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

Attila Komjathy, Mark Butala, Xiaoqing Pi, Byron Ijima, Brian Wilson, 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

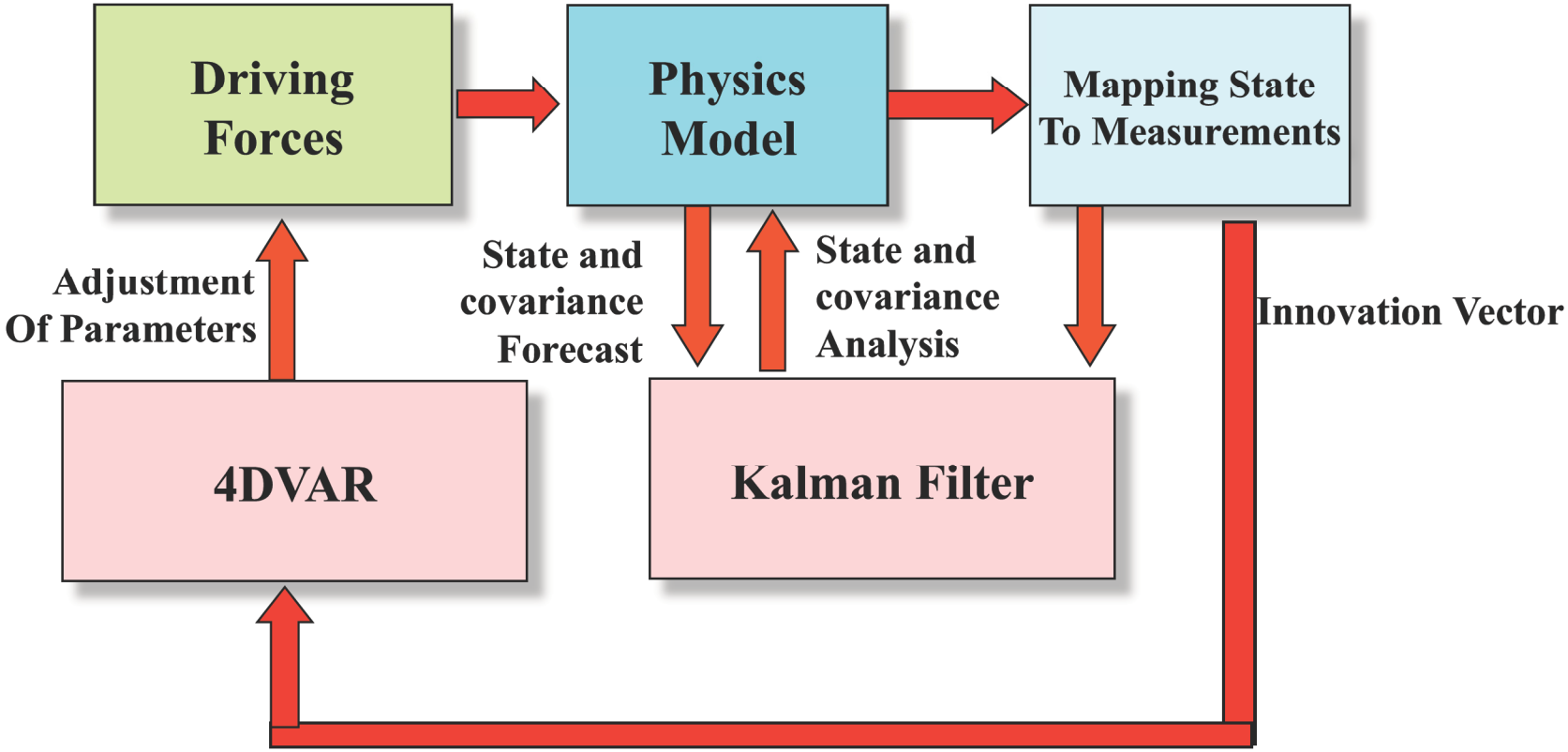
Introduction

- Global Assimilative Ionosphere Model (GAIM)
- Regional study of the Republic of South Africa (RSA) on November 21st, 2008
- Data sources
  - Ground based GPS measurements
  - Space-based (COSMIC and C/NOFS)
- Comparison to ionosonde measurements in the RSA
- Other recent advances:
  - GAIM prediction accuracies
  - Nested grid capabilities
  - Real-time GAIM assimilations
  - Ionospheric TEC perturbation imaging
- Conclusions

Data Sources

- Ground-based GPS Data
  - High-precision TEC data from 200+ sites
  - 30-sec sampling
- Space-based ionospheric radio occultation data
  - COSMIC/FORMOSAT-3 data (10-sec cadence)
  - CNOFS data (10-sec cadence)
- First time assimilation of COSMIC and C/NOFS has been performed

Global Assimilative Ionospheric Model
Data Assimilation Process

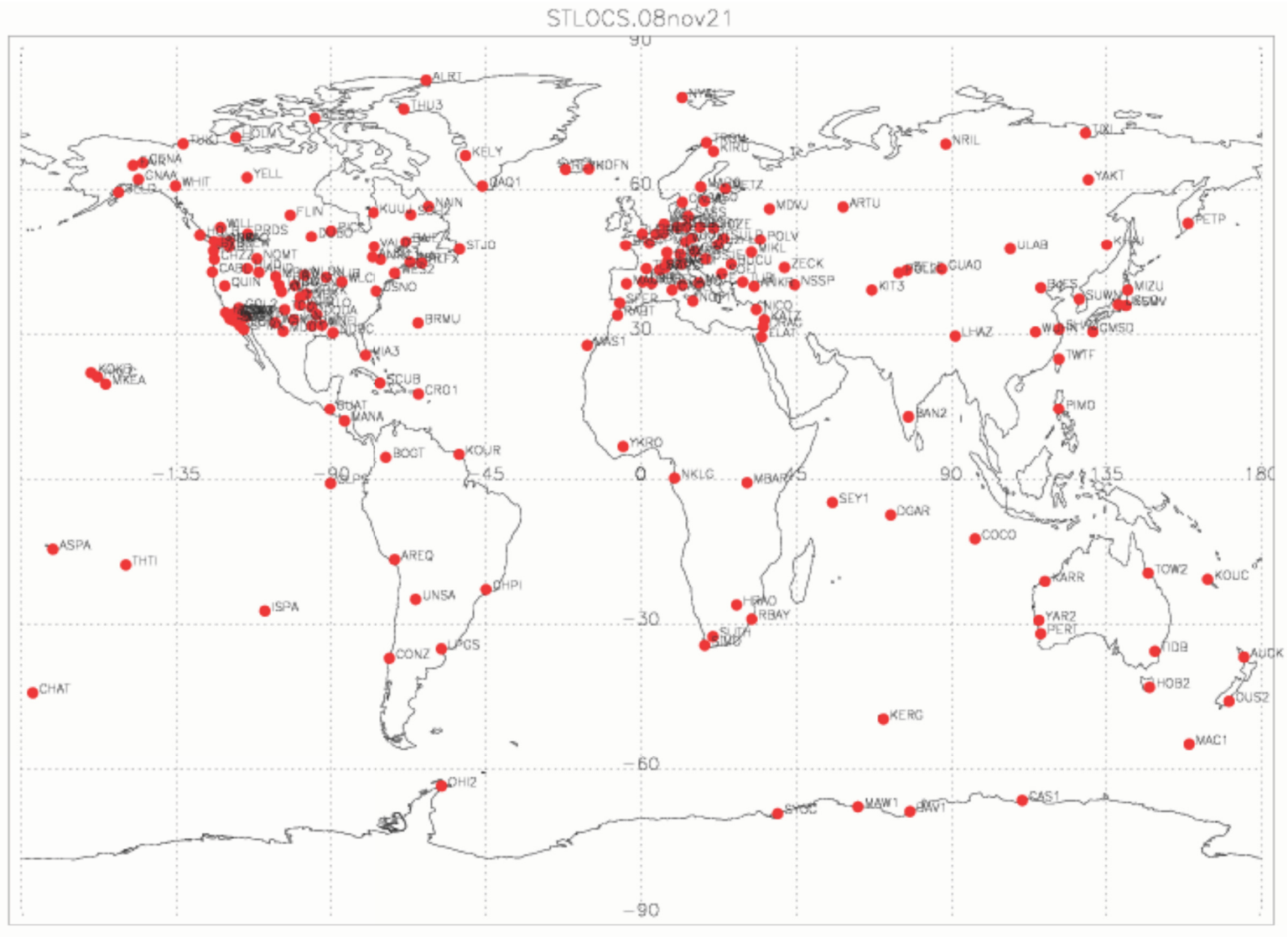


- 4-Dimensional Variational Approach
  - Minimization of cost function by estimating driving parameters
  - Non-linear least-square minimization
  - Adjoint method to efficiently compute the gradient of cost function
  - Parameterization of model "drivers"
- Kalman Filter
  - Recursive Filtering
  -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

