Modeling the evening ionosphere with data assimilation techniques during pre-storm and storm days of March 2015

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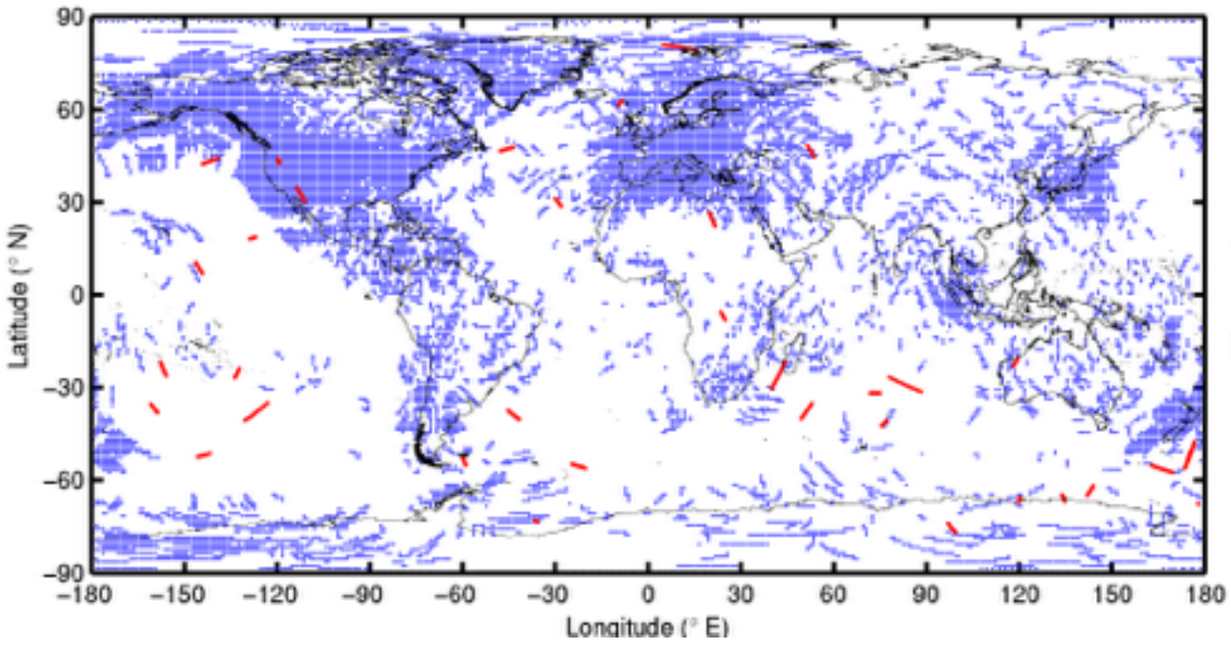
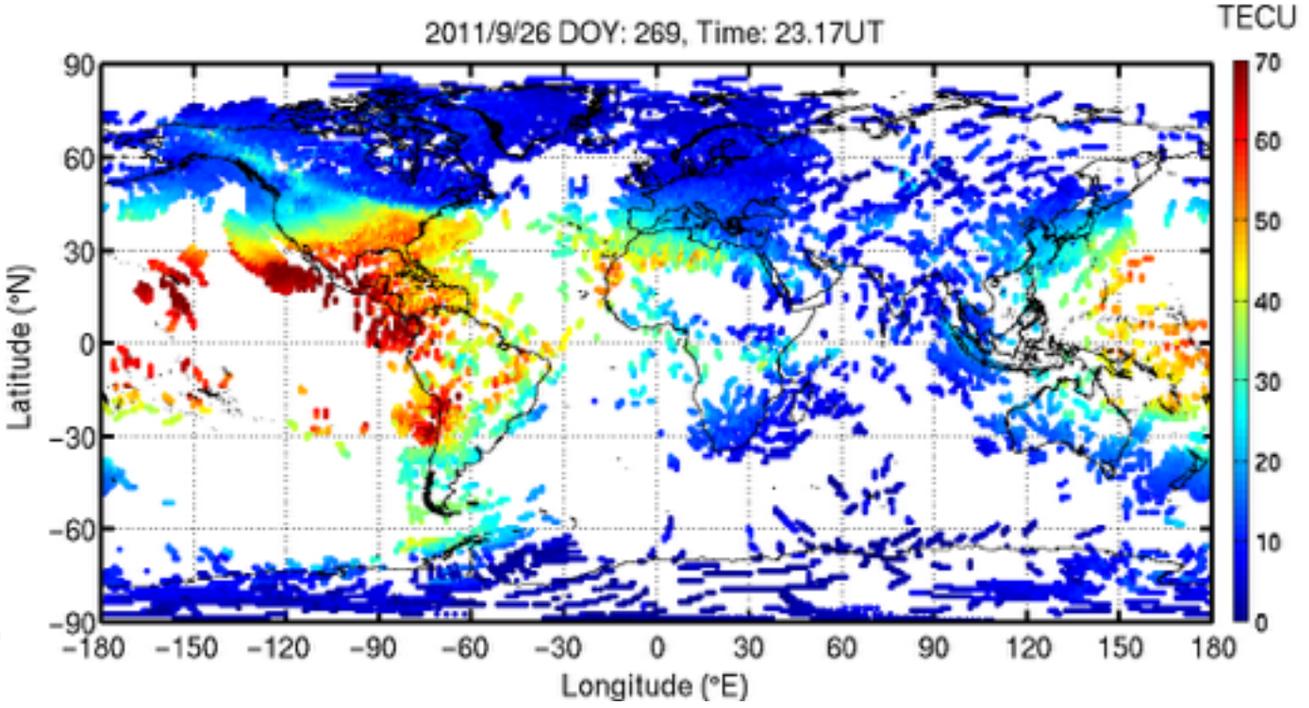
Global distribution of ground-based GNSS and FORMOSAT-3/COSMIC



