Multimodel Ensemble Prediction System (MEPS): Ensemble Modeling with Data Assimilation Models for Space Weather Specifications and Forecasts

From Data Assimilation to Prediction:

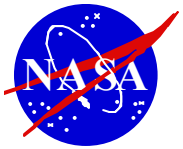
Assimilative Modeling of Ionospheric Disturbances

Presented by Xiaoqing Pi

Jet Propulsion Laboratory, California Institute of Technology

NASA-NSF Space Weather Modeling Collaboration
NASA Ames Research Center, CA
May 30, 2017

MEPS Team



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Jet Propulsion Laboratory

X. Pi, A. J. Mannucci, M. Butala, B. D. Wilson, and A. Komjathy

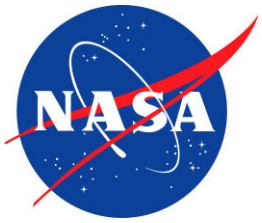
University of Southern California

C. Wang and G. Rosen











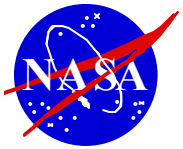
GAIM Development and Storm Studies

- **Understanding the impact of various data types in different approaches**
  - Assimilation of various data types into GAIMs
  - Multiple modeling approaches

- **GAIM improvement**
  - Understanding tradeoff of modeling approaches
  - Improving assimilative techniques
  - Augmentation of assimilative data sources

- **Aiming at prediction**
  - Characterization of space weather effects on the ionosphere
  - Understanding what it takes to predict the effects

Global Assimilative Ionospheric Modeling Spatial and Temporal Variations



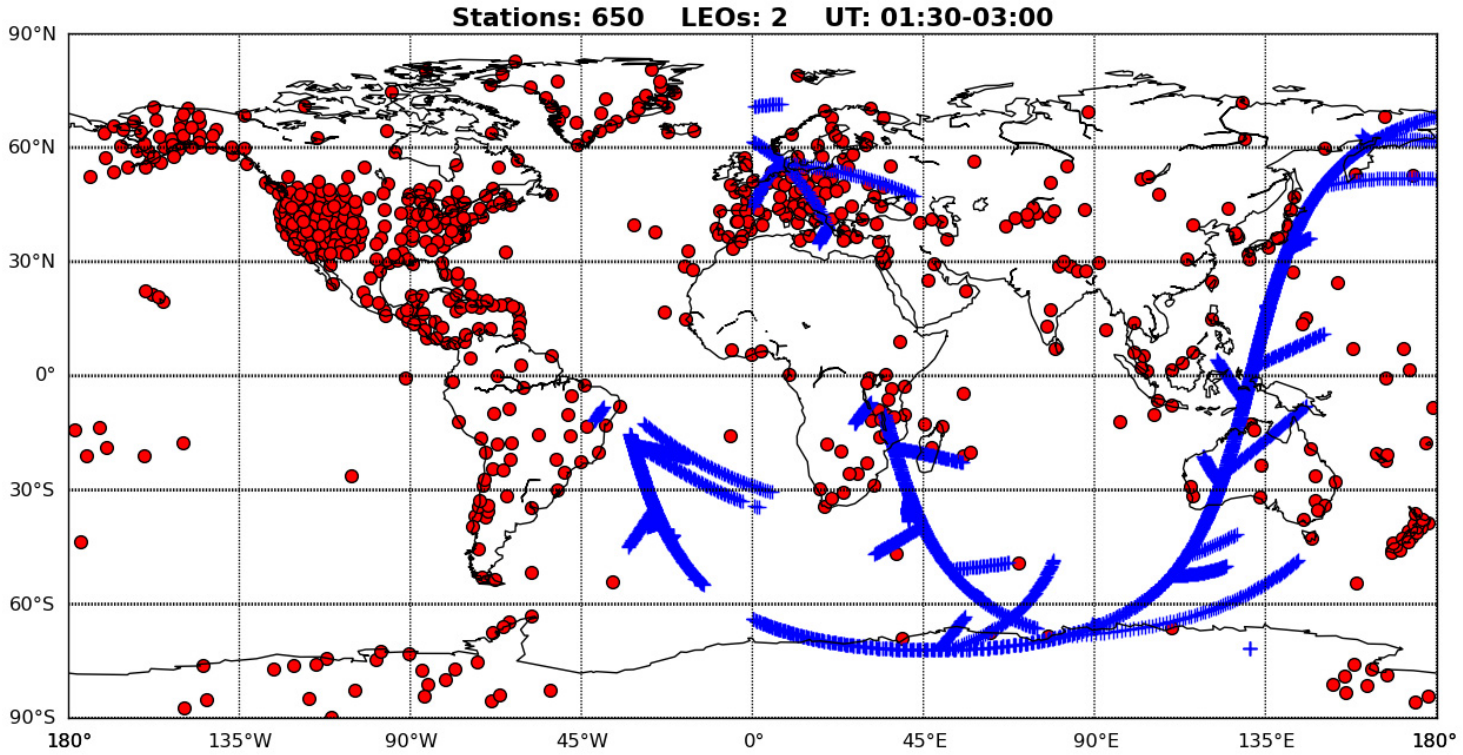
- **Basic M-I-T coupling processes that drive large-scale mid- and low-latitude ionospheric disturbances**
  - Electrodynamics: penetration, disturbance dynamo, SAPs, etc.
  - Thermospheric circulation changes: wind, traveling atmospheric disturbances (TADs), composition changes
- **What it takes to predict these processes and effects?**
  - Upstream perturbations: IMF, solar wind velocity, electric field, etc.
  - M-I coupling $\rightarrow$ plasma convection, AE, particle precipitation, etc.
  - Ion drag and heating $\rightarrow$ global circulation of the thermosphere
- **Need to predict when, where, and how severe quantitatively**
  - Ionospheric effects during the different phases of geomagnetic storm, local time sectors, extent of latitudes
- **Models can work forward, and backward, to understand, specify, and characterize spatial and temporal variations of the ionosphere**

