GNSS Analysis in a Multi-GNSS, Multi-Signal Environment

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Introduction

The modernization of the existing and the deployment of new Global Navigation Satellite Systems (GNSS) introduce new code modulations and additional carrier frequencies. Furthermore, different GNSS receiver tracking and multipath mitigation techniques result in a broad variety of new observation types. It has been shown that improvements, resulting from the on-going developments strongly benefits from the combination of observations on different frequencies, from different GNSS, tracked by different receiver types with different settings and tracking philosophies and as a consequence affected by respective different biases. Consequently, one of the key parameters to combine the various observations in an optimal way, is the understanding and handling of these biases. For this reason, ESOC has developed a fundamentally new GNSS analysis approach for today's multi-GNSS, multi-signal environment. The general difference of this method compared to current practice is that it avoids the formation of any kind of differenced observables and linear combination. In the ESOC approach, internally called the "raw method", all available observations from all available GNSS are incorporated into a single parameter estimation process.

Standard dual-frequency ionosphere-free linear combination

Makes use of ionosphere-free linear combinations.

Pros:

- Straightforward removal of first-order ionospheric effect

Cons:

- Original observation residuals and biases are not accessible.
- Different ionospheric corrections for the same signal path, different for pseudo-range and carrier phase observations, as well as for different ionosphere-free linear combinations (L1/L2 vs. L1/L5).
- Unclear how to handle the enormous number of possible linear combinations and related biases.
- Joint processing of different GNSS and signals (frequencies, modulations) requires the set up of additional bias parameters.

Raw observation processing

Makes use of undifferenced (raw) observations.

Pros:

- Preserves physical characteristics of observations and biases.
  - Allows the analysis of original signal, observation related effects like noise, multipath, PCOs, PCVs, UPDs, UCDs.
  - Enabling the application of real physical models as functional clock models for H-Masers
- Estimation of a unique ionospheric delay correction per signal path
- Straightforward solution; processing of observations "as they are"
- Allows combined processing of all observations irrespectively of their GNSS, carrier frequency or code modulation.
- Allows individual observation selection, editing and weighting.

Cons:

- Significant increase of computational power (more unknown parameter, observations)
- The conservation of the original physical characteristics and biases makes it necessary to understand them and the correct handling of the biases becomes a key parameter.

Experimental setup

Processing strategies:

- Standard ionosphere-free (float valued ambiguities)
- Raw observation processing

Observation data:

16 days of MGEX observation data, including:
- ~ 83 globally distributed multi GNSS stations (GPS+GLO+GAL)
- ~ 34 stations tracking BeiDou
- ~ 22 stations tracking QZSS

Observations used:

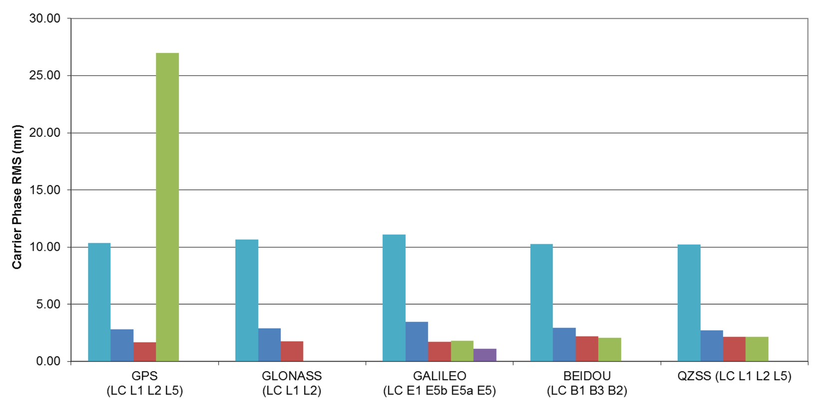
	Code/Phase
Ionosphere-free LC observations	GPS: L1-L2 GLO L1-L2 GAL E1-E5b BEI B1, B2 QZS: L1-L2
Raw observations	GPS: L1, L2, L5 GLO: L1, L2 GAL: E1, E5a, E5, E5b BEI: B1, B2, B3 QZS: L1, L2, L5

Observation weighting:

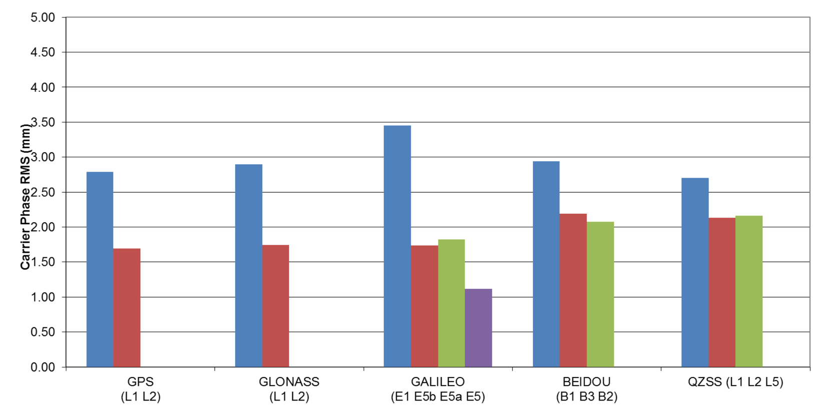
	Phase	Code
Ionosphere-free LC observations	10 mm	1.0 m
Raw observations	2 mm	0.5 m

Carrier phase residuals

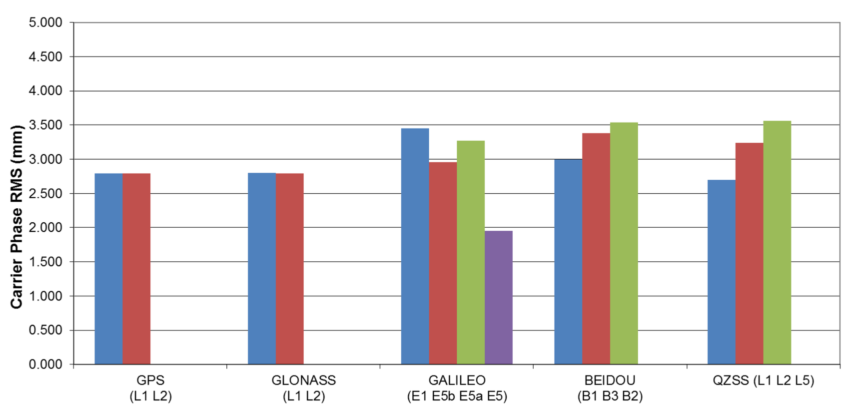
The figures below show the RMS of the carrier phase residuals for the ionosphere-free linear combination (LC) and the different individual undifferenced (raw) observations, sorted by GNSS.



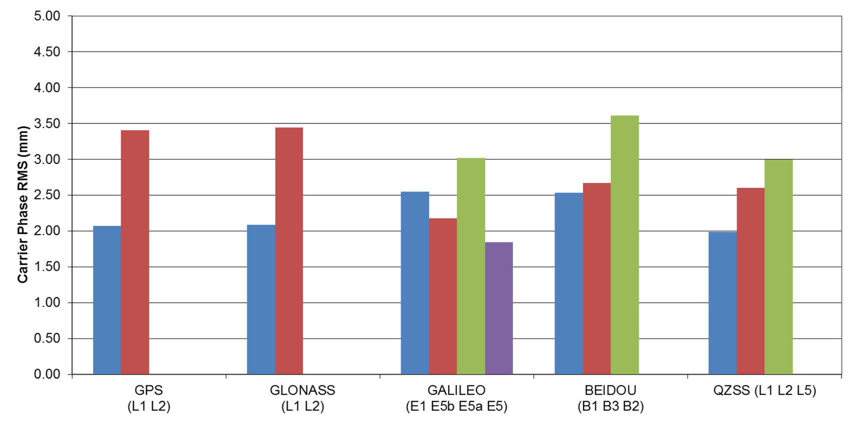
The most striking features in this figure are the:
- High noise of the GPS L5 phase residuals, indicating a inconsistency between the three carrier signals (L1, L2, L5) of the GPS IIFs.
- LC residuals which are about 5 times higher than for individual observations; commonly a factor of 3 is expected.



This figure shows the RMS of the phase residuals, neglecting L5 and LC residuals. Surprisingly enough, the phase observations on L1 show the highest residuals. The reason for this is the negligence of the ionospheric impact in the weighting scheme.



