Impact of FORMOSAT-7/COSMIC-2 GNSS RO observations on midlatitude and low-latitude ionosphere specification

Chih-Ting Hsu[1], Tomoko Matsuo[1], and Jann-Yenq Liu[2]

Ann and H. J. Smead Aerospace Engineering Sciences, University of Colorado Boulder, CO

Graduate Institute of Space Science, National Central University, Taoyuan, Taiwan

University of Colorado Boulder

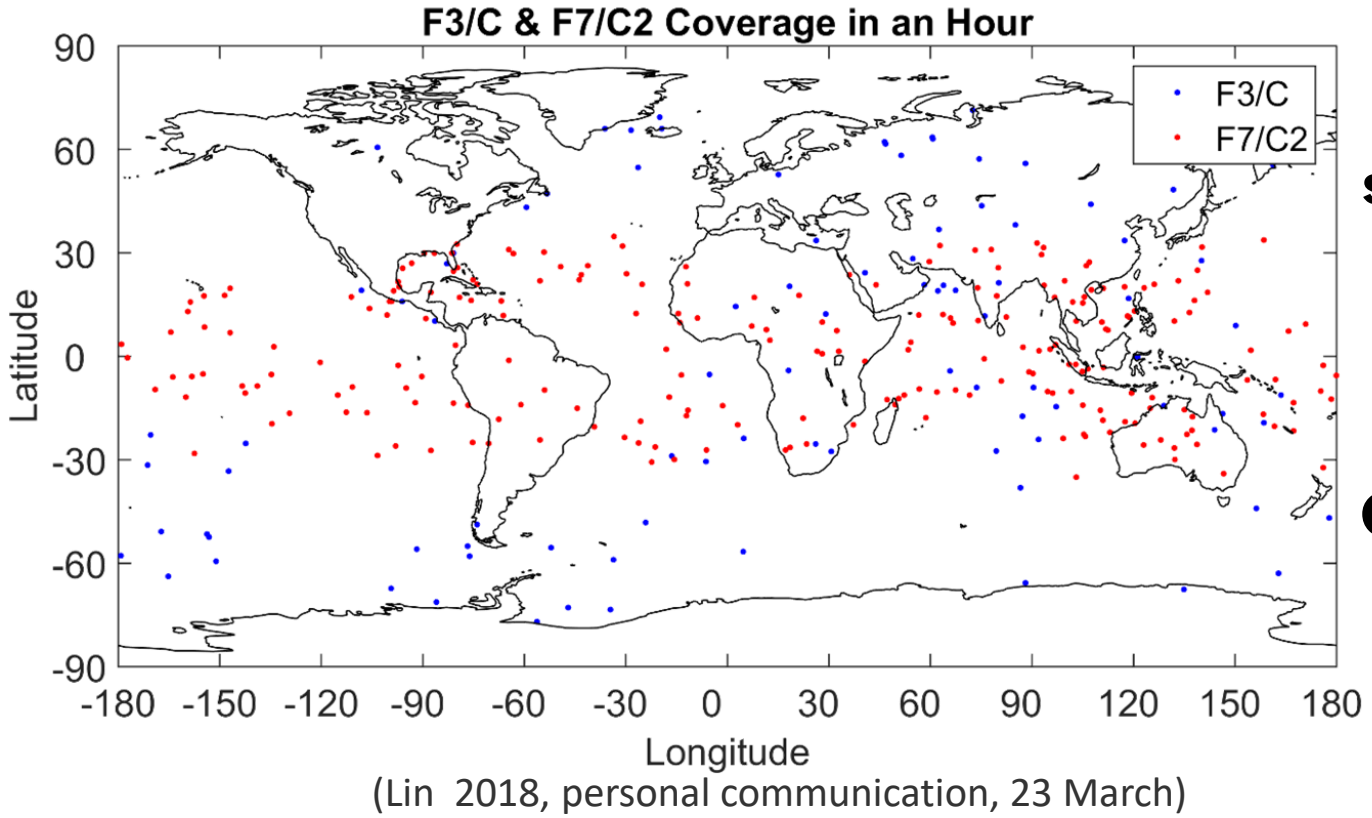
國立中央大學 National Central University

CCAR

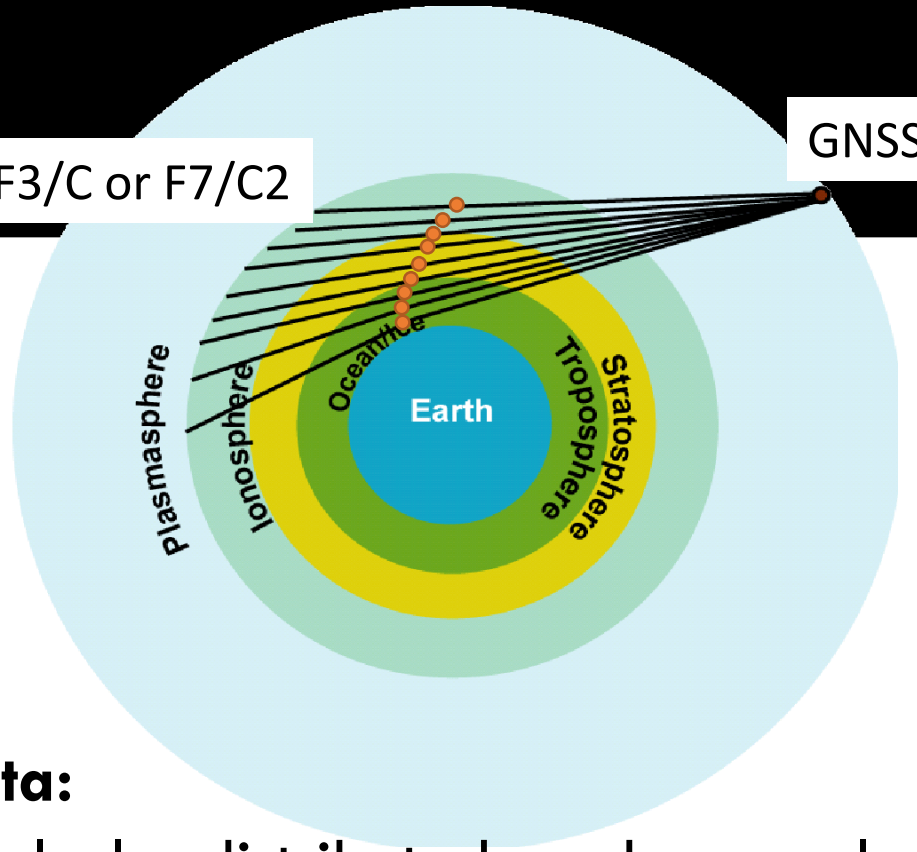
Data Assimilation of RO sTEC

$$\text{sTEC} = \int n_e dl = -\frac{f^2}{40.3 \times 10^6} \int (n-1) dl = -\frac{f^2 S}{40.3}$$

$$\text{sTEC} = \frac{(S_1 - S_2) f_1^2 f_2^2}{40.3(f_1^2 - f_2^2)}$$



(Lin 2018, personal communication, 23 March)



sTEC data:

