An Update on GPS-Ionosphere Support for NASA's Earth Observation Satellites

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Continuing Contributions

Justification:

- To achieve the highest possible accuracy, single-frequency altimeter measurements need to be calibrated for ionospheric delays.
- JPL continues to provide robust procedures and calibration for ocean altimeters and NASA's Earth Observation Satellites, relying on data from the global IGS network. The accuracy of our sub-satellite ionospheric delays is better than 1 cm (at 13.6 GHz).

Main Contributions During Last Year:

- We have continued to provide the highest quality of global ionospheric corrections for the altimeter community (e.g.,Jason-1, ENVISAT, etc).
- We provided AQUARIUS team at GSFC with a new algorithm (GAIM) to improve the accuracy of future surface salinity signals by reducing uncertainties in ionosphere model (NASA NRA proposal submitted in March 2009 – sadly, did not get selected).
- We ported our software to a completely independent operational backup processing facility (separate computer, backup power supply, etc.) in case the primary run fails.
- We started exploring the possibility of using GAIM for ionospheric calibration for altimeters, AQUARIUS, etc.

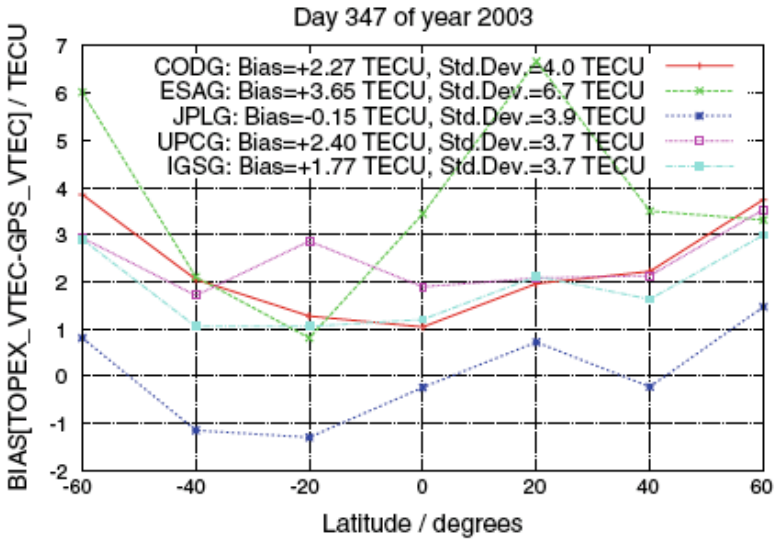
Continuing Efforts (unchanged)

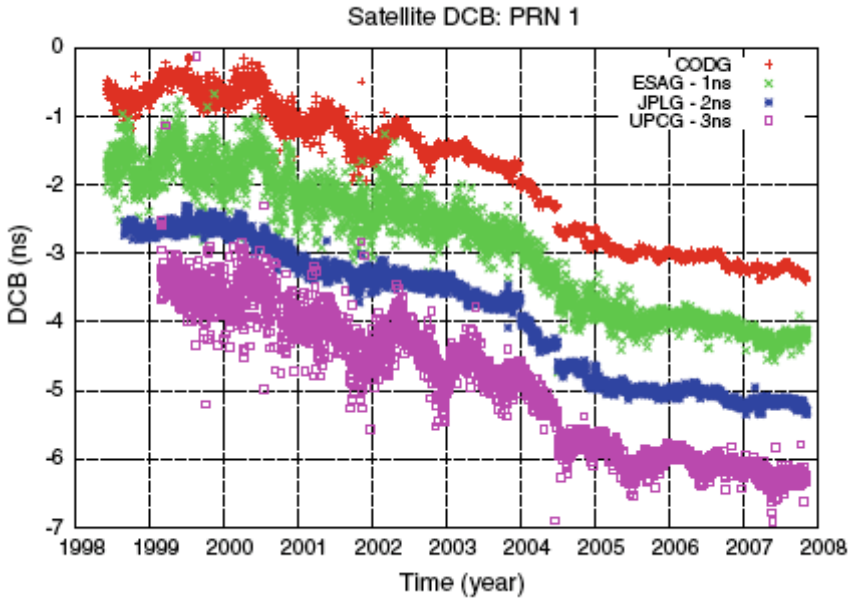
Worldwide Use of GIM Products:

