JPL/USC GAIM: USING COSMIC AND GROUND-BASED GPS DATA TO ESTIMATE IONOSPHERIC STATE IN NEAR REAL-TIME

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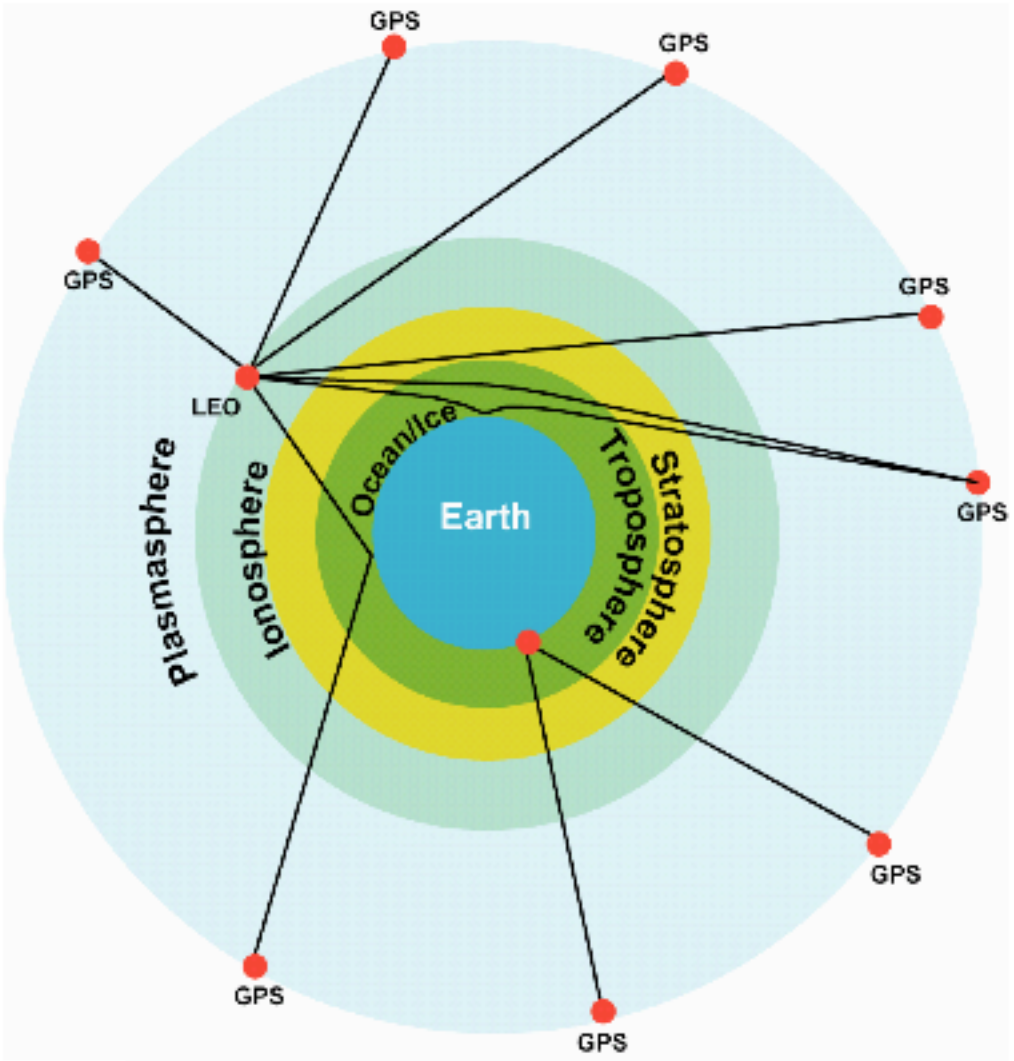
Outline

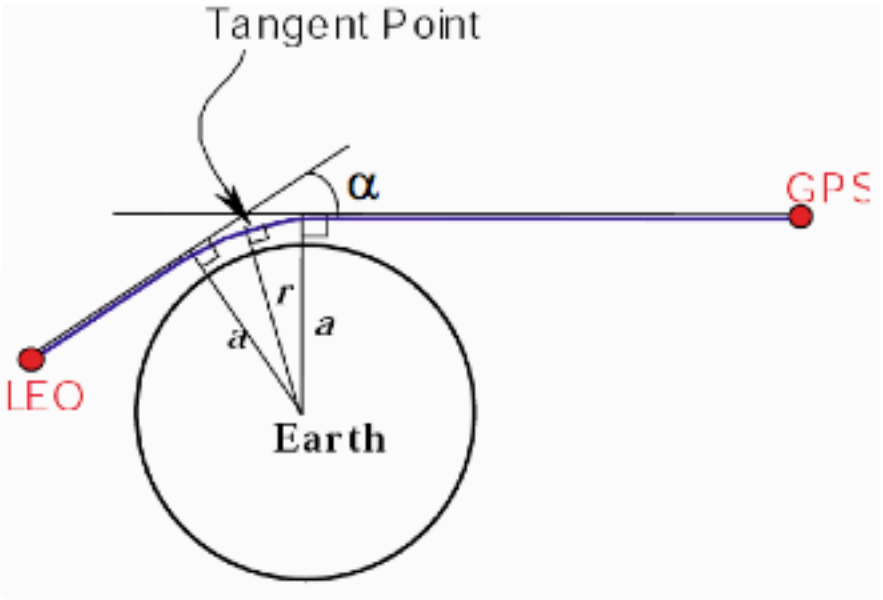
- Introduction
- JPL GAIM input data quality and comparisons
- Two questions:
  - What impact does the COSMIC data have on GAIM profile shape?
  - What difference does the medium resolution GAIM run make compared to low resolution run?
- Assimilating ground-based GPS and COSMIC into JPL/USC GAIM (Sept 21, 2006):
  - Comparison of GAIM climate, ground-data only, ground and COSMIC and Jicamarca ISR data;
  - Comparison of low and medium resolution GAIM runs.
- JPL/USC GAIM VTEC, NmF2, HmF2 validation using Jicamarca ISR
- Conclusions & Future Plans

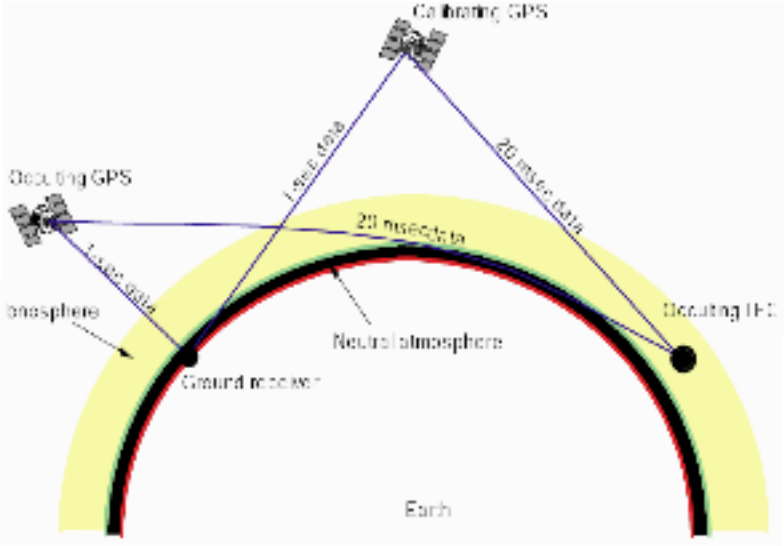
Overview of GPS Remote Sensing Applications

- **FROM GROUND**
  - Troposphere
  - Ionosphere
- **FROM SPACE**
  - Troposphere
  - Stratosphere
  - Ionosphere
  - Plasmasphere
- **Ocean Reflection**



Occultation Geometry



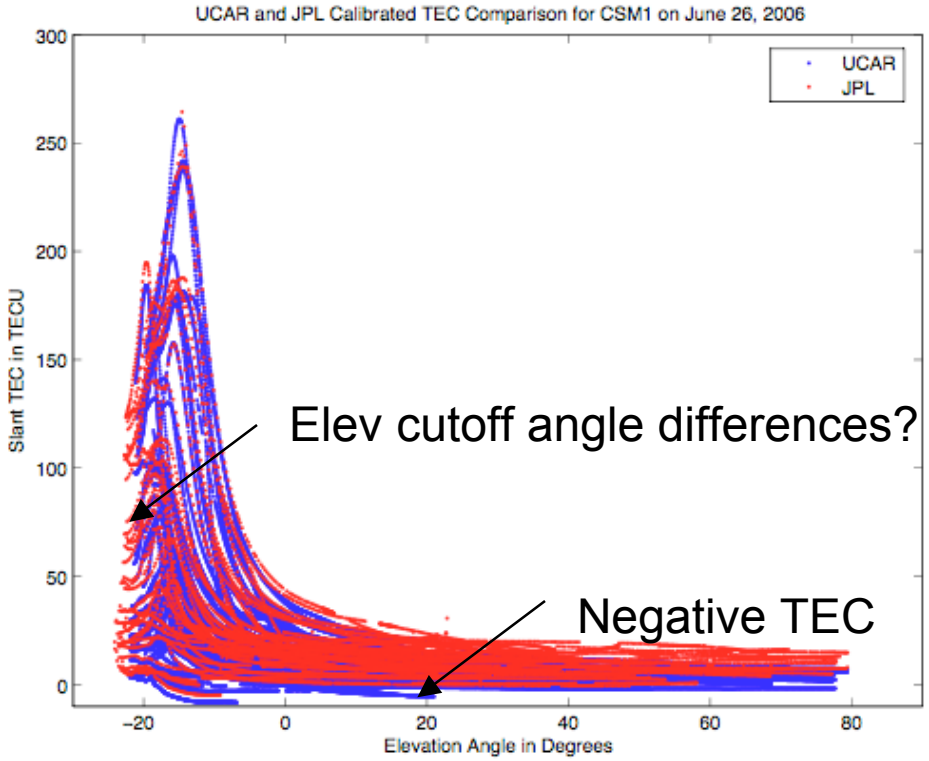


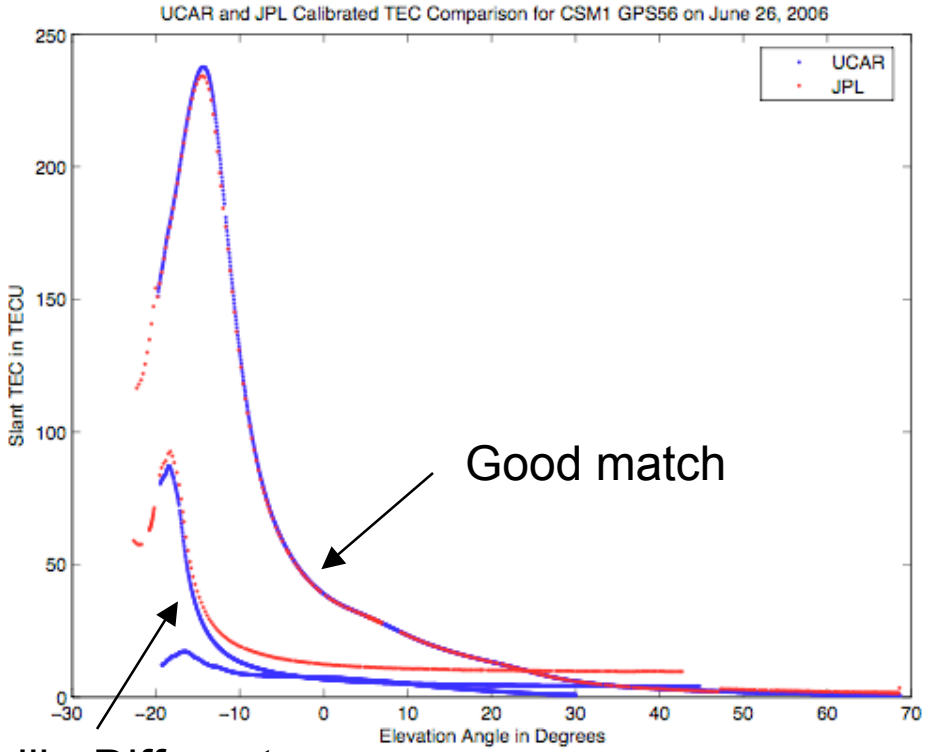
- **Single Frequency Retrievals**
- **Dual Frequency Retrievals**
  - **TEC = const. x (L1 – L2)**
  - **α ~ dTEC/dt**

$$\alpha(a) = 2a\int_{a}^{\infty} \frac{1}{\sqrt{a'^2 - a^2}} \frac{d\ln(n)}{da'} da'$$

$$\ln(n(r)) = \frac{1}{\pi}\int_{nr}^{\infty} \frac{\alpha}{\sqrt{a^2 - r^2 n^2}} da$$

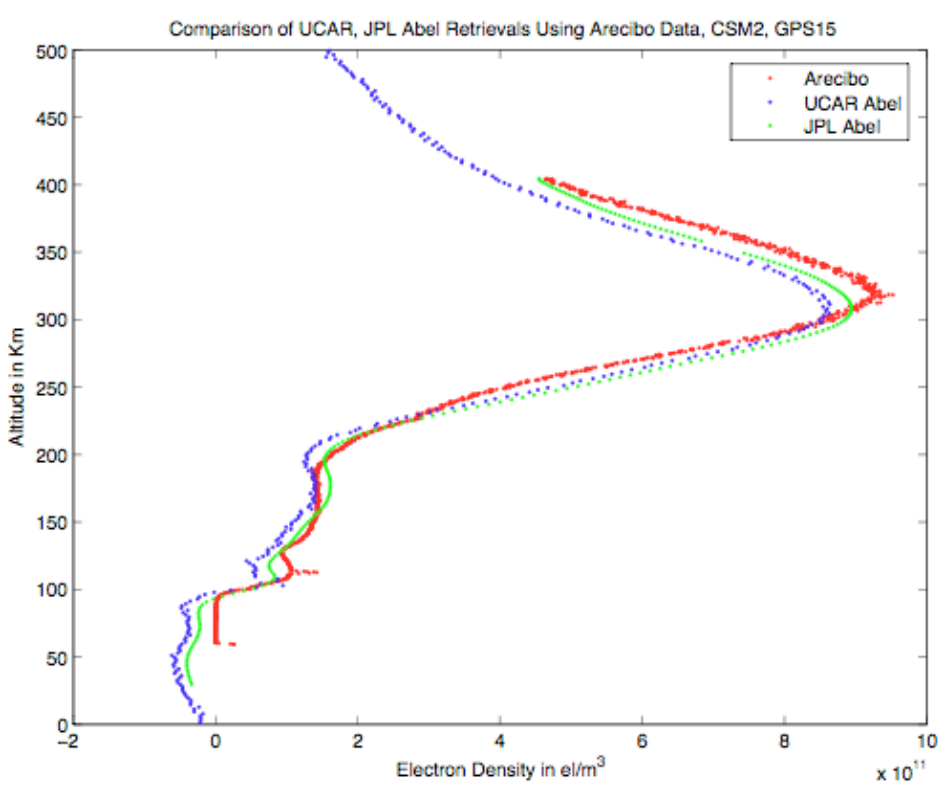
Comparison of Calibrated Slant TEC Measurements for June 26, 2006

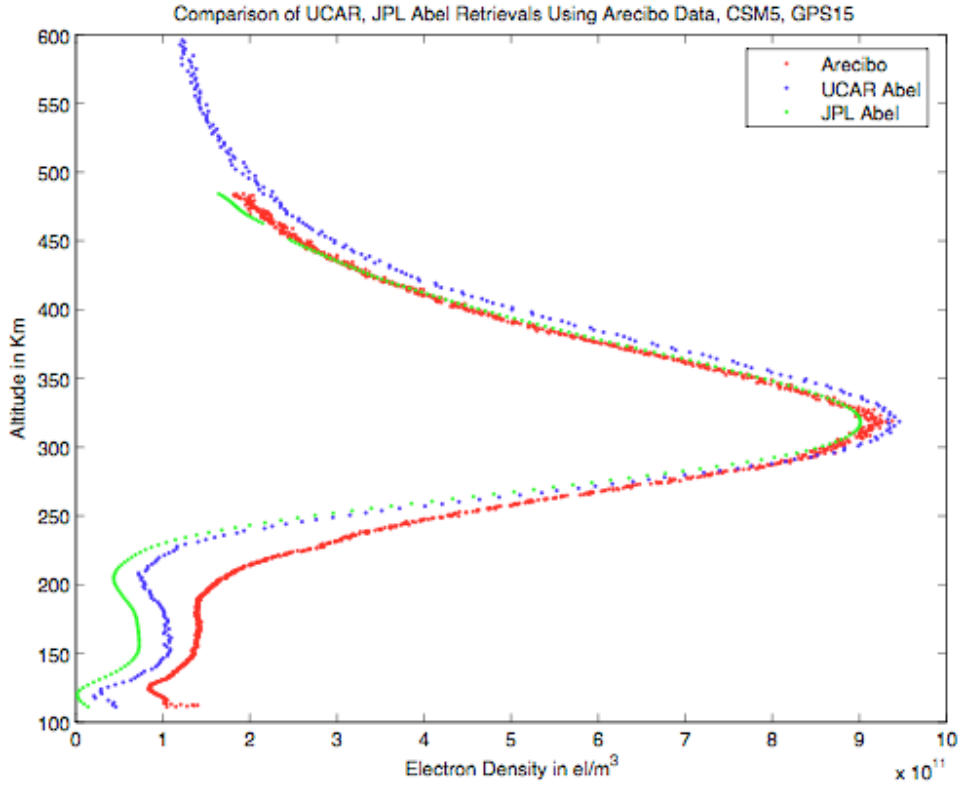




- An example of comparison of calibrated TEC between JPL and UCAR
- Currently there appears to be a 1-2 TECU bias between JPL and UCAR slant TEC
- Similar data volumes between JPL and UCAR

Validating UCAR and JPL Abel Profiles Using Arecibo ISR Measurements for June 26, 2006

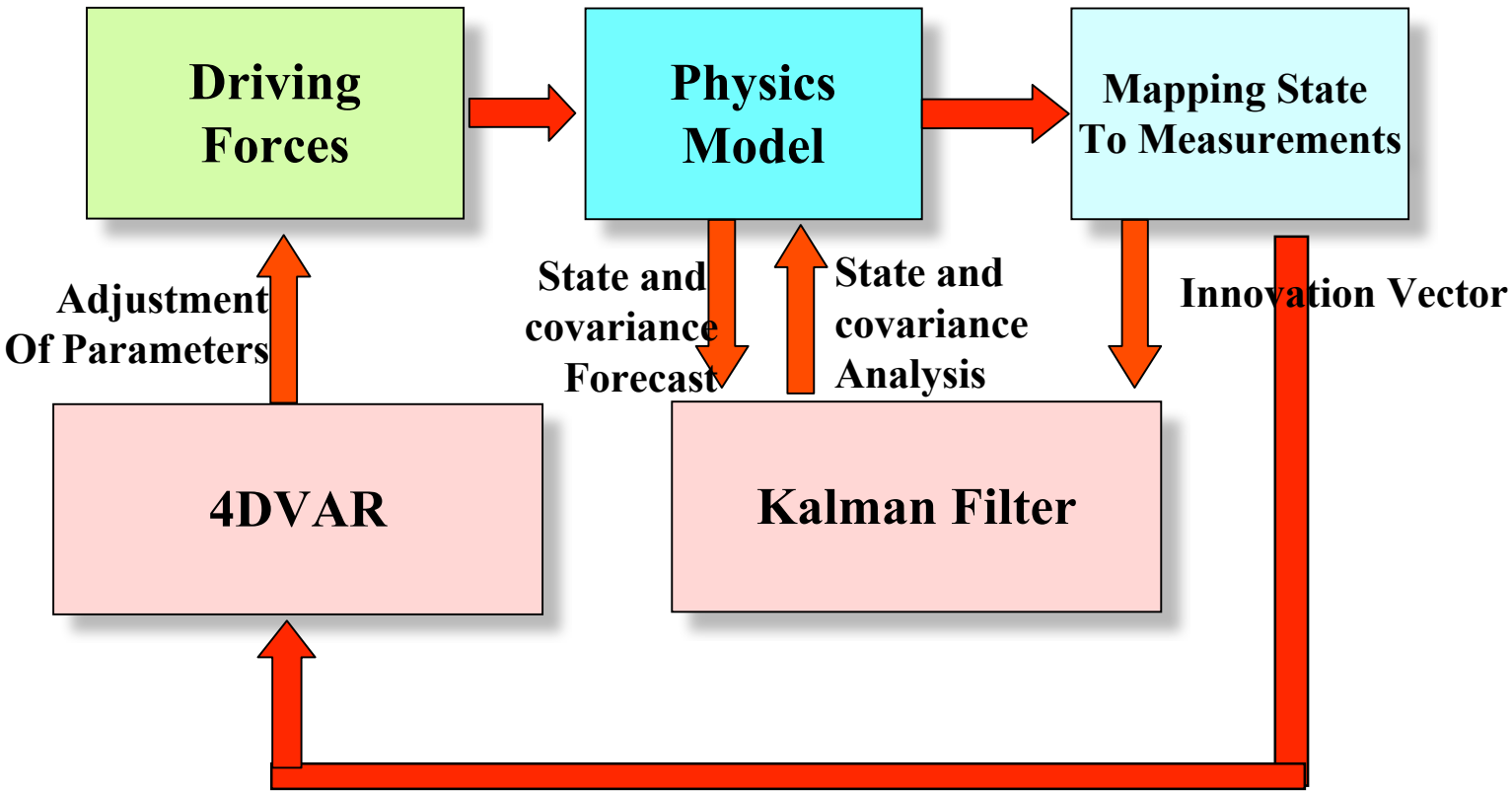




- E-region error in naive Abel profiles: negative electron densities
- 4 out of 6 spacecrafts are in final orbital altitudes

