Insights from ionospheric forecasts with physics-based models: TEC and energy budget

X. Meng, A. J. Mannucci, O. P. Verkhoglyadova, and B. T. Tsurutani

Jet Propulsion Laboratory, California Institute of Technology

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Outline

- Ionospheric forecast study overview
- Result I: TEC forecast variable
- Result II: ionosphere-thermosphere energy partitioning
- Summary

Forecast Study Overview

- In short: "**Forecast-mode" simulations with physics-based ionospheric models for past geomagnetic storms**

- Ionospheric models used: **GITM** [Ridley et al., 2006] and **TIE-GCM** [Richmond et al., 1992]

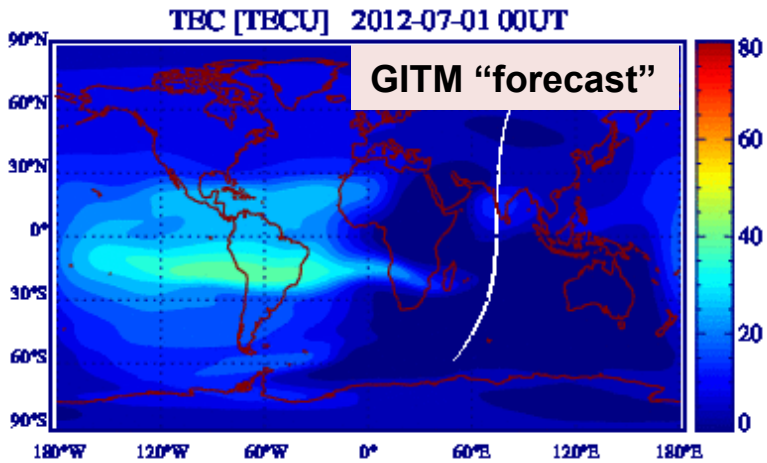
- "Forecast-mode" simulation set-up:
  - forecastable inputs such as F10.7 flux, Kp index, solar wind conditions (from OMNI data or ENLIL, CORHEL, SWMF predictions)
  - no parameter tuning
  - TIE-GCM forecast-mode is still under developement

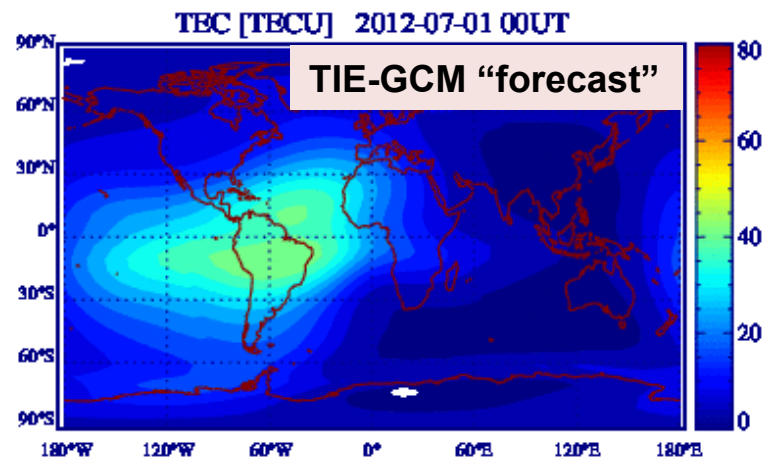
- Events undergoing detailed study:
  - 8 high-speed-stream (HSS) storms during 2006 - 2013
  - 5 coronal mass ejection (CME) storms during 2003 - 2015

