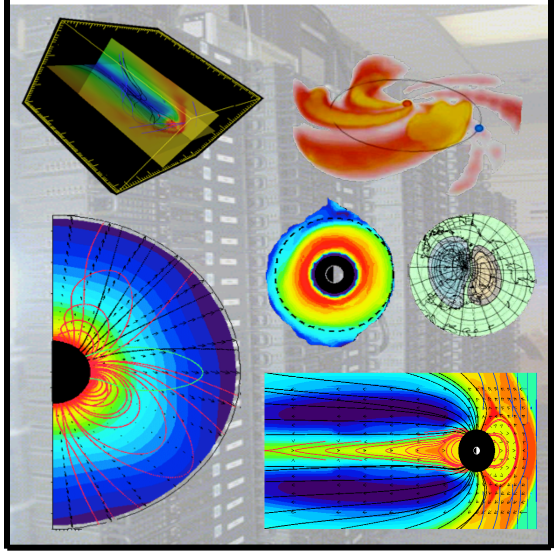
COMMUNITY
COORDINATED
MODELING
CENTER



Assessment of the predictive capability of IT models at the Community Coordinated Modeling Center

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http://ccmc.gsfc.nasa.gov

NASA Goddard Space Flight Center

CCMC Goals and Activities

- Bridge the gap between science and space weather operations
- Make modern space science models available to the research community
- Evaluate scientific research models for transition from research to operations
- Develop real-time systems
- Develop Space Weather tools
- Support NASA space weather situational awareness

CCMC CEDAR/GEM-CEDAR Modeling Challenges

- Ne, NmF2, hmF2, and vertical drift study since 2009
  - Nine events (quiet/moderate/strong storms)

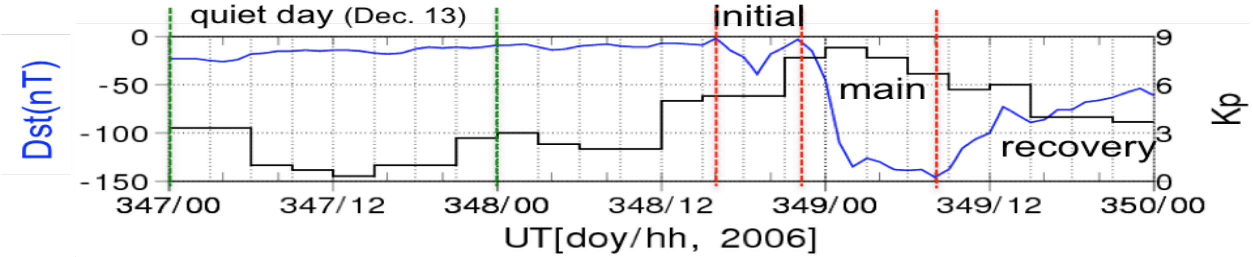
- Neutral density/Satellite drag study
  - at CHAMP orbits
  - Higher altitudes (> 600 km)

- Poynting Flux study
  - at DMSP tracks
  - Six storm events

- Global TEC study since 2011
  - Eight longitude sectors
  - 2006 AGU storm, 2013 March storm

Global TEC

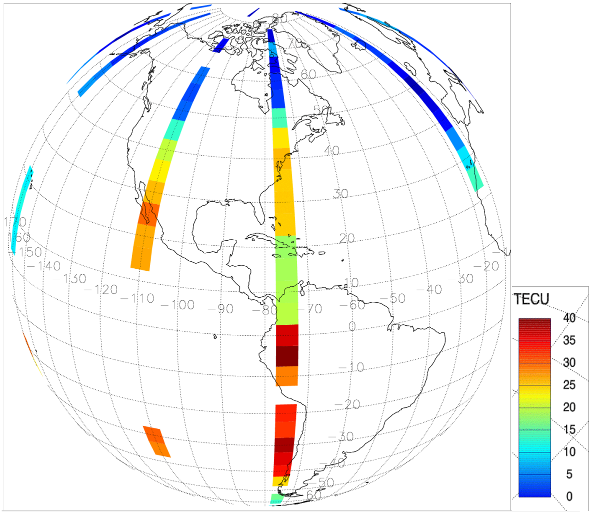
- Time interval: E.2006.347-349 (2006/12/13 - 12/16)



- Eight longitude sectors:

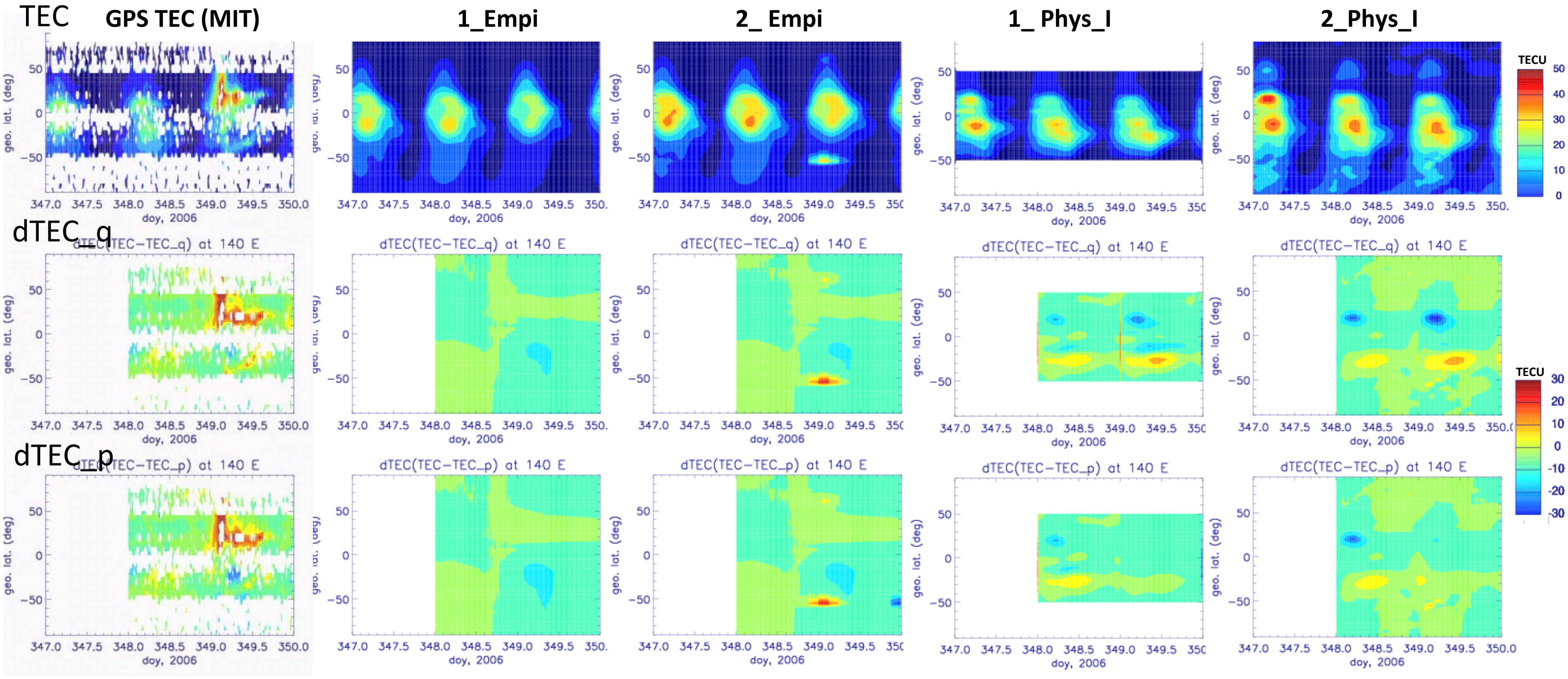
  25-30, 90-95, 140-145, 175-180°E,
  200-205, 250-255, 285-290, 345-350°E

- Observations :
  - GPS vertical TEC (provided by MIT and JPL)
    - data bin : 5° lat × 5° lon × 15 min
  - IGS (International GNSS service) vertical TEC
    - data bin : 2.5° lat × 5° lon × 2 hrs



