Mitigation of ionospheric effects on Swarm GPS observations and kinematic orbits

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Motivation

Large high frequency noise at polar and equatorial areas

Systematic errors at geomagnetic bands along ±15° in the gravity field
Strategies to mitigate the impacts of scintillation

1) Simple elimination of noisy parts impacts:
   - Strength of the positioning reduced
   - Ambiguity estimation more difficult
   - Low degrees of gravity field solutions affected

2) Downweighting of noisy observations:
   - Many observations are disturbed simultaneously

3) Physically based mitigation of the impacts
Structure

1. Impact of ionospheric scintillations
2. Mitigation of the effects at polar areas
3. Mitigation of the effects at equatorial areas
4. Conclusions
1. Impacts of ionospheric scintillations

Two kinds of impact:
- Large high frequency noise at polar areas and some equatorial areas
- Systematic errors at equatorial areas
Filtering using Mátern family matrix

Step 1
- Preprocessing step
- Subtraction of the mean and polynomial fitting of the observations

OMC or detrended OBS

ΔOMC
Δ₄OBS
ΔGF

Step 2
- Noise detection in the preprocessed observations
- Rate of change $\left|\frac{d\sigma}{dt}\right|$ with $\sigma$ ionospheric free linear combination of carrier phase observations
- Empirical threshold $3\sigma \ 0.012 \text{ ms}^{-1}$

Step 3
- Extraction of the iono-TS: minimal length 250 s
- Filtering with adequate VCM

Mátern covariance matrix

Step 4
- Reconstruction of the observations
Mátern covariance matrix

- An adequate fully populated covariance matrix \( W \) is built based on the knowledge of the ionospheric spectral density:
  \[
  w(\tau) = (\alpha \tau)\nu K_\nu(\alpha \tau)
  \]

- The filtered time series corresponding to ionospheric scintillations is extracted from the identified time series:
  \[
  y' = \gamma \hat{y},
  \]
  with \( \hat{y} = W^{-\frac{1}{2}}y \), \( \gamma = \frac{\sigma_{\varphi,\text{ref}}}{\sigma_{\hat{y}}} \), and \( \sigma_{\varphi,\text{ref}} = 3 \text{ mm} \)

- The filtered time series have the similar spectral density with the normal observations, when \( \alpha = 1.5 \) and \( \nu = 1 \).
Improved kinematic orbit determination

Daily RMSE in radial direction can be reduced by around 20%.

DoY 333, 2015 Swarm A
Ionospheric filtering with OMC

November, 2015, Swarm A

Original

Filter OMC

PSD$^{1/2}$ of Res [cm/(Hz$^{1/2}$)]

PSD$^{1/2}$ of Res [cm/(Hz$^{1/2}$)]

Frequency [Hz]

Frequency [Hz]
Correction of systematic errors

DoY 135, 2015 Swarm A

Using white noise instead of systematic errors
Improved gravity field

Gravity field from original orbits
RMS = 1.047 m

Gravity field from corrected orbits
RMS = 0.718 m

Swarm A, April 2015
5. Conclusions

- Mátern covariance matrices with $\alpha = 1.5$ and $\nu = 1$ are used to mitigate the impact of noise increase due to ionospheric scintillations and these homogenize the observation noise.

- The high frequency noise caused by ionospheric scintillations is strongly eliminated using Mátern covariance matrix, with 20% in the radial direction.

- Systematic errors at equatorial areas can be eliminated using white noise instead, in order to reduce the errors in the gravity field.
Thank you for your attention