Development of A Multimodel Ensemble Prediction System to Specify Ionospheric Weather

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MEPS Development

Multimodel Ensemble Prediction System (MEPS): A New Strategy for Space Weather Science, Specifications and Forecasts

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Data Assimilation Models & Data Sources

	LAT	LON	Driver Estimation	I, T, E
GAIM-GM	Mid & Low	Global		I
GAIM-BL	Mid & Low	Global		I
GAIM-FP	Mid & Low	Global	Y	I
GAIM-4DVAR	Mid & Low	Global	Y	I
IDED-DA	High	Global	Y	I & E
Mid-Low Electro DA	Low	Global	Y	I & E
GTM-DA	Global	Global		T

Ionosphere	Electrodynamics	Thermosphere
Ground-Based GPS-TEC	Ground magnetometers	Satellite UV emissions
Satellite-Based GPS Occultation	DMSP cross-track velocities	In situ neutral densities and winds
Ionosonde and Digisonde	SuperDARN LOS velocities	Satellite accelerometer and drag
In situ N_e	Iridium magnetometers	FPI winds
911Å, 1356Å, limb, disk (UV)	ACE IMF, Dst	ISR Neutral parameters
Solar UV, EUV	Solar UV, EUV	Solar UV, EUV

Why MEPS?

- Prediction accuracy is affected by different model approaches
- No single model is perfect, and different model approaches serve different requirements with their own advantages
- MEPS can help to
  - identify model-independent results
  - analyze strengths and weakness of various modeling and data assimilation techniques
  - provide more useful specifications and forecasts than those obtained from a single model

National Hurricane Center multi-model ensemble forecast for hurricane Rita.

Examples

Differences in physics models

- Grid structure
- Lagrangian vs. Eulerian approach
- Finite difference vs. finite volume
- Magnetic field model
- Empirical models
- Physics parameters & chem reaction coeff

Differences in data assimilation techniques & data sources

- Various recursive filters (Gauss-Markov, bend-limited, assemble, etc.)
- Variational approaches (3DVAR, 4DVAR, etc.)
- Line-of-sight vs. in-situ observations
- Radio vs. optical observations
- State vs. driver observations

Ionospheric Forecast Using GAIMs

- **Specification of initial conditions for short-term forecast (~2 hours)**
  - Data assimilation allows us to reproduce ionospheric weather conditions
  - Empirical drivers will overwhelm the initial state in a short while
  - The forecast can be updated every 12~15 minutes with assimilation of new data to counter the climatological model
- **Estimation of model drivers if drivers forecast is not available**
  - May help improve and extend forecast under quiet conditions $\rightarrow$ using corrected drivers
  - May only work for limited time under storm conditions due to rapid change of the drivers
- **Assimilative electrodynamical and thermospheric models**
  - To specify drivers under storm conditions
  - Relying on upstream driver forecast

Study of Ionospheric Storms Using MEPS

Objectives

- Characterization of ionospheric storms and responses to various solar–magnetospheric-thermospheric perturbations on global scales using data assimilation models
- Investigation of various driving processes

Models involved

- GAIM-GM, GAIM-BL, GAIM-FP, GAIM-4DVAR, IDED-DA, and Mid-Low Electro DA (the models are run “as is”)

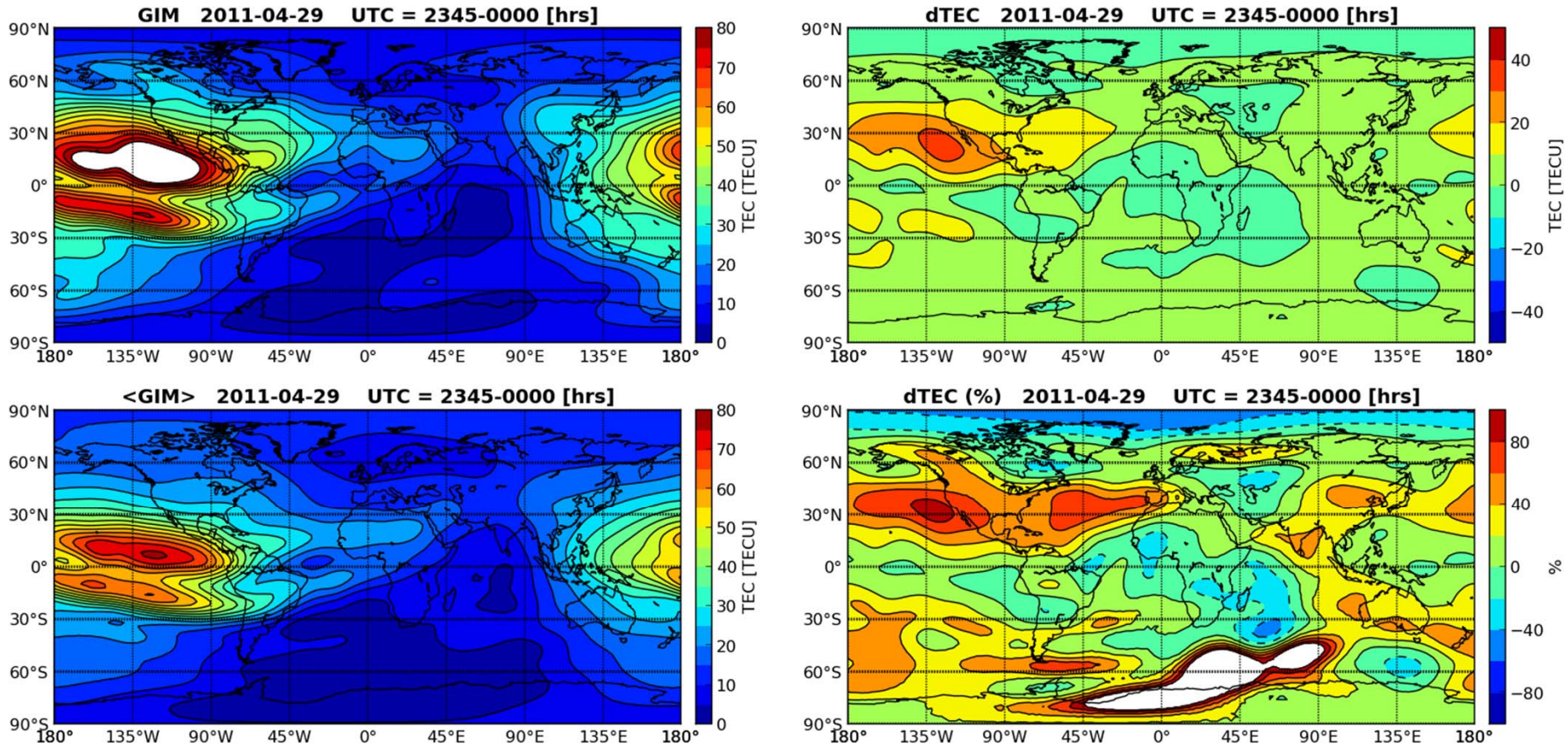
Data assimilated

- Ground-based and space-based GPS TEC, ionosonde/digisonde, magnetometer, SuperDARN, etc.