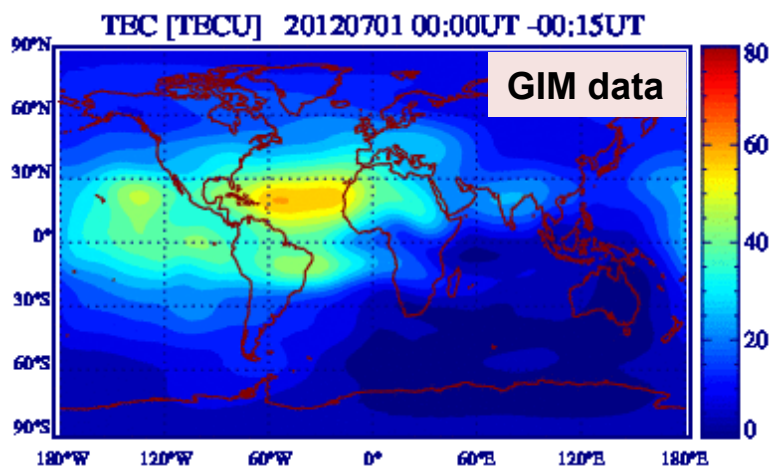
Forecast Study – TEC Maps

- "Forecasted" TECs are compared to Global Ionospheric Maps (**GIM**) [Mannucci et al. 1998], which provide GPS-derived TEC data.

June 2012 HSS Event







geomagnetic coordinates

TEC Forecast Variable

- **Step 1**: Divide the globe into grid boxes of size 30° (longitude) x 15° (latitude) in geomagnetic coordinates.
- **Step 2**: Compute the mean TEC within each grid
- **Step 3**: For each day, define and calculate the TEC perturbation as

GIM TEC Forecast Variable

$$dTEC_{GIM}(UT, lon, lat) = \frac{TEC_{GIM}(UT, lon, lat) - TEC_{GIM,quiet}(UT, lon, lat)}{\sigma_{TEC,GIM,quiet}(UT, lon, lat)}$$

GITM TEC Forecast Variable

$$dTEC_{GITM}(UT, lon, lat) = \frac{TEC_{GITM}(UT, lon, lat) - TEC_{GITM,quiet}(UT, lon, lat)}{\sigma_{TEC,GIM,quiet}(UT, lon, lat)} * Scale(UT)$$

where $$Scale(UT) = \frac{median(TEC_{GIM,quiet}(UT, *, *))}{median(TEC_{GITM,quiet}(UT, *, *))}$$

- **TIE-GCM TEC Forecast Variable** is defined the same way as for GITM.

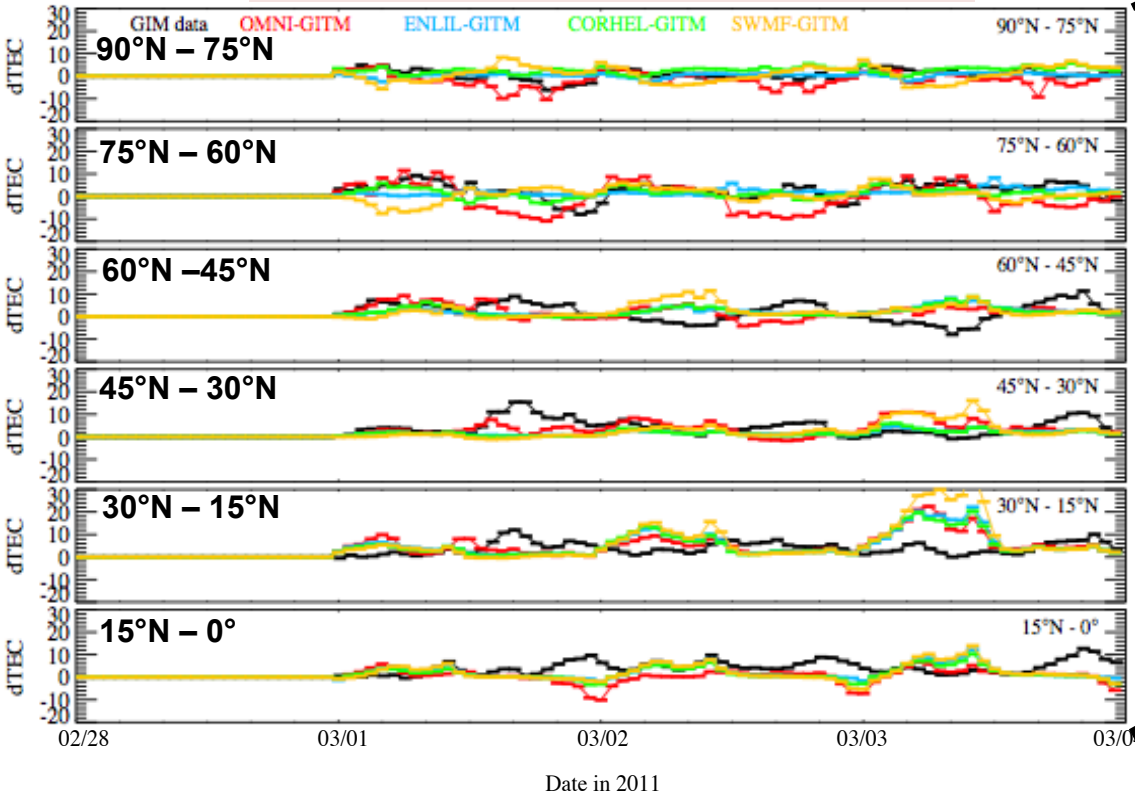
- The quiet day is selected from days before each storm event with daily Ap < 6.