26 September 2011 Geomagnetic Storm



Ionospheric Data Assimilation Models

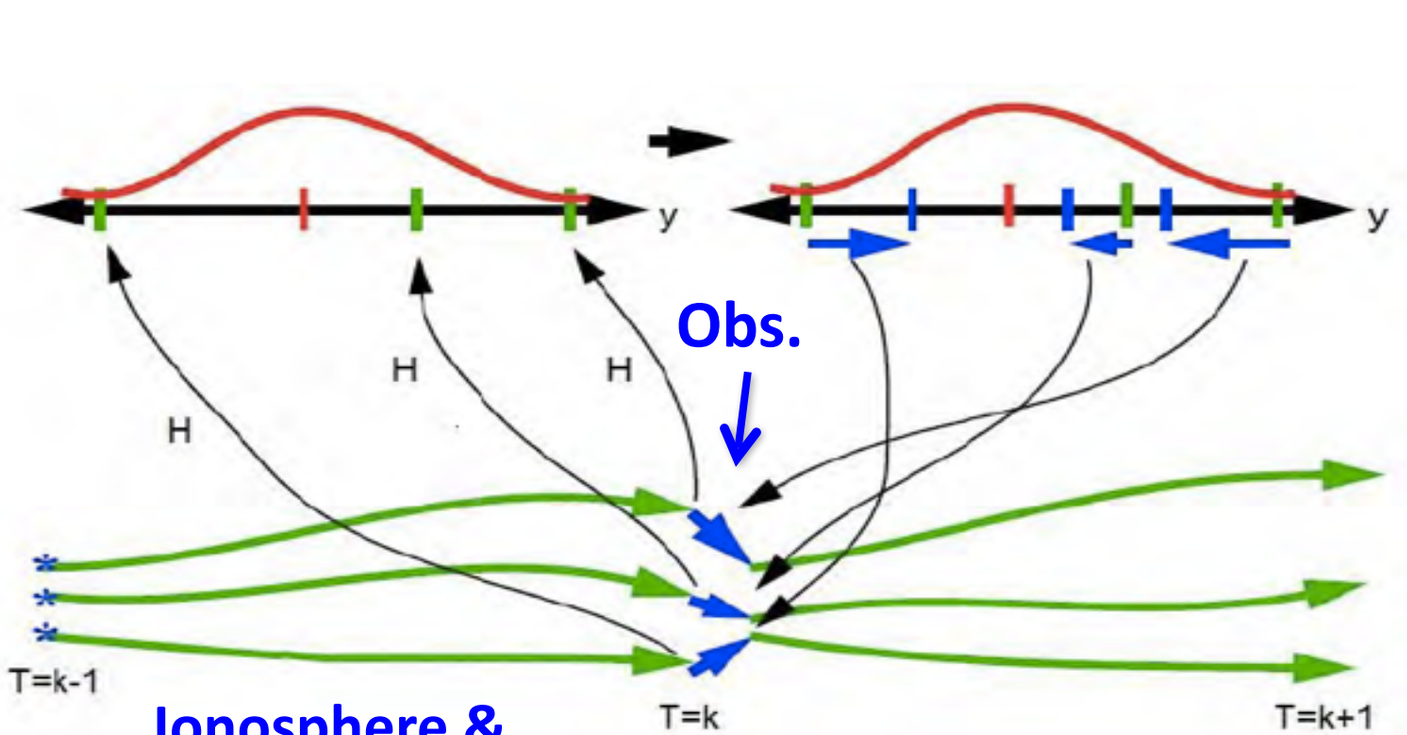
Observations → **Method** ⇄ **Model**

- Ionosonde/digisonde
- ISR
- GPSTEC
- GPS RO
- IVM
- Airglow/EUV Imager

- 3D-Var
- 4D-Var
- KF
- EnKF
- LETKF

$[O]$
[U]
[V]
[TN]
$[O+]$
$[Ne]$

- FPFIM
- IFM
- IPM
- TIEGCM
- SAMI-3
- GAIA

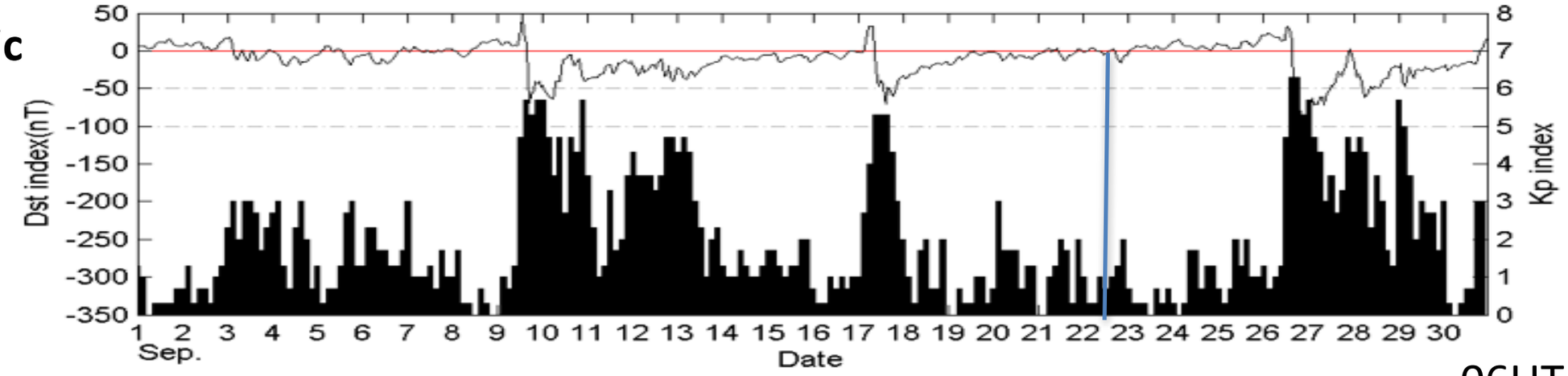


Ionosphere & thermosphere model

State variables:
neutral temperature (TN),
oxygen density (O),
neutral zonal wind (U),
meridional wind (V),
$[O^+]$ ion density

DART-TIEGCM:
90 theoretical ensemble model runs:
solar flux (F10.7),
cross-tail potential
hemispheric power (Kp)

Moderate Magnetic Storm September 2011



00UT

06UT

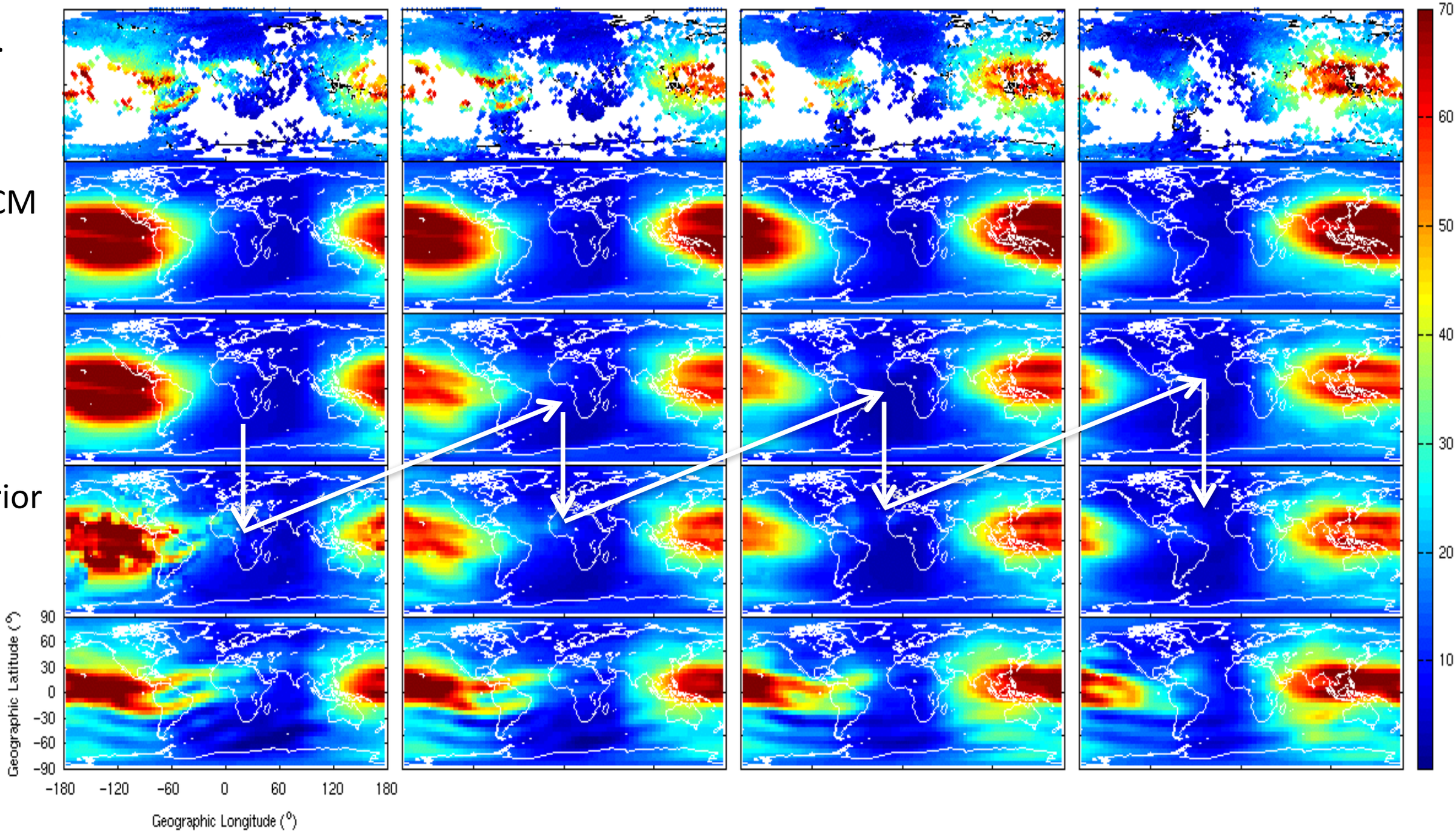
Obs.

TIE-GCM

Prior

Posterior

GIM

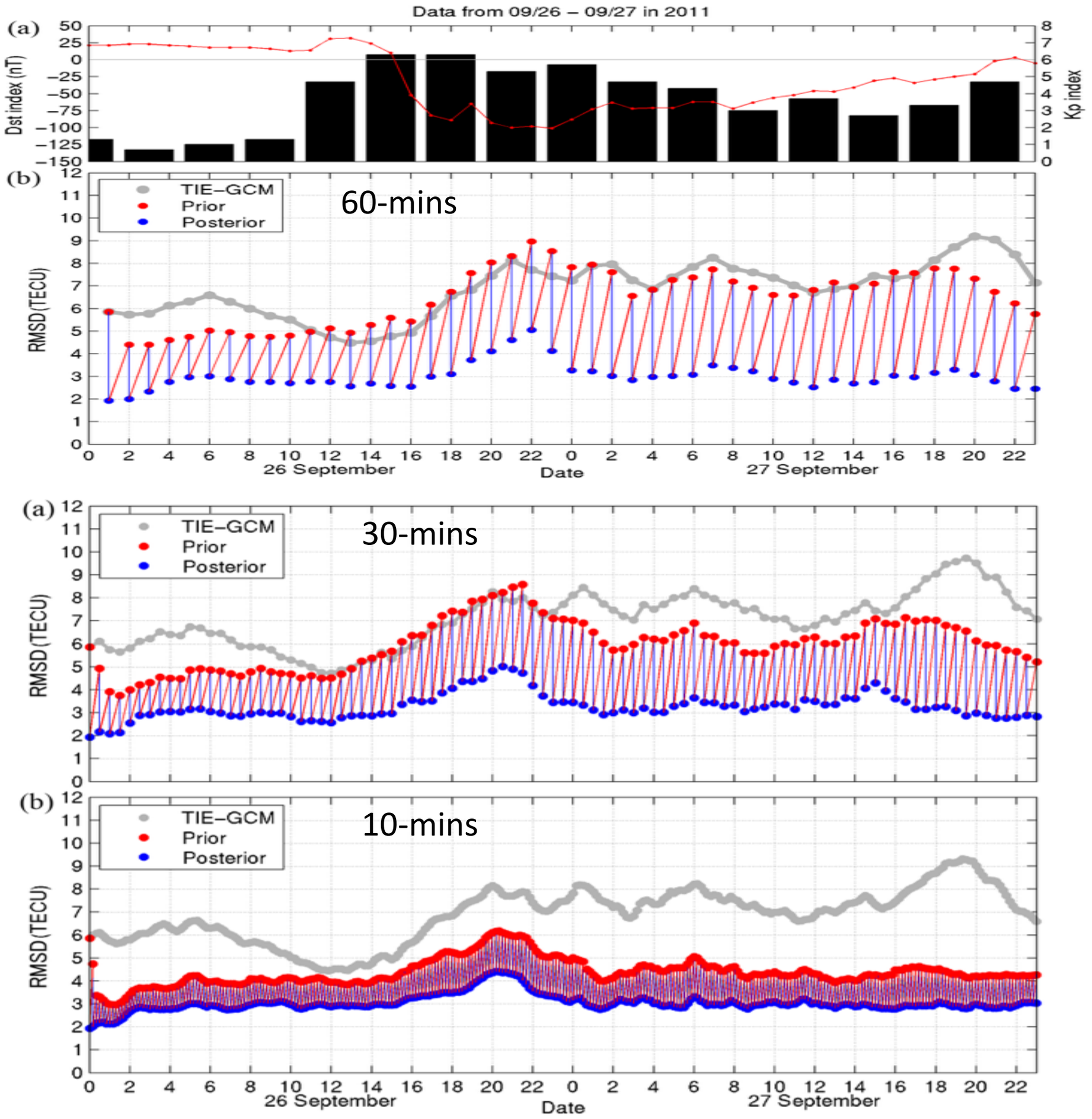


90 ensembles:
F10.7,
Cross-tail Potential,
hemispheric Power
(Kp)
→ **Random**

State variables:
(TN),
(O),
(U),
(V),
[O^+]

if the assimilation cycle is 60 mins., the result is similar to or worse than NO assimilation.