Storm cases & quiet references

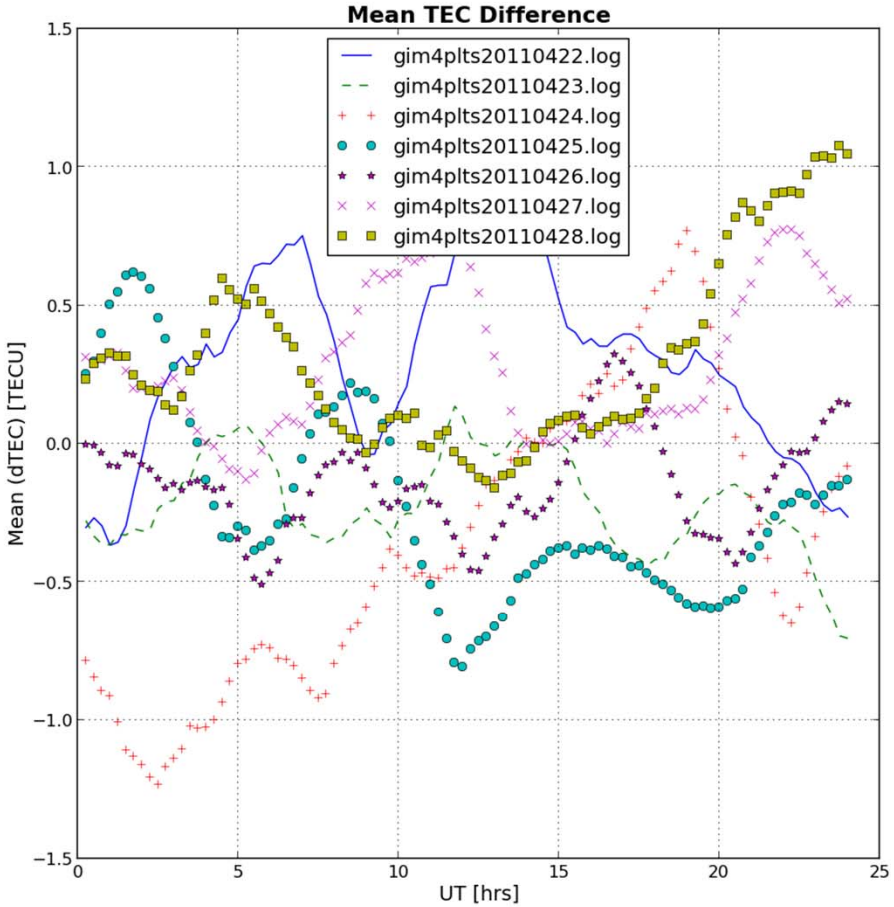
- A high-speed stream (HSS) storm case (2011-04-29 – 2011-05-01)
- A CME storm case (2013-03-17)
- Quiet-time references before the storms: a representative day before each storm is selected as a quiet-time reference when daily ionospheric variability is the least compared with other days (assessed using TEC data)

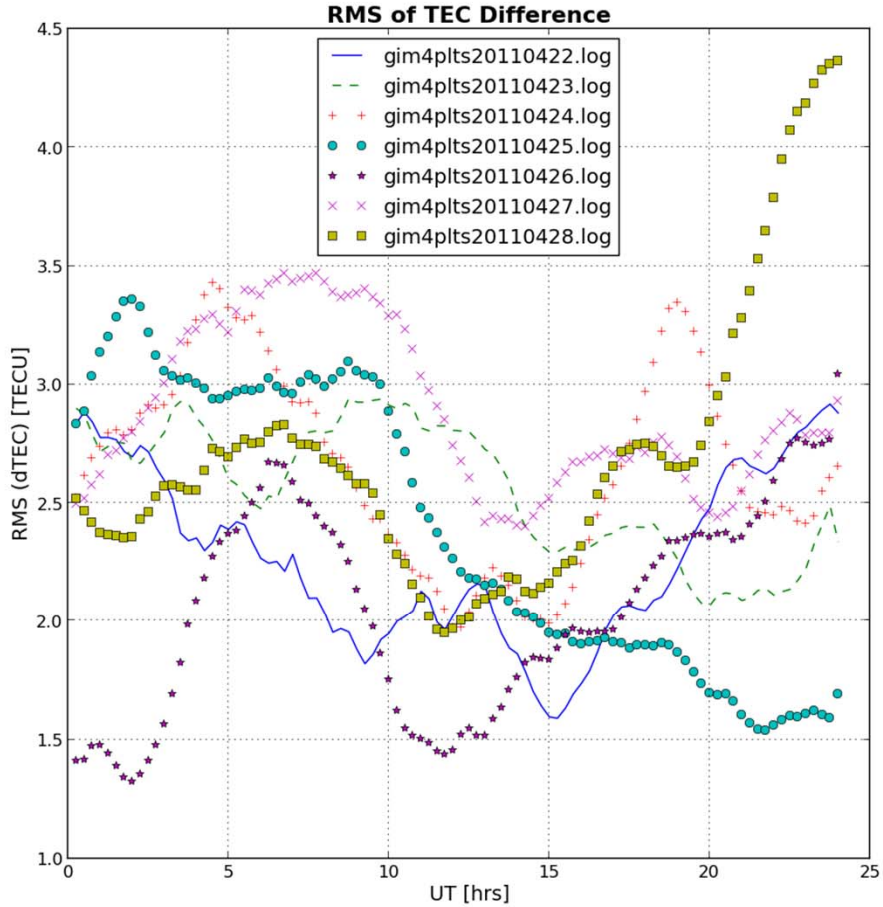
GPS-Based Global TEC Maps (2D) Ionospheric Storm on 4/29/2011



An averaged global TEC pattern (<GIM>) for a UT interval is derived from global ionospheric maps (GIMs) during seven geomagnetically quiet days prior to the storm day at the same UT. Differential TEC maps (right column) show difference between the event and the quiet-time pattern.

