Validation of Ionospheric Models using COSMIC TEC Measurements

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Introduction

- ➢ Assessed ionospheric models against slant TEC (STEC) to assess model accuracy
  - *Most ionospheric studies validate ionospheric model output against vertical total electron content (TEC)*
  - *STEC is a more stringent test of the models because it assesses the model's horizontal AND vertical gradients*
- ➢ Used occultation slant TEC measurements
- ➢ Time interval of study: 2012 days 126-172 (May 5 – June 20)
  - *Time interval was an arbitrary choice based on GAIM data availability from runs made at NRL*
  - *Runs using ground-based GPS, ionosondes, and COSMIC-RO*
- ➢ Models tested:
  - *GAIM – NRL runs assimilating ground-based GPS, ionosondes, and COSMIC-RO*
  - *IRI 2007 & 2012*
  - *NeQuick – European model*
  - *SAMI-3 runs (different time period Oct-Dec 2011)*

COSMIC Satellites
Constellation Observing System for Meteorology, Ionosphere, & Climate

- ➤ COSMIC is a joint mission between the US and Taiwan, (Republic of China)
  - *6-satellites launched into LEO orbit on April 14, 2006*

- ➤ Principal instrument is the GPS Occultation Experiment (GOX)
  - *~2500 occultations made per day*
  - *Slant TEC routinely inverted to produce electron density profiles*
  - *Products are available on-line at the UCAR CDAAC website*
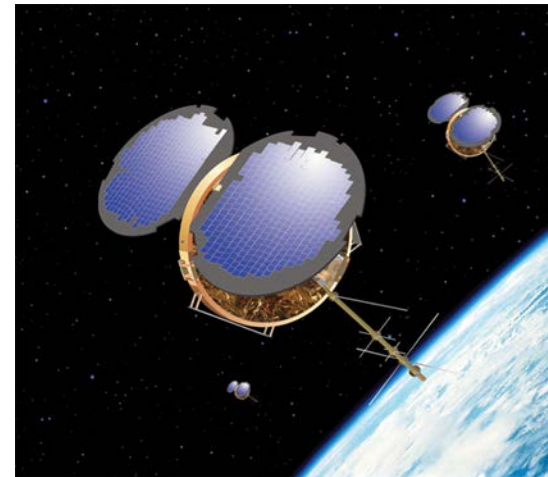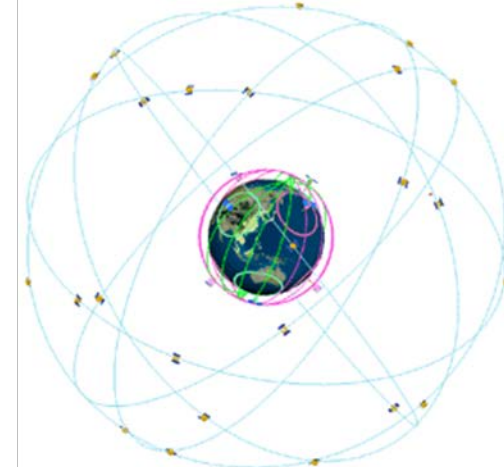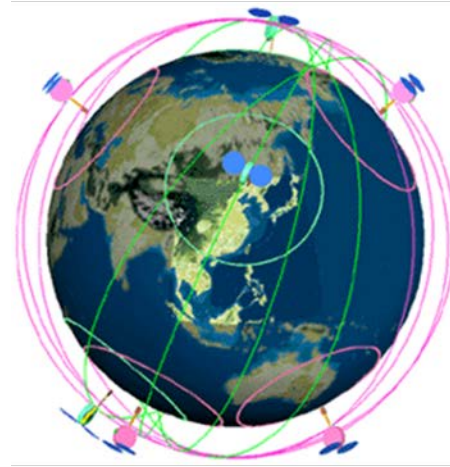
COSMIC STEC vs. Models

➢ The Slant Total Electron Content for each model studied was calculated for each line of sight from all occultations

➢ There were 44,872 COSMIC occultations available during this time interval

- *For a total of 20,834,046 lines-of-sight*
- *Complete global and local time coverage*

