96th Annual Meeting
American Meteorological Society
13th Conference on Space Weather
Advances in Space Weather Modeling and Prediction, Part II
New Orleans, LA Jan 11-14, 2016

Quantifying Total Electron Content Forecasts during Ionospheric Storms

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Acknowledgements:
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Aaron Ridley, U Michigan

NASA/NSF Partnership for Collaborative Space Weather Modeling
Community Coordinated Modeling Center
Heliospheric and Community Model Developers (ENLIL, CORHEL, SWMF)

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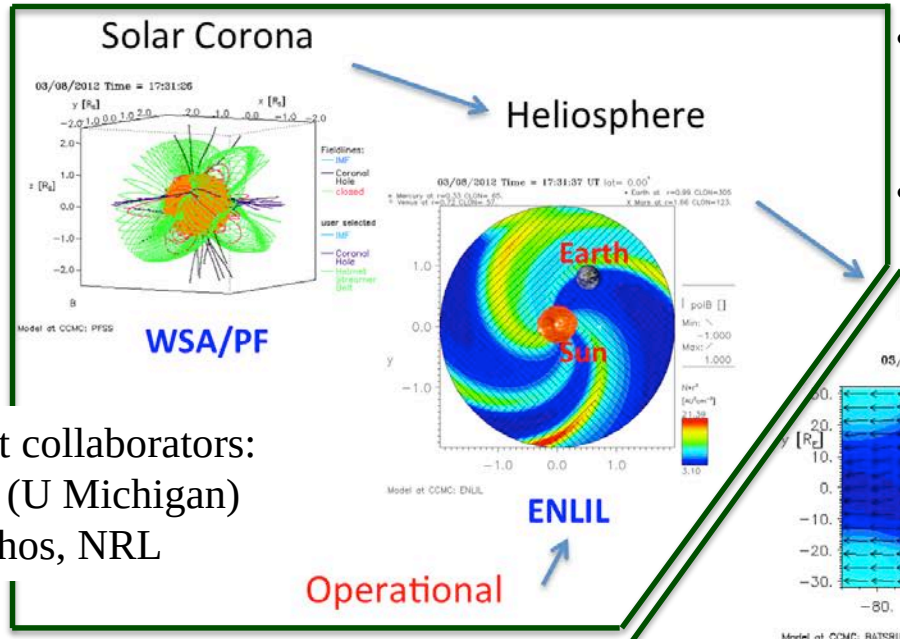
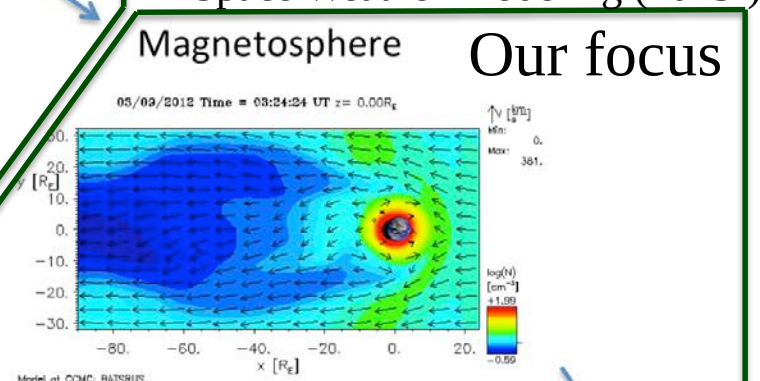
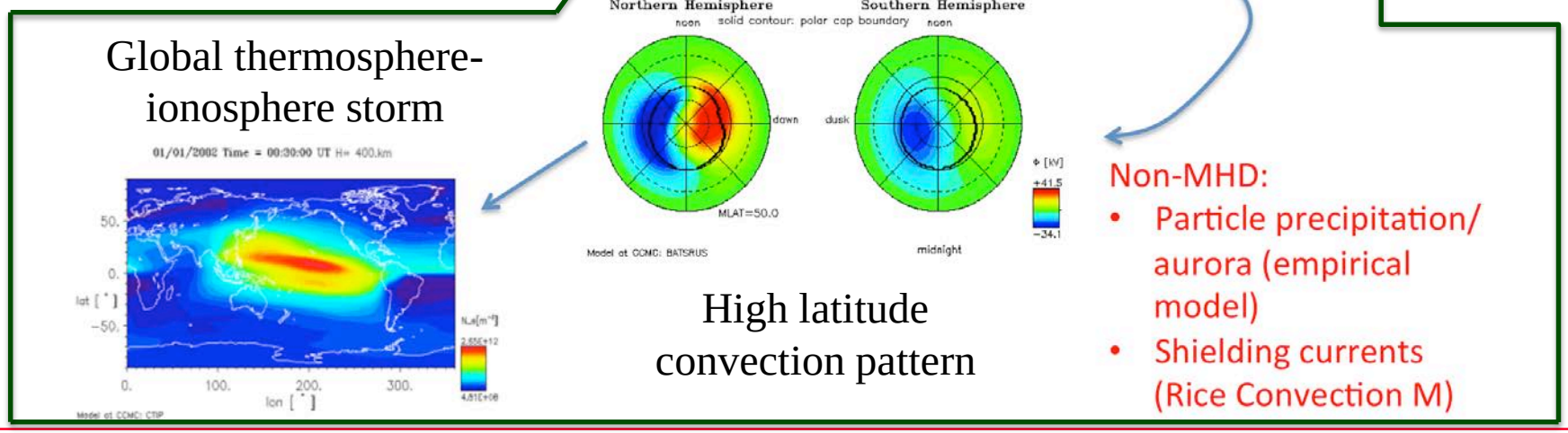