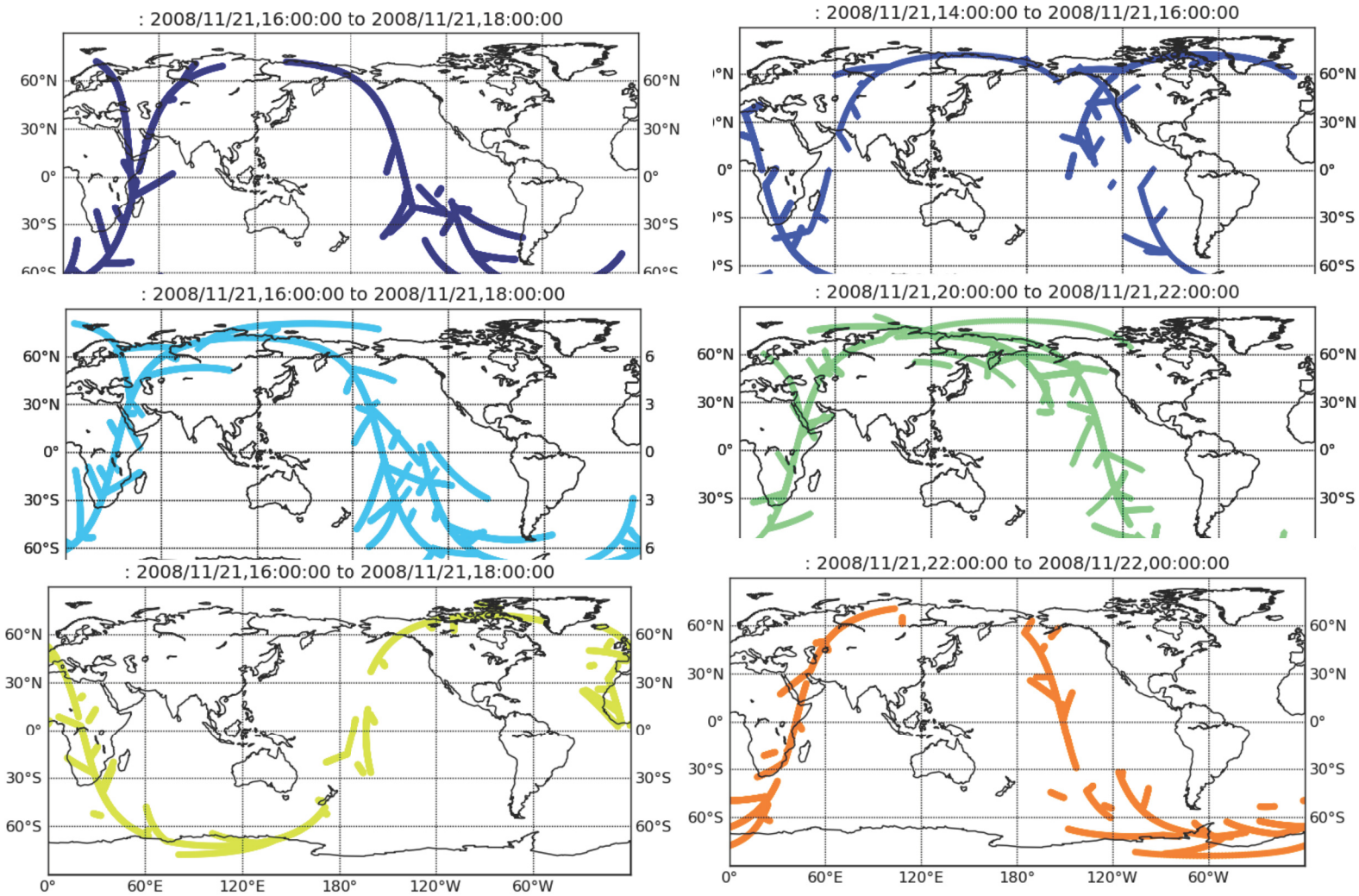
    Optimal interpolation

    Band-Limited Kalman filter

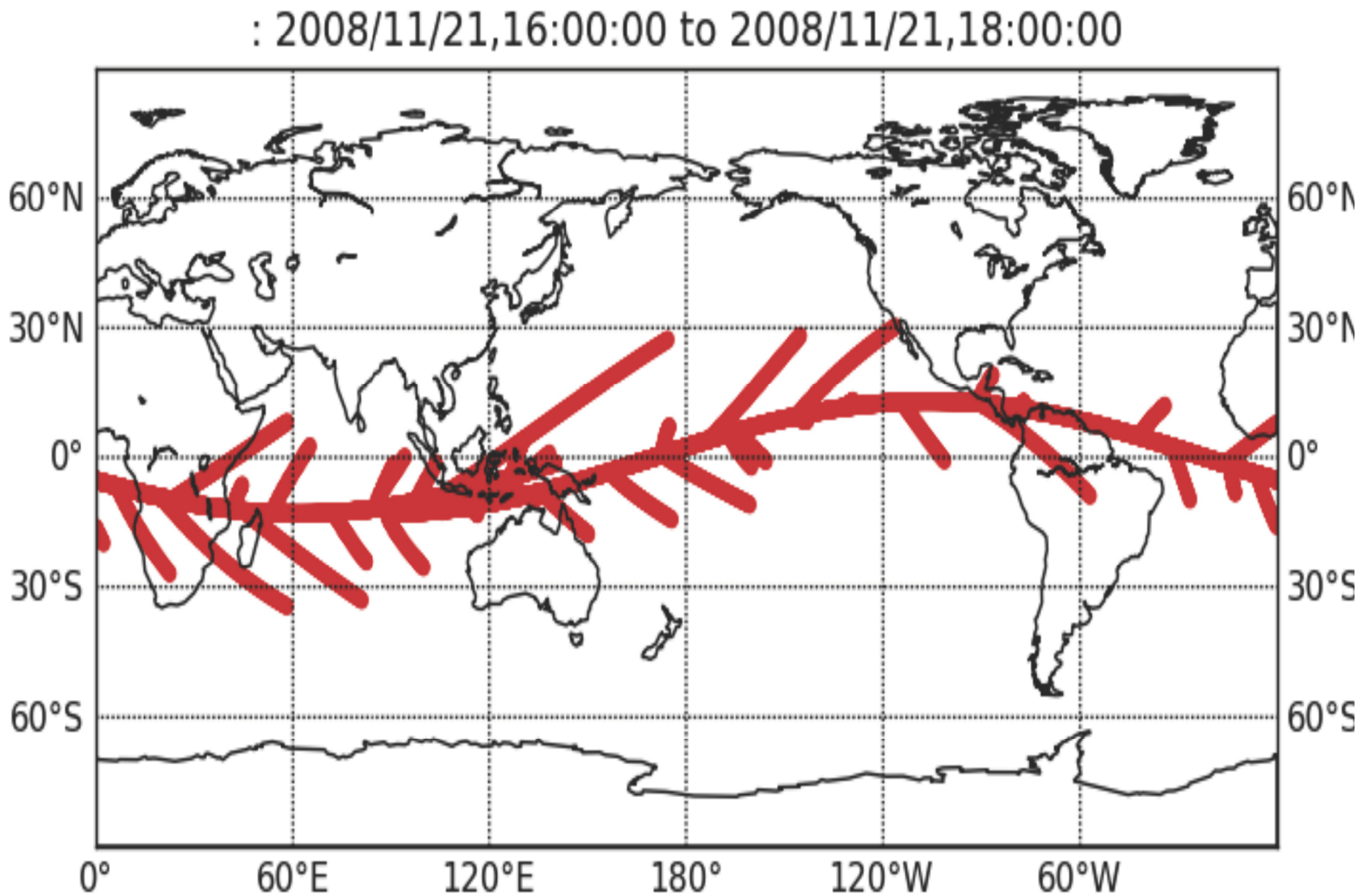
Ground Coverage for Nov 21, 2008



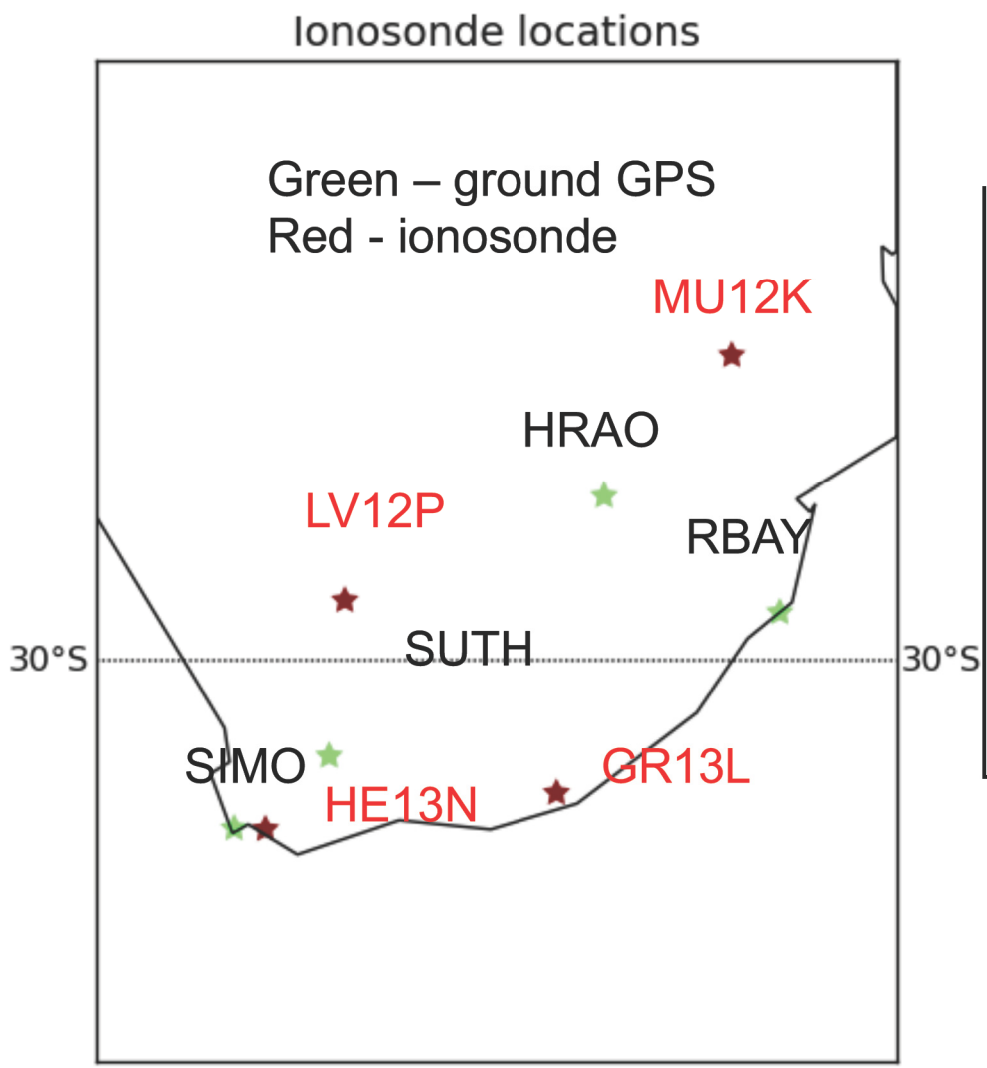
COSMIC Coverage on Nov 21, 2008

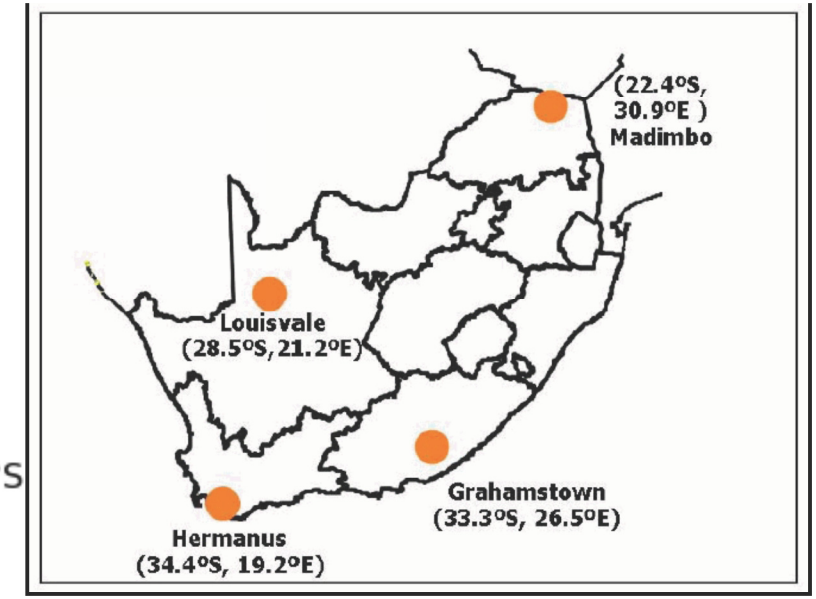


CNOFS Coverage on Nov 21, 2008



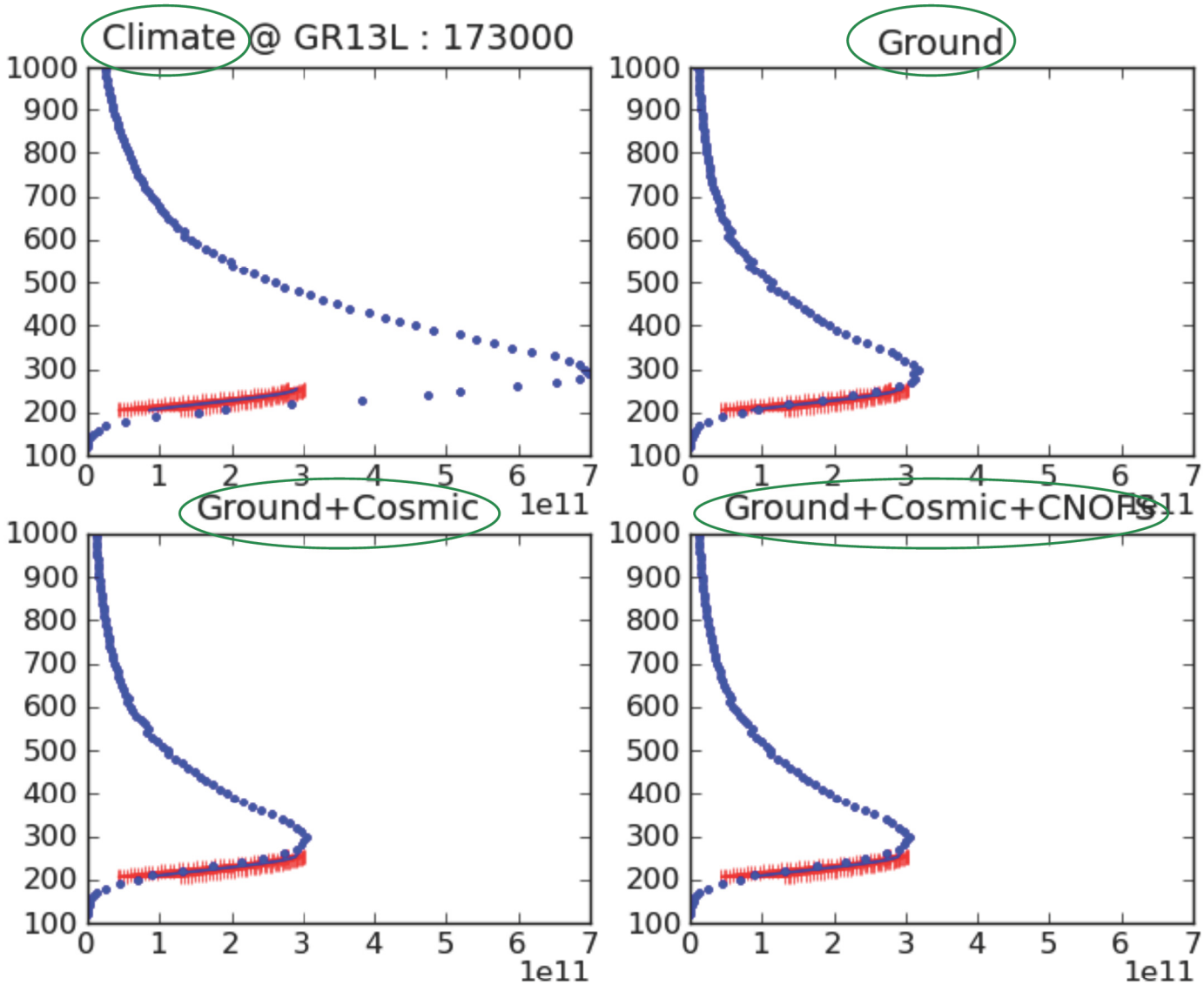
Ionosonde Locations in RSA



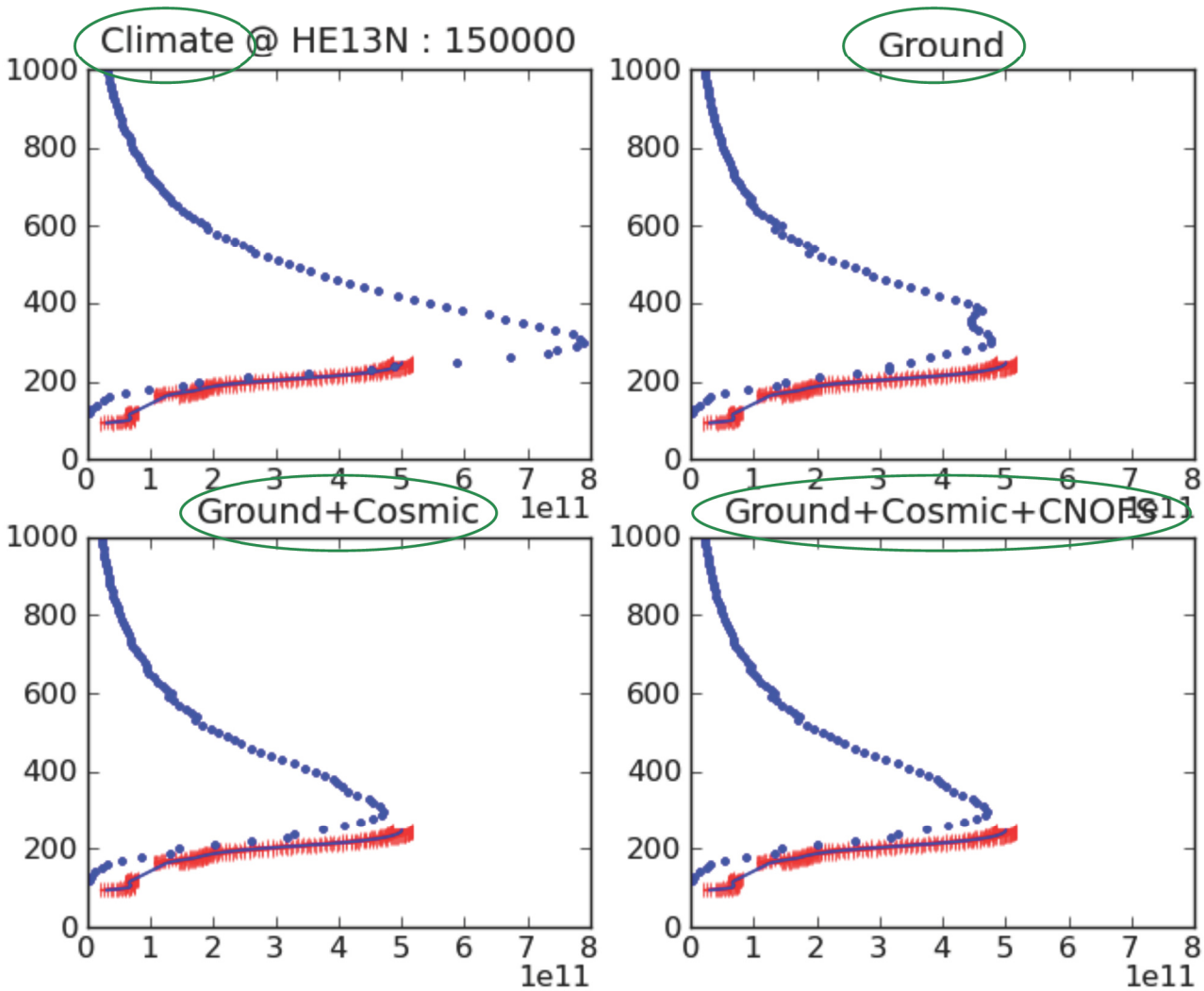


Courtesy of L. McNamara

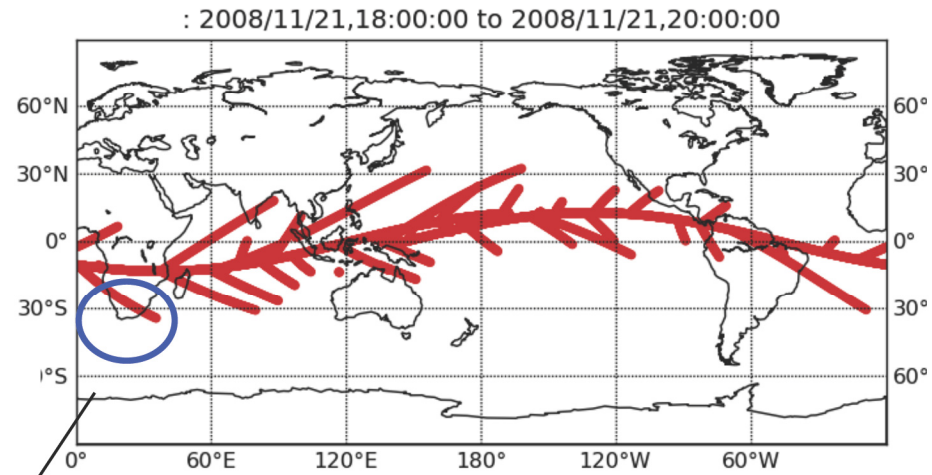
Profile Examples – COSMIC Impact

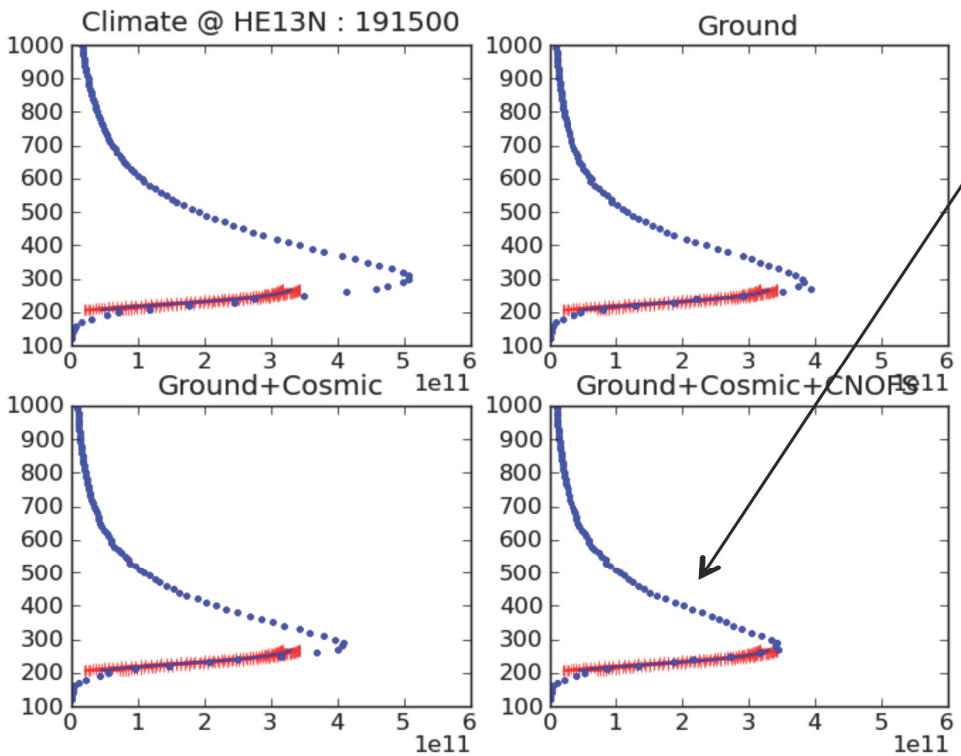


Profile Examples – COSMIC Impact

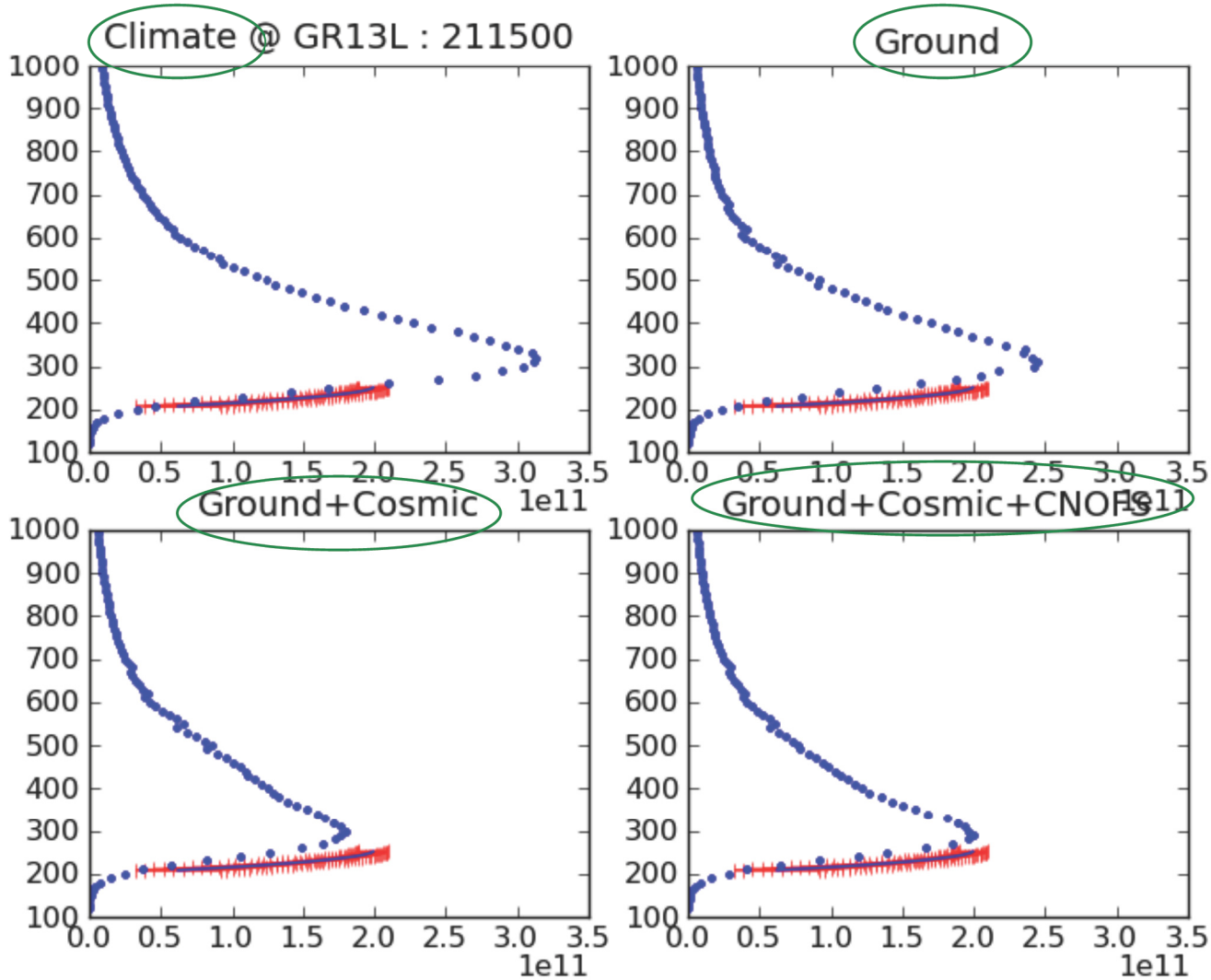


Profile Examples – C/NOFS Impact