Arecibo calibrated profiles are courtesy of Prof M. Kelley and V. Wong of Cornell University

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

Input Data Types

- **Ground GPS Data (Absolute TEC)**
  - >200 5-min. to Hourly Global GPS Ground Stations
  - Assimilate >300,000 TEC points per day
- **Space GPS Data (Absolute or Relative TEC)**
  - CHAMP (@ 440 km)
  - SAC-C (@ 700 km)
  - IOX (@ 800 km)
  - GRACE (@ 350 km)
  - Topex/Poseidon (@1330 km) (Upward looking only)
  - Jason 1 (@1330 km) (Upward looking only)
  - C/NOFS & COSMIC constellation
- **UV airglow data (135.6 nm radiance)**
  - LORAAS on ARGOS, GUVI on TIMED
  - SSUSI/SSULI on DMSP
  - TIP on COSMIC
- **Other Data Types**
  - TEC from TOPEX/JASON Altimeters
  - Ionosonde bottomside profiles
  - DMSP in situ
  - CHAMP in situ
  - GRACE cross-links

Kalman Assimilation Runs for Sept 21, 2006

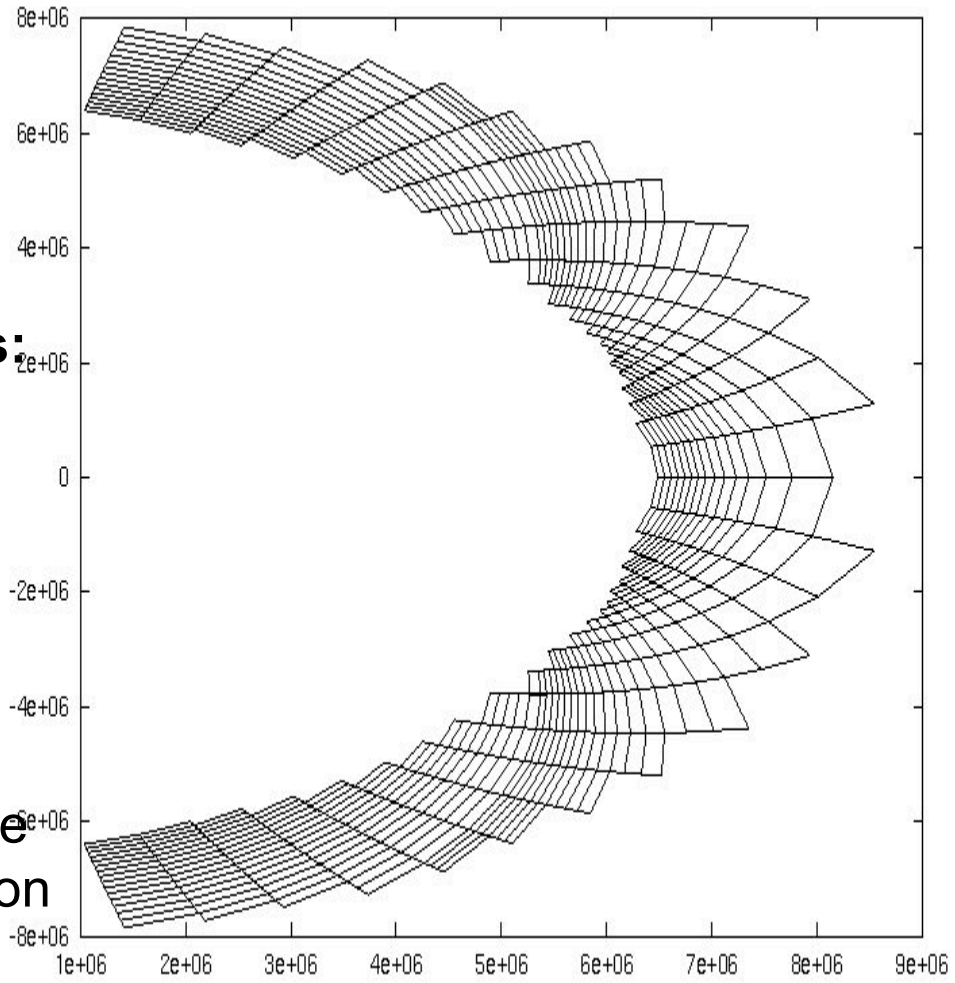
- Three runs:
  - GAIM Climate (no data)
  - Ground GPS TEC (200 sites)
  - Ground + COSMIC links (upward & occultation)
- **Medium and Low Resolution runs:**

  2.5 Vs. 5.0 Lat. In Deg.

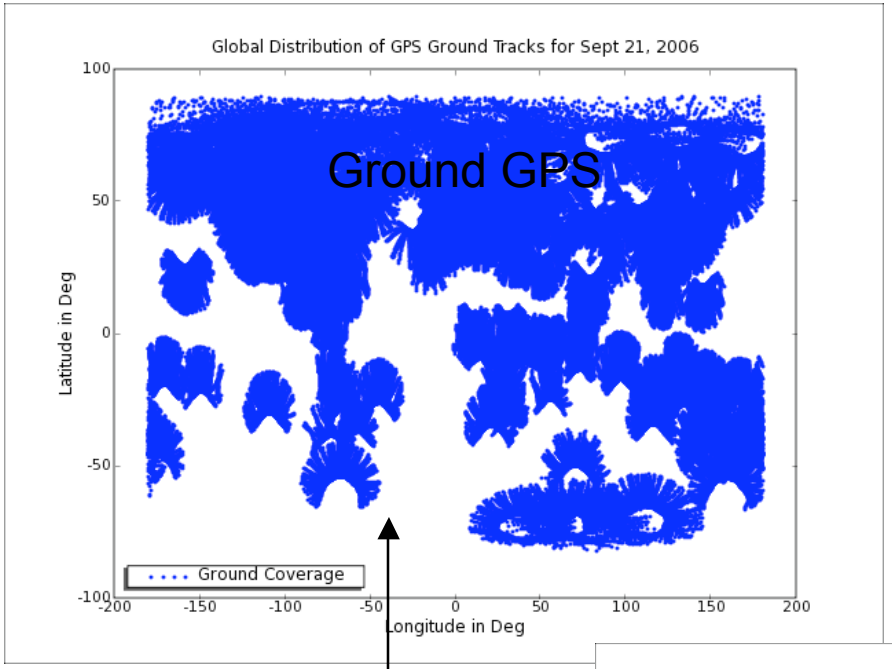
  10.0 Vs. 15.0 Lon. in Deg.

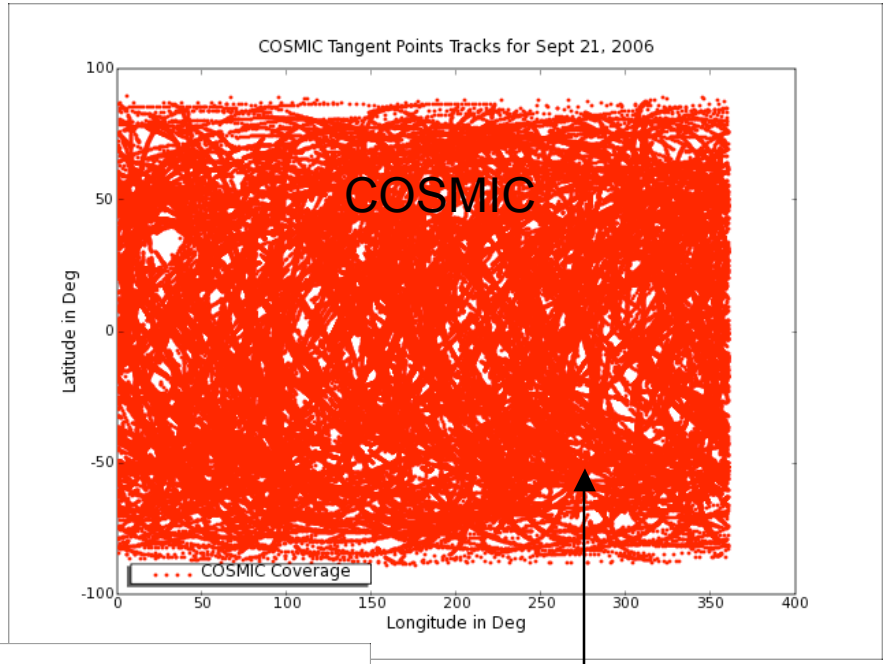
  40 Vs. 80 Alt. in km

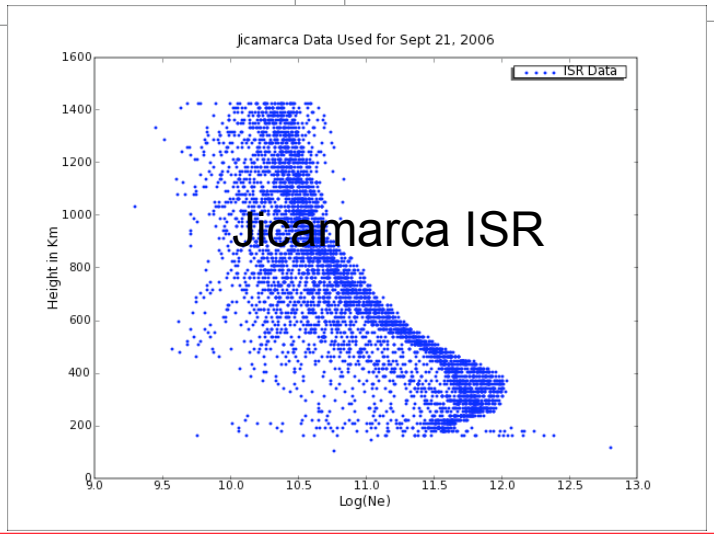
  100,000 Vs. 18,000 voxels
- Sparse Kalman filter:
  - Update & propagate covariance
  - Truncate off-diagonal covariance that is beyond physical correlation lengths



Ground, COSMIC and Jicamarca ISR Coverage for Sept 21, 2006



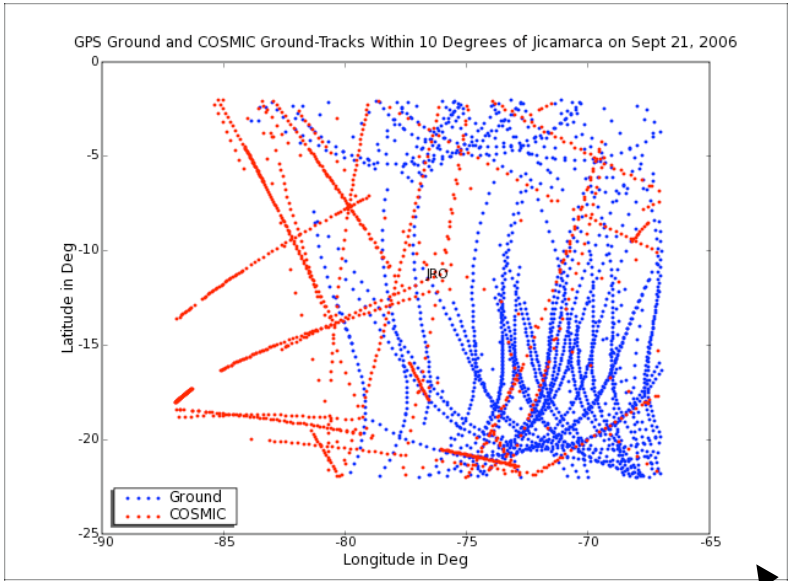


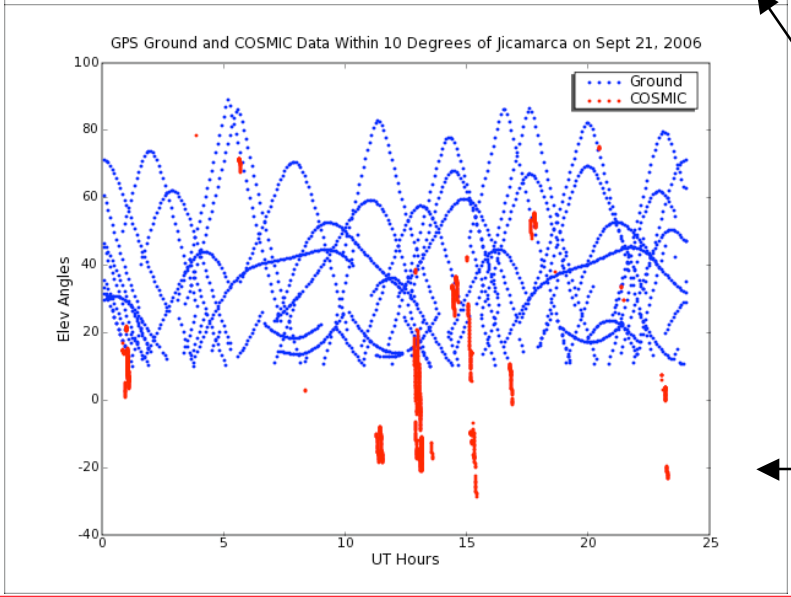


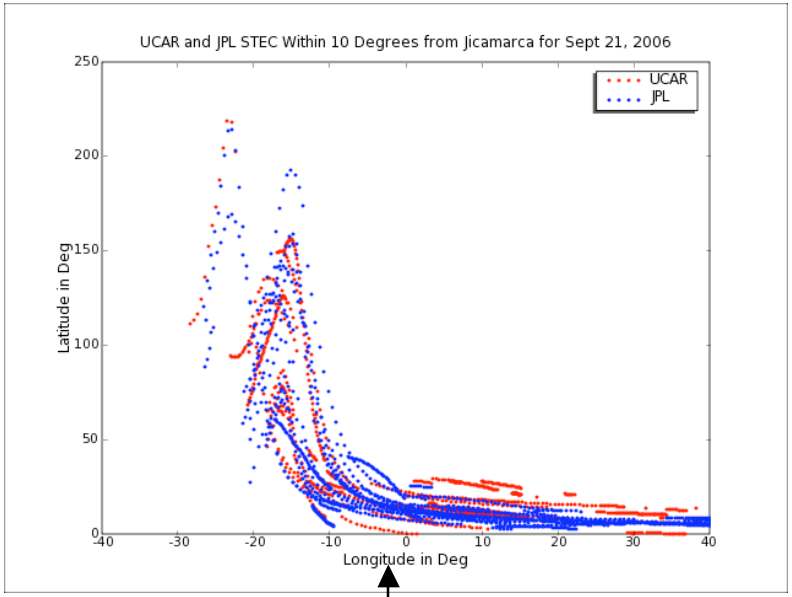
dense but unevenly distributed coverage

less dense yet evenly distributed coverage

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





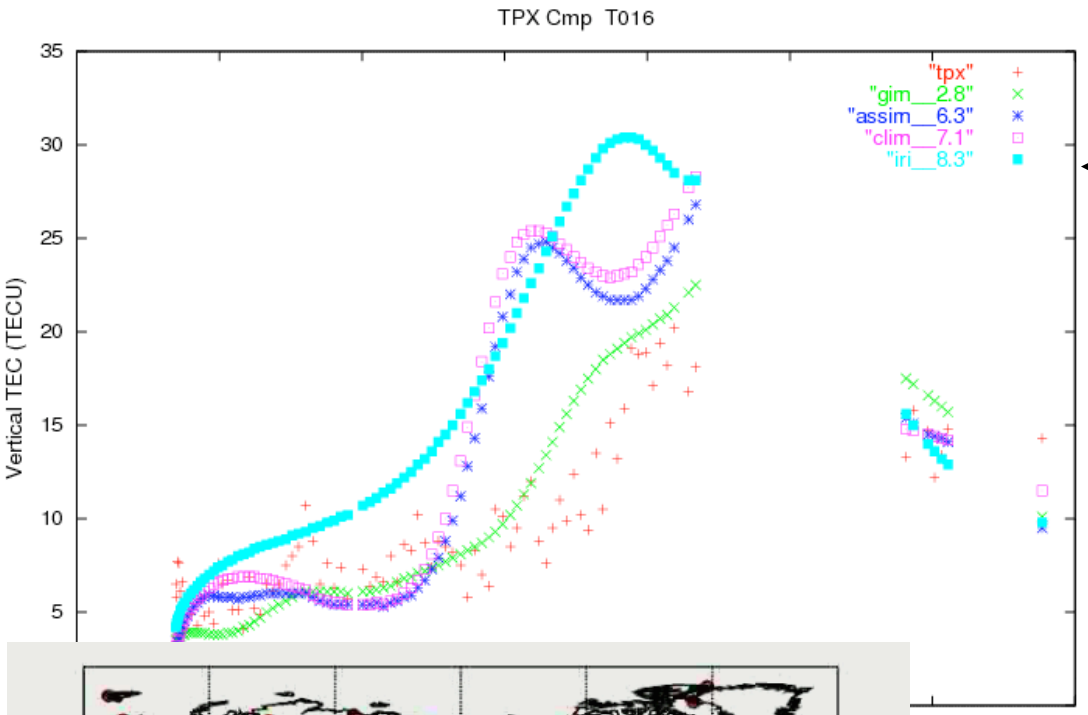


Comparison of UCAR and JPL calibrated TEC near Jicamarca

Ground and COSMIC ground tracks near Jicamarca

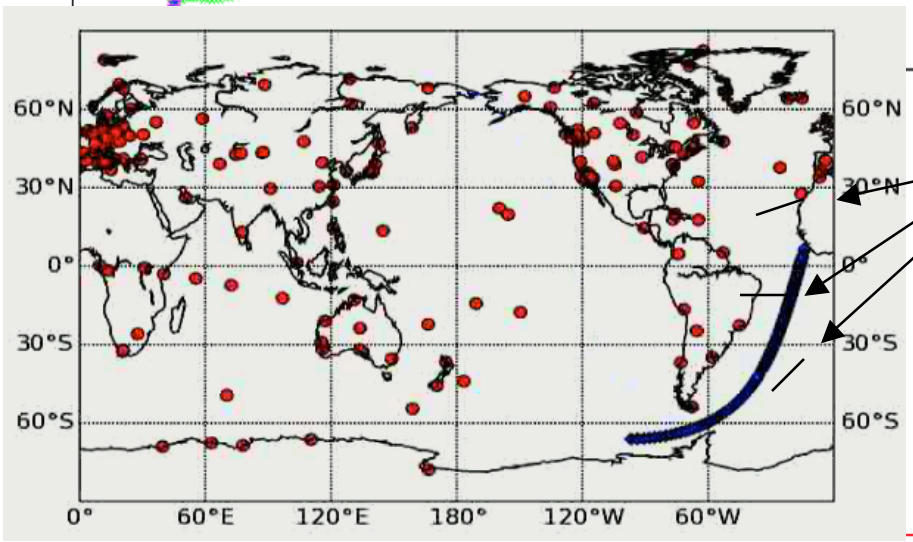
Ground and COSMIC data availability near Jicamarca