- *CNES* uses our GIM ionospheric corrections (instead of DORIS) as part of GDR for Jason. ENVISAT (off-line products) has used GIM corrections since May 2006.
  - GIM correction requested for Jason-2, Cryosat-2 and AltiKa missions (off-line products). CNES performs extensive testing and validation of JPL products on a yearly basis.
  - CNES continues to claim that the GIM corrections are the "most stable and the only one that can be used for monitoring the stability of the dual-frequency corrections at the level necessary to support studies of global sea-level change." CNES performs routine checks comparing Jason-1 and ENVISAT to GIM to detect any pbs in dual-freq corrections.
- *IGS* uses NASA GIM maps and combines them with other processing centers' products. JPL products have been and still are the most accurate compared to Jason VTEC data. JPL products are downloaded most often.
- *NOAA/NESDIS* indicates that the JPL GIM products are essential for corrections of single-frequency altimeter data from GFO, ERS-2.
  - NOAA testimonials indicate that "JPL products are more accurate and delivered more reliably than those of other centers."
  - Dozens of altimeter data users worldwide in ocean monitoring hurricane forecasting and geophysics. In addition, NOAA uses JPL GIM for stable long-term reference in studies of sea level and climate change.

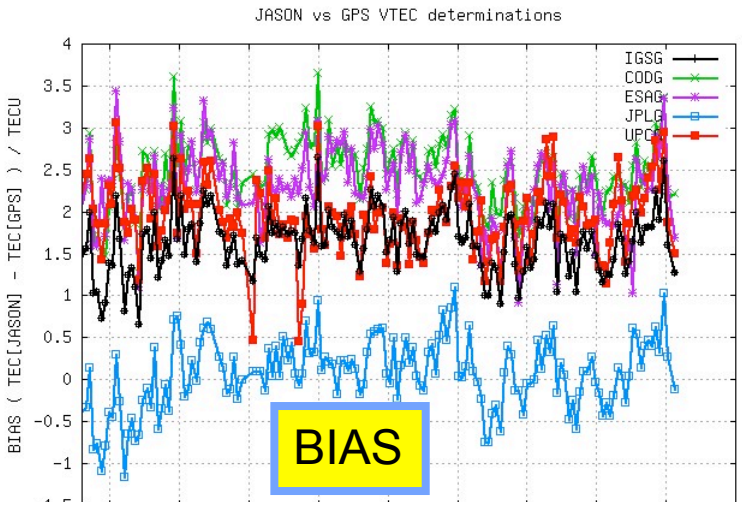
Continuing Efforts: AQUARIUS

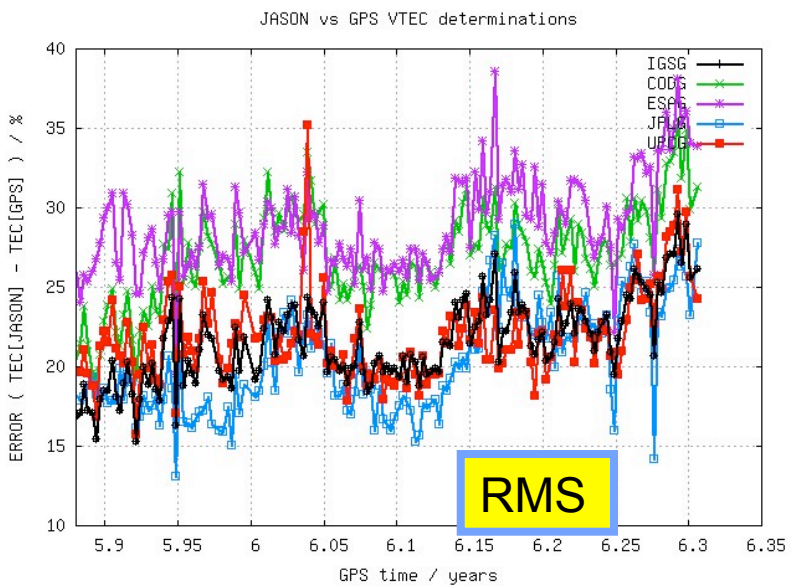
- We submitted NASA NRA proposal "Improved Ionospheric Calibration in the retrieval of sea surface salinity from Aquarius measurements" in March 2009 (P.I. Saji Abraham, Co-Is: Attila Komjathy and Dieter Bilitza)
- We worked with the AQUARIUS Team to improve the detection of climate related sea surface salinity signals for AQUARIUS, due for launch in May 2010, by reducing the uncertainties in ionosphere model.
  - We provided the AQUARIUS team with an algorithm to update IRI-2007 coefficients sets using GPS-derived vertical and slant TEC measurements, TOPEX/Jason data and possible COSMIC-derived TEC.