Data Assimilated into GAIMs: Examples

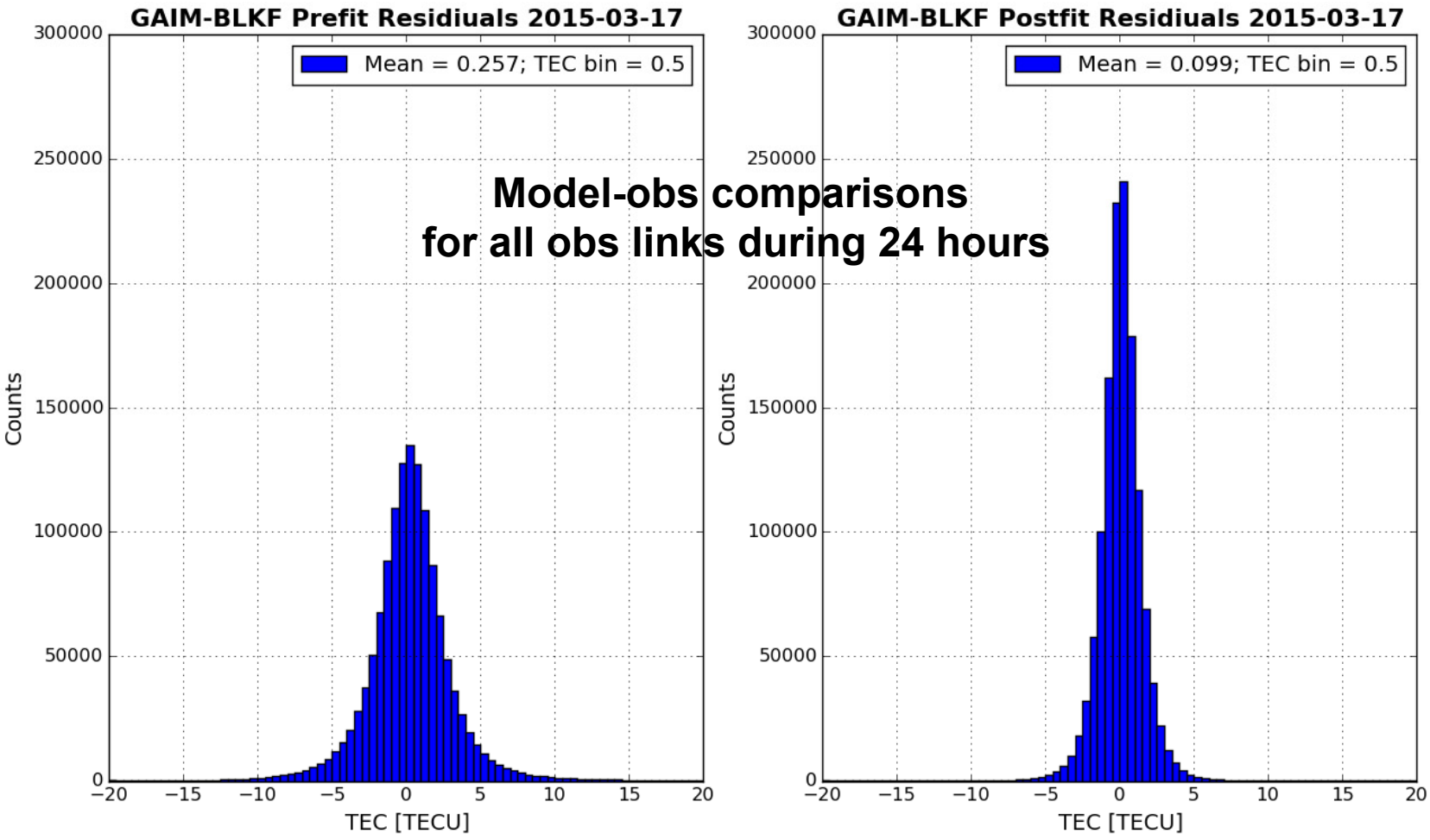
GPS Ground and radio occultation data

2013-03-16 and 2013-03-17
~530 ground GPS stations
5 COSMIC satellites

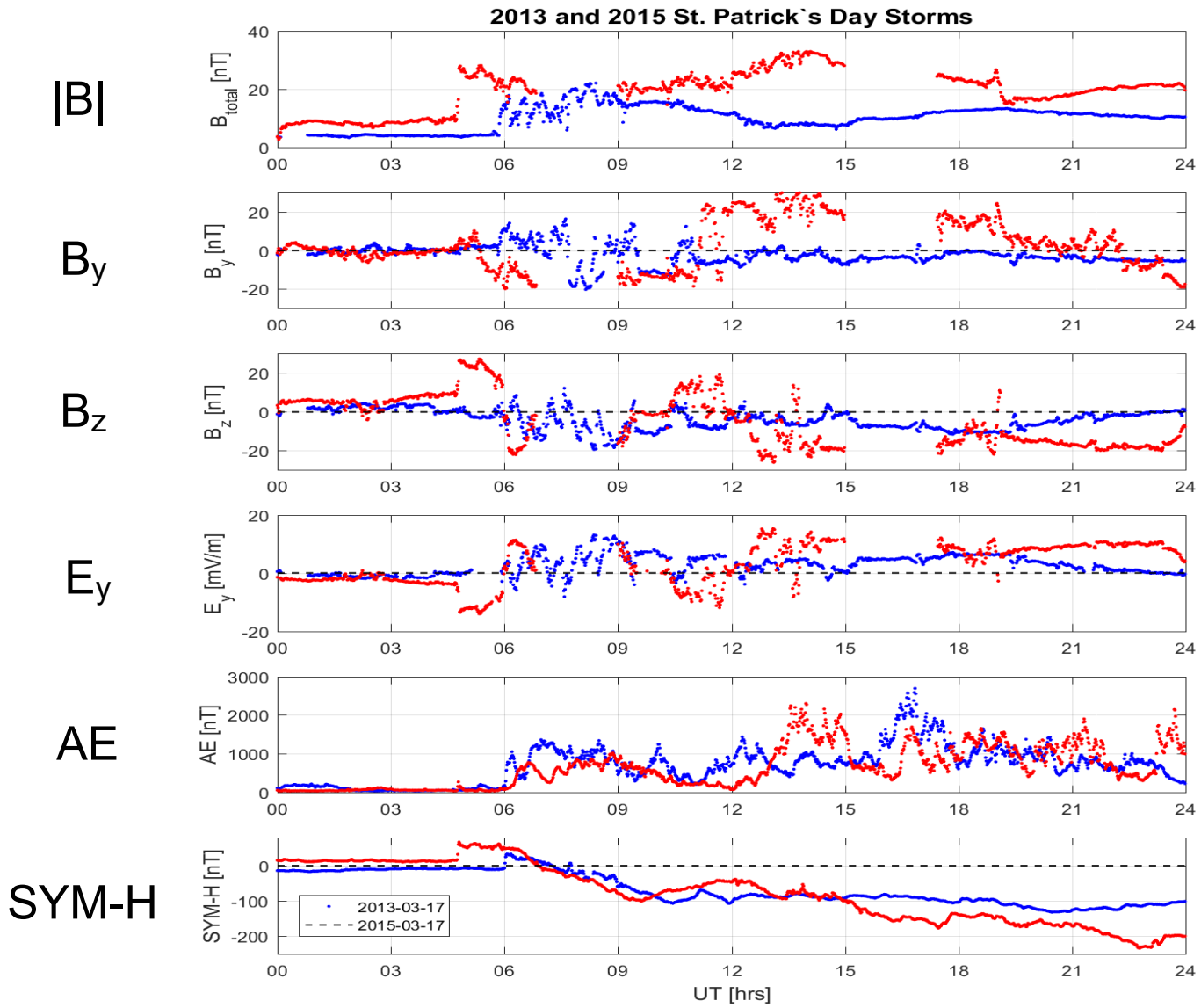
2015-03-16 and 2015-03-17
~650 ground GPS stations
2 COSMIC satellites



