Aliasing Effects of Short-Period Errors in GNSS Time Series

K.E. Abraha (1), F.N. Teferle (1), A. Hunegnaw (1) and R.Dach (2)

(1) Geophysics Laboratory, University of Luxembourg, Luxembourg

(2) Astronomical Institute, University of Bern

Contact: K.E. Abraha (email: kibrom.abraha@uni.lu)

IGS Workshop, 3-7 July 2017
Paris, France

Introduction

In Global Navigation Satellite System (GNSS) coordinate time series, un-modelled or insufficiently modelled short-period errors may propagate into longer periods due to aliasing effects. These aliasing effects are sensitive to data sampling deficiencies and GNSS orbit-repeat periods. The latter is an indication that short-period errors may propagate into coordinate estimates differently for different GNSS constellations. The completeness (see Figure 1 for status) of other GNSS such as GLObalnaya NAvigatsionnaya Sputnikovaya Sistema (GLONASS) and European GNSS (GALILEO) provides (will provide) the opportunity of combining more than a single system and hence reduce system-specific effects.

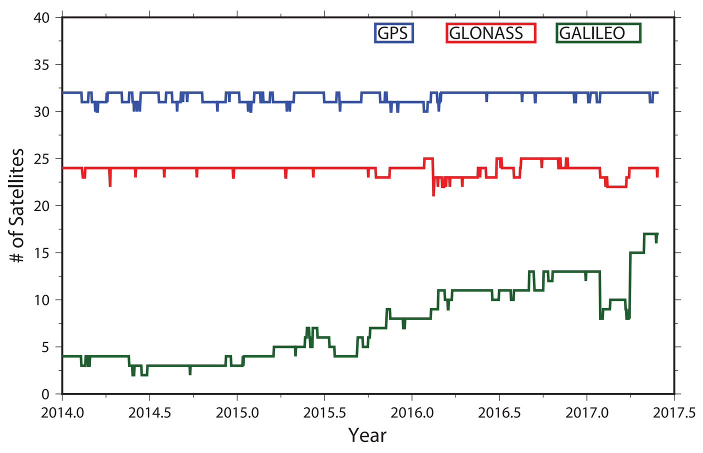


Figure 1: The number of satellites for GPS (blue line), GLONASS (red line) and GALILEO (green line) for the period January 2014 to June 2017. On average, 31 and 24 satellites are available throughout the period for GPS and GLONASS, respectively. GALILEO reaches the same order of magnitude as GLONASS in terms of the number of satellites in 2017.

In a 24 h Global Positioning System (GPS) data processing, (sub-)daily periods alias into longer periods due to both under samping and orbit-repeat effects. In a combined solution the longer orbit-repeat periods of other constellations reduce the aliasing effects of (sub-)daily periods due to the GPS orbit-repeat period (approximately a sidereal day). GLONASS and GALILEO have orbit-repeat periods of 8 and 10 sidereal days, respectively. As a consequence, systematic errors which recur with the orbit-repeat periods can be seen in the GNSS derived products such as coordinate time series (see Figure2). The benefits of the longer orbit-repeat periods of these constellations on reducing aliasing effects and identifying aliased from direct errors is demonstrated in this poster. GPS-only, GLONASS-only, combined GPS+GLONASS, and GPS+GLONASS+GALILEO PPP solutions are considered. Details of the PPP data processing settings are described in Abraha et al., 2016.