- Center for Integrated Space Weather Modeling (2000's), LWS TR&T, NSF, MURI, etc.
- NASA/NSF Partnership for Collaborative Space Weather Modeling (2013-)

Current collaborators:
CSEM (U Michigan)
Antiochos, NRL

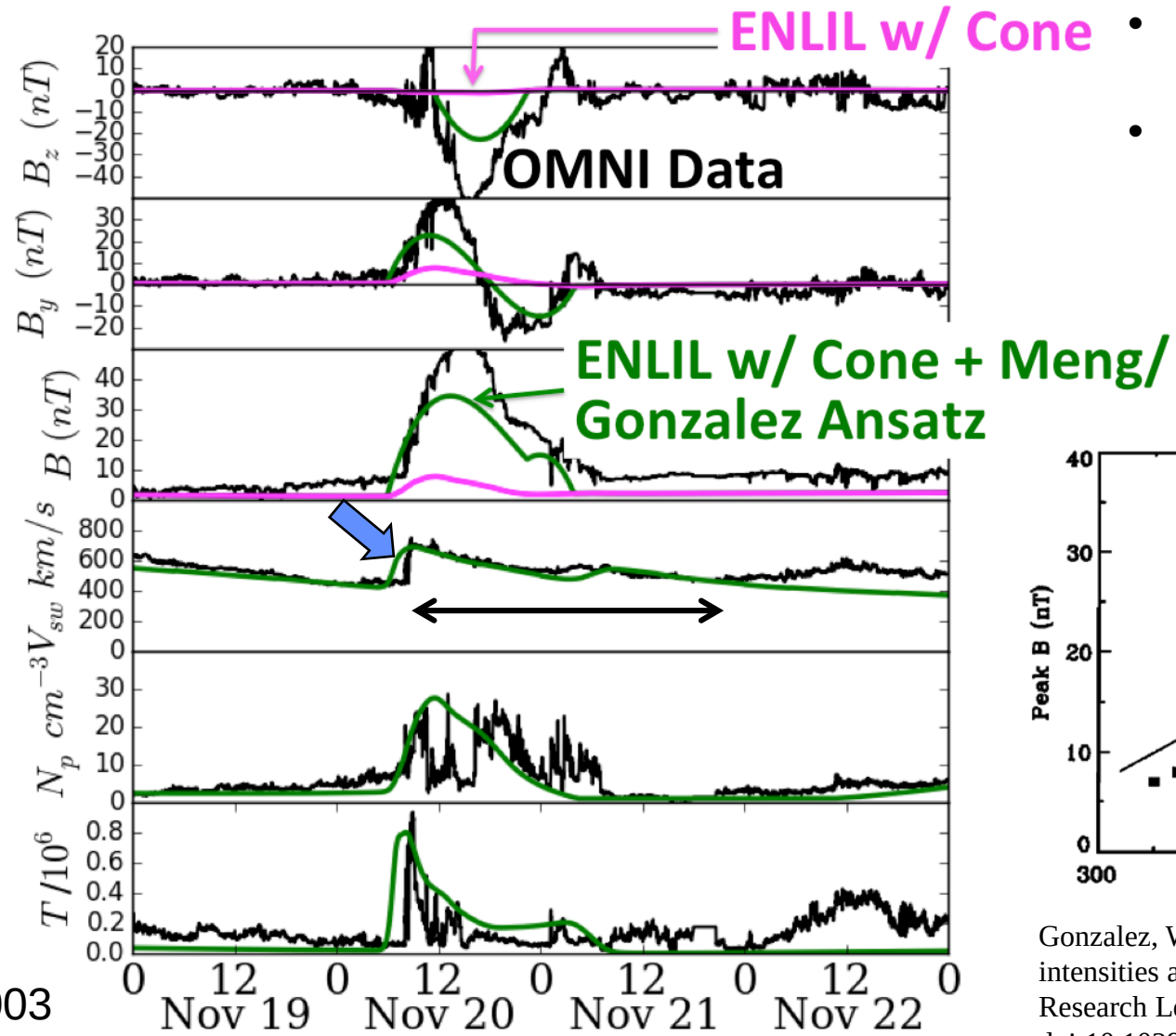




Prospects For Heliosphere Forecasts

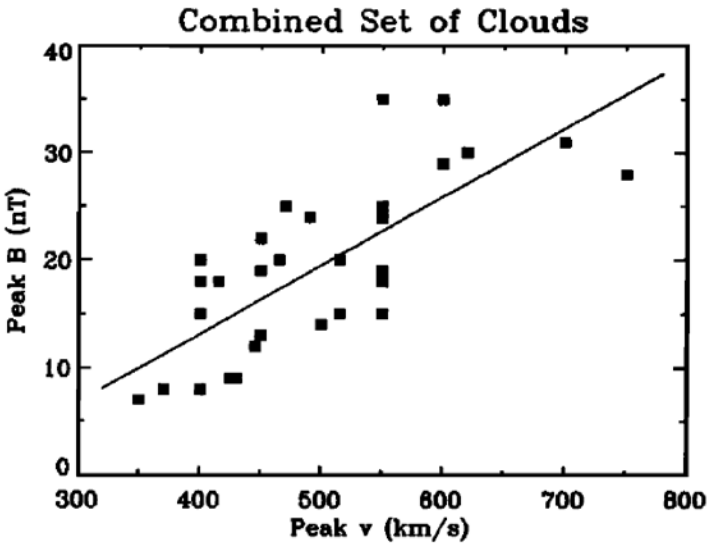
- **Operational forecasts of the arrival time of geomagnetic disturbances (ENLIL)**
- **ENLIL + CONE model for CMEs – insufficient magnetic field – run by CCMC**
- **A simple ansatz based on an empirical formula was developed to provide magnetic component estimates**
- **Soon CCMC will be running AWSOM (-R) with EEGGL – includes magnetic field model (flux rope) embedded in the CME**
  - **Bart van der Holst, Igor Sokolov, Chip Manchester, Gabor Toth, Darren DeZeeuw and Tamas Gombosi**
- **L5 monitor – improved timing particularly for fast CMEs**

