Assimilating Ground and Space-Based GPS Measurements Using JPL/USC GAIM To Monitor Space Weather

Attila Komjathy, Brian Wilson, Vardan Akopian, Xioaqing Pi,
Byron Iijima, Miguel Dumett and Anthony J. Mannucci

Jet Propulsion Laboratory

California Institute of Technology

M/S 238-600

4800 Oak Grove Drive

Pasadena CA 91109

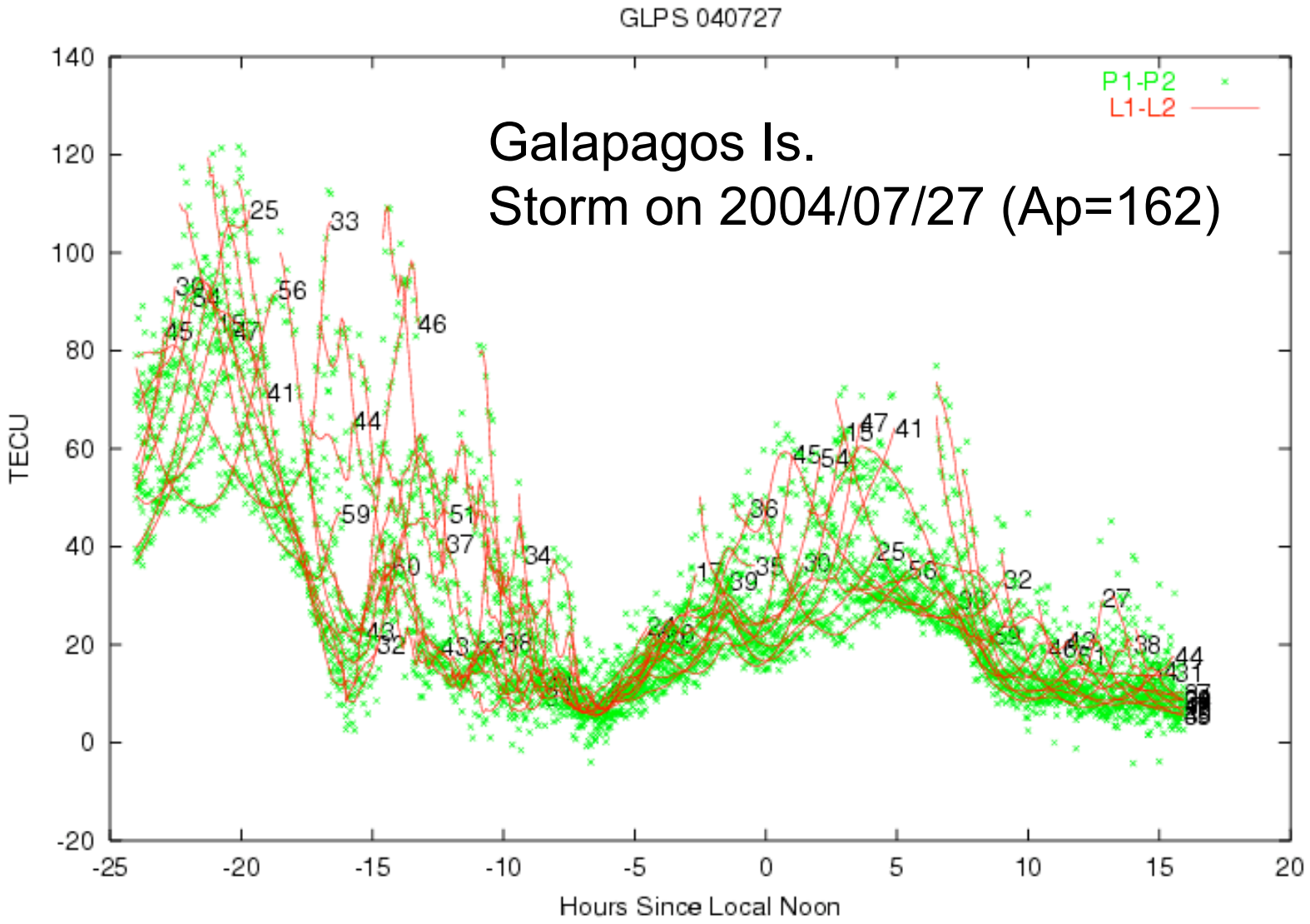
Email: Attila.Komjathy@jpl.nasa.gov

January 26-28, 2009 Presented at the ION 2009 International Technical Meeting, Anaheim, CA

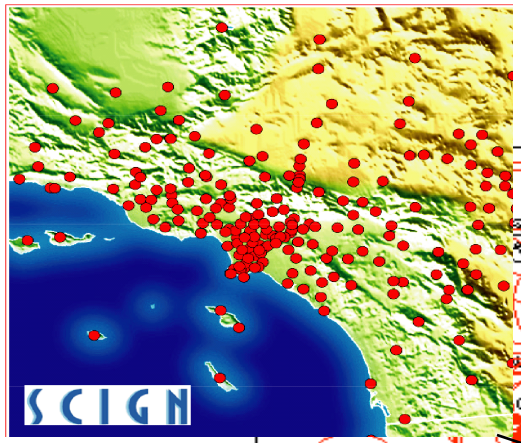
Outline

- **Ionospheric Remote Sensing Using GPS: One Person's Signal Is Another Person's Noise**
  - Global ground GPS network: TEC mapping, storms, etc.
  - Space-based GPS Limb Scans: profiles & irregularities
- **Global Assimilative Ionosphere Model (GAIM)**
  - First-principles physics model, with an adjoint
  - Assimilation: Kalman filter & 4DVAR
    - Estimate driver parameters and 3D density grid
  - Questions: What impact COSMIC data will have on estimated profile shapes, VTEC, NmF2 and HmF2 directly affecting space weather monitoring ?
  - Three case studies: Arecibo, Jicamarca and Millstone ISR

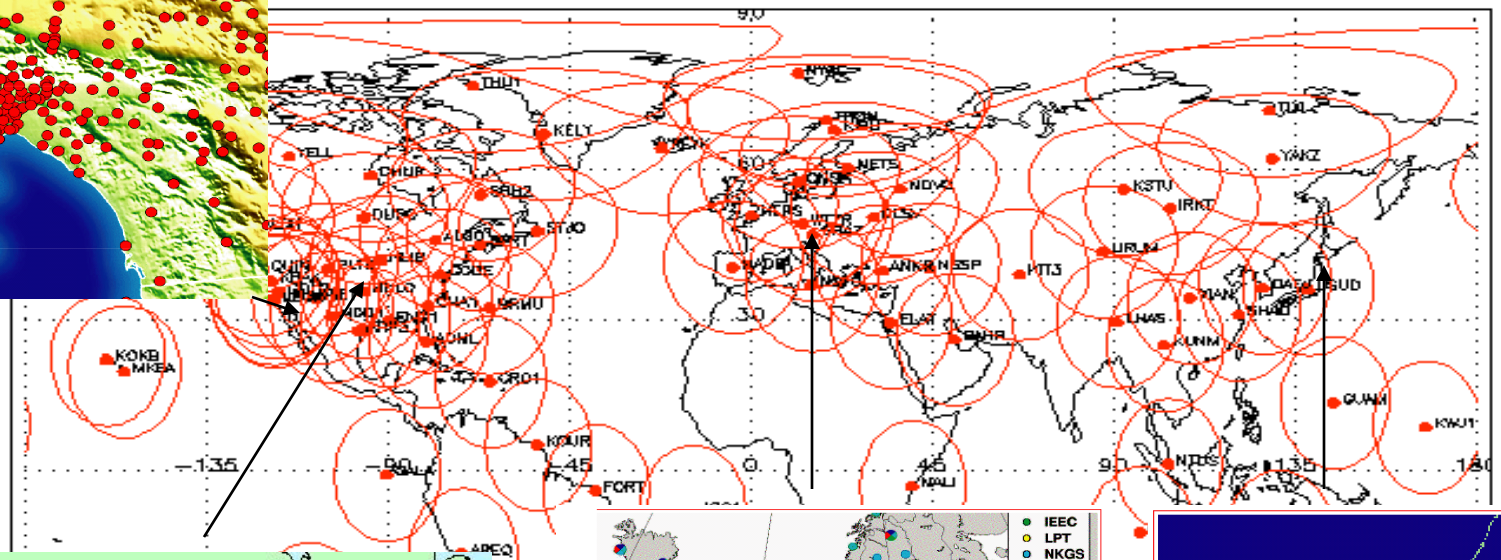
Information Content of GPS Slant TEC: An Example for Low Latitude

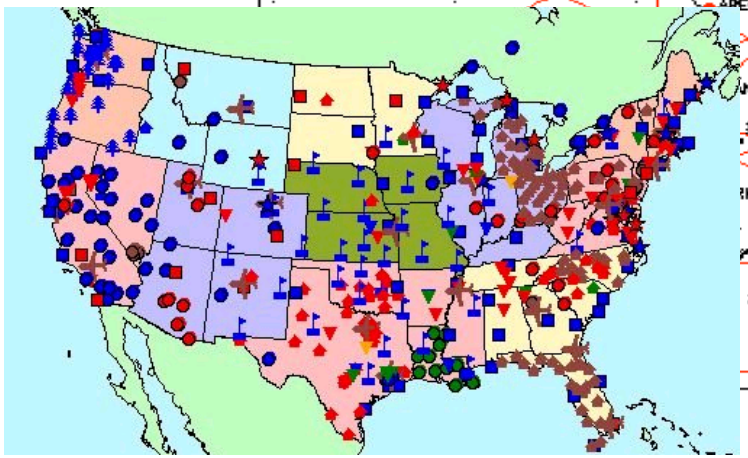


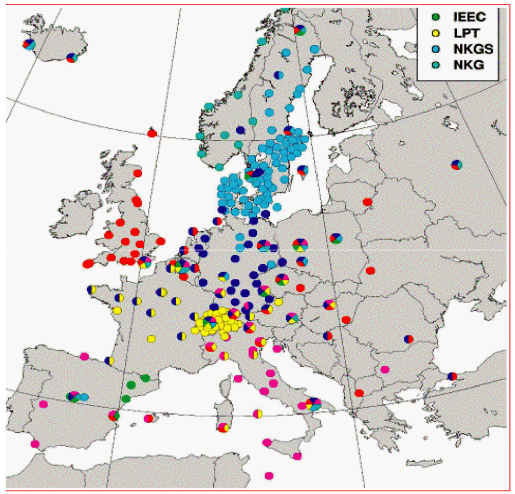
Coverage of Daily IGS Network and Regional Networks

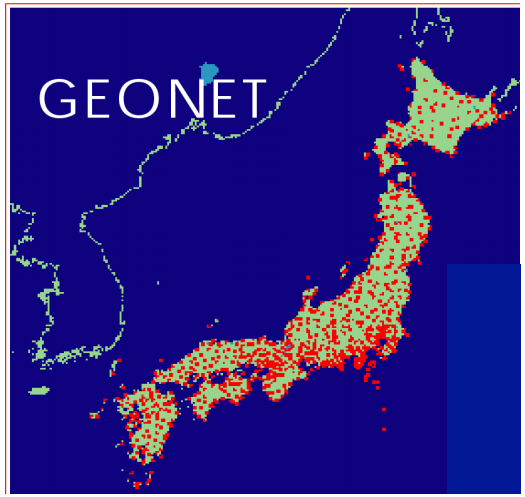


(10 degree elevation mask; 450 km shell height)