- **Final output**: hourly *dTEC* for every 30° x 15° grid box

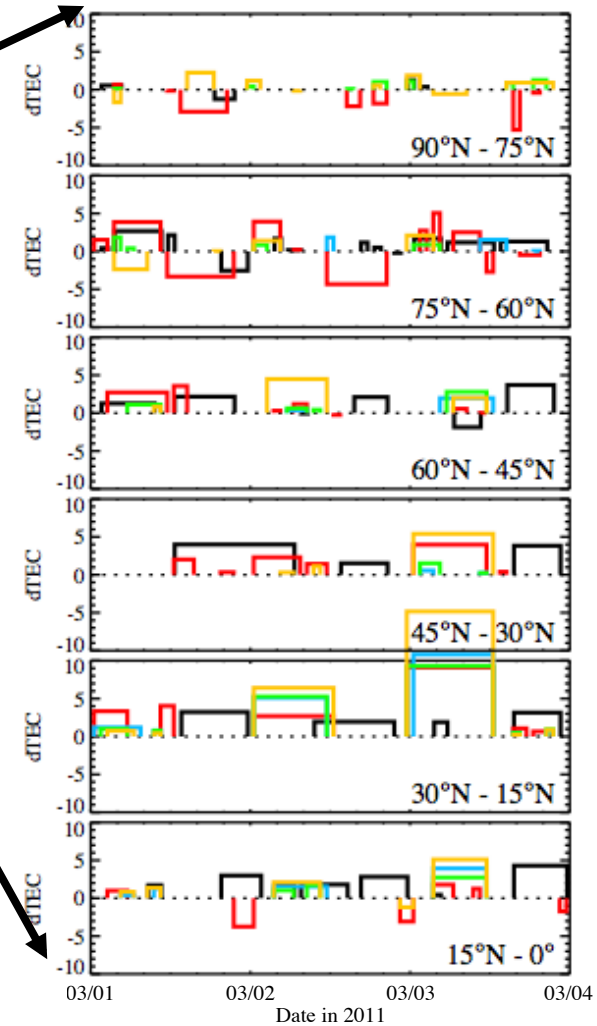
Forecast Variable Visualization I

OMNI-GITM
ENLIL-GITM
CORHEL-GITM
SWMF-GITM

Forecast Variable for the **Feb 2011** Event
Geomagnetic Longitude **0°E - 30°E**

