Recent Advances in Ionospheric Specific Specifications and New Applications Using GNSS Measurements

Attila Komjathy, David Galvan*, Brian Wilson, Mark Butala, Xiaoqing Pi, Byron Ijima, Vardan Akopian and Anthony J. Mannucci

Jet Propulsion Laboratory

California Institute of Technology

M/S 238-600

4800 Oak Grove Drive

Pasadena CA 91109

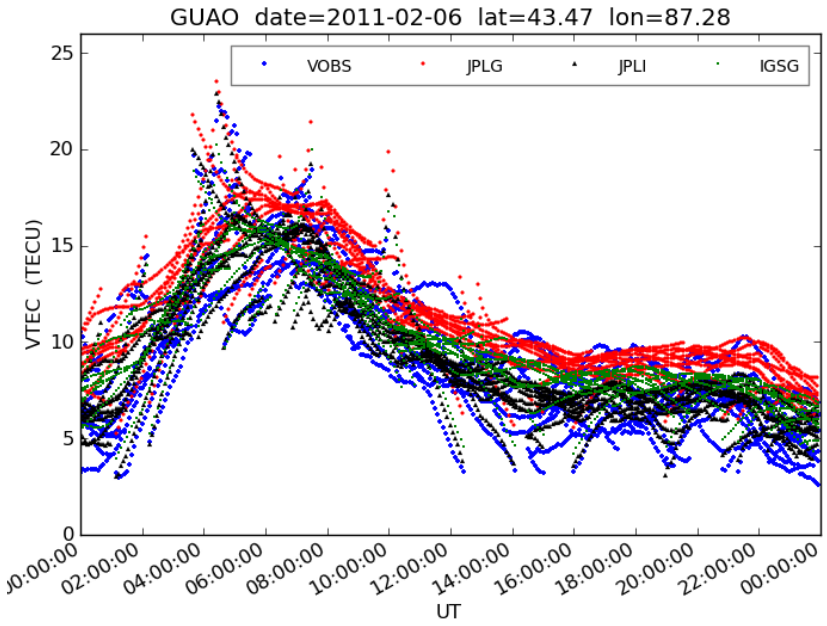
Email: Attila.Komjathy@jpl.nasa.gov

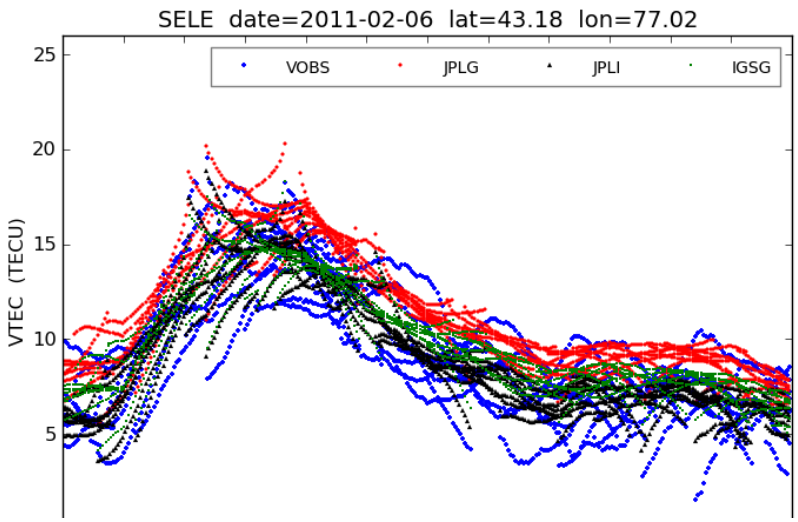
** Now at RAND Corporation*

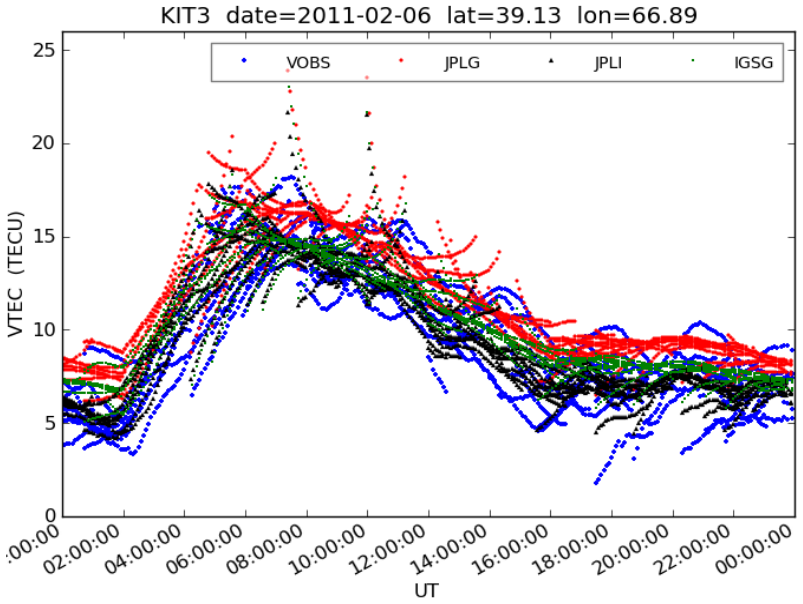
Introduction

- GIM enhancements at JPL for 2D ionospheric products
  - Increased temporal and spatial resolution
  - Latitude dependent mapping function
  - Routine validation of receiver bias estimates using SCORE
- Global Ionospheric Assimilative Model (GAIM) 3D products – post-processed and real-time GAIM products ingesting
  - ground based GPS and GLONASS measurements
  - space-based data (COSMIC and C/NOFS)
- Estimating high precision ionospheric TEC perturbations. New and upcoming applications for natural hazard imaging and early warning systems
  - Tsunami modeling and imaging using TEC observations
  - Volcanic eruptions and nuclear tests imaging
  - Monitoring TIDs, high and low-latitude disturbances
- Conclusions

Comparison of JPLI with Other Products for Feb 6, 2011

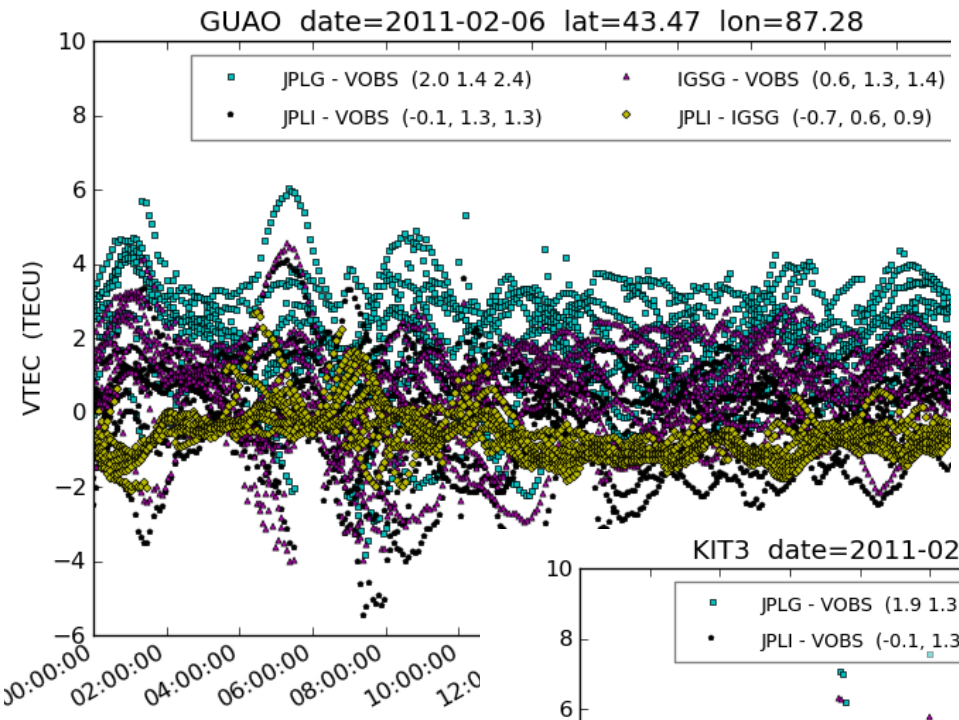


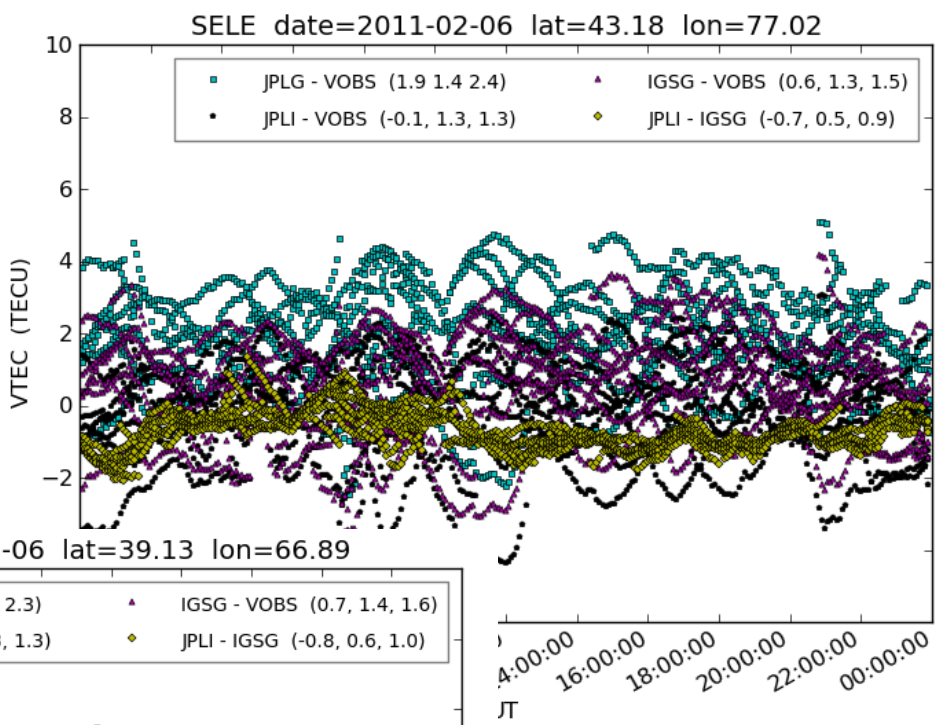


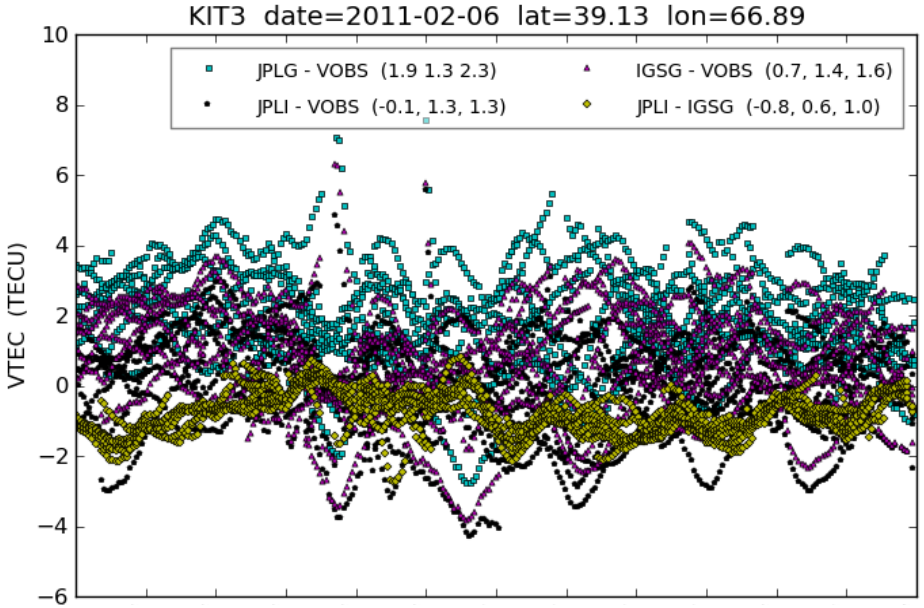


- JPLG, IGS IONEX product resolution: 2.5 x 5.0 degrees at every 2 hours
- New JPLI IONEX file resolution: 1 degree by 1 degree at every 15 minutes – the highest operational GIM product resolution
- Regular gridded IONEX format
- Typical un-compressed file size: 33 MB/day
- Regular IGS IONEX product size: 1 MB/day