➢ To minimize model representation error and to better inter-compare models

- *All models run on GAIM spatial and temporal grid: resulting in similar representation errors between models*
- *Electron density interpolated onto line of sight using tri-cubic Catmull-Rom spline interpolators and integrated*
- *8th order Simpsons' rule integrations were used with 101 points along the LOS to minimize representation error*
- *Testing indicated line-of-sight integration error <0.1%*
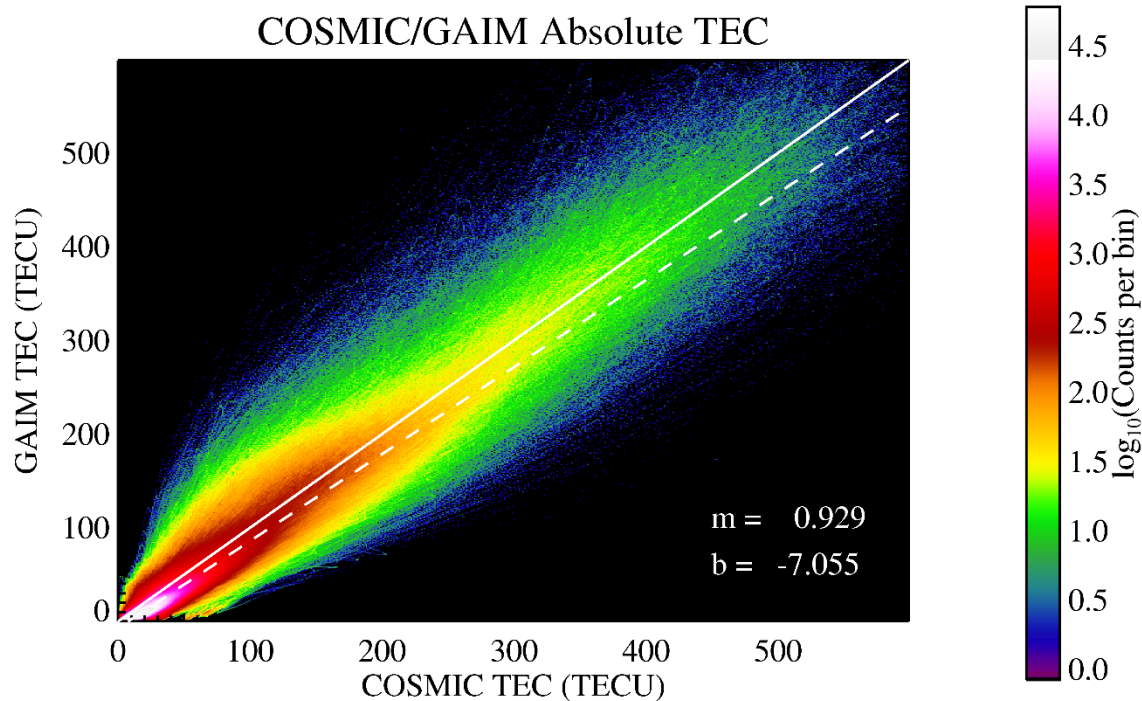
GAIM-NRL/COSMIC Comparison
Absolute TEC

- ➢ Base 10 logarithm of the frequency of occurrence of pairs of TEC values is shown
  - *Tends to enhance the outliers and TEC pairs with low frequency of occurrence*
  - *Solid white line indicates unity slope – perfect correlation*
  - *Dashed line indicates trend-line*

- ➢ High degree of correlation between GAIM and COSMIC TECS
  - *There is a TEC bias present – indicates TEC from plasmasphere*
 - *Trend line slope is less than unity – GAIM is underestimating TEC by ~7%*

COSMIC/GAIM Absolute TEC

m = 0.929
b = -7.055

The Scatter-plot comparison tells you how well GAIM data assimilation is doing in reproducing the observed ionosphere and any biases present

