Coupled Thermosphere-Ionosphere Data Assimilation

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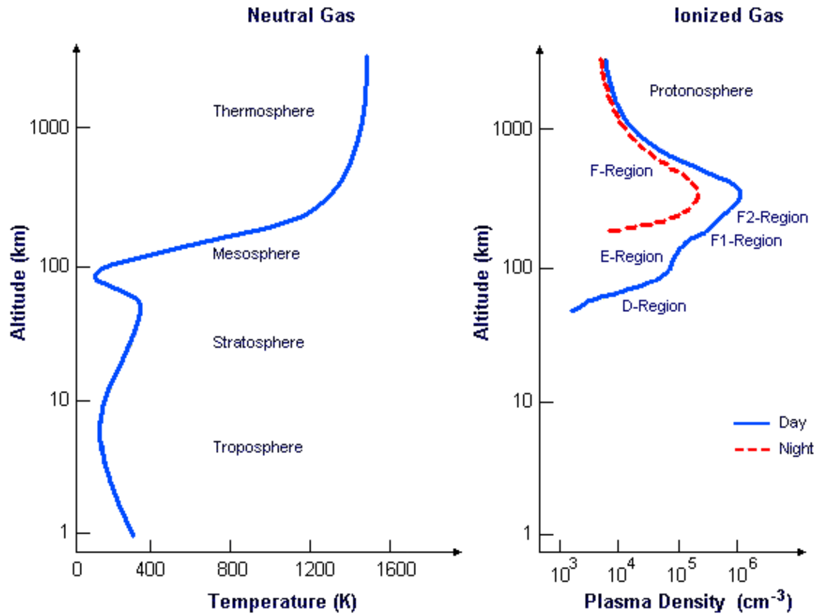
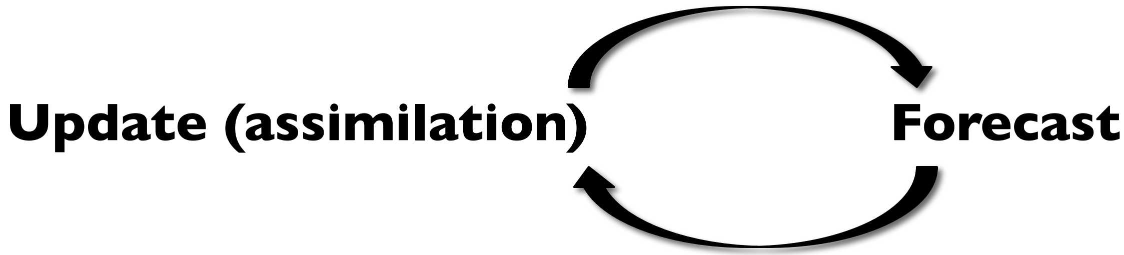


Hsu et al., JGR under review, 2014; Chartier et al., to be submitted, 2014; Lee et al., JGR 2012; Lee et al., JGR 2013; Matsuo et al., 2013; Matsuo and Araujo-Pradere, RS 2011; Matsuo et al., to be submitted, 2014; Matsuo et al., JGR 2013; Matsuo, AGU monograph 2013; Matsuo and Araujo-Pradere, RS 2011

Thermosphere-Ionosphere Coupled Data Assimilation



WEAK COUPLING – *only through forecast cycles*
STRONG COUPLING – *through both assimilation/forecast cycles*

<u>Advantages of strongly coupled data assimilation</u>

1) Infer unobserved thermospheric states from abundant ionospheric observations and facilitate ionospheric forecasts
2) Inform model dynamics through self-consistent assimilation increments among model states (e.g., winds, temperature, plasma and neutral constituents, etc…)

Ensemble Kalman filtering with NCAR-TIECGM

forecast step

$$p(\mathbf{x}_t | \mathcal{Y}_{t-1})$$

update step

$$p(\mathbf{x}_t | \mathcal{Y}_t) \propto p(\mathbf{y}_t | \mathbf{x}_t) p(\mathbf{x}_t | \mathcal{Y}_{t-1})$$

