Assimilative Modeling of Low-Latitude Ionosphere

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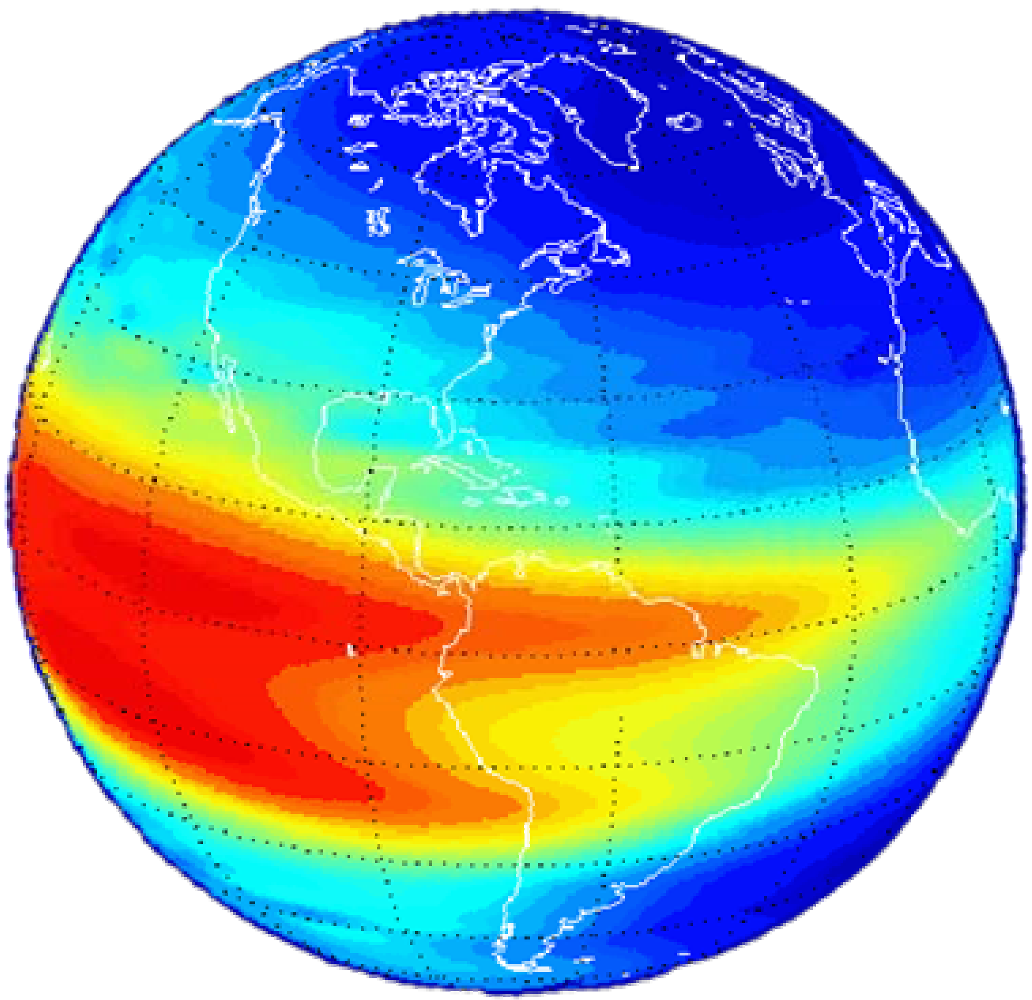
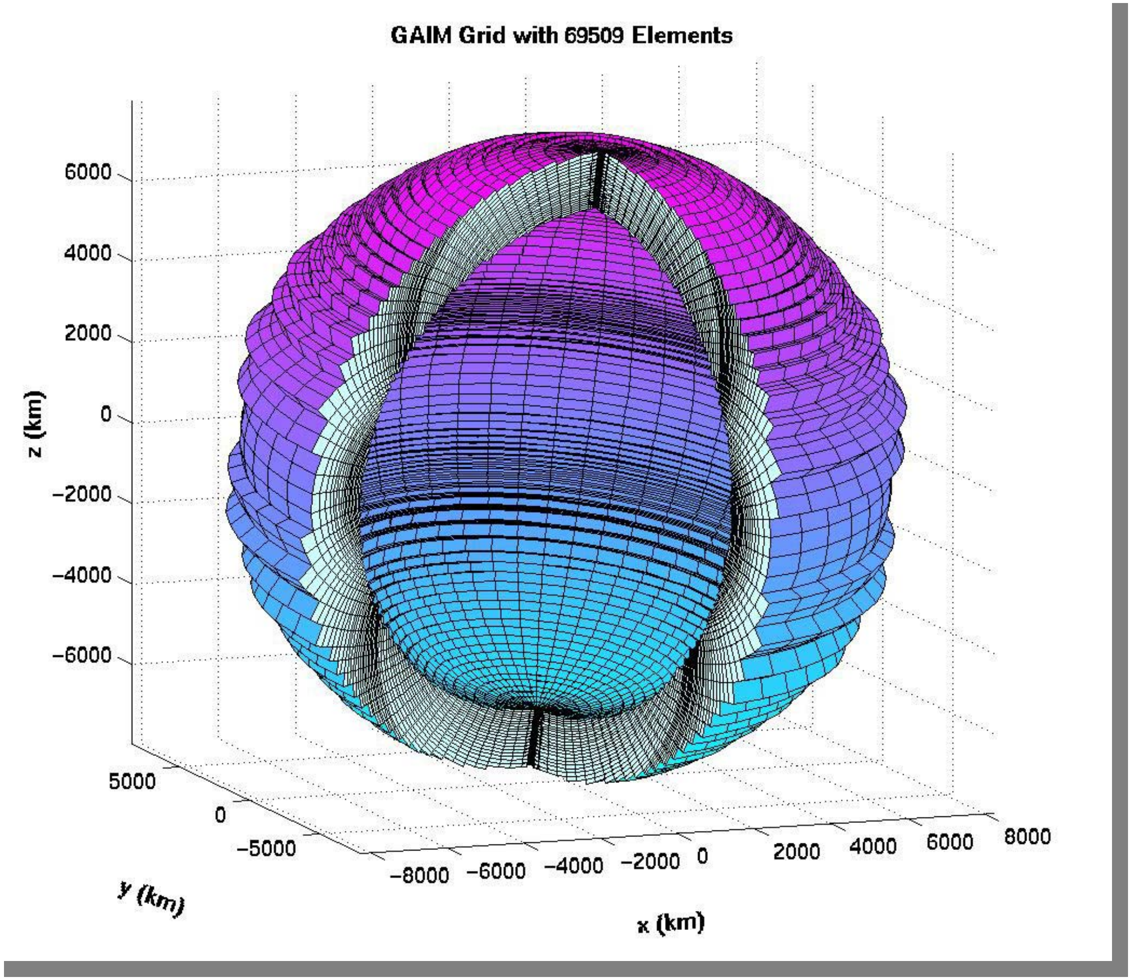
Global Assimilative Ionospheric Model

- **Physics Forward Model**
  - Solving plasma continuity and momentum equations numerically for ion and electron densities
- **Numerical Scheme**
  - Finite volume on a fixed Eulerian grid
  - Hybrid explicit-implicit time integration scheme
- **Inputs**
  - Empirical models for solar EUV spectrum, ξ_a, **E** or **E**×**B** drift, $\mathbf{U}_n$, N_n and T_n, driven by indices of F10.7cm solar flux and magnetic Ap, as well as inputs for high lat
- **Outputs**
  - n_i (presently O^+) and n_e
  - Estimated **E**×**B** drift (zonal), meridional wind, etc. at low latitudes



Global Assimilative Ionospheric Model

- **Grid**
  - Fully 3-D fixed Eulerian grid
  - Geomagnetic eccentric titled dipole frame
  - Full and partial plasma flux tubes
- **Coverage**
  - Global
  - Regional
    - Global in longitude and regional in latitude
    - Regional in both lat and longitude
  - *F* region
    - Presently 150 – 1500 km for O^+
- **Resolution**
  - Δt: (1) Forward integration - a few seconds to ~2 minutes; (2) a few to 12-minutes for updating physics parameters
  - $\Delta \boldsymbol{r}$: flexible