ENLIL, ENLIL w/ CONE, Enhanced



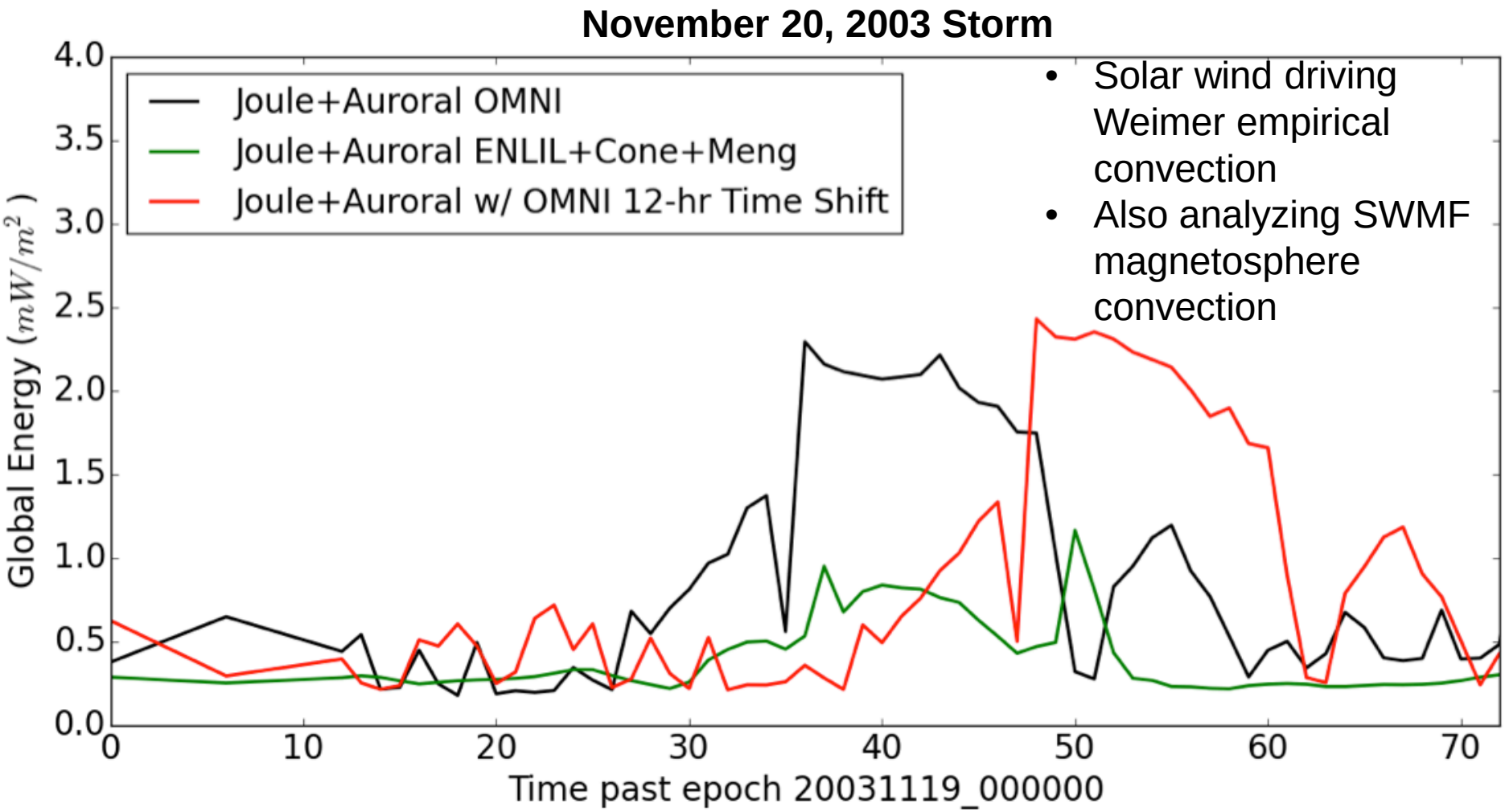
2003

- CONE hydrodynamics provides time of arrival
- Ansatz provides B field components based on velocity profile and Gonzales et al., 1998



Gonzalez, W. D., et al. (1998), Magnetic cloud field intensities and solar wind velocities, Geophysical Research Letters, 25(7), 963–966, doi:10.1029/98GL00703.

