Swarm GPS Receiver Performance under the Influence of Ionospheric Scintillation

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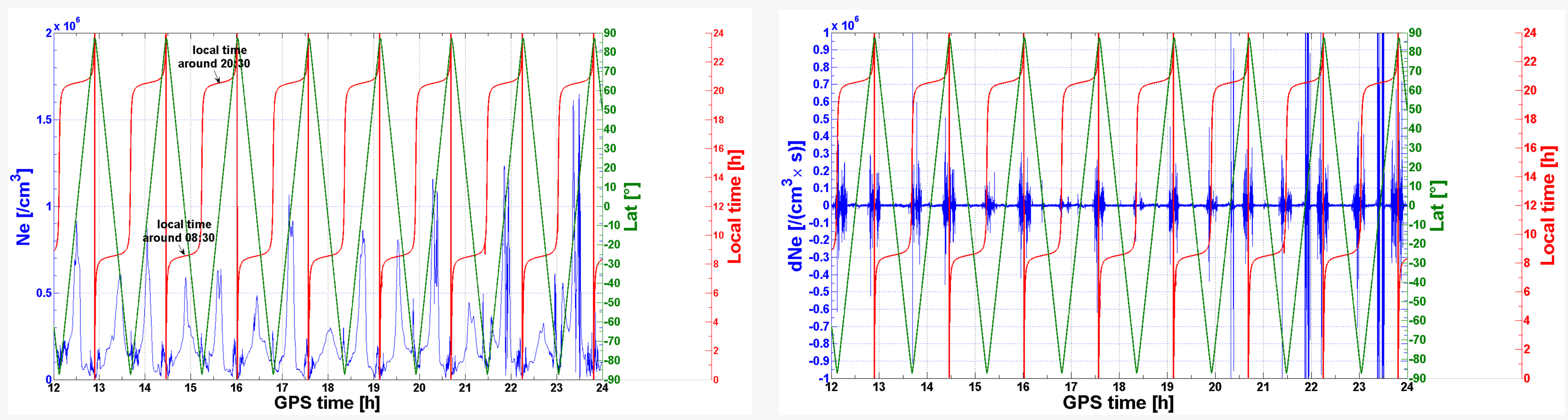
Introduction

The Swarm mission launched on November 22, 2013 is ESA's first constellation of satellites to study the dynamics of the Earth's magnetic field and its interaction with the Earth system. This mission consists of three identical satellites in near-polar orbits, two flying almost side-by-side at an initial altitude of 460 km, the third flying in a higher orbit of about 530 km. Each satellite is equipped with a high precision 8-channels dual-frequency GPS receiver for precise orbit determination, which is the essential fundament in order to take full advantage of the data information provided by this constellation, e.g. for the recovery of gravity field. The quality of the final orbit determination depends on the observation data from the receivers.

In this contribution, we will analyse the performance of the Swarm on-board receivers, especially under the influence of ionospheric scintillation, which can lead to the phase disturbances, cycle slips, or even loss of signal tracking. This analysis is a prerequisite for high quality satellite positioning as well as a sound study of the ionosphere. The performance of receivers on three Swarm satellites are similar, so the analyse will mainly focus on Swarm A.