“Quiet-Time” Ionospheric Variability

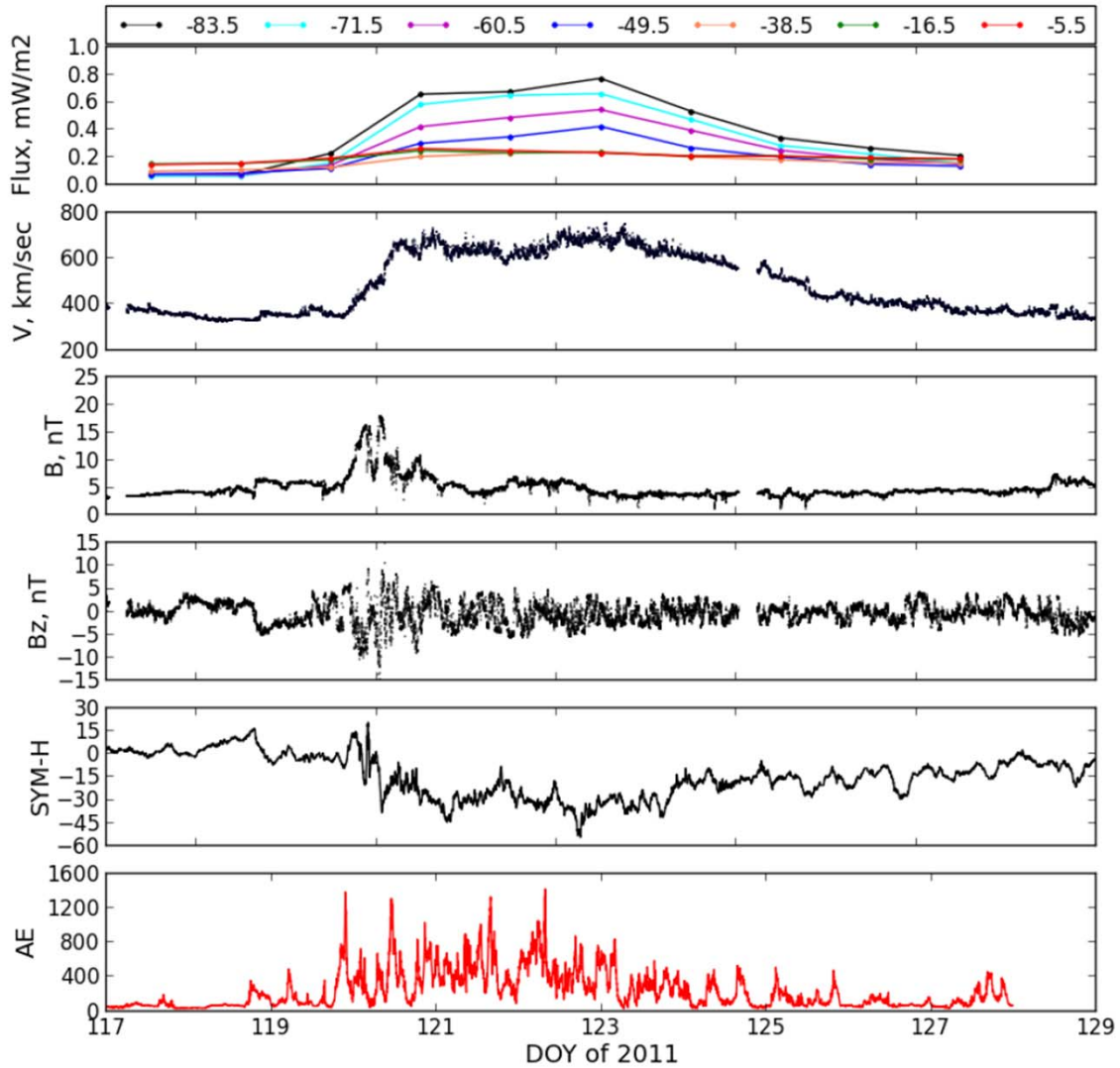




The global mean and RMS of TEC difference are derived from grid differential TEC map for each 15-minute interval. 24-hour variations of the mean and RMS show ionospheric daily variability and are used to identify a quiet reference for the storm study.

A High-Speed Stream Storm Case

- An HSS event occurred on 2011-04-19 when Bz also turned southward
- A moderate storm defined by Dst (SYM-H) level
- The storm lasted a few days
- Auroral electroject was active for a few days
- Quick-look global ionospheric TEC maps are used to examine storm features visually before running MEPS models