MODEL - TIEGCM

$$\mathbf{x}_t^{(k)} = M_t(\mathbf{x}_{t-1}^{(k)}, F_t + \epsilon^{(k)})$$

$$\mathbf{x} = \{U, V, T, [O], [O2], Ne, \ldots, F\}$$

dissipative forced dynamics

high-dimension

OBSERVATIONS

$$\mathbf{y}_t = H(\mathbf{x}_t) + \boldsymbol{\epsilon}_t$$

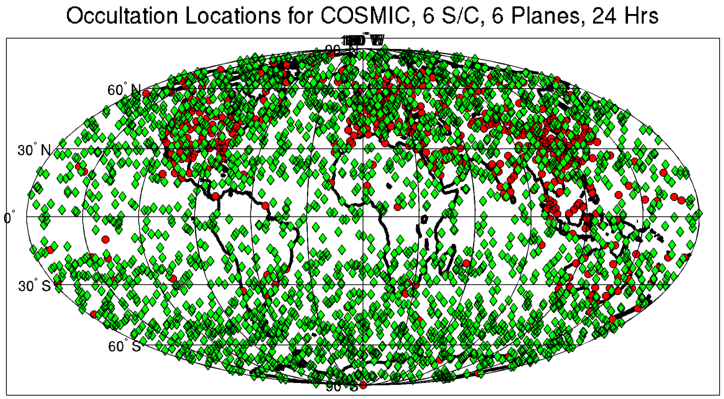
electron density $\mathbf{y} = \{Ne\}$

irregular and sparse

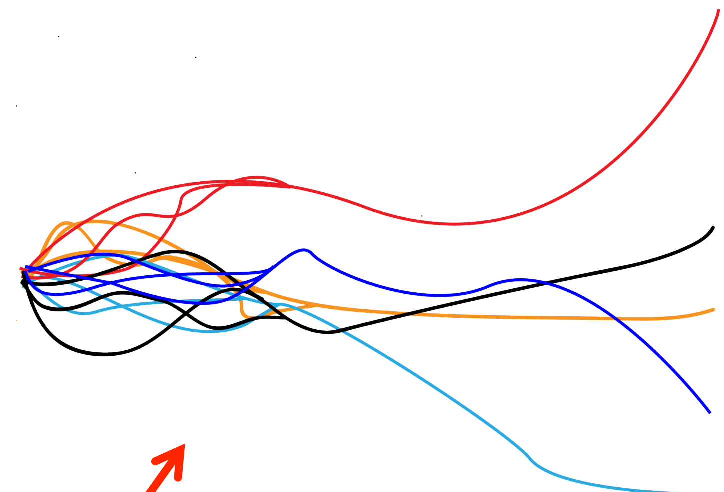
Data Assimilation Research Testbed http://www.image.ucar.edu/DARes/DART

