ENSEMBLE DATA ASSIMILATION FOR UPPER ATMOSPHERE SPECIFICATION AND FORECASTING

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References: *Matsuo and Araujo-Pradere, RS, 2011; Lee et al., JGR, 2012; Matsuo et al., JGR, 2013; Lee et al., 2013; Matsuo, AGU monograph, 2014; Hsu et al., JGR, 2014; Chartier et al., JGR, 2015; Chen et al., JGR, 2016*

Support: *AFOSR grant FA9550-13-1-0058*

What works and what doesn't

What works and what doesn't

1 ***Strongly coupled*** thermosphere-ionosphere data assimilation approaches work better than ***weakly coupled*** approaches for both ionosphere and thermosphere specification and forecasting.

Coupled thermosphere-ionosphere data assimilation

Forecast

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

Update (Assimilation)

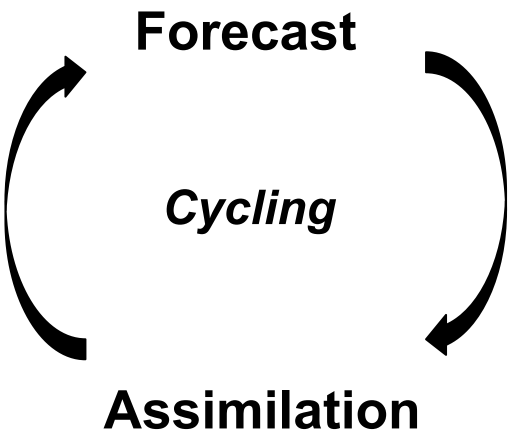
$$p(\mathbf{x}_t|\mathcal{Y}_t) \propto p(\mathbf{y}_t|\mathbf{x}_t)p(\mathbf{x}_t|\mathcal{Y}_{t-1})$$

WEAK COUPLING only through forecast cycles

STRONG COUPLING through both assimilation/forecast steps

Ensemble square root filter with TIEGCM/DART

Ensemble Filter - DART



Model - TIEGCM

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

high-dimension
dissipative forced dynamics

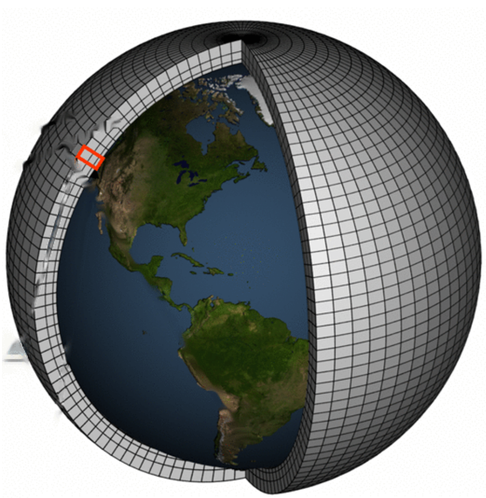
Observations

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

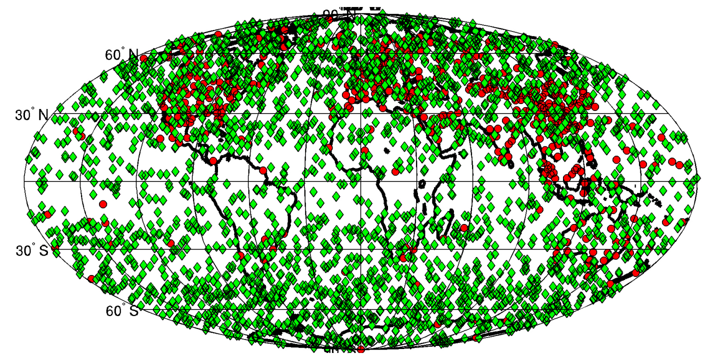
irregular and sparse

Data Assimilation Research Testbed *[Anderson et al., 2001, 2003, 2009]*
Thermosphere-Ionosphere Electrodynamics GCM *[Richmond et al.,1992]*

NCAR TIEGCM



COSMIC or Ionosonde Electron Density



Ensemble Forecasting

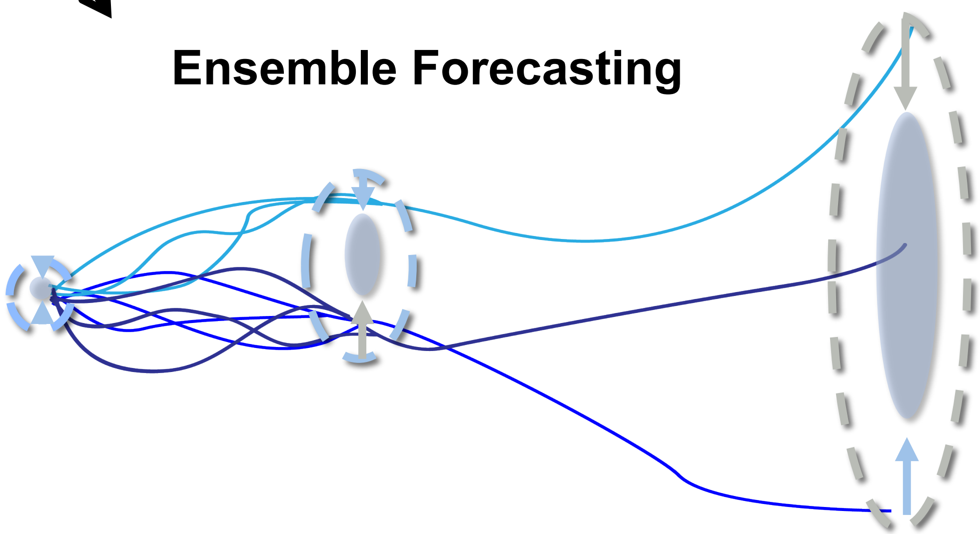


Image Courtesy: UCAR & GFDL

Strongly coupled ionosphere-thermosphere data assimilation yields better analysis than weakly coupled approaches

