Global assimilative ionospheric modeling and the Tiny Ionospheric Photometer on the COSMIC constellation

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Abstract

- The Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) uses the Tiny Ionospheric Photometer (TIP) to characterize the nighttime ionosphere. TIP is a compact, nadir directed, narrow-band, ultraviolet photometer operating at the 135.6 nm wavelength. This emission is produced by recombination of O+ ions and electrons, which is the natural decay process for the ionosphere. At night, the strength of the emission is proportional to the square of the peak electron density. TIP measures the horizontal structure of the ionosphere with 15-30 km resolution and high sensitivity, providing remarkable detail even during solar minimum conditions. With six sensors on COSMIC providing global coverage, TIP is a valuable resource for evaluating ionospheric models. We present a comparison of TIP data with models which employ global assimilation of ionospheric measurements. Ground-based GPS observations are routinely ingested and serve as the primary data source for assimilative models. With the launch of the COSMIC constellation in 2006, research has begun on assimilating GPS radio occultations. These space-based observations provide global coverage and promise to improve ionospheric specification in both a vertical and horizontal sense. Comparison with TIP reveals the horizontal performance of these models and demonstrates the improvement obtained from ingesting radio occultation data.

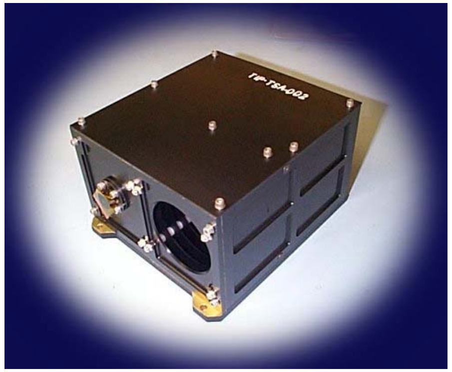
Overview

- *Does ingesting the Radio Occultation data improve the horizontal specification of the equatorial ionosphere*?
- FORMOSAT-3/COSMIC
  - Radio occultation (RO)
  - Tiny Ionospheric Photometer (TIP)
  - TIP serves as coincident, independent truth for evaluation of models assimilating RO data
  - Early in mission (best case)
    - 4 spacecraft are in same orbital plane
    - equivalent to constellation with 24 spacecraft
  - Post-sunset Equatorial Ionospheric Anomaly (difficult case)
- Comparisons of TIP with GAIMUSC
  - GAIM ingests COSMIC RO data and ground GPS data
  - IFM and IRI also included in analysis

FORMOSAT-3 COSMIC Overview

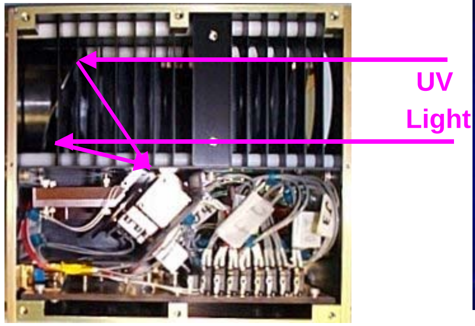
- Constellation Observing System for Meteorology, Ionosphere and Climate
- April 2006 Launch
  - Six spacecraft placed into initial 500 km altitude
- Final Configuration as of December 2007
  - Six orbit planes
  - 72 degree inclination
  - 800 km altitude
- Sensors
  - GPS Occultation
  - Tiny Ionospheric Photometer
  - Tri-Band Beacon
- Satellite Operations Control Center in Taiwan
- Data Analysis and Archive Center in Boulder, Colorado
- 3-year Mission (5-year Goal)

TIP Payload Overview



Sensor Module:

- Photomultiplier tube observes UV light
- Strontium fluoride filter passes 131-160 nm emissions
- Very high sensitivity ~600 counts/s/Rayleigh

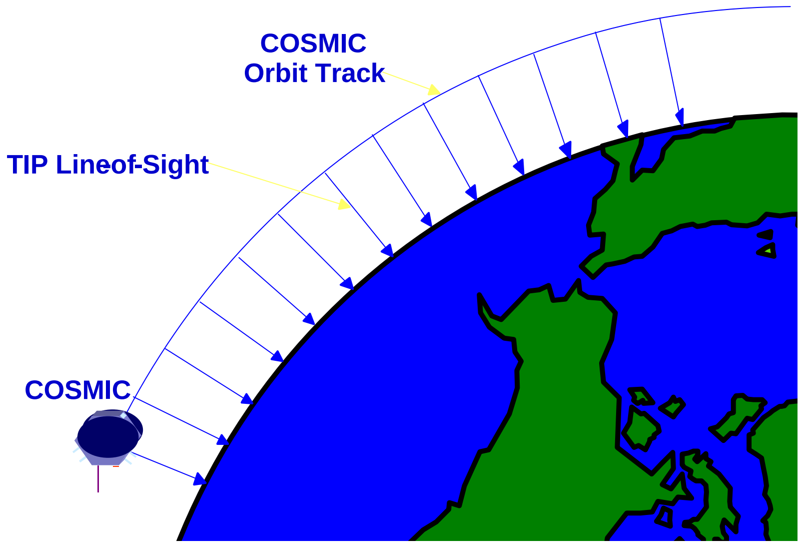


Measures intensity of naturally occurring 135.6-nm airglow, caused by the decay of the nighttime ionosphere.

Intensity is proportional to the vertical sum of the electron density-squared,

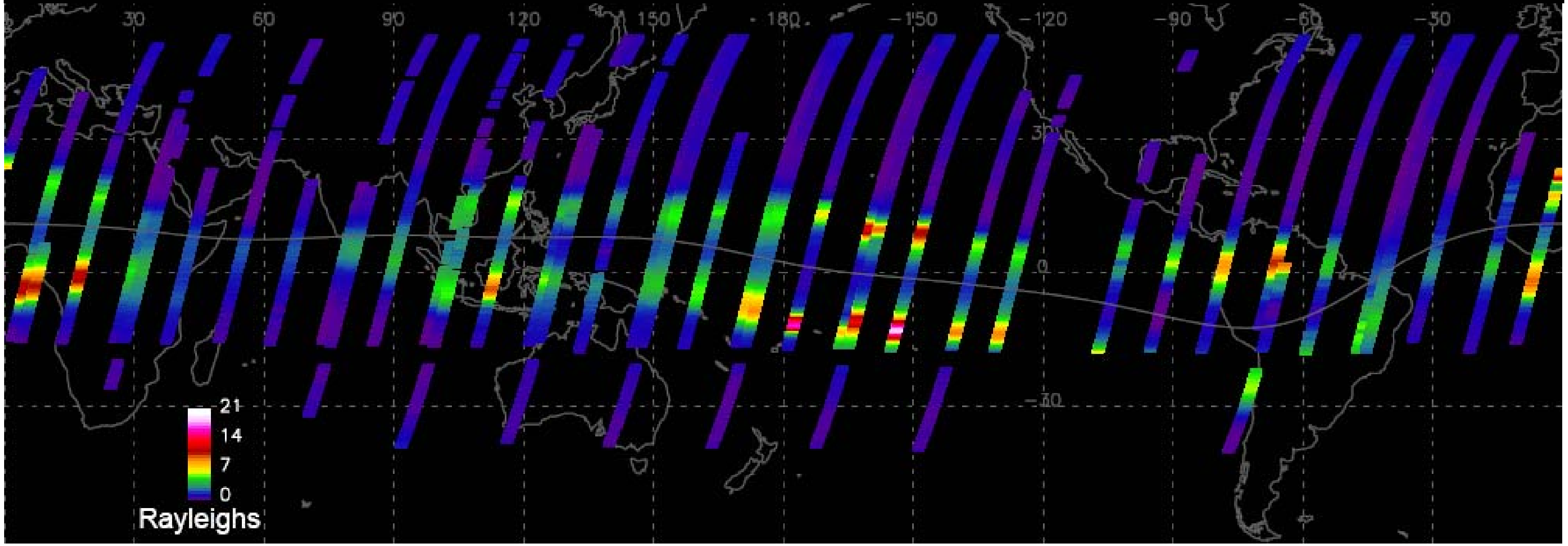
$$I \propto \int N_e^2$$

Nadir pointing 3.8° circular field-of-view yields 30-km horizontal resolution from an altitude of 800 km (15-km at 500-km altitude).