A CME Event: 2013-03-17

|B|

By

Bz

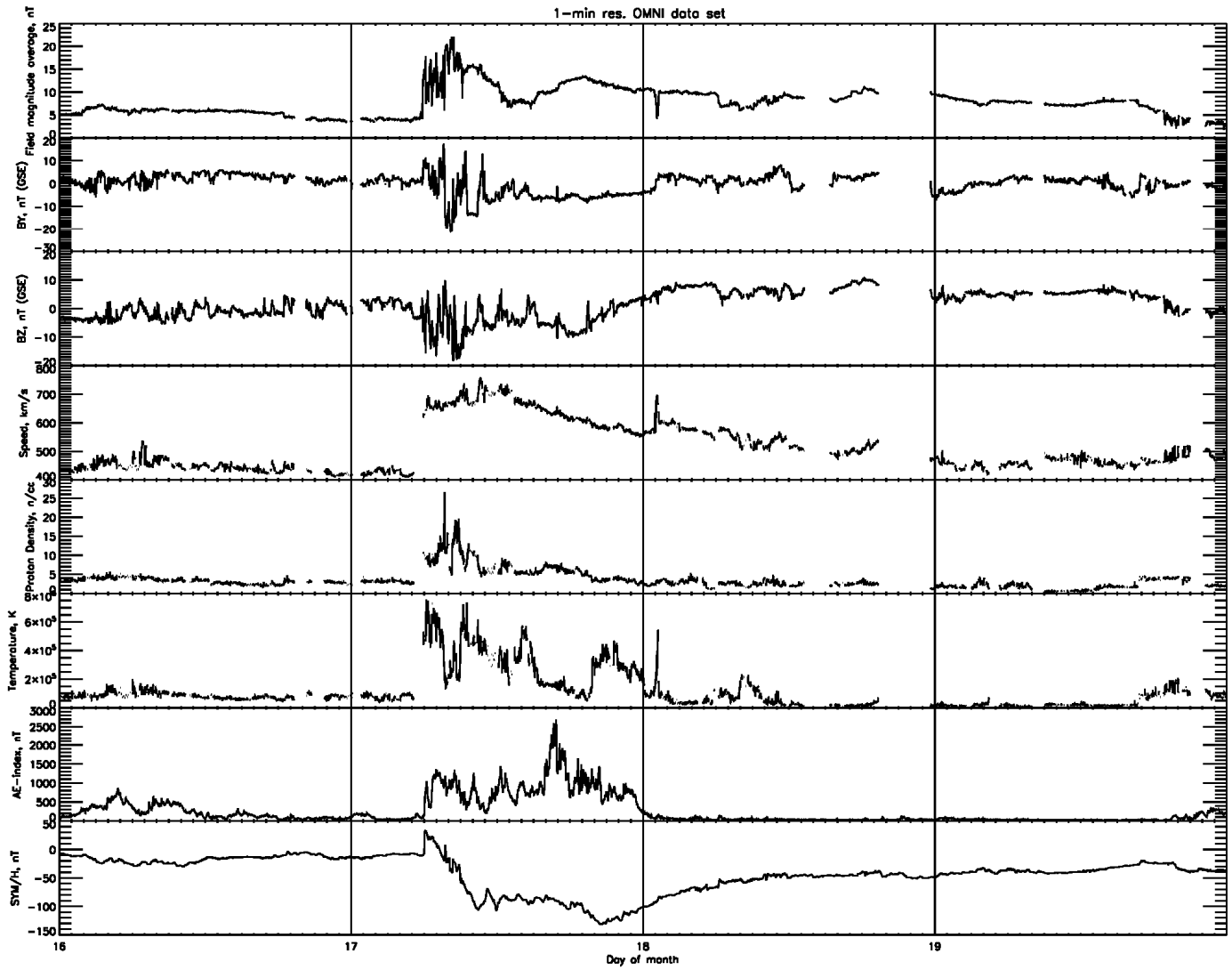
v

n_p

T

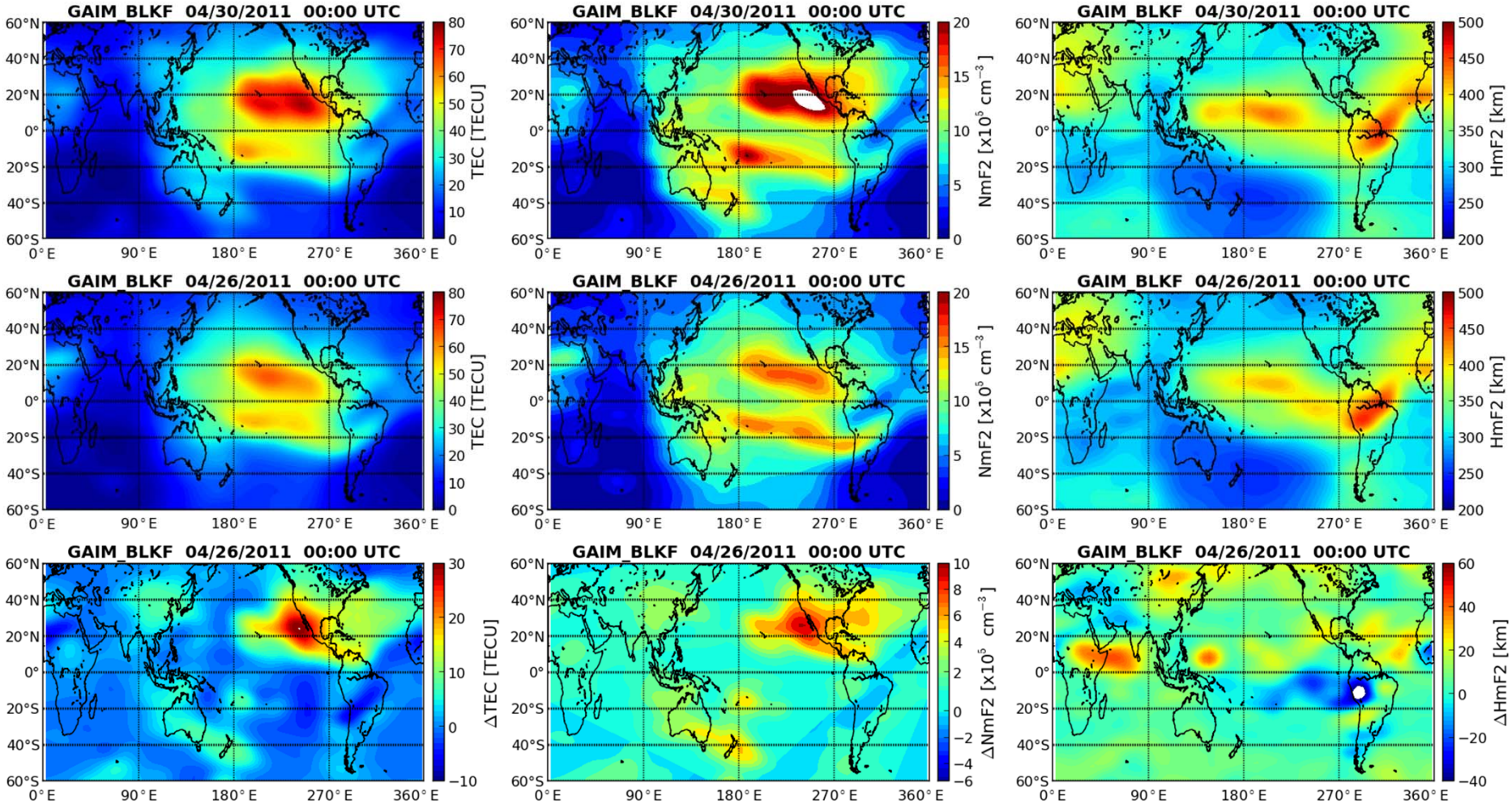
AE

SYM-H



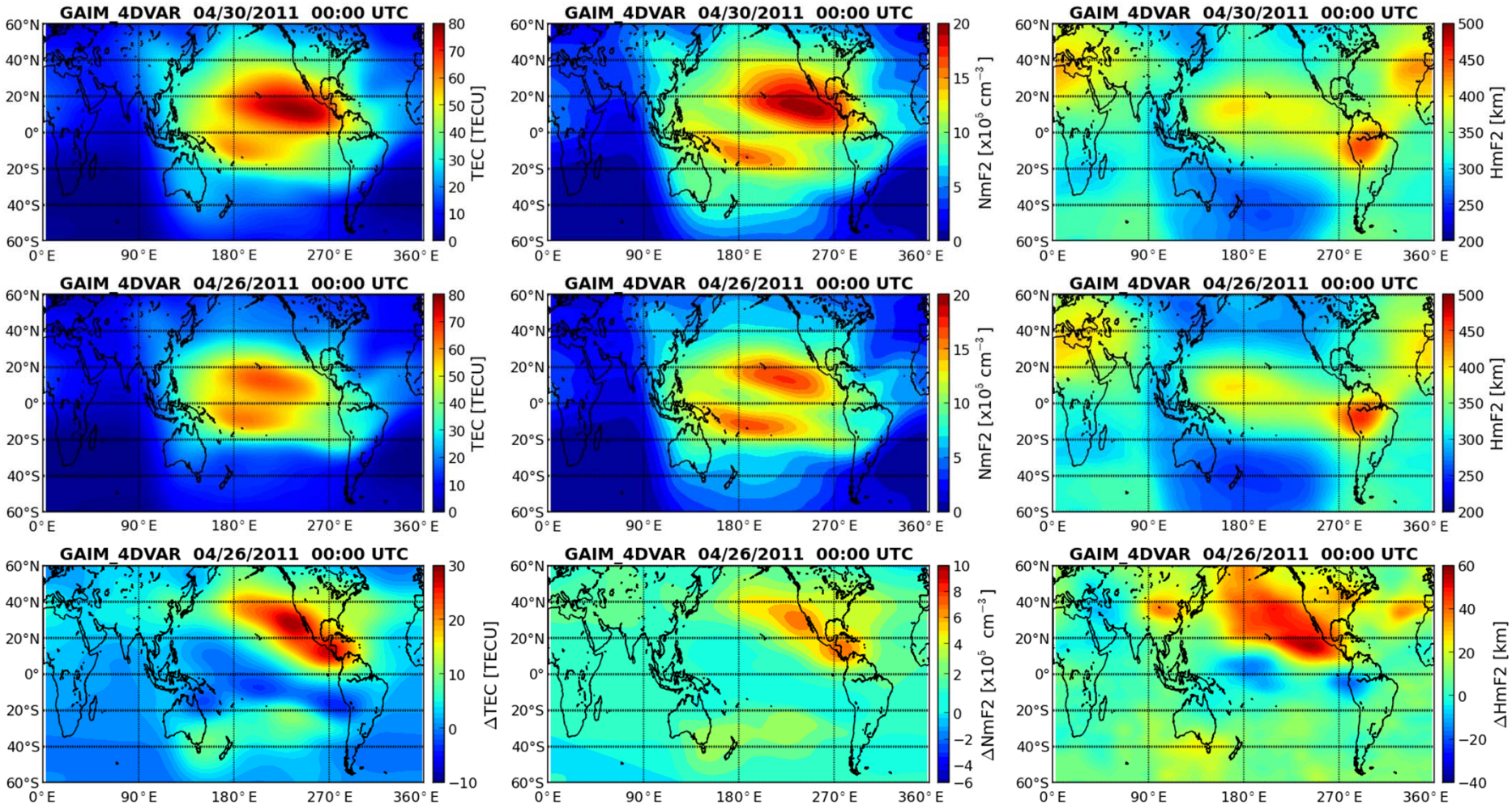
Max K_p $\rightarrow$ 6

GAIM-BL Results (Sample): TEC, NmF2, and HmF2



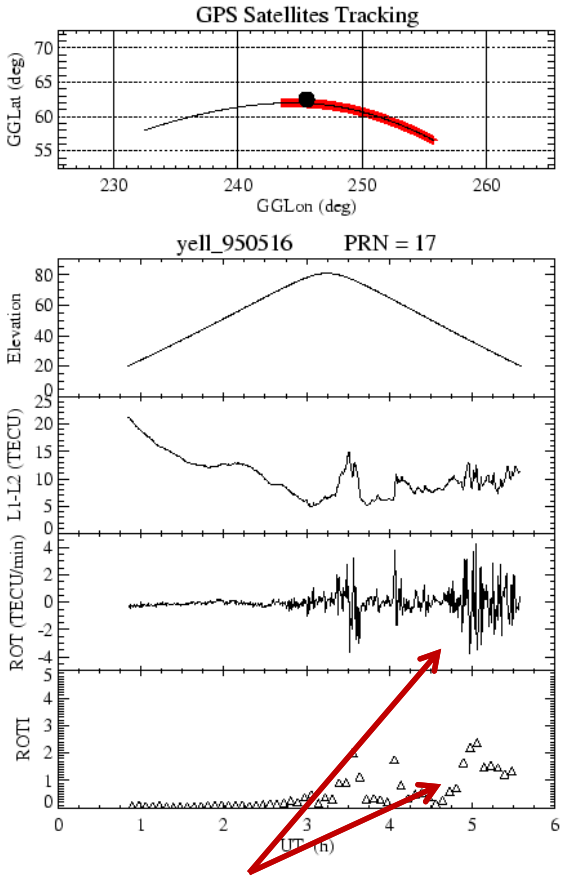
