Ionospheric Specification and Forecast by Ensemble Assimilation of FORMOSAT-7/COSMIC-2 Slant Total Electron Contents to a Coupled Model of the Thermosphere, Ionosphere, and Plasmasphere

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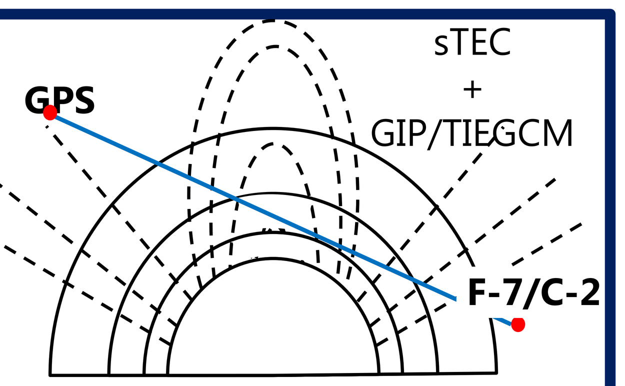
Introduction and Background



The Formosa Satellite 7/Constellation Observing System for Meteorology, Ionosphere and Climate 2 (F-7/C-2) radio occultation mission can provide high temporal- and spatial- resolution slant total electron content (sTEC) data globally, with six satellites at low inclination orbits and another six at high inclination orbits, planned to be launched in the future, respectively. It has a great potential to improve ionospheric data assimilation. In this study, synthetic F-7/C-2 sTEC data are assimilated into to the Global-Ionosphere-Plasmasphere /Theremosphere-Ionosphere-Electrodynamics General Circulation Model (GIP/TIEGCM) [Pedatella et. al., 2011] by using the Grid-point Statistical Interpolation Ensemble Kalman Filter (GSI EnKF) [Whitaker and Hamill, 2001]. Observing System Simulation Experiments (OSSEs) of F-7/C-2 sTEC data are carried out with different localization scale lengths to assess the impact of covariance localization on data assimilation analysis.

Experiment Setup

83-member GIP/TIEGCM ensemble simulations are initialized by perturbing the model drivers according to a normal distribution. These drivers are solar 10.7cm radio flux (F107), cross-tail potential drop (CP), and auroral hemispheric power (HP).

- Mean value of F107, CP, and HP: $90\times10^{-22}\frac{WHz}{m^2}$, 45 kV, and 16 GW respectively.
- Standard deviation of F107, CP, and HP: $5\times10^{-22}\frac{WHz}{m^2}$, 10 kV, and 2 GW respectively.

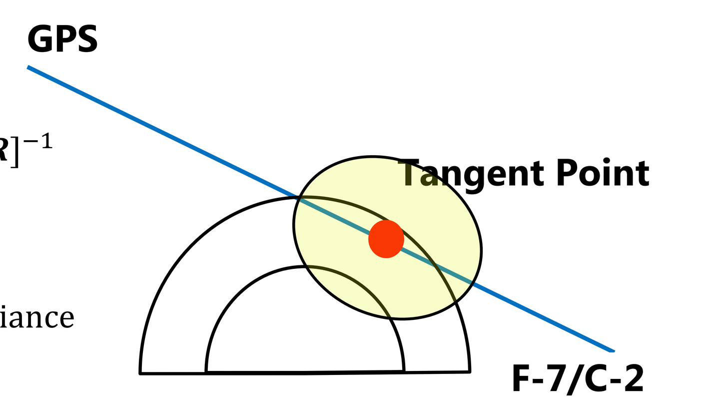
Synthetic F-7/C-2 sTEC data are sampled from the "truth" simulation with following drivers.

- F107, CP, and HP: $120\times10^{-22}\frac{WHz}{m^2}$, 55 kV, and 16 GW respectively.

Parametric Covariance Localization

The ensemble-based covariance needs to be localized around observation locations to minimize the effects of spurious correlations due to sampling errors. The ensemble-based covariance is multiplied by localization matrix element by element .

Note that the ensemble-based covariance is here localized around the tangent point even though sTEC is a non-local observation.



$$K=[(\rho\circ P^f)H^T][H(\rho\circ P^f)H^T+R]^{-1}$$

K : Kalman gain
ρ : localization matrix
H : forward operator
P^f: ensemble-based forecast error covariance
R : observation error covariance

Horizontal Localization Function

The Gaspari-Cohn [1999] function is used for both horizontal and vertical localization. Horizontal localization parameter $L_h$is defined in kilometer. In the following experiments, 4 different horizontal localization parameters (1,000,000km, 5,000km, 2,000km, and 1,000km) are applied.