OSSEs – Global Ionosonde electron density

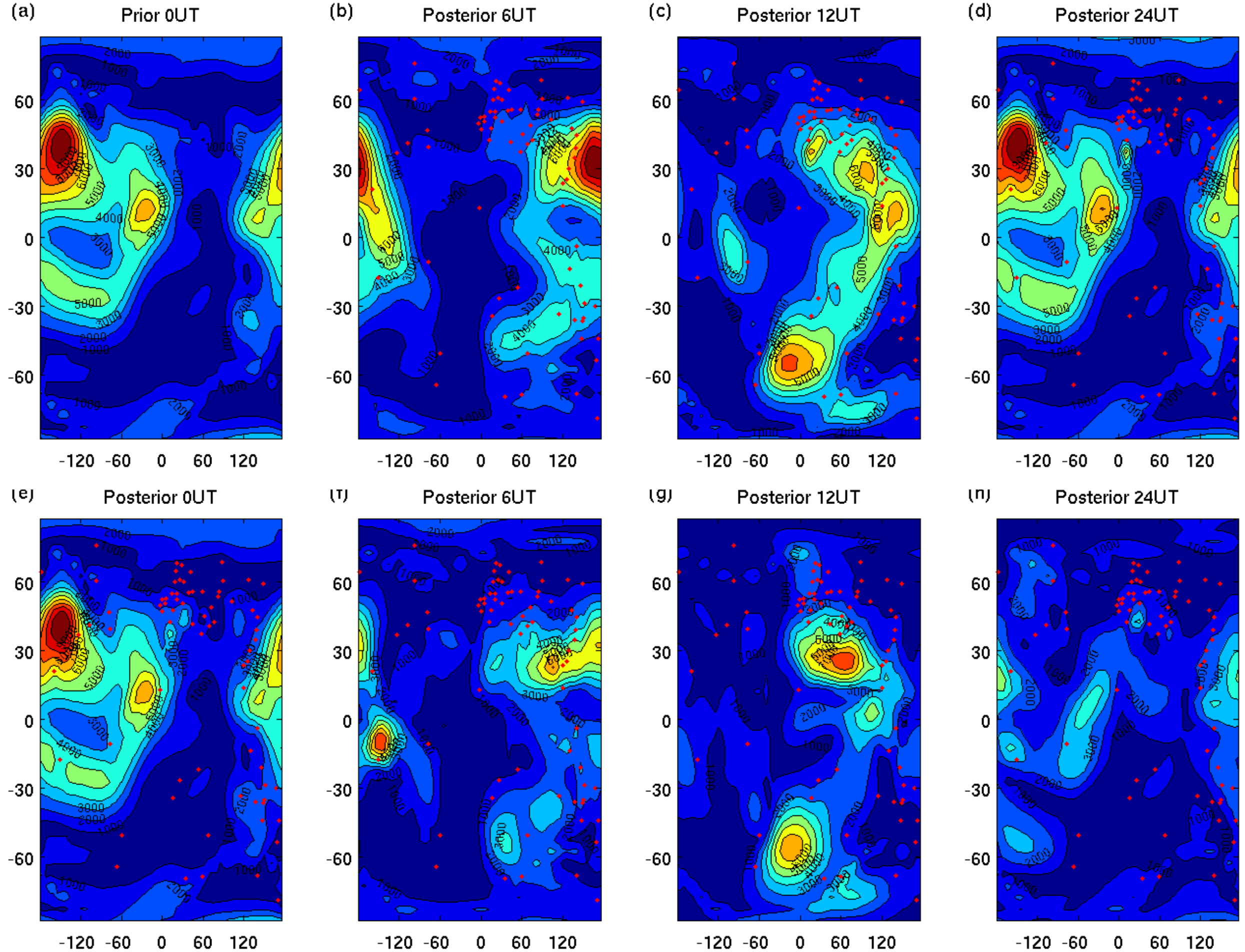
Electron density RMSE

WEAK COUPLING

update f_{e^-}

STRONG COUPLING

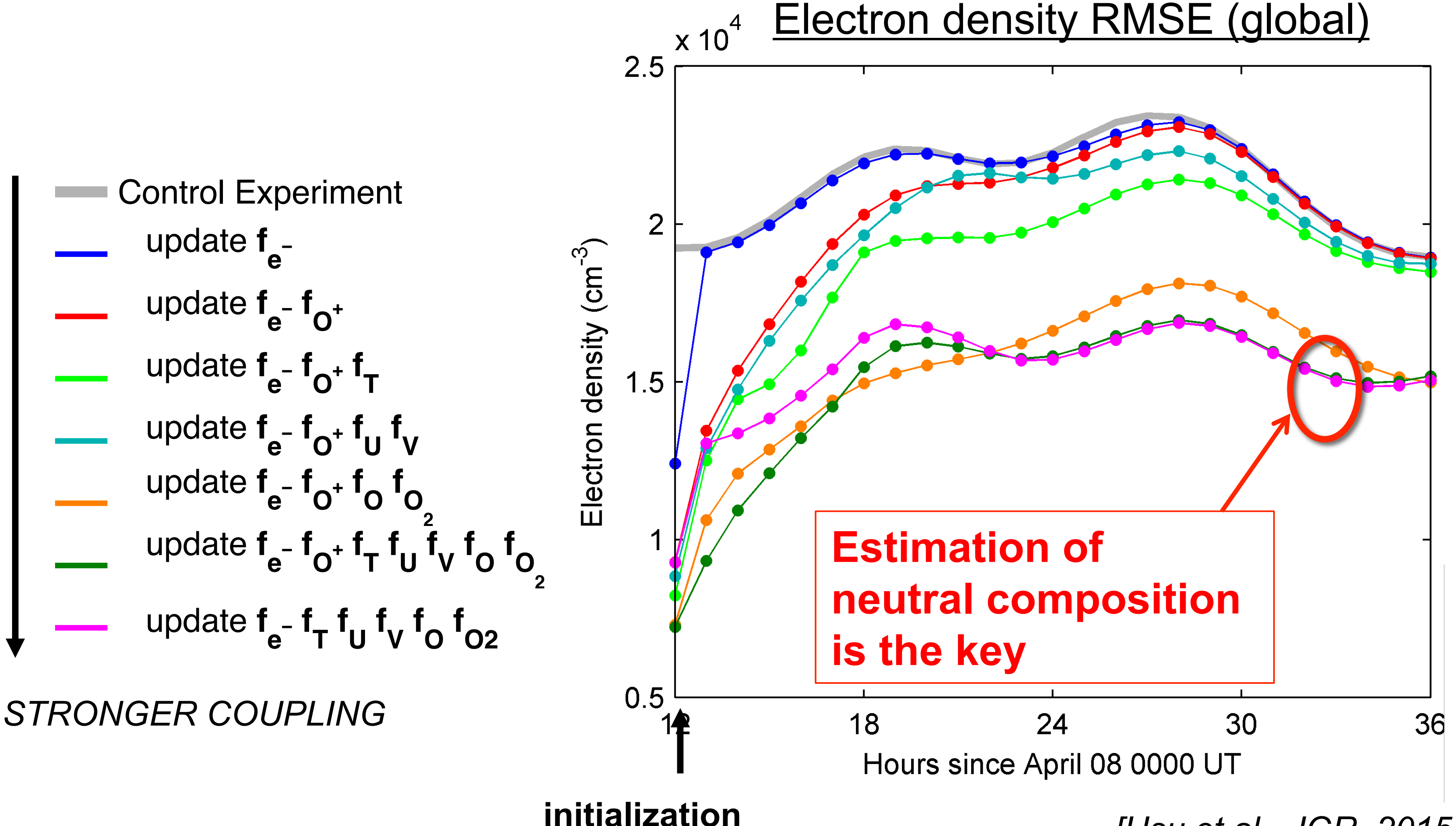
update f_{e^-} f_T f_U f_V f_O f_{O2}



[Matsuo and Araujo-Pradere, RS, 2011]

Strongly coupled data assimilation can extend predictability of the ionosphere more than 24 hours

Ensemble forecast initialized by COSMIC assimilation



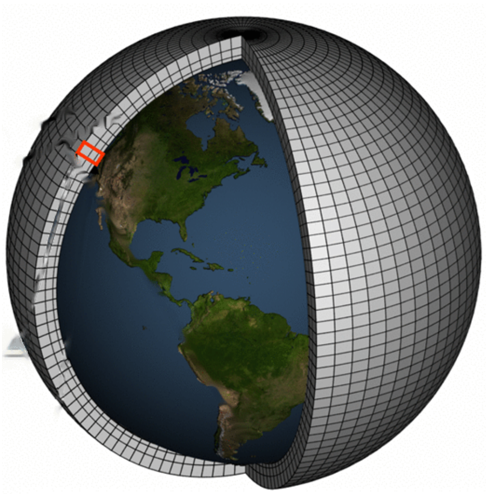
[Hsu et al., JGR, 2015]