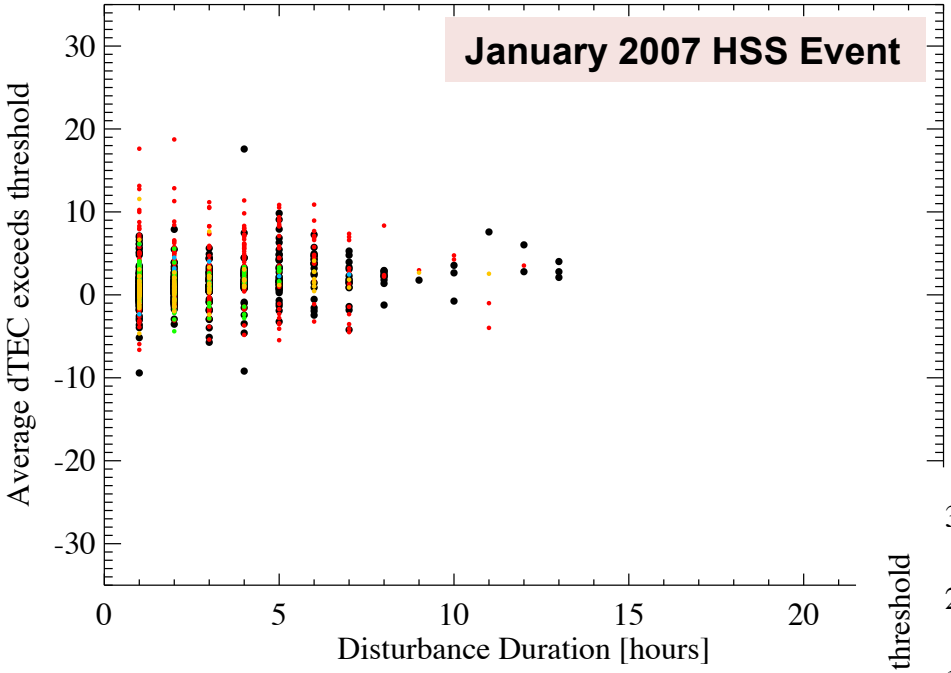


Average Forecast Variable for |dTEC| > 4

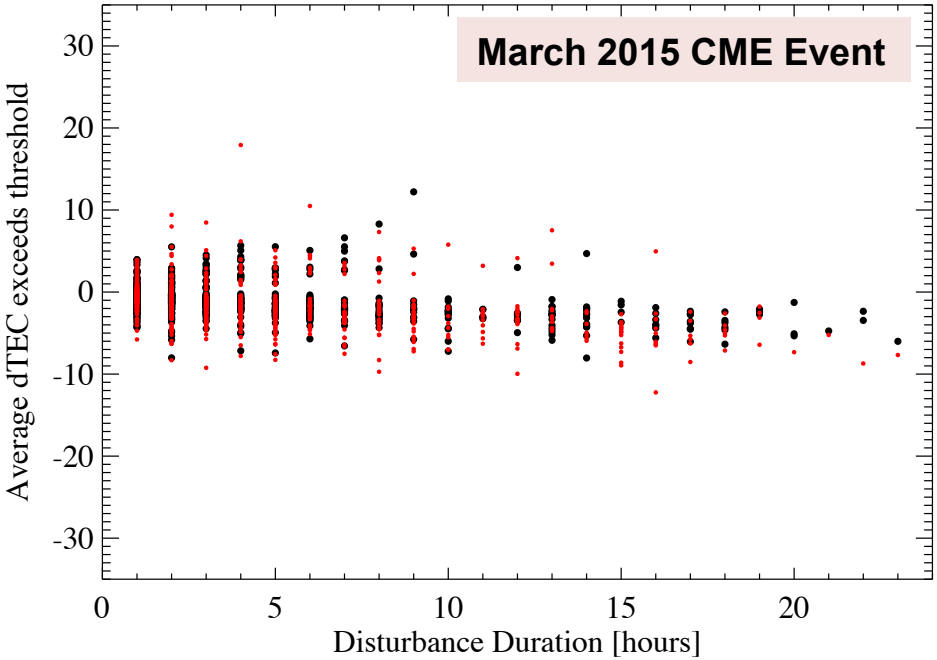


Average TEC Forecast Variable: indicates for how long and by how much |dTEC| exceeds a certain level.