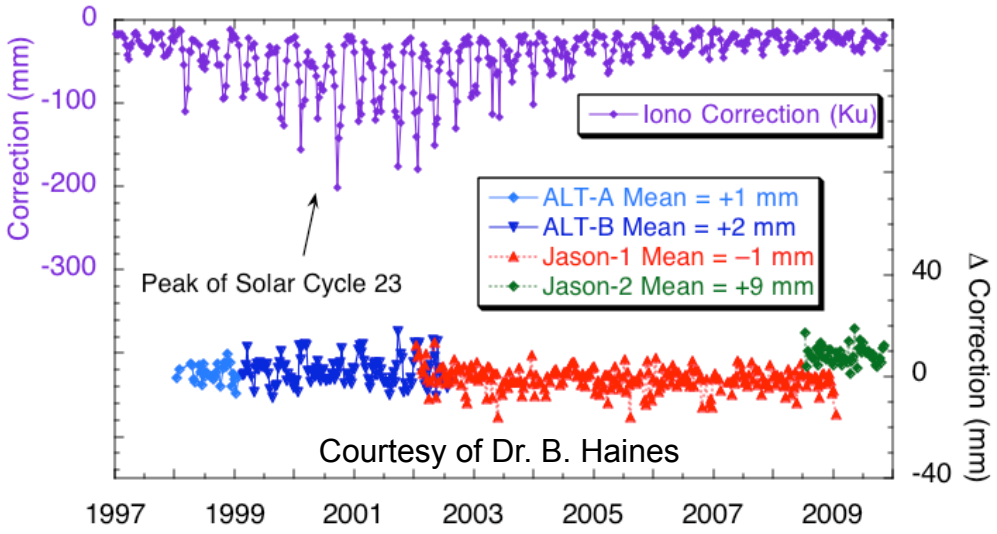




Continued Calibration of Ionospheric Delay at Harvest



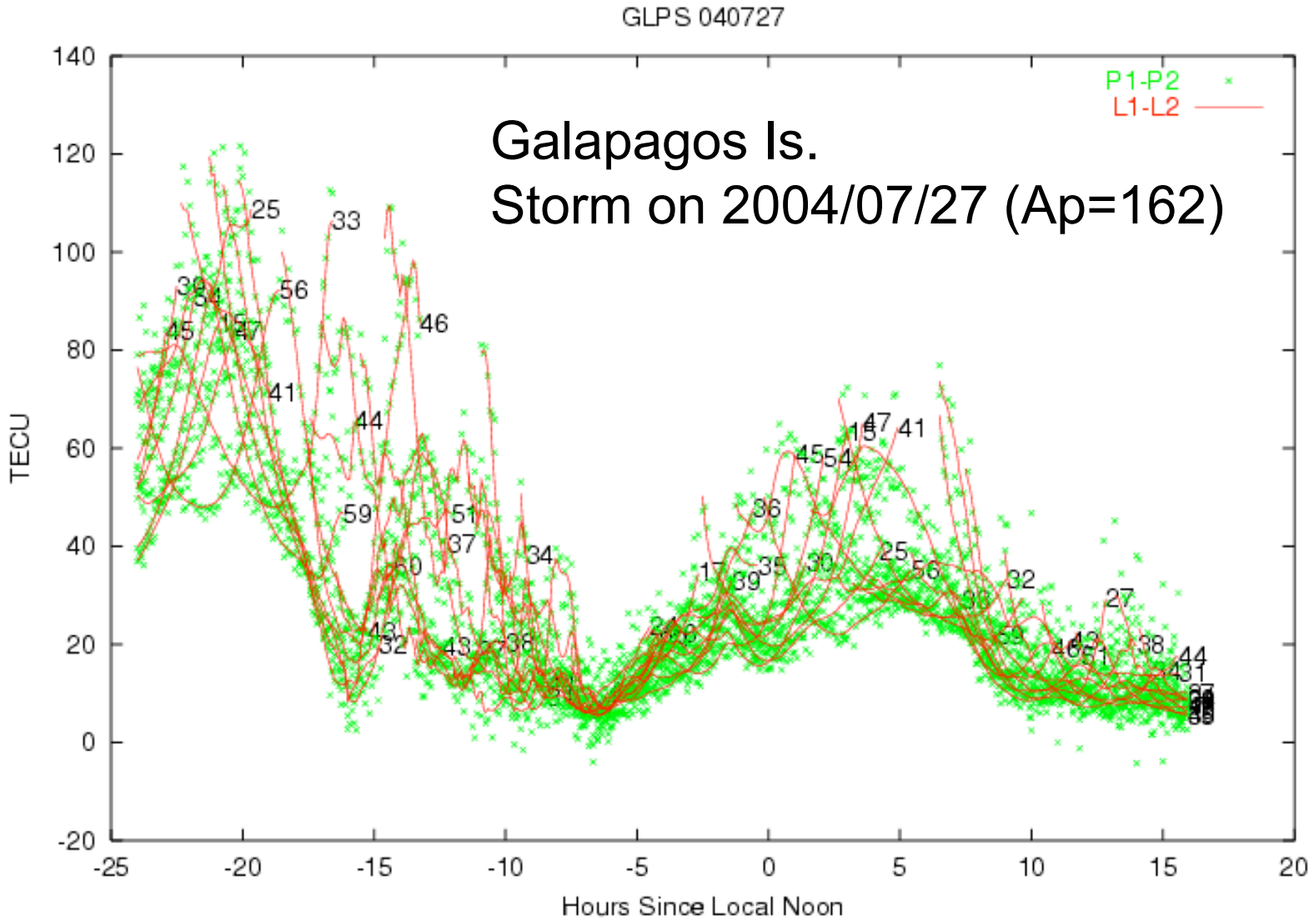




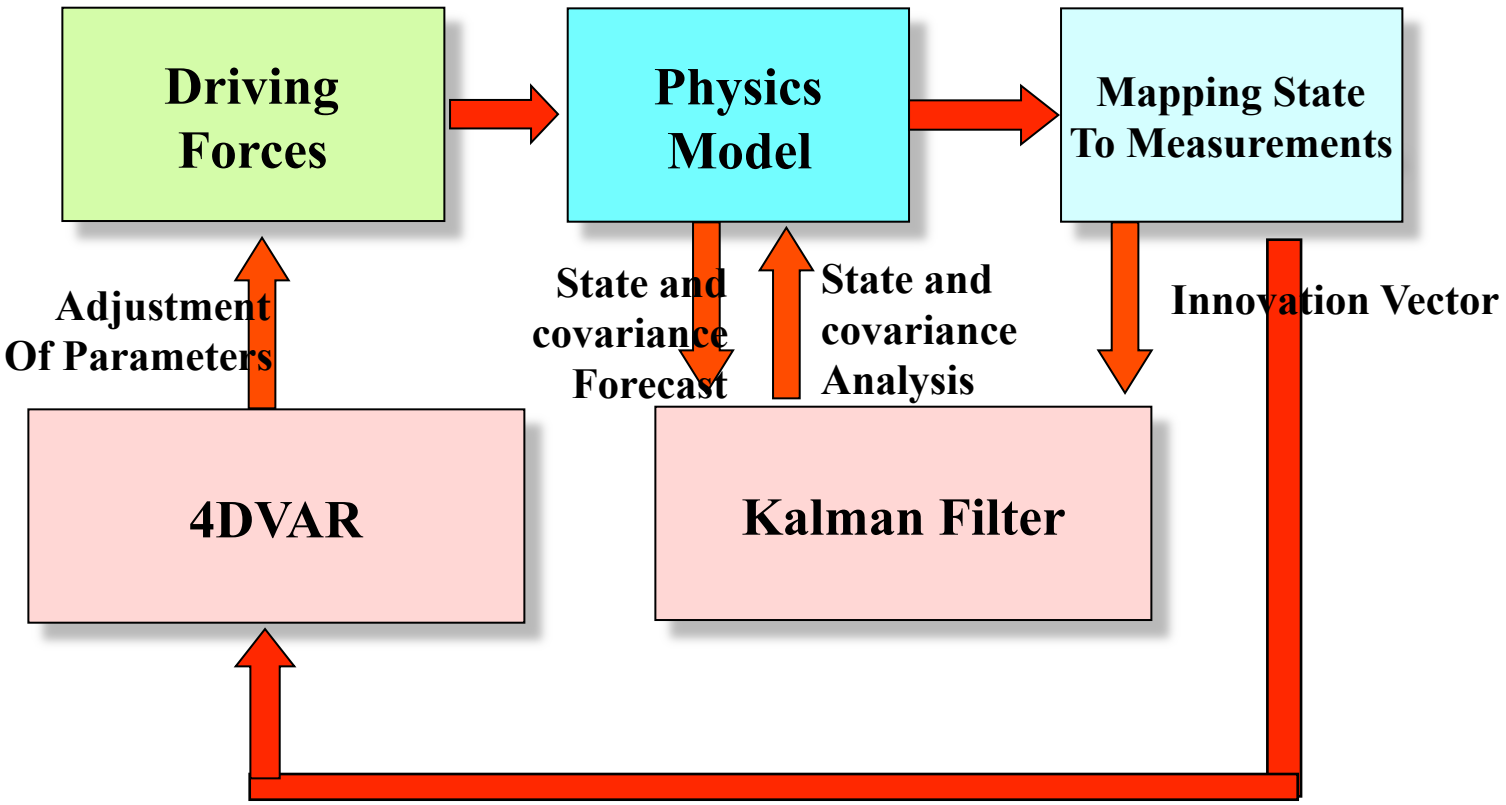
Harvest: Ku-Band Ionosphere Calibration Using JPL GPS Ionosphere Maps:

GIM's repeatibility is a factor of 2 better than its counterpart's resulting in better determination of measurement system drift, hence potential sea-level rise