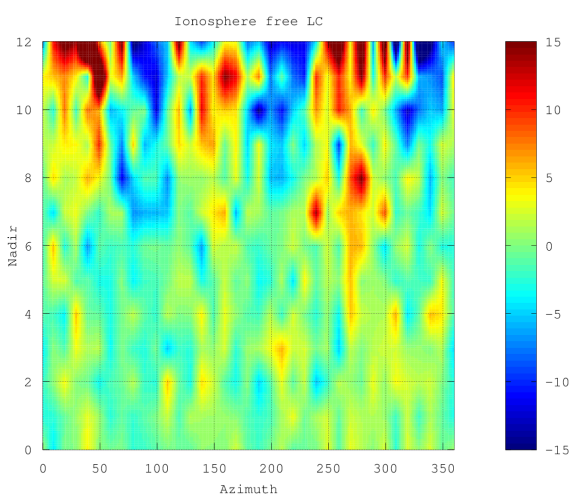
To demonstrate the impact of the ionosphere effect on the residuals, this figure shows the same residuals as in the previous graphic, but this time scaled a posteriori by the influence of the ionosphere ($\sigma\ freq_{L1}^2 / \sigma\ freq^2$).



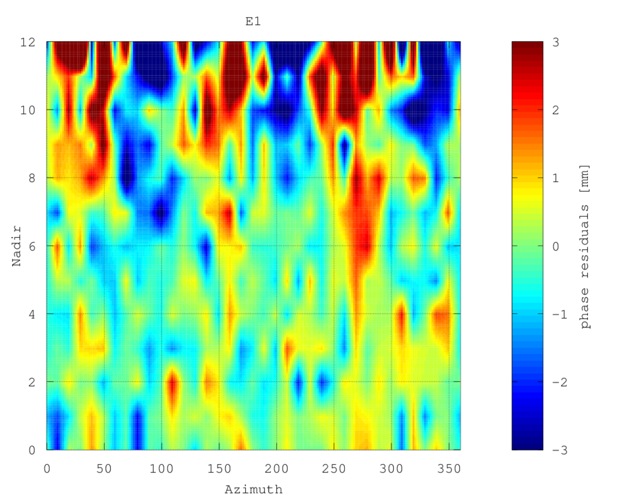
This figure shows the residuals, considering the impact of the ionosphere in the actual observation weighting. In contrast to the previous figure the residuals of the L2 carrier phase observations have become significantly worse.

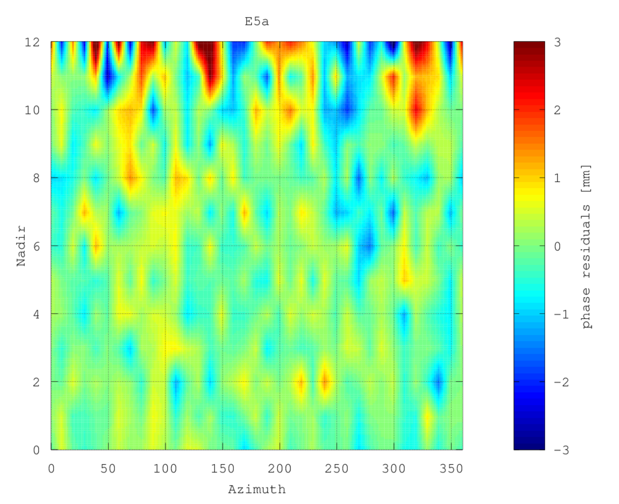
Galileo phase residuals

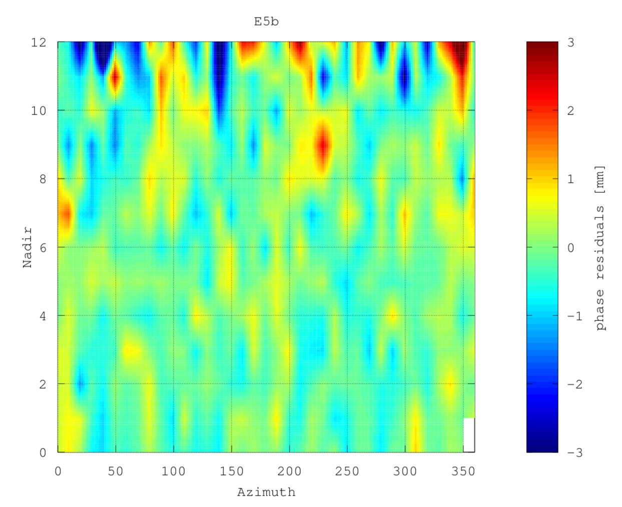
The first figure shows the Galileo ionosphere-free LC phase residuals (4 days, all satellites, no PCOs & PCVs applied). It demonstrates that the Galileo satellite antenna phase pattern has a clear direction-dependent behaviour. In fact, this is not a major problem, as long as the characteristics are known precisely.



