**, 191-202, 1998.

Ware, R.H., D.W. Fulker, S.A. Stein, D.N. Anderson, S.K.Avery, R.D. Clark, K.K. Droegemeier, J.P. Kuettner, J. B. Minster, and S. Sorooshian, Suominet: A Real-time National GPS Network for Atmospheric Research and Education, *Bull. Atm. Met. Soc.* **81**, 677-694, 2000.

Yi, D., J.-B. Minster, C. R. Bentley, The effect of ocean tidal loading on satellite altimetry over Antarctica, *Antarctic Science*, **12**, 119-124 2000.

Hofton, M.A., J.B. Blair, J.-B. Minster, J.R. Ridgway, N.P. Williams, J.L. Bufton, and D.L. Rabine, An airborne scanning laser altimetry survey of Long Valley, California, *Int. J. Remote Sensing*, 21, 2413-2437, 2000.

Sandwell, D.T. L. Sichoix, D. Agnew, Y. Bock, and J.B. Minster, Near real-time radar interferometry of the Mw 7.1 Hector Mine Earthquake, *Geophys, Res. Lett.*, **27**, 3101-3104, 2000.

GILLES PELTZER

Earth and Space Science Division, University of California Los Angeles, Los Angeles
and Jet Propulsion Laboratory, California Institute of Technology, Pasadena
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EDUCATION:

- Ecole Polytechnique de Paris, 1979. Major: Mechanics-Physics
- D.E.A.: Geophysics-Geochemistry, University Paris VII, 1980.
- Doctorat de 3° cycle: University Paris VII, Paris, January 1983, with honours.
- Doctorat d'Etat: University Paris VII, Paris, September 1987, with honours.

PROFESSIONAL EXPERIENCE:

2000-	Professor, Earth and Space Science Division, University of California, Los Angeles.
2000-	Research Scientist, Jet Propulsion Laboratory, California Institute of Technology, Pasadena (joint appointment with UCLA).
1993-2000	Research Scientist, Jet Propulsion Laboratory, California Institute of Technology, Pasadena.
1992-1993	Charge de Recherche, CNRS, Observatoire Midi-Pyrenées, Toulouse, France, on leave of absence from JPL.
1990-1992	Research Scientist, Jet Propulsion Laboratory, California Institute of Technology, Pasadena.
1988-1990	Resident Research Associate at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA.
1985-1990	Charge de Recherche, Centre National de la Recherche Scientifique, Institut de Physique du Globe, Paris.
1983-1984	Attache de Recherche, Centre National de la Recherche Scientifique, Institut de Physique du Globe, Paris.
1980-1982	Allocataire de Recherche, Ecole Polytechnique of Paris.

PROFESSIONAL AFFILIATIONS:

American Geophysical Union, Seismological Society of America

FIVE RELEVENT PUBLICATIONS

Peltzer, G., P. Rosen, F. Rogez, and K. Hudnut, Postseismic rebound in fault step-overs caused by pore fluid flow, Science, 273, 30 August, 1996.

Peltzer G., F. Crampe, and G. King, Evidence of nonlinear elasticity of the crust from the Mw7.6 Manyi (Tibet) earthquake, Science, 286, 272-276, 1999.

Pollitz F., G. Peltzer, and R. Burgmann, Mobility of continental mantle: Evidence from postseismic geodetic observations following the 1992 Landers earthquake, J. Geophys. Res., 105, 8035-8054, 2000.

Peltzer G., F. Crampe, S. Hensley, and P. Rosen, Transient strain accumulation and fault interaction in the Eastern California Shear Zone, Geology, in press.

Peltzer G., F. Crampe, and P. Rosen, The Mw7.1 Hector Mine, California earthquake: Surface rupture, surface displacement field, and fault slip solution from ERS SAR data, Comptes Rendus Acad. Sc., Paris, in press.

ERIC J. RIGNOT

EDUCATION

PhD, Electrical Engineering, University of Southern California, 1991.
M.Sc.s, Electrical and Aerospace Engineering, University of Southern California, 1987-88.
Engineer Degree, Ecole Centrale des Arts et Manufactures, Paris, 1986.

PROFESSIONAL EXPERIENCE

Research Assistant, University of Southern California, 1986-1988. Member of Technical Staff, Radar Science and Engineering Section, JPL, 1988-1996. Research Scientist, Radar Science and Engineering Section, JPL, 1996-present.

MEMBERSHIPS AND HONORS

JPL Director Lew Allen Award for Excellence in 1998, Jet Propulsion Laboratory. Prize Paper Award IEEE Geos. Rem. Sens. Soc. Best Peer-Reviewed Journal Paper 1994. Prize Paper Award IEEE Geos. Rem. Sens. Soc. Best Paper IGARSS'90 Symposium. 11 NASA certificates of recognition between 1988 and 1993. Member AGU and IGS.

COMMITTEE MEMBERSHIP

Editor, IGS's Ann. Glaciol., Member of NASA's Solid Earth Science Working Group, and Member of NASA's Alaska SAR Facility User Working Group.

SELECTED PEER-REVIEWED SCIENTIFIC PUBLICATIONS (~ 50 total)

Rignot, E., W.B. Krabill, S.P. Gogineni, I. Joughin. 2001. Contribution to the glaciology of northern Greenland from InSAR, *J. Geophys. Res.*, 106(D24), 34,007.

Rignot, E. 2001. Rapid retreat and mass loss of Thwaites Glacier, West Antarctica, *J. Glaciol*, 47(157), 213-222.

Rignot, E., K. Echelmeyer and W.B. Krabill. 2001. Penetration depth of InSAR signals in snow and ice, *Geophys. Res. Lett*., 28(18), 3501-3504.

Vaughan, D.G. and 9 others. 2000. A review of ice-sheet dynamics in the Pine Island Glacier basin, West Antarctica, in *Ant. Res. Ser. 77* (AGU, Washington D.C. 2000), 237-256.

Rignot, E. 1998. Fast recession of a West Antarctic Glacier, *Science*, 281, 549-551.

Rignot, E., S. P. Gogineni, W. B. Krabill and S. Ekholm. 1997. North and northeast Greenland ice discharge from satellite radar interferometry, *Science*, 276, 934-937.

Rignot, E. 1996. Tidal motion, ice velocity and melt rate of Petermann Gletscher, Greenland, measured from radar interferometry, *J. Glaciol*., 42(142), 476-485.

Rignot, E., S. J. Ostro, J.J. Van Zyl, and K.C.Jezek. 1993. Unusual Radar Echoes from the Greenland Ice Sheet. *Science*, 261, 1710-1713.

RECENT COLLABORATORS

Gino Casassa, Univ. de Magellanes, Chile; Keith Echelmeyer, Univ. of Alaska, Fairbanks, AK: Prasad Gogineni, Univ. of Kansas, KA: Bernard Hallet, Univ. of Washington, Seattle, WA: Stanley Jacobs, Lamont Observatory, NY: William Krabill, NASA Wallops, VA: Douglas MacAyeal, Univ. of Chicago, IL: Charlie Raymond, University of Washington, WA: David G. Vaughan, British Antarctic Survey, Cambridge, U.K.

PAUL ALAN ROSEN

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EDUCATION

Stanford University, Stanford, CA
Ph.D. in Electrical Engineering, conferred January 1989
University of Pennsylvania, Philadelphia, PA
B.S., M.S. in Electrical Engineering, 1981-1982

RELEVANT RESEARCH EXPERIENCE

March 1998 – present Visiting Associate, Caltech Division of Geological and Planetary Sciences. Collaborative research and development in applications of radar interferometry to solving geophysical problems in crustal movements.

1992--present Technical Group Supervisor (1995): Jet Propulsion Laboratory, Pasadena, CA Interferometric SAR Algorithm Development Group, Radar Science and Engineering Section. Studies of the uses of spaceborne synthetic aperture radar for topographic mapping of the earth's land surfaces, and for detection of temporal change by interferometric methods. Principal Investigator and three-fold Co-Investigator for NASA Topography and Topographic Change Program, three-fold Co-Investigator for NASA Natural Hazards Program. Principal Investigator of the Japanese NASDA Research Initiative in Radar Interferometry and Tropical Mapping. Project Element Manager for Shuttle Radar Topography Mission Algorithm Development.

PUBLICATIONS

Rosen, P. A., S. Hensley, F. Li, I. Joughin, S. Madsen, D. Goldstein (2000). Synthetic Aperture Radar Interferometry, Proc. IEEE, 88(3), 333-382.

Rosen, P. A., C. L. Werner, E. J. Fielding, S. Hensley, S. M. Buckley, P. Vincent (1997). Aseismic creep along the San Andreas fault at Parkfield, CA measured by radar interferometry. GRL, 25, 825-828.

Rosen, P. A., S. Hensley, H. A. Zebker, F. H. Webb, E. J. Fielding (1996). Surface deformation and coherence measurements of Kilauea Volcano, Hawaii from SIR-C radar interferometry. J. Geophys. Res., 101, 23,109-23,125.

Peltzer, G., P. Rosen, F. Rogez K. Hudnut (1998). Poroelastic rebound along the Landers 1992 earthquake surface rupture, J. Geophys. Res. 103(B12), 30,131-30,145.

Tobita, M., S. Fujiwara, S. Ozawa, P. A. Rosen, E.J. Fielding, C. L. Werner, M. Murakami, H. Nakagawa, K. Nitta, M. Murakami (1998) Deformation of the 1995 North Sakhalin earthquake detected by JERS-1/SAR interferometry, Earth Planets Space, 50, 313-325.

Galloway, D. L., K. W. Hudnut, S. E. Ingebritsen, S. P. Phillips, G. Peltzer, F. Rogez, P. A. Rosen (1998). INSAR Detection of Aquifer-System Compaction and Land Subsidence, Antelope Valley, Mojave Desert, California. Water Resources Res. , 34(10), 2572-2585.

Fujiwara, S., P. A. Rosen, M. Tobita, M. Murakami (1998). Crustal deformation measurements using JERS-1 SAR interferometry near the Izu peninsula, Japan. J. Geophys. Res., 103, 2411-2426.

Zebker H.A., P. A. Rosen, and S. Hensley (1997). Atmospheric effects in interferometric synthetic aperture radar surface deformation and topographic maps, J. Geophys. Res., 102, 7547-7563.

Peltzer, G., P. A. Rosen, F. Rogez, K. Hudnut (1996). Post-seismic rebound in fault step-overs caused by pore fluid flow. Science, 273, 1141.

Peltzer, G., P. A. Rosen (1995). Surface displacement of the 17 May 1993 Eureka Valley, California, earthquake observed by SAR interferometry. Science, 268, 1333.

David T. Sandwell

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Present Position: Professor of Geophysics, Scripps Institution of Oceanography

Education:

Ph.D., 1981	University of California at Los Angeles, Geophysics and Space Physics
M.S., 1978	University of California at Los Angeles, Geophysics
B.S., 1975	University of Connecticut, Major Physics, Minor Mathematics

Professional Experience:

1989-93	Scripps Institution of Oceanography, Associate Professor.
1985-89	University of Texas at Austin, Center for Space Research, Research Scientist
1982-85	National Geodetic Survey, Research Geophysicist.
1976-81	University of California at Los Angeles, Research Assistant.

Other Experience:

6/01-	Associate Editor of *Journal of Geophysical Research*
10/99-	Chair of Western North America InSAR Consortium (WInSAR)
9/98-6/01	Member of NRC Space Studies Board, Committee on Earth Studies
10/95-12/00	AGU Editor of *Earth Interactions*, Electronic Journal
5/95 -12/96	Member of NRC, US Committee on Geodynamics

Awards and Memberships:

12/97	Fellow of the American Geophysical Union
9/98-	Society for Exploration Geophysics
6/77-	American Geophysical Union
6/80-	International Association of Geodesy

Experience Relevant to the ECHO Mission

- Chair of Western North America InSAR Consortium (WInSAR) and WInSAR PI on ALOS investigation
- Manage the SIO X-band downlink facility for acquisition of ERS and Radarsat SAR data.
- Scientific investigator on spaceborne radar missions including: Geosat, Magellan, ERS-1, Topex/Poseidon, ERS-2, SRTM, Envisat, Jason, and ALOS.
- Teach classes in: *Satellite Remote Sensing, Synthetic Aperture Radar Interferometry, Geodynamics, The Earth*
- Maintain a web site *topex.ucsd.edu* to deliver scientific products to other scientists, corporate researchers, students, and interested public.

Relevant Publications

Price, E. J. and D. T. Sandwell, Small-scale deformation associated with the Landers 1992 California earthquake mapped by InSAR Phase Gradient, *J. Geophys. Res., 103*, 27001-27016, 1998.

Sandwell, D. T. and E. J. Price, Phase gradient approach to stacking interferograms, *J. Geophys. Res., 103*, 30183-30204, 1998.

Sandwell, D. T., L. Sichoix, D. Agnew, Y. Bock, and J-B. Minster, Near-real-time radar interferometry of the Mw 7.1 Hector Mine Earthquake, *Geophys. Res., Lett., 27*, 3101-3104, 2000.

Sandwell, D.T. and L. Sichoix, Topographic phase recovery from stacked ERS interferometry and a low resolution digital elevation model, *J. Geophys. Res., 105*, B12, 28211-28222, 2000.

Sandwell, D. T., L. Sichoix, and B. Smith, Hector Mine Earthquake: Vector Near-Field Displacement from ERS InSAR, submitted to *Bull. Seismo. Soc. Am.,* October 16, 2000.

Jacobs, A., D. Sandwell and L. Sichoix, Hector Mine earthquake: Postseismic Deformation from ERS Interferometry, submitted to *Bull. Seismo. Soc. Am.,* October 16, 2000.

Baer, G., U. Schattner, D. Wachs, D. Sandwell, S. Wdowinski, The Lowest Place on Earth is Subsiding – an InSAR Perspective, submitted to *GSA Bulletin*, November 2000.

Paul Segall
Department of Geophysics
Stanford University

Education:

1976	B.A.	*Summa Cum Laude*, Earth Sciences, Case Western Reserve University
1976	M.S.	Earth Science, Case Western Reserve University
1981	Ph.D.	Geology, Stanford University

Career Experience:

1981-1993	Project Chief, U.S. Geological Survey Branch of Tectonophysics
1989-1993	Associate Professor (Research), Geophysics, Stanford University
1993-1998	Associate Professor, Department of Geophysics, Stanford University
1998-	Professor, Department of Geophysics, Stanford University

Honors and Awards:

1990	James B. Macelwane Medal, American Geophysical Union
1990	Fellow, American Geophysical Union
1998	Fellow, Geological Society of America

Recent Professional Service:

1997-2000	N.S.F. Panel Member, Instruments and Facilities Program
1998	NASA Solid Earth and Natural Hazards, Review Panel
1998-present	Member, Southern California Integrated GPS Network, Advisory Board
1999	Chair, U.C. Santa Cruz, Institute of Tectonics Advisory Committee.
1999-2000	Member, N.R.C. Review of USGS Volcano Hazards Program
2000-present	Member, UNAVCO Steering Committee
2000-present	President Elect, Teconophysics Section, AGU.
2000-present	Member, Meetings Committee, AGU.

Recent Publications Relevant to Proposed Research:

1999 Aoki, Y., Paul Segall, Teruyuki Kato, Peter Cervelli, Seiichi Shimada, Imaging magma transport from inversion of deformation data: The 1997 seismic swarm off the Izu Peninsula, Japan, ***Science***, vol. 286, 927-930.

1999 Battaglia, M., C. Roberts, P. Segall, Magma intrusion beneath Long Valley caldera confirmed by temporal changes in gravity, ***Science***, 285, 2119-2122.

2000 Owen, S., P. Segall, M. Lisowski, M. Murray, M. Bevis, and J. Foster, The January 30, 1997 eruptive event on Kilauea Volcano, Hawaii, as monitored by continuous GPS, submitted to ***Geophysical Research Letter***s. v. 27, 2757-2760.

2000 Kenner, S. and P. Segall, The Mechanics of Intraplate Earthquake Generation with Application to the New Madrid Seismic Zone, U.S.A., ***Science***, v. 289, pp.2329-2332.

2000 AmelungF., S. Jónsson, H. Zebker, and P. Segall, Widespread uplift and trap door faulting on Galapagos volcanoes, ***Nature***, v. 407 No. 6807 P. 993 – 996.

Biographical Sketch: Mark Simons

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Education

B.S. Geophysics and Space Physics, University of California, Los Angeles, June 1989.

Ph.D. Geophysics, "Localization of gravity and topography: Constraints on the tectonics and mantle dynamics of Earth and Venus", Massachusetts Institute of Technology, February 1996.

University of California education abroad program at the University of Bergen, Norway, 1988.

University of California, Santa Barbara, 1983-1985 (concurrent with high school).

Honors and Awards

Seismological Laboratory Postdoctoral Fellowship, Caltech, 1995-1997.

Volvo Graduate Fellow, 6th symposium on the frontiers of science, National Academy of Sciences, November, 1995.

Outstanding Student Planetology Paper, American Geophysical Union, Spring meeting, 1993.

NSF Graduate fellowship honorable mention, 1989 and 1990.

UCLA Deans Honors and College Honors, 1989.

Handin Undergraduate Scholarship, UCLA, 1988-1989. C.W. Ball Award, Earth and Space Sciences, UCLA, 1988.

Society of Exploration Geophysicists Scholarship, 1985-1989.

Employment

Assistant Professor of Geophysics, Caltech, Pasadena, California, 1997-present.

Postdoctoral Scholar, Caltech, Pasadena, California, 1995-1997.

Graduate research assistant, Dept. of Earth, Atmospheric and Planetary Sciences, M.I.T, Cambridge, Massachusetts, 1989-1995.

Teaching assistant, Dept. of Earth, Atmospheric and Planetary Scis., M.I.T., Fall 1992.

Relevant Publications

Preliminary Report on the 10/16/99 M7.1 Hector Mine, California earthquake, Scientists of the USGS, SCEC, and CDMG, *Seismol. Res. Lett.*, **71**, 11-23, 2000.

Deformation and seismicity in the Coso geothermal area, Inyo County, California: Observations and modeling using satellite radar interferometry, Y. Fialko and M. Simons, *J. Geophys. Res.*, **105**, 21781-21793, 2000.

Deformations due to a pressurized horizontal circular crack in an elastic half-space, with applications to volcano geodesy, Y. Fialko, Y. Khazan, and M. Simons, *Geophys. J. Int.*, in press, 2001.

Finite source modeling of magmatic unrest in Socorro, New Mexico, and Long Valley, California, Y. Fialko, M. Simons, and Y. Khazan, *Geophys. J. Int.*, in press, 2001.

On-going inflation of the Socorro magma body, New Mexico, as imaged by Interferometric Synthetic Aperture Radar, Y. Fialko and M. Simons, *Geophys. Res. Lett.*, submitted 2001.

Co-seismic slip from the July 30, 1995, Mw 8.1 Antofagasta, Chile, earthquake as constrained by InSAR and GPS observations, M. Pritchard, M. Simons, et. al., *Geophys. J. Int.*, submitted 2001.

Location and mechanism of the Little Skull Mountain Earthquake as constrained by satellite radar interferometry and seismic waveform modeling, R. Lohman, M. Simons, and B. Savage, *J. Geophys. Res.*, submitted 2001.

Biographical Information : Wayne Thatcher

Education:

Ph.D. (Seismology), California Institute of Technology, Pasadena	1971
B.Sc (Honors in Physics and Geology), McGill University, Montreal	1964

Experience:

Research Geophysicist, U.S. Geological Survey	1971-Present
Visiting Professor, California Institute of Technology, Pasadena	March-June 1998
Visiting Scientist, Centre Nationale d'Etudes Spatiales, Toulouse, France	April-Aug 1996
Visiting Research Fellow, Oxford University, United Kingdom	1992-1993
Chief, Branch of Tectonophysics, U.S. Geological Survey	1984-1989
Program Coordinator, Earthquake Prediction Research, National Earthquake Hazard Reduction Program,	1984-1989
Visiting Scientist, Earthquake Research Institute, Tokyo University, Japan	1978-1979

Committees to Render Scientific Judgement (Last 5 years):

Member, Steering Committee, UNAVCO GPS Consortium	1994-1996, 2001-2003
Member, NSF Continental Dynamics Program Review Panel	1998-
Member, EarthScope Sttering Committee	2000-
Member, Plate Boundary Observatory, Steering Committee	1999-
Member, WInSAR Steering Committee	1999-

Honors and Awards:

Editor’s Citation for Excellence in Reviewing, Journal of Geophysical Research, AGU, 1998
Meritorious Service Award, U. S. Geological Survey, 1994
Royal Society Senior Research Fellow, Dept. of Earth Sciences, Oxford University, 1992
Fellow, American Geophysical Union, 1992

FIVE MOST RELEVANT PUBLICATIONS

Thatcher, W., G. R. Foulger, B. R. Julian, J. Svarc, E. Quilty, G. W. Bawden, 1999, Present day deformation across the Basin and Range Province, western United States, *Science*, *283*, 1714-1718.

Wicks, C., W. Thatcher, and D. Dzurisin, 1999, Migration of magmatic fluids beneath Yellowstone Caldera inferred from satellite radar interferometry, *Science*, *282*, 458-462.

Thatcher, W., and P. C. England, Ductile shear zones beneath strike-slip faults:implications for the thermomechanics of the San Andreas fault zone, *J. Geophys. Res.*, *103*, 891-906, 1998.

Thatcher, W., G. Marshall and M. Lisowski, Resolution of fault slip along the 470-km-long rupture of the great 1906 San Francisco earthquake and its implications, *J. Geophys. Res.*, *102*, 5353-5367, 1997.

Thatcher, W., Microplate versus continuum descriptions of active tectonic deformation, *J. Geophys. Res.*, *100*, 3885-3994, 1995.

Thatcher, W., Nonlinear strain buildup and the earthquake cycle on the San Andreas fault, *J. Geophys. Res.*, *88*, 5893-5902, 1983.

FIVE ADDITIONAL SIGNIFICANT PUBLICATIONS

Thatcher, W., and D. Massonnet, Crustal deformation at Long Valley Caldera, eastern California, 1992-1996, inferred from satellite radar interferometry, Geophys. Res. Lett., 20, 2519-2522, 1997.

Sagiya, T., and W. Thatcher, Coseismic slip resolution along a plate boundary megathrust: the Nankai Trough, southwest Japan, *J. G. R.*, *104*, 1111-1129, 1999.

Thatcher, W., and Rundle, J.B., A viscoelastic coupling model for the cyclic deformation due to periodically repeated earthquakes at subduction zones, *J. Geophys. Res.. 89*, 7631-7640, 1984.

Howard A. Zebker

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EDUCATION

1976	B.S., Engineering and Applied Science, California Institute of Technology
1979	M.S., Engineering, University of California at Los Angeles
1984	Ph.D., Electrical Engineering, Stanford University

HONORS AND AWARDS

1999	Fellow, IEEE
1998	Dana Adams Griffin Award, School of Engineering, Stanford University
1995	Best paper award, IEEE Geoscience and Remote Sensing Society (IGARSS 95)
1990	U.S. Patent No. 4,975,704: Method for Detecting Surface Motions and Mapping Small Terrestrial or Planetary Surface Deformations with SAR
1990	NASA Group Achievement Award, Airborne Imaging Radar System Team
1989	U.S. Patent No. 4,829,303: Data Volume Reduction for Imaging Radar Polarimetry
1988	Jet Propulsion Laboratory Director's Research Achievement Award
1988	Best paper award, IEEE Geoscience and Remote Sensing Society
1984	U.S. Patent No. 4,450,447: Synthetic Aperture Radar Target Simulator
1982	NASA Group Achievement Award, Shuttle Imaging Radar (SIR-A) Development Team
1979	NASA Group Achievement Award, Seasat-A Synthetic Aperture Radar Team
1984-1995	Multiple NASA Certificates of Achievement for New Technology

RELATED PUBLICATIONS

Zebker, H. A., P.A.Rosen, and S. Hensley, “Atmospheric effects in interferometric synthetic aperture radar surface deformation and topographic maps,” J. Geophys. Res. - Solid earth, Vol. 102, No. B10, pp. 7547–7563, April 10, 1997.

Zebker, H.A., P.A. Rosen, S. Hensley, and P. Mouginis-Mark, Analysis of active lava flows on Kilauea volcano, Hawaii, using SIR-C radar correlation measurements, Geology, Vol. 24, No. 6, pp. 495-498, 1996.

Zebker, H.A., P.A. Rosen, R.M. Goldstein, A. Gabriel, and C. Werner, On the derivation of coseismic displacement fields using differential radar interferometry: the Landers earthquake, JGR-Solid Earth, Vol. 99, No. B10, pp 19617-19634, October 10, 1994.

Zebker, H.A., and J. Villasenor, Decorrelation in interferometric radar echoes, IEEE Trans. Geo. Rem. Sensing, Vol 30, no. 5, pp 950-959, September, 1992.

Zebker, H. A., and R. M. Goldstein, Topographic Mapping Derived from Synthetic Aperture Radar Measurements, J. Geophys. Res. 91, 4993-9, 1986.

MARIA T. ZUBER

Education

Ph.D. Geophysics, Brown University, 1986; *Sc.M.* Geophysics, Brown University, 1983.
B.A. Astrophysics (honors) and Geology, University of Pennsylvania, 1980.

Employment

E.A. Griswold Prof. of Geophysics and Planetary Sci., MIT, 1998-Present; Prof. of Geophysics and Planetary Sci., MIT, 1995-1998; Prof. of Geophysics, Johns Hopkins Univ., 1995; Senior Research Scientist, NASA/GSFC, 1994-Present; Second Decade Society Associate Prof. of Geophysics, JHU, 1993-1995; Geophysicist, NASA/GSFC, 1986-1992; NRC Research Associate, NASA/GSFC, 1985-1986; Research Assistant, Dept. of Geological Sci., Brown Univ., 1980-1985.

Honors and Awards

Fellow, American Geophysical Union, 2001; Visiting Committee, Jet Propulsion Laboratory, 2001-Present; NASA Group Achievement Award for the Mars Program Independent Assessment Team, 2000; NASA Group Achievement Award for the Mars Global Surveyor Science Team, 2000; Distinguished Leaders in Science Lecturer, National Academy of Sciences, 1999; NASA Group Achievement Award for the Near Earth Asteroid Rendezvous spacecraft encounter of Asteroid 253 Mathilde, 1998; NASA Exceptional Scientific Achievement Medal, 1995; JHU David S. Olton Award for Outstanding Contributions to Undergraduate Student Research, 1995; NASA Group Achievement Award for the Deep Space Program Science Experiment Lunar Orbit Mission Operations Support Team, 1994; JHU *Oraculum* Award for Excellence in Undergraduate Teaching, 1994; NASA Outstanding Performance Award, 1988-1992; NASA Peer Award, 1988.

Selected Professional Involvement

Board of Reviewing Editors, *Science,* 2000-Present; Co-investigator, NASA MESSENGER Mission to Mercury, 1999-Present; NASA Space Science Advisory Committee, 1999-Present; President, Planetary Sciences Section, American Geophysical Union, 1998-2000; President-elect, 1996-1998; NASA Europa Orbiter Science Definition Team, 1997-1999; NAS Committee on Earth Gravity from Space, 1996-1997; Chair, NASA/Mars Surveyor 1998 Lander Science Payload Selection Panel, 1995; Team Leader, Laser Ranging Investigation, NASA Near Earth Asteroid Rendezvous Mission, 1994-Present; Deputy Principal Investigator, Mars Orbiter Laser Altimeter, Mars Global Surveyor Mission, 1994-Present; NAS Committee on Planetary and Lunar Exploration, 1994-1996.

Selected Refereed Publications (out of >90 in peer-reviewed journals)

Montesi, L.G.J., and M.T. Zuber, A unified description of localization for application to large-scale tectonics, submitted to *J. Geophys. Res.,* 2001.

Tracadas, P.W., M.T. Zuber, D.E. Smith, and F.G. Lemoine, Density structure of the upper thermosphere of Mars from measurements of air drag on the Mars Global Surveyor spacecraft, *J. Geophys. Res.,* in press, 2001.

Behn, M.D., and M.T. Zuber, A comparison of ocean topography derived from Shuttle Laser Altimeter-01 and TOPEX/POSEIDON, *IEEE Remote Sensing, 38,* 1425-1438, 2000.

Zuber, M.T, et al., Internal structure and early thermal evolution of Mars from Mars Global Surveyor topography and gravity, *Science, 287,* 1788-1793, 2000.

Smith, D.E., M.T. Zuber, R.M. Haberle, D.D. Rowlands, and J.R. Murphy, The Mars seasonal CO_2 cycle and the time variation of the gravity field: A General Circulation Model simulation, *J. Geophys. Res., 104,* 1885-1896, 1999.

Zuber, M.T., et al., Observations of the north polar region of Mars from the Mars Orbiter Laser Altimeter, *Science, 282,* 2053-2060, 1998.

L.2 STATEMENT OF WORK AND FUNDING INFORMATION

1. INTRODUCTION

The overall ECHO Mission, including science objectives, requirements and schedule, is described in the main body of this proposal. This Statement of Work and Funding Information describes the scope of work to be performed by, Jean-Bernard Minster of The Scripps Institution of Oceanography (PI), and JPL (including the instrument subcontracts), collectively referred to below as “Contractor”.

2. OBJECTIVES

ECHO brings a fundamentally new data type to the study of changes of the Earth’s surface: time series of spatially continuous, vector maps of surface change associated with earthquakes, volcanoes, ice sheets and glaciers. This is accomplished through a single measurement—millimeter-level surface deformation at resolutions of tens of meters with worldwide accessibility. Surface deformation data is collected by ECHO’s Synthetic Aperture Radar (SAR) antenna. Ball Aerospace will provide the antenna radar panels; the radar electronics will be provided by JPL.