Information Content of GPS Slant TEC: An Example for Low Latitude



Global Assimilative Ionospheric Model
Data Assimilation Process



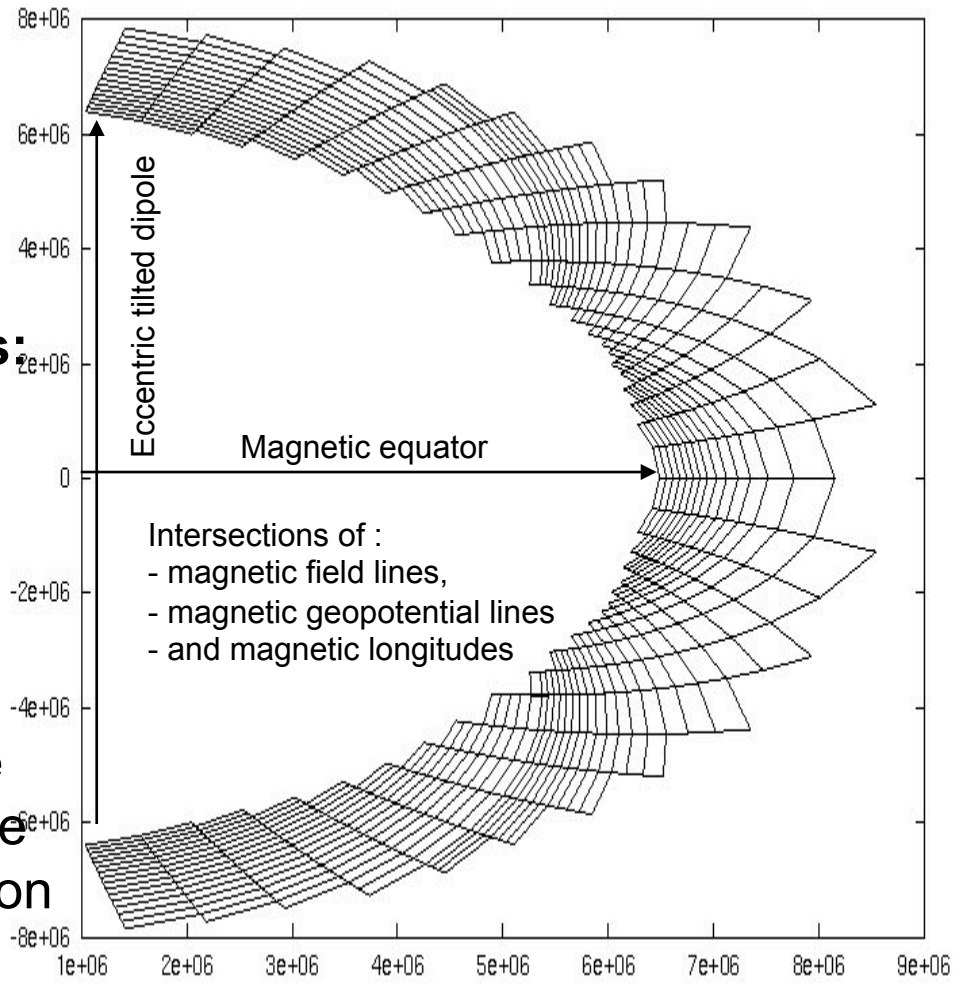
- 4-Dimensional Variational Approach
  - **Minimization of cost function by estimating driving parameters**
  - **Non-linear least-square minimization**