Typical Accuracy Assessment for Modeling Storms



Storm Events:
2013 and 2015 St. Patrick's Day



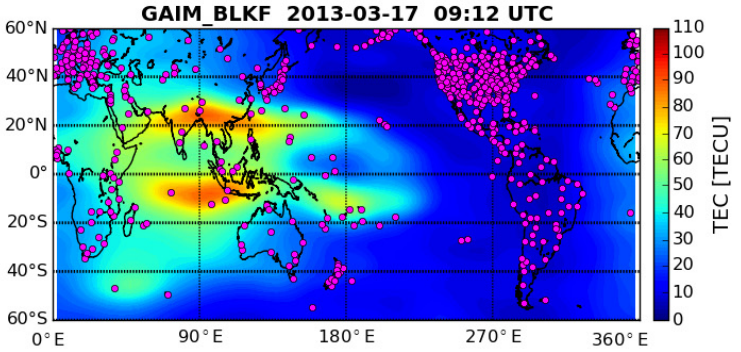
2013-03-17
$K_{p,max} \rightarrow 6$

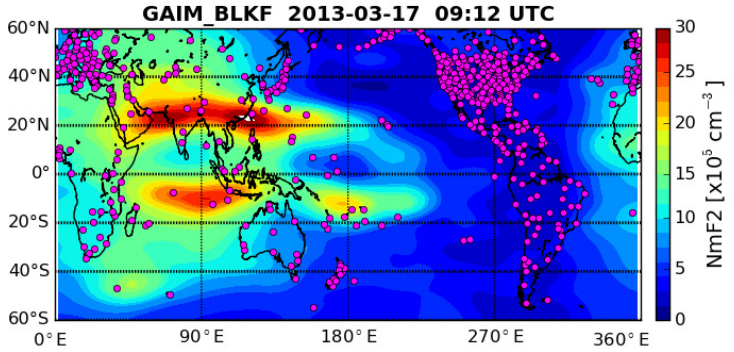
2015-03-17
$K_{p,max} \rightarrow 8$

Equatorial Anomaly Enhancement during Storm

17 Mar 2013

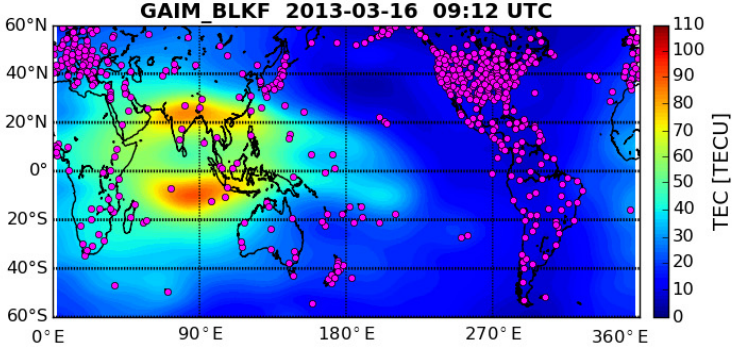
TEC Storm

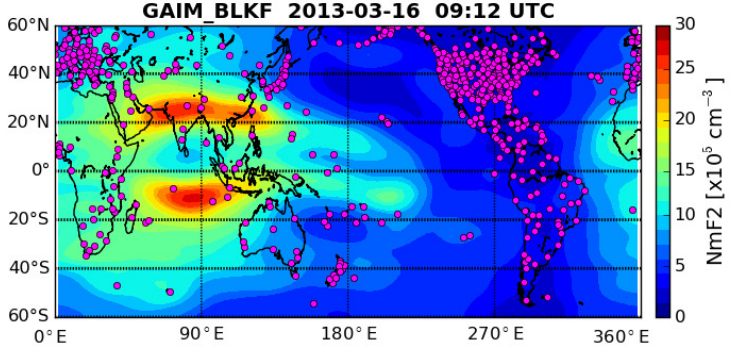




n_mF_2 Storm

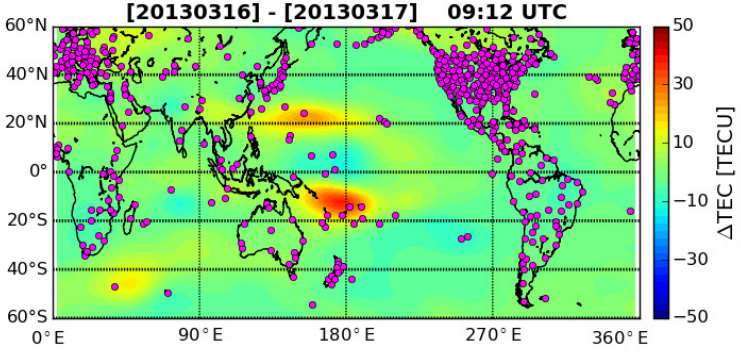
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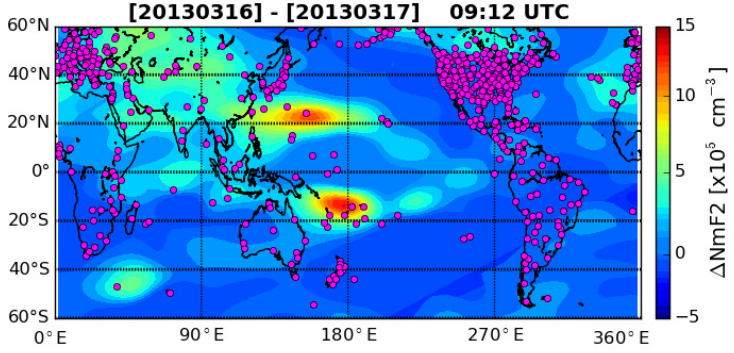




n_mF_2 Quiet

ΔTEC



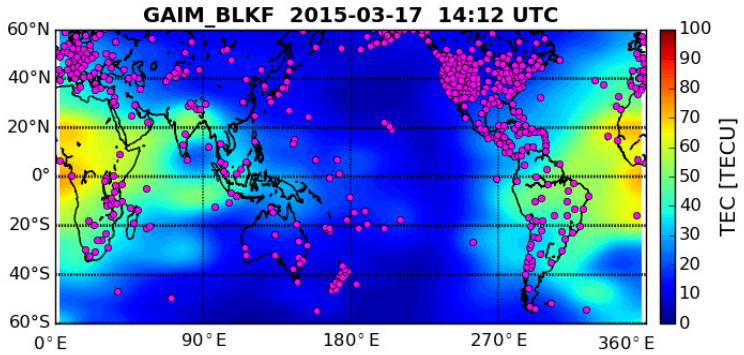


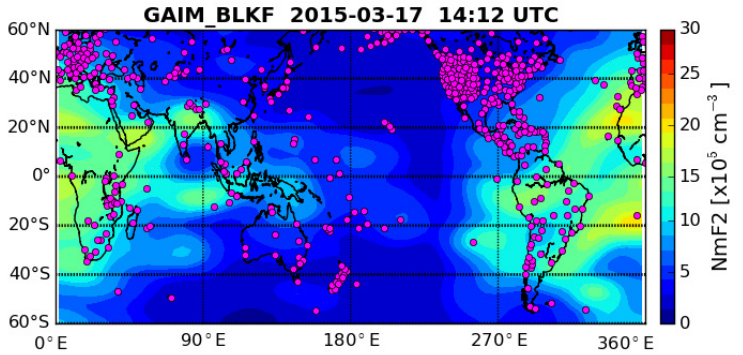
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Equatorial Anomaly Depletion during Storm

17 Mar 2013

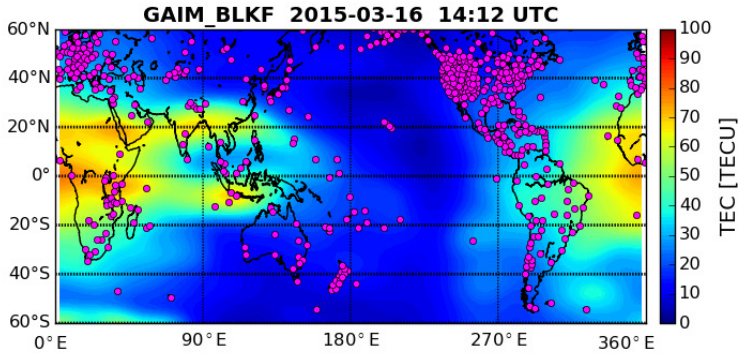
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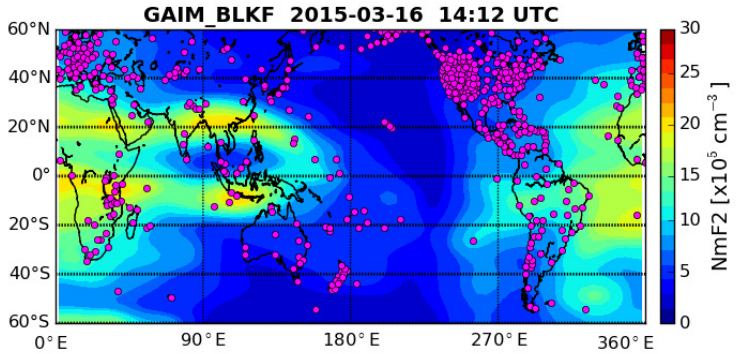