The ECHO spacecraft will study the Earth from a 760km altitude, 8-day repeat sun-synchronous orbit. The 5-year mission seeks to answer the following science questions:

- How does strain accumulate along faults and plate boundaries and is released during the earthquake cycle?
- What are the spatial and temporal deformation patterns of volcanoes worldwide, and how can these data help predict eruptions?
- What is the rate and variability of ice discharge and what is its relation to sea level rise and climate change?

These questions address two of the five key research priorities of the NASA *Earth Science Enterprise* (ESE) *Research Strategy for 2000-2010:* Primary Forcings of the Earth System, and Earth System Responses and Feedback Processes.

Detailed Science Objectives are as follows:

- Seismic Hazards
  - Detect and map inter-seismic and pre-seismic transient strains
  - Derive models of faulting and crustal rheology from vector co- and post-seismic displacement maps
  - Assimilate vector maps of surface deformations through various stages of the earthquake cycle in large-scale numerical simulations
- Volcanology
  - Derive models of magma migration from the spatial and temporal extent of deformation preceding and accompanying eruptions
  - Quantify Pressure changes at depth resulting from magma intrusion beneath the world’s active volcanoes
  - Analyze the spatial extent of new material deposited during an eruption
- Ice Sheets and Glaciers
  - Determine ice velocity and discharge by ice streams and glaciers worldwide and quantify their contributions to sea-level rise
  - Characterize the temporal variability in ice flow well enough to separate short-term fluctuations from long-term change

- Provide critical data to determine the fundamental forcings and feedbacks on ice stream and glacier flow to improve the predictive capabilities of ice-sheet models.

3. MANAGEMENT APPROACH

Overall responsibility for the success of the project rests with the Principal Investigator (PI) Jean-Bernard Minster of the Scripps Institution of Oceanography. He leads the science team and provides mission leadership throughout development and flight operations, and dataset processing. He is assisted by Deputy PIs Paul Rosen (JPL) and Howard Zebker (Stanford University), and by JPL Project Manager (PM) Kim Leschly.

The PI is supported by a Project Advisory Board, consisting of the PI as chairperson; Charles Yamarone, JPL Deputy Director for Space and Earth Science Programs; M. Strodl, Vice President for Finance of Astrium GmbH; G. Chodil, Vice President of Ball Aerospace and Technologies Corporation Civil Space Systems; and Franklin M. Orr, Dean of the School of Earth Sciences at Stanford University. The primary role of the board members is to ensure that their organizations provide the PI with the support he needs from the members' respective organizations.

The JPL Project Manager manages the project for the PI, and is responsible for: overall risk management; leading project implementation planning; appointing element managers; managing oversight of activities, detecting and correcting problems; reporting regularly on the technical schedule and financial status; representing JPL to NASA, other government agencies, industry, and institutions on matters pertaining to the project, and managing industrial partnership relationships.

Our industrial partner, Astrium GmbH, is responsible for ECHO spacecraft development and manufacturing, integration assembly and test, instrument integration, spacecraft-level systems engineering and product assurance, and spacecraft operations.

Ball Aerospace and Technology Corporation will be responsible for the design and development of the radar panels, test of the panels at Ball facilities, documentation of interfaces and execution of tests, support of radar integration and test at JPL, support of spacecraft integration and test at Astrium, and management of the antenna deployment structure subcontract.

The Project Engineer and system engineering staff function as a team to develop requirements and designs that are responsive to the science objectives and ensure mission success at minimal risk. The Project System Engineering Team (PSET) is responsible for defining systems and interfaces, identifying design options and leading trade studies, manage system technical resources, and monitoring verification and validating activities.

Safety & Mission Assurance is involved in all phases and at all levels of the Project.

The Education and Public Outreach Manager reports directly to the PI, ensuring that E/PO is prominent throughout the mission.

4. DESCRIPTION OF WORK

A) The Jet Propulsion Laboratory (JPL) has been invited to submit a detailed Step 2 Proposal for the ECHO mission, in accordance with the Two-Step Proposal Process described in NASA Announcement of Opportunity AO-01-OES-01 ("the AO").

B) The work to be performed for the proposed mission is more particularly described in the main body of this proposal, and in Section 10, below ("Scope of Work" subsections).

C) The work is performed in five phases, as follows:

1. Mission Concept Studies, now completed, comprising the preparation and evaluation of the Step One and Step Two proposals required by the AO (Phase 1);
2. Mission Definition and Preliminary Design (Phase 2);
3. Mission Detailed Design (Phase 3);
4. Mission Development and Launch (Phase 4); and
5. Mission Operations and Data Analysis, Archival and Dissemination (Phase 5).

NASA shall formally authorize the Contractor to proceed in each of phases 2 through 5 by Contracting Office direction.

5. MISSION ASSURANCE

Mission Assurance will be performed in accordance with NASA/Caltech prime contract NAS7-1407, Section E-2, Safety and Mission Assurance. Mission assurance requirements are set forth in the Management Plan of the ECHO Mission Step 2 Proposal.

6. SPECIAL REQUIREMENTS

A) Governmental Responsibilities: None at this time.

B) International Partnerships:

For the proposed ECHO mission, the German Aerospace Center (DLR) will provide a Russian DNEPR launch vehicle and Mission Operations through the German Space Operations Center at no cost to NASA. If the project is selected, an international agreement between NASA and DLR will be written for ECHO, establishing the terms of international cooperation between ECHO partners.

The responsibilities of each partner are provided in Appendix 7 as part of the draft international agreement between NASA and DLR. An ITAR exemption will be used by NASA/JPL to transfer any export controlled interface technical data to DLR and their contractors. In the event any hardware is temporarily exchanged between NASA/JPL and DLR, a NASA Import Certificate and the use of a government ITAR exemption will be required to import and export hardware respectively. A State Department export license will be required to permanently ship any required hardware as the launch will take place in Baikonur, Kazakhstan, of the Russian Federation. NASA will be the applicant of the permanent export license for all NASA owned property.

The provider of the ECHO spacecraft will be Astrium GmbH, a foreign contractor to JPL. The spacecraft will be procured under a firm fixed price contract. As a result of this international contract, JPL will be applying for multiple export licenses from the Department of State. A Technical Assistance Agreement is required so that JPL may have technical discussions with Astrium personnel regarding the integration of the US components. Additionally, export licenses will be required so that JPL may temporarily ship hardware to the contractor in Germany on a regular basis.

Each US party involved in the ECHO Project will be responsible for complying with the International Traffic and Arms Regulations and the Export Administration Regulations. US contractors and academic institutions which are part of the ECHO

Team are required to obtain the necessary licenses from the Department of State and Commerce to work with the foreign partner and foreign contractor. As long as the export licenses are obtained in a timely manner, it is not anticipated that any of the export requirements will pose any risk of delay for the project.

7. DELIVERY SCHEDULE

A) Deliverables	
1. Phase 1: Mission Concept Studies a) Submit Step One and Step Two Proposals	Completed
2. Phase 2: Mission Definition and Preliminary Design a) Systems Requirements Review (SRR) b) Preliminary Design Review (PDR) c) Mission Design Review (MDR) d) Confirmation Readiness Review (CRR) e) Mission Confirmation Review (MCR) f) Project Plan g) Project Requirements Document h) Monthly status reports/reviews on project formulation activities delivered to the ESSP Program Manager by the 10th of the following month i) Quarterly Status Reviews/Presentations to the ESSP Program Manager j) Monthly and Quarterly financial management reports. Financial (533M,Q) Reports shall be submitted to the NASA ESSP Program Manager k) Monthly and Quarterly financial management reports in a format approved by the NASA ESSP Program Manager l) Annual budget review support m) Major Review Reports n) E/PO Plan	Not Applicable Until Authorized
3. Phases 3 and 4: Mission Detailed Design, Development and Launch a) Critical Design Review (CDR) b) Mission Operations Plan for Phase 5 c) Science Data Management Plan d) Pre-Environmental Test Review (PER) e) Pre-Ship/Operational Readiness Review (PSR/ORR) f) Spacecraft delivery to launch site g) Flight Readiness Review (FRR) h) Mission Readiness Review (MRR) i) Launch completed by the end of the launch window j) Verified operational spacecraft k) E/PO products l) Weekly 1-page written reports to the ESSP Program Manager (e.g. by e-mail and entered on HQ server) m) Monthly status reports/reviews on project implementation activities delivered to the ESSP Program Manager by the 10th of the following month n) Quarterly Status Reviews/Presentations to the ESSP Program Manager	Not Applicable Until Authorized

o) Monthly and Quarterly financial management reports. Financial (533M,Q) Reports shall be submitted to the NASA ESSP Program Manager p) Monthly and Quarterly financial management reports in a format approved by the NASA ESSP Program Manager q) Annual budget review support r) Major Review Reports s) Incident Reports	
4. Phase 5: Mission Operations & Data Analysis, Archival and Dissemination a) Perform flight operations b) E/PO products, as generated c) Validated science products, as generated and archived in USGS EROS data center. d) Weekly 1-page written reports to the ESSP Program Manager (e.g. by e-mail and entered on the HQ server) e) Monthly status reports/reviews on project implementation activities delivered to the ESSP Program Manager by the 10th of the following month f) Quarterly Status Reviews/Presentations to the ESSP Program Manager g) Monthly and Quarterly financial management reports. Financial (533M,Q) Reports shall be submitted to the NASA ESSP Program Manager h) Monthly and Quarterly financial management reports in a format agreed to with the NASA ESSP Program Manager i) Annual budget review support j) Major Review Reports	Not Applicable Until Authorized

8. PERIOD OF PERFORMANCE

Phase	Description	Beginning Date	End Date
1	Mission Concept Studies	Sept 2001	Feb 2002
-	Selection	June 2002	
2	Mission Defn & Prelim Design	Nov 2002	Aug 2003
3	Mission Detailed Design	Oct 2003	May 2004
4	Mission Devmt & Launch	May 2004	Sept 2006
5	Mission Ops & Data Analysis, Archival and Dissemination	Sept 2006	Sept 2011

9. COST ESTIMATE

The total cost estimate for the ECHO mission is $288.2M (Real Year dollars). Contributions from the USGS and DLR total $43.5M. The ECHO Step 2 proposal is also being submitted to the NSF to seek the supplemental funds required for full mission development. If accepted by NASA ESSP and the NSF, ECHO will be funded by both agencies. Most of the NSF funds will be used to cover the PI costs, however, exact distribution of agency funds will be dependent upon the final funding profile.

The specific cost estimates for each phase are provided below. The details of these cost estimates and sources of funding are set forth in the attached Proposal.

A) Cost Estimates by Phase: PI Institution

Principal Investigator: Bernard Minster, SIO

1. Mission Concept Studies: No NASA funding is provided.	
2. Mission Definition and Preliminary Design:	$1,081K
3. Mission Detailed Design:	$634K
4. Mission Development and Launch:	$4,045K
5. Mission Operations & Data Analysis, Archival and Dissemination:	$4,779K

B) Cost Estimates by Phase: Jet Propulsion Laboratory

1. Mission Concept Studies: No NASA funding is provided.	
2. Mission Definition and Preliminary Design:	$11,292K
3. Mission Detailed Design:	$10,070K
4. Mission Development and Launch:	$44,058K
5. Mission Operations & Data Analysis, Archival and Dissemination:	$7,098K

10. SCOPE OF WORK

A) PI Institution

1. Mission Concept Studies

The Principal Investigator (PI), Bernard Minster, leading the study team, has developed detailed science requirements for the succeeding phases. The PI has reviewed the science investigation description, and modified it as necessary, to provide updated information for instrument technical requirements to form the basis for further development during Phase 2. The PI has approved the cost plan and the implementation and management plans that accompany it and provided a written commitment that, if chosen, the mission cost will be limited to that proposed. The PI has approved any science performance changes and reported them to NASA. The instrument providers have analyzed the information provided by the PI, and provided updated cost and schedule information for each instrument to be developed.

2. Phase 2

Ball Aerospace, in coordination with the PI, will specify antenna-to-spacecraft interfaces and mission operations requirements. They will provide data to support the inheritance review. The PI will approve any science performance descopes and report them to NASA.

3. Phases 3 and 4

The PI will provide oversight of all science instrument design, development, manufacture and testing to ensure delivery of the science instruments within the agreed parameters established for the Project. The PI will approve any science performance descopes and report them to NASA. The Instrument provider will develop, manufacture and test their hardware prior to delivery of the instruments to the spacecraft provider.

4. Phase 5

   The PI will organize the collection, analysis and dissemination of data, including the publication of scientific findings and communication of results to the public.

B) The Jet Propulsion Laboratory:

1. Concept Study

   JPL has performed trade studies to optimize mission design, integrated the mission operations, ground and data systems, refined the management plan, provided a detailed cost analysis, and coordinated further development of the education, public outreach, technology, and small / small disadvantaged business plans. JPL has also prepared the cost plan that accompanies the PI's commitment to accomplish the mission at the proposed cost.

2. Phase 2

   JPL will manage and coordinate preliminary design efforts leading to a Preliminary Design Review (PDR). This includes a Systems Requirements Review, Software Requirements Review, inheritance/peer reviews, and defining and documenting institutional support requirements and commitments from all participants.

   Under a JPL Contract, our industrial partner, Astrium GmbH, will perform spacecraft trades resulting in the documentation necessary to meet the requirements of the spacecraft PDR. It will also provide data to support the inheritance review.

   Under a JPL Contract, Ball will be responsible for the design and development of the radar panels, documentation of interfaces, and management of the antenna deployment structure subcontract. They will perform instrument trades resulting in the documentation necessary to meet the requirements of the Instrument PDR, including instrument requirements, spacecraft interface and mission requirements.

   Stanford and Vexcel Corporation will work collaboratively with the science team to define the requirements and design of the ground data system.

   JPL will support the Mission Design Review, Confirmation Readiness Review and Mission Confirmation Review, which are part of the approval process for transitioning to Phases 3 and 4.

3. Phases 3 and 4

   JPL will manage detailed design and implementation, including mission assurance and progress reporting, and will initiate at least the following reviews: Critical Design Review, Pre-Environmental Test Review, Pre-Ship/Operational Readiness Review, and Flight and Mission Readiness Reviews for the spacecraft.

   The completed antenna panels will be shipped to JPL for electrical integration and test. The tested panels and radar GSE will be shipped to AEC-Able Engineering for mechanical integration with the antenna deployment structure, while the radar electronics are sent to Astrium for integration with the bus. The integrated antenna and structure will be shipped to Astrium for integration with the spacecraft bus.

Astrium and DLR will coordinate with JPL to develop the mission operations center. Command and control will be through the GSOC in Germany, under the direction of a JPL mission operations lead.

Stanford and Vexcel will work collaboratively to develop, deploy, and test the ground data system.

4. Phase 5

The spacecraft will be operated by the DLR through the German Space Operations Center under the direction of the JPL mission operations center, and the data returned via two X-band downlink stations (Alaska SAR Facility and University of Miami). Science data acquisition planning will be carried out at the planning center at Scripps. The returned science data will be distributed via the Ground Data System, developed by Stanford University. All ECHO data also will be available online throughout the mission at the San Diego Supercomputing Center. In addition, the data will be maintained at USGS EROS data center (the permanent archive.)

The Southern California Earthquake Center will be responsible for Education and Outreach during Phase 5.

L.3 CERTIFICATIONS

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91109-8099
(818) 354-4321

JPL

Date: **January 18, 2002**

Refer to: 231-2001-055C

To whom it may concern:

Subject: Certifications

This is to advise you that the California Institute of Technology, Jet Propulsion Laboratory (JPL) submits the enclosed JPL proposal to perform work pursuant to the JPL prime contract with NASA.

Under Contract No. NAS7-1407, research for NASA is performed at JPL in accordance with individual JPL task orders issued under the contract. The enclosed proposal, if accepted, will be performed under this contract. All certifications that NASA requires for JPL were provided to NASA in connection with the award of Contract NAS7-1407 signed September 21, 1998 and effective September 21, 1998. All certifications applicable under Contract No. NAS7-1407 apply to all task orders issued thereunder.

As such, additional certifications accompanying JPL proposals are unnecessary.

For information purposes, a list of the JPL prime contract certifications is enclosed.

The certifications and their applicability may be confirmed by contacting Mr. Carl C. Weber, Procurement Officer, NASA Management Office-JPL, 4800 Oak Grove Drive, Pasadena, California 91109 (telephone: (818) 354-5359).

Cordially,

Stephen L. Proia, Manager
Contracts Management Office

CCB:sb

Enclosure

CERTIFICATIONS PROVIDED BY THE CALIFORNIA INSTITUTE OF TECHNOLOGY, JET PROPULSION LABORATORY (JPL) TO NASA IN CONNECTION WITH NASA'S AWARD OF CONTRACT NO. NAS7-1407 SIGNED SEPTEMBER 21, 1998.

(ALL CERTIFICATIONS APPLICABLE UNDER CONTRACT NO. NAS7-1407 APPLY TO ALL TASK ORDERS ISSUED THEREUNDER.)

CERTIFICATION NO., FAR REFERENCE, AND TITLE:

K-1.1 [52.203-11], CERTIFICATION AND DISCLOSURE REGARDING PAYMENTS TO INFLUENCE CERTAIN FEDERAL TRANSACTIONS (APR 1991)

K-1.2 [52.204-3], TAXPAYER IDENTIFICATION (JUNE 1997)

K-1.3 [52.204-5], WOMEN-OWNED BUSINESS (OCT 1995)

K-1.4 [52.209-5], CERTIFICATION REGARDING DEBARMENT, SUSPENSION, PROPOSED DEBARMENT, AND OTHER RESPONSIBILITY MATTER (MARCH 1996)

K-1.5 [52.215-4], TYPE OF BUSINESS ORGANIZATION (OCT 1997)

K-1.6 [52.215-6), PLACE OF PERFORMANCE (OCT 1997)

K-1.7 [52.219-1], SMALL BUSINESS PROGRAM REPRESENTATIONS (JAN 1997)

K-1.8 [52.222-21], CERTIFICATION OF NONSEGREGATED FACILITIES (APR 1984)

K-1.9 [52.222-22], PREVIOUS CONTRACTS AND COMPLIANCE REPORTS (APR 1984)

K-1.10 [52.222-25], AFFIRMATIVE ACTION COMPLIANCE (APR 1984)

K-1.11 [52.223-1], CLEAN AIR AND WATER CERTIFICATION (APR 1984)

K-1.12 [52.223-13], CERTIFICATION OF TOXIC CHEMICAL RELEASE REPORTING (OCT 1996)

K-1.13 [52.225-1], BUY AMERICAN CERTIFICATE (DEC 1989)

K-1.14 [52.226-2], HISTORICALLY BLACK COLLEGE OR UNIVERSITY AND MINORITY INSTITUTION REPRESENATIONS (MAY 1997)

K-1.15 [52.227-6], ROYALTY INFORMATION (APR 1984)

K-1.16 [52.227-15], REPRESENATION OF LIMITED RIGHTS DATA AND RESTRICTED COMPUTER SOFTWARE (JUN 1987)

K-1.17 [52.230-1], COST ACCOUNTING STANDARDS NOTICES AND CERTIFICATION (APR 1996)

K-1.18 [52.245-79], USE OF GOVERNMENT-OWNED PROPERTY (JULY 1997)

L.4 PRELIMINARY MISSION DEFINITION AND REQUIREMENTS AGREEMENT

L.4.1 MISSION OVERVIEW

The primary goal of the ECHO mission is to obtain a time series of spatially continuous, vector maps of surface change associated with earthquakes, volcanoes, ice sheets and glaciers. This goal will be achieved by measuring millimeter-level surface deformation at resolutions of tens of meters with worldwide accessibility. The principal geographic focus areas include regions of active tectonics and regions of glaciation.

The time series deformation data provided by ECHO will be able to detect slow (weeks to years) transient deformations that have only been inferred or observed occasionally in isolated seismic, volcanic, or glacial areas. The long-term nature of the ECHO mission will allow the scientific community to answer three overarching science questions:

- How does strain accumulate along faults and plate boundaries and is released during the earthquake cycle?
- What are the spatial and temporal deformation patterns of volcanoes worldwide, and how can these data help predict eruptions?
- What is the rate and variability of ice discharge and what it its relation to sea level rise and climate change?

These questions address two of the five key research priorities of the NASA *Earth Science Enterprise* (ESE) *Research Strategy for 2000-2010:* Primary Forcings of the Earth System, and Earth System Responses and Feedback Processes. Specifically, ECHO is designed to characterize, understand, and model: *i) "How is the Earth's surface being transformed and how can this information be used to predict future changes?"* and *ii) "How is global sea level affected by climate change*?"

Implementation of the mission will be efficient and cost effective due to international collaboration. The ECHO Principal Investigator (PI), Dr. Bernard Minster of the Scripps Institution of Oceanography, has established teaming arrangements with two Deputy-Principal Investigators: Dr. Paul Rosen of the Jet Propulsion Laboratory for the Space Segment and Dr. Howard Zebker of Stanford University for the Ground Segment. The mission is managed by Jet Propulsion Laboratory. ECHO is proposed jointly to NASA ESSP and to the National Science Foundation, as a component of the multi-disciplinary, multi-agency EarthScope national initiative. Collaborating on the mission are Astrium GmbH, The German Aerospace Center (DLR), Ball Aerospace and Technologies Corporation (BATC), Vexcel Corporation, Stanford University, and the US Geological Survey.

The PI will have overall responsibility for the total mission, including the instrument, spacecraft, ground system, mission planning and operations, data processing and analysis, and data distribution. The PI will be supported by experienced teams for management and engineering, which have established close and efficient working relationships. The Deutsche Zentrum fur Luft and Raumfahrt (DLR) will work under an International Memorandum of Understanding (IMOU) with NASA. Under JPL Contracts, BATC will provide the radar antenna panels, Astrium GmbH will provide the spacecraft, and Stanford University and Vexcel Corporation will provide the ground data system.

L.4.2 SCIENCE OBJECTIVES

L.4.2.1 Baseline Science Mission

Primary Objective:

The primary objective of the ECHO mission is to provide a continuous time series of spatially continuous, vector maps of surface change associated with earthquakes, volcanoes, ice sheets and glaciers. By providing the first continuous time series of data, ECHO will reveal areas of surface deformation previously unobserved, and significantly increase our understanding of Earth's fundamental processes. Monitoring inter-seismic strain is the highest priority objective, followed closely by studying volcanoes and ice/glacier sheets.

Secondary Objectives:

ECHO data will be useful for studying other geophysical phenomena as well. One example, among many, is the study and management of groundwater aquifer systems. Although withdrawal of water from subsurface aquifers represents only a small term in the global water cycle, the limited nature of this resource directly determines the habitability of many arid areas. ECHO observations will lead to better models and improved management of this important resource, which is becoming scarce. Other examples include landslides, floods, oil extraction, and coastal erosion, all of which include aspects of the NASA ESE natural hazards strategic goal.

Baseline Science Objectives Summary

ECHO will meet its baseline science objectives with a low-cost SAR system aboard a single dedicated spacecraft. A 5-year mission is required to meet these objectives. The L-Band SAR uses two sub-bands with 70-MHz separation to permit ionospheric corrections similar to the L1/L2 GPS approach. While the instrument is based on existing technology, it represents a major leap forward in measurement capability in that, unlike other SAR missions, ECHO is optimized specifically for InSAR to overcome the many limitations of existing systems.

Key features of the instrument and mission design that will help achieve the science objectives are as follows:

- L-band minimizes temporal decorrelation.
- No competing science objectives or other instruments complicate the mission.
- Two sub-bands separated by 70 MHz allow correction of ionospheric effects.
- Onboard GPS for cm-level orbit and baseline knowledge improves calibration.
- Orbit maintenance within a 250-m tube guarantees that every scene is interferometrically valuable.
- A right/left slew capability of the spacecraft allows the fixed-mount radar antenna to point to either side of the orbit plane, permitting vector displacement measurements and full coverage of polar regions.
- Frequent coverage is possible for target areas to reduce artifacts from atmospheric and other noise sources, through time-series analysis techniques.
- Electronic beam steering minimizes spacecraft interactions for acquisition, and allows greater flexibility in science planning via wide-swath ScanSAR operations.
- A ScanSAR capability which will allow deformation mapping over broad swaths in areas previously surveyed at full resolution. This capability is most compatible with regional-scale tectonic deformation issues.

In the baseline mission, science data will be acquired and archived at an average rate of 7 minutes per orbit (the design will accommodate up to 8.5 minutes per orbit). These data will be provided to users in raw format, along with the software necessary to process them to calibrated range-displacement maps.

The ECHO ice sheet objectives require an accuracy of 1 m yr^{-1} over scales of 200 km and greater. This requirement translates into a displacement accuracy of 11 mm over 8 days. Averaging of multiple observations (1-4) and/or longer intervals (> 8day) can provide this accuracy.

L.4.2.2 Minimum Science Mission

Characterization of co-seismic and post-seismic portions of the crustal strain budget on several major plate boundaries is a minimum requirement. Global accessibility would still be required to sample a sufficient number of events. Measurement of inter-seismic deformation throughout a single plate boundary zone is also a minimum requirement.

Observation of the full set of 600 active volcanoes is a minimum goal. Sampling of at least every other month is a minimum objective.

A minimum subset of the ice sheet objectives could be met with a single ice sheet mapping and frequent sampling of roughly 40 glaciers worldwide.

L.4.2.3 Science Data Products

L.4.2.3.1 Science Data Rights

There will be no proprietary science data rights for the mission. ECHO will provide free and open distribution of satellite radar echo data consistent with NASA and US. Government data policy. The ECHO ground system will distribute data to the science community in two ways: Internet access, and requests to the long-term archive. All higher-level products will be distributed in EOS-HDF format for compatibility with EOSDIS, although production of such datasets by the science team will be limited to mission-defined natural laboratories. Other products will be generated and distributed through the science community.

The basic ECHO products are Level-1A SAR data, consisting of Level-0 SAR signal data, Doppler analysis, precision orbit state vectors, and other meta-data necessary to produce calibrated measurements of deformation using the ECHO supplied software. ECHO will maintain a uniform and consistent format to simplify processing.

The project-supplied processing software will be distributed to the science community. Scientists will use the software to generate higher level products quickly and efficiently. For interferometry, where time-series analysis is the essence of the science observation, scientists must fulfill their specific requirements by processing the data themselves. The delivery of high-level products is as fast as the transfer of archive data to the local computer, and involves several hours of data analysis and processing locally.

The project-supplied processing software will produce high-level products. Level 1B products include the processed SAR imagery (single look complex) and associated meta data for geolocation. Level 2 products include SAR interferograms, correlation maps, and other intrinsically interferometric meta-data, such as refined-baselines, and phase parameters. Level 3 products include geo-coded and calibrated displacement maps and associated meta-data.

Higher level science products will be generated by the science team in each of three “natural laboratories”, Southern California for earthquakes, Hawaii for volcanoes, and west Antarctica for ice sheets. These products will include regional velocity maps, stress change maps, and source models. The general science community will be funded to produce similar products through a follow-on NASA research opportunity, as well as through NSF and US Geological Survey (USGS) research grant programs.

L.4.2.3.2 Measurement Requirements

Characterizing inter-seismic strain accumulation is the highest priority science objective and drives accuracy requirements. A baseline-mission single-component accuracy requirement of 2 mm yr^{-1} over spatial scales of a few hundred km for inter-seismic objectives will allow estimation of strain accumulation on locked faults with long-term slip-rates of 10-20 mm yr^{-1}. This requirement will also allow estimation of average strain rates of order 10^{-7} yr^{-1}, and is achieved by averaging multiple observations over a 5-year mission.

For volcano studies the baseline mission must cover the principal volcanic regions of the Earth at least monthly. Two components of displacement must be recorded with an accuracy of 5-10 mm over distance scales of 25-50 km.

The ECHO ice sheet objectives require an accuracy of 1 m yr^{-1} over scales of 200 km and greater. This requirement translates into a displacement accuracy of 11 mm over 8 days. Averaging of multiple observations (1-4) and/or longer intervals (> 8day) can provide this accuracy.

L.4.2.3.3 Descope Options

ECHO relies on a single simple instrument. The main hardware descope would be removal of the phase shifters for electronic steering and ScanSAR. The spacecraft—through mechanical roll of the entire structure—then would be used to steer the beam. This does not compromise the baseline objectives, but loss of beam agility would add cost and complexity to the instrument tasking, and therefore, Mission operations This modification would have to be implemented before CDR to save roughly $1M.

Removing the BlackJack GPS receiver and associated POD activity is another descope option. Orbits better than 1 m could be achieved with less expensive and less capable single-frequency GPS receivers. This accuracy is sufficient for navigation, but insufficient for science analysis without relying more heavily on ground control for interferometric baseline estimation. Removing the BlackJack receiver would save up to $5M, depending on when development was stopped. This would make the science analysis more labor intensive, and thus, slow science analysis and reduce the overall rate of science return.

Another descope that achieves cost savings, at the expense of the science return, involves reduction in the data volume. By reducing the total data requirement, it is possible to limit the ground system to a single ground station, reduce the archive and distribution load by roughly 20-30%, and reduce the size of the onboard storage device. All of these reductions in hardware occur during Phase 3/4 (formerly phase C/D.) Cost savings of roughly $10M can be expected and potentially greater savings (at significant cost to the science production rate) could be achieved if the distributed archive concept is scaled back or replaced by a tape distribution system from EROS Data Center only.

Removing the ScanSAR timing vernier would disable ScanSAR operations and save approximately $1M if implemented by CDR. The impact on science objectives is minimal, as ScanSAR is an experimental mode.

L.4.3 MISSION AND PROJECT REQUIREMENTS

L.4.3.1 Mission Cost and Budgetary Requirements

ECHO is a PI-led, cost-capped mission. As proposed, the mission shall be accomplished with a cost to NASA ESE of no more than $125M and a total NASA mission cost of no more than $175M. Cost management is the responsibility of the Project Manager (PM). The PM will identify and resolve budget problems, and will report status regularly to the NASA sponsor. The PI will be prepared to recommend mission termination if in his judgement, the successful achievement of established science/applications objectives, as defined in this proposal, is no longer likely within the committed cost and schedule reserves.