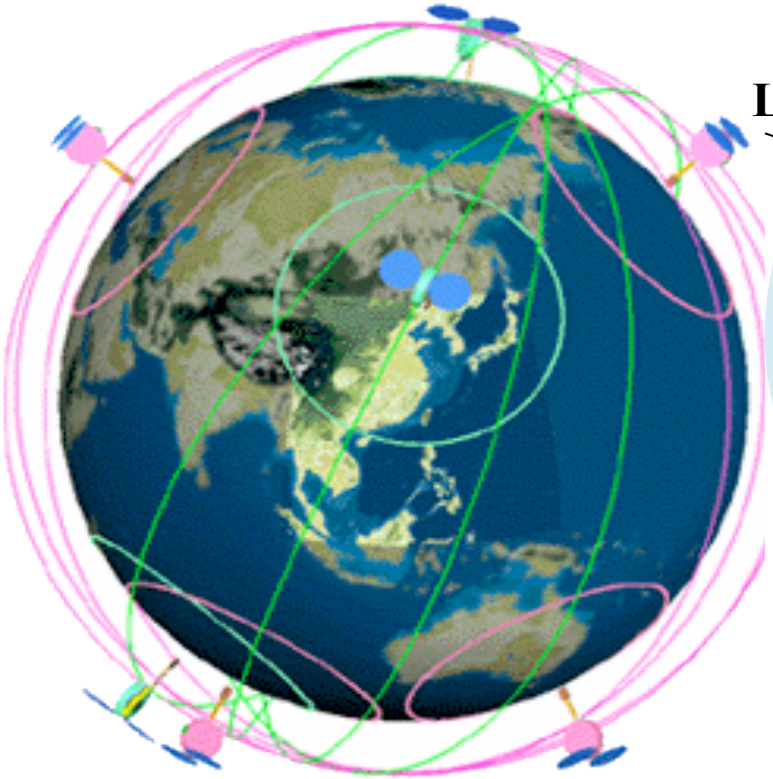


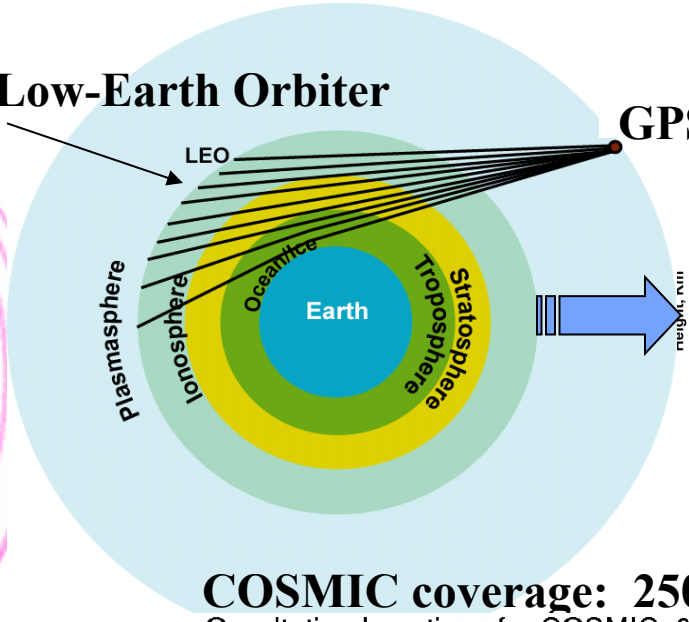




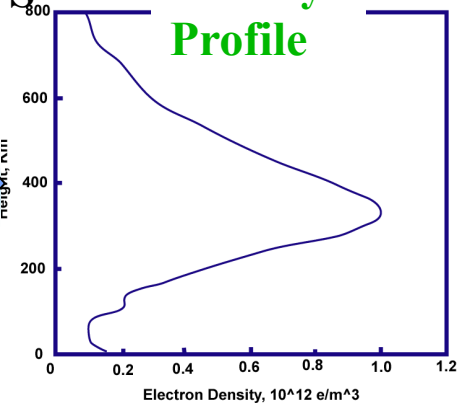


COSMIC
Ionospheric Weather Constellation



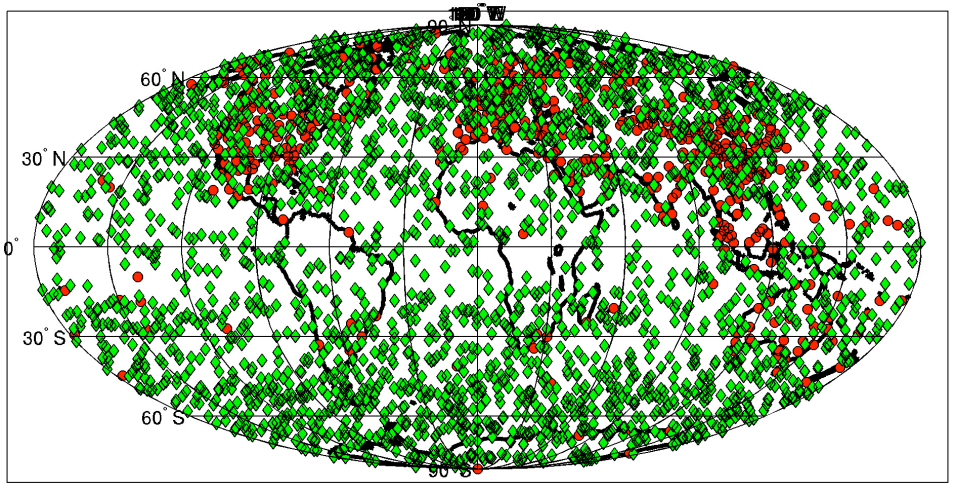


Electron Density Profile



COSMIC coverage: 2500 profiles/day

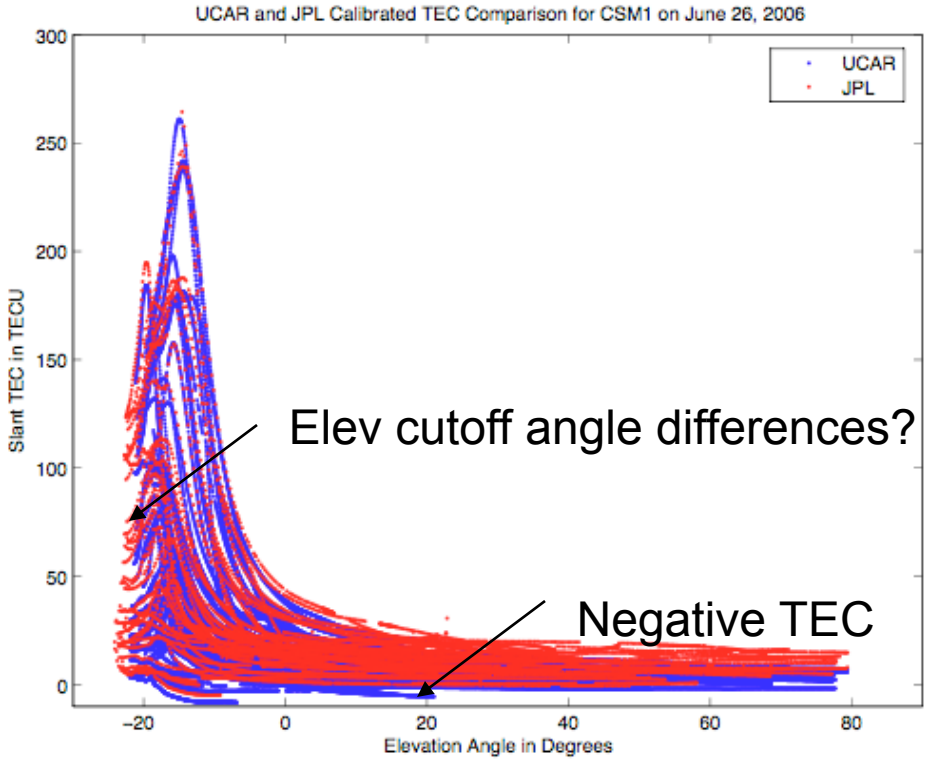
Occultation Locations for COSMIC, 6 S/C, 6 Planes, 24 Hrs

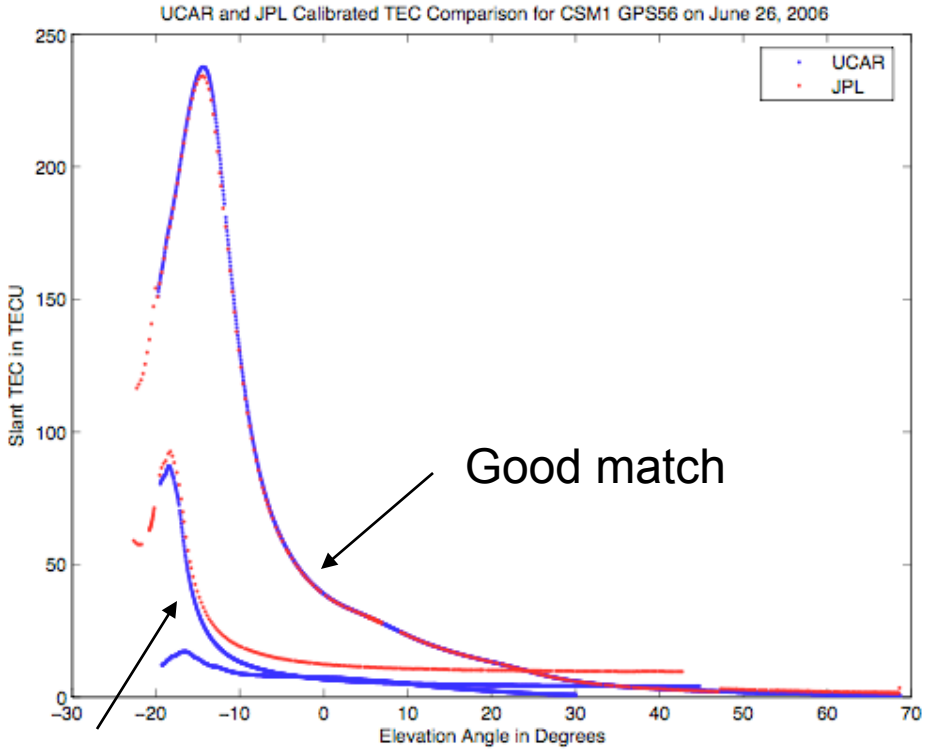


Six-satellite COSMIC constellation
Launched April 14, 2006

NSF NASA USAF NOAA NSPO ONR

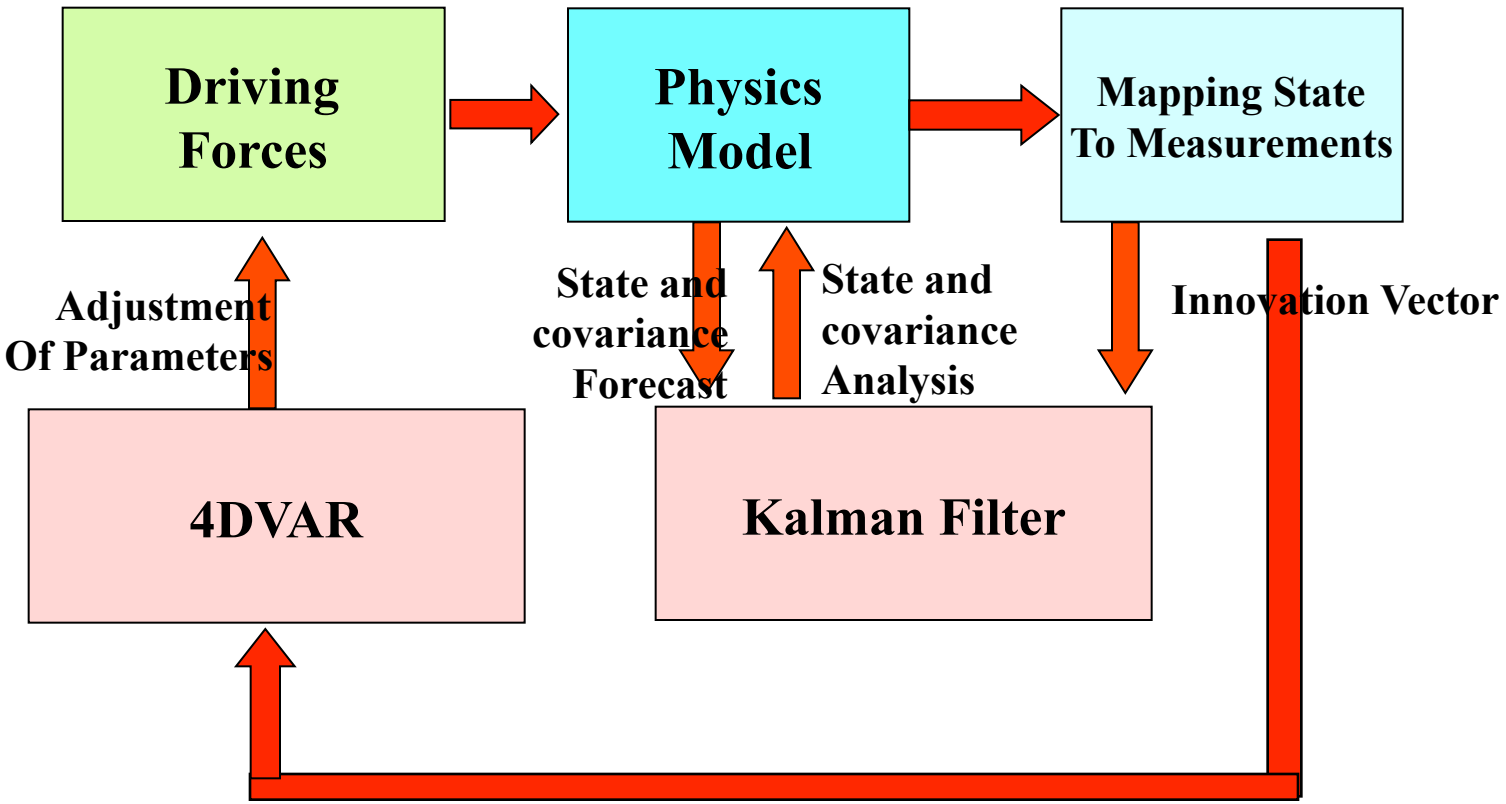
Comparison of Calibrated Slant TEC Measurements: An Example





- An example of comparison of calibrated TEC between JPL and UCAR
- Currently there appears to be a 1-2 TECU bias between JPL and UCAR slant TEC
- Similar data volumes between JPL and UCAR

