Earth rotation and GNSS orbits from one-day and three-day arcs

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Introduction

The Center for Orbit Determination in Europe (CODE) is one of the analysis centers of the International GNSS Service (IGS). It is, amongst others, estimating satellite orbits and consistent sets of Earth rotation parameters (ERP) for the final product line of the IGS using the development version of the Bernese GNSS Software (Dach et al., 2007). The solutions are derived from a combined multi-system (GPS and GLONASS) analysis of the GNSS tracking data.
Since September 2012 two series of final solutions are operationally generated and submitted to the IGS: The first is based on the observations from exactly one day (official IGS requirement), whereas the second uses observations of three consecutive days to get one orbital arc and piecewise linear ERPs, which are continuous at the boundaries of the middle day.
The same two solution types were produced for the second reprocessing campaign of the IGS (covering the interval from 1994 to the end of 2013, where GLONASS started only in 2002). The estimation of polar motion rates reveals serious deficiencies in the 1-day solutions, due to interferences with sub-daily ERPs. Suspicious signatures in the time series of the estimated parameters not visible in the 3-day long-arc solutions are systematically disturbing the results of the 1-day solutions. Artifacts with periods typical for the GLONASS constellation are clearly visible in the 1-day solutions, but to a much lesser extent in the long-arc solutions.
This becomes even more evident in an alternative series generated as consistent (even regarding the station selection) GPS- and GLONASS-only products over four years from Jan-2008 to Dec-2011 (Meindl, 2011 and Meindl et al., 2013).

Description of the solutions

All solution types presented here are based on daily normal equation files. The 1-day and the 3-day solutions have the following characteristics:

- Triple use of the data of a particular day in three subsequent 3-day solutions
- Station coordinates estimated as constant over 1 and 3 days, respectively
- Continuity of ERPs at the boundaries of the middle day
- Continuity of the orbits at the boundaries of the middle day

Subsequently, the two solutions from CODE's second reprocessing effort are labeled as CF2 (1-day solution) and CO2 (3-day long-arc solution). An alternative 1-day solution (COL) with continuous 3-day orbital arcs has been computed for comparison purposes.

	CRD	ERP	ORB	SORB	TRP
CF2	1/1d	2/1d	1/1d	1/1d	13/1d
CO2	1/3d	4/3d	1/3d	5/3d	37/3d
COL	1/1d	2/1d	1/3d	5/3d	13/1d

Tab. 1: Number of parameter sets (coordinates, ERPs, orbital elements, pseudo-stochastic pulses, and troposphere) per number of associated days of the two official CODE contributions to the IGS repro2 activity (CF2 and CO2) as well as of the alternative 1-day solution supported by long-arc orbits (COL).

References

Dach, R., U. Hugentobler, M. Meindl, P. Fridez edts. (2007) The Bernese GPS Software Version 5.0, Astronomical Insitute of the University of Bern, Switzerland
Meindl, M. (2011) Combined Analysis of Observations from Different Global Navigation Satellite Systems. Geod.-geophys. Arbeiten in der Schweiz, Vol. 83, ETH Zurich, Switzerland
Meindl, M., G. Beutler, D. Thaller, R. Dach, A. Jäggi (2013) Geocenter coordinates estimated from GNSS data as viewed by perturbation theory. Adv. Space Res., Vol. 51(7), pp. 1047-1064

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Satellite orbit misclosures

The misclosure of an orbit at the day boundary is an indicator for the quality of the solution. The results from the 3-day analysis (and the 1-day solution with 3-day orbital arcs) are in general very accurate and consistent in time.