$$r=\frac{|x_{model}-x_{obs}|}{L_h}$$

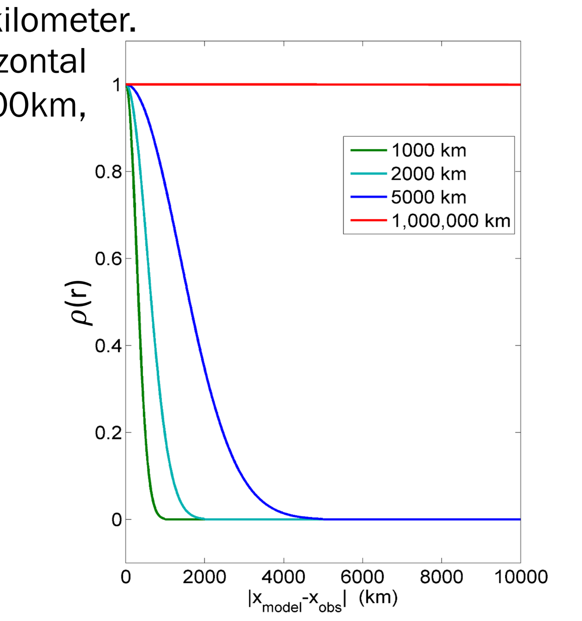
For $r\le1$

$$\rho(r)=e^{-(\frac{r}{0.388})^2}$$

For $r>1$

$$\rho(r)=0$$

L_h : horizontal localization parameter
x_{obs}: location of tangent point
x_{model}: location of model grid



Vertical Localization Function

Vertical localization parameter L_v is defined in nature log of pressure. In the following experiments, 7 vertical localization parameters (ln(pressure) = 1, 5, 10, 14, 20, 50, and 100) are applied.

