Benefits of SLR in epoch reference frames

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ABSTRACT

In the actual terrestrial reference frame realizations the station motions are approximated by linear velocities (multi-year reference frames). But this parameterization is not adequate, since we know that the station movements include not modeled non-linear parts due to various geophysical effects. One possibility to overcome this deficiency in the modeling is to estimate the station positions more frequently by computing epoch reference frames in addition to the conventional multi-year reference frames. SLR is the primary technique to determine the origin of the reference frame (i.e., center of mass) together with station coordinates, EOP and gravity field parameters. To combine the station coordinates of the different techniques (SLR, GPS, VLBI), stations with at least two techniques available (colocation sites) are used. The coordinates of the different techniques at the colocation sites are tied together using terrestrial difference vectors (local ties). The quality of the transfer of the origin information from SLR to the other techniques depends strongly on the connection of the different station networks within the combination. Therefore and because of the different accuracies of the local ties, the selection of the local ties, which should be used, is one crucial part of the combination process.

In this study we analyze the quality of the datum realization by comparing the obtained epoch reference frames with a multi-year solution. Furthermore we discuss the impact of the temporal resolution on the datum realization. The coordinates of the terrestrial pole are validated w.r.t. the International Earth Rotation and Reference Systems Service (IERS) 08 C04 time series.

1 Introduction

The station coordinates in global terrestrial reference frames are changing with time. In the latest realization of the International Terrestrial Reference System (ITRS), the ITRF2008, the station coordinates are parameterized as a coordinate triple (X, Y, Z) at a reference epoch t_0 and a constant velocity per station coordinate component [Altamimi et al., 2011]. The DGFI realization of the ITRS is called DTRF2008 [Seitz et al., 2011]. Due to this parameterization multi-year reference frames do not consider high-frequency time variations like seasonal signals caused by inter alia atmospheric loading. These discrepancies between a regularized position and the instantaneous position should be considered with conventional corrections [Petit et al., 2010]. Since recent geophysical models are not accurate enough, possibilities to overcome this deficiency in the parameterization are to consider not modeled non-linear station motions by mathematical functions. Another possibility is to estimate epoch reference frames which are valid only for a certain time interval assuming that the movement of the station is negligible within that time period. Abrupt changes in the station coordinates, which are caused for example by an earthquake, could be considered in multi-year reference frames by introducing discontinuities whereas epoch reference frames consider them automatically. Epoch reference frames allow the estimation of station coordinates in an inter-technique combination (GPS, VLBI, and SLR) with a high temporal resolution (Fig. 1). The temporal resolution of the obtained solutions depends on the arc length (7-day/28-day) in the SLR only solution. Fig. 1 shows the different parameterizations of the station coordinates (x-component) of the GPS station Arequipa in Peru (Domes number 42202M005). In the multi-year solution, five jumps were introduced to approximate the abrupt change and the non-linear post seismic behavior of the coordinates with a piecewise linear polygon (solution numbers A01 to A06). The station coordinates are not included within the multi-year solution during the year right after the earthquake (24.6.2001 until 25.8.2002) because to the short time spans.

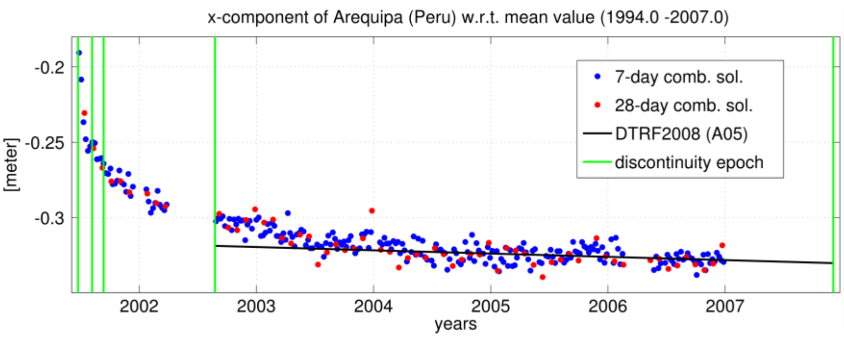

Fig. 1: Different parameterizations of the station position of the GPS station Arequipa (Peru).