Chen et al., (2016)

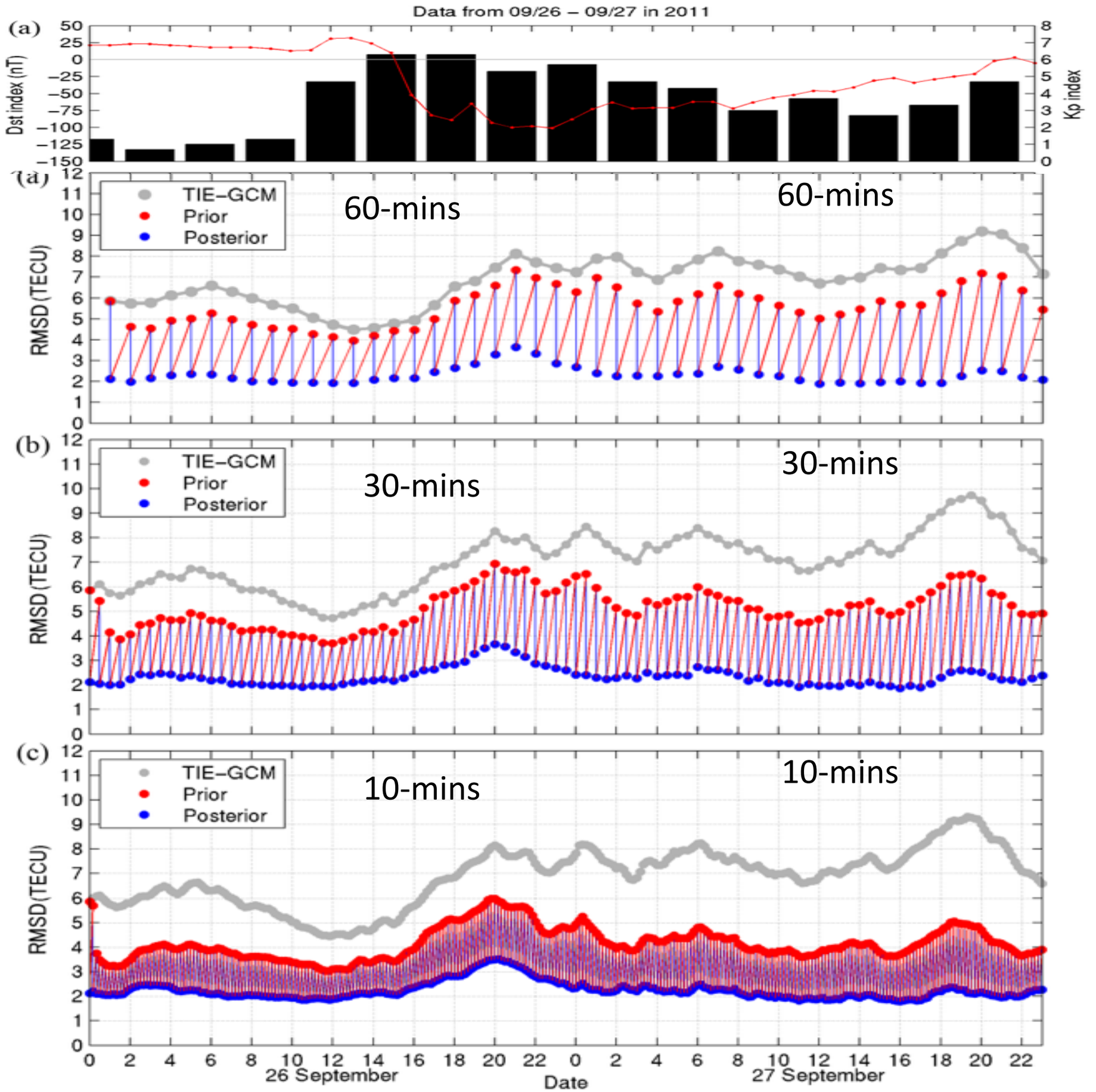


90 ensembles:
F10.7,
Cross-tail Potential,
hemispheric Power (Kp)
→ **Random**

State variables:
[O^+]

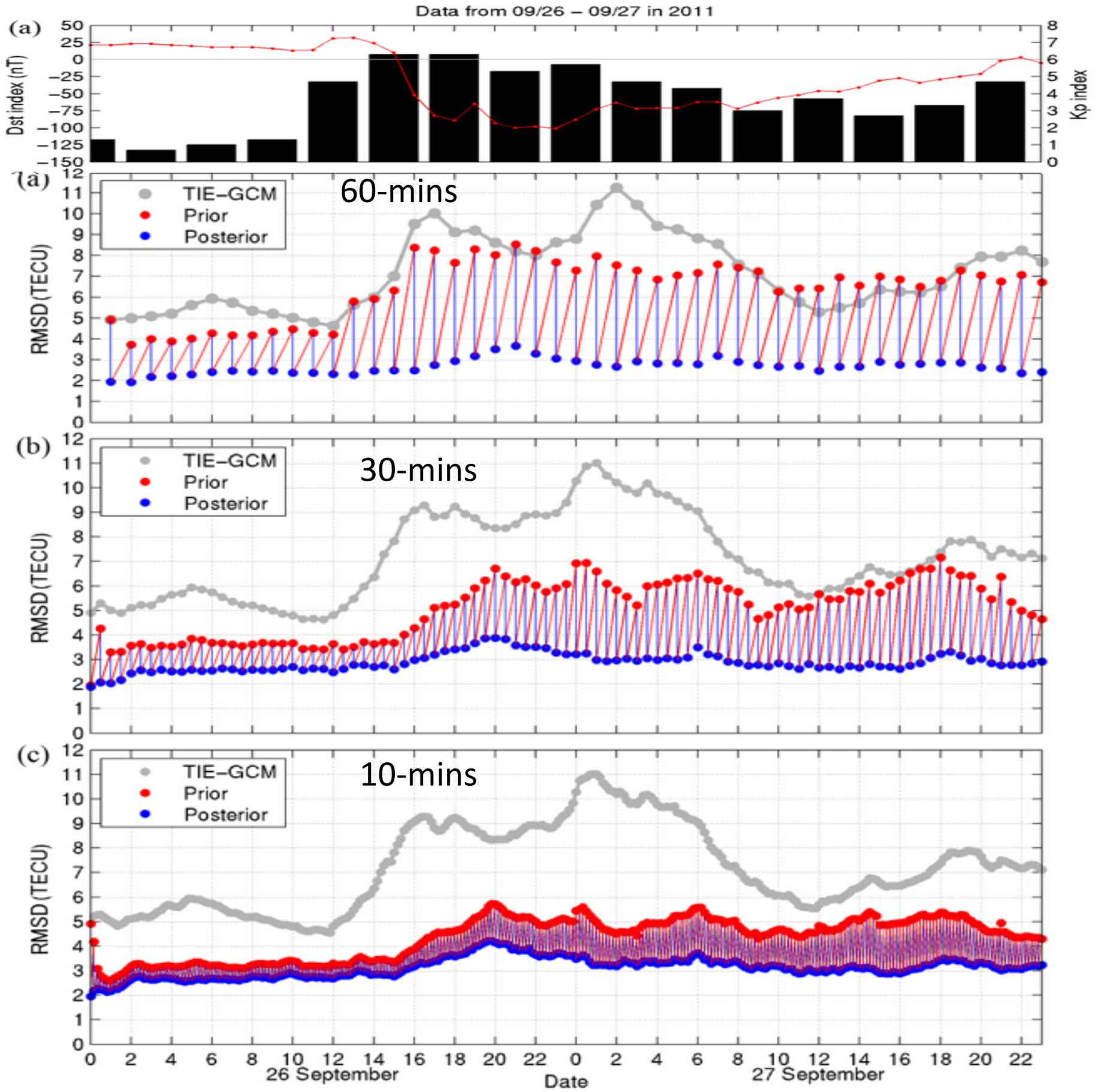
if the state variable is only [O^+], the variations of forecast/nowcast follows the background model.

Chen et al., (2016)



90 ensembles:
F10.7,
Cross-tail Potential,
hemispheric Power (Kp)
→ **Realistic +**
small perturbation

State variables:
(TN),
(O),
(U),
(V),
[O^+]