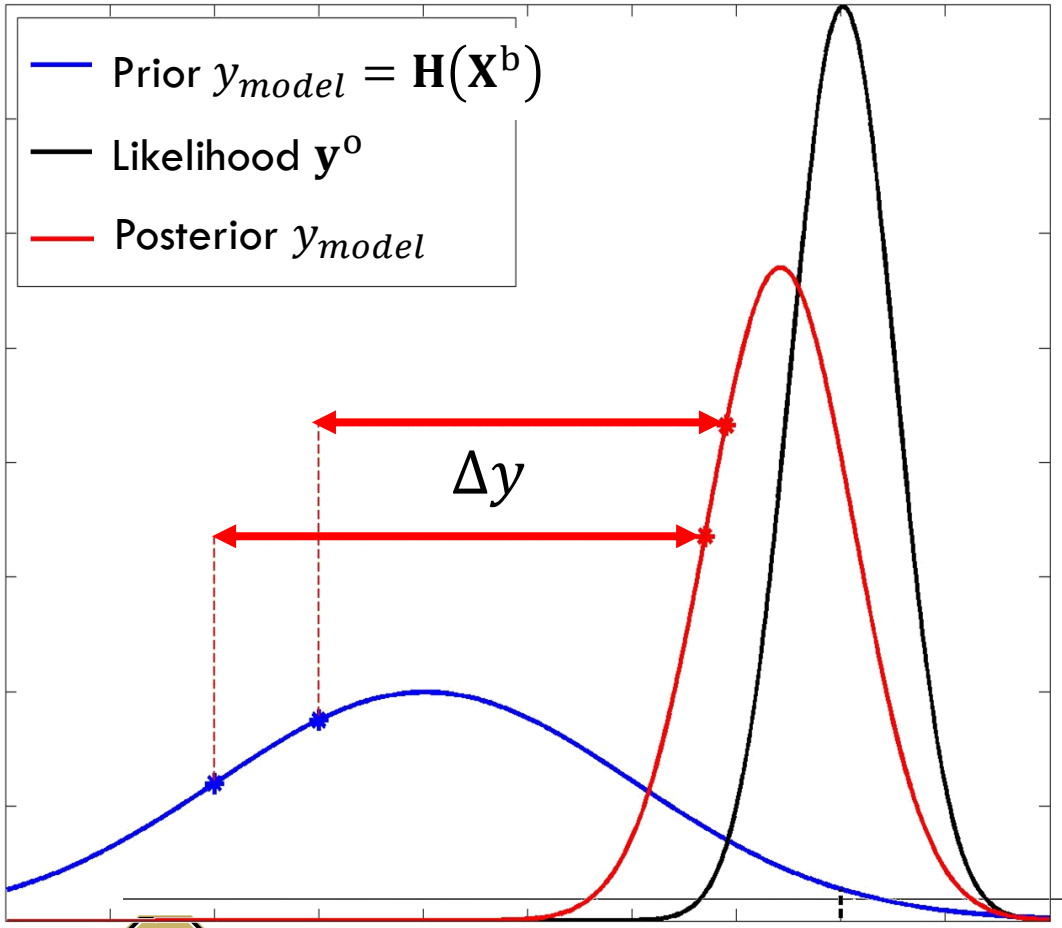
Irregularly distributed and sparsely sampled in space and time. Large day-to-day variability.

GIP/TIE-GCM model:

Global and complete in space and time. Small day-to-day variability.

NOAA GSI Ensemble Square Root Filter

Deterministic update by Ensemble Square Root Filter (EnSRF, Whitaker & Hamill, 2002) explained using Bayes' rule



$$\bar{\mathbf{X}}^a = \bar{\mathbf{X}}^b + \mathbf{K}(\mathbf{y}^o - \mathbf{H}(\bar{\mathbf{X}}^b))$$

$$\mathbf{X}_n^a - \bar{\mathbf{X}}^a = (\mathbf{X}_n^b - \bar{\mathbf{X}}^b) + \tilde{\mathbf{K}}(-\mathbf{H}(\mathbf{X}_n^b - \bar{\mathbf{X}}^b))$$

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

$$\tilde{\mathbf{K}}_k = (1 \pm (R/(\mathrm{H}\mathrm{P}^b\mathrm{H}^T + \mathrm{R})))^{-1}\mathbf{K}$$

$$\mathbf{P}^b\mathbf{H}^T \sim \frac{1}{N-1}\sum_{n=1}^{N}(\mathbf{X}_n^b - \bar{\mathbf{X}}^b)[\mathbf{H}(\mathbf{X}_n^b - \bar{\mathbf{X}}^b)]^T$$

$$\mathbf{H}\mathbf{P}^b\mathbf{H}^T \sim \frac{1}{N-1}\sum_{n=1}^{N}[\mathbf{H}(\mathbf{X}_n^b - \bar{\mathbf{X}}^b)][\mathbf{H}(\mathbf{X}_n^b - \bar{\mathbf{X}}^b)]^T$$

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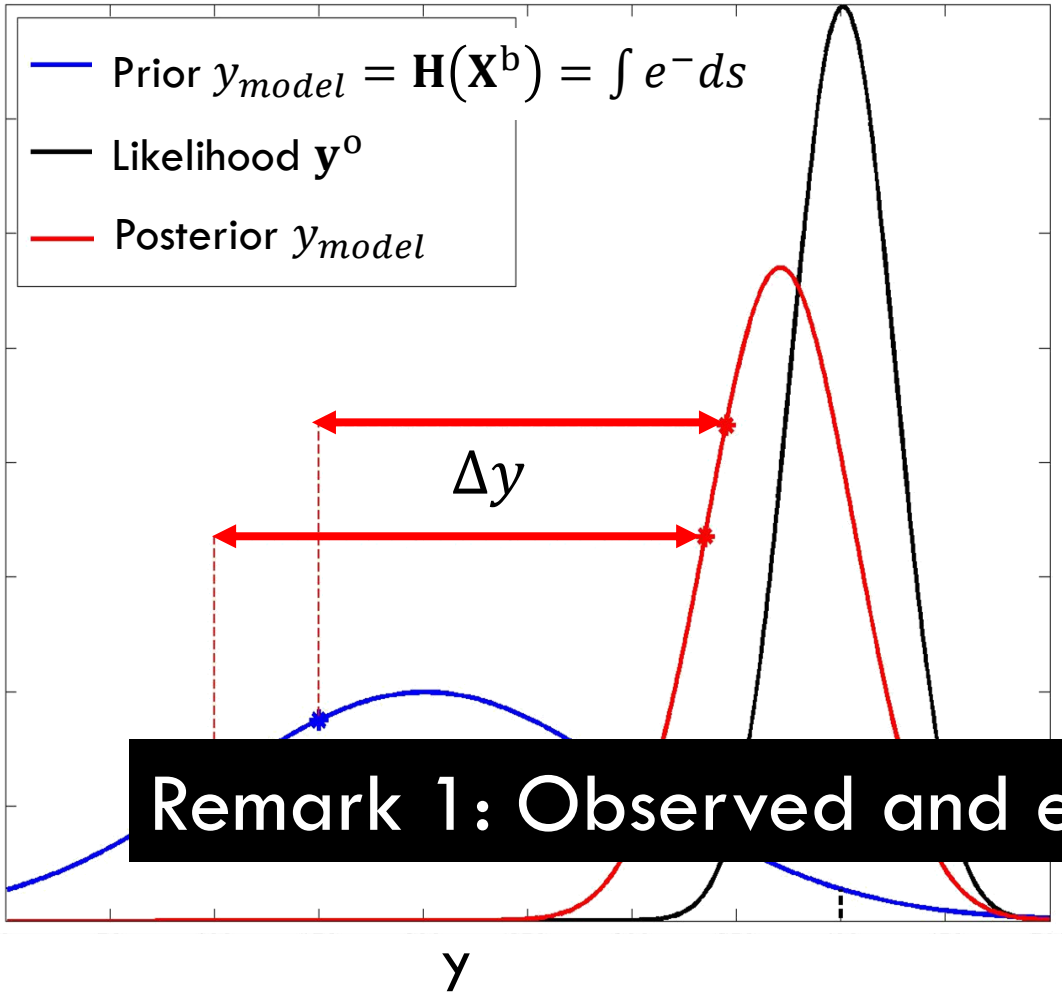