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

Kalman Assimilation Runs: Three Case Studies

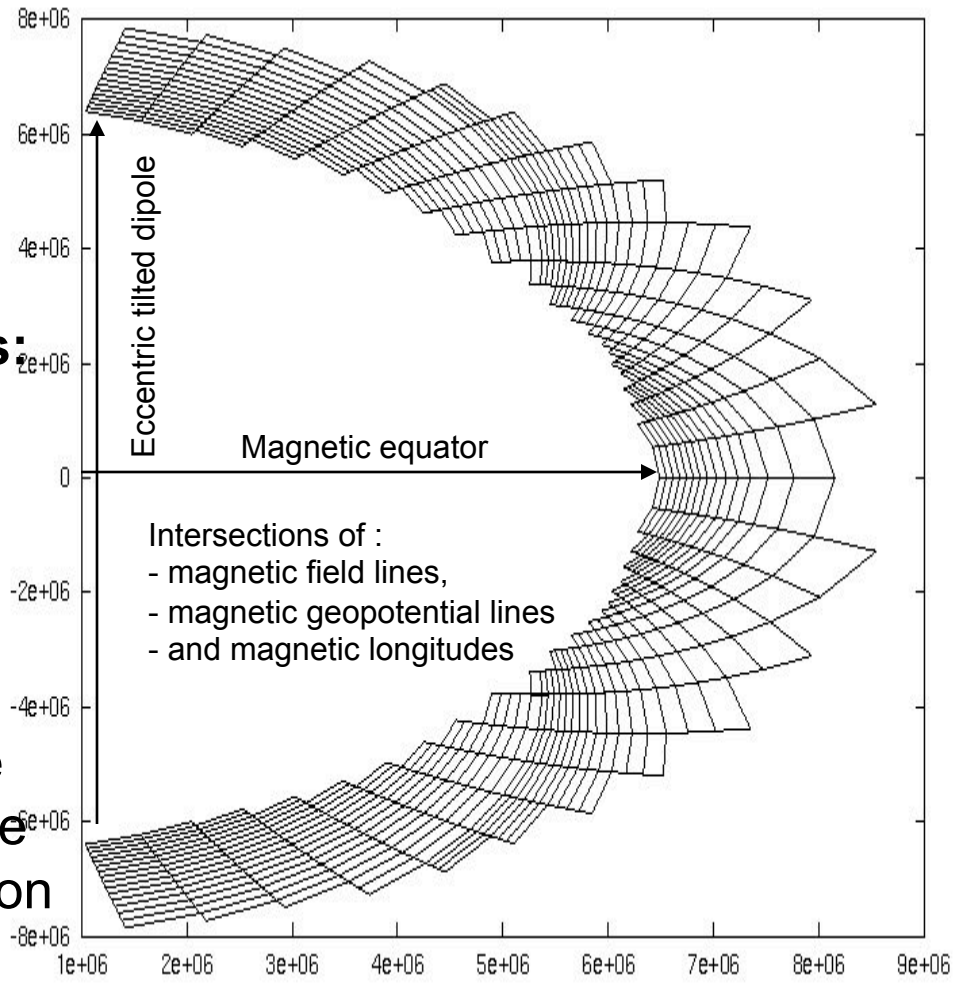
- Three runs:
  - GAIM Climate (no data)
  - Ground GPS TEC (200 sites)
  - Ground + COSMIC links (upward & occultation)
- **Medium and Low Resolution runs:**

  2.5 Vs. 5.0 Lat. In Deg.

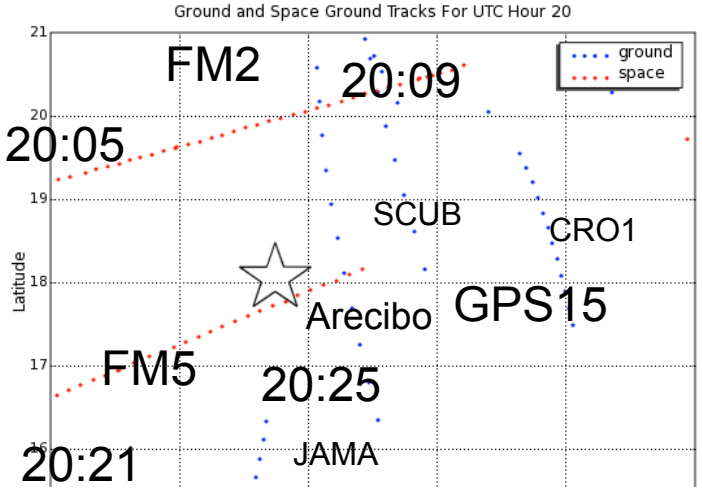
  10.0 Vs. 15.0 Lon. in Deg.

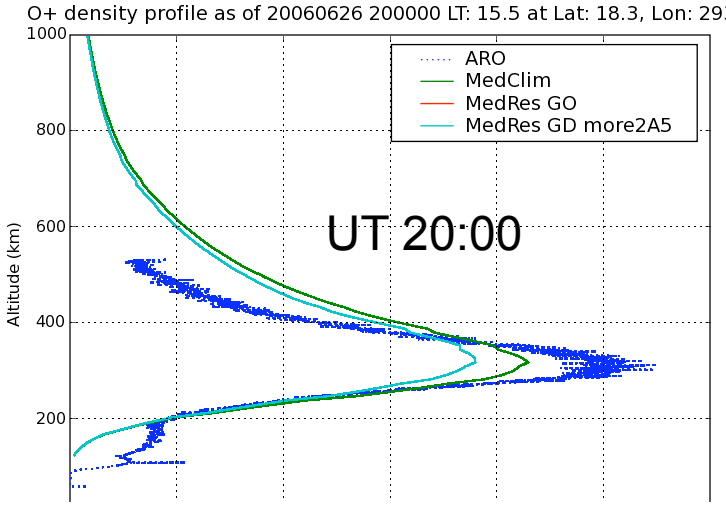
  40 Vs. 80 Alt. in km

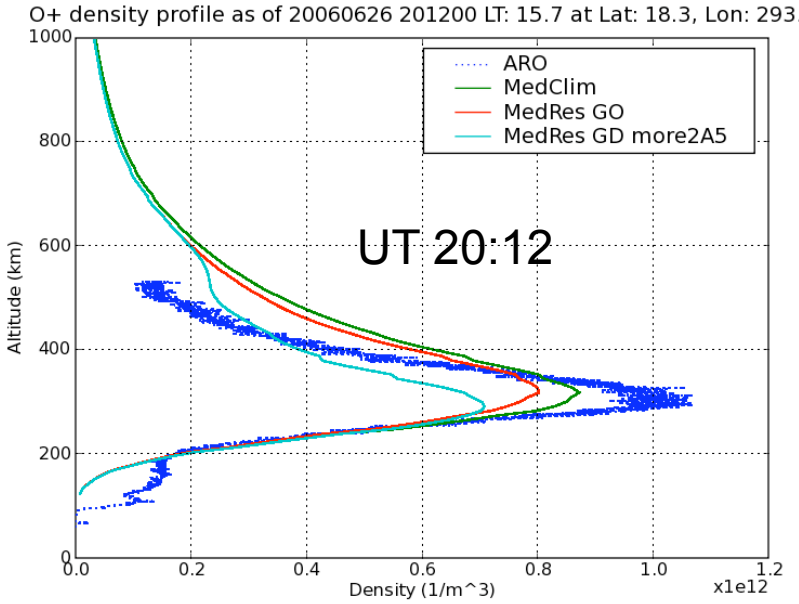
  100,000 Vs. 18,000 voxels
- Sparse Kalman filter:
  - Update & propagate covariance
  - Truncate off-diagonal covariance that is beyond physical correlation lengths