n_mF_2 Storm

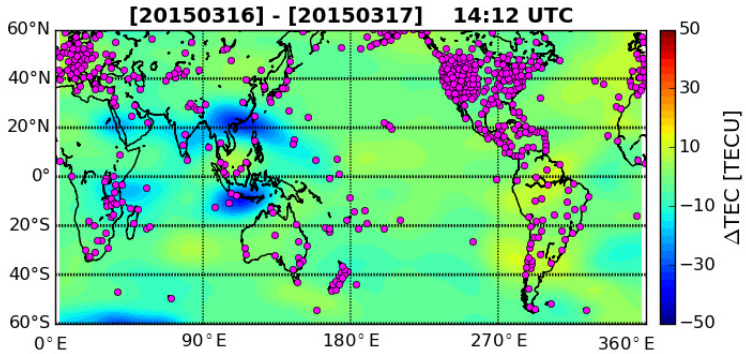
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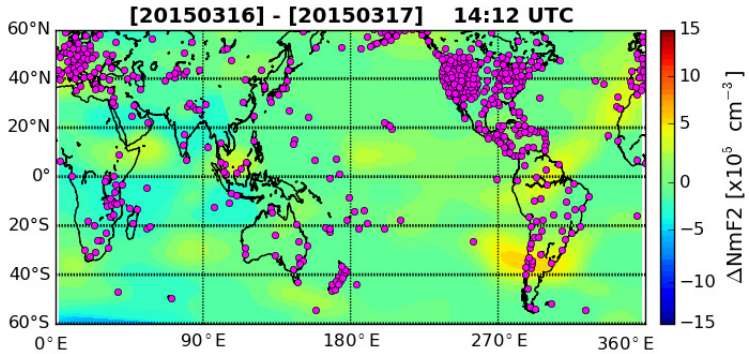




n_mF_2 Quiet

ΔTEC



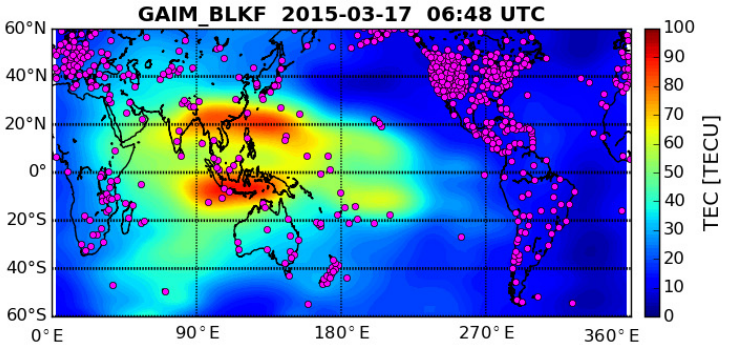


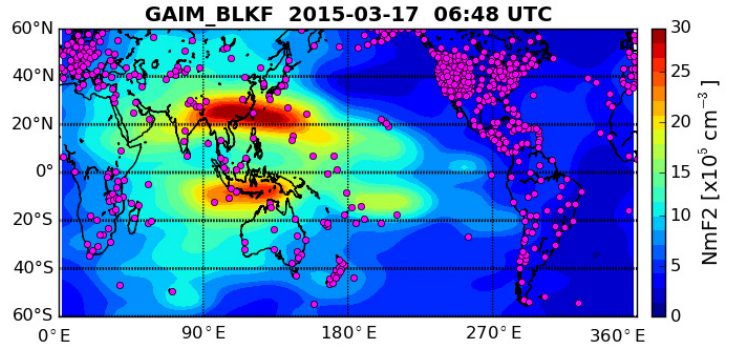
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Equatorial Anomaly Enhancement during Storm

17 Mar 2015

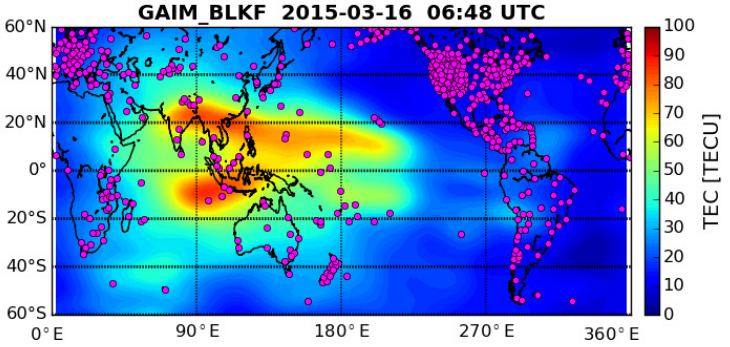
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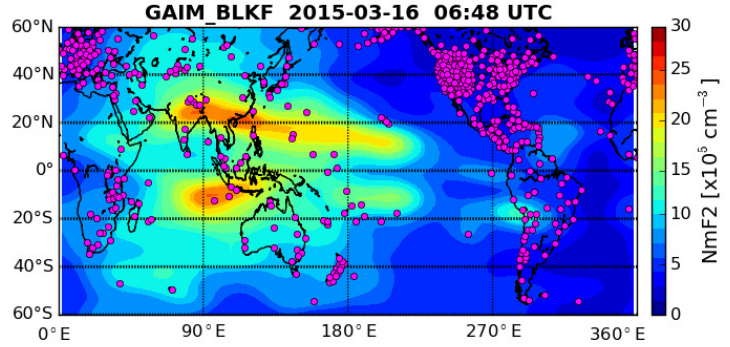




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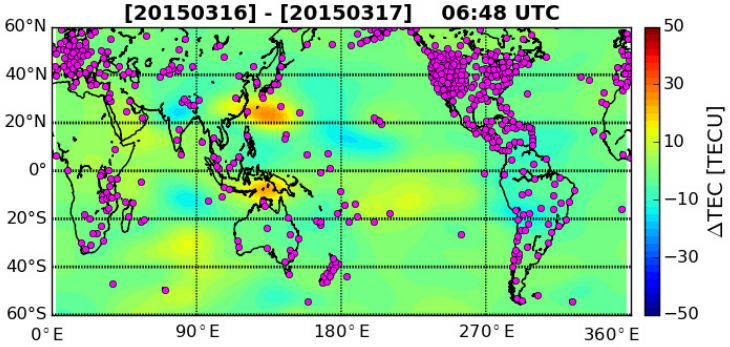
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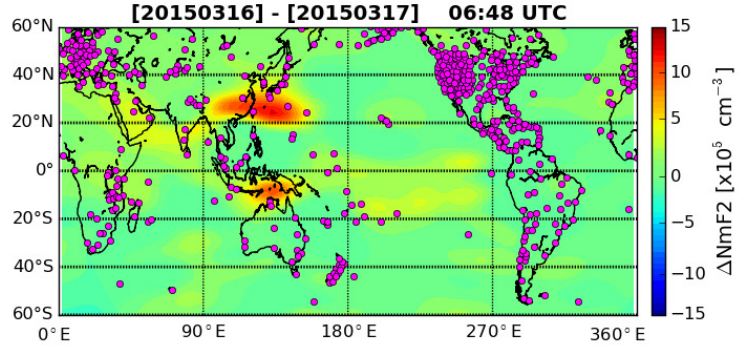