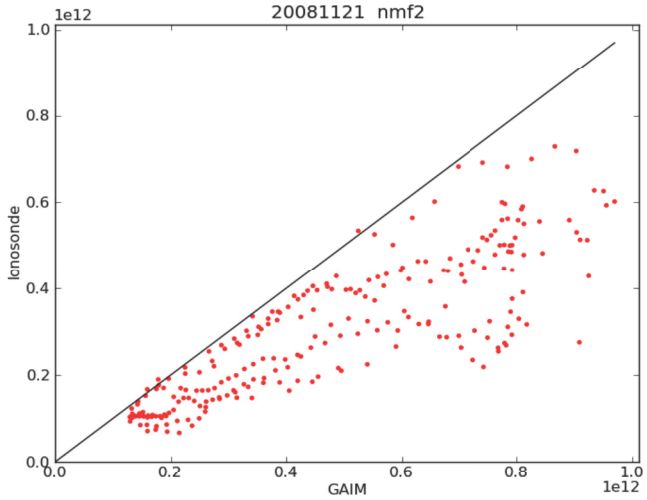


Profile Examples – C/NOFS Impact

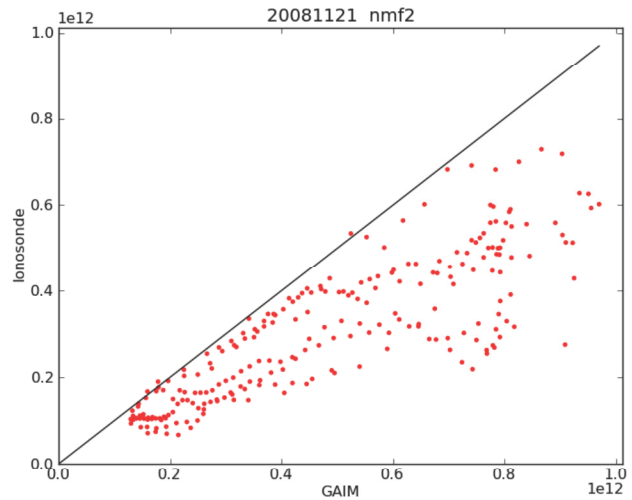


Nmf2 (e/m^3) Statistics for Nov 21, 2011

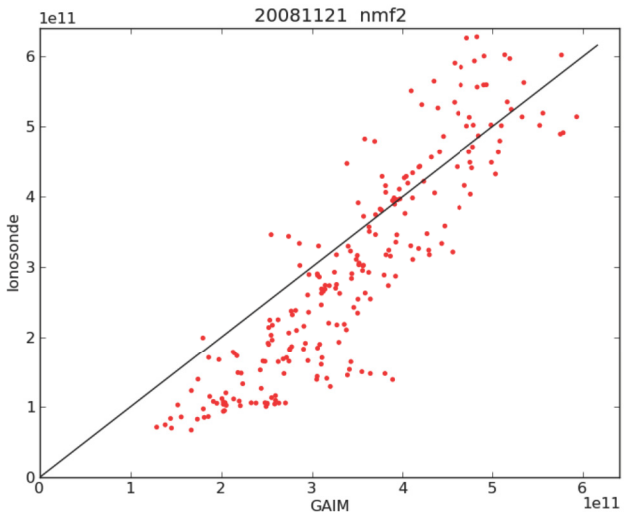
Climate



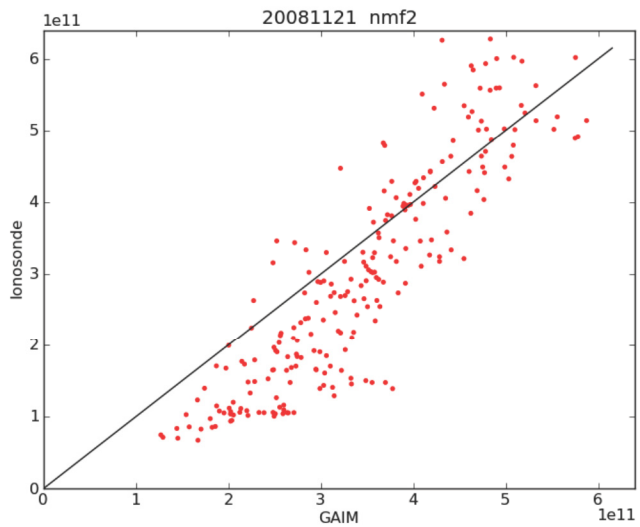
Ground



Ground + Cosmic

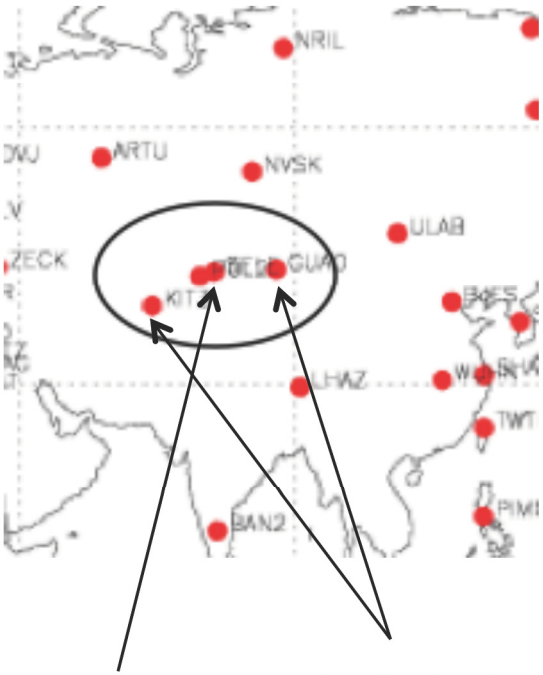


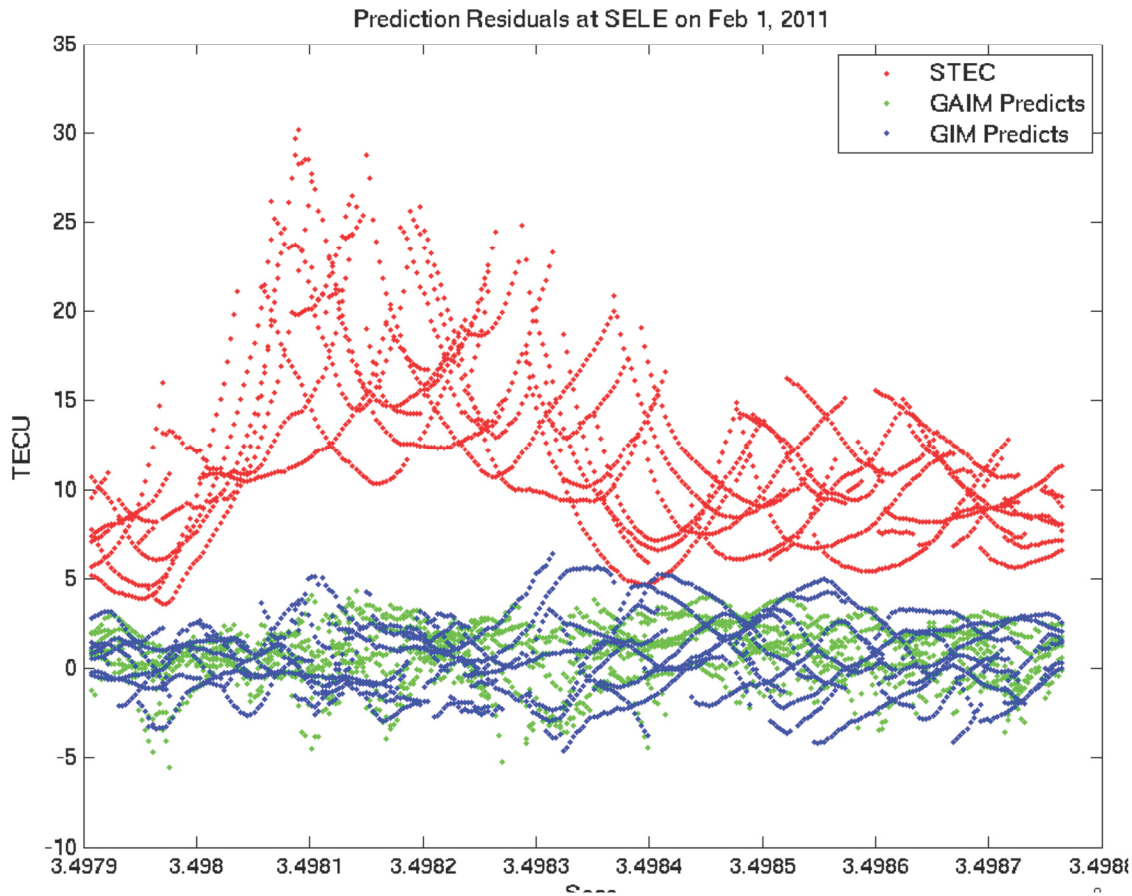
Ground+Cosmic+CNOFS



Slopes:
Climate: 0.565
Ground: 1.387
G+C: 1.352
G+C2: 1.349

Recent GAIM Prediction Accuracy for SELE on Feb 1, 2011

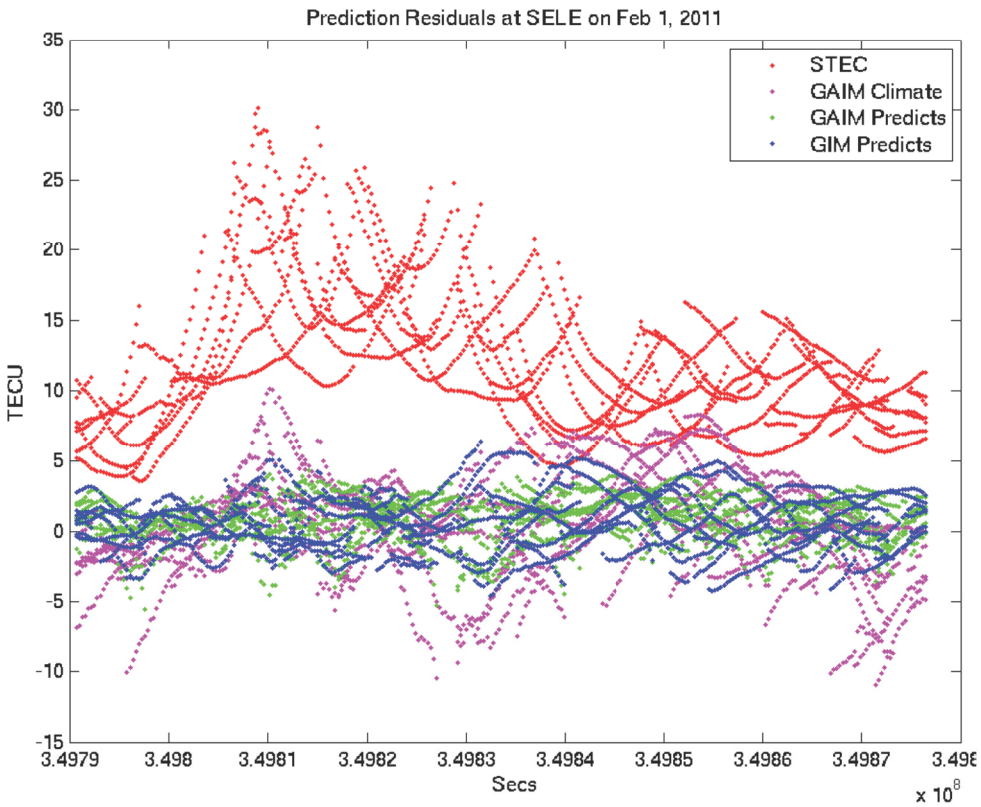


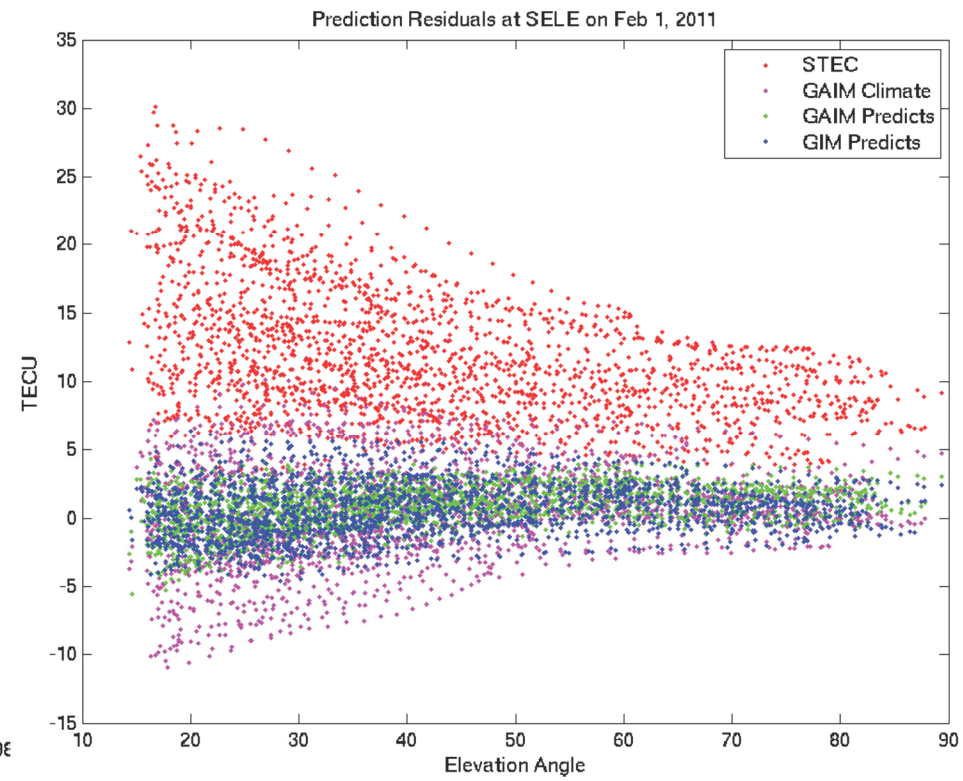


GAIM – ground-GPS only assimilation

Predictions:
GIM RMS = 1.94 TECU
