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The Benefit of Triple Frequency on Cycle Slip Detection

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Introduction

- At the time of writing, all the Global Navigation Satellite Systems support or are designed to support triple- or multi- frequency, which is expected to have advantages over single- and dual- frequency.
- Correctly detecting and repairing cycle slips can help extend the latency of the fixed ambiguities, estimate the ionospheric delay, reduce the measurement noise and finally improve the positioning precision of the carrier phase.
- This paper will conduct research on how triple-frequency can benefit the cycle-slip detection process.

Method Review

- High-order phase differencing
  1. Single frequency
  2. 3-order differencing
  3. Based on the assumption that the ionospheric bias, tropospheric bias, satellite orbit error, satellite and receiver clock errors vary smoothly with time
  4. A cycle slip may break this assumption, making the detection value not fit the polynomial derived from the former 10 epochs.

- Doppler integration
  1. Single frequency
  2. Doppler measurements are only affected by rates of biases, such as ionospheric bias
  3. Part of the bias is eliminated in the calculation
  4. A cycle-slip may break the agreement between the Doppler measurement and the time-differenced phase measurement

Method Review

- Ionospheric residual
  1. Dual frequency
  2. Ionospheric residual can be used as the detection value, as a cycle slip could bring a sudden jump in the ionospheric residual
  3. Very precise but it is not easy to decide which frequency the cycle slip occurs and the magnitude

Method Review

- **Triple-frequency cycle-slip detection**

✓ **Step 1**

$$\Delta N_{(0,1,-1)} = \frac{\Delta P_{(0,1,1)} - \Delta\Phi_{(0,1,-1)}}{\lambda_{(0,1,-1)}}$$

$$\left|\Delta N_{(0,1,-1)}\right| > 0.5$$

$$\Delta\breve{N}_{(0,1,-1)} = \left[\Delta N_{(0,1,-1)}\right]_{\text{round-off}}$$

$$\Delta\breve{\Phi}_{(0,1,-1)} = \Delta\Phi_{(0,1,-1)} + \lambda_{(0,1,-1)}\Delta\breve{N}_{(0,1,-1)}$$

✓ **Step 2 & 3**

$$\Delta N_{(i,j,k)} = \frac{1}{\lambda_{(i,j,k)}}\left(a\Delta P_1 + b\Delta P_2 + c\Delta P_3 + d\Delta\breve{\Phi}_{(0,1,-1)} - \Delta\Phi_{(i,j,k)}\right)$$

Method Review

- Method to decide optimal combined signals and coefficients
  1. Noise level
  2. Ionospheric effect

- Optimal combined signals
  - (1,-6,5) and (4,-5,0)

Modified Hatch Melbourne Wübbena combination

Method partly published in:

Zhao et al (2017), *Cycle-slip Detection for Triple-frequency GPS Observations Under Ionospheric Scintillation*, ION GNSS+, Portland Oregen USA

Full method currently under review

Numerical Tests

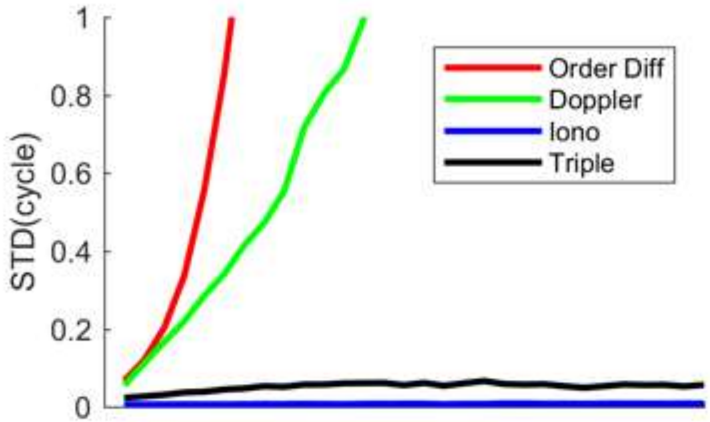
- Configuration

1. The original 1s observations are decimated into intervals up to 30s.
2. All data samples are divided based on satellite elevation angles, such as 5°~20°, 20°~40°, 40°~60° and >60°.
3. Artificial cycle slips with magnitude from 1 to 20 are added into all these samples.