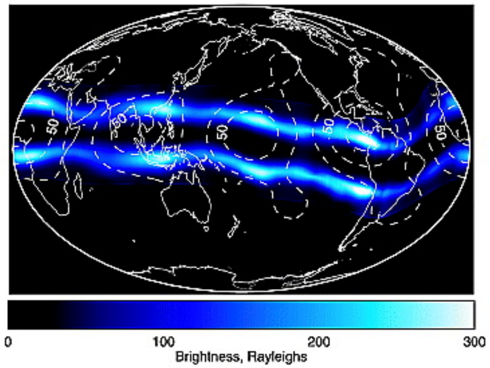


Variability of Post-Sunset Equatorial Ionosphere

One-Day Composite FUV Image of Ionosphere at 2100 local time from multiple LEO spacecraft on COSMIC



- TIP reveals the complexity of low latitude ionospheric drivers, vertical drift and meridional winds, as a function of longitude
- Global 4-cell pattern is similar to observations by IMAGE FUV at equinox, solar maximum – attributed to atmospheric tides by Immel *et al.*, 2006

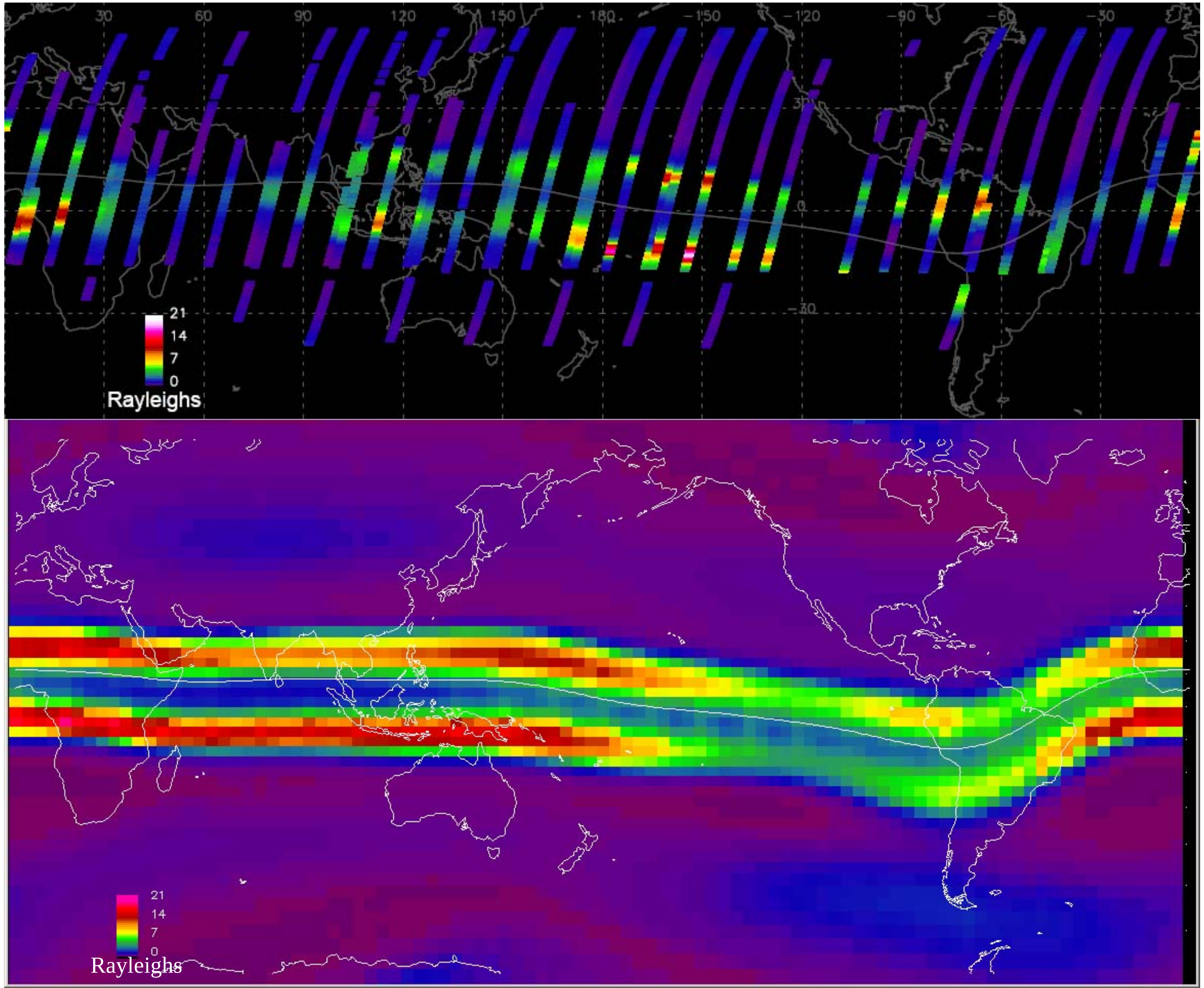


TIP and IFM Climatology

2100LT for 14 Sep 2006

135.6-nm Radiance from TIP

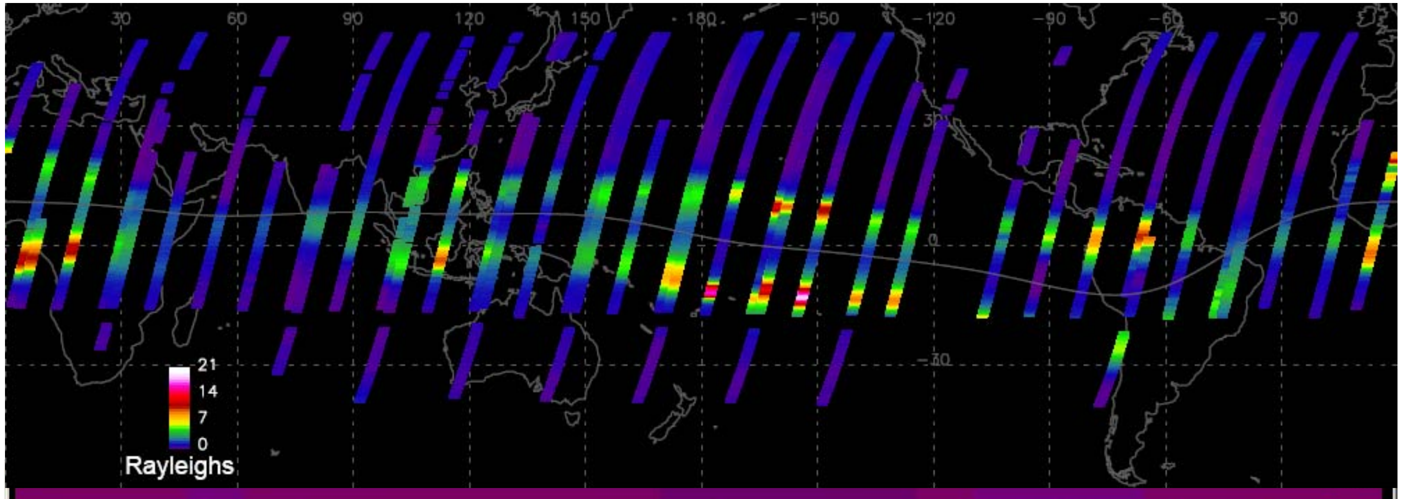
135.6-nm Radiance from IFM



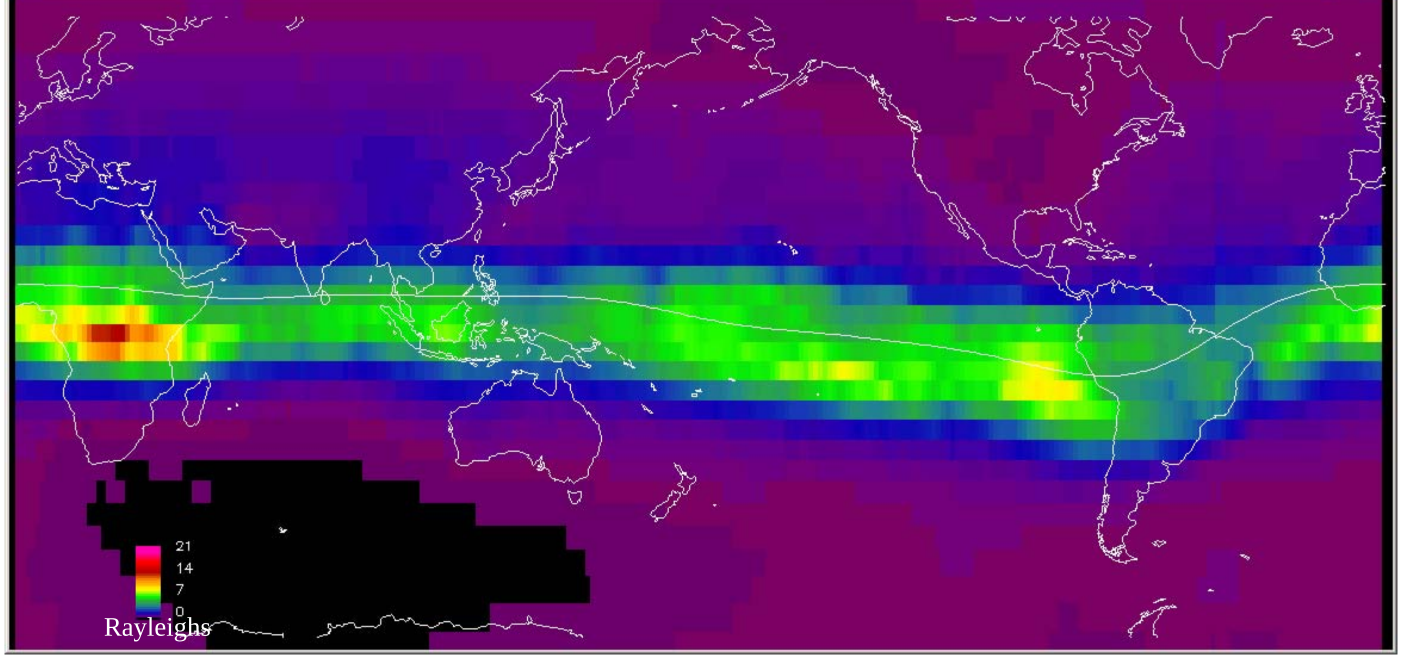
TIP and IRI Climatology

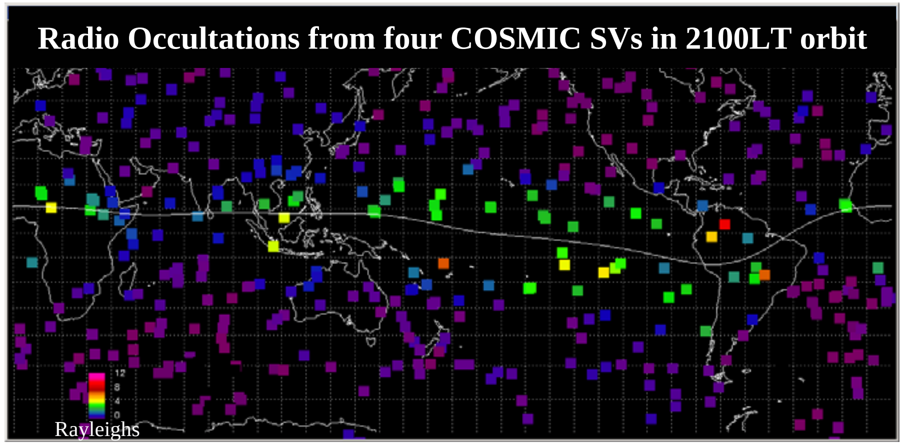
2100LT for 14 Sep 2006

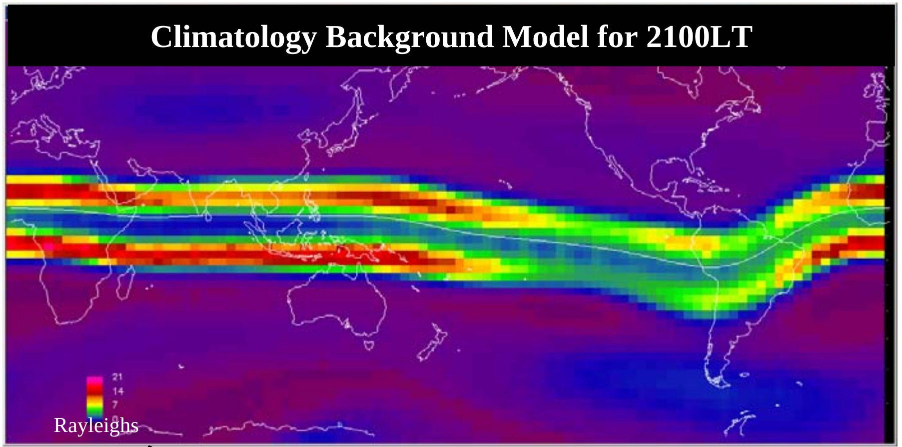
