Preparing the Bernese GPS Software for the analysis of SLR observations to geodetic satellites

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Abstract

The Bernese GPS Software is extended to become a full SLR analysis software. As a minimum requirement, the software should be capable to estimate satellite orbits, station coordinates, and Earth rotation parameters from SLR data. The data set of the ILRS Benchmark is used to test the quality of the solutions.
Comparisons with solutions generated by other established ILRS analysis centers and orbit repeatability studies demonstrate the quality that is actually achieved.

1. Introduction

The Bernese GPS Software (Dach et al., 2007) was originally developed to process Global Navigation Satellite System (GNSS) data. Consequently, the program structure and the implemented models (especially for satellite orbits) initially followed the needs for GNSS satellites.

Nevertheless, the software is already capable to compute SLR residuals for given satellite orbits and station coordinates. For this application, CODE (Center for Orbit Determination in Europe) is currently acting as an associated analysis center of the ILRS performing quicklook analyses using SLR measurements to GNSS satellites (two GPS and three of the GLONASS satellites are actually tracked by the ILRS).

In cooperation with Bundesamt für Kartographie und Geodäsie (BKG), the Bernese GPS Software (BSW) is now being generalized in order to be able to analyze SLR observations to geodetic satellites, like Lageos and Etalon, as well. This means, that the major work has to be done in the framework of the orbit modelling and the implementation of SLR-specific parameters (e.g., range biases).

At the moment, the analysis of SLR data with the BSW includes the estimation of station coordinates, Earth rotation parameters (ERP), and satellite orbits (i.e., osculating elements and dynamical orbit parameters). The paper summarizes the actual status of the Lageos-1 orbits using the data set of the ILRS Benchmark.

Processing strategy

Following the specifications for the ILRS Benchmark, we focus on the data set between October 10, 1999 and November 6, 1999, i.e., a time span of 28 days. This data set contains SLR observations of 13 stations to Lageos-1. As it is requested to divide the 28-day orbit into sub-arcs of 4 days for the dynamical orbit parameters, the processing is performed in two steps:

1. Generation of 4-day normal equation systems (NEQs) based on SLR observations. The NEQs contain the parameters of interest, i.e., osculating elements, dynamical orbit parameters, station coordinates, Earth rotation parameters.
2. Accumulation of the 4-day NEQs of step 1 to a 28-day solution by transforming the osculating elements to one common set, but estimating the dynamical orbit parameters separately for each 4-day interval (see Brockmann (1997) for a detailed description of the procedure).

Several solution types were generated with the BSW. They mainly differ concerning the estimated parameters. An overview of the generated solution types and their characteristics is given in Table 1.

One major difference between the solution types is the set up of dynamical orbit parameters. For solution types B and C only a minimal number of dynamical orbit parameters is estimated, i.e., only an empirical constant along-track acceleration every four days. Solution type D improves the orbit parameterization by additionally estimating 4-day once-per-revolution terms in the radial and cross-track component.

Another difference between the solution types is the handling of the station coordinates and ERPs: The solutions of type B only contain orbit parameters, i.e., station coordinates and ERPs are fixed to their a priori values. Contrary, the station coordinates and ERPs are estimated for solution types C and D using loose constraints of 1 m for these parameters.
The 28-day solutions “B28” and “C28” correspond to the ILRS Benchmark types “B” and “C”, respectively.

In addition, we generated series of solutions covering a shorter time span, i.e., eight, twelve, and 16 days (labelled accordingly in Table 1). Within each series, the solutions were generated using data sets shifted by one day, e.g., the 8-day solutions were computed for the days 1-8, 2-9, 3-10, etc. When comparing two adjacent orbital arcs (e.g., the arcs for days 1-8 and days 2-9) we have seven, eleven and 15 overlapping days in the case of the 8-, 12-, and 16-day solutions, respectively. This allows us to perform orbit repeatability studies for the different solution types.

Table 1: Estimated parameters and their temporal resolution in different solution types.

Solution type	Osculating elements	Along-track constant	Radial once-per-revolution	Cross-track once-per-revolution	Coordinates, ERP
B8	8 d	4 d			fix
B12	12 d	4 d			fix
B16	16 d	4 d			fix
B28	28 d	4 d			fix
C28	28 d	4 d			loose
D8	8 d	4 d	4 d	4 d	loose

Orbit comparisons

As an external validation, the 28-day orbits for the Benchmark types B and C (B28, C28 in Table 1) are compared to the corresponding orbits computed by BKG using the UTOPIA software (developed at CSR, Texas) and by GFZ using EPOS.

Figure 1 shows the residuals in radial, along-track and cross-track components for the comparison of the BSW-derived orbit with that from BKG and GFZ for solution type B. The dark lines represent the mean residual for one revolution. Thus, we see, that the residuals in radial and cross-track components mainly have a once-per-revolution signature, whereas the residuals in along-track additionally have a daily signature. The origin of these differences still has to be investigated.