What works and what doesn't

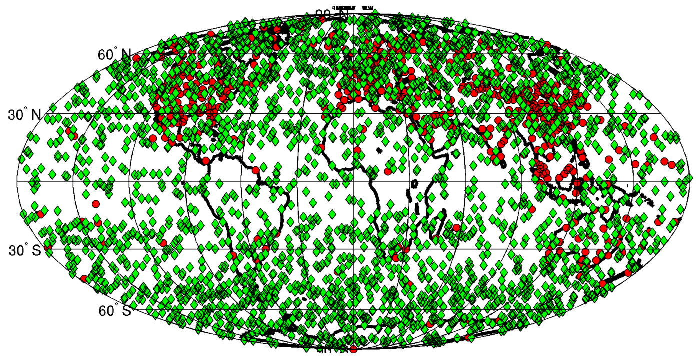
1. ***Strongly coupled*** thermosphere-ionosphere data assimilation approaches work better than ***weakly coupled*** approaches for both ionosphere and thermosphere specification and forecasting.

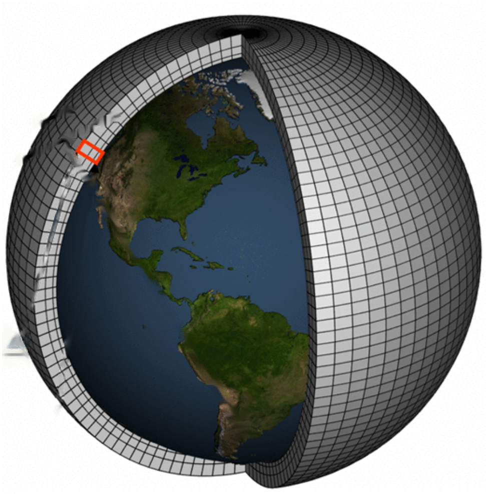
2. ***Large amount of indirect measurements*** (e.g. from GPS) are more effective than ***small amount of direct measurements*** (e.g. from accelerometers) for global neutral mass density specification and forecasting.

NCAR TIEGCM



COSMIC Electron Density





CHAMP Mass Density

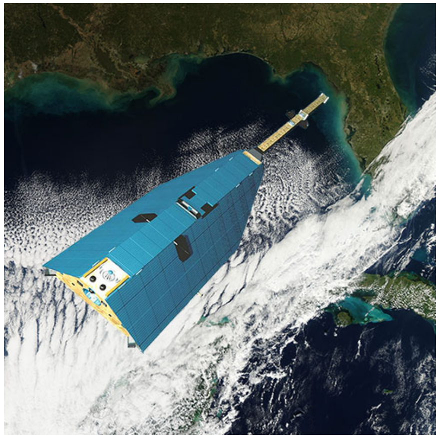


Image Courtesy: UCAR, GFDL & GFZ

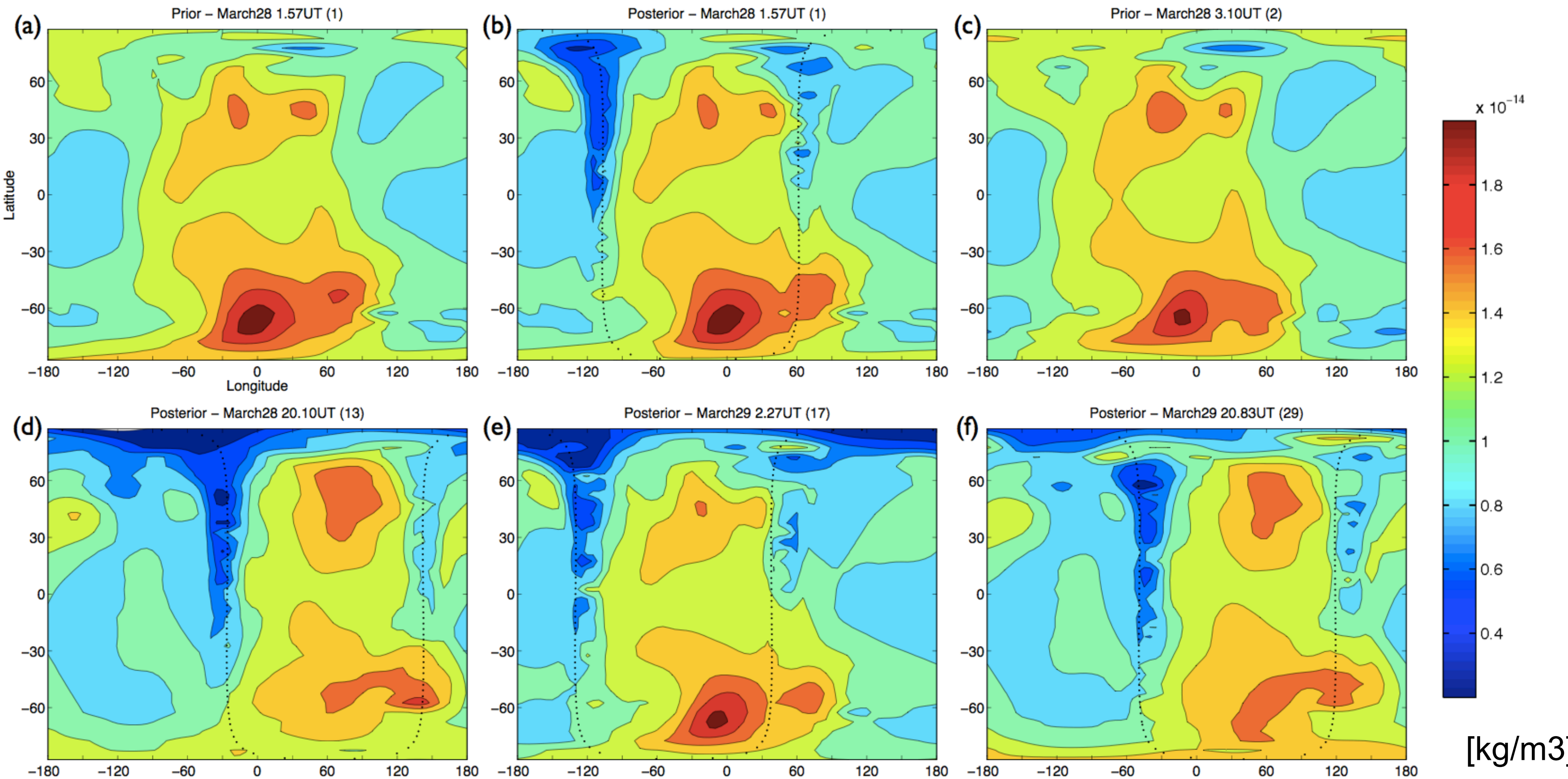
Error reduction only occurs in vicinity of CHMAP orbit with limited global impact

OSSEs – CHAMP neutral mass density

WEAK COUPLING

update f_T f_O f_{O_2}

Neutral mass density RMSE (over 320-450 km)