Ionospheric Electron Density

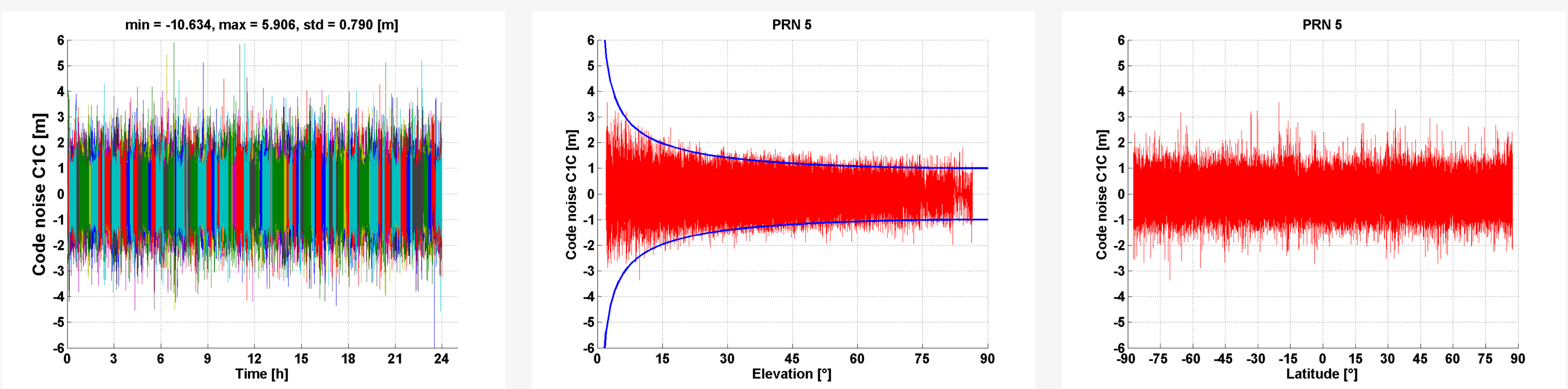


(a) Ionospheric electron density (b) Rate of ionospheric electron density

Fig. 1: Ionospheric electron density and its rate at Swarm altitude for Swarm A from 12-24 h on day 333 of 2015

- Ionospheric scintillation is caused by the irregularities in electron density as the wave travels through the ionosphere.
- The ionospheric electron density is derived from the current measured at the Electric Field Instrument (EFI) on Swarm satellite
- At high latitude area (above 60°) the ionospheric electron density is low but varies often rapidly.
- At equatorial area ionospheric irregularities do not occur every time. From 12:00 to 20:00 the electron density is high but changes slowly and after 20:00 the ionosphere becomes very active (around 20:30 local time).
- At mid-latitude there is generally no ionospheric scintillation.