Forecast Variable Visualization II



OMNI-GITM
ENLIL-GITM
CORHEL-GITM
SWMF-GITM

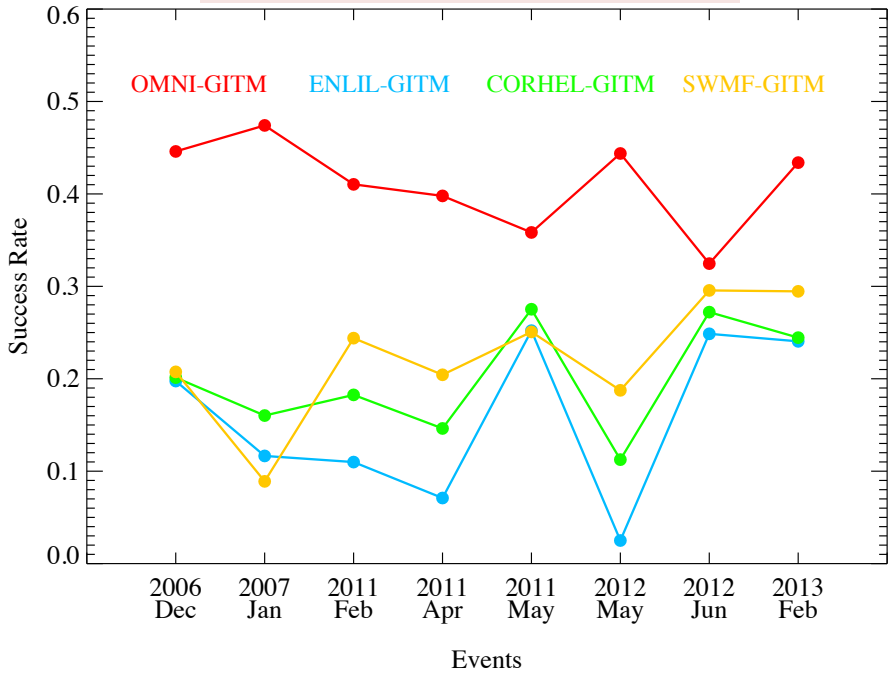


Threshold dTEC = +/- 4

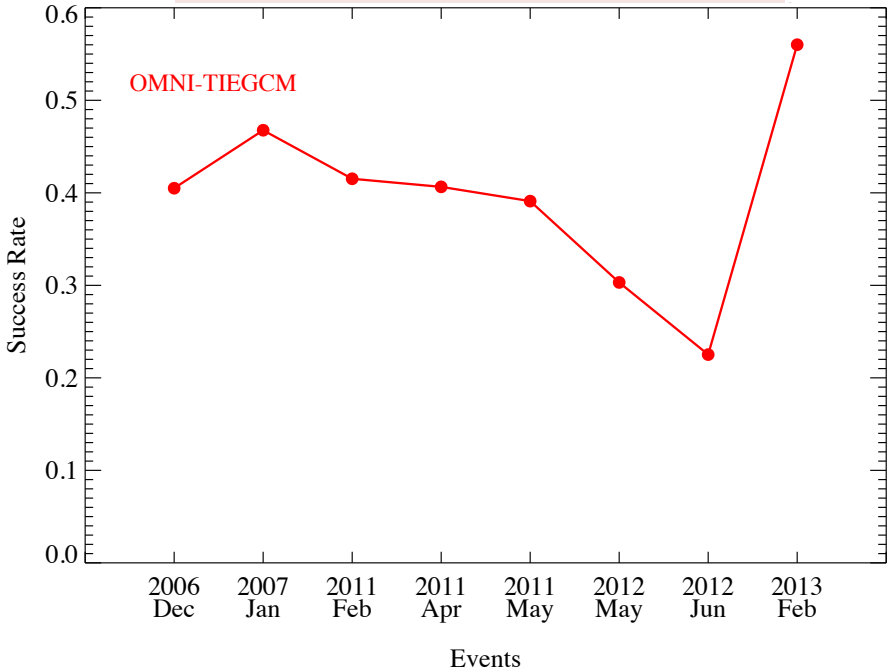
Forecast Evaluation

GIM data: number of all TEC disturbances with |dTEC| > 4
GITM and **TIE-GCM**: number of GIM TEC disturbances reproduced by the simulations, with time error +/- 3 hours