GAIM RMS = 1.71 TECU

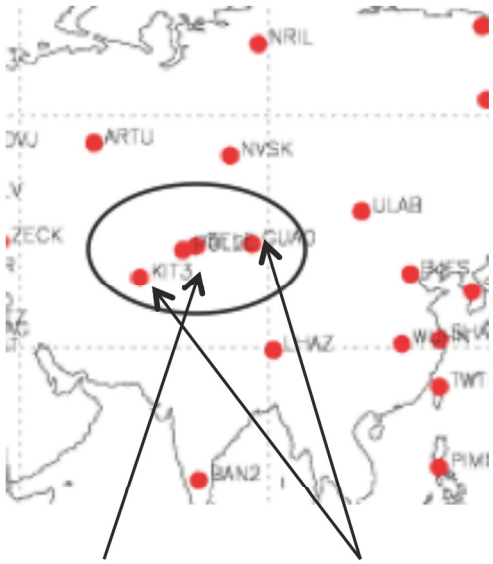
Recent GAIM Prediction Accuracy for SELE on Feb 1, 2011

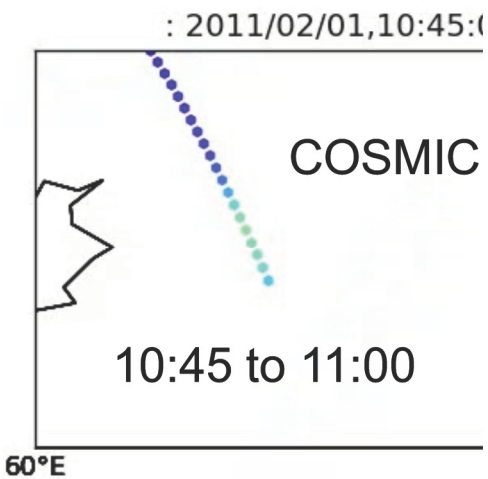


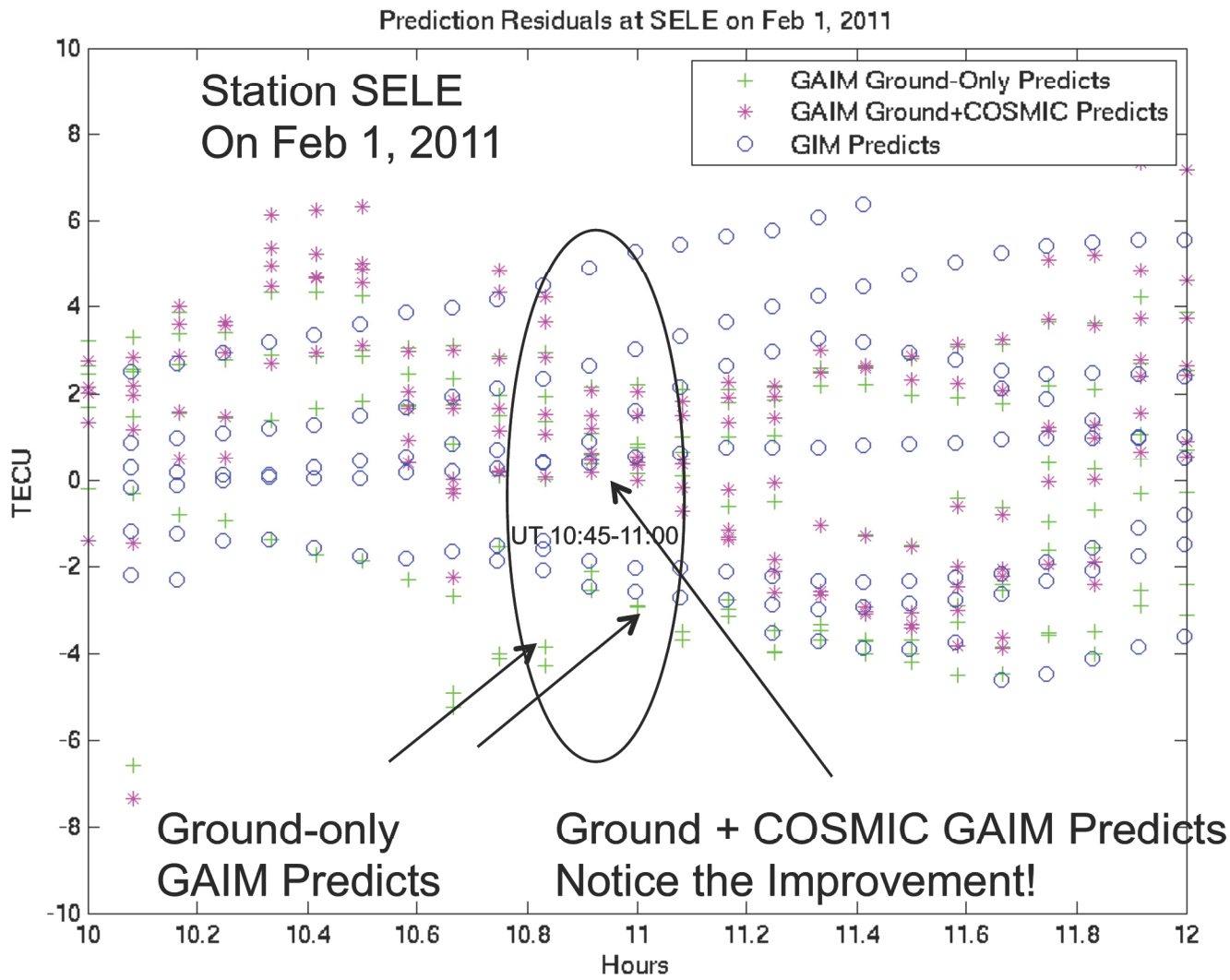


Predictions:
Climate RMS = 3.41 TECU
GIM RMS = 1.94 TECU
GAIM RMS = 1.71 TECU

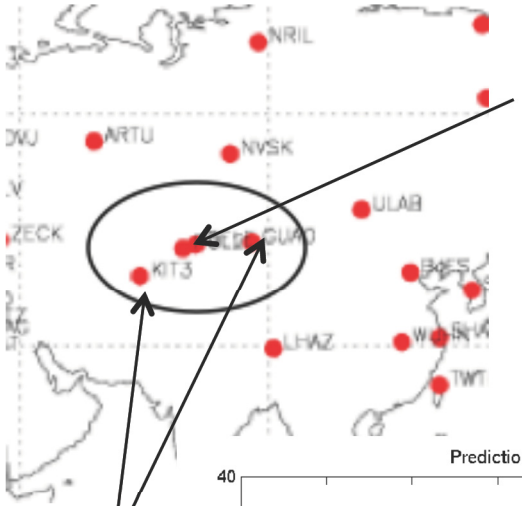
GAIM Prediction Accuracy Using Ground and COSMIC Assimilation on Feb 1, 2011







GIM, GAIM, Predictions for KIT3 on Feb 1, 2011



Included

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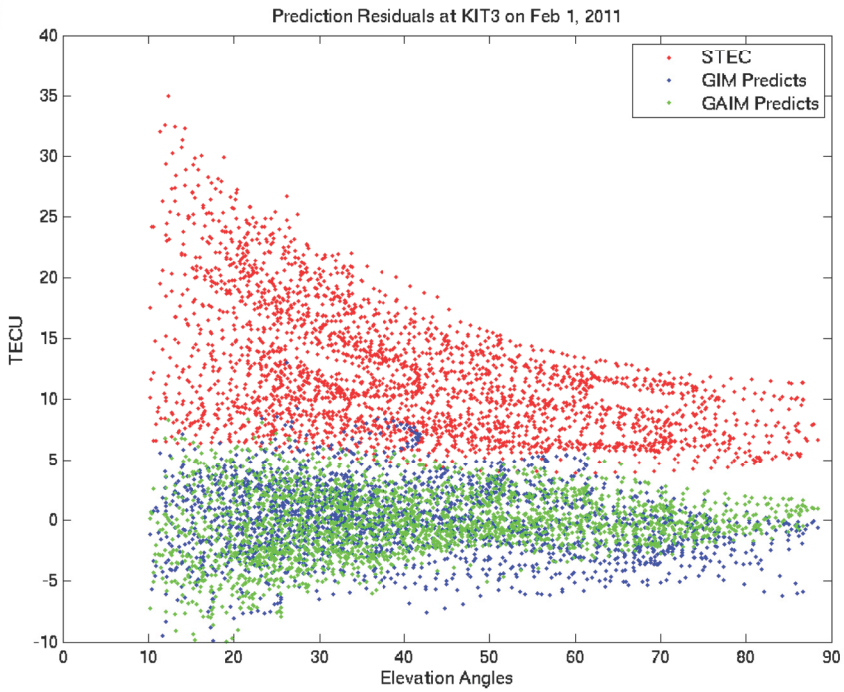
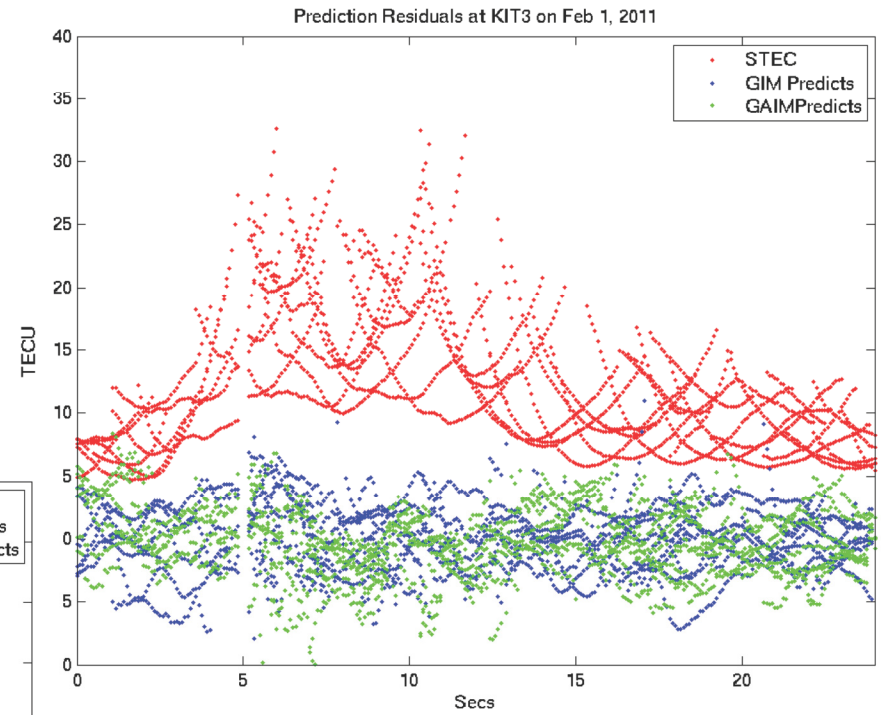
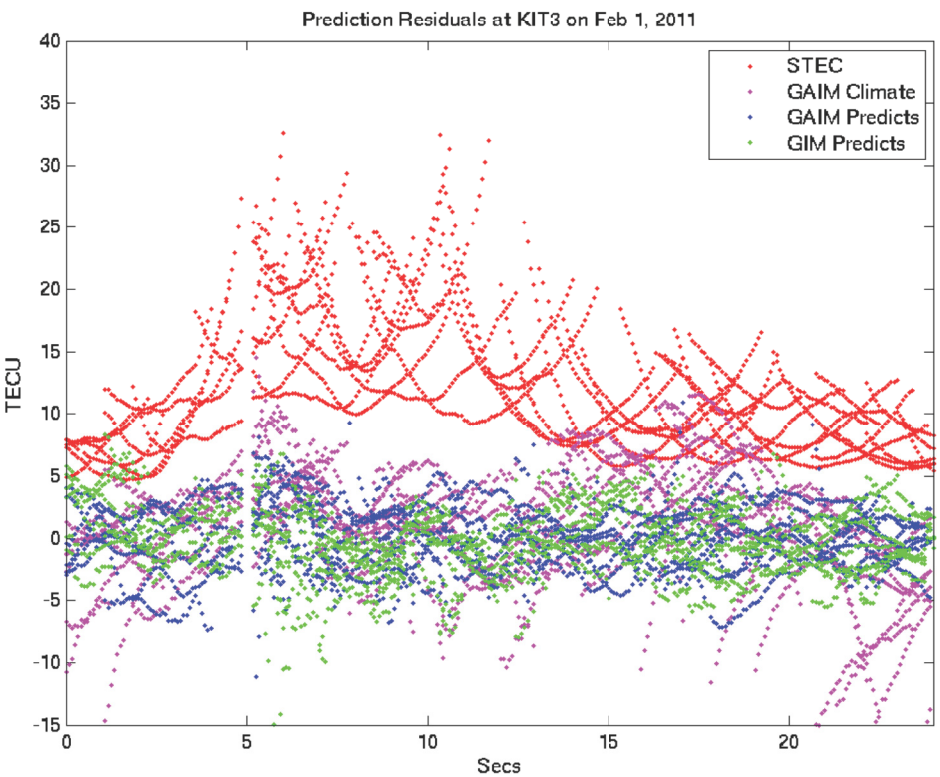
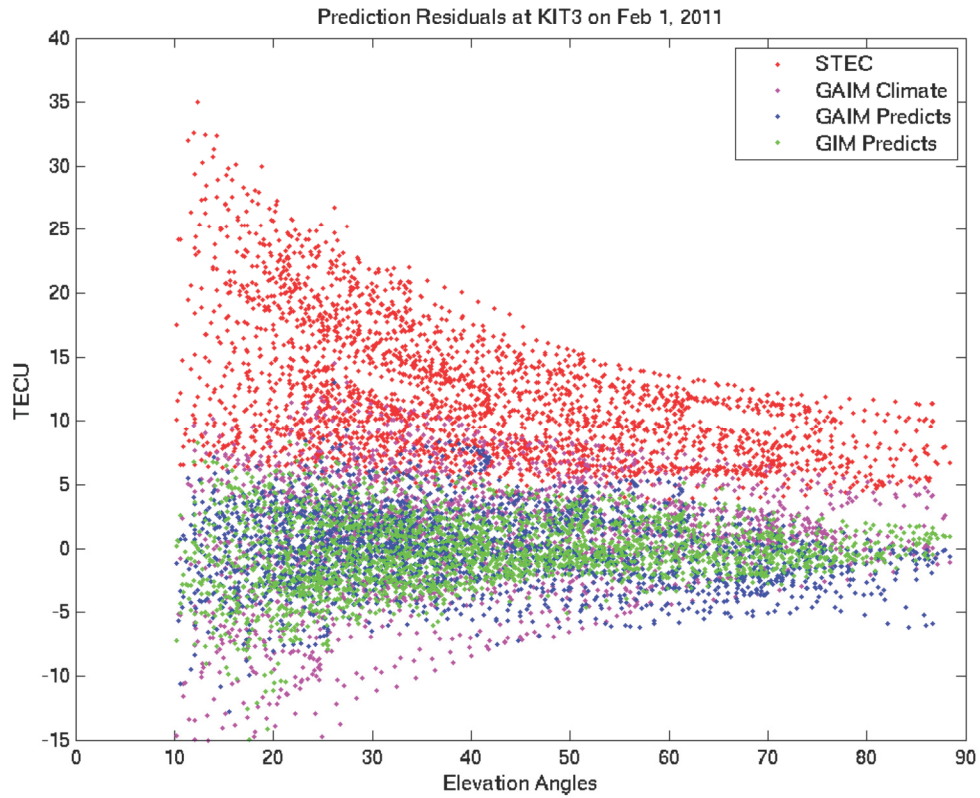