L.4.3.2 Schedule

The Level-1 schedule milestones are listed as follows:

• System Requirements Review	Nov 2002
• Mission Design Review	Aug 2003
• Critical Design Review	May 2004
• Pre-Ship Review	Feb 2006
• Internal Progress Reviews	Monthly
• Deliver Spacecraft to Launch Site	Aug 2006
• Launch	Oct 2006
• End of Mission	Oct 2011

L.4.3.3 Management System

The mission will establish an effective and efficient management system which will assure that the science objectives can be accomplished within the schedule and cost limitations. As a minimum the following management requirements will be met:

- The ECHO mission will be managed as a cost-capped project.
- All hardware and software will be verified through robust testing;
- Quality assurance program will be consistent, or exceed, standards set in ISO 9000;

- The Principal Investigator (PI) will exercise overall responsibility for the mission implementation and the leadership of the US Science Team;
- The PI will form and chair a Project Management Team (PMT) which will coordinate all program elements between organizations in both countries;
- A DLR appointed scientist will serve as a member of the Science Team, and provide management oversight of all German operations in support of this project;
- The Project Manager (PM), acting through JPL, will lead the satellite and system implementation effort, and be responsible for the mission and systems engineering team;
- DLR will be the lead agency for mission operations for this project, although JPL will continue an MOS monitoring and verification function throughout;
- Kosmotros (through DLR) will be the lead agency for the launch vehicle of this project.

Any requisite modifications to these requirements for Phase 3, 4, and 5 will be defined during Phase 2.

L.4.3.3.1 Scheduling

A fully integrated scheduling system will be established and implemented during Phase 2 to manage all project elements. This system will include the development of network schedules and critical paths. A Level-1 baseline schedule will be developed during Phase 2 and approved by NASA.

L.4.3.3.2 Performance Metrics

A system to measure mission progress compatible with the scheduling and cost control systems will be established and implemented during Phase 2.

L.4.3.3.3 Key Personnel

Changes in the key personnel, defined as the Principal Investigator and the Project Manager, or changes in either Deputy PIs, will be subject to NASA approval. The key DLR personnel, or any changes in such personnel will be approved by the collaborating organizations.

L.4.3.3.4 Contract Deliverables

Major contracts which are developed as part of the mission will reflect the science nature of the investigation. As appropriate, deliverables will focus on the science products, and incentive plans will reflect the science deliveries. For this mission, primary emphasis is placed on cost and schedule.

L.4.3.3.5 Incentive Fee Plans

Implementation contracts will provide incentives to the contractor for both adherence to cost commitments and technical performance. Subcontracts from JPL for the ECHO Mission will be negotiated prior to selection and issued shortly after selection. Subcontractors include Astrium GmbH, Ball Aerospace and Technology Corporation, Stanford University, and Vexcel Corporation. Upon completion of contract negotiations, a discussion of fee pools and incentive plans will be added to this section.

L.4.3.4 Legal Requirements

The Project will abide by all necessary U.S. federal (including NASA), state and local laws and regulations.

L.4.3.5 New Facilities

There are no new project specific major facilities required for this mission

L.4.3.6 Descope Plan

The PI is responsible, directly and indirectly, through recommendations to the GSFC Mission Manager, for implementing the Descope Plan when it appears that the mission cannot meet its baseline science requirements. If a descope is necessary, the Descope Plan will describe how the Mission will meet the minimum science, budget and schedule requirements.

A preliminary descope list is shown in Table L.4-1.

Table L.4-1: Preliminary Descope List

Descope Option	Implications	Latest decision w/ no adverse schedule impact	Potential Cost Savings	Impact on Science Objectives
1. Eliminated electronic beam steering	Simplifies antenna design, implementation and testing. Loss of ScanSAR mode.	PDR	$1M	Minimal
2. Replace project supplied dual frequency GPS receiver and associated precision orbit determination with commercial unit	Less precision in orbit determination	PDR	$4M-5M	More laborious science computations, additional software development for science processor, some users would require additional training.
3. Reduce volume of science data	Limits ground system to single ground station, reduces the archive & distribution load by 20-30%, reduces onboard data storage requirement	Phase 4	$4	Reduced science return. Minimum mission.
4. Scale back the regional archive network	Some data will not be available unless ordered from permanent archive, slowing down access	CDR, before implementation	$10M	Reduce timely science during the mission by limiting access to the data. Overall mission science would not be impacted if future funding enabled science work.
5. Remove ScanSAR timing vernier.	Disable ScanSAR to ScanSAR operations	CDR	$1M	Minimum, as ScanSAR mode is experimental

L.4.4 MISSION RESPONSIBILITIES

L.4.4.1 Principal Investigator and Science Team

The Principal Investigator (PI), Bernard Minster, will be responsible to NASA for achieving the objectives of the mission. Paul Rosen and Howard Zebker are the ECHO deputy PI's, responsible for the space segment and ground segment, respectively. The PI has designated a single individual as Project Manager (PM), Kim Leschly of JPL, and shall delegate to him the requisite responsibility and authority to manage and administer the effort to implement the ECHO mission. This group of four makes up the top level Project Management Team (PMT). The PI will make decisions related to mission objectives in consultation with the PMT. The PI will also lead the scientific analysis team responsible for data analysis and EPO.

The PM shall have delegated to him the requisite responsibility and authority to manage and administer the effort to implement the ECHO mission. The PM shall ensure that all the objectives associated with the implementation effort are accomplished within schedule and cost constraints, and provide timely reporting of overall progress.

The tasks of the PMT, which consists of the PI, Deputy PIs, and PM, are to ensure that the program is guided in a responsive manner to maximize the science gains for the mission cost consistent with the constraints of ESSP.

The Science Team's responsibilities are described in detail in Section F.5 of the original Step II proposal.

The PI may change the composition of the science team to meet the objectives of the Mission, with notification of such changes to the ESSP Project Office. International participation will be consistent with the NASA/DLR Memorandum of Understanding.

L.4.4.2 Industrial Partners

JPL will provide oversight & management to implement the mission, including all phases of the mission, including providing management oversight of the contract to Astrium for the spacecraft, management oversight of the Ball Corporation contract, management oversight of the ground data system contracts to Stanford University and Vexcel Corporation, project system engineering necessary to implement the mission, and Mission Assurance. JPL will design, build and test the L-band radar electronics for the science instrument, and be responsible for the integration and testing of the Ball-built L-band active phased-array antenna with the radar electronics. JPL will support integration and testing of the radar and spacecraft in Germany. JPL will design, build and test a GPS receiver and Star Camera package for integration to the Astrium spacecraft and support integration and test of the GPS and spacecraft in Germany. JPL will develop a mission operations plan and operations interface to the German Space Operations Center. JPL will participate in science team activities through the involvement of the Deputy PI and two science team members including the design, building and testing of processing software for the radar data delivered by the flight system as part of the science team activity, and participation in calibration and validation activities during Phase 5 (formerly Phase E)

Astrium GmbH will perform design and development of the spacecraft bus, integration and test of the spacecraft and payload at the contractor's facility, environmental test at the contractor's facility, delivery of the flight system to the launch site by 2 months before launch, support of launch operations, and in orbit commissioning.

Ball Aerospace and Technology Corporation will be responsible for the design and development of the radar panels, test of the panels at Ball facilities, documentation of interfaces and execution of tests, support of radar integration and test at JPL, support of spacecraft integration and test at Astrium, and management of the antenna deployment structure subcontract.

Stanford will manage and maintain the Network Transfer System (NTS). Stanford is responsible for the design and development of a computer system that receives high-rate radar data from the ground stations, transfers the data to a distributed set of archive centers and sends documentation of its transactions to a catalog system. Stanford will test the system and deliver all design and test documents to the project.

Vexcel will perform design and development of the ground station data capture and level 0 processing system, web-based catalog system, and five network-based archive and distribution systems, designed to receive data from the Network Transfer Subsystem. Vexcel will integrate and test the system in concert with Stanford. Vexcel will manage the operations and maintenance of the archive and distribution centers and the capture systems.

L.4.4.3 Other Team Members

Alaska SAR Facility services subcontract: ASF will operate their receiving station to acquire ECHO data sufficiently often to meet project needs—roughly 60 minutes per day of downlink time. ASF will install the ECHO data capture system and level 0 processor, and operate the system.

University of Miami Ground Station services: University of Miami will provide downlink services for ECHO X-band high-rate data for the life of the ECHO project. The Project will provide upgrades to the existing capture hardware to accommodate the 300Mbps downlink, and Miami will staff the center to ensure data system integrity, roughly 4 passes per day. The Project will work with the University of Miami Ground Station personnel to smoothly incorporate ECHO acquisition timelines into the ground station tasking plan.

USGS EROS Data Center (EDC) National Archive: The USGS EDC will design, build, and test a national archive system that will allow access to the ECHO SAR data in a form compatible with the EOSDIS requirements. The system will ingest ECHO data in native Level-0 format and process it to granules and meta-data suitable for the EDC archive, catalogue and user-interface systems.

San Diego Supercomputer Center Near-line Archive (SDSC): The SDSC will store and distribute the entire ECHO mission data set during the life of the mission, under contract with the PI. The data will be stored and distributed in the native format supplied by the Vexcel Level-0 processor, and will therefore be very inexpensive to implement.

Regional Archive Centers: Five regional archive data centers will be established to distribute large-volume ECHO SAR data to the science community. The centers will be located at Stanford University, California Institute of Technology, National Snow and Ice Data Center, Massachussetts Institute of Technology, and Howard University. Each center will be provided with an archive system by the project. The center will supply facilities resources and internet-2 connectivity for the life of the project. The system will be monitored for health and safety by center administrators, but it will be maintained by the ECHO project.

L.4.5 NASA RESPONSIBILITIES

The NASA HQ Code IY will provide support in expediting ITAR issues and in the development of a Memorandum of Understanding (MOU) with the international partners on the ECHO mission. The NASA HQ Code Y will work with the other agencies, the National Science Foundation and the USGS, to resolve jointly funding profile issues. The GSFC ESSP Project Office will provide mission funding, contract administration and programmatic oversight for the ECHO mission. To implement the ECHO Mission, the ESSP Project Office will provide funds directly to two members of the ECHO Team—SIO and JPL as requested by the PI. Furthermore, the ESSP Project Office may provide other mission-unique support, only as may be requested by the PI in writing and agreed upon by the ESSP Project Manager. In the event such support is requested, a portion of the PI’s mission funds would be retained by the ESSP Project Resources Office, to be disbursed as requested by the PI.

L.4.6 REPORTING AND NASA REVIEWS

The Project will utilize a rigorous review process in accordance with JPL D-10401. It will be similar to the successful CloudSat Project review process. Table L.4-2 describes project level reviews, their purpose, and timing. Reviews will include all of the types of reviews called for in the AO and in the NIAT report:

- Critical Milestone Reviews
- Peer Reviews, which will precede Critical Milestone Reviews, and will provide in-depth assessment of technical material (Program and project management may attend these reviews)
- Product Integrity Reviews by the line management of the organizations performing the work of the Project. These reviews include participation in Critical Milestone Reviews and in Peer Reviews, and also include reviews at the system and subsystem level, where appropriate. These and peer reviews will be conducted consistent with the JPL Reviews Process, which incorporates the recommendations of the NIAT
- Red Team Reviews, beginning at CDR.
- Independent Reviews lead by the JPL and GSFC Systems Management Offices (SMO).

The intent of the review process is to assess progress during the formulation, implementation, and operation phases of the Project. Reviews will address the adequacy of the Project definition and the understanding of the driving requirements, interfaces, capabilities, and verification methods. Reviews also will be used to demonstrate understanding of the driving technical risks and the intended means by which those risks will be mitigated. In addition, the reviews will address the adequacy of margins.

Critical Milestone reviews will include a description of the disposition of all requests for action (RFAs) from the peer reviews. The review board will be informed of the disposition of RFAs after each review.

Reviews will be consolidated where practical. For example, peer reviews and heritage reviews will be consolidated. The MDR will be held at the end of the mission Formulation Subprocess and will be combined with the PDR. Also, Red Team reviews will be integrated with formal reviews. An Integrated Independent Review Team (IIRT) will comprise experts who are fully independent of the ESSP Office and the Project and largely independent of the performing organizations. The

Table L.4-2: Reviews Summary (All dates will be based on a 08/01/2001 start)

Review	Purpose	Timing
System Requirements Review (SRR) and Software Requirements Review (SWRR)	Formally examine the agreed-to mission science, operations and technical (Level 1 and Level 2) requirements Assess Level 2 SW requirements Traceability of these requirements will be demonstrated	11/02
Informal Peer Reviews And Heritage Reviews	Provide in-depth review of the preliminary design and any inherited designs/hardware/ software at the subsystem level by knowledgeable peers	For 30 days prior to PDR/MDR
Preliminary Design Review (PDR), Mission Design Review (MDR)	PDR: • Examine preliminary designs of all mission subsystem and system components for technical feasibility with respect to the mission requirements • Assess the mission design at the subsystem and system levels • MDR: • Does the Mission, Spacecraft and Instrument Design, as presented, reflect a level of maturity that meets the mission science requirements? • Are the Management Processes used by the Mission Team sufficient to develop and operate the Mission? • Do the cost estimates, control processes and schedules indicate the mission will be ready to launch on time and within budget? • Risk assessments and compliance with JPL Design principles will also be described	PDR 7/03 MDR 8/03
Confirmation Readiness Review (CRR)	Earth Explorers Program approval for mission to proceed into Implementation	8/03
Mission Confirmation Review (MCR)	Associate Administrator, Office of Earth Science approval for the mission to proceed into Implementation	9/03
Informal Peer Reviews	Provide in-depth review of the detailed design and test planning at the subsystem level by knowledgeable peers	For 30 days prior to CDR
Critical Design Review (CDR), Software Critical Design Review (SWCDR), and Red Team Review	Assess readiness of design approaches, mission operations planning, as well as test planning for all flight systems	5/04
Informal Peer Reviews	Provide in-depth review of the readiness of each subsystem for integration and test by knowledgeable peers	For 30 days prior to PER
Pre- Environmental Review (PER), Software Test Readiness Review (SWTRR), and Red Team Review	Assess the readiness of the flight hardware, software and required environmental test facilities to begin acceptance testing Verify readiness of Ground System to support integration and testing	2/06
Pre-Ship/Operational Readiness Review (PSR/ORR) and Software Acceptance Review (SWAR)	Verify that all system elements meet the requirements of the mission and are ready to proceed into final launch preparations. Verify that testing has been completed with no unacceptable open issues Validate the readiness of the flight hardware and software and ground system	
Mission Readiness Review (MRR)	Assess readiness of all mission systems to proceed with the launch campaign Assess readiness to proceed with full-up, routine operations	8/06 L – 30 to 42 days

Table L.4-2: Reviews Summary (All dates will be based on a 08/01/2001 start) (Continued)

Launch Readiness Review (LRR)	Update mission status and certify final flight readiness of all mission elements	9/06
	Verify that all open issues from the MRR have been resolved	L – 1 to 2 days

IIRT will be led by two co-chairs; one each from the GSFC SMO and the JPL SMO, who will be responsible to the GSFC PMC and the Office of Earth Science for the conduct and reporting of the Integrated Independent Reviews

L.5 DRAFT INCENTIVE PLANS

Summary of major ECHO partners and incentive plan requirements:

1. PI Organization: Scripps Institution of Oceanography at the University of California, San Diego.

   Scripps is an educational institution and receives no fee. Thus, no incentive plan is required.
2. Managing Organization: NASA Jet Propulsion Laboratory

   JPL receives a fee from NASA and that fee is at risk and is subject to return to NASA if the mission fails.
3. Spacecraft Contractor: Astrium GmbH

   The contract with Astrium will be firm fixed price; thus no incentive plan is required.
4. Antenna Provider: Ball Aerospace and Technologies Corporation

   The Ball Antenna contract costs described in the proposal assume a cost-plus fixed fee contract, with a fee of 10% for the contract duration.

   The actual contracts with Ball Aerospace and Technologies Corporation will be negotiated as soon as possible after mission funds are received. The Phase 2 contract will be cost-plus fixed-fee. During phases 3/4, the contract will be incentive-based with terms to be negotiated before the start of Phase 3/4. A draft incentive plan for Ball Aerospace is provided following this summary.
5. Ground Data System: Vexcel

   JPL will negotiate a cost-plus fixed-fee contract with Vexcel for the ground data system. Since the contract has a fixed fee (10%), no incentive plan is required.
6. Network Transfer System: Stanford University

   Stanford is an educational institution and receives no fee. Thus, no incentive plan is required.

ECHO Proposal
Incentive Plan for Ball Aerospace

DRAFT

Background

Under the terms of the accompanying draft Mission Definition and Requirements Agreement, the Principal Investigator and JPL intend to contract with our Industry Partner, Ball Aerospace and Technologies Corporation (the Contractor), for the ECHO spacecraft antenna radar panels. The following draft Incentive Fee Plan has been prepared to provide the cost and performance fee philosophy for the efforts performed by the Contractor under the resulting Phase 3/4/5 contract for the ECHO spacecraft antenna (the Contract). The fee base is the negotiated costs for Phase 3, Phase 4 and Phase 5 efforts under the Contract.

Incentive Fee Plan—General

In accordance with the ECHO Mission Definition and Requirements Agreement, the Incentive Fee Plan for the Contract shall meet the following requirements:

> The proposed contract type should incentivize the contractor for both adherences to cost commitments and technical performance. Since the quality of scientific requirements met during the performance of this contract is highly dependent on the specific execution of the mission, it is suggested that the form of the contract be structured under a Cost Plus Incentive Fee/Performance Award Fee structure. Under this structure the following guidelines apply:

The total fee pool (up to 12% of the Target Cost, as defined below) will be divided equally between the cost (6%) and performance (6%) pools. This division could change depending on the cost, schedule and technical risk actually envisioned as part of the Project's risk management efforts determined in the formulation phase. Fee may be paid provisionally during the performance of the contract, but the final value of the fee earned will be determined after the mission has been completed and the scientific data has been delivered. Provisional payments will be refunded if the payments exceed the contractor's incentive fee earned.

Incentive Fee Plan—Cost Share

The cost incentive structure will be based on a Target Cost being negotiated along with a Target Fee. The Target Cost will be the negotiated estimated cost of the contract to the Industry Partner, not including cost of money. The Target Fee will be an amount between zero and 12% of the Target Cost. A cost incentive Share Ratio will also be negotiated based on the cost risk agreed to for Phase 3/4/5. When the contract is completed, the Delta Cost will be calculated as the difference between Target Cost and the Industry Partner's actual cost, and the Delta Fee will be calculated as the Delta Cost times the Share Ratio, subject to a maximum ofthe amount in the Cost Pool. The Target Fee will be will be increased by the Delta Fee if the actual cost is less than the Target Cost, and decreased by the Delta Fee if the actual cost is greater than the Target Cost. The total fee awarded to the Industry Partner, after calculation of the Cost Share and Performance Share under this Incentive Fee Plan, will not exceed 12% of the Target Cost.

Incentive Fee Plan—Performance Share

The performance share awarded will be based on the ECHO spacecraft antenna being available to meet the science objectives as defined in the Mission Definition and Requirements Agreement. This amount will not exceed the amount in the Performance Pool, and will decrease for partial ability to meet the science objectives.

L.6 RELEVANT EXPERIENCE AND PAST PERFORMANCE

L.6.1 JPL RELEVANT EXPERIENCE AND PAST PERFORMANCE

L.6.1.1 Introduction

In the early 1990s, JPL made a commitment to its NASA and non-NASA customers and sponsors that from that point on, we would deliver all products on cost and on schedule. To date we have had a near 100% success in meeting this commitment: Virtually all missions and flight instruments completed since 1990 have been completed to the full satisfaction of our customers with the exceptions noted below. All of JPL's PI-led missions currently under development are on track for achieving their baseline or near-baseline mission science objectives.

The major exceptions to achieving full customer satisfaction were 1) the Mars Observer (MO) mission, which exceeded the originally proposed cost and schedule, and failed just as it reached Mars; 2) the Mars Climate Orbiter (MCO) mission, which failed to enter orbit around Mars and is thought to have entered the planet's atmosphere and most likely burned up; and 3) the Mars Polar Lander (MPL) mission, which failed upon arrival at Mars and is thought to have crashed on the surface as a result of a premature shutdown of the lander's descent engines. JPL has learned from these experiences and has aggressively instituted numerous changes in the ways we do business to assure that the problems that beset these Mars missions will not happen again.

As part of this effort, JPL conducted its own reviews, and contributed to external reviews of the MO, MCO, and MPL failures. Several review boards have sought out the root causes and ways to avoid these failures in the future. The NASA Integrated Assessment Team (NIAT) report provides a summary of recommended actions. The JPL approach for ensuring mission success addresses these recommendations, including:

- Adopting design principles (NIAT Action 5) for all projects
- Adopting mission assurance principles (NIAT Actions 1, 8, 9, 13, and 14) and operations principles for all projects
- Reinforcing the training of managers at JPL, including updates to the Project Manager (PM) course, Project Element Manager course, and Cognizant Engineer courses (NIAT Actions 2.1 and 2.2). All PMs and prospective PMs are now required to receive the updated training
- Creating Centers of Excellence to promote the use of advanced engineering methods (NIAT Action 3), and a Planning Center to promote the use of advanced planning and management methods
- Distributing technology development throughout the Directorates of JPL, to ensure relevant technology development and to revitalize the technologies used on missions (NIAT Actions 3, 4 and 6)
- Ensuring that risk management is fully implemented on all projects (NIAT Action 7) and that Problem/Failure Reporting is fully implemented on all projects
- Developing a more rigorous formal review process with an integrated peer review process, and establishing stricter criteria for transition from one life cycle phase to the next (NIAT Action 10)
- Adopting principles for cost and schedule reserves (NIAT Action 11) that apply to all future projects
- (In progress) Completing the definition of JPL processes and lifecycle, in JPL's library of governing documents for process-based management (NIAT Action 12)
- Re-establishing the role of line management in the assurance of mission success, and clarification of other project roles and procedures defined in JPL's library of governing documents for process-based management (NIAT Actions 15 and 16).
- JPL is committed to ensuring the highest confidence possible for the success of future missions. As testimony to JPL's commitment to implementing these changes, many of the mis-

sions described in what follows have been restructured and/or received significant budgetary enhancements (with the full support of our customer) to more fully ensure mission success.

L.6.1.2 Relevant JPL Missions

ACRIMSAT
Description: *Launch:* December 20, 1999 *Mass:* 115 kg, fueled *Science instruments:* Active cavity radiometer The Active Cavity Radiometer Irradiance Monitor Satellite (ACRIMSAT) is designed to monitor variations in the total amount of the Sun's energy reaching Earth. This energy, called total solar irradiance, creates the winds, heats the land and drives ocean currents. Theories suggest that a significant fraction of Earth's global warming may be solar in origin due to small increases in the Sun's total energy output since the last century. By measuring incoming solar radiation, climatologists will be able to improve their predictions of climate change and global warming over the next century. Similar instruments were flown on the Solar Maximum satellite in the 1980s and the Upper Atmosphere Research System (UARS) satellite in the 1990s. ACRIMSAT was launched December 20, 1999, as a secondary payload on a Taurus rocket from Vandenberg Air Force Base. ACRIMSAT is in a 685-km altitude polar orbit. The Taurus' primary payload was the Korea Multi-Purpose Satellite, or KompSat. The ACRIMSAT instrument was designed and built by JPL, which also manages the mission. The spacecraft was designed and built by Orbital Sciences Corp.
Relevance to ECHO Mission: JPL instrument and instrument electronics design and test. Very large payload integration from payload perspective. Instrument project management, system engineering, mission assurance, data analysis, data processing and dissemination.
Cost and Schedule Performance: Cost and Schedule Performance: ACRIMSAT was originally budgeted at $19M to deliver the spacecraft bus, the ACRIM instrument, a ground station, and to provide five years of mission operations. The cost to NASA of the shared launch (originally planned on a Pegasus) was $6M, for a total mission cost of $25M. The final, delivered cost of the ACRIMSAT mission was $30M. There were several reasons for this cost increase: 1) There was a customer-directed change in the launch vehicle from a Pegasus to a Taurus; 2) As result of the recent Mars mission failures and the Lewis mission failure, the project incurred additional operations costs to insure mission success. The project was unable to absorb these costs as all reserves were used during Phase C/D (primarily to cover an additional two months of testing during I&T), and had to request more funding from the sponsor (Code Y). The project initially met all schedule milestones, but missed the launch date by two months, primarily as a result of the additional testing required and the customer-directed change in launch vehicle.
Point of Contact: Ronald J. Zenone, Project Manager JPL, M/S 171-400, (818) 354-2543

Genesis

Description:

Planned Launch: July 30, 2001

Mass: 494-kilogram (1,089-pounds)

Science instruments: Solar wind collector arrays, ion monitors, ion concentrator

Purpose: Collect solar wind samples for return to Earth

The Genesis mission will provide clues on the nature of the formation of the solar system by collecting samples of the solar wind, material flowing outward from the Sun. Comparing them with known compositions of the planets will help in the effort to understand our cosmic origins.

Following launch in summer 2001, the Genesis spacecraft will be placed into orbit around the L1 Lagrange point, a point between Earth and the Sun where the gravity of both bodies is balanced. Genesis will unfurl its collector arrays and begin collecting particles of the solar wind that will imbed themselves in specially designed high purity wafers. After two years, the sample collectors will be re-stowed and returned to Earth for a mid-air helicopter recovery of the sample return capsule.

Genesis is the fifth mission selected under NASA's Discovery Program. The principal investigator is Dr. Donald Burnett of the California Institute of Technology. Lockheed Martin Astronautics designed and built the spacecraft. Los Alamos National Laboratory developed and built the ion and electron spectrometers and solar wind concentrator. NASA/JSC has responsibility for curation of the returned samples. JPL has the technical responsibility for developing the collector arrays and the payload canister, integrating and testing the entire payload, and managing, designing and operating the mission.

Relevance to ECHO Mission: Cost-capped, PI-led project. Same approach as ECHO, i.e., system contract for spacecraft bus, and project management, project system engineering, and mission design/navigation performed by JPL.

Cost and Schedule Performance:

Genesis has met all major milestones throughout the development phase. The project was on schedule for meeting the original launch date of February 10, 2001, but the launch was delayed to July 30, 2001 by NASA HQ because of a concern that the spacecraft contractor might not be able to support ATLO for both Genesis and 2001 Mars Odyssey (which had an April 7, 2001 launch date), should an unforeseen problem arise. The Genesis project used the additional time to retire risks associated with the star tracker. The original proposed budget for Genesis was $216.2M (including launch vehicle), but customer-directed changes in scope associated with the Mars Climate Orbiter and Mars Polar Lander failures increased this by $16M. The changes in scope included additional reviews, safety and mission assurance, validation and verification efforts, and systems engineering support. The launch delay resulted in a cost increase of $27M, for a total mission cost of $259.2M. At no time during the development were any descopes implemented that would affect the mission's baseline science goals.

Point of Contact:

Chester N. Sasaki, Project Manager

JPL, M/S 264-626, (818) 354-9298

Jason 1

Description:

Launch: December 7, 2001

Purpose: Measure sea surface heights

Jason 1 is an oceanography mission to monitor global ocean circulation, study the ties between the oceans and atmosphere, improve global climate forecasts and predictions, and monitor events such as El Niño conditions and ocean eddies. It is a follow-on to the Topex/Poseidon mission, which has been measuring ocean topography since 1992. Like its predecessor, Jason 1 is a joint mission of the United States and France. These two satellites will provide a unique global view of the oceans that is impossible to acquire using traditional ship-based sampling.

Like Topex/Poseidon, Jason 1 will be able to measure the large and small hills and valleys of the ocean's surface. These measurements of ocean topography allow scientists to calculate the speed and direction of ocean currents and monitor global ocean circulation.

The global ocean is Earth's primary storehouse of solar energy. Jason 1's measurements of sea-surface height will reveal where this heat is stored, how it moves around Earth by ocean currents, and how these processes affect weather and climate.

Jason 1 has been designed to directly measure climate change through very precise millimeter-per-year measurements of global sea-level changes.

The Jason 1 satellite, its altimeter instrument and a position-tracking antenna have been built in France. The spacecraft will also carry a radiometer instrument to measure water vapor, a Global Positioning System receiver and a laser retroreflector array built in the United States.

Jason 1 was launched in December 2001 from California's Vandenberg Air Force Base.

Weighing 500 kilograms (about 1,100 pounds), Jason 1 is one-fifth the size of Topex/Poseidon. After launch, Jason 1 will fly in tandem with Topex/Poseidon, doubling the science data return for as long as Topex/Poseidon remains in good health. Jason 1 will then assume Topex/Poseidon's former flight path. The mission is planned to last for five years.

Relevance to ECHO Mission: International collaboration. JPL provided radiometer, GPS receiver and laser reflector array. Provided project management and mission assurance for JPL portion of mission.

Cost and Schedule Performance:

The Jason 1 project is currently under its revised budget. The launch was originally scheduled for May of 2000, but as a result of a series of delays requested by the project's French international partner, the current launch date has been slipped to December 7th, 2001. The project received additional funding for the impact of those delays on the JPL effort, and is currently underrunning.

Point of Contact:

Gary Kunstmann, Project Manager

JPL, M/S 264-686, (818) 354-6038

QuikScat

Description:

Launch: June 19, 1999

Mass: 970 kg, fueled

Science instruments: Scatterometer

Purpose: Systematic measurement of near-surface ocean wind vectors

SeaWinds on QuikSCAT was a rapid recovery mission to restore the flow of ocean wind vector data after the loss of NASDA's Advance Earth Observing Satellite (ADEOS) carrying the NASA Scatterometer instrument (June 1997). JPL has overall mission responsibility, other mission participants include Goddard, NOAA, Oregon State University, US Air Force, and the Japanese Space Agency (NASDA).