Energy Estimated by GITM



- Solar wind driving Weimer empirical convection
- Also analyzing SWMF magnetosphere convection

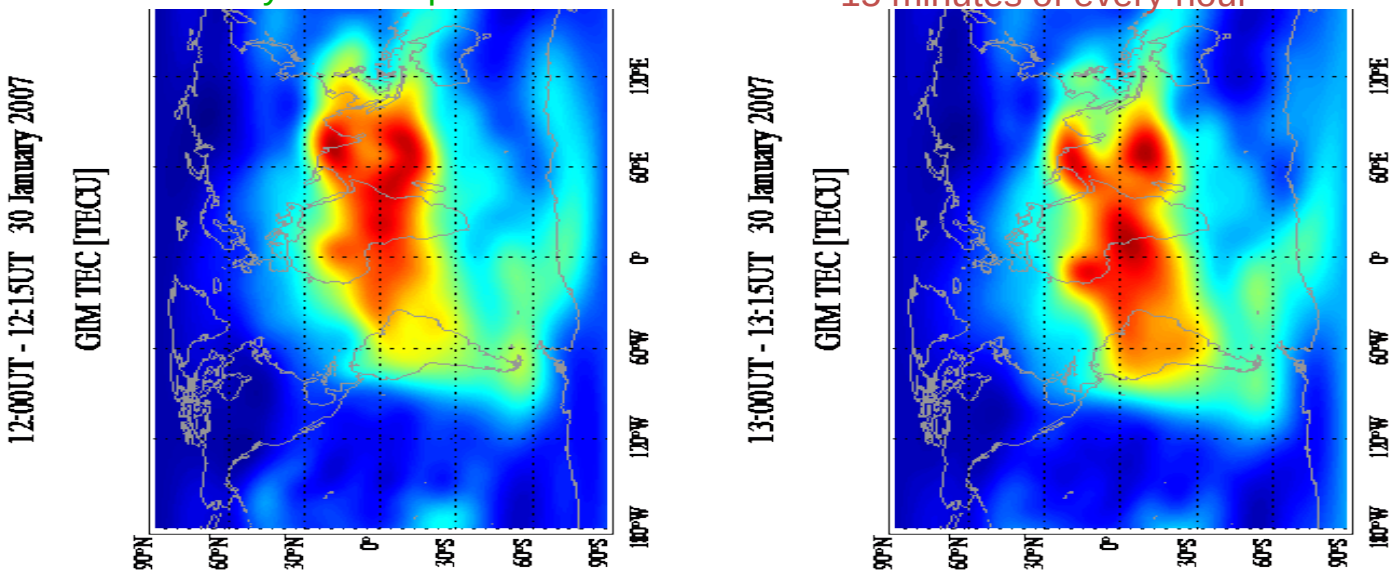
Energy analysis paper:
Verkhoglyadova et al. (2016) Estimation of Energy Budget of Ionosphere-Thermosphere System During Two CIR-HSS Events: Observations and Modeling, J. Space Weather Space Climate, under review, Topical Issue "Scientific Challenges in Thermosphere-Ionosphere Forecasting"

Theremosphere-Ionosphere Forecasts

- **Based on Global Ionosphere-Thermosphere Model (GITM) [Ridley et al. 2006]**
- **"Forecast mode": inputs are F10.7, solar wind from OMNI data or ENLIL, CORHEL, SWMF predictions for the heliosphere w/ Ovation Prime auroral**
- **Alternative high latitude driving: SWMF magnetosphere**
- **Data product: Global Ionospheric Maps (GIM) [Mannucci et al. 1998] based on GPS-derived TEC data.**

GITM: hourly TEC maps

GIM: averaged TEC for the first 15 minutes of every hour



TEC maps from OMNI-driven **GITM** and **GIM** for the January High Speed Stream 2007 storm

GITM "TEC" is integrated electron density between 100 km – 600 km altitudes.