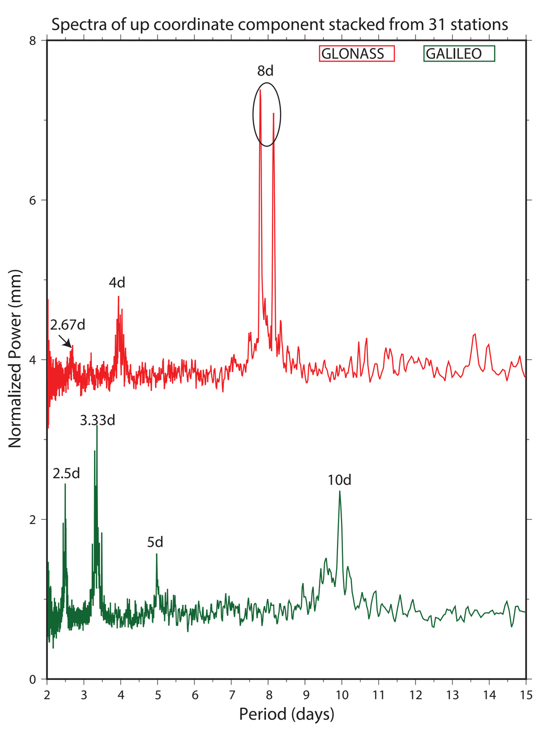
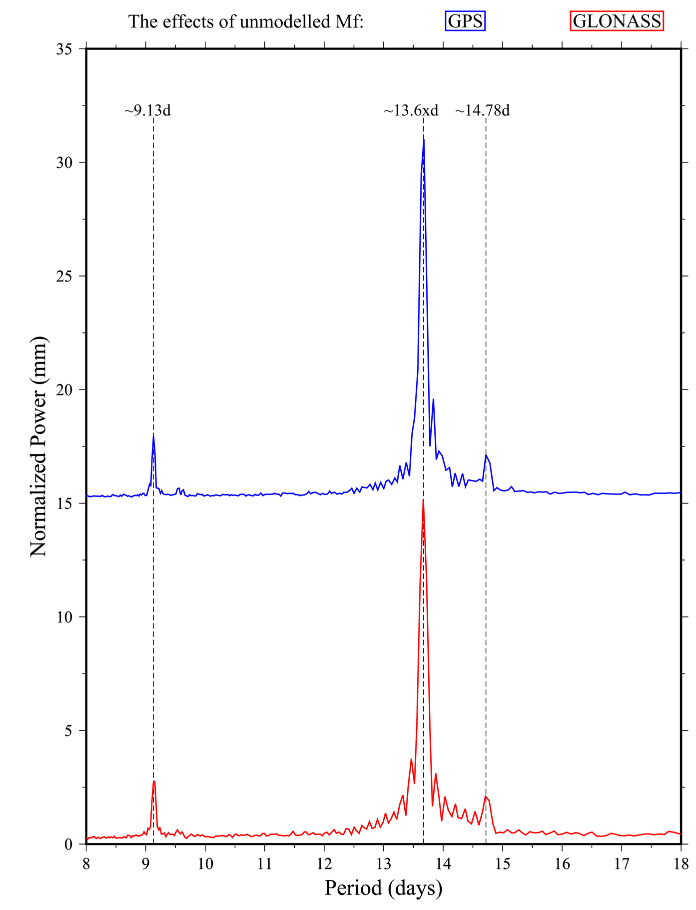
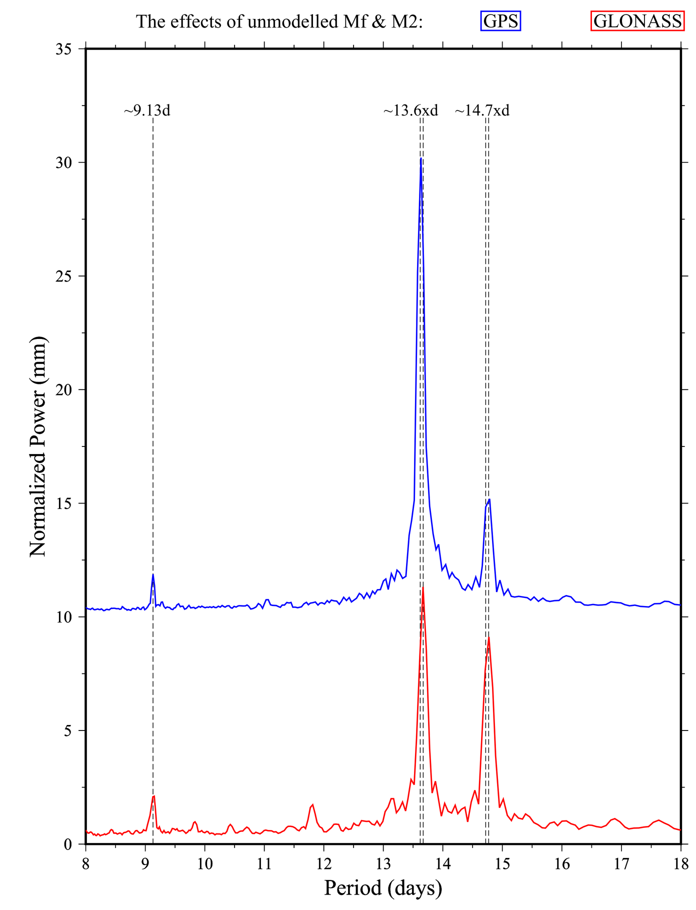