The QuikSCAT mission includes a scatterometer (JPL modified SeaWinds instrument in development for launch on ADEOS-II), spacecraft (GSFC/Ball), launch vehicle (USAF/ LMSC Titan II), mission operations (Ball/LASP), and ground data processing (JPL), archiving and distribution (PO.DAAC).

SeaWinds on QuikSCAT uses a Ku-band scatterometer (radar) instrument to measure ocean surface radar backscatter from which near-surface ocean wind vectors are derived in ground data processing. QuikSCAT data is used for scientific studies as well as for operational meteorological modeling and forecasts.

The QuikSCAT mission was designed for a two-year life with a goal of three years. QuikSCAT has now operated successfully for 2 1/2 years returning 98% of the possible total wind vector data during that time.

Relevance to ECHO Mission: Rapid implementation, JPL-managed system contract with large instrument. Management approach similar to ECHO, i.e., system contract with multiple partners.

Cost and Schedule Performance:

QuikScat went from the authorization to proceed to launch readiness in one year. The project met all major milestones, however, the launch was delayed seven months because of problems with the launch vehicle. QuikScat was able to meet this remarkable schedule because of several factors. The project was directed to use the existing Seawinds instrument, which was originally designed to fly on a Japanese spacecraft, and adapt it to a new bus. Furthermore, the project was able to use Ball Aerospace's existing QuikBird spacecraft (an Earth-imaging mission for a failed, third-party commercial venture) and adapt it to fly Seawinds. The original planned cost for the QuikScat mission was $85M ($39M for the spacecraft, $12M for Seawinds, $8M for science and mission operations, and $26M for launch services). The project was completed for $90M. The additional $5M covered the delay in launch and was fully supported by NASA Code Y.

Point of Contact:

James E. Graf, Project Manager

JPL, M/S 264-440, (818) 354-4765

SRTM

Description:

On February 11, 2000, the Shuttle Radar Topography Mission (SRTM) payload onboard the Space Shuttle Endeavour launched into space. With its radars sweeping most of the land surfaces of the Earth, SRTM acquired enough data during its ten days of operation to obtain the most complete near-global high-resolution database of the Earth’s topography.

To acquire topographic (elevation) data, the SRTM payload was outfitted with two radar antennas. One antenna was located in the Shuttle’s payload bay, the other on the end of a 60 meter (200 foot) mast that extended from the payload bay once the Shuttle was in space.

The Shuttle Radar Topography Mission (SRTM) is an international project spearheaded by the National Imagery and Mapping Agency (NIMA) and the National Aeronautics and Space Administration (NASA).

Relevance to ECHO Mission: International collaboration on a large SAR mission

Cost and Schedule Performance:

The development was successfully completed in the 36-month scheduled period. SRTM was ready for launch from KSC aboard the Shuttle in September 1999. The development included the 60m retractable mast and the electronically steerable phased array outboard antenna. The launch was delayed until February 2000 due to extensive Shuttle rework of cabling following a flight anomaly. The SRTM funding proposed in December 1996 was $89,754K plus $7,800 of reserve. The budget at flight completion in March 2000 was $131,694K, including actuals through the flight plus the estimate to complete the data processing. The growth included the cost of 5-month launch delay and the addition of several capabilities not initially proposed. The additional capabilities included:

1. “cold gas” reaction system to reduce the expenditure of Shuttle attitude control gas due to 60m mast
2. antenna “beam auto-tracker” to provide active pointing of the outboard antenna beam to assure coincidence with the in-board antenna beam
3. closed-loop optical capability for controlling the phase of the outboard signal path to assure phase stability relative to the in-board signal
4. power and motor controller functions for the outboard assembly to satisfy Shuttle safety requirements

Point of Contact:

Dr. Yunjin Kim

JPL, Mail Stop 180-405, phone: 818-354-9500

Stardust

Description:

Launch: February 7, 1999

Mass: 385 kg total, consisting of 254-kg spacecraft and 46-kg sample return capsule, plus 85 kg fuel

Science instruments and subsystems: Aerogel dust collectors, sample return capsule, comet and interstellar dust analyzer, dust flux monitor, navigation camera

Stardust will fly through the cloud of dust that surrounds the nucleus of a comet and, for the first time ever, bring cometary material back to Earth.

Stardust is the first U.S. mission dedicated solely to a comet and will be the first to return extraterrestrial material from outside the orbit of the Moon. Stardust's main objective is to capture a sample from the well-preserved comet Wild-2.

Launched February 7, 1999 from Cape Canaveral, Florida, on a Delta II rocket, Stardust collected interstellar dust as it flew through the solar system in spring 2000. On January 15, 2001, the spacecraft executed a flyby of Earth. In summer and fall 2002, the spacecraft will again collect interstellar dust.

On January 2, 2004, Stardust will fly through comet Wild-2 and collect cometary particles for analysis. On January 15, 2006, samples of comet and interstellar dust will be delivered in a return capsule that will land in the Utah desert.

Stardust is the fourth mission selected under NASA's Discovery Program. The principal investigator is Dr. Donald C. Brownlee of the University of Washington. Lockheed Martin Astronautics designed and built the spacecraft. Instruments were provided by JPL, the Max Planck Institute for Extraterrestrial Physics, and the University of Chicago. JPL provides mission management, mission design, navigation, and operations support. NASA/JSC will support curatorial aspects of the returned samples.

Relevance to ECHO Mission: Cost-capped, PI-led project. Same approach as ECHO, i.e., system contract for spacecraft buss with project management, project system engineering, and mission design/navigation performed by JPL. International collaboration.

Cost and Schedule Performance:

Stardust met all major milestones during its 36.0 month development schedule. Stardust was originally budgeted at $197.6M (including launch vehicle). The breakdown of this is $9.6M for Phase B, $117.8M for Phase C/D (not including the launch vehicle), and $37.2M for Phase E, for a total of $164.6M (not including the launch vehicle). The launch vehicle cost is approximately $33M. Phase C/D was completed with approximately $1M in reserve, which was subsequently transferred to Phase E. The original budget assumed that operations would be shared with the Mars Surveyor Operations (MSO) program (i.e., the Stardust mission would leverage off of the pre-existing MSO infrastructure), and that MSO would be operating three additional missions: Mars Global Surveyor (MGS), Mars Climate Orbiter (MCO), and Mars Polar Lander (MPL). Unfortunately MCO and MPL were lost. As a result, the Stardust contribution to MSO increased by approximately $2M, bringing the total mission cost to $199.6M. This increase also covered the cost of additional customer-directed reviews based on the loss of MCO and MPL. At no time during the development were any descopes implemented that would affect the mission's baseline science goals.

Point of Contact:

Kenneth L. Atkins, Project Manager

JPL, M/S 264-459, (818) 354-4480

Topex/Poseidon

Description:

Launch: August 10, 1992

Mass: 2,500 kilograms (about 5,510 pounds)

Purpose: Measure sea surface heights

JPL’s Seasat mission established that a satellite could use radar pulses to measure its altitude from Earth's surface. Taken over the world’s oceans, these measurements could provide a high-fidelity view of the changing heights of the seas. That became the focus for the joint U.S.-French Topex/Poseidon mission. Under the joint plan between NASA and France's National Center for Space Studies (known as CNES for its acronym in French), the United States provided the satellite, altimeter, a microwave radiometer, an experimental satellite tracking receiver and various spacecraft subsystems. France supplied launch on an Ariane 42P rocket from French Guiana in South America, as well as two instruments on the satellite—a solid-state altimeter and a Doppler tracking receiver. Topex is short for “Ocean Topography Experiment,” the name of the original U.S. mission proposal, while Poseidon was the name of the original French mission proposal.

From its orbit 1,336 kilometers (830 miles) above Earth’s surface, Topex/Poseidon measures sea level every 10 days using the altimeter instruments developed by NASA and CNES. Using this information, scientists can relate changes in ocean currents to atmospheric and climate patterns. Measurements from the satellite's radiometer provide estimates of the total water-vapor content in Earth's atmosphere, which is used to correct errors in the altimeter measurements. These combined measurements allow scientists to chart the height of the seas across ocean basins with an accuracy of less than 10 centimeters (4 inches).

Although originally planned for a three- to five-year mission, Topex/Poseidon continues to operate nine years after its launch. Among other science findings, Topex/Poseidon provided a unique view of the El Niño phenomenon of the late 1990s, an unusual water warming in the eastern Pacific Ocean. That El Niño was followed by a rebound effect of cold water conditions that came to be known as La Niña.

The satellite was built for JPL by Fairchild Space Co.

Relevance to ECHO Mission: International collaboration with contributed launch vehicle and launch operations. JPL provided project management and mission assurance for the U.S. provided instruments and systems.

Cost and Schedule Performance:

Description

Point of Contact:

Charles Yamarone, Project Manager

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CloudSat

Description:

Planned Launch: April, 2004

Purpose: Radar studies of clouds

CloudSat's will be the first spacecraft to study clouds on a global basis. In conjunction with ESSP 3-CENA and Aqua, CloudSat will use an advanced radar to "slice" through clouds to see their vertical structure, providing a completely new observational capability from space (current weather satellites can only image the uppermost layers of clouds). CloudSat's primary goal is to furnish data needed to evaluate and improve the way clouds are represented in global models, thereby contributing to better predictions of clouds and thus to their poorly understood role in climate change and the cloud-climate feedback.

CloudSat is the third mission selected under NASA's Earth System Science Pathfinder (ESSP) Program. The principal investigator is Dr. Graeme Stephens of the Colorado State University. CloudSat is an international and interagency mission with project management by JPL. Partners include the Canadian Space Agency, the U.S. Air Force and the U.S. Department of Energy. Ball Aerospace is designing and building the spacecraft.

Relevance to ECHO Mission: Cost-capped ESSP mission with similarities to ECHO. P.I. mission with spacecraft procured by JPL in a multi-partner environment with international participation. Radar will be developed by a contractor and integrated with a commercial bus.

Cost and Schedule Performance:

At the direction of the customer (NASA Code Y), CloudSat is co-manifested to launch with the ESSP 3-CENA mission. Unfortunately, ESSP 3-CENA has been forced to delay its launch by nine months because of development problems. Therefore, upon completion of I&T, CloudSat will be put in storage for six months to await the launch of ESSP 3-CENA. CloudSat was originally budgeted at $119.7M (including the shared launch). During Phase B, the project incurred unexpected cost growth in several areas. Both JPL and the spacecraft contractor incurred increases in their overhead. Additionally, in response to the Mars Climate Orbiter and Mars Polar Lander failures, the project had to implement extra mechanisms to insure mission success. Finally, there were several areas of unexpected growth that resulted as a better understanding of the mission developed during Phase B. The customer provided the project with a small augmentation, bringing the budget up to $123M. This was not enough to cover the increases and still maintain an acceptable level of reserves. As a result, the project implemented a pre-defined descope. The Profiling A-Band Spectrometer/Imager (PABSI) instrument was eliminated with the complete concurrence of the customer. Nevertheless, even with the loss of PABSI, the mission is still above the performance floor science objectives. After the Confirmation Review, the customer provided a second augmentation to cover the launch delay associated the ESSP 3-CENA mission. The current budget is now $136.5M. The project currently has 19% in reserves on the cost-to-go at CDR.

Point of Contact:

Thomas R. Livermore, Project Manager

JPL, M/S 233-306, (818) 354-1118

Deep Impact

Description:

Planned Launch: January, 2004

Purpose: Comet penetrator

Deep Impact will travel to comet Tempel 1 and release a small impactor, creating a hole in the side of the comet. The main spacecraft will measure and observe the gas released from the crater, to discover what makes up fresh comet material, and to understand the internal structure of a comet.

The impactor will form a football-field-sized crater, seven stories deep. Ice and dust debris will be ejected from the crater, revealing the fresh material beneath. Sunlight reflecting off the ejected material will provide a dramatic brightening, potentially visible from Earth, that will fade slowly as the debris dissipates into space and falls back onto the comet. This is the first attempt to peer beneath the surface of a comet revealing freshly exposed material for clues to the early formation of the solar system.

Deep Impact is the eighth mission selected under NASA's Discovery Program. The principal investigator is Dr. Michael A'Hearn of the University of Maryland. Ball Aerospace will design and build the spacecraft.

Relevance to ECHO Mission: Cost-capped, PI-led mission. Similar approach to ECHO, i.e., system contract for spacecraft bus, with project management, project system engineering, mission design/navigation, and mission operations support performed by JPL.

Cost and Schedule Performance:

The originally proposed budget for Deep Impact was $270.5M (including the launch vehicle and operations). Since selection, the project has proposed several changes to the implementation plan to ensure a higher level of confidence in mission success, i.e., the project has appropriately responded to the NASA Integrated Assessment Team (NIAT) report. These proposed changes were accepted by the customer, and the budget was augmented with an additional $8.7M to bring the total to $279.2M. There has been no compromise in the project's goal to complete the baseline mission proposed to NASA.

Deep Impact originally failed to pass its Confirmation Review (CR). At the time of the CR, even with the $8.7M augmentation, the project's reserve posture was slightly more than 20%, and had what was judged to be a marginal level of schedule reserve (even though all milestones had been met prior to the CR). As a result, the CR review board gave the project a "marginal" rating for the possibility of mission success, which was deemed to be unacceptable by the customer. The project was directed to replan the implementation so as to achieve acceptable levels of cost and schedule reserve. This has since been done and Deep Impact has successfully passed its CR. The project now has 23% reserves on cost-to-go and an additional month of schedule reserve compared to the original plan. It is important to note that no descopes were implemented that would affect the mission's baseline science goals.

Point of Contact:

Brian K. Muirhead, Project Manager

JPL, M/S 301-350, (818) 393-1013

GRACE

Description:

Planned Launch: November, 2001

Purpose: Measure Earth's gravitational field with high precision

The Gravity Recovery and Climate Experiment (GRACE) mission will accurately map variations in the Earth's gravity field over its 5-year lifetime. The GRACE mission will have two identical spacecraft flying about 220 kilometers apart in a polar orbit 500 kilometers above the Earth.

GRACE will be able to map the Earth's gravity fields by making accurate measurements of the distance between the two satellites, using GPS and a microwave ranging system. It will provide an efficient and cost-effective way to map the Earth's gravity fields with unprecedented accuracy. The results from this mission will yield crucial information about the distribution and flow of mass within the Earth and it's surroundings.

The gravity variations that GRACE will study include: changes due to surface and deep currents in the ocean; runoff and ground water storage on land masses; exchanges between ice sheets or glaciers and the oceans; and variations of mass within the Earth. Another goal of the mission is to create a better profile of the Earth's atmosphere.

GRACE is the first mission scheduled to launch under NASA's Earth System Science Pathfinder Program, and is a joint partnership between the NASA and Deutsche Forschungsanstalt für Luft und Raumfahrt (DLR) in Germany. Dr. Byron Tapley of The University of Texas Center for Space Research (UTCSR) is the PI, and Dr. Christoph Reigber of the GeoForschungsZentrum (GFZ) Potsdam is the Co-Principal Investigator (Co-PI). Project management, systems engineering, mission design, and instrument development activities are carried out by JPL. The spacecraft is provided by Astrium GmBH (Friedrichshafen, Germany) under contract to JPL

Relevance to ECHO Mission: ESSP, cost-capped, PI-led mission. Like ECHO, GRACE is a international partnership between NASA and the DLR, with a spacecraft provided by Astrium, and project management provided by JPL. Both missions feature integration of systems/ instruments from multiple partners.

Cost and Schedule Performance:

GRACE was originally slated for a June, 2001 launch, but a joint decision between the PI, the project, and the sponsor (GSFC) has resulted in a five-month slip in the planned launch date. This was done to allow time to add resiliency and redundancy to the spacecraft design to mitigate risks. This time is also being used to add new capabilities and redundancies to the instruments to improve mission reliability.

The total cost to NASA for GRACE was originally budgeted at $85.9M (not including the launch vehicle, which is supplied by DLR). The slip in the launch date and associated activities have resulted in a new budget of $93.2M. As of June, 2001, the project has spent $69M. Of the remaining $24.2M in cost-to-go, $4.2M (21%) has been allocated for reserves. $1.0M of these reserves (equal to 15% of the remaining cost on foreign contracts) has been pre-allocated to cover exchange rate fluctuations on the spacecraft contract with Astrium. At no time during the development have any descopes been implemented that would affect the mission's baseline science goals.

Point of Contact:

Edgar (Ab) S. Davis, Project Manager

JPL, M/S 264-664, (818) 354-8644

SeaWinds on AEDEOS 2

Description:

Planned Launch: November, 2002

SeaWinds Instrument Mass: 200kg

Purpose: Systematic raday measurement of near-surface ocean wind vectors

SeaWinds on ADEOS-2 is a follow-on mission for the Japanese Space Agency's (NASDA's) Advanced Earth Observing System (ADEOS) mission carrying the NASA scatterometer (NSCAT) instrument. SeaWinds on ADEOS-2 is a partnership between NASA, NASDA and NOAA with NASA/JPL providing the SeaWinds scatterometer instrument, instrument operations, scattereometer ground data system, data processing, distribution and archiving, and the operational data processing software.

The SeaWinds instrument is a Ku-band scatterometer (radar) that measures ocean surface radar backscatter from which near-surface ocean wind vectors are derived in ground data processing. SeaWinds data are used for scientific studies and for operational meteorological modeling and forecasts.

The SeaWinds instrument uses a novel circular scanning antenna approach that represents a significant advance over its predecessor instrument, NSCAT. The SeaWinds mass is 70% that of NSCAT but is only a small fraction of the volume. More significantly, SeaWinds uses a single spinning reflector antenna instead of NSCAT's six fan beam antennas, making SeaWinds significantly easier to accommodate on a spacecraft bus. JPL's SeaWinds scanning antenna instrument approach provides a broader measurement swath than the NSCAT instrument thereby increasing daily wind vector coverage from 60% to more than 90% of the Earth's surface.

SeaWinds on ADEOS-II is design for a three year life with a goal of five years.

Relevance to ECHO Mission: International collaboration on a radar mission. Science team supporting development of ground data processing system.

Cost and Schedule Performance:

JPL delivered the SeaWinds instrument to NASDA in March 1999 consistent with the NASA/NASDA schedule agreement. NASDA subsequently delayed the launch of ADEOS-II as a result of a failure of NASDA's H-II rocket and delays in the development of NASDA's H-IIA rocket planned to launch ADEOS-II.

The SeaWinds instrument was developed and delivered to NASDA within the JPL-NASA budget agreement.

Point of Contact:

Moshe Pniel, Project Manager

JPL, M/S 264-626, (818) 354-7052

L.6.2 BALL AEROSPACE AND TECHNOLOGIES (BATC)

L.6.2.1 Introduction

Ball Aerospace & Technologies (Ball) has a long history of supporting NASA on PI-led science missions. Ball has over 40 years experience in providing both spacecraft and scientific instruments. BATC is unique in the industry in terms of the breath and depth of our space hardware and software experience, having placed over 75 major systems on-orbit. No science data has ever been lost due to a failure of a Ball-designed or produced piece of space hardware. Ball is currently the industry partner on two ESSP missions, CALIPSO and CloudSat, and the direct experience gained from these programs will be used to advantage on ECHO.

BATC, through it's Antenna and Communications Division has a long history in providing Synthetic Aperture Radar (SAR) antenna to NASA, beginning with SEASAT in the 1970s' to SRTM in the 1990s. It is our goal to continue this successful relationship on the ECHO program taking the best advantage of the various business areas within Ball. The ECHO program will be managed through Ball Civil Space Systems (CSS). Program management and systems engineering for spaceborne scientific instruments and spacecraft are a core competency for CSS. Ball CSS will play the key role of managing the interfaces between antenna, spacecraft and radar instrument. Ball CSS will also manage the development of the ECHO SAR antenna through Ball's Antenna and Communications Technologies (ACT) and the extendible support structure major subcontract.

Ball ACT has designed and manufactured the antennas for all of NASA's spaceborne Synthetic Aperture Radar (SAR) missions from SEASAT in the late 1970's to the Shuttle Radar Topography Mapper (SRTM) in the late 1990's. The SEASAT satellite was launched in 1978 and included a SAR instrument that featured a lightweight L-band antenna and a novel antenna deployment/support structure. Ball designed and built the passive, 10.8m by 2.2m, L-band antenna and collaborated with Spar Astro Aerospace on the development of the deployment/support structure. Once on orbit, the antenna deployed and operated as designed throughout the life of the spacecraft.

The SIR-A, flown in 1981, was the first operational space shuttle payload for which Ball built the L-band SAR antenna positioned inside the shuttle cargo bay. The 1984 SIR-B SAR antenna was similar to that flown on SIR-A except that the antenna folded into three segments to accommodate other shuttle payloads and was steered mechanically in elevation. Ball not only designed and built the L-band SAR antenna but was responsible for the structure and the redundant deployment and steering electric motors and VDAs.

The successes of SIR-A and SIR-B provided the impetus for SIR-C, which was to demonstrate the value of both multi-parameter SAR operation and distributed transmit and receive electronics in antennas. Ball designed and built the 12m by 3m L-band and 12m by 0.75m C-band antenna arrays, both of which were active, quad-polarized arrays capable of electronic beamsteering in both directions, as well as the T/R modules used in each (252 for L-band, 504 for C-band). SIR-C was flown twice in 1994 and produced unprecedented seasonal earth science data. SIR-C was flown twice in 1994 and produced unprecedented seasonal earth science data.

In 1996 Ball began development of an antenna to be flown with the original SIR-C antenna for an interferometric SAR mission - Shuttle Radar Topography Mapper (SRTM). This new antenna system, called the Outboard Antenna Subsystem (OAS), used twelve active C-band receive panels, an RF combiner network, a control and power distribution unit (CPDU) and a beam auto tracker (BAT). These OAS components were delivered to JPL in 1998, integrated during 1999 and flew aboard STS-99 in February 2000 to complete a highly successful 11 day, 3-D mapping mission of 80% of the Earth's landmass.

Ball is proud of our long-term relationship with JPL in SAR research and development for NASA and looks forward to applying the knowledge gained from this past experience to the ECHO program. We are committed to providing the ECHO team with the highest level of engineering and technical support to ensure a successful mission.

L.6.2.2 Relevant Projects

CloudSat

Description:

Launch: April, 2004

Purpose: CloudSat is an experimental satellite mission designed to measure the vertical profiles of cloud liquid water and ice contents and related cloud physical and radiative properties. CloudSat will fly a microwave (94 Ghz) radar that is capable of observing a large fraction of clouds and precipitation from very thin cirrus clouds to thunderstorms producing heavy precipitation, in addition to viewing their vertical structure. CloudSat's primary goal is to furnish data needed to evaluate and improve the way clouds are represented in global climate models, thereby contributing to a better understanding of clouds and their role in climate change and the cloud-climate feedback.

CloudSat is a co-manifested launch with the ESSP CALIPSO mission. CoudSat will fly in orbital formation as part of a constellation of satellites including CALIPSO, Aqua (multi-sensor platform that is part of NASA's Earth Observing System), and PARASOL (a satellite carrying a polarimeter) in a 705 kilometer orbit.

CloudSat is the third mission selected under NASA's Earth System Science Pathfinder (ESSP) Program. The Principal Investigator is Dr. Graeme Stephens of Colorado State University. CloudSat is a multinational and interagency mission with project management at JPL. CloudSat is a partnership between Colorado State University, NASA JPL, the Canadian Space Agency, the US Air Force, and the US Department of Energy. Ball Aerospace is the industrial partner providing the spacecraft bus and instrument integration to the spacecraft.

Relevance to ECHO Mission: ESSP, cost-capped, PI-lead mission with similarities to ECHO. PI-led mission with spacecraft procured by JPL in a multi-partner environment with international participation. Active radar system with demanding power and safety considerations.

Cost and Schedule Performance:

The CloudSat program is being managed on an aggressive cost and schedule baseline to satisfy the guidelines of an ESSP mission. The original program was priced at $29.9M, which included Phases B–E. The Phase B time line was lengthened due to customer funding constraints and a better understanding of the scope of work which needed to be completed. The activities of the program were changed due to funding constraints and the eventual de-scope, which eliminated one of the instruments. Phase C/D/E cost and schedule increased mainly due to a six month slip of the delivery date of the instrument to Ball, who will perform the integration and test activities. The schedule slip will move Ball to de-staff the project for six months and then staff up for the I&T activities, which in turn will cause additional costs. The current baseline for Phases B–E is $37.4M.

Point of Contact:

Randy Coffey, Project Manager

Ball Aerospace & Technologies Corp., M/S CO-8, 1600 Commerce St., Boulder, CO 80301, (303) 939-4570

CALIPSO

Description:

Launch: April, 2004

Purpose: Provide a three-year global set of data on aerosol and cloud properties, radiative fluxes, and atmospheric state. CALIPSO will fly in formation with the EOS Aqua spacecraft, producing coincident data set with instruments on Aqua providing the first global measurement suite of observationally-based estimates of aerosol direct radiative forcing of the climate. The CALIPSO mission will have three nadir-viewing science instruments on a dedicated spacecraft flying in a polar orbit 705 kilometers above the Earth.

CALIPSO will acquire the needed measurements for a better understanding of tropospheric aerosols and clouds to more thoroughly understand their role in climate forcing—one of the highest priority science questions in global climate change research. CALIPSO will fly a dual-wavelength polarization-sensitive lidar, an imaging infrared radiometer (IIR) and a Wide Field-of-View Camera (WFC). The lidar will penetrate cloud levels down to the Earth's surface, over land and water, providing a high-resolution cross-section of cloud and aerosol content. The IIR provides calibrated infrared radiances optimized for cirrus particle size retrieval. The WFC will acquire high spatial resolution imagery. These instruments are integrated into a single package with a common optical bench, optics, instrument controller, and structural and thermal components provided by Ball. Ball is responsible for the lidar and WFC.

A fully-redundant PROTEUS spacecraft bus will be provided by the French Centre National D’Etudes Spatiales (CNES). As is the case for ECHO, this ESSP mission is a joint partnership between NASA and a foreign partner. Integration of the science instruments onto the spacecraft bus will occur in Europe, as is the case for ECHO. CALIPSO will be launched on a government-procured SELV-II B-class launch vehicle.

Dr. David Winker of the NASA Langley Research Center is the Principal Investigator, and Dr. Patrick McCormick of Hampton University and Dr. Jaques Pelon of the Institut Pierre Simon, Laplace, Paris, France are the Co-Principal Investigators.

Relevance to ECHO Mission: ESSP, cost-capped, PI-lead mission. As on CALIPSO, Ball will be participating in the science instrument development on ECHO. Like CALIPSO, ECHO is an international partnership between NASA and a foreign partner with a complex international project organization. On CALIPSO, the instrument to spacecraft integration is planned to be done at the Alcatel facility in France. A similar approach is planned for ECHO with integration taking place in Germany. We have developed the team and methodologies to handle the coordination and interface control with foreign partners. Both ECHO and CALIPSO are active sensors with demanding power constraints and safety issues.

Cost and Schedule Performance:

Calipso was originally slated for a launch in the first quarter of 2003. The launch has been delayed until April 2004. Several factors have contributed to this including technical difficulties on the JASON program which have impacted the Calipso schedule and funding delays in 2000-2001 resulted in delay in work. The total cost to NASA for Ball's portion of Calipso is $61M. Of this, approximately $7M is cost growth. The cost growth is largely accounted for by lessons learned in managing the interface between international partners and the unanticipated need for space qualifying a large number of electrical parts.

Point of Contact:

Mark LaPole, Project Manager

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(303) 939-6795

Spaceborne Imaging Radar-C (SIR-C)

Description:

Launch: Month, Year April 1994 (STS-59) and September 1994 (STS-68)

Purpose: Synthetic Aperture Radar (SAR) measurements from space to obtain radar images of the Earth's surface for Earth system sciences studies, including geology, geography, hydrology, oceanography, agronomy and botany.

SIR-C was part of the SIR-C/X-SAR joint project of the National Aeronautics and Space Administration (NASA), the German Space Agency (DARA) and the Italian Space Agency (ASI). This project was the next step in a series of spaceborne imaging radars, beginning with SEASAT in 1978, continuing with SIR-A (1981), Germany's Microwave Remote Sensing Experiment (1983), and SIR-B (1984). All these programs contributed to Ball's experience in lightweight panel fabrication, high power handling in a space environment, and integrated, low-loss feed networks. In January 1994 Ball delivered the SIR-C L-band and C-band active phased arrays to Jet Propulsion Laboratory (JPL) for installation on JPL's structure. SIR-C completed two flights, the first in April 1994 and the second in October 1994. The SIR-C antenna consists of three apertures; L-band size is 2.9m x 12 m, C-band size is 0.75m x 12 m, and the X-band slotted waveguide antenna (provided by Germany and Italy) is 0.4 m x 12 m. The L-Band antenna included 252, 50 Watt peak power T/R modules, 4-Bit PIN diode phase shifters and associated control electronics designed, fabricated, and tested at Ball. In addition, the C-Band antenna system incorporated 512, 11 Watt T/R modules, phase shifters and control electronics also developed by Ball.

Performance History:

All technical requirements were met or exceeded. The L-band antenna performance exceeded specification by more than 5 dB and the C-band antenna met specifications by more than 2 dB. On-orbit performance was excellent with all objectives met. Of the 18 C-band panels, only one exhibited intermittent operation but this in no way affected mission success.

Relevance to ECHO Mission: ESSP, cost-capped, PI-led mission. Like ECHO, SIR-C/XSAR was a joint international partnership consisting of National Aeronautics and Space Administration (NASA), the German Space Agency (DARA) and the Italian Space Agency (ASI). The ECHO antenna is similar to that of SIR-C in that it will require an active aperture incorporating highly efficient distributed T/R modules, power and control electronics.