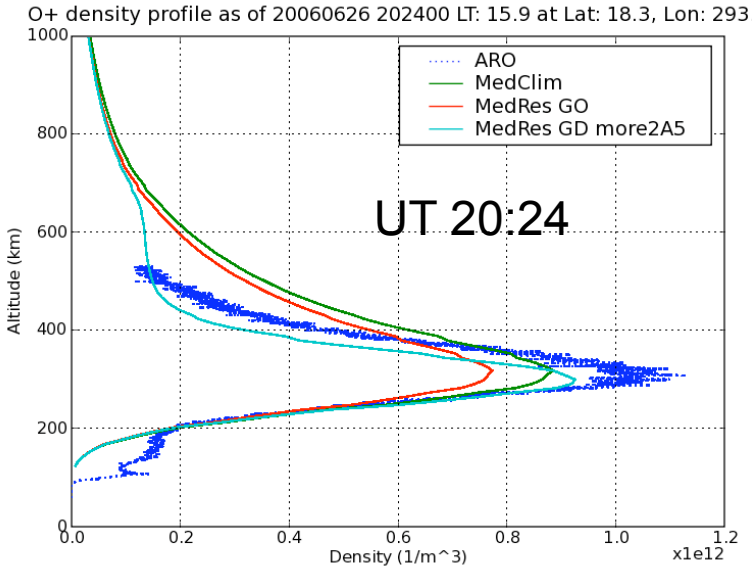


Case 1: Arecibo ISR Study for June 26, 2006

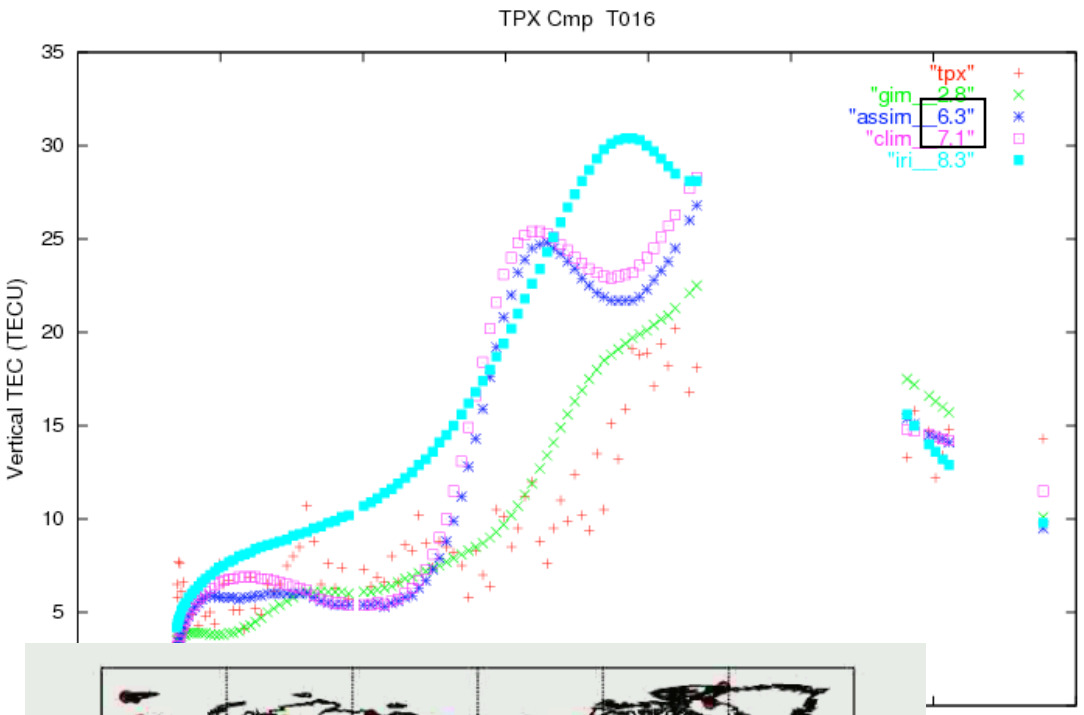






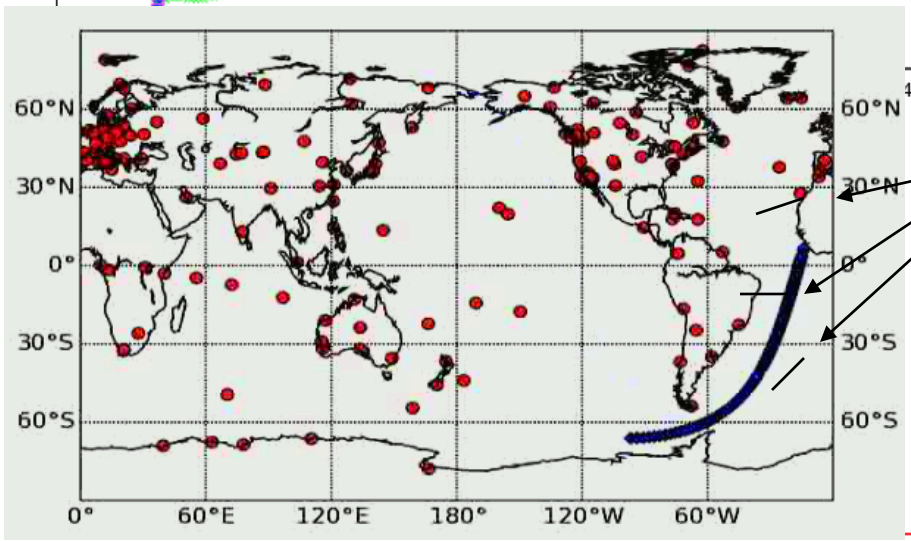


GAIM Validation Using Jason-2 Vertical TEC for June 26

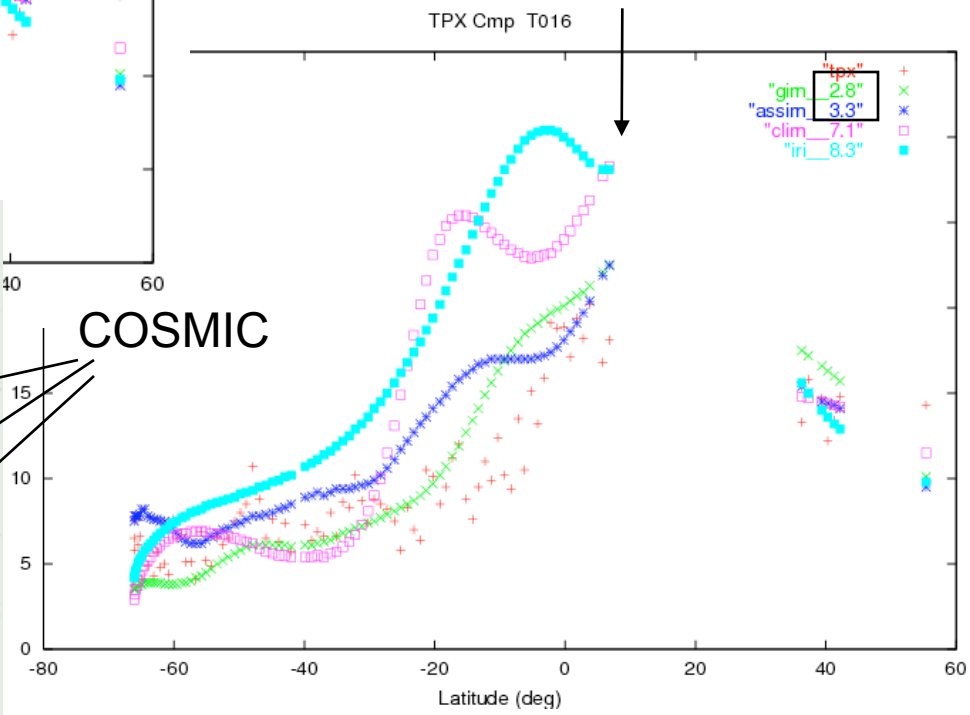


Ground-data only

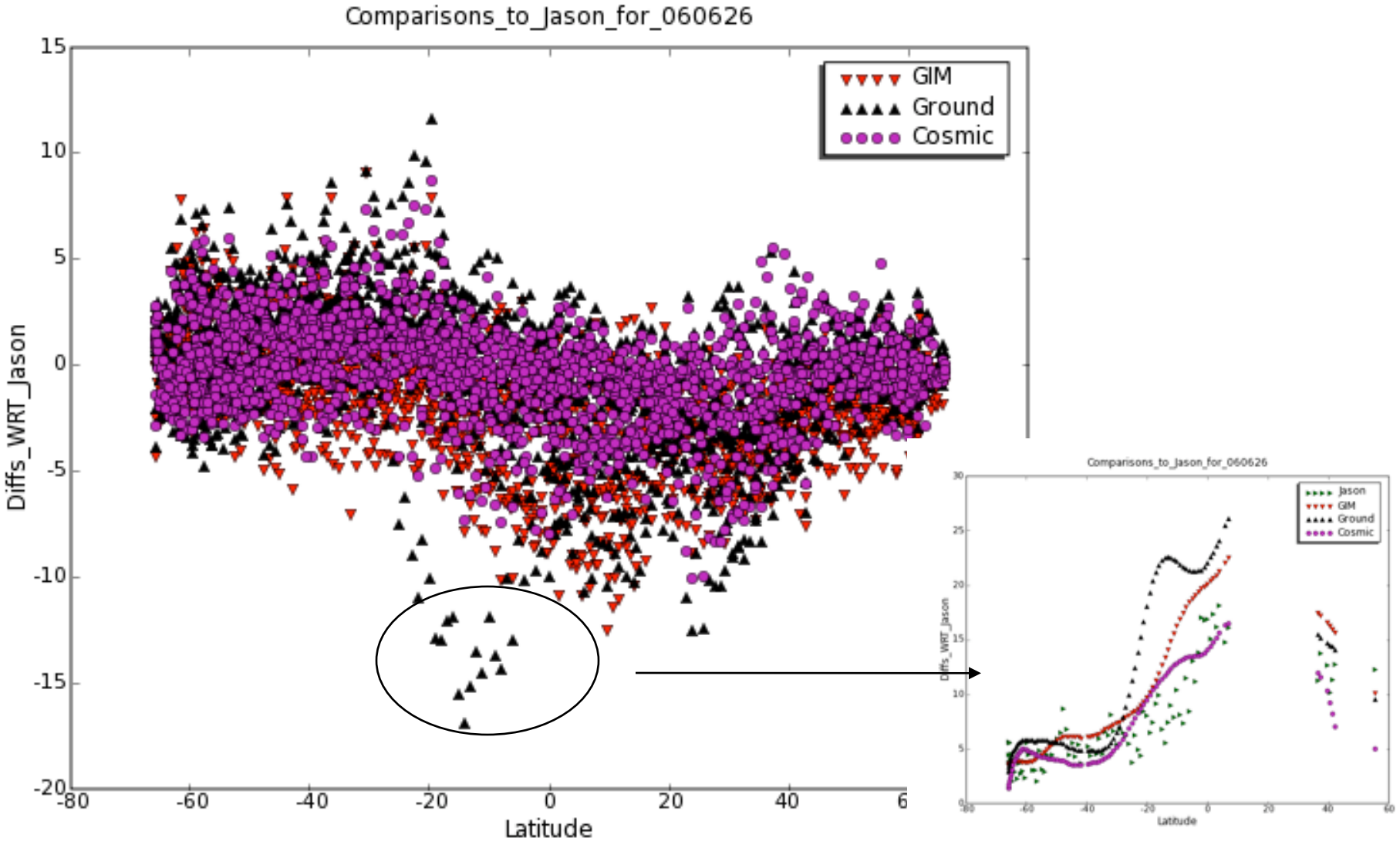
Ground and space data



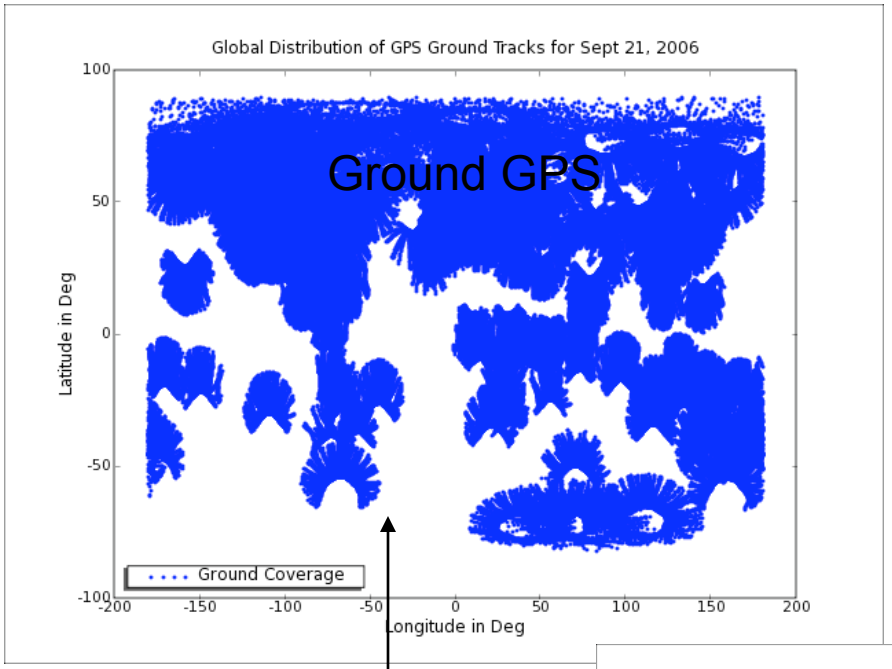
COSMIC

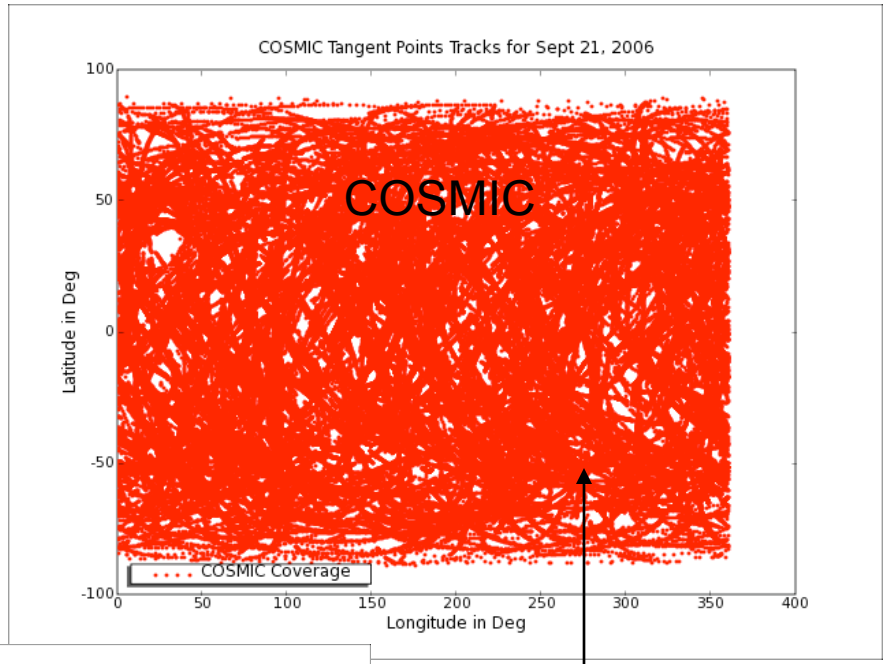


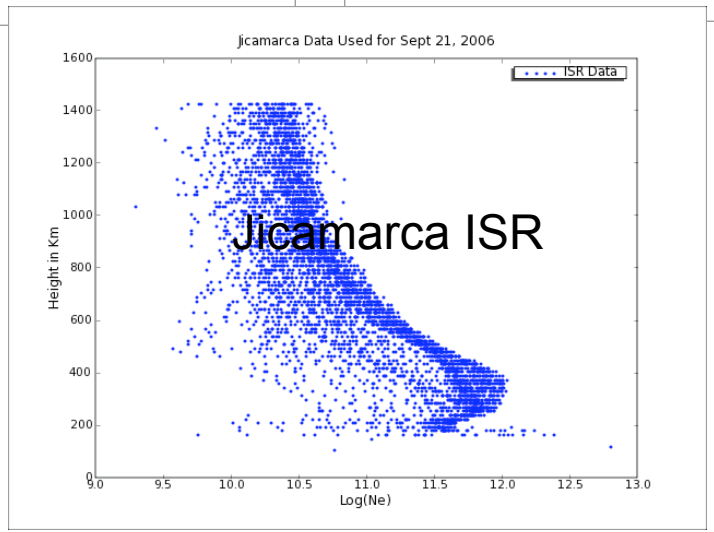
Comparison of Jason VTEC with Ground-only and COSMIC Assimilation for June 26, 2006