The residuals of the orbit comparison for solution type C are shown in Figure 2. The conclusions that can be drawn from this comparison are similar to those from the comparison for solution type B.

It is especially important to see that the radial component, what is the major component to be determined by SLR, agrees quite well.

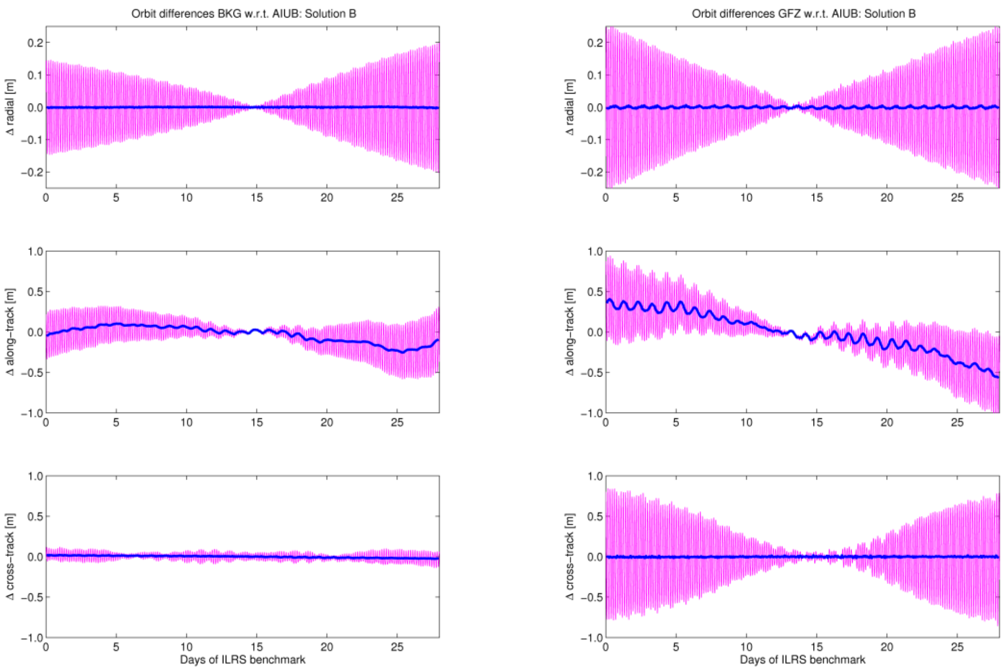

Figure 1. Residuals of orbit comparison for the Benchmark solution type “B” (i.e., solution B28 in Table 1). Left: BKG vs. BSW, right: GFZ vs. BSW (dark line: mean residual over one revolution).

For an internal validation we perform orbit repeatability studies for the 8-, 12- and 16-day solution series of type B, and for the 8-day solution series of type D. As described in section 2, we compare adjacent orbital arcs within one solution type. The RMS of the residuals for each overlapping time span gives the measure for the repeatability. Figure 3 shows the repeatability for the solution series analyzed. Again, it is important to see that the radial component shows a good repeatability.

The level of the repeatability does not differ much between different arc lengths of one solution type (B8, B12, B16). But the repeatability can be clearly improved by estimating once-per-revolution terms in radial and cross-track direction in addition to constant along-track accelerations (i.e., D8 compared to B8). This behaviour may be an indication that the dynamical orbit parameters absorb deficiencies in the orbit modelling.