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ΔTEC



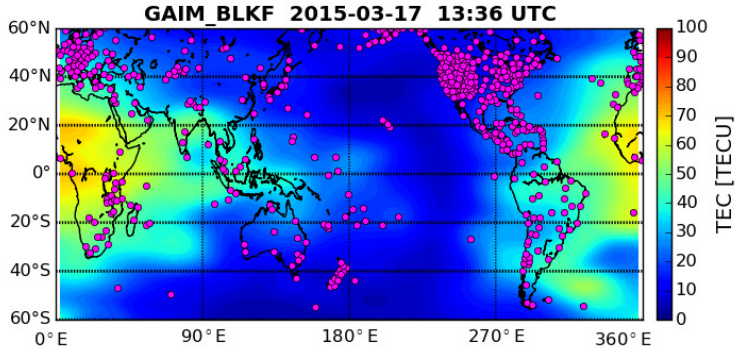


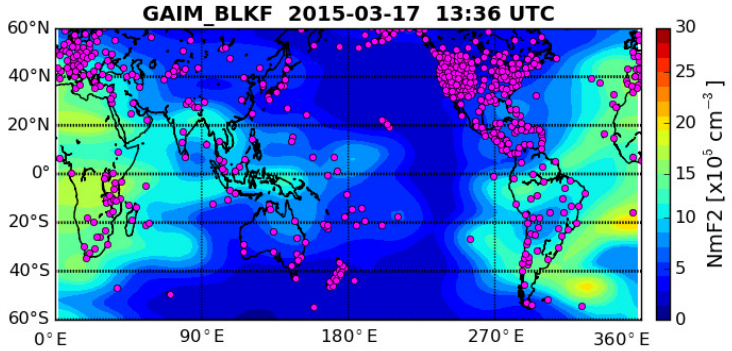
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Equatorial Anomaly Depletion during Storm

17 Mar 2015

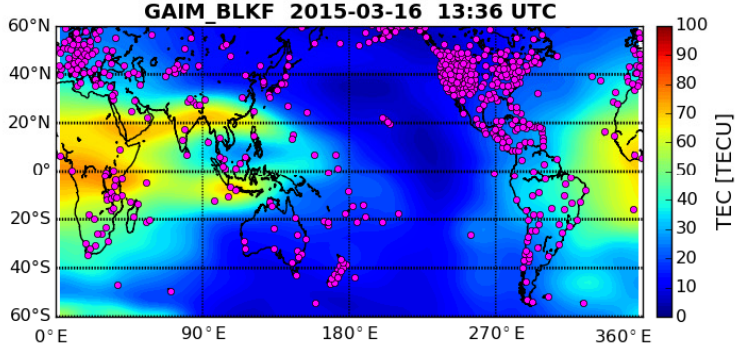
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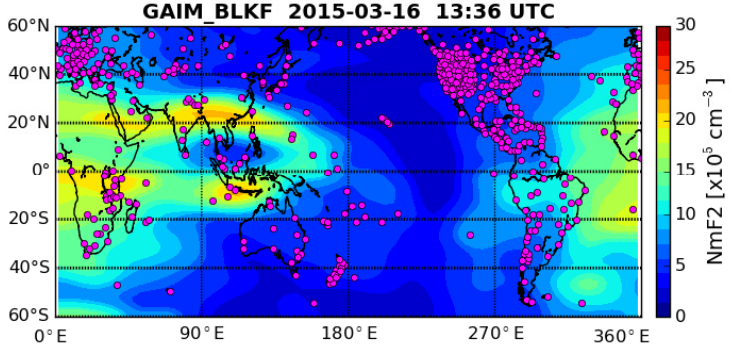




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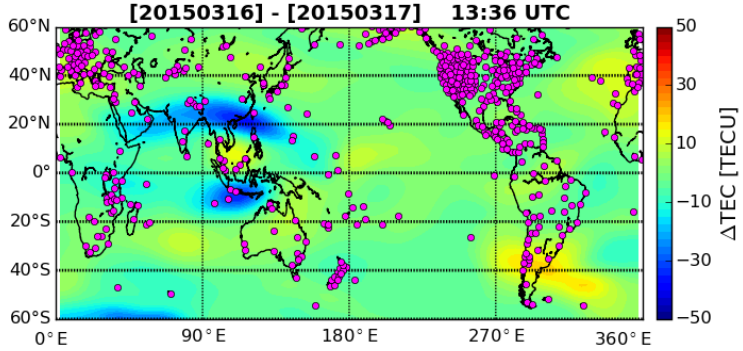
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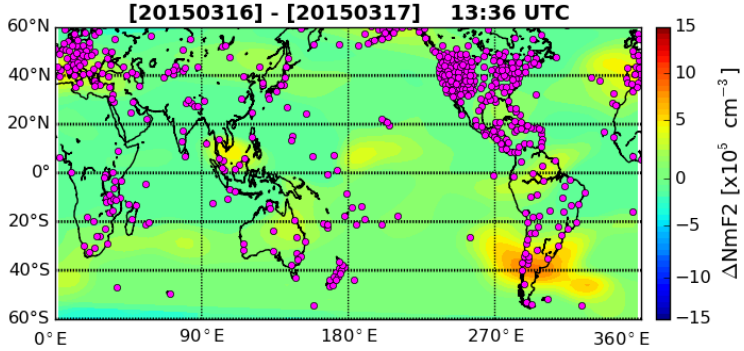




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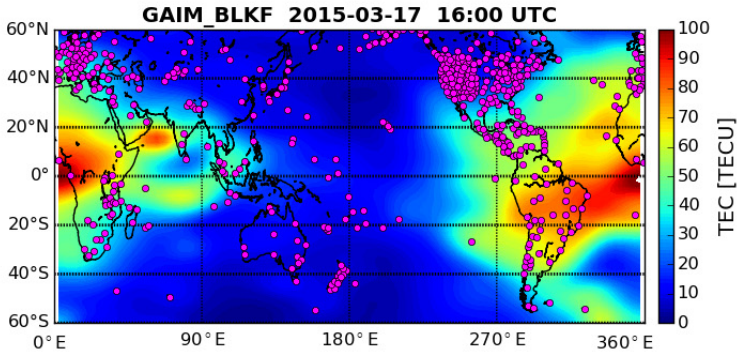


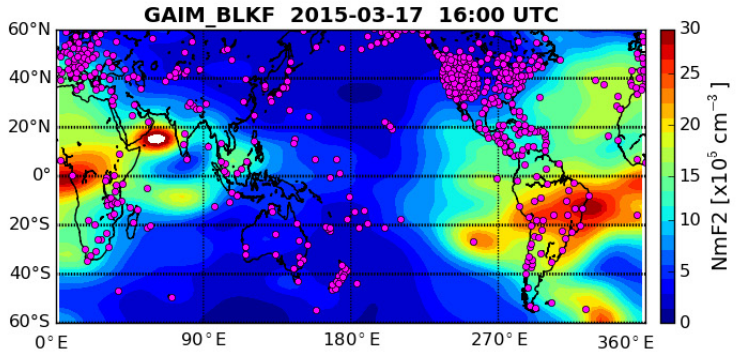
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Hemispheric Asymeetry during Storm