GAIM-NRL/COSMIC Comparison
Relative TEC

- ➢ Topside TEC at 0° elevation is subtracted from each profile
  - *Removes some of the plasmasphere bias*
  - *White line indicates unity slope – perfect correlation*
- ➢ High degree of correlation between GAIM and COSMIC TECS
  - *TEC bias much smaller than it was for absolute TEC*
 - *Trend line slope indicates GAIM underestimating TEC by ~2%*
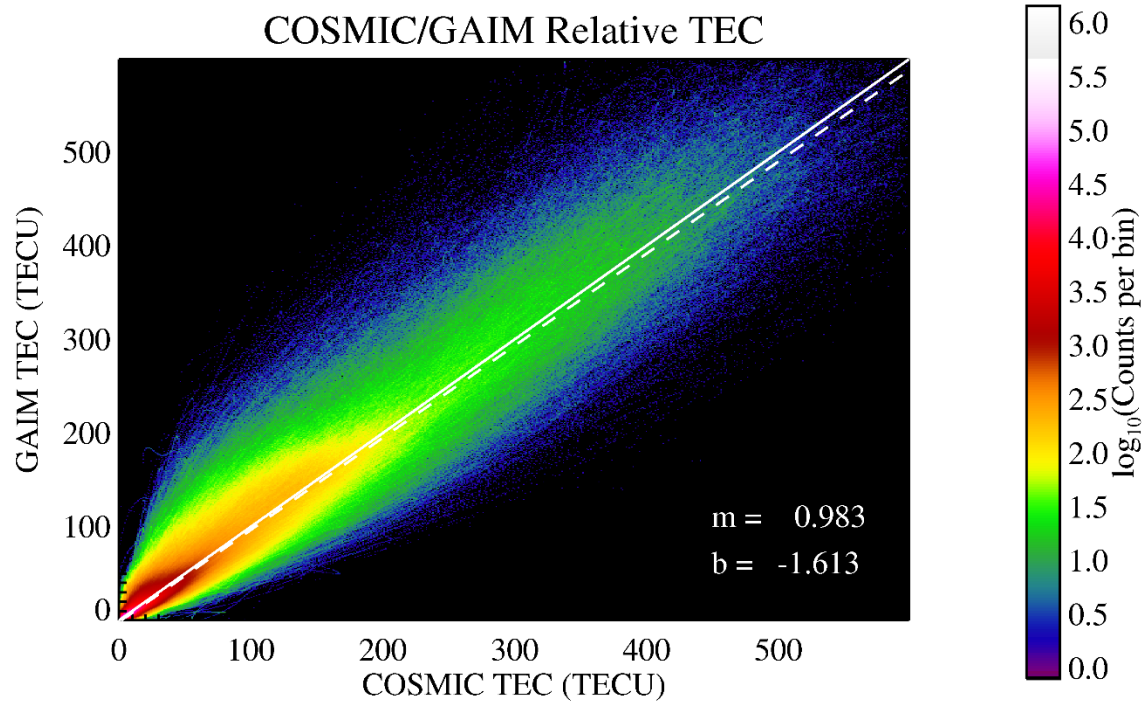

COSMIC/GAIM Relative TEC

m = 0.983
b = -1.613

The Scatter-plot comparison tells you how well GAIM data assimilation is doing in reproducing the observed ionosphere

TEC Probability Distribution Functions

➢ Since the COSMIC and GAIM TECs were correlated with trendline slope of unity

- *Can take differences in TEC to determine the width of the distribution*
- *Panel below shows the result*

➢ Panels at right show cuts through the probability distribution at various TEC values