Code Noise

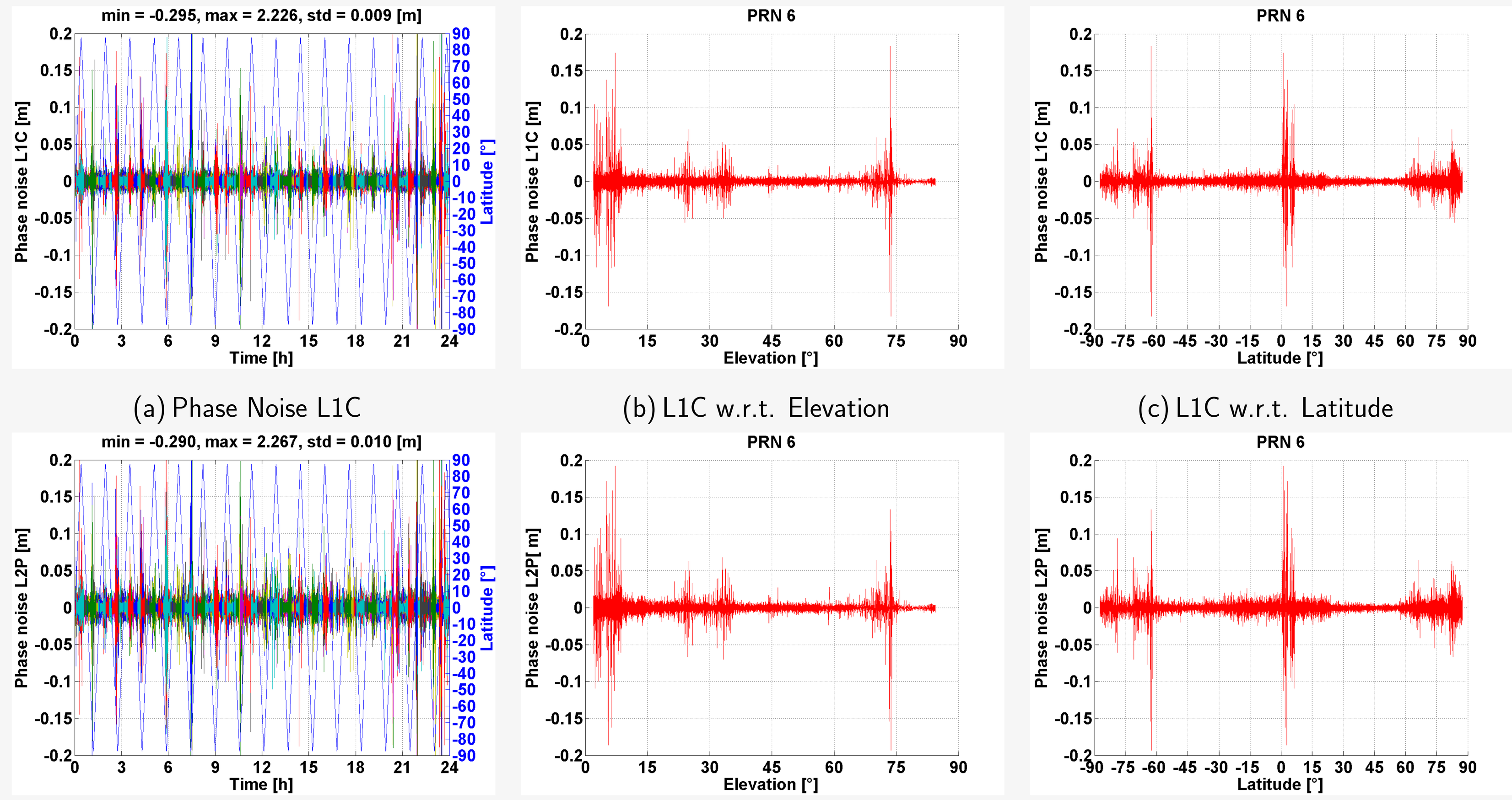


(a) C1C for all GPS satellites (b) C1C w.r.t Elevation for PRN 5 (c) C1C w.r.t Latitude for PRN 5

Fig. 2: C1C Noise for Swarm A on Day 333 of 2015 derived from multipath linear combination

- 99% of the code noise is smaller than 2m. (Fig.3a)
- Standard deviation of the code noise is around 0.8m, which is much larger than the standard deviation 0.13m determined by means of double-difference zero-baseline on-ground test from Zangerl (2014).
- No significant elevation-dependence above 15°.
- Latitude-independence reveals that the code observations are not disturbed by the ionospheric scintillation. (Fig.3c)

Phase Noise



(a) Phase Noise L1C (b) L1C w.r.t. Elevation (c) L1C w.r.t. Latitude
(d) Phase Noise L2P (e) L2P w.r.t. Elevation (f) L2P w.r.t. Latitude

Fig. 3: L1C and L2P Noise for Swarm A on Day 333 of 2015, derived from 2-times differentiations of successive phase observations from RINEX file after removing geometric distance , local orbit time ascend ≈ 20 : 30, *decend* ≈ 08 : 30

- Since the quality of the final kinematic products depends completely on the GPS observation data available, the accuracy of carrier phase is most important to the orbit determination.
- Large noise occurs periodically at the equator after 20h (GPST) in ascending arcs and during whole day at high latitude area ((Fig.3a,d)), where ionospheric scintillation occurs often (Fig.1).
- Satellites at high elevations are also affected by ionospheric scintillation (Fig.3b,e).
- The disturbances on L1 and L2 are similar.

Cycle Slip

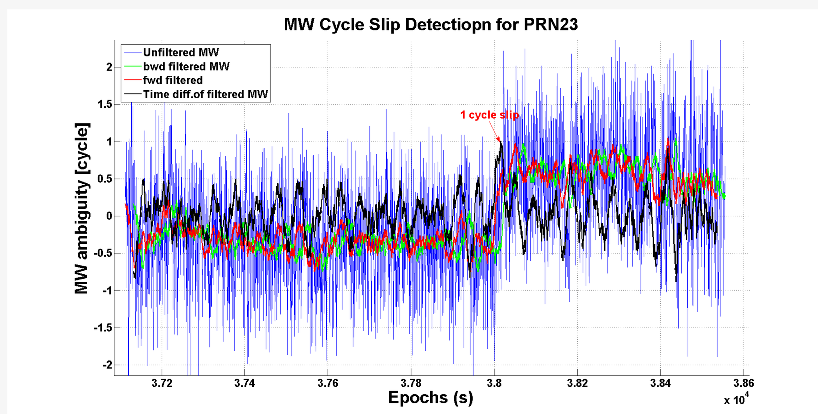


Fig. 4: Cycle slip detection with Melbourne-Wübbena combination using FBMWA methode