Predictions:
GIM RMS = 2.53 TECU
GAIM RMS = 2.71 TECU

Climate, GIM, GAIM Predicts for KIT3 on Feb 1, 2011



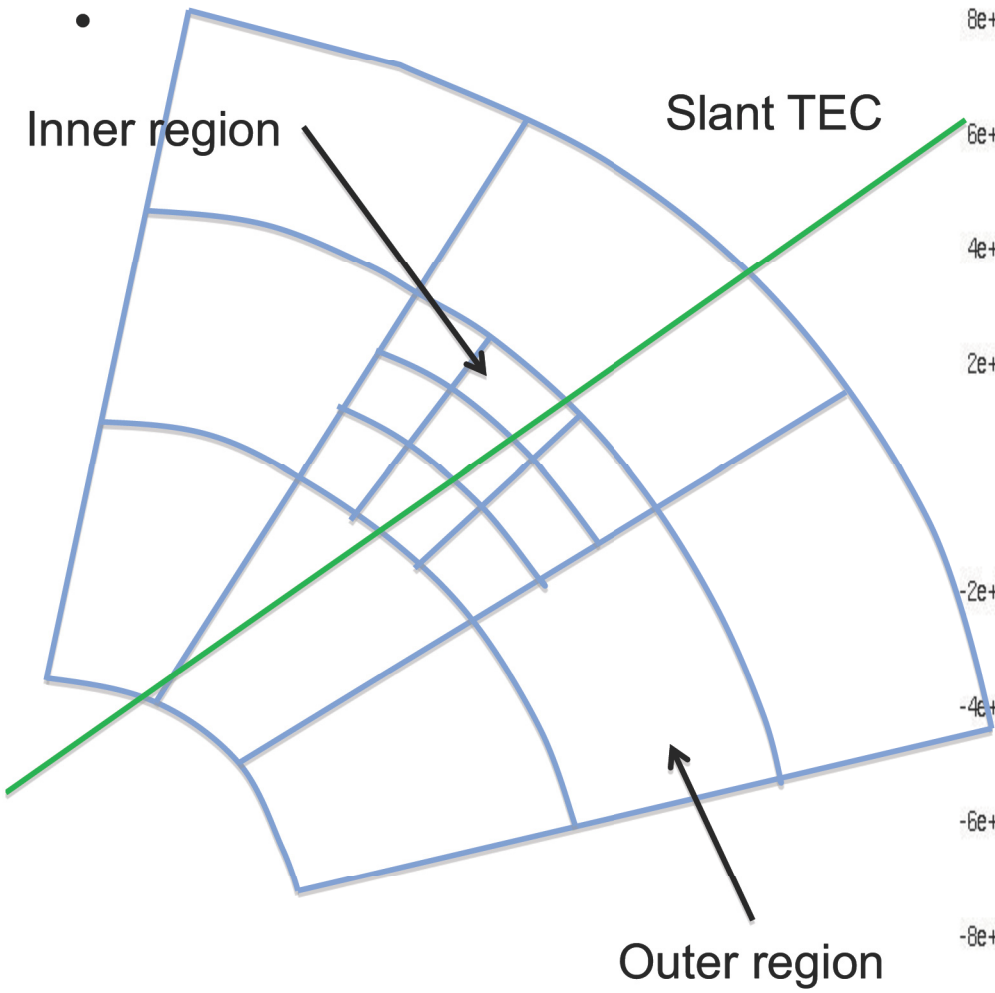


Predictions:
Climate RMS = 4.25 TECU
GIM RMS = 2.53 TECU
GAIM RMS = 2.71 TECU

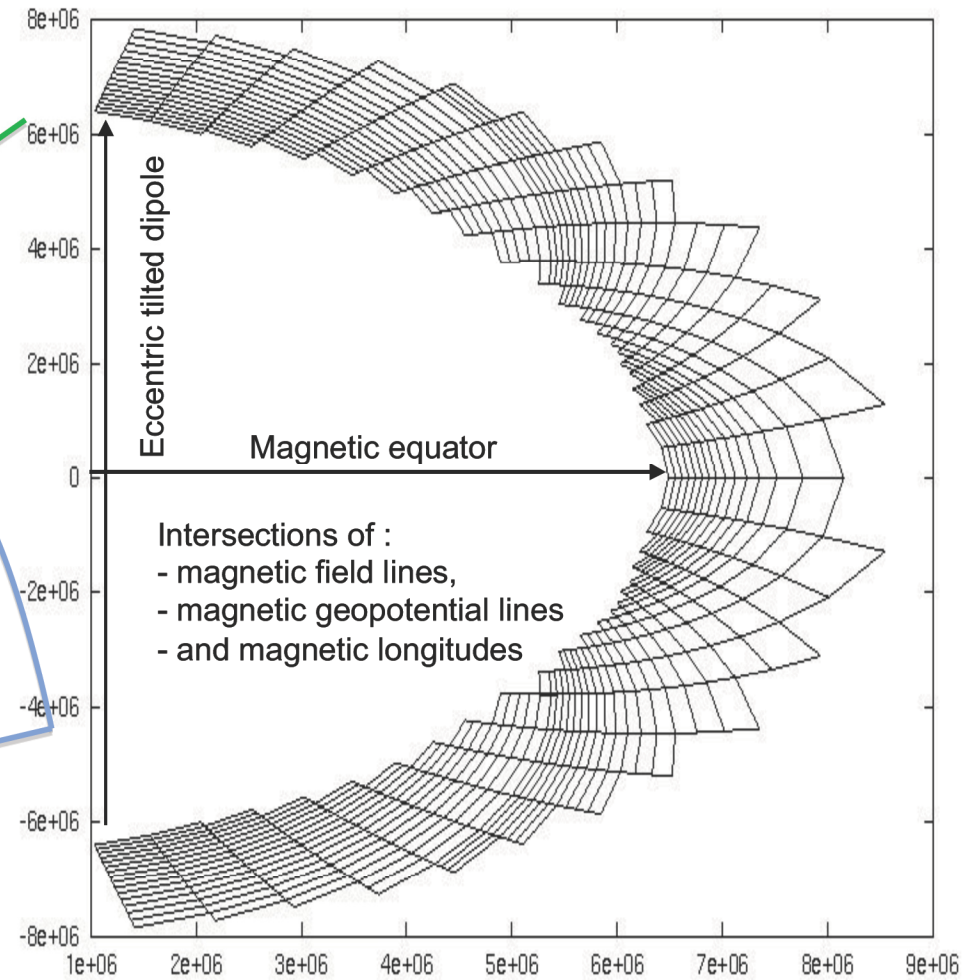
Nested Grid (NGAIM)

- NGAIM grid resolutions:
  - Global grid resolution: 2.5 x 10 degrees lat/lon, 40 km altitude
  - Nested grid resolution: 1 x 2 degrees lat/lon, 20 km altitude
- Forward physics models are coupled at boundary of nested region
  - Global grid provides density and flux on nested boundary using ghost cells
  - Two forward physics models, two Kalman filter runs
  - Both density grids used to properly model TEC links
- Show results from two periods:
  - Halloween storm (Oct 29-31, 2003)
    - ~300 CORS stations in US
  - Florida feature on Oct 31, 2003
    - 200 GPS stations globally, plus ~40 CORS stations near/in Florida
- Advantages:
  - Near real-time execution
  - Can run multiple nested regions at one time (on separate CPUs)

GAIM and Nested GAIM Grids



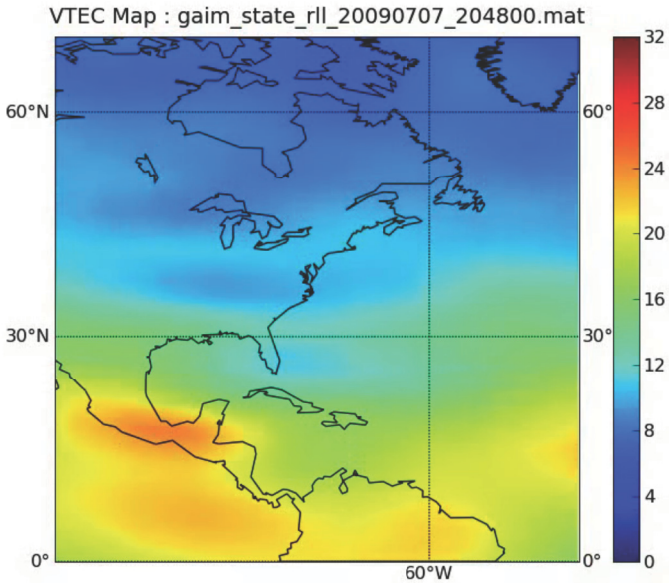
GAIM Nested Grid

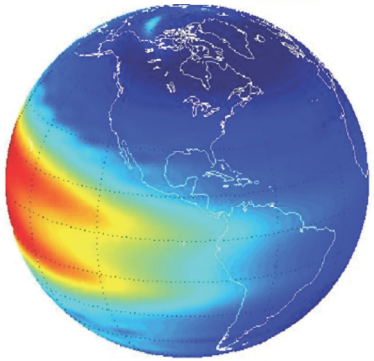


Regular GAIM Grid

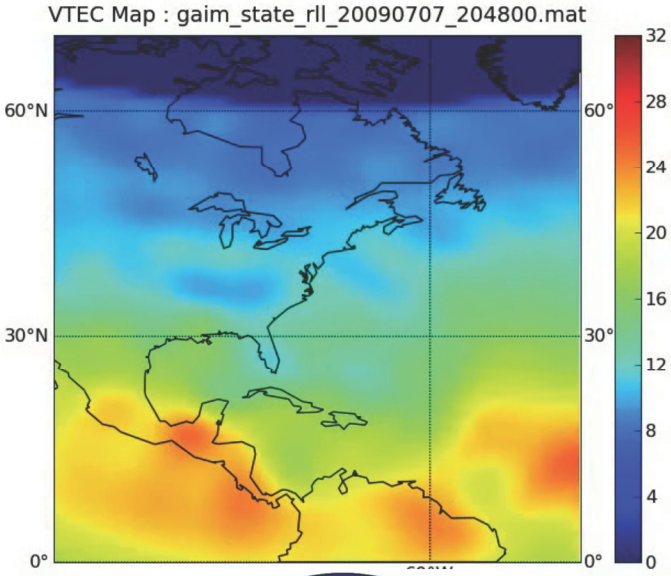
Nested Grid Capability (NGAIM)