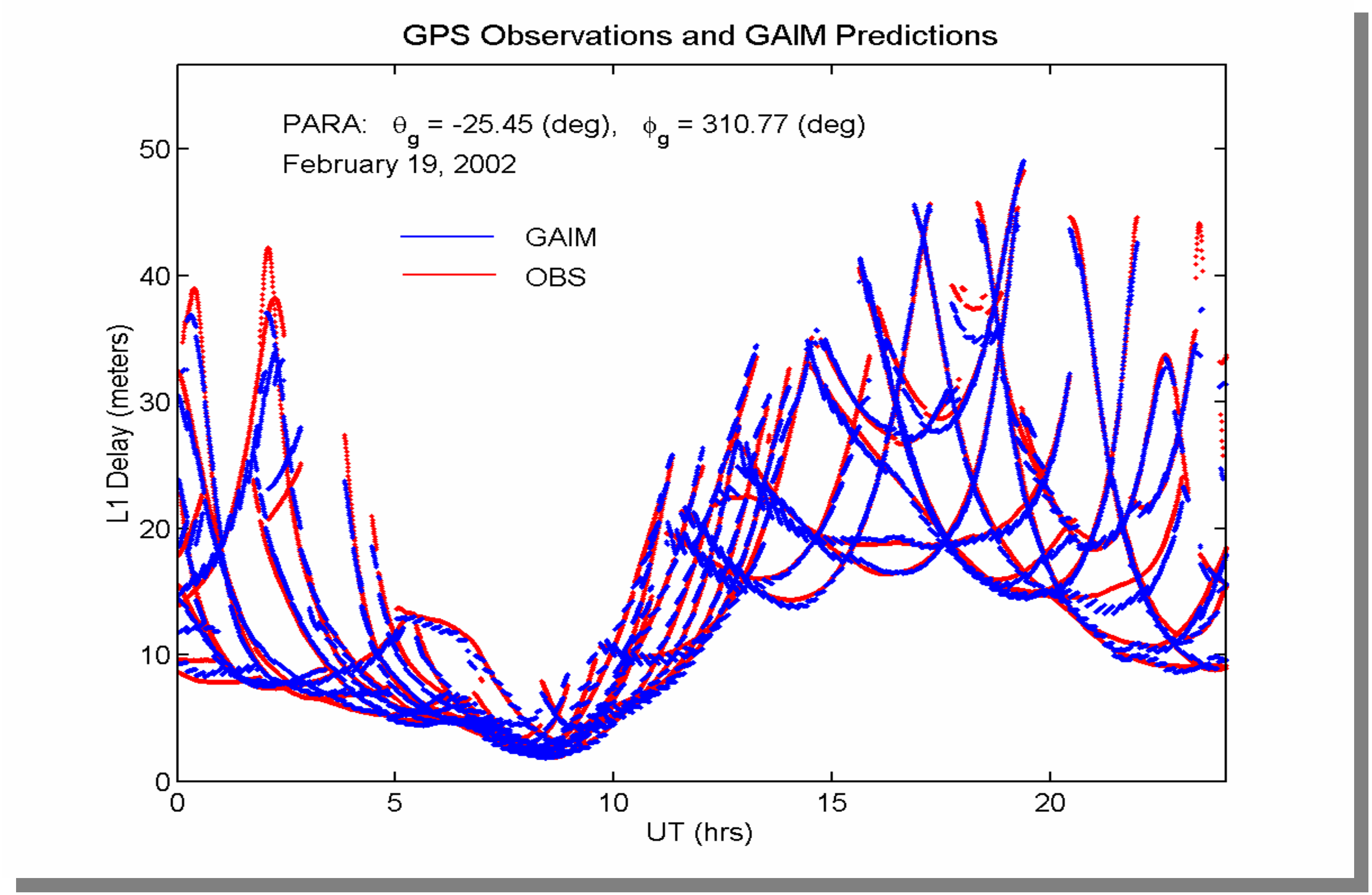
Optimization Techniques for Data Assimilation

- Recursive Filtering – Kalman Filter
  - Covariance estimation and state correction
    - Optimal interpolation
    - Band-limited Kalman filter
- 4-Dimensional Variational Approach (4DVAR)
  - To minimize cost function by estimating driving parameters
  - Non-linear least-square minimization
  - Parameterization of model “drivers”
- Data Assimilation Sources
  - Ground-based and space-borne GPS measurements of line-of-sight TEC
  - Airglow emission (radiances)
  - n_e profiles and parameters as well as in situ measurements
  - Driving parameters

Validation Campaign: "Blind Test"

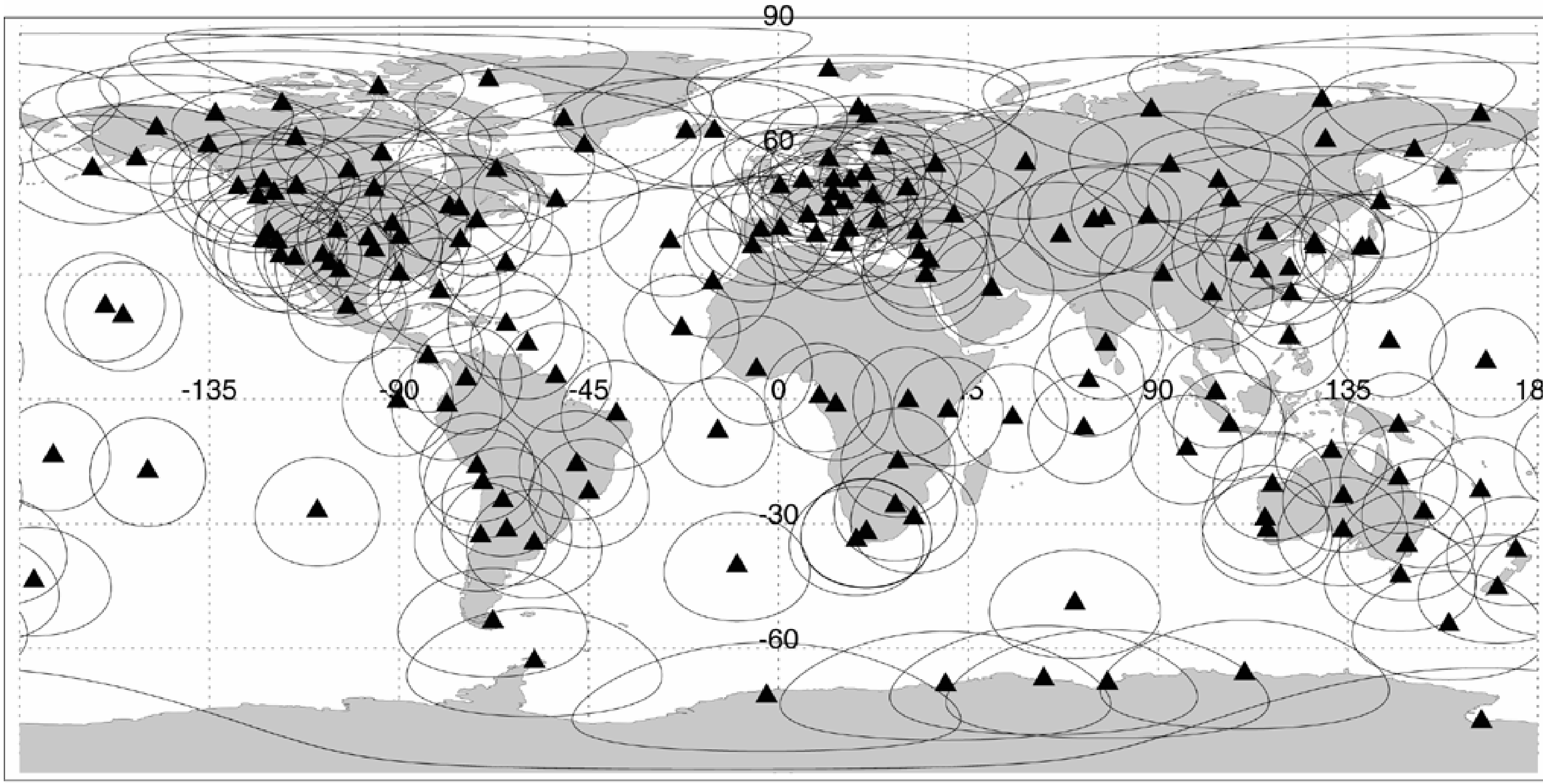
- Regional and global GAIM processes
  - Climatology GAIM runs with and without JRO-ISR measurements of plasma vertical drift
  - *Assimilation of Line-of-sight absolute TEC* measured from the IGS Global GPS Network and three LEO satellites
  - Optimization techniques
    - ✓ *Kalman Filter*: Covariance estimation and state correction
    - ❖ 4DVAR: Estimation of model drivers
- Model Accuracy Assessment
  - Comparison with TOPEX measurements of vertical-TEC above oceans
  - Comparison with digisonde measurements of n_mF_2 and h_mF_2
  - Blind test: No tuning of GAIM optimization coefficients and parameters!
- Validation with JRO-ISR n_e profiles

GAIM Predictions of Slant TEC



IGS Global GPS Network

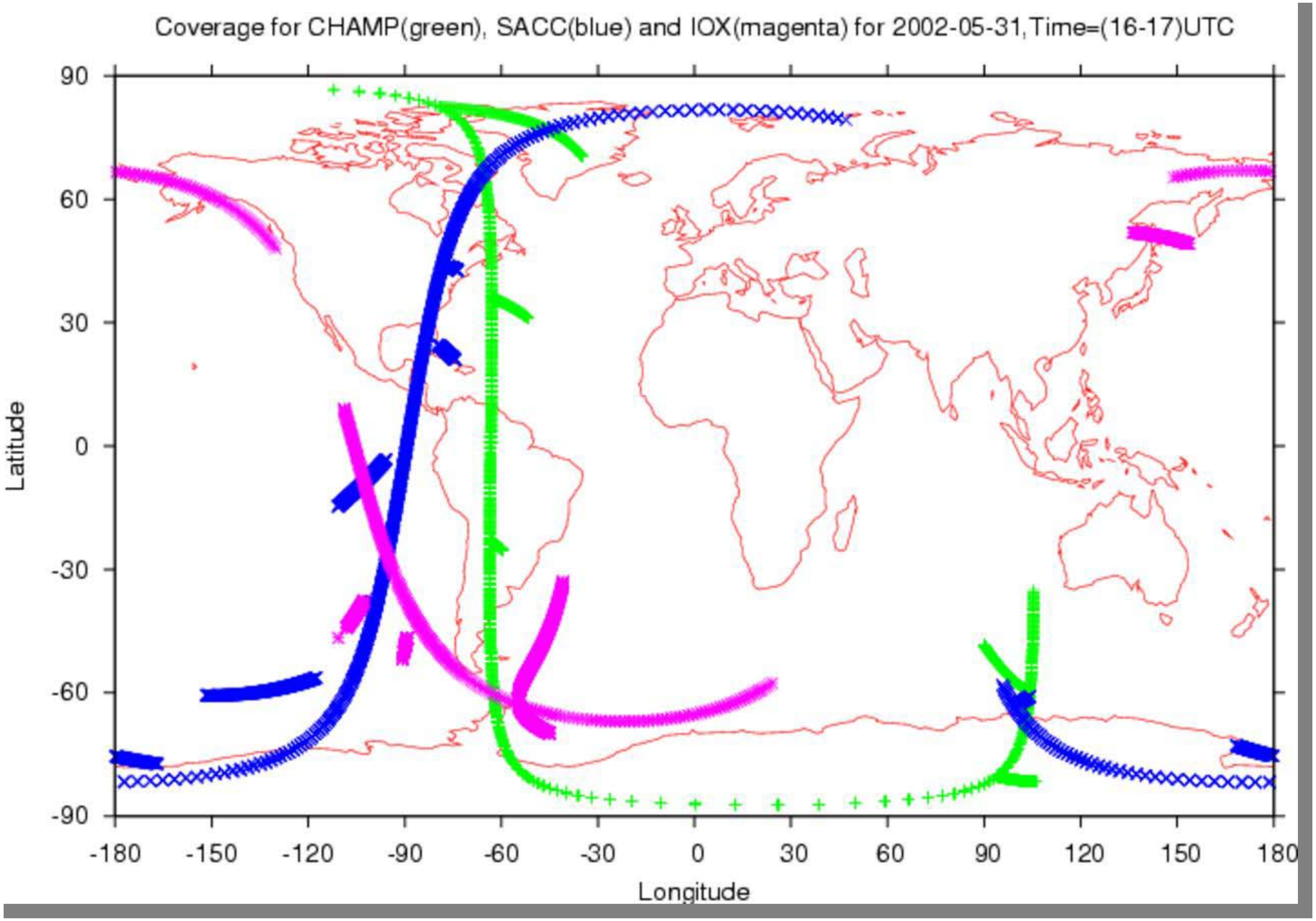
IGS Global GPS Network (present)