Figure 2: Stacked spectra (over 31 globally distributed stations) of daily (up) coordinate time series from a PPP solution. Specific to this Figure, three daily PPP solutions, which are GPS+GLONASS, GPS+GALILEO and GPS-only, are generated. At last the GLONASS solution (red line) is defined as (combined GPS+GLONASS minus GPS-only) & the GALILEO solution (green line) as (combined GPS+GALILEO minus GPS-only). This is to avoid the less number of observations/satellites (see Figure 1) to create GALILEO-only solution. The differences reveal the effects of GLONASS and GALILEO observations in the combined solution. Plotted in this figure are the normalized power vs period of the high-frequency section of the up coordinate component (from 2 to 15 days). System-specific periods can be seen from the Figure for both GLONASS and GALILEO. Eight day (8d) period and its second (4d) and third (2.67d) harmonics for GLONASS and 10d period and its second (5d), third (3.33d) and fourth (2.5d) harmonics for GLAILEO solutions are evident. For GALILEO the third and fourth harmonics have bigger powers than the first and second ones. The associated harmonics of the 8d and 10d periods in GLONASS and GALILEO, respectively, reveal systematic errors in the orbits which reappear with the orbit-repeat periods.

Continued ...



Figures 5: Effect of un-modelled fortnightly tidal wave (Mf) on GPS (blue line) and GLONASS (red line) up coordinate time series. Strong signal at 13.6xd period and weak signals for periods at 9.13d and 14d are visible as an effect of un-modelled Mf tidal wave for both solutions. This is the effect of a direct tidal error at Mf (not an alias). We don't have any explanation for the periods at 9.13d and 14.78d but the 13.6xd (which is 13.66d) is the main period of an un-modelled Mf.



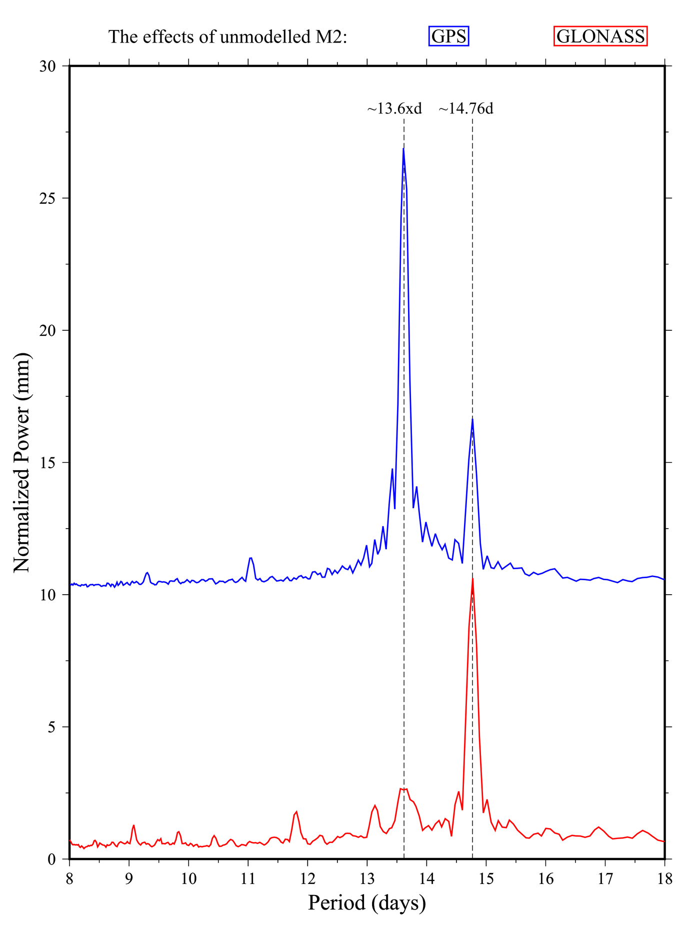
Figures 6: Effect of un-modelled M2 & Mf on GPS (blue line) and GLONASS (red line) up coordinate time series. Strong signal at 13.6xd period and weak signals at periods at 9.13d and 14d (as in Figure 5) are visible as a combined effect of un-modelled Mf and M2 tidal waves. For GPS, the main period at 13.6xd is a combination of an aliased effect from M2 and direct effect from Mf. This indicates that aliases of (sub-)daily periods coincide with direct effects of long-periods, where constellations with long orbit-repeat periods benefit on identifying and/or reducing the effect.