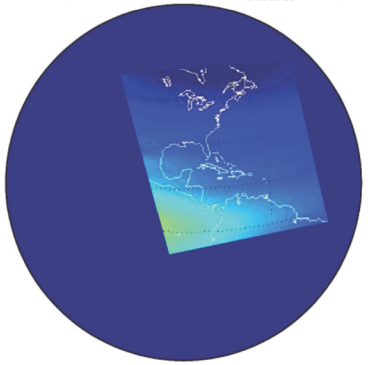
Global Model



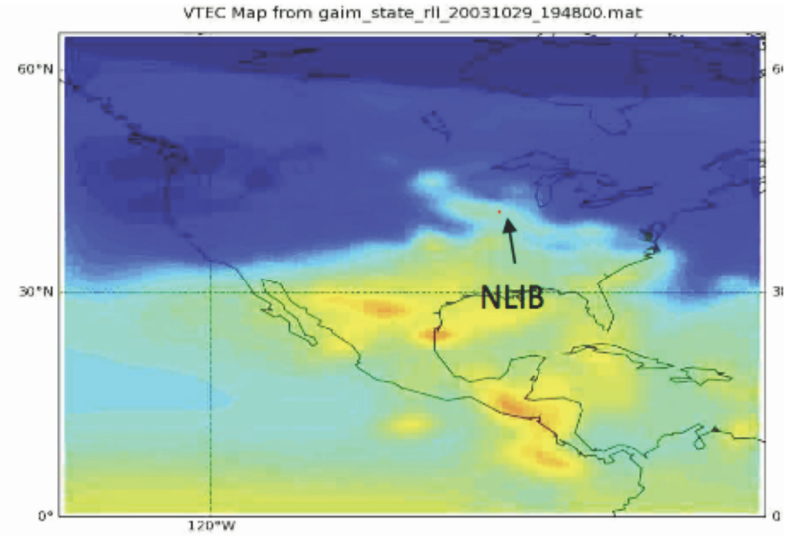


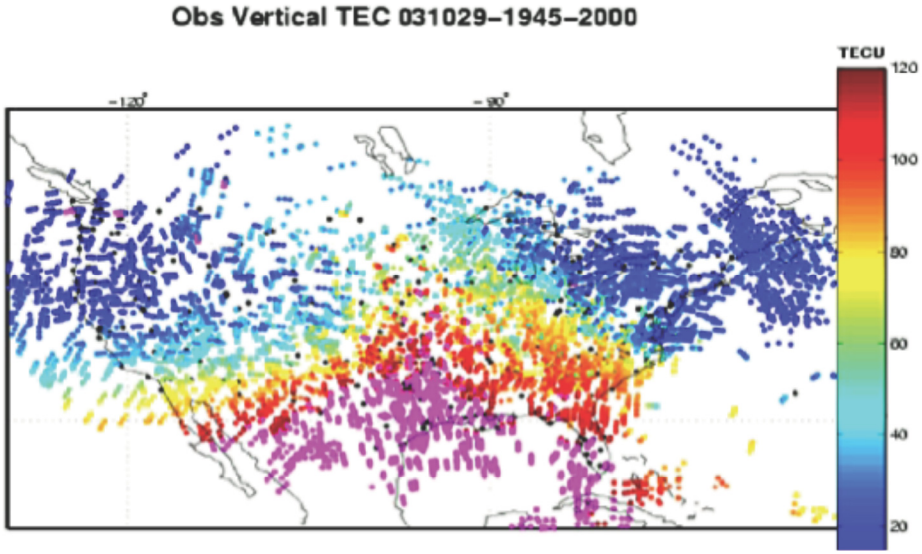
Nested Section

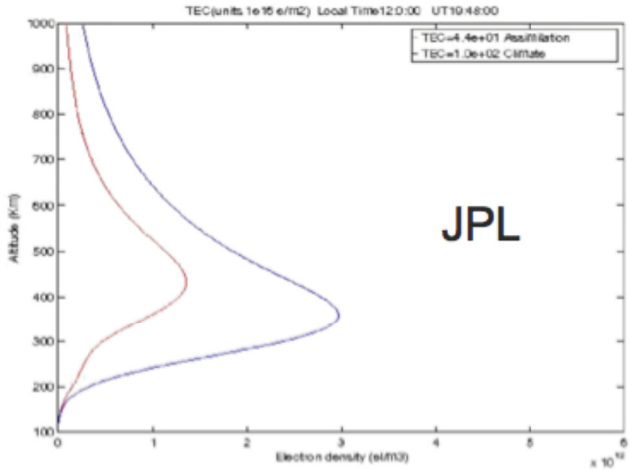


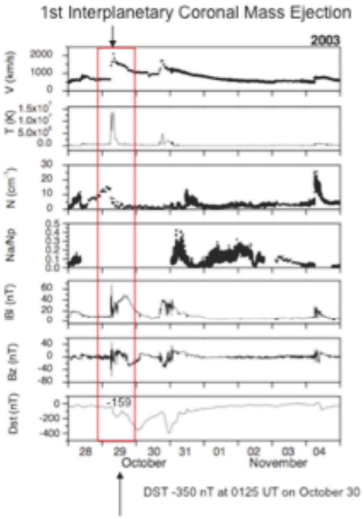


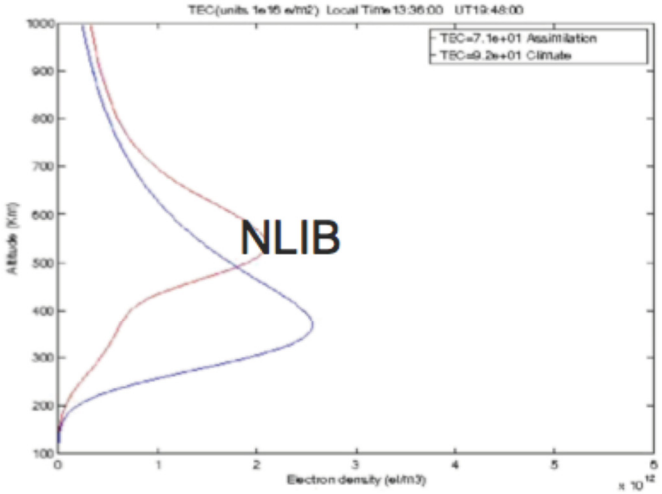
Storm Day: Oct 29, 2003, NGAIM and Truth Storm Features at NLIB





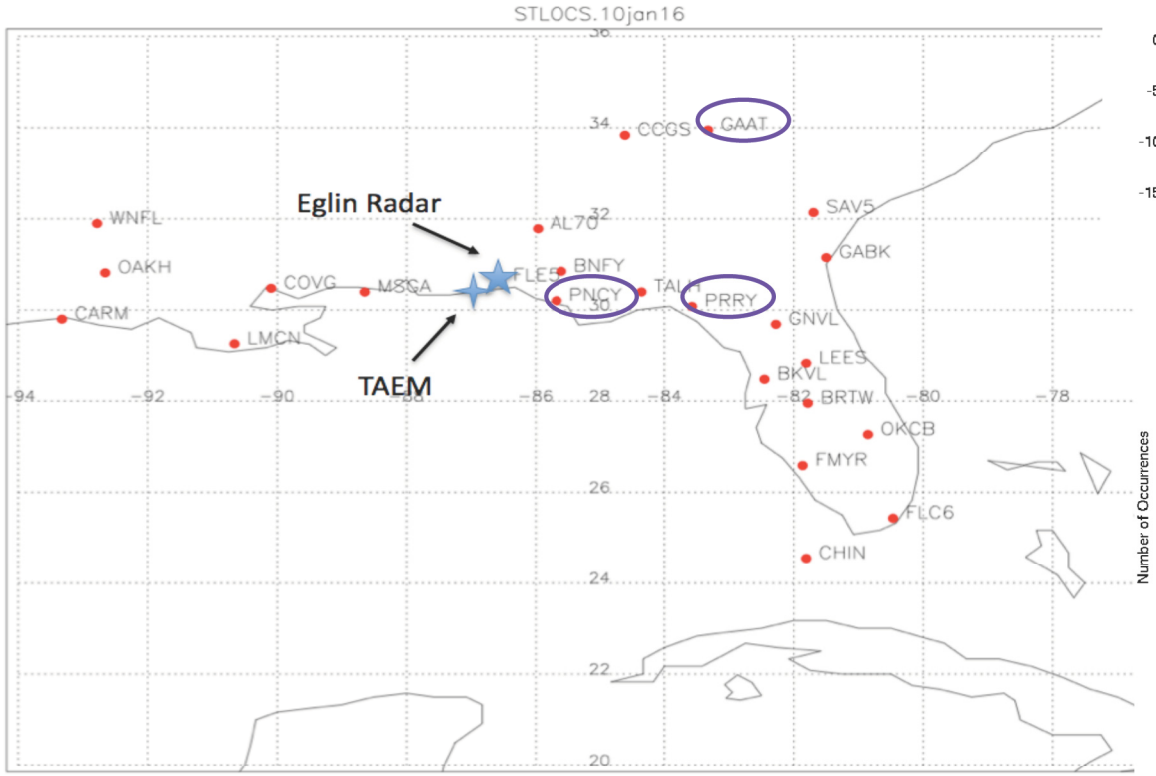


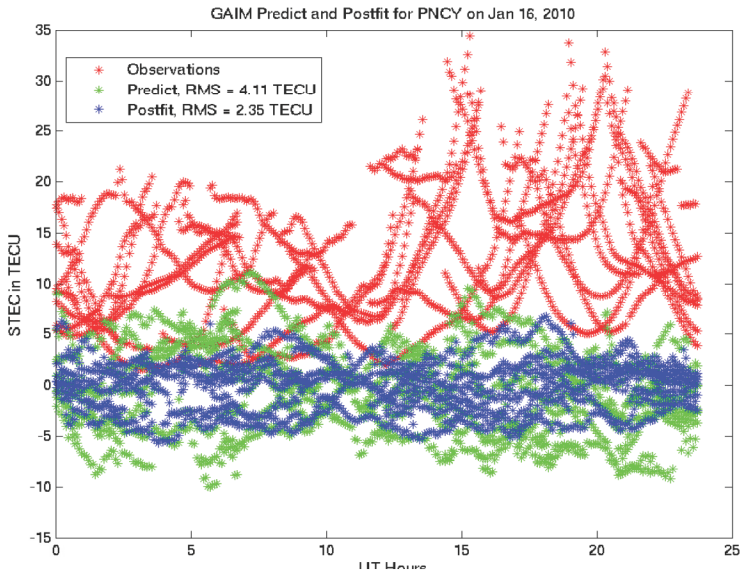


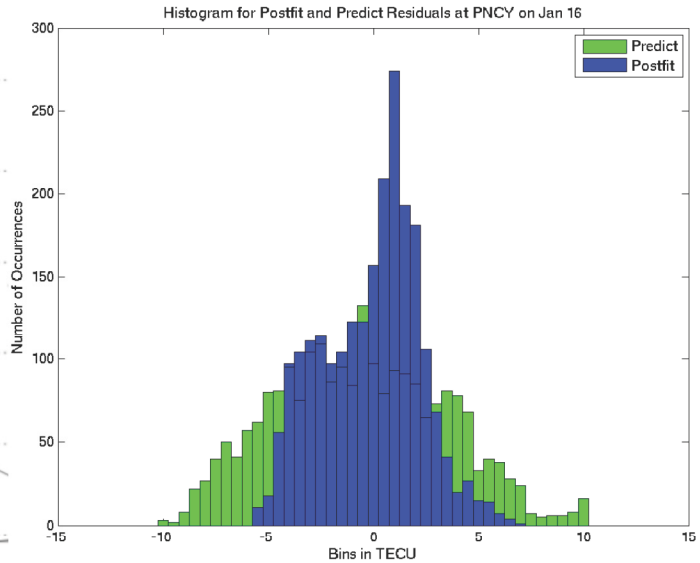


Nested GAIM Validation Near Eglin Radar

- NGAIM run with TAEM only, Jan 16, 2010
- Predict observed slant TEC for surrounding, CORS GPS sites
- Prediction RMS error of 3 – 4 TECU