Assimilation for 2015 St. Patrick Storm

- Diff. high lat. forcing
- Heelis & Weimer
- 10-mins cycle

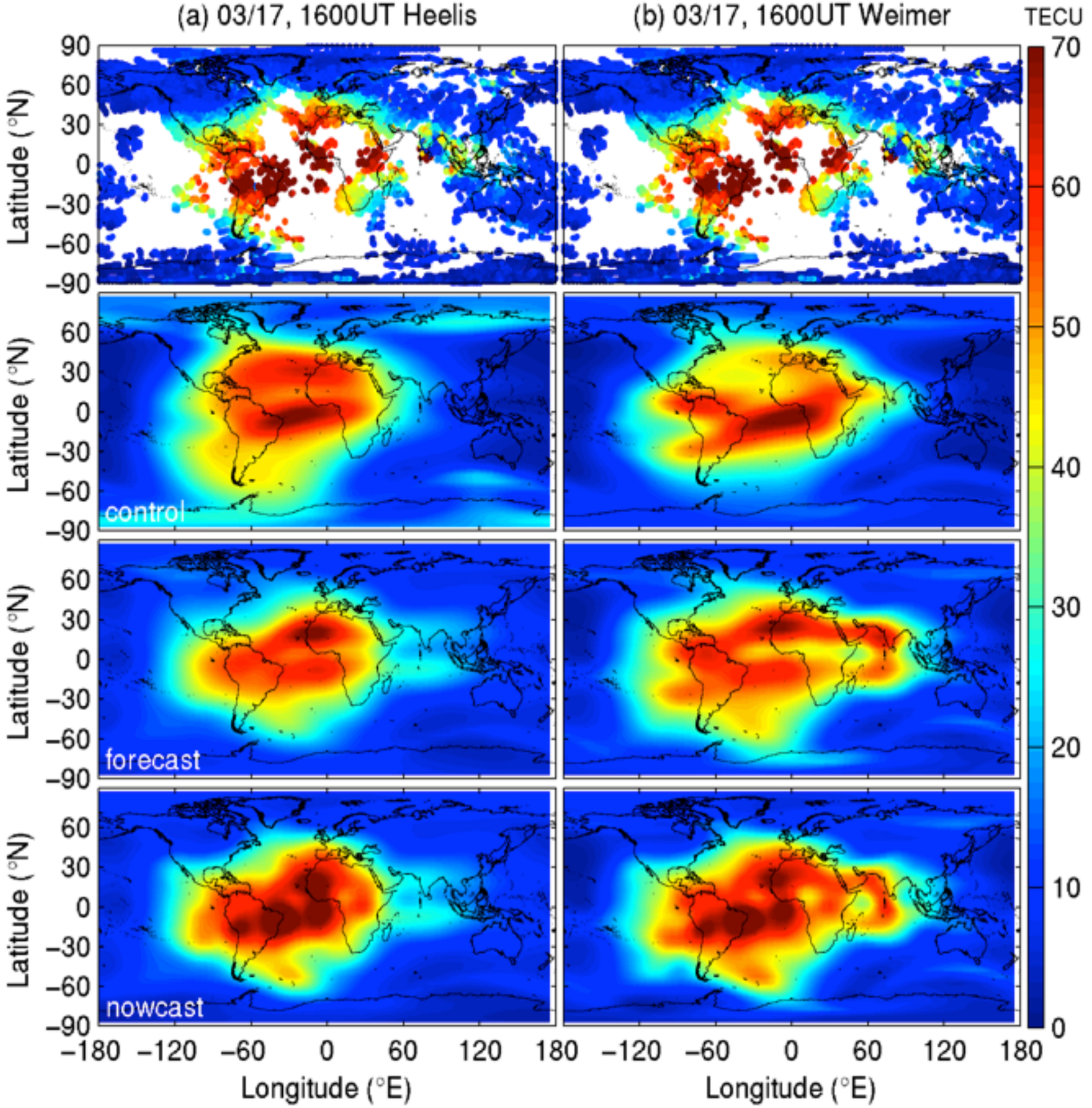
Chen et al., 2016 shows that if assimilation cycle is 60 mins., the result is similar to or worse than NO assimilation.

- Un-obs. state var.
  Tn, V, U, [O], [O_2]
  adjusted based on each of their relationships with TEC
  [*Matsuo et al., 2012; Lee et al., 2012; Hsu et al., 2015; Chen et al., 2016*]

- Indicating importance of driving force of the background model

High Lat. Forcing

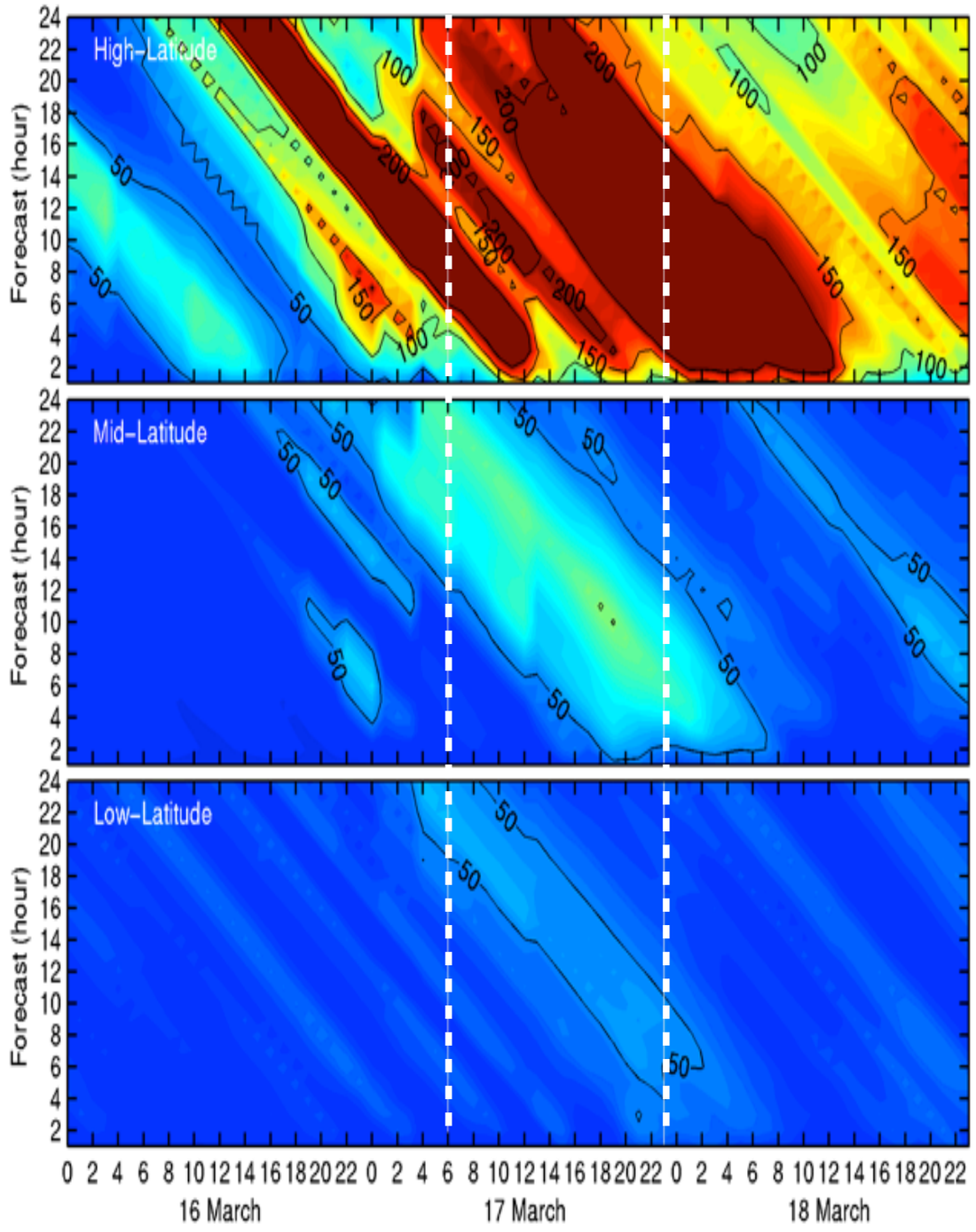
Heelis Weimer



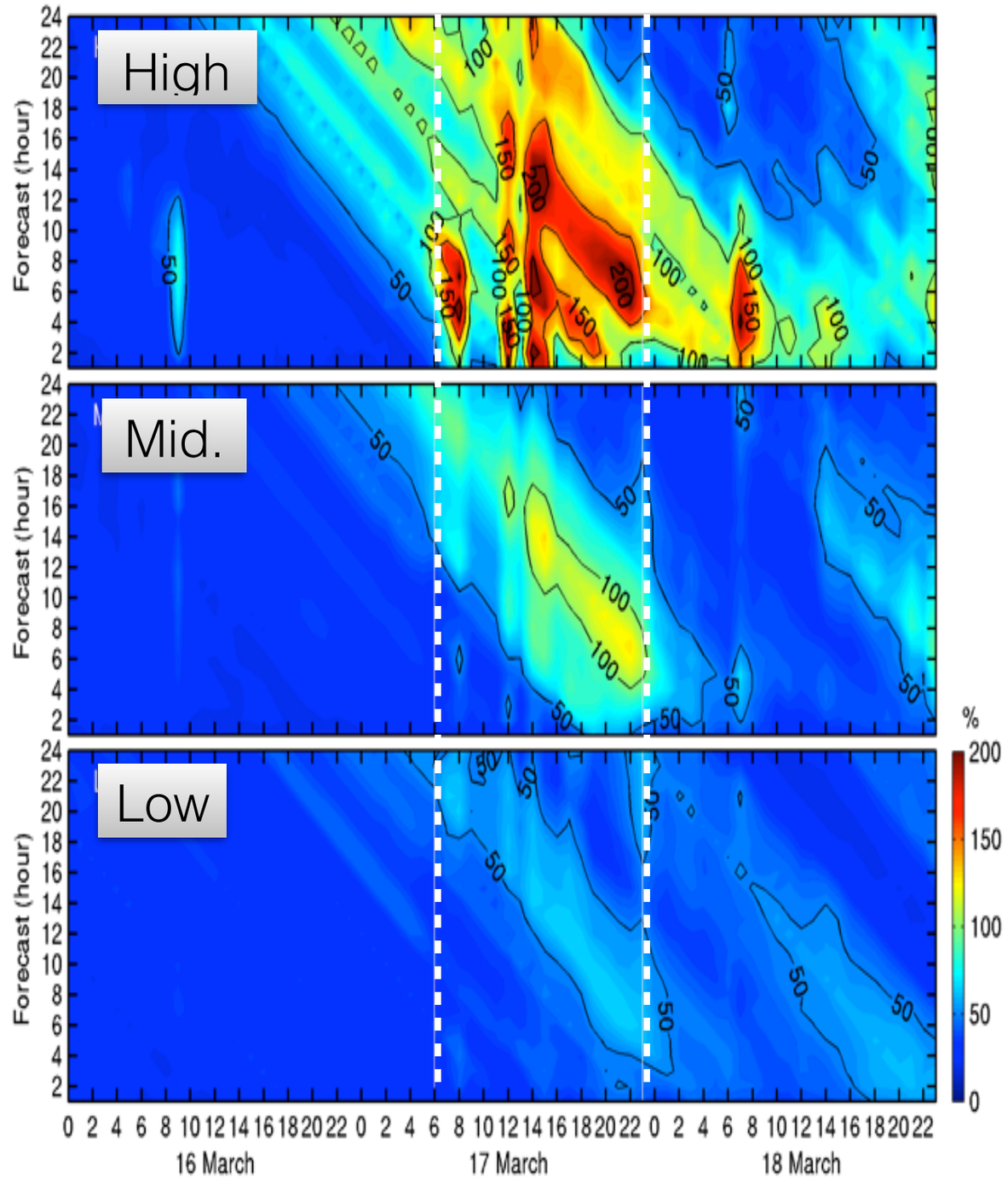
12-hour forecast time/error @ various latitudes