2 Epoch reference frames

2.1 Data and processing scheme

The calculation of epoch reference frames at DGFI is based on the combination at the normal equation level (see Fig. 2). For SLR normal equations (NEQs) with an arc length of seven days or 28 days are used. The GPS NEQs have a daily resolution starting from midnight whereas the VLBI NEQs contain the observations of a 24-hour observation session which start at various epochs different from midnight. If the different techniques are combined, the EOPs are the only common parameters and are stacked whereas the station coordinates are handled as different parameters. To combine the station coordinates, the terrestrial difference vectors (local ties) between the techniques at the colocation sites (station, where at least two techniques are available) are used. The calculation of epoch reference frames could be distinguished into two main steps. In the first step, the intra-technique treatment, the technique-specific NEQs are prepared for combination which means that different parameterizations for example of the EOPs have to be equalized. This is necessary because the VLBI EOPs are parameterized as an offset and a rate at the reference epoch of the observation session. This parameterization has to be adapted to the piecewise linear polygon parameterization of the SLR and GPS EOP. In the second step of the calculation the different space geodetic techniques are combined. Therefore, the local ties at the colocation sites are introduced in the combination. Variance factors are estimated in order to obtain relative weights of the different techniques.

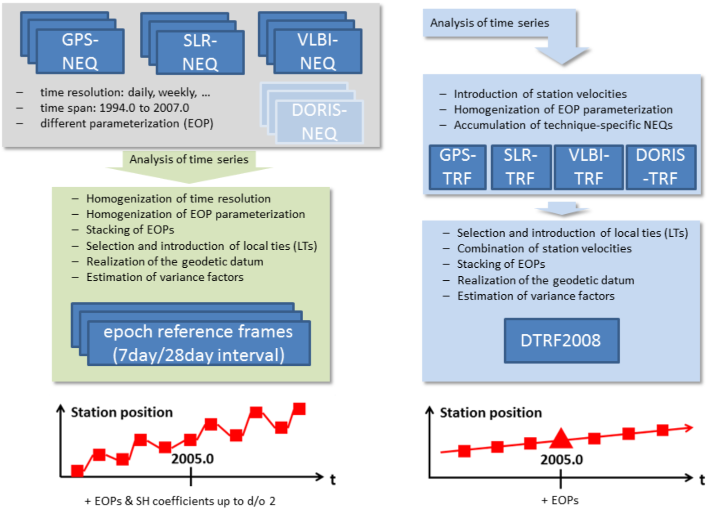

Fig. 2: Processing scheme for epoch and multi-year reference frames.

2.2 Geodetic datum

The geodetic datum is defined by assessing the origin, the orientation and the scale of the estimated reference frame. One way to define this is described in the IERS Conventions 2010 [Petit et al., 2010]: the origin of the ITRF2008 should not show any translations at a reference epoch t_0 or any translation rates w.r.t. the SLR technique-only solution. The scale of the ITRF2008 should be realized as a weighted mean scale of SLR and VLBI. Hence, there should be no scale factor at a reference epoch t_0 and no scale rates w.r.t. the weighted mean scale of SLR and VLBI. The orientation of the ITRF2008 should be defined by a No-Net-Rotation (NNR) condition for a subset of GPS stations w.r.t. the previous realization of the ITRS, the ITRF2005. Therefore, the rotation angles between the epoch solution and the multi-year solution should be zero at a reference epoch t_0. The rotation rates should also be zero over time. In contrast to the multi-year reference frames (datum definition by the IERS Conventions), for epoch reference frames only the time-independent part of the datum definitions has to be realized which means that no conditions for the rates of the datum parameters have to be introduced in the combination (Fig. 3).