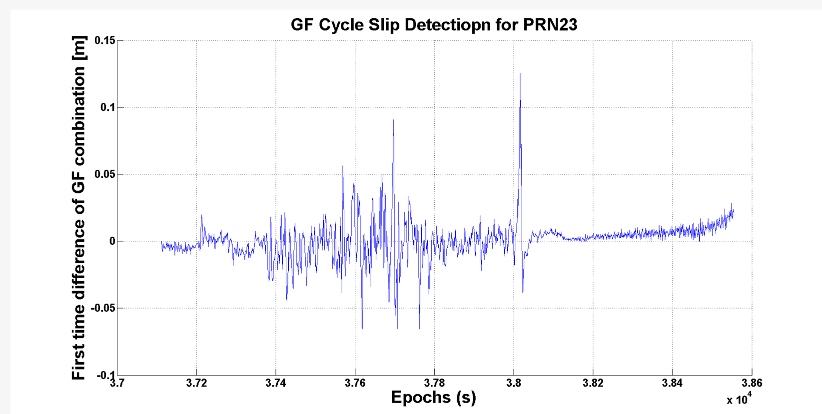
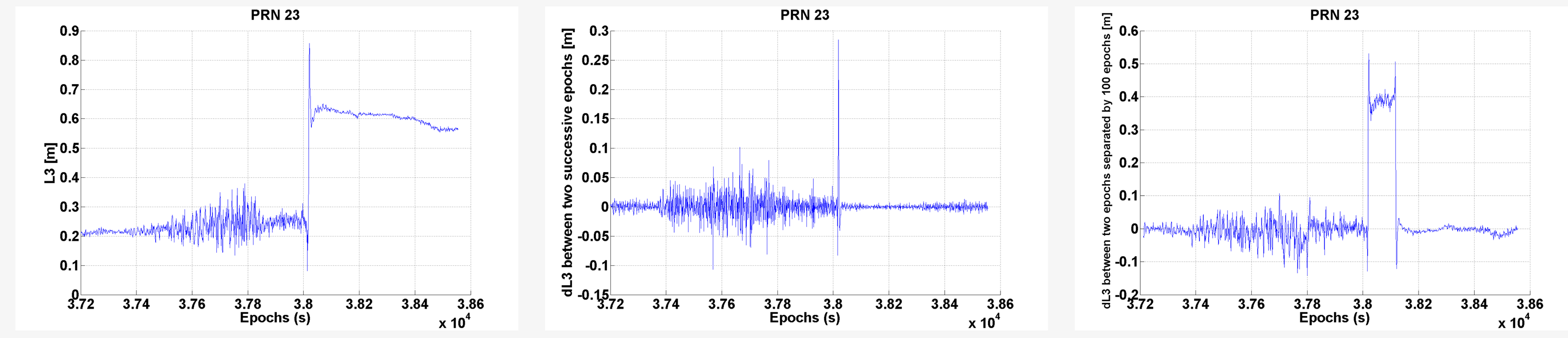


Fig. 5: Cycle slip detection with geometry-free combination

- Using Melbourne-Wübbena and ionosphere-free combination together, the cycle slip can be detected and repaired .
- Due to the large code noise, small cycle slips (1 or 2) cannot be detected with the classical TurboEdit methode (Blewitt) with Melbourne-Wübbena combination. So a forward and backward moving window averaging (FBMWA) method is applied to reduce the influence of large noise (Cai, 2013) (Fig.4).
- Due to the rapid variation of the ionospheric delays and the large phase noise at ionosphere active areas, the geometry-free combination is not suitable for Swarm receivers (Fig.5),

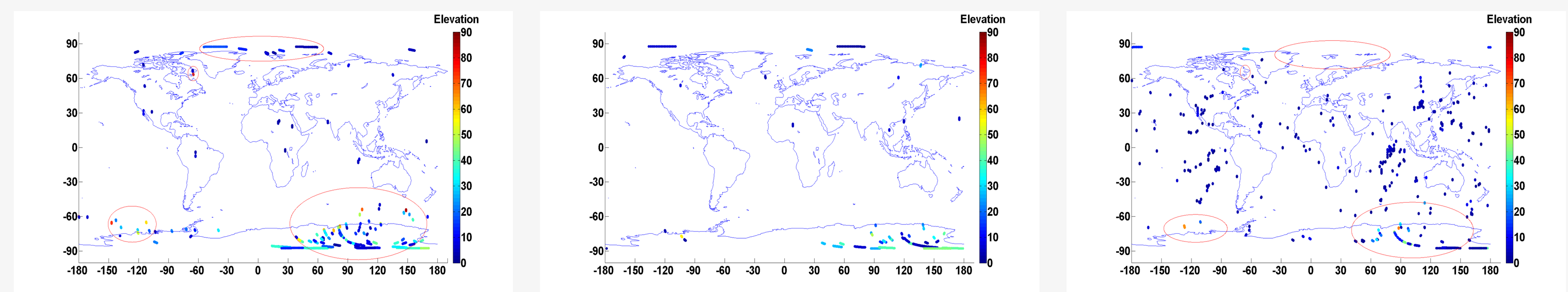


(a) Ionosphere-free combination $L_3 - \rho' - c\delta t_r = N$
(b) $\Delta_1 L_3$ between two successive epochs $\Delta_1 L_3 - \Delta_1 \rho' - c\Delta_1 \delta t_r = \Delta_1 N$
(c) $\Delta_{100} L_3$ between two epochs separated by 100 epochs $\Delta_{100} L_3 - \Delta_{100} \rho' - c\Delta_{100} \delta t_r = \Delta_{100} N$

Fig. 6: Cycle slip detection with ionosphere-free combination

- First time difference of ionosphere-free combination (geometric distance and phase-based receiver clock error are already removed) is used to detect the cycle slip. In order to determine the cycle slip exactly and distinguish them from outliers, the difference between two epochs separated by 100 epochs is used instead of two successive epochs (Fig.6).