GAIM Validation Using Jason-2 Vertical TEC for June 26

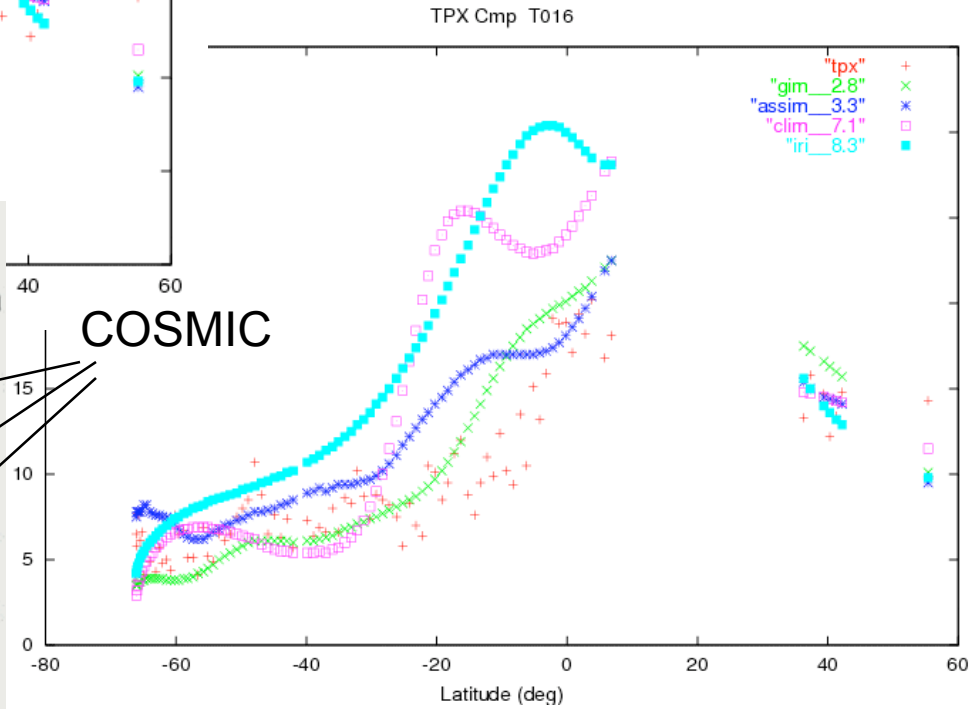


Ground-data only

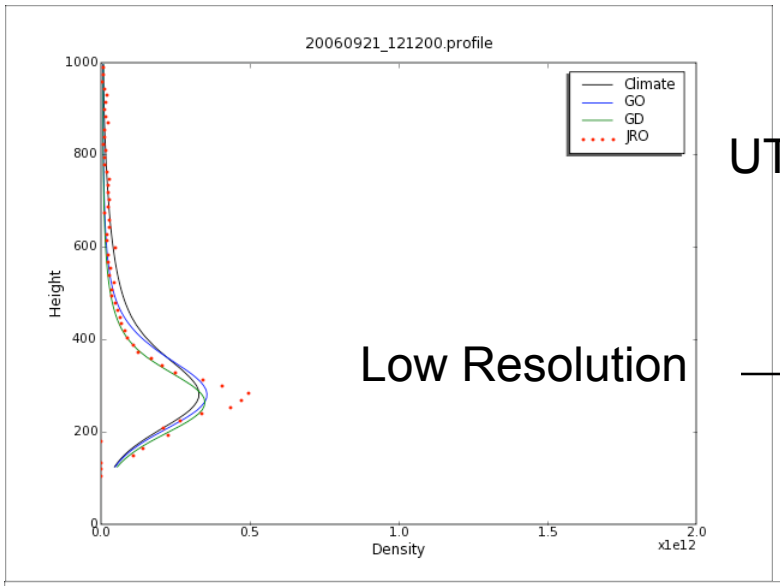
Ground and space data



COSMIC

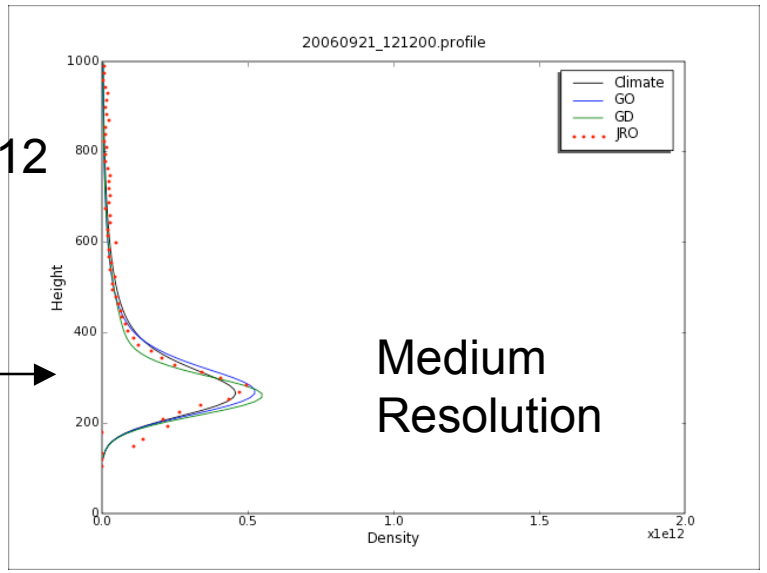


Comparison of Low and Medium Resolution GAIM Profiles at Jicamarca

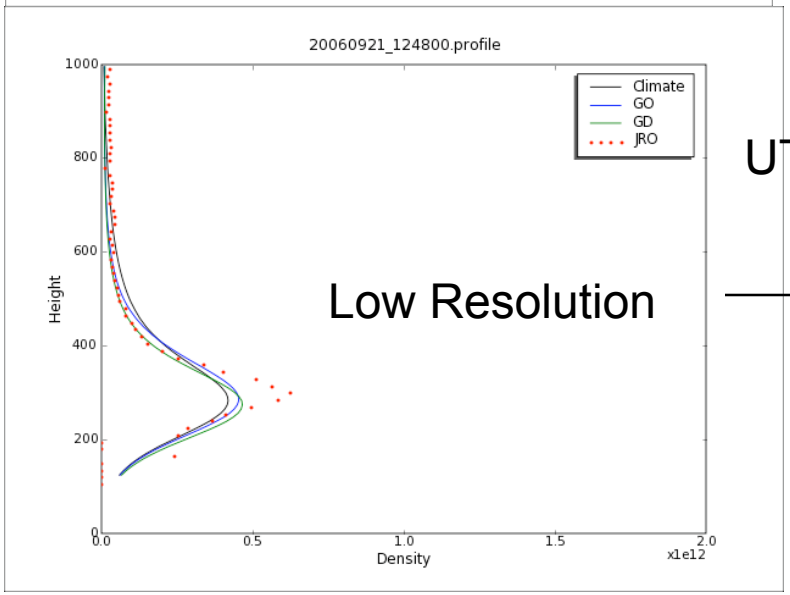


UT 12:12

Low Resolution

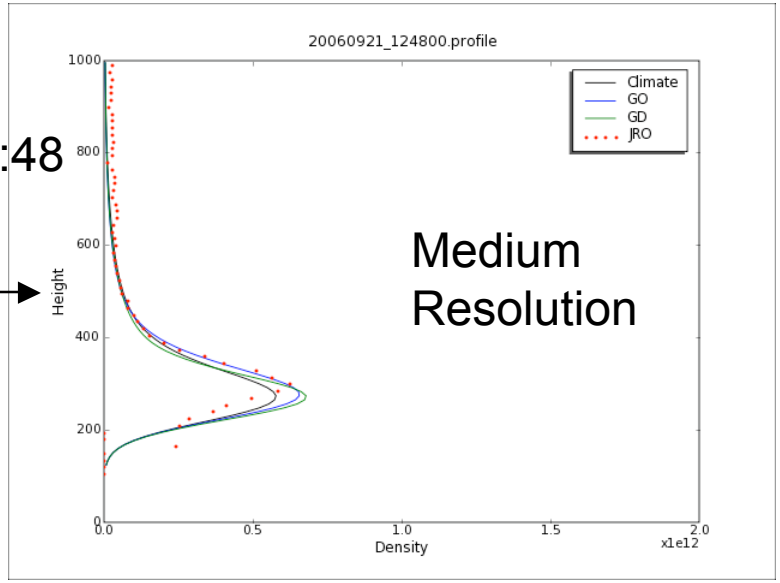


Medium Resolution



UT 12:48

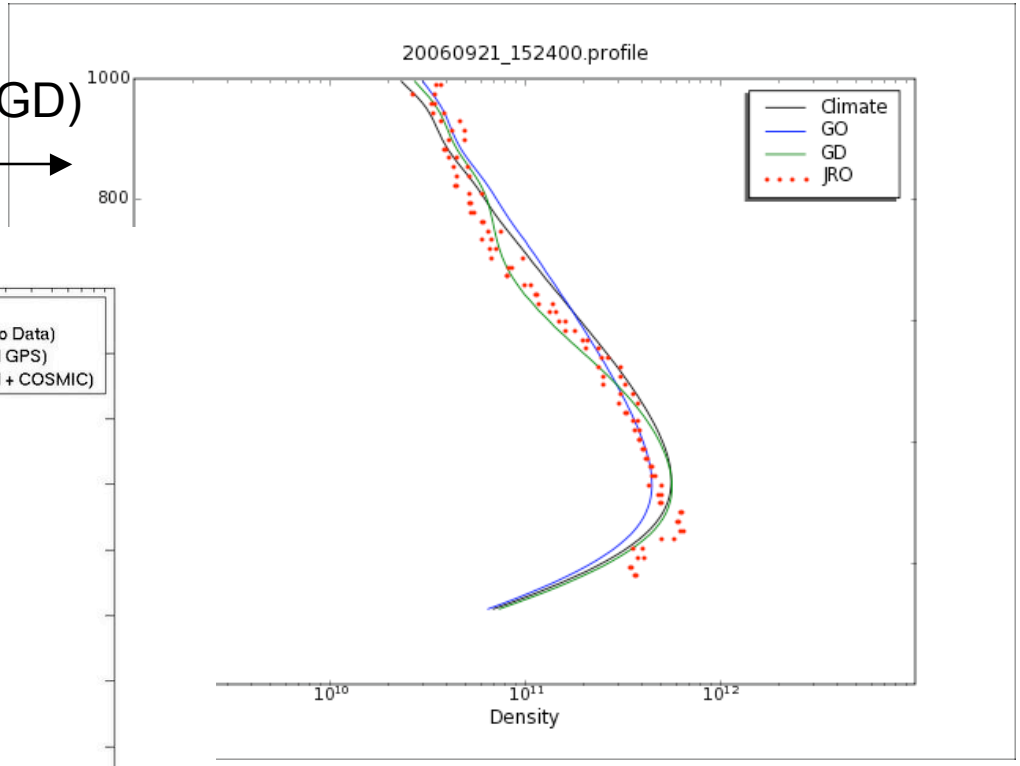
Low Resolution

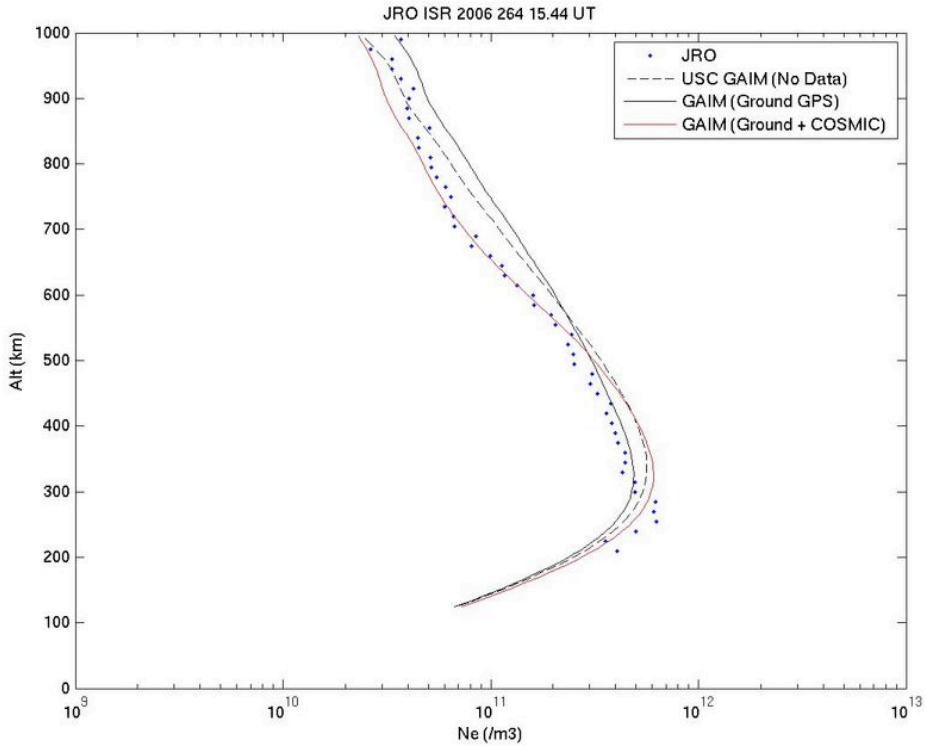


Medium Resolution

Comparison of AFRL and JPL GAIM Assimilation Using USC/JPL GAIM

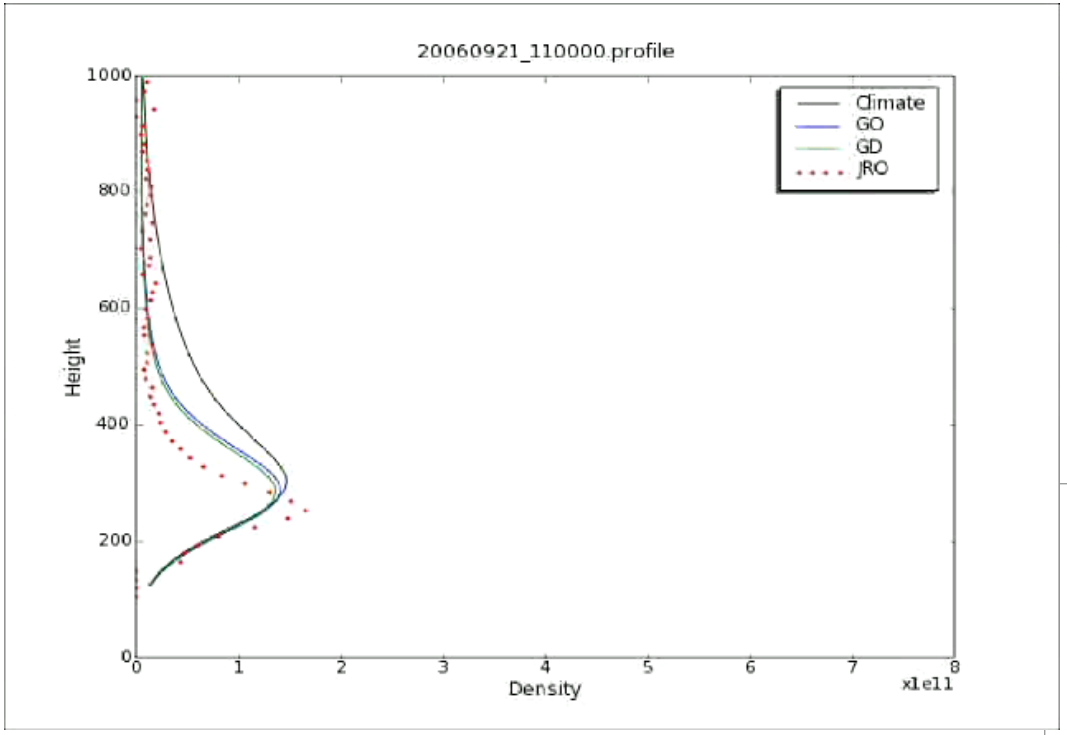
JPL/USC GAIM using GAIM climate, ground-only (GO), ground+COSMIC (GD) and Jicamarca ISR (log scale)



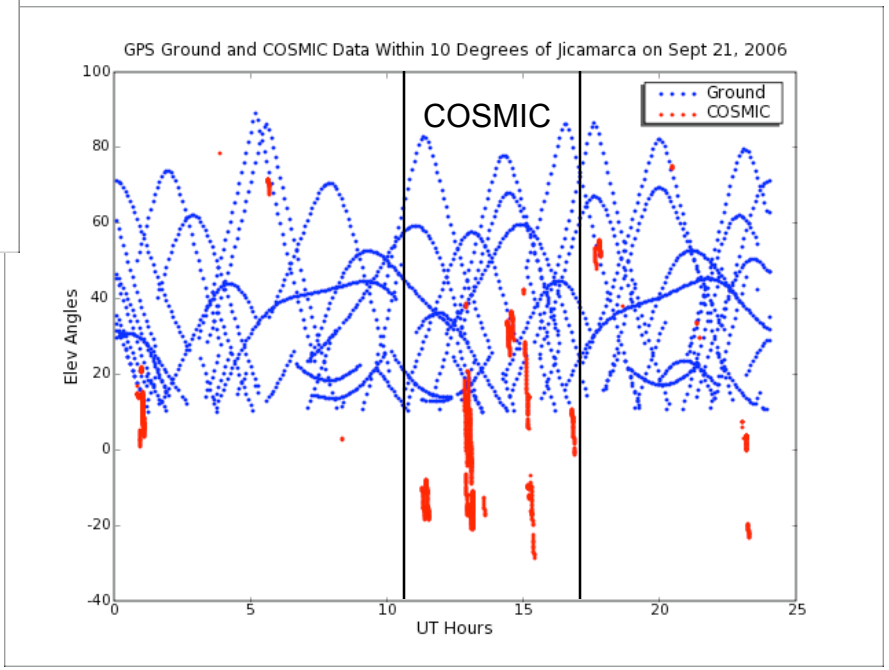


Courtesy of Capt. Craig Baker of AFRL

GAIM Assimilating Ground-GPS and COSMIC Data: A Jicamarca Comparison

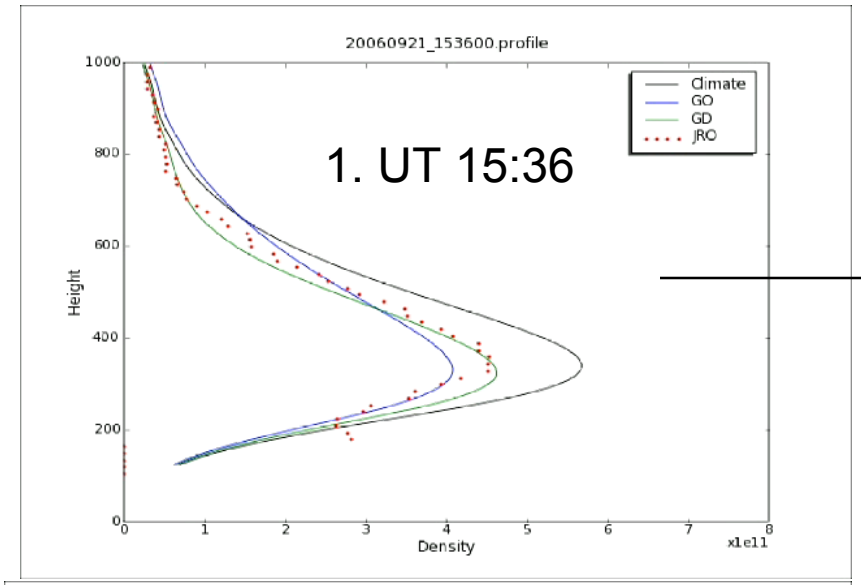


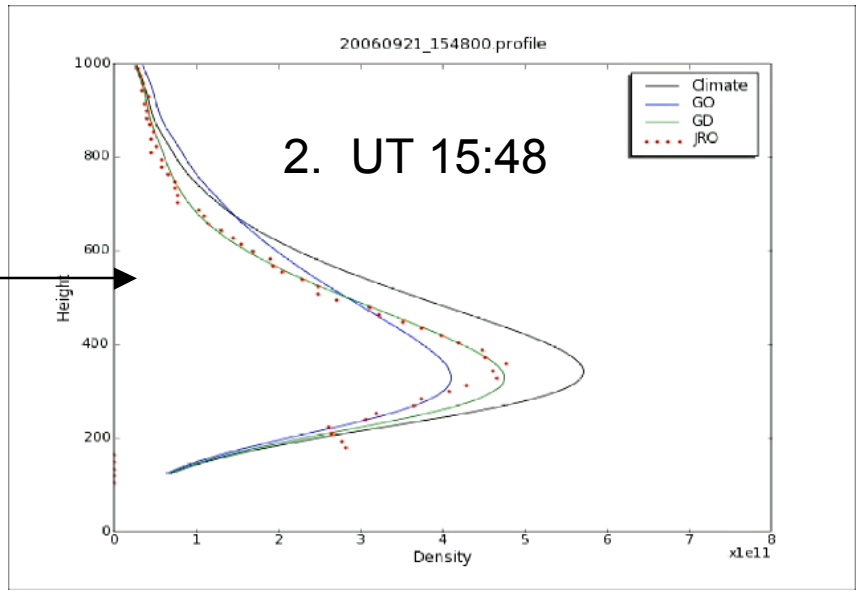
GPS ground-data and COSMIC data availability near Jicamarca