GITM "Forecast" Performance



TIE-GCM "Forecast" Performance

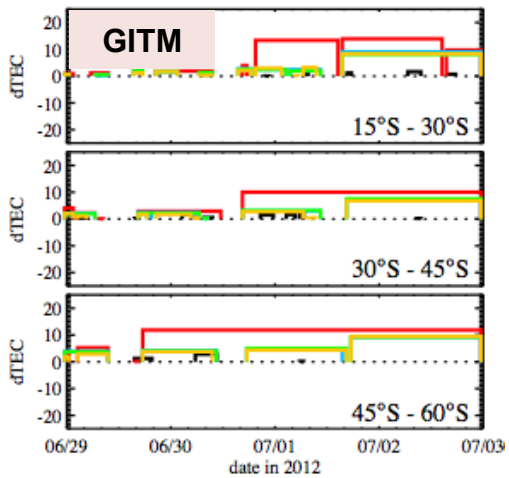


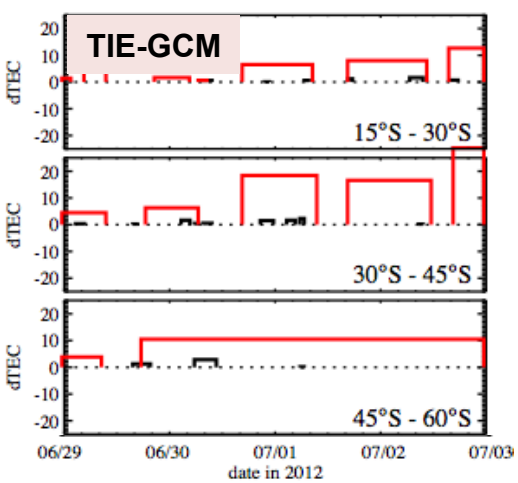
"Forecast" Success Rate:

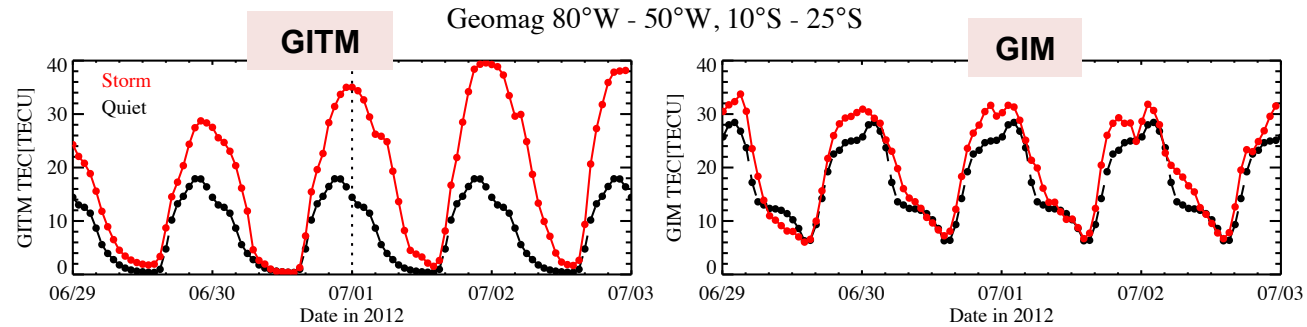
$$\frac{\text{"forecasted" TEC Disturbances}}{\text{GIM TEC Disturbances}}$$