135.6-nm Radiance from TIP

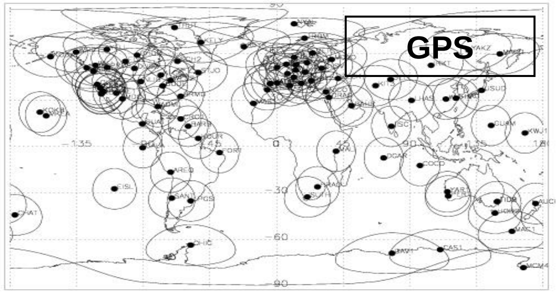


135.6-nm Radiance from IRI



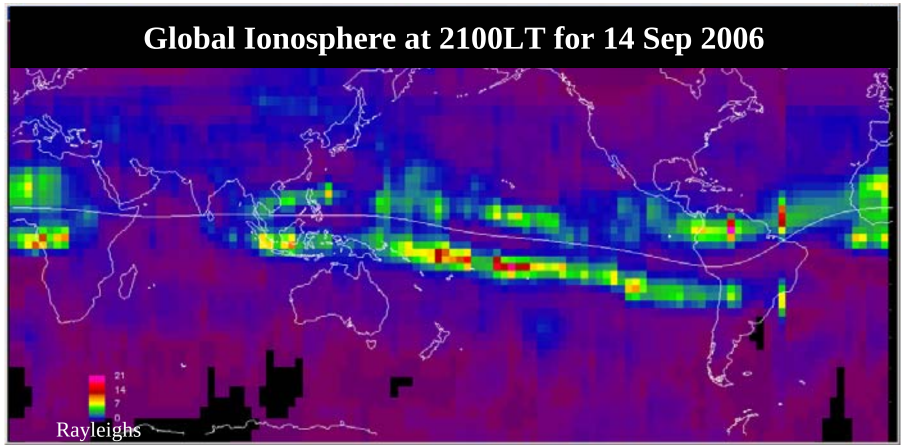






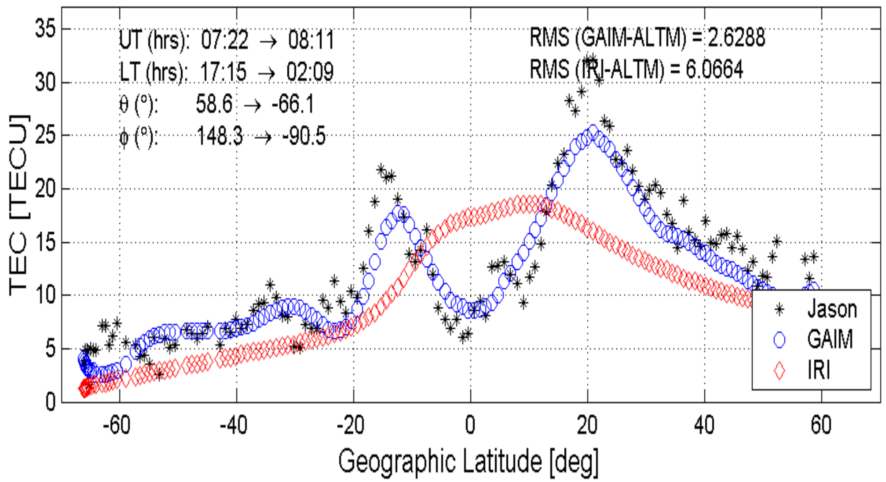
GAIMUSC

Global Assimilation of Ionospheric Measurements

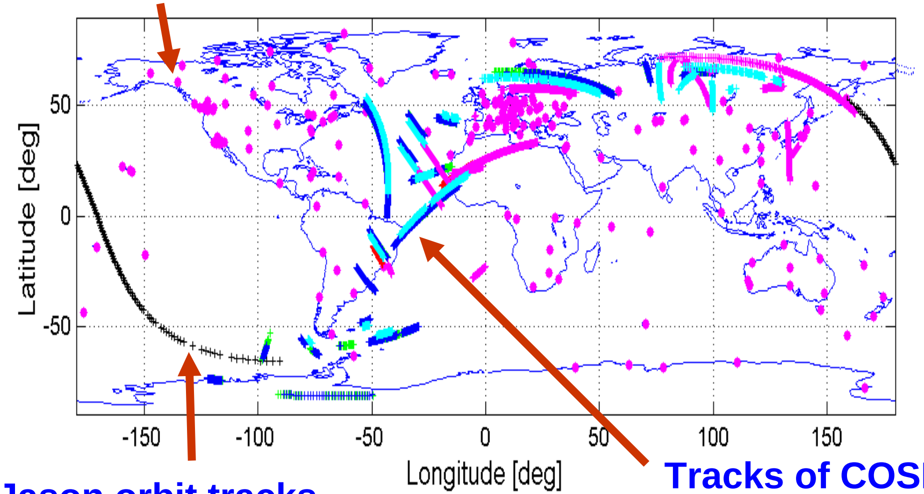


Validation of GAIM Using Altimeter TEC Measurements

TEC along Jason orbit tracks



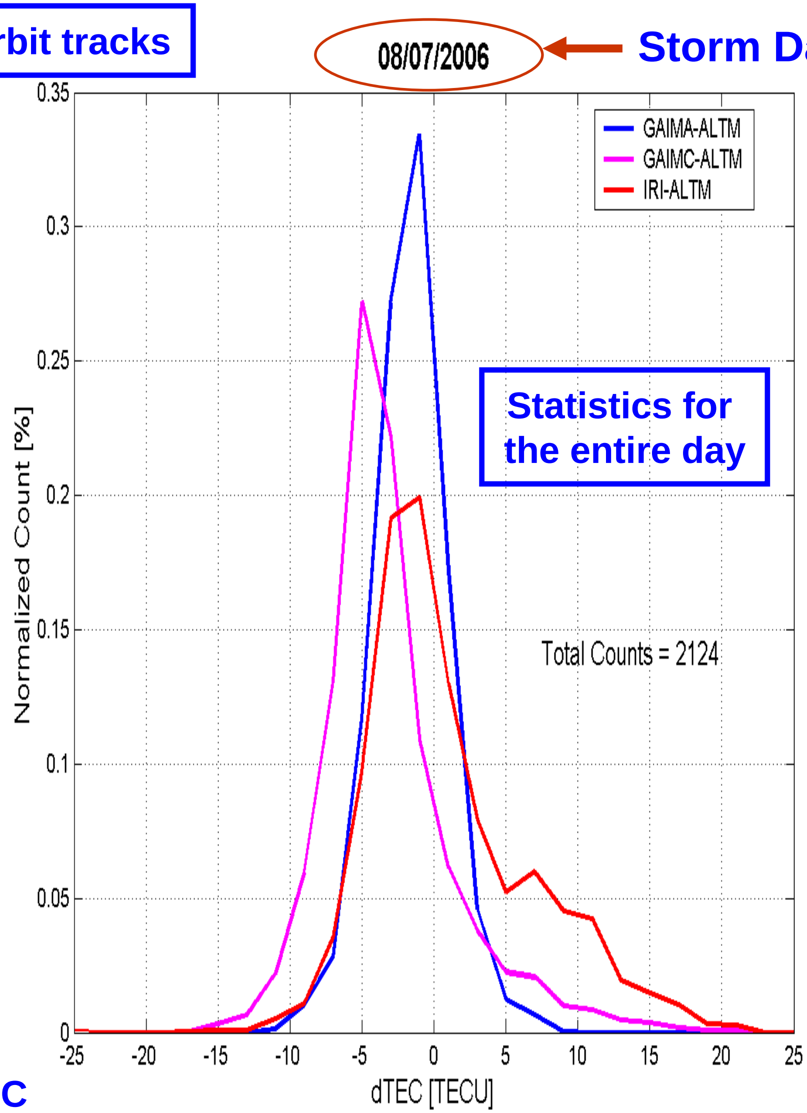