TIEGCM http://www.hao.ucar.edu/modeling/tgcm

COSMIC Electron Density

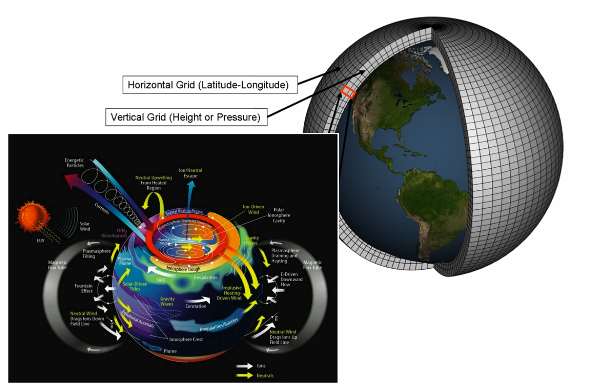


Ensemble Forecast



data assimilation

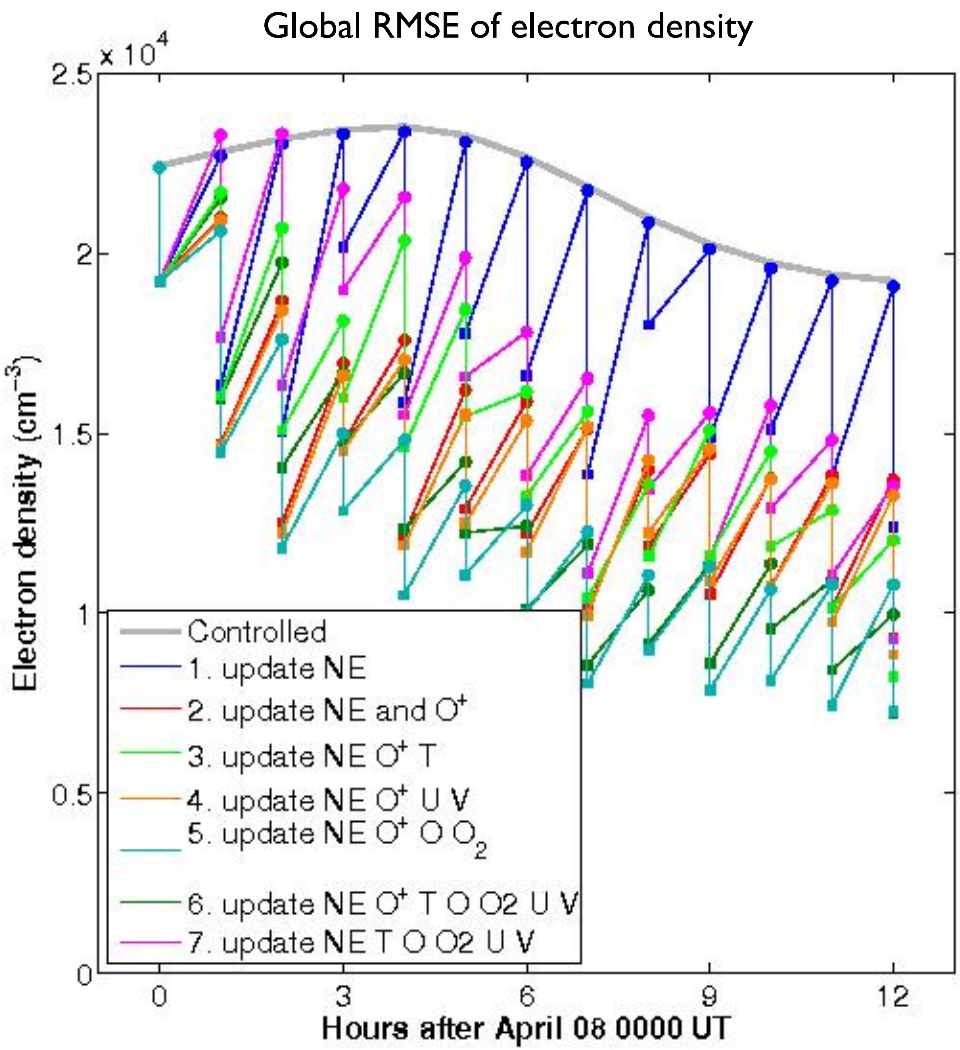
Coupled T-I Model



Initialization with assimilation analyses

OSSE – COSMIC electron density profiles

2437 profiles/day; Apr 8 2008; 60 min assimilation cycle; 90 ensemble member