- *HWHM of distributions is about 15-20% for all TEC values*

TEC Difference PDF

PDF Cut at = 10 TECU

PDF Cut at = 50 TECU

PDF Cut at = 150 TECU

Cut at = 300 TECU
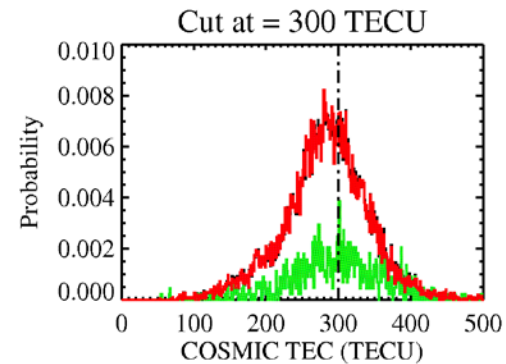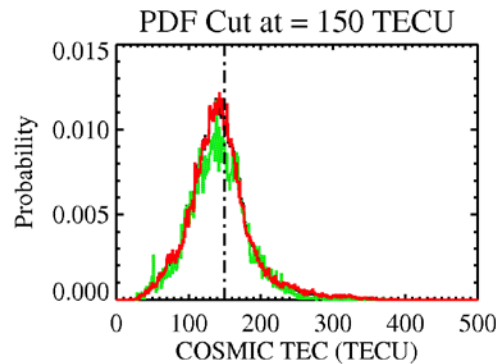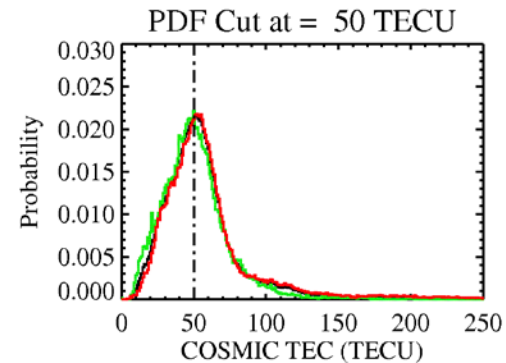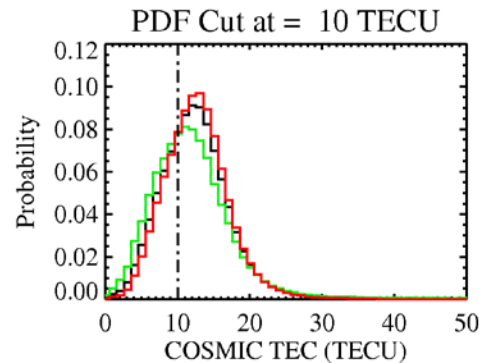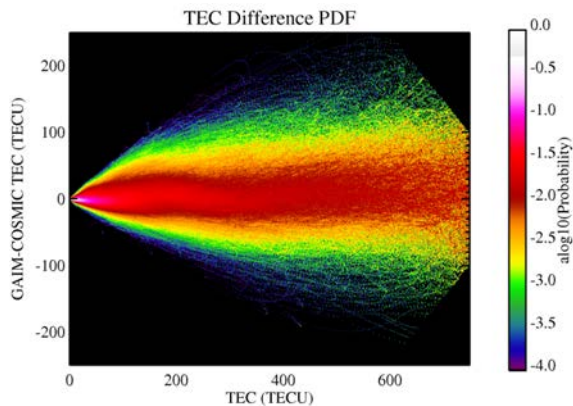
Black – all, green – nighttime, red – daytime

Day to Day Scatter and Causes

- Tested three potential causes of scatter
  - *Geomagnetic and solar variability*
  - *Day-to-day variability of space weather & data availability*
  - *Model resolution (next page)*

