Some Aspects Concerning the SLR Part of ITRF2005

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Abstract

Two combined solutions for the ITRF2005 were generated independently by two ITRS Combination Centres, IGN, Paris and DGFI, Munich. A comparison of the two ITRF2005P solutions shows in general a good agreement, but the scale and scale rate of the SLR network differs significantly. To investigate this difference a number of tests were performed. It was found that the actual SLR results are consistent with the ITRF2005 solution of DGFI, whereas there is a bias of about 2 ppb compared to the IGN solution. The translation parameters between both ITRF2005 solutions are in good agreement. We also compared the VLBI and SLR scale through co-locations with GPS. This comparison showed the importance of a proper choice and weighting of local ties at co-location sites for the connection of the technique-dependent reference frames. Especially the sites at the southern hemisphere influence the resulting scale of the combined product.

Introduction

Within the re-organized IERS structure, there are three Combination Centres for the International Terrestrial Reference System (ITRS) at Deutsches Geodätisches Forschungsinstitut (DGFI), Munich, Institute Géographique National (IGN), Paris, and National Resources Canada (NRCan), Ottawa. The ITRS Product Center at IGN is coordinating the processing. DGFI and IGN provided each one solution for ITRF2005. Both used their own software and applied their preferred strategy. This guarantees independent results and allows a decisive validation and quality control of the results.

The combination strategy of IGN is based on the solution level by simultaneously estimating similarity transformation parameters w.r.t. the combined frame along with the adjustment of station positions and velocities. The ITRF2005 computations done at DGFI use unconstrained normal equations from the solutions of the different techniques.

This paper briefly summarizes the combination methodology of the ITRS Combination Center at DGFI. Main subject is a comparison of the ITRF2005 solutions of IGN and DGFI. The focus thereby is on the SLR part of ITRF2005.

Combination methodology of DGFI

The general concept of the ITRS Combination Center at DGFI is based on the combination of normal equations and the common adjustment of station positions, velocities and EOP. The computations are performed with the DGFI Orbit and Geodetic Parameter Estimation Software (DOGS). Details on the combination procedure and the mathematical background are given in various publications (e.g., Angermann et al., 2004; Angermann et al., 2006; Drewes et al., 2006; Krügel and Angermann, 2006; Meisel et al., 2005). Figure 1 shows the data flow and the combination methodology for the ITRF2005 computation.

The combination methodology of DGFI comprises the following major steps:

- Analysis of ITRF2005 input data and generation of normal equations
- Analysis of time series and accumulation per-technique (intra-technique combination)
- Comparison and combination of different techniques (inter-technique combination)
- Generation of the ITRF2005 solution by applying minimum datum conditions

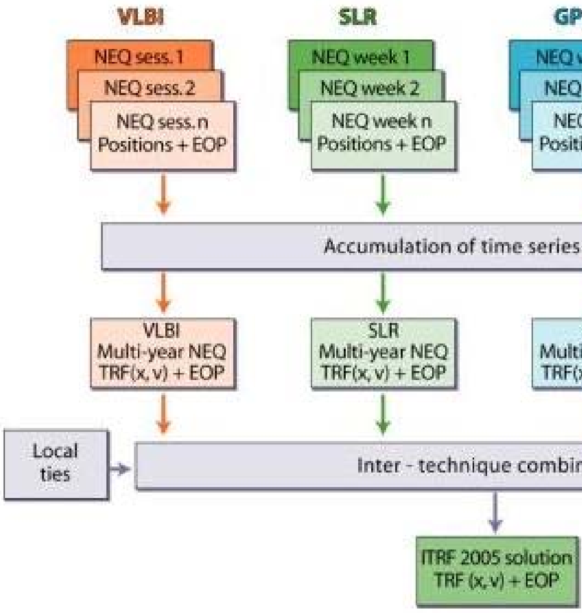

***Figure 1**. Data flow and computation procedure for the ITRF2005 solution of DGFI*

The final ITRF2005 solution comprises station positions, velocities and daily EOP estimates as primary results. In addition epoch position residuals and geocenter coordinates are obtained from the time series combination. The reference epoch for station positions is 2000.0. The rather inhomogeneous data quality and quantity of the space geodetic observation stations is reflected in the accuracy and reliability of the ITRF2005 station position and velocity estimations. This holds in particular for a number of SLR and VLBI stations, but also for some GPS and DORIS stations with few observations. Another aspect is that the new type of ITRF2005 solution contains many stations with several solution ID's. As a consequence the station positions and velocities are valid only for a certain period of time, which has to be known and considered by the users. Furthermore co-location sites may have different station velocities for co-located instruments, if their estimated velocities differ significantly.

