SCANF: A Simultaneous Cycle Slip And Noise Filter For GNSS Radio Occultation Signal Processing

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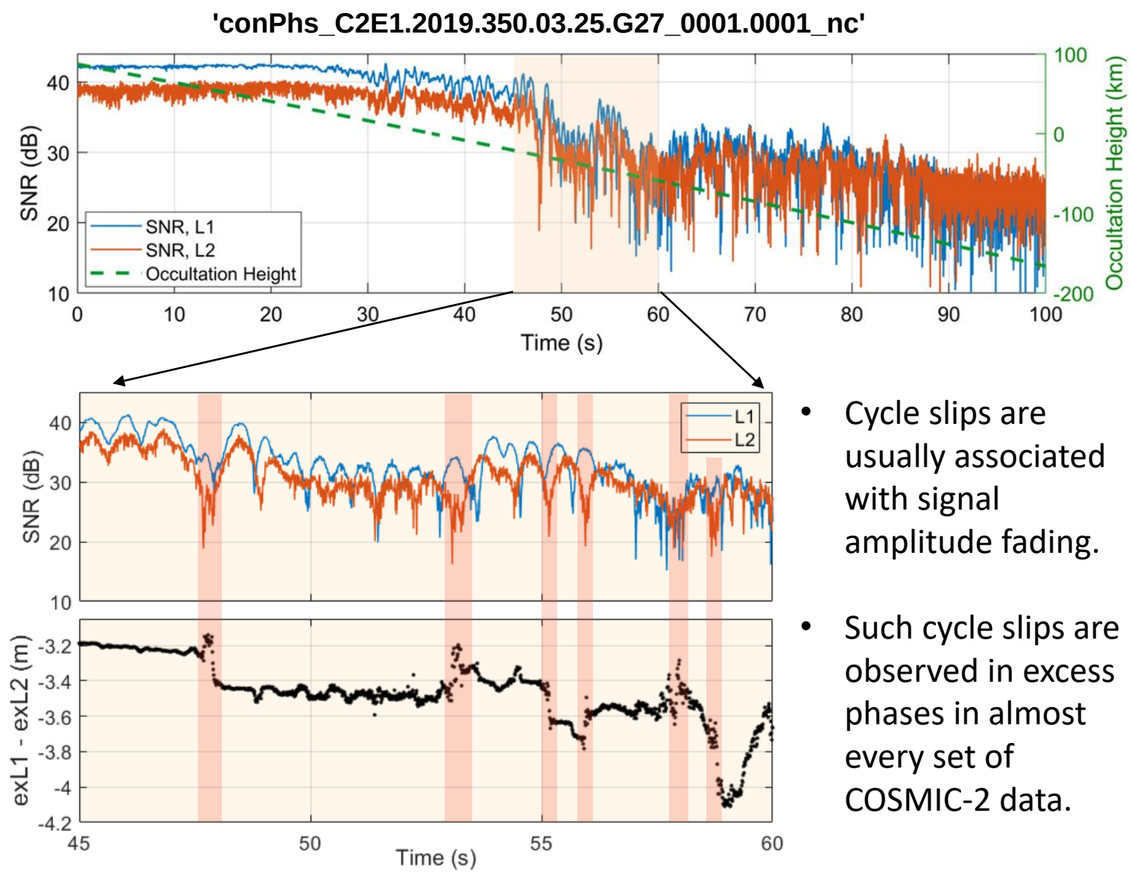
1. Introduction

Cycle slips in carrier phase estimations are a major error source in GNSS-RO retrievals and lead to the rejection of a large number of measurements in critically needed regions. Cycle slips occur when the signal SNR is low. For GNSS-RO, low SNR is associated with signals traversing the lower troposphere and plasma irregularities in the ionosphere. This poster introduces SCANF, a state-based filtering method to unwrap GNSS-RO phase measurements from high-rate Open Loop (OL) tracking to mitigate cycle slips. It can be summarized as follows:

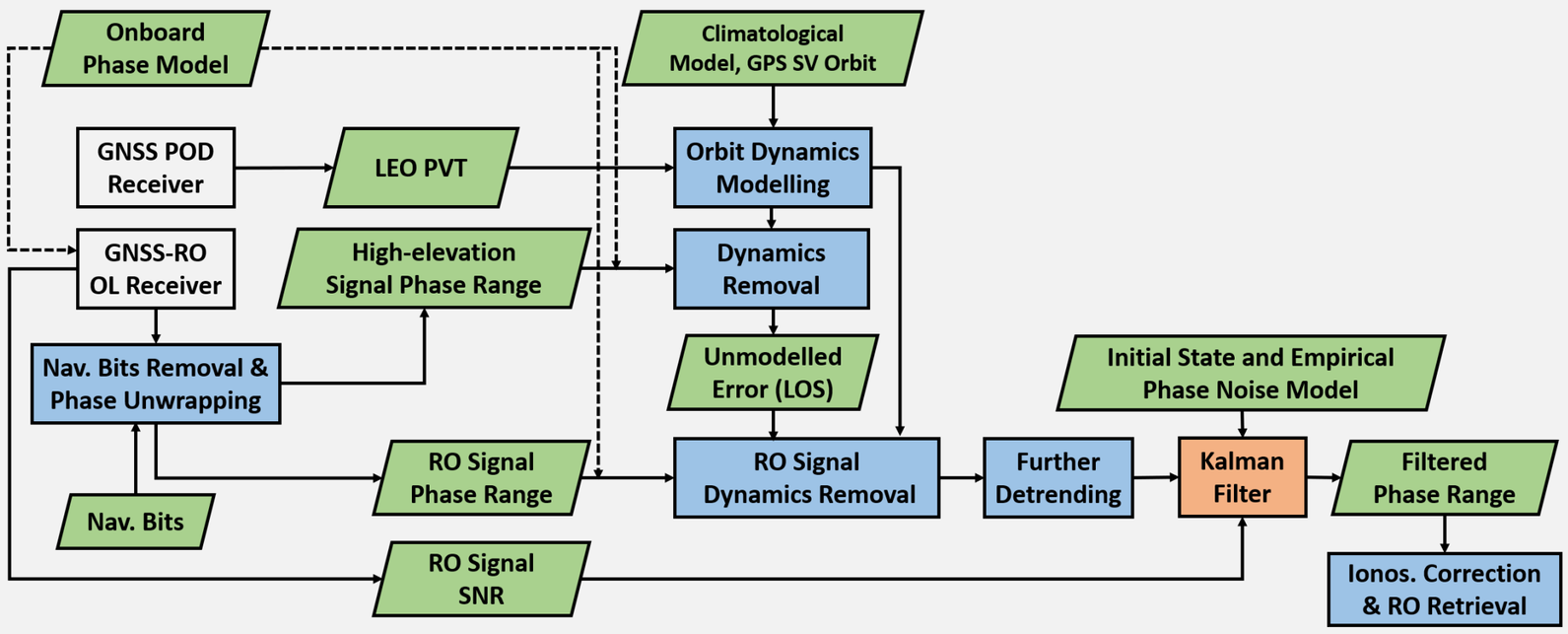
1) The SCANF inputs are raw dual-frequency phase measurements from OL tracking after removing navigation data bits and phase dynamics such as precise orbits, high-rate clock biases, climatological models, etc.;
2) The residual phase dynamics is modeled based on contributions from the ionospheric effects (dispersive) and the mis-modeled portion of the tropospheric effects (non-dispersive) with a carefully chosen noise covariance matrix;
3) The measurement model adopts an adaptive noise covariance based on high-rate SNR estimations;
4) A Kalman filter takes the above information to estimate integer-cycle biases which contain cycle slips and reduces noise contributions.

2. COSMIC-2 Cycle Slips Example



- Cycle slips are usually associated with signal amplitude fading.
- Such cycle slips are observed in excess phases in almost every set of COSMIC-2 data.

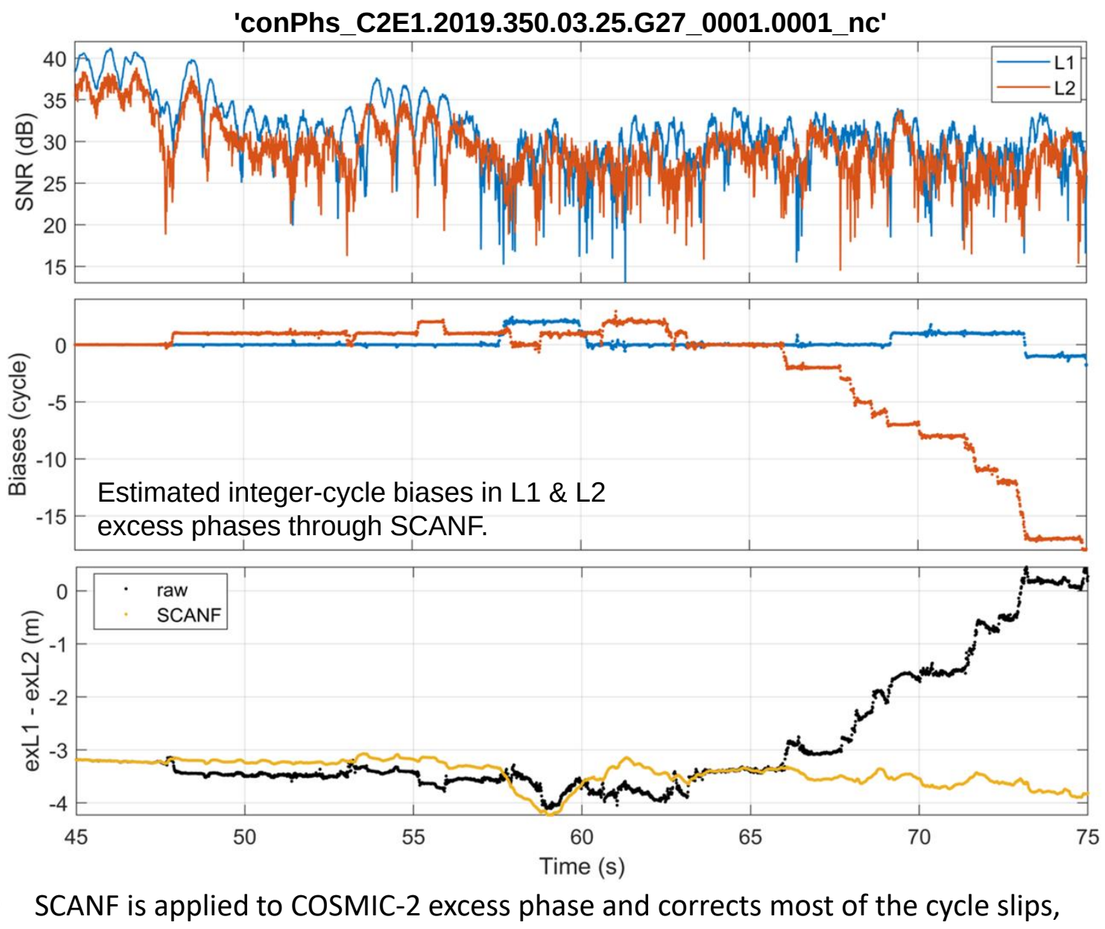
3. Simultaneous Cycle-slips And Noise Filtering (SCANF)