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sTEC

$O^+, e^-, etc.$

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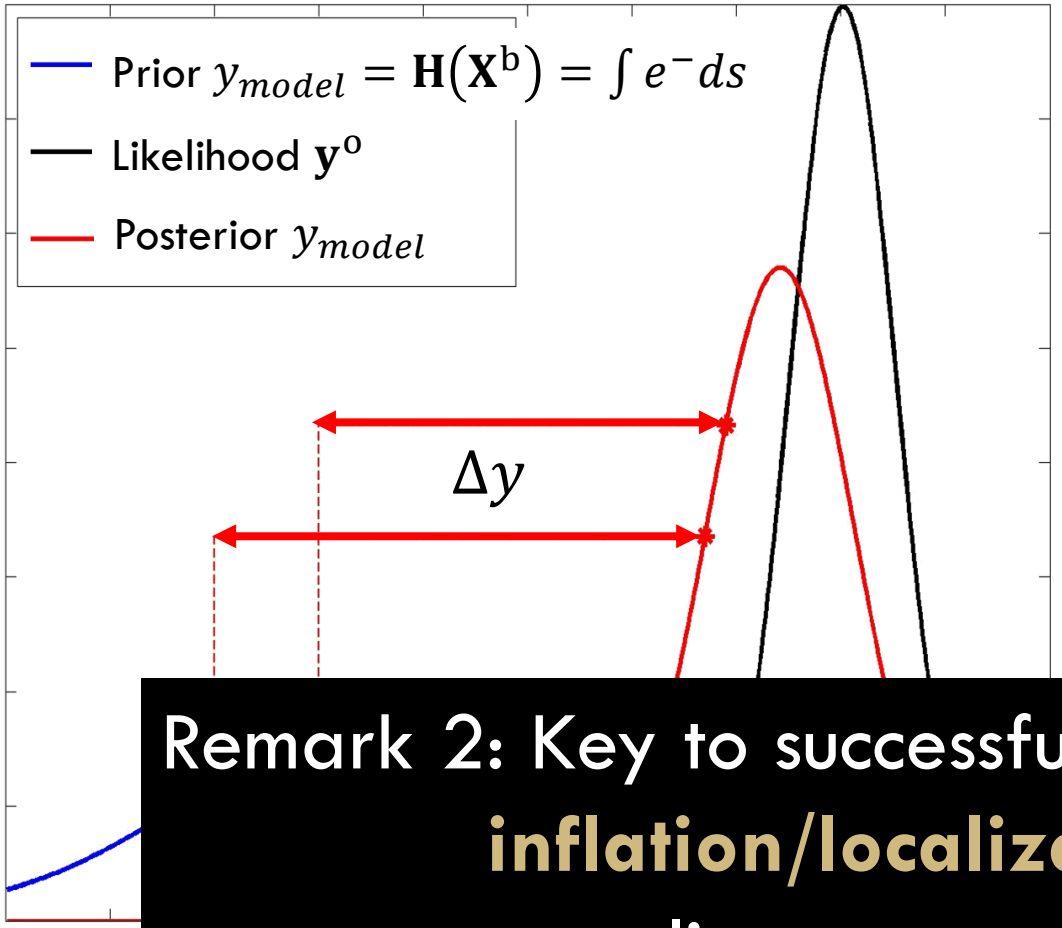
Remark 1: Observed and estimated variables are different.

NOAA GSI Ensemble Square Root Filter

Deterministic update by Ensemble Square Root Filter (EnSRF, Whitaker & Hamill, 2002) explained using Bayes' rule



