The International Terrestrial Reference Frame - Latest Developments

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Abstract

The major goal of this paper is to give an overview about latest developments regarding terrestrial reference frame computations. Some aspects related to the latest ITRS realization, the ITRF2005, are addressed. The combination strategies of the ITRS Combination Centres of IGN and DGFI are compared and the impact of the different strategies on the terrestrial reference frame results is discussed. The paper also summarizes some of the latest developments performed by the technique centres (i.e., IGS, ILRS, IVS, IDS) to achieve further improvements for the generation of new time series for the computation of the ITRF2008, which is currently under examination. Another issue is the identification of remaining deficiencies and the development of improved concepts for future terrestrial reference frame computations.

1. Introduction

The latest version of the International Terrestrial Reference Frame, the ITRF2005, has been released by the ITRS Center in October 2006. The situation after the release of the ITRF2005 was dominated by the discussion on the scale problem, mainly the inconsistency between the VLBI and the SLR scale. For the first time in ITRF history, SLR did not contribute to the scale definition, instead this was solely determined by VLBI. SLR observations showed a significant bias w.r.t. the ITRF2005 scale, which makes it impossible to use the ITRF2005 directly for the SLR processing. As a consequence of this problem, IGN has provided a second (re-scaled) ITRF2005 solution for SLR users in December 2006. During the analyses of the ITRF2005 results it was found, that the scale of the ITRF2005 solution computed by the ITRS Combination Center of DGFI (ITRF2005-D) is consistent with the SLR observations (Angermann et al., 2009a; Müller and Angermann, 2008). A comparison between the ITRF2005 solutions of IGN and DGFI has shown, that the station positions and velocities are in good agreement (small R.M.S. differences after similarity transformations). Also 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 at epoch 2000.0) and 0.13 ppb/yr (drift) between the IGN and DGFI solutions has been found, which accumulates to more than 2 ppb in 2008 (Angermann et al., 2009a).

Several analyses have been performed to investigate the discrepancies reported above and to achieve improvements for future realizations of the terrestrial reference frame. In this context the combination strategies of both ITRS Combination Centers have been compared and their effect on the ITRF results has been investigated (see chapter 2). In chapter 3 some technique-specific issues, primarily related to the scale realization, are addressed. Chapter 4 presents various SLR test computations to investigate the impact of range bias estimation on the scale. Remaining deficiencies and concepts for future improvements are addressed in chapter 5, and finally, conclusions are given in chapter 6.

2. Comparison of IGN and DGFI combination strategies for ITRF2005

The ITRS Combination Centres of IGN and DGFI computed each a solution of the ITRF2005. The computation strategy of IGN is on the solution level by simultaneously estimating similarity transformation parameters with respect to the combined frame along with the adjustment of station positions, velocities and EOP (Altamimi et al., 2007). The strategy applied at DGFI is based on the combination of normal equations and the common adjustment of station positions, velocities and EOP (see e.g., Angermann et al., 2004; Drewes et al., 2006; Angermann et al., 2009a). A comparison of the combination strategies of both ITRS Combination Centres is provided in Tab. 1.

Table 1. Comparison of the combination strategies of IGN and DGFI

	IGN	DGFI
Software	CATREF	DOGS-CS
Time series combination	Stacking of minimum constrained Solutions by 7 parameter transformations	Accumulation of normal equations, without transformations
Inter-technique combination	Combination of per-technique solutions by 14 parameter transformations IGN used all available local ties with appropriate weighting	Accumulation of per-technique datum-free normal equations, without transformations DGFI used a selected set of local ties with appropriate weighting
ITRF2005 datum - Origin - Scale - Rotation - Rotation rate	 SLR VLBI 3 NNR conditions w.r.t. ITRF2000 3 NNR conditions w.r.t. NNR NUVEL-1A	 SLR VLBI + SLR (weighted mean) 3 NNR conditions w.r.t. ITRF2000 3 NNR conditions w.r.t. APKIM2005