GPS grnd station



Jason orbit tracks

Tracks of COSMIC occul. tangent points

Storm Day

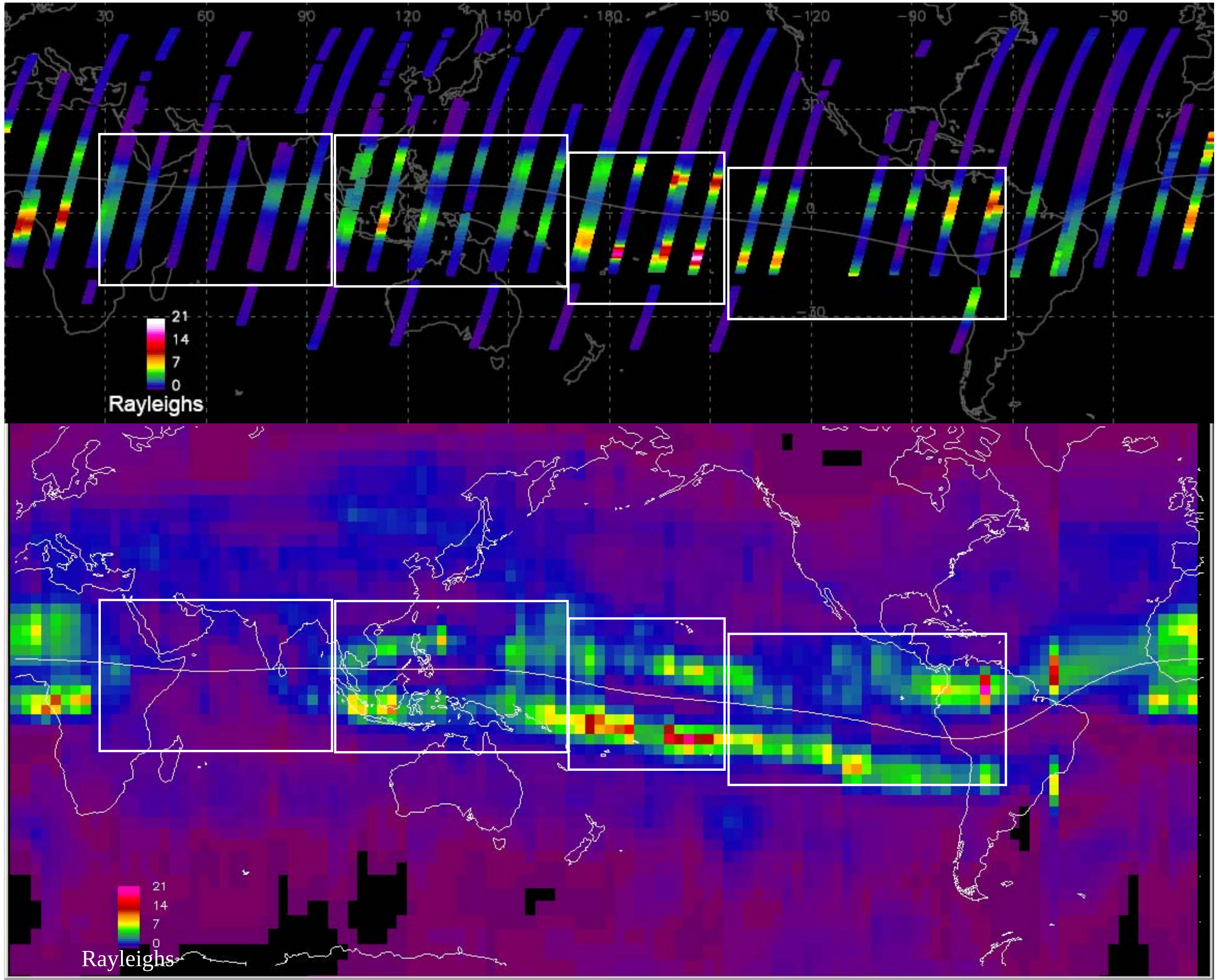


Statistics for the entire day

GAIMUSC Shows Remarkably Similar Non-migrating Tide Pattern on 14 Sep 2006

135.6-nm Radiance from TIP

135.6-nm Radiance from GAIM profiles

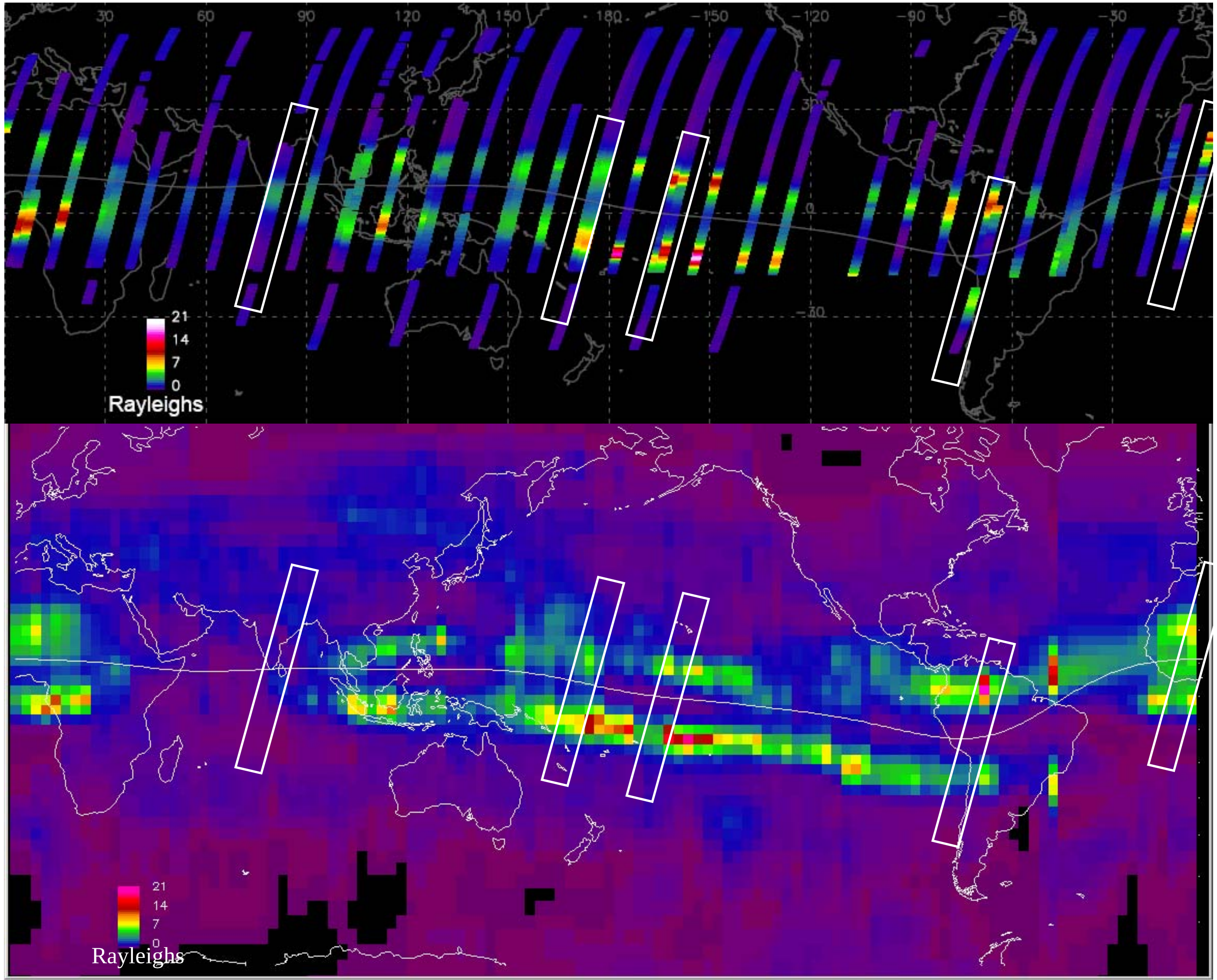


Comparison of TIP and GAIMUSC