Main results (Figures 3, 4, 5, and 6):

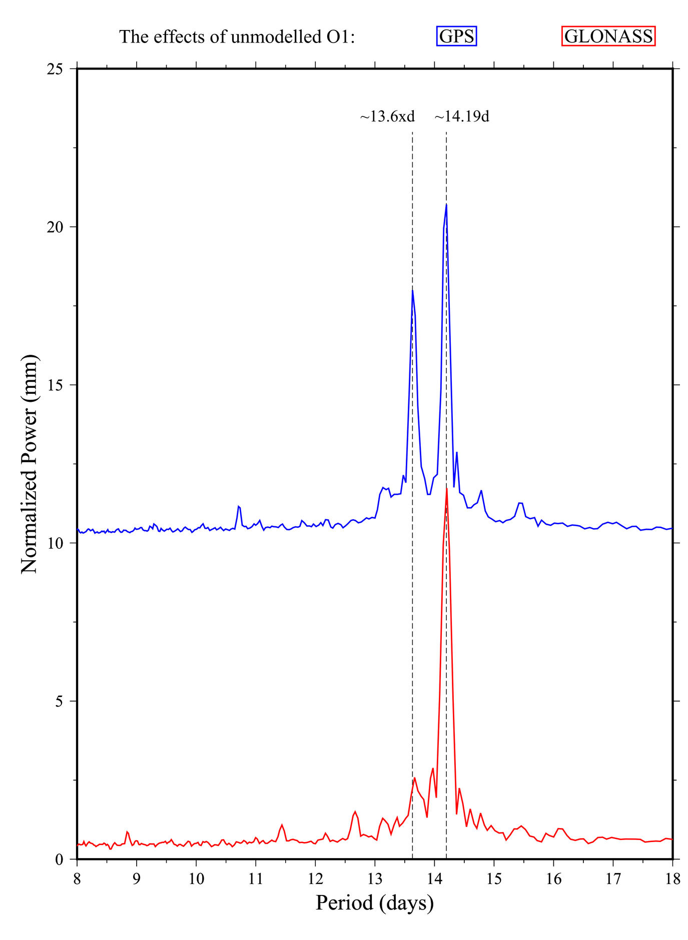
- Un-modelled M2 causes two periods at 13.6xd and 14.76d for GPS while only one period at 14.76d for GLONASS (Figure 3). Similarly, unmodelled O1 causes two periods at 13.6xd and 14.19d for GPS while only one period at 14.19d for GLONASS (Figure 4).
- The 13.6x day period in GPS-only solutions (Figures 3 & 4) is an alias period of M2/O1 due to the GPS orbit-repeat. In 24h data processing, GLONASS-only solutions don't contain this period.
- Unmodelled long-period Mf, however, shows a period at 13.6xd with similar power for both GPS and GLONASS solutions. This coincides with the alias period of M2/O1 due to GPS orbit-repeat. GPS/GNSS derived products from the IGS and its Analysis Centers (ACs) show a strong line at 13.6xd, which is reported as a direct tidal error at Mf/75,565 (Rebischung et al., 2016).
- GPS-only and GLONASS-only PPP solutions in Abraha et al., 2016 show a 13.6xd period for the former while it is not discernible for the latter.
- Is the 13.6xd period in the IGS ACs GNSS derived products a direct error at Mf/75,565 or an alias of (sub-)daily errors? For the former, GLONASS-only PPP should have shown discernible period at 1.36xd.
- The experiments of this study demonstrate that the 13.6xd period in the IGS solutions can be a contribution from both direct and aliased tidal errors.