Algorithm. SCANF

Input: $\hat{\Phi}_{L1}$, $\hat{\Phi}_{L2}$, $C/N_{0,L1}$, $C/N_{0,L2}$
Output: $\mathbf{x}^+$, $\mathbf{P}^+$
Initialization:
$k \leftarrow 1$
$\mathbf{x}^+[k-1] \leftarrow \left[\hat{\Phi}_{L1}[0]\ \hat{\Phi}_{L2}[0]\ 0\ 0\right]^T$
$\mathbf{P}^+[k-1] \leftarrow \mathbf{P}[0]$
while $k \leq \text{length}(\hat{\Phi}_{L1})$ **do**
Prediction:
$\mathbf{x}^-[k] \leftarrow \mathbf{A}\mathbf{x}^+[k-1]$
$\mathbf{P}^-[k] \leftarrow \mathbf{A}\mathbf{P}^+[k-1]\mathbf{A}^T + \mathbf{Q}$
Bias Estimation:
Find $m_{L1}, m_{L2} \in \mathbb{Z}$:
that minimizes $|\ \mathbf{y}[k] - \mathbf{H}\mathbf{x}^-[k] - \mathbf{B}[k]\ |$
for $\mathbf{B}[k] = \left[\lambda_{L1} m_{L1}\ \lambda_{L2} m_{L2}\right]^T$
Update:
$\mathbf{K}[k] \leftarrow \mathbf{P}^-[k]\mathbf{H}^T(\mathbf{H}\mathbf{P}^-[k]\mathbf{H}^T + \mathbf{R}[k])^{-1}$
$\mathbf{x}^+[k] \leftarrow \mathbf{x}^-[k] + \mathbf{K}[k](\mathbf{y}[k] - \mathbf{x}^-[k] - \mathbf{B}[k])$
$\mathbf{P}^+[k] \leftarrow (\mathbf{I} - \mathbf{K}[k]\mathbf{H})\mathbf{P}^-[k]$
$k \leftarrow k + 1$

4. Cycle Slips Correction Results



- SCANF is applied to COSMIC-2 excess phase and corrects most of the cycle slips, which correspond to an excess phase error of ~4m.
- The receiver clock fluctuations (with a magnitude of several centimeters) were not removed before applying SCANF (high-rate receiver clock bias estimates are not available from COSMIC-2).

5. Conclusion and Future Work

- The SCANF method is applied to sample COSMIC-2 excess phase measurements and demonstrated effectively mitigate cycle slips. Due to lack of true reference, the performance needs to be further evaluated based on the RO retrievals using the SCANF outputs.
- The performance of SCANF can be improved for GNSS-RO by removing the receiver clock fluctuations from the input phases and characterizing the phase dynamics due to ionospheric and/or tropospheric effects. The characterization is being conducted based on data from mountain-top RO experiments in Haleakala, Hawaii.
- The research being conducted also includes cycle slips correction for triple-frequency RO measurements, new algorithms for GNSS-RO baseband signal processing, etc.

Acknowledgement

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Reference

[1] Wang, Y., B. Breitsch and Y. T. J. Morton, "A State-Based Method to Simultaneously Reduce Cycle Slips and Noise in Coherent GNSS-R Phase Measurements From Open-Loop Tracking," in *IEEE Transactions on Geoscience and Remote Sensing*, doi: 10.1109/TGRS.2020.3036031.

[2] Morton, Yu, et al. "Keynote: Mountain-top radio occultation with multi-GNSS signals: Experiment and preliminary results." Proceedings of the ION 2017 Pacific PNT Meeting. 2017.