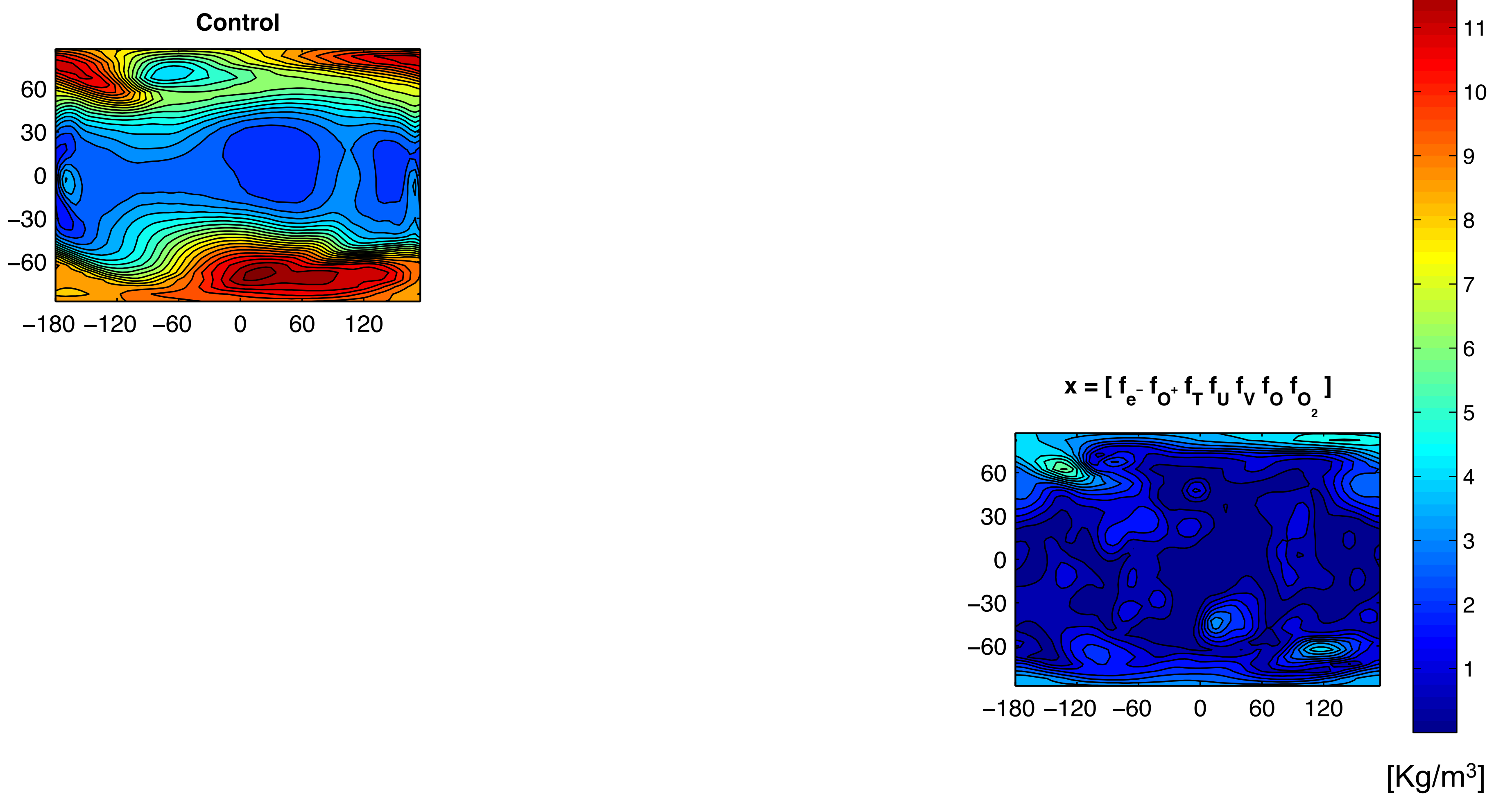


[Matsuo et al., JGR, 2013]

Global error reduction is achieved by assimilation of COSMIC data by coupled thermosphere-ionosphere data assimilation