$$r=\frac{|ln(P_{model})-\ln(P_{obs})|}{L_v}$$

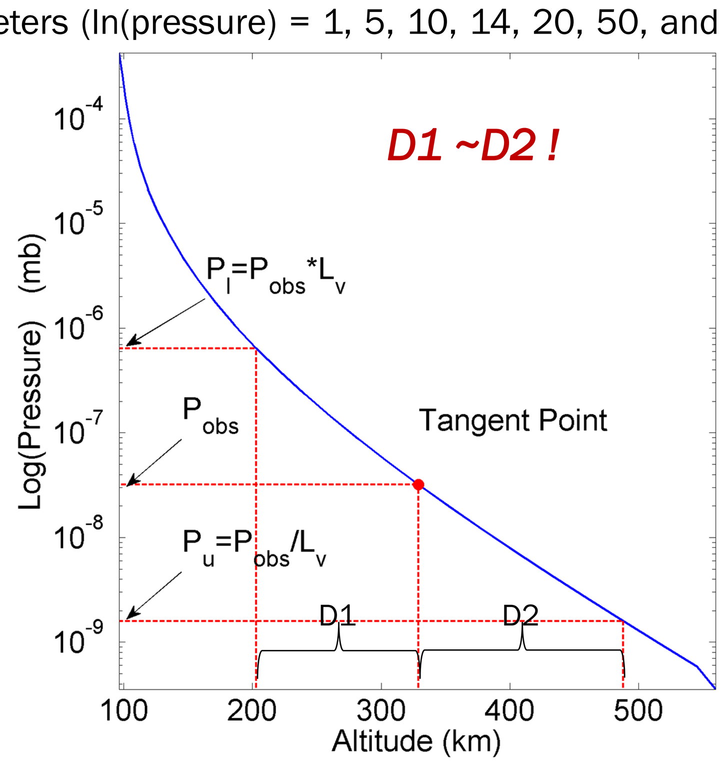
For $r\le1$

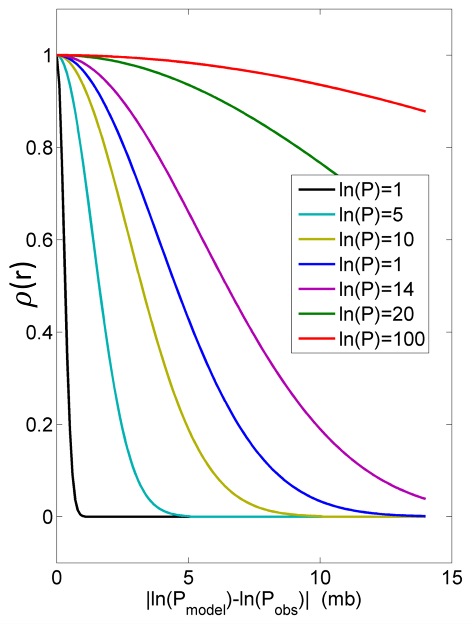
$$\rho(r)=e^{-(\frac{r}{0.388})^2}$$

For $r>1$

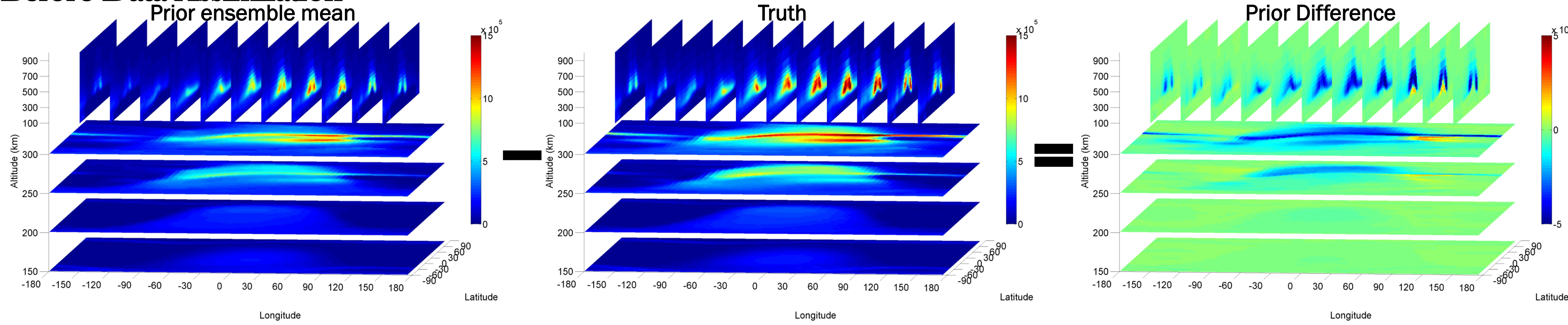
$$\rho(r)=0$$

L_v : vertical localization parameter
P_{obs}: pressure at tangent point
P_{model}: pressure at model grid