10 degree elevation mask. Subionospheric height at 450 km.

IGS data are assimilated into GAIM on a daily basis and a subset is assimilated in real-time.

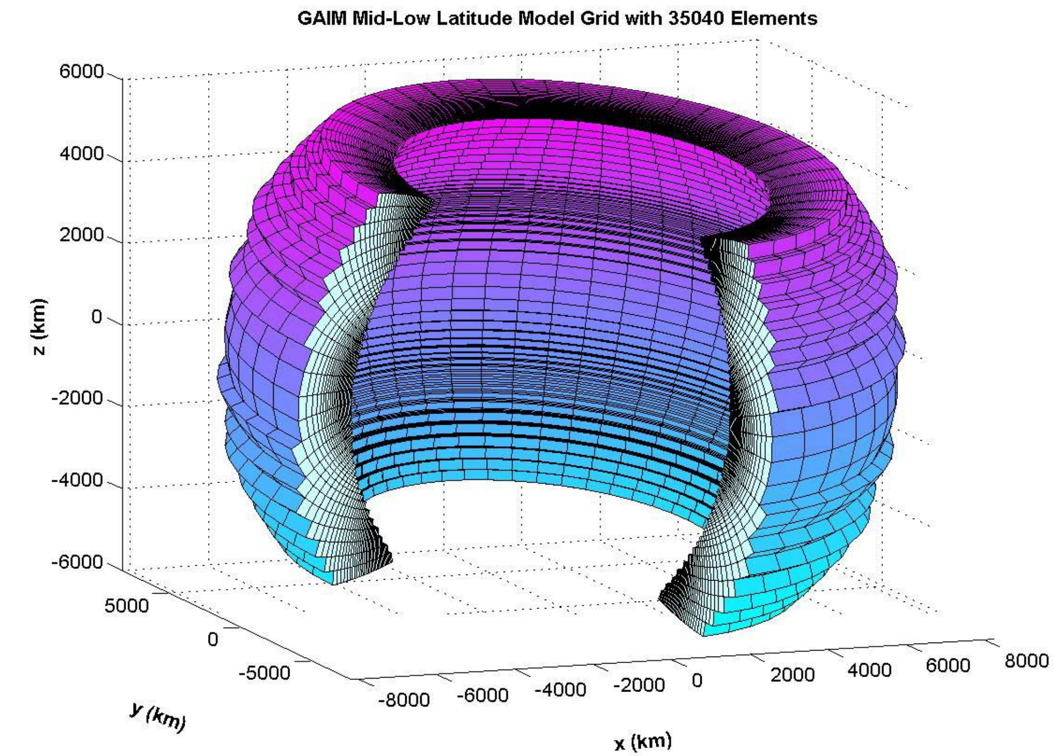
Orbital Tracks of Space-Borne GPS Receivers



GPS occultation data and orbital data (uplooking) are assimilated into GAIM.

GAIM Low-Latitude Grid

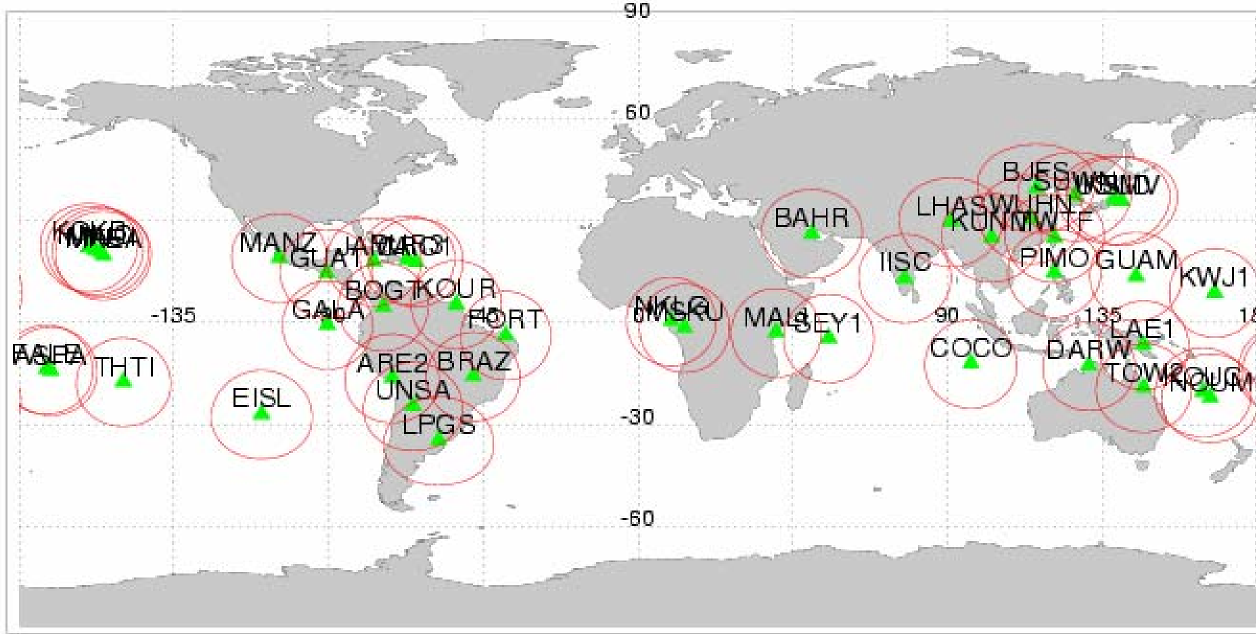
- **Grid**
  - Fully 3-D fixed Eulerian grid
  - Geomagnetic eccentric titled dipole frame
  - Full and partial plasma flux tubes
- **Coverage**
  - Regional
    - Global in longitude and regional in latitude
    - ±30° magnetic latitudes
  - *F* region (150 – 1500 km for O^+)



Regional GPS Data for the Campaign

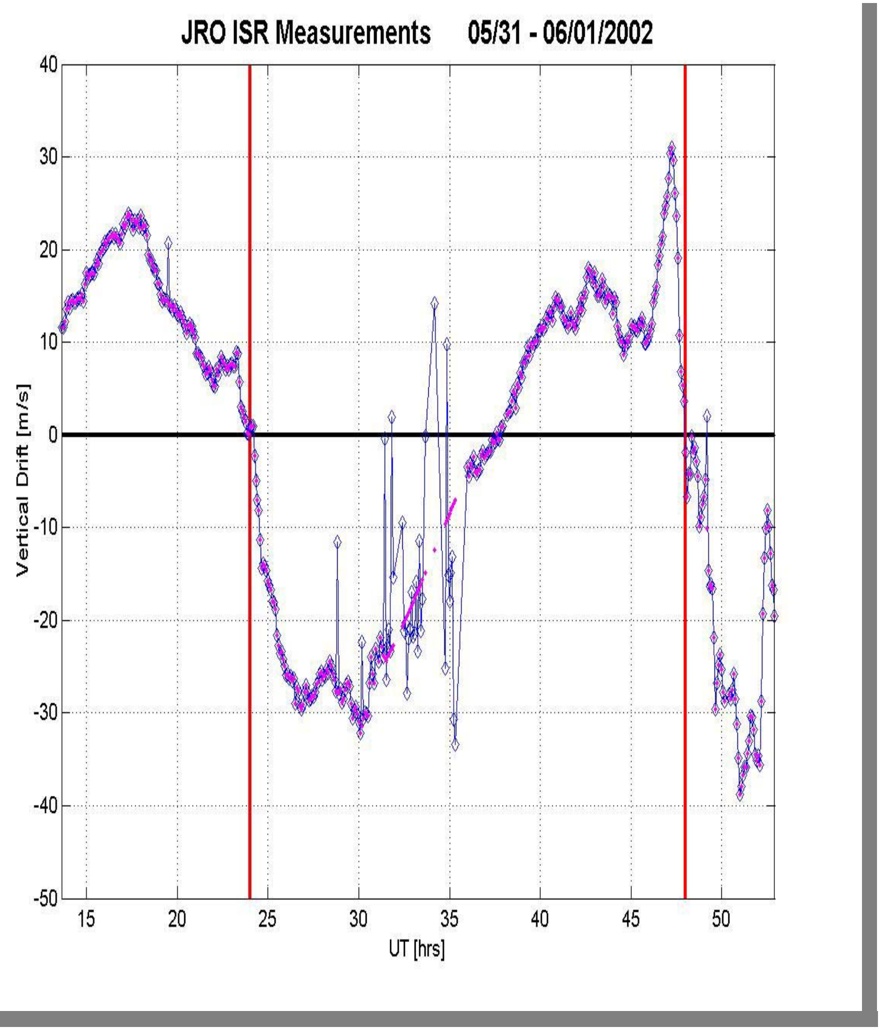
- 49, 44, 50 IGS GPS sites for 5/31/2002, 6/1/2002, and 6/2/2002, respectively
- Global in longitude
- Data outside bounded region (±30° mlat) are excluded in the regional GAIM runs
- 5-minute sampling rate from 30-sec sampled data
- ~532 data samples/10-minutes