17 Mar 2015

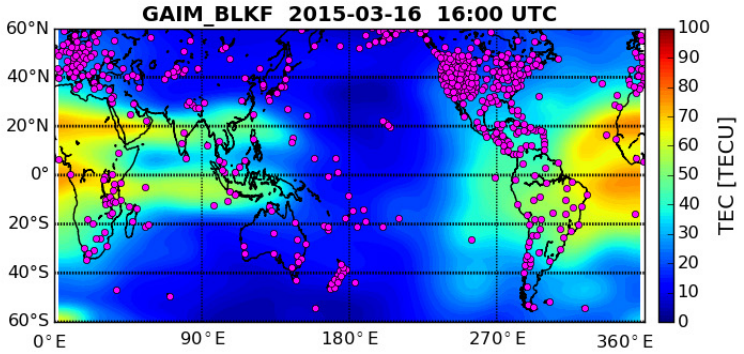
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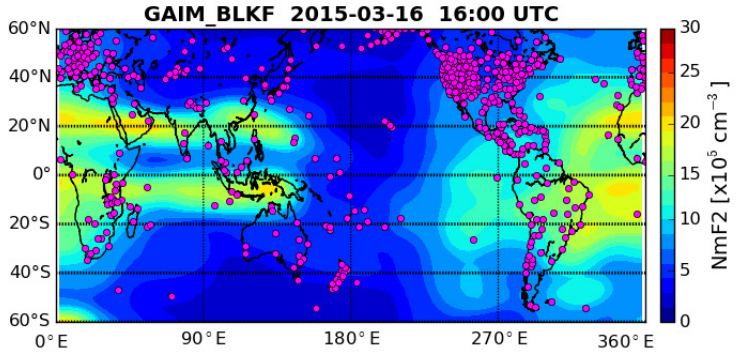




n_mF_2 Storm

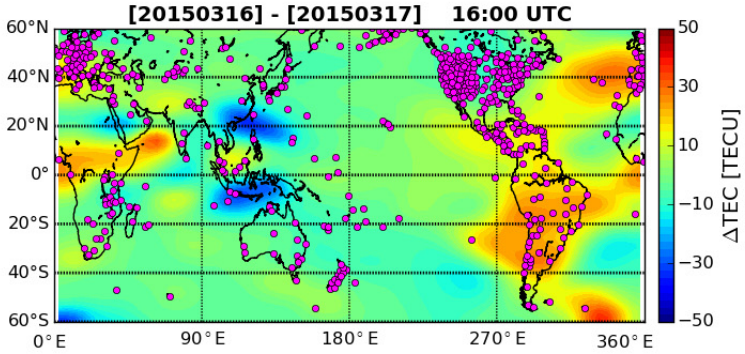
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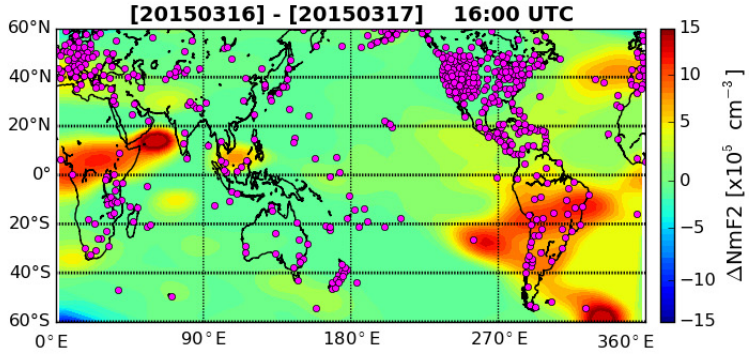




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ΔTEC



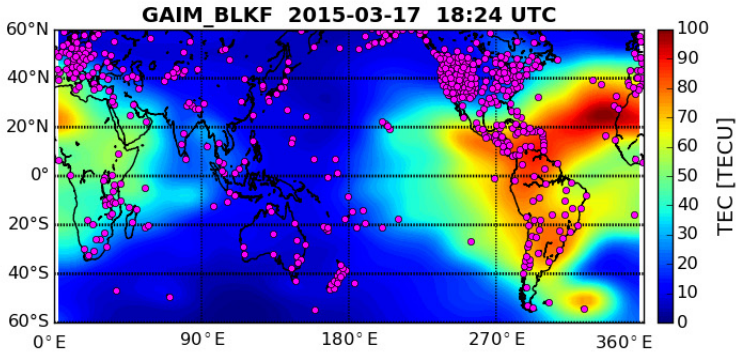


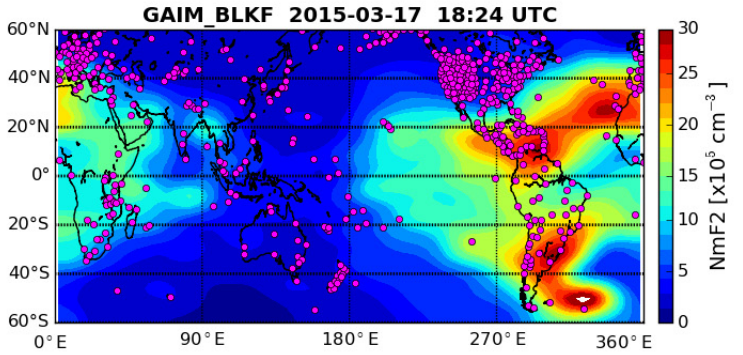
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Hemispheric Asymmetry during Storm

17 Mar 2015

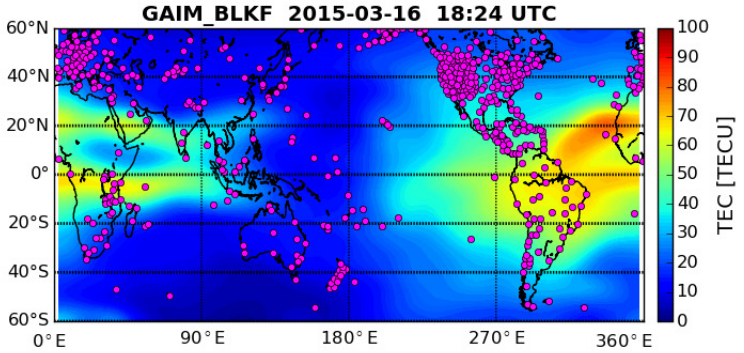
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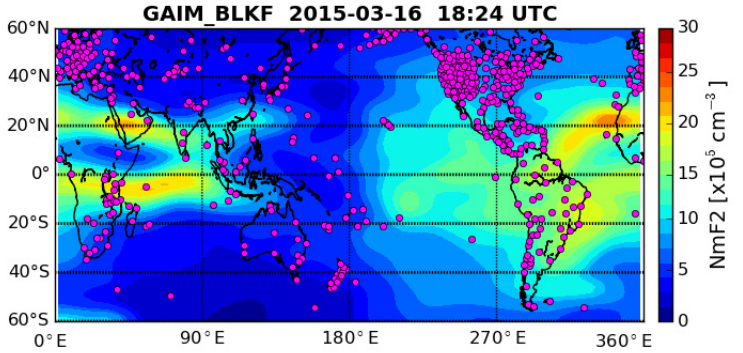




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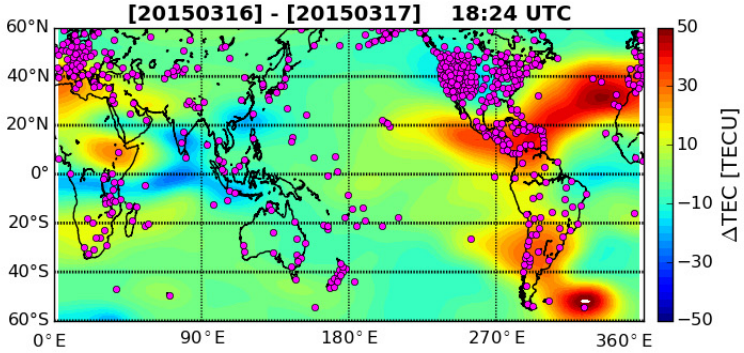
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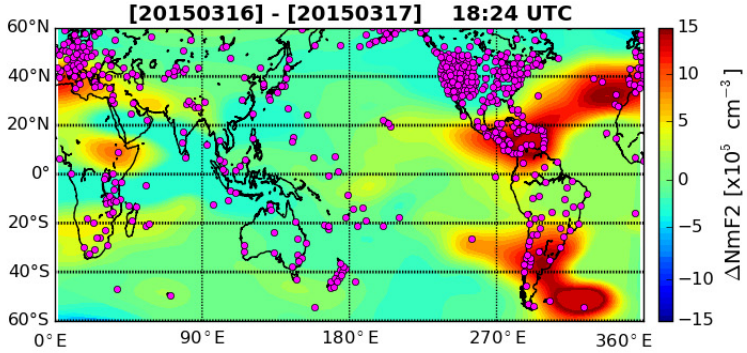