Case 2: Ground, COSMIC and Jicamarca ISR Coverage for Sept 21, 2006



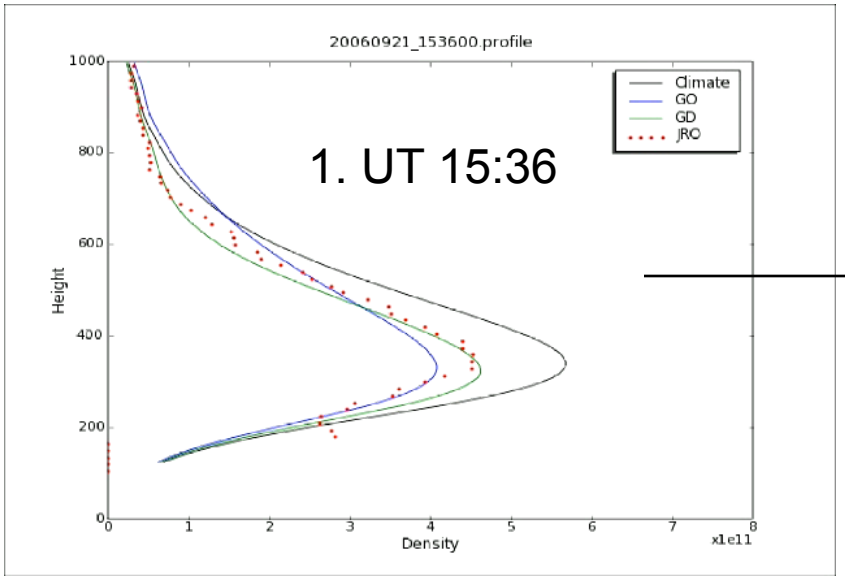


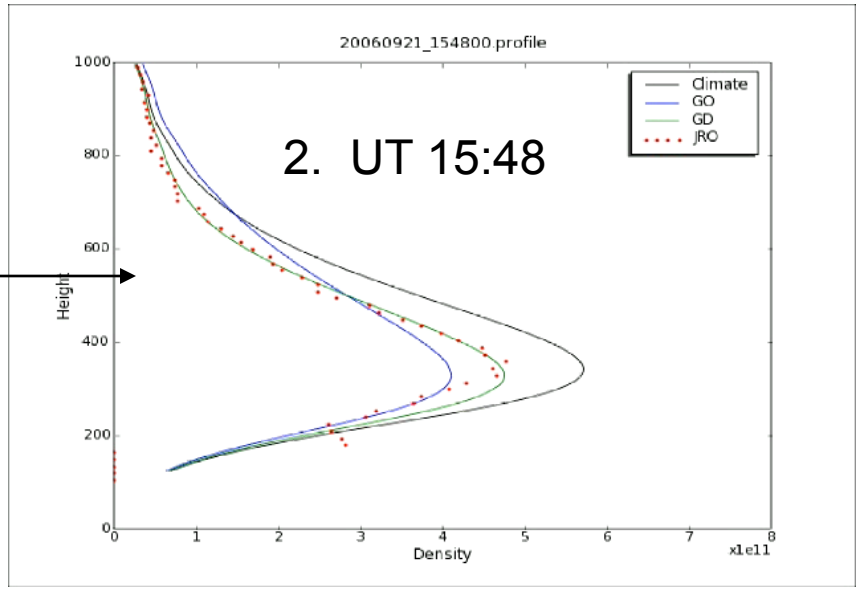


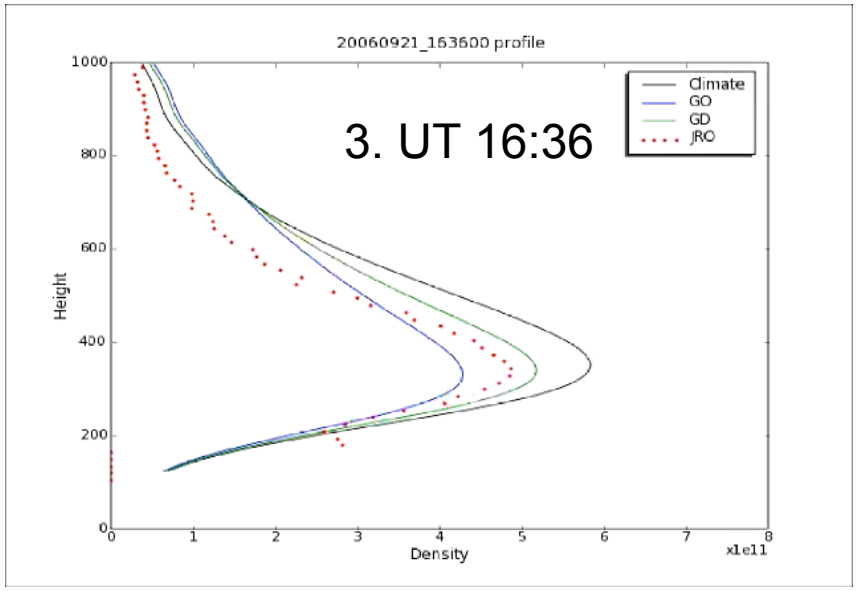
dense but unevenly distributed coverage

less dense yet evenly distributed coverage

An Example of COSMIC Impact on Profile Shape







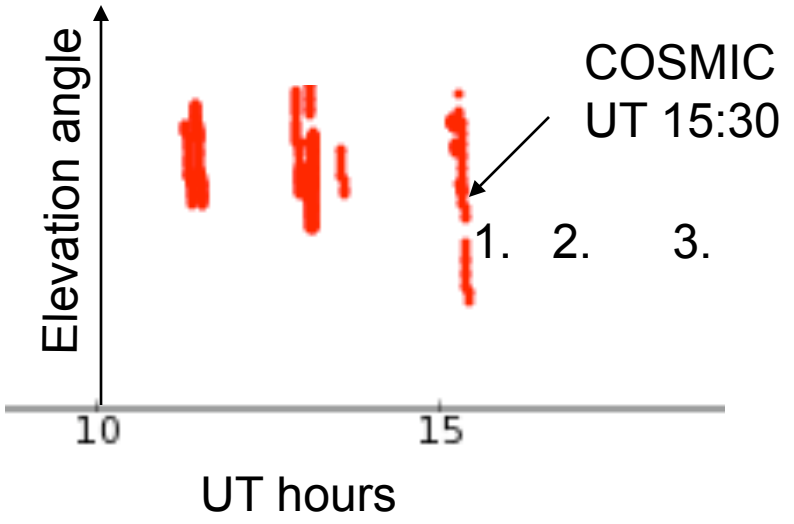
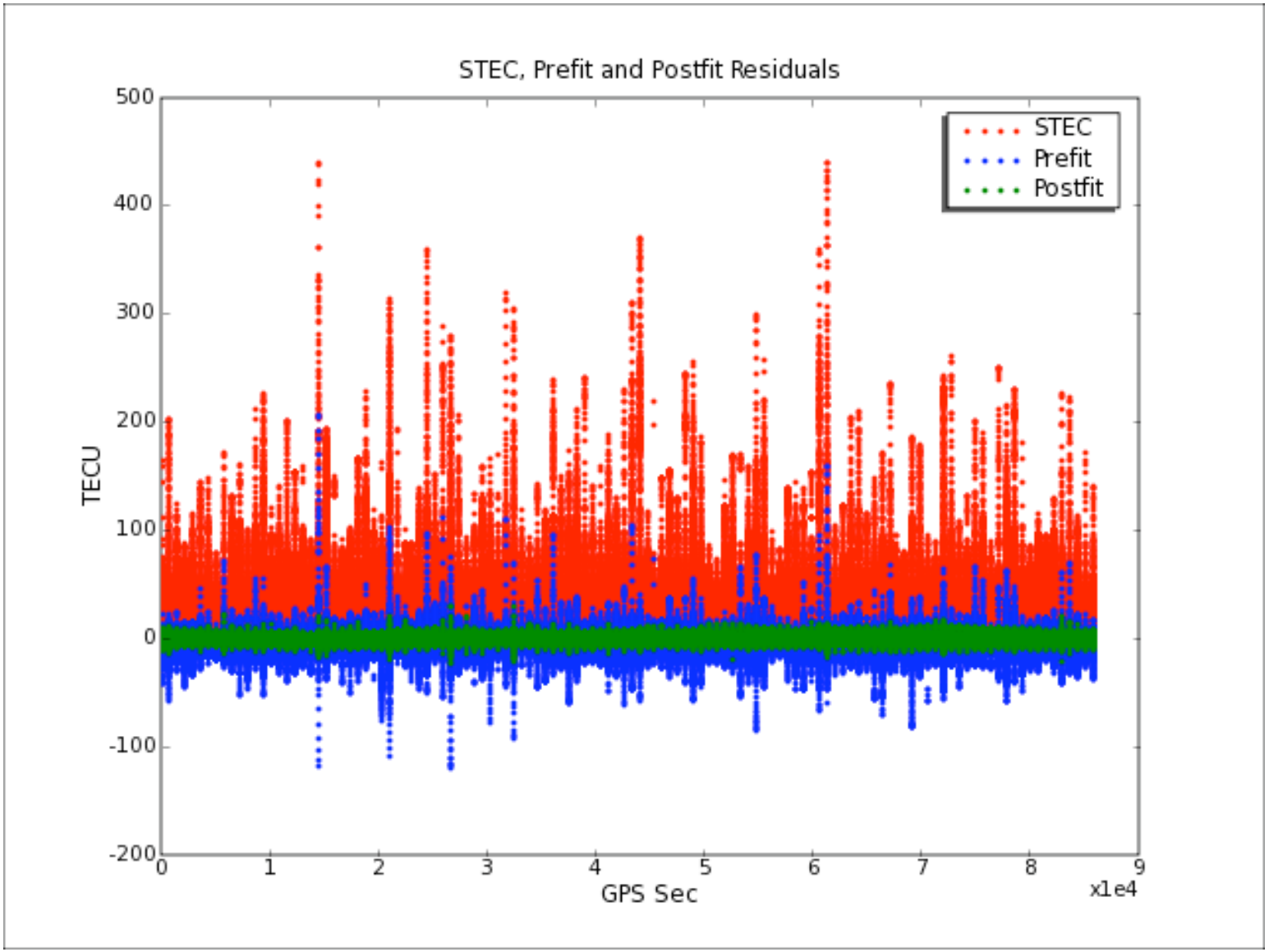
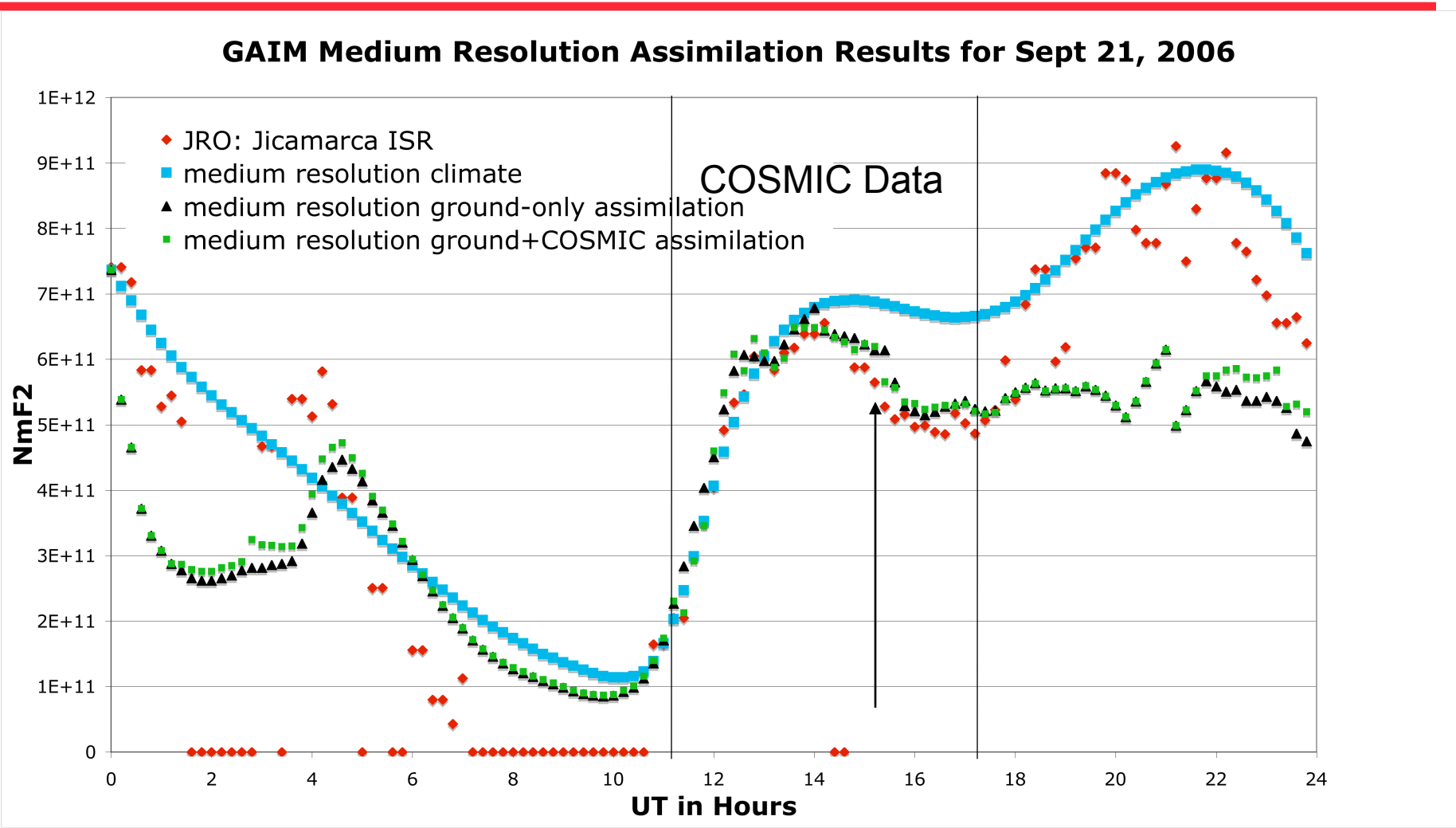