Basis For Storm Feature Identification

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

GIM TEC Metric

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

GITM TEC Metric

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

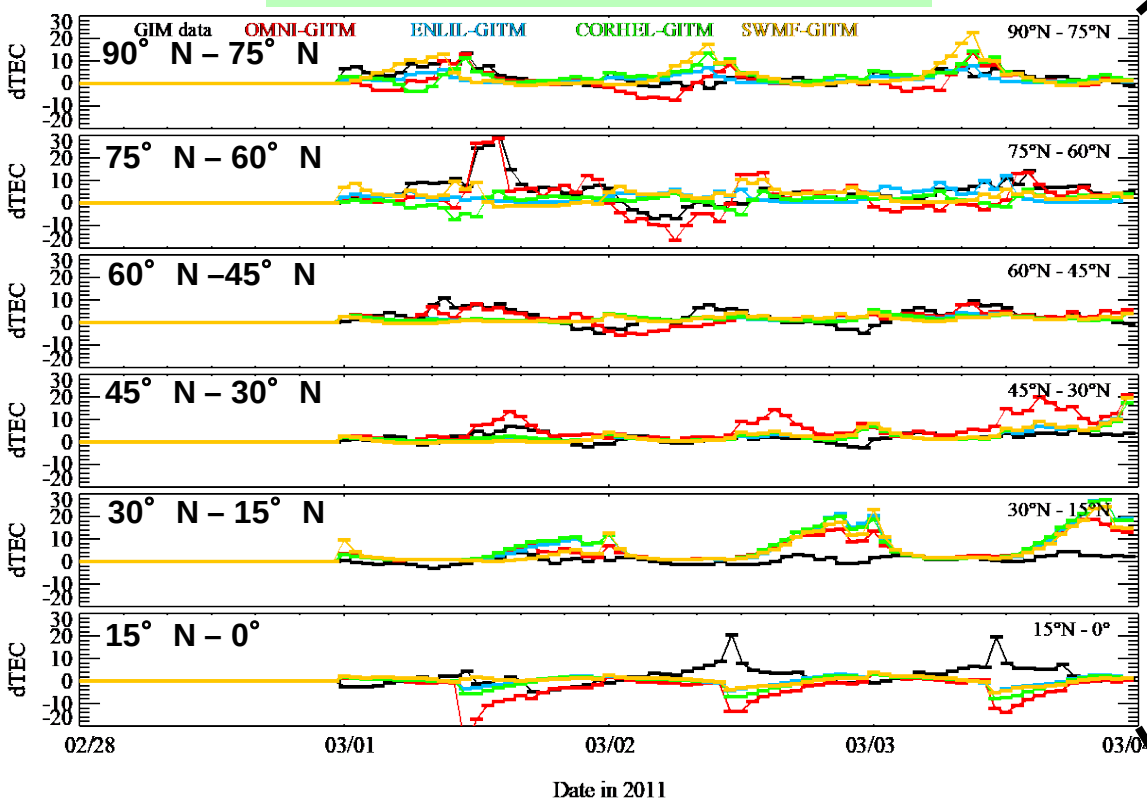
where $$Scale(UT) = \frac{median(TEC_{GIM,quiet}(UT, *, *))}{median(TEC_{GITM,quiet}(UT, *, *))}$$

- **The quiet day is selected from the days before each storm event with daily Ap < 6**
- **Final output: hourly *dTEC* for every 30° x 15° grid box**
- **May require modification for CMEs (superstorms)**