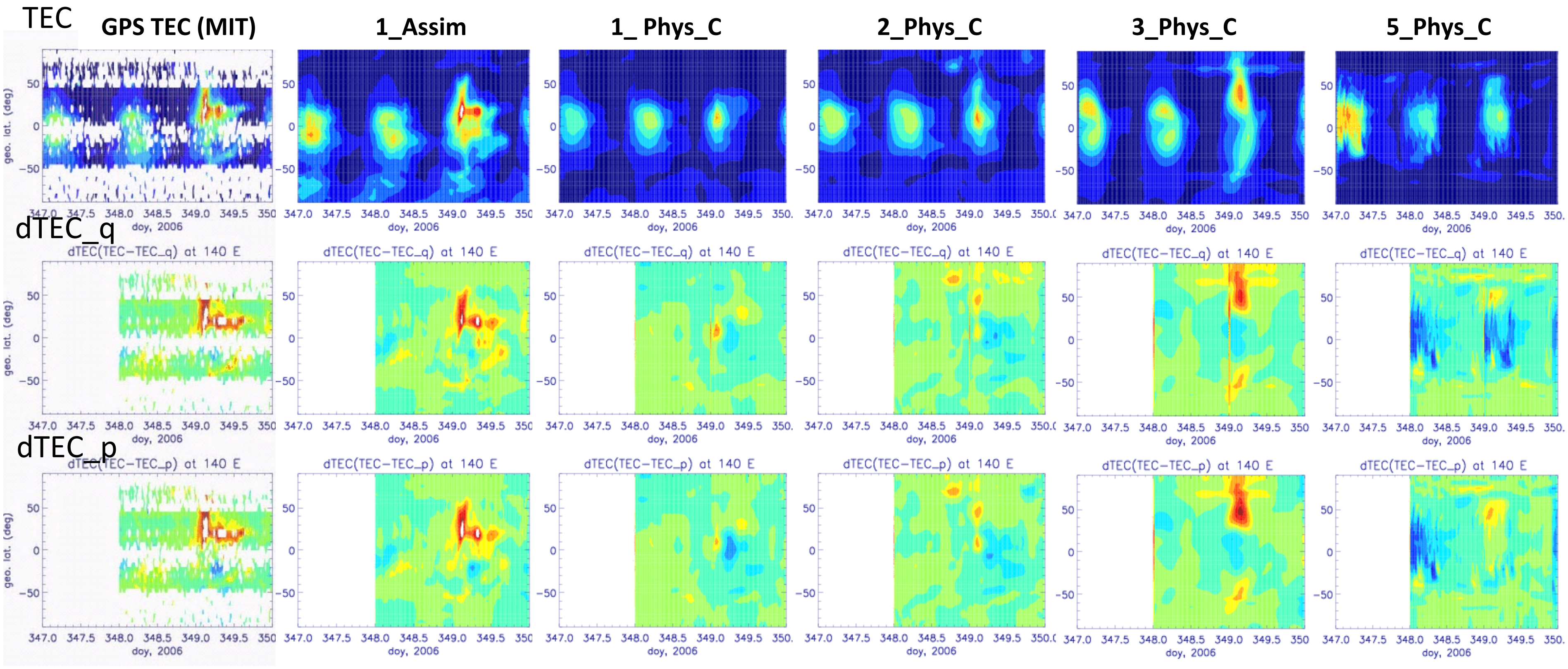
- More than 10 model simulations

Observed/Modeled TEC and dTEC in 140°E



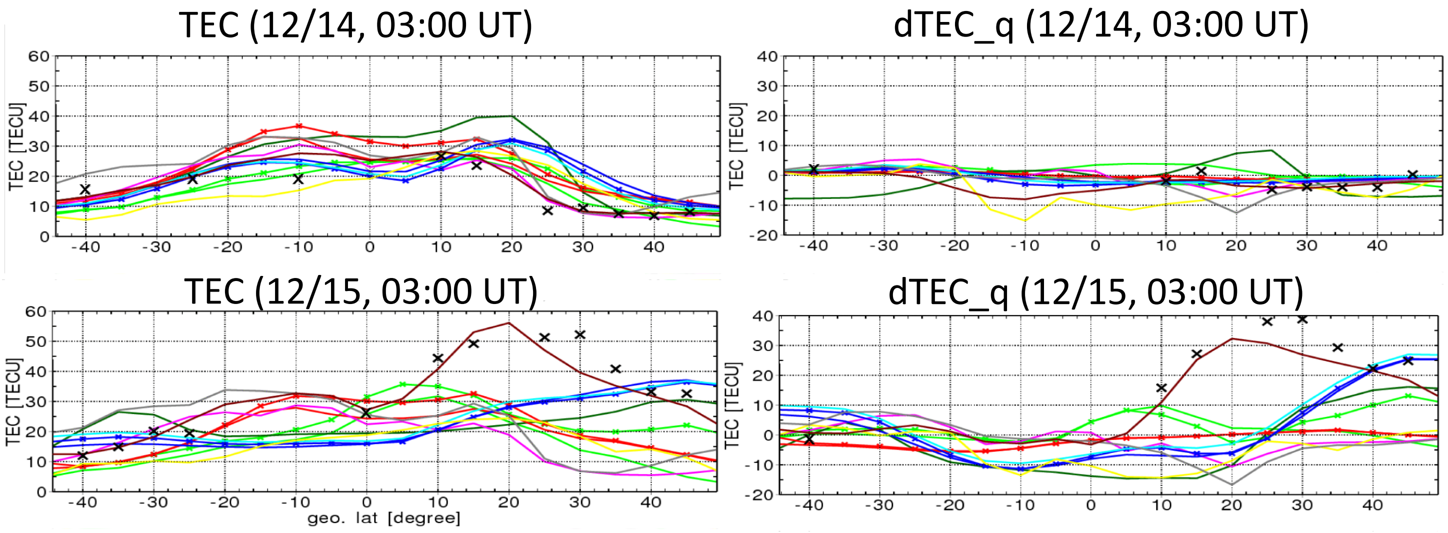
- **dTEC_q=** TEC_today –TEC (quiet day:12/13)
- **dTEC_p=** TEC_today –TEC (previous day)
- None of empirical and ionospheric physics based models predict well TEC increase in northern low latitudes.
- Two physics based ionosphere models relatively well predict TEC increase in southern middle latitudes.