Illustration for TEC data, GAIM Prefit and Postfit Residuals

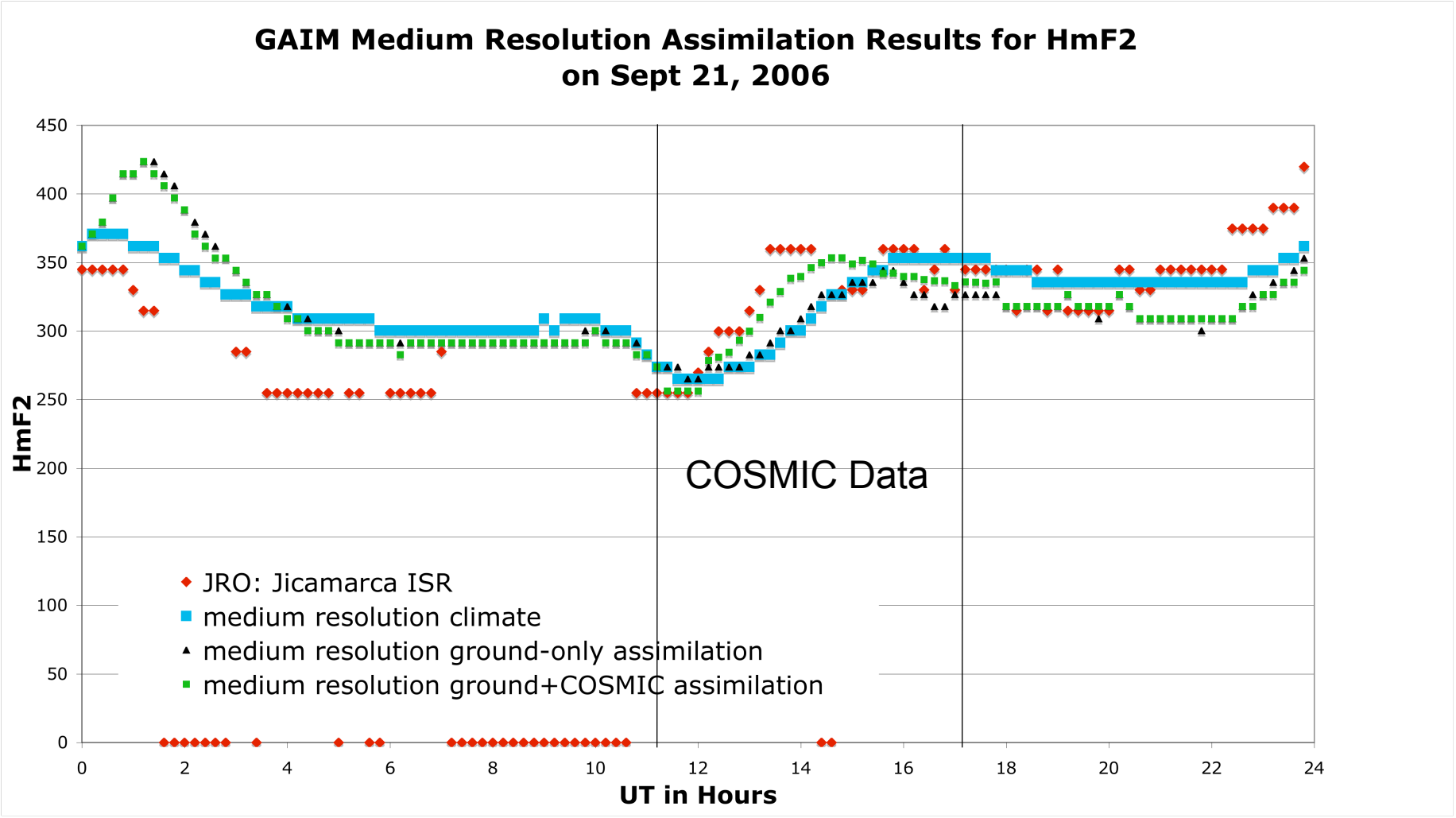


NmF2 Comparison with Jicamarca ISR



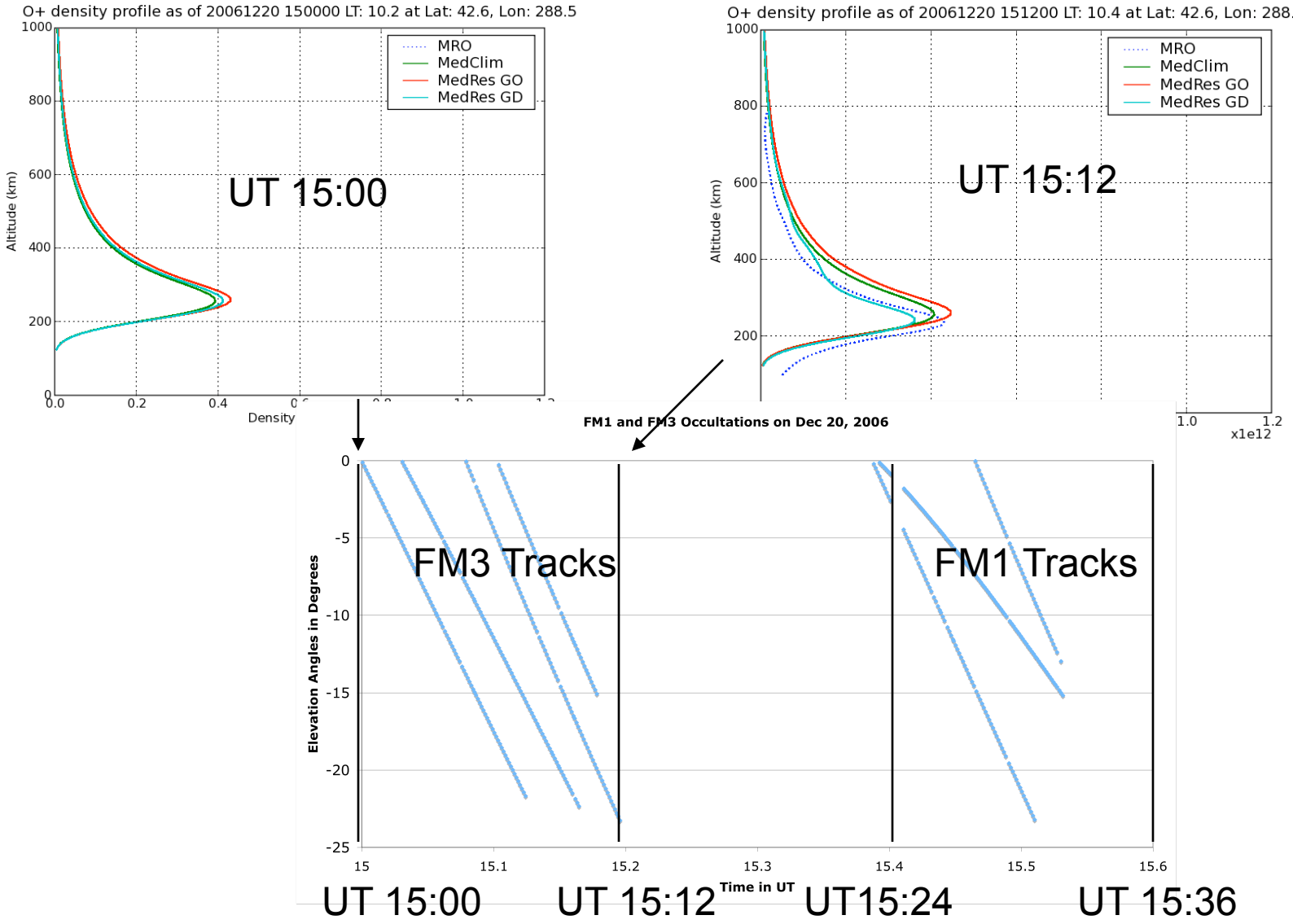
Medium resolution GAIM NmF2 with COSMIC data matches well during the dense data period 11-17 UT