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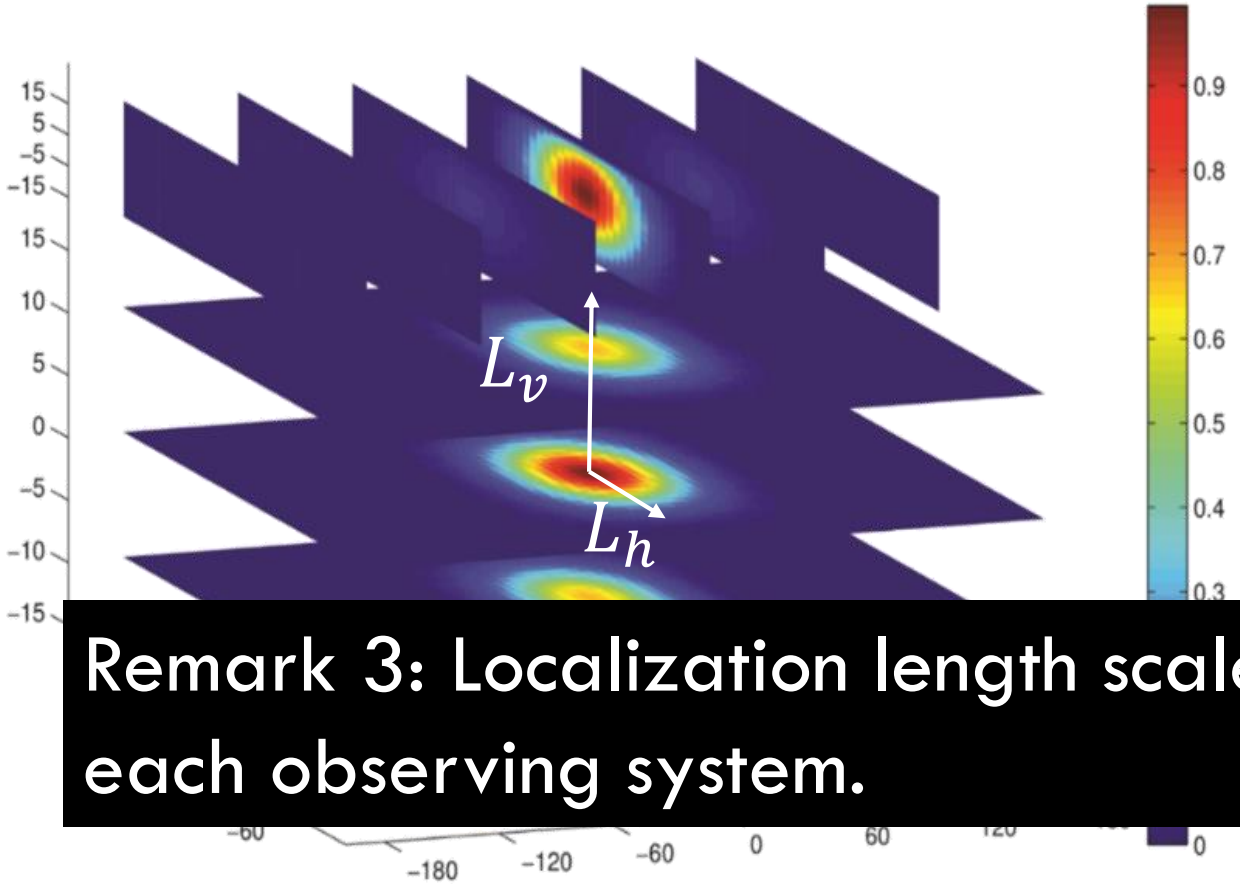
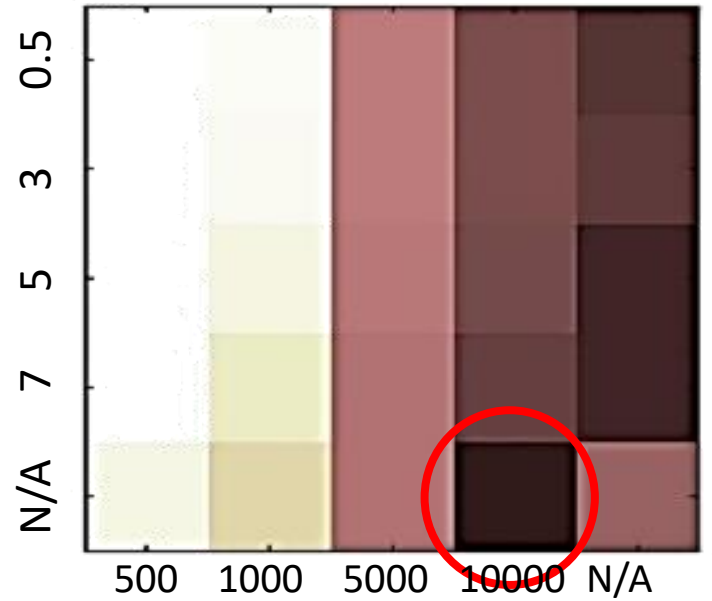
Remark 2: Key to successful implementation of EnSRF is **covariance inflation/localization** to correct for issues resulting from sampling errors.

NOAA GSI EnSRF – Covariance Localization

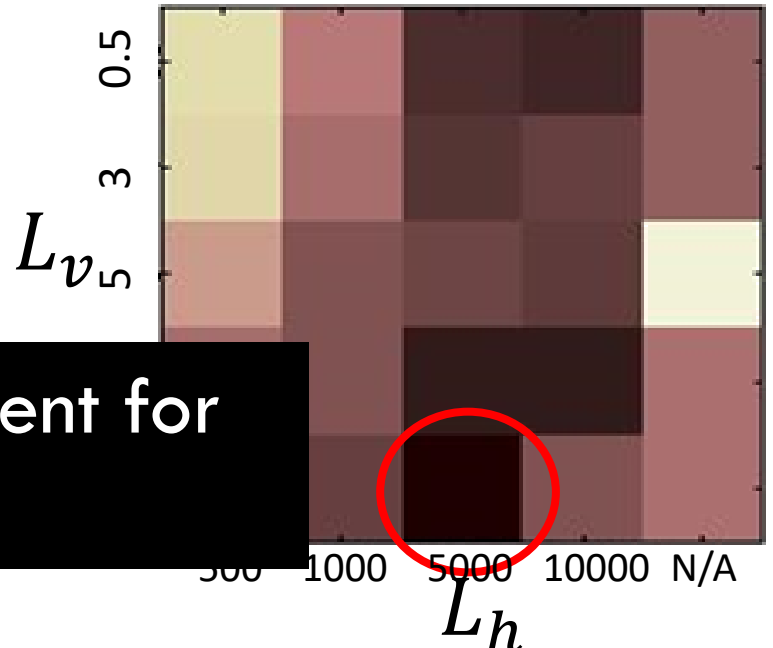
25 experiments with ensemble size 70 (1750 model runs) and different covariance localization length scale for each observing system.



Error of F-3/C Experiment



Error of F-7/C-2 Experiment



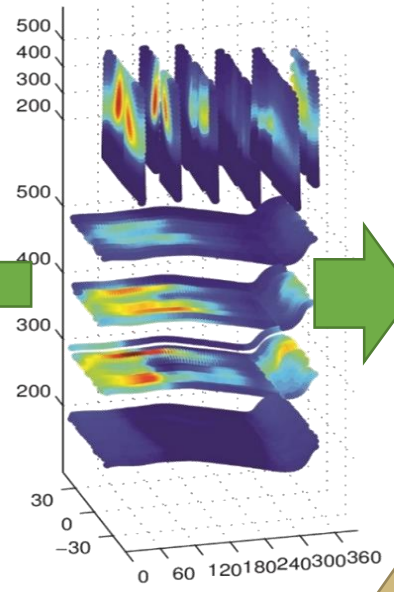
Remark 3: Localization length scales are different for each observing system.

Observing System (Simulation) Experiment

OSE

Real Observation

Model



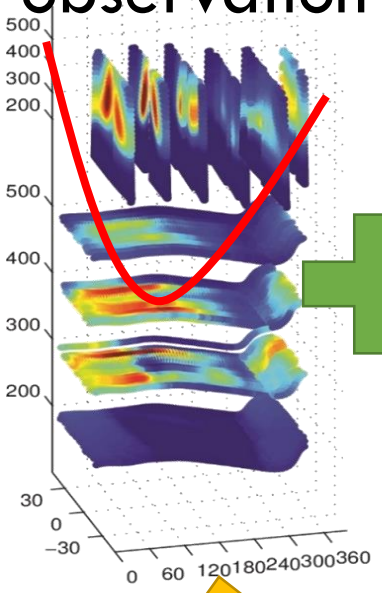
Result

?