Cost and Schedule Performance:

Cost: The factors discussed in the performance history also drove the program costs. Ball's initial bid of $12.5M was based on use of commercial parts with selected screening, a streamlined program, and a mechanical design based on SIR-B. None of these assumptions survived very long. The final cost of $41M consisted of the original proposed $12.5M, directed and constructive changes of $18M, and $11.5M of overrun. A considerable amount of the overrun was due to unanticipated material cost.

Schedule: SIR-C was initially scheduled for its first flight in May 1989, but did not actually fly until April 1994. The loss of the Challenger in January 1986 caused extended delays and Shuttle manifest changes. The program schedule was repeatedly lengthened due to NASA's yearly funding limits, redesign efforts to meet new safety requirements, and parts procurement problems. In spite of this, Ball met the final revised schedule and did not cause any launch delay.

Point of Contact:

Gary R. Salisbury, Project Manager

Ball Aerospace & Technologies Corp. 303-533-7122

Shuttle Radar Topography Mapper (SRTM)

Description:

Launch: February 2000

Purpose: To use C-band and X-band interferometric synthetic aperture radars (IFSARs) to acquire topographic data over 80% of Earth's land mass (between 60degN and 56degS) during an 11-day Shuttle mission. The primary objective of this program was to produce 3-D maps of the Earth for the Department of Defense.

In October 1996, Jet Propulsion Laboratories (JPL) awarded Ball a Cost Plus Fixed Fee contract ($6,400,000) for the Shuttle Radar Topography Mission (SRTM) program. The SRTM hardware consists of the previously-flown, Ball-built, Sp Imaging Radar-C (SIR-C) and a new antenna named the Outboard Antenna Subsystem (OAS). Ball designed, manufactured, and tested the OAS hardware including:

- C-band Antenna Panels—12 panels including the active electronics to provide ±20° elevation steering with 30.6 dBil antenna gain per panel
- RF Combiner Network—phase and amplitude stable over temperature to combine 24 RF inputs into 2 RF outputs
- Control and Power Distribution Unit (CPDU)—required to process JPL SCANSAR commands and supply DC-power and phase values to electronically steer the OAS antenna in elevation
- Beam Auto Tracker (BAT)—provides RF amplitude feedback to the CPDU to compensate for potential azimuth misalignments between the OAS and SIR-C antenna beams
- Signal/Power Harness—provides DC-power and digital signals between the CPDU and the 12 OAS antenna panels

Relevance to ECHO Mission: ESSP, cost-capped, PI-led mission. SRTM was a joint international partnership consisting of National Aeronautics and Space Administration (NASA), the German Space Agency (DARA) and the Italian Space Agency (ASI). The ECHO antenna is similar to that of SIR-C/XSAR and SRTM in that it will require an active aperture incorporating highly efficient distributed T/R modules, power and control electronics. The aperture design will take advantage of the experience gained from SIR-C and SRTM in developing lightweight, conformal antennas incorporating supporting structure and distributed electronics.

Cost and Schedule Performance:

Cost: The initial contract value was for $6.4M with a final contract cost of $9M. The $2.6M increase in contract value was driven by the addition of new requirements outside the scope of the original contract. These new requirements were primarily contained in the Control and Power Distribution Unit (CPDU) and the addition of the Beam Auto-Tracker (BAT) of approximately $1,100,000. These amounted to $2,200,000 of the increase. The remaining increase, amounting to only 5% of the total, was due to cost growth.

Schedule: The program began in October 1996 with the majority of the design and development occurring in 1997. SRTM antenna panels were assembled and tested and the eighteen SIR-C C-band panels were retested at Ball during the first half of 1998. All twelve SRTM and SIR-C C-Band panels were delivered to JPL by the 3rd quarter of 1998. The Beam Auto Tracker (BAT) was delivered during 4th quarter of the same year. All 110 program contractual requirements were met or exceeded.

The SRTM data flight occurred Feb. 11–22, 2000 on STS-99 and successfully fulfilled all mission objectives. Twelve terabytes of raw data are currently being processed into digital elevation maps.

Point of Contact:

Don E. Figgins, Ball Antenna and Communications Technologies

Ball Aerospace & Technologies Corp (303) 533-7465

L.6.3 ASTRIUM GMBH

L.6.3.1 Introduction

Astrium was established in the year 2000 as a merger of the space related business sections of the German company Daimler-Chrysler Aerospace and the British-French consortium Matra Marconi Space (MMS), thus setting up the leading space company in Europe. Astrium is one of the few companies on the international market offering the complete range of space related products, covering launcher and launch services, satellites, orbital infrastructure systems as well as related ground segments. It develops and manufactures satellite platforms, its major subsystems as well as optical/radar instruments and scientific payloads.

Astrium activities are spread over Europe including sites in France (Toulouse and Velicy), Great Britain (Stevenage, Portsmouth and Poynton) and Germany (Ottobrunn, Friedrichshafen, Bremen, Jena and Lampoldshausen). The number of employees totals approximately 7500. The entire company is organised in three divisions, “Space Infrastructure,” “Telecommunications & Navigation” and “Earth Observation & Science,” each enclosing activities in all three countries.

Activities related to the proposal for the ECHO core spacecraft are concentrated on project and engineering departments located in the division “Earth Observation & Science” in Friedrichshafen, referred to as Astrium GmbH in the context of this description.

The experience of Astrium GmbH is based on more than 30 years of engagement in space development activities, in the role of prime contractor as well as subcontractor for all major spacecraft subsystems. Countless studies, developments and mission support activities have been performed, mainly in the area of science (earth science, astronomy, interplanetary probes), earth observation and meteorology, for customers world-wide like NASA, ESA, Nasda, DLR, INTELSAT, KARI etc. Up to this day, all satellites procured under Astrium GmbH prime leadership have operated successfully in-orbit, the majority significantly beyond their required life time.

Especially with its role as prime contractor for the ERS-1 and ERS-2 radar satellites and the development of radar instruments for the ERS-1/2 missions as well as for the JPL SRTM mission, Astrium GmbH has proven its capability to manage programmatically challenging and technologically demanding SAR programs. Astrium GmbH is presently executing a program in a private-public partnership with the German space agency DLR for the TerraSAR-X program. Within this program, which is considered the predecessor for ECHO in terms of the bus qualification, Astrium GmbH is responsible for the development of the bus, based on the AstroBus core spacecraft, the development of the X-band radar instrument, as well as for the integration, test, launch and in-orbit commissioning of the overall spacecraft.

For the purpose of demonstrating ECHO related experience, Astrium references to four missions which have been submitted to the NASA Rapid Spacecraft Development Office (RSDO) in the context of the 2001 on-ramp proposal for the FlexBus core spacecraft, the technical predecessor of the AstroBus core spacecraft of TerraSAR and ECHO. These programs provide a representative cross-section from the many Astrium GmbH programs and customers. Performance evaluation sheets from the involved customers are available with the RSDO at Goddard Space Flight Center. JPL and NASA ESSP are encouraged and feel at liberty to use this customer rating information when considered helpful.

L.6.3.2 Relevant Experience

CHAMP

Description:

Launch Date: July 15, 2000

Purpose: Measure Earth's gravitational and magnetic fields as well as plasma particle distribution over time and space.

In particular CHAMP is employed to perform the following three scientific tasks:

- global long- to medium-wavelength *Earth Gravity field* mapping with applications in geophysics, geodesy and oceanography,
- global *Earth magnetic field/charged particle* mapping with applications in geophysics and solar-terrestrial physics, and
- *atmosphere/ionosphere* sounding with applications in global climate studies, operational weather forecasting, disaster research and navigation.

The CHAMP spacecraft has been injected into an orbit with an inclination of 87° and an initial altitude of 454 km. The altitude is designed to decay such that Champ will see a final altitude of about 200 km at the end of its 5 years mission life time. With a total length of 8 m (deployed instrument boom) and a weight of approximately 450 kg, the spacecraft accommodates complimentary instrumentation, as

- ultra-sensitive accelerometer
- scalar and vector magnetometers
- digital ion drift meter
- ionosphere sounding GPS
- laser retro-reflector.

CHAMP is a national German mission lead by the GeoForschungszentrum Potsdam (GFZ), the German geophysical research institute, with Dr. Christoph Reigber being the PI.

Further information: http://op.gfz-potsdam.de/champ/index_CHAMP.htm

Relevance to ECHO Mission: First FlexBus/AstroBus, cost-capped, PI-led mission. Inclusion of JPL instrumentation.

Cost and Schedule Performance:

The original development phase was planned to be 30 months. In agreement with the PI and DLR, a total slip of 12 months has been introduced in order to allow for the inclusion of customer required contract changes and delays due to problem and failure mitigation in the area of solar cell accommodation, battery manufacturing and OBDH internal ACTEL parts failure.

Astrium complied to the cost cap of the original contract (DM 30.5 Mio). Offset to the initial price only occurred where additional effort has been requested by the customer resulting in an end-of-contract price of DM 35.0 Mio.

Point of Contact:

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GRACE

Description:

Planned Launch Date: March 2002

Purpose: Measure Earth's gravitational field with high precision

The Gravity Recovery and Climate Experiment (GRACE) mission will accurately map variations in the Earth's gravity field over its 5-year lifetime. The GRACE mission will have two identical spacecraft flying about 220 km apart in a polar orbit 500 km above the Earth.

GRACE will be able to map the Earth's gravity fields by making accurate measurements of the distance between the two satellites, using GPS and a microwave ranging system. It will provide an efficient and cost-effective way to map the Earth's gravity fields with unprecedented accuracy. The results from this mission will yield crucial information about the distribution and flow of mass within the Earth and it's surroundings.

The gravity variations that GRACE will study include: changes due to surface and deep currents in the ocean; runoff and ground water storage on land masses; exchanges between ice sheets or glaciers and the oceans; and variations of mass within the Earth. Another goal of the mission is to create a better profile of the Earth's atmosphere.

GRACE is the first mission scheduled to launch under NASA's Earth System Science Pathfinder Program, and is a joint partnership between the NASA and Deutsche Forschungsanstalt für Luft und Raumfahrt (DLR) in Germany. Dr. Byron Tapley of The University of Texas Center for Space Research (UTCSR) is the PI, and Dr. Christoph Reigber of the GeoForschungsZentrum (GFZ) Potsdam is the Co-Principal Investigator (Co-PI). Project management, systems engineering, mission design, and instrument development activities are carried out by JPL. Spacecraft, payload integration, and launch support are provided by Astrium GmBH (Friedrichshafen, Germany) under contract to JPL

More information: http://essp.gsfc.nasa.gov/grace/

Relevance to ECHO Mission: ESSP, cost-capped, PI-led mission. Like ECHO, GRACE is an international partnership between NASA and the DLR, with a spacecraft provided by Astrium, and project management provided by JPL. Both missions feature integration of systems/ instruments from multiple partners.

Cost and Schedule Performance:

GRACE was originally slated for a June, 2001 launch, but a joint decision between the PI, the project, and the sponsor (GSFC) has resulted in a five-month slip in the planned launch date. This was done to allow time to add resiliency and redundancy to the spacecraft design to mitigate risks. This time is also being used to add new capabilities and redundancies to the instruments to improve mission reliability.

The total cost to NASA for GRACE was originally budgeted at $85.9M (not including the launch vehicle, which is supplied by DLR). The slip in the launch date and associated activities have resulted in a new budget of $93.2M. The Astrium contract price increase by 5.7M Euro as a result of the launch slip and customer initiated changes in the required effort.

At no time during the development have any descopes been implemented that would affect the mission's baseline science goals.

Point of Contact:

Edgar (Ab) S. Davis, Project Manager

JPL, M/S 264-664, (818) 354-8644

SRTM

Description:

Launch Date: February 11–22, 2000 on STS 99

Purpose: Complete High-Resolution Digital Topography

The Shuttle Radar Topography Mission (SRTM) was an international project spear-hea-ded by the National Imagery and Mapping Agency and NASA-JPL. Its objective was to obtain the most complete high-resolution digital topo-graphic database of the Earth by obtaining elevation radar data on a near-global scale through C-Band and X-Band interferometric synthetic aperture radars on its 11 days flight onboard Space Shuttle Endeavour in February 2000.

The X-band radar system contributing to this the successful mission has been developed and built by Astrium GmbH.

The 12 terabytes of raw data are currently being processed by JPL into digital elevation maps on two tracks.

1. Systematic processing of the global data on a continent-by-continent basis. North America is first and are planned to be available for distribution by Spring, 2002. All processing should be complete by Fall, 2002.
2. Processing of smaller data sets covering sites of scientific interest designated by SRTM Principal Investigators is currently proceeding. Each site covers a number of 1 degree by 1 degree latitude and longitude “cells,” and when completed should be publicly available.

Further information: http://www.jpl.nasa.gov/srtm/

Relevance to ECHO Mission: NASA-JPL/DLR bi-national partnership. Demonstration of Astrium’s expertise in the design and manufacturing of radar instrument and, considering the spacecraft prime role in the programs ERS-1 and ERS-2 the experience to build a spacecraft for SAR instrument application as is necessary for ECHO. Furthermore, the successful cooperation with JPL in the SRTM program is considered a solid basis for continuing this spirit in the ECHO program.

Cost and Schedule Performance:

The SRTM mission was originally planned to take place on September 16, 1999. The actual mission took place in February 11, 2000 due to problems related with the orbiter (STS-99).

The total cost for the Astrium portions in the original contract amounted to DM 36,402,935. The final contract price, resulting from customer initiated changes, amounted to DM 42,782,345.

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XMM

Description:

Launch Date: December 10, 1999

Purpose: X-Ray Multi-Mirror Mission

The X-Ray Multi Mirror (XMM) spacecraft, built for the European Space Agency under the prime contractor leadership of Astrium GmbH.

The main goal of the most powerful X-ray telescope ever placed in space is to solve many cosmic mysteries, ranging from enigmatic black holes to the formation of galaxies. For this reason it carries three very advanced X-ray telescopes, each containing 58 high-precision concentric mirrors, delicately nested to offer the largest collecting area possible to catch the elusive X-rays. These mirror modules allow XMM to detect millions of sources, far greater than any previous X-ray mission. With its five X-ray imaging cameras and spectrographs, and its optical monitoring telescope, the new space observatory will for the next ten years define the cutting edge of X-ray astronomy.

Astrium GmbH was responsible for the development of the spacecraft as the prime contractor leading an international consortium of European companies. The spacecraft has been successfully commissioned and is operating successfully now for more than 1 years in orbit.

Further information: http://sci.esa.int/home/xmm-newton/index.cfm

Relevance to ECHO Mission: Demonstration of Astrium GmbH capability to manage an international consortium for a highly complex spacecraft and instrument in schedule and in price.

Cost and Schedule Performance:

The XMM mission has been implemented in time and Astrium GmbH was granted the full schedule incentive.

The original contract price amounted to 198 Mio Euro. The final contract price amounted to 231 Mio. Euro due to additional effort requested by the customer. Astrium GmbH could demonstrate a significant underspent w.r.t. the final contract value.

Point of Contact:

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Within the last years no Astrium GmbH contract has been terminated. Only one contract for the ROCSat program (Taiwan), selected by the customer in a competitive environment, did not come into effect due to export license restrictions imposed by the German government.

L.6.4 VEXCEL CORPORATION

L.6.4.1 Introduction

Vexcel Corporation is an internationally recognized remote sensing systems and services company. Vexcel's aligned capabilities and business interests are focused in the related technical disciplines including radar signal processing, remote sensing ground systems, GIS/mapping production services, and photogrammetry. The company specializes in providing end-to-end system solutions and markets a line of hardware and software products, as well as data processing services. Since its founding in 1985, Vexcel has expanded its technical expertise to include skills in a broad base of remote sensing technologies and their corresponding data processing systems.

More than 50 percent of Vexcel's staff of engineers, scientists, and technicians hold advanced degrees. They are highly qualified in their respective fields and bring a depth of experience to a wide variety of projects. Vexcel has established itself as a world leader in a number of technical areas including:

- i) synthetic aperture radar image formation algorithms and advanced radar signal processing techniques;
- ii) satellite ground stations including high rate telemetry systems and turnkey remote sensing data processing;
- iii) mapping systems and services utilizing both optical and radar data, including advanced interferometry and stereo techniques;
- iv) high accuracy urban model database creation, including both building heights, terrain data, and demographic information;
- v) three-dimensional modeling from electro-optic sensors and aerial photography for engineering and CAD applications.

Vexcel's emphasis on quality complements its focus on the needs of its clients. The company's list of satisfied customers spans six continents. They range from small businesses to major aerospace companies to world renowned research organizations. Clients and partner companies such as Ball Aerospace, MIT Lincoln Laboratory, Sandia National Labs, Jet Propulsion Laboratory, Lockheed Martin, Space Imaging, TRW, Raytheon, NEC, Mitsubishi, DARPA, NASA, NASDA, European Space Agency, NSF, Qwest, Ericsson, Alcatel, Adelphia, among many others, have relied on Vexcel's expertise, products, and services in recent years.

Vexcel is classified as a small business.

L.6.4.2 Relevant Projects

ALOS/PALSAR Processing System (2001–2002—fixed price)
Description: In 2001, Vexcel Corporation was awarded a subcontract from Mitsubishi Electric Corporation (MELCO) to provide the Earth Remote Sensing Data Analysis Center (ERSDAC) of Japan with the data processing system for the next generation Japanese synthetic aperture radar (SAR) sensor, known as PALSAR. Under the exclusive contract, Vexcel is adapting its "3D SAR Processing System™" to meet the specific needs of PALSAR. The processing system will ingest raw PALSAR data and produce information rich SAR imagery products. The PALSAR sensor is one of three instruments onboard the Advanced Land Observation Satellite (ALOS), scheduled to launch in 2003. ALOS/PALSAR is the follow-on Japanese SAR mission to the now inactive JERS SAR satellite. Aside from a stripmap SAR mode, the sensor—and the Vexcel processing system—will also include a ScanSar mode and a multi-polarimetric mode. The processing system will produce Level 0 products as well as L1 (single-look complex), and orthorectified and geocoded map projections.
Relevance to ECHO Mission: The PALSAR processing system development effort is similar to that planned for the ECHO processing system. Both ECHO and PALSAR represent end-to-end processing systems that include Level 0 processing, image formation for both stripmap and ScanSAR modes, and orthorectification and geocoding of resulting imagery. (ECHO, in addition, includes the development of interferometry software—as well as Level 1 and Level 2 processing directed to a broader base of users.) Vexcel's experience with this project will help drive the planning and execution of the ECHO project. It will likely streamline the development effort based on lessons learned.
Cost and Schedule Performance: Cost of the system is approximately US $2,000,000. In the Fall of 2001, the most recent major milestone was accomplished on time. The complete system was delivered to the customer for factory acceptance testing. These tests are currently underway.
Point of Contact: Henry Frick Project Manager (303) 583-0211

University of Miami Ground Station (2001—fixed price)
Description: Vexcel is currently under contract to provide a complete turnkey ground station to the University of Miami Rosensteil School of Marine Sciences. Vexcel is the prime contractor and is providing all of the Agency Interfaces, Control, Scheduling, Data Ingest, Archive, Catalog and Processing components. The Miami Facility—or The Center for Southeastern Tropical Advanced Remote Sensing (CSTARS)—will have a ground reception capability consisting of two 11.25-meter antennas, and will be initially configured to receive ERS, Radarsat, and SPOT data. System reliability will be bolstered by two UNIX-based capture systems that are cross-strapped to assure maximum redundancy. Matrixing of the ground system components will provide ready expandability. In addition to the complete hardware system, Vexcel will provide complete processing capabilities for these sensors including Levels 0 and 1 products. Vexcel will complete the project in October of 2002.
Relevance to ECHO Mission: The ground station system for the University of Miami is a fully capable, multi-sensor system, including reception and processing of the SAR sensors ERS and Radarsat. The fact that Vexcel is installing this system significantly reduces any risk associated with upgrades for the ECHO system to 300 Mb/s. In addition, integration of the ECHO ground system will be facilitated by the existing relationship between Vexcel and the University of Miami, and by Vexcel's familiarity with the facility.
Cost and Schedule Performance: Cost of the system is in excess of US $5,000,000 and is currently scheduled for on-time completion in the Fall of 2002.
Point of Contact: Henry Frick Project Manager (303) 583-0211

Space Imaging (1999, 2000, 2001—fixed price)

Description:

Vexcel has supplied the standard data ingest and Level 0 processing subsystem for all of Space Imaging stations that receive IRS-1C/1D. The standard system comprises a Silicon Graphics Origin 200 computer with Vexcel's PCIDIF-I and PCIDIF-O interface cards, a fibre-channel disk array, and specialized software to interface to IRS-1C/D processing systems. These direct capture systems are capable of 2-channel at 160 Mbps on input and output.

In the Space Imaging ground stations, the direct-capture units will be the primary reception system for IRS-1C/D, Landsat 7, ERS, and RADARSAT. The systems will also serve as a backup IKONOS capture and playback system in the event of failure of the main IKONOS capture capability. Vexcel has recently supplied systems for Space Imaging in their Norman, Oklahoma and Abu Dabi locations. Vexcel is under contract for the station to be installed in Myanmar. Vexcel has also developed a software interface to the IRS processing system eliminating the custom hardware required by users of the Antrix processing system. This software is now part of the standard product offering by Space Imaging for IRS.

Relevance to ECHO Mission: A ground station system in support of the ECHO Mission could utilize subsystems of the Space Imaging/IRS systems as the basis for its design and functionality. High rate ingest capabilities and Level 0 processing are independent of the data type (Radar vs. electro-optical). This project further demonstrates and provides heritage for successful implementation of Vexcel technology.

Cost and Schedule Performance:

Cost for the systems to date are less than US $1,000,000 and have been delivered on time and performed reliably to specifications.

Point of Contact:

Jim Curlander

Project Manager

(303) 583-0213

Alaska SAR Facility (1998—fixed price)
Description: Vexcel supplied the Alaska SAR Facility (ASF) with five direct capture systems capable of capturing the live downlink from the ERS, JERS and RADARSAT satellites. The systems consist of an Origin 200 or Origin 2000 with a striped RAID and DLT drive. The first system was delivered under contract to the Jet Propulsion Laboratory in August 1998. It also includes the capability to process the data to a standard Level 0 product including frame synchronization, filtering, ancillary data decoding and analysis and data formatting. An additional four systems were ordered in 1999. Subsequent systems were acquired in 2000. The systems include the capability to process the data to a standard Level 0 product including frame synchronization, filtering, ancillary data decoding and analysis and data formatting. ASF has purchased a site license for Vexcel's Focus SAR processor in early 2001 and will use this system for creation of phase preserving single-look complex images in support of the Antarctic Mapping Mission. Vexcel is also developing the interferometric processor and mapping package for this mission under contract to Bryd Polar Research Center in Ohio.
Relevance to ECHO Mission: This project further demonstrates the capture and processing technology and provides heritage for the capture and processing systems to be delivered under ECHO. In addition, Vexcel's previous work with the Alaska SAR facility provides familiarity with the facility and it's operations.
Cost and Schedule Performance: Cost for the systems to date are in excess of US $1,000,000. The systems were delivered on time and performed reliably to specifications.
Point of Contact: Jim Curlander Project Manager (303) 583-0213

Hiroshima Institute of Technology (1997—fixed price)

Description:

Vexcel supplied a complete transportable ground station with on-board data processing to create Level 0 and Level 1 CEOS data products. A Laboratory facility was also provided to perform identical tasks, with the exception of data reception. This ground station included the satellite dish, data capture system (direct to disk) and data processing system including Level 0 processing and SAR processing for ERS, JERS and RADARSAT. Both facilities are also capable of creating all levels of SAR data products including Interferometric DEM creation, Differential Interferometry, and Orthorectification.

The front end (dish and electronics) were procured from Datron Transco, Simi Valley, CA. Vexcel performed the integration with the data capture and processing system. The raw data and the Level 0 products are both captured onto DLT tape jukeboxes for archive and later processing to L1 and higher products.

At the Ground Station Facility data is automatically processed direct from the downlink to imagery. The installation was completed March 30, 1997.

Relevance to ECHO Mission: The ground station system for the Hiroshima Institute of Technology is a fully capable, multi-sensor system, including reception and processing of the SAR sensors ERS and Radarsat. This system is a excellent example of a successful design, development, and implementation of a satellite ground data reception and processing facility.

Cost and Schedule Performance:

Cost for the system was approximately US $5,000,000. The system was delivered on time and performed reliably to specifications.

Point of Contact:

Jim Curlander

Project Manager

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L.7 DRAFT INTERNATIONAL AGREEMENT(S)

L.7.1 OVERVIEW OF EARTH CHANGE AND HAZARD OBSERVATORY (ECHO)

ECHO, an Earth System Science Pathfinder class mission, is an international partnership between NASA and the German Aerospace Center (DLR) to collect interferometric SAR (InSAR) data and return the data to Earth. The mission has three major objectives:

- Study how strain accumulates and is released during the earthquake cycle,
- Understand spatial and temporal deformation patterns of volcanoes, and
- Determine the rate and variability of ice discharge and its relation to sea level rise and climate change.

The mission will launch in October 2006 to a 760 km sun-synchronous orbit, with an 8-day repeat cycle. The nominal mission duration is five years.

The project is led by Dr. Jean-Bernard Minster of the Institute of Geophysics and Planetary Physics at the Scripps Institution of Oceanography. He is joined by Dr. Howard Zebker, Stanford University, Deputy PI for the ground segment, and Dr. Paul Rosen, JPL, Deputy PI for the space segment.

DLR will contribute a Dnepr launch vehicle and mission operations services. After selection, NASA will establish a Letter of Agreement between NASA and DLR outlining the terms of the partnership.

L.7.2 PROPOSED INTERNATIONAL COLLABORATION

For the ECHO mission, NASA will use its best efforts to fulfill the following responsibilities:

1. Provide oversight & management to implement the mission, including all phases of the mission
2. Participate in science team activities
3. Provide management oversight to the spacecraft provider for the spacecraft, spacecraft integration and test, and mission operations support.
4. Provide project system engineering necessary to implement the mission
5. Provide Mission Assurance
6. Design, build and test the L-band radar electronics for the science instrument
7. Integrate and test an L-band active phased-array antenna with the radar electronics
8. Support integration and test of the radar and spacecraft in Germany
9. Design, build and test a GPS receiver and star camera package for integration to the spacecraft
10. Support integration and test of the GPS and spacecraft in Germany
11. Develop a mission operations plan and operations interface to the German Space Operations Center
12. Provide management oversight of the ground data system contracts.
13. Design, build and test processing software for the radar data delivered by the flight system
14. Participate in calibration and validation activities during Phase 5.

DLR will use its best efforts to fulfill the following responsibilities.

1. Procure a Dnepr launch vehicle for the launch of the ECHO satellite
2. Conduct mission operations through the German Space Operations Center (GSOC) to command the spacecraft according to Project/Science Requirements. GSOC will make downlinked telemetry available to NASA, and accept mission plans from NASA to be incorporated in the uplink sequence

L.7.3 ECHO POINTS-OF-CONTACT

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4800 Oak Grove Drive
Pasadena, CA 91109
Phone: 818-354-3201
Fax: 818-354-5075
Email: Kim.Leschly@jpl.nasa.gov

Ernst Koenemann
Leiter Erdbeobachtung (Lead, Earth Observation,RD-RE)
DLR-Deutsches Zentrum f.Luft- und Raumfahrt (German Aerospace Center)
Postfach / PO Box 300364
D-53183 Bonn
Phone: +49-228-447-627, 582 Sekr.
Fax: +49-228-447-747
Email: Ernst.Koenemann@dlr.de

L.7.4 SCIENCE DATA RIGHTS

Unless otherwise agreed between NASA and the PI, all science data resulting from this cooperative activity will be made available to all users without restriction at no more than the cost of dissemination, through appropriate data archives in the United States and Germany. In the event that reports or publications based upon this data are copyrighted, the parties and NASA shall have a right under the copyright to reproduce, prepare derivative works from, perform, display, and distribute copies of such copyrighted work for their own purposes royalty-free. If data resulting from missions have commercial value, data information rights and policies must be negotiated with NASA on a case-by-case basis.

L.7.5 TRANSFER OF GOODS AND TECHNICAL DATA

The parties are obligated to transfer only those technical data (including software) and goods necessary to fulfill their respective responsibilities under this agreement, in accordance with the following provisions:

1. The transfer of technical data for the purpose of discharging the parties' responsibilities with regard to interface, integration, and safety shall normally be made without restriction, except as required by national laws and regulations relating to export control or the control of classified data. If design, manufacturing, and processing data and associated software, which is proprietary but not export controlled, is necessary for interface, integration, or safety purposes, the transfer shall be made and the data and associated software shall be appropriately marked. Nothing in this article requires the parties to transfer goods or technical data contrary to national laws and regulations relating to export control or control of classified data.
2. All transfers of proprietary technical data and export-controlled goods and technical data are subject to the following provisions. In the event a Party finds it necessary to transfer goods which are subject to export control or technical data which is proprietary or subject to export controls, and for which protection is to be maintained, such goods shall be specifically identified and such technical data shall be marked with a notice to indicate that they shall be used and disclosed by the receiving Party and its related entities (e.g., contractors and subcontractors) only for the purposes of fulfilling the receiving Party's responsibilities under the programs implemented by this Agreement, and that the identified goods and marked technical data shall not be disclosed or re-transferred to any other entity without the prior written permission of the furnishing Party. The receiving Party agrees to abide by the terms of the notice, and to protect any such identified goods and marked technical data from unauthorized use and disclosure, and also agrees to obtain these same obligations from its related entities prior to the transfer.
3. All goods, marked proprietary data, and marked or unmarked technical data subject to export control, which are transferred under this Agreement, shall be used by the receiving Party exclusively for the purposes of the programs implemented by this Agreement.