HmF2 Comparison with Jicamarca ISR

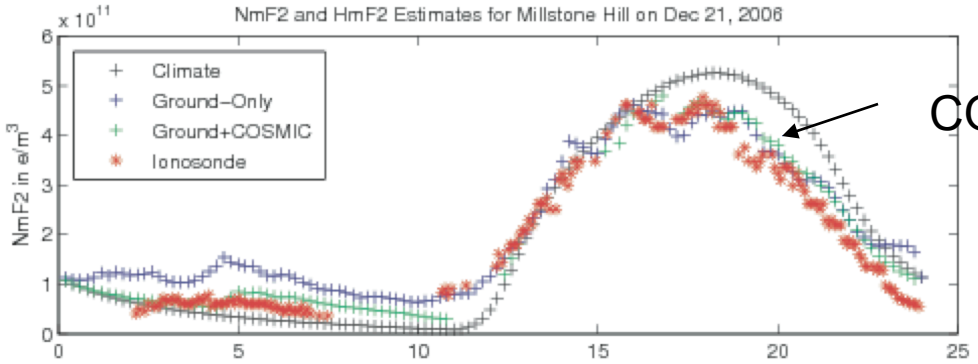


Medium resolution GAIM HmF2 with COSMIC matches best with truth

Case 3: GAIM Millstone Hill Radar Validation for Dec 20, 2006

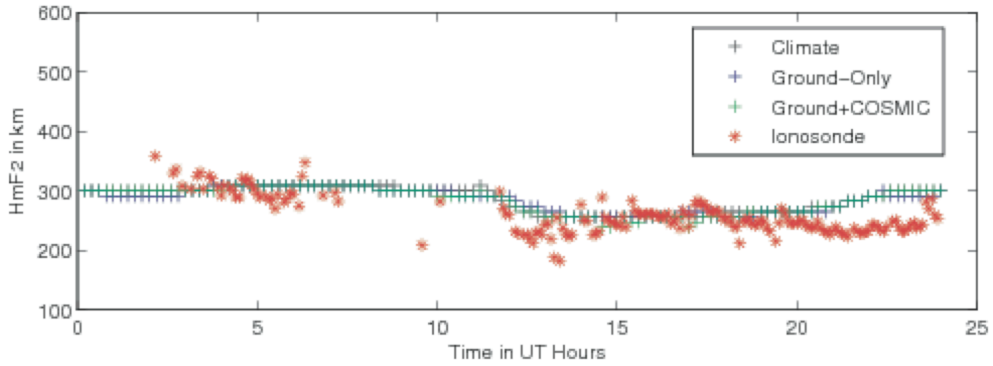


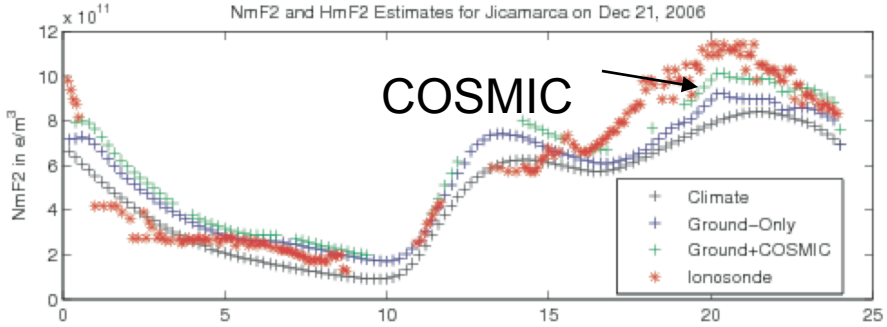
Ionosonde Comparison for Dec 21, 2006



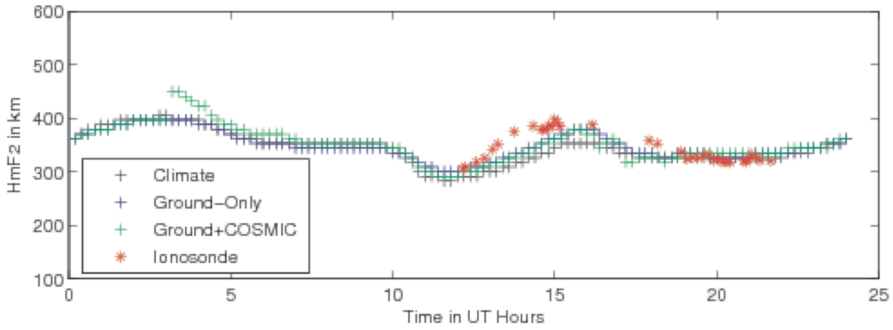
COSMIC

Millstone Hill Ionosonde



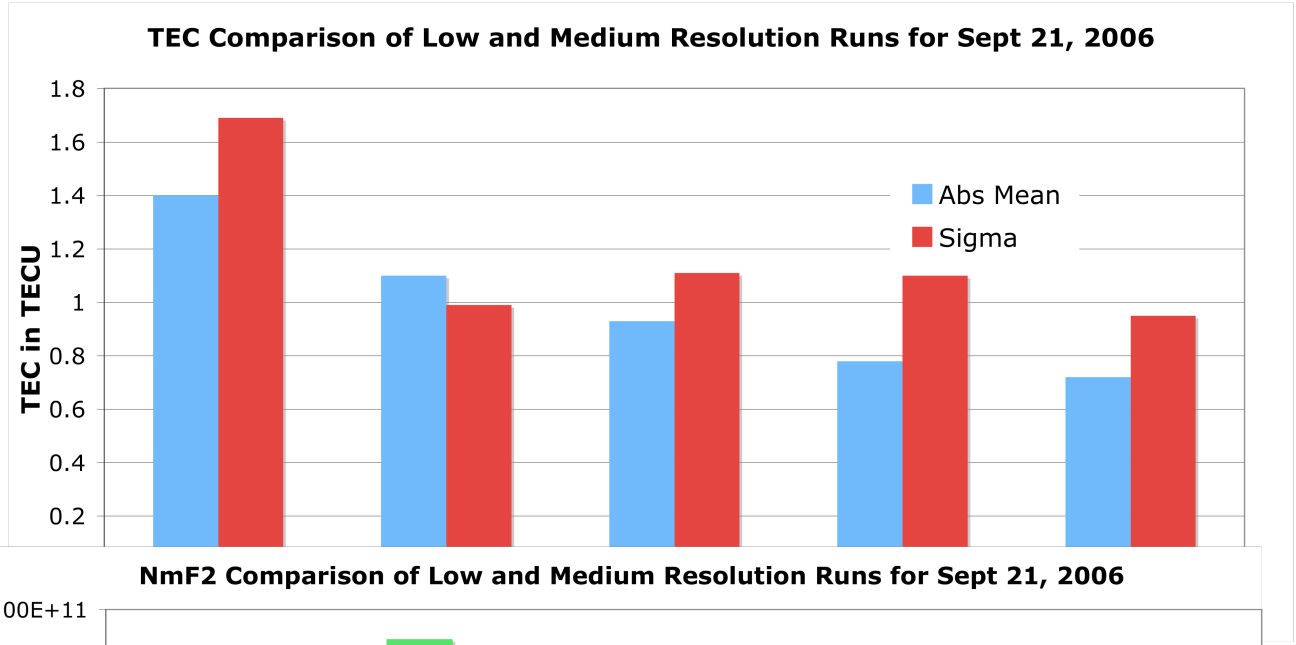


Jicamarca Ionosonde

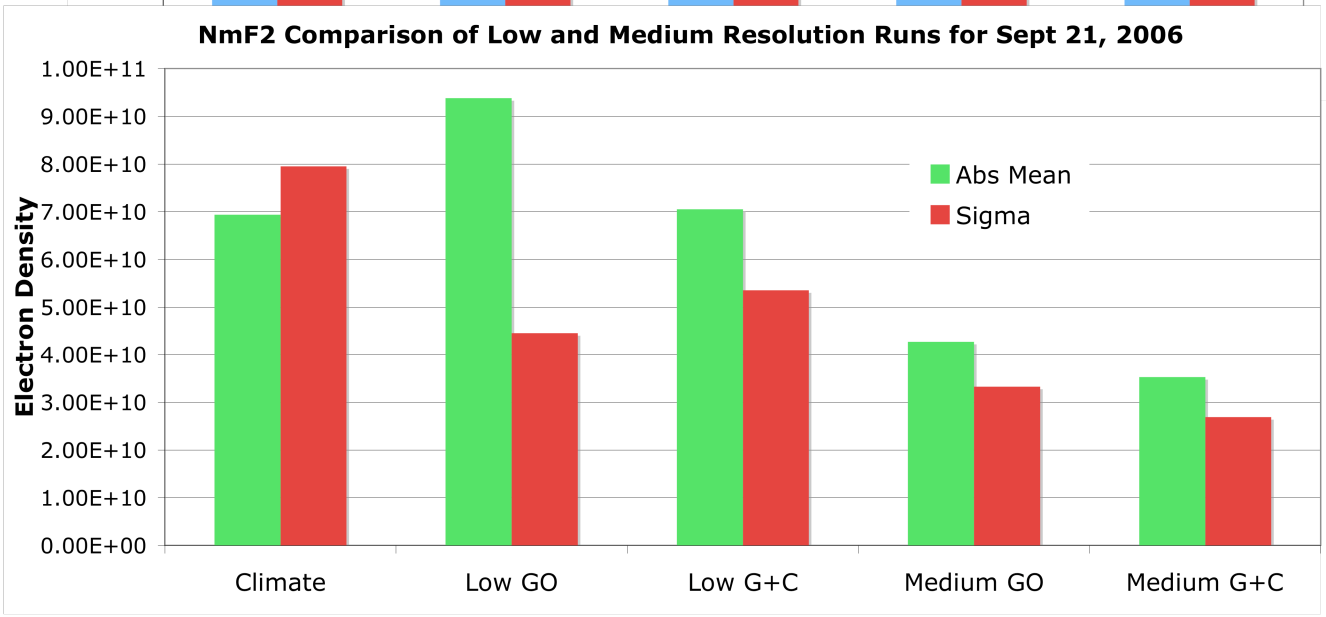


Summary of Results Using ISR

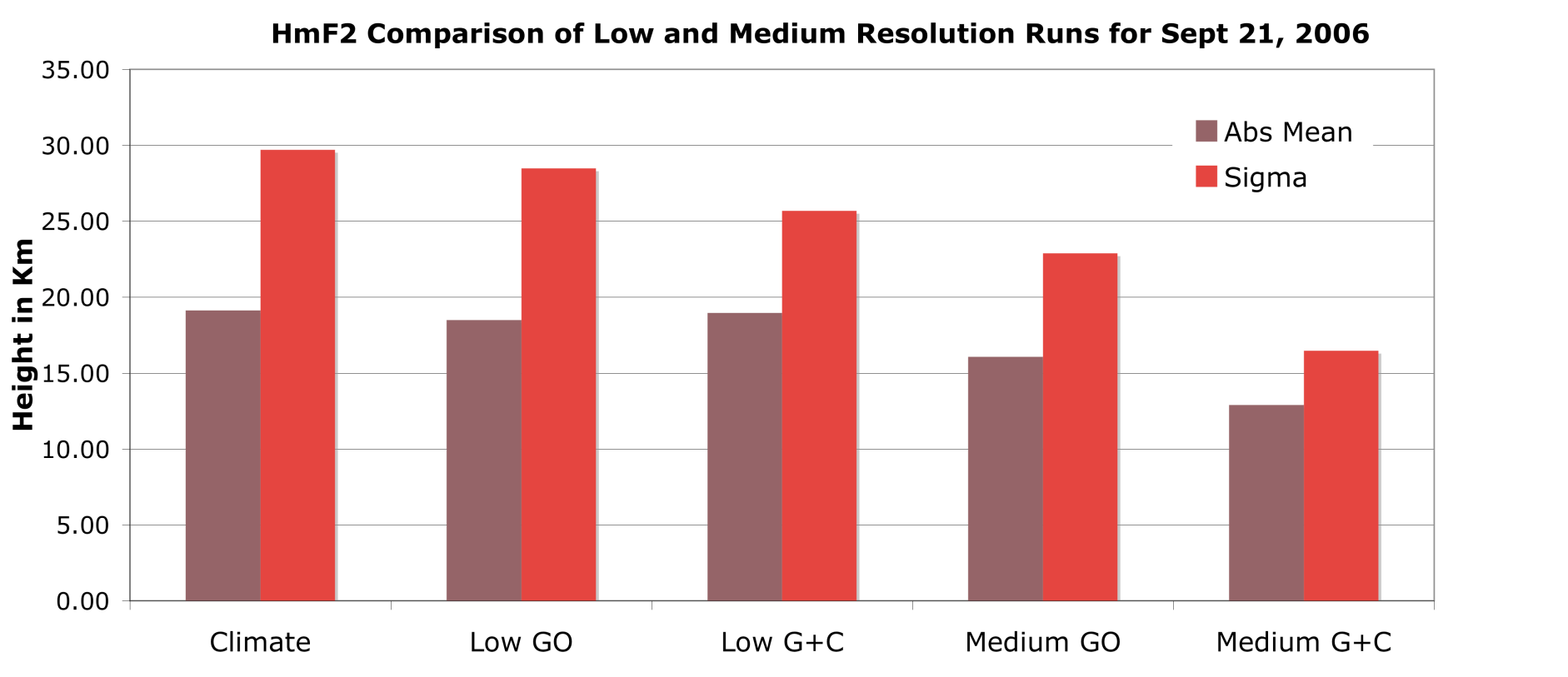
TEC



NmF2



Summary of Results Using ISR



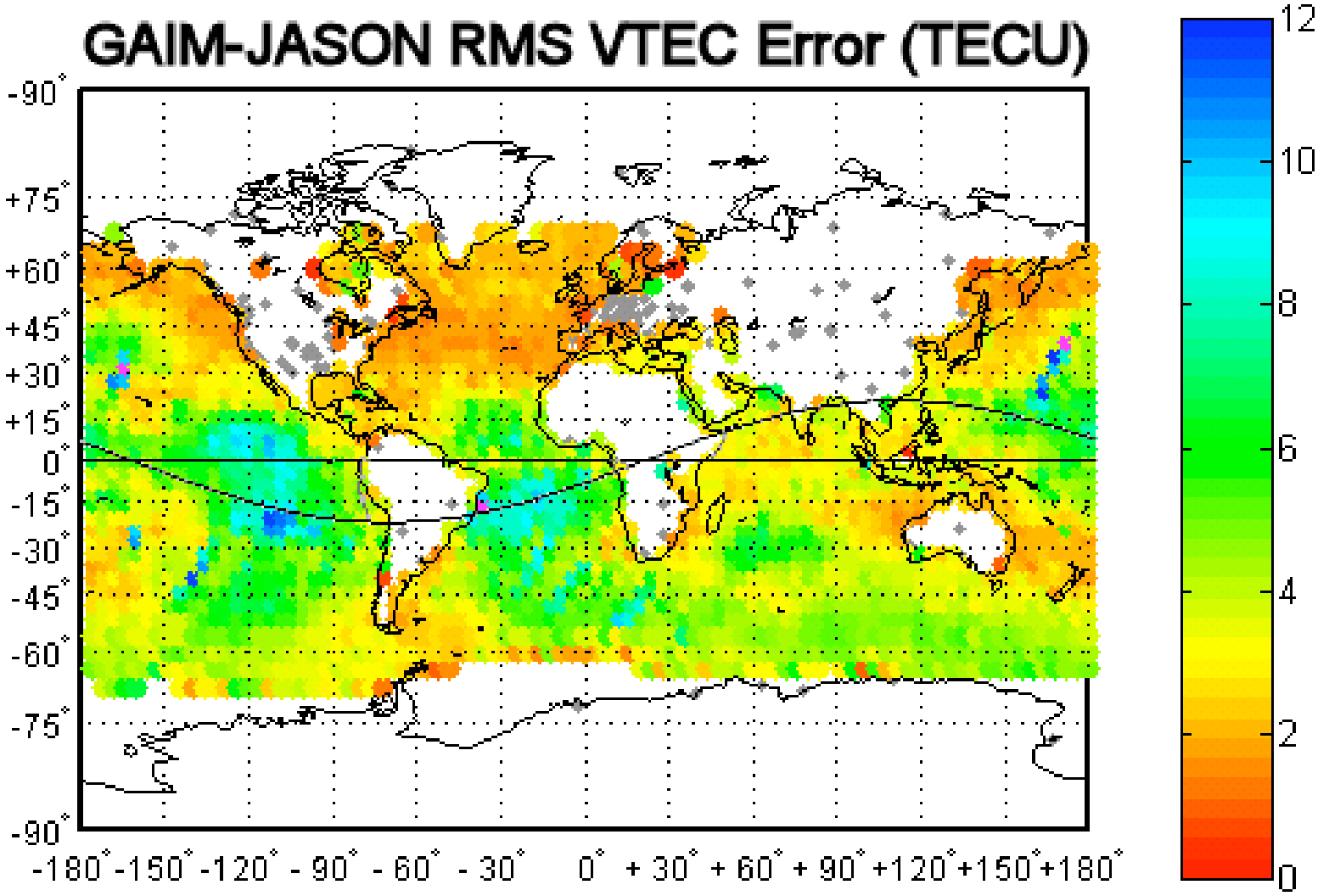
GO = Ground-GPS only GD = Ground + down-looking COSMIC

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.