TEC and density increases over North America in the afternoon during the storm main phase.

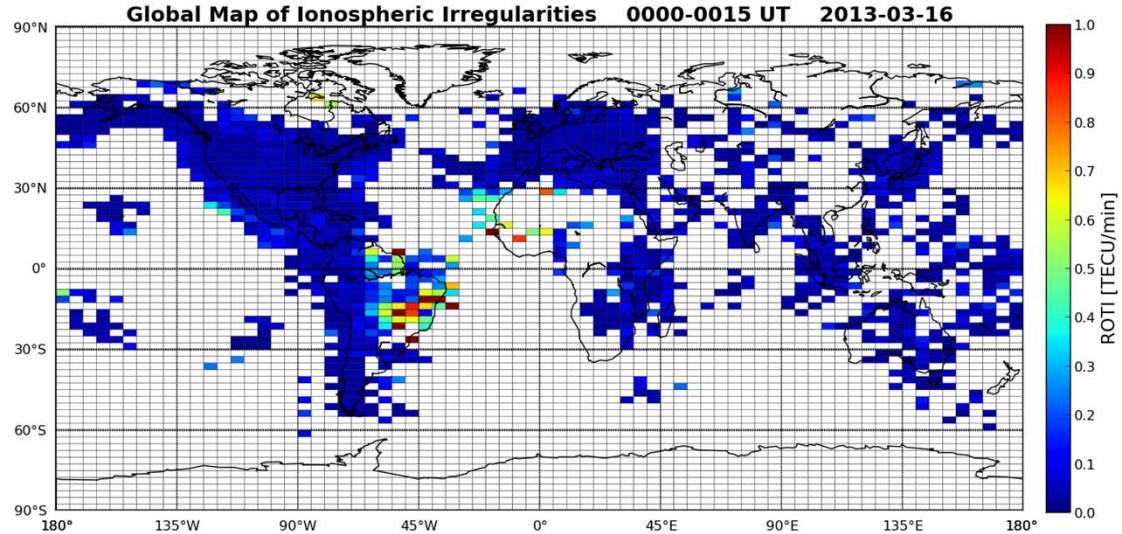
GAIM-4DVAR Results (Sample): TEC, NmF2, and HmF2

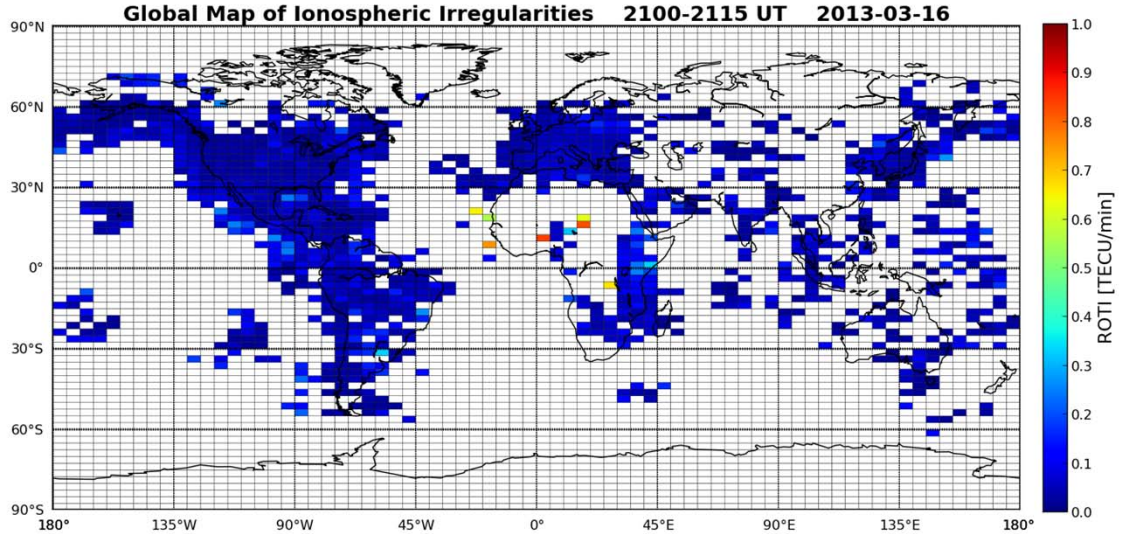


4DVAR driver estimation grid: drift - 24 spline functions/coefficients; wind – ΔLAT = 10°, ΔLON = 15°; solar EUV flux/photo-ionization prod – one scaling factor