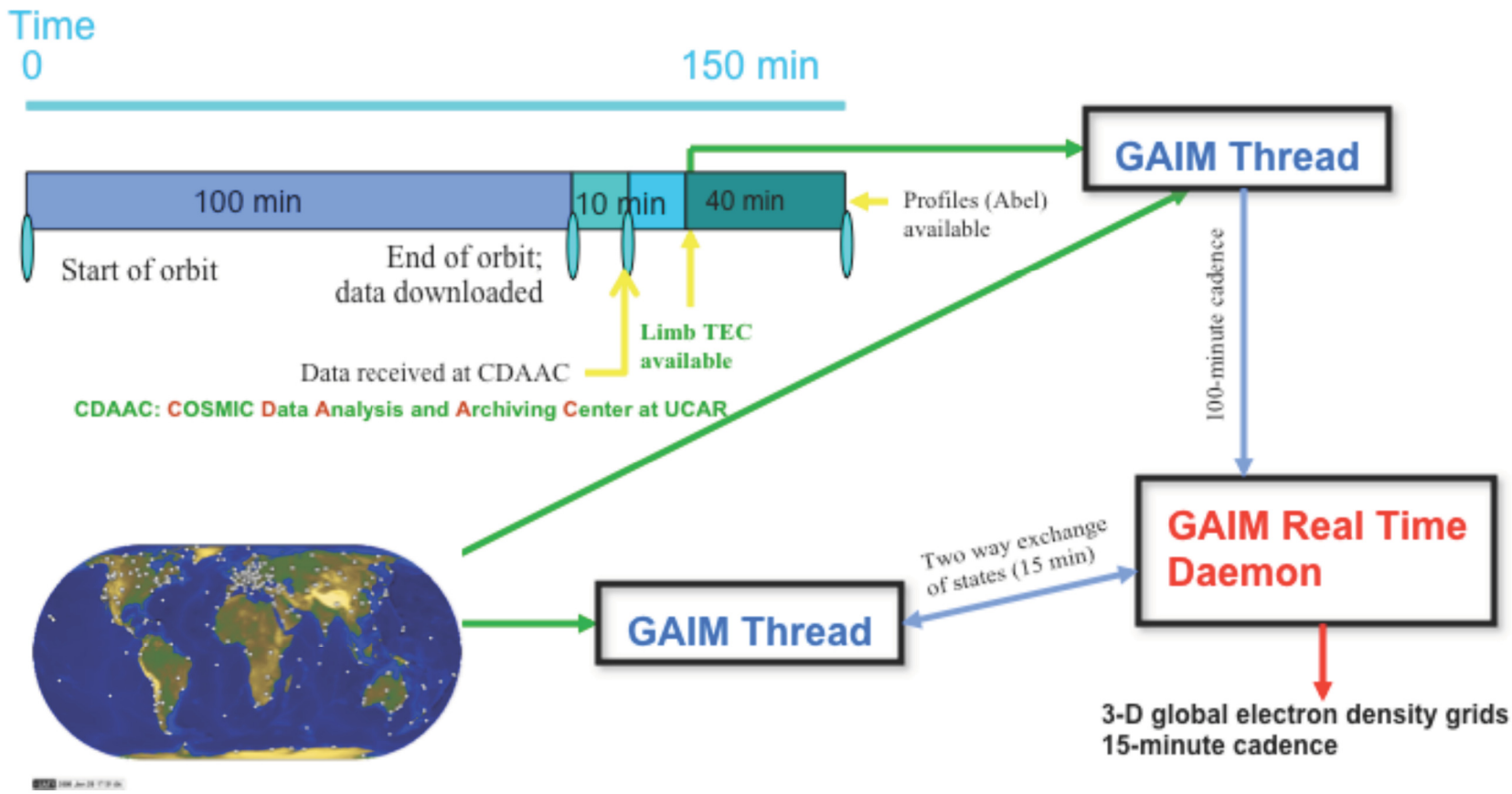




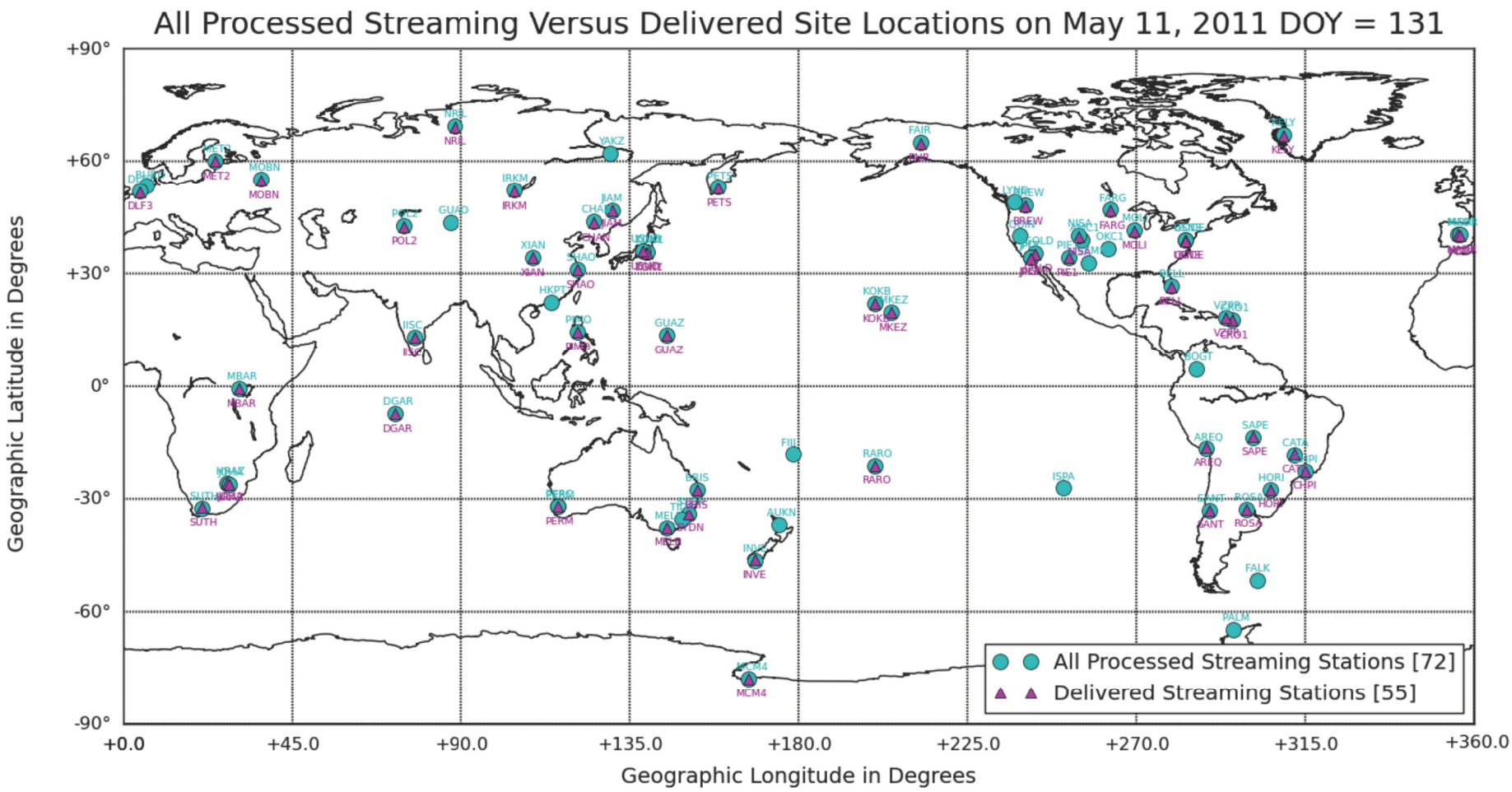
Real-Time GAIM: Assimilating Ground TEC and COSMIC

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

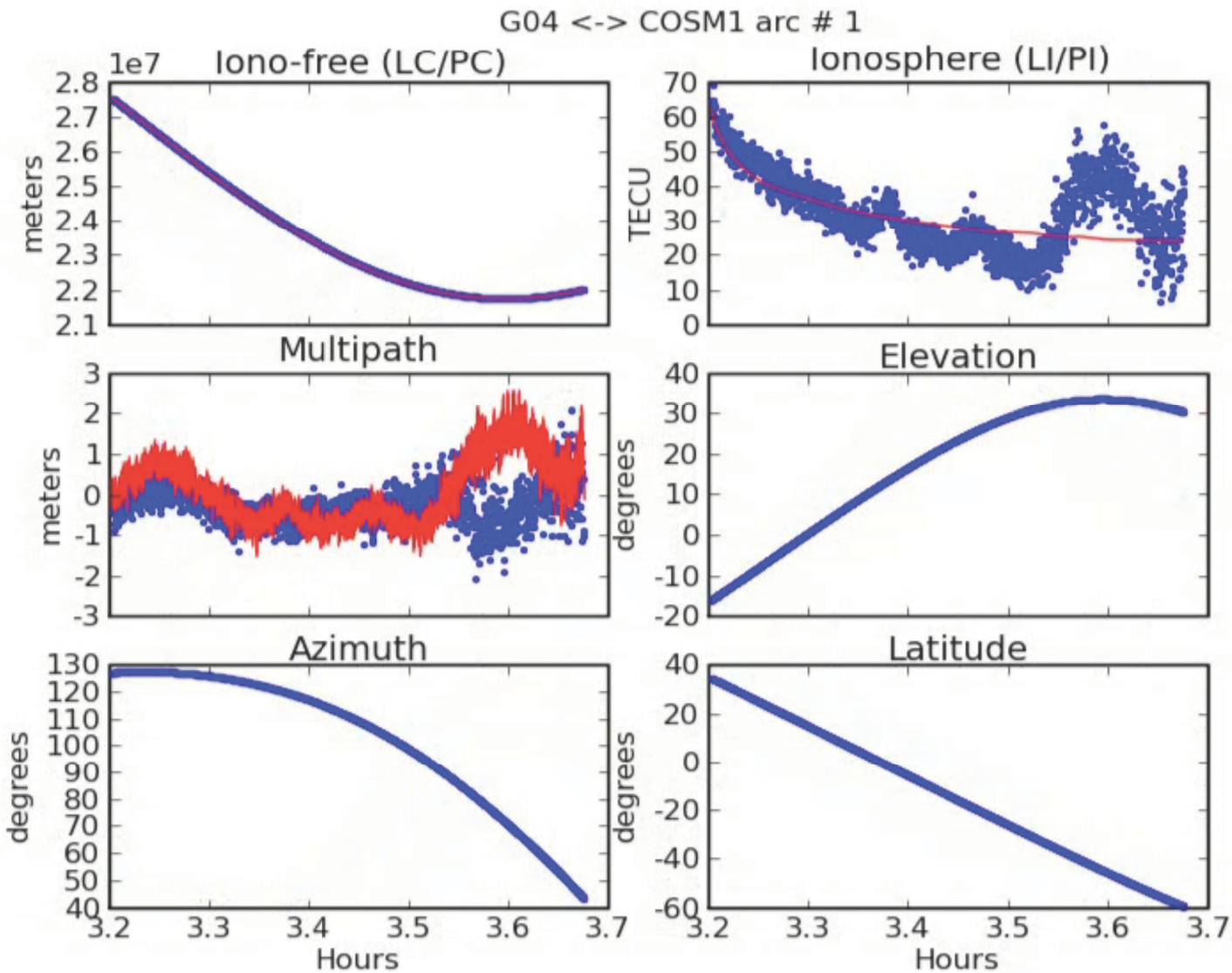
COSMIC data: 20 - 120 minutes latency



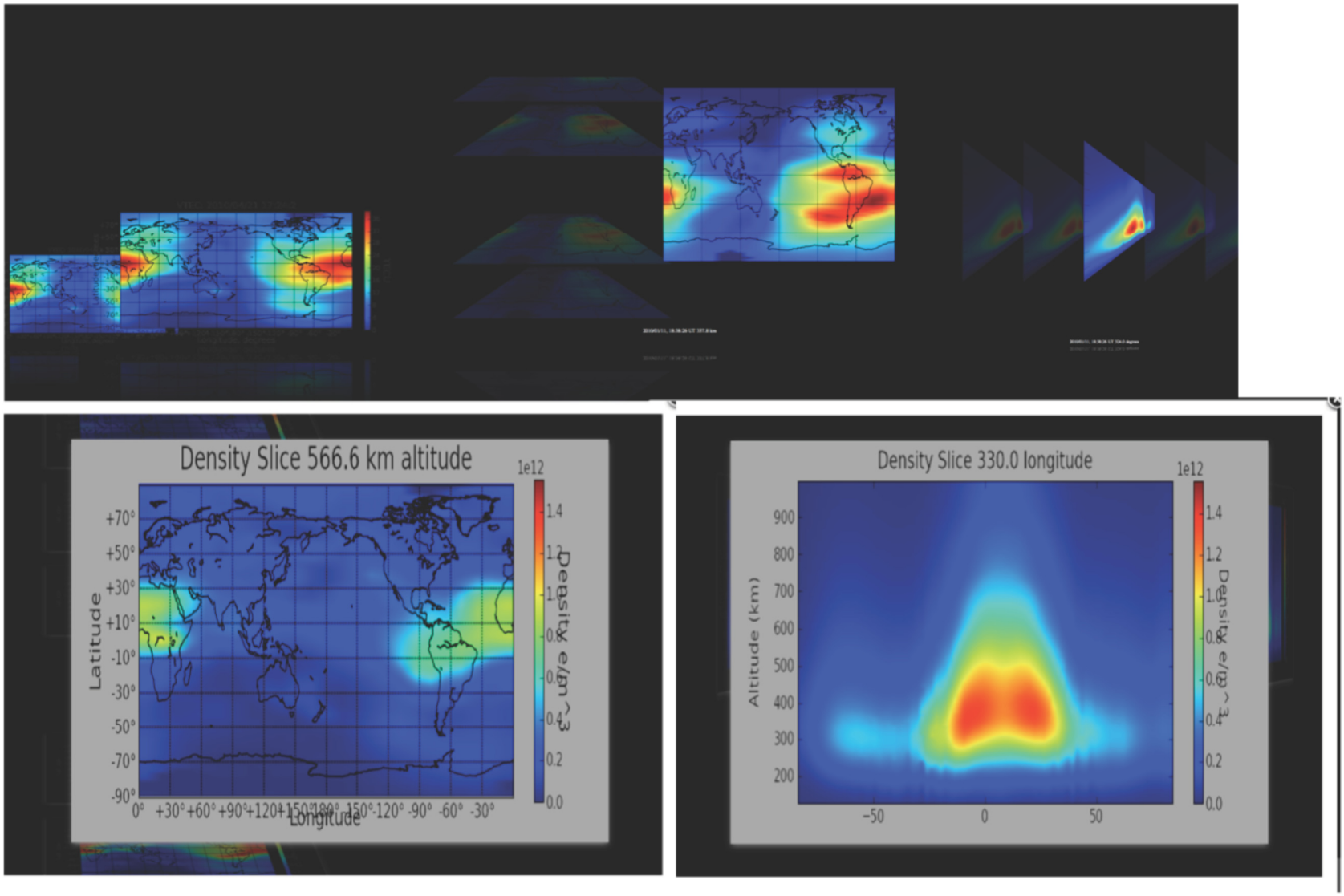
Stations Used for Real-Time GAIM



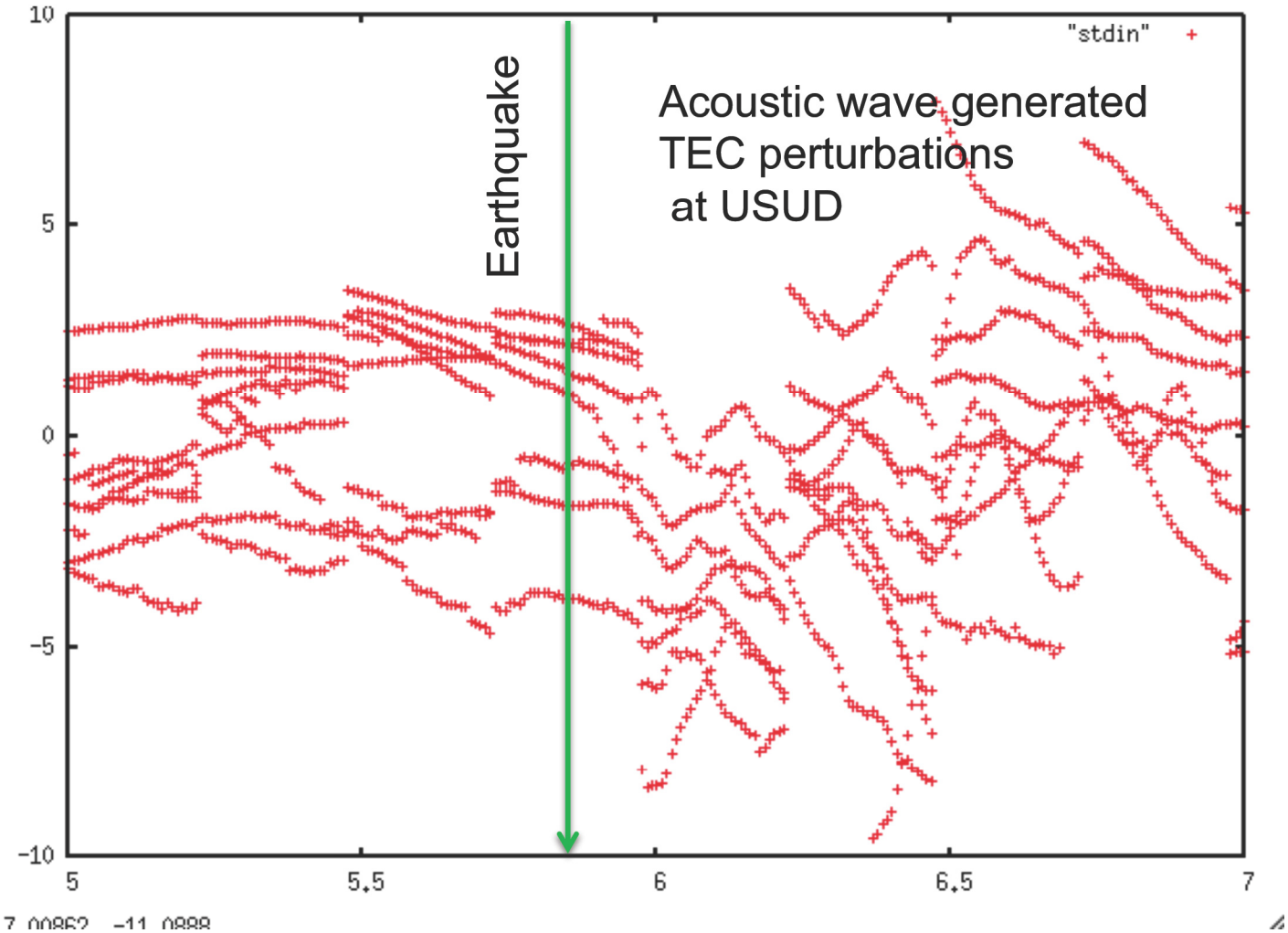
GAIM Real-Time System: Multipath Weighting