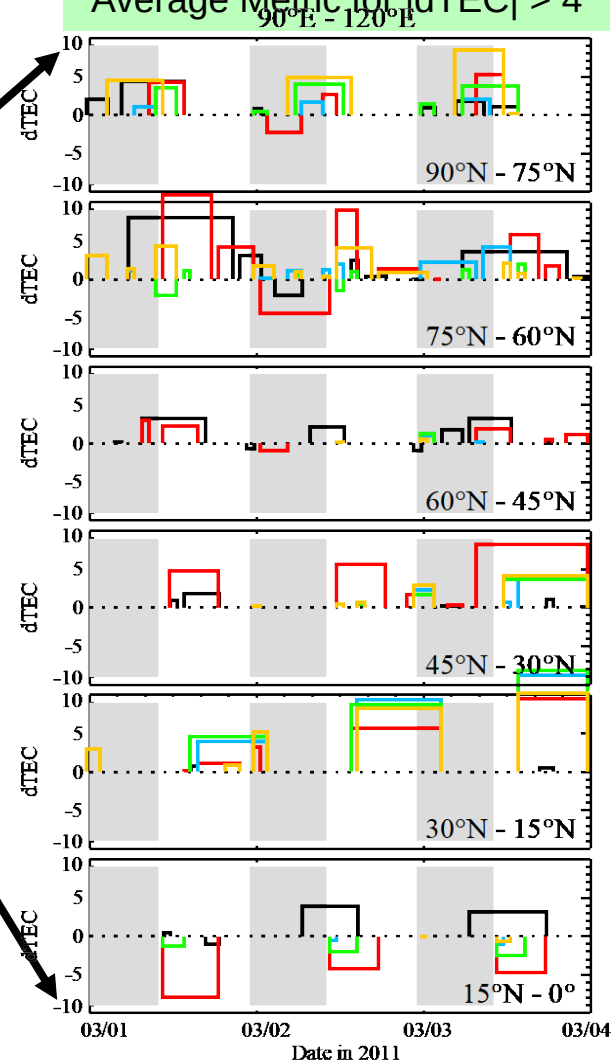
Initial forecasts will be for integrated density between 100-600 km

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

TEC Metric for the **Feb 2011** Event
Longitude **90° E - 120° E**



Average Metric for |dTEC| > 4



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

Number of TEC Disturbances During All Storm Days

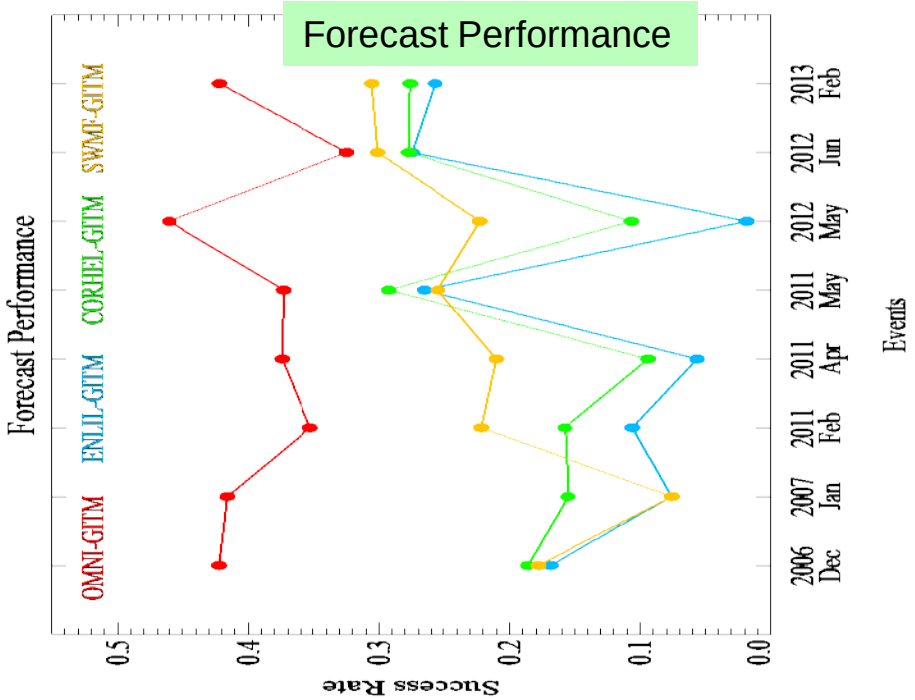
Event	GIM	OMNI GITM	ENLIL GITM	CORHEL GITM	SWMF GITM
Dec 2006	758	320	128	141	135
Jan 2007	618	257	47	96	47
Fen 2011	641	226	68	101	142
Apr 2011	457	171	26	43	96
May 2011	769	287	204	225	196
May 2012	328	151	6	35	73
Jun 2012	764	248	210	212	230
Feb 2013	1031	435	265	285	315