Missing Observations within one Month

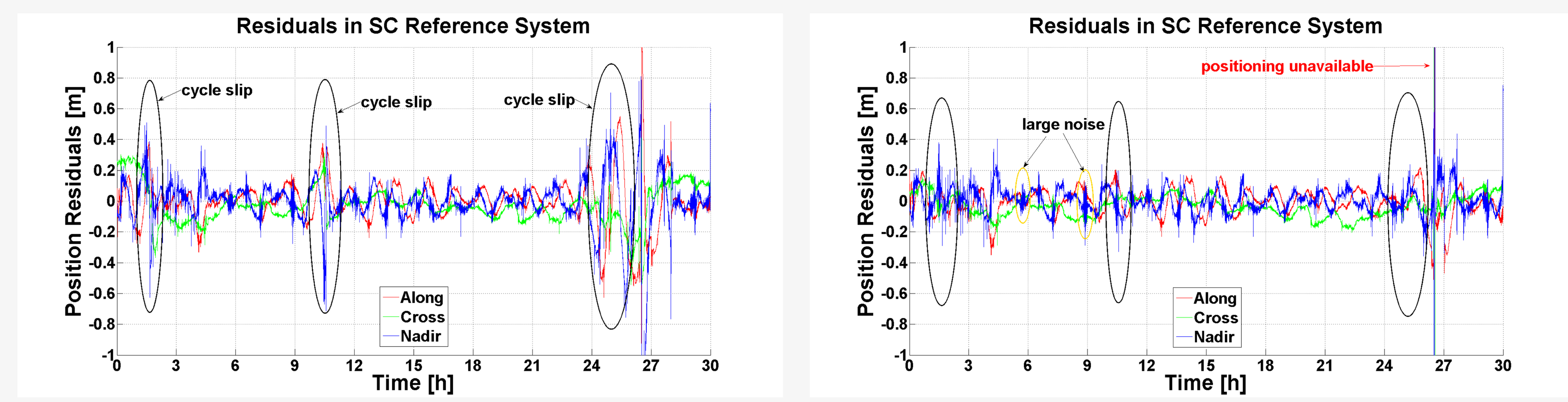


(a) Swarm A (b) Swarm B (c) Swarm C

Fig. 7: Missing observations in September 2015 for Swarm A,B,C

- Most missing observations occur at equatorial and polar areas, even for GPS satellites at high elevations (color bar).
- In May 2015, the receiver on Swarm C was updated. Compared with Swarm A, the robustness of the tracking at the ionosphere irregular area is improved, but the receiver is not stable for satellites at low elevations (compare Fig.7a with c).
- The new settings were also uplinked to Swarm A and B in October 2015.

Position Residuals



(a) Without cycle slip detection (b) With cycle slip detection

Fig. 8: Position Residuals with/without cycle slip detection on Day 333 of 2015 (3 hours from last and next day) with respect to medium-precision orbit determination from Level 1B product

- Observations from Level 1B product are processed with forward/backward Kalman filter.
- Large phase noise and cycle slips degrade the accuracy of the kinematic orbit.
- Sometimes the number of tracked GPS satellites is even below four due to ionospheric scintillation, which makes the positioning unavailable.

Conclusions

Under ionospheric scintillations:

- Receivers may lose lock, even for satellites at high elevations.
- Phase observations are disturbed, yielding variations of up to 20cm in POD.
- Cycle slips are difficult to repair due to large noise. New approch is proposed and tested.

References

Zangerl, F. et al. (2014). SWARM GPS precise orbit determination receiver initial in-orbit performance evaluation. In: *Proceedings ION GNSS+*, September from 8-12, 2014, Tampa, Florida, pp.1459-1468.

Cai, C. et al. (2013). Cycle slip detection and repair for undifferenced GPS observations under high ionospheric activity.. In: *GPS Solutions, 17(2)*, pp.247-260.

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