Validating EGSIEM Reprocessing Products by LEO POD and PPP

IGSWS2017:PS08-04

International GNSS Service
Workshop 2017
3 - 7 July, 2017, Paris, France

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Introduction

In 2015, AIUB (Astronomical Institute, University of Bern) has initiated a dedicated reprocessing campaign (Repro15) providing a consistent set of GNSS clock and orbit products to the European Gravity Service for Improved Emergency Management (EGSIEM) project. The reprocessing is based on the CODE analysis strategy as of Summer 2015, including the extended ECOM (Empirical CODE Orbit Model). For the first time, GLONASS 5s clock corrections were computed. An overview on the available products is:

	GPS	GLONASS
Orbits	since 1994	since 2002
clock corrections 30 s	since 2000	since 2008
clock corrections 5 s	since 2003	since 2010

For validation of the products firstly a LEO (Low Earth Orbit) POD (Precise Orbit Determination) for GRACE was performed using the new products. To use of LEO POD for validating GNSS orbits and clock corrections has the advantage that with one receiver a global coverage is checked. The disadvantage is that only GPS products can be validated because no LEO is currently supporting GLONASS. For that reason, also kinematic PPP (Precise Point Positioning) for a limited number of ground stations from the IGS network has been done. As the reference the reprocessing1 (Repro01) series of CODE was used because there are consistent clock corrections available.

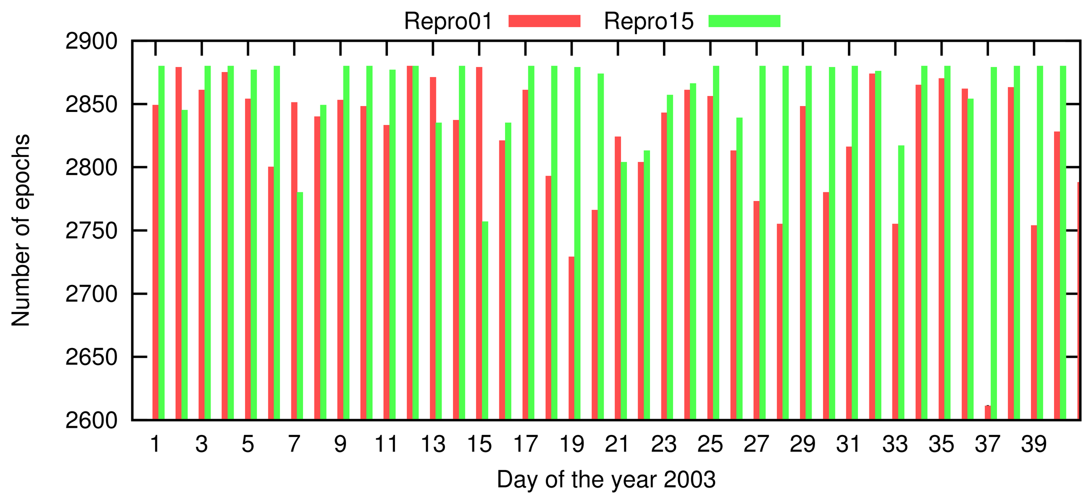

Figure 1: Number of epochs available for G22, from Repro01 and Repro15 satellite clock corrections for the first 40 days in 2003.

As can be seen from Figure 1, for the period shown the number of available epochs for Repro15 products is in overall more complete.

GRACE Precise Orbit Determination

For LEO POD we are using a PPP style processing. This requires a consistent set of GPS orbits and satellite clock corrections. Reduced-dynamic and kinematic GRACE orbits are computed using the latest development version of the Bernese GNSS Software. Based on the ionosphere-free linear combination of undifferenced GPS phase observations the following parameters are estimated in a least-squares adjustment with arc length of 24 h:

- reduced-dynamic orbits: initial conditions, constant empirical accelerations in radial, along-track, and cross-track directions, 6 min piecewise-constant accelerations (constrained) in the same directions, receiver clock corrections per epoch, carrier phase ambiguities (float)
- kinematic orbits: three-dimensional positions and receiver clock offsets per epoch, carrier phase ambiguities (float)

For this study two orbit solutions of the year 2008 are compared. One solution was generated using GPS orbits and 30 s GPS clock products from CODE's contribution to Repro01, while the second orbits were generated using the corresponding products from Repro15. Results are shown in Figure 2 (see column 2), where it can be noticed, that when using Repro15 products, the daily RMS values of the ionosphere-free carrier phase residuals are lower than when using Repro01. In terms of the average values, calculated over the entire year, the improvement for the reduced-dynamic orbits is 0.40 mm while for the kinematic case 0.44 mm.