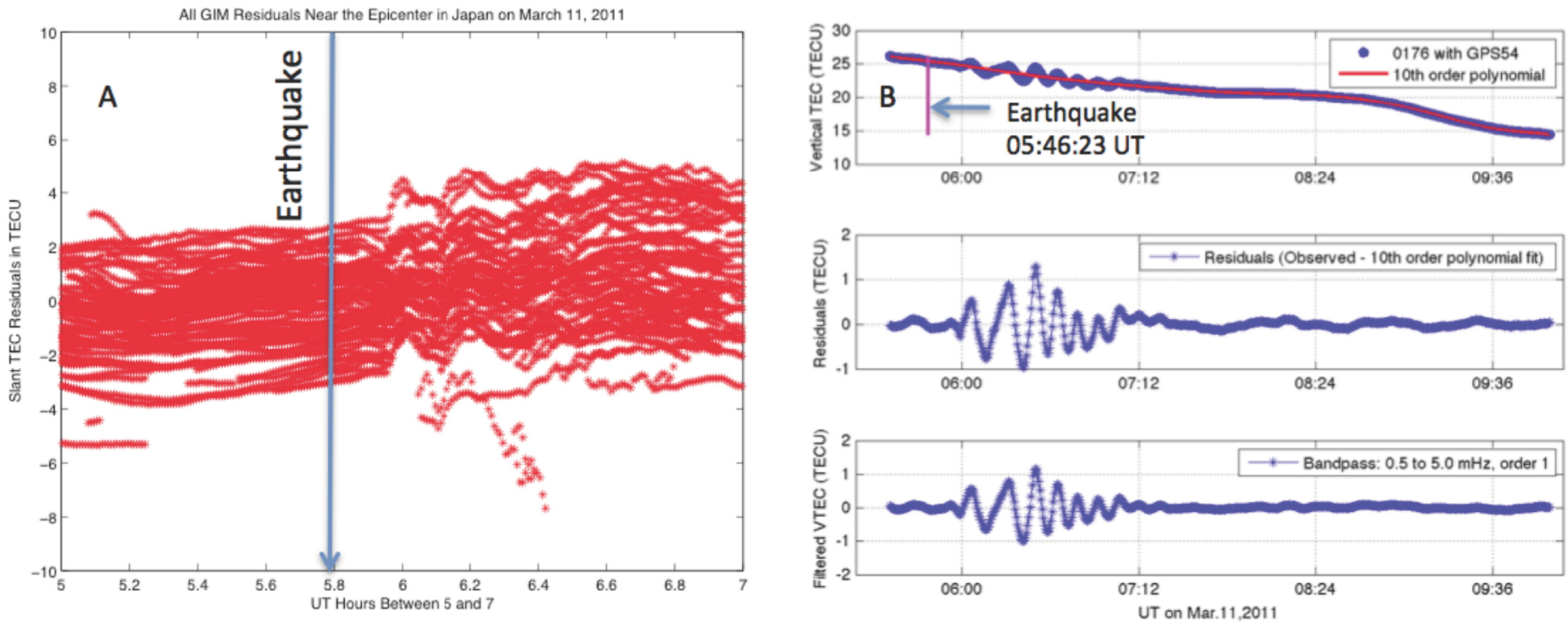
Real-Time GAIM: Web Interface



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

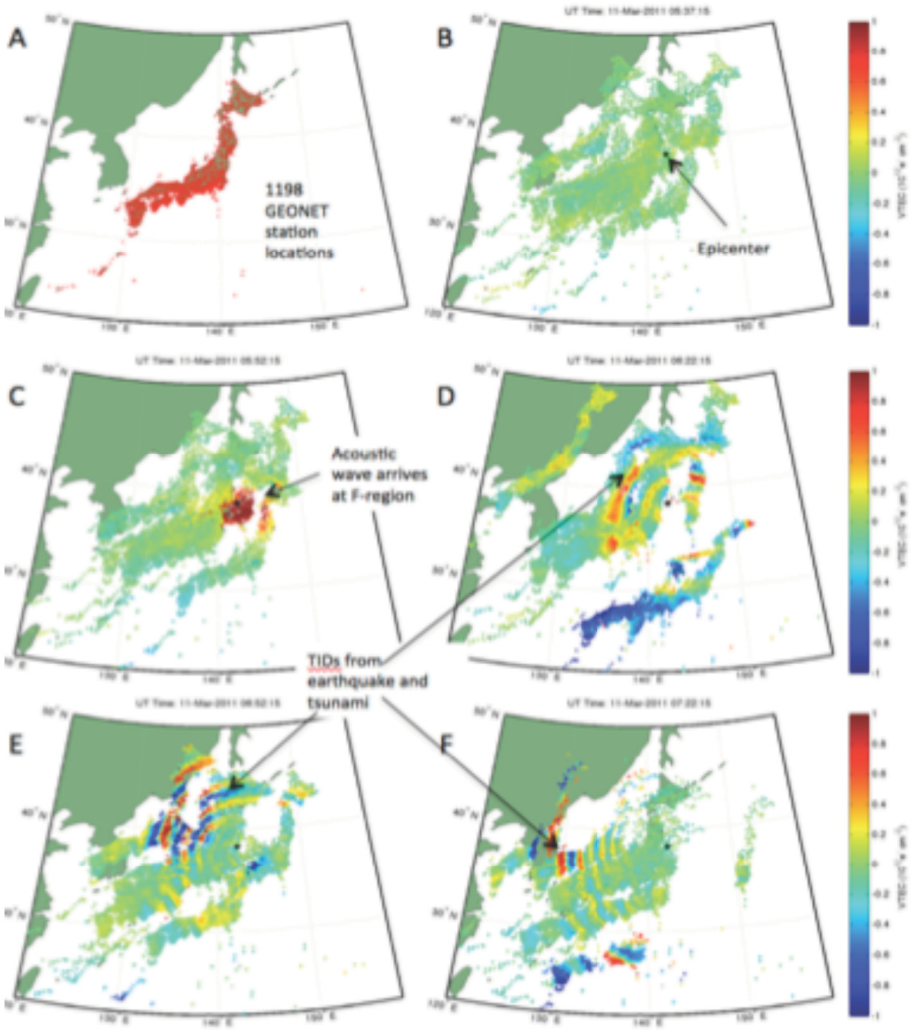


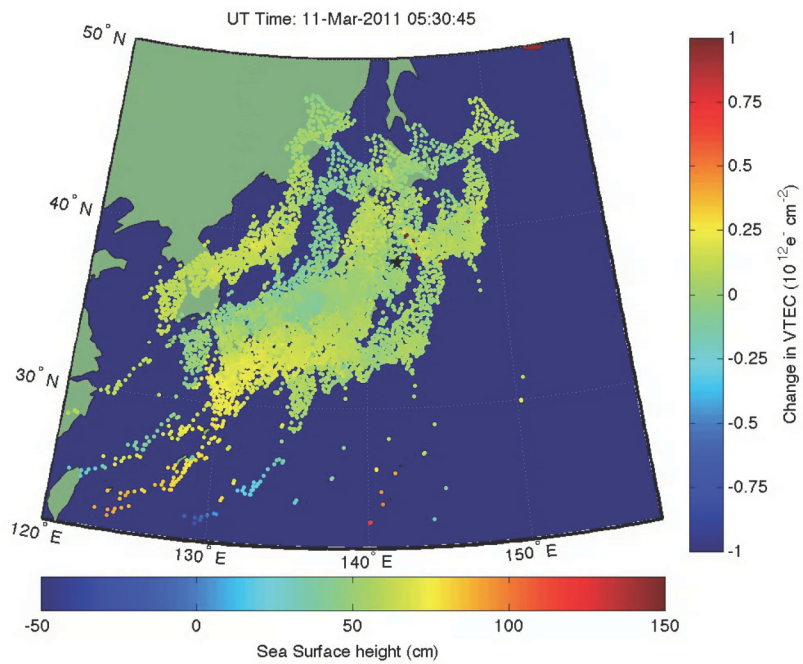
March 11 Tohoku Earthquake and Tsunami Impact



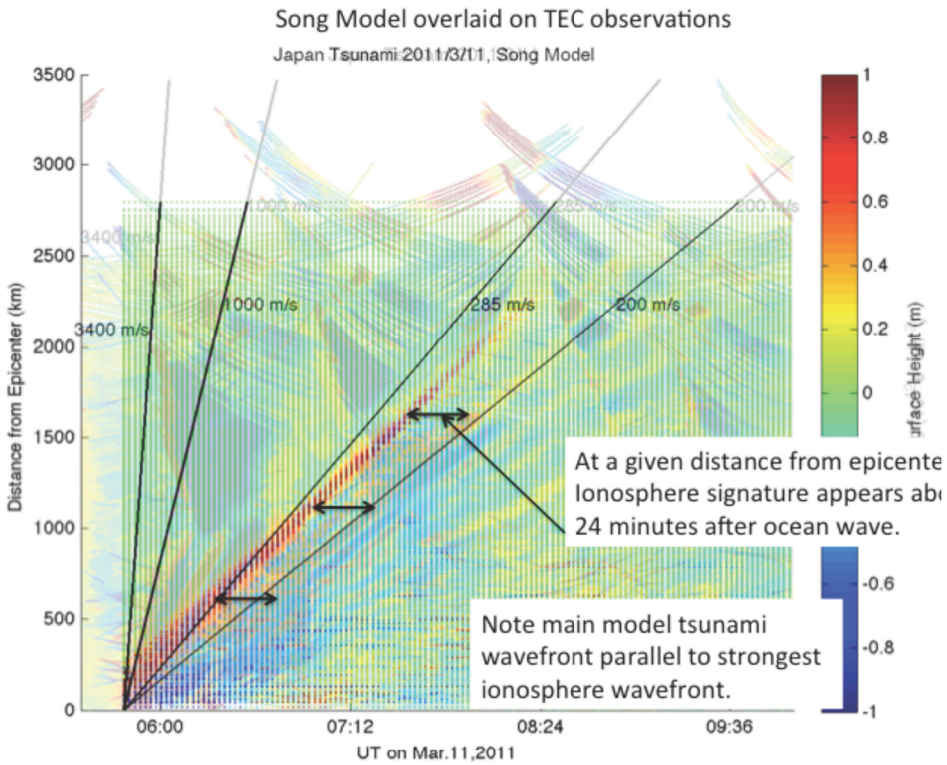
GIM residuals (a) and band-pass filtered slant TEC measurements. Panel (b) indicates an example for filtered TEC observations.

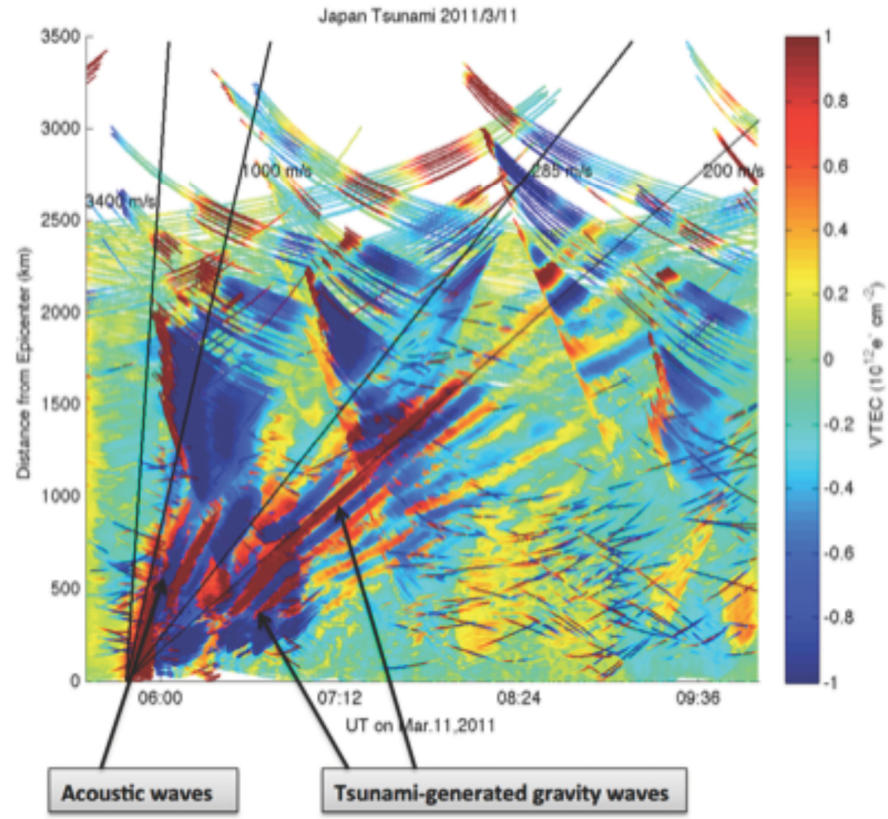
Earthquake and Tsunami Impact on Ionosphere





Acoustic and Gravity Waves Detected in Ionosphere





Conclusions

- Assimilation of Ground + COSMIC + C/NOFS shows improved agreement with ionosonde measurements of Nmf2 and Hmf2.
- Though limited in quantity, C/NOFS does make improvements to vertical structure
- Future plans: extend analysis to a global scope to better gauge the improvements made by C/NOFS
- We would like to acknowledge Leo McNamara (AFRL) for his ionosonde data from the Republic of South Africa.

Acknowedgement

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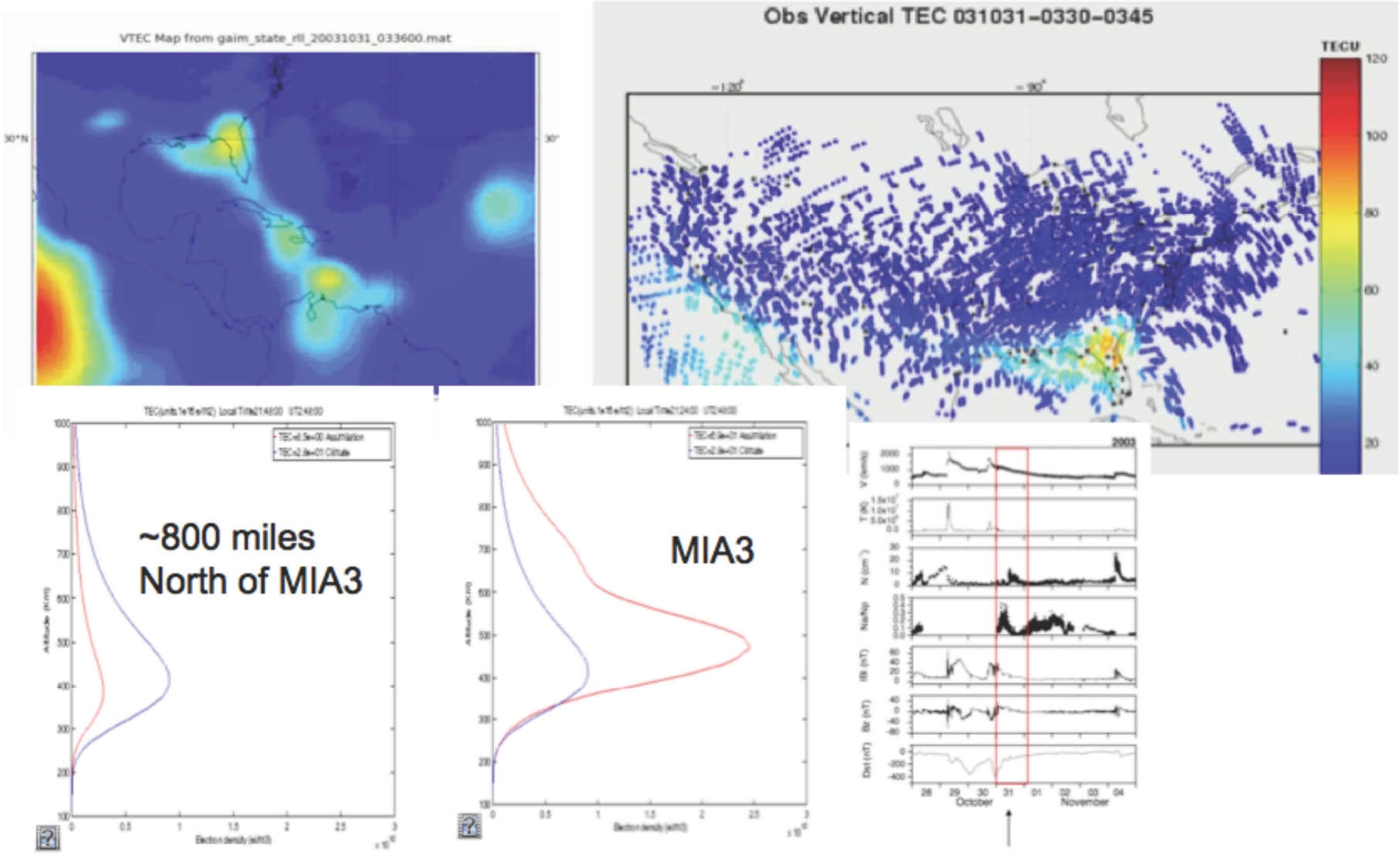
October 31, 2003 NGAIM VTEC Map, the Florida Feature