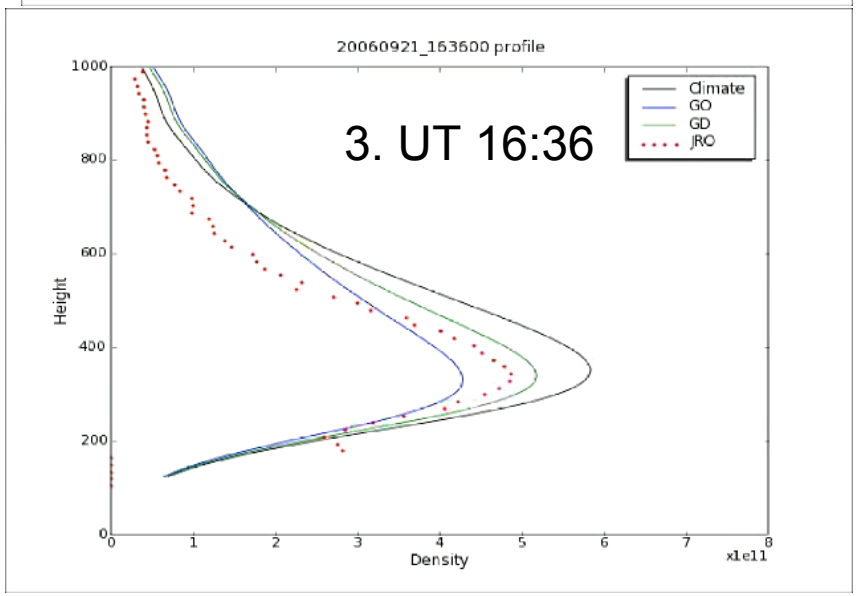


Assimilation results using climate, ground-only (GO), ground+COSMIC (GD) and Jicamarca ISR (JRO)

An Example of COSMIC Impact on Profile Shape







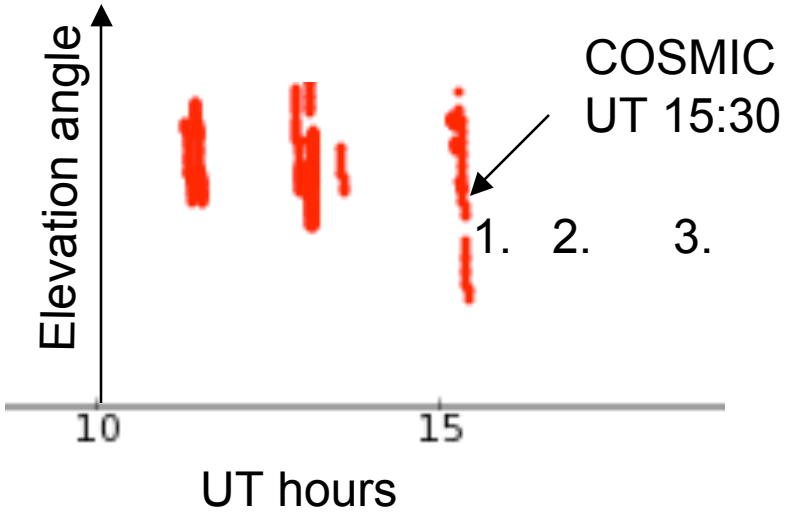
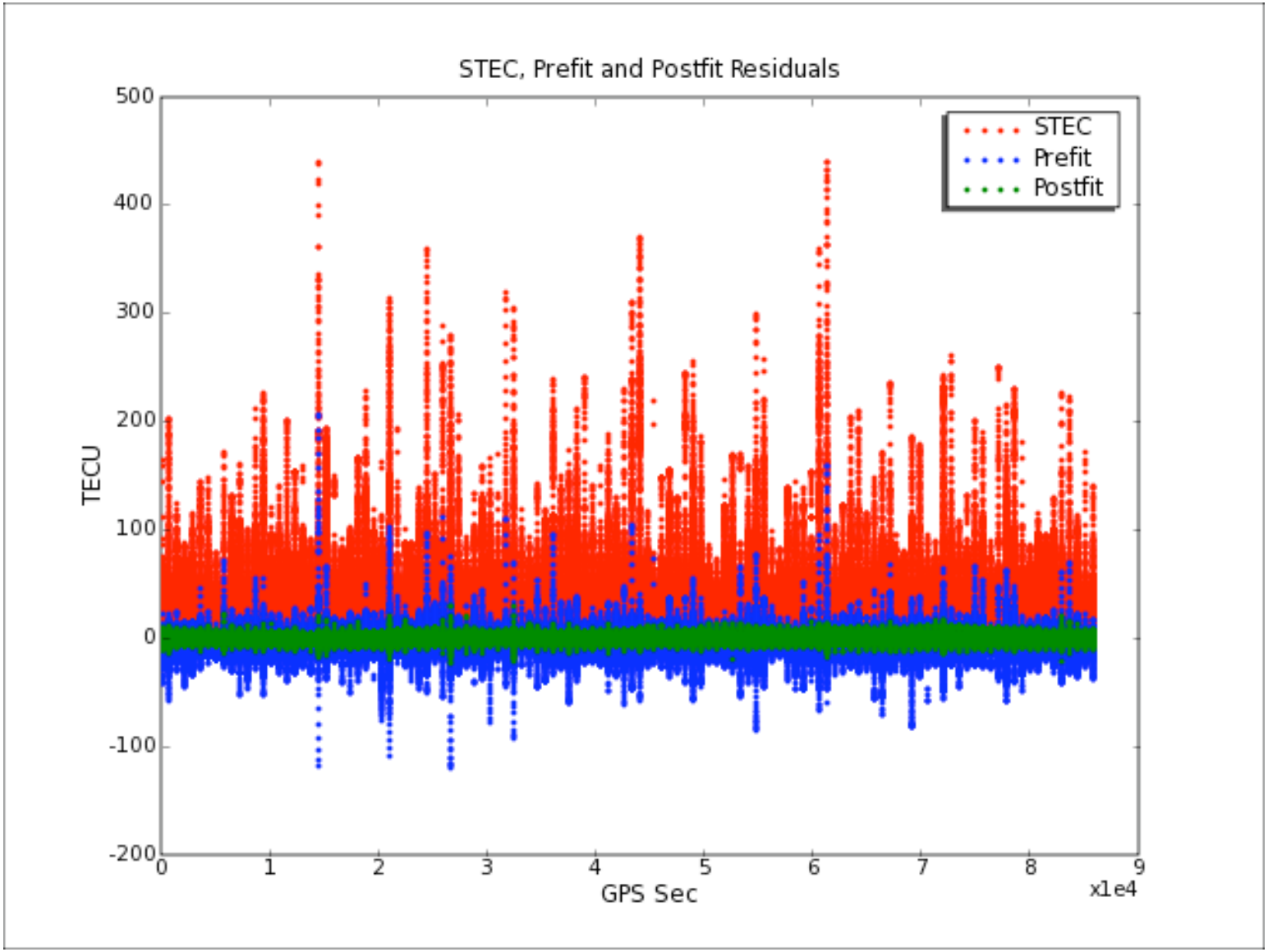
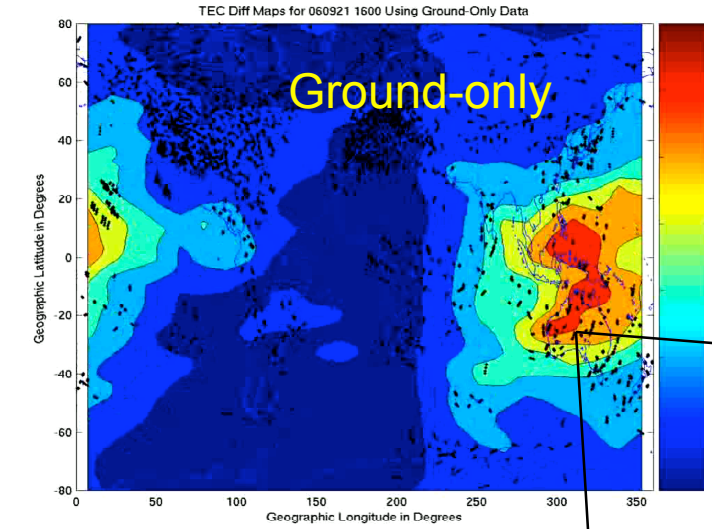
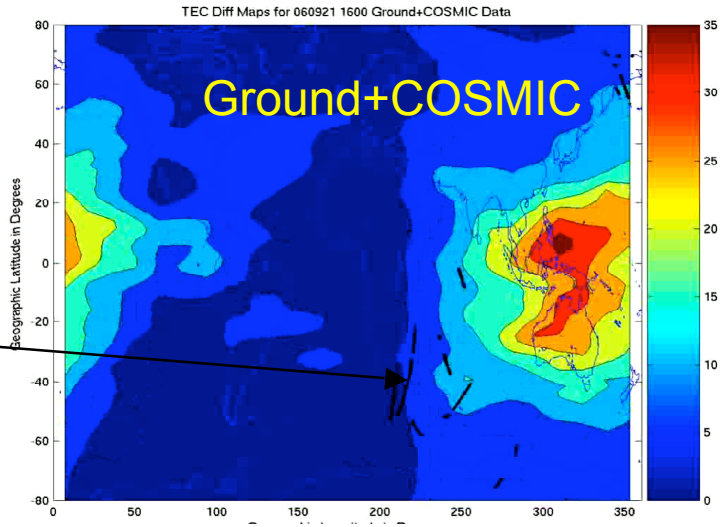


Illustration for TEC data, GAIM Prefit and Postfit Residuals

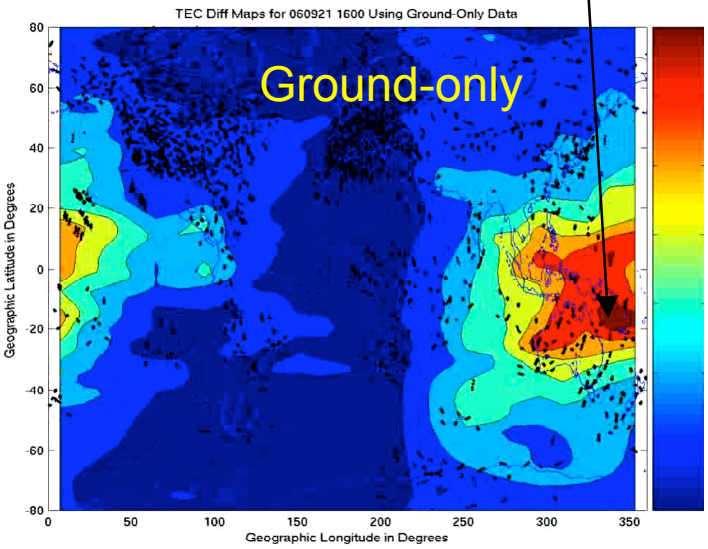


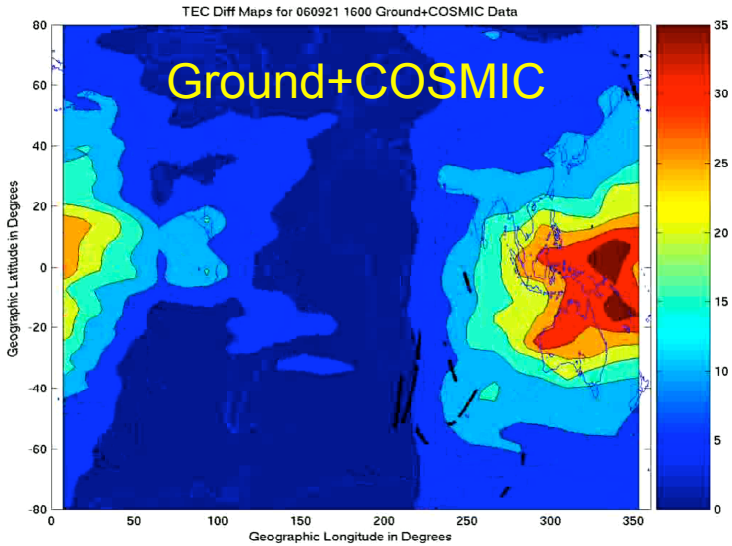
Comparison of Low and Medium Resolution GAIM VTEC Maps