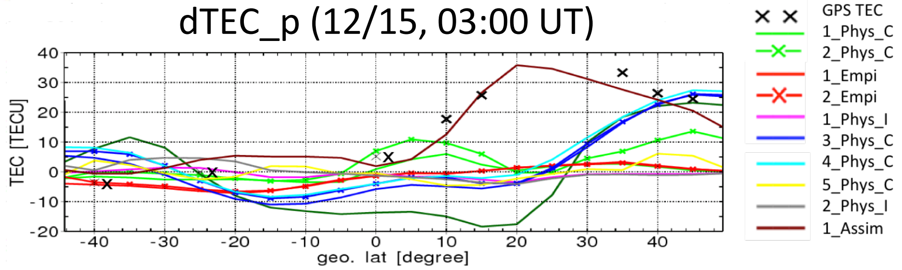
Observed/Modeled TEC and dTEC in 140°E



- Data assimilation model simulation shows the best performance.
- Data assimilation and coupled models show TEC increase in northern hemisphere better compared to empirical and ionosphere models.
- 3_Phys_C shows high TEC increase in higher latitudes compared to other simulations.
- 1, 2 and 5_Phys_C do not produce equatorial anomaly.

Observed/Modeled TEC and dTEC in 140°E

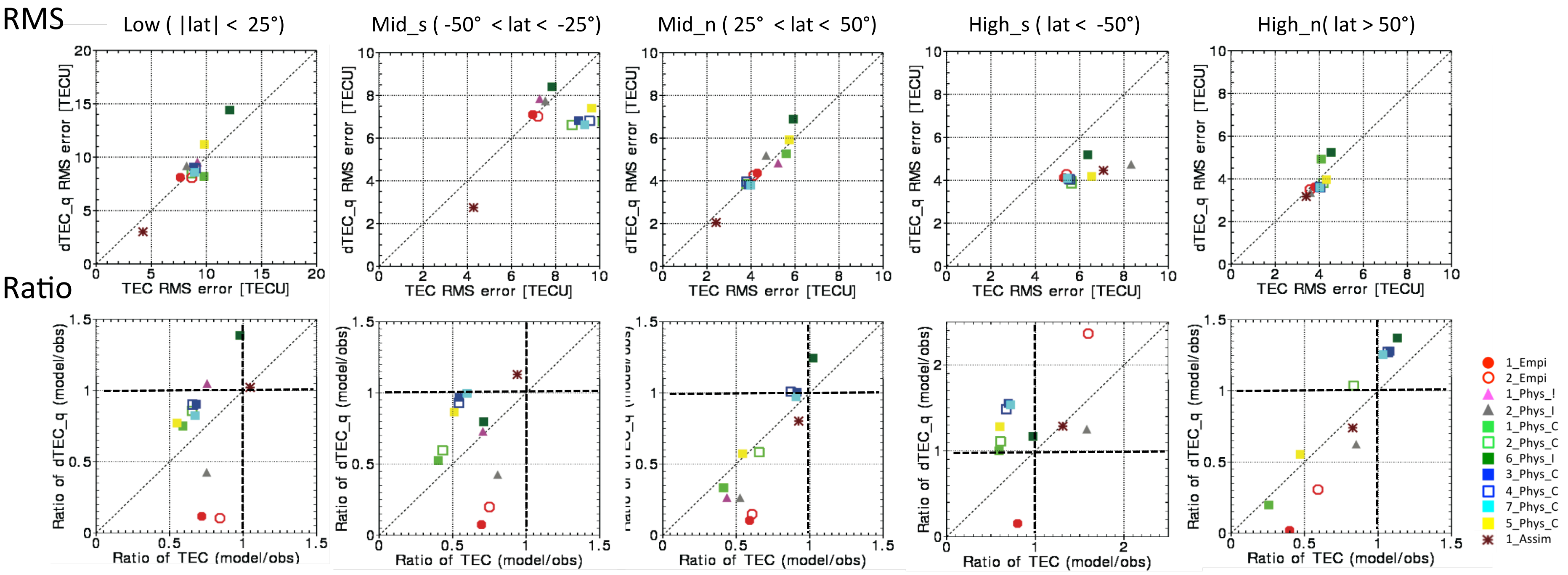




Models

- tend to overestimate TEC during quiet period
- fail to reproduce TEC enhancement during the main phase of the storm.
- Physics-based coupled models (blue and green lines) produce dTEC_q and dTEC_p peak values better than TEC peak in higher latitudes, even though the location of the peak does not agree with the GPS TEC peak latitude.