Effects of (sub-)daily errors on GNSS coordinate time series

To see the effects of un-modelled (sub-)daily errors on GNSS coordinate time series, controlled errors are introduced in the semi-diurnal (M2), diurnal (O1) and fortnightly (Mf) constituents of an ocean tide model. Non-overlapping daily (24-hour data sampling) PPP solutions (Station coordinates, troposphere parameters, receiver clocks) are then generated for GPS-only and GLONASS-only solutions without (reference solution) and with introducing the errors. Coordinate differences are then computed between the reference solution and the solutions when the errors are introduced separately for GPS and GLONASS. Spectra of the up coordinate differences are then computed and stacked over a global set of stations (31) and plotted in Figure 3 (for M2), Figure 4 (for O1), Figure 5 (for Mf) and Figure 6 (for Mf & M2) as normalized power vs period.



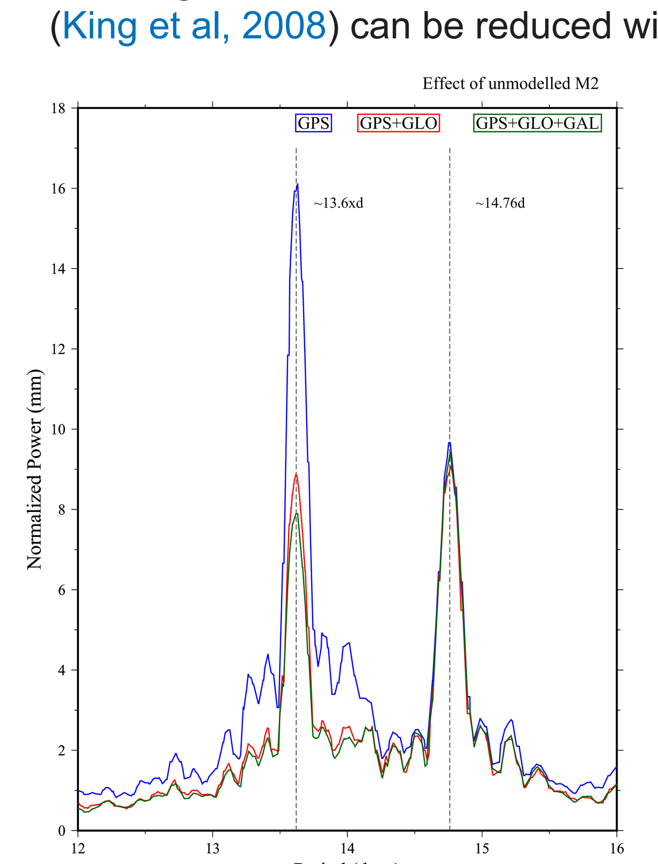
Figures 3: Effect of un-modelled M2 on GPS (blue line) and GLONASS (red line) up coordinate time series. Periods at 13.6xd (x is positive integer) and 14.76d for GPS and only a period at 14.76d for GLONASS are evident as an effect of the un-modelled M2 tidal wave (vertical dotted lines). The 13.6xd period is singular to GPS and is the alias effect due to the GPS orbit-repeat. The 14.76-day period is present in both solutions and is the alias effect due to the 24h data sampling. The two adjacent periods beat at a nearly semiannual period for GPS (results not shown here).