Comparison of JPLI with Other Products for Feb 6, 2011

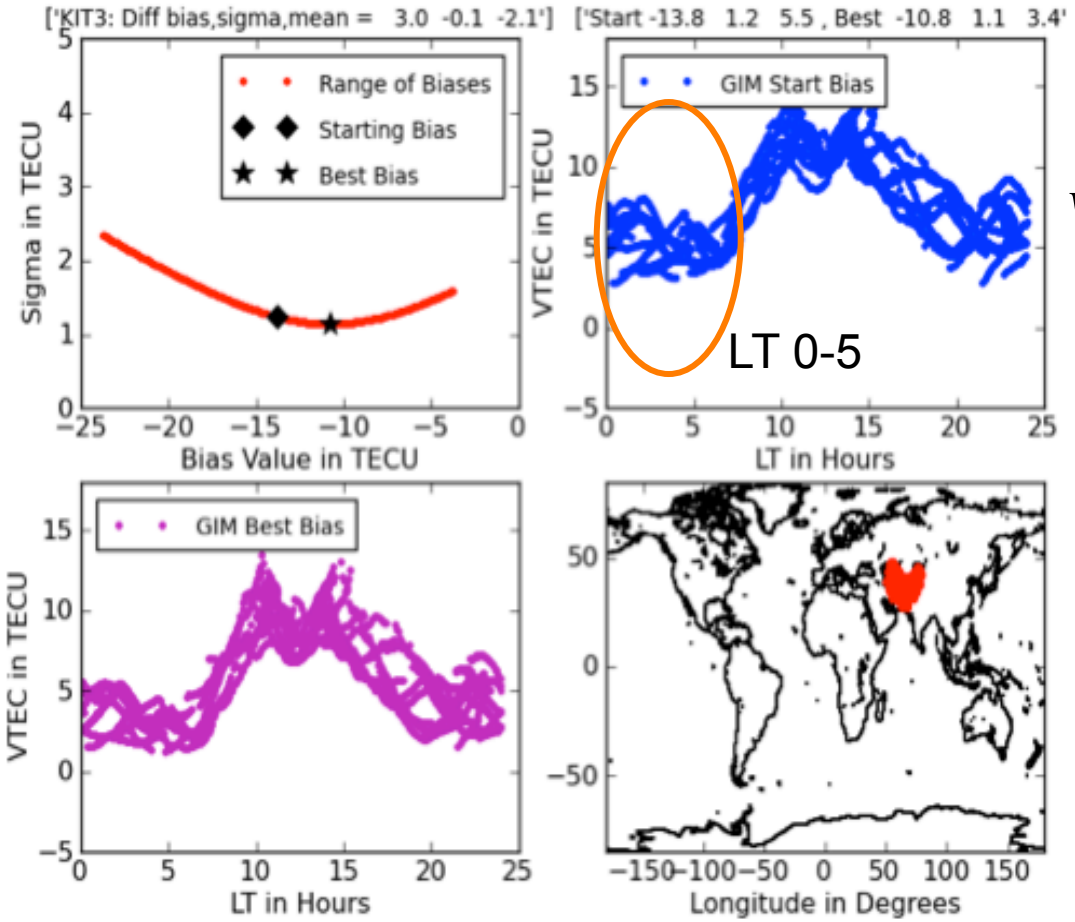






JPLG, JPLI and IGS comparisons

Routine Daily Bias Comparisons with SCORE Algorithm



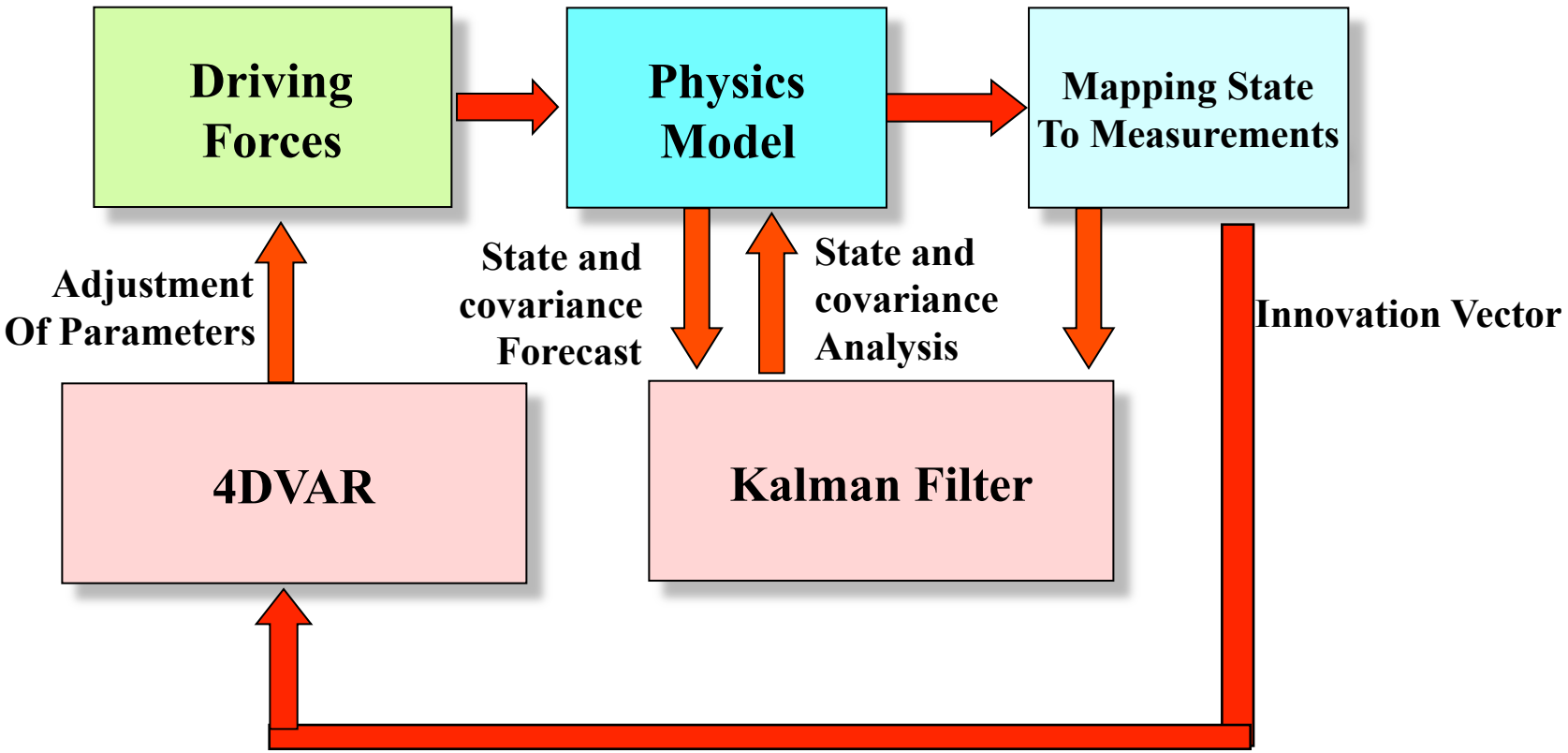
$$VOBS = M(h, El) * \left[SOBS + b^{sat} + b_{rcv} \right]$$

where

$b^{sat} + b_{rcv}$ GIM-estimated satellite and receiver biases

Best Bias is computed as the minimum of the standard deviation curve above

Global Assimilative Ionospheric Model
Data Assimilation Process



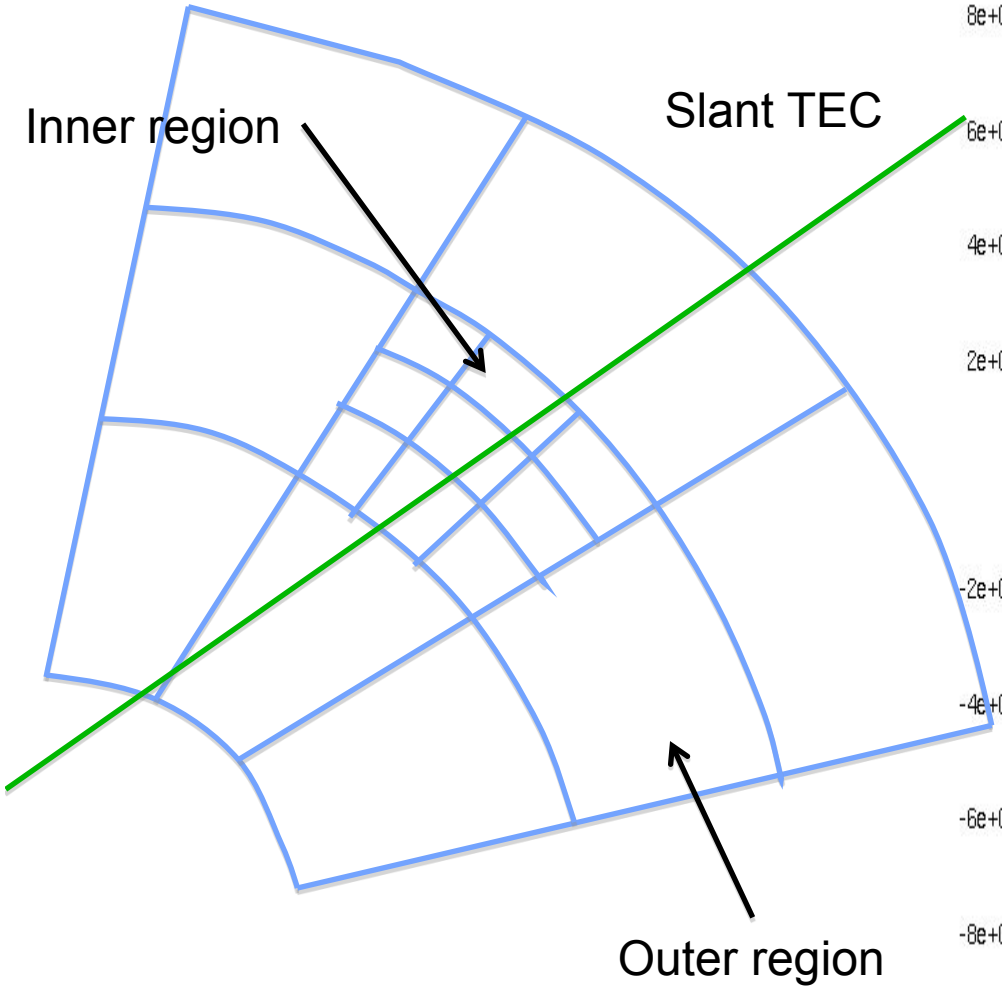
- 4-Dimensional Variational Approach
  - Minimization of cost function by estimating driving parameters
  - Non-linear least-square minimization
  - Adjoint method to efficiently compute the gradient of cost function
  - Parameterization of model "drivers"

- Kalman Filter
  - Recursive Filtering
  - Covariance estimation and state correction