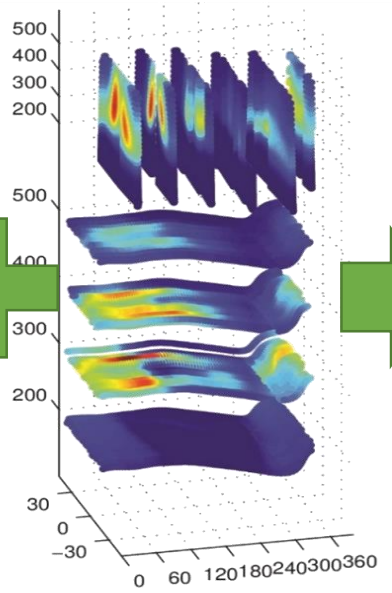
Independent observation

OSSE

Synthetic observation



Model



Result

?

Nature Run (NR)

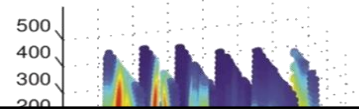
Observing System (Simulation) Experiment

OSE

Real Observation

Model

Result

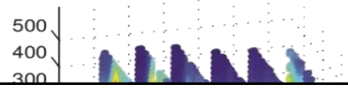


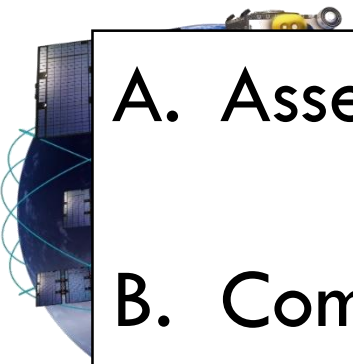
OSSE

Synthetic observation

Model

Result





A. Assess the impact of the F-3/C with OSE.

B. Compare the impact of the F-7/C-2 & F-3/C with OSSEs.

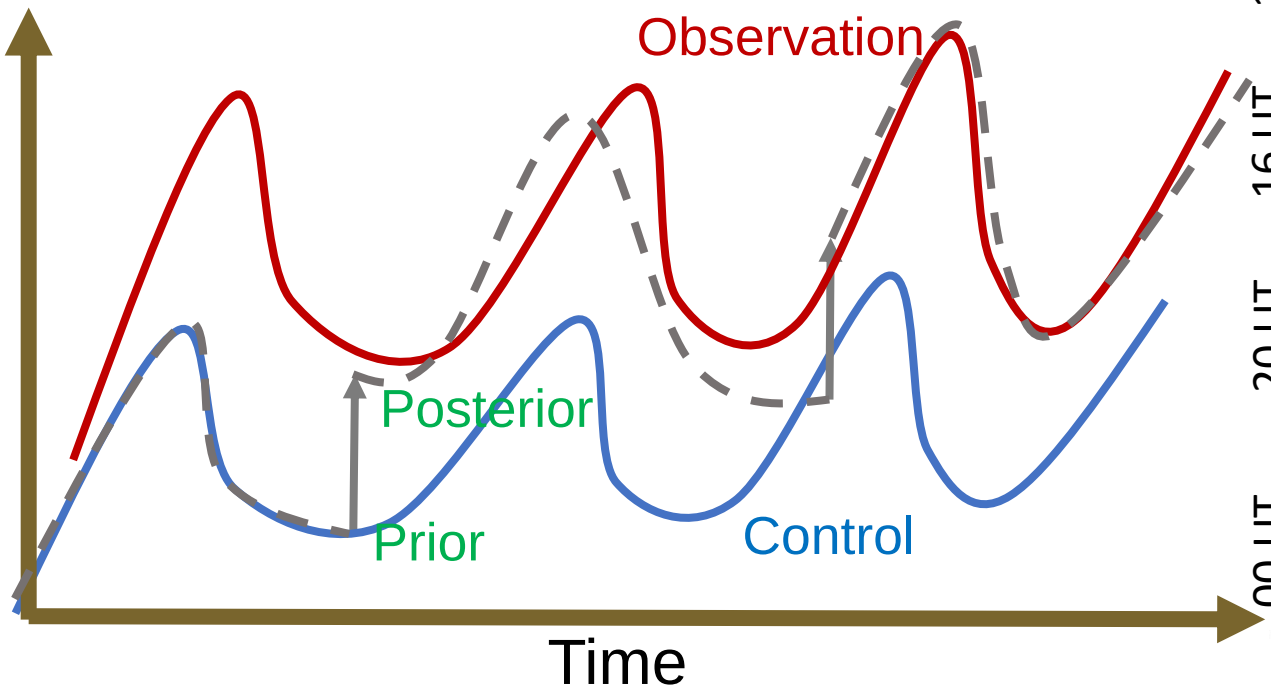
➔ Understand the impact of the F-7/C-2 on ionospheric specification.