OSSEs – COSMIC electron density

Neutral mass density RMSE



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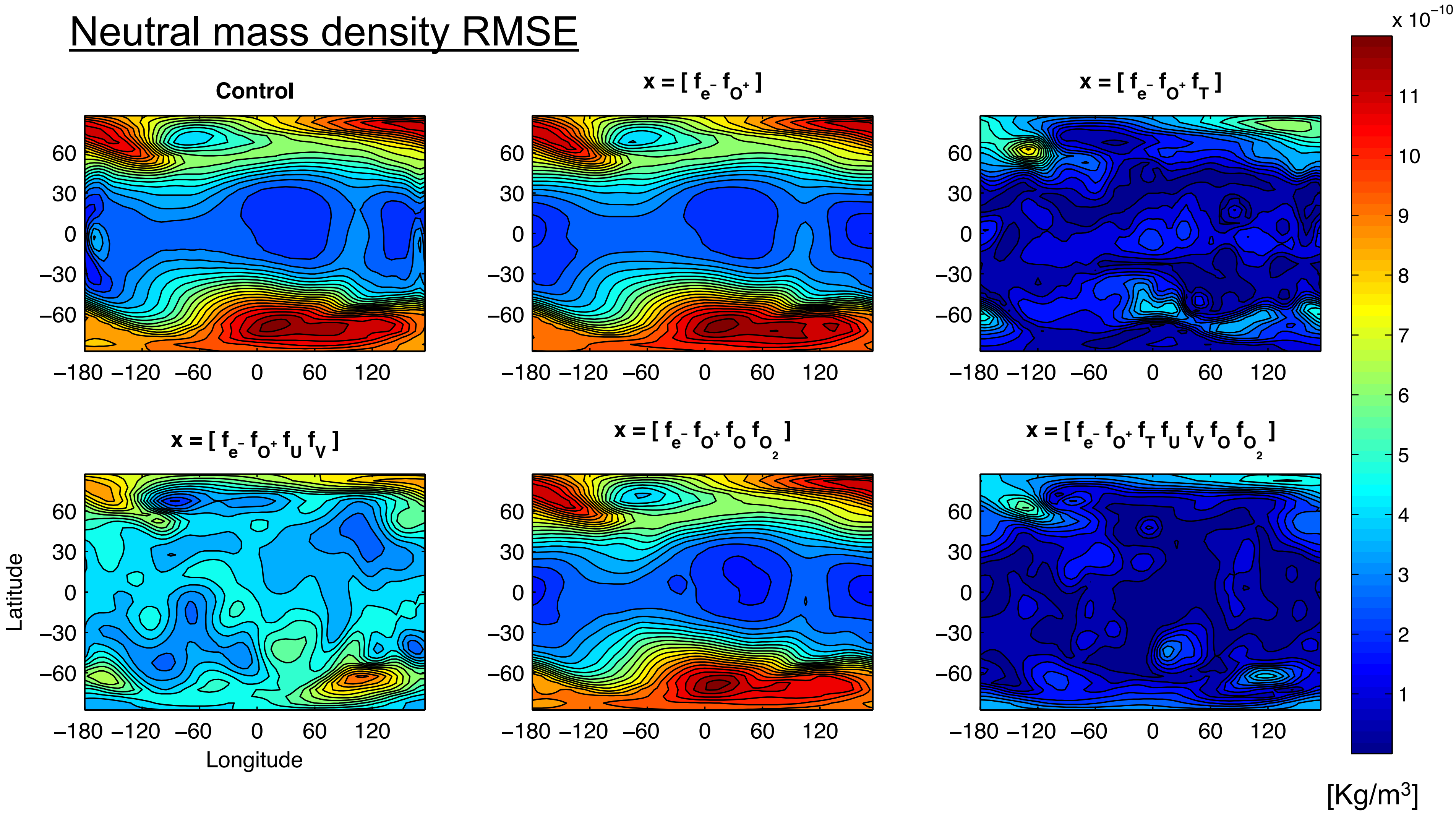
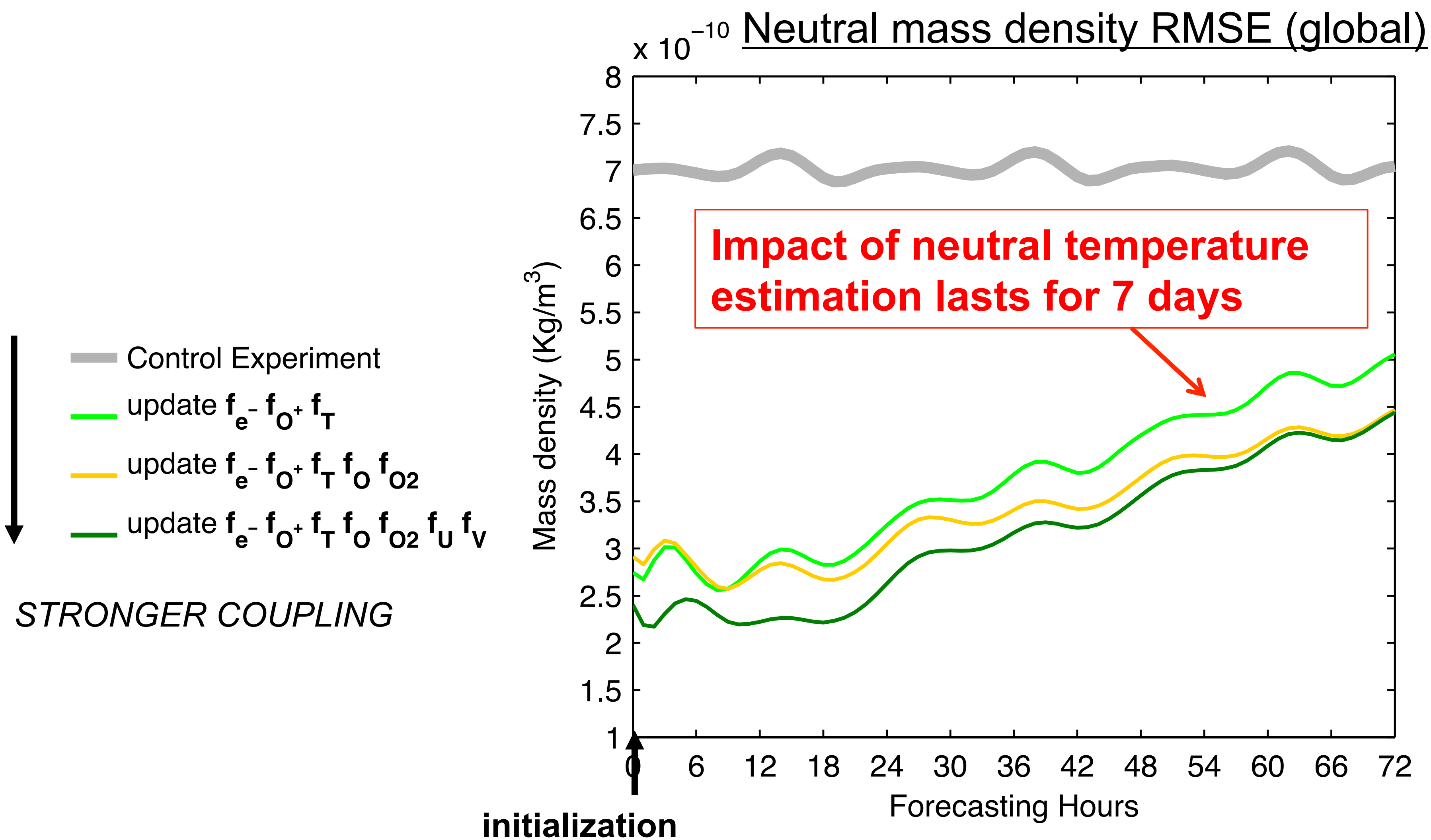
Neutral mass density RMSE

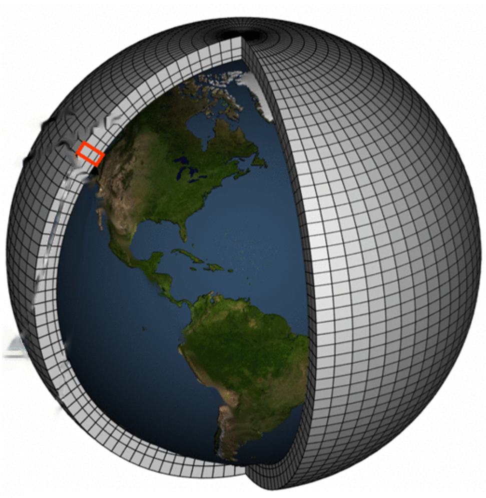


Strongly coupled data assimilation can extend predictability of the thermosphere more than 72 hours

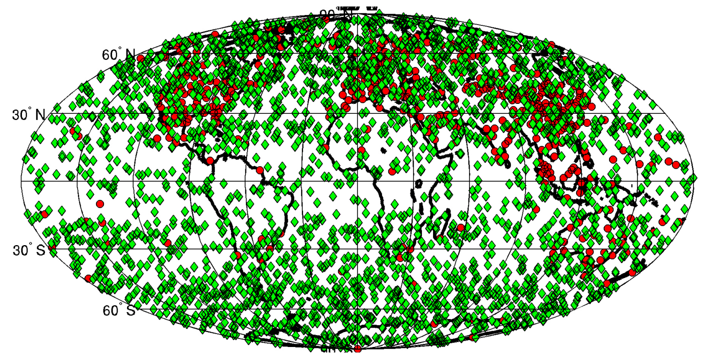
Ensemble forecast initialized by COSMIC assimilation