- Top plots show variation of trend line slope as a function of time starting from May 5, 2012
  - *Top panel shows variation of trend line slope with time, uncertainty in the slope is smaller than plot symbols*
  - *Center panel shows 10.7 cm solar flux variability – affects photochemical creation of the ionosphere*
  - *Bottom panel shows a_p (in nano-Teslas) geomagnetic index – an indicator of variations in plasma transport due to magnetospheric influences*
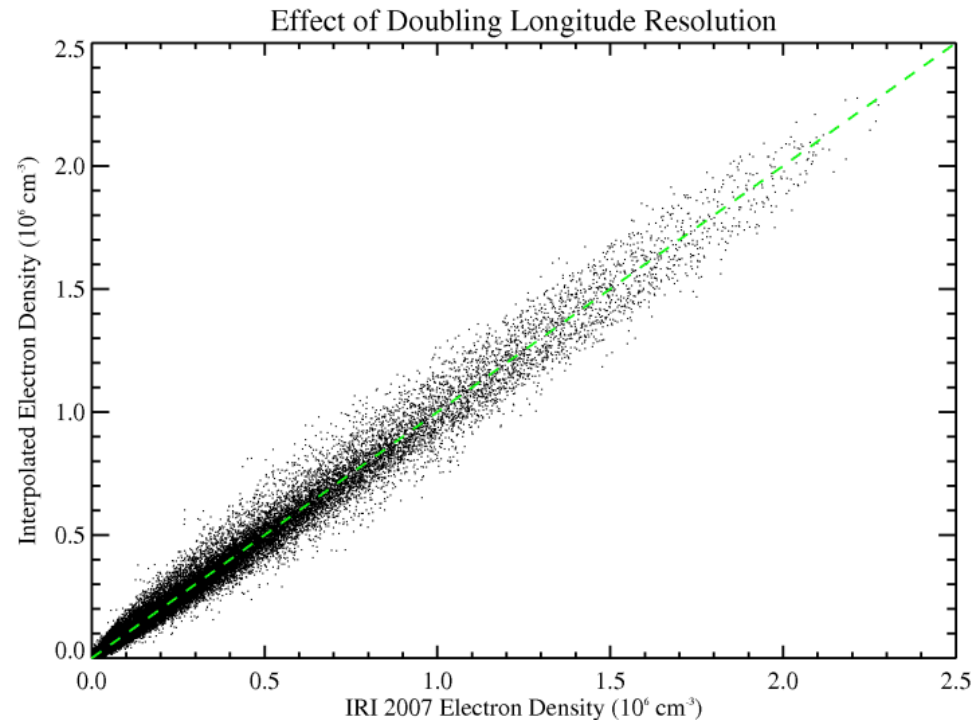

Trendline Slope Variation with Time

10.7 cm Solar Flux
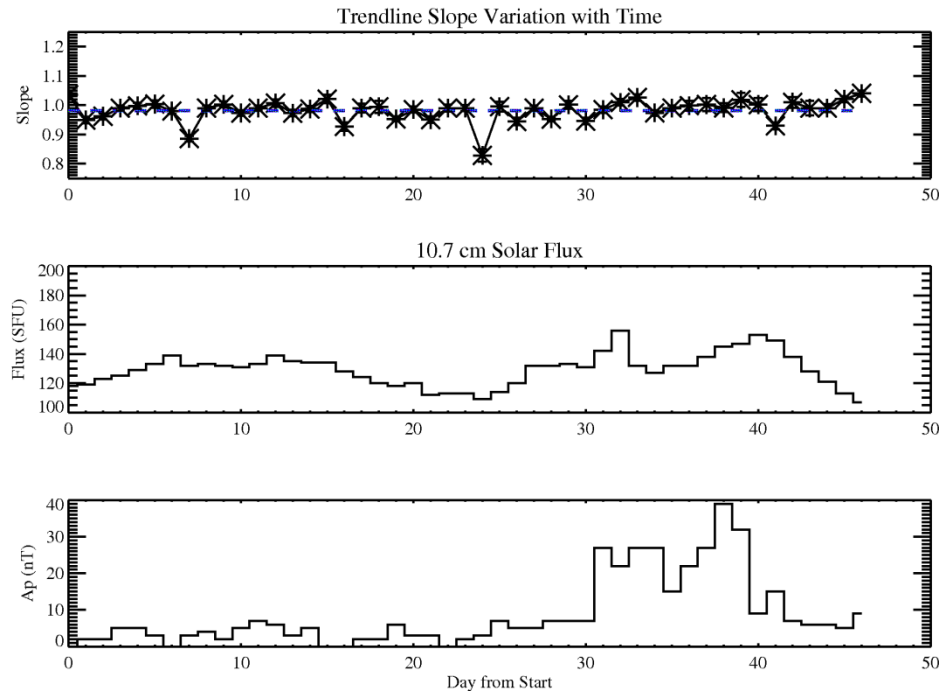
No correlation is evident between geomagnetic indices and trendline slope ➔ scatter is not caused by geomagnetic or solar activity