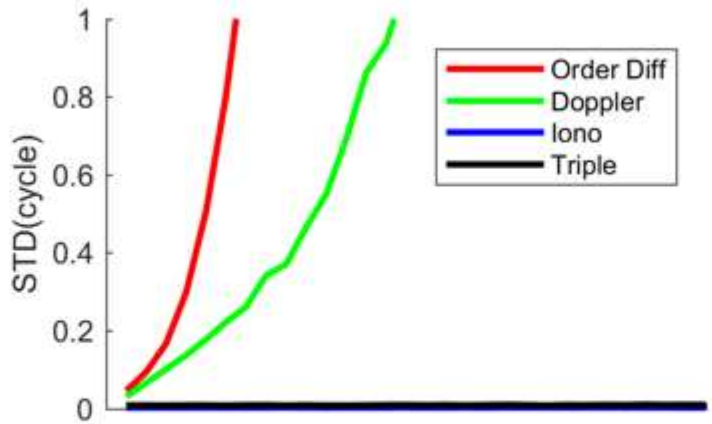
- Criteria to evaluate the performance

1. Standard deviation (STD) of the detection value
2. Missed detection rate (MR) : the ratio of the false alarms to the number of the total epochs using the data samples without artificial cycle slips
3. Success rate (SR) : ratio of the correctly detected to the totally added cycle slips

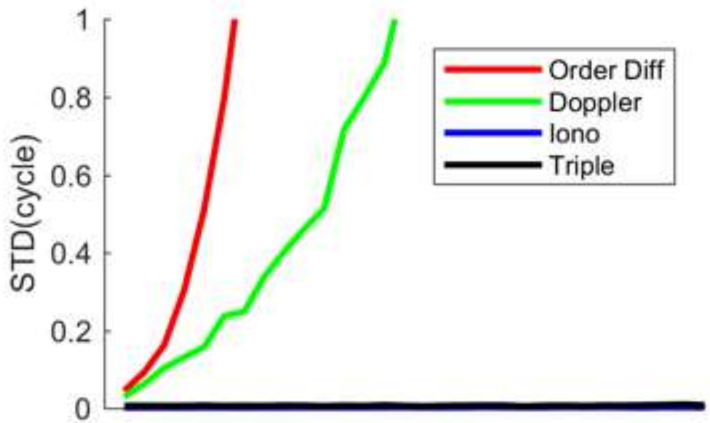
The standard deviation of the detection values



