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SLR-GNSS analysis in the framework of the ITRF2013 computation

D. Thaller (1), O. Roggenbuck (1), K. Sosnica (2), P. Steigenberger (3), M. Mareyen (1), C. Baumann (2), R. Dach (2), A. Jäggi (2)

(1) Bundesamt für Kartographie und Geodäsie (BKG), Frankfurt/Main.
(2) Astronomical Institute University of Bern (AIUB).
(3) Institut für Astronomische und Physikalische Geodäsie, TU München.
daniela.thaller@bkg.bund.de

Abstract. *Pre-combined SLR-GNSS solutions are studied and the impact of different types of datum definition on the estimated parameters is assessed. It is found that the origin is realized best by using only the SLR core network for defining the geodetic datum and the inclusion of the GNSS core sites degrades the origin. The orientation, however, requires a dense and continuous network, thus, the inclusion of the GNSS core network is absolutely needed.*

1. Introduction

The International Terrestrial Reference Frame (ITRF) is based up to now on common Earth rotation parameters (ERPs) and co-located observing sites for connecting the four space-geodetic techniques (e.g., Altamimi et al., 2011). The call for participation for the upcoming ITRF2013 asked for the first time also for pre-combined solutions. This allows to use the co-location at satellites, too, e.g. by using Satellite Laser Ranging (SLR) observations to satellites of the Global Navigation Satellite Systems (GNSS), or by using SLR and microwave GNSS data onboard Low Earth Orbiting (LEO) satellites. All these types of pre-combined solutions are evaluated within the working group “Combination at the Observation Level (COL)” of the IERS (Gambis et al., 2013).
We will focus here on the pre-combined solutions with the GPS and GLONASS satellites used as satellite co-location for connecting GNSS and SLR techniques. Thus, the SLR observations to the GNSS satellites play a key role. Experiences gained with this type of combined solutions are documented in, e.g., Thaller et al. (2011) and Thaller et al. (2014). The intention of this paper is to assess the impact of the method of datum definition on the estimated parameters.

2. Combined SLR-GNSS analysis

We use three different types of data in the combination:

(1) Microwave data to GPS and GLONASS satellites,
(2) SLR data to LAGEOS and Etalon satellites,
(3) SLR data to GPS and GLONASS satellites.

The first two data sets represent the “standard” data that is used for generating the ITRF. By using only these two data sets, the space-geodetic techniques GNSS and SLR can be combined only via station co-location and ERPs. The third data set allows us to combine both techniques via satellite co-locations, i.e., those GPS and GLONASS satellites that are tracked by the SLR stations. Figure 1 lists the number of GPS/GLONASS satellites that we can use as satellite co-location: we have only two GPS satellites, but the number of GLONASS satellites that have been tracked fortunately augmented during the past years. At the moment, six GLONASS satellites are in the official tracking plan of the ILRS, but several of the well-performing SLR sites track the remaining GLONASS satellites as well, if the observing schedule at the SLR site has some time left. It can be seen from Fig. 1 that the augmenting number of GLONASS satellites tracked by SLR sites greatly increased the number of SLR observations per day.

For the studies presented here, we focus on the time span 2009 – 2013, i.e., five years with at least six GLONASS satellites that can be used as co-location. Weekly solutions have been generated. The analysis and combination procedure is identical to that described in Thaller et al. (2014), and we especially refer to Fig. 1 therein for more details. The Bernese GNSS Software (Dach et al., 2007) with the extensions for SLR analysis is used for the studies.

As demonstrated earlier (e.g. Thaller et al., 2011), the local ties are not necessarily needed for the SLR-GNSS combination via satellite co-location. The selection of core sites for the datum definition is, however, a critical issue. No-net-rotation (NNR) and no-net-translation (NNT) conditions are applied for the core sites. The NNT condition is needed as we estimate geocenter coordinates. We study the impact of three different selections of core sites on the estimated parameters:

(1) Use only GNSS core sites (i.e., about 90 sites per weekly solution);

(2) Use only SLR core sites (i.e., usually less than ten sites per weekly solution);

(3) Use the combined set of GNSS and SLR core sites.

The GNSS core sites offer the advantage of a well-distributed global network with almost the same network in every week. Contrary to that, the SLR core sites represent a sparse network only which is far away from being global. In addition, the network configuration is changing from week to week even for the core sites.