Comparison of the ITRF2005 solutions of DGFI and IGN

For comparisons we performed similarity transformations between both solutions. These transformations were done separately for each technique by using good reference stations. The RMS differences for station positions and velocities show a very good agreement (after similarity transformations). This holds in particular for "good" stations with several years of continuous observations without discontinuities (Table 1). For weakly estimated stations (e.g., observation time < 2.5 years, different solutions caused by discontinuities) larger discrepancies do exist, which are in most cases within their standard deviations.

Most of the transformation parameters agree within their estimated standard deviations, except for the scale and its time variation of the SLR network. A significant difference of about 1 ppb (offset) and 0.13 ppb/yr (rate) between the ITRF2005P solutions of DGFI and IGN has been found, which accumulates to nearly 2 ppb in 2006 (see Table 2). The scale difference is not visible in the pure SLR intra-technique solutions of IGN and DGFI. This indicates that the difference between both ITRF2005P solutions is caused within the inter-technique combination.

From these comparisons it is obvious that the major problem of the ITRF2005 is the significant difference in the SLR scale. The analysis of weekly SLR solutions in 2006 has shown that the scale is in good agreement with the ITRF2005P solution of DGFI, whereas there is a significant scale bias of about 2 ppb w.r.t. the IGN solution (see Figure 2), which is equivalent to a difference of 1.3 cm in SLR station heights. It was argued by IGN that this "scale problem" is a consequence of a scale bias between VLBI and SLR. Because of the apparent discrepancies the scale of the IGN solution was defined by VLBI only, whereas the scale of the DGFI solution is defined by the SLR and VLBI data.

***Table 1**. RMS differences for station positions and velocities between IGN and DGFI solutions for ITRF2005 for "good" Reference stations (25 VLBI, 22 SLR, 57 GPS, 40 DORIS stations).*

ITRF2005P DGFI - IGN	Positions [mm]	Velocities [mm/yr]
GPS	0.31	0.14
VLBI	0.79	0.34
SLR	1.82	0.66
DORIS	3.32	1.11

***Table 2**. Scale differences between the pure intra-technique and the ITRF2005P solutions of DGFI and IGN.*

	SLR		VLBI	
	offset [ppb]	drift [ppb/yr]	offset [ppb]	drift [ppb/yr]
Pure intra-technique solutions (IGN – DGFI)	-0.17 ± 0.06	0.01 ± 0.02	0.16 ± 0.05	0.01 ± 0.02
ITRF2005 P solutions (IGN – DGFI)	0.86 ± 0.12	0.13 ± 0.03	-0.12 ± 0.06	0.03 ± 0.03