$$RMSD = \sqrt{\frac{\sum_{i=1}^{n}(x_{obs.,i} - x_{model,i})^2}{n}}$$

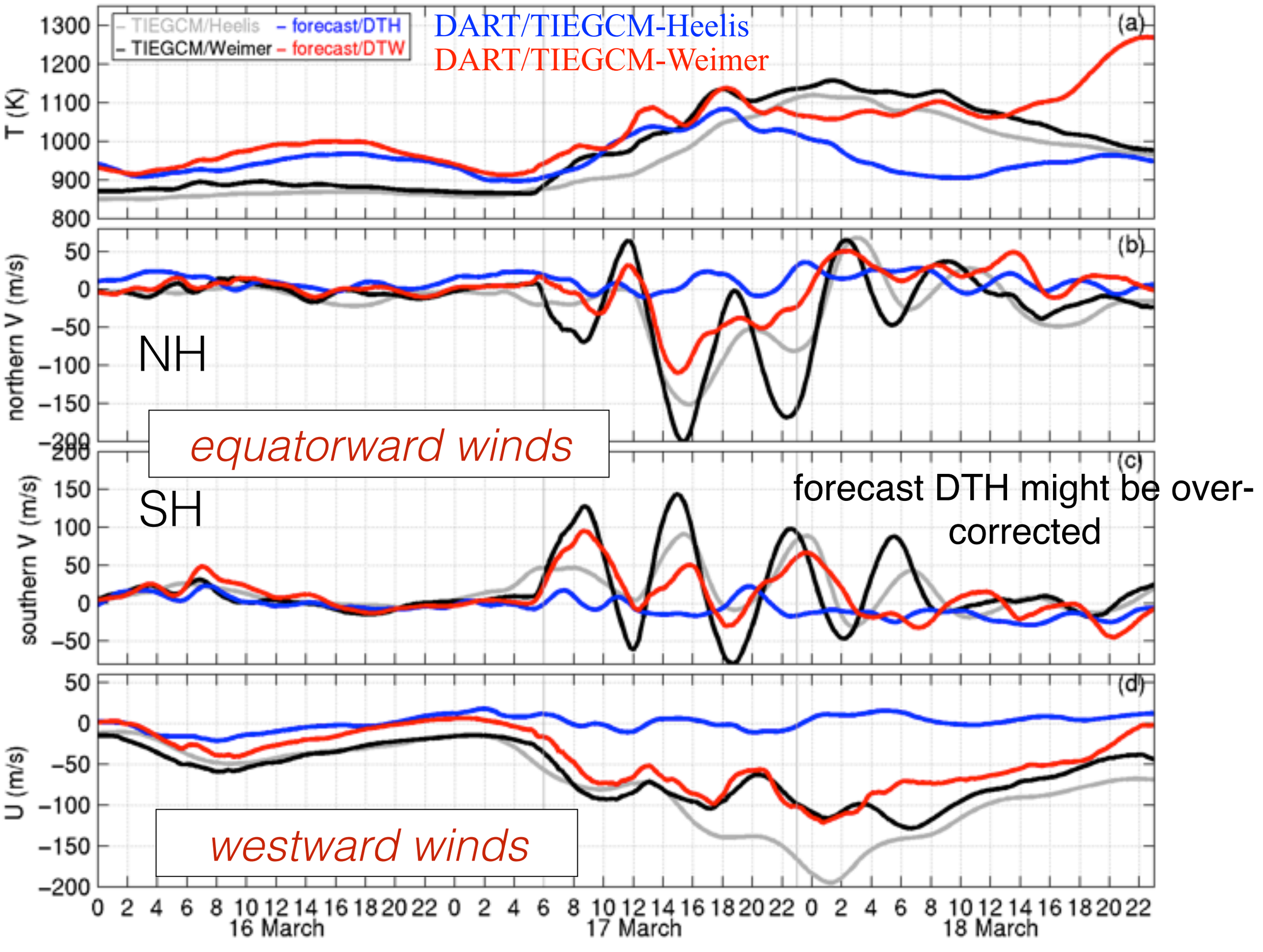
DART/TIEGCM-Heelis



DART/TIEGCM-Weimer



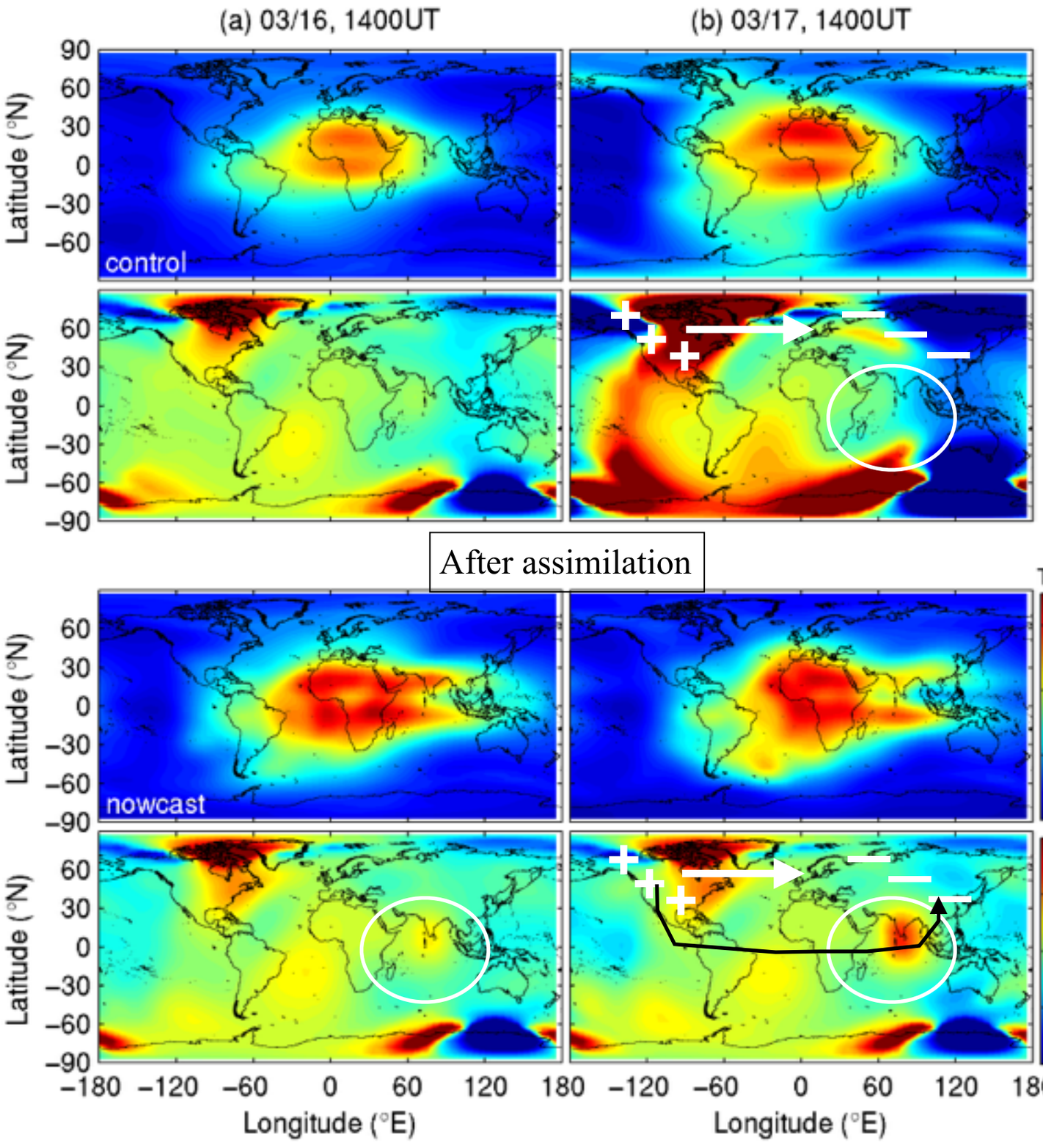
Adjustments of un-observed state variables