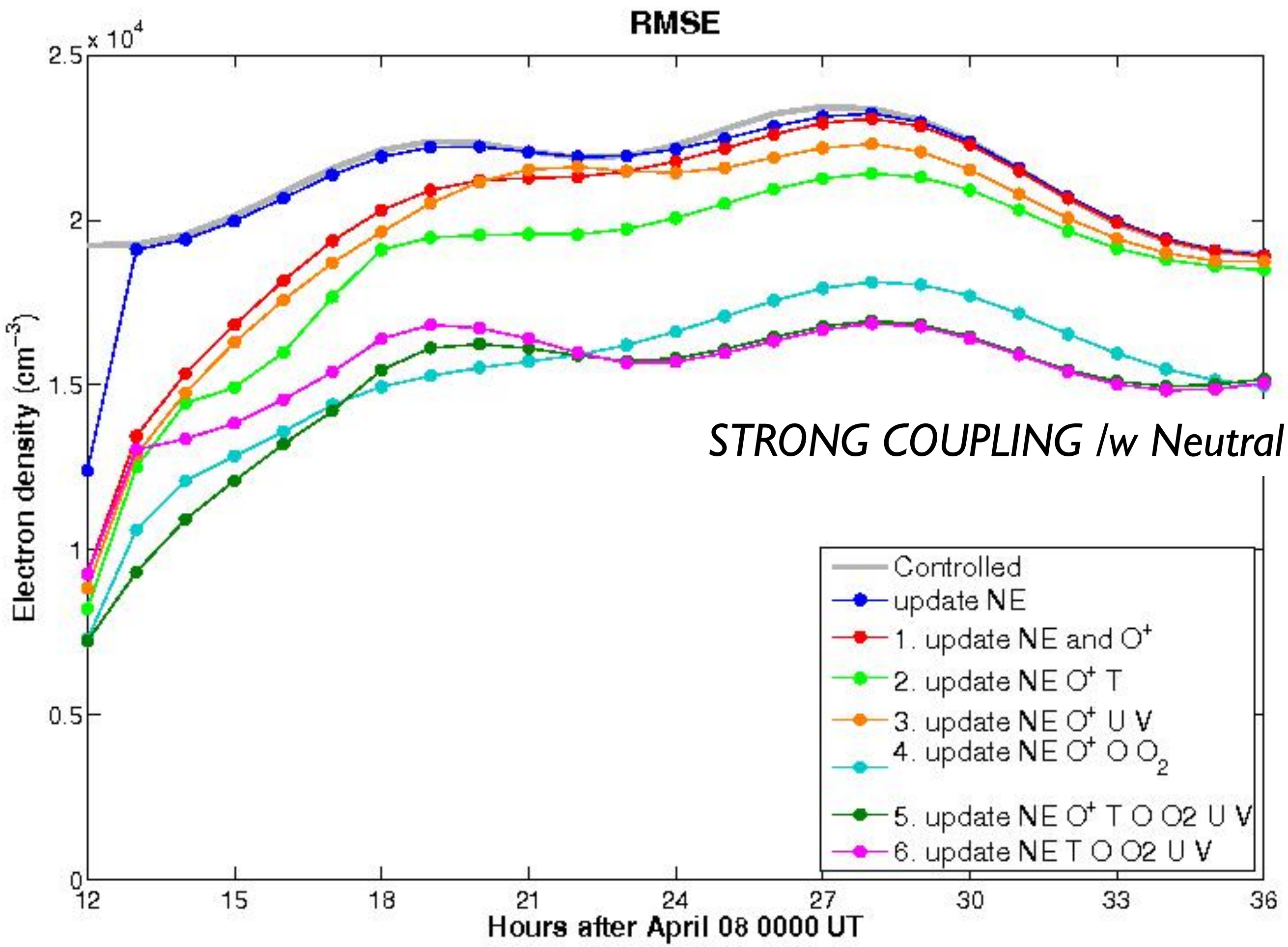
WEAK COUPLING

STRONG COUPLING

[Hsu et al., 2014]

OSSE – 24-hour Ensemble Forecast Experiment Initialized by Data Assimilation Analysis

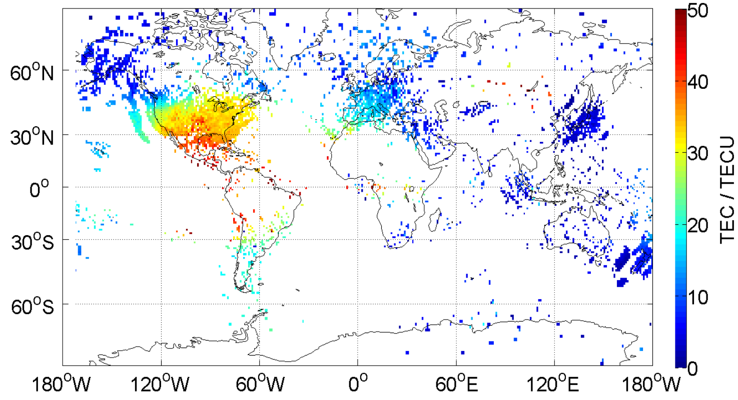
Global RMSE of electron density forecast computed from 90 ensemble members



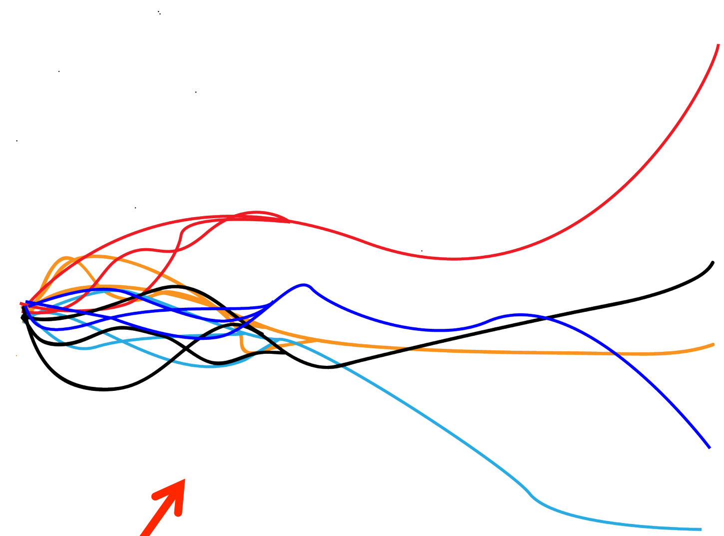
STRONG COUPLING /w Neutral Compositions

[Hsu et al., 2014]