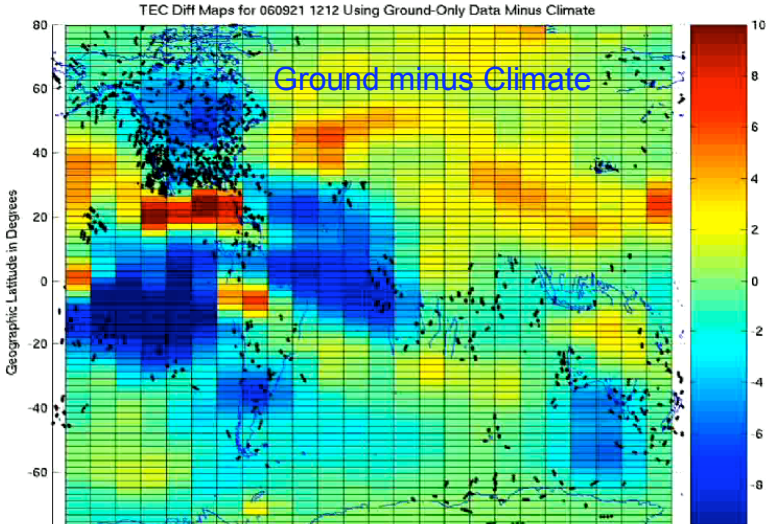
Low resolution

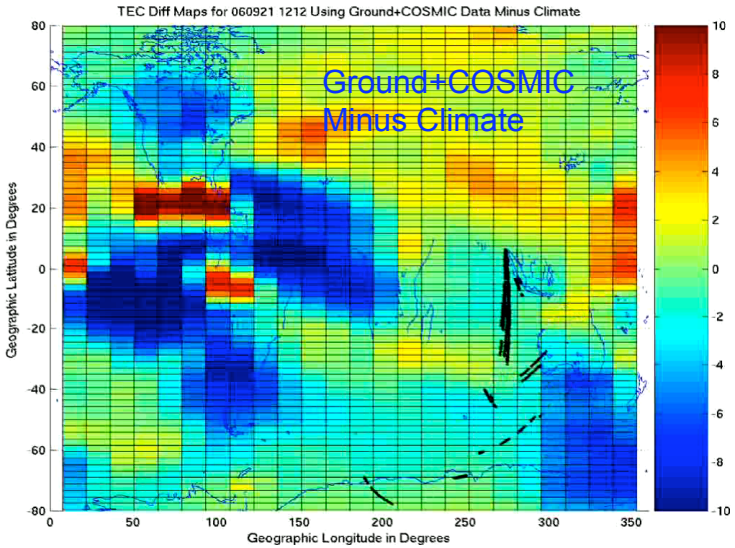


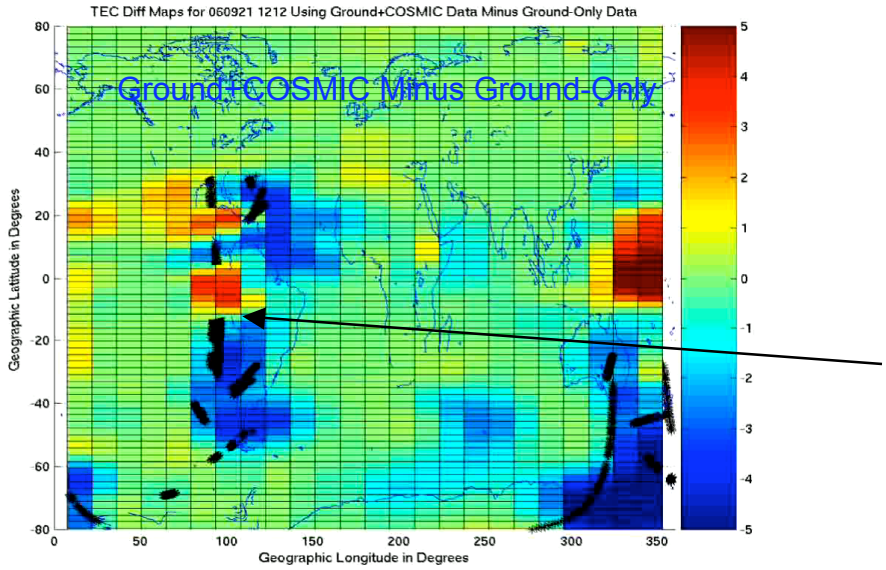


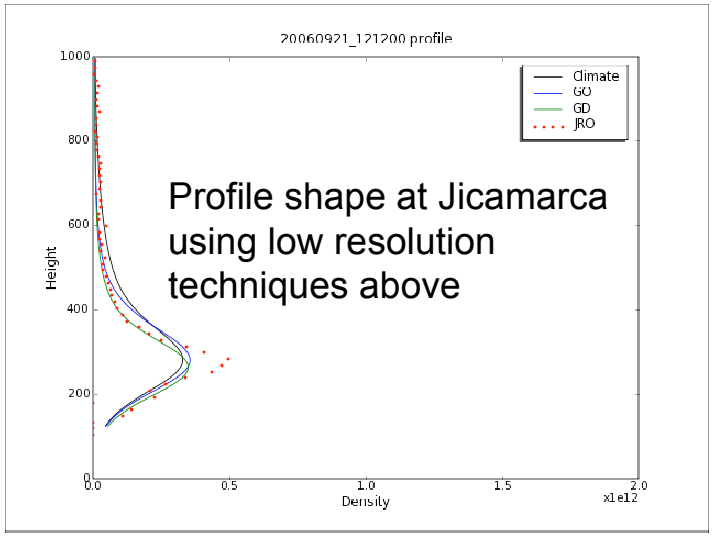
Medium resolution

Low Resolution GAIM VTEC Difference Maps

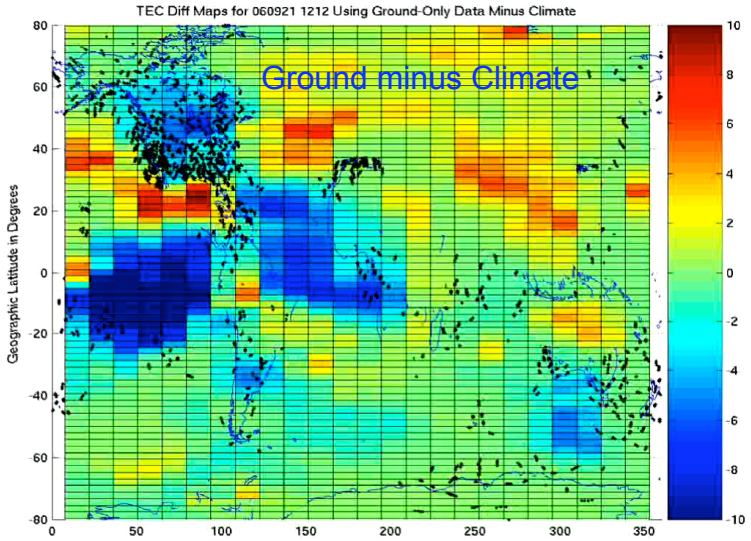


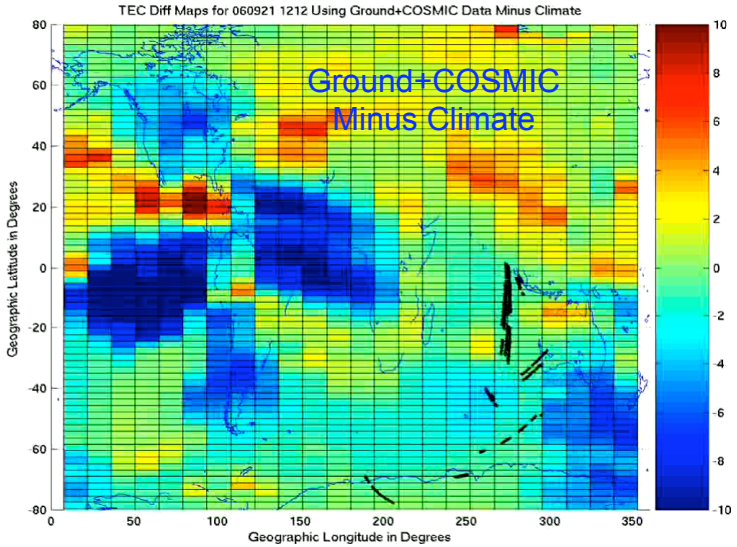


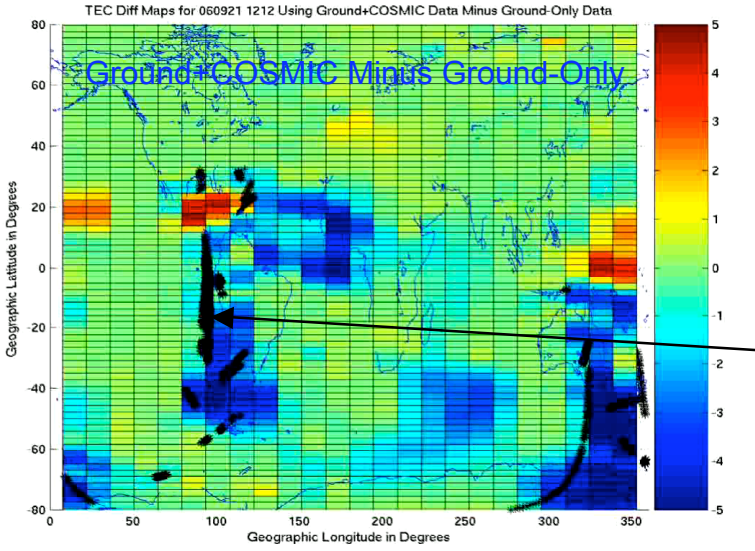


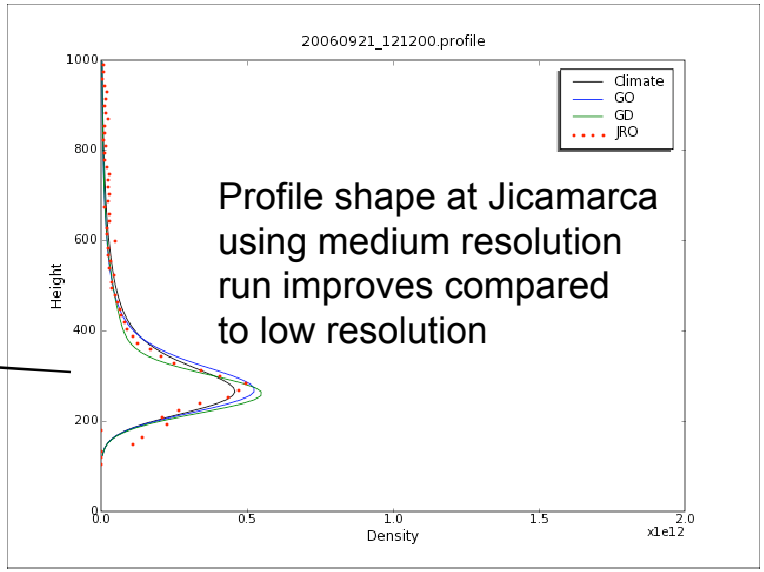


Medium Resolution GAIM VTEC Difference Maps

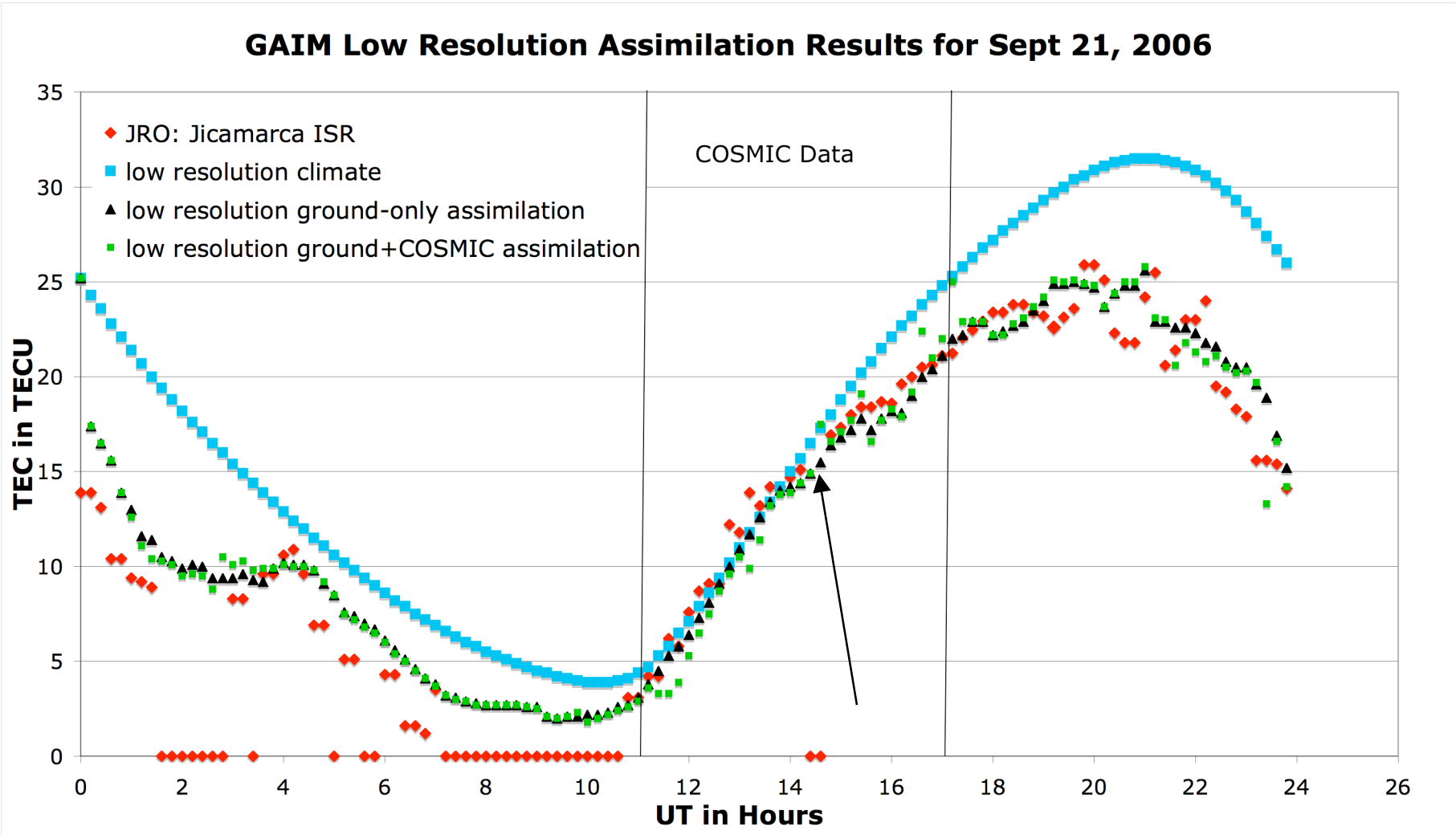






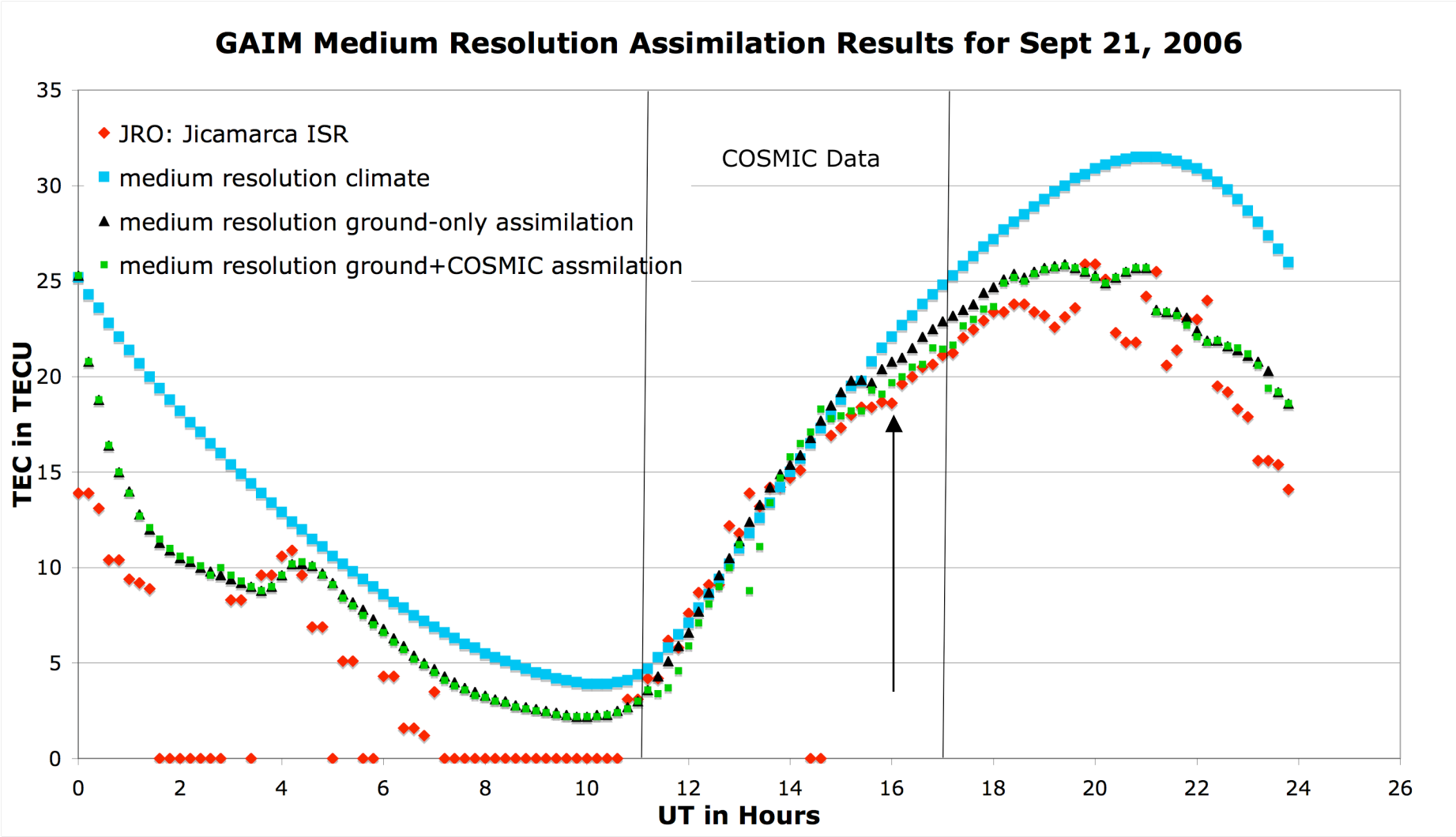


TEC Comparison for Low Resolution



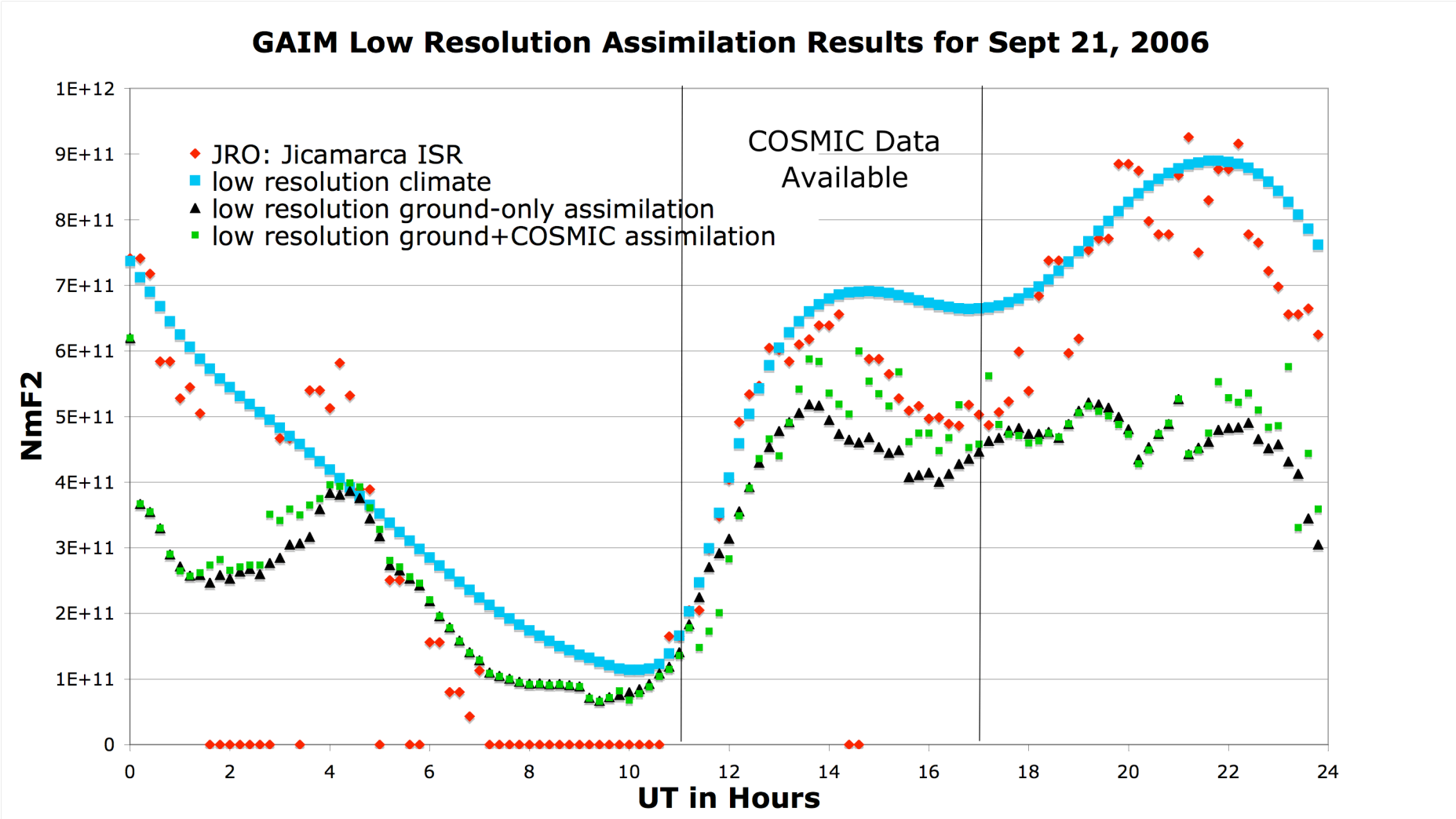
Low resolution ground-data only GAIM run matches Jicamarca VTEC well due to nearby GPS ground sites; COSMIC not needed to get the TEC correct.

TEC Comparison for Medium Resolution



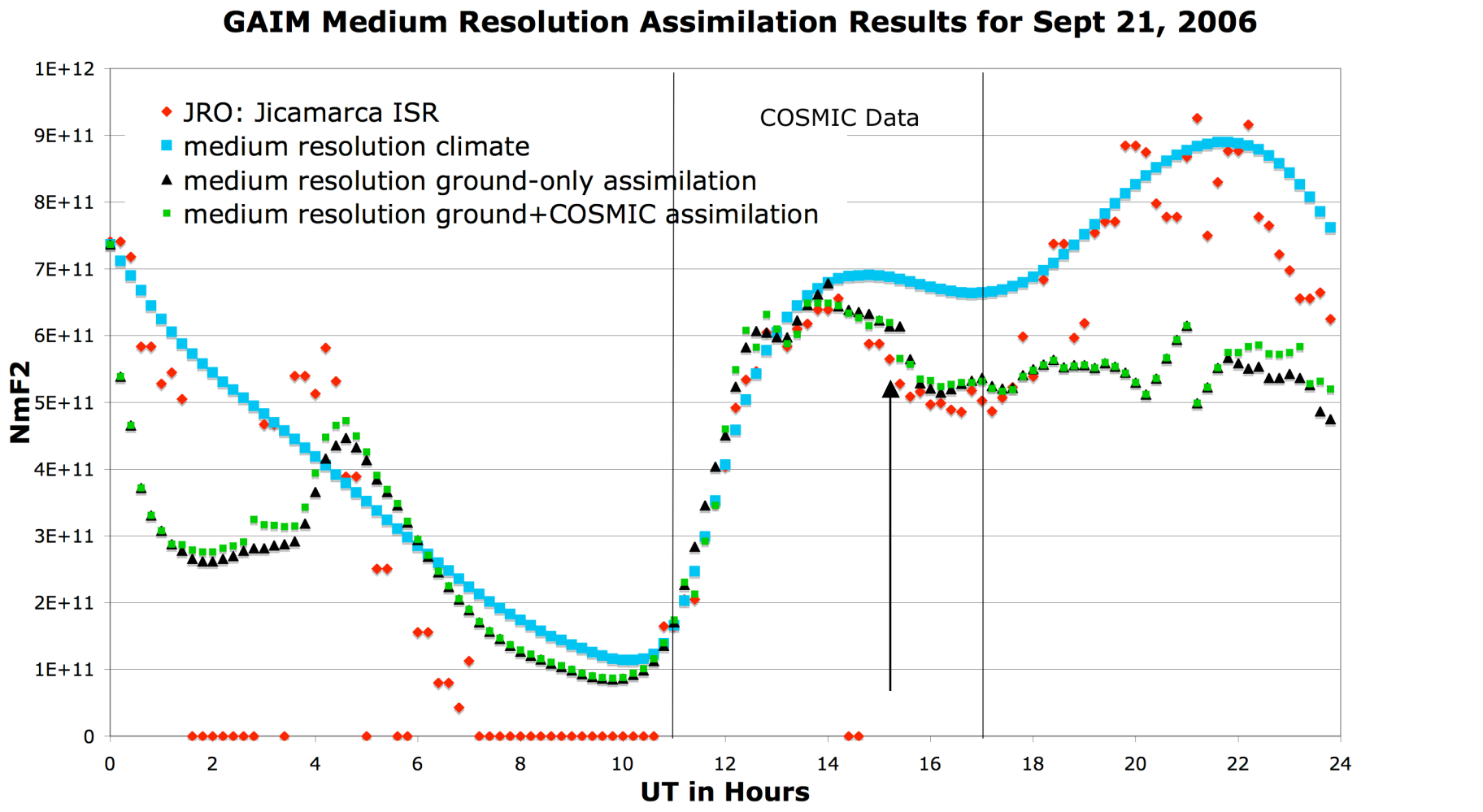
Medium resolution ground-data only GAIM run matches VTEC even better