n_mF_2 Quiet

ΔTEC



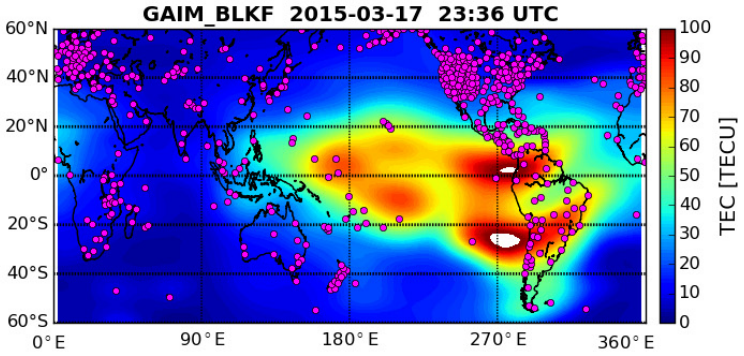


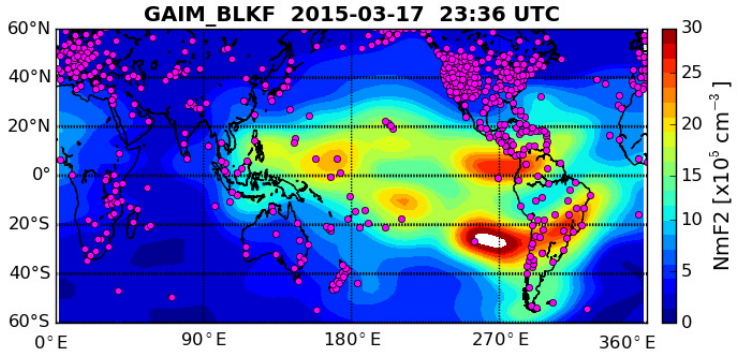
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Equatorial Anomaly Enhancement during Storm

17 Mar 2015

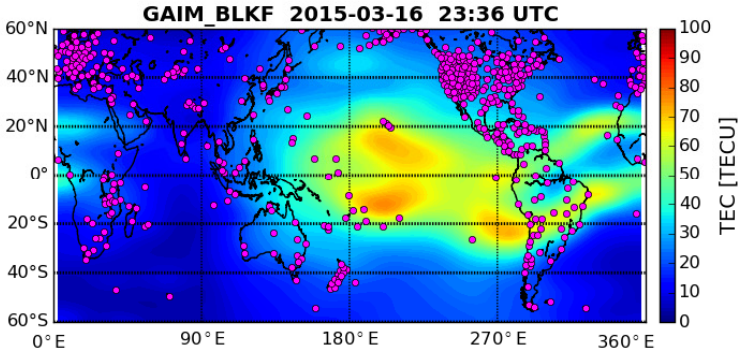
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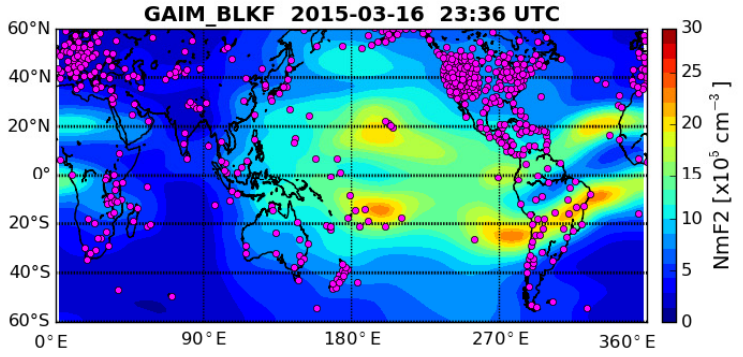




n_mF_2 Storm

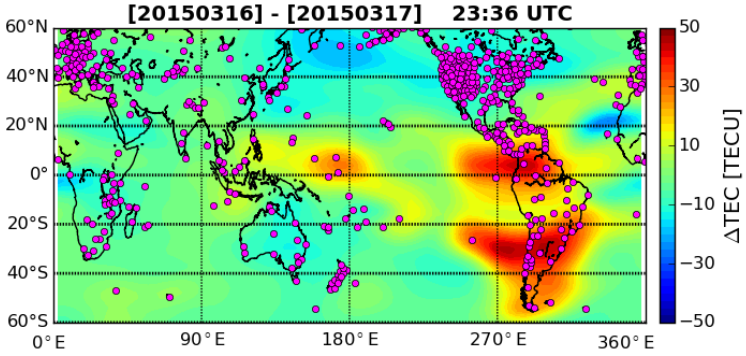
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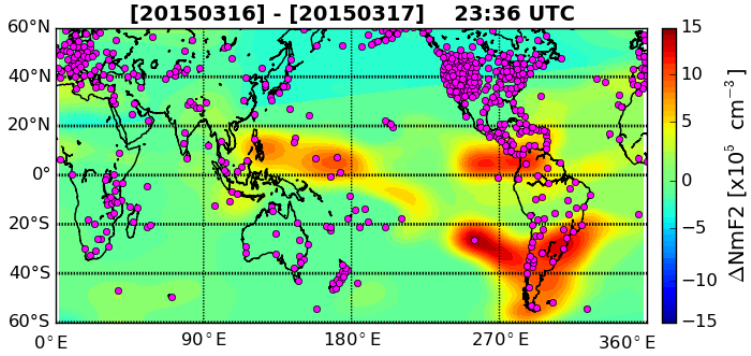