Diagnostic Case Study

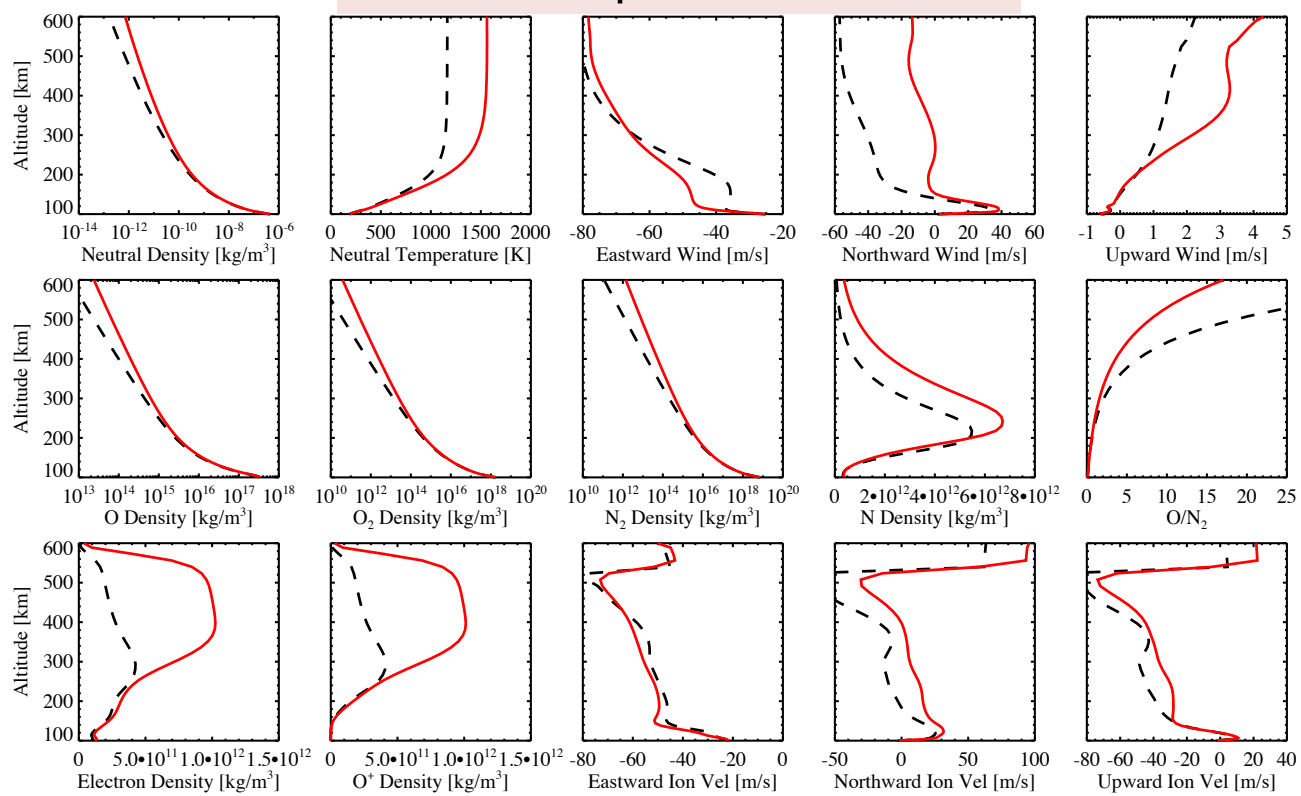
June 2012 HSS Event
Geomagnetic Longitude
90°W – 60°W







GITM-simulated profiles at 00UT on 07/01



Insights from Forecast Variable Study

- Proposed TEC forecast variable and its visualizations are effective forecast products.

- GITM “forecasts” and TIE-GCM “forecasts” have similar performance. Solar wind **model** driven “forecasts” are worse than solar wind **data** driven ones.

- Both GITM and TIE-GCM vastly overestimate TEC responses to the June 2012 HSS storm. An initial diagnostic study shows highly-elevated F layer in the GITM simulation.

IT Energy Study

- Motivation: understand how well the ionospheric models reproduce the ionosphere-thermosphere (IT) energy transport during geomagnetic storms.

- Method
  - Obtaining IT energy budget from forecast-mode **GITM** simulations
  - Comparing with empirical estimates and satellite measurements of IT energy budget.