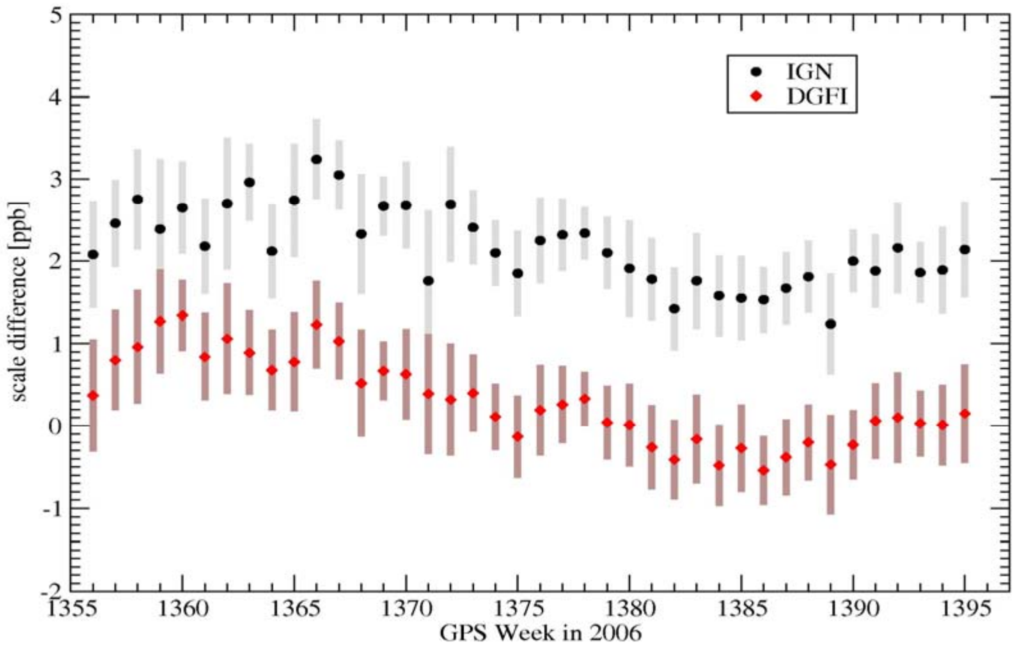

***Figure 2**. Scale of ITRF2005P solutions of IGN and DGFI w.r.t. to the combined SLR solution (ILRSA)*

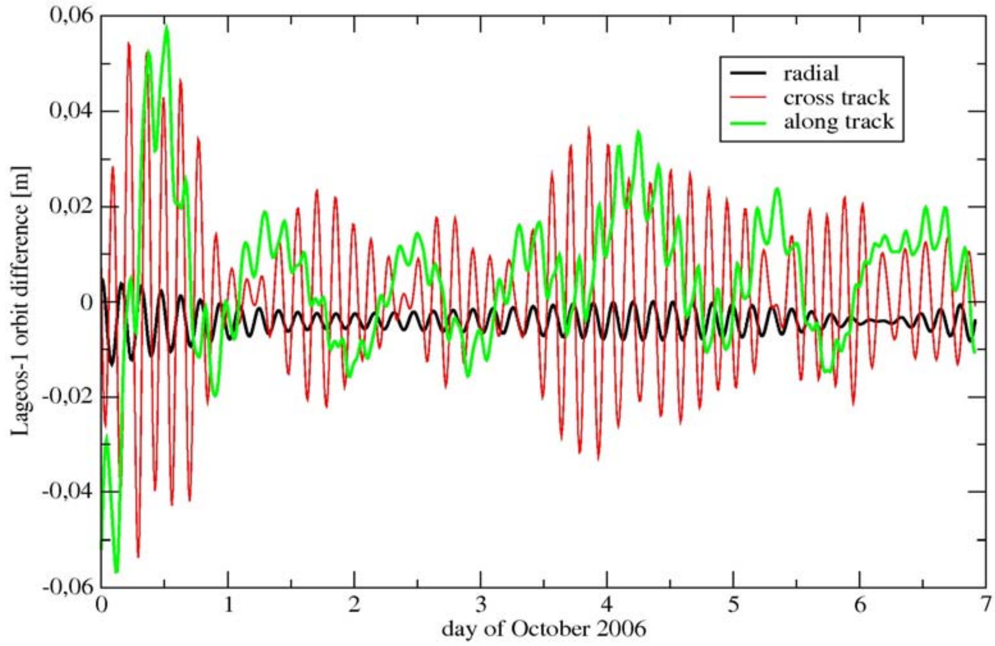

Figure 3. *Difference between IGN and DGFI solution for a weekly Lageos-1 orbit.*

This scale difference is also reflected in the resulting satellite orbits. For a comparison we solved a weekly Lageos-1 orbit with fixed station coordinates, one with the DGFI solution, the other with the IGN solution, solving for all internal arc parameters and polar motion (X-, Y- pole and dUT1). The resulting orbits were compared in radial, cross- and along track to investigate the influence of the scale difference. In figure 3 the radial offset of about 5 mm is clearly visible. The cross and along track components only show a revolution dependent signal which results from the radial orbit bias, but there is no systematic error. This comparison indicates that the scale of the IGN solution will produce biased satellite orbits.