Global Map of Ionospheric Irregularities & Scintillation



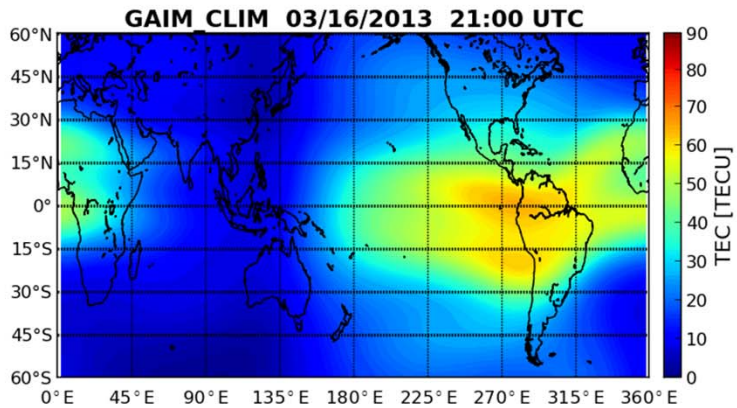


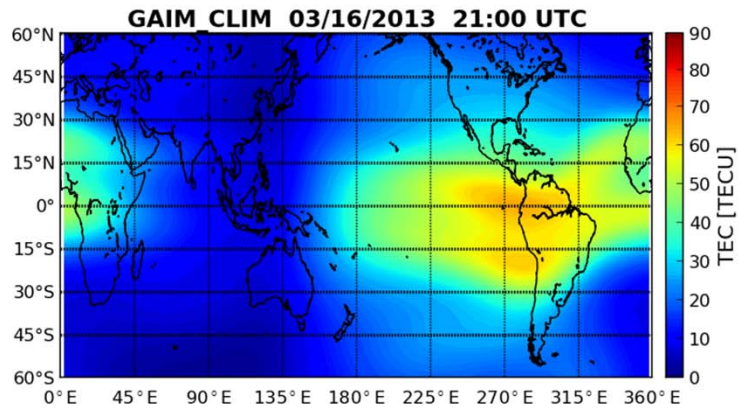


- Fundamentals of ROTI
- GMIISs show conditions of irregularities and scintillation

Comparison between Climatological and Assimilative Modeling

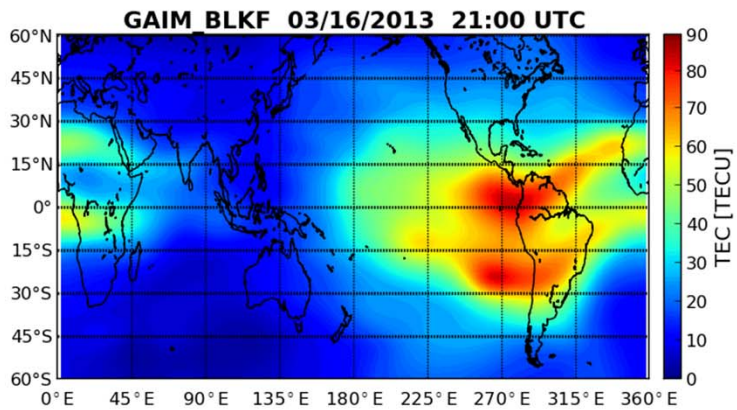
CLIM

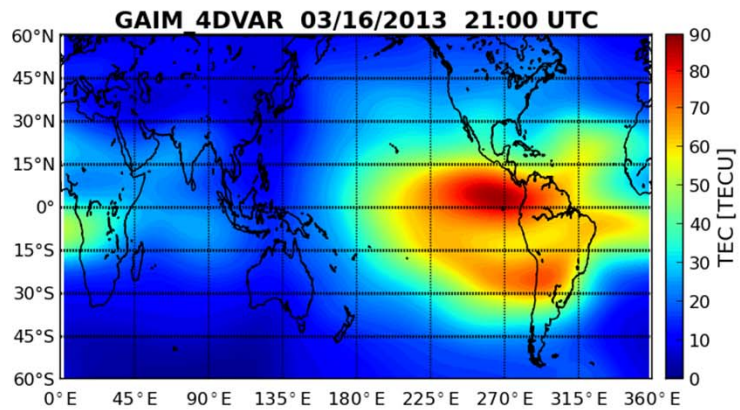




CLIM

BLKF



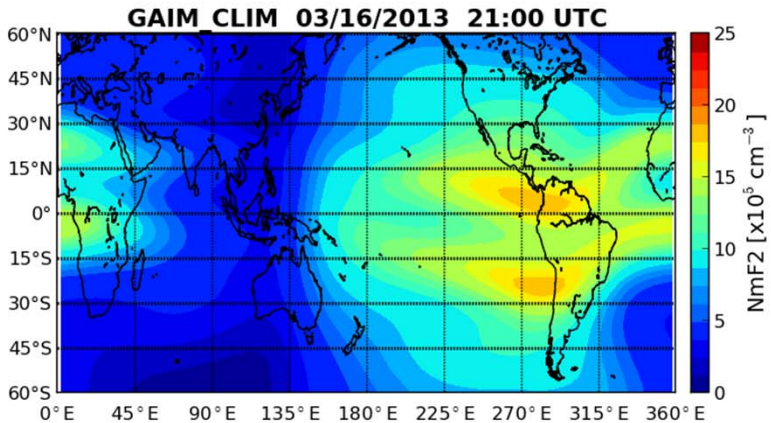


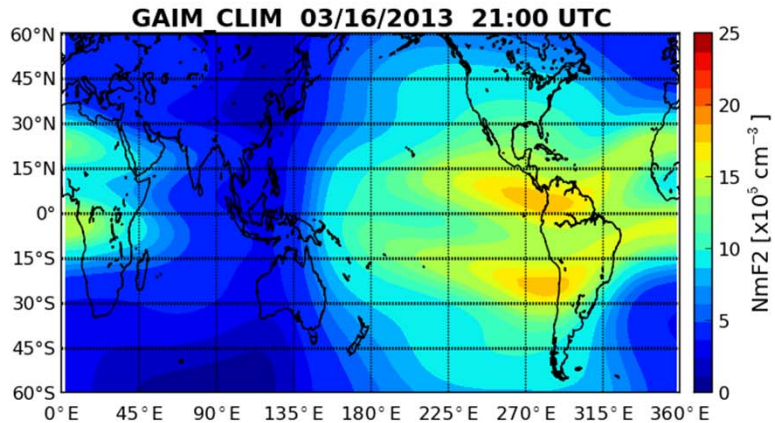
4DVAR

- **TEC** under **quiet** conditions
- Enhanced TEC in “weather” is shown in data assimilation results from different techniques