A major difference is that IGN is estimating similarity transformation parameters between epoch solutions as well as between per-technique solutions and the combined frame. DGFI accumulates normal equations without performing similarity transformations. As outlined for example in Drewes (2009a), the estimation of similarity transformation parameters may be critical. One problem is, that all common motions of the stations of the reference network are transformed into the similarity parameters (translation, orientation, scale factor). According to the ITRS definition, the origin of the terrestrial reference system shall be fixed in the geocenter, and coordinate changes caused by the station movements must go to the individual station coordinates and not into the datum. Another difference between the IGN and DGFI solutions is, that different sets of local ties have been used for the inter-technique combinations. It was found, that this can produce an effect on the scale of the SLR network in the order of 1 ppb (see Müller and Angermann, 2008). Furthermore the datum definition is different in both ITRF2005 solutions: The scale of the IGN solution is defined by VLBI only, whereas the scale of the DGFI solution is realized by a weighted mean of the SLR and VLBI solutions. For the definition of the rotation rate, IGN uses the geophysical model NNR NUVEL-1A and DGFI the APKIM2005 model based on ITRF2005 station velocities (Drewes, 2009b).

3. Technique-specific issues

The technique centres for the different space techniques (i.e., IVS, ILRS, IGS, IDS) investigated the modelling and processing strategies to identify remaining deficiencies and to improve the consistency of their observation time series as input for the ITRF2008 computation, which is currently under examination. Below some of the latest developments are addressed for the different space techniques:

- ***VLBI***: From a refined analysis and comparison of VLBI time series generated by different analysis centres using different software systems it was found, that some of the analysis centres using CALC/Solve have obviously not correctly applied the pole tide model. The impact on the scale of the VLBI data submitted for ITRF2005 is in the order of 0.5 ppb (in direction to the SLR scale). Other issues that were addressed by the IVS include the modeling of antenna thermal deformation, investigations regarding the impact of loading effects (hydrology, pressure) and the implementation of improved tropospheric models (e.g., Nothnagel et al., 2009; Tesmer et al., 2008).

- ***SLR***: Because of the scale problems between SLR and the ITRF2005 a second realization (ITRF2005_rescaled) was computed by IGN. This solution is consistent with the SLR scale and has been used by the ILRS analysis working group for the computation of a new set of station coordinates and velocities, the SLRF2005. This SLR reference frame includes all ITRF2005 SLR stations, and in addition also some newer and older sites that were not included in the ITRF2005. Because of possible technical problems of the laser ranging systems (e.g., counter problems) the estimation of range biases may be required. Various test computations have been performed to investigate the impact of range bias estimation on the scale definition. Some results of these computations are presented in chapter 4 (see also Angermann and Müller, 2009).
- ***GPS***: Major shortcomings regarding the input data for ITRF2005 were that the data were not homogeneously reprocessed by the contributing analysis centres, and that relative antenna phase centre corrections were applied for the processing. In order to be consistent with absolute antenna phase centre corrections, the IGS has computed the IGS05 reference frame, which is currently used for the computation of the IGS products. The new submissions for the ITRF2008 are homogeneously processed and combined series based on absolute antenna phase center corrections. A serious problem in case of GPS is that there are many stations with several equipment changes resulting in a large number of discontinuities. This weakens the long-term stability of the solutions and complicates the co-location with the other space techniques.
- ***DORIS***: For precise orbit determinations (POD), the so-called DPOP2005 solution with updated DORIS station coordinates and velocities was computed in the ITRF2005 frame (Willis et al., 2009). Furthermore, the modelling and parameterization for the processing of the DORIS data was improved by the contributing analysis centres. Progress has also been achieved regarding the generation of ITRF2008 input data, which are now combined time series SINEX files.

4. Tests of SLR-dependent influences on the ITRF scale

Based on the SLRF2005, DGFI has reprocessed the SLR time series from 1993 to 2005 using the new bias values. As shown in figure 1, the new biases did not significantly change the SLR scale. There is no offset and only a slight drift of 0.1 ppb/year between the old and the new SLR solutions. Furthermore, the SLR observations were processed backwards for the period 1983 to 1992 by computing 15-day arc solutions. The corresponding time series of the SLR scale w.r.t. the SLRF2005 are shown in figure 2. The results indicate that also for the earlier data the SLR scale is consistent with the SLRF2005. However, there are some systematic deviations in the year 1992 (which need to be further investigated), and the data before 1984 show higher variations which is mainly due to a weak SLR station network geometry during that earlier period.