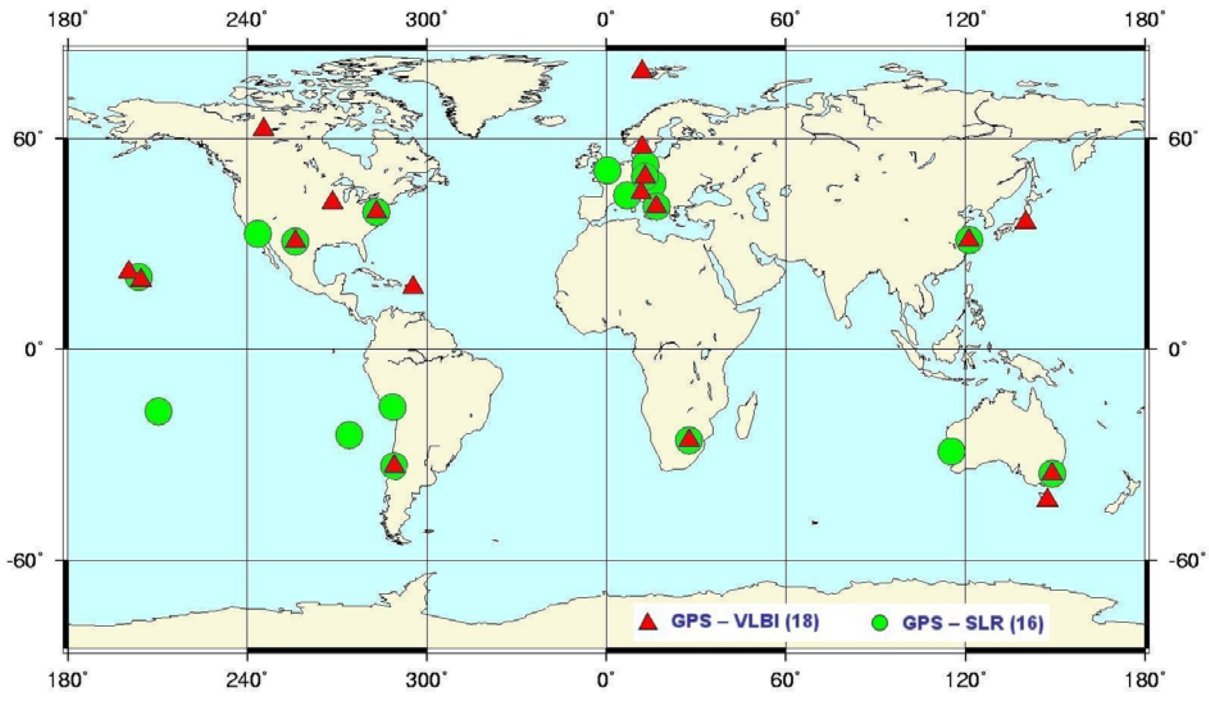

Figure 4. *Available co-location sites between GPS, SLR and VLBI*

Figure 5. *Observation period of southern hemisphere collocation sites*

Investigation of the scale differences

We used the intra-technique solutions of the DGFI combination for ITRF2005 to investigate the scale of VLBI and SLR. Since the number and spatial distribution of good co-location sites between VLBI and SLR is not sufficient to get reliable results for a direct comparison of the scale, we used an "indirect" approach via the GPS network and consider the GPS intra-technique solution as reference for this specific study. We used "good" co-location sites and local ties to refer the VLBI and SLR solutions to an "arbitrary" GPS frame (see Fig. 4).

The geographical distribution and quality of SLR tracking stations is in particular problematic in the Southern hemisphere. Therefore we focus on these stations and on the co-locations with GPS. Fig. 5 shows the GPS and SLR observation periods and the estimated ITRF 2005 precision for 8 SLR-GPS co-location sites on the southern hemisphere. DGFI used for the connection of the reference frames all stations except Easter Island and Conception because of poor SLR data. In the IGN solution the Australian sites Yarragadee, Mt. Stromlo, Orroral and Tahiti are down-weighted. Thus the reference frame connection in the IGN solution was realized mainly via the remaining 4 co-location sites on the Southern hemisphere, from which Easter Island and Conception are poorly observed by SLR. This indicates that the integration of GPS and SLR networks in the Southern hemisphere is rather poor in the IGN solution.

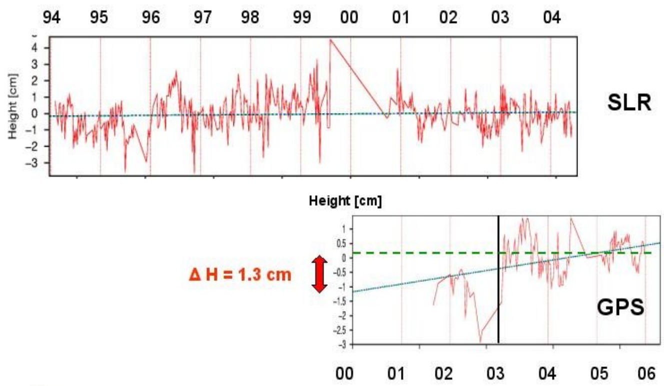

Figure 6. *Jump in the Haleakala time series*

Table 3: Scale difference between SLR and VLBI obtained from DGFI ITRF2005P solution.