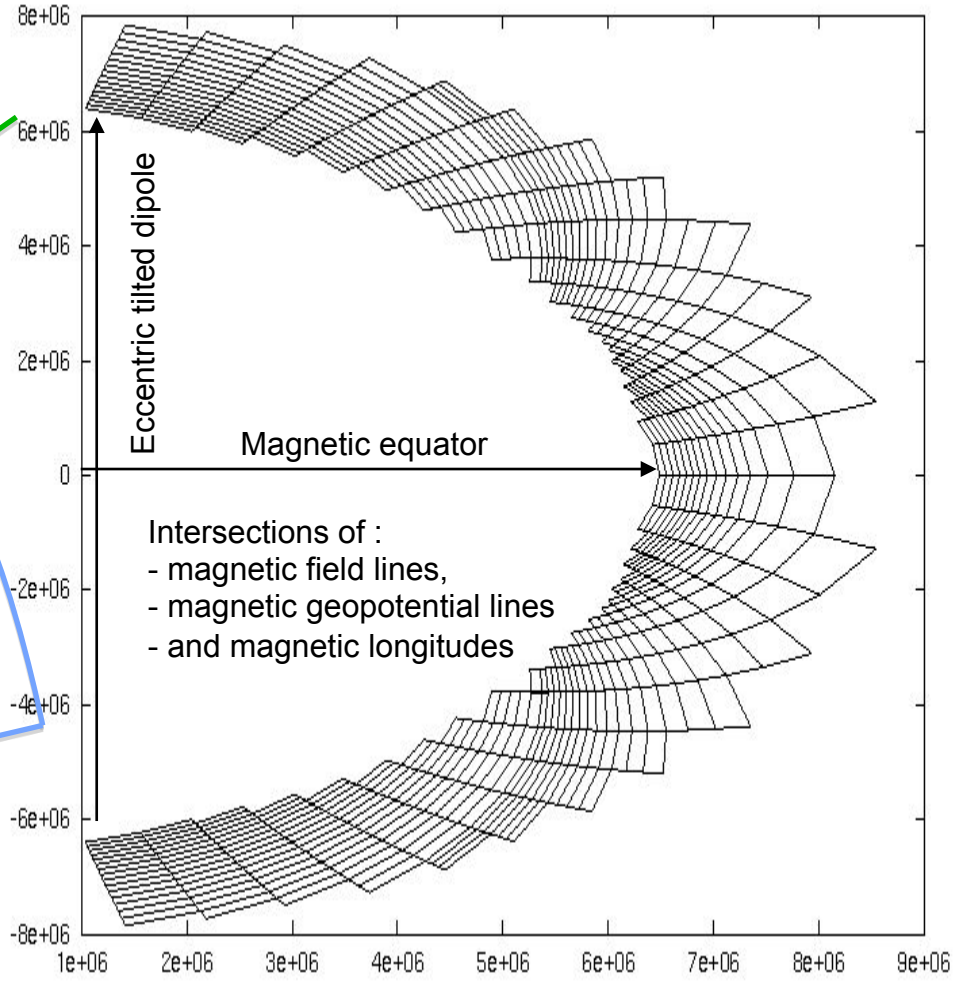
    Optimal interpolation

    Band-Limited Kalman filter

GAIM and Nested GAIM Grids

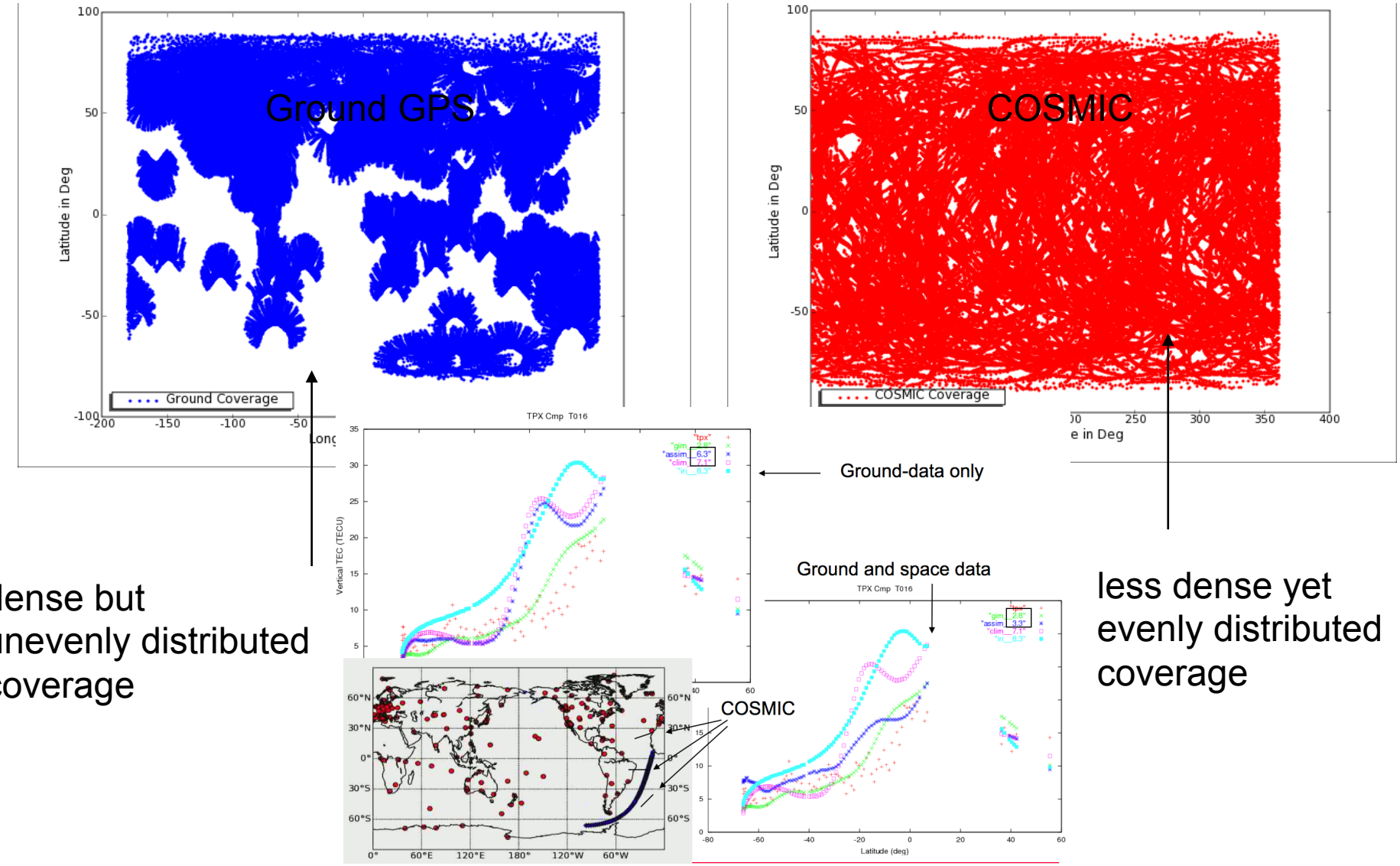


GAIM Nested Grid



Regular GAIM Grid

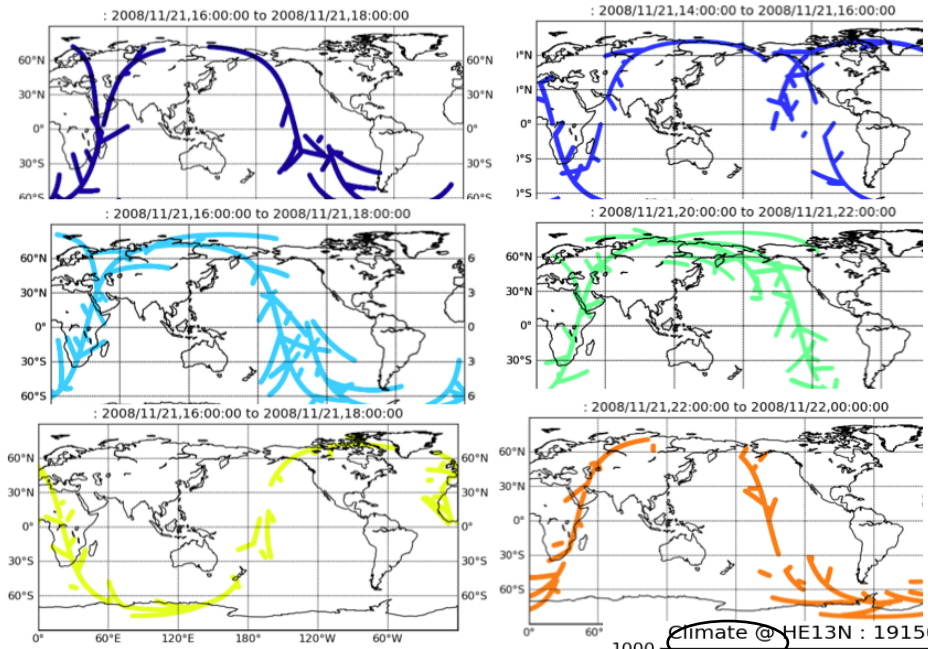
Typical Ground GPS and COSMIC for Sept 21, 2010



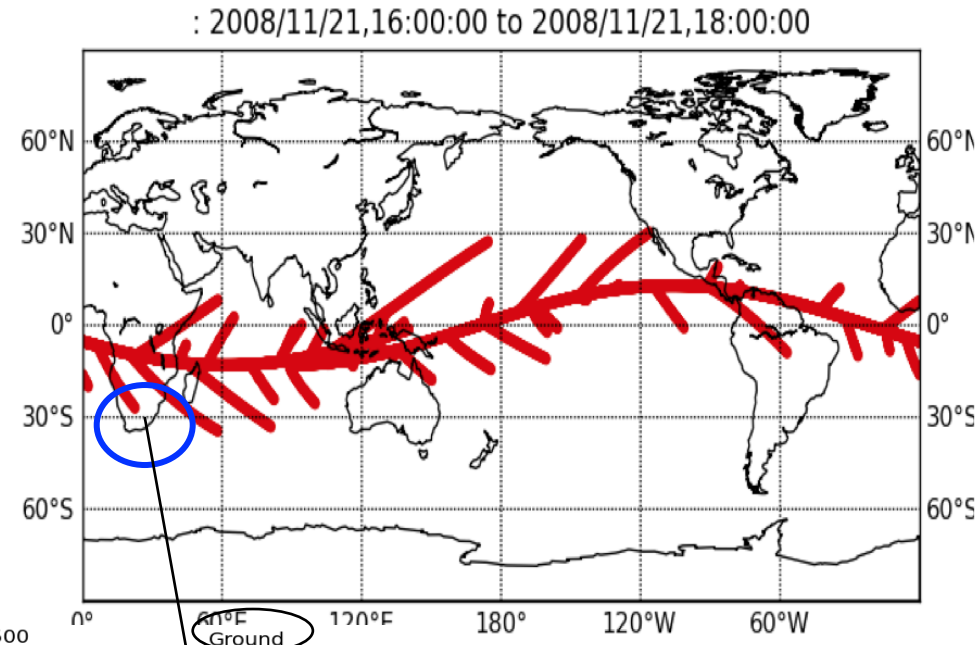
dense but unevenly distributed coverage

less dense yet evenly distributed coverage

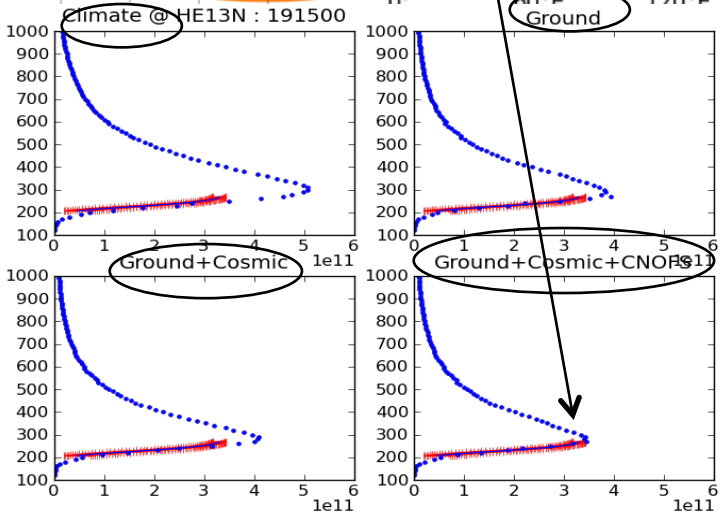
COSMIC and C/NOFS Coverage on Nov 21, 2008