Model Spatial Resolution

➢ Plot shows the effect of model resolution on the scatter

- *IRI2007 was used as a proxy for GAIM as its gradients should be similar to those in GAIM*
- *IRI2007 was run at 7.5° longitude resolution and compared to interpolations of IRI2007 run at the 15° resolution of GAIM*

➢ Results indicate the model spatial resolution is one of the primary causes of the scatter

Effect of Doubling Longitude Resolution

Interpolated Electron Density (10^6 cm^3) vs *IRI 2007 Electron Density (10^6 cm^3)*

Results: Model Comparisons

- ➤ GAIM model showed excellent performance typically within 2% of COSMIC sTEC
- ➤ SAMI-3 model underestimated the TEC by ~6%
- ➤ Climatology models also performed well against COSMIC:
  - *IRI 2007: -7%*
  - *IRI 2012: -11%*
  - *NeQuick: -16%*
  - *Might be improved by adjusting 10.7 cm solar flux proxy used as model driver*
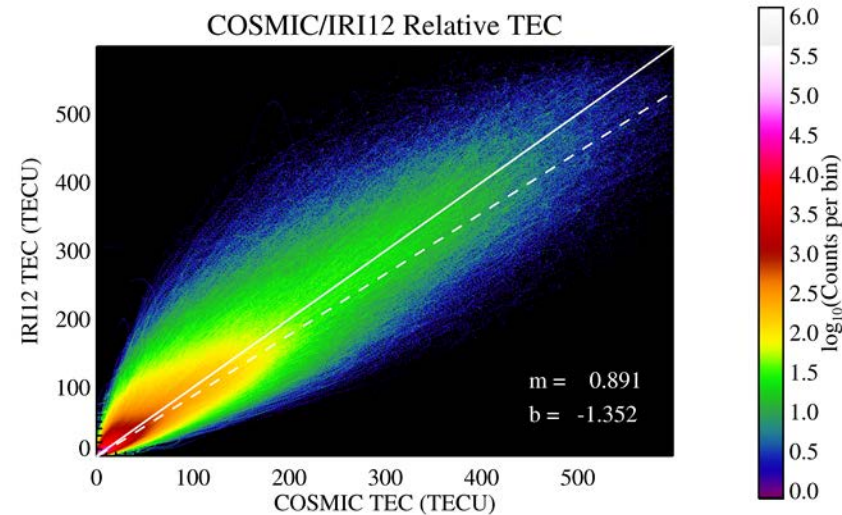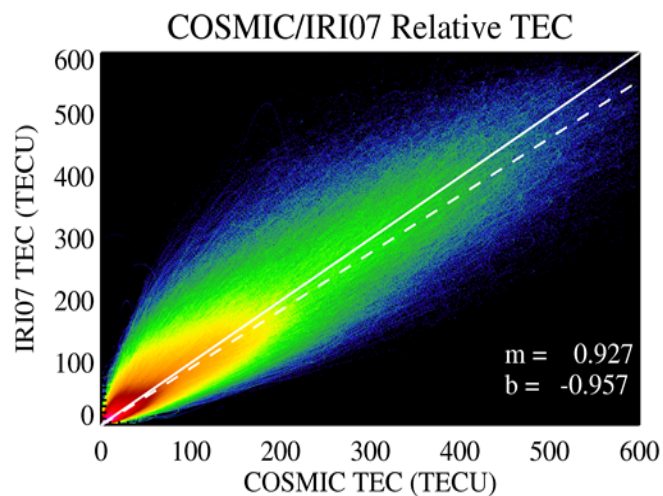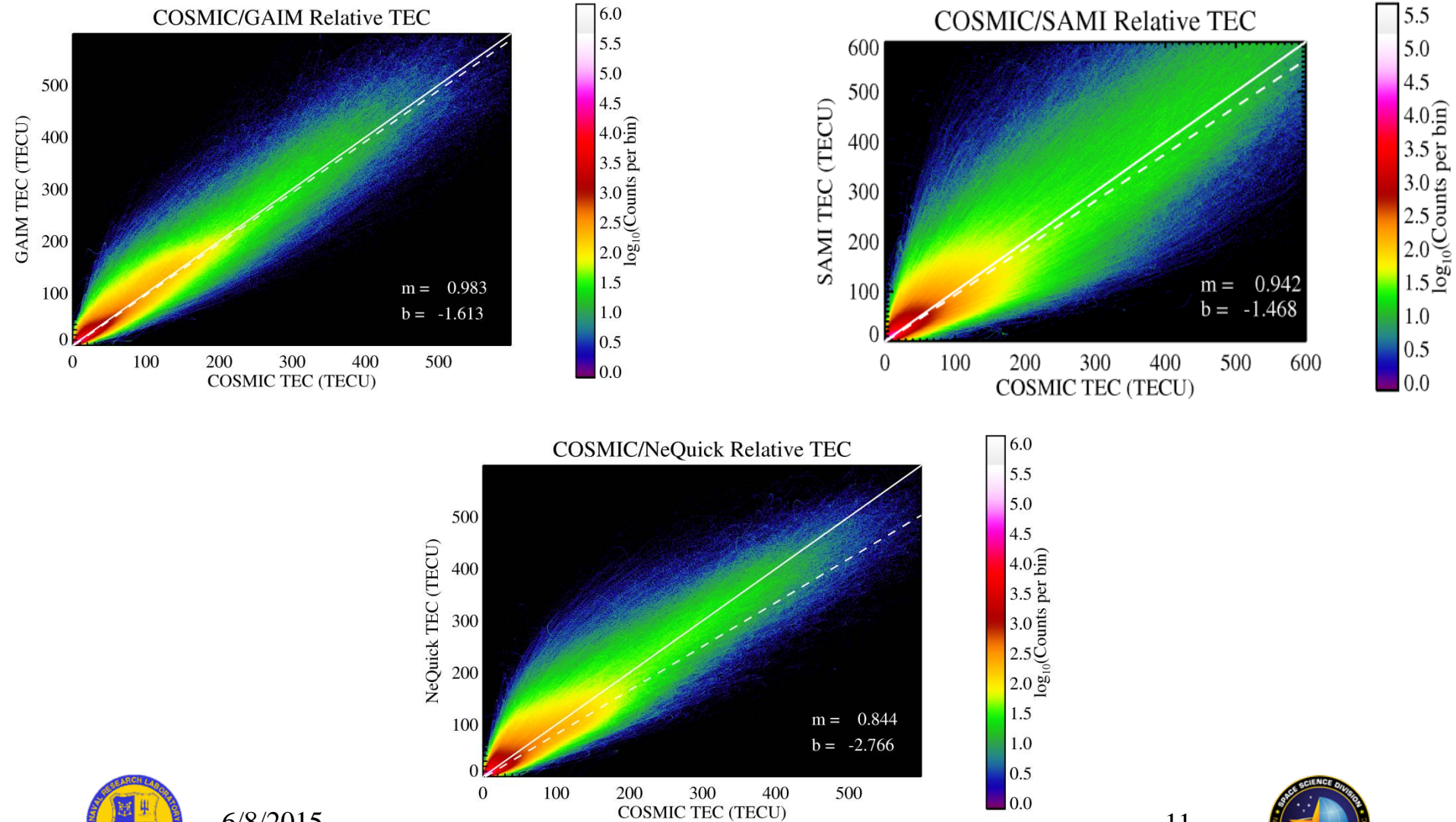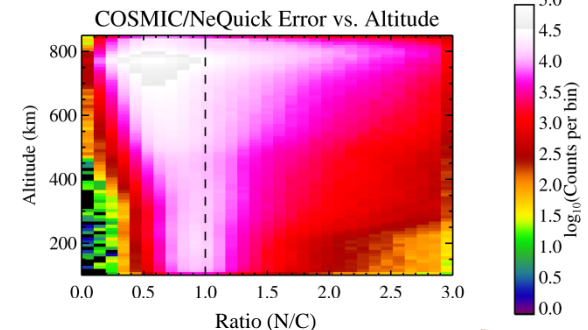
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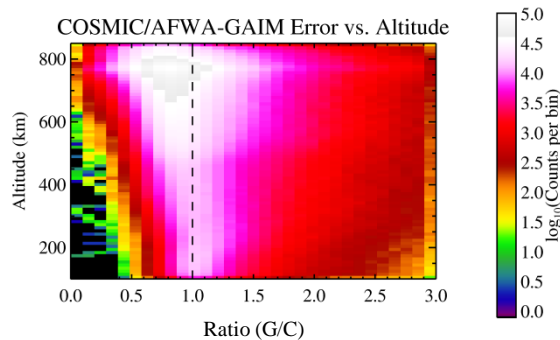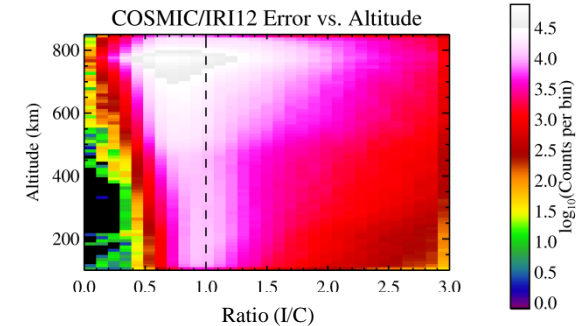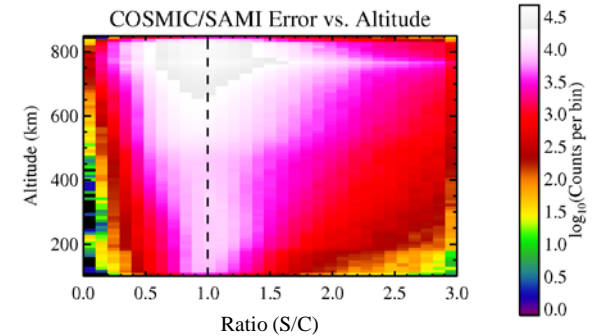
Topside and TEC Error