NmF2 Comparison for Low Resolution



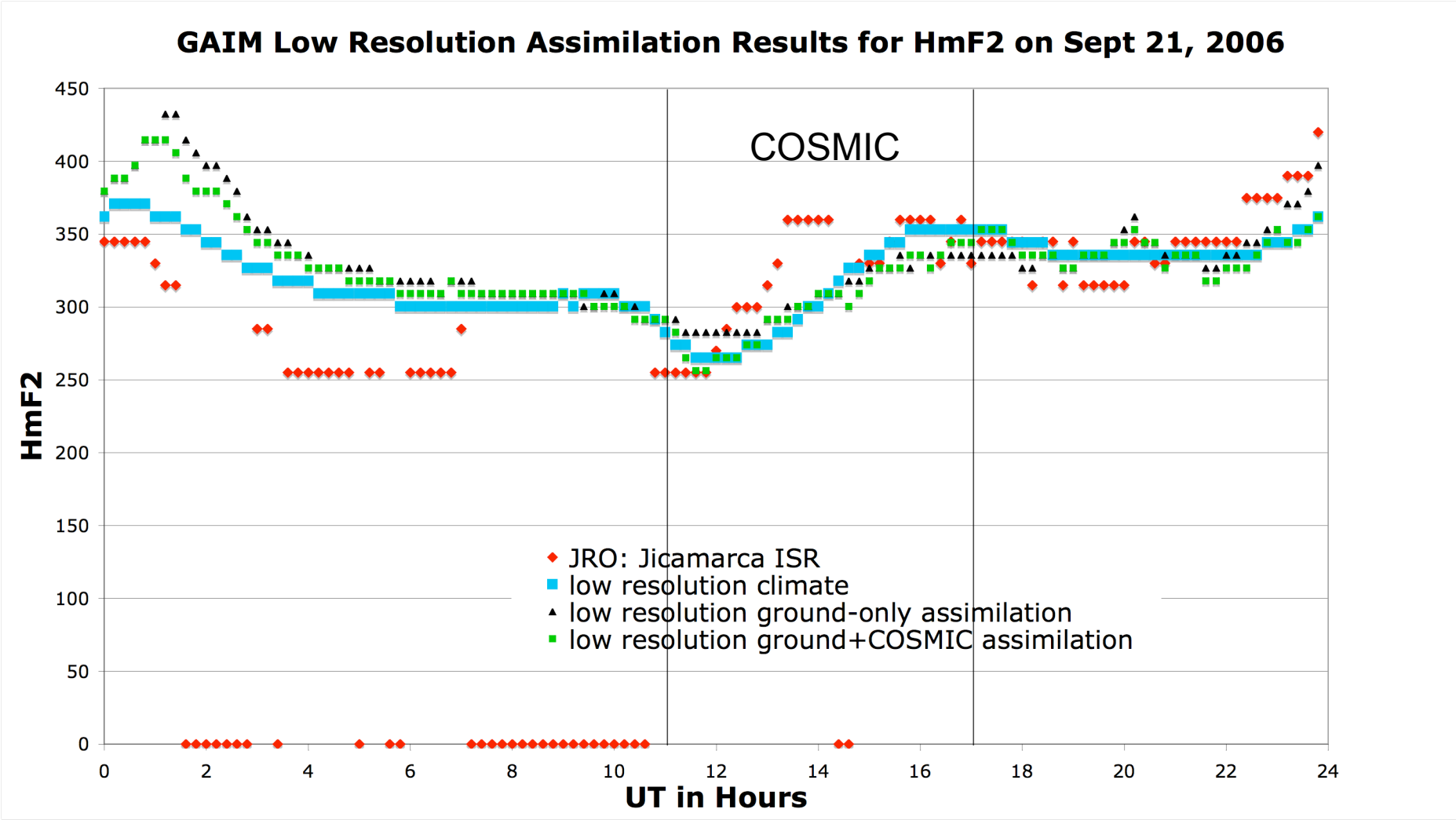
Low resolution GAIM NmF2 with COSMIC data is a better match than ground-only but noisier

NmF2 Comparison For Medium Resolution



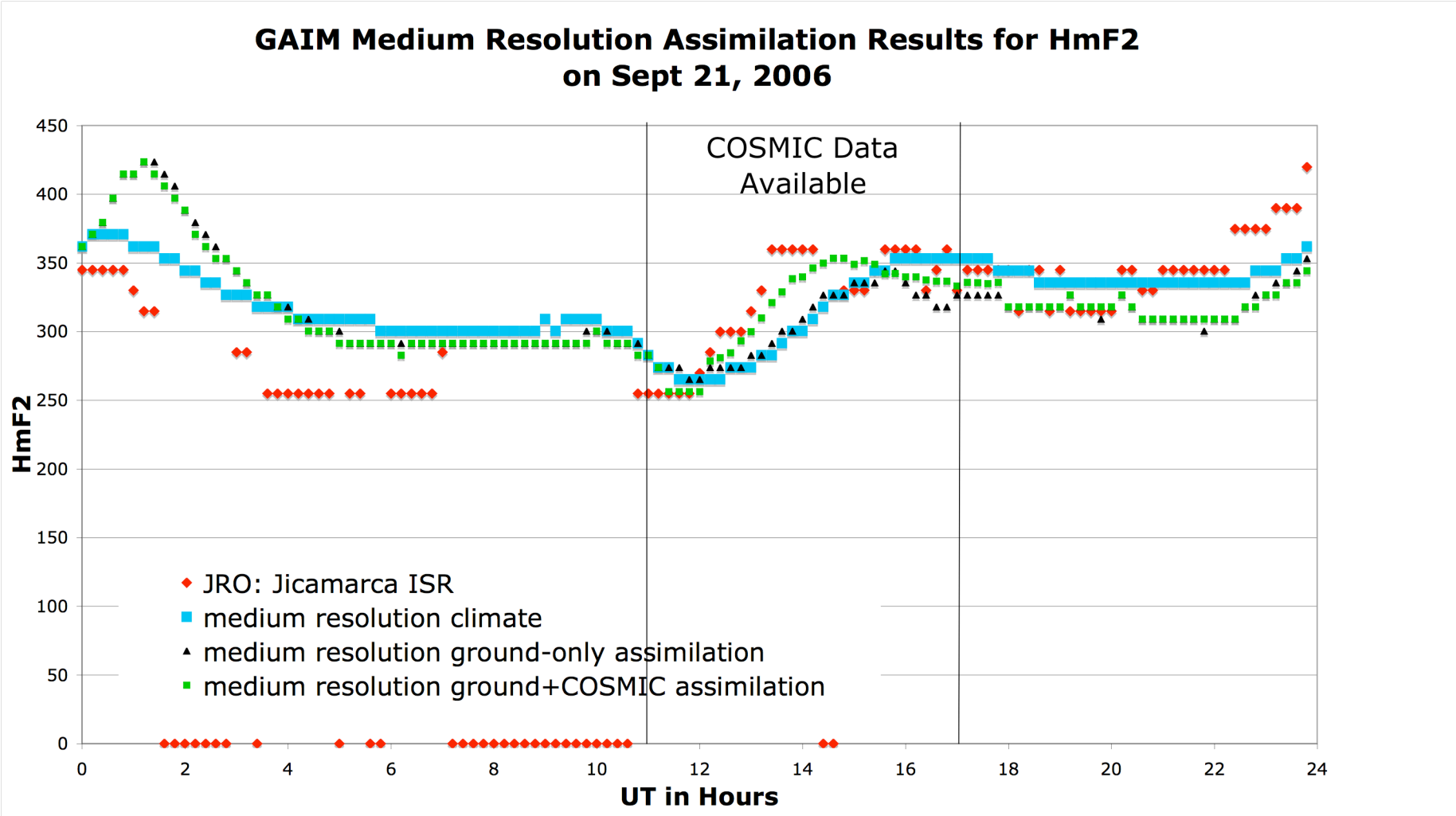
Medium resolution GAIM NmF2 with COSMIC data matches well during the dense data period 11-17 UT

HmF2 Comparison for Low Resolution



Low resolution GAIM HmF2 with COSMIC does not match with truth well

HmF2 Comparison for Medium Resolution

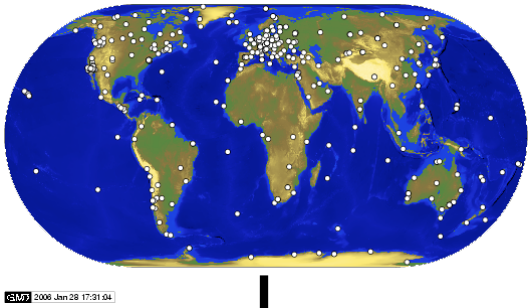


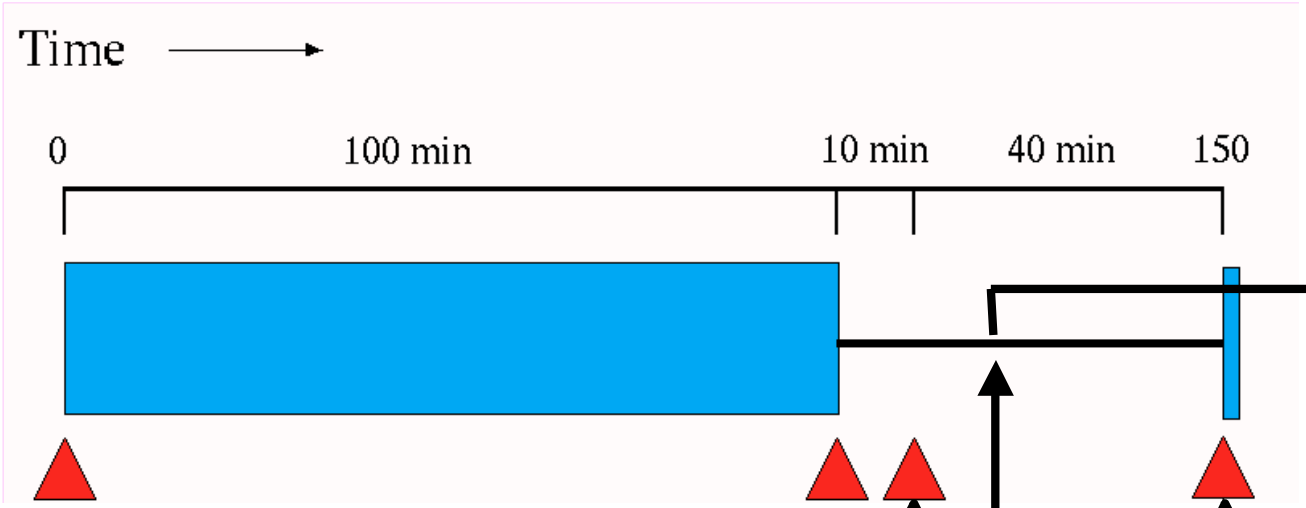
Medium resolution GAIM HmF2 with COSMIC matches best with truth

COSMIC Demo 2007

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

COSMIC data: 120+ minutes latency





GAIM

3-D global electron density grids 15-minute cadence

CDAAC: COSMIC Data Analysis and Archiving Center at UCAR

Summary and Conclusions

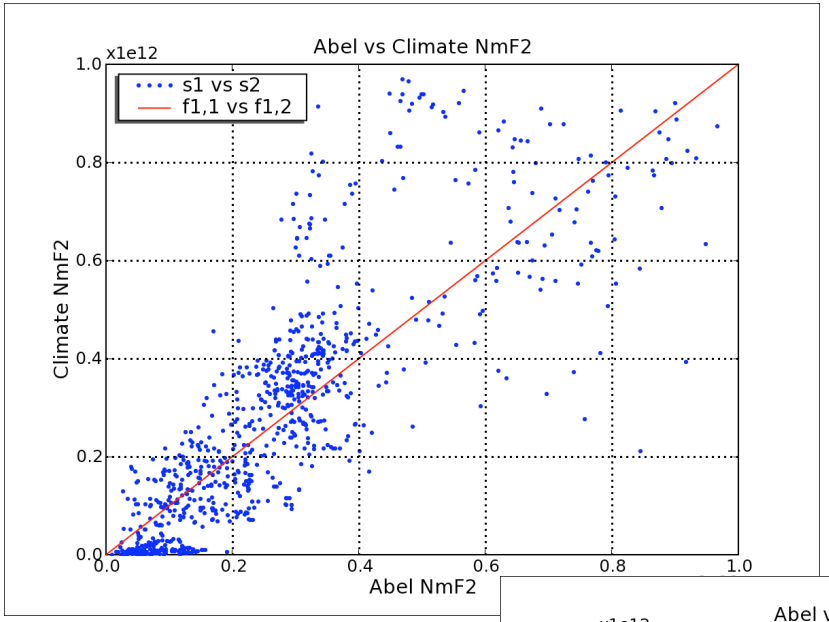
- JPL now routinely generates calibrated TEC and Abel electron density retrievals using COSMIC data.
- Performed GAIM assimilation using data from 200 ground-based GPS and six COSMIC satellites for Sept 21, 2006.
  - Ground-only, ground+COSMIC and climate GAIM runs performed.
  - GAIM profiles are validated using Jicamarca, Jason VTEC and Abel profiles.
- Jicamarca validation results show that assimilating COSMIC data improves NmF2 and Hmf2 significantly: i.e., resulting in improved profiles shapes. Assimilating COSMIC does not seem to improve TEC accuracy.
- Medium resolution GAIM runs using COSMIC measurements provide better agreement with Jicamarca truth for VTEC, NmF2 and HmF2 compared to low resolution GAIM runs.

Future Plans

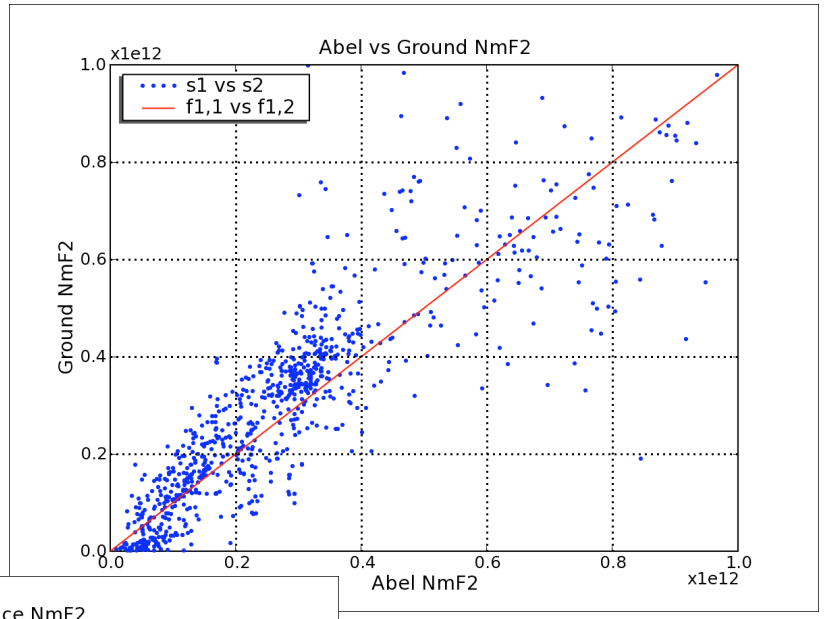
- Routinely inter-compare receiver bias estimates, calibrated TEC, and Abel profiles between UCAR and JPL.
- Continue comparing GAIM and Abel profiles to ISR's for neighboring Sep. 20 and 22, 2006 days and develop statistics.
- NRT GAIM Demo ingesting Ground GPS TEC and COSMIC TEC
  - Operational demo
  - Accumulate validation statistics
    - Density profiles vs. Abel
    - Density profiles vs. ISR
    - VTEC vs. JASON
- 4DVAR Driver Estimation for low & mid-latitudes
  - Input Ground and COSMIC TEC
  - Estimate two drivers simultaneously:
    - ExB drift velocity
    - Neutral wind

BACKUP SLIDES

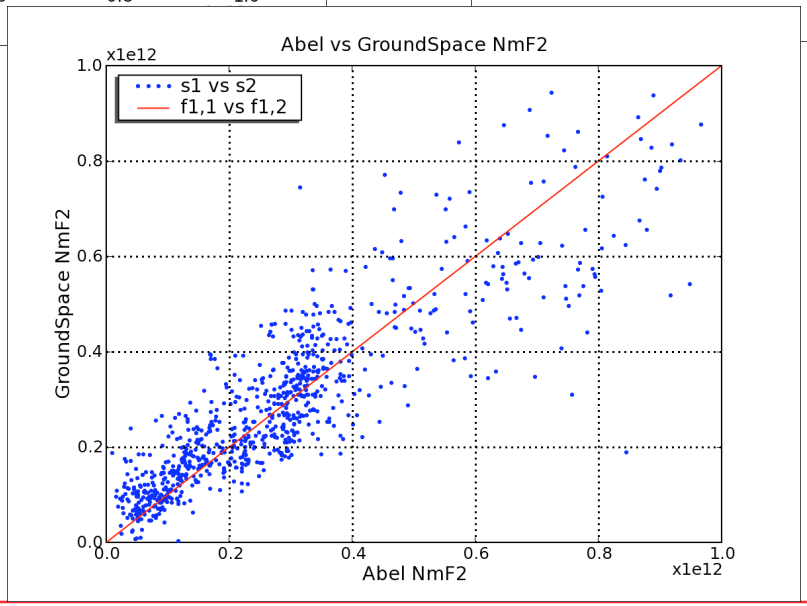
Comparing GAIM NmF2 to Abel: June 26, 2006



Climate (no data)