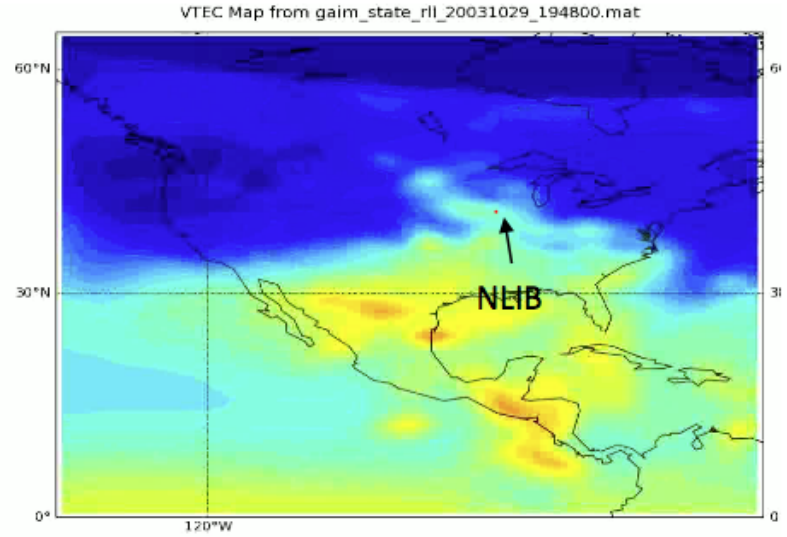
COSMIC Coverage

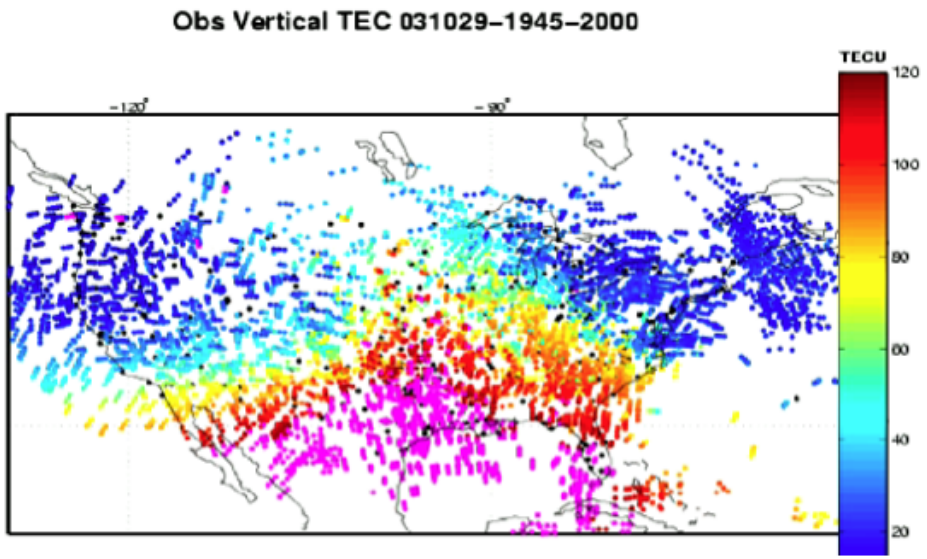


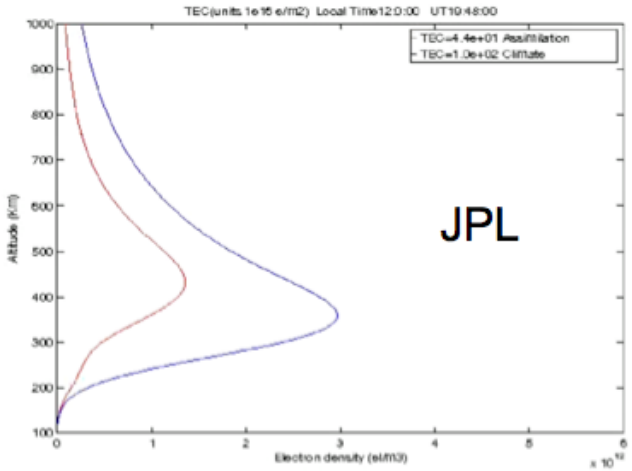
C/NOFS Coverage

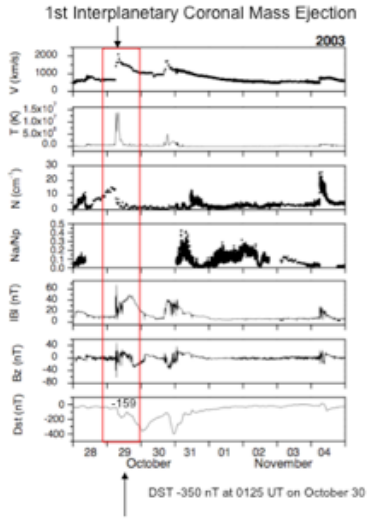


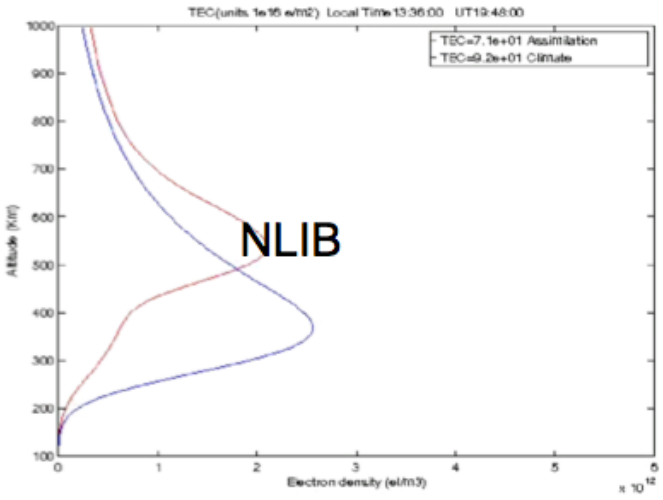
Storm Day: Oct 29, 2003, NGAIM and Truth Storm Features at NLIB





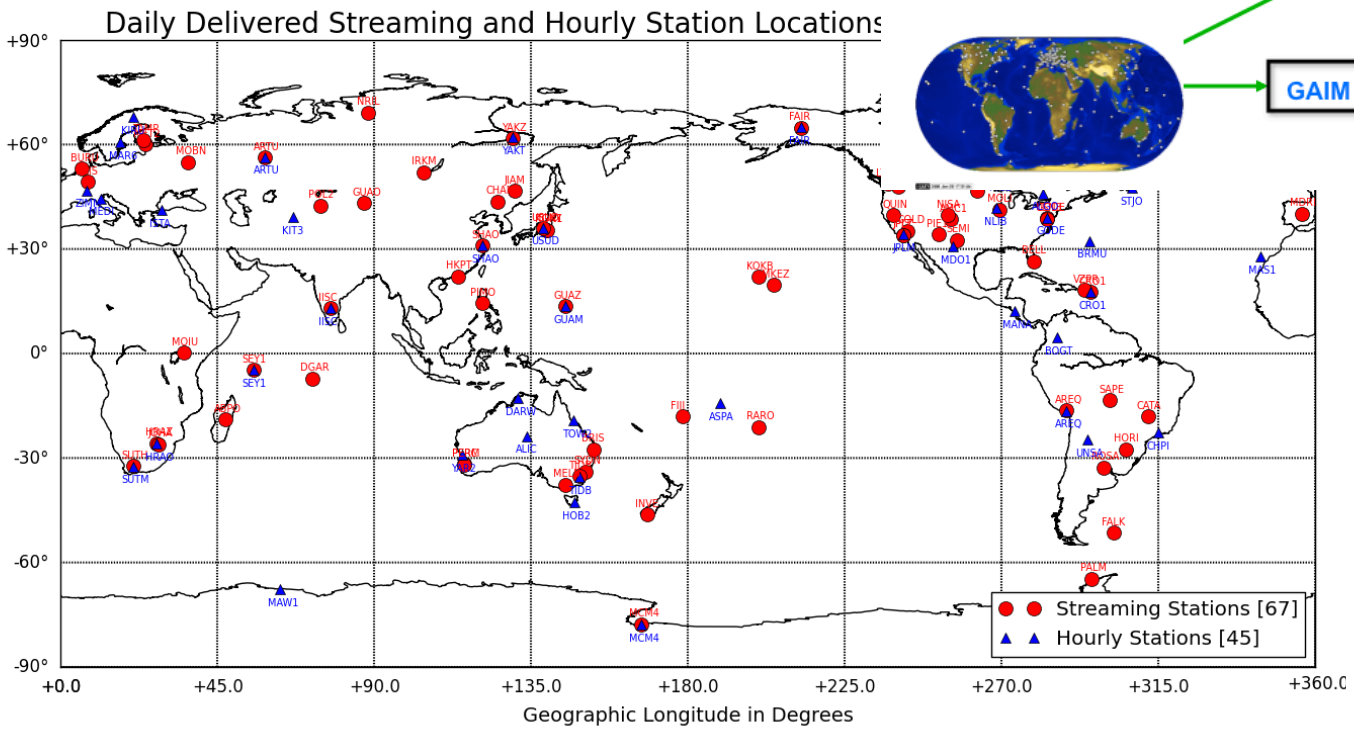






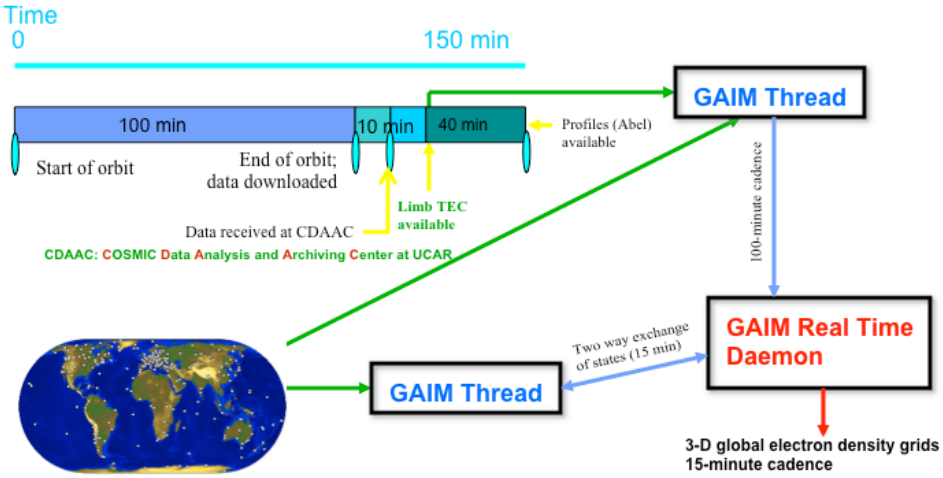
Real-Time GAIM: Assimilating Ground TEC and COSMIC Measurements

Real-Time Streaming and Hourly Stations on July 9, 2012



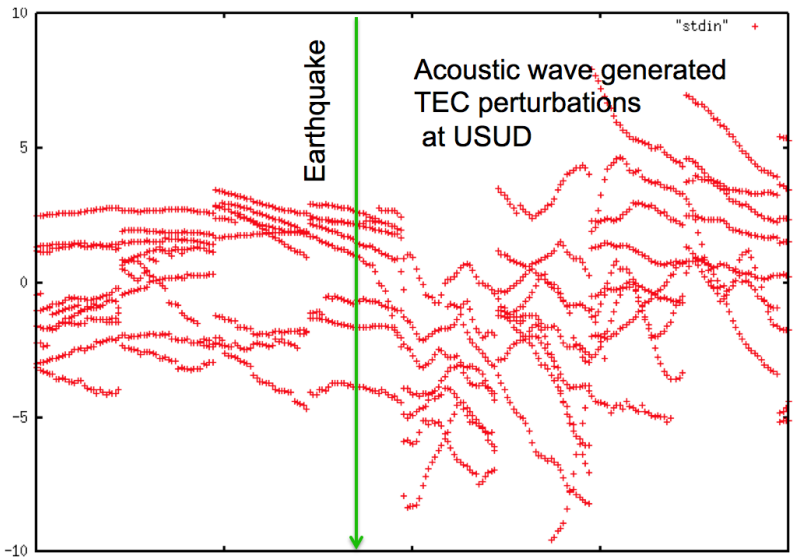
Global ground network data: 5-minute and 1-hour latency