- All models underestimating topside sTEC
  - *GAIM: -15%*
  - *SAMI-3: -5%*
  - *IRI 2007 & 2012: -25%*
  - *NeQuick: -40%*
  - *GAIM vertical correlation length modified to ingest SSULI data*
    - Improved spatial structure in model, raised peak height – might have improved topside
    - Might have improved vertical profiles driven by ingestion of COSMIC radio occultation TEC

- Underestimation of scale-height should cause underestimate of vTEC
  - *However, other studies have shown GAIM to reproduce vTEC accurately*
  - *Low scale height can be compensated for by increased peak density or by other adjustments to the plasma distribution*

COSMIC/SAMI Error vs. Altitude

COSMIC/IRI12 Error vs. Altitude

COSMIC/NeQuick Error vs. Altitude

COSMIC/AFWA-GAIM Error vs. Altitude

Summary (1 of 2)

- ➢ The GAIM model agreed very well with the measured COSMIC RO and DORIS slant TECs
  - *The absolute sTEC showed an additive bias of -7 TECU and a multiplicative bias of 0.93*
  - *This was substantially reduced by correcting for the plasmasphere to an additive bias of -1.6 TECU and a multiplicative bias of ~0.98 or essentially zero error!*
- ➢ However, the scatter between the measurements and the model is problematic
  - *This is approximately 15% at all TEC values*
    - A 1-σ error of 15 TECU at 100 TECU
  - *Poor spatial resolution and few sources for ingested data cause this error*
- ➢ Also, there is a topside bias of ~-15% ➔ this can lead to vertical TEC and nmF2 errors
  - *Might have been fixed when the vertical correlation length was increased to accommodate SSULI data*

Summary (2 of 2)

➢ The other models agreed reasonably well with the measured COSMIC RO slant TECs

- *Additive biases were a few TECU*
- *Multiplicative biases were 6-15%*

➢ However, the scatter between the measurements and the models is problematic

- *The scatter was larger than GAIM's 15% at all TEC values* ➔ *especially for SAMI-3*
- *Results might be improved by tweaking the model inputs to adjust to the geomagnetic and solar conditions*

➢ Also, there are a topside biases present

- *These are from 25-50%* ➔ *these can lead to vertical TEC and nmF2 errors*

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