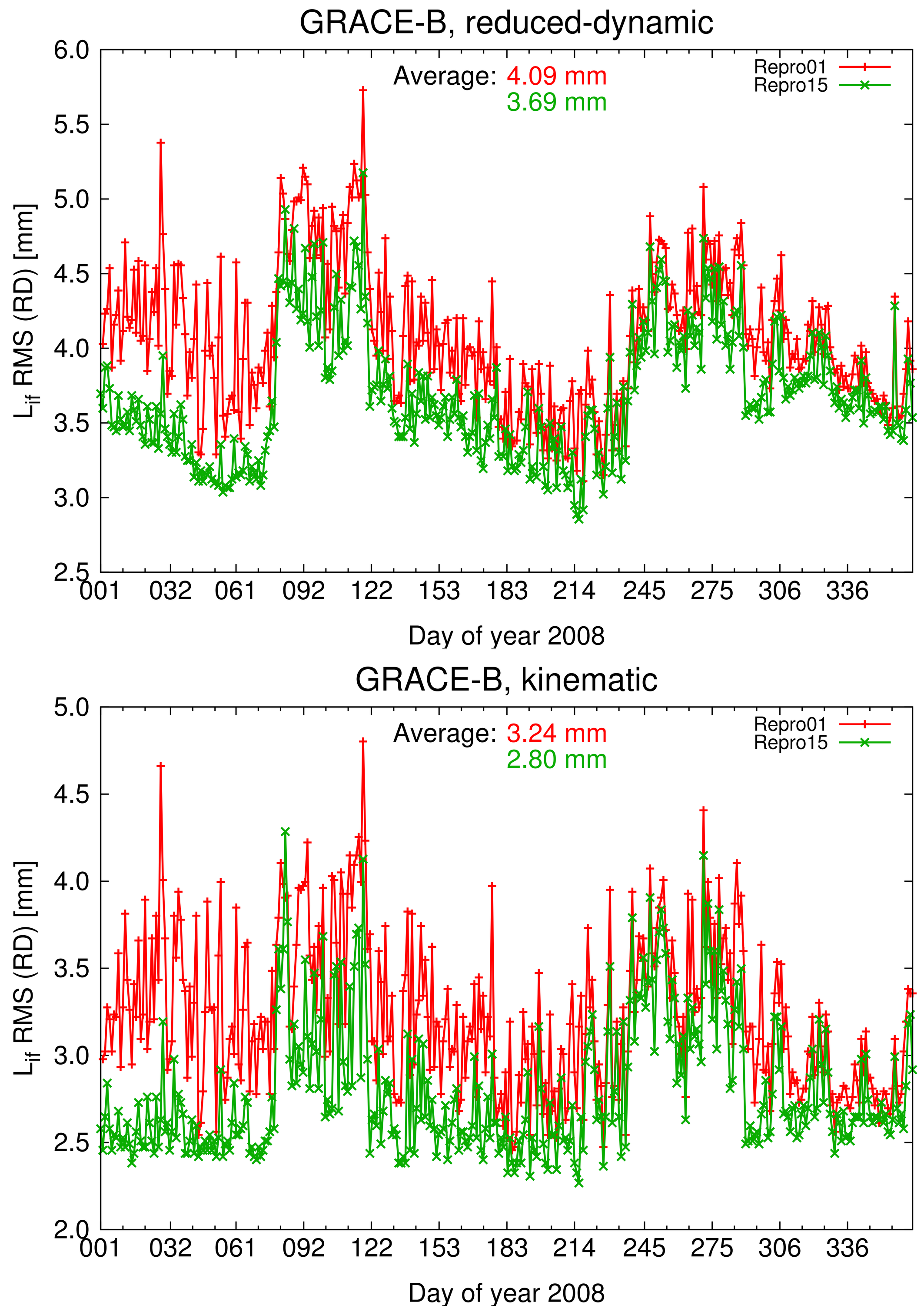

Figure 2: Ionosphere-free carrier phase residuals of reduced-dynamic (top) and kinematic (bottom) POD for GRACE-B. The numbers indicate the average values over the entire year.

Another important quality indicator is the consistency between the reduced-dynamic and the kinematic orbits, shown in Figure 3.