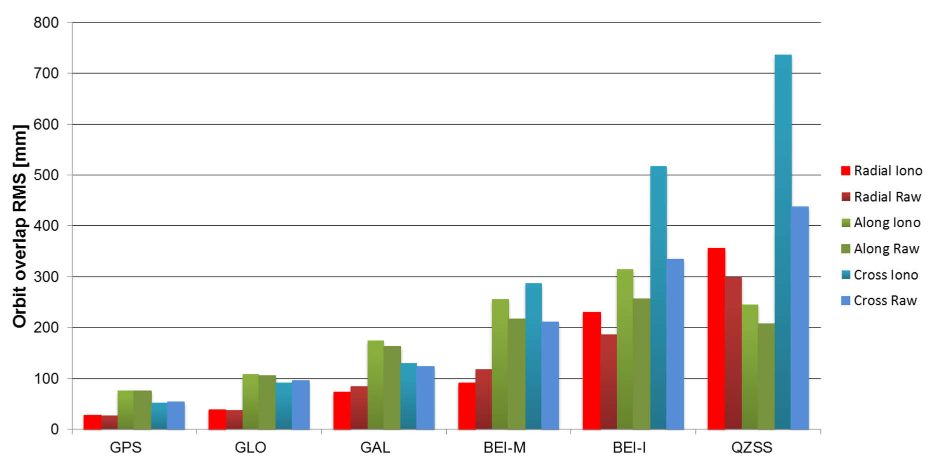
As well known the antenna characteristics differ, depending on the frequency and therewith on the selected raw observation or linear combination. The following figures, showing the phase residuals for E1, E5a & E5b, confirm this statement. When comparing the residuals for the different frequencies, significant systematic differences becomes obvious between the E1 and E5 frequency band. Whereas E1 shows the most pronounced characteristic. However, these values are by no means absolute. They rather represent the relative differences between the frequencies, distributed according to the weighting scheme applied.







Orbit accuracy



The accuracy of orbit and clock estimates is expected to benefit from the increased number of available observations. The figure shows the error RMS of day-to-day orbit overlaps. When comparing the accuracy of the orbit overlaps based on the standard ionosphere-free processing against the raw processing results, no improvement was found for GPS, Glonass and Galileo orbits. However, this is not surprising, given the fact that these results are based on dual frequency data only. Furthermore the orbit accuracy, at least for GPS and Glonass, reached the accuracy level of the available models. In contrast, for the less accurate orbit estimates of BeiDou and QZSS a significant improvement was found.

Conclusions

It is a matter of fact that the knowledge of observation specific biases as PCOs/PCVs is an essential factor for highest accuracy. Their understanding and handling is mandatory for the combination of observations on different frequencies, and therewith to benefit from the diversity of the developing GNSS environment.

The benefits of the ESA/ESOC "raw method" are:
- The ability to jointly process all kind of observations, irrespective of their belonging to a GNSS, their carrier frequency or code modulation.
- A five times lower noise compared to ionosphere-free LC observations.
- A unique ionosphere correction per signal path, primarily derived from phase measurements.
- Access to the original physical characteristics of the individual observations (noise, multipath, PCO/PCV).
- Individual observation selection, editing and weighting, allowing, for instance, to take advantage of the highly precise Galileo E5 (AltBOC) carrier phase and pseudo-range observations.

References

Erik Schönemann, Matthias Becker, Tim Springer: ***A new approach for GNSS analysis in a multi-GNSS and multi-signal environment.*** Journal of Geodetic Science. Volume 1, Issue 3, Pages 204 - 214, ISSN (Online) 2081-9943, ISSN (Print) 2081-9919, DOI: 10.2478/v10156-010-0023-2, June 2011

Erik Schönemann: ***Analysis of GNSS raw observations in PPP solutions.*** Schriftenreihe der Fachrichtung Geodäsie (42). Darmstadt. ISBN 978-3-935631-31-0 URI: http://tuprints.ulb.tu-darmstadt.de/id/eprint/3843, 2013

IGS Workshop 2014 | Pasadena | California | USA | June 23-27