L.7.6 LIABILITY

If the successful proposing team has elements of foreign cooperative activity, a cross-waiver of liability may be required at the appropriate time.

L.8 NASA PI PROPOSING TEAMS

The ECHO Project proposal is submitted by a non-NASA PI, therefore this section is not applicable.

L.9 CONTRACTUAL REQUIREMENTS

The AO requires and appendix of contractual requirements providing the list of project deliverables and exceptions (if any) to the educational and/or commercial organization contracts. The list of deliverables can be found in Appendix L.2 (the ECHO Statement of Work).

JPL takes exception to the generic Educational Institute contract. Should JPL be selected for an ESSP task, all work will be performed under NASA Contract NAS7-1407.

Under NASA Contract NAS7-1407, Caltech performs research and development task and operates the Jet Propulsion Laboratory for NASA. This Contract is a Cost Reimbursable Award Fee type contract. The costs to be charged for the proposed work must be consistent with contractual provisions and established procedures for costing under the current contract between NASA and Caltech (i.e., for work performed under the Contract, NASA provides JPL with the authority to incur costs and enables Caltech to receive reimbursements via drawdowns from a Letter of Credit). JPL does not bill the Government for costs. JPL has no negotiated pricing or billing rates. Government audit is performed on a continuing basis by a Defense Contract Audit Agency resident team.

The JPL point of contact for contractual matters is Ms. Robyn D. Young, at (818) 354-7647.

L.10 LETTERS OF ENDORSEMENT

Jet Propulsion Laboratory
University of California, San Diego (UCSD), Scripps Institution of Oceanography

Agency Partners

National Science Foundation
U. S. Geological Survey

International Partner Letters

Deutsches Zentrum für Luft und Raumfahrt (DLR)

Science Team Letters

Thomas H. Jordan, UCSD,
Institute of Geophysics and Planetary Physics
Ian Joughin, Jet Propulsion Laboratory
Gilles Peltzer, University of California, Los Angeles,
Department of Earth and Space Science
Eric Rignot, Jet Propulsion Laboratory
Institute of Geophysics and Planetary Physics
Jean Bernard Minster, UCSD, Scripps Institution of Oceanography,
Institute of Geophysics and Planetary Physics
David Sandwell, UCSD, Scripps Institution of Oceanography,
Institute of Geophysics and Planetary Physics
Paul Segall, Stanford University
Mark Simons, California Institute of Technology,
Division of Geological and Planetary Sciences
Dr. Wayne Thatcher, U.S. Geological Survey
Howard A. Zebker, Stanford University
Maria T. Zuber, Massachusetts Institute of Technology (MIT),
Department of Earth, Atmospheric, and Planetary Sciences

Industrial Partner Letters

Astrium GmbH
Ball Aerospace & Technologies Corp., Civil Space Systems
Vexcel Corporation

Ground Data System Letters

California Institute of Technology, Division of Geological and Planetary Sciences
MIT, Department of Earth, Atmospheric, and Planetary Sciences
Howard University, College of Engineering, Architecture and Computer Sciences,
Department of Systems and Computer Science
University of Coulder at Boulder, Cooperative Institute for Research in Environmental Sciences,
National Snow and Ice Data Center
Stanford University, David Packard Electrical Engineering

Downlink Station Letters

Geophysical Institute, University of Alaska Fairbanks

University of Miami,
Rosenstiel School of Marine and Atmospheric Science

UCSD, National partnership for Advanced Computational Infrastructure,
San Diego Supercomputer Center

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91109-8099
(818) 354-4321

JPL

January 24, 2002

Refer to: 100-CE:kp

Professor Jean-Bernard Minster
Institute of Geophysics and Planetary Physics
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92037

Dear Professor Minster:

Subject: Joint Proposal entitled, "Earth Change and Hazard Observatory (ECHO)"

Reference: NASA Announcement of Opportunity entitled, "Earth System Science Pathfinder (ESSP) Mission," dated May 18, 2001 (AO 01-OES-01)

The Jet Propulsion Laboratory is pleased to be your partner on the ECHO mission. We look forward to a productive relationship during the implementation of this mission.

The Jet Propulsion Laboratory is committed to providing the support described in the proposal on the cost and schedule assuming that NASA funds the proposal. JPL endorses the participation of Dr. Paul Rosen and Dr. Ian Joughin as co-investigators on your science team.

Please refer to JPL Proposal Number 83-6806 on all written correspondence to JPL pertaining to this proposal.

If you have any questions regarding JPL's participation on this proposal, please contact Mr. John Crawford of my staff at (818) 354-6471.

Sincerely,

Charles Elachi
Director
Jet Propulsion Laboratory

BERKELEY • DAVIS • IRVINE • LOS ANGELES • RIVERSIDE • SAN DIEGO • SAN FRANCISCO SANTA BARBARA • SANTA CRUZ

INSTITUTE OF GEOPHYSICS AND PLANETARY PHYSICS
OFFICE OF SYSTEMWIDE DIRECTOR
SCRIPPS INSTITUTION OF OCEANOGRAPHY
Ph:(619)534-5650 , 534-4453. Fax: (619)534-2902

LA JOLLA, CALIFORNIA 92093-0225

January 29, 2002

ESSP AO NASA Peer Review Services, Code Y
500 E. Street, SW, Suite 200
Washington DC 20024-2760

Dear ESSP Proposal Review Coordinator:

I am pleased to submit the attached Earth System Science Pathfinder (ESSP) Step-2 proposal, entitled "***Earth Change and Hazard Observatory (ECHO)***" in response to NASA AO-01-OES-01. I am the proposed Principal Investigator. Dr. Paul Rosen of the Jet Propulsion Laboratory and Professor Howard Zebker of Stanford University are Deputy Principal Investigators.

ECHO is a collaborative effort between the Regents of the University of California, University of California, San Diego, Scripps Institution of Oceanography, and the Jet Propulsion Laboratory, the US Geological Survey, the Southern California Earthquake Center, and the Deutschen Zentrum für Luft-und Raumfahrt (DLR). Major contractors include Ball Aerospace & Technologies Corp., Astrium (Germany) and Vexcel, Inc.

This proposal is submitted jointly to NASA and to the National Science Foundation. Major support for the mission is also planned from the US Geological Survey and from DLR,

Sincerely yours,

Jean Bernard Minster
Professor of Geophysics, Scripps Institution of Oceanography
Director, Systemwide, Institute of Geophysics and Planetary Physics
University of California

Agency Partners

NATIONAL SCIENCE FOUNDATION
4201 WILSON BOULEVARD
ARLINGTON, VIRGINIA 22230

OFFICE OF THE
ASSISTANT DIRECTOR
FOR GEOSCIENCES

November 9, 2001

Dr. Ghassem R. Asrar
Associate Administrator for Earth Science
NASA Headquarters
Washington, D.C. 20546-0001

RE: Announcement of Opportunity (NASA AO-01-OES-01)

Ghassem
Dear ~~Dr.~~ Asrar:

The National Science Foundation has been working on behalf of the Earth Sciences community to develop the EarthScope initiative. An essential element of that effort is the establishment of Interferometric Synthetic Aperture Radar (InSAR) capability. The InSAR capability of the proposed "Earth Change and Hazard Observatory" (ECHO) satellite will be of great importance for monitoring Earth surface changes, especially as related to continental dynamics and to earthquake and volcanic hazards.

I understand that the ECHO proposal requests funding from both NASA and NSF, and it has successfully passed the initial review for the Earth System Science Pathfinder (ESSP) Missions competition. Concurrent with the NASA full-proposal evaluation, NSF expects to receive a proposal for the joint support of ECHO and we then will begin the review process. If the ECHO proposal is received by February 4, 2002, the initial NSF mail and panel review could be completed by April 2002. If it is successfully reviewed and funds are available for its support, the ECHO project would require approval by the NSF Director's Review Board and by the National Science Board. The earliest that we could receive National Science Board approval is August 2002.

An important part of National Science Board review will be the evaluation of NASA-NSF coordination of project milestones, management and funding. If the proposal is successful in both our review procedures and funding is provided within our respective budgets, we suggest that a Memorandum of Understanding be developed between us that addresses the joint NASA and NSF funding and management of the project.

The primary contacts for review and coordination of the ECHO proposal within the Directorate for Geosciences will be Dr. James Whitcomb, Section Head for Special Projects, and Dr. Herman Zimmerman, Director, Division of Earth Sciences. We look forward to working with you to bring this exciting project to fruition.

Sincerely,

Margaret

Margaret Leinen
Assistant Director

United States Department of the Interior

U.S. GEOLOGICAL SURVEY
Office of the Director
Reston, Virginia 20192

In Reply Refer To:
Mail Stop 102

JAN 28 2002

Dr. Jean-Bernard Minster
Director, Institute of Geophysics and Planetary Physics
University of California
Scripps Institution of Oceanography
La Jolla, California 92093

Dear Professor Minster:

The U.S. Geological Survey (USGS) is pleased to be considered as a potential partner in the Earth Change and Hazards Observatory (ECHO) mission proposal to the National Aeronautics and Space Administration (NASA) Earth System Science Pathfinder Program. Spaceborne Synthetic Aperture Radar (SAR) interferometric data have significant potential benefit to many USGS science programs. Consequently, I am enthusiastically in support of your proposal and will seek resources to provide long-term data archiving services for the project as well as participation in real-time monitoring and research applications.

USGS's proposed contribution on the data management aspects includes personnel resources, data management systems, and facilities required to receive and archive mission data, interface with the scientific user community, and deliver products as required. These responsibilities align well with USGS's desire to more aggressively apply remote sensing technology to our science directions, and with existing responsibilities of the National Satellite Land Remote Sensing Data Archive for long-term satellite data management.

We estimate that to support these archiving and distribution activities will require an investment of an estimated $7,800,000 for development (FY 2004-FY 2005), followed by an estimated $3,000,000 annually during the 5-year mission life (FY 2006-FY 2010). This cost estimate assumes FY 2002 dollars (without an escalation factor for inflation), that the anticipated production volume requires one prime shift of operations support, and that the products to be distributed are L0 data from which users will construct their own repeat-pass interferograms. Given these considerations, this support represents a substantial USGS commitment that would require a budget initiative, with FY 2004 providing the earliest opportunity for submission.

If the USGS were to assume real-time monitoring activities for the ECHO mission, in support of several USGS programs including Earthquake and Volcano Hazards, a greatly expanded initiative will need to be developed. The ECHO mission will provide an unprecedented opportunity to sample active deformation remotely in real-time. This data stream will complement existing real-time land based systems. Forecasting and predictive capabilities in natural hazards will require integration and calibration of land and space-based measurements which NASA and the USGS, working together, are uniquely qualified to carryout.

Given the caveat that an FY 2004 initiative will be required for the USGS to fulfill either or both of these commitments (data archiving and real-time monitoring), the USGS enthusiastically agrees to join as a partner in the ECHO mission. ECHO Mission data policy may significantly affect the overall mission support cost, depending upon the approach proposed regarding cost recovery of products distributed. Therefore, I propose that, should your proposal be successful, we immediately begin to work with you to develop that policy statement jointly to ensure that overall mission objectives are met while also ensuring that our appropriations initiative is properly scoped.

If unsuccessful in securing adequate funding to support mission operations at the level indicated, the USGS would not be able to support data acquisition, archiving, and distribution during the mission without reimbursement from the ECHO project. In that event, a later funding initiative (FY 2010 and beyond) would then be required for the USGS to assume responsibility for long-term preservation of the data upon conclusion of the operational mission.

Please contact R.J. Thompson, Land Remote Sensing Program Coordinator, (703) 648-5057 or (605) 594-6162 if you need additional information. I wish you success in your proposal.

Sincerely,

Chip Groat

Charles G. Groat
Director

International Partner Letters of Endorsement

[illegible]

Prof. Dr. Achim Bachem Mitglied des Vorstandes

DLR Deutsches Zentrum
für Luft- und Raumfahrt e.V.

Postfach 300364
D-53183 Bonn

Königswinterer Str. 522-524
D-53227 Bonn

Telefon (02 28) 4 47-100
Telefax (02 28) 4 47-704
E-Mail achim.bachem@dlr.de

Jet Propulsion Laboratory
Dr. Charles Elachi
Pasadena

USA

Telefax: 001-818-354-2946 vel. 18.12

Bonn, 17.12.2001

ECHO Mission Proposal

Dear Mr. Elachi,

We have the pleasure to inform you, that we consider the Earth System Science Pathfinder Proposal ECHO to be of high priority with respect to our programmatic objectives. A US – German co-operation in ECHO could be a further important milestone in the successful long term co-operation in SAR projects, starting in the 80th with SRL-1, SRL-2 and SRTM.

Regarding the framework of a co-operation we would like to propose the successful model we used for the GRACE mission, in which co-operation took place between a large variety of institutions and organisations. In the case of a selection of ECHO as a candidate for one of the next ESSP-missions, DLR would therefore consider to provide the launch vehicle and the mission operations to the ECHO project, including eventually a German ground segment.

Since we share the objectives of ECHO as a scientific mission we would welcome the participation of German scientists in this mission. Therefore the participation of German scientists as Co-Investigators in the ECHO science team, the access to the data and the scientific data rights for German scientists would be a major driver for a positive decision of DLR to our contribution.

A detailed definition of the contributions and data rights should be subject to a no-exchange-of-funds MoU between DLR and NASA, as it had been done for the above mentioned missions in a for all sides satisfactory manner.

We are looking forward to working with NASA on this mission and remain at your disposal to further define the terms of this co-operation.

Best Regards

Science Team Letters of Endorsement

USC
UNIVERSITY
OF SOUTHERN
CALIFORNIA

Department of
Contracts and Grants

January 23, 2002

University of California, San Diego
Institute of Geophysics and Planetary Physics
8765 Biological Grade, EAMS Code 6317
La Jolla, CA 92037

Attention: Dr. J. Bernard Minster

Subject: Proposal Entitled:
"EARTH CHANGE AND HAZARD OBSERVATORY: SCIENCE SUPPORT"

Principal Investigator:	Dr. Thomas H. Jordan
Amount Requested:	$785,003
Period:	10/1/02 thru 9/30/11

We are pleased to forward the enclosed proposal for your consideration and approval. This proposal has been approved by the administration of the University and signed by Lloyd Armstrong, Jr., Provost and Senior Vice President for Academic Affairs

Should you have any questions of a technical nature regarding this proposal, please contact the Principal Investigator. Information of a business or administrative nature should be directed to the attention of the undersigned at the address below or at (213) 740-6064. My E-Mail address is nbennett@bcf.usc.edu.

Sincerely yours,

Nann L. Bennett

Nann L. Bennett
Contract and Grant Administrator

Enclosures

University of
Southern California
Los Angeles,
California 90089-1147
Tel: 213 740 7762
Fax: 213 740 6070
web page:
www.usc.edu/dept/
contracts/

Jet Propulsion Laboratory
California Institute of Technology

4800 Oak Grove Drive
Pasadena, California 91109-8099

(818) 354-4321

Mail Stop 300-235

JPL

January 29, 2002

Jean-Bernard Minster
Professor of Geophysics
University of California
IGPP (0225)
Scripps Institution of Oceanography
La Jolla, CA 92093

Dear Bernard,

This letter is to express my commitment as a Co-I on the Science Team for the ECHO proposal. My institutional endorsement is implied by the JPL signature on the cover page. My costs are included in the overall JPL costing. My role will include developing processing algorithms, defining science requirements for ice sheet studies, and conducting Cal/Val experiments as part of the West Antarctic Natural Laboratory. I look to forward to working with you toward a successful ECHO mission.

Sincerely

Ian

Ian Joughin

ian@rgps1.jpl.nasa.gov (818) 354-1587 Fax: (818) 393-3077

UNIVERSITY OF CALIFORNIA, LOS ANGELES

UCLA

1868

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SANTA BARBARA • SANTA CRUZ

DEPARTMENT OF EARTH AND SPACE SCIENCES
3806 GEOLOGY BUILDING
BOX 951567
LOS ANGELES, CALIFORNIA 90095-1567

TEL: (310) 825-3880
FAX: (310) 825-2779

January 24, 2002

Pr. Bernard Minster
Scripps Institution of Oceanography
Director, systemwide, Institute of Geophysics and Planetary Physics
University of California
IGPP (0225)
Scripps Institution of Oceanography
La Jolla, CA 92093

Dear Pr. Minster,

If the ECHO proposal to the NASA ESSP program by PI Dr. Bernard Minster is selected, Dr. Gilles Peltzer (Co-I) will provide the following goods and/or services:

- Conduct before launch studies to specify mission science requirements for earthquake studies.
- Conduct Cal/Val experiments over seismic faults in the Southern California natural laboratory.
- Investigate the effects of atmospheric delay on the recovery of large-scale deformation patterns in ECHO data.

Our estimated total cost for this task is $785K, subject to final negotiations. Attached is a detailed description of how our costs were estimated.

Sincerely,

Gerald Schubert

Gerald Schubert
Professor/Chair of Dept. of Earth and
Space Sciences, UCLA

Jet Propulsion Laboratory
California Institute of Technology

4800 Oak Grove Drive
Pasadena, California 91109-8099

(818) 354-4321

January 25, 2002

Dr. Jean-Bernard Minster,
Scripps Institution of Oceanography,
Director, Systemwide, Institute of Geophysics and Planetary Physics
University of California,
La Jolla, CA 92093

Dear Bernard:

I am writing to confirm my keen interest in participating in the NASA ESSP Earth Change and Hazard Observatory (ECHO) mission, if selected, as a Member of the ECHO Science Team. As part of this team, my main responsibilities will be to help define ice-sheet and glacier mapping objectives, participate in the calibration/validation acquisition planning and calibration/validation experiments for ice sheet studies, implement simulation and validation tools for ECHO observations of glacier flow, develop a natural laboratory in West Antarctica for science demonstration, and participate in education and outreach activities dealing with Cryospheric studies.

Attached you will find a one page work statement, budget justification, and budget spreadsheet. The total cost for the duration of the mission is $K645 for FY02 - FY 11. The signature page from the JPL authorizing official is represented by the cover page of the ECHO proposal.

I am very pleased to be part of this effort.

Sincerely,

Dr. Eric Rignot
Research Scientist, JPL

4800 OAK GROVE DRIVE MAIL STOP 300-235 • PASADENA/CA • 91109-8099
PHONE: 818 354 1640 • FAX: 818 393 3077 • EMAIL: ERIC@ADELIE.JPL.NASA.GOV

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OFFICE OF SYSTEMWIDE DIRECTOR
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Ph: (619)534-5650, 534-4453. Fax: (619)534-2902

LA JOLLA, CALIFORNIA 92093-0225

January 29, 2002

To the ECHO Team

This is to express our enthusiastic support for the Earth System Science Pathfinder (ESSP) Step-2 proposal, entitled "***Earth Change and Hazard Observatory (ECHO)***" in response to NASA AO-01-OES-01.

Researchers at the Scripps Institution of Oceanography are extremely interested in all aspects of a Synthetic Aperture Radar mission designed specifically for repeat pass interferometry applications. Especially exciting is the possibility to merge and interpret simultaneously ground observations and satellite observations.

For instance, within the Southern California *Nartural Laboratory*, ground-based observations are currently collected by a large scientific community dealing with all aspects of earthquake geology and earthquake physics, from paleoseismology to strong motion, to geodetic deformation. This involves numerous universities, many of which are members of the Southern California Earthquake Center, the US Geological Survey, JPL, and numerous State, County, and city agencies. Adding systematic radar observations to this collection has long been a dream of the community. The ECHO open data policy will permit unprecedented access to SAR data by all researchers, and will surely lead to major advances in the science of earthquakes, volcanoes and the cryosphere, thereby addressing directly two of the main NASA Earth Science Enterprise strategic objectives, namely natural hazards, and sea-level change.

Sincerely,

Jean Bernard Minster
Professor of Geophysics, Scripps Institution of Oceanography
Director, Systemwide, Institute of Geophysics and Planetary Physics
University of California

David Sandwell

David Sandwell
Professor of Geophysics, Scripps Institution of Oceanography
Institute of Geophysics and Planetary Physics

STANFORD UNIVERSITY
STANFORD, CALIFORNIA 94305-4125

OFFICE OF SPONSORED RESEARCH
651 Serra Street, Room 260

Fax (650) 723-1654

January 24, 2002

In reply refer to:
SPO #26500

Prof Jean-Bernard Minster
Principal Investigator, ECHO
IGPP, Mail Code 0225
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093

Title: "Earth Change and Hazard Obervatory"
Principal Investigator: Paul Segall
Department: Geophysics
Period: October 1, 2003 - September 30, 2012
Amount Requested: $785,000

Dear Prof Minster:

On behalf of Stanford University, it is a pleasure to submit the referenced proposal requesting new grant support. Additional copies of the proposal and supporting materials are also enclosed.

Stanford University is a nonprofit U.S. institution of higher education which conducts fundamental research in basic and applied science and engineering, which is widely and openly published and made available to the scientific and academic community. Stanford does not undertake classified work or research requiring national security controls. Fundamental research is defined as the conduct of basic and applied research in science and engineering where the resulting information is ordinarily published and shared broadly in the scientific community. Stanford University has adopted an Openness in Research policy, which is available for review on the World Wide Web at http://www.stanford.edu/dept/DoR/rph/2-6.html. Based on the University's Openness in Research Policy and federal laws prohibiting discrimination based on nationality, country of origin, ethnicity, gender, race or religion, Stanford cannot accept any conditions of award which would restrict any member of the research group, including faculty, students and staff, from the ability to participate fully in all of the intellectually significant portions of the project. Do not send Stanford any material you believe to be export controlled. In the event that Sponsor makes such a disclosure to Stanford, Stanford reserves the right to immediately terminate the Agreement. In the event of termination Stanford shall recover costs for all non-cancellable commitments.

There are legal and policy restrictions on what information Stanford, as the grant recipient, would be permitted to disclose about any of its faculty, staff, and students, and there is no mechanism by which Stanford, as signatory, could impose a disclosure requirement such as this on the participating individuals. Each individual would have to agree to provide such data (assuming it goes beyond the C.V. type of information which is provided as part of the grant proposal). We could not agree to this on their behalf.

Thank you for your consideration of this proposal and should you require additional information, please feel free to contact me at the number indicated below.

Sincerely,

Catherine Boxwell
Contract Officer
(650) 725-6864

CB/mjb
Enclosures

cc: Linda Farwell, Mitchell 365 (2215)

CALIFORNIA INSTITUTE OF TECHNOLOGY
Pasadena, California 91125, U.S.A.

Division of Geological and Planetary Sciences
Mail Code: 170-25
email: ems@expet.caltech.edu
Telephone (626) 395-6108
FAX (626) 795-6028

January 22, 2002

Professor Jean-Bernard Minster
Principal Investigator, ECHO
IGPP, Mail Code 0225
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093

Dear ~~Professor~~ Bernard Minster,

This letter serves as an endorsement of the participation by Mark Simons, Assistant Professor of Geophysics in the Division of Geological and Planetary Sciences, as a member of the science team for the Earth Change and Hazard Observatory (ECHO) project. I fully acknowledge and support Professor Simons as a member of this team and the role that he shall play.

Sincerely,

Edward Stolper

Edward M. Stolper
William E. Leonhard Professor of Geology and
Chairman, Division of Geological and
Planetary Sciences

USGS
science for a changing world

24 January 2002
Menlo Park, California

Professor Bernard Minster
Scripps Institution of Oceanography
IGPP (0225)
La Jolla, CA 92093

Dear Professor Minster,

We are delighted to learn about the proposed ECHO mission, fully support its objectives, and are pleased to submit a proposal with Dr. Wayne Thatcher as the USGS lead scientist contributing to the mission.

The USGS Earthquake and Volcano Hazards Programs are concerned with the assessment, monitoring and mitigation of seismic and volcanic hazards in the US. From the results obtained by the InSAR group at the USGS using radar satellite data, as well as elsewhere, we are fully convinced that InSAR can play a major role in fulfilling these tasks.

Our experience, however, has also shown us the limitations of the current generation of SAR spacecraft and their immediate successors. For example, our recent discovery of uplift at the Three Sisters in Oregon was made using ERS InSAR. However, if we want to see how volcanoes inflate from month to month we need regular SAR acquisitions guaranteed to be suitable for interferometry.

Likewise, satellite radar observations have shown that, in addition to providing fundamental constraints on earthquake ruptures, e.g. for the Landers and Hector Mines earthquakes in California, InSAR can record the slower interseismic and postseismic motions. These observations can help us determine the rheology of the crust and mantle around faults, fundamental knowledge if we are to understand the earthquake cycle. However, to exploit these observations fully requires complete time series that only a dedicated mission such as ECHO can provide.

We also welcome the ECHO proposal plan to make raw satellite radar data freely available via the Internet. Encouraging as many people as possible to work with the data is sure to develop the field, and lead to fundamental advances in understanding volcanic and earthquake processes. In turn, this will enhance our ability to use InSAR in monitoring volcanic and seismic hazards.

Sincerely,

Terry Keith

Terry Keith
Chief Scientist
Western Region Volcano Hazards Team

Mary Lou Zoback

Mary Lou Zoback
Chief Scientist
Western Region Earthquake Hazards Team

STANFORD UNIVERSITY
STANFORD, CALIFORNIA 94305-4125

OFFICE OF SPONSORED RESEARCH
651 Serra Street, Room 260

Fax (650) 723-1654

January 24, 2002

In reply refer to:
SPO #26501

Prof Jean-Bernard Minster
Principal Investigator, ECHO
IGPP, Mail Code 0225
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093

Title:	"Earth Change and Hazard Observatory"
Principal Investigator:	Howard A. Zebker
Department:	Geophysics
Period:	October 1, 2002 - September 30, 2011
Amount Requested:	$5,288,916

Dear Prof Minster:

This package contains a Statement of Work and budget estimates for Stanford University supporting the Earth Change and Hazard Observatory (ECHO) proposal to NASA and the National Science Foundation. We include here a brief summary of our plans for both the support of Science Team activities, and our involvement in the development and operations of the Ground Data System.

Stanford University is a nonprofit U.S. institution of higher education which conducts fundamental research in basic and applied science and engineering, which is widely and openly published and made available to the scientific and academic community. Stanford does not undertake classified work or research requiring national security controls. Fundamental research is defined as the conduct of basic and applied research in science and engineering where the resulting information is ordinarily published and shared broadly in the scientific community. Stanford University has adopted an Openness in Research policy, which is available for review on the World Wide Web at http://www.stanford.edu/dept/DoR/rph/2-6.html. Based on the University's Openness in Research Policy and federal laws prohibiting discrimination based on nationality, country of origin, ethnicity, gender, race or religion, Stanford cannot accept any conditions of award which would restrict any member of the research group, including faculty, students and staff, from the ability to participate fully in all of the intellectually significant portions of the project. Do not send Stanford any material you believe to be export controlled. In the event that Sponsor makes such a disclosure to Stanford, Stanford reserves the right to immediately terminate the Agreement. In the event of termination Stanford shall recover costs for all non-cancellable commitments.

There are legal and policy restrictions on what information Stanford, as the grant recipient, would be permitted to disclose about any of its faculty, staff, and students, and there is no mechanism by which Stanford, as signatory, could impose a disclosure requirement such as this on the participating individuals. Each individual would have to agree to provide such data (assuming it goes beyond the C.V. type of information which is provided as part of the grant proposal). We could not agree to this on their behalf.

Thank you for your consideration of this proposal and should you require additional information, please feel free to contact me at the number indicated below.

Sincerely,

Catherine Boxwell

Catherine Boxwell
Contract Officer
(650) 725-6864

CB/mjb
Enclosures

cc: Lauren Nelson, Mitchell 365 (2215)

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Cheryl Magoveny, Contract Administrator
Office of Sponsored Programs
Massachusetts Institute of Technology
77 Massachusetts Avenue, Room E19-750
Cambridge, Mass. 02139-4307

1861

Telephone (617) 253-4170
Fax (617) 253-4734
magoveny@mit.edu

January 24, 2002

Dr. Jean-Bernard Minster
Scripps Institution of Oceanography
IGPP, Mail Code 0225
University of California, San Diego
LaJolla, CA 92093

Dear Dr. Minster:

The Massachusetts Institute of Technology herewith submits a new proposal entitled, "Earth Change and Hazard Observatory," to be performed under the direction of Professor Maria T. Zuber in the Department of Earth, Atmospheric, and Planetary Sciences. The proposal is for the period of October 1, 2002 through September 30, 2012, with a total estimated cost of \$789,838(\$509,775 direct costs; \$280,063 F&A costs

If you have questions of a technical matter, please contact Dr. Zuber at (617) 253-6397. If you have any questions concerning administration, please contact the undersigned.

Sincerely,

Cheryl Magoveny
Senior Contract Administrator

Enc.

Cc: M. Zuber
J. Politano

Department of Earth Atmospheric and
Planetary Sciences
Massachusetts Institute of Technology

77 Massachusetts Avenue
Cambridge, Massachusetts 02139-4307
Phone 617.253.2127
Fax 617.253.8298
www-eaps.mit.edu

January 24, 2002

Prof. Jean-Bernard Minster
Principal Investigator, ECHO
IGPP, Mail Code 0225
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093

Dear Professor Minster:

The Department of Earth, Atmospheric and Planetary Sciences of the Massachusetts Institute of Technology extends its full and enthusiastic support for the Earth Change and Hazard Observatory (ECHO) mission that is being proposed by you and your team to NASA and the National Science Foundation. The Department is pleased to endorse the participation of Professor Maria Zuber as an ECHO co-investigator and will provide the institutional support required for her to carry out her investigation during all mission phases.

ECHO will provide a rich data set for studying the dynamically changing Earth and we are pleased to be involved in this exciting endeavor.