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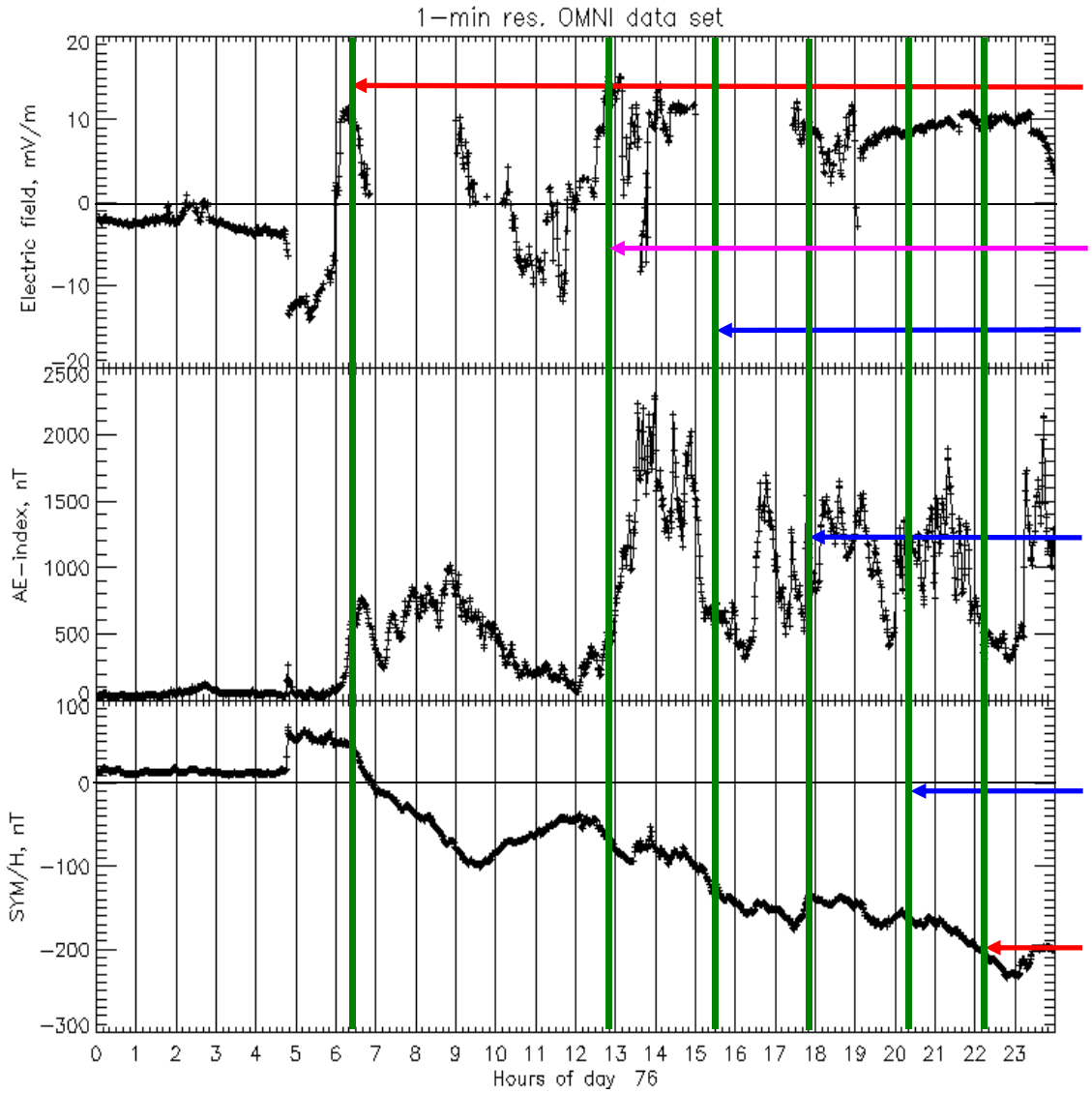
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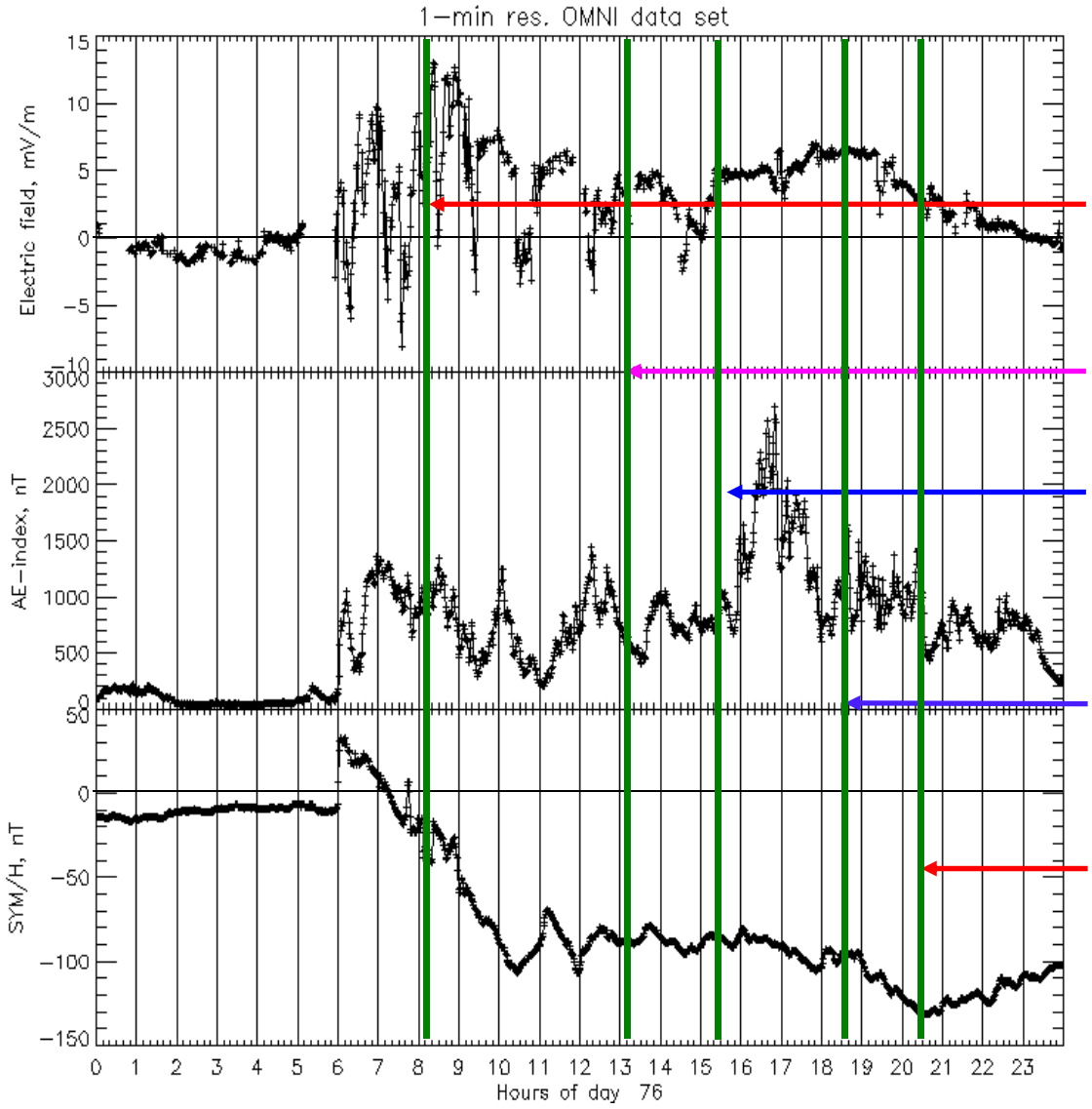
Δn_mF_2

Chronology of Ionospheric Disturbances during the Main Phase: 17 Mar 2015



- 06-07 UT: Equatorial ionospheric anomaly (EIA) ↑ in the afternoon sector
- 13-14 UT: Depletion of EIA
- 15-16 UT: Significant daytime hemispherical asymmetry (S↑) in middle- and low-latitude regions and the evening EIA depletion
- 17-19 UT: Reversal of hemispherical asymmetry in density ↑ – now in the northern hemisphere mid- and low-latitude regions
- 20-21 UT: Another reversal of the hemispheric asymmetry in density enhancement
- After 22 UT: Significant and EIA ↑ around the dusk sector

Chronology of Ionospheric Disturbances during the Main Phase: 17 Mar 2013



- 08-09 UT: Equatorial ionospheric anomaly (EIA) ↑ in the afternoon sector
- 13-16 UT: Depletion of EIA in the evening sector
- 15-17 UT: Hemispherical asymmetry in density ↑ in the southern hemisphere mid- and low-latitude regions
- 18-22 UT: Daytime mid-latitude Density ↑ in the southern hemisphere
- 20-22 UT: Significant daytime EIA ↑

Summary

- **Predicting ionospheric effects of space weather needs to address**
  - When: storm phases, durations
  - Where: latitude and longitude extent
  - How severe: magnitude of disturbances
  - Non uniformity: symmetry and asymmetry
- **From data assimilation to prediction**
  - *Assimilative forward modeling (AFM)*: with updated state to provide accurate initial state for short-term forward prediction
  - *Assimilative backward characterization (ABC)*: identify quantitatively the connections between the ionospheric state and electrodynamical and thermospheric drivers, IMF, solar wind, magnetospheric electric field, etc.