Generally speaking, a dense global and continuously observing network allow for the best datum definition, thus, the GNSS core network should be better suited than the SLR core network. Several studies have already demonstrated, however, that the geocenter estimated from GNSS satellites suffer from orbit modeling deficiencies (see, e.g., Meindl et al., 2013). Based on this aspect one would vote for using the SLR network for datum definition.

We computed combined weekly SLR-GNSS solutions for all three different sets of core sites. The resulting geocenter coordinates and polar motion are discussed in the subsequent section.

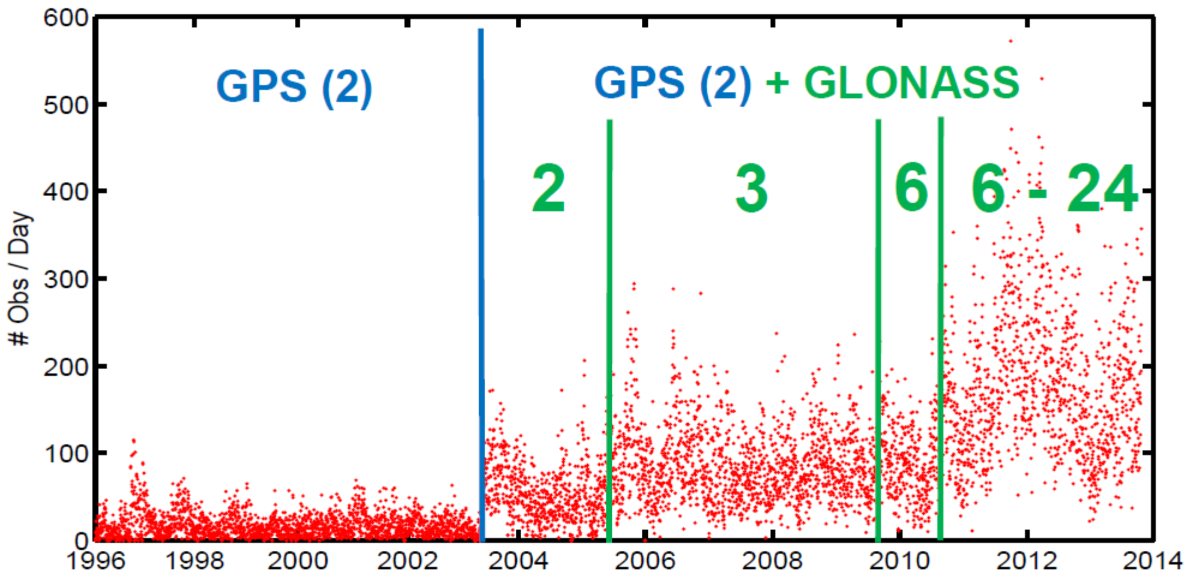

Figure 1. Number of SLR tracking data per day to GPS and GLONASS satellites. The number of satellites tracked for different time spans are indicated, too.

3. Results of combined SLR-GNSS analysis

Geocenter coordinates are chosen to evaluate the realization of the origin, and polar motion is chosen to evaluate the realization of the orientation for the different sets of core sites. The scale is omitted here because it is not affected by the three tested sets of core sites.

3.1. Geocenter coordinates

Figure 2 (top) shows that the estimated geocenter z-coordinate heavily depends on the set of core sites used for the datum definition. When using the SLR sites (i.e., blue curve), the time series is almost identical to an SLR-only solution based on LAGEOS and Etalon data only (i.e., pink curve). When using the GNSS core sites (i.e., green curve), the time series clearly differs: the range of the weekly estimates are larger by a factor of about three. But more striking is the different signature: The solutions based on the SLR core sites mainly show an annual signal, whereas for the solution based on the GNSS core sites the draconitic year of the GNSS orbits (i.e., 352 days) dominates the time series.