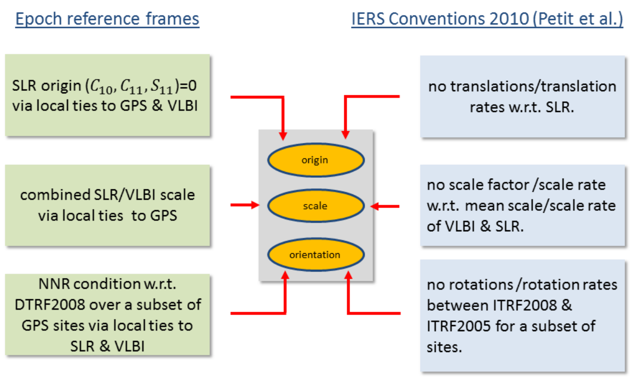

Fig. 3: Different realizations of the geodetic datum.

In the combination process the local ties play a very crucial role. The quality of the geodetic datum of the estimated epoch reference frames depends strongly on the accuracy of the local ties and the global distribution of the colocation sites. The local ties are used for connecting the station coordinates of the different techniques in order to get a most stable and homogeneous global station network within the combination. Because of this the local tie handling in the combination directly affects the quality of the datum realization in the different network parts. For the orientation in x- and y-direction, the coordinates of the terrestrial pole play an important role in the combination, too.

2.3 Results and Comparisons

Additionally to the station coordinates, the epoch solutions contain consistently estimated ERPs and gravity field parameters of degree two (parameters of degree zero are fixed to one, parameters of degree one are fixed to zero). To validate the quality of the realized datum parameters, the transformation parameter time series of a seven parameter Helmert-Transformation are derived w.r.t. a multi-year solution like the DTRF2008 which has a much more stable geodetic datum than the obtained epoch reference frames. The coordinates of the terrestrial pole are compared to the official reference time series IERS 08 C04. The estimated UT1-UTC values and the gravity field parameters of degree two are analyzed in Bloßfeld et al., 2011.

2.3.1 Quality of the realized geodetic datum

The left side of Fig. 3 shows which techniques are used for realizing the datum parameters. To validate the quality of the realized origin, the mean offsets of the SLR technique-only solution w.r.t. the DTRF2008 and the mean offsets of the GPS and the VLBI stations of the combined terrestrial reference frame (TRF) could be compared. Tab. 1 shows that the GPS stations of the combined TRF of the 7-day solution are in a good agreement with the DTRF2008, whereas the SLR only solution shows an offset of about -3 mm in the x-direction. Furthermore, the VLBI stations of the combined TRF show an offset of -4 mm in the y-component of the origin. The weighted RMS (WRMS) values for all techniques are between 4 and 6 mm for the x- and y-translation parameters and around 1 cm for the z-translation parameters, respectively. These accuracies also hold for the 28-day solution.

The orientation of the combined TRF is realized by a NNR condition for a subset of GPS stations w.r.t. the DTRF2008. Tab. 1 shows the rotational offsets of the GPS only solution and the SLR/VLBI part of the combined TRF. The NNR condition ensures that the rotation angles of the GPS only solution are equal to zero. Nevertheless Tab. 1 shows that small rotations are estimated. This is an effect of the transformation, where the GPS stations are not weighted equally and therefore small rotations are estimated. The agreement of the datum information within the combination is below 2 mm for the SLR station network and 3.5 mm for the VLBI station network, respectively. The WRMS values of the rotation parameters for the GPS only solution are less than 1 mm whereas the WRMS values for the SLR/VLBI station network in the combination are between 3 and 4 mm for the 7-day and the 28-day solution. This increased scatter of the gained parameters is caused by the inhomogeneous distribution of colocation sites and stations used for transformation and the accuracy of the used local ties.

The scale is realized as the mean scale of SLR and VLBI, which is emphasized by the values given in Tab. 1. The GPS network scale in the combined solution is a good approximation of the mean scale of SLR and VLBI.

Tab. 1: Mean offsets of the transformation parameters between the epoch reference frames and DTRF2008. Only values which are relevant for the validation of the geodetic datum are displayed.