Global GPS Network (06/01/2002)

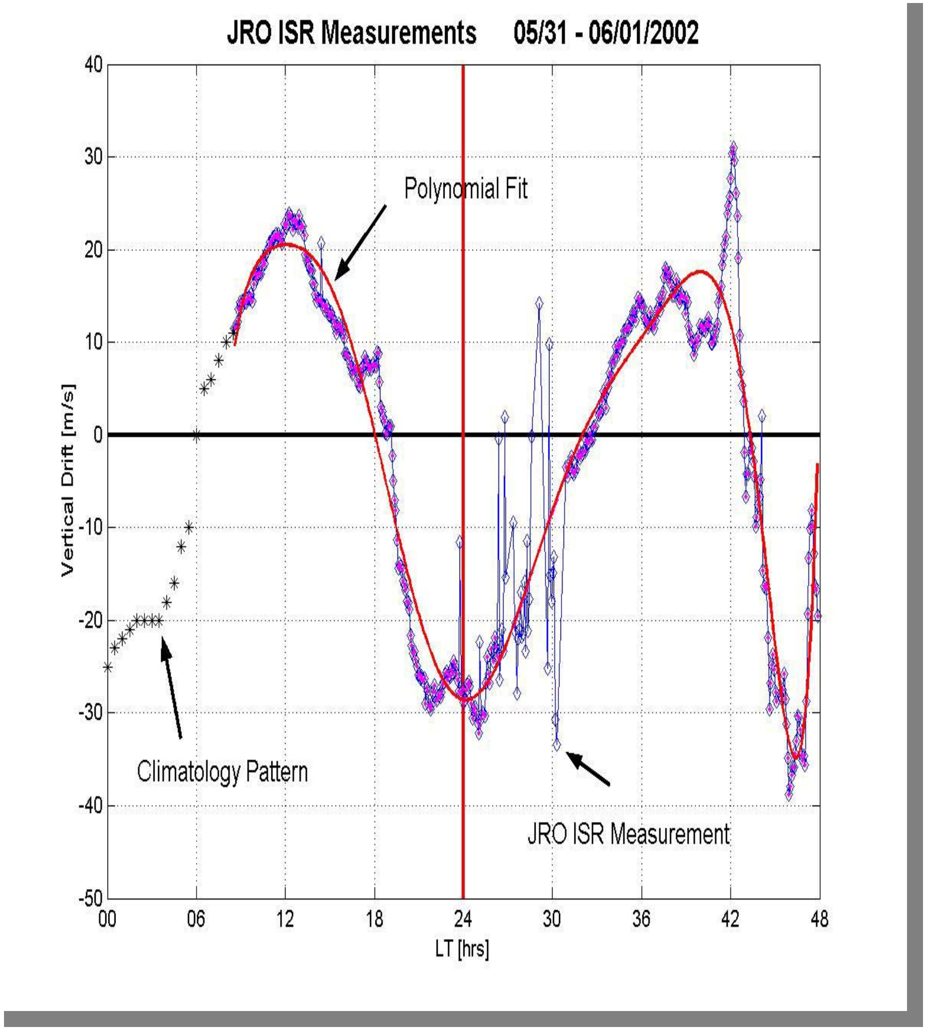


10 degree elevation mask. Subionospheric height at 450 km.

Jicamarca ISR Measurements Plasma Vertical Drift



UT

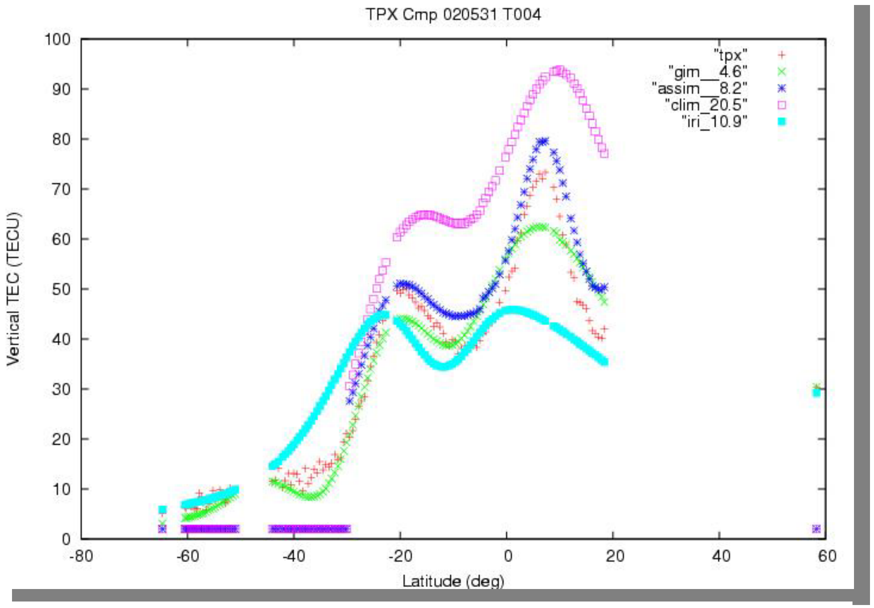


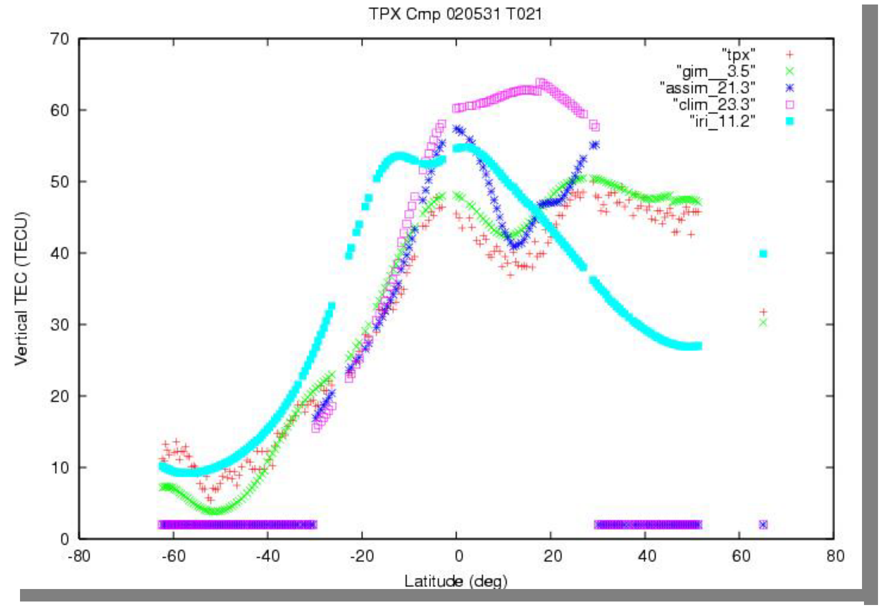
LT

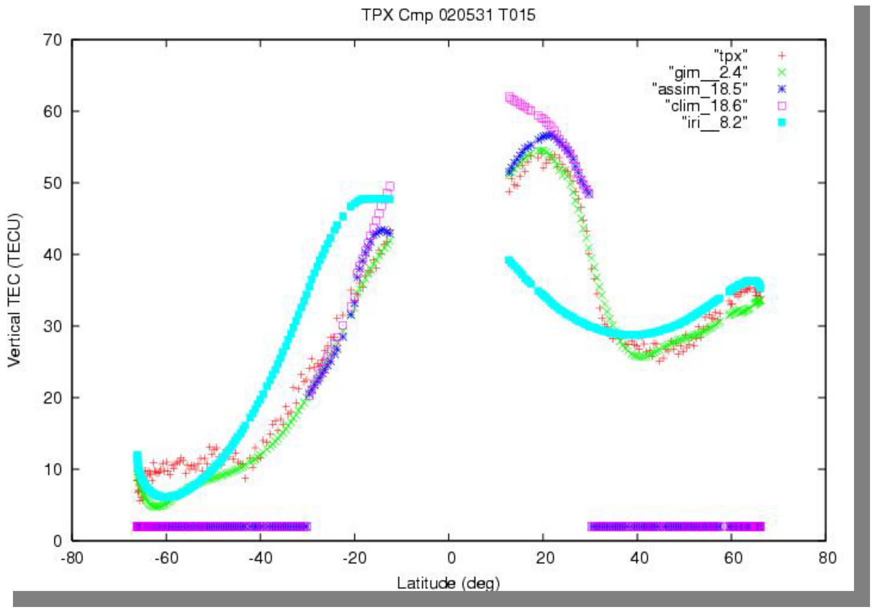
- Assimilation of *ISR drift* and *ground GPS data* only