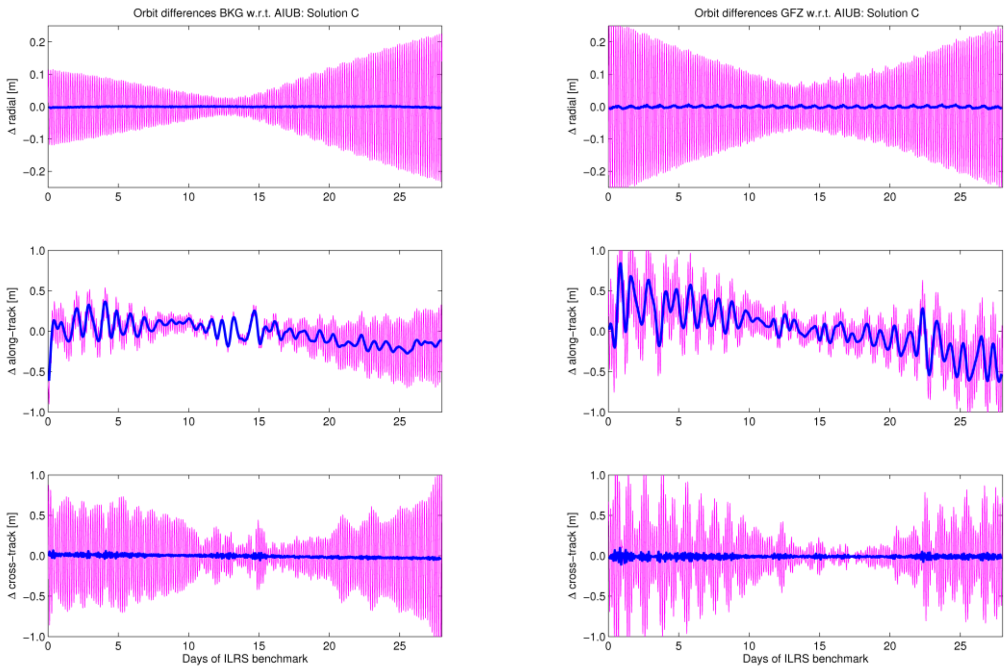

Figure 2. Residuals of orbit comparison for the Benchmark solution type “C” (i.e., solution C28 in Table 1). Left: BKG vs. BSW, right: GFZ vs. BSW (dark line: mean residual over one revolution).

Conclusions

The orbits of Lageos-1 generated with the Bernese GPS Software have a quality that is comparable to that of other ILRS analysis centers. Furthermore, the radial component shows a very good behaviour. This is important to see, because the radial component is the major component to be determined by SLR.

Nevertheless, there are several improvements to be done. The next steps to improve the SLR analysis with the Bernese GPS Software will be:

- Improve/extend the a priori models (e.g., Earth albedo);
- Implement the estimation of range biases according to the specifications of the ILRS;
- Develop a procedure for screening observations in order to detect outliers automatically and reliably.

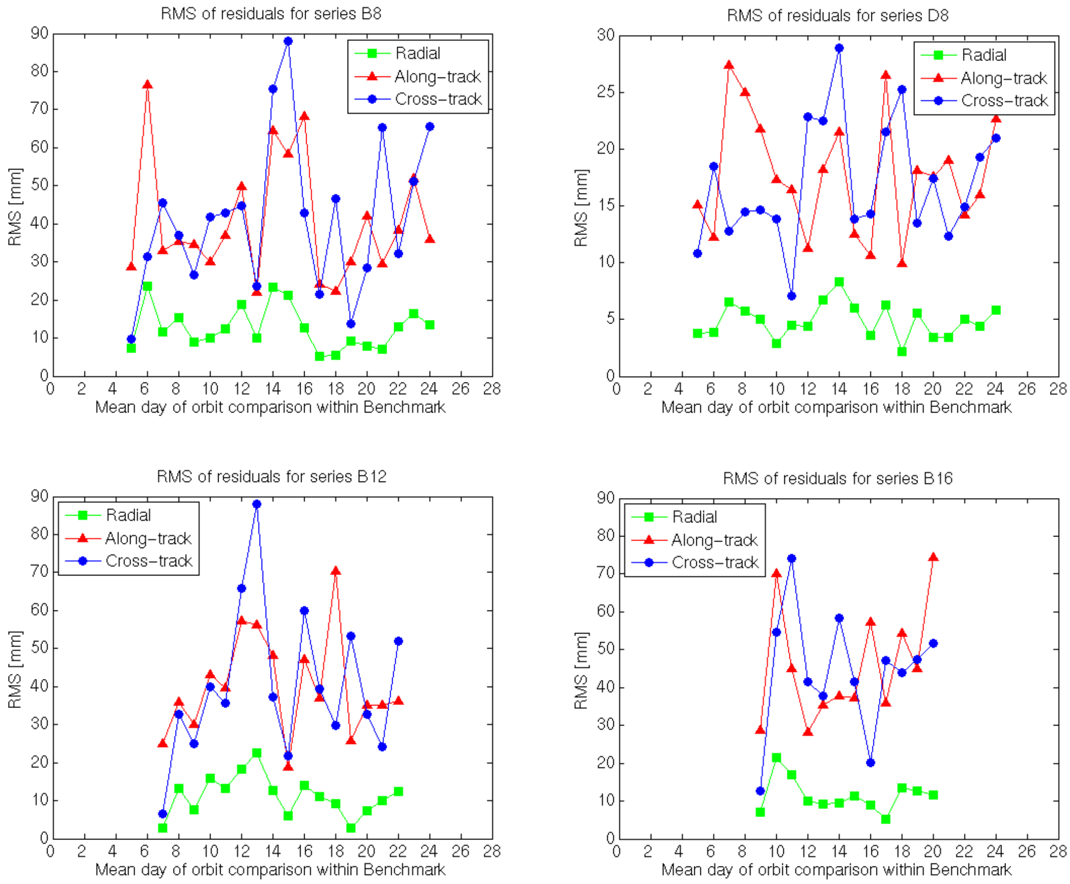

Figure 3. Comparing adjacent orbital arcs for different solution types. Note the different scale of the y-axis for solution D8!

Acknowledgement

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References

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