[cm]	Tx	Ty	Tz	Rx	Ry	Rz	Sc
SLR	-0.293	-0.173	0.093				0.138
GPS				0.083	0.066	-0.008	
VLBI							-0.274
comb. (SLR)				-0.090	0.174	-0.032	
comb. (GPS)	-0.055	-0.142	0.095				-0.081
comb. (VLBI)	-0.023	-0.428	-0.085	-0.312	-0.002	0.243	

2.3.2 Quality of the pole coordinates (x, y)

The ERPs are compared with the IERS 08 C04 time series. The left side of Fig. 4 shows the differences of the coordinates in x-direction of the terrestrial pole w.r.t. to the IERS reference time series. It is clearly visible, that SLR shows the highest scatter. The corresponding WRMS values are displayed on the right side of Fig. 4. All solutions use a piecewise linear polygon representation of the pole coordinates with estimated offsets at midnight. The WRMS of the GPS and VLBI only solutions and both combined solutions (7-day/28-day) is below 1 cm. The GPS only solution shows the smallest WRMS value (cca. 3 mm). The scatter of the combined solutions is higher than the scatter of the GPS only solution. This could be due to the fact that the WRMS of the SLR only solution is about 1.2 cm. The high scatter results from the not well estimated coordinates of the terrestrial pole at the borders of the satellite arc. Also the VLBI only pole coordinates could be affected by some systematic effects and therefore could cause the increased scatter within the combination. If the two combined solutions are compared, the 28-day solution has a higher scatter than the 7-day solution which needs to be further investigated.

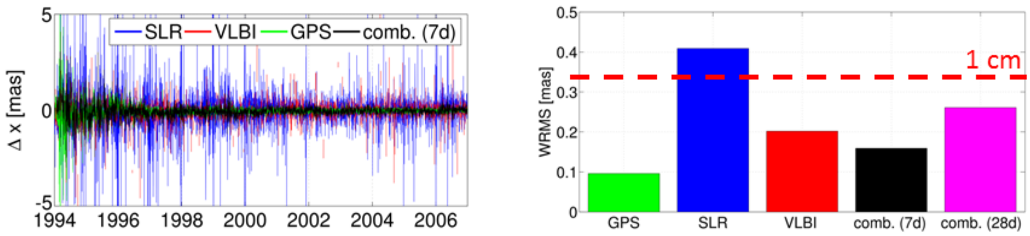

Fig. 4: Left: X-component differences of the terrestrial pole w.r.t. the IERS 08 C04 time series. There are displayed the technique-only solutions SLR, GPS and VLBI and the combined solution with a seven day arc length; Right: WRMS values of the differences of the technique-only solutions and both combined solutions (7-day/28-day).

3 Conclusions

The DGFI SLR solution contains consistently estimated station coordinates, ERPs and gravity field parameters. In the combination with GPS and VLBI, SLR plays a fundamental role for realizing the geodetic datum. SLR is the unique technique to provide the most stable information about the origin and together with VLBI it is used to realize the scale. The results in subsection 2.3.1 show that the geodetic datum in epoch reference frames could be realized with a mean accuracy of 3 mm and WRMS values of about 5 mm for the orientation and the scale w.r.t. the multi-year solution DTRF2008. The origin shows offsets below 4.5 mm with WRMS values up to 1 cm. Therefore, the accuracy of the geodetic datum of the more stable multi-year solution DTRF2008 could not be reached with the epoch solutions at present. However, the epoch reference frames could be a reasonable additional product to the multi-year solutions in order to represent the non-linear station motions in a better way. The validity of the station coordinates after big earthquakes could also be improved with epoch reference frames. The results discussed in subsection 2.3.2 show that the most accurate estimation of the coordinates of the terrestrial pole in the combined solution could be estimated if a temporal resolution of seven days is used. The 28-day solution has a higher scatter. The pole coordinates of the GPS only solution show the smallest scatter of the analyzed solutions. The SLR only and VLBI only pole coordinates might be falsified by systematic effects within the solutions.

Acknowledgements

The presented results are worked out in a project within the research group “Earth rotation and global dynamic processes”. This research group is funded by the German Research Foundation DFG. The authors want to thank the DFG for making the work in this project possible.

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