RMS and Ratio ($\mathrm{Max}_{\mathrm{model}}/\mathrm{Max}_{\mathrm{obs}}$) for all 8 longitude sectors



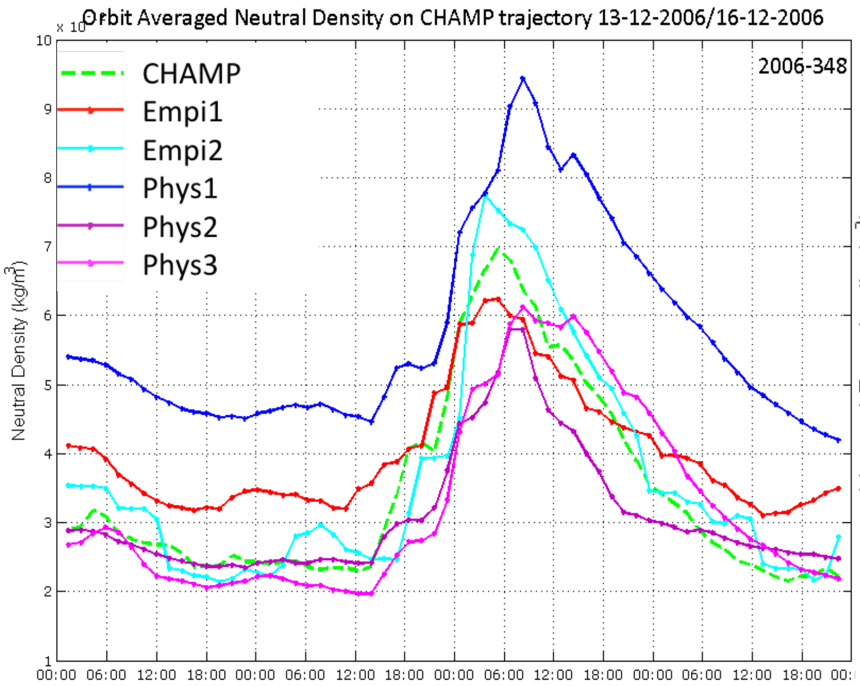
- x and y axes correspond to the skill scores for TEC and dTEC_q predictions.
- RMS errors are smaller for dTEC_q than for TEC in southern middle and high latitudes, especially for physics-based coupled models.
- In terms of ratio, the physics based coupled (squares) and data assimilation models have better scores than the empirical models.

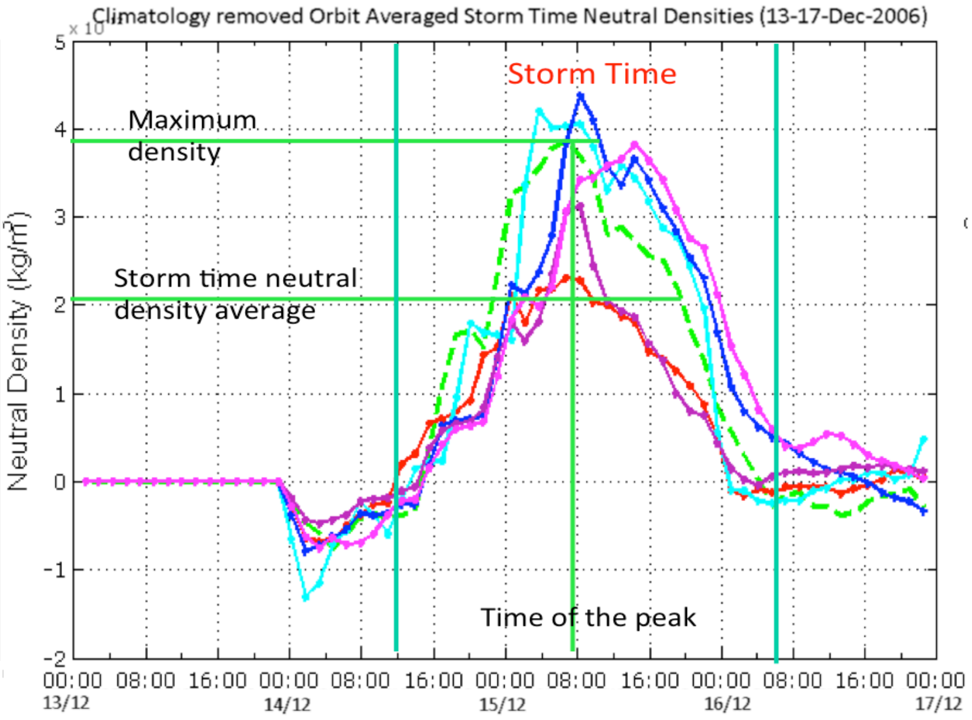
Neutral Density

- Along CHAMP satellite trajectories:
  - orbit averaged density
- 2006/12/13-12/16
- Models used for the study
  - two empirical model simulations
  - three physics-based coupled IT model simulations
- To assess the models' capability to capture storm effects several shifting approaches were performed: e.g.,
  - shifting to zero by subtraction of the quiet time neutral density
    : Nden_current – Nden (quiet day:12/13)
  - shifting to CHAMP data by subtracting the quiet time mean difference between the observation and modeled values