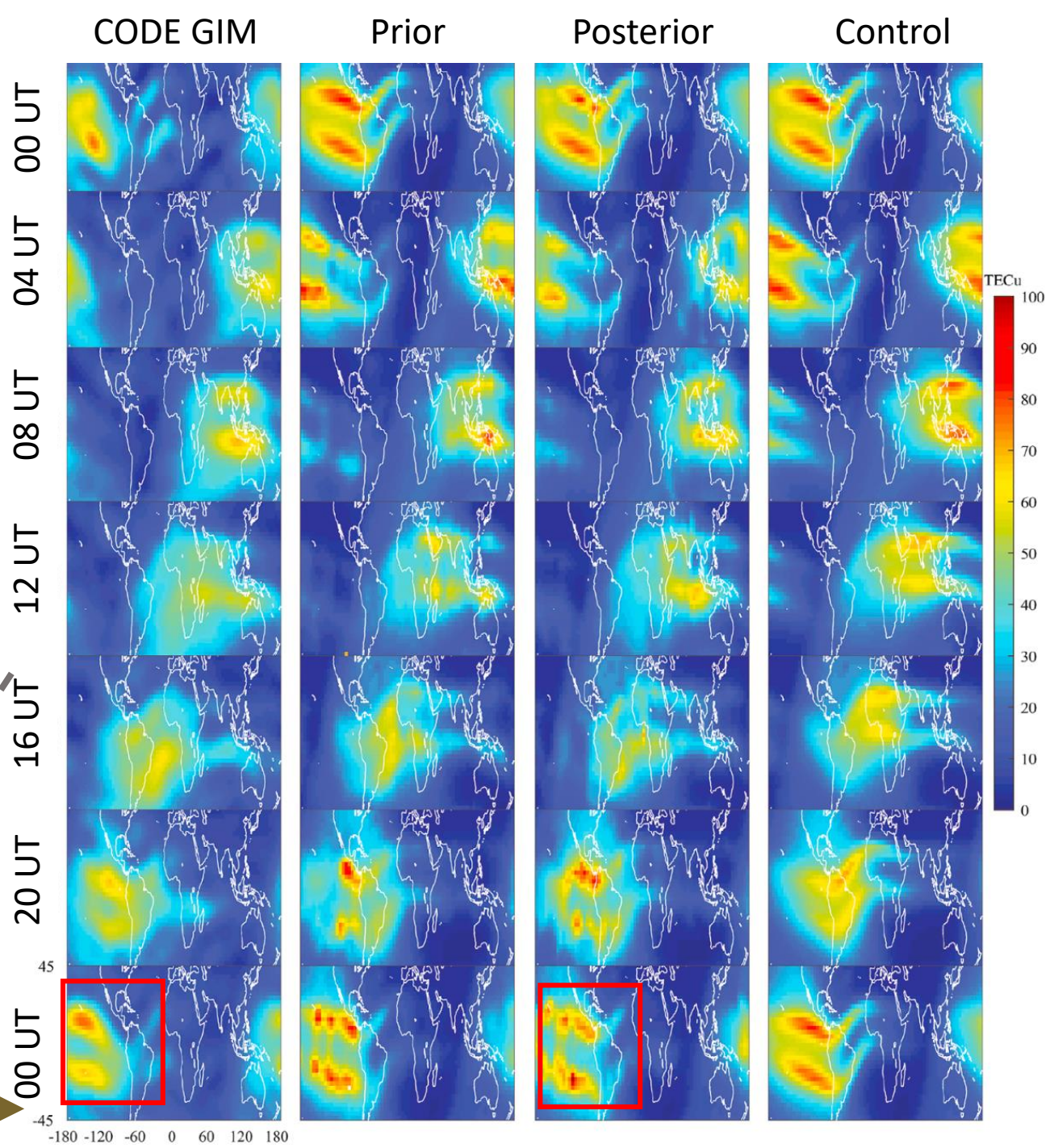
Independent observation

Nature Run (NR)

A. OSE of the FORMOSAT-3/COSMIC

- Observation: F-3/C RO during Jan. 1, 2013
- Validation data: CODE GIM
- Assimilation cycle: 1 hour
- Assimilation period: 24 hours