14 Sep 2006 FM1 FM3 FM6 (2100 LT)

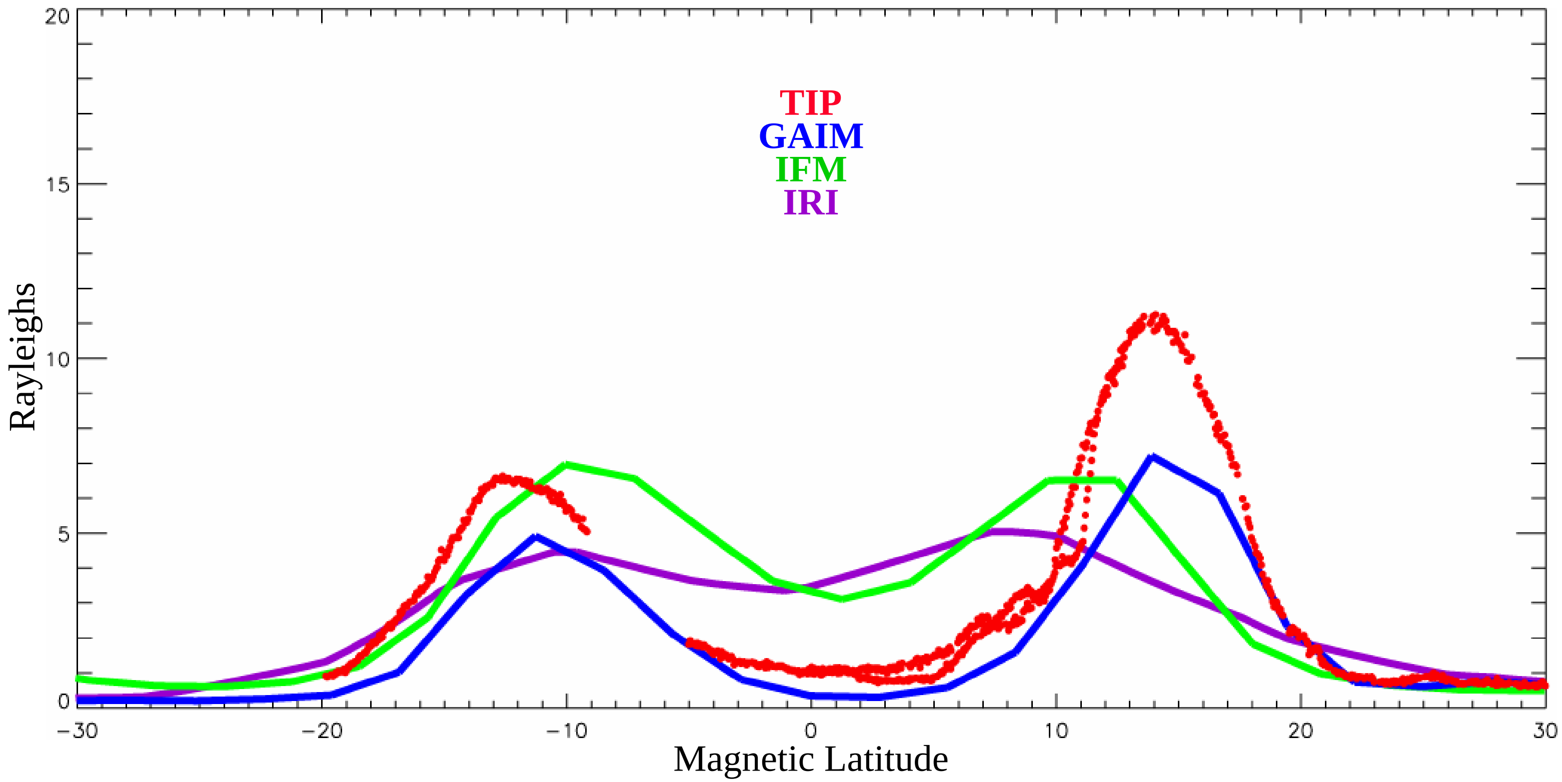
135.6-nm Radiance from TIP

135.6-nm Radiance from GAIM profiles



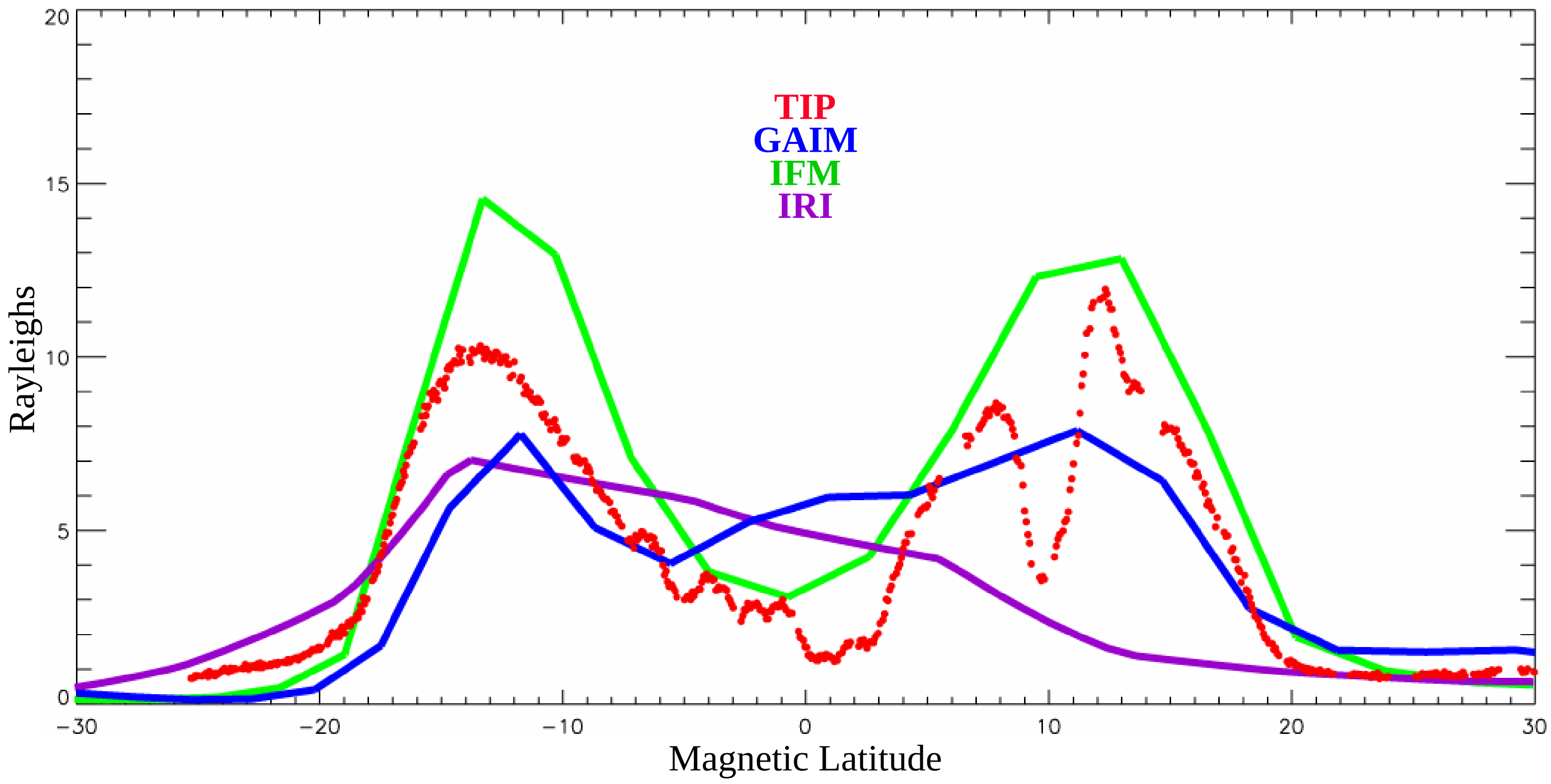
South American Pass

- TIP pass shows details of asymmetric anomaly
- GAIM captures location of crests and depth of trough, slightly underestimates crest magnitude
- Climatological models fail to accurately locate crests and depth of trough