Storm-time eastward E-field adjustments

2015 St. Patrick' Day storm (17 March)

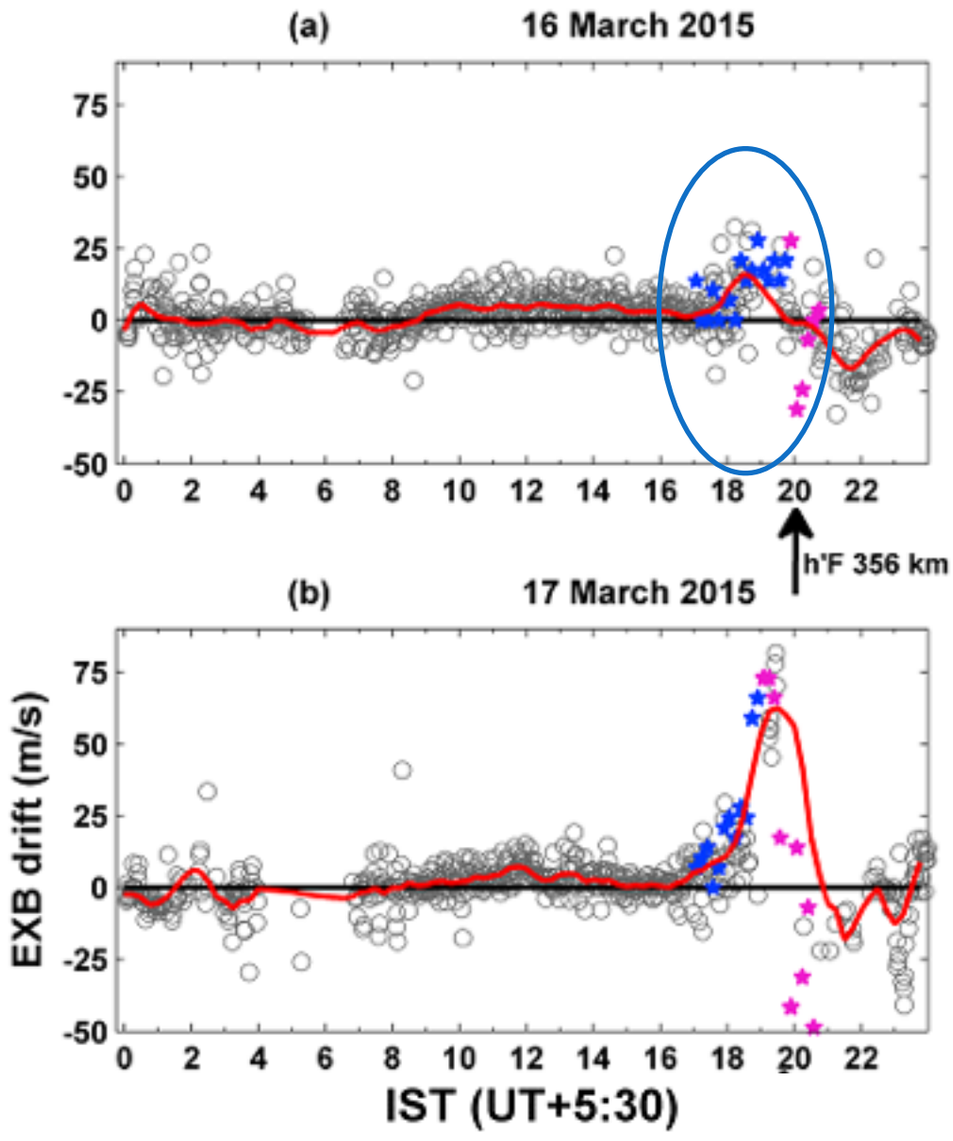
without assimilation



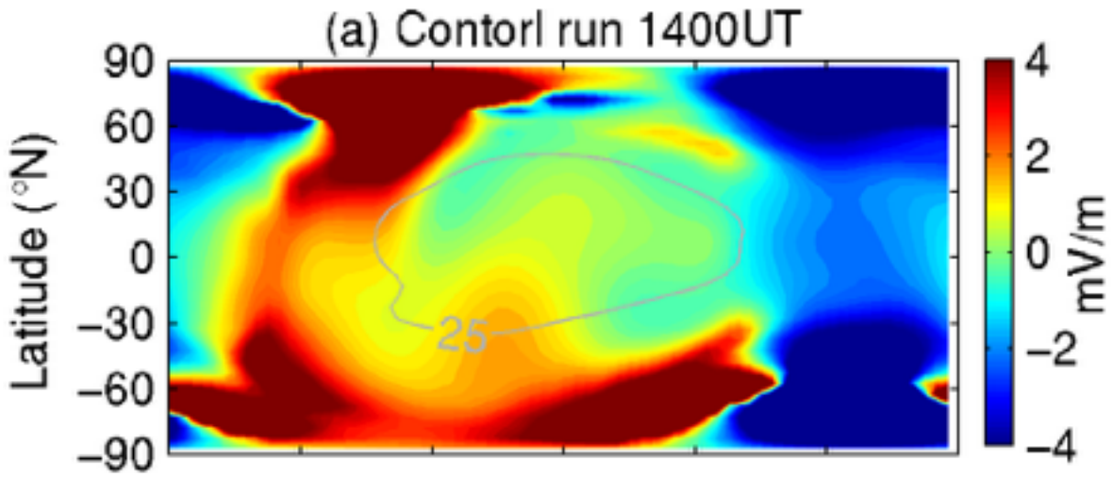
Ionosonde-derived PRE vertical drifts

Joshi et al., [*2016*]

- Heelis model as high latitude convection specifications.
- Dusk eastward E-field appears after assimilation of TECs.
- ExB @ dusk of 16/17 March
  - Heelis ~ 31 / 78.8 m/s
  - Weimer ~ 25 / 129.4 m/s

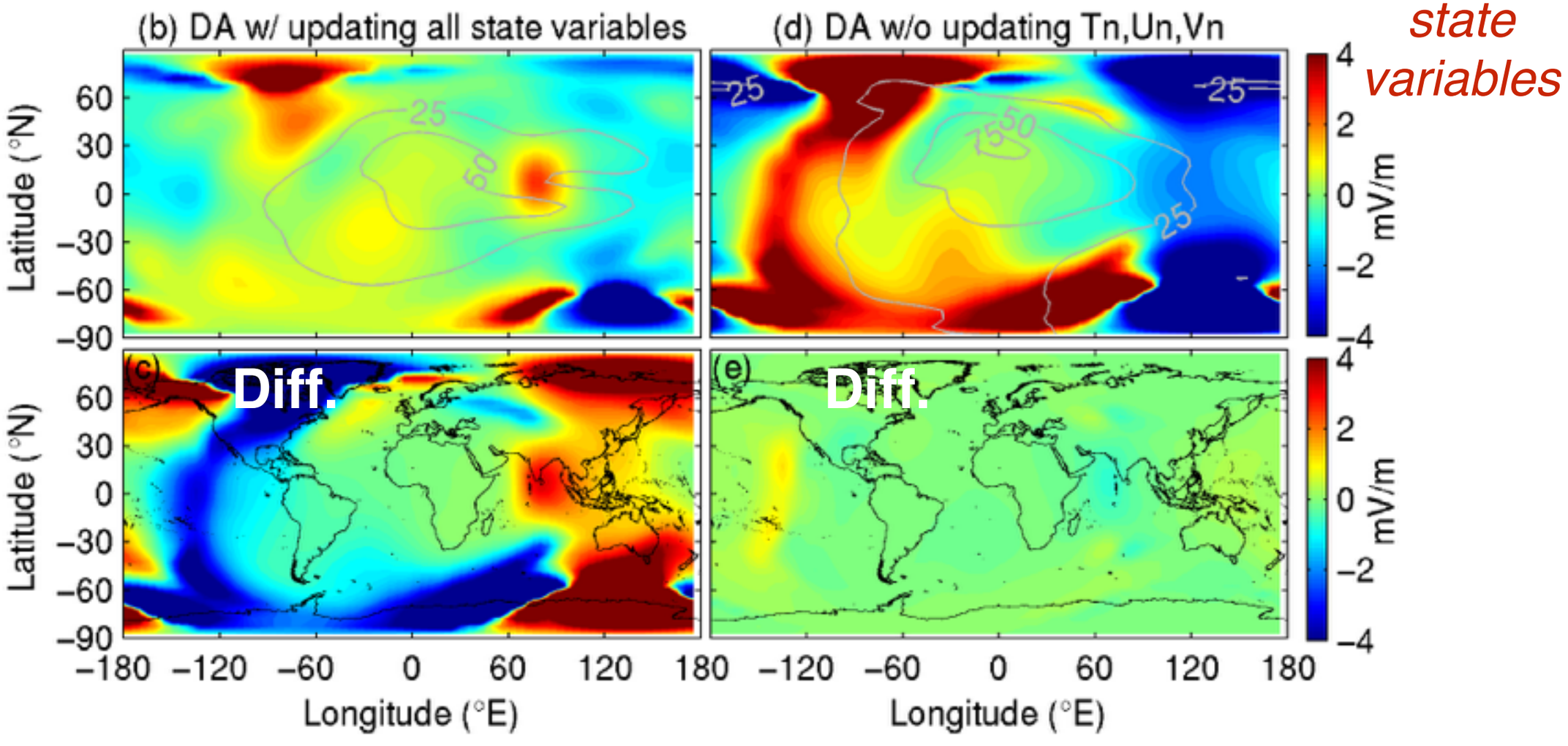


*Storm-time eastward E-field adjustments are affected when **neutral winds** are state variables*