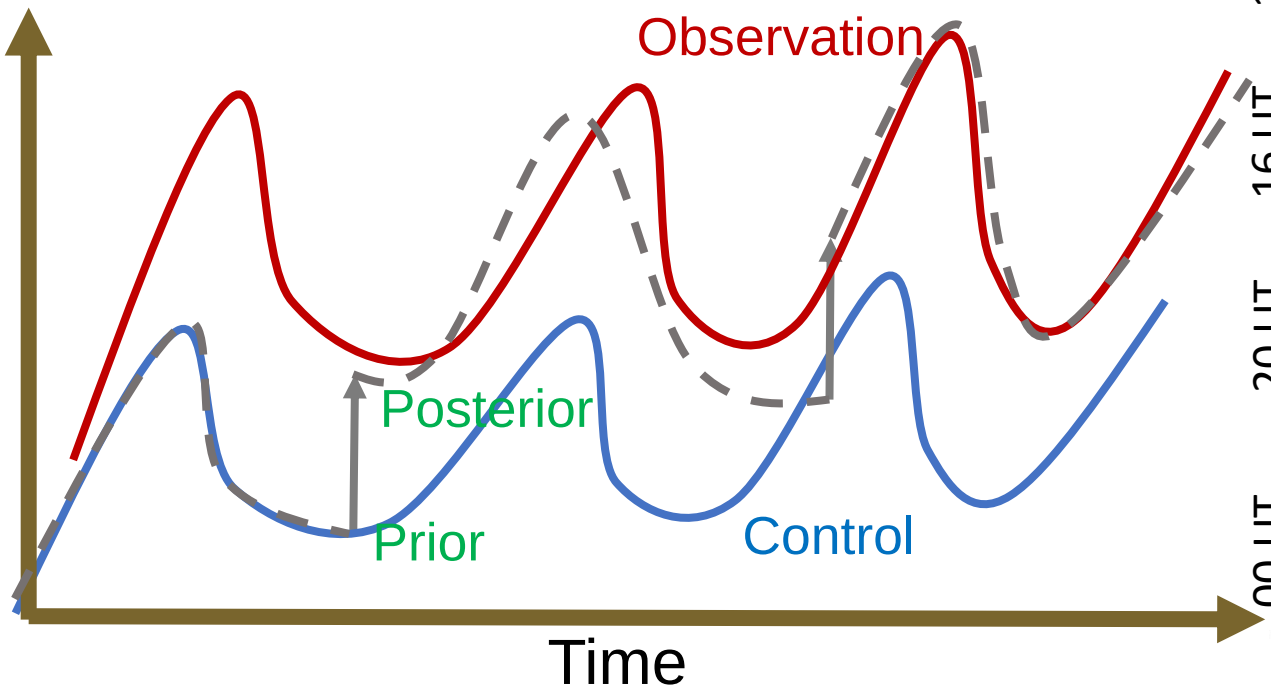


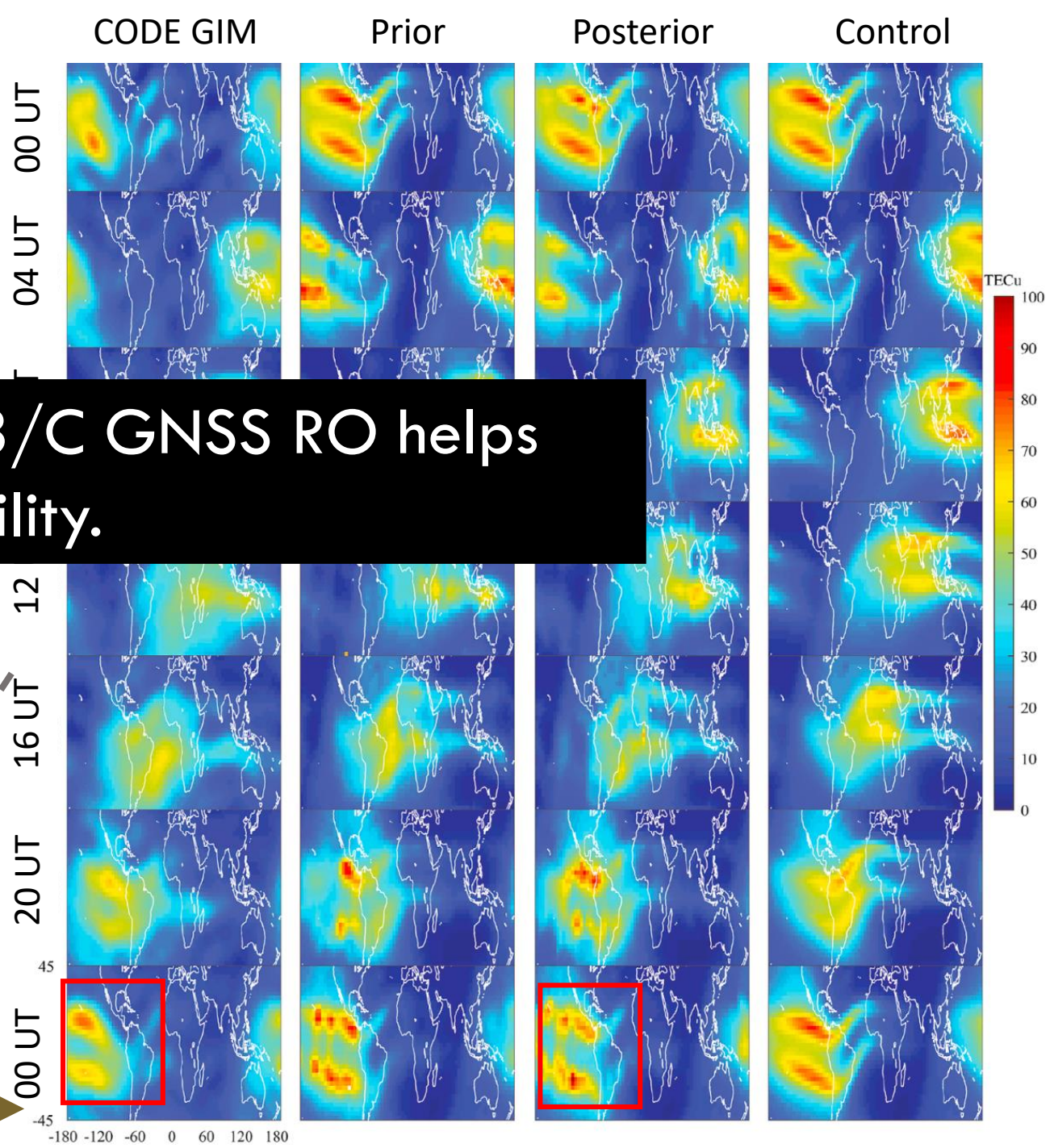


A. OSE of the FORMOSAT-3/COSMIC

- Observation: F-3/C RO during Jan. 1, 2013
- Valida
- Assimil
- Assimilation period: 24 hours

Remark 4: Assimilation of F-3/C GNSS RO helps introduce day-to-day variability.



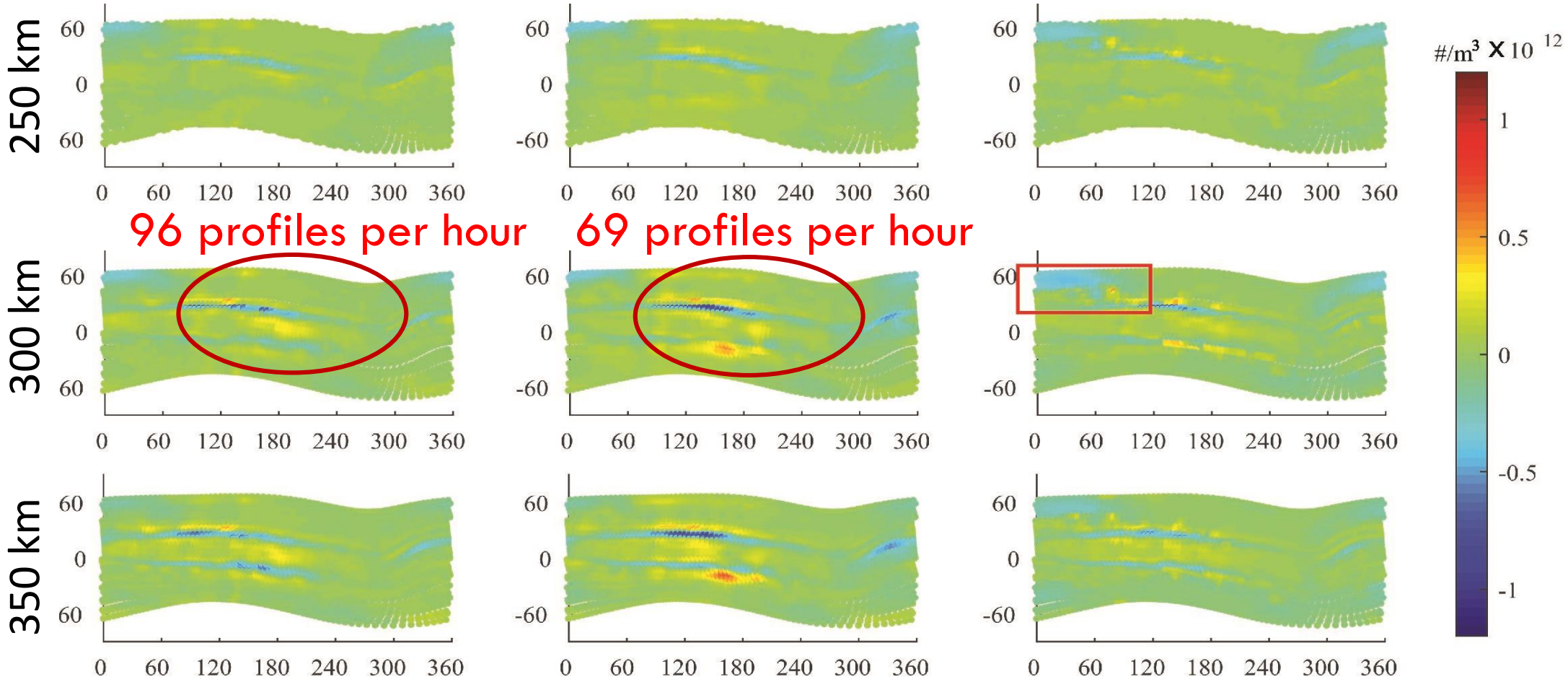


B. OSSEs for FORMOSAT-3/COSMIC & FORMOSAT-7/COSMIC-2

	OSSE-F3C-09	OSSE-F3C-13	OSSE-F7C2
Observing System	F3/C January 1 2009	F3/C January 1 2013	F7/C2
Average Number of sounding per hour	96	69	368
Horizontal Localization	10,000 km	10,000 km	5,000 km
Low & midlatitude RMSE (after 24-hour assimilation)			
High-latitude RMSE			

B. OSSEs for FORMOSAT-3/COSMIC & FORMOSAT-7/COSMIC-2

$$\bar{e}_{posterior} - \bar{e}_{NR}$$



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	OSSE-F3C-09	OSSE-F3C-13	OSSE-F7C2
Observing system	F3/C January 1 2009	F3/C January 1 2013	F7/C2
Average number of sounding per hour	96	69	368
Horizontal localization	10,000 km	10,000 km	5,000 km
Low & midlatitude RMSE ratio (after 24-hour assimilation)	0.39	0.51	**0.33**
High-latitude RMSE ratio	0.52	0.63	**0.74**