Regards,

Ronald G. Prinn
TEPCO Professor and Department Head

Industrial Partner Letters of Endorsement

astrium

Astrium GmbH - 88039 Friedrichshafen

Charles Elachi, Director
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109-8099

Name
Albert Zaglauer
Bernhard Doll
Telefon
+49(0)7545/8-9992
+49(0)7545/8-9060
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+49(0)7545/8-5869
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Ihre Zeichen	Unsere Zeichen	Datum
	A.2002-0019-4-1/Bri/tb	23.01.2002

ECHO spacecraft; explanation on technical and cost basis heritage
Ref.: Earth System Science Pathfinder (ESSP) Missions
NASA Announcement of Opportunity AO-01-OES-01

Dear Dr. Elachi,

Astrium GmbH feels privileged to have the opportunity supporting the ECHO mission proposal.

As the technical and programmatic proposal baseline is now settled Astrium finally likes to summarize the key assumptions and baselines.

1. Technical Baseline and Heritage:

The proposed technical baseline for the spacecraft design and AIT flow is described in Annex 1 to this letter. The technical baseline is considering all ECHO specific technical and programmatic aspects and allows to a maximum extent the exploitation of heritage gained in the programs CHAMP, GRACE and TerraSAR-X. It also is in full compliance with the in house AstroBus standard ensuring the utilization of existing designs and well-developed AIT processes.

Applied EEE parts quality standards are outlined in Annex 2 to this letter.

Due to the fact that Astrium is put in charge by DLR to manage the technical and contractual interface with the launcher for TerraSAR-X and ECHO it is ensured that the same launcher configuration, separation system etc. will be utilized for TerraSAR-X and ECHO.

By implementing a so called two step approach no system engineering tasks but only unit manufacturing will be subcontracted to suppliers. This approach minimizes interface definition and control work and allows the implementation of customer needs as late as possible.

The environmental test facilities planned to be used at IABG, Munich are well known to JPL and GSFC.

Astrium GmbH
Geschäftsgebäude:
An der Bundesstraße 31
88090 Immenstaad/Bodensee
Sitz der Gesellschaft:
München

Bayerische Hypo-
und Vereinsbank AG Lindau
1 285 599 (BLZ 600 202 90)

Deutsche Bank AG Friedrichshafen
3 550 100 (BLZ 650 700 84)

Vorsitzender des
Aufsichtsrates
Armand Carlier

Geschäftsführung:
Dr. Klaus Enßlin

Astrium GmbH
Earth Observation
& Science Division

88039 Friedrichshafen
Deutschland/Germany

0/04.2001

2. Price Basis and Heritage

The price estimated is based on costs extracted from valid supplier reference proposals for TerraSAR-X components. For most of the components we have two or more potential suppliers. A final selection will be performed in a competitive manner. The reference suppliers' list is attached to this letter as Annex 3. Astrium in house scope of work is defined and costed according to ESA cost calculation schemes as for the GRACE proposal. The technical changes to TerraSAR-X are mainly limited to the structural and thermal design.

It is Astrium´s intention to execute the contract on the proposed technical and economical baseline. The nearly completed GRACE contract is a good example to prove this attitude.

The design to cost target of 47 MUSD (Firm Fixed Price) as outlined in the attached breakdown (Annex 4) is considered appropriate but needs to be substantiated by preparing detailed specifications in frame of ECHO phase B.

3. TerraSAR-X Status

The program TerraSAR-X is progressing well in phase 1 which will conclude in a preliminary design review end of March 02. Phase 2 (basically a phase C/D/E scope of work) will start without any bridging to phase 1. The final contract will cover both phases and will be signed in March 02. The risk of cancellation of the program is to Astrium´s assessment negligible. Anyhow Astrium´s contribution to the ECHO program will not be dependent on the TerraSAR-X contract signature.

Astrium GmbH hopes that this proposal support is convincing for JPL and NASA and will help to get the ECHO mission selected.

Be assured that Astrium GmbH will allocate resources and personnel with high priority to ensure a successful ECHO mission. In particular, Astrium GmbH will support the ESSP site visit at JPL to clarify any issues related to the spacecraft development, integration and test.

Sincerely

Astrium GmbH

ppa. M. Strodl

ppa. A. Setzer

Annex 1:	Spacecraft Technical Description (Input to JPL Proposal) – 16 pages
Annex 2:	Outline of TerraSAR EEE parts level specification -1 page
Annex 3:	TerraSAR spacecraft reference suppliers list – 1 page
Annex 4:	Potential cost breakdown - 1 page

Ball Aerospace
& Technologies Corp.
Civil Space Systems

21 January 2002

CSS.02.CBM.005

Institute of Geophysics and Planetary Physics
Scripps Institute of Oceanography
University of California, San Diego
La Jolla, California 92093-0225

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109-8099

Attention: Jean-Bernard Minster, Principal Investigator
Frank Webb, JPL Proposal Manager

Subject: Proposal for Step 2 ESSP ECHO Mission

Reference: NASA ESSP AO 01-OES-01

Ball Aerospace Civil Space Systems is pleased to submit our cost for the ECHO Step 2 proposal. We are very pleased to be part of the ECHO team and are committed to being a full partner in this exciting mission. Ball has the skills and infrastructure needed to produce the ECHO antenna subsystem, and we will continue to assist the PI, JPL, and the Science Team with mission, design, and performance trades to ensure the final concepts offers the highest science value for the lowest cost.

BATC Civil Space Systems (CSS) will be responsible for administering the development of the phased array antenna through Ball Antenna and Communications Technologies, systems engineering associated with the phased array development, administering the requirements flowdown to the phased array subsystem, and providing interface control between the antenna, spacecraft and radar instrument, and management of the extendible support structure subcontract. The hardware items that BATC will be providing are the L-band phased array, the extendible support structure for mounting the antenna to the spacecraft and the antenna controller.

with AEC-ABLE Engineering for the extendible support structure based on successful completion of the extendable mast for SRTM and successful completion of the RADARSAT-2 mechanism.

The price for Ball's effort on ECHO is $21,257,407 in real year dollars. Summaries of WBS elements by cost are provided. Also provided is a cost summary, subcontracts items list and travel summary. The values include all elements of cost including inflation and 10% fee, and are based on a Cost-Plus-Fixed-Fee (CPFF) contract.

BATC looks forward to working closely with the Project and Mission Integrators in the successful completion of this strategically important Program. Our primary experience is in producing mission hardware to support scientific investigations, and we will continue to work with you to enhance the science while protecting the cost cap. Because we have a staff who understand the science as well as the instrument, you will realize reduced costs and risk relate to interfaces. The ECHO mission fits our core competency; we are dedicated to providing all needed resources and a highly competent staff. We hope our effort has helped you put together a winning proposal and we look forward to proceeding with the next phase.

If you have any questions or require any additional information of a contractual nature, please contact Ms. Beth C. McGilvray at (303) 939-4070. Ms. McGilvray has the authority to negotiate this proposal on behalf of BATC/CSS. Please contact the BATC/CSS ECHO Proposal Manager Mr. Thomas Kampe at (303) 939-5455 for technical or programmatic information.

Sincerely,

G. J. Chodil
Vice President
Civil Space Systems

CB McGilvray
C. B. McGilvray
Manager of Contracts
Civil Space Systems

Attachment:

ECHO Step 2 Cost Summary

Volume I: Work Statement

Title: ECHO Ground Data System: Data Reception, Processing, Catalog, Archive, and Distribution Subsystems

Date Submitted: January 18, 2002

Submitted to:
Paul Rosen
JPL, California

Submitted by:
Vexcel Corporation*
4909 Nautilus Court
Boulder, CO 80301

Telephone: (303) 444-0094
Fax: (303) 583-0246

Authorizing Institutional Official
John C. Curlander, Ph.D.
President and CEO

E-mail jcc@vexcel.com

Contract Management:
Paul Bodnar
Controller
Vexcel Corporation
4909 Nautilus Court
Boulder, CO 80301

Technical POC:
David Cohen
Vexcel Corporation
303 583-0235
cohen@vexcel.com

*Vexcel is classified as a small business

Volume II: Cost Proposal

Title:	ECHO Ground Data System: Data Reception, Processing, Catalog, Archive, and Distribution Subsystems
Date Submitted:	January 18, 2002
Submitted to:	Paul Rosen JPL, California
Submitted by:	Vexcel Corporation* 4909 Nautilus Court Boulder, CO 80301
Telephone: Fax:	(303) 444-0094 (303) 583-0246
Authorizing Institutional Official	John C. Curlander, PhD President and CEO
E-mail	jcc@vexcel.com
Contract Management: Paul Bodnar	Controller Vexcel Corporation 4909 Nautilus Court Boulder, CO 80301
Technical POC David Cohen	Vexcel Corporation 303 583-0235 cohen@vexcel.com

*Vexcel is classified as a small business

Ground Data System Letters of Endorsement

CALIFORNIA INSTITUTE OF TECHNOLOGY
Pasadena, California 91125, U.S.A.

Division of Geological and Planetary Sciences
Mail Code: 170-25
email: ems@expet.caltech.edu
Telephone (626) 395-6108
FAX (626) 795-6028

January 22, 2002

Professor Jean-Bernard Minster
Principal Investigator, ECHO
IGPP, Mail Code 0225
Scripps Institutiuon of Oceanography
University of California, San Diego
La Jolla, CA 92093

Dear ~~Professor Minster~~ Bernard,

Caltech is pleased to support and participate in the Earth Change and Hazard Observatory (ECHO) proposal to NASA and the National Science Foundation. In particular, we are pleased to serve as one of the archive and distribution nodes of the ECHO Ground Data system. We are happy to meet our obligations as defined in the accompanying proposal and look forward to a meaningful collaboration.

We understand that the ECHO project will deliver to our site necessary computing equipment, networking interfaces, and software comprising the archive, along with centralized system administration services and support for local operational personnel and costs as described in the proposal and its appendices. Our own contribution will be to provide and assure the high-rate Internet connections required for the efficient operation of the node. Details for these activities will be developed during the first year of the proposed implementation, before the Mission Confirmation Review, through discussion with the PI and his Deputies.

ECHO represents an exciting new Earth science mission -- one that we are very interested in seeing through to success and in which we hope to play a significant role.

Sincerely,

Edward Stolper

Edward M. Stolper
William E. Leonhard Professor of Geology and
Chairman, Division of Geological and
Planetary Sciences

Department of Earth Atmospheric and
Planetary Sciences
Massachusetts Institute of Technology

77 Massachusetts Avenue
Cambridge, Massachusetts 02139-4307
Phone 617.253.2127
Fax 617.253.8298
www-eaps.mit.edu

January 24, 2002

Prof. Jean-Bernard Minster
Principal Investigator, ECHO
IGPP, Mail Code 0225
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093

Dear Professor Minster,

MIT is pleased to support and participate in the Earth Change and Hazard Observatory (ECHO) proposal to NASA and the National Science Foundation. In particular, we are pleased to serve as one of the archive and distribution nodes of the ECHO Ground Data System. We are happy to meet our obligations as defined in the accompanying proposal and look forward to a meaningful collaboration.

We understand that the ECHO project will deliver to our site necessary computing equipment, networking interfaces, and software comprising the archive, along with centralized system administration services and support for local operational personnel and costs as described in the proposal and its appendices. Our own contribution will be to provide and assure the high-rate Internet connections required for the efficient operation of the node. Details for these activities will be developed during the first year of the proposal implementation, before the Mission Confirmation Review, through discussion with the PI and his Deputies.

ECHO represents an exciting new Earth science mission˜one that we are very interested in seeing through to success and in which we hope to play a significant role.

Sincerely,

Ronald G. Prinn
TEPCO Professor and Department Head

HOWARD UNIVERSITY

COLLEGE OF ENGINEERING, ARCHITECTURE
AND COMPUTER SCIENCES
DEPARTMENT OF SYSTEMS AND COMPUTER SCIENCE

January 17, 2002

Prof. Jean-Bernard Minster
Principal Investigator, ECHO
IGPP, Mail Code 0225
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093

Dear Professor Minster:

Howard University is very pleased to support and participate in the Earth Change and Hazard Observatory (ECHO) proposal to NASA and the National Science Foundation. In particular, we are pleased to serve as one of the archive and distribution nodes of the ECHO Ground Data System. We are happy to meet our obligations as defined in the accompanying proposal and look forward to a meaningful collaboration.

We understand that the ECHO project will deliver to our site necessary computing equipment, networking interfaces, and software comprising the archive, along with centralized system administration services and support for local operational personnel and costs as described in the proposal and its appendices. Our own contribution will be to provide and assure the high-rate Internet connections required for the efficient operation of the node. This high-speed connection is consistent with the university's strategic plan, known as the Strategic Framework for Action II. Details for these activities will be developed during the first year of the proposal implementation, before the Mission Confirmation Review, through discussion with the PI and his Deputies.

ECHO represents an exciting new Earth science mission-one that we are very interested in seeing through to success and in which we hope to play a significant role.

Sincerely,
Ronald Leach
(Ronald J. Leach)
Professor and Chair

2300 6th Street, NW
Washington, DC 20059

1867

(202) 806-6595
Fax (202) 806-4531

University of Colorado at Boulder

Cooperative Institute for Research in Environmental Sciences

Campus Box 449
Boulder, Colorado 80309-0449
(303) 492-5171

January 11, 2002

Prof. Jean-Bernard Minster
Principal Investigator, ECHO
IGPP, Mail Code 0225
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093

Dear Professor Minster,

The National Snow and Ice Data Center (NSIDC) is pleased to support and participate in the Earth Change and Hazard Observatory (ECHO) proposal to NASA and the National Science Foundation. In particular, we are pleased to serve as one of the archive and distribution nodes of the ECHO Ground Data System. We are happy to meet our obligations as defined in the accompanying proposal and look forward to a meaningful collaboration.

We understand that the ECHO project will deliver to our site necessary computing equipment, networking interfaces, and software comprising the archive, along with centralized system administration services and support for local operational personnel and costs as described in the proposal and its appendices. Our own contribution will be to provide and assure the high-rate Internet connections required for the efficient operation of the node. In addition, we expect that the NSIDC user services staff will play some role in provision of data services for ECHO. We are interested in working with the ECHO PI team to assure effective utilization of ECHO data by the snow and ice community. Details for these activities will be developed during the first year of the proposal implementation, before the Mission Confirmation Review, through discussion with the PI and his Deputies.

NSIDC is particularly well situated on the local University of Colorado, and Boulder research community wide area networks. We already have access to gigabit internet circuits and it should be cost-effective to upgrade our internet access to the higher rates described in the proposal. NSIDC currently manages and distributes Earth Observing System (EOS) data that can be synergistically utilized by ECHO data users. I have included a copy of our last Annual Report, which offers a brief description of the activities at NSIDC. I suggest that those interested in learning more about NSIDC consult our web pages at: http://nsidc.org

ECHO represents an exciting new Earth science mission—one that we are very interested in seeing through to success and in which we hope to play a significant role.

Sincerely,

Ronald L S Weaver

Ronald L. S. Weaver, Scientific Manager
National Snow and Ice Data Center
303-492-7624
weaverr@nsidc.org

BRUCE A. WOOLEY
CHAIRMAN, DEPARTMENT OF ELECTRICAL ENGINEERING
ROBERT L. AND AUDREY S. HANCOCK PROFESSOR OF ENGINEERING

STANFORD UNIVERSITY
DAVID PACKARD ELECTRICAL ENGINEERING
350 SERRA MALL, #175
STANFORD, CALIFORNIA 94305-9505
(650) 723-5782
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wooley@cc.stanford.edu

January 22, 2001

Prof. Jean-Bernard Minster
Principal Investigator, ECHO
IGPP, Mail Code 0225
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093

Dear Professor Minster,

Stanford University is pleased to support and participate in the Earth Change and Hazard Observatory (ECHO) proposal to NASA and the National Science Foundation. In particular, we are pleased to serve as (i) host of the Network Transfer Subsystem and (ii) one of the archive and distribution nodes of the ECHO Ground Data System, as well as (iii) deliver and operate the Validation Processing Subsystem. We are happy to meet our obligations as defined in the accompanying proposal and look forward to a meaningful collaboration.

We recognize that part of our contribution will be to provide and assure the high-rate Internet connections and infrastructure required for the efficient operation of the Ground Data System. Details for these activities will be developed during the first year of the proposal implementation, before the Mission Confirmation Review, through discussion with the PI and his Deputies.

ECHO represents an exciting new earth science mission, one that we are very interested in seeing through to success and in which we hope to play a significant role.

Sincerely,

Bruce A. Wooley

Bruce A. Wooley
Chairman

Downlink Station Letters of Endorsement

GI 02-76

RESEARCH PROPOSAL

to

VEXCEL CORPORATION

TITLE: ECHO-3 DOWNLINK AND DISTRIBUTION BY ASF

AMOUNT: $2,949,961 **START DATE:** 01/01/04 **DURATION:** 5 years

SUBMITTING INSTITUTION:
Geophysical Institute
University of Alaska Fairbanks
903 Koyukuk Drive
P.O. Box 757320
Fairbanks, AK 99775-7320

MAKE GRANT PAYABLE TO:
Geophysical Institute
University of Alaska Fairbanks

IRS NO.: 92-6000147 **CONGRESSIONAL DISTRICT NO.:** Alaska

ENDORSEMENTS

January 2002

Roger W. Smith
Principal Investigator
Geophysical Institute
(907) 474-7416

Robert Shefchik
Assistant Director for Finance
Geophysical Institute
(907) 474-7646

Roger W. Smith
Director
Geophysical Institute
(907) 474-7416

Ted DeLaca
Vice Provost for Research
Office of Sponsored Programs
University of Alaska Fairbanks
(907) 474-5991

The University of Alaska offers equal educational and employment opportunities.
All questions and information should be addressed to Robert Shefchik.

UNIVERSITY OF
Miami

January 24, 2002

Dr. Paul Rosen
Jet Propulsion Laboratory
Mail Stop 300-235
4800 Oak Grove Drive
Pasadena, CA 91109 USA

Dear Dr. Rosen:

The University of Miami's Rosenstiel School of Marine and Atmospheric Science (RSMAS) is pleased to submit this proposal for participation in the Earth Change and Hazards Observatory (ECHO) response to NASA's ESSP Announcement of Opportunity. We are currently developing extensive infrastructure for the reception, processing, and analysis of SAR and electro-optical satellite imagery. The proposed ECHO SAR interferometry mission will compliment ongoing activities and leverage the RSMAS ground reception system, which will be in place by the end of 2002.

Of primary utility to the ECHO mission, the University is currently installing two 11.3 meter tracking antennas and a multi-satellite reception system. The antennas will provide redundant access to the ECHO satellite for 3 to 4 passes per day – augmenting Alaska SAR Facility (ASF) capabilities as well as providing a backup system in case of temporary ASF failure.

Our assumptions for this project are:

- Mission launch will occur in late 2006
- The Miami facility will acquire data for up to 4 passes per day
- No uplink or satellite scheduling will be provided
- The ECHO project will supply the following:
  - RF front-end hardware (demodulator and bit synchronizer) for the ECHO 300Mb/s downlink
  - All processing hardware and software for data capture, ingest, processing, and backup to tape
  - All spares, replacement hardware, and software upgrades
  - Acquisition planning system
  - All required media, e.g., tapes for backup

Rosenstiel School of Marine and Atmospheric Science
Division of Marine Geology and Geophysics
4600 Rickenbacker Causeway
Miami, Florida 33149-1098
(Office) 305 361-4663 (Fax) 305 361-4632

- RSMAS will provide the ECHO program with facility space for:
  - Three computers (a PC and two UNIX workstations)
  - A RAID disk array
  - An AIT tape drive, and storage for twenty tapes
- RSMAS will provide a part time system administrator with responsibilities including changing tapes twice per week and monitoring routine system performance. We understand that Vexcel Corporation will have complete remote access to this system to perform additional monitoring and software maintenance.

Based on the above assumptions, we propose a cost profile as follows:

GFY07	GFY08	GFY09	GFY10	GFY11
$67k	$69k	$71k	$73k	$76k

We look forward to working with JPL and Vexcel Corporation in the implementation of this important mission.

Sincerely,

Timothy H. Dixon
Professor, Marine Geology and Geophysics,
University of Miami

Otis Brown,
Dean, Rosenstiel School of Marine and Atmospheric Sciences,
University of Miami

UNIVERSITY OF CALIFORNIA, SAN DIEGO UCSD

BERKELEY • DAVIS • IRVINE • LOS ANGELES • RIVERSIDE • SAN DIEGO • SAN FRANCISCO SANTA BARBARA • SANTA CRUZ

NATIONAL PARTNERSHIP FOR ADVANCED COMPUTATIONAL INFRASTRUCTURE
SAN DIEGO SUPERCOMPUTER CENTER, MC 0505
(619) 534-5000

9500 GILMAN DRIVE, BLDG 109
LA JOLLA, CALIFORNIA 92093-0505

Jan 15, 2002

Dr. Jean-Bernard Minster
Professor of Geophysics, Scripps Institution of Oceanography
Director, systemwide, Institute of Geophysics and Planetary Physics
University of California
IGPP (0225)
Scripps Institution of Oceanography
La Jolla, CA 92093

Dear Bernard:

The San Diego Supercomputer Center (SDSC) is strongly interested in supporting the ECHO Synthetic Aperture Radar proposal. The formation of scientific data collections that describe the environment is an essential mechanism for advancing Earth Systems science. At SDSC, infrastructure has been developed that facilitates the creation and storage of collections that contain hundreds of Terabytes of data.

The SDSC facilities include an archival storage system with a capacity that is being upgraded to seven Petabytes in size in 1st Quarter 2002. The SDSC software infrastructure includes the HPSS archival storage system for managing the archive, data handling systems for accessing distributed data based on the Storage Resource Broker, and collection management software for building scientific data collections, based on an Extensible Metadata Catalog. With these technologies, the storage and management of a 250-Terabyte data collection is feasible.

The SDSC facilities that will be provided in support of the project will be sized to meet the growing storage requirements of the ECHO Synthetic Aperture Radar project. SDSC will provide tape-based archival storage for infrequently accessed data. The tapes will be housed in tape robots (near-line storage), and will be accessible both from applications running on SDSC compute platforms, and from remote sites over the Internet. For large-scale analyses of the data collection, the National Partnership for Advanced Computational Infrastructure supports peer-reviewed allocations of compute resources at SDSC.

Based on engineering estimates and reasonable assumptions about usage, the mission life cost is estimated to be $750,000 with a growth curve proportional to the data volume. SDSC costs for providing storage in a near-line tape archive are anticipated to be about $1,000 per terabyte-year. The costs for managing the associated collection catalog will scale with the number of files and the access rate over the expected 5-year life-time of the ECHO Synthetic Aperture Radar project.

Sincerely yours,

Anke Kamrath
Acting Executive Director
San Diego Supercomputer Center

L.11 REFERENCES

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ECHO
Launcher Specification

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TABLE OF CONTENTS

CHANGE CONTROL SHEET

Issue	Date	Sheet	Description of Change
Draft 1	16.01.02	all	Initial Issue
Draft 2	24.01.02	all	Issue after detailed discussion with Kosmotras about Launch Service
Draft 3	29.01.02	all	Update of ECHO wet mass, incl. the contingencies and margin

1 SCOPE

This document defines the technical requirements relevant for a potential ECHO launch service contract. The required launch service include the provision of

- the launcher, including the required extension of the fairing
- the launcher adapters, one flight identical model and one flight model, each including a pyro system
- the umbilical connector(s)
- the separation strategy, dynamic analysis, verification and hardware
- guiding system(s) for the separation of the heat shield and satellite, if needed
- services needed for the launch campaign

Customer = Astrium GmbH

Contractor = ISC Kosmotras

2 MISSION OVERVIEW

To be updated according the ECHO mission definition.

3 REFERENCE DOCUMENTS

Reference Documents (RD's) are for general guidance in that their use is not mandatory, but they shall be given preference over other documents covering similar subjects.

RD 01	ECHO Mission and System Requirements Specification, EC-AED-RS-0001 (not existing yet)
RD 02	tbd

4 INJECTION AND SEPARATION PARAMETERS

ECHO is presently planned to be launched in 4th quarter of 2006 and separated in the following orbit / condition:

	Requirement	Tolerance
Orbit	circular, 400 km altitude Sun-Synchronous	+/- 10 km
Inclination	98.44°	+/- 0.05 °
Eccentricity	0.0011° - 0.0012°	
Local Time of Ascending Node	18:00 o'clock	+/- 0.25 hrs
Separation Direction	within orbit plane in anti-flight direction	0.1 ° half cone (TBC)
Separation Rates	< 2 °/sec (TBC) around all axis	
Separation Velocity	< 1.0 m/sec (TBD)	

Launch Window: tbd.

All above parameters incl. launch date will be finally fixed by the customer 18 months prior to the intended launch date.

- The launch adapter shall remain on the launch vehicle (TBC).
- The launch vehicle shall not impact or contaminate the satellite during or after separation.

5 SATELLITE INTERFACE DATA

5.1 General

All data and figure given in this document are preliminary and may be subject of change due to ongoing design and analysis efforts.

A launcher interface control document shall be established by the contractor and mutually agreed between al parties.

5.2 Physical Properties

Key parameters for the ECHO s/c in launch configuration are:

	Nominal Value	Uncertainty
Wet Mass (1):	1540 kg	+/- 3 %
Outer Dimensions	see attached sketches	+/- 5 mm
CoG Position		+/- 8 mm
X	2550 mm	(above Separation Plane)
Y	0 mm	
Z	0 mm	
Moment of Inertia		+/- 5 %
Ixx	450 kgm2, TBC	
Iyy	2900 kgm2, TBC	
Izz	2900 kgm2, TBC	
Natural Frequency		------
Axial (hardmounted)	> 80 Hz, TBC	
Lateral (hardmounted)	15 - 20 Hz, TBC	

Note:

(1) with contingencies / margins and with satellite fixed parts of the separation system.
It is up to the customer to increase the spacecraft mass up to the lift off capability considering a 2200 mm fairing extension of 1700 kg for the planned orbit (To be specified in DID).

5.3 Mechanical Interfaces

Dynamic Payload Envelope

The attached sketches defines the payload dynamic envelope for the accommodation of the ECHO satellite and the launcher I/F w.r.t. the s/c build co-ordinate system.

The ECHO s/c stays within this dynamic payload definition of the contractor (see annex, based on the launcher user guide, page 29). In addition, the customer will reduce this definition by 5 (at the adapter level) up to 20 mm at the s/c tip to cope with potential deviations / displacements from the nominal s/c shape.

Launch Adapter

The launcher adapters (one flight identical adapter and one flight adapter), as well as the separation system and the umbilical connectors (both sides) are part of the contractor delivery.

The adapter height is 240 mm between the 3th stage and the separation plane. The volume required for the accommodation of launcher electronic boxes is defined in the annex. The height of this volume is 310 mm plus 40 mm margin above the separation plane.

On request some of this volume may be used for non structural spacecraft elements e.g. harness routing of the antenna etc.

The asymmetrical arrangement of the six interface points is accepted by the contractor.

Mounting of the separation system is performed from beneath the separation plane. No specific access requirements exist on spacecraft side.

The stiffness of the launch adapter shall be sufficient to meet the natural frequency requirement of the launcher.

Items, which remains on the s/c after separation shall be delivered to the customer in advance system level environmental test.

The final integration of the satellite to the launcher adapter and the separation system final integration is in the responsibility of the contractor.

Separation

Any spacecraft design respecting the dynamic envelope given (see annex) is safe with respect to collision free separation from heat shield and from third stage. This will be proven by analysis and tests conducted by the contractor.

Analysis will take into account the s/c configuration as well as worst case assumptions on all separation relevant parameters (e.g. asym-metrical thrust, separation forces).

Furthermore, the customer performs a qualification test campaign, which includes:

- Fit check with the s/c dummy
- Adapter strengths verification (vibration)
- Heat shield and s/c separation / extraction test

The separation tests shall be performed with 1-g compensation and worst case disturbance condition.

In case the customer s/c separation analysis indicates problems detected by independent review boards (from NASA and/or JPL) adequate technical solutions (e.g. guiding systems) shall be implemented by the contractor.

5.4 Electrical Interfaces

After integration of the s/c onto the launcher adapter, basic electrical check-out and battery recharge will be performed via an umbilical connector. The type of the connector is TBD by the contractor. The number of pins shall be 37 to 70 (TBD).

Preferred location for this umbilical connector(s) is outside of the hexagonal primary structure for adequate access. A symmetrical configuration is preferred.

The contractor shall provide both sides of all umbilical connectors including connector safer for testing and any other required devices (TBD).

The power handling capability shall be 10 A (TBC) at least via 6 pins. This lines shall be separated.

The umbilical harness shall to be routed into an appropriate check-out room. The connection shall be cut earliest 2 (?) hrs (TBC) prior lift-off.

Electrical grounding of the s/c shall be performed via the launch adapter (TBD Ohm).

During lift-off the ECHO satellites are powered off, except the Power Conditioning and Distribution Unit (PCDU) which is directly connected to the battery.

5.5 Hazardous Elements

The ECHO satellites contains the following hazardous elements:

- Vessel(s) with (max.) 160 kg (TBD) of hydrazine propellant under 24 bar. Pressurant gas will be GN2 or GHe . Proof pressure is 1.5 x MEOP (TBD).
- One NiH2 battery with TBD pressure vessels filled at 55 bar (TBC). Proof pressure is 1.5 x MEOP.
- Pyro devices for mechanism to be released after separation from launcher.

The provision of propellant and pressurant gas is customer´s task. The contractor will support the transport and handling tasks at the launch site. Especially safety related infrastructure and equipment will be provided by the contractor.

Fuel loading of the spacecraft will be done by the contractor using own equipment or customer provided equipment. Baseline version for contract is fuelling operations to be executed by the contractor.

Fuel loading process can be executed in the high bay where all flight preparation is performed. Spill devices etc. will be provided by the contractor.

The contractor shall state compliance with all range safety aspects concerning the above mentioned materials and proof factors.