  - **Adjoint method to efficiently compute the gradient of cost function**
  - **Parameterization of model "drivers"**
- Kalman Filter
  - **Recursive Filtering**
  - **Covariance estimation and state correction**

    Optimal interpolation

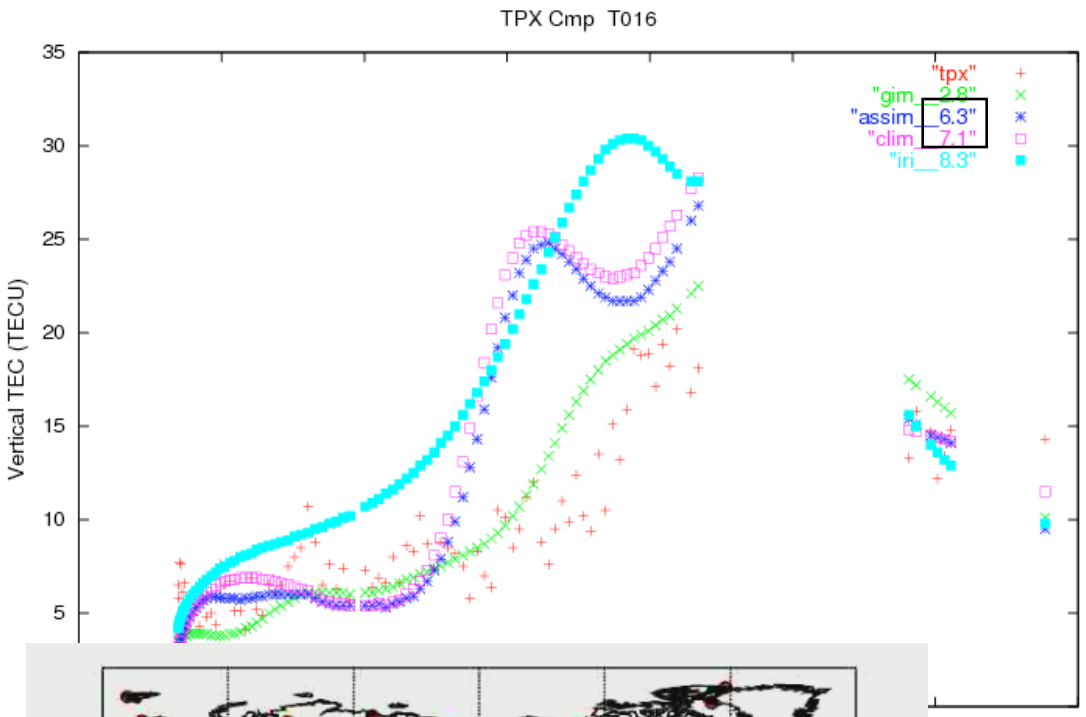
    Band-Limited Kalman filter

Global Assimilative Ionospheric Model (GAIM)