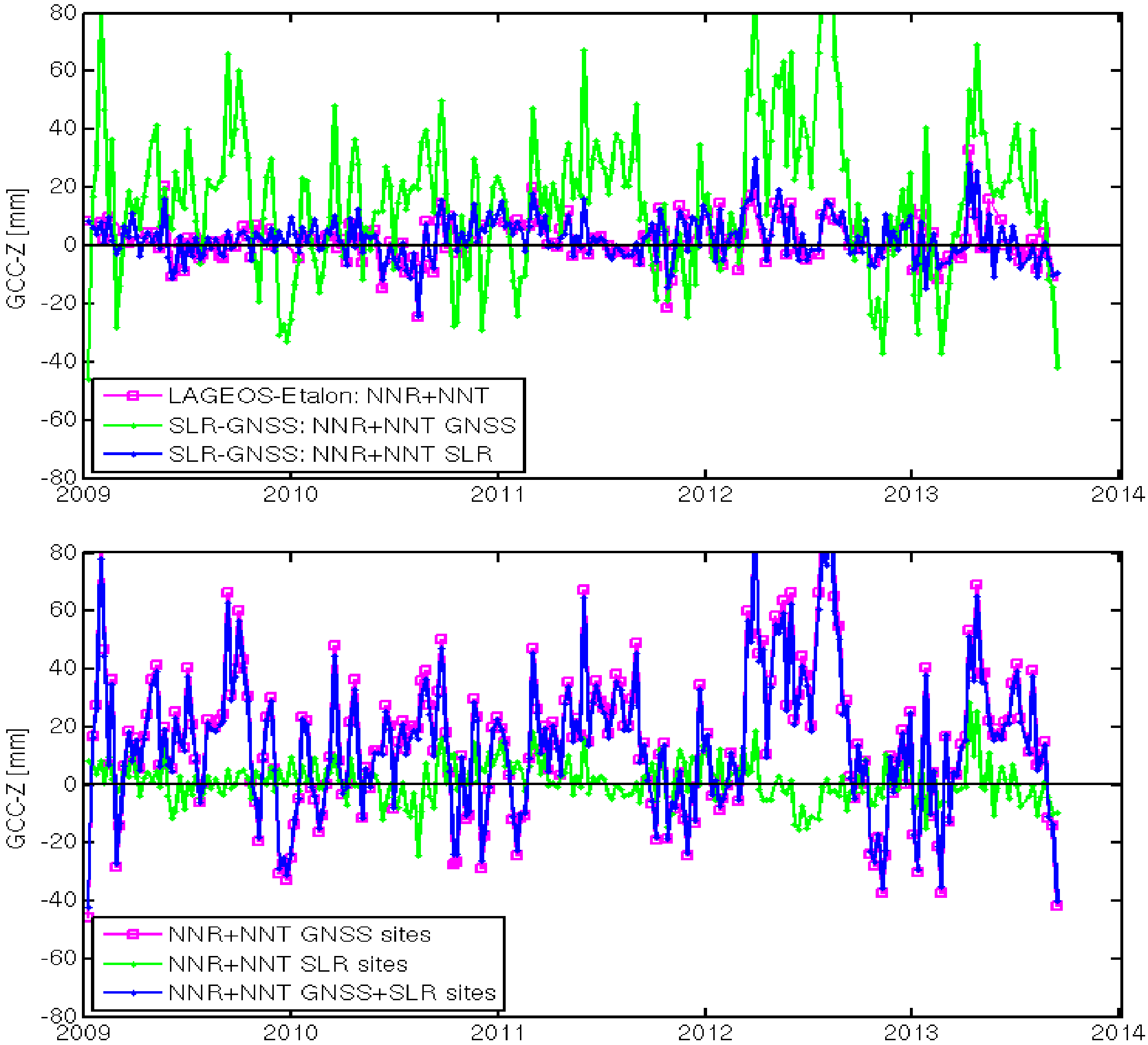

Figure 2. Estimated geocenter z-coordinates using different sets of core sites for the datum definition (i.e., NNR and NNT conditions w.r.t. ITRF2008).

Figure 2 (bottom) shows that the draconitic signal does not vanish if the combined set of GNSS and SLR core sites are used for the NNR and NNT conditions. This behavior is, however, not astonishing as there are usually at maximum ten SLR core sites compared to about 90 GNSS core sites per weekly solution.

The x- and y-coordinate of the geocenter are less affected by the set of core sites (see Fig. 3). The draconitic signal is, however, visible in the solution series based on GNSS core sites, although the amplitude is much smaller than for the z-coordinate of the geocenter.

From the resulting geocenter coordinates time series we can conclude that the GNSS core sites should not be included into the datum definition of combined SLR-GNSS solutions.