6 ENVIRONMENTAL REQUIREMENT

6.1 On-Ground Environment

Check-out transport and storage of the ECHO satellite shall be carried out in climatically and cleanliness-controlled areas only. The parameters specified in the table below shall not be exceeded. Care shall be taken, that the dew point is never reached on flight H/W.

Parameter	**Assembly, Integration**	**Transportation, Storage**
Temperature	20°C ± 10°C	0°C up to +35°C [1)]
Relative Humidity	50% ± 10%	< 70%
Pressure	Ambient	Ambient to 15 km flight altitude
Rate of Pressure Change	N/A	< 2 kPa/s
Cleanliness	Class 100 000 (or equivalent)	Class 100 000 (or equivalent)

1) Conditions for battery according to supplier requirements

The following external climatic boundaries apply for the transport container, when the ECHO satellite is inside:

Parameter	Minimum	Maximum
Container surface Temperature:	-20°C (1)	+40°C
Relative Humidity:	0%	90%
Rate of Pressure Change:	0	< 2 kPa/s
Pressure:	15 km flight altitude	Ambient pressure

Notes: (1) In case the temperature drops below - 20 °C an access to power of 400 V shall be provided in order to operate a heater inside the transport container

With respect to cleanliness, the transport container shall not be in the open to prevent from direct exposure to e.g. rain, sun or dust.

The mechanical loads during transport shall be below those defined hereafter.

Activity	Forward / Aft	Starboard / Port	Up / Down
Handling / Hoisting	± 0,3 g	± 0,3 g	1,0 ± 0,5 g
Transportation	± 0,4 g	± 0,5 g	1,0 ± 0,7 g
Transport Shock	TBD		

6.2 Fairing Environment

The temperature under the faring is maintained within+10 °C to +25 °C with relative humidity less then 70 % (TBC).

6.3 Launch Environment and System Tests

In the following the ECHO project assumption on structural design and verification is outlined for the proto-flight approach.

The contractor shall provide actual data for the load environment and shall at the end state compliance with the proposed design and verification approach.

Spacecraft dimensioning and testing takes into account safety factors which are defined by the spacecraft authority. The following safety factors will be taken into account:

- 2.0 for ground handling
- 1.5 during launch while LV is moving inside the TLC
- 1.3 during launch after the LV exits from the TLC
- 1.3 during LV flight

6.3.1 Quasi-Static Loads

Forces and moments at the interface of the satellite to launcher are limited by the quasi static design loads of 2.5 g (TBC) lateral and 10.8 g (TBC) in axial direction at the satellite CoG. This loads are used as notch limits for vibration testing.

To verify the adequacy of the structural design either a **static load test** with the satellite and/or a **low frequency vibration test** is planned **(TBD).**

6.3.2 Low Frequency Vibrations

Levels and frequency ranges are depending on the definitions of the specific user's guide. In addition, the contractor shall perform a coupled analysis to support the potential vibration test definition.

If the s/c will undergo a low frequency vibration test, notching will be performed to limit the loads below above defined design loads.

6.3.3 Acoustic Noise

An acoustic noise acceptance test with flight sound pressure levels plus a test factor of +2 dB (TBC) will be applied to the launch configuration.

6.3.4 Random Vibration

Random vibration is not planned. Expected loads are considered to be covered by the acoustic tests.

6.3.5 Shock

ECHO will be designed to withstand shocks resulting from the activation of separation pyro devices. Levels and frequency distribution shall be taken form the launcher handbook. Shock loads will be verified by satellite separation test in launch configuration.

Shock induced loads due to fairing and stage separation are assumed to be lower than those defined for the separation from adapter.

6.3.6 Interface Tests between Spacecraft and Launcher

The design and development process of the launch adapter, the heat shield and the separation system shall be verified by following tests to be conducted by the contractor:

- Fit check
- Separation dynamics test
- Structural strength verification

6.3.7 Thermal Loads

During ascent the s/c is subject to a heat flux originating from the aero-dynamically heated fairing. The net heat flux density shall not exceed 1000 W/m^2 (TBC).

6.3.8 Static Pressure Trop during Ascent

The maximum pressure trop during ascent shall not exceed 3500 N/m^{2}s (TBC).

6.3.9 Gas Dynamic Effect

Any thermal impact from the 3th stage motor plume shall be below 5 W hr/m^2.

Any s/c contamination due to sedimentation of solid or liquid particles from 3th stage motor combustion shall be avoided.

The contract shall perform an analysis showing the effect of the 3th stage motor operation on the s/c.

6.4 Electromagnetic Compatibility

ECHO will switched off during launch and ascent. No RF transmission or reception is required from the s/c.

7 MODEL PHILOSOPHY

Step 1 :

Step 1 includes all tests at the contractor´s premises (load tests, fit check, separation dynamics) and will be performed in the Ukraine. Witnessing of the tests by customer is recommended

The test set up for the structural qualification will be:

Element	Model	Provider
Third stage structure	Simulator	Kosmotras
Spacecraft adapter	Flight model	Kosmotras
Spacecraft	Either FM primary structure equipped with mass dummies or a specifically built structural dummy of the spacecraft	Astrium or Astrium/Kosmotras
Fairing extension	Flight model	Kosmotras
Heat shield	Flight model	Kosmotras
Fairing	Flight model	Kosmotras

The test set up will be properly equipped with accelerometers allowing to gain detailed information on the loads at the adapter/spacecraft interface. At least 50 accelerometers and recording data with a resolution of 0.1 Hz are mandatory. A closed loop control to avoid overtesting of the spacecraft structure is mandatory as well.

In case a spacecraft dummy will be used it has to represent mass, CoG, interface stiffness and eigenfrequency.

Step 2:

Step 2 covers all tests at the customer´s premises which will be a system level vibration, acoustic and shock test utilising a flight identical model of the adapter and one set of pyros to be fired together with the flight model s/c. The test will be performed in Munich, Germany. Presence of launch vehicle experts for these tests is mandatory. One set of separation device pyros needs to be fired during this test campaign.

8 OPERATIONAL REQUIREMENTS

- Access to satellite and GSE containers shall be provided at any time during transportation and storage
- Energy supply (diesel or 400 V) for air conditioning system of transport containers shall never be interrupted for more than 6 hrs (TBC).
- Umbilical connectors shall be routed to 'launcher block house', where checkout equipment is situated. Connection is supposed to be terminated with lift off.
- Battery charging access via umbilical connector shall never be interrupted for more than 4 hrs (TBC).
- Access to s/c red tag items shall be guaranteed till closure with heat shield.
- The adapter design must allow mounting and de-mounting of the s/c.

- Purging the fairing (including s/c) with clean and dry air / nitrogen.

9 PROVIDED ITEMS

9.1 Contractor Provided Items

The ECHO launch service includes:

- ECHO launch and separation in orbit / condition as defined in chapter 4
- Transport of ECHO satellites and its GSE from Airport at the launch site
- Transport back of the GSE to above Airport
- ? Insurance for transport within customer facilities ?
- All customs formalities and duties

9.1.1 Hardware

- One Launch Vehicle with extended (2200 mm) fairing, including all necessary support equipment
- One flight identical adapter and one FM adapters, including all necessary mounting tools, parts and devices
- Three separation systems:

  - one for qualification testing of the launch vehicle (at contractor site / Ukraine)
  - one for acceptance testing of the satellite (at customer site, Munich), see remark below
  - one for flight

  including all necessary pyro devices, mounting tools, parts and devices
- Guiding systems for safe separation (if needed)
- Umbilical connector(s), including counter parts and connector savers
- Any hardware or task needed to install the ECHO s/c on the launch adapter / launcher, such that the customer's task at the launch site is limited to satellite preparation.

Remark:

A flight identical launch adapter, together with the separation system and its actuator(s) shall be available for system testing. The contractor is responsible for the transport of this hardware (with transport container to/from Munich), experts for test support and result analysis.

9.1.2 Facilities and Services

- Cleanroom facilities (MIK) for the ECHO for a 4 weeks period, with environmental conditions as defined in chapter 6.1 and primary power supply including back up system for uninterrupted provision of power.
- Fuelling and pressuring facilities, equipment in the MIK incl. operational support
- Crane equipment with 5 tones capability and hook height above floor level of at least 10 m (TBC)
- Fork lifter with 10 tones capability for moving of 20 feet ISO containers
- GSE facilities in the vicinity of the s/c for a 5 weeks period
- GSE facilities in the vicinity of the launcher for a final checkout (up to 1 day) and battery conditioning after installation at the launcher (up to 4 hrs before lift off / until begin of launcher fuelling ?)

- Offices for the ECHO team (about 25 persons) for a 5 weeks period
- Overnight accommodation of a 25 men team for a 5 weeks period (booking support only)
- GSE facilities in the vicinity of the launch pad for final check-out and battery charging for up to 5 days and until 2 hrs prior lift-off)
- all local transport infra-structure to handle the s/c and the GSE
- team transport and escort within Moscow and launch site
- support of emergency shipments
- provision of telecommunication and www access
- medical support
- customs clearance at Moscow International Airport for import and export to/from Germany/US

9.1.3 Analysis and Documentation

- Launcher Coupled Dynamic Analysis (LCDA), including launch adapter analysis to be performed:

  -) one after s/c design freeze
  -) one before test program and
  -) one after test results evaluation
- Analysis of a defined separation strategy such to exclude the risk of collision between ECHO satellite and the upper stage shroud items
- Analysis of a defined separation strategy such to exclude the risk of collision between ECHO satellite and the upper stage elements covering the first 10 orbits
- Detailed inputs to a launch campaign plan according the ECHO specific needs for check-out at the launch site
- Detailed interface documentation
- Provision of ECHO injection data gained via launcher tracking / telemetry within 40 (TBD) minutes after first passage over launch site via Tax or e-mail to GSOC in the form and with the accuracy as provided by the launch authorities. The detailed description of this (interface, form of parameters and accuracy) has to be provided to GSOC at least L - 6 month. This shall support the acquisition of the ECHO s/c by the full ground station network in case of contingencies (initial acquisition failed) and for verification of the injection-orbit in case of nominal first acquisition.
- A post launch evaluation final report covering detailed launch / injection data
- All documents necessary for range safety

9.2 Customer Provided Items

9.2.1 Hardware

- ECHO satellite
- GSE in containers, transported to the Airport at the launch site with an intermediate stop at Moscow International airport for customs clearance only. This stop is limited to several hours only and does not require any unpacking of cargo.
- Hydrazine and pressurant gas in adequate transport containers

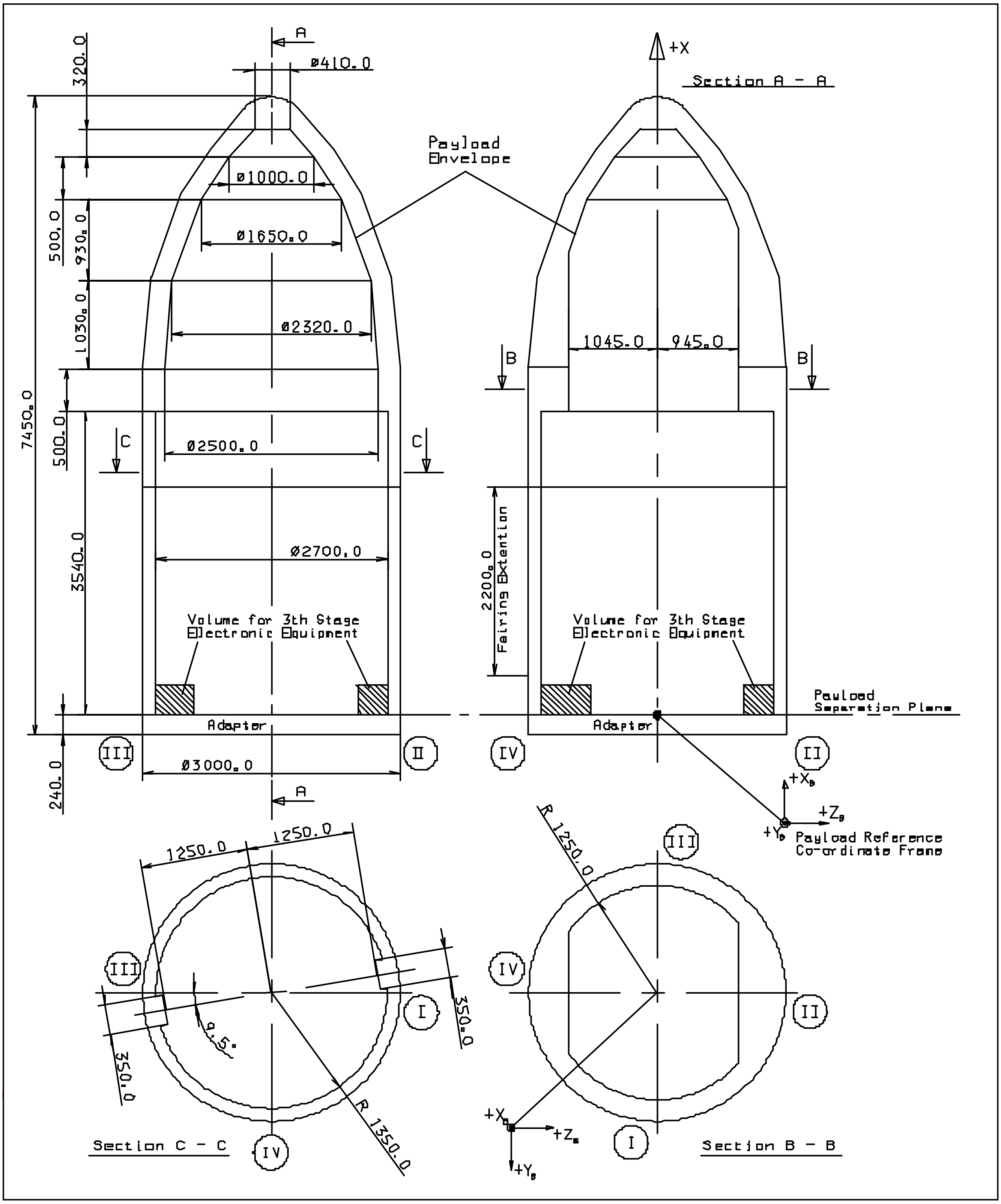
As a first assumption the baggage will consist of two 20 feet ISO containers and a TBD number of single boxes with an overall volume equivalent to an additional 10 feet ISO container. The overall gross weight is estimated to 20 metric tons (TBC).

9.2.2 Documentation and Software

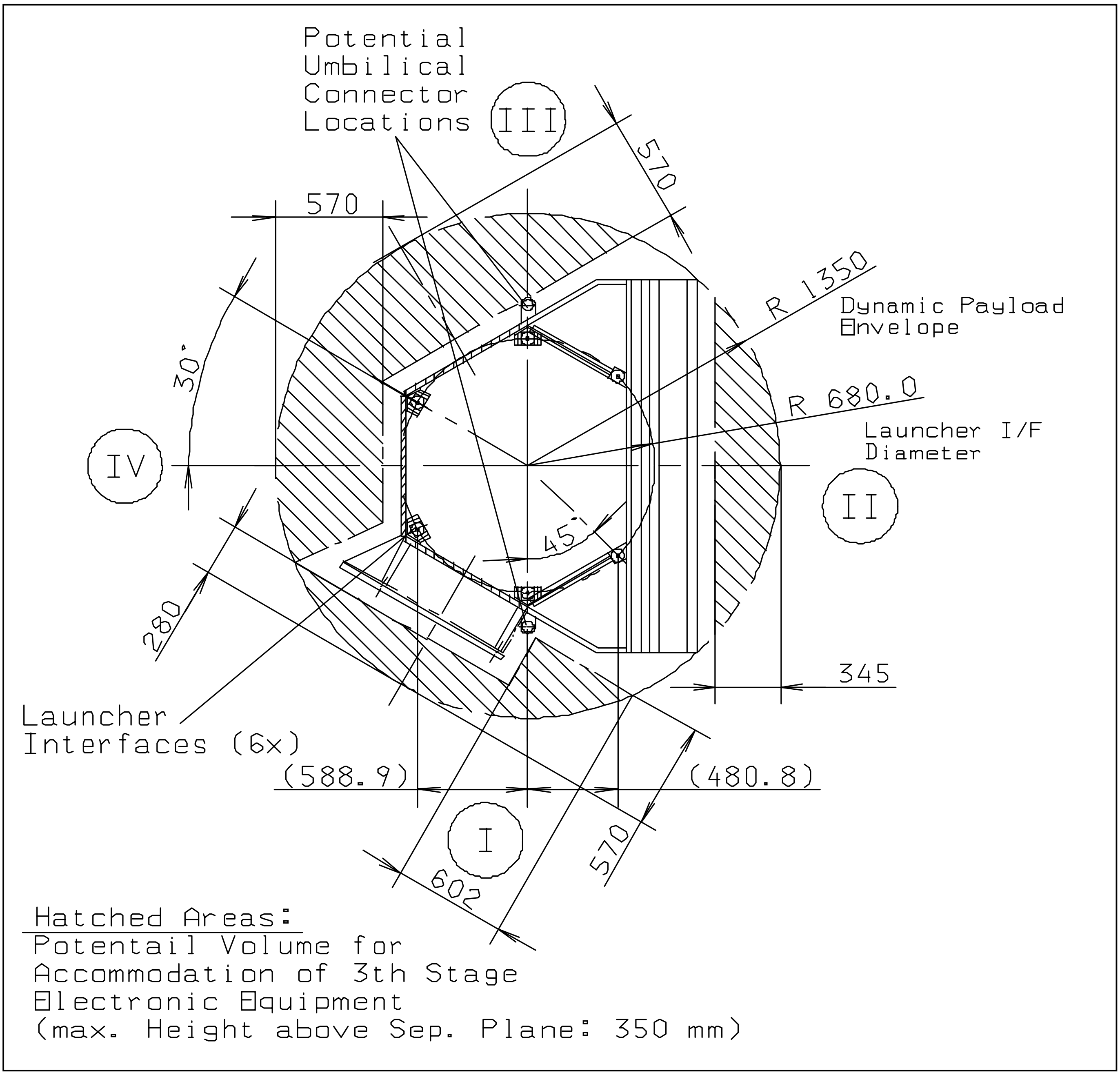
- Mission Related Data
- Physical Properties
- Spacecraft Operation Plan
- Inputs to Launcher ICD
- Science and Mission Requirements Document
- Safety Submissions
- Spacecraft Dynamic Model
- Spacecraft Mechanical Environment Test Results
- Final Mission and Spacecraft Data
- Spacecraft Operations Plan at Range Site
- Orbit Tracking Operations Requirements

ANNEX 1: ECHO INTERFACE DEFINITIONS

Figure 1: Dnepr-1 Payload Volume (Extended Fairing)



Fig



Hatched Areas:
Potentail Volume for
Accommodation of 3th Stage
Electronic Equipment
(max. Height above Sep. Plane: 350 mm)

L.12 ACRONYMS AND ABBREVIATIONS

AARC	Arctic and Antarctic Research Center
ACT	(Ball) Antenna and Communications Technologies (organization)
ADC	analog-to-digital converter
ADCS	Attitude Determination and Control System
AI&T	assembly, integration, and test
ALOS	Advanced Land Observation Satellite
AO	Announcement of Opportunity
AOC	attitude and orbit control
APID	application packet ID
ARTP	(NASA/JPL) Advanced Radar Technology Program
ASF	Alaska Synthetic Aperture Radar Data Facility
ASM	Acquisition and Safe Mode
Astrium GmbH	(integration and test services company)
ATBD	Algorithm theoretical basis document
ATLO	Assembly, Test, and Launch Operations (for entire S/C and instrument)
BER	bit error rate
BFPQ	block floating-point quantization
BITE	Built-In Test Equipment
BOL	Beginning of Life
BTPD	Ball Telecommunications Products Division (providing antenna)
BW	beamwidth
C&DH	command and data handling
Cal/Val	calibration/validation
CAS	cost accounting standard
CASB	Cost Accounting Standards Board
CCB	Configuration Control Board
CDMG	California Division of Mines and Geology
CDR	Critical Design Review
CEO	(Southern California Earthquake Center) Communication, Education, and Outreach
CFRP	carbon fiber reinforced plastic
CM	configuration management
COBRA	
COE	(U.S.) Corps of Engineers
COTS	commercial off the shelf
CPDU	Control and Power Distribution Unit
CPU	central processing unit
CPV	
CRR	Confirmation Readiness Review
CTBA	
CTS	coax transfer switch
CTU	
CUREE	Consortia of Universities for Earth Systems Education

DA	data acquisition
DCS	Data Catalog System
DDA	dual drive actuator
DDHA	Detailed Design Hazard Analysis
DES	Digital Electronics Subsystem [p. 18]
DLR	Deutsches Zentrum für Luft und Raumfahrt (German space agency)
Dnepr	(rocket)
DNS	(JPL) Desktop and Network Services
DOD	depth of discharge
DPA	destructive physical analysis
DPI	Deputy Principal Investigator
DSLEESE	Digital Library for Earth Systems Education
DSN	Deep Space Network
DVM	Design verification matrix
DWP	data window position

EAR	(U.S.) Export Administration Regulations
ECHO	Earth Change and Hazard Observatory
ECR	Engineering Change Request
EDC	EROS (Earth Resources Operation Systems) Data Center
EEE	electronic, electrical and electromechanical (parts)
EERI	Earthquake Engineering Research Institute
EIS	(JPL) Enterprise Information Services
ELV	expendable launch vehicle
EOL	End of Life
EOSDIS	Earth Observation System Data Information System
EPA	Environmental Protection Agency
EPA	Environmental Protection Agency
EPO	Education and Public Outreach
EPOO	(JPL) Education and Public Outreach Office
ERC	
ERC32	(processor)
EROS	(USGS) Earth Resources Operation Systems
ERS	Earth Resources Satellite
ES&T	(JPL) Earth Science and Technology Directorate
ESA	European Space Agency
ESE	(NASA) Earth Science Enterprise
ESIP	NASA Federation of Earth Science Information Providers
ESMOS	(JPL) Earth Science Mission Operations Center [? G-4]
ESSP	Earth System Science Pathfinder (NASA program)
EVM	Earned Value Management (system)

FE	Formal Educuation (NASA ESE objective)
FE_{CS}	Formal Education Curriculum Support
FEMA	Federal Emergency Management Agency
FE_{SC}	Formal Education Systemic Change
FE_{SS}	Formal Education Student Support

FE_{TP}	Formal Education Teacher/Faculty Preparation
FFP	firm fixed price
FFRDC	Federally Funded Research and Development Center
FMEA	failure modes and effects analysis
FNMOC	Fleet Numerical Meteorology and Oceanography Center
FPGA	field programmable gate array
FSW	flight software
FTA	fault tree analysis
FTE	(labor) full-time equivalent
G&A	General and Administrative
GDS	Ground Data System
GIS	geographic information systems
GLIMS	Global Land Ice Monitoring from Space
GPMC	Governing Program Management Council
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
GSE	ground support equipment
GSFC	Goddard Space Flight Center (Greenbelt, MD)
GSOC	German Spacecraft Operations Center
GUI	graphical user interfacw
HAZUS	(FEMA PC-based lGIS earthquake, flood, and wind loss-estimation software)
HK	housekeeping
HPA	High power amplifier [p. 16]
HPC	high priority command
HRCR	Hardware Review and Certification Requirement (form)
HSI	hierarchical storage interface
I&T	integration and test
I/Q	in-phase/quadrature
IA	Interdivisional Authorization
IABG	(company doing integration and test)
ICD	Interface Control Document
ICE	Independent Cost Estemation
ICESat	Ice, Cloud and land Elevation Satellite
IE	Informal Educuation (NASA ESE objective)
IF	intermediate frequency
IFU	interface unit
IGPP	Institute of Geophysics and Planetary Physics (La Jolla, California)?
IGS	International GPS Service
IIRT	Integrated Independent Review Team
IM	Instrument Manager
IMS	integrated master schedule
InSAR	Interferometric synthetic aperture radar
IPCC	Intergovernmental Panel on Climate Change
IR	Infrared

IRIS	Incorporated Research Institutions for Seismology
IST	Integrated Software Test
ITAR	(U.S.) International Traffic in Arms Regulations
ITSS	(Raytheon) Information Technology and Scientific Services
IV&V	independent validation and verification
KSLOC	kilo-SLOC (thousand source/software lines of code)?
LA	Los Angeles (California)
LCL	latch current limit
LEO	low Earth orbit
LNA	low-noise amplifier
LRR	Launch Readiness Review
LV	launch vehicle
MAM	Mission Assurance Manager
MCR	Mission Confirmation Review
MDR	Mission Design Review
MERR	Mission Event Readiness Review
METOP	Meteorological Operational Weather Satellite
MIMIC	monolithic microwave integrated circuit
MLI	multi-layer insulation
MM	Mission Manager
MMIMIC	monolithic microwave integrated circuit
MMR	Monthly Managemenent Review
MO&DA	Mission Operations and Data Analysis
MOA	Memorandum of Agreement
MOM	Mission Operations Manager
MOS	Mission Operations System
MOU	Memorandum of Understanding
MPS	Mission Planning/Scheduling
MRR	Mission Readiness Review
NASDA	National Space Development Agency (of Japan)
NCO	Numerically Controlled Oscillator
NEPA	National Environmental Policy Act
NIAT	NASA Integration Action Team
NISDC	National Ice Snow Data Center
NOA	New Obligation Authority
NOAA	National Oceanographic and Atmospheric Administration
NOM	normal mode
NPG	NASA Policy Guideline
NRZ-L	non-return-to-zero-levelm
NSF	National Science Foundation
NTS	Network Transfer Subsystem
OBC	On-Board Computer
OCM	orbit control mode

ODC	Other Direct Cost
OES	(California) Office of Emergency Services
OFFEC	(German satellite mission)
ORR	Operational Readieness Review
OSS	(NASA) Office of Space Science
P/FR	Problem/Failure Report
PAB	printed antenna board
PBO	Plate Boundary Observatory
PCAT	(JPL) Project Cost and Analysis Tool
PCB	printed circuit board
PCU	power control unit
PD	Professional Development
PDA	Power Distribution Assembly
PDMS	(JPL) Product Data Management System
PDR	Preliminary Design Review
PE	Project Engineer
PER	Pre-Environmental Review
PIND	particle impact noise detection
PIP	Project Implementation Plan
PLL	phase-locked loop
PM	Project Manager
PMC	Program Management Council
PMCM	(JPL) Parametric Mission Cost Model
POD	precision orbit determination
pps	pulse per second
PRF	pulse repetition frequency
PSA	Project Schedule Analyst
PSE	Project System Engineer
PSET	Project-Level System Engineering Team
PSR	Pre-Ship Review
PUS	Packet Utilization Standard
QA	quality assurance
QBS	(Ball) Quality Business System
RAM	random access memory
RCTU	Radar Control and Timing Unit
Rec/Del	Receivable/Deliverable
RF	radio frequency
RFA	request for action
RFES	Radio Frequency Electronics Subsystem
RM	risk management
RMS	(JPL institutional) Resource Management System
ROI	repeat orbit interferometry
ROI_PAC	Repeat Orbit Interferometry Package (code)
ROM	read-only memory
ROSI	Repeat Orbit ScanSAR Interferometric (processor and preprocessor)

RS	Reed Solomon
RT	real time
RTEMS	Real-Time Executive for Multiprocessor Systems
RTR	Red Team Review (Phase I)
RTTC	(NASA) Regional Technology Transfer Center(s)
RY	real year (usually dollars)
S/C	Spacecraft
SAC-C	Scientific Applications Satellite–C (joint mission of Argentine space agency and NASA)
SAF	(JPL) Spacecraft Assembly Facility
SAFOD	San Andreas Fault Observatory at Depth
SAN	storage area network
SAPG	Science Applications Planning Group
SAR	Synthetic aperture radar
Scan-SAR	scan rapidly across three beams
SCC	spacecraft control computer
SCEC	Southern California Earthquake Center
SCIGN	Southern California Integrated GPS Network (GPS = Global Positioning System)
SDAP	Science Data Analysis Projects
SDD	System Design Document
SDLC	Synchronous Data Link Control
SDRAM	synchronous dynamic random access memory
SDSC	San Diego Supercomputer Center
SEP	Support Electronics Package
SIO	Scripps Institution of Oceanography (La Jolla, California)
SIR-C	Shuttle Imaging Radar-C
SLA	Shuttle Laser Altimetry
SMA	safety and mission assurance
SMO	Systems Management Office
SNR	signal to noise ratio
SoCalHUG	Southern California HAZUS Users Group (HAZUS is FEMA’s earthquake, flood, and wind loss-estimation software)
SOW	Statement of Work
SQA	Software Quality Assurance
SRD	System Requirements Document
SRL	Significant Risk List
SRR	Systems Requirements Review
SRTM	Shuttle Radar Topography Mission
SSM	Second surface mirror
SSR	Solid State Recorder
StaLO	Stable Local Oscillator
STS	Space Transportation System (Space Shuttle)
SU	Stanford University
SVF	software validation facility
SWAR	Software Acceptance Review
SWCDR	Software Critical Design Review

T/P	TOPEX/POSEIDON
T/R	transmit/receive
TC	telecommand
TM	telemetry
TMLCC	Total Mission Life Cycle Cost
TRL	Technology Readiness Level
TRR	Test Readiness Review (integration and test)
TWTA	traveling wave tube amplifier
UART	Universal Asynchronous Receiver-Transmitter (interface)
UCSD	University of California at San Diego
USCOE	U.S. Corps of Engineers
USGS	United States Geological Survey
UTC	Universal Time, Coordinated
VAL	validation
vBNS+	Very high performance Backbone Network Service
WBS	Work Breakdown Structure
WInSAR	Western North American Interferometric SAR Consortium
WIRE	Wide-Field Infrared Explorer (satellite)?
WSOA	Wide Swath Ocean Altimeter