Comparison between Climatological and Assimilative Modeling

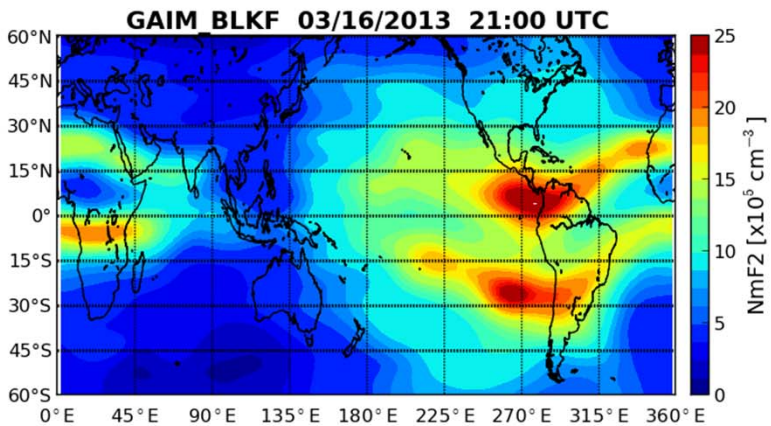
CLIM

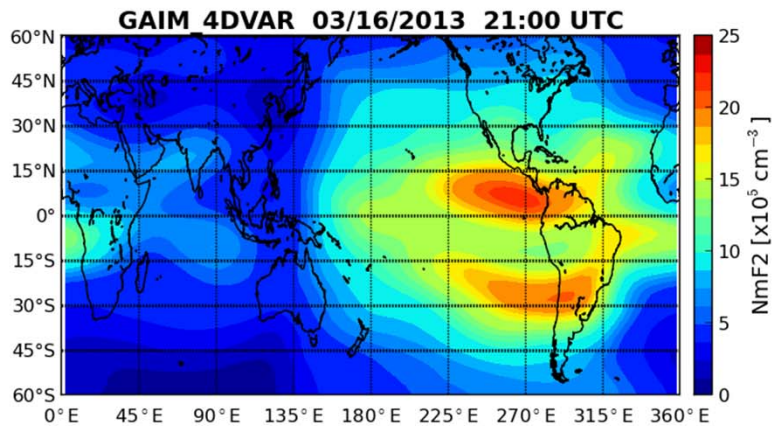




CLIM

BLKF

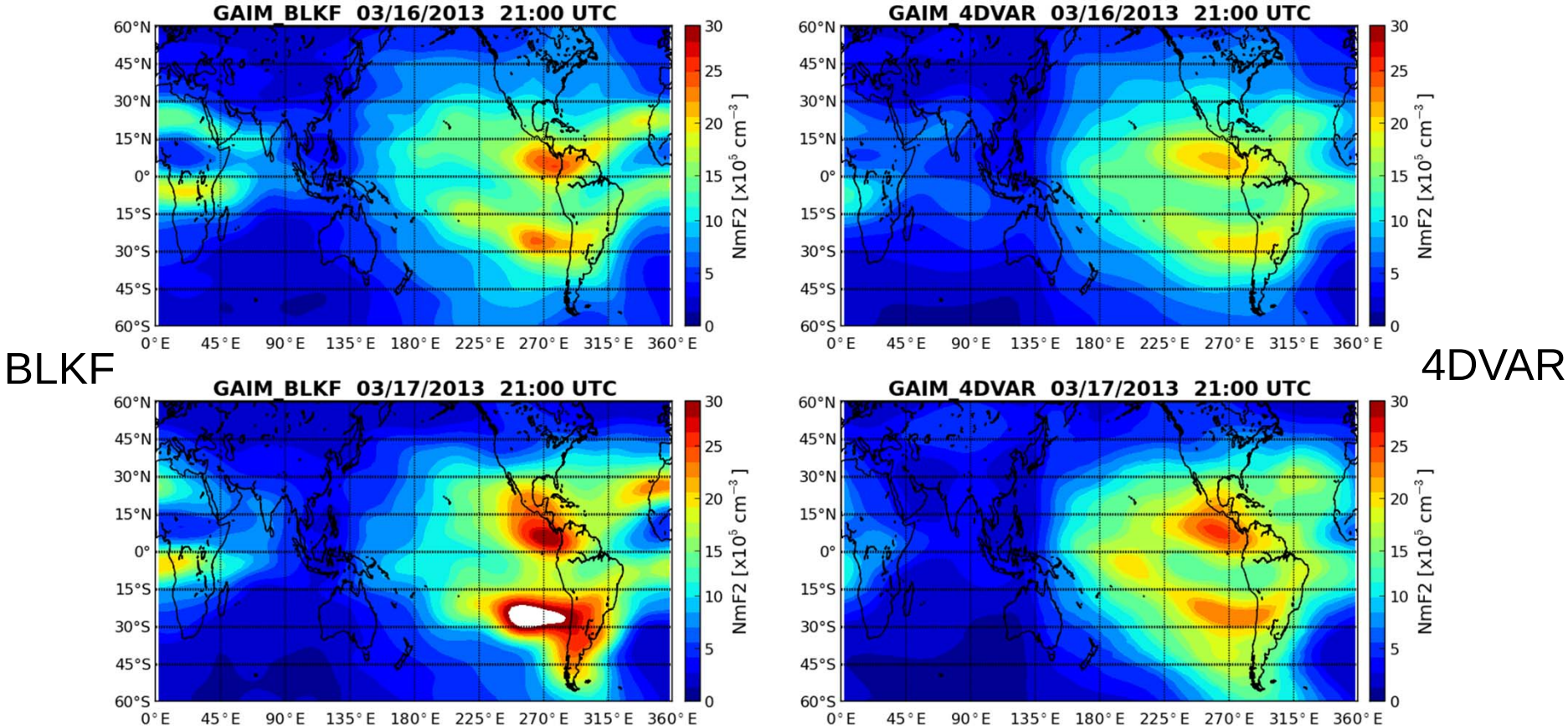




4DVAR

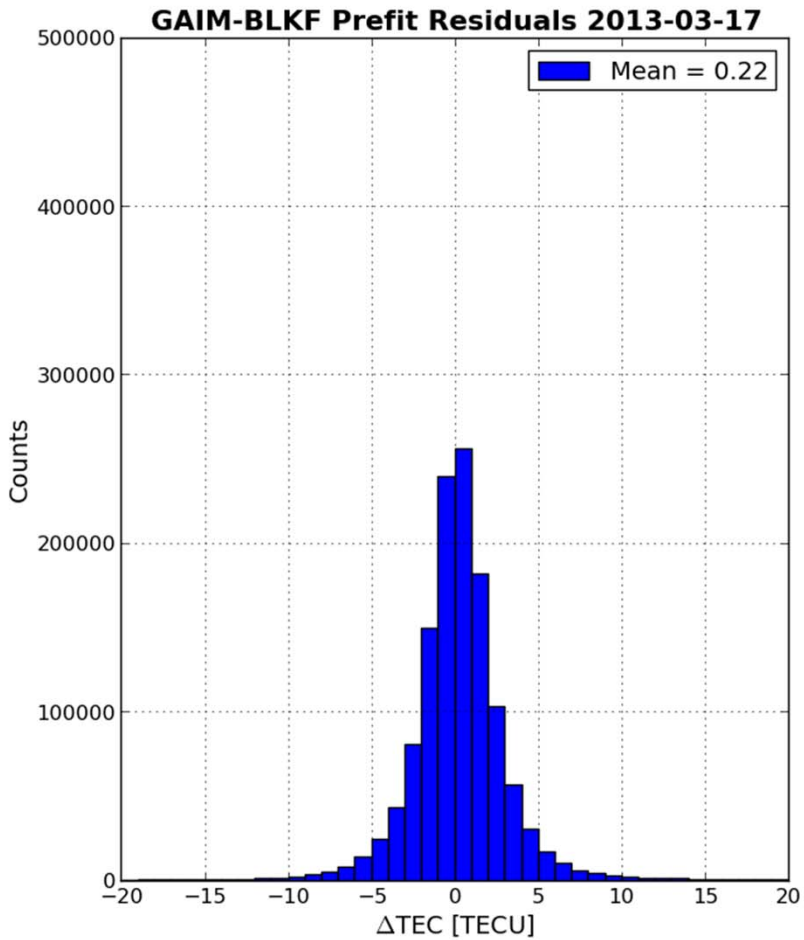
- **NmF2** under **quiet** conditions
- Enhanced peak density in “weather” is shown in data assimilation results