COSMIC data: 20 - 120 minutes latency

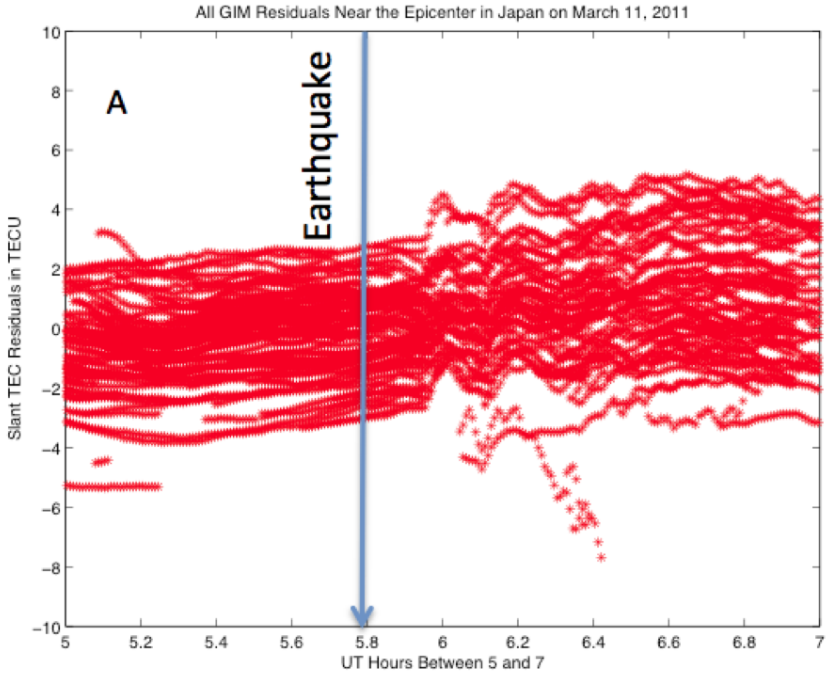


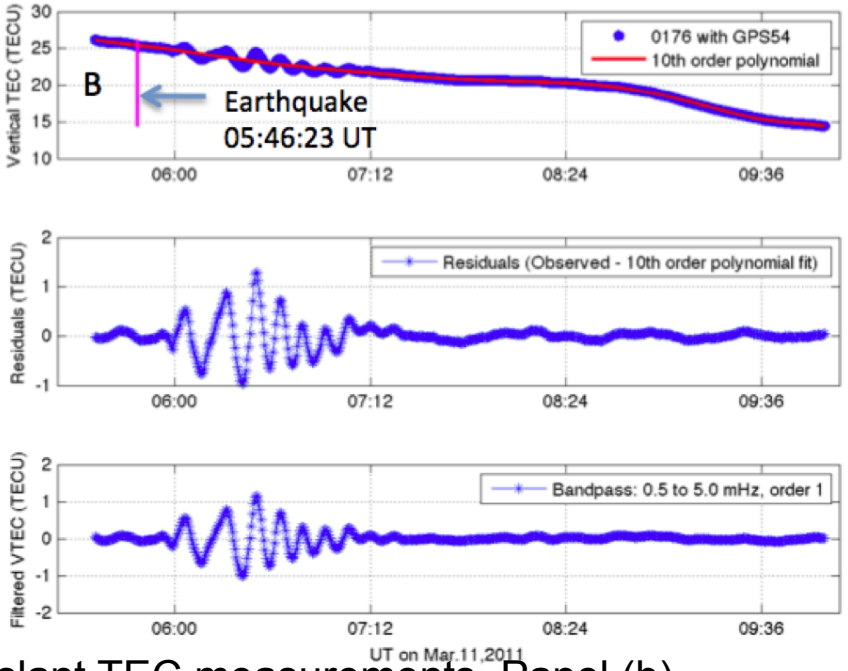
Thanks to NASA's GDGPS system

NASA's GDGPS R&D role is highly valuable and gratefully acknowledged



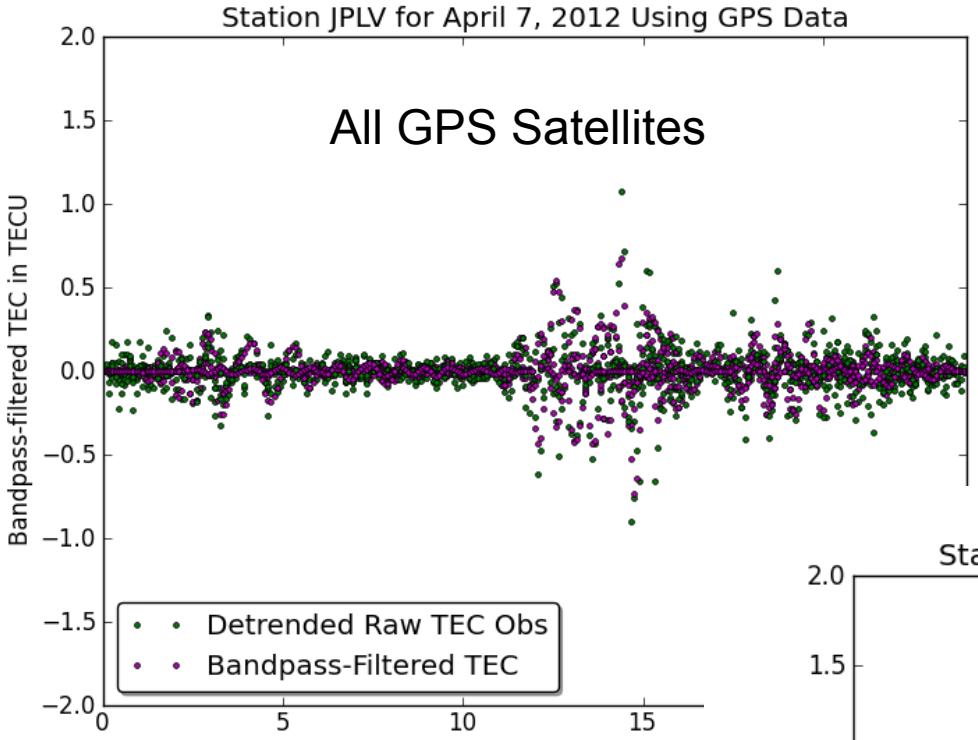
Real-Time GAIM TEC Residuals for Tohoku Earthquake on March 11, 2011

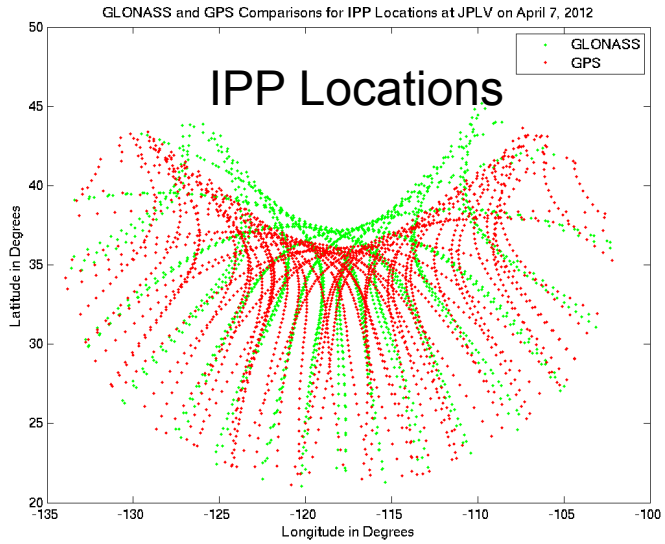


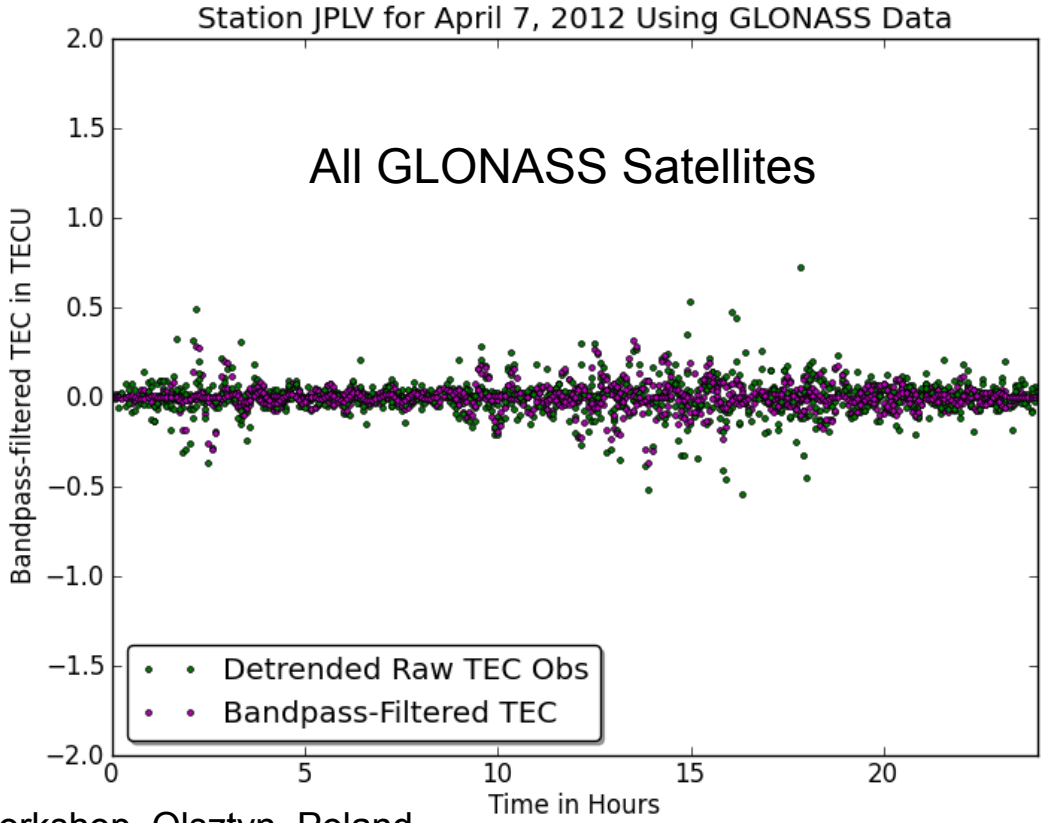


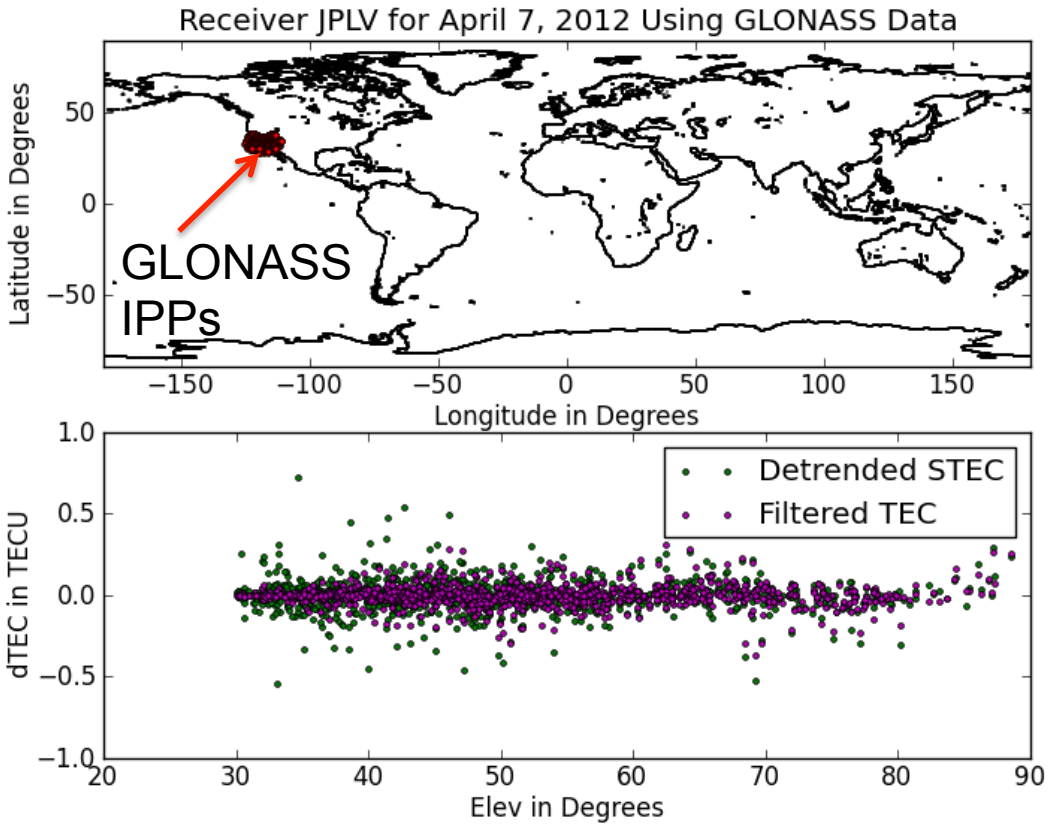
GIM residuals (a) and band-pass filtered slant TEC measurements. Panel (b) indicates an example for filtered TEC observations.