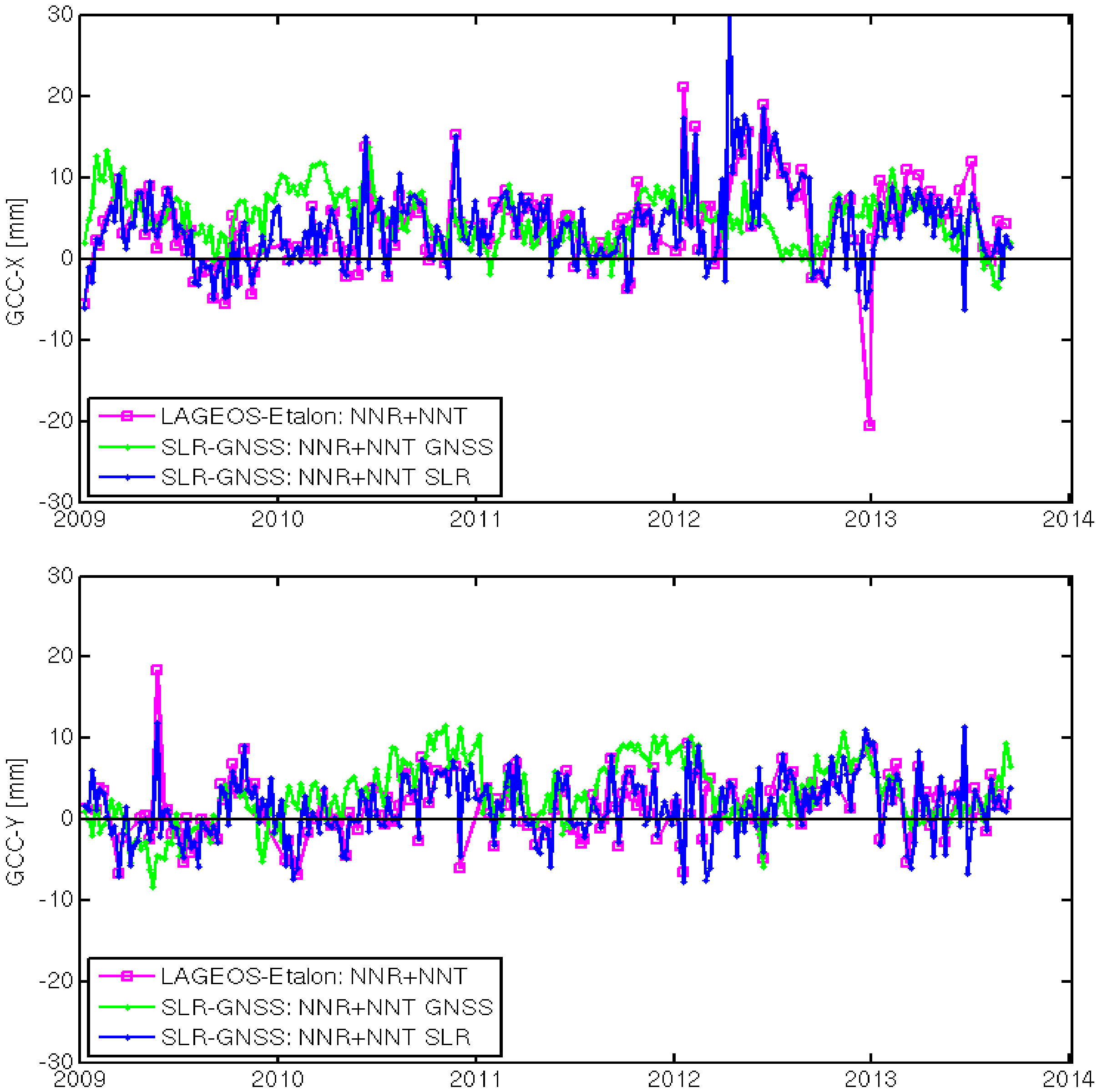

Figure 3. Estimated geocenter x- and y-coordinates using different sets of core sites for the datum definition (i.e., NNR and NNT conditions w.r.t. ITRF2008).

3.2. Earth rotation parameters

The polar motion estimates are compared to the IERS-08-C04 series for all solution types. Figure 4 shows the x-pole time series for the combined SLR-GNSS solutions with the three sets of core sites (as explained in Sec. 2). When using the SLR sites only, the polar motion time series shows deviations w.r.t. IERS-08-C04 up to several hundred microarcseconds, i.e., a similar order of magnitude that is known from SLR-only solutions provided by the ILRS.
As soon as the GNSS core sites are used for the datum definition, the deviations are mostly below 100 microarcseconds.
The differences between the solution based on the GNSS core sites only and the solution based on GNSS and SLR core sites are very small for polar motion, and the solution using GNSS and SLR core sites together for the NNR conditions are slightly better.
From the polar motion series we can conclude that the GNSS core sites have to be included in the NNR condition.