- Events studied
  - 2 out of 8 HSS storms
  - 2 out of 5 CME storms

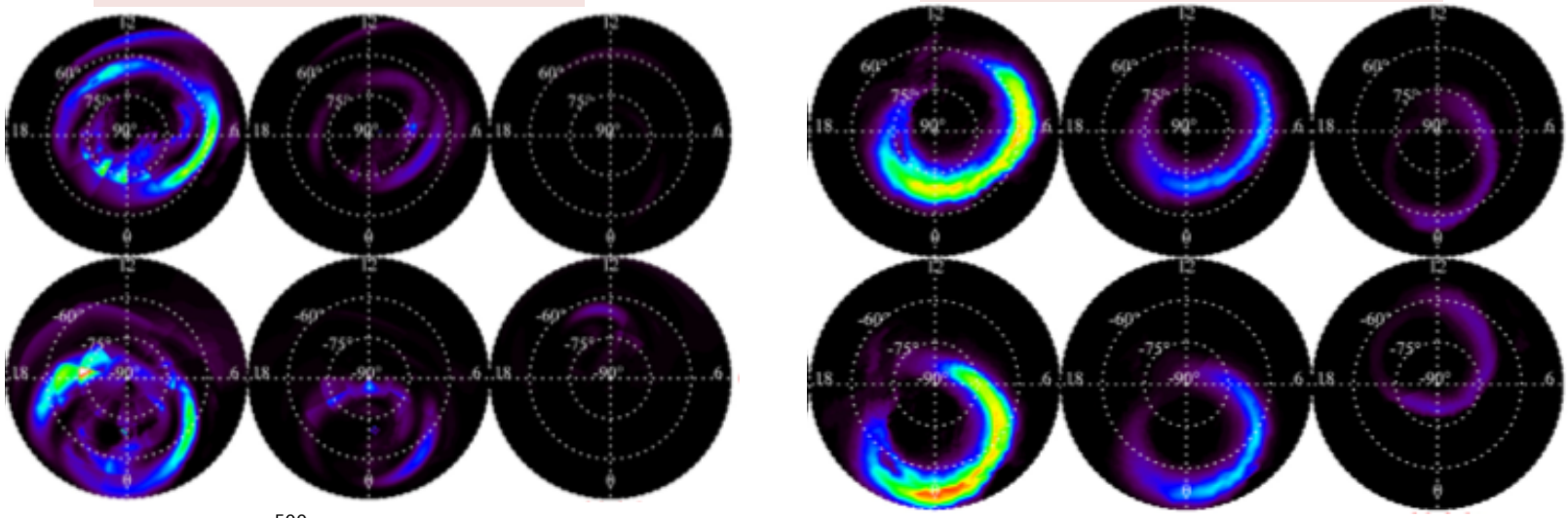
IT Energy Study Results

GITM-simulated Joule heating | **January 2007 HSS** | **GITM-simulated Auroral heating**

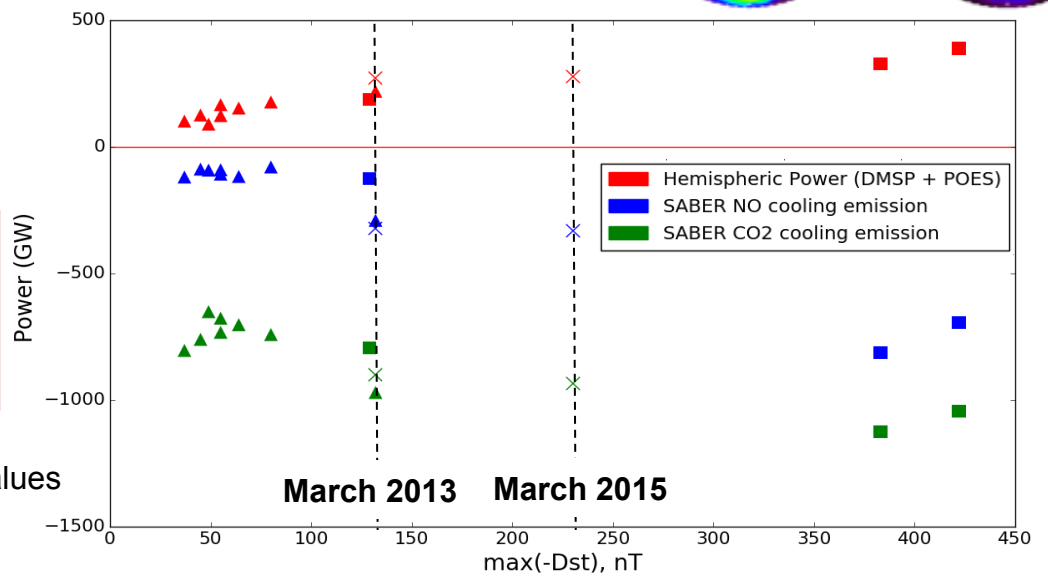
Northern hemisphere

geographic coordinates

Southern hemisphere



Simulated Vs. Measured IT energy



Crosses: GITM-derived values

Verkhoglyadova et al., 2016

Insights from IT Energy Study

- GITM “forecasts” capture the main features of the IT energy coupling for the 2 HSS and 2 CME storms we studied.
- For March 2013 CME storm: GITM global auroral heating power agrees with the empirical estimate; global NO cooling and CO2 cooling powers show good agreement with SABER measurements.
- Modeled NO cooling patterns show discrepancies from measurements: underestimation in high-latitudinal regions.
- We are investigating modeled and observation-derived Joule heating.

Summary

- We performed forecast-oriented ionospheric modeling with fully physics-based models and developed a TEC forecast variable for scientific study.
- To understand “forecasts”, a detailed investigation of model physics is being conducted.
- Energy partitioning is being analyzed in detail as an important modeling constraint. More events are planned.
- We will include additional CME events.

Acknowledgement

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