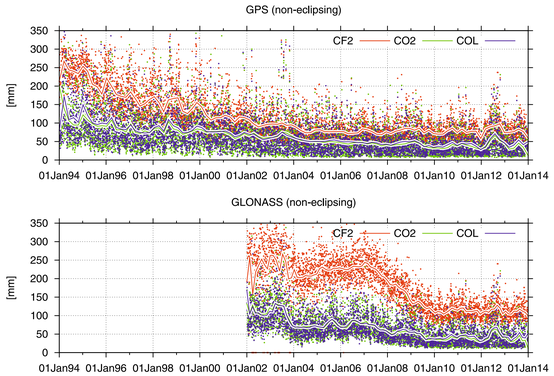

Fig. 1: Daily mean three-dimensional orbit misclosures in the terrestrial frame of all non-eclipsing GPS (top) and all non-eclipsing GLONASS satellites (bottom) at the boundaries of subsequent days from the 1-day and 3-day solutions of CODE's repro2 series. Smoothed values are provided, as well.

The orbit misclosures of the CO2 and COL solutions are very similar but significantly smaller than those of the 1-day solution CF2 due to the long-arc computation. Especially in the early years of GPS and GLONASS the improvements are remarkable.

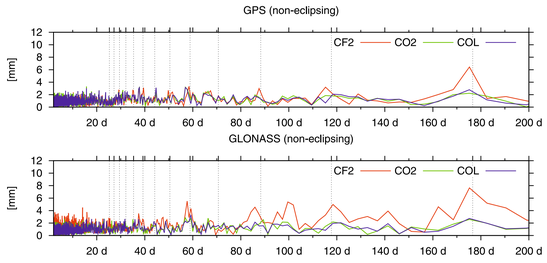

Fig. 2: Spectra of the orbit misclosures of the non-eclipsing GPS (top) and GLONASS satellites (bottom) between 01-Jan-2002 and 01-Jan-2014. GNSS-related frequencies (the lower harmonics of the draconitic year of GLONASS are provided by vertical lines) in the orbit misclosures in the terrestrial frame are reduced in the 3-day solution CO2 and in the solution COL (in particular for the GLONASS constellation) compared to the 1-day solution CF2 (in red).

The improvement of the daily orbit misclosures for the 3-day long-arc solutions is not a big surprise. But the reduction of non-geophysical periods in the time series could not be expected. Almost no spectral lines remain in the traditional 3-day solution (CO2) as well as in the solution COL, where all parameters (including ERPs and station coordinates, e.g., for the datum definition) refer to exactly one calendar day except of the orbits.

Analysis of the ERP series

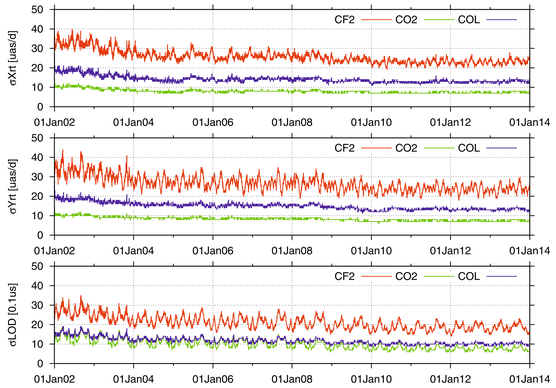

Fig. 3: Formal a posteriori errors of the polar motion rates in X and Y, and of the length of day parameter (LOD) from the three solution types CF2, CO2 and COL. The estimation of ERP rates in a GNSS analysis benefits significantly (by a factor of 2 or more) from using long-arc satellite orbits. There is a further improvement if the ERPs are considered continuous at the day boundaries (only in the CO2 solution).

The misclosure of the polar coordinate is the difference of the forward extrapolated coordinate to the second day boundary with its rate for one day and the backward extrapolated coordinate of the following day to its first day boundary.