Figures 4: Effect of un-modelled O1 on GPS (blue line) and GLONASS (red line) up coordinate time series. Periods at 13.6xd and 14.19-day for GPS and only a period at 14.19-day for GLONASS are evident as an effect of un-modelled O1 tidal wave. The 13.6x-day period is singular to GPS and is the alias effect due to the GPS orbit-repeat. The 14.19-day period is present in both solutions and is the alias effect due to the 24h data sampling. The two adjacent periods beat at a nearly annual period for GPS (results not shown here).

Remarks

- Identifying and/or mitigating Un-modelled and technical errors are vital for the fullest usage of GNSS time series for reference frame definition (Altamimi et al., 2016) and study of geophysical signals.
- In a 24h GNSS data processing, Un-modelled errors, e.g., at (sub-)daily tidal constituents, alias due to both under sampling effects and orbit-repeat periods.
- In the traditional 24h data processing, however, aliases of (sub-) daily errors due to orbit-repeat period are not expected for constellations with longer orbit-repeat periods such as GLONASS and GALILEO (Figures 2 and 3).
- By employing the observations from multiple GNSS it is possible to reduce aliasing effects due to a single constellation (Figure 7) and potentially provide a means to identify aliased from direct errors in the estimates (Figure 3, 4, 5, and 6).
- The experiments of this study partially explain that the source of the 13.6xd period observed in GNSS derived products from the IGS and its ACs can be both aliased and direct tidal errors with the former seems to be contributing more.
- The use of GNSS time series for retrieving tidal harmonic signals (King, 2006, Martens et al, 2016) and studying implications for mantle anelasticity (Kang et al, 2015) can be contaminated by aliased signals. Combined GNSS solutions will provide benefits for this types of geophysical applications on reducing the effect. Moreover, the effects of (sub-)daily signals on semi-annual and annual periods (King et al, 2008) can be reduced with combined GNSS solutions.



Figures 7: Daily GPS-only, combined GPS+GLONASS, and combined GPS+(GLO)NASS+(GAL)ILEO PPP solutions are generated with (reference solution) and without correcting M2 tidal constituent while all the other constituents are corrected. Up coordinate differences are computed for the three solutions between the reference solution and the solution without M2 correction. Spectra of the (up) coordinate differences are stacked for 31 stations globally and plotted in this figure as blue line (GPS), red line (GPS+GLO) and green line (GPS+GLO+GAL). The coordinate differences are equally normalized and plotted as power vs period in the figure. The period at 13.6xd which is the alias period of un-modelled M2 due to the GPS orbit-repeat, is well reduced in the combined solutions. Including GALILEO to the combined solution already shows benefits on reducing the effects of aliasing even before the system has reached its full constellation.

Acknowledgements:

This work is funded by the Fonds National de la Recherche Luxembourg (contract number 6835562). The computational resources used in this study were provided by the High Performance Computing Facility at the University of Luxembourg. We also acknowledge the IGS and its analysis centers for data and products.

References:

Abraha KE, et al. (2016) GNSS related periodic signals in coordinate time series from Precise Point Positioning. Geophys J Int.
Altamimi, Z, et al. (2016) ITRF2014: A new release of the International Terrestrial Reference Frame modeling nonlinear station motions. J Geophys Res
Kang K, et al. (2015) Stacking global GPS verticals and horizontals to solve for the fortnightly and monthly body tides: Implications for mantle anelasticity. J Geophys Res
King M (2006) Kinematic and static GPS techniques for estimating tidal displacements with application to Antarctica. J Geodyn
King MA, et al. (2008) Subdaily signals in GPS observations and their effect at semiannual and annual periods. Geophys Res Lett
Martens HR, Simons M, Owen S, Rivera L (2016) Observations of ocean tidal load response in south America from subdaily GPS positions. Geophys J Int
Rebischung, P. et al. (2016) Error analysis of the IGS repro2 station position time series. Presented at the IGS Workshop 2016, Sydney, 9 February 2016

Presented at: International GNSS Service (IGS) workshop, 3-7 July 2017, Paris, France