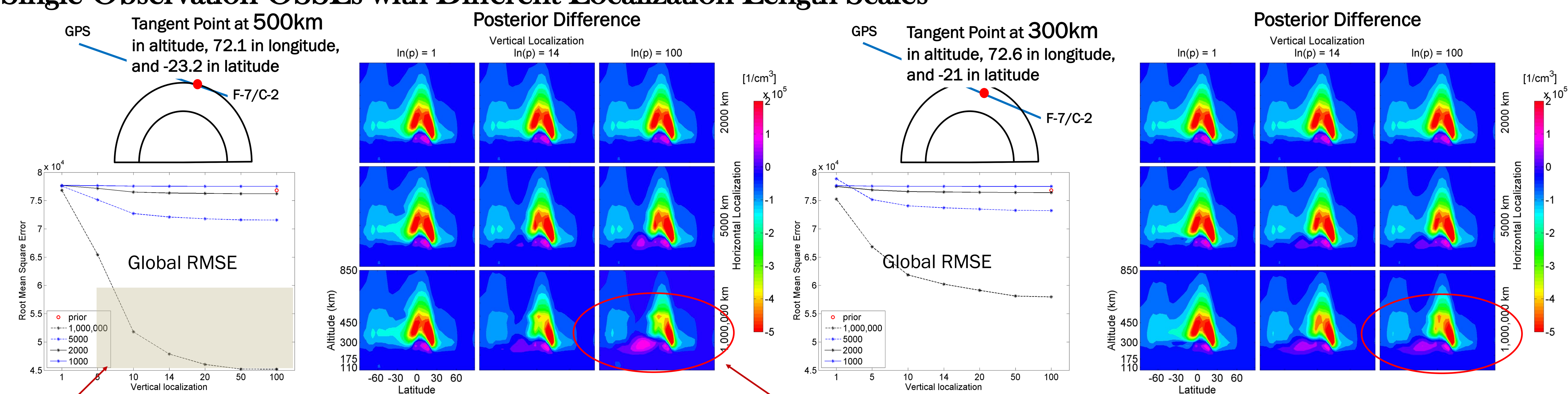




Before Data Assimilation



Single Observation OSSEs with Different Localization Length Scales



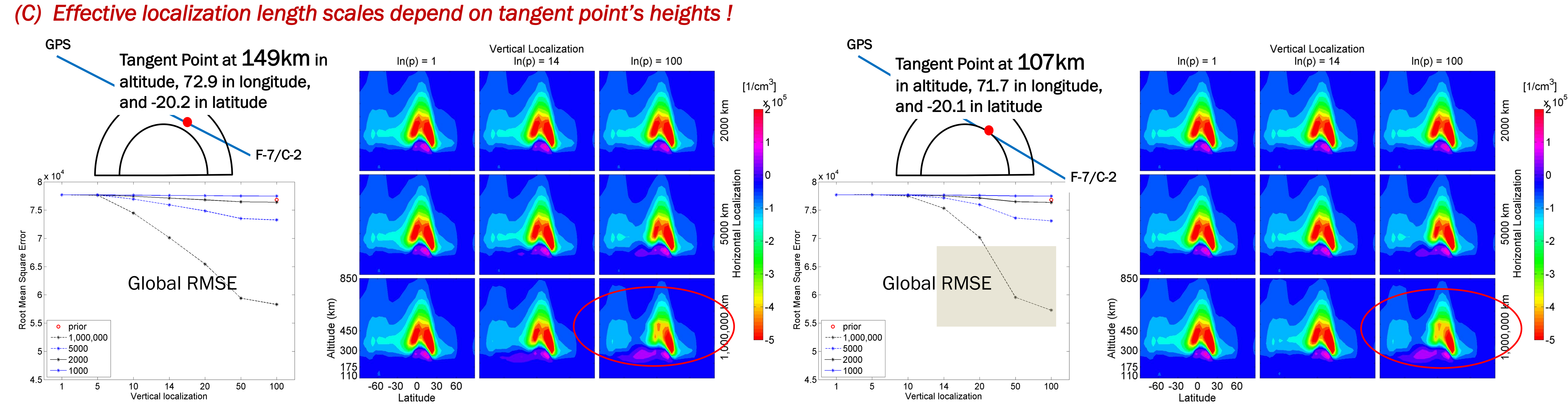
Posterior Difference

(B) E-/F-region error becomes larger/smaller !

(A) The larger the localization length scales are, the smaller global RMSE !

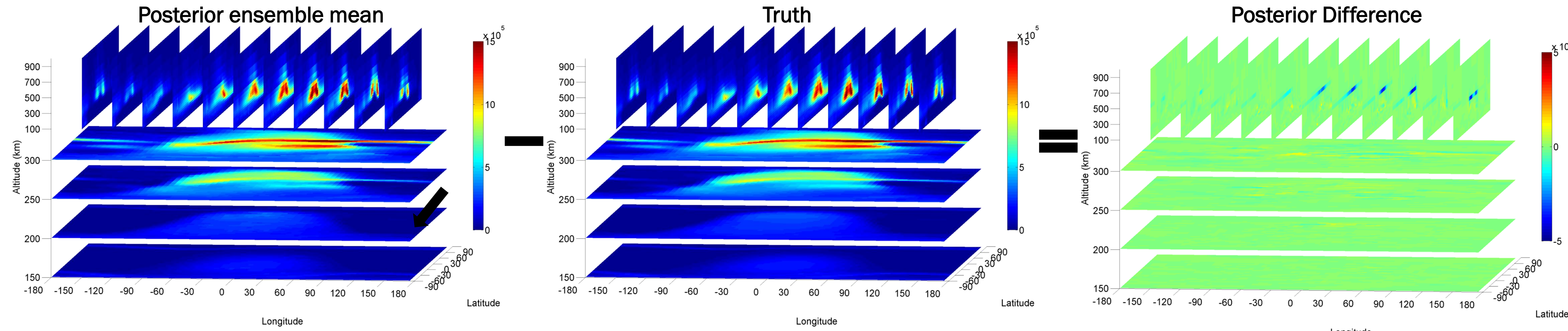
(C) Effective localization length scales depend on tangent point's heights !

Posterior Difference



After Data Assimilation

(D) Posterior difference becomes smaller thanks to the covariance localization!



- 707 profiles over 1 hour • L_v: ln(p) =100 • L_h: 1,000,000 km

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Summary

- 112 OSSEs for the F-7/C-2 observing system are conducted to assess the impact of covariance localizations on data assimilation analysis.
  - *Conclusion A*: Large horizontal and vertical localization length scales yield the smallest error globally.
  - *Conclusion B*: Large horizontal and vertical localization cases lead to large/small errors in the E-region/F-region.
  - *Conclusion C*: For lower altitude tangent point sTEC observations, it is better to use larger vertical localization length scales (in terms of ln(pressure)).
- 707 F-7 profiles (~700,000 sTEC data) are assimilated with L_v =100 and L_h= 1,000,000 km.
  - *Conclusion D*: The covariance localization helped reduce the electron density analysis errors.

Future Work

- Apply an altitude-dependent horizontal and vertical localization by estimating the empirical localization function [Lei et. al., 2015].
- Conduct assimilation-forecast cycling experiments to examine the impact of estimating both thermospheric and ionospheric states on ionospheric forecasting [Hsu et. al., 2014]