NCAR TIEGCM



COSMIC Electron Density Profile



CHAMP Mass Density

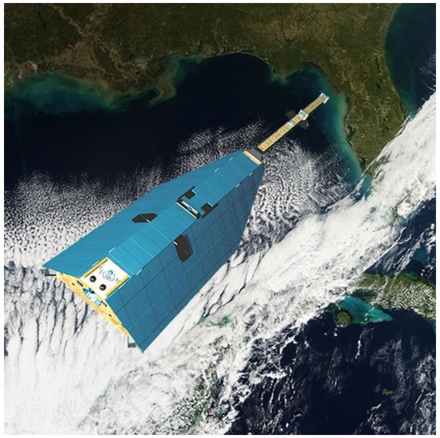
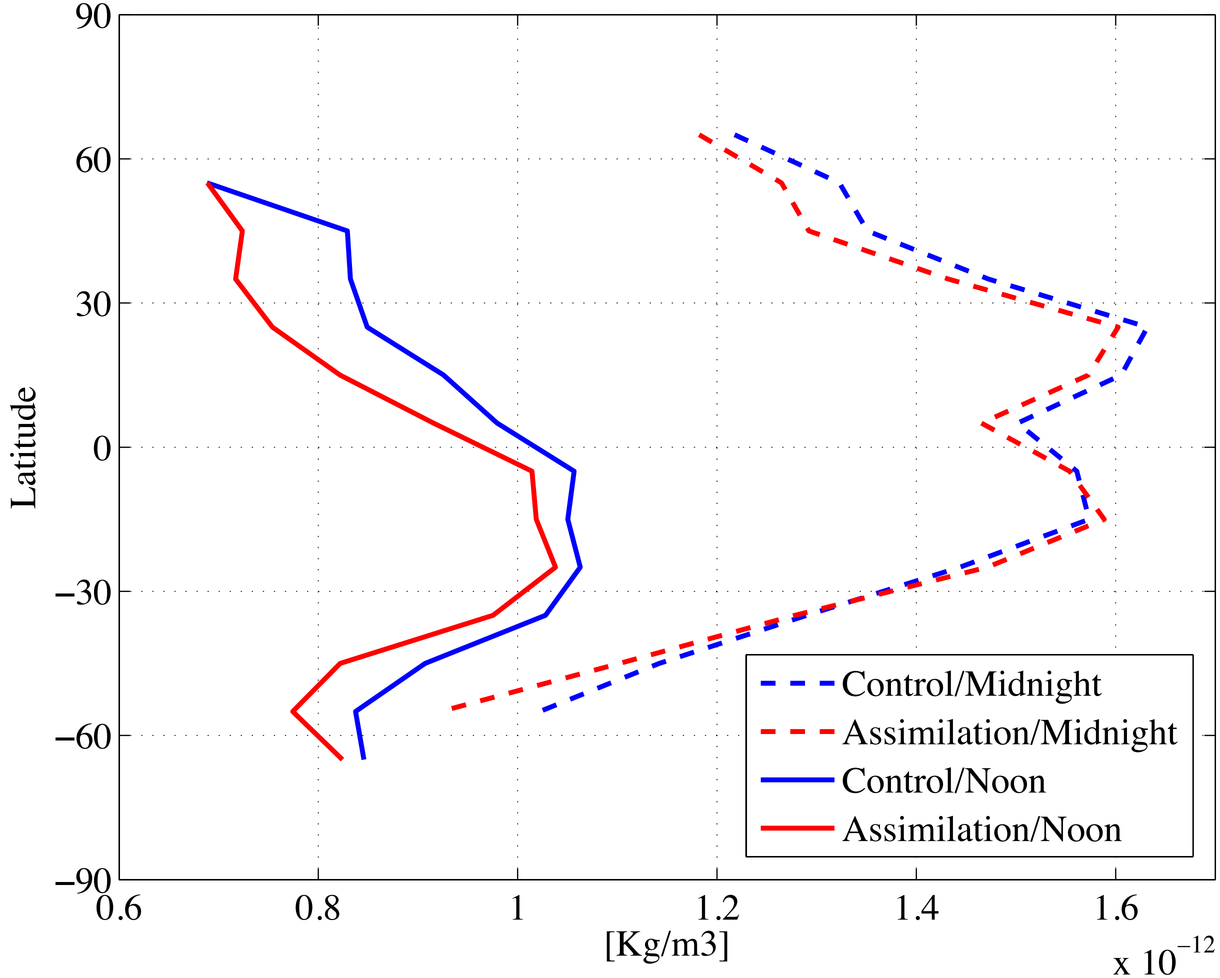


Image Courtesy: UCAR, GFDL & GFZ

Mass density can be estimated from COSMIC electron density via coupled thermosphere-ionosphere data assimilation

Comparison to 2-day (30 orbits) of CHAMP density observations

RMS difference



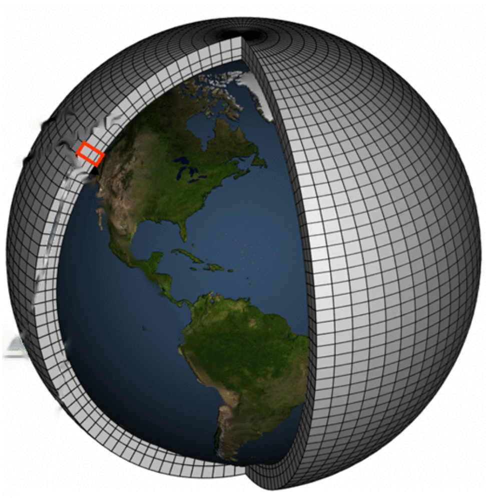
What works and what doesn't

1. ***Strongly coupled*** thermosphere-ionosphere data assimilation approaches work better than ***weakly coupled*** approaches for both ionosphere and thermosphere specification and forecasting.

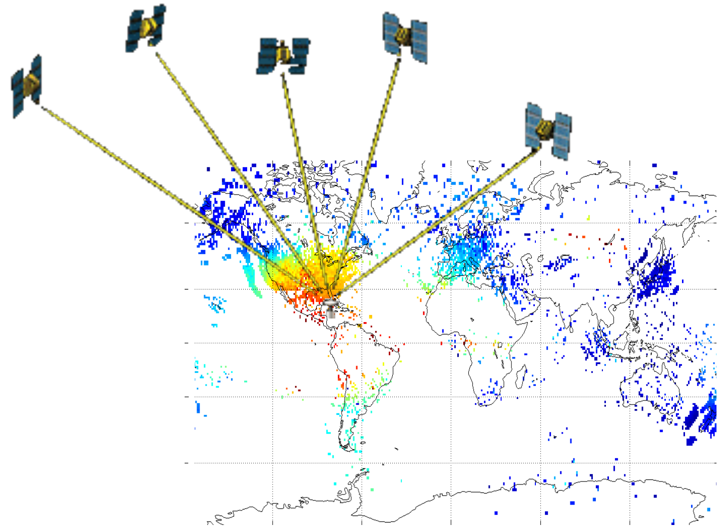
2. ***Large amount of indirect measurements*** (e.g. from GPS) are more effective than ***small amount of direct measurements*** (e.g. from accelerometers) for global neutral mass density specification and forecasting.

3. ***Rapid forecast-assimilation cycling*** (e.g. ~10 minutes) helps to reduce unrealistic model error growth due to unbalanced increment than **slow cycling** (e.g. ~1 hour).