Ground-based GPS TEC

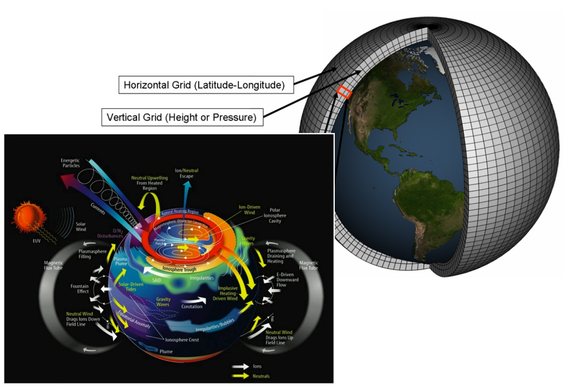


Ensemble Forecast



data assimilation

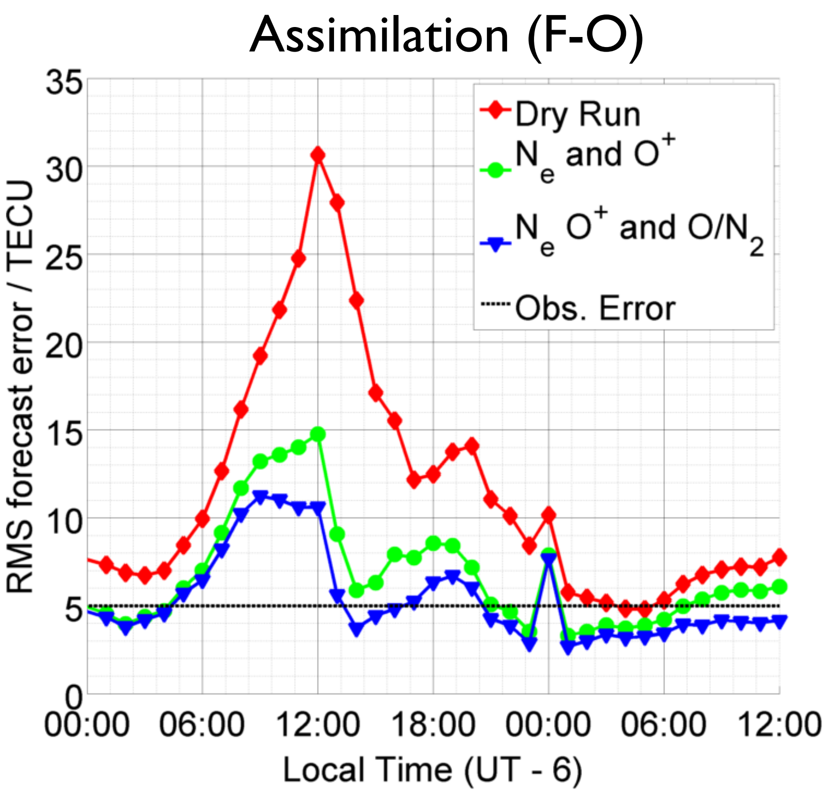
Coupled T-I Model

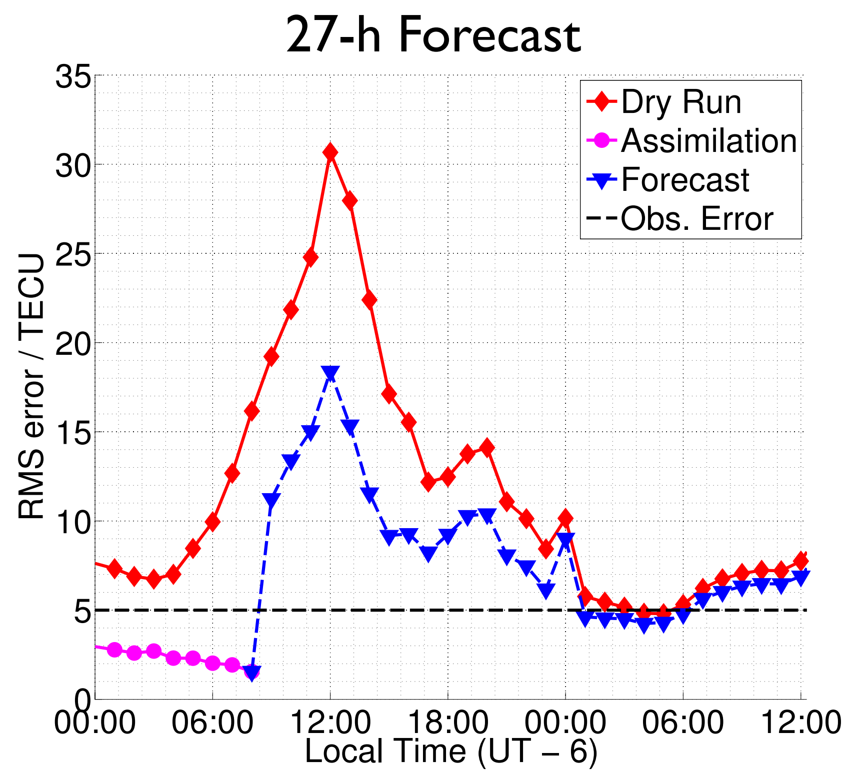


Initialization with assimilation analyses

ASSIMILATION and FORECAST – Ground-based TEC

*4000 GPS stations; Sep 10-11 2005 (**Kp 7-8**); 60 min assimilation cycle; 90 ensemble member*



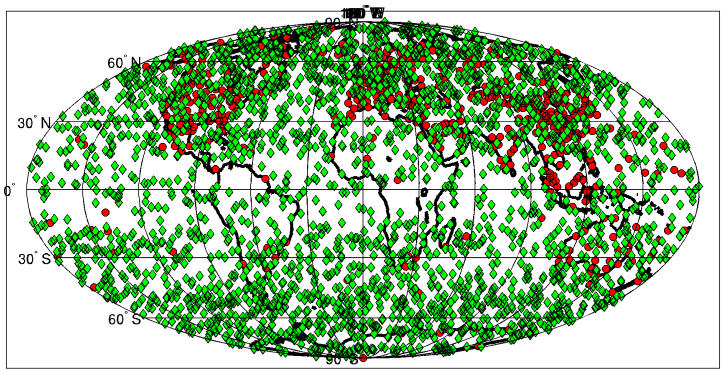


Comparison with GUVI/SSUSI data confirmed that O/N_2 was successfully inferred by GPS-TEC