Neutral Density at CHAMP orbits

Orbit averaged neutral density (12/13-12/16)

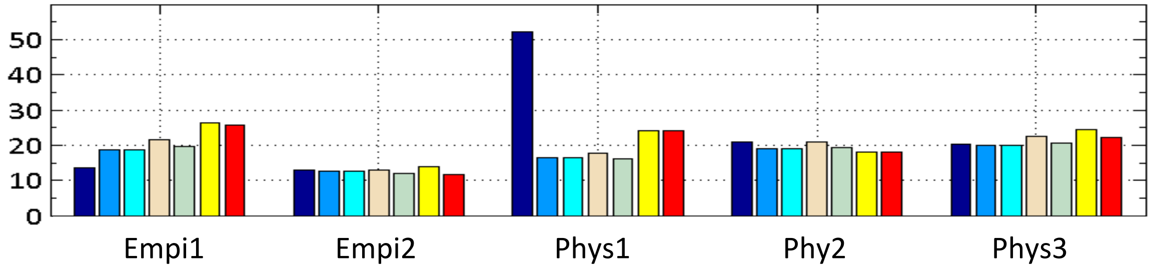




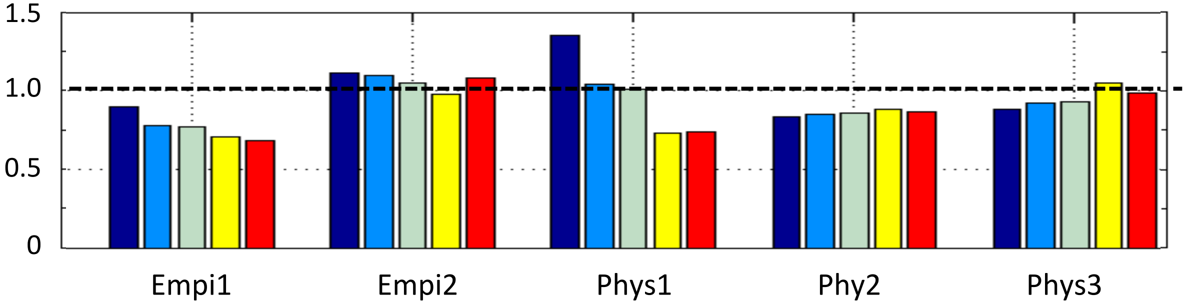
- Noticeable difference in baselines of the models
- Quantities for storm impact quantification:
    - maximum density
    - storm time neutral density average
    - time of peak

RMS, Ratio (Max$_{model}$/Max$_{obs}$) and Timing Error

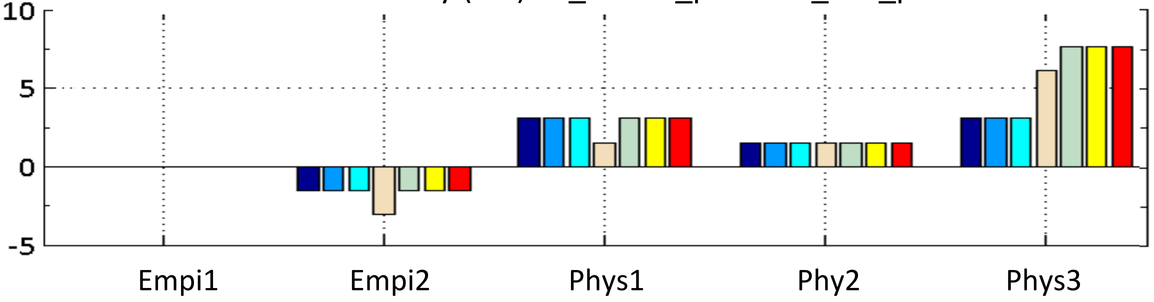
Normalized RMS Error: RMS/(Max_obs - Min_obs)



Ratio of Modeled neutral density peak to CHAMP peak



Time Delay (hrs) : T_model_peak - T_obs_peak

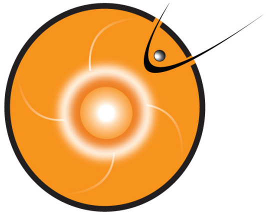


🟦 Without any shift

🟩 Shift to 0 using quiet time modeled value = Nden_current – Nden (quiet day:12/13)