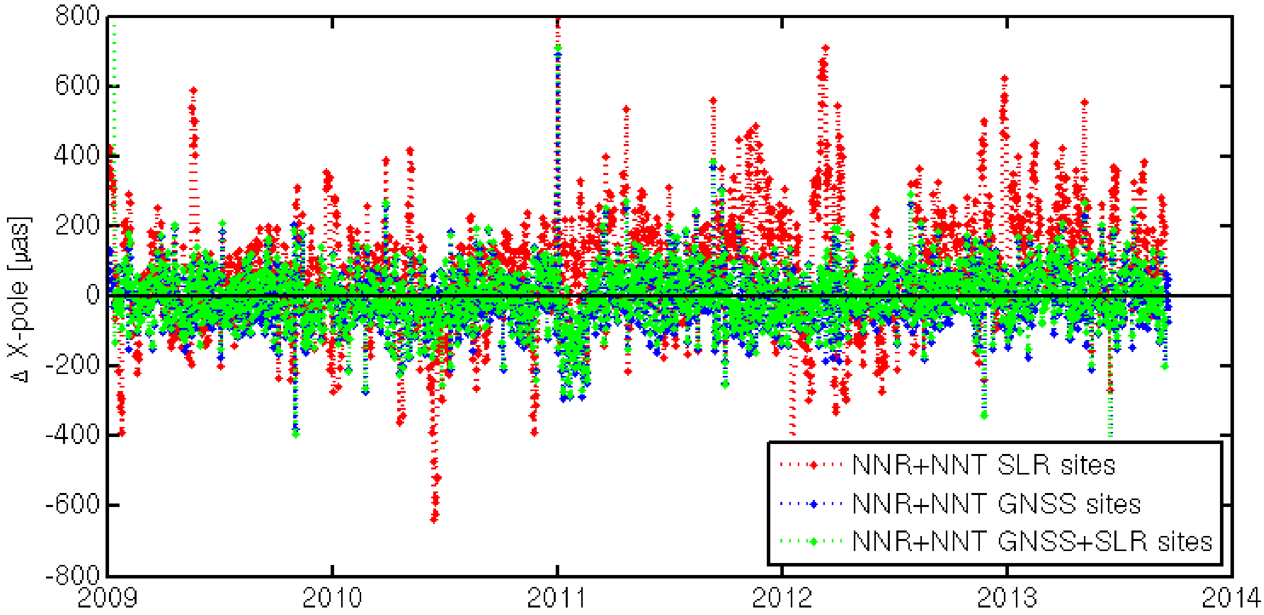

Figure 4. Estimated x-pole coordinates w.r.t. IERS-08-C04 using different sets of core sites for the datum definition (i.e., NNR and NNT conditions w.r.t. ITRF2008).

4. Summary and conclusions

We studied the impact of different types of datum definition on combined SLR-GNSS solutions when satellite instead of station co-locations are used. The quality of the datum realization is evaluated by the geocenter coordinates regarding the origin, and by the polar motion series regarding the orientation.
On the one hand we have seen that GNSS orbit modelling issues propagate into the geocenter estimates as soon as the GNSS core sites are included in the datum definition of the combined solutions. Thus, the best origin is realized by using the SLR core network only.
On the other hand we have seen that the sparse and changing network of SLR core sites clearly degrades the polar motion series if the datum definition for the combined SLR-GNSS solutions is

based solely on the SLR core network. Thus, the GNSS core network has to be included into the datum definition in order to realize the orientation in the best possible way.
As a consequence of the studies presented we can state that there is no single set of core sites that guarantees the optimal datum definition for orientation and origin. It rather depends on the parameters of interest.
One option as a compromise could be to use the SLR core network for the NNT condition and the GNSS core network (or GNSS plus SLR core network) for the NNR condition. This type of combined solutions, however, will not be independent of the local ties used in the reference frame, e.g., ITRF2008. But the procedure would be similar to the ITRF computations up to now, i.e., defining the origin by SLR only and defining the orientation by a mixture of all space-geodetic techniques.

Acknowledgements

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