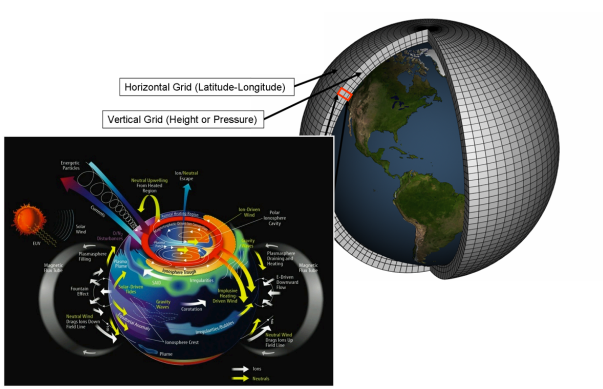
[Chartier et al., 2014]

COSMIC electron density

Occultation Locations for COSMIC, 6 S/C, 6 Planes, 24 Hrs



data assimilation



CHAMP neutral density

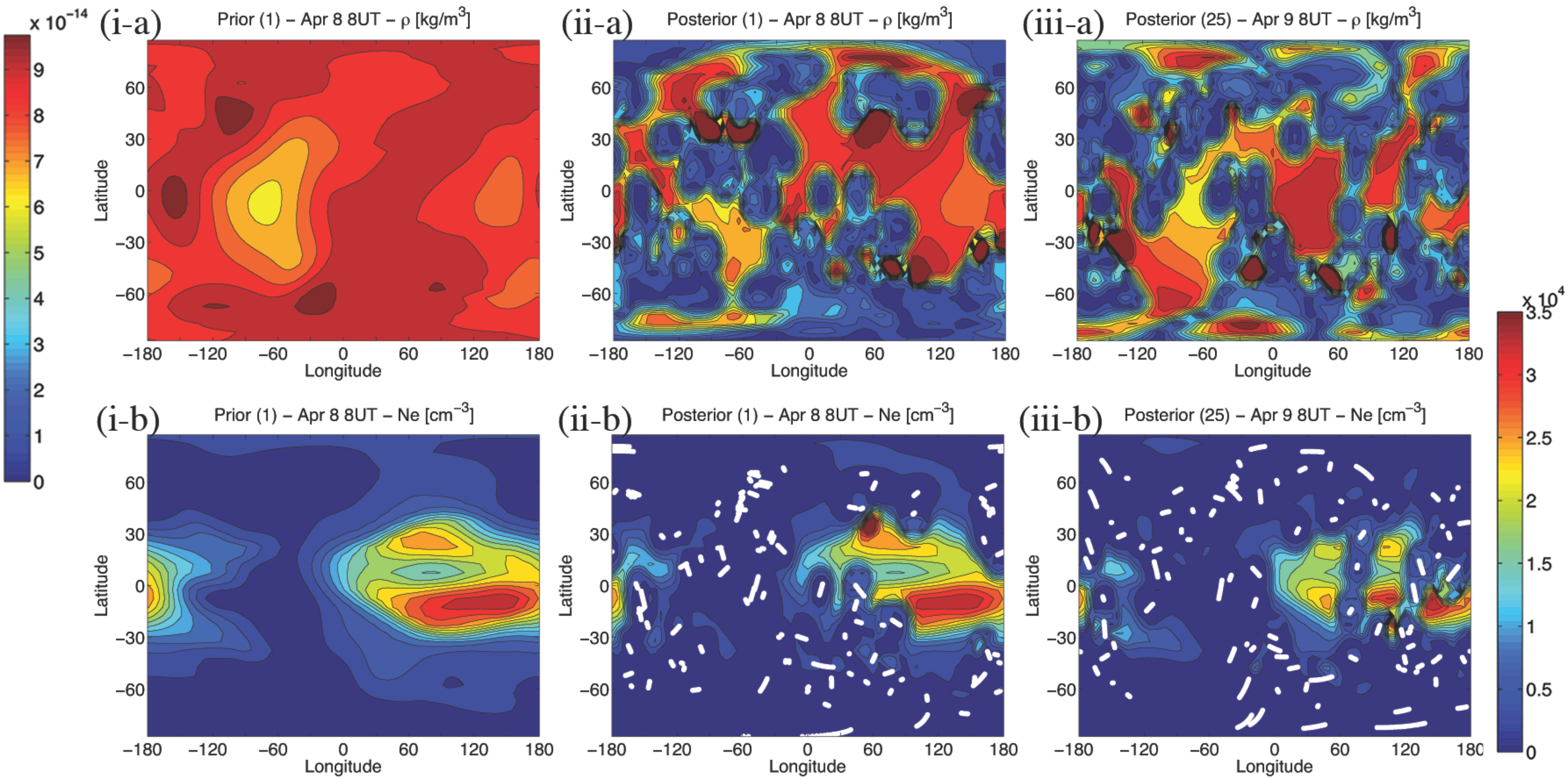
Infer unobserved thermosphere states

OSSE – COSMIC electron density profiles

2437 profiles/day; Apr 8 2008; 60 min assimilation cycle; 90 ensemble member

RMSE of neutral (top) and electron density (bottom) (pressure level 10-29; 150-500km)