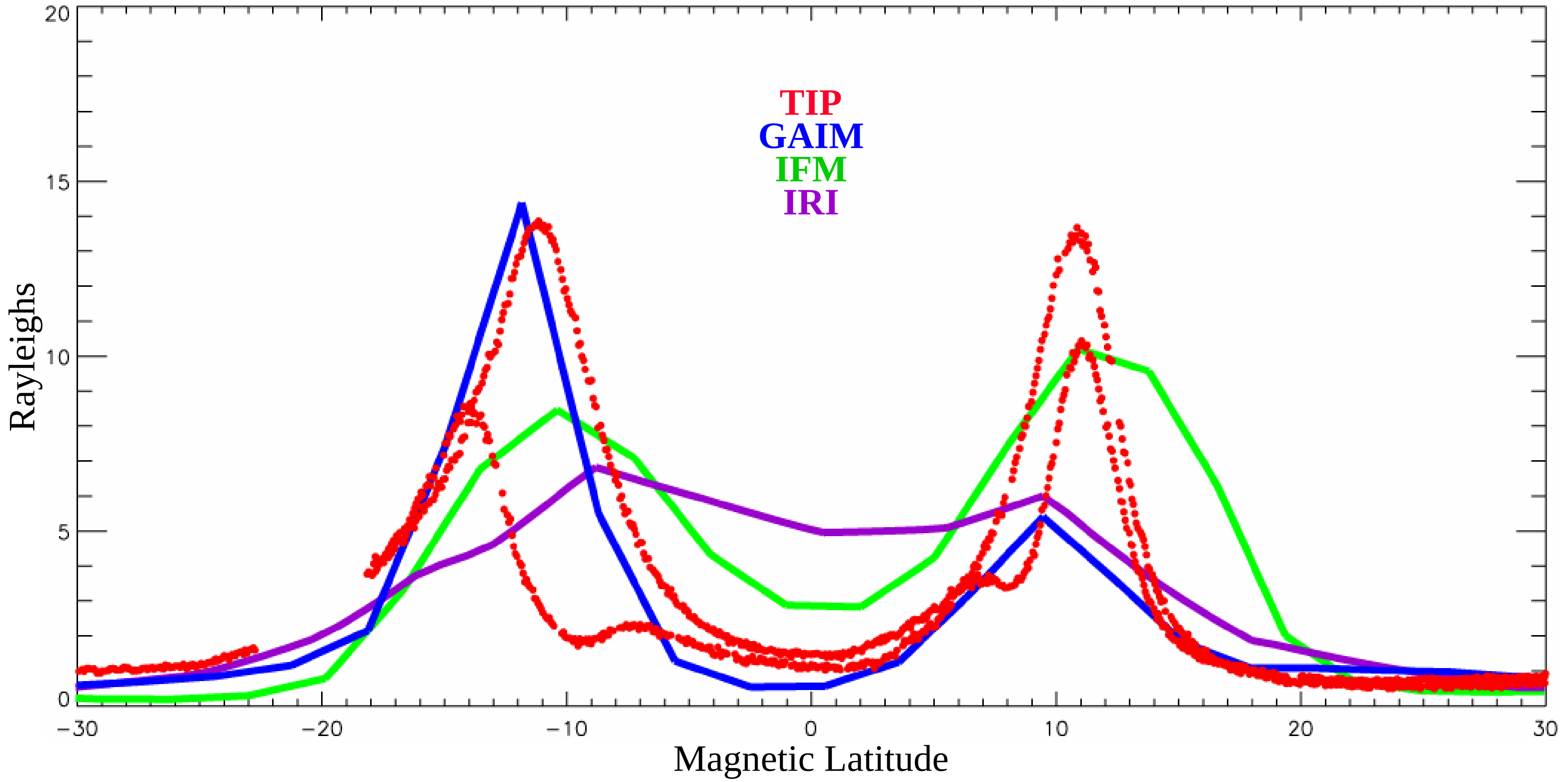
African Pass

- TIP pass shows anomaly modified by the presence of irregularity structures
- GAIM captures location of crests but not the depth of trough
- IFM accurately represents the crest location and depth of trough
- IRI doesn't show double crested anomaly or trough



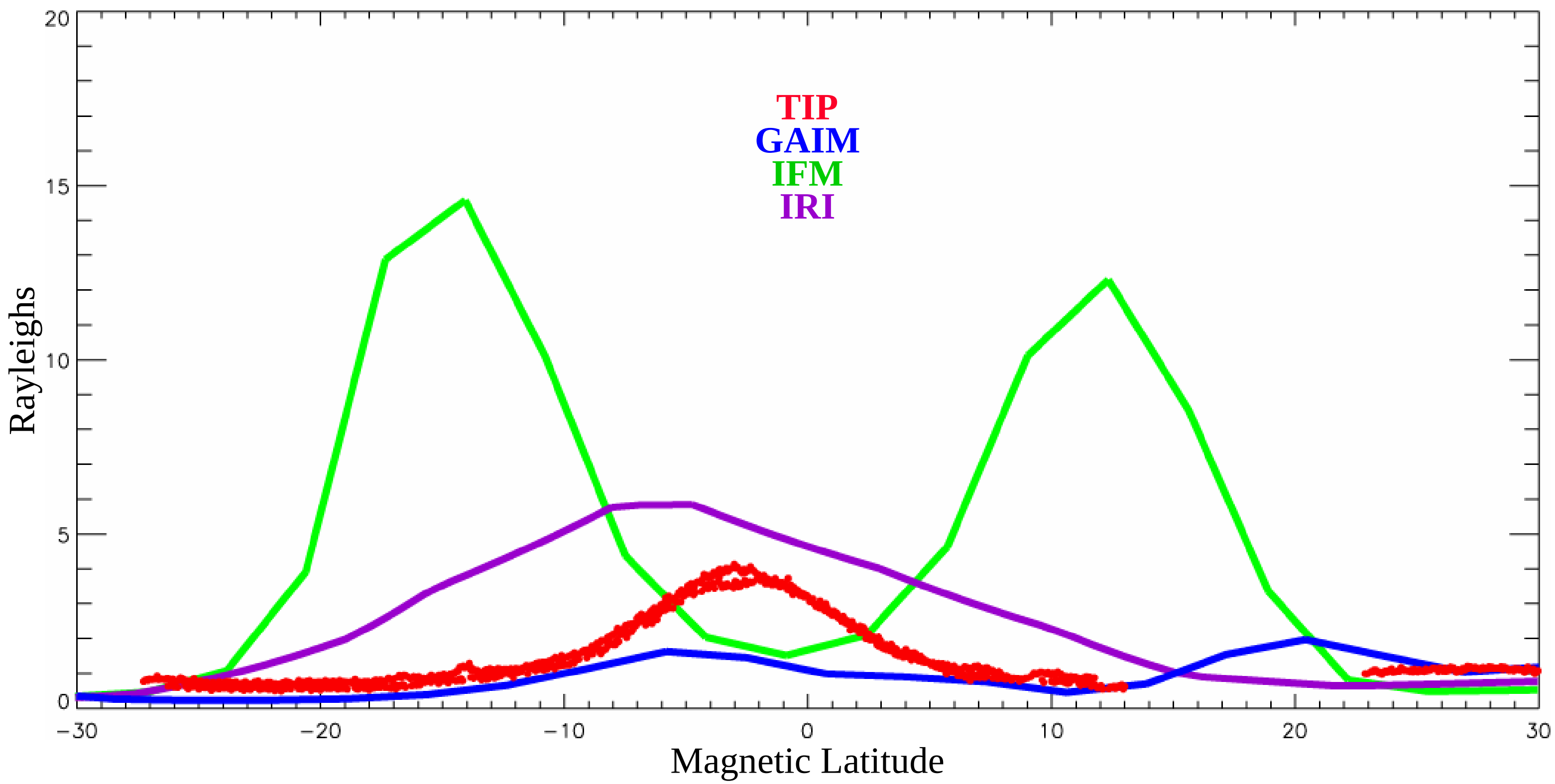
Hawaiian Sector Pass

- TIP pass shows symmetric anomaly and the presence of depletions
- GAIM captures location of crests and depth of the trough, underestimates northern crest
- IFM overestimates the width of the crests, underestimates depth of trough
- IRI shows only a hint of double-crested anomaly with almost no trough