Summary

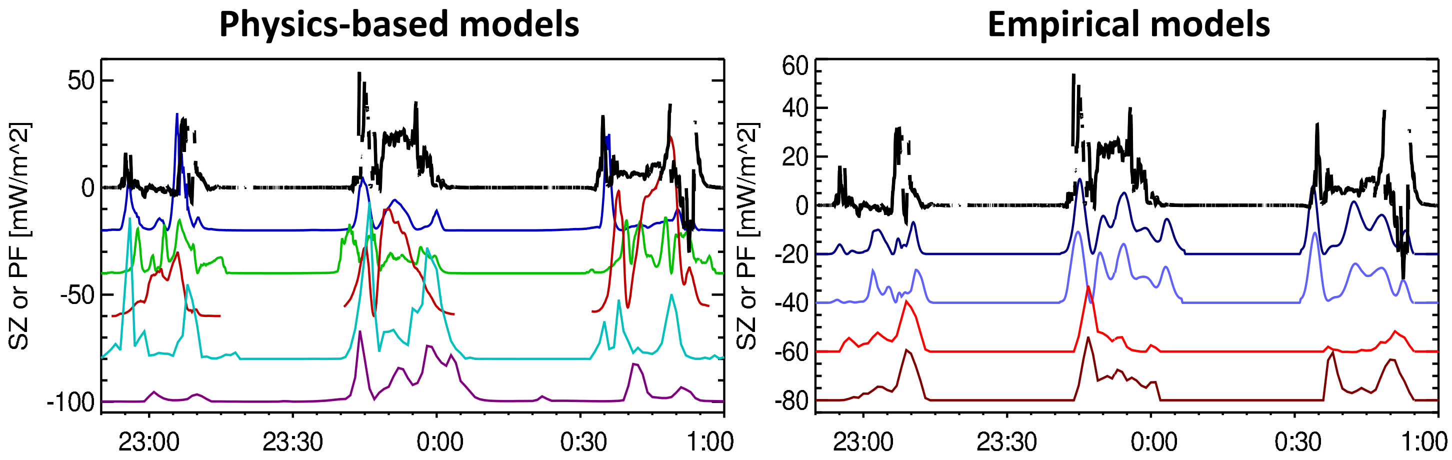
- Model-data comparison of TEC, Neutral density along the CHAMP, and DMSP Poynting Flux for 2006 Dec. storm
- More than 10 model simulations of the Ionosphere-Thermosphere (IT), including 3-dimensional IT models and 2-dimensional ionospheric electrodynamics modules of global magnetosphere MHD models
- Eliminating quiet time climatology gives a better way to determine the actual storm-time response and to remove baselines of both the modeled and the observed data.
- Model performance depends on metrics, parameters, latitudes, and data preparation approaches (e.g., shifting, averaging and etc.).
- Ensemble of model simulations will allow for the models to supplement each other's shortcomings.
  - Determine quiet (current) time values using data assimilation/empirical models and forecast the values using physics-based models.



Poynting Flux/Joule Heating

- Poynting Flux along DMSP satellite track
- Joule Heating:
  calculated by using height-integrated currents and Pedersen conductance
- 2006/12/14-12/16
- Models used for the study
  - Five physics-based model simulations from
    - coupled IT models
    - 2-dim ionospheric electrodynamics modules of global magnetosphere MHD models
  - Four empirical model simulations