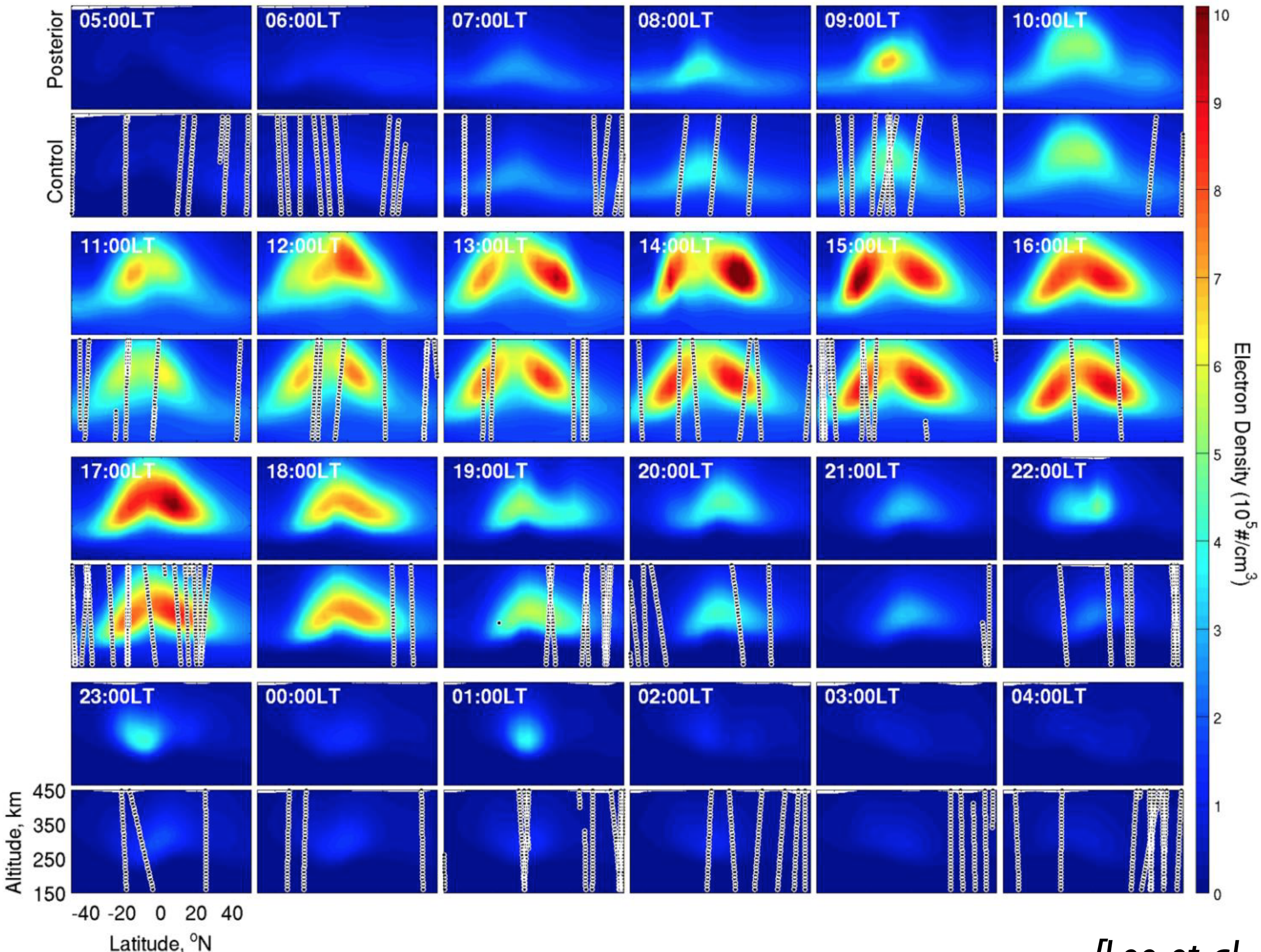
STRONG COUPLING $\mathbf{x} = \{U, V, T, [\mathrm{O}], [\mathrm{O}_2], \mathrm{Ne}\}$



[Matsuo et al., 2012]