	Δ Scale offset [ppb]	Δ Scale drift [ppb/yr]
SLR - VLBI	0.40 ± 0.42	0.04 ± 0.10
SLR – VLBI *	**0.26 ± 0.41**	**0.03 ± 0.09**

*** : Discontinuity for GPS station Maui introduced**

We also investigated the position time series of co-location sites. As an example Fig. 6 shows the GPS and SLR position time series for the co-location site Maui on Hawaii. A clear jump is visible in the GPS time series at the end of 2002, which affects the height estimation by about 1.3 cm. We have introduced a discontinuity for the GPS station Maui and we solved for two solutions. To test the influence of the jump we performed a 14 parameter similarity transformation between the GPS and SLR solutions and compared the resulting residuals. As shown in Fig. 7 the relatively large height residual for Maui disappeared completely.

The scale parameters obtained from the singularity transformations of the SLR and VLBI solutions w.r.t. GPS are arbitrary numbers, but the difference of the scale parameters is independent from the "arbitrary" GPS scale. The estimated scale difference between VLBI and SLR are shown in Table 3. If the discontinuity for GPS station Maui is introduced the scale differences are 0.26 ± 0.41 ppb for the offset and 0.03 ± 0.09 ppb/yr for the drift. Thus the results of the DGFI ITRF2005P solution do not indicate any evidence for a scale bias between VLBI and SLR.

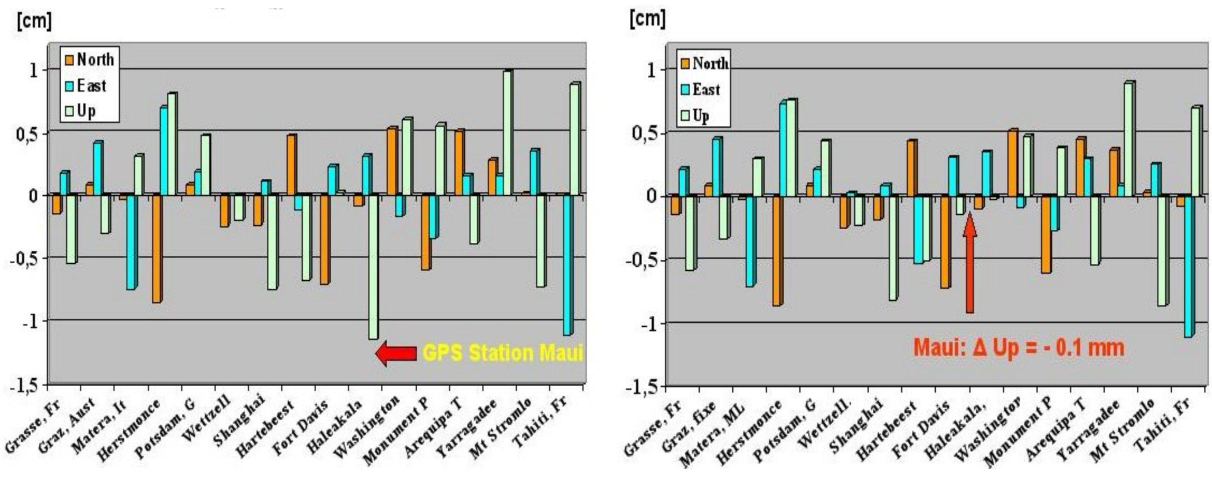

***Figure 7**. Station position residuals for 16 SLR-GPS colocation sites. The left figure shows a height residual for Maui of 1.2 cm, which is reduced to almost zero, if the jump for GPS station is introduced (see right figure).*

Conclusion

The DGFI and IGN for the ITRF2005 are in good agreement for the station positions and velocities (after similarity transformations), but a significant difference has been observed for the scale of the SLR network. As the discrepancies are not visible in the pure SLR intra-technique solutions of IGN and DGFI, they are most likely caused by a different combination procedure and in particular by the implementation of local tie information. Furthermore the IGN solution reveals an apparent difference in SLR and VLBI scales, which led to the exclusion of SLR data for the scale definition of the ITRF2005. The ITRF2005 solution of DGFI does not show this apparent scale difference between SLR and VLBI and it relies on the data of both techniques to define the scale. The analysis of the actual SLR tracking data show a good agreement with the scale of the ITRF2005 solution of DGFI, whereas there is a misfit of about 2 ppb w.r.t. the IGN solution.

Acknowledgement

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