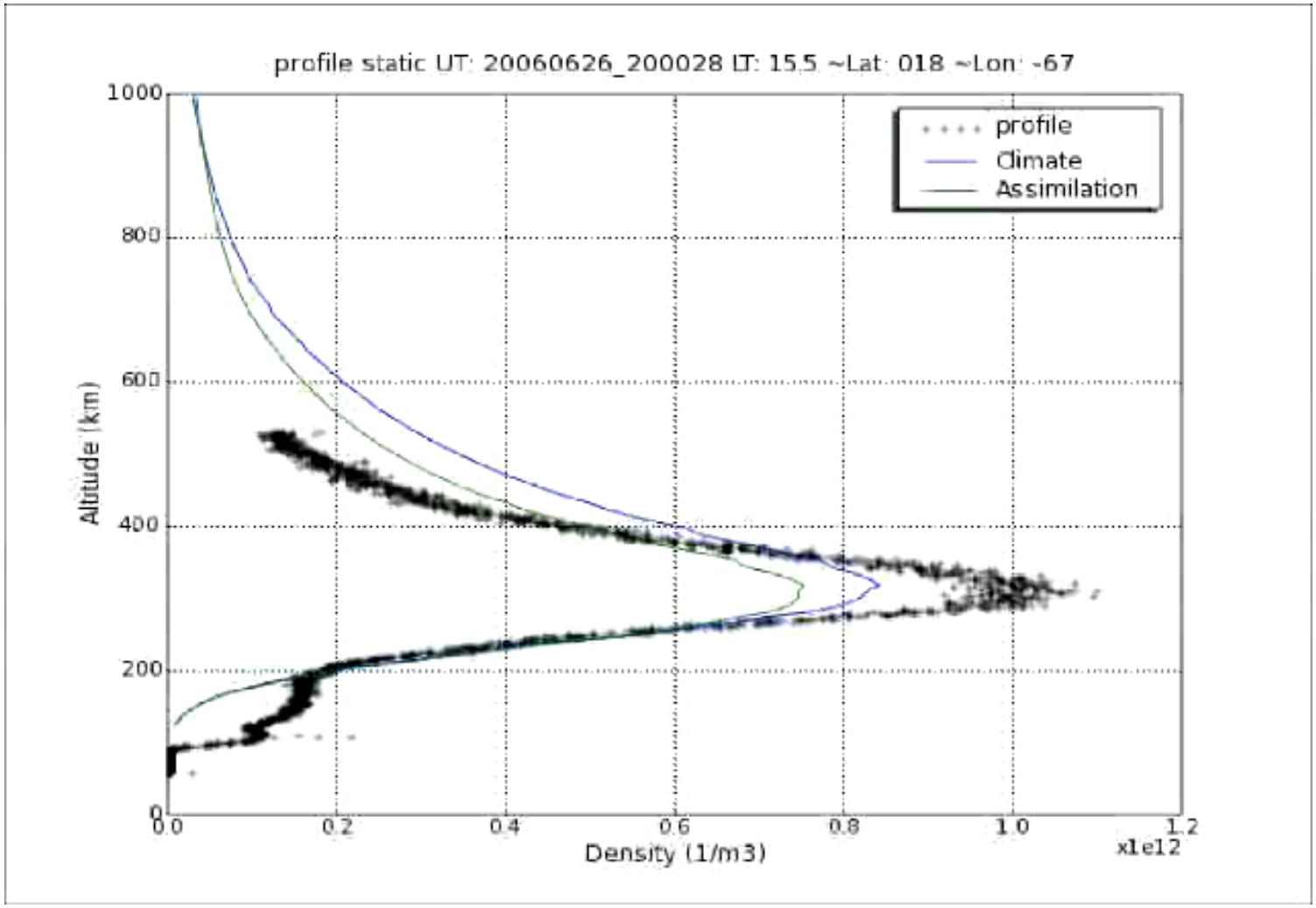


Ground only

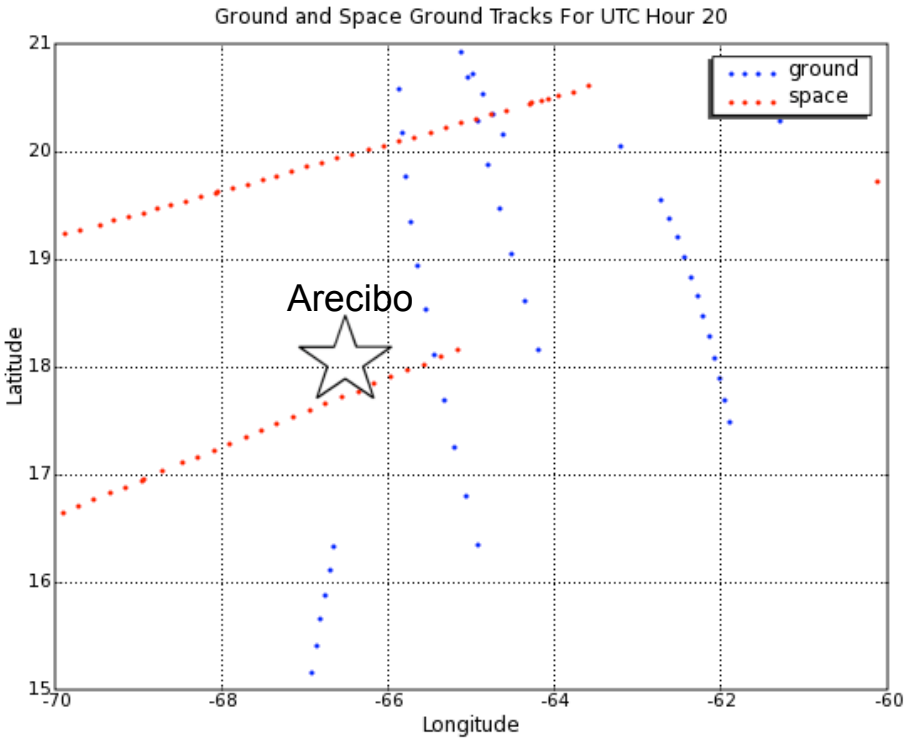


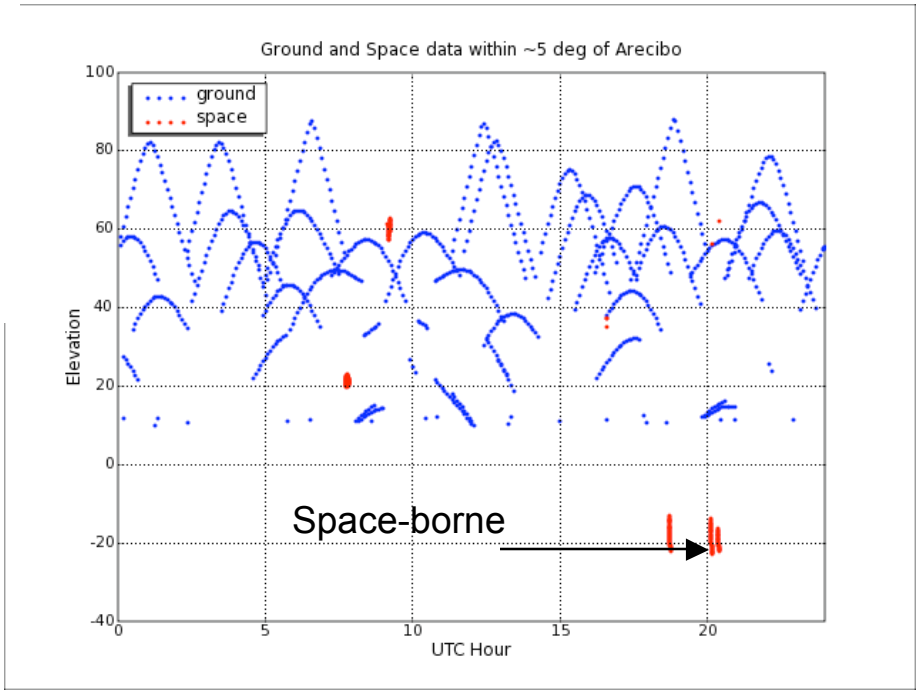
Ground + Space

GAIM Assimilation Using Ground and COSMIC Data



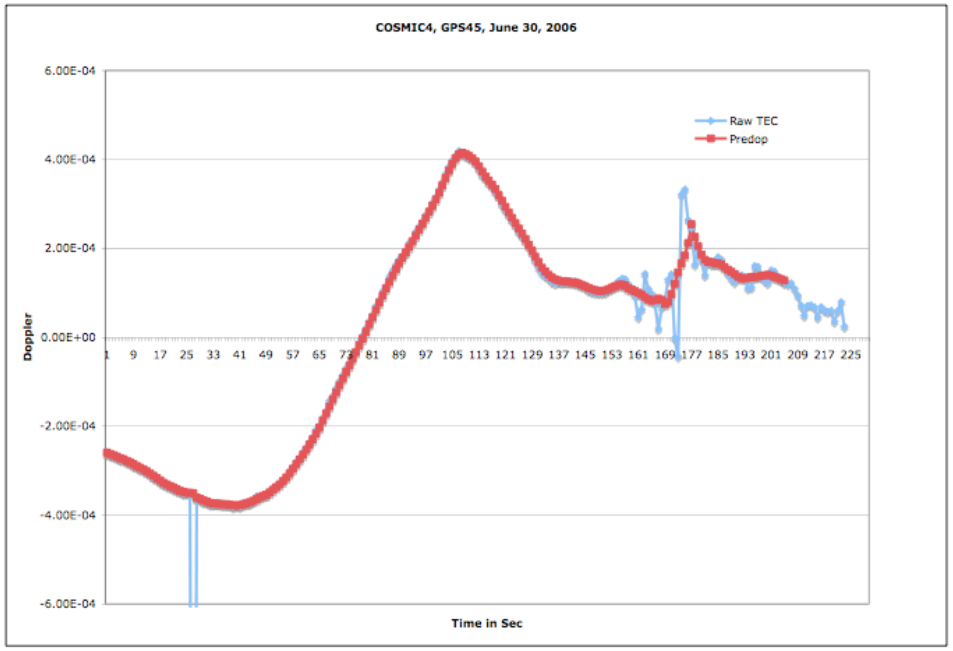
Ground Tracks: GAIM Assimilation for June 26, 2006 Using Ground and COSMIC Data

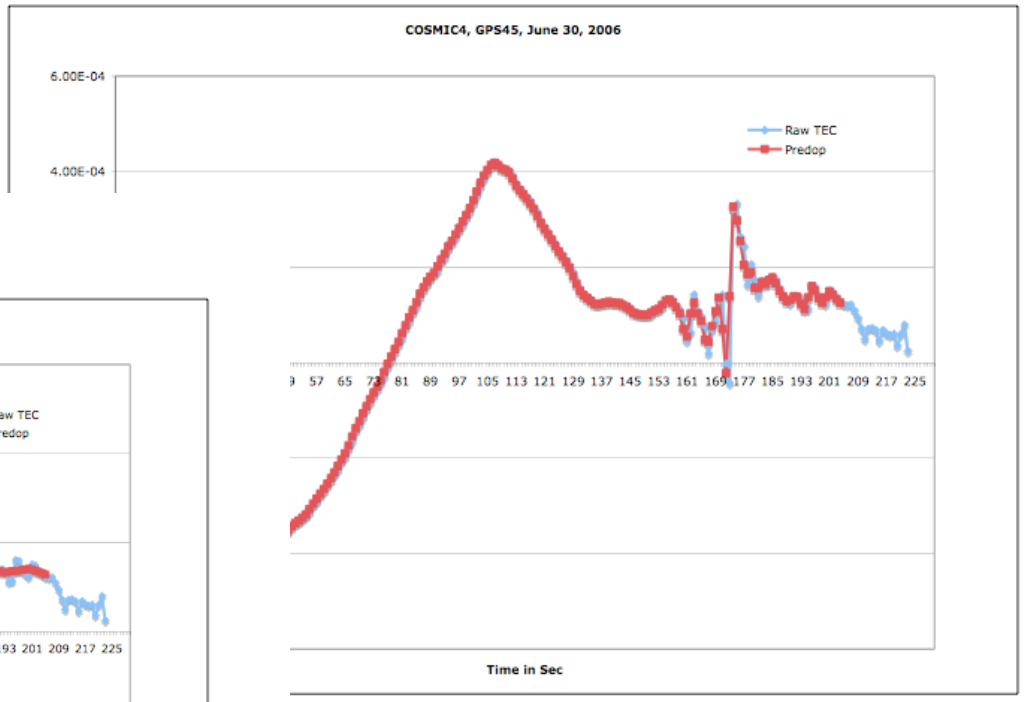




The Impact of Smoothing on Abel for June 26, 2006

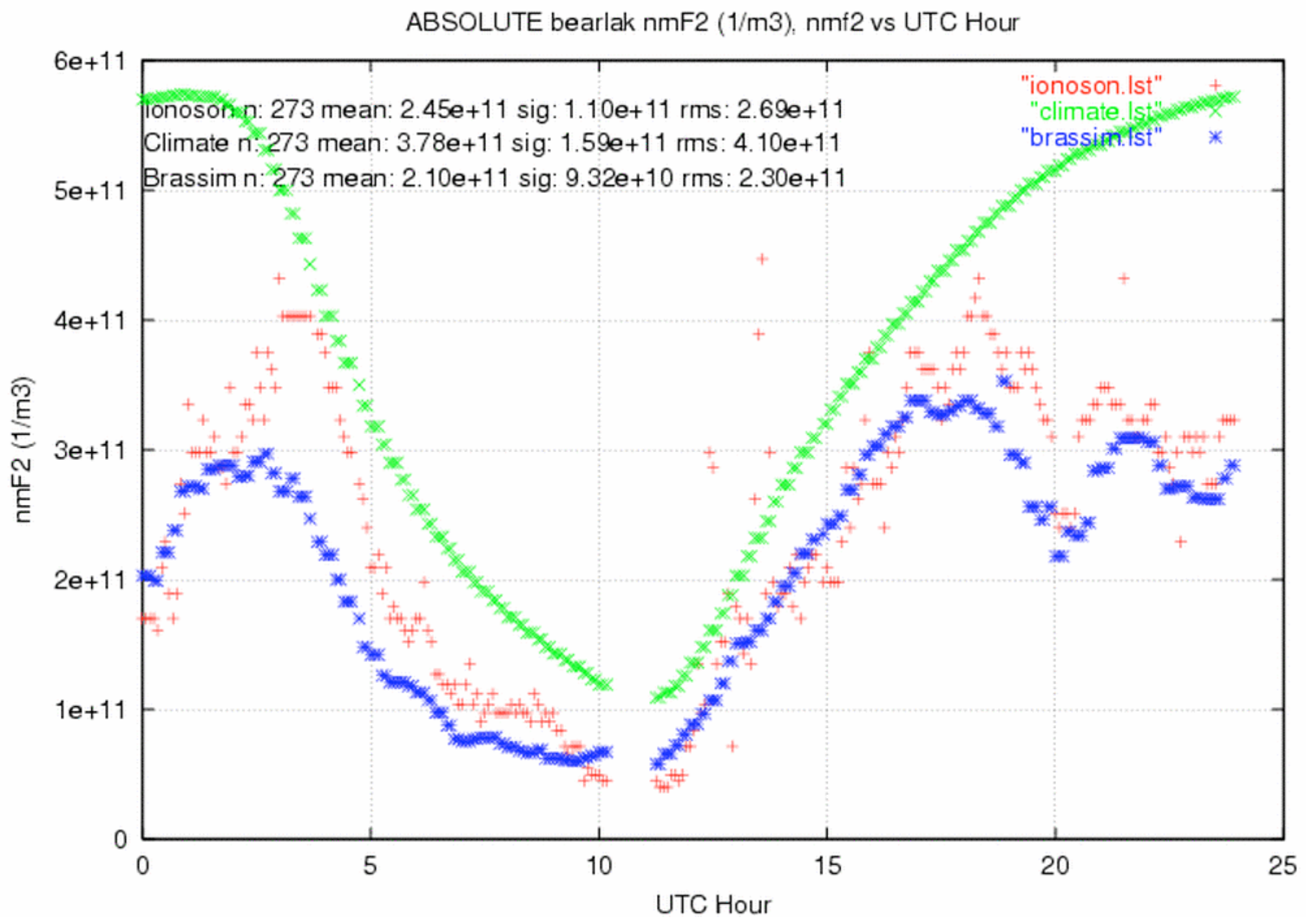
Smoothing filter



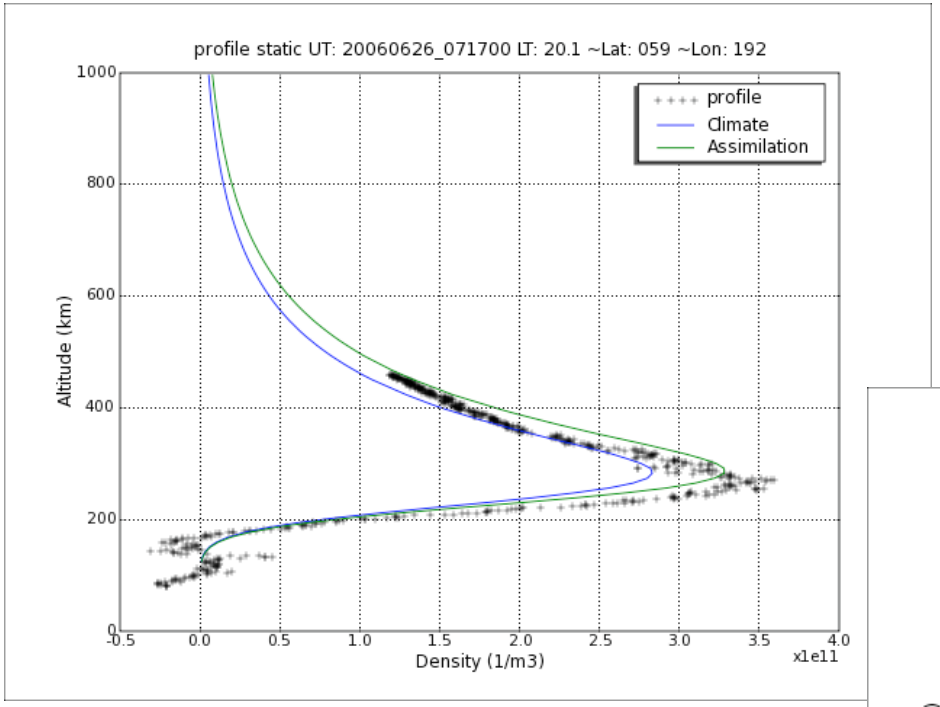


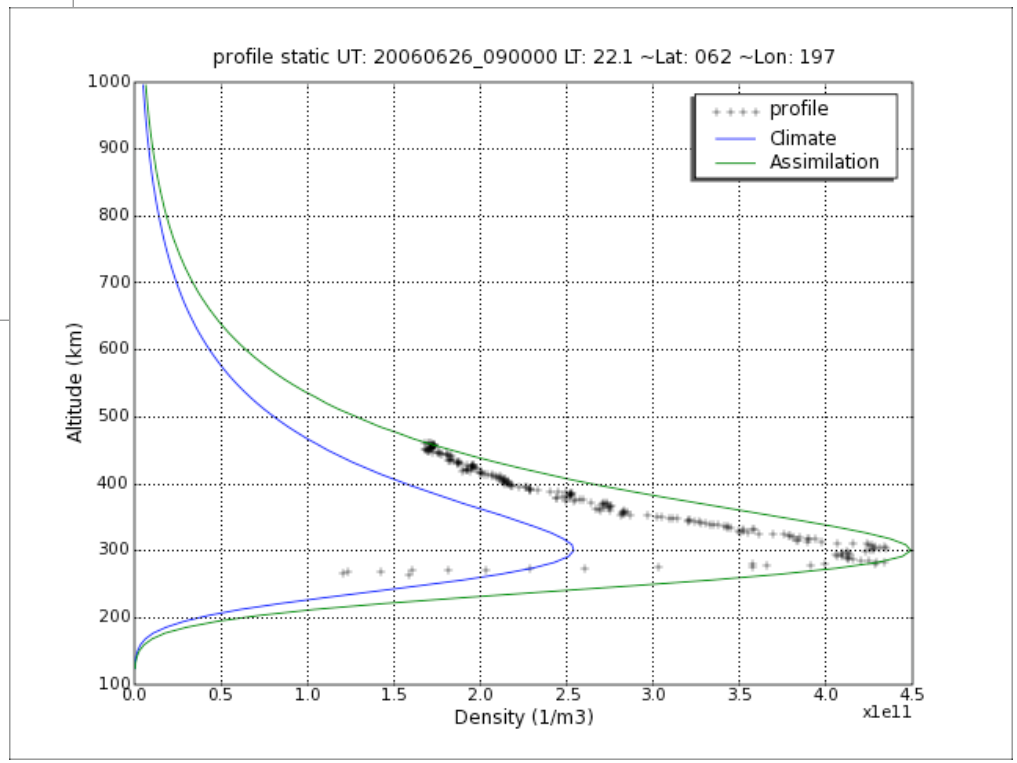
No Smoothing

NmF2 Comparison: Bear Lake



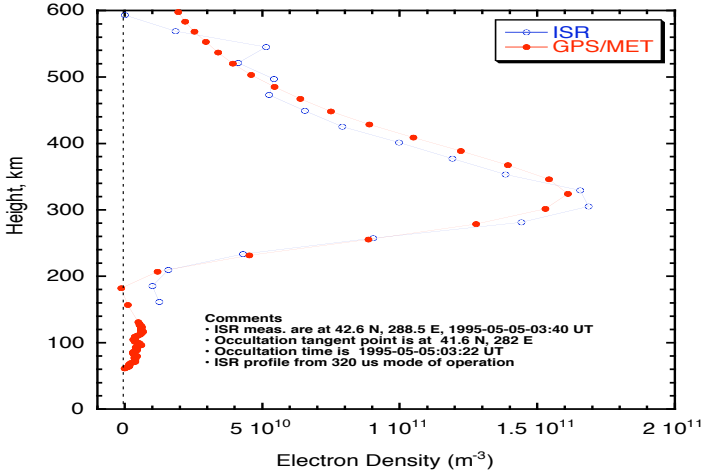
GAIM Validation Using Arecibo Profiles



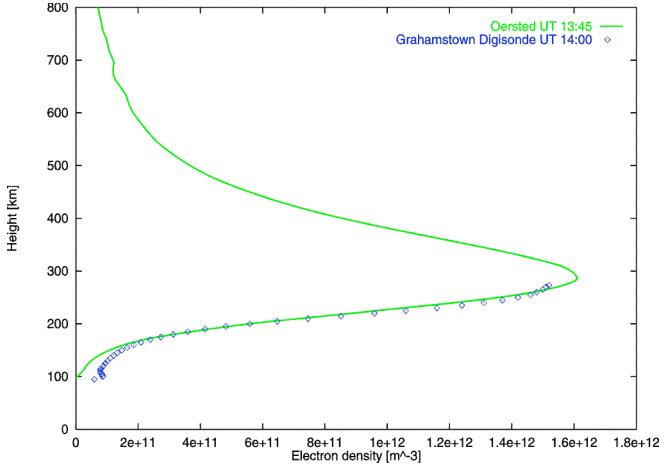


Historic examples of Abel electron density profiles

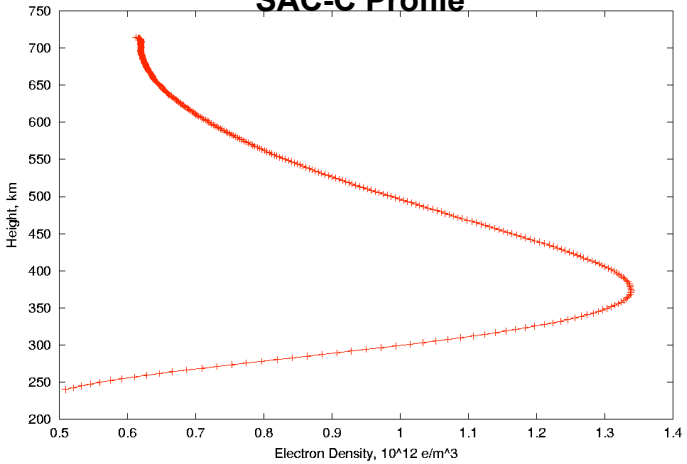
GPS/MET Profile
(Compared to Millstone hill radar)