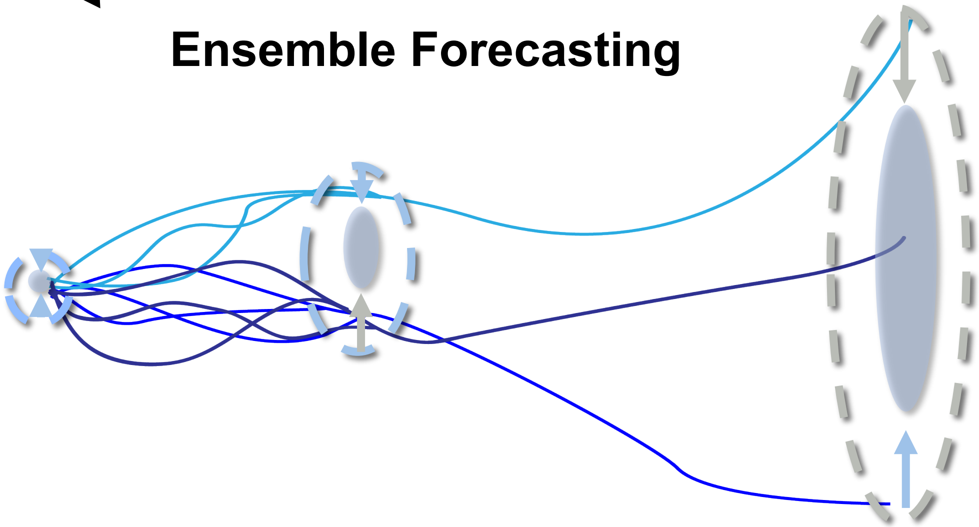
NCAR TIEGCM



GPS Total Electron Content



Ensemble Forecasting



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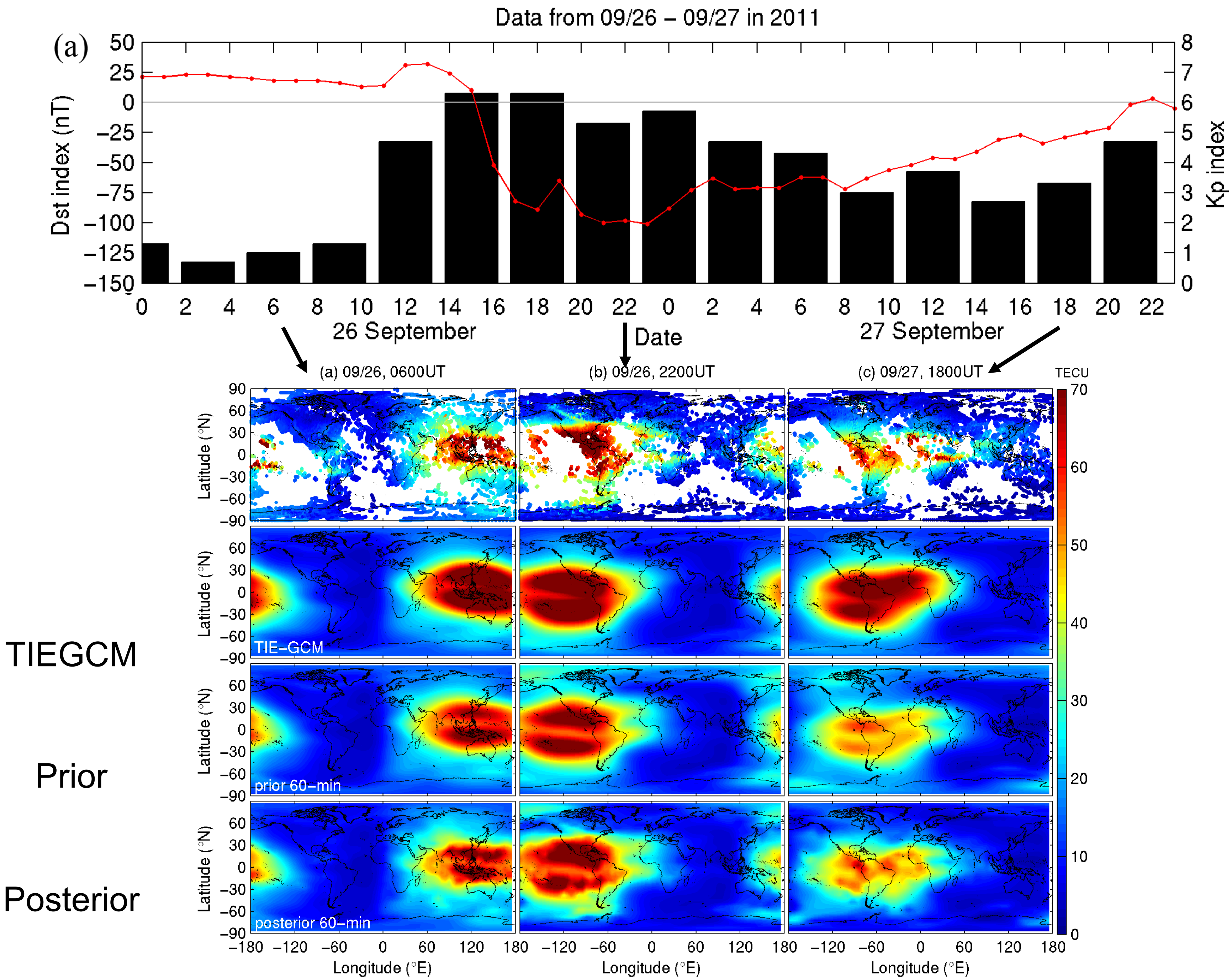
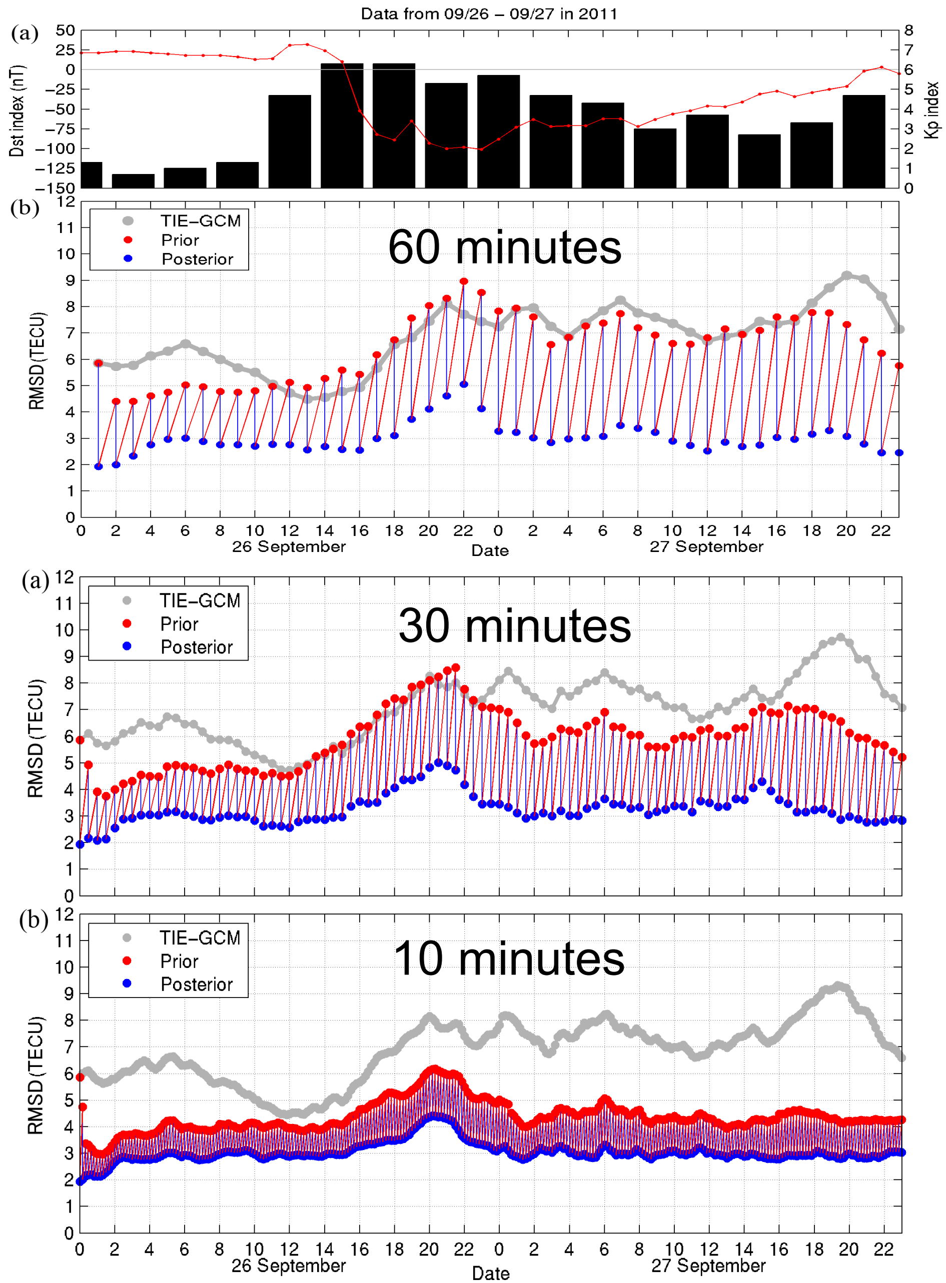
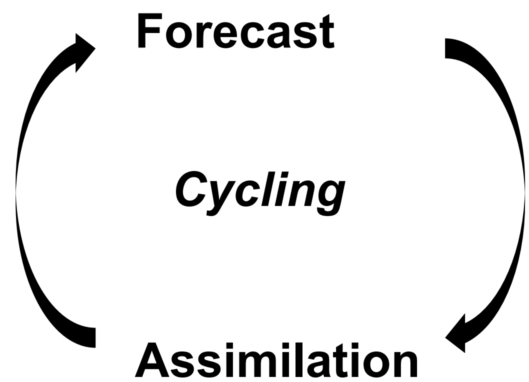