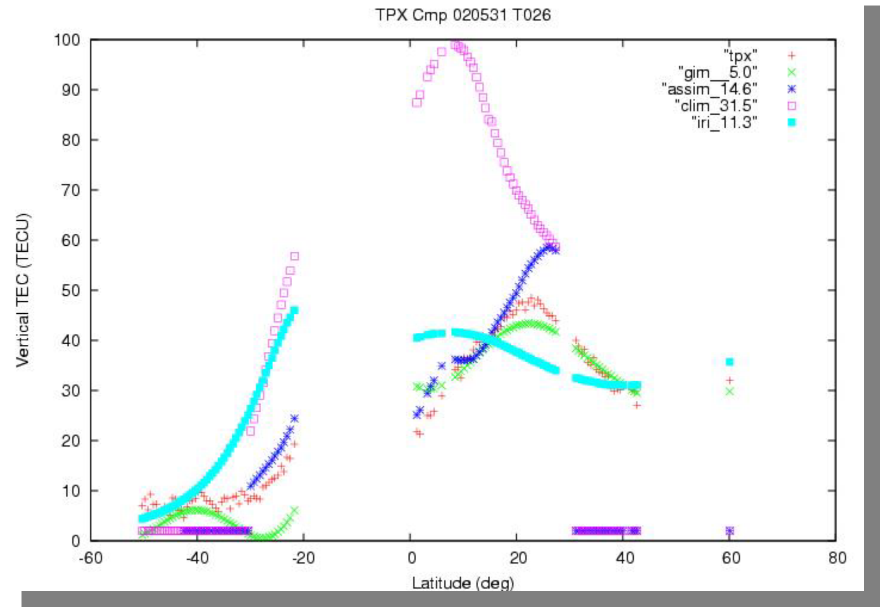
✓ GPS satellite and receiver bias estimation
✓ ground-based (200 sites) and space-borne (3 LEO's)