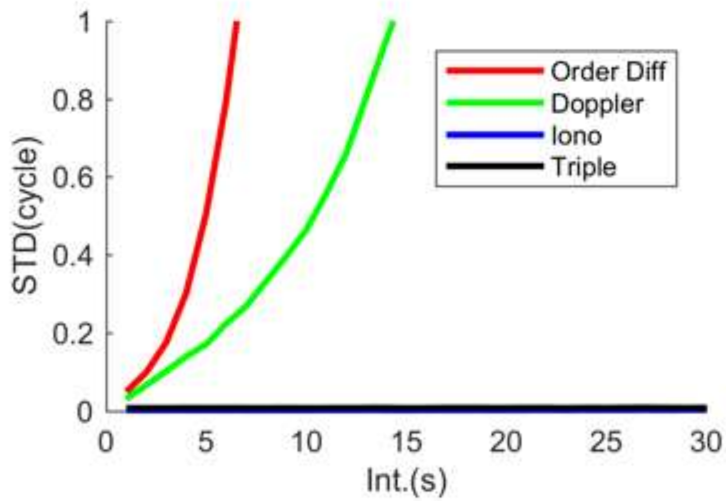
5°~20°



40°~60°

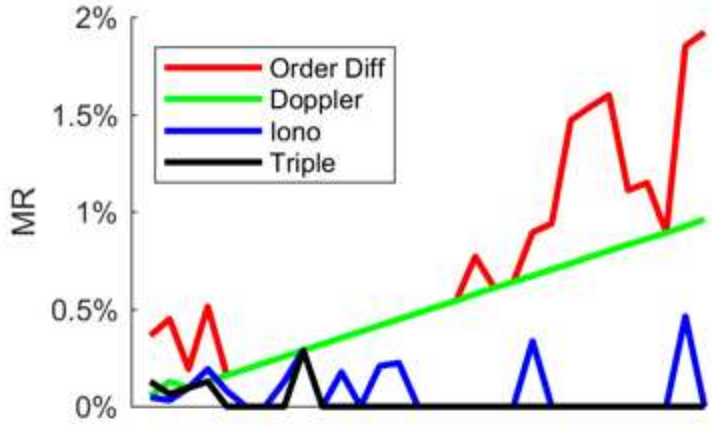


20°~40°

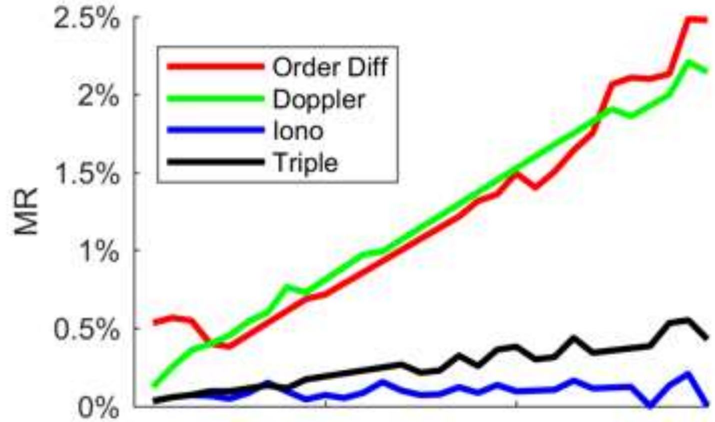


>60°

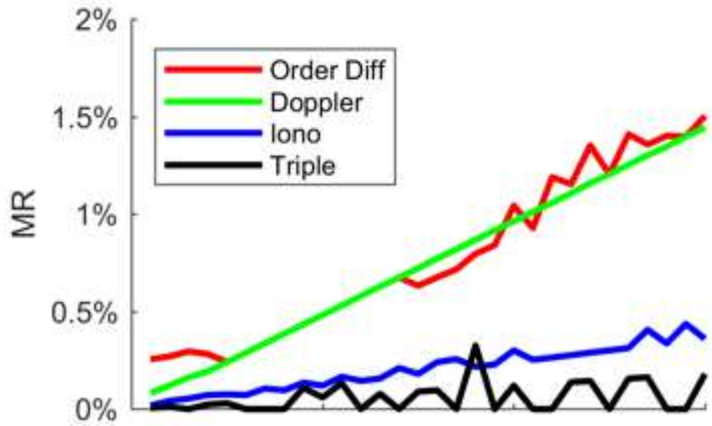
The missed detection rate



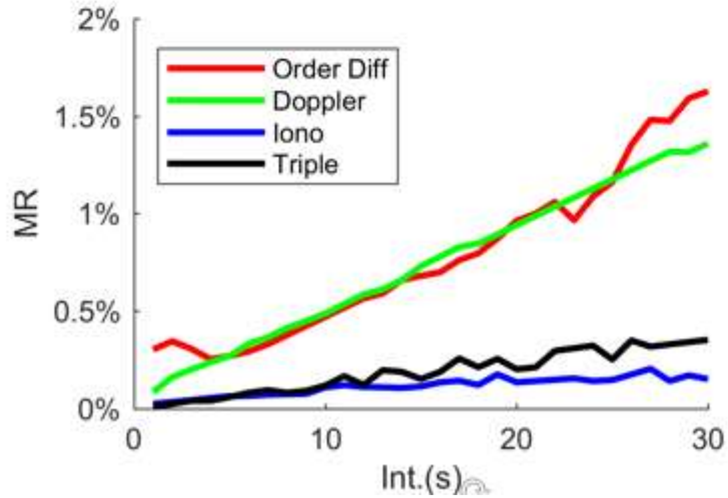
5°~20°



40°~60°



20°~40°



>60°

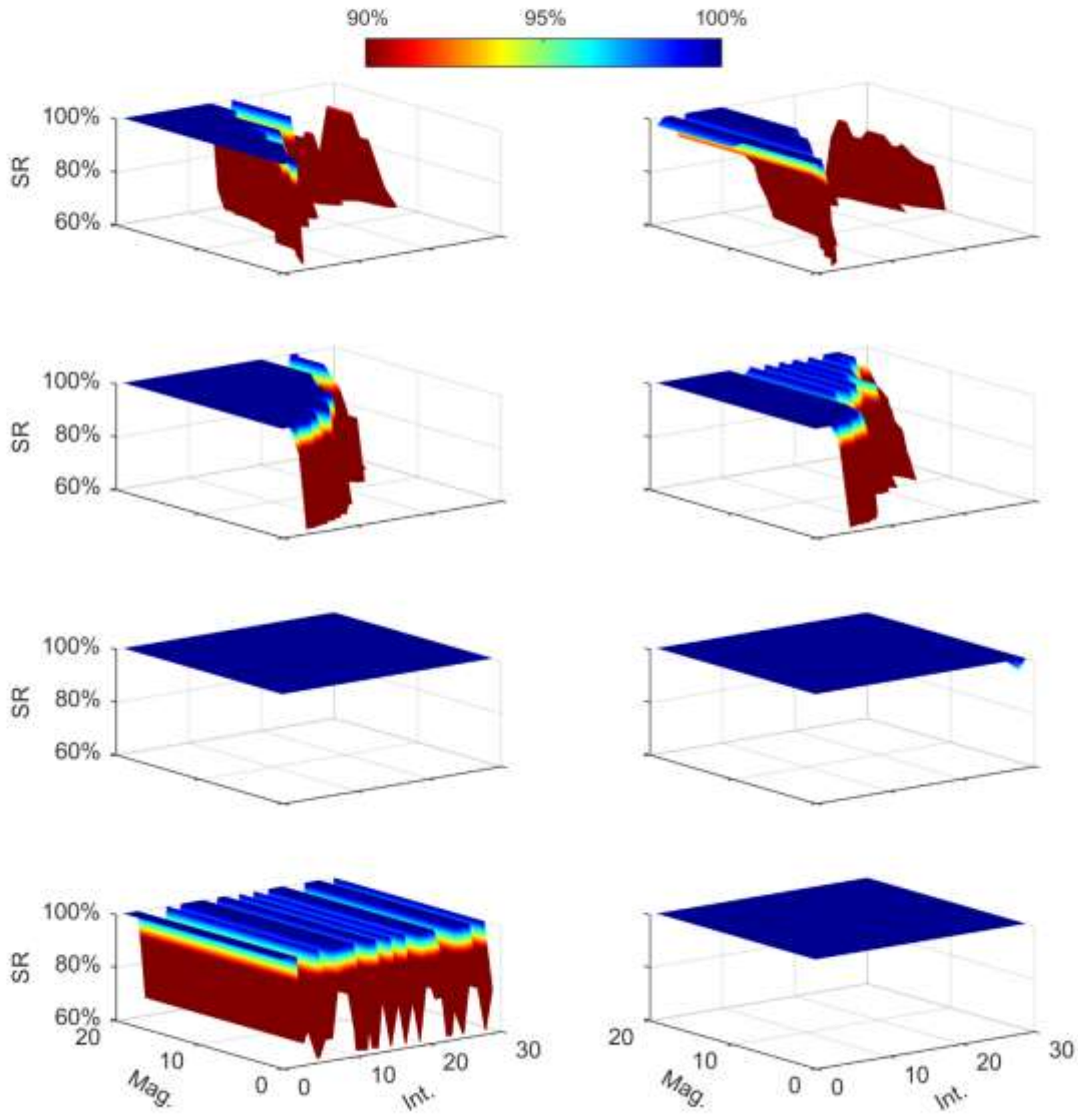
The success rate

High-order phase differencing