Eastward E-field

neutral winds are state variables

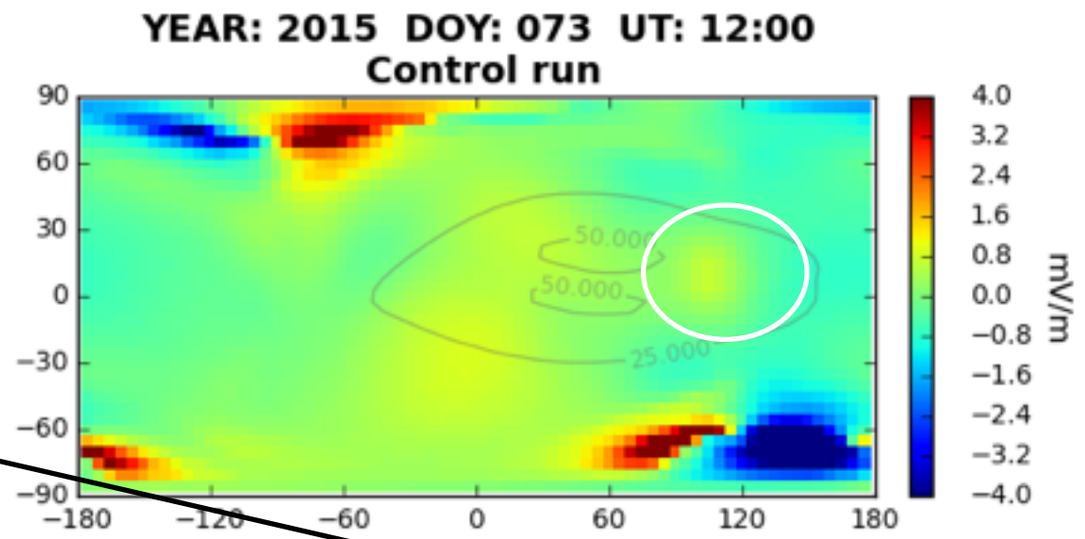


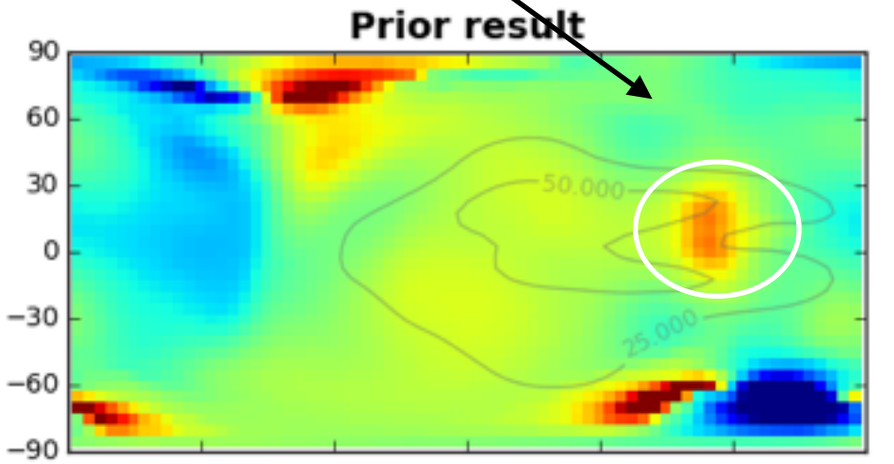
neutral winds are state variables

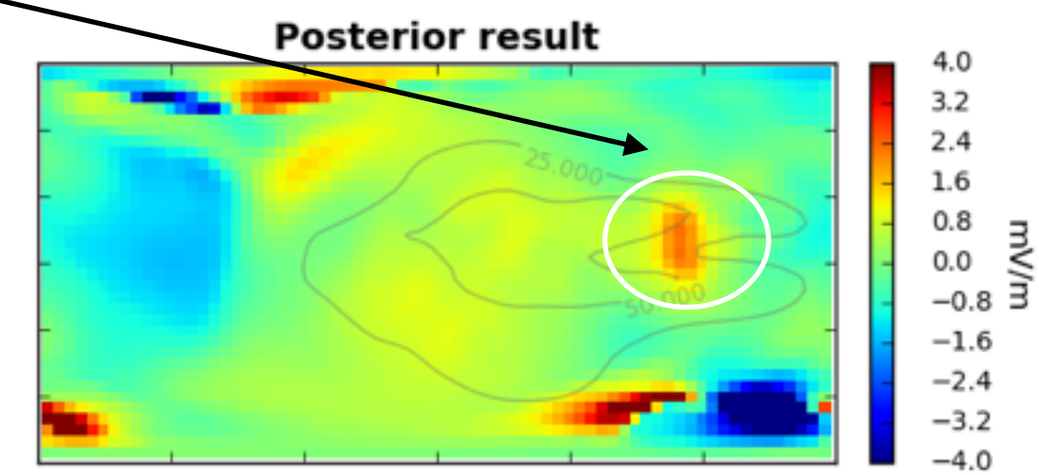
3-days before the storm, **during quiet time** (14 March 2015)

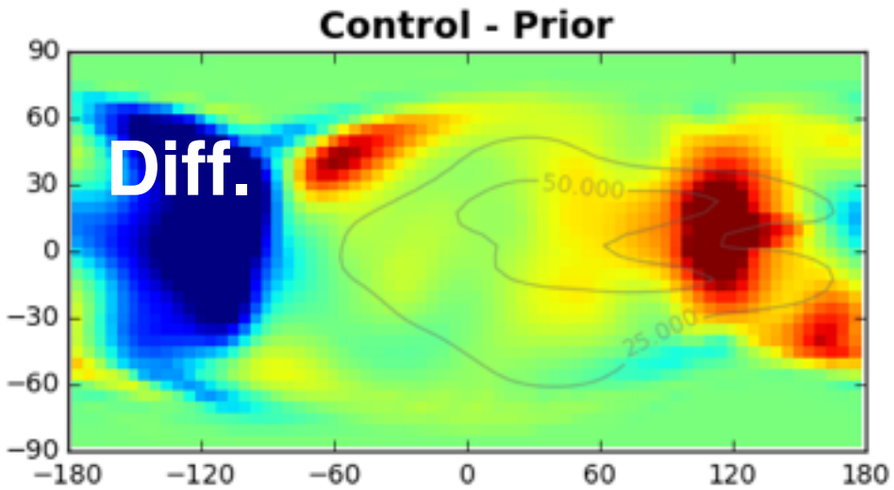
Eastward PRE E-field is strengthened after assimilation