TEC Comparison: GAIM vs. TOPEX

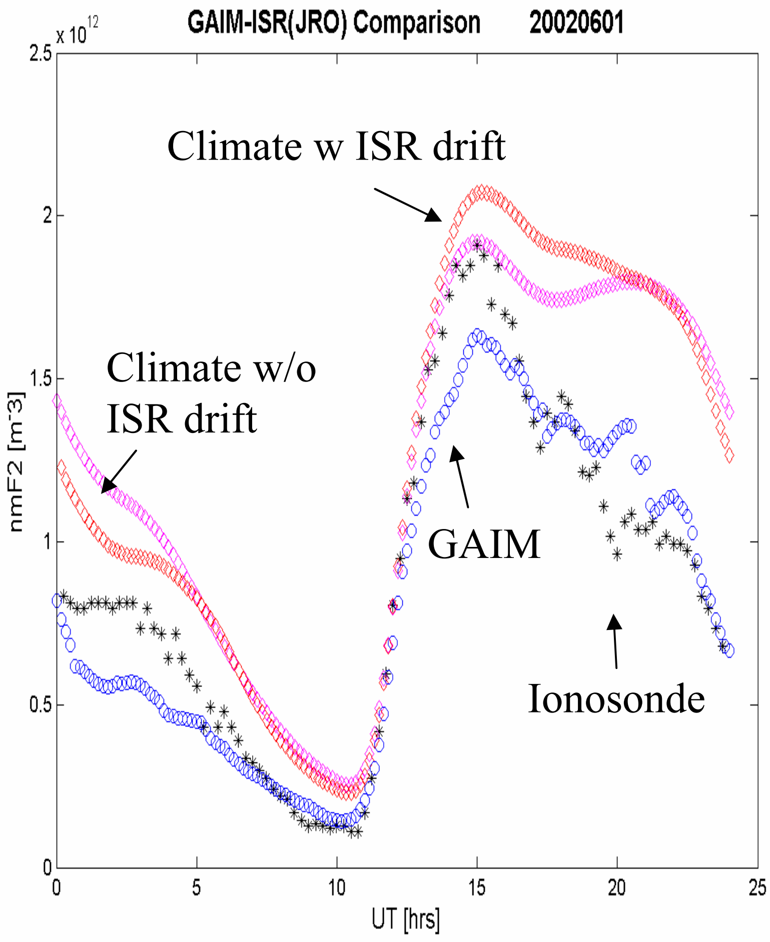




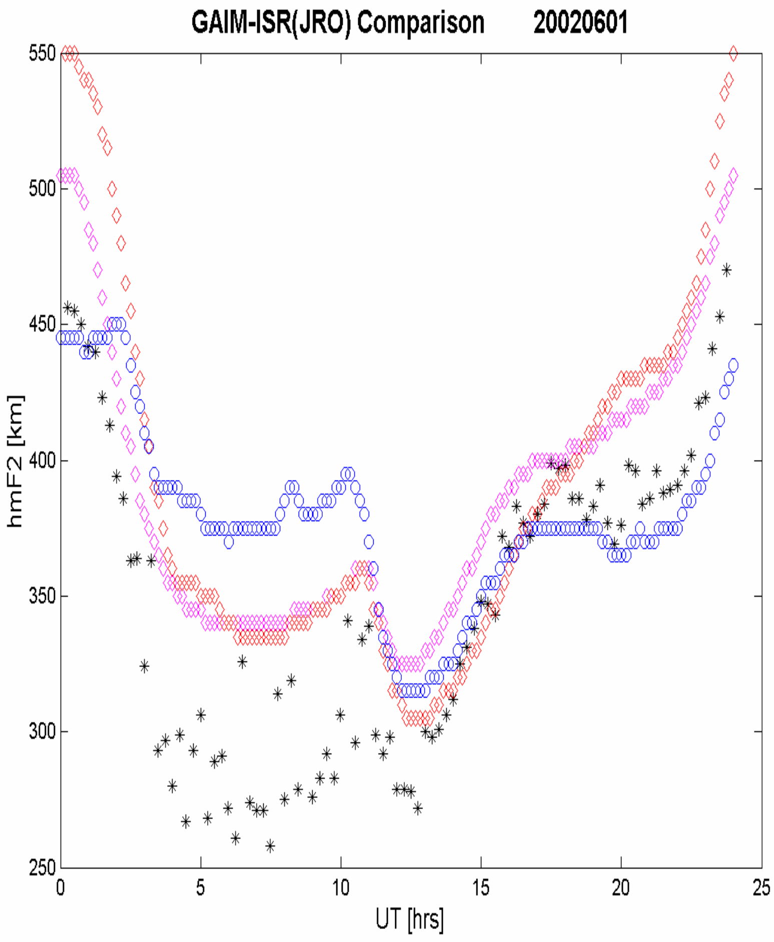




Comparison with Digisonde Data



n_mF_2



h_mF_2

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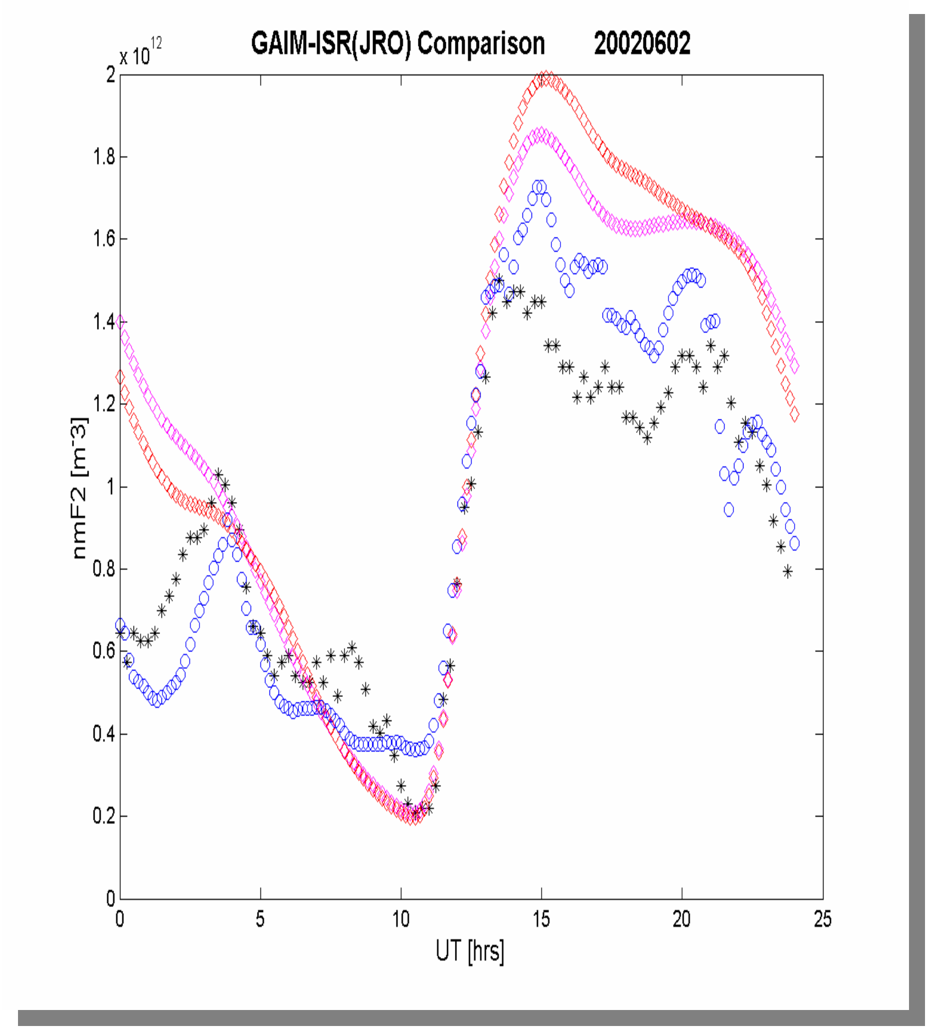
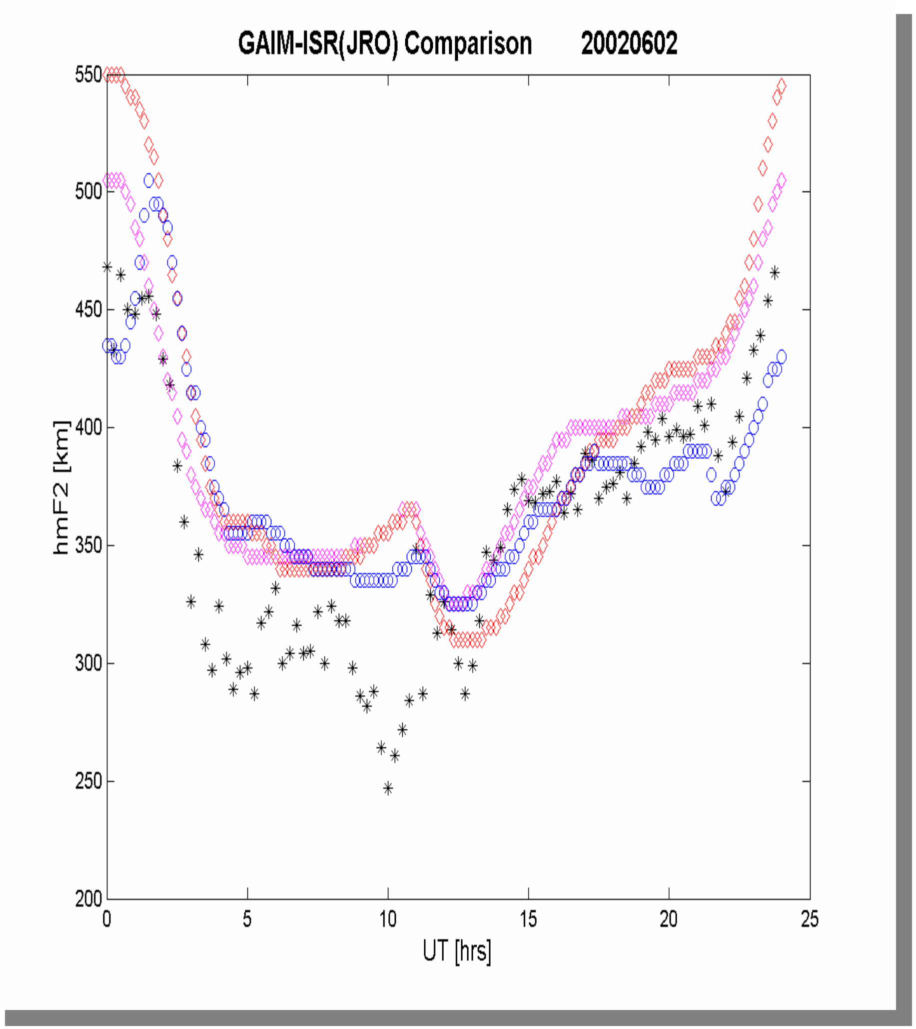


n_mF_2

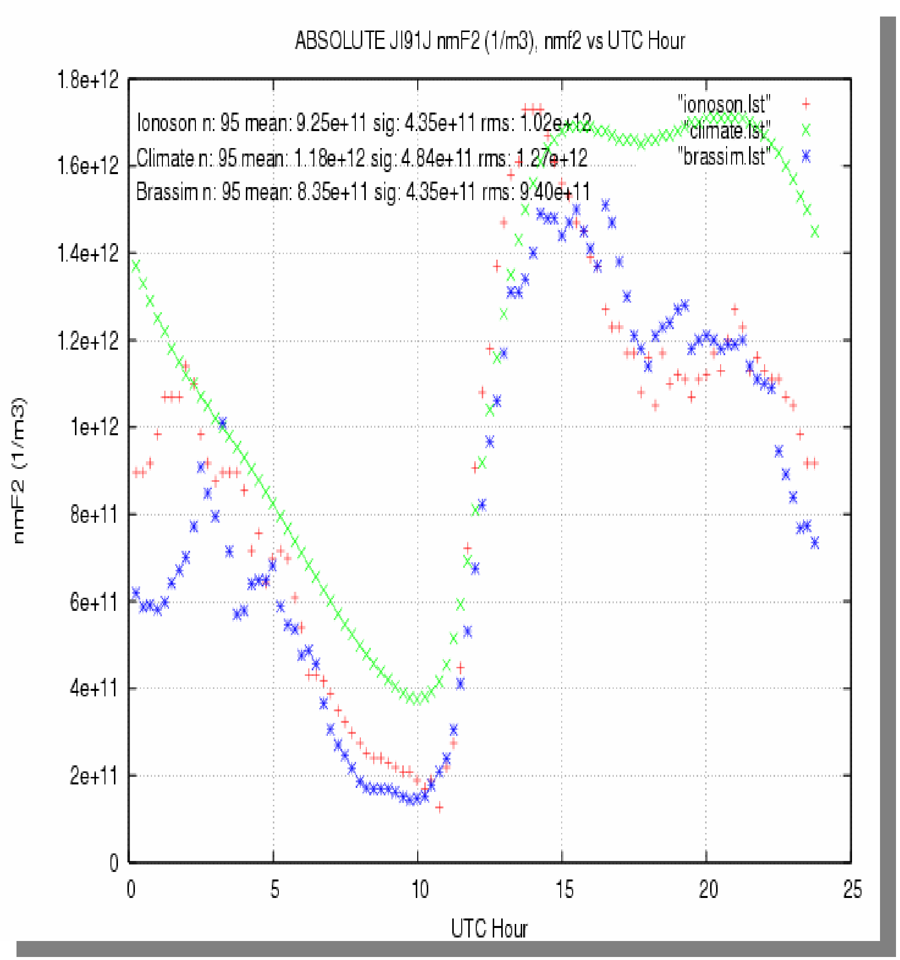


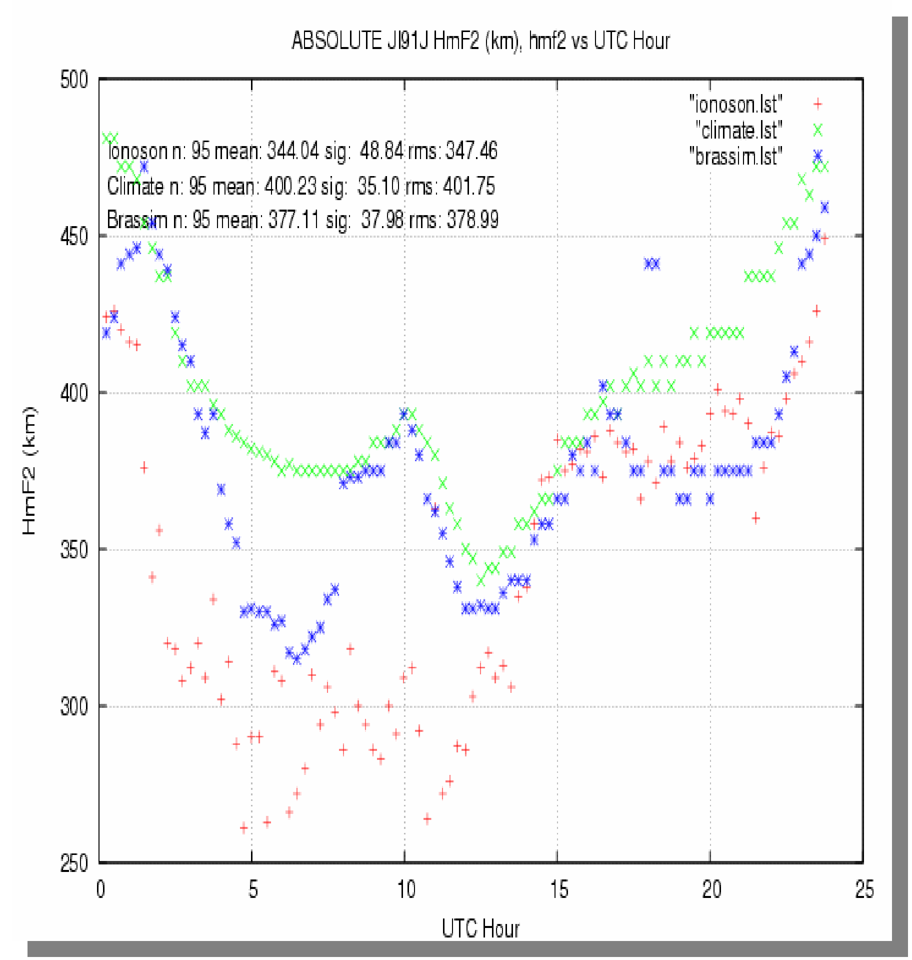
h_mF_2

- Assimilation of *ISR drift* and *ground as well as space GPS data*

- Three LEO's
  - CHAMP, SAC-C, and IOX
  - Occultation links
  - Orbit-determination links
    - Mostly upward looking
- Only LOS TEC is assimilated, not inverted profiles