Poynting Flux/Joule Heating

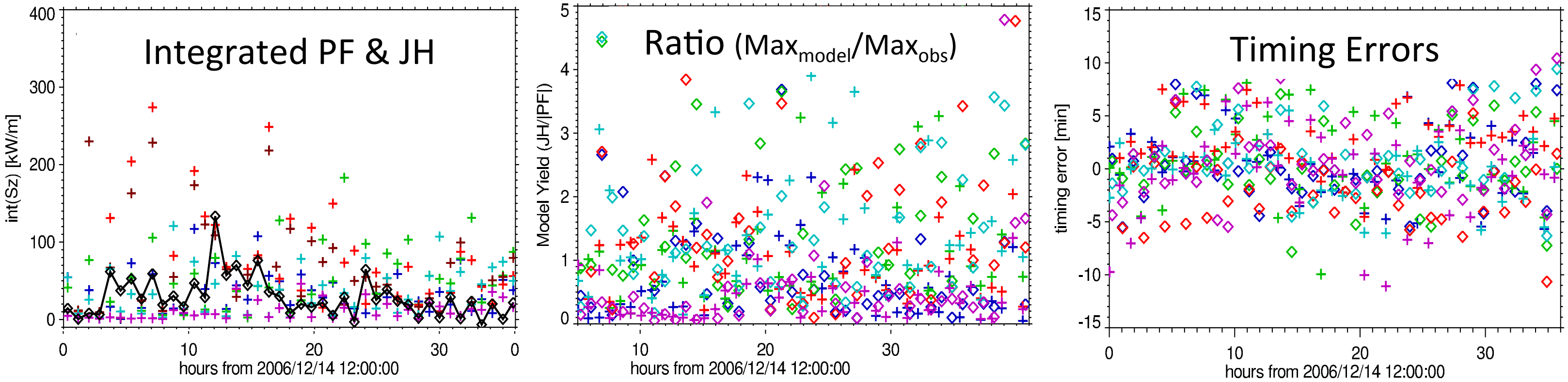

Physics-based models

Empirical models

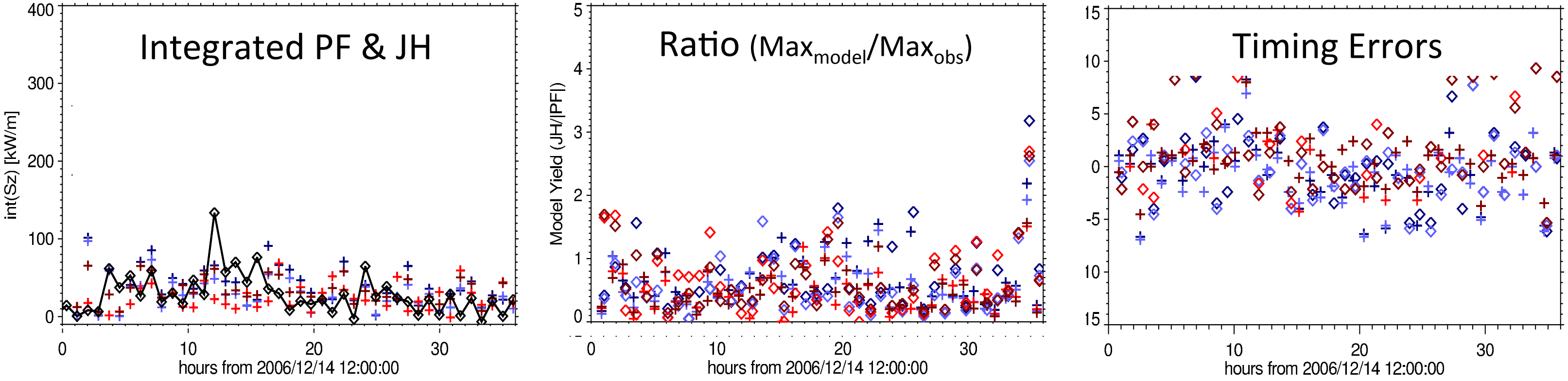
- Three passes through the auroral zone at the onset of the storm (adjacent traces in the stack plots are by -20 mW/m^2)
- Model results were interpolated onto the DMSP tracks.
- analyzed in each pass of the auroral zone (i.e., satellite orbit segments within 45 degrees of the northern and southern magnetic poles)
- Joule heating derived from the ionospheric electrodynamics of magnetosphere MHD models > the observations: MHD models tend to overestimate electric potentials.

Ratio (Max$_{model}$/Max$_{obs}$) and Timing Error

Physics-based model



Empirical models



- PF (black lines) and JH (colors) integrated along the DMSP-F15 satellite track during polar region crossing
- Model Yields: maximum Joule Heat value/maximum Poynting Flux observed
- Time difference in the occurrence of maximum value: T_model_max - T_obs_max

(cross: inbound toward magnetic pole, diamonds: outbound away from pole).

Model Simulations used for the study

Model Setting ID	
1_IRI*	IRI-2007, empirical ionospheric model
2_IRI*	IRI-2012 using IRI-corr for topside Ne and CCIR F-peak
1_SAMI3_HWM93*	SAMI3 with the neutral wind model HWM93
1_USU-IFM*	IFM driven by F10.7, Kp and empirical inputs for the thermosphere parameters
1_CTIPE*	CTIPe driven by Weimer electric potential model, 2°×18°, 15 levels in logarithm of pressure
2_CTIPE	CTIPe runs at NOAA/SWPC with Weimer 2005 using 1-minute solar wind and IMF from ACE; (f10.7+f81)/2
4_GITM*	GITM 2.0 driven by Weimer electric potential model
1_TIE-GCM*	TIE-GCM1.93 driven by Heelis electric potential model with constant critical co-latitudes
2_TIE-GCM	TIE-GCM1.94 driven by Weimer electric potential model with dynamic critical co-latitudes
3_TIE-GCM	TIE-GCM1.94 driven by Weimer electric potential model with dynamic critical co-latitudes and with double resolution
4_TIE-GCM	TIE-GCM1.94 with Weimer 2005 and SABER/TIDI lower boundary conditions in double resolution
5_TIE-GCM	TIE-GCM1.94 driven by AMIE with constant critical cross-over latitudes (fixed at 55 and 70 mlat)
1_UAM	Upper Atmosphere Model (UAM), A.A. Namgaladze et al., FAC as external driver
2_UAM	UAM with AMIE electric potentials as external drivers
3_UAM	UAM with Weimer-2005 (and/or Weimer-96) electric potentials
1_USU-GAIM*	USU-GAIM23 with GPS TEC observations from up to 400 ground stations

*Runs performed at the CCMC

Models in blue: for the study of “Role of drivers”