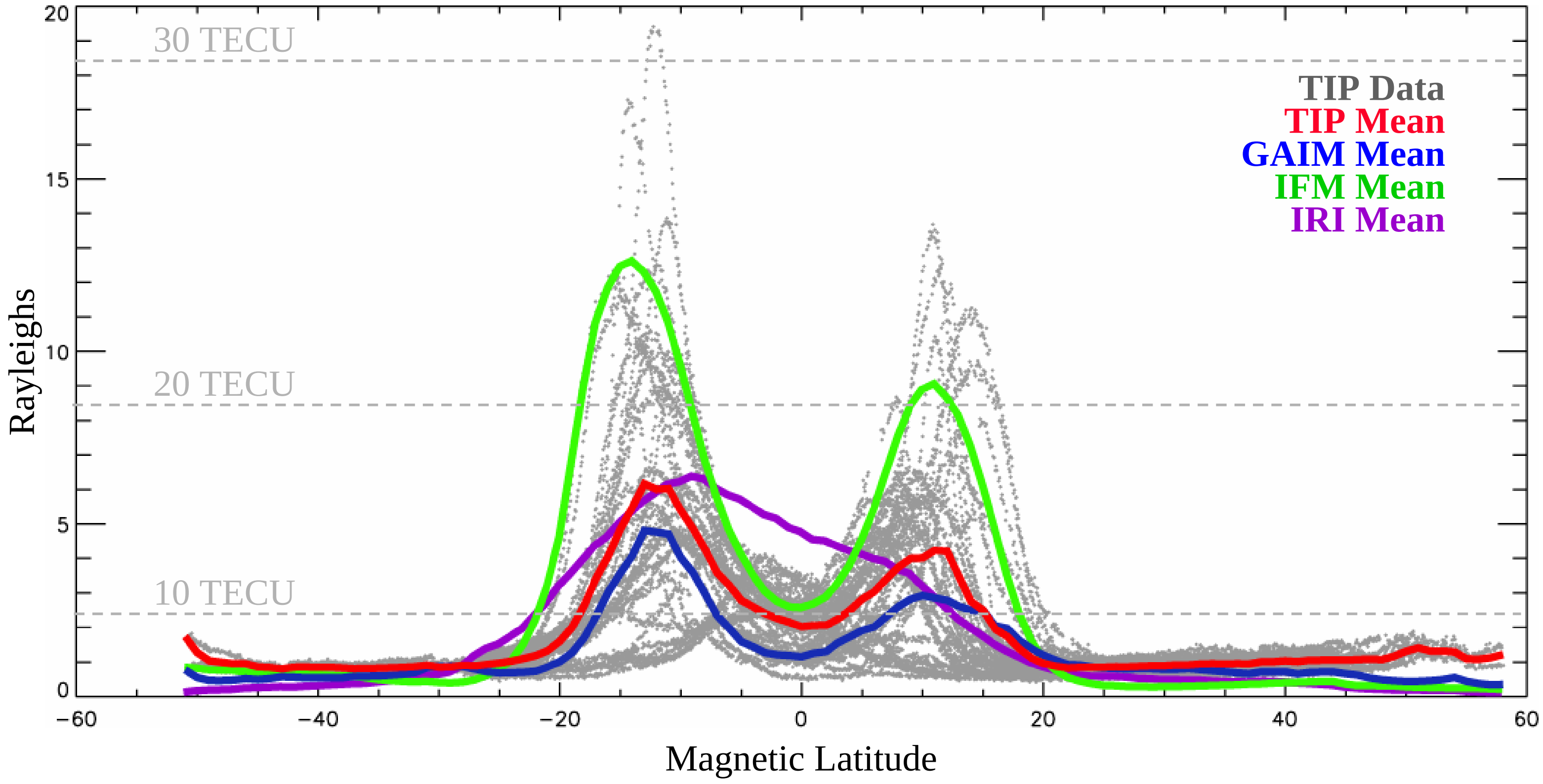
Indian Pass

- TIP pass shows absence of anomaly
- GAIM shows similar equatorial blob, although underestimated
- IFM does not capture this feature – still shows anomaly
- IRI's lack of anomaly is not a bad representation in this case, although much wider in latitude



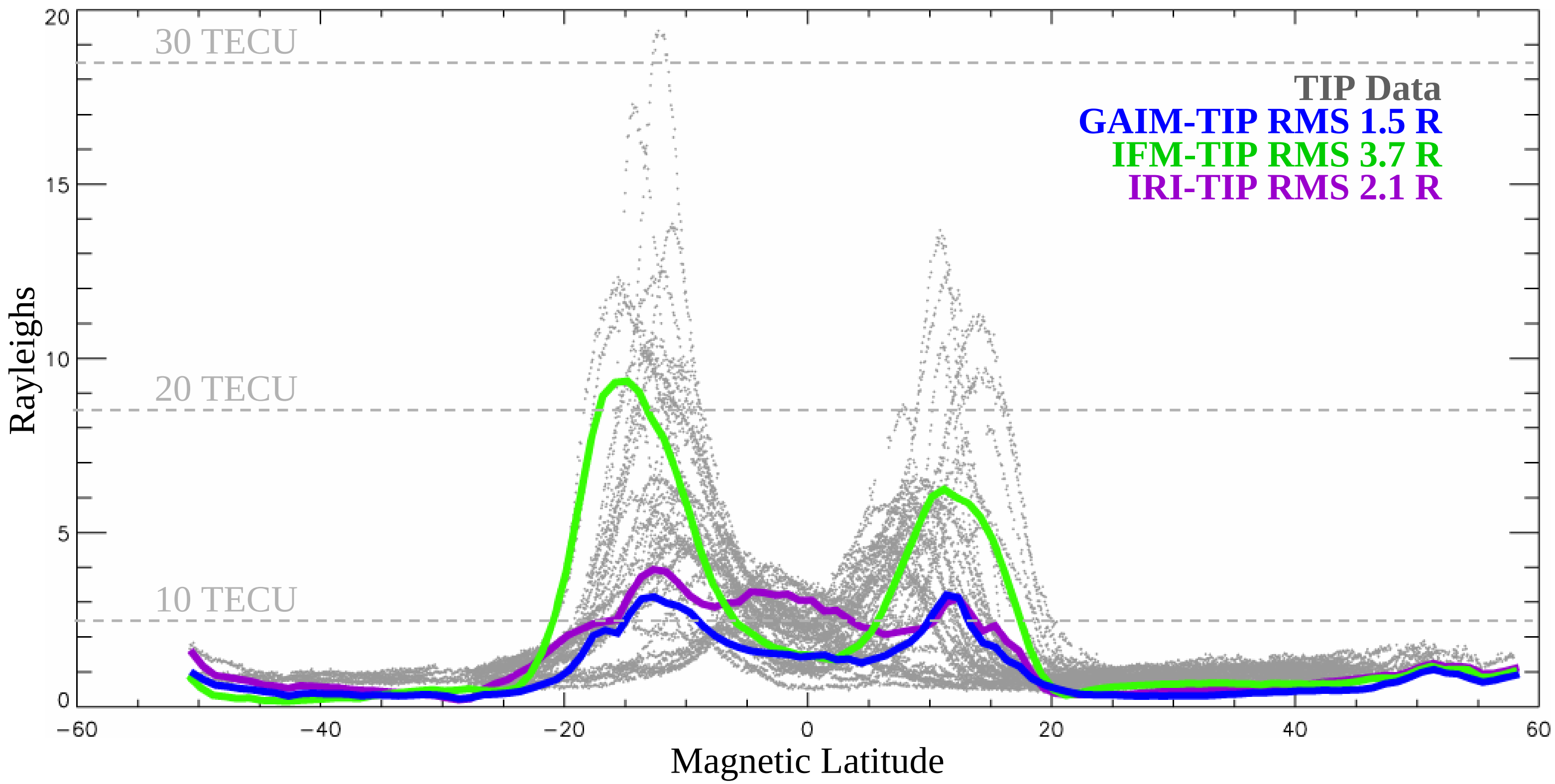
Average Equatorial Ionospheric Anomaly

- TIP data shows highly variable distribution of equatorial anomalies
- TIP average shows slight asymmetry in favor of Southern Hemisphere
- GAIM reproduces global anomaly with slightly less magnitude
- IFM routinely overestimates crest magnitude and width
- IRI doesn't show double crested anomaly or trough, reasonable mean



RMS Error as a Function of Magnetic Latitude

- GAIM shows significantly less error than IFM or IRI
  - Further error reduction, if source of bias identified
- IFM is statistically worse than IRI
- Even though IRI doesn't show an anomaly at 2100LT, on average it does better than IFM at the crests and worse than IFM in the trough



Conclusions

- TIP shows longitudinal variability of the post-sunset equatorial anomaly due to influence of non-migrating tides
- IFM and IRI models do not show similar tidal influence
- GAIMUSC captures the global variability of post-sunset equatorial anomaly
  - Assimilating ground-based GPS, and multiple RO sensors in same orbit (best case)
  - Morphology of equatorial anomaly is remarkably similar to TIP (qualitative)
  - Magnitude of the anomaly crests and trough are statistically better than IFM and IRI (quantitative)
  - Ingesting RO data helps specify the low latitudes more accurately in the horizontal direction!