Doppler integration

Ionospheric residual

Triple-frequency



5°~20° 20°~40°

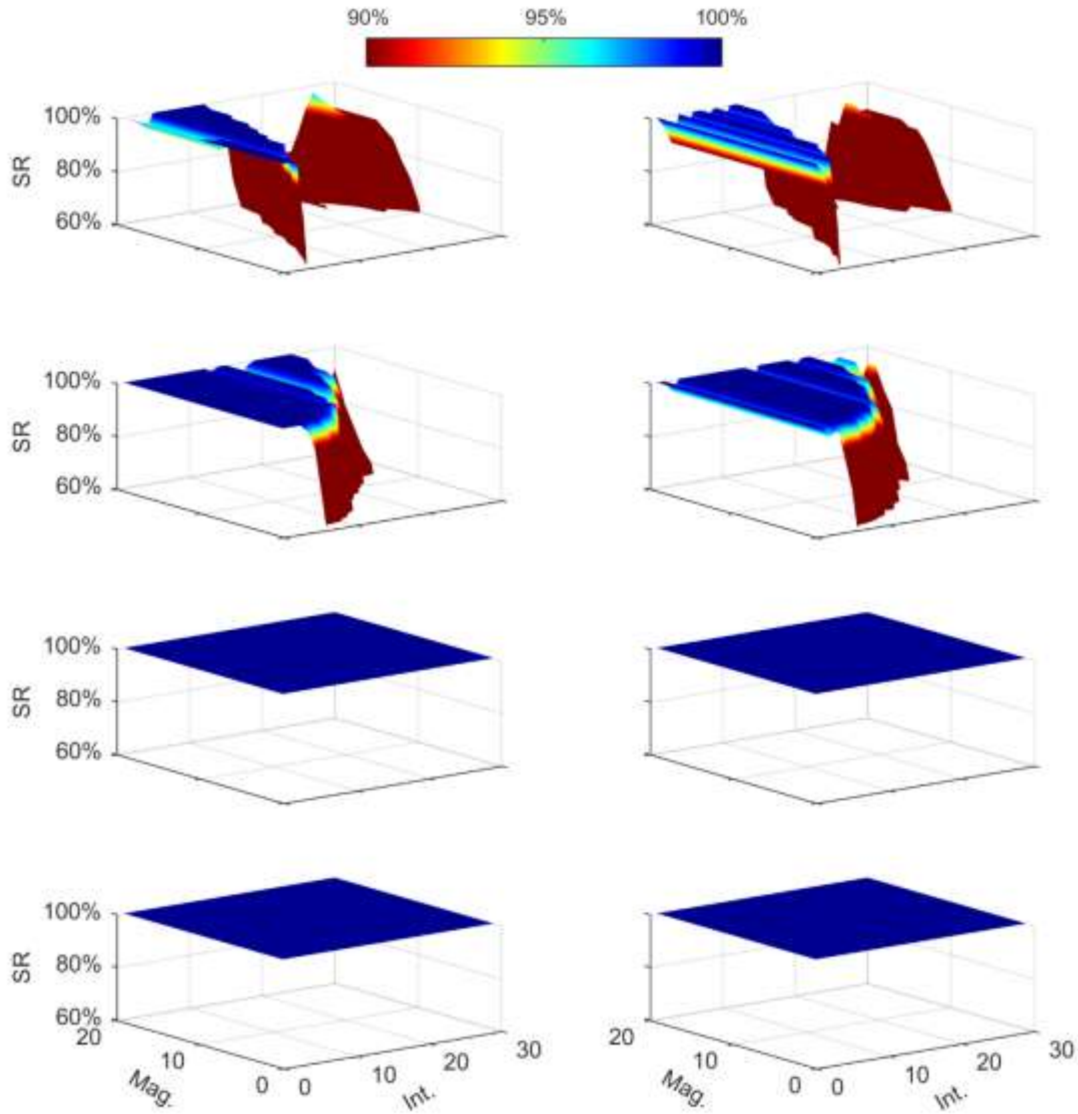
The success rate

High-order phase differencing

Doppler integration

Ionospheric residual

Triple-frequency



40°~60° >60°

Conclusions

- Compared to the high-order phase differencing and the Doppler integration, the proposed triple-frequency cycle-slip detection method can provide a more reliable performance
- For observations with low elevation angles, not all the cycle slips can be detected by the triple-frequency method. In such cases, the ionospheric residual could help, although it cannot fix the slips in real time.

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Thank you! Any Questions?

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