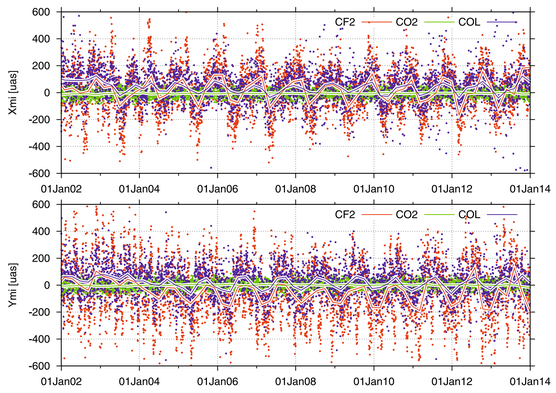

Fig. 4: Pole misclosures from the three solutions CF2, CO2 and COL (smoothed values are provided, as well). There is almost no variation in the time series of the pole misclosures of CO2.

Differences of the x-pole coordinate from several ERP series w.r.t. the CO2 series were calculated and analyzed.

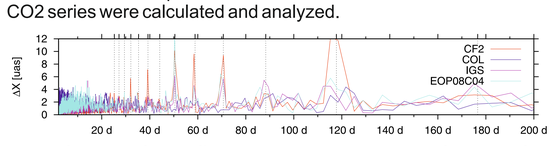

Fig. 5: Spectra of the differences in the x coordinate of the pole from CF2, COL, the operational IGS solution and EOP08C04 w.r.t. CO2. Some frequencies in CF2 are also present in the IGS as well as in the

Single- versus multi-GNSS solutions

From Meindl (2011) and Meindl et al. (2013) four year data sets of a combined GPS+GLONASS (CMB) and consistent single-system solutions (GPS, GLO) based on the observations from a global network of 92 GPS/GLONASS receivers are available. The 1-day (CF2) and 3-day (CO2) processing schemes were applied for comparison purposes.
The ERP misclosures (Fig. 6) show that 1-day GLONASS ERP series are not of a good quality. The 3-day GLONASS solutions are, however, only about a factor 2 to 3 weaker than the corresponding GPS solutions. The combined solutions are roughly of the same quality as the GPS-only solutions.

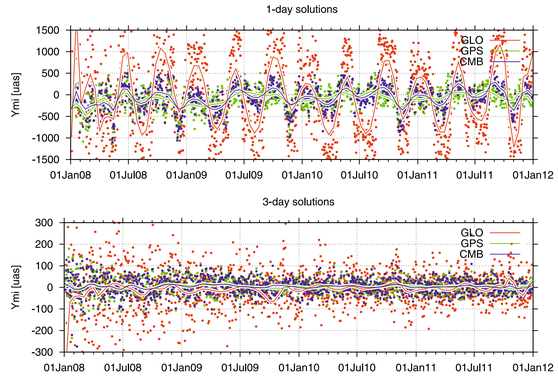

Fig. 6: Pole misclosures of the Y component from the two single-system solutions (GPS, GLO) and the combined solution (CMB).

Not only the variances but also the spectral lines (Fig. 7) of all solution types are significantly reduced by applying the 3-day long-arc processing scheme compared to the 1-day scheme.

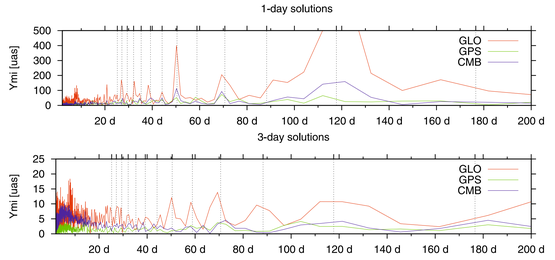

Fig. 7: Spectra of the Fourier transformation of pole misclosures from the two single-system solutions and the combined solution with the 1-day and 3-day long-arc scheme (note the difference in scale).

Summary

- **One-day IGS products have the distinct advantage of statistical independence.**
- **They do, however, have the distinct disadvantage to provide weak rates of polar motion in x and y, and a LOD of mediocre quality containing significant artifacts from the orbits.**
- **The 1-day solution relying on 3-day long-arc orbits (called here COL), might be a good/acceptable compromise.**
- **Long-arc analysis is preferable in general for ERP estimation.**

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