Comparison with Digisonde Data



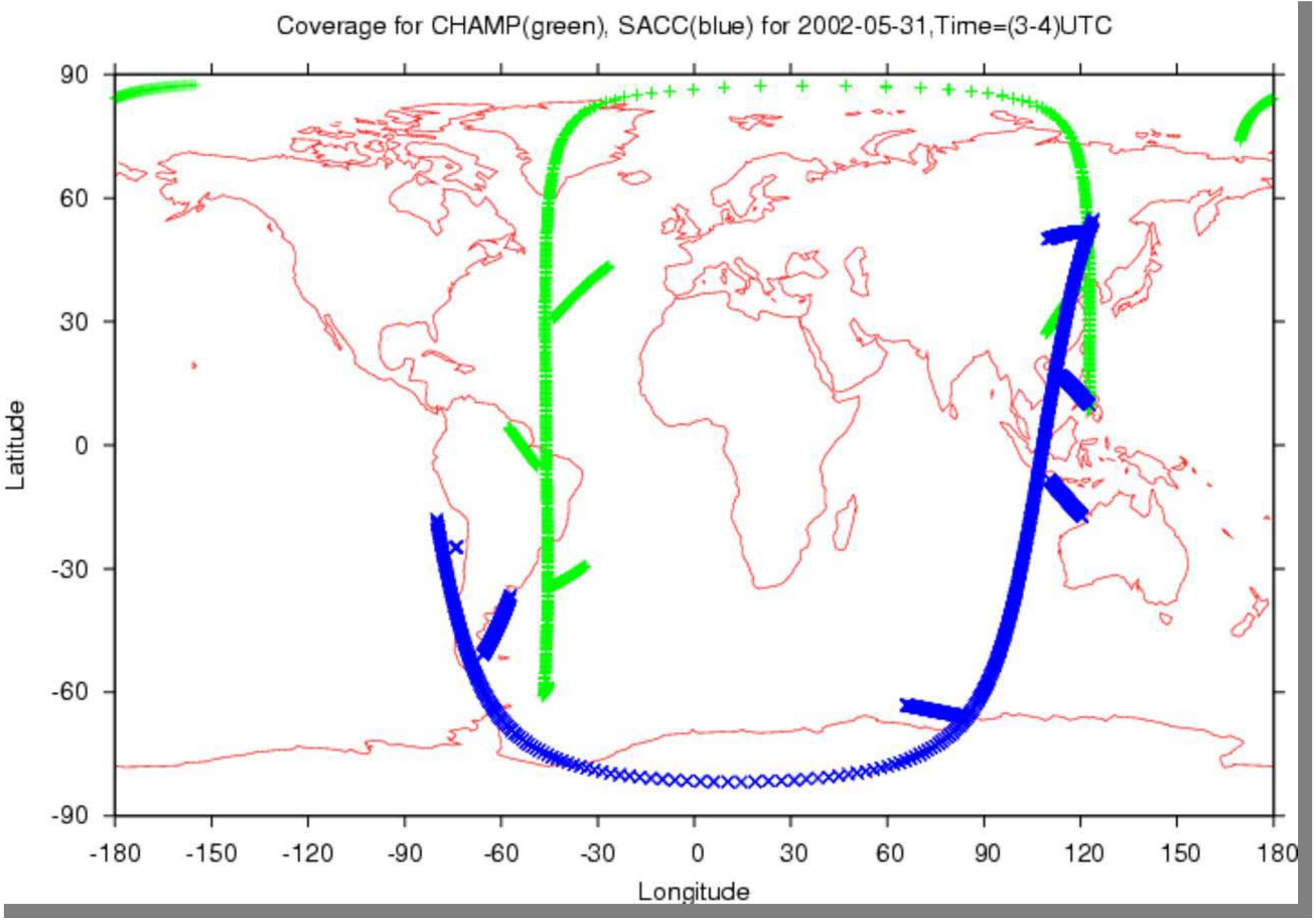


05/31/2002

n_mF_2

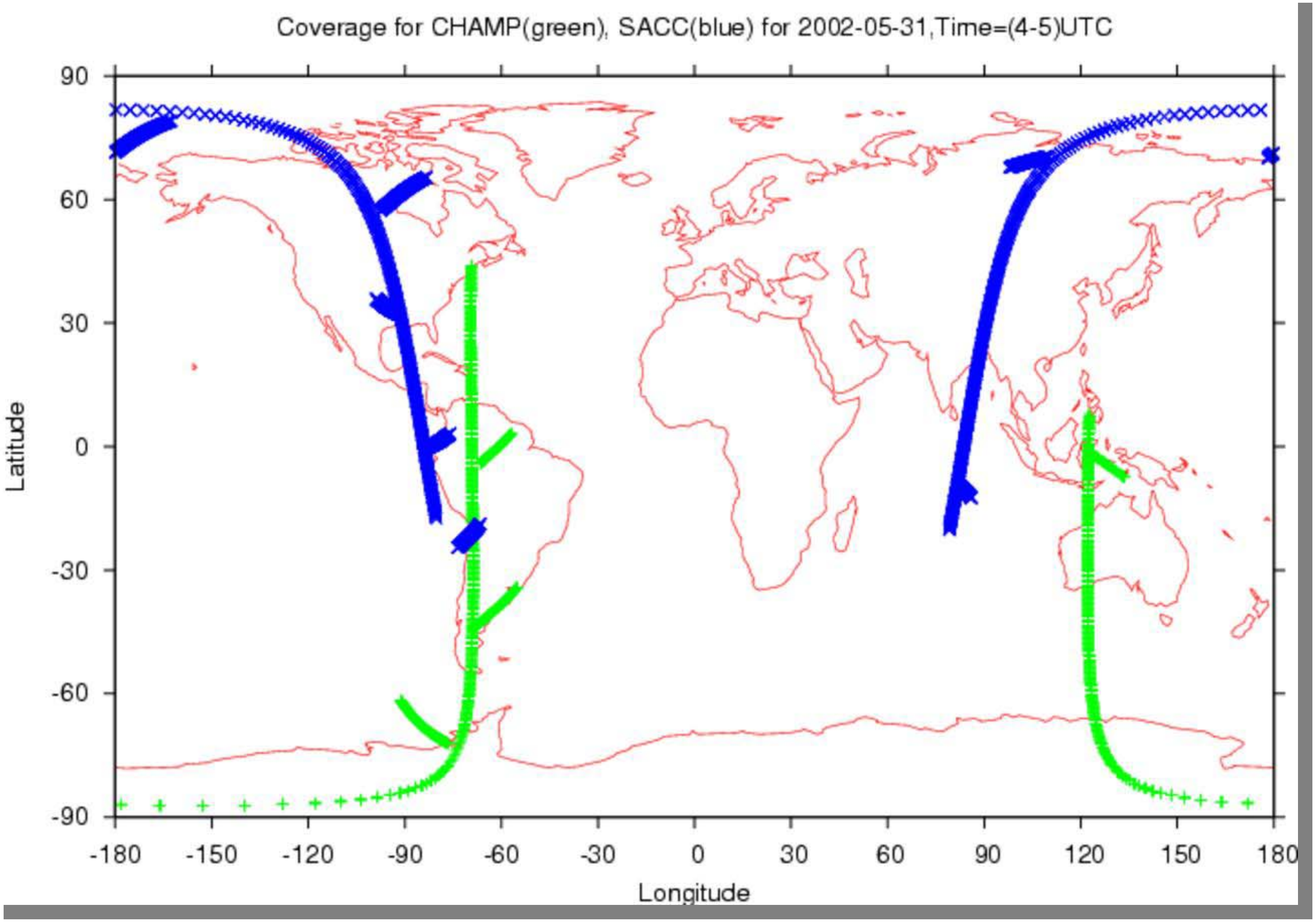
h_mF_2

Orbital Tracks of Space-Borne GPS Receivers



LEO Satellites pass through nearby region of the modeling.
GPS occultation data help to improve hmF2.