ASSIMILATION – COSMIC electron density profiles

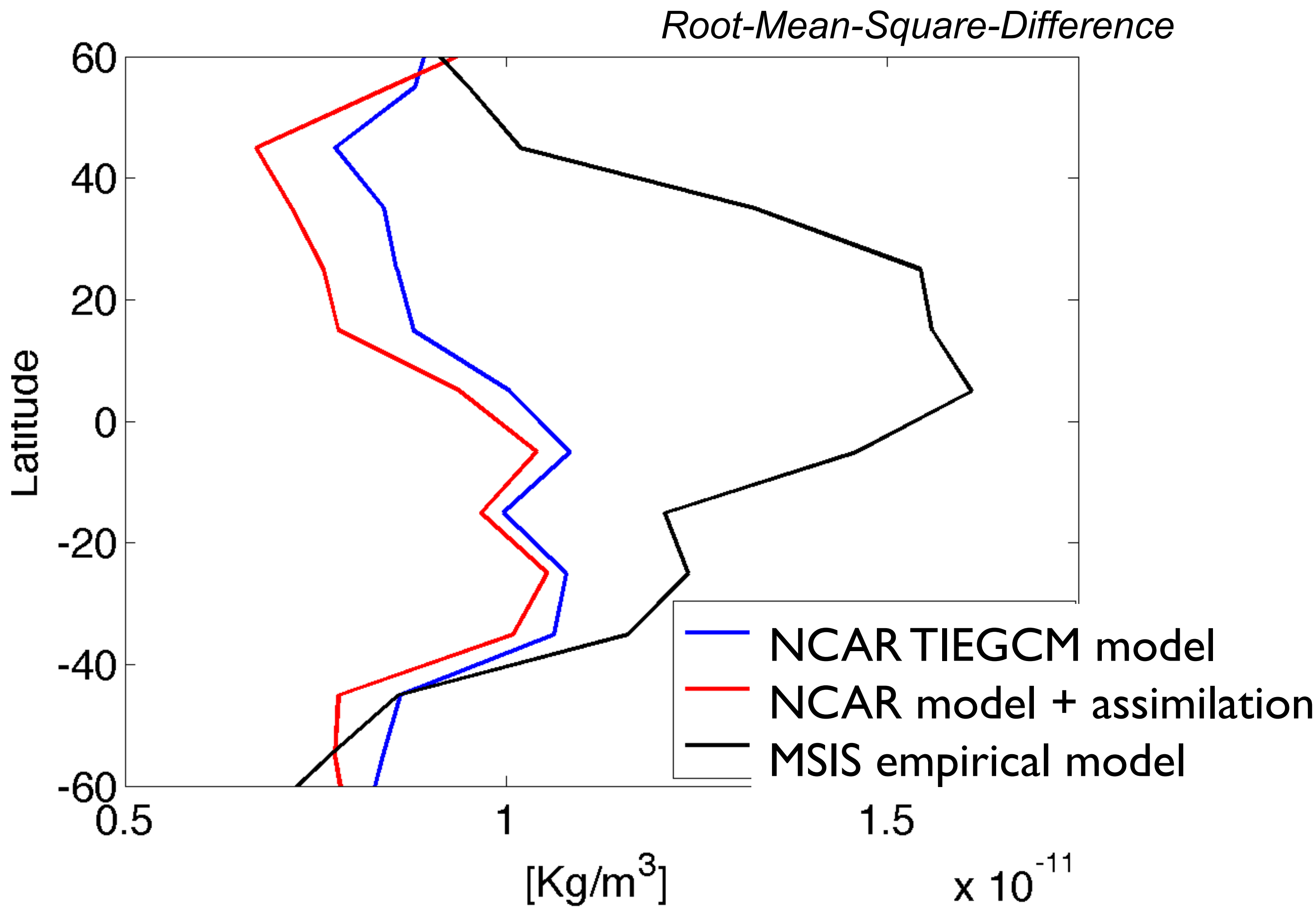
April 8-9 2008; 60 min assimilation cycle; 90 ensemble member



[Lee et al., JGR, 2012]

Mass Density Prediction vs. CHAMP Observation

STRONG COUPLING $\mathbf{x} = \{U, V, T, [\mathrm{O}], [\mathrm{O}_2], [\mathrm{Ne}]\}$



[Matsuo et al., 2014]

Summary - Coupled Data Assimilation

WEAK COUPLING – only through forecast cycles
STRONG COUPLING – through both assimilation/forecast cycles

1) Inform model dynamics through self-consistent assimilation increments among model states (e.g., winds, temperature, plasma and neutral constituents, etc…)
2) Improve our capability to forecast the ionosphere forecast
3) Infer unobserved thermospheric states from abundant ionospheric observations
4) Increase geophysical information content of RO and ground-based GPS observations

All the DART/TIEGCM assimilation tools used in this work are available from http://www.image.ucar.edu/DAReS/DART