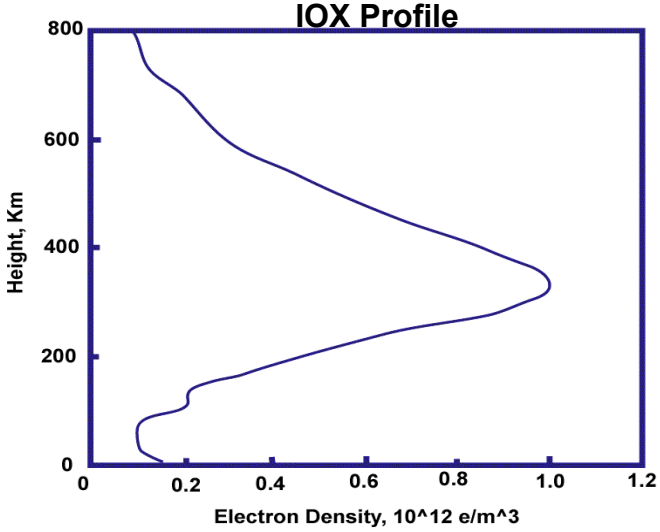
Oersted Profile
(Compared to nearby ionosonde)



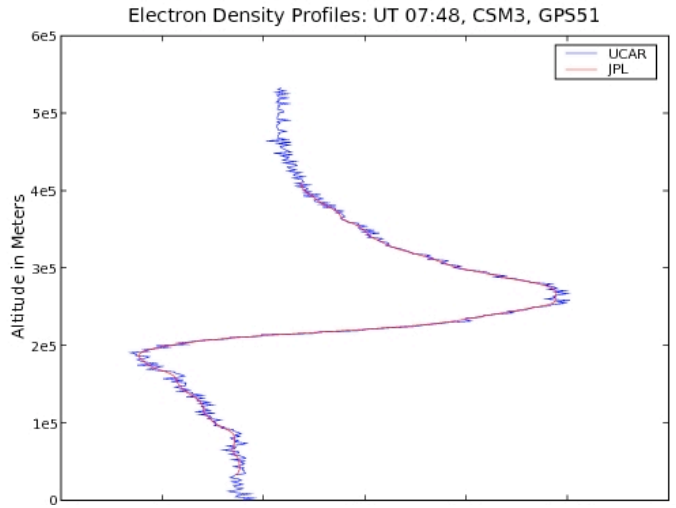
SAC-C Profile

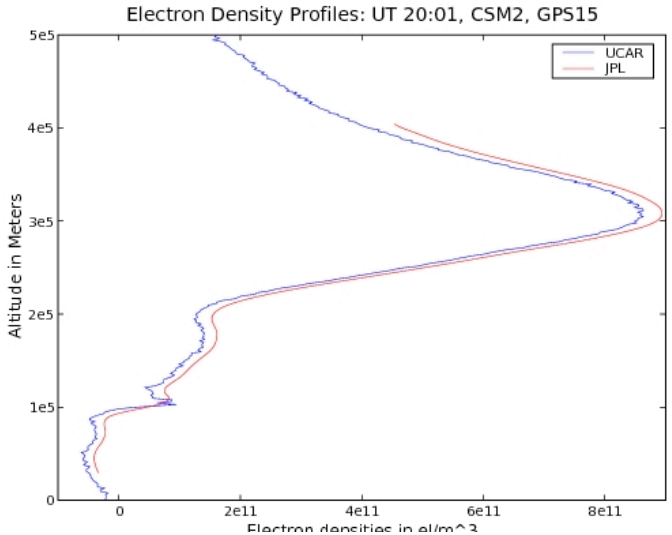


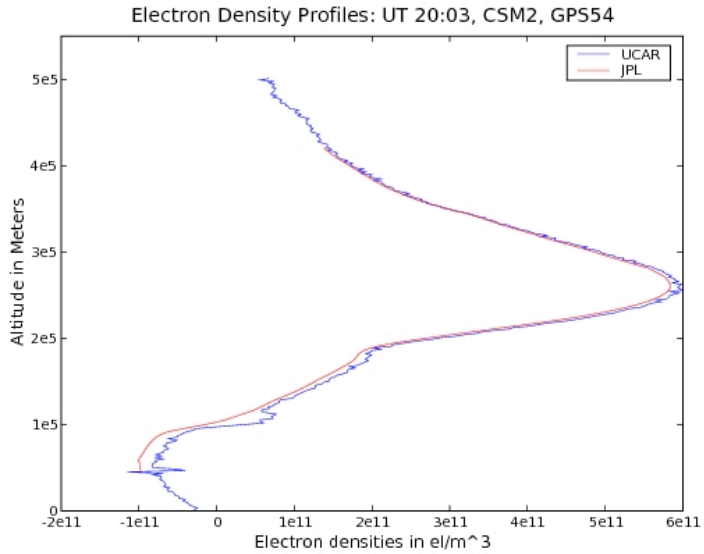
IOX Profile

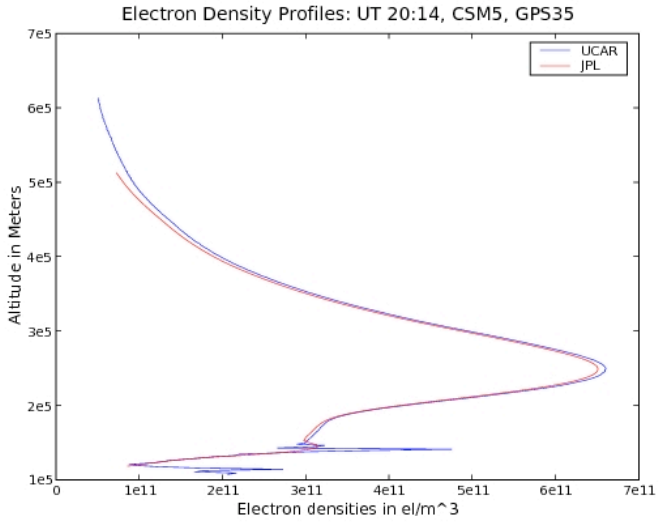


Comparison of UCAR and JPL Abel Profiles June 26, 2006



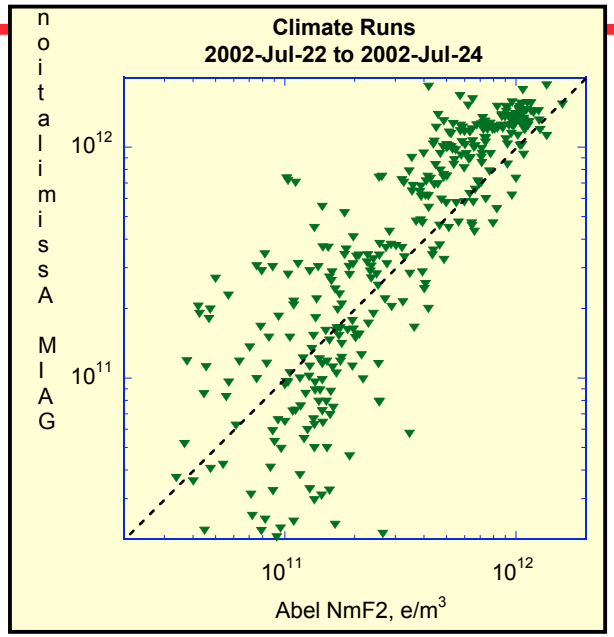


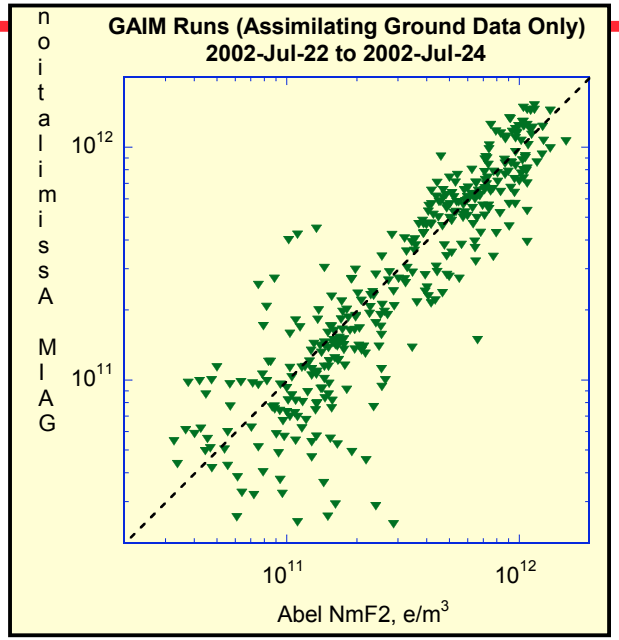


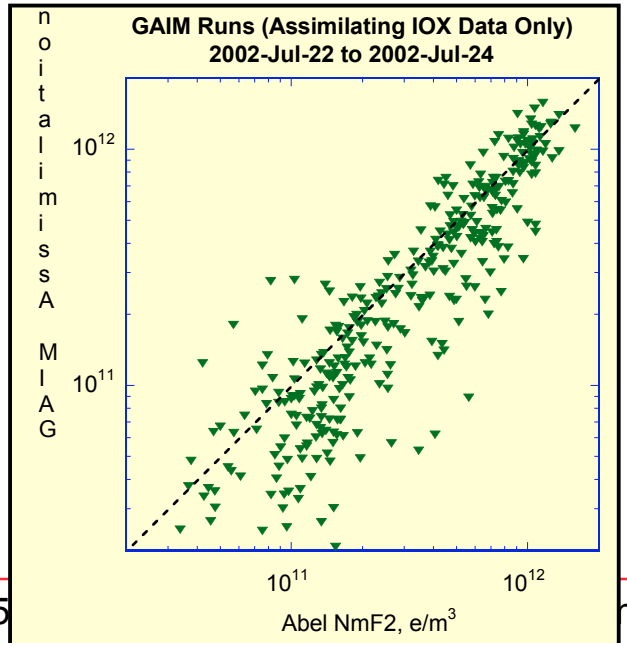


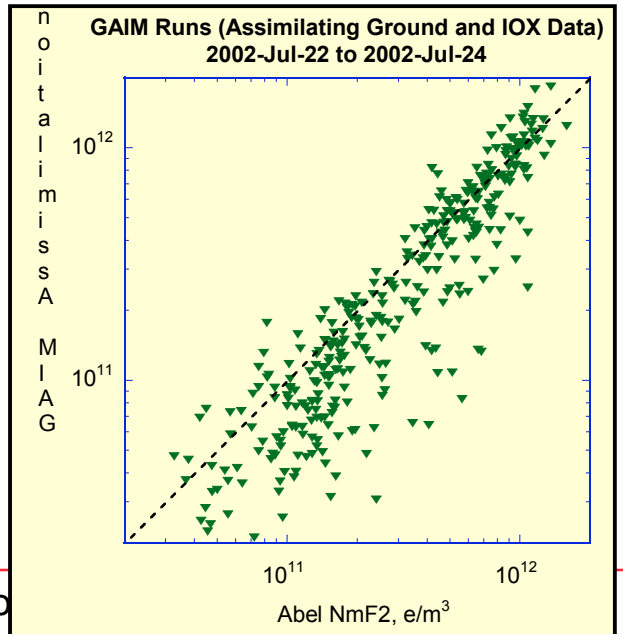
UCAR and JPL Abel profiles usually agree well

GAIM vs. Abel NmF2 Comparison

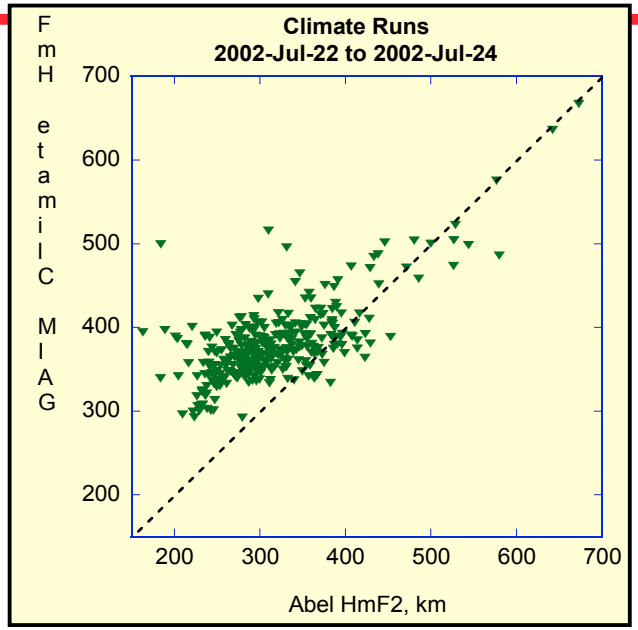


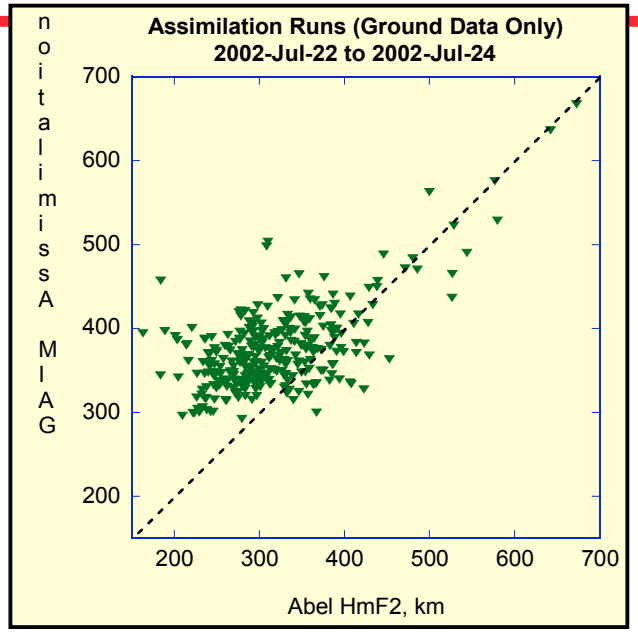


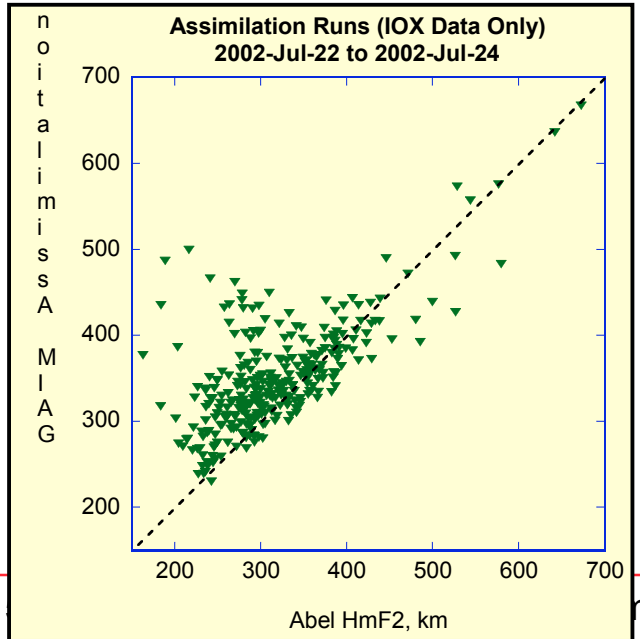


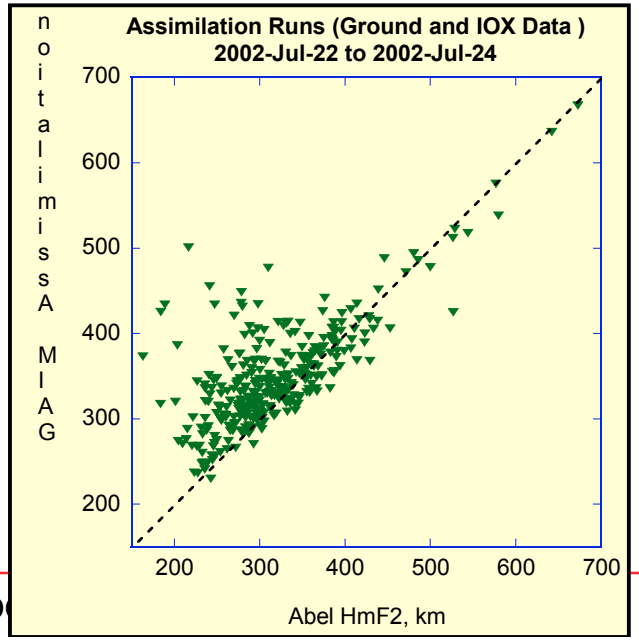


GAIM vs. Abel HmF2 Comparison

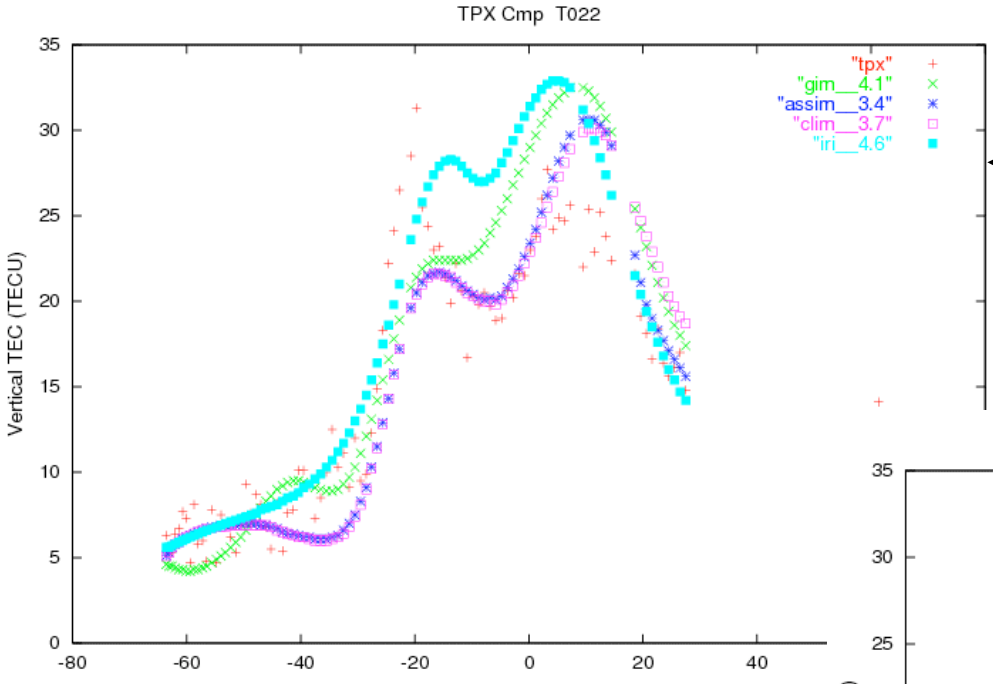








GAIM Validation Using Jason-2 Vertical TEC



Ground-data only

Ground and space data