Orbital Tracks of Space-Borne GPS Receivers



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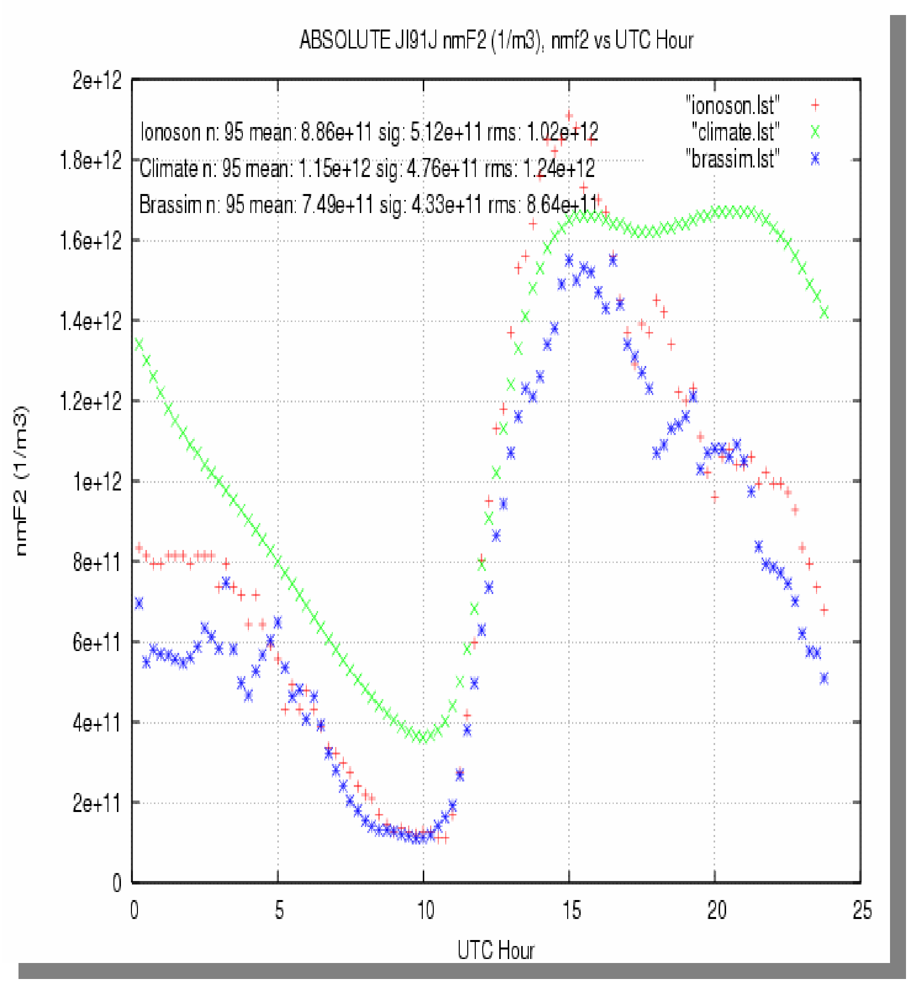
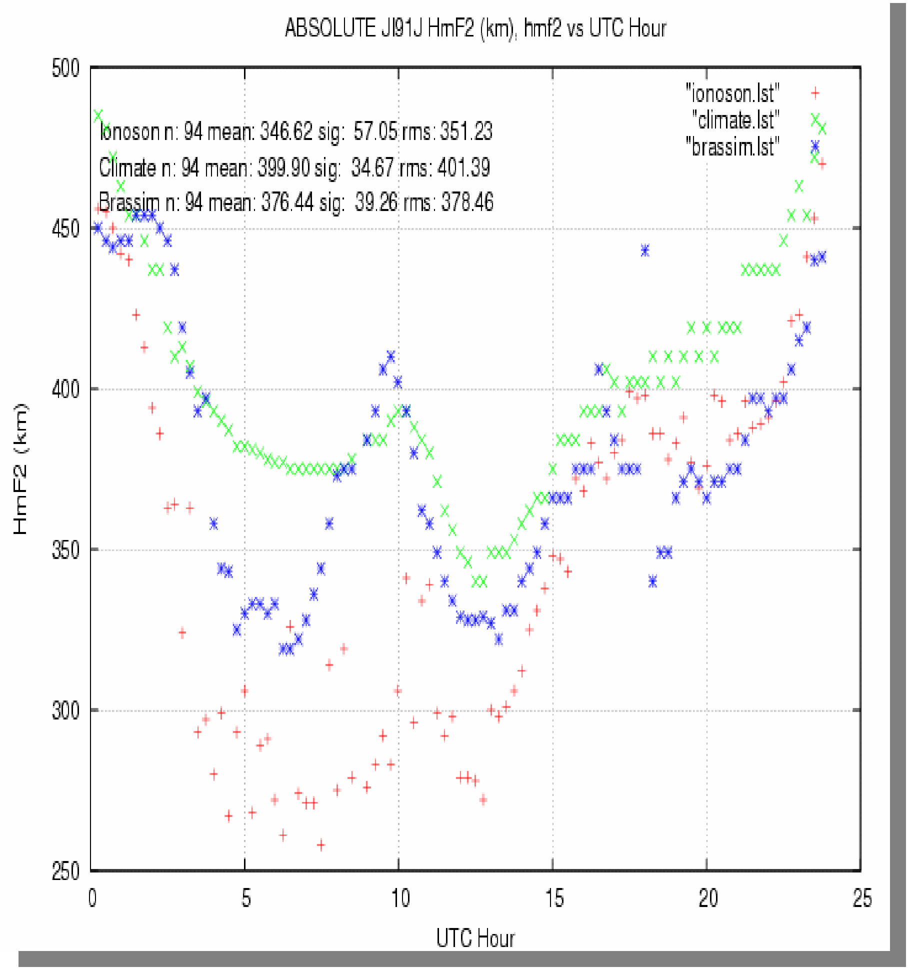




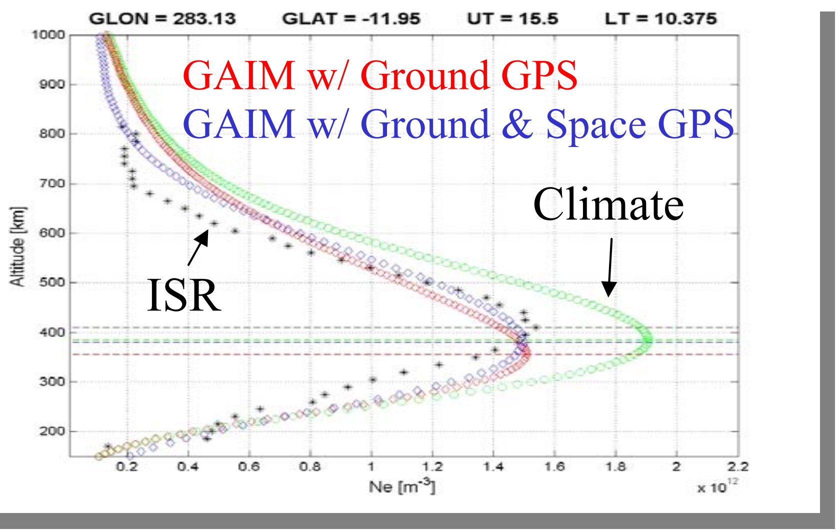
06/01/2002

n_mF_2

h_mF_2

Comparison with Jicamarca ISR n_e Profiles

05/31/2002



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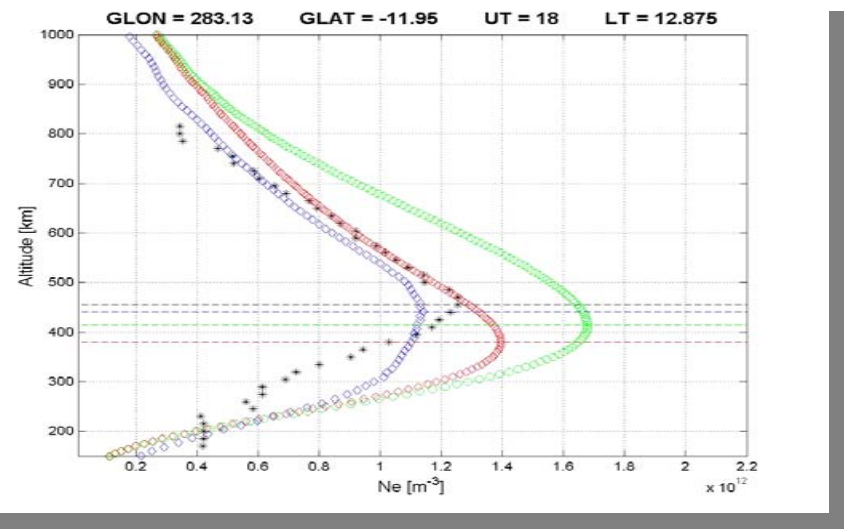

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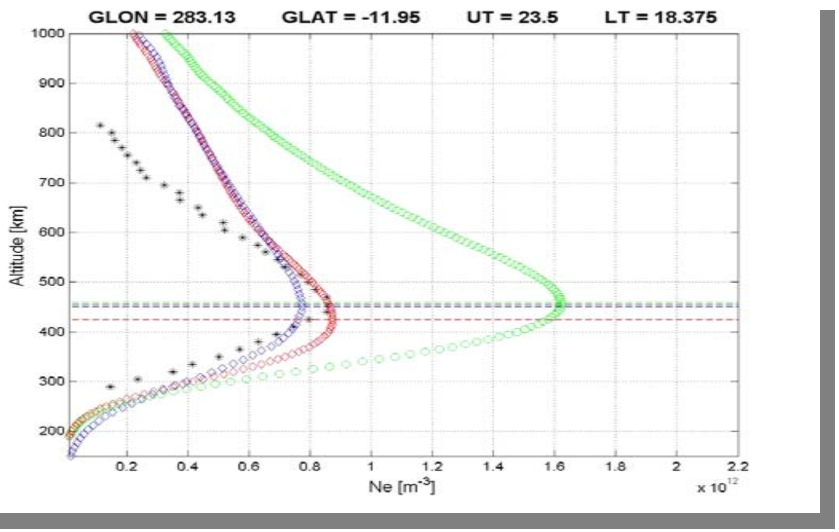

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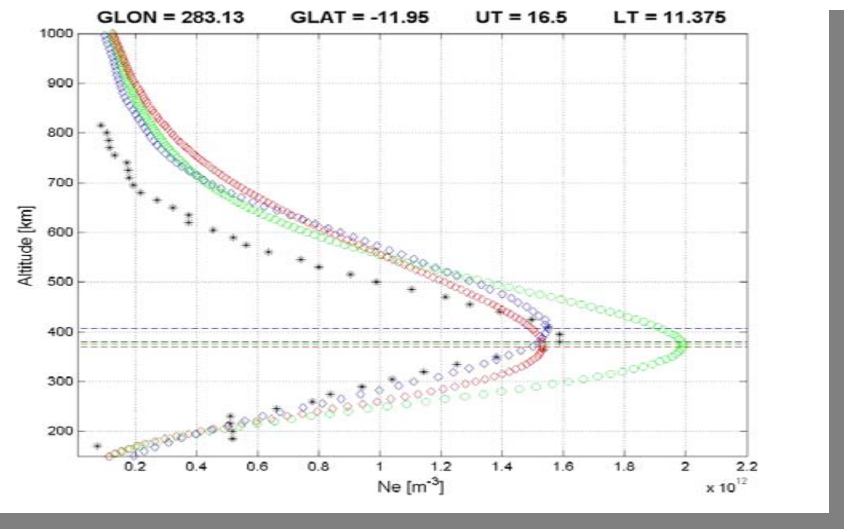

Summary

- It is effective to model TEC and n_mF_2 by assimilating ground GPS data
- Assimilation of both ground and space GPS data makes it more effective to model h_mF_2
- Further Investigations
  - Nighttime profiles, particularly h_mF_2
  - Topside profile: Representativeness error?
  - Importance of assimilating other “drivers” at low latitudes besides weather drift