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

Forecast Success Rate:

$$\frac{\text{GITM TEC Disturbances}}{\text{GIM TEC Disturbances}}$$

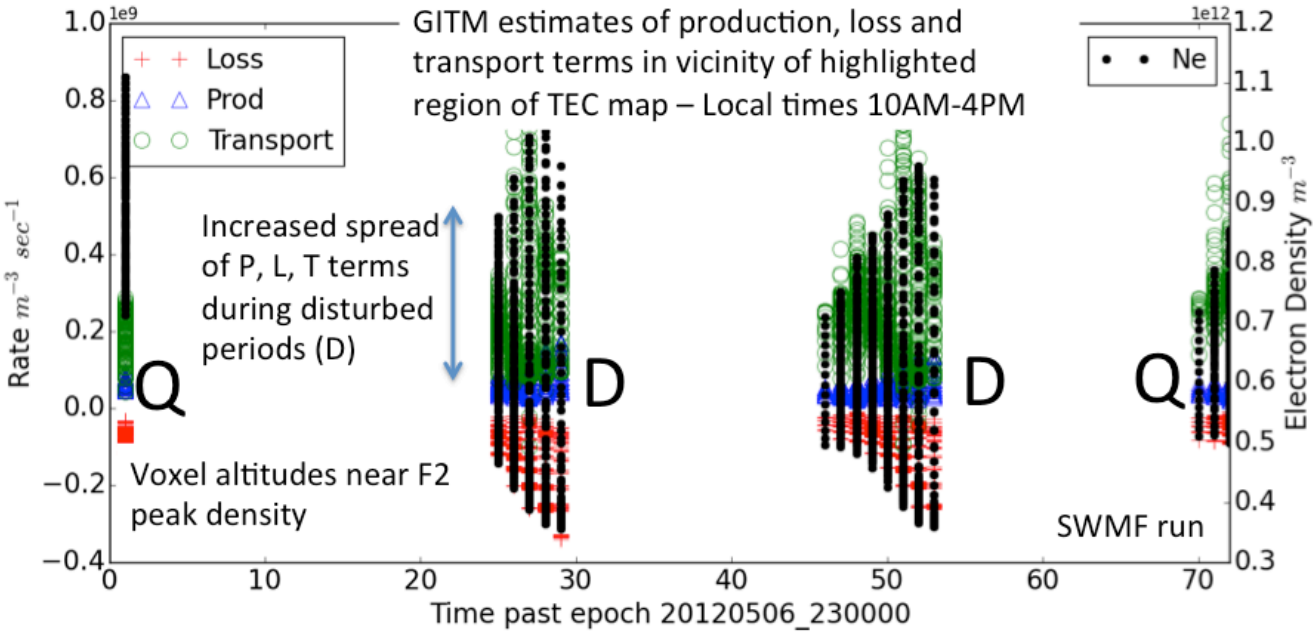
Forecast Performance



Plans: "Term" Analysis

- **Identify storm features (positive phase, negative phase, peak density altitude, etc.)**
- **Assess "model physics" associated with the features**
- **Compare to data such as electric fields, winds, etc.**

Production, loss and transport terms in vicinity of a TEC increase feature – GITM voxels near density peak



Related publication:

X. Meng, A. J. Mannucci, O. P. Verkhoglyadova, and B. T. Tsurutani, (2016) "On Forecasting Ionospheric Total Electron Content Responses to High-Speed Solar Wind Streams," J. Space Weather Space Climate, under review, Topical Issue "Scientific Challenges in Thermosphere-Ionosphere Forecasting"

Conclusion

- **Developing thermosphere-ionosphere forecasting approach based on TEC**
- **Heliospheric drivers and thermosphere-ionosphere response**
- **Focus on forecasting storm features in particular geographic locations**
- **Planning detailed term analysis to diagnose model strengths and weaknesses**

- **Time of arrival is likely to be a critical component of any TI forecast**
  - **Easier to forecast for larger storms (higher velocity magnetic cloud)**