[Chen et al., JGR, 2016]

Rapid cycling helps reduce unrealistic model error growth





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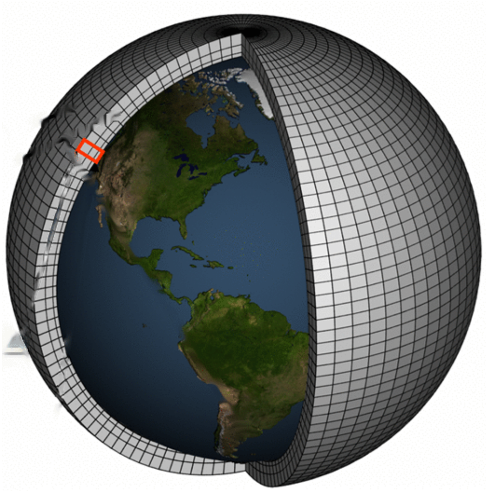
NCAR TIEGCM



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CHAMP Mass Density

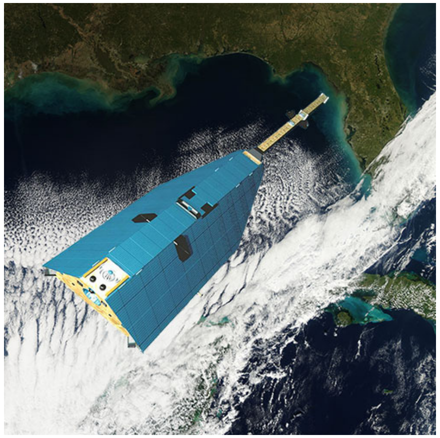
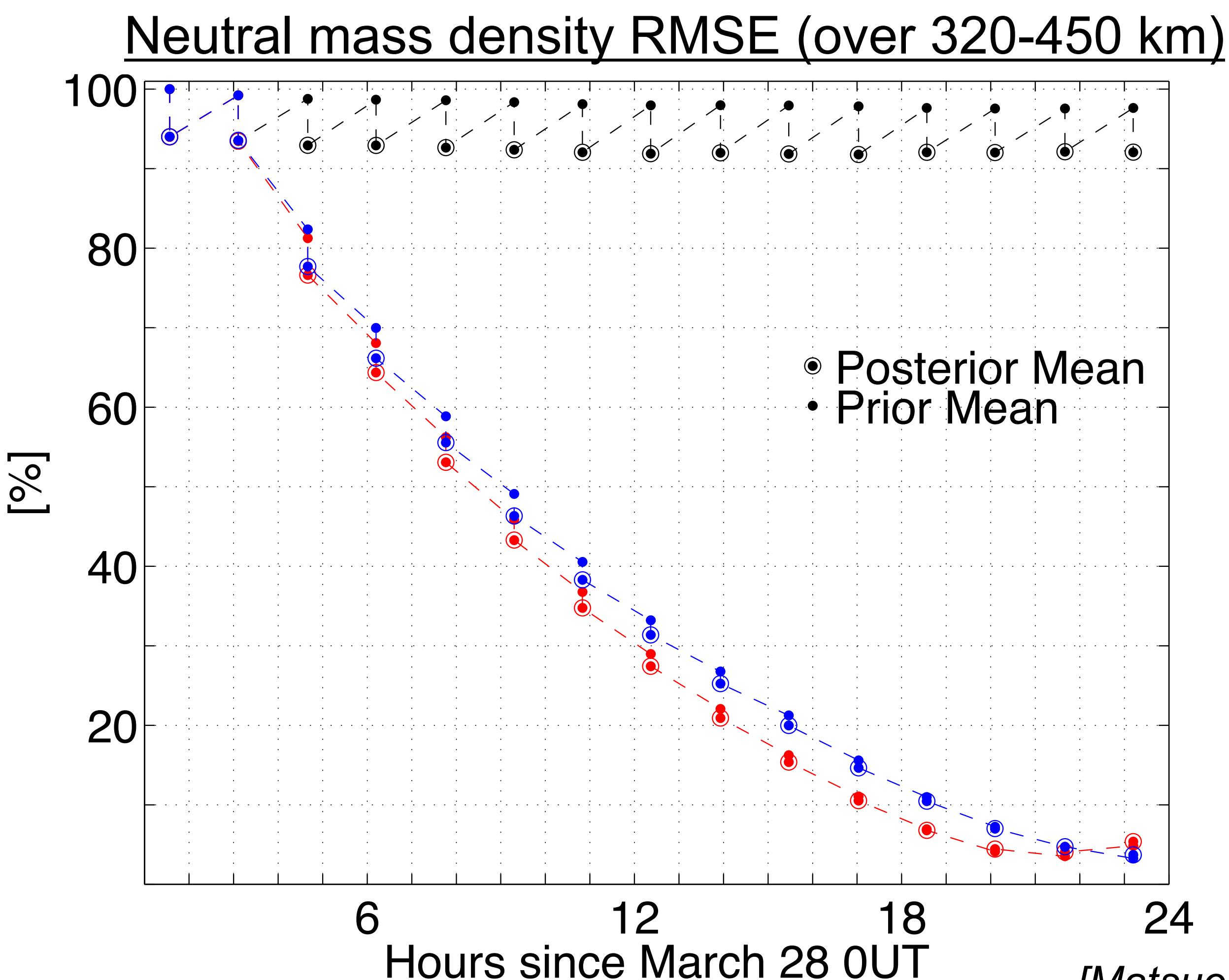


Image Courtesy: UCAR, GFDL & GFZ

Global error reduction achieved by forcing estimation

Filter degeneracy issues. Parameter estimation works well when model errors originates only from parameter misspecification.

OSSEs – CHAMP neutral mass density



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