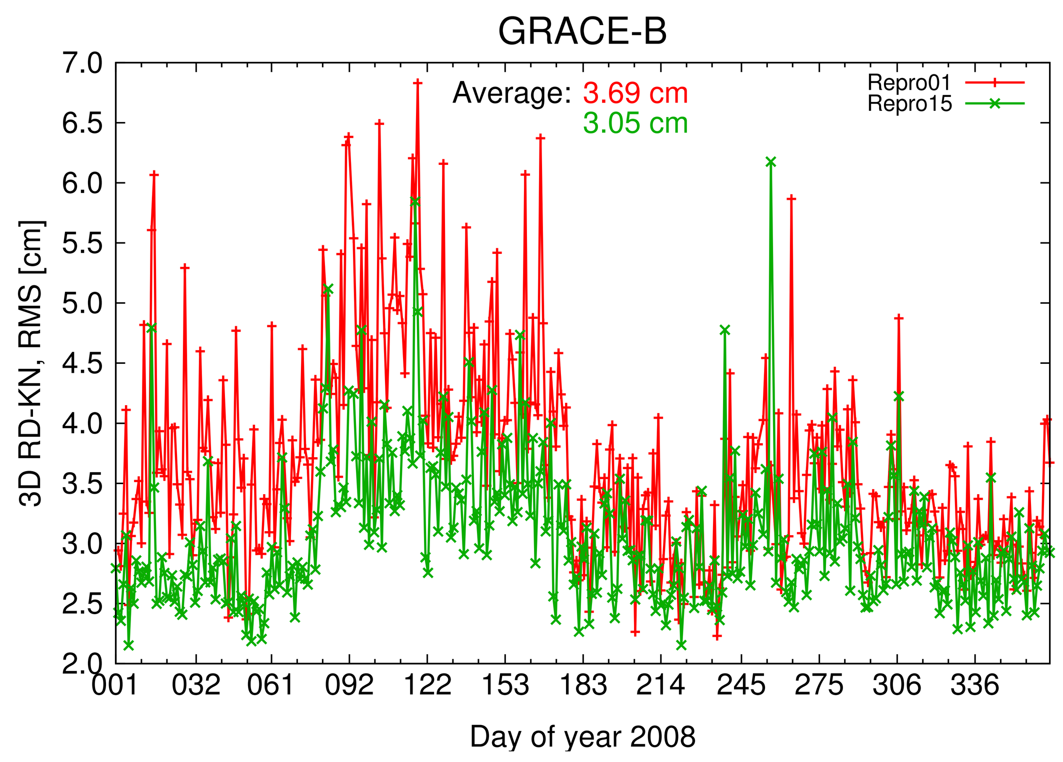

Figure 3: Daily RMS values of 3D differences between the reduced-dynamic and the kinematic orbits for GRACE-B. Values larger than 7 cm have been removed.

Figure 3 shows that using Repro15 products leads to an average reduction in the daily RMS of the 3D differences of about 6 mm.

Since the two GRACE satellites are equipped with SLR reflectors, this allows an independent orbit validation in terms of Satellite Laser Ranging (SLR). The differences between the SLR measurements and the GPS-derived orbits are computed without estimating any parameters. Normal points from 16 SLR stations (coordinates from SLRF2008) have been used for the validation. Table 1 is summarizing the results of the SLR validation in terms of the mean, standard deviation and RMS values for reduced-dynamic and kinematic orbits, respectively.
From Table 1 (see column 3) it can be noticed that when using Repro15, the SLR validation shows better results with respect to the Repro01. For instance, the difference in the standard deviation of the SLR residuals for GRACE-B red-dyn. is 4.41 mm smaller, which correspond to a reduction by 25%.
K-band range residuals are reduced from about 6.6 mm to 5.8 mm in the reduced-dynamic case and from 19.5 mm to 16.2 mm for the kinematic orbits in average over the entire year 2008.

Table 1: Mean and standard deviation in mm of SLR residuals over the entire year 2008 for reduced-dynamic and kinematic orbits.

Reduced-dynamic orbits	GRACE-A	GRACE-B
Repro15	-1.19/12.98	-2.64/14.17
Repro01	-1.41/18.19	-3.24/18.58
Kinematic orbits	GRACE-A	GRACE-B
Repro15	-1.28/17.04	-2.10/19.76
Repro01	-2.15/20.01	-2.89/23.05

PPP for Ground Stations

In addition, a GPS/GLONASS kinematic PPP has been performed for 7 selected stations for the year 2011, using both types of products.