Station JPLV Tracking GPS + GLONASS



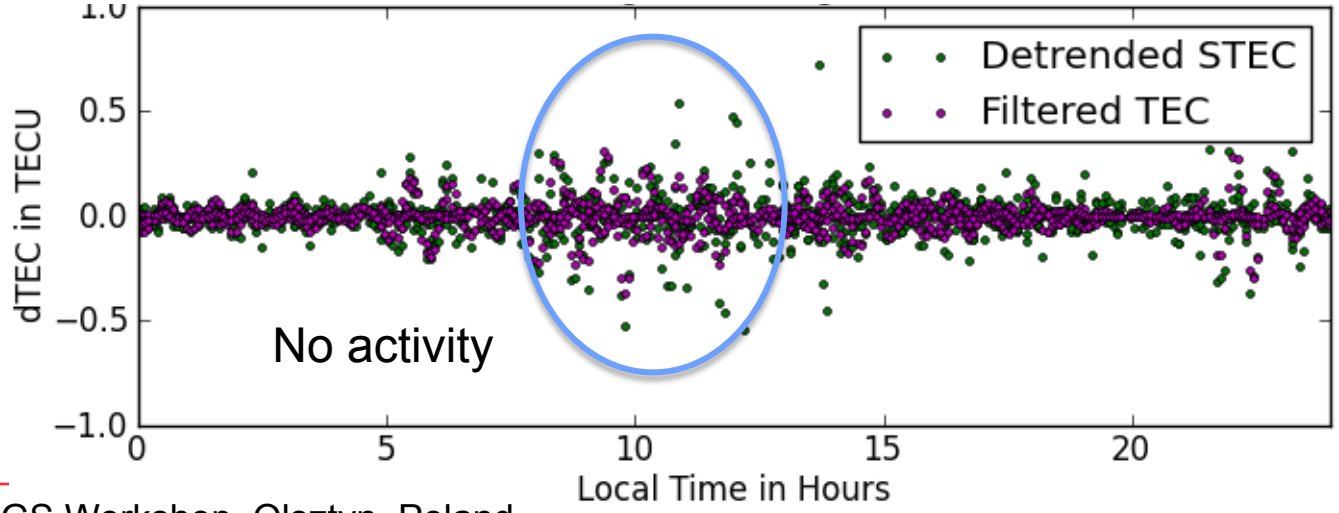






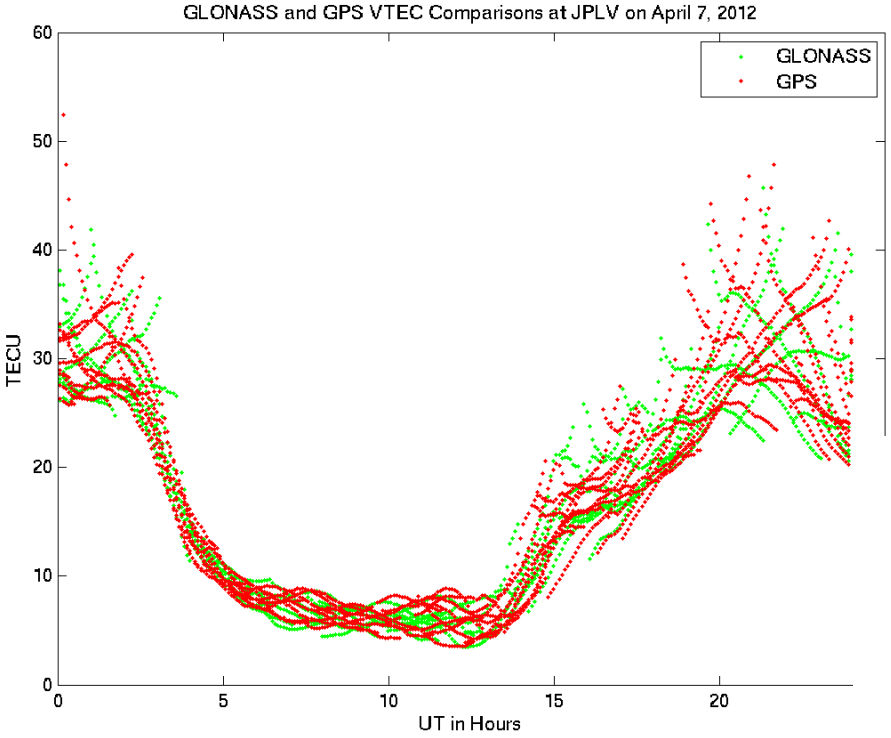
GLONASS Only

Elevation Angle Dependence



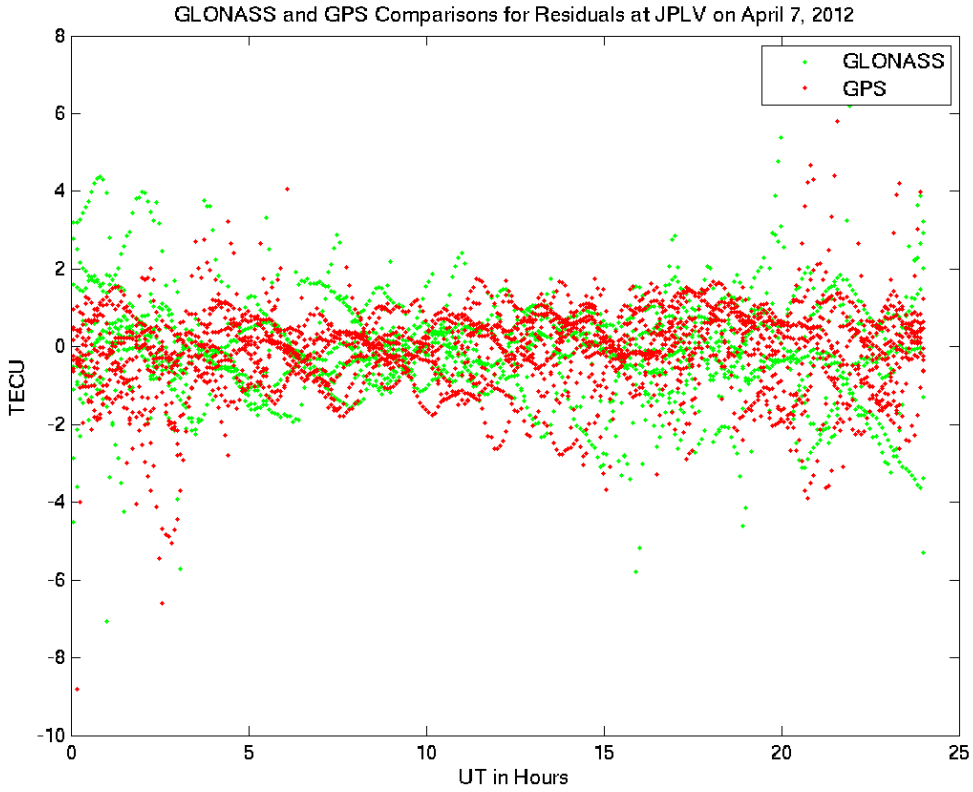
Local Time Dependence

TEC and Residuals for GPS and GLONASS

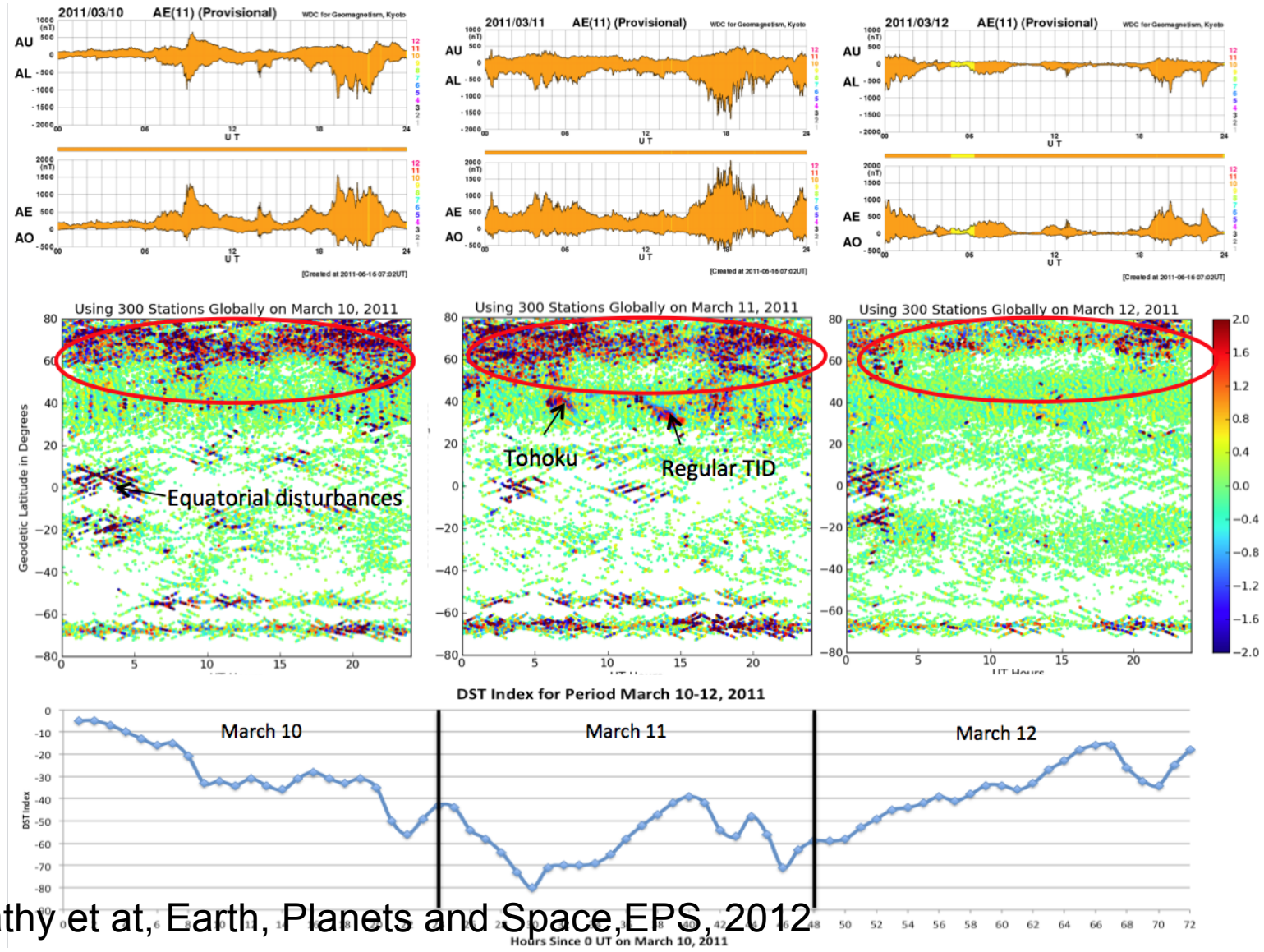


GPS and GLONASS VTEC at JPLV

GPS and GLONASS TEC Residuals

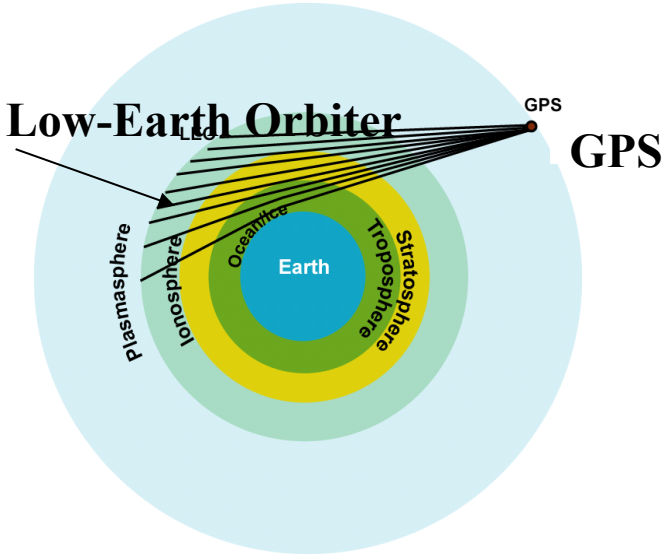


Global Natural Hazard Imaging Using IGS Stations on March 10-12, 2012



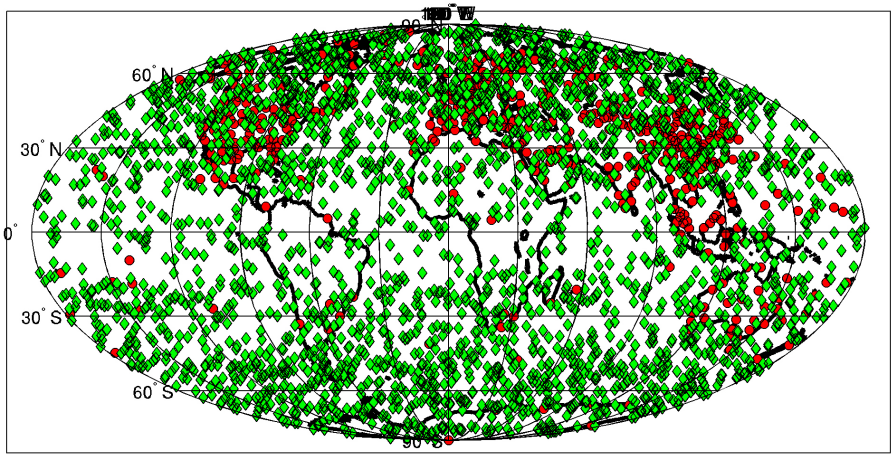
Komjathy et at, Earth, Planets and Space,EPS, 2012

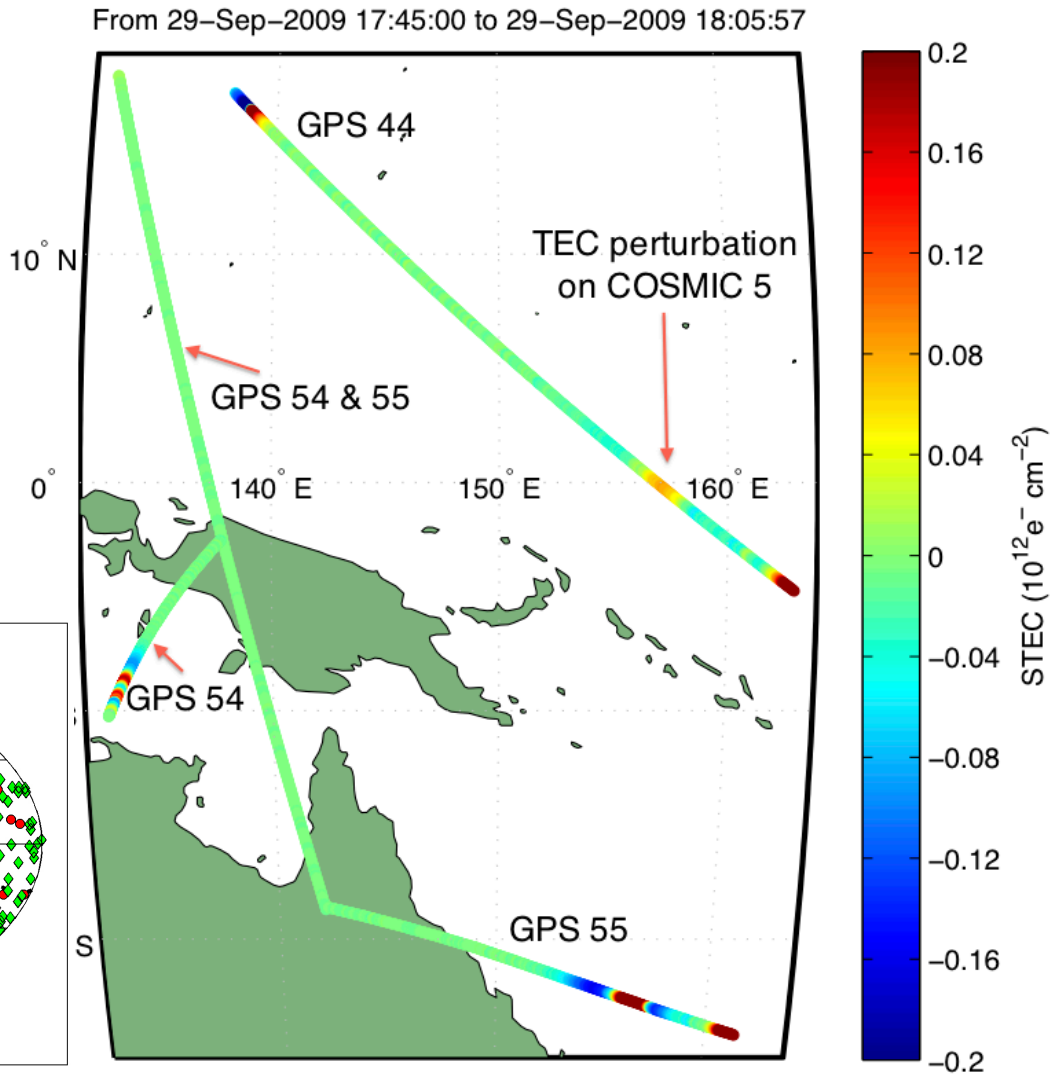
COSMIC Space-Borne TEC Measurements for Sept 29, 2009 Samoa Earthquake



COSMIC coverage: 2500 profiles/

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





GRL, 2011 Reported Ionospheric TEC Precursors: We Are Skeptical!