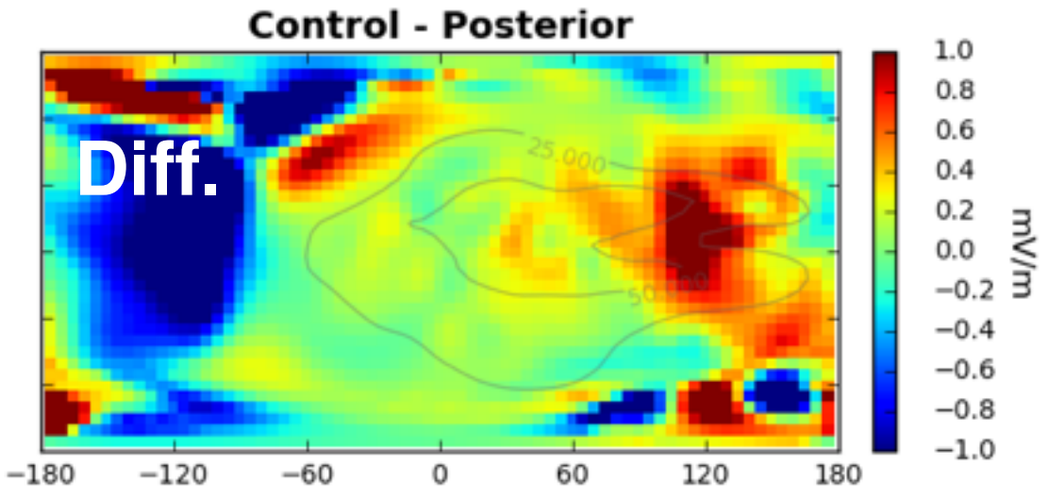
neutral winds are state variables





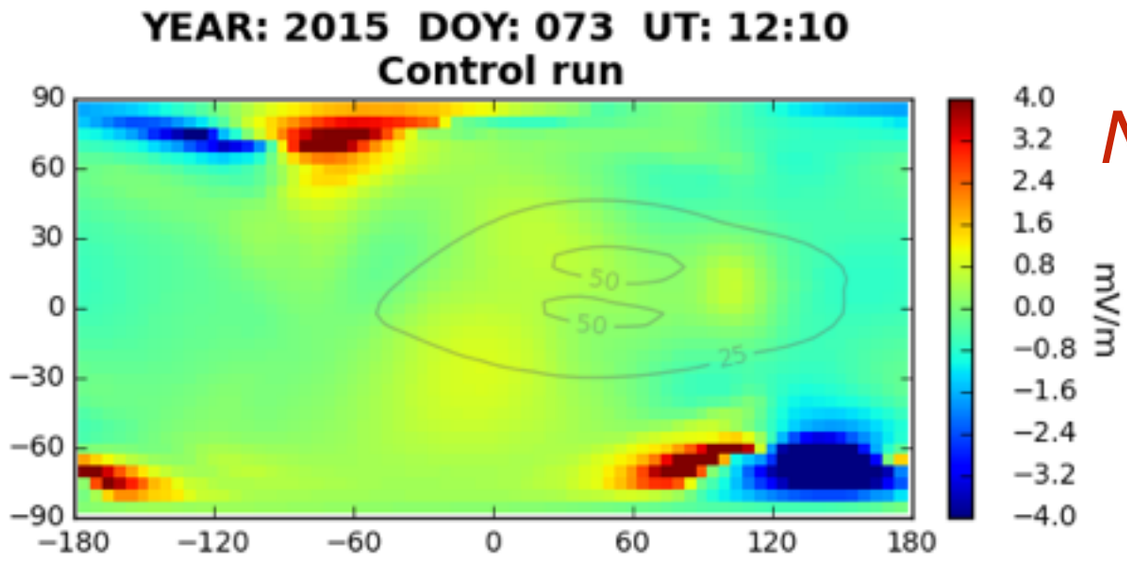




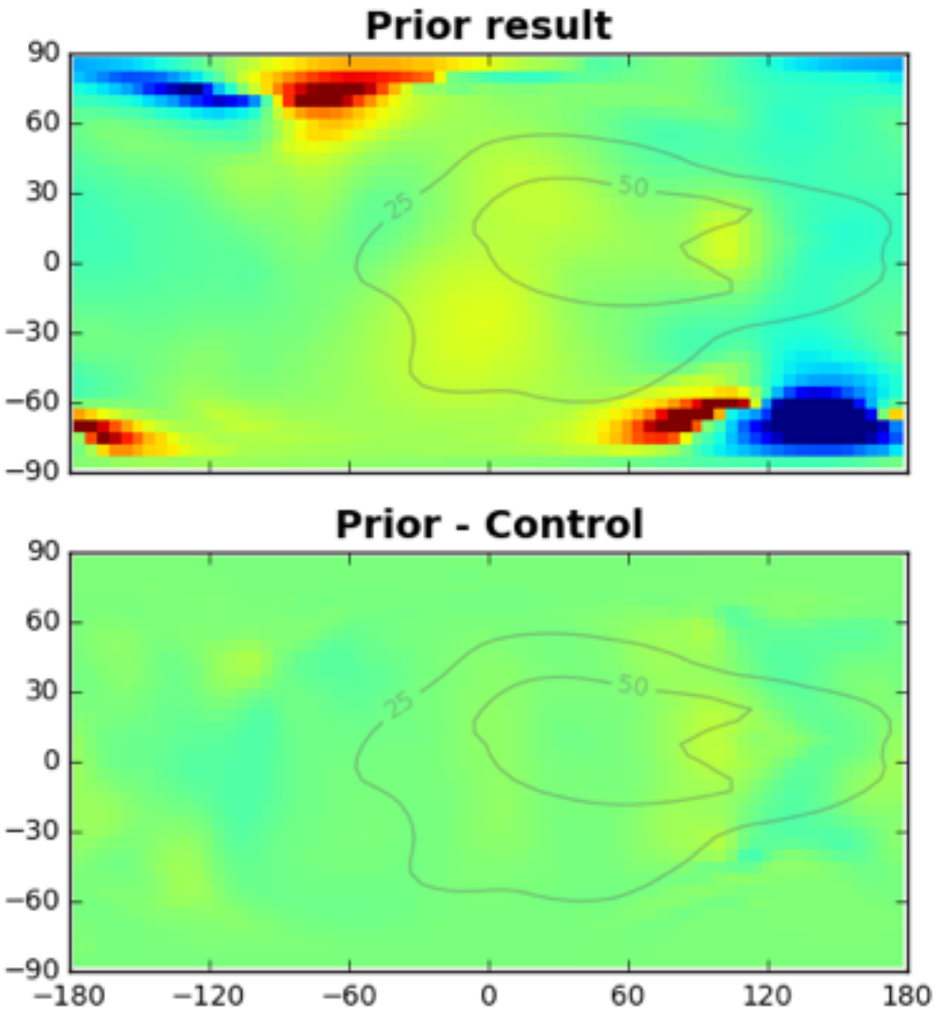


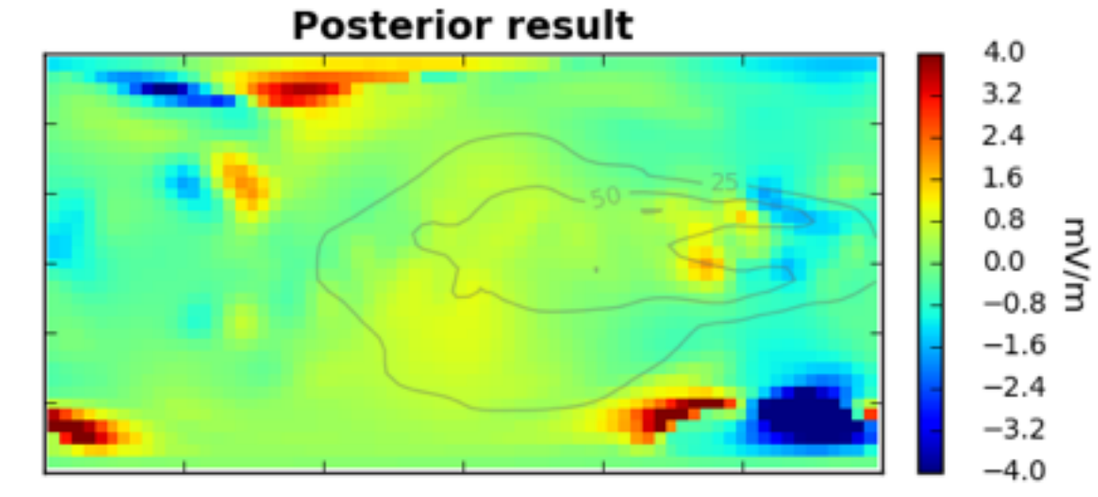
3-days before the storm, **during quiet time** (14 March 2015)

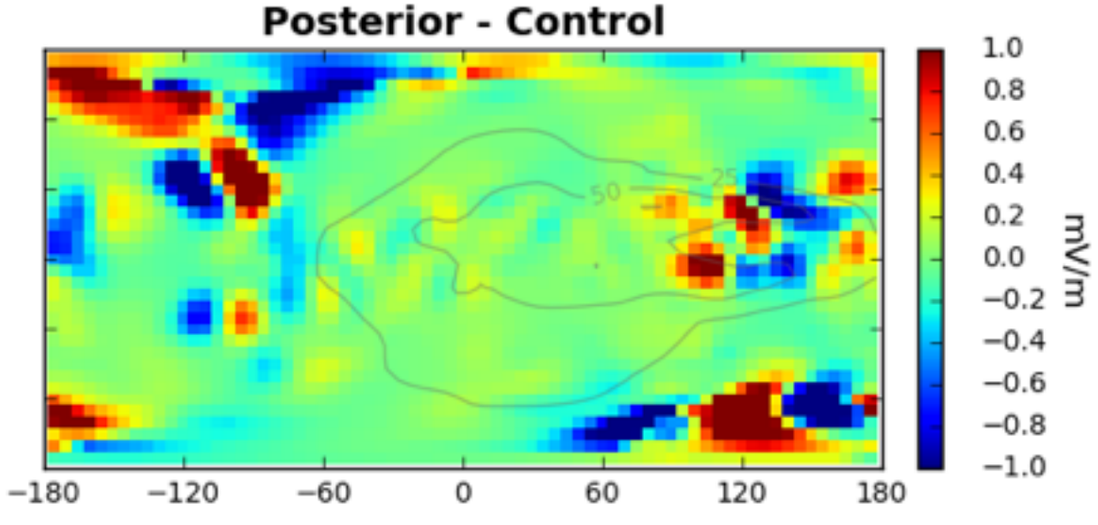
Eastward PRE E-field remains weak after assimilation



neutral winds are NOT state variables







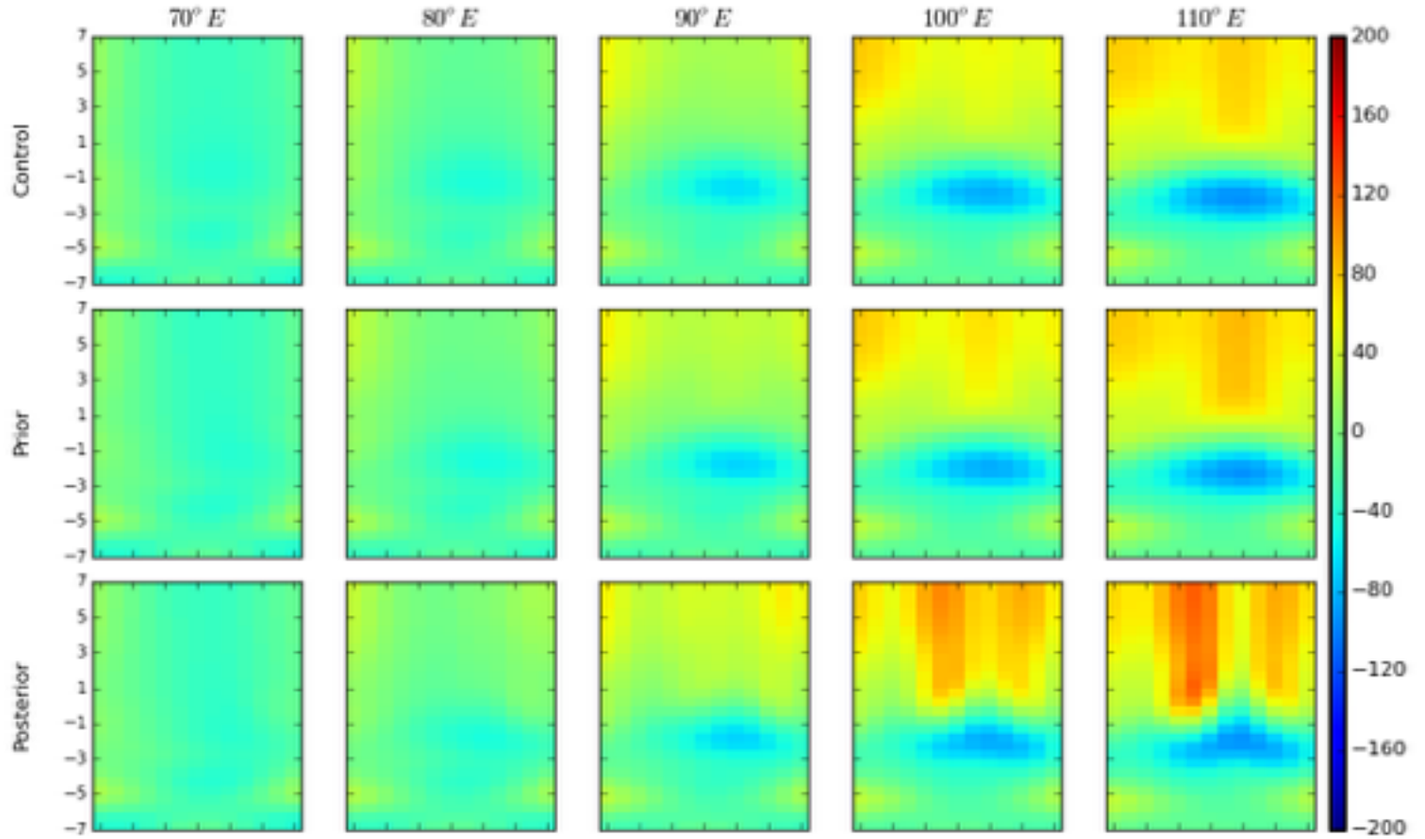
Summary:

1. Thermosphere model is important for forecast capability.

2. The 12-h forecast shows that the low- and mid-latitude ionosphere forecast are acceptable (< 70% RMSE) for several hours, where as high latitude forecast is very limited.

3. Assimilation of TEC improves evening E-field modeling through changing the neutral winds for both quiet and storm times.

Un for NO wind as the state variables



Un for winds as the state variables