- Three runs:
  - GAIM Climate (no data)
  - Ground GPS TEC (200 sites)
  - Ground + COSMIC links (upward & occultation)
- **Medium and Low Resolution runs:**
  2.5 Vs. 5.0 Lat. In Deg.
  10.0 Vs. 15.0 Lon. in Deg.
  40 Vs. 80 Alt. in km
  100,000 Vs. 18,000 voxels
- Sparse Kalman filter:
  - Update & propagate covariance
  - Truncate off-diagonal covariance that is beyond physical correlation lengths

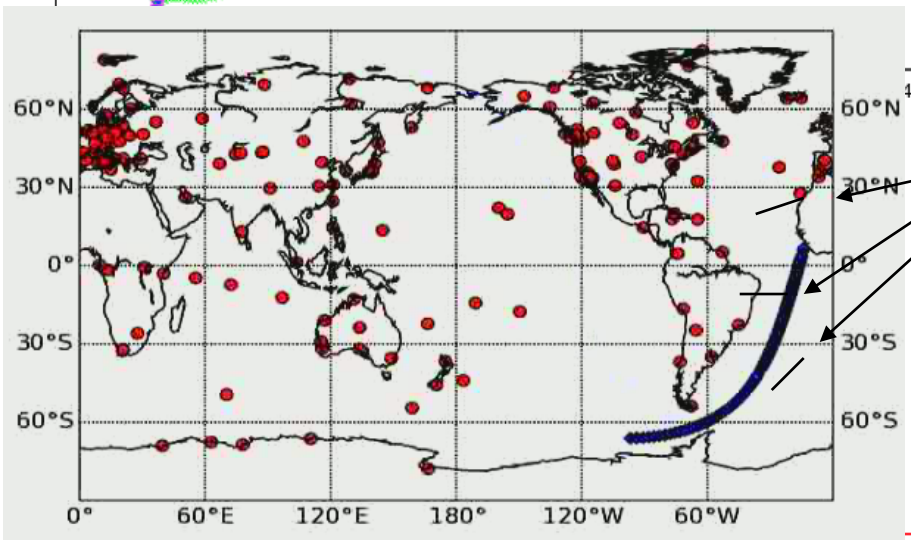


GAIM Validation Using Jason-2 Vertical TEC for June 26

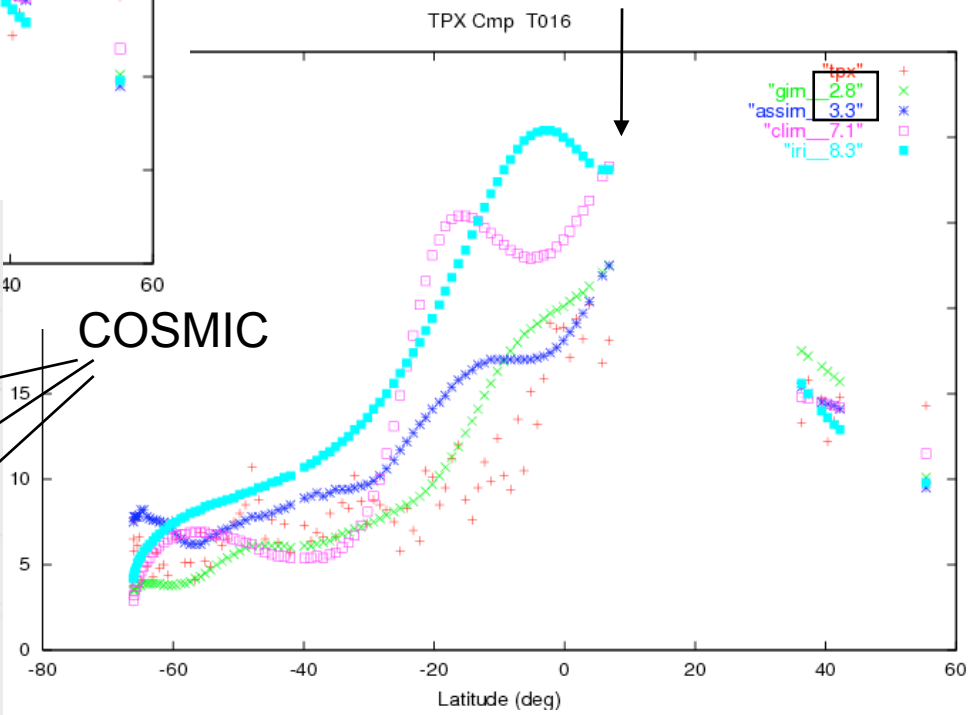


Ground-data only

Ground and space data



COSMIC



Three-Day Comparison with Jason VTEC

		Mean	Sigma	RMS	Min	Max
	GIM	-1.61	2.88	3.31	-12.5	9.1
06/26/06	**Ground**	-0.24	3.26	3.27	-17.26	11.7
	Ground+COSMIC	-0.29	2.26	***2.28***	-10	8.72
		Mean	**Sigma**	**RMS**	**Min**	**Max**
	GIM	-2.01	3.48	4.02	-13	11.2
09/21/06	**Ground**	-1.08	3.45	3.62	-13	11.2
	Ground+COSMIC	-0.31	2.66	***2.67***	-10.16	11.36
		Mean	**Sigma**	**RMS**	**Min**	**Max**
	GIM	-1.95	2.58	3.24	10.7	8.2
12/21/06	**Ground**	-1.3	4.32	4.51	-17.9	10.8
	Ground+COSMIC	0.49	2.45	***2.54***	-18.8	9.36

The use of COSMIC+ground-GPS data over ground-GPS only significantly improved TEC predictions for all 3 days processed: 30, 28 and 44% respectively.

Conclusions

- We have continued to provide the highest quality of global **ionospheric corrections** for the altimeter community (e.g.,Jason, ENVISAT, etc).

- We provided **AQUARIUS** team at GSFC with a new algorithm (GAIM) to improve the accuracy of future surface salinity signals by reducing uncertainties in ionosphere model (NASA NRA proposal submitted in March 2009 – sadly, did not get selected).