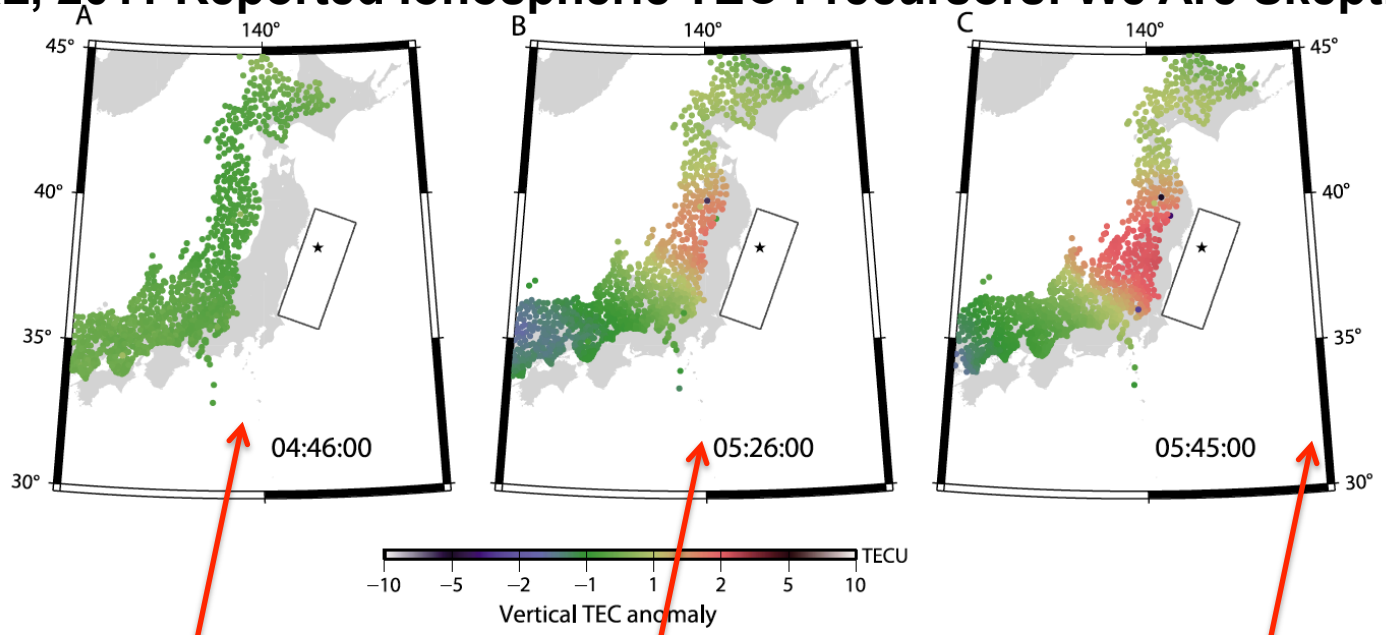
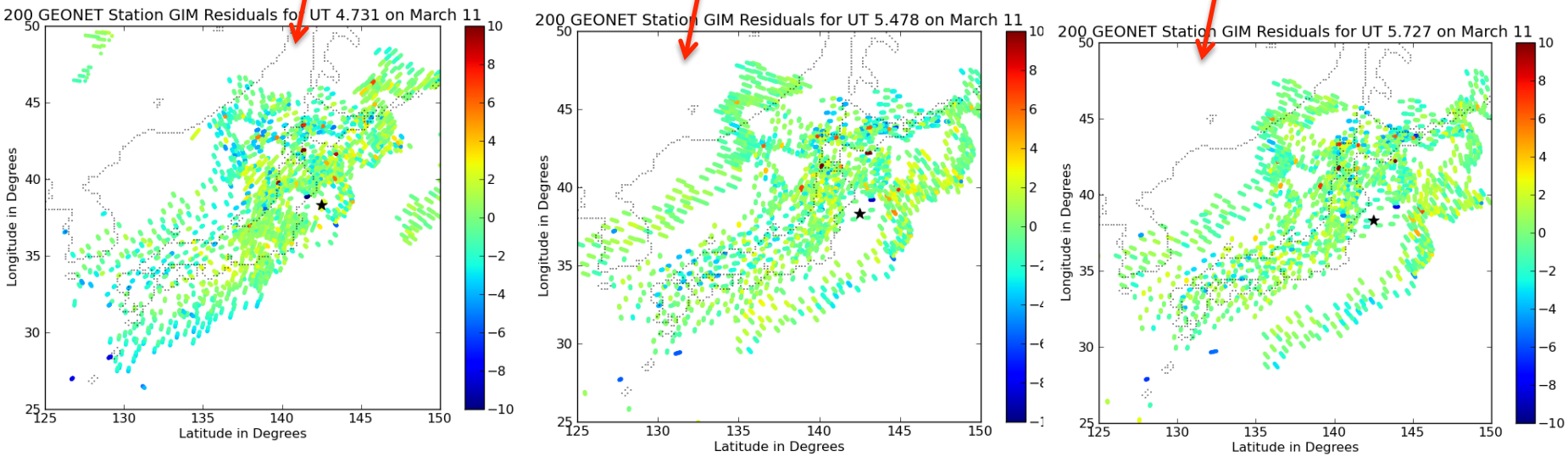
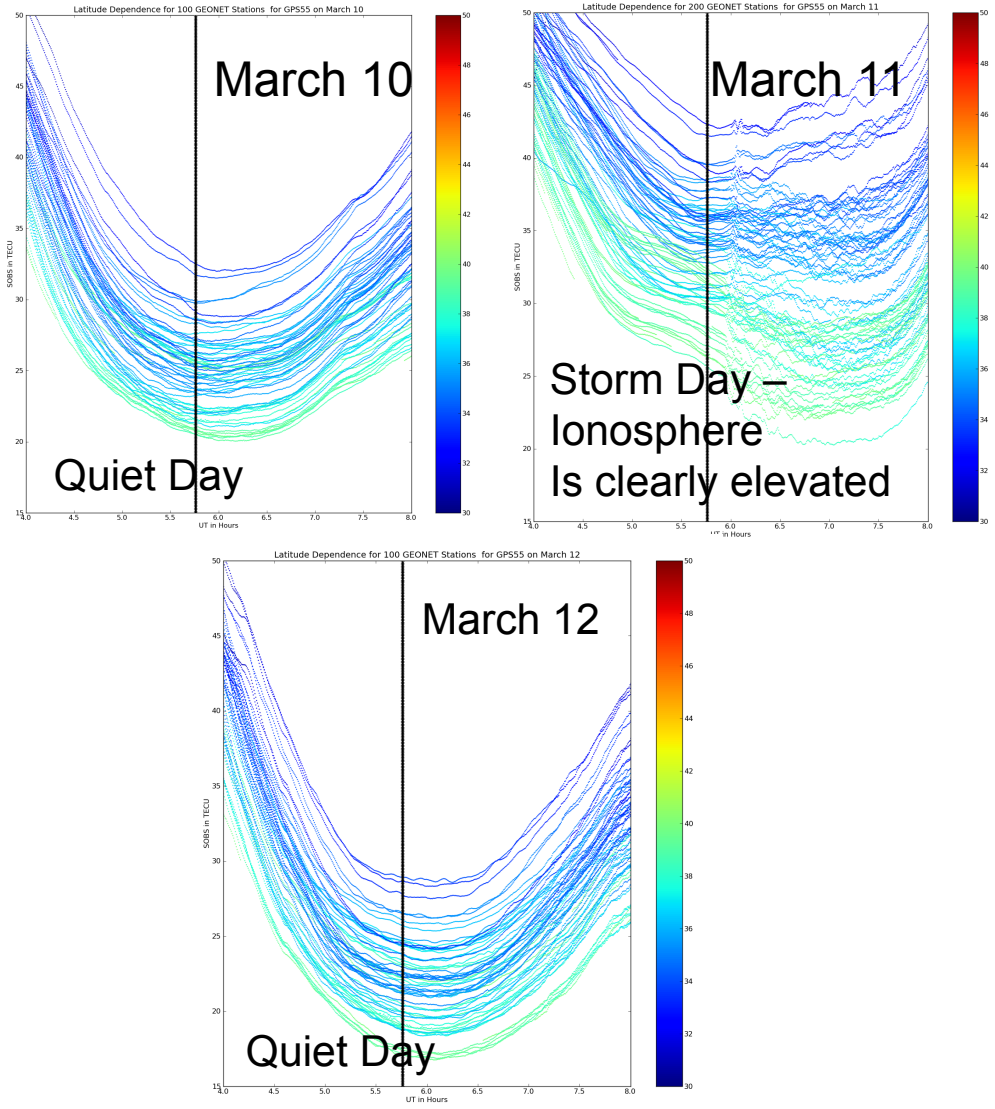
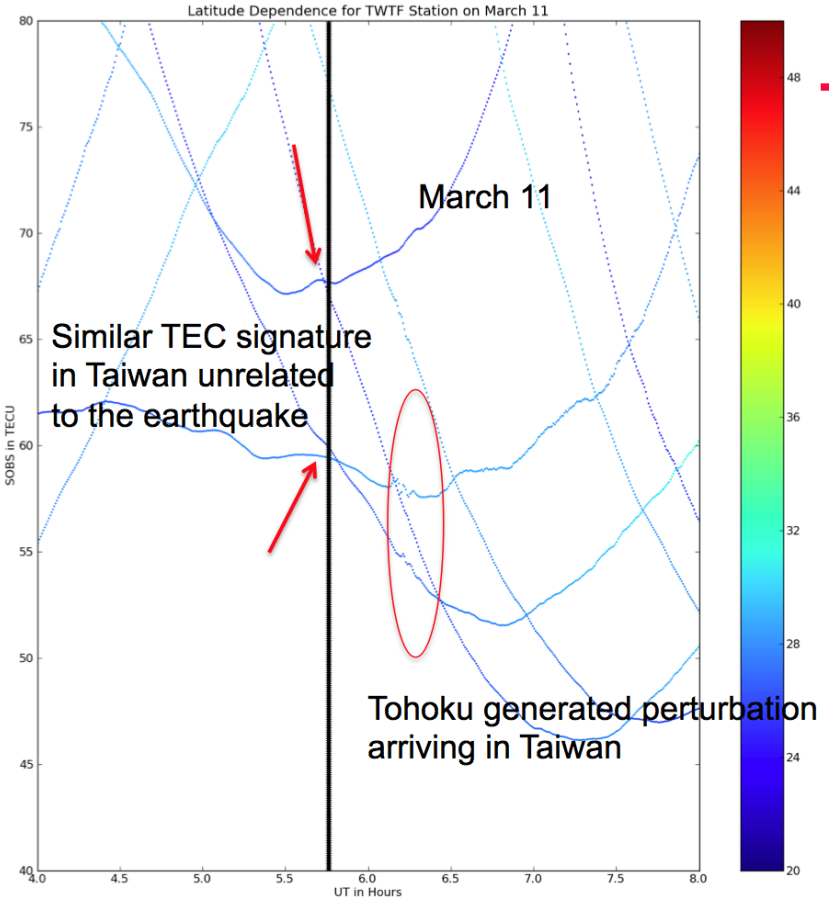


Figure 3. Vertical TEC anomalies at three time epochs, (a) 1 hour, (b) 20 minutes, and (c) 1 minute before the earthquake, observed at GEONET stations with the satellite 15. Positive anomalies (red color) are seen to grow near the focal region.