B. OSSEs for FORMOSAT-3/COSMIC & FORMOSAT-7/COSMIC-2

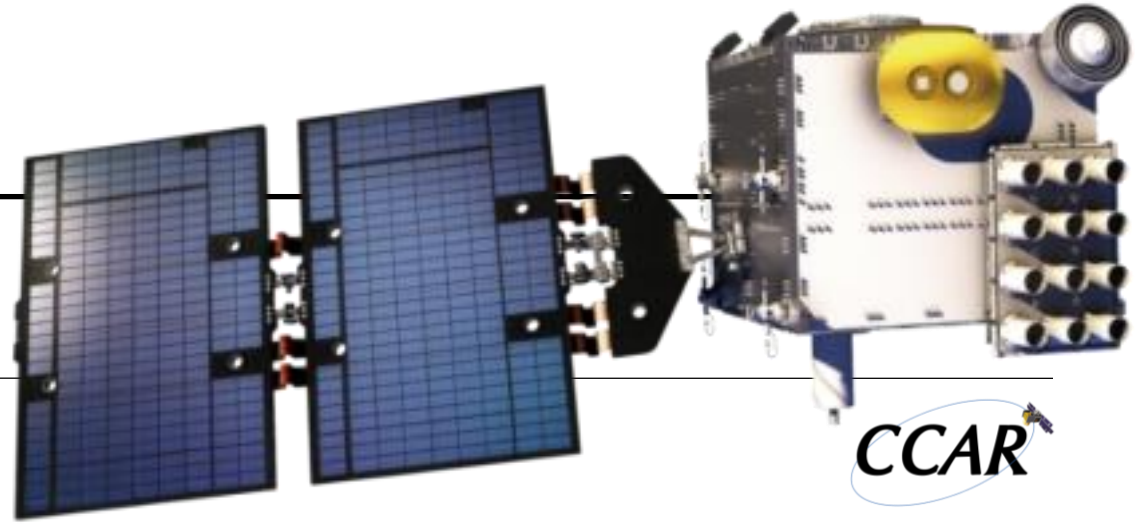
	OSSE-F3C-09	OSSE-F3C-13	OSSE-F7C2
Observing system	F3/C January 1 2009	F3/C January 1 2013	F7/C2
Average nu per hour			
Horizontal			
Low & mid (after 24-h			
High-latitu			

Remark 5: In comparison to the F-3/C, the F-7/C-2 has higher impact on ionospheric specification in mid- and low-latitude region.

Remark 6: Comparative OSSEs of the F-3/C (09 vs 13) shows importance of sufficient amount of RO coverage.

More Information on FORMOSAT-7/COSMIC-2

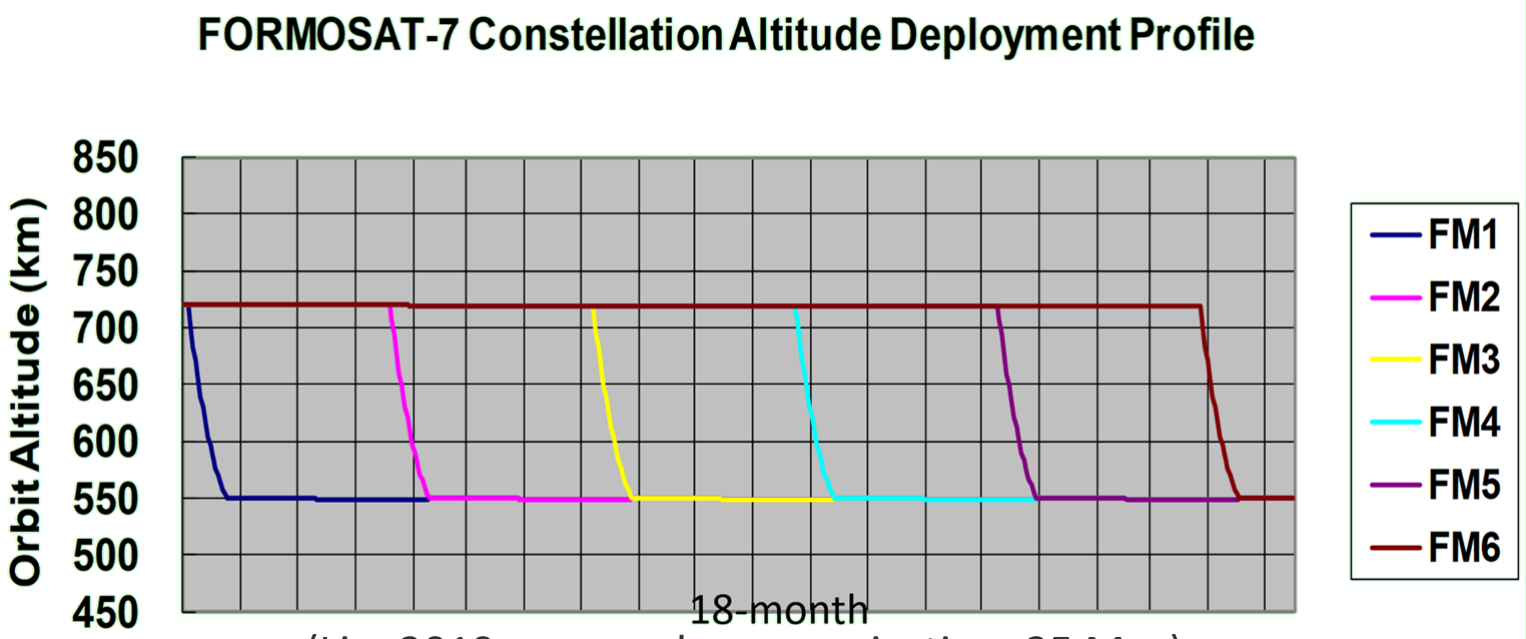
Orbit	Altitude 520~ 550 km, 24 degree inclination
Period	About 97 minutes
Constellation	6 SC to low-inclination-angle orbit
GNSS RO Payload	TGRS
Scientific Payload	IVM and RF Beacon Instrument
Launch Vehicle	Falcon Heavy
Launch Schedule	June 24, 2019
Mission Life	5 years



More Information on FORMOSAT-7/COSMIC-2

2019/1/28-30 — 2019/04 — LD-40~36 days — Launch Date (LD)

Pre-Ship Review & Operations Readiness Review	Shipping Satellites from NSPO to Launch Site	Mission Readiness Review & ESC#12



(Liu 2019, personal communication, 25 May)

Satellites will be separated to 6 orbital planes with 60-deg separation to a mission orbit of 520 km altitude **19 months after launch.**

Conclusions

- Optimization of EnSRF parameters (e.g. covariance localization) is important for each observing system. (Hsu et al., JGR, 2017)
- OSE shows that data assimilation of F-3/C RO sTEC can **introduce observed variability into the model**. (Hsu et al., ESS, 2018)
- OSSEs show that **F-7/C-2** can **improve the mid- and low-latitude ionospheric specification considerably by 33%**. (Hsu et al., ESS, 2018)
- **F-7/C-2 are going to be launched on 24th June !**

Relevant Poster: DATA03, Poster Section, Tuesday

References

Hsu, C.-T., Matsuo, T., Yue, X., Fang, T.-W., Fuller-Rowell, T., Ide, K., & Liu, J.-Y. (2018). Assessment of the impact of FORMOSAT-7/COSMIC-2 GNSS RO observations on midlatitude and low-latitude ionosphere specification: Observing system simulation experiments using Ensemble Square Root Filter. *J. Geophys. Res.: Space Phys.*, 123, 2296–2314.

Hsu, C.-T., Matsuo, T., & Liu, J.-Y. (2018). Impact of assimilating the FORMOSAT-3/COSMIC and FORMOSAT-7/COSMIC-2 RO data on the midlatitude and low-latitude ionospheric specification. *Earth and Space Sci.*, 5, 875–890.

Whitaker, J. & Hamill, T. M. (2002) Ensemble data assimilation without perturbed observations. *Mon. Wea. Rev.*, 130, 1913–1924.