- We ported our software suite to a completely independent operational **backup processing** facility (separate computer, backup power supply, etc.) in case the primary run fails.

- We now routinely **assimilate GIM** ionospheric products into GAIM to generate accurate ionospheric specifications (i.e., VTEC, electron density profile, HmF2, NmF2, etc). We now operationally validate products using Jason VTEC measurements.

- Komjathy, A., B. Wilson, X. Pi, V. Akopian, M. Dumett, B. Iijima, O. Verkhoglyadova, and A. J. Mannucci (2009). JPL/USC GAIM: On The Impact of Using COSMIC And Ground-Based GPS Measurements To Estimate Ionospheric Parameters, *Journal Geophysical Research*, doi:10.1029/2009JA014420, in press.

Backup Slides

JPL/USC GAIM

- Physics-Based Forward Model, Matching Adjoint Model
  - Developed to explicitly support data assimilation
- Use Kalman filter and 4DVAR (with adjoint model) to simultaneously solve for:
  - 3D ion & electron density state every 5 minutes
  - Key ionospheric drivers such as low-latitude ExB vertical drift, neutral winds, & production terms
- Opportunity to take advantage of new global data sources:
  - Ground GPS network (>900 daily sites, >170 hourly sites)
  - FUV radiances (LORAAS, GUVI, DMSP SSUSI/SSULI)
  - COSMIC GPS occultation constellation (6 sats.)
- Continuous daily GAIM runs & validation against:
  - TOPEX vertical TEC, independent GPS slant TEC
  - Ionosonde FoF2, HmF2, & bottom-side profiles
  - Density profiles from Abel Inversions of occultation data