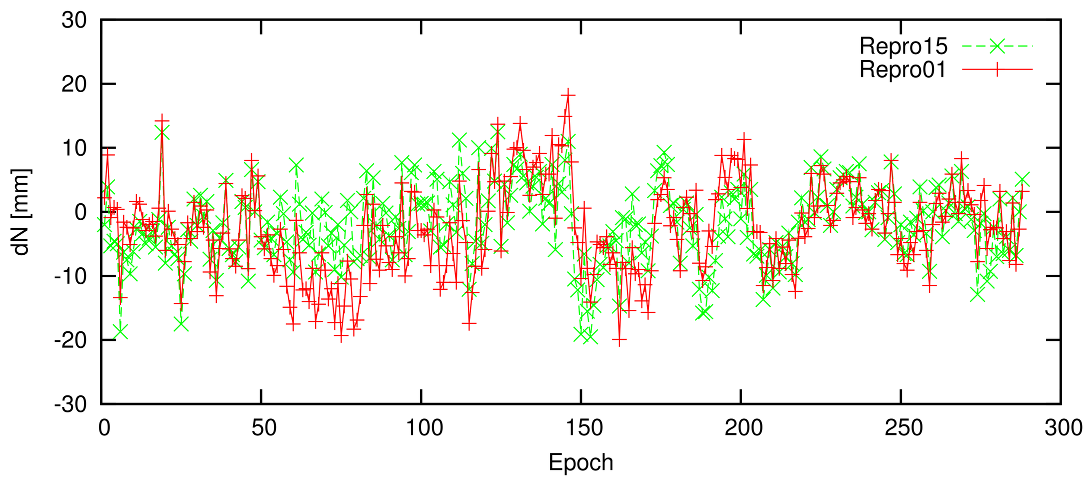

Figure 4: Difference between the estimated kinematic coordinates and the a priori coordinates for the north component for station GRAZ on January 01, 2011, 5 min sampling.

Figure 5 shows the daily RMS values of the above differences, with a reduction of about 4 mm when using Repro15.

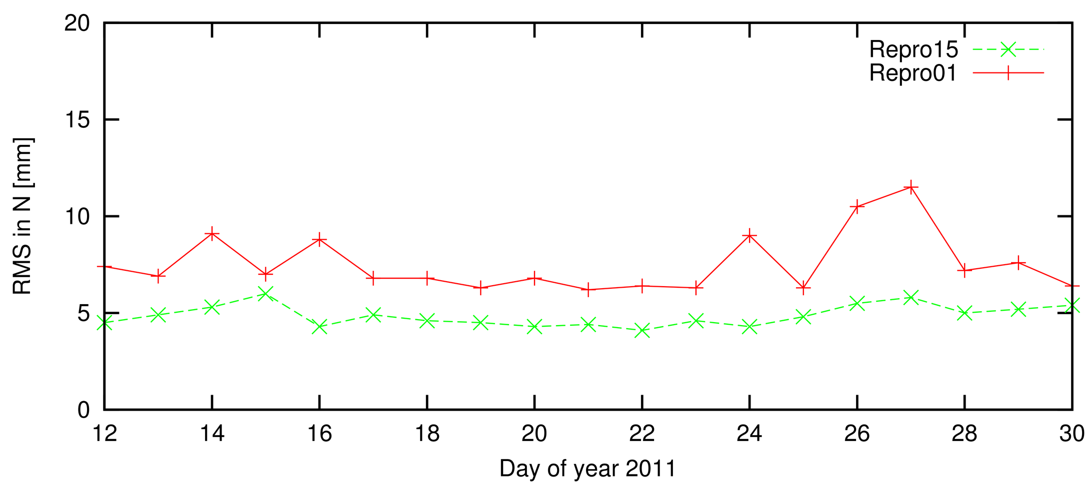

Figure 5: RMS of the differences between the estimated kinematic coordinates and the a priori coordinates for the north component for station GRAZ.

Last but not least, Table 2 is presenting the coordinate repeatability in N, E and U component for selected stations considered in the PPP analysis, with improvement when using Repro15.

Table 2: Coordinate repeatability in north, east and up component for three selected stations considered in the PPP analysis.

	Repro15 N/E/U [mm]	Repro01 N/E/U [mm]
ADIS	1.40/2.56/5.18	3.43/6.78/16.09
GRAZ	0.84/1.27/4.24	2.27/3.70/5.70
WHIT	4.85/2.53/6.28	6.44/4.43/7.91

Summary and conclusions

The presented results regarding carrier-phase residuals, orbit consistency, SLR validation and K-Band range residuals confirm the improvement of Repro15 with respect to Repro01 for LEO POD. This is in particular important for the EGSIEM project (see poster of Meyer et.al., in session "PS07: Scientific Applications of IGS Products").
The kinematic PPP for ground stations is in line with the LEO POD including the GLONASS products. Even if it is not shown on the poster, kinematic GPS and GLONASS results are on the same level of quality, but the combined GPS+GLONASS solution is superior.

Poster compiled by A. Sušnik, June 2017
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Acknowledgment: This research was supported by the European Union's Horizon 2020 research and inovation program under the grant agreement No. 637010. All views expressed are those of the authors and not the Agency.

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