Comparison between Assimilative Models

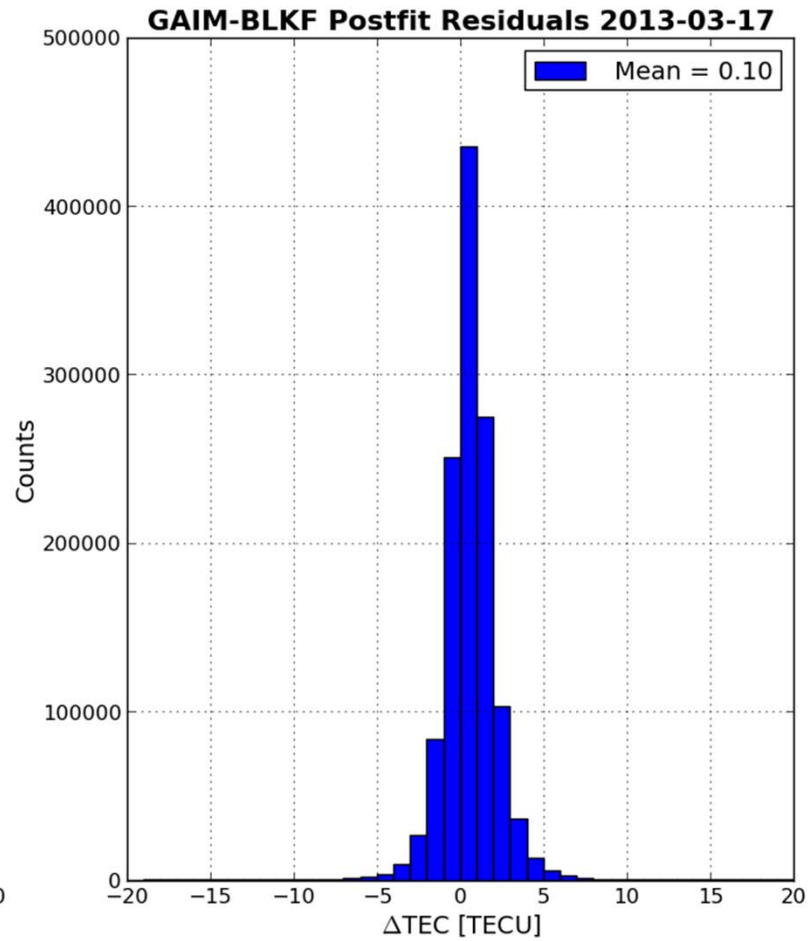


- **NmF2** under both **quiet** and **storm** conditions
- Enhanced peak density during the storm shown in data assimilation results

Assessment of Model Accuracy for Storms

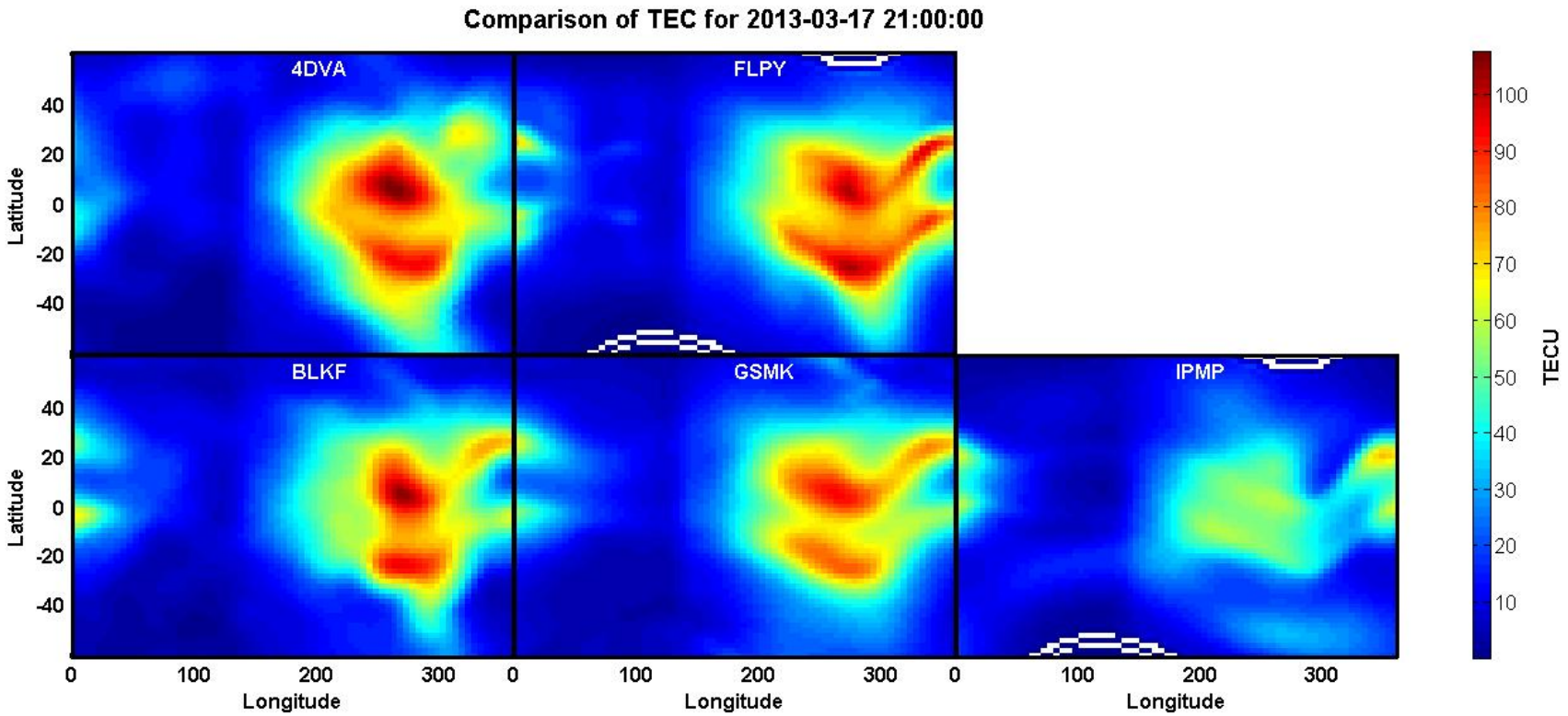


Prefit



Postfit

TEC Comparison for Storm Conditions



- Agreement in TEC enhancement (magnitude) except one model
- Some differences in the extension and width of equatorial anomaly
  - Four models show enhanced TEC in the southern hemisphere beyond 30°S latitude

On-Going Studies

- **Characterization of ionospheric storms**
  - LAT, LT, LON, and ALT patterns of larger-scale disturbances
  - Timing of ionospheric responses to space weather perturbations
  - Driving processes during various storm phases
- **Comparison with electrodynamical, thermospheric and wind models**
  - Electrodynamical vs. wind & TAD effect
  - Thermospheric composition changes
- **Impact of assimilating various data types on models**
  - Integrated (TEC) vs. in-situ (volume densities)
  - Radio vs. optical
- **Assessment of advantages and limitations of different data assimilation techniques**