GPS55 Using 100 GEONET Stations in Japan on March 10-12, 2011





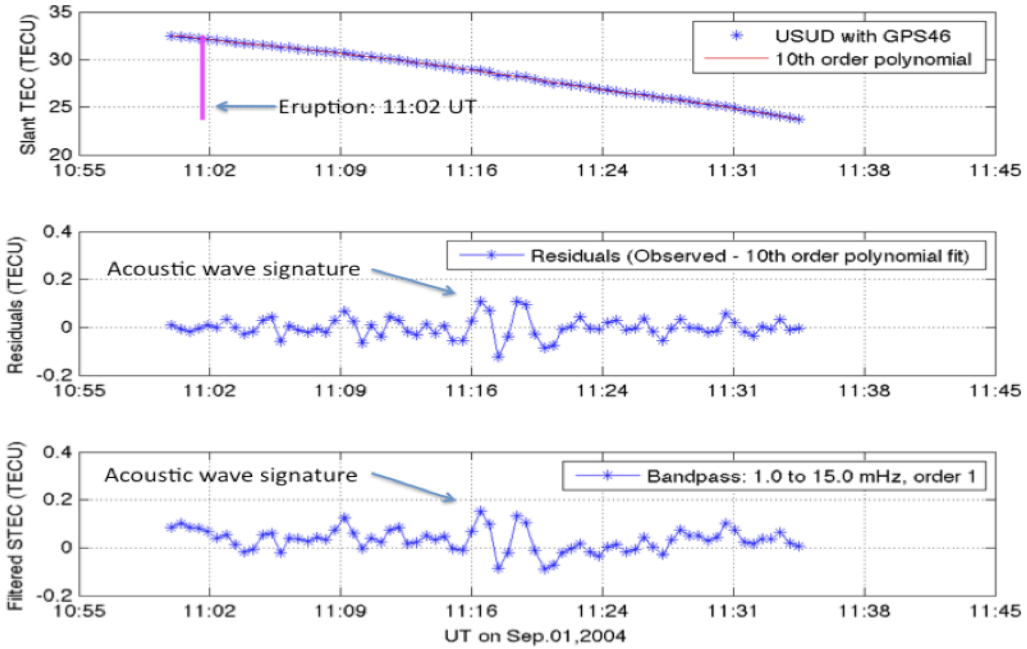
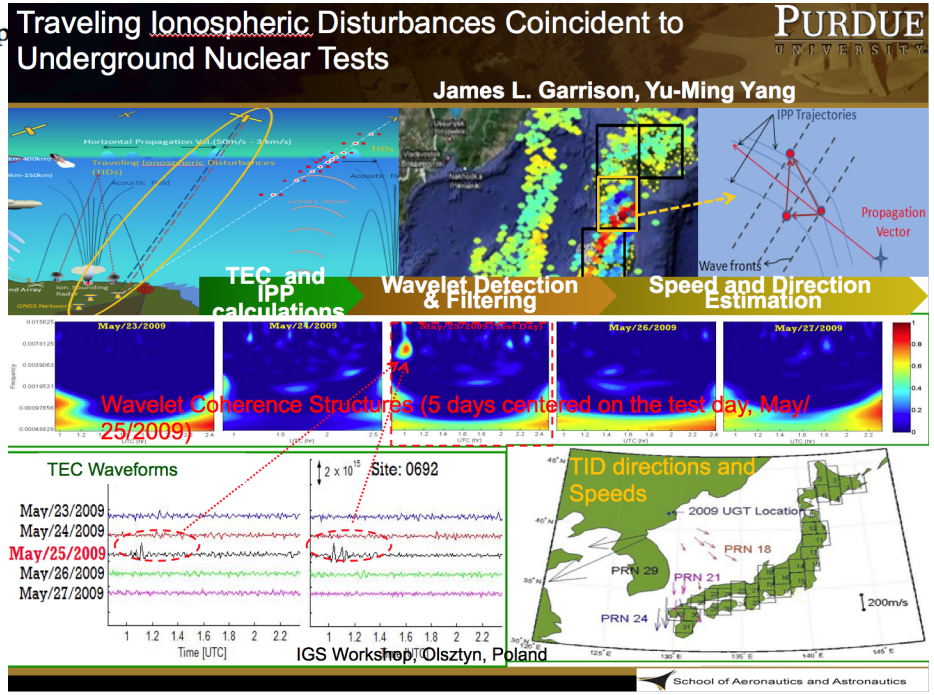


Figure 5. Acoustic wave TEC perturbations caused by the Asama volcano erup of Sep 1, 2004, observed by USUD ground GPS station.

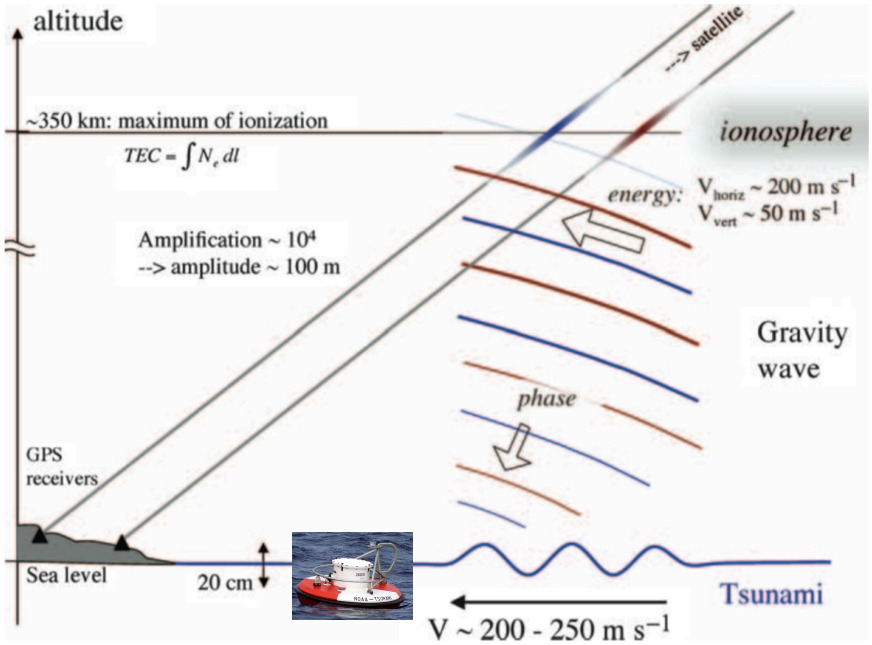
Detection of Volcanic Eruptions in GPS TEC Data for Sept 1, 2004 Asama Volcano in Japan

Detection of Underground Nuclear Tests in North Korea in May 2009



Tohoku Tsunami: March 11, 2011

Tsunami Wave Height Model: Tohoku Tsunami Estimated by NOAA



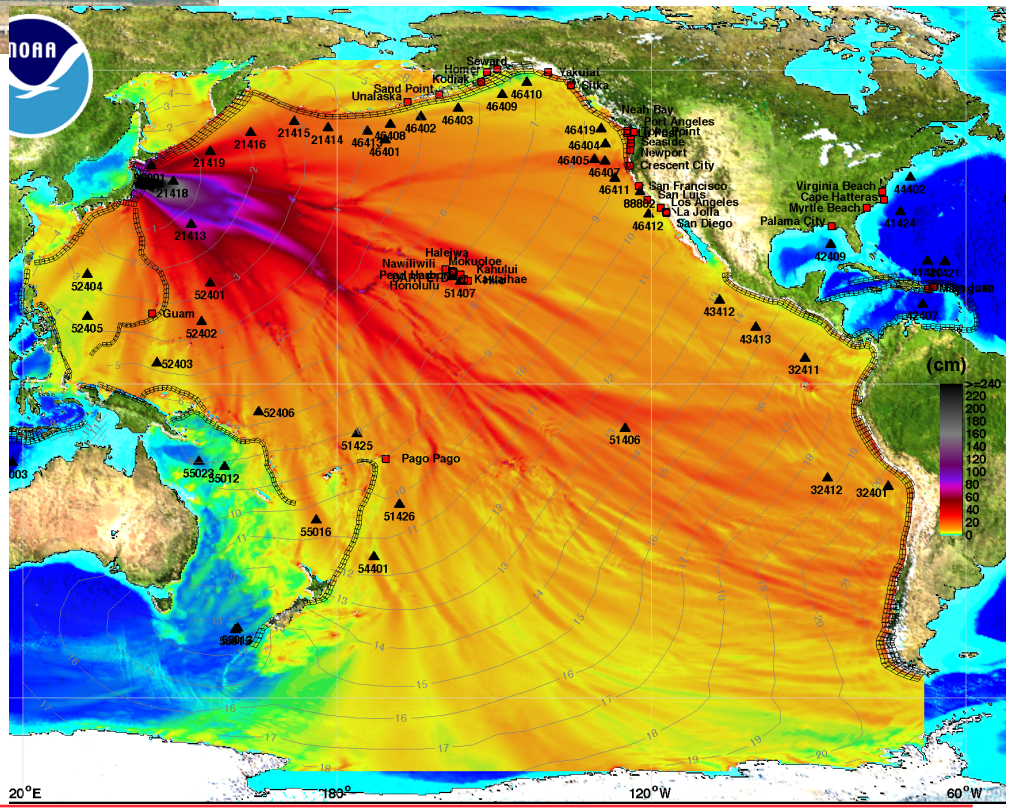
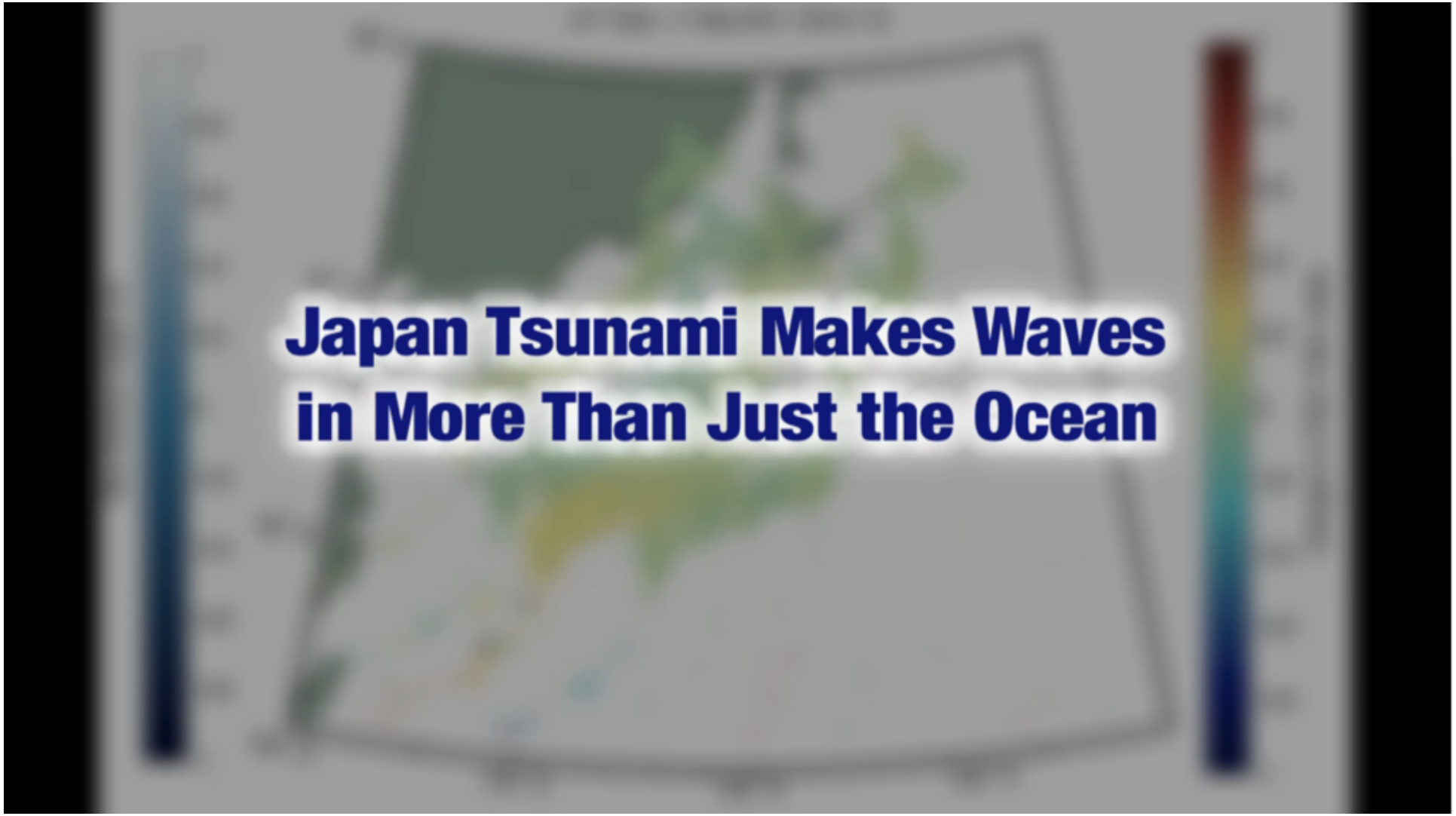


Figure from *Artru et al.,* (2005).



Galvan, D. A., A. Komjathy, M. P. Hickey, P. Stephens, J. Snively, Y. Tony Song, M. D. Butala, and A. J. Mannucci (2012), *Ionospheric signatures of Tohoku-Oki tsunami of March 11, 2011: Model comparisons near the epicenter*, **Radio Science**, 47, RS4003, doi:10.1029/2012RS005023.

Conclusions

- Continuing improvements for JPL 2D and 3D ionospheric products
- Validating of various products and biases are ever more important
- Assimilation of Ground GPS + COSMIC + C/NOFS shows improved agreement with ionosonde measurements of Nmf2 and Hmf2.
- Now and upcoming applications include GAIM-based natural hazards generated TEC perturbation imaging and modeling of earthquakes, volcanic eruptions, tsunamis.
  - Detecting TEC perturbations using ground and space-based data
  - New science applications: estimating acoustic and gravity wave speeds and direction
  - Community seems to pushing earthquake precursors: several papers have been published by others – we are skeptical!

- This research was performed at the Jet Propulsion Laboratory/California Institute of Technology under contract to the National Aeronautics and Space Administration