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

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Data Assimilation of RO sTEC

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

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

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.

(Lin 2018, personal communication, 23 March)
Deterministic update by Ensemble Square Root Filter (EnSRF, Whitaker & Hamill, 2002) explained using Bayes’ rule

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

\[
X^a_n - \bar{X}^a = (X^b_n - \bar{X}^b) + \tilde{K}(-H(X^b_n - \bar{X}^b))
\]

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

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

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

\[
H P^b H^T \sim \frac{1}{N-1} \sum_{n=1}^{N} [H(X^b_n - \bar{X}^b)] [H(X^b_n - \bar{X}^b)]^T
\]
Deterministic update by **Ensemble Square Root Filter** (EnSRF, Whitaker & Hamill, 2002) explained using Bayes’ rule

\[
\tilde{X}^a = \tilde{X}^b + K(y^o - H(\tilde{X}^b))
\]

\[
X_n^a - \tilde{X}^a = (X_n^b - \tilde{X}^b) + 1/K(H(X_n^b - \tilde{X}^b))
\]

\[
K = [\rho^b \circ (P^b H^T)] [\rho^b \circ (H P^b H^T + R)]^{-1}
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**Remark 1:** Observed and estimated variables are different.
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.
25 experiments with ensemble size 70 (1750 model runs) and different covariance localization length scale for each observing system.

Remark 3: Localization length scales are different for each observing system.
Observing System (Simulation) Experiment

OSE

Real Observation Model Result

OSSE

Synthetic observation Model Result

Nature Run (NR)

Independent observation
### Observing System (Simulation) Experiment

#### 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.

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**OSE**

<table>
<thead>
<tr>
<th>Real Observation</th>
<th>Model</th>
<th>Result</th>
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**OSSE**

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CCAR
A. OSE of the FORMOSAT-3/COSMIC

- Validation data: CODE GIM
- Assimilation cycle: 1 hour
- Assimilation period: 24 hours
A. OSE of the FORMOSAT-3/COSMIC

- Validation data: CODE GIM
- Assimilation cycle: 1 hour
- Assimilation period: 24 hours

Remark 4: Assimilation of F-3/C GNSS RO helps introduce day-to-day variability.
<table>
<thead>
<tr>
<th>Observing System</th>
<th>OSSE-F3C-09</th>
<th>OSSE-F3C-13</th>
<th>OSSE-F7C2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F3/C</td>
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<tr>
<td></td>
<td>January 1 2009</td>
<td>January 1 2013</td>
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</tr>
<tr>
<td>Average Number of</td>
<td>96</td>
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<td>368</td>
</tr>
<tr>
<td>sounding per hour</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Horizontal Localization</td>
<td>10,000 km</td>
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<td>Low &amp; midlatitude RMSE</td>
<td></td>
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B. OSSEs for FORMOSAT-3/COSMIC & FORMOSAT-7/COSMIC-2

$e_{\text{posterior}} - e_{\text{NR}}$

OSSE-F3C-09

OSSE-F3C-13

OSSE-F7C2

250 km

300 km

350 km

96 profiles per hour

69 profiles per hour

# / m³ × 10⁻¹²
## B. OSSEs for FORMOSAT-3/COSMIC & FORMOSAT-7/COSMIC-2

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<td>0.39</td>
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<tr>
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**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

<table>
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<tr>
<th><strong>Orbit</strong></th>
<th>Altitude 520~ 550 km, 24 degree inclination</th>
</tr>
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<tbody>
<tr>
<td><strong>Period</strong></td>
<td>About 97 minutes</td>
</tr>
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<td><strong>Constellation</strong></td>
<td>6 SC to low-inclination-angle orbit</td>
</tr>
<tr>
<td><strong>GNSS RO Payload</strong></td>
<td>TGRS</td>
</tr>
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<td><strong>Scientific Payload</strong></td>
<td>IVM and RF Beacon Instrument</td>
</tr>
<tr>
<td><strong>Launch Vehicle</strong></td>
<td>Falcon Heavy</td>
</tr>
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<td><strong>Launch Schedule</strong></td>
<td>June 24, 2019</td>
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<td><strong>Mission Life</strong></td>
<td>5 years</td>
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More Information on FORMOSAT-7/COSMIC-2

2019/1/28-30  2019/04  LD-40~36 days  Launch Date (LD)
Pre-Ship Review & Operations  Shipping Satellites from NSPO to Launch Site  Mission Readiness Review & ESC#12

Liu 2019, personal communication, 25 May

FORMOSAT-7 Constellation Altitude Deployment Profile

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

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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