GAIM Driven By Ground GPS Only versus JASON VTEC

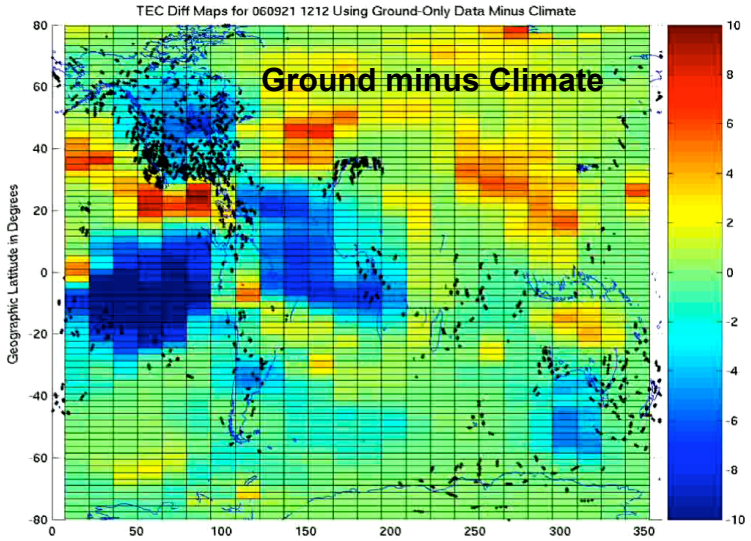


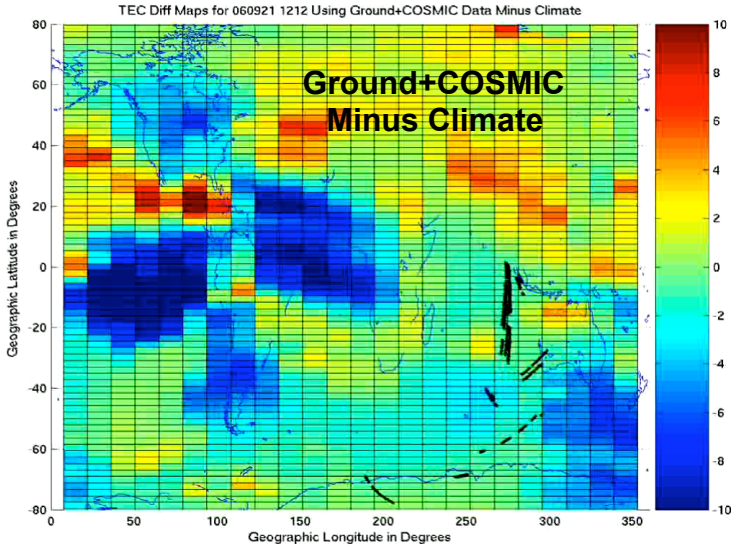
Summary and Conclusions

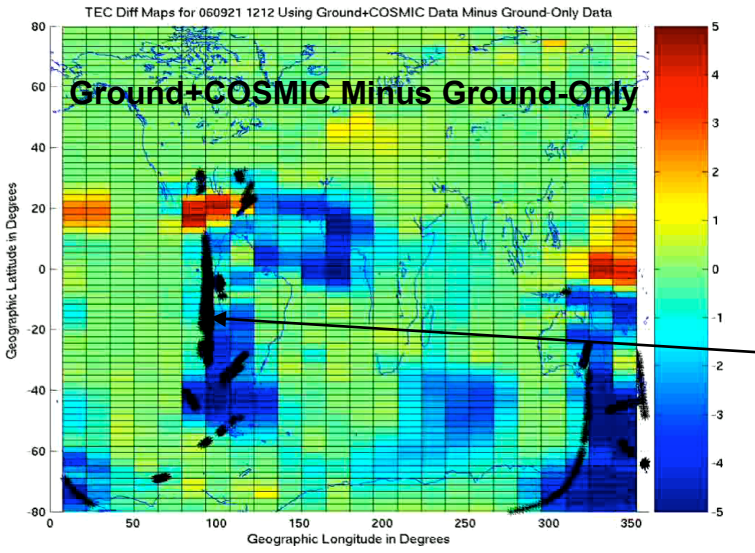
- JPL now routinely generates calibrated TEC and electron density profiles using COSMIC data.
- Performed GAIM assimilation using data from 200 ground-based GPS and six COSMIC satellites for World Days June 26, Sept 21 and Dec 20, 2006.
  - Ground-only, ground+COSMIC and climate GAIM runs performed.
  - GAIM profiles are validated using GIM, Arecibo, Jicamarca, Millstone Hill ISR, ionosonde, Jason VTEC.
- ISR validation results show that assimilating COSMIC data improves **NmF2** and **Hmf2**: i.e., resulting in **improved profiles shapes**. Assimilating COSMIC does seem to show marginal improvement in TEC accuracy at the ISR sides.
- Jason validation indicates significant improvement in **VTEC** space **globally** when assimilating COSMIC data

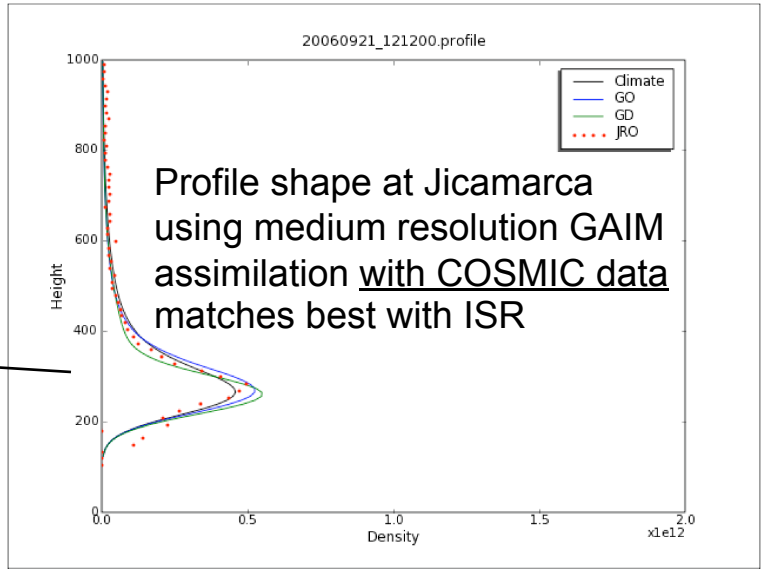
Backup Slides

Medium Resolution GAIM VTEC Difference Maps for Case 2

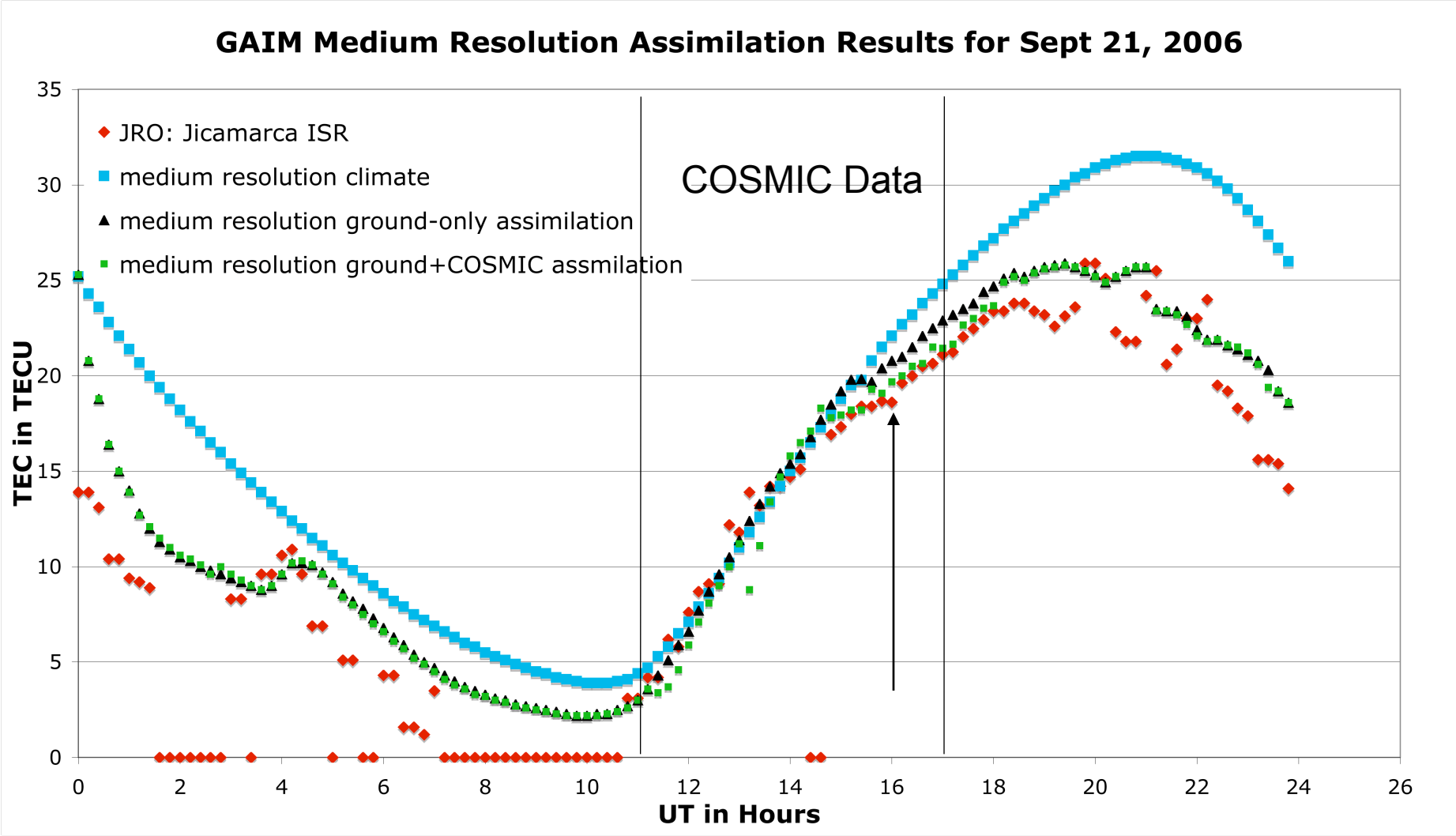




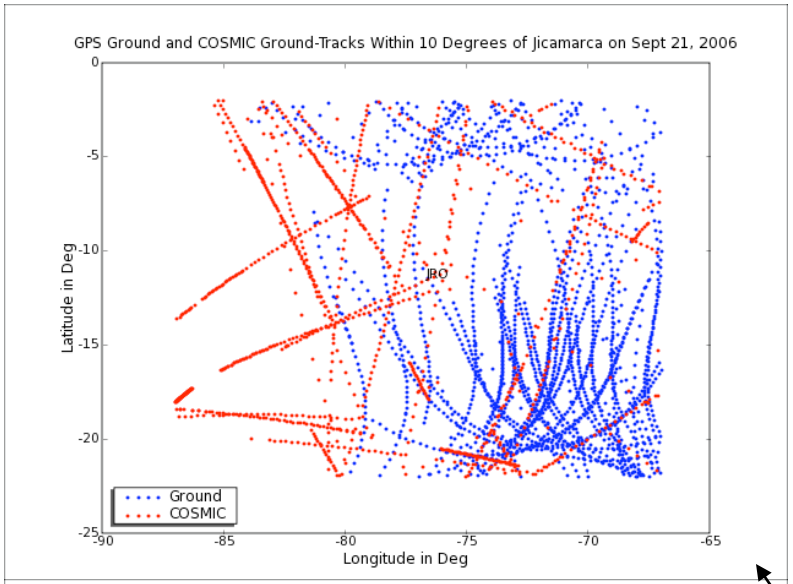


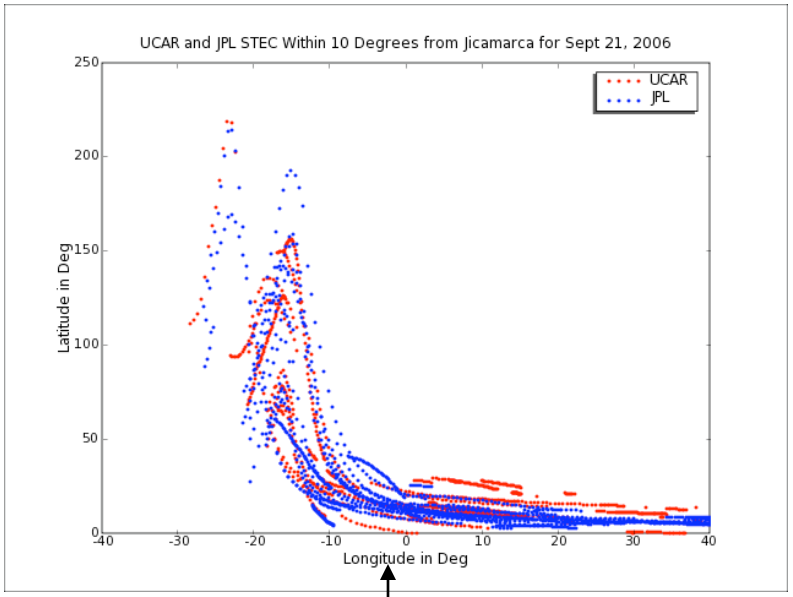


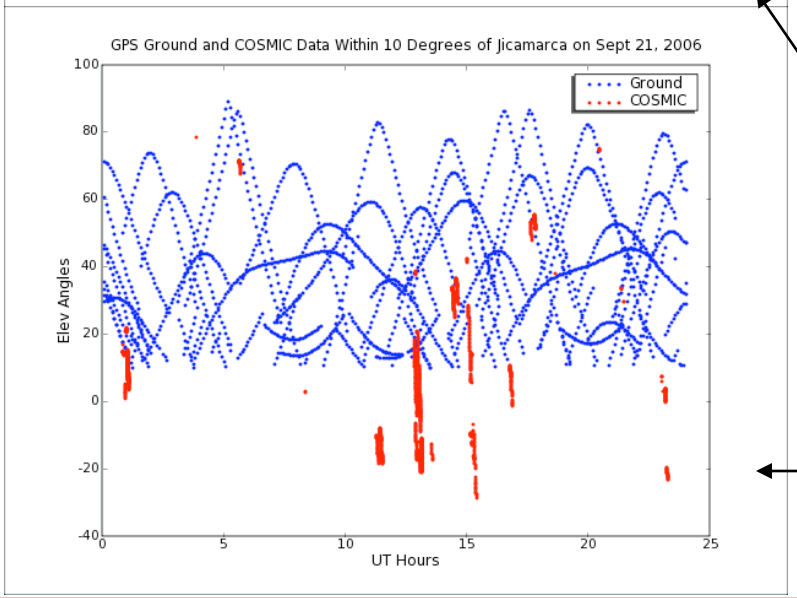
TEC Comparison with Jicamarca ISR



UCAR and JPL Raw GPS Data Processing Results for Sept 21, 2006







Comparison of UCAR and JPL calibrated TEC near Jicamarca

Ground and COSMIC ground tracks near Jicamarca

Ground and COSMIC data availability near Jicamarca