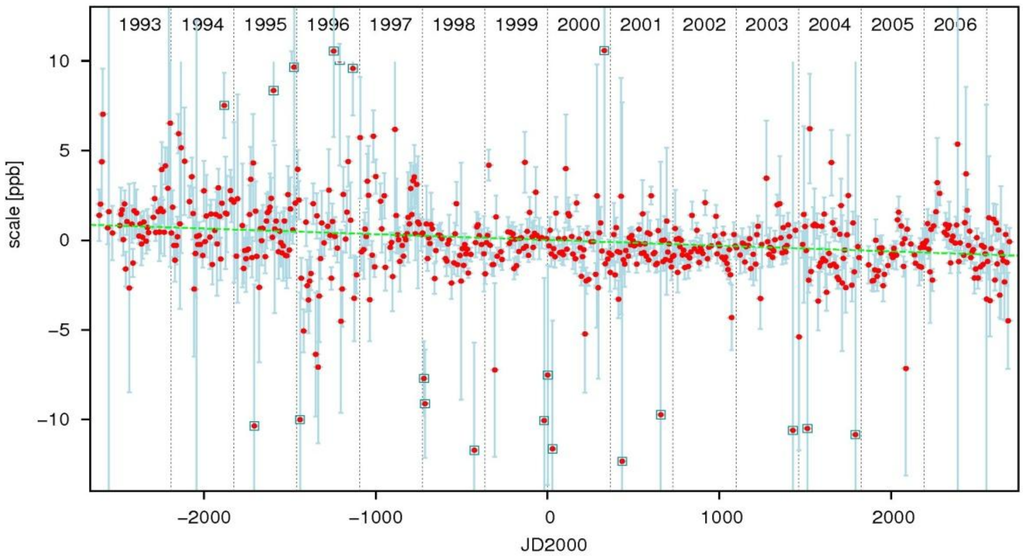

Figure 1. Time series for the scale obtained from the weekly SLR solutions (new bias values) w.r.t. SLRF2005 (offset: 0.0 ± 0.1 ppb , drift –0.1 ± 0.03 ppb/year).

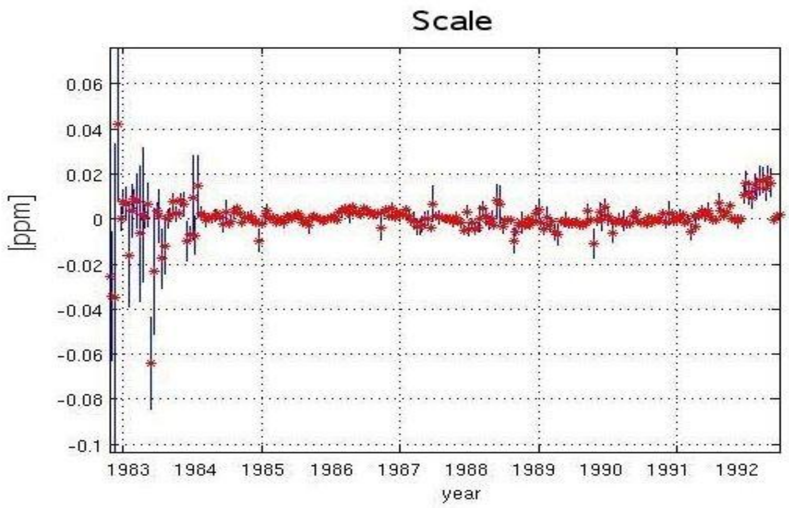

Figure 2. Scale difference from 15 arcs between SLRF2005 and the newly processed DGFI solution between 1983 and 1992

The major outcome of this test computations is that the SLR scale has a high long-term stability, that it is consistent with the SLRF2005, and that there is no significant effect of the bias handling strategy on the SLR scale. Similar results were obtained in earlier test computations performed at DGFI (for more details see Angermann and Müller, 2009).

5. Developments and future concepts

Although a remarkable progress has been achieved for the analysis and combination of the different space techniques in the last years, there are still some remaining deficiencies for the computation of the terrestrial reference frame. One problem is, that the input data sets are not fully consistent. On the international level, the standards for modeling and parameterization have not yet been (totally) unified among the analysis centres.

Within the GGOS-D project, homogeneously processed observation time series have been generated for the different space geodetic observation techniques, as the basis for the computation of a GGOS-D terrestrial reference frame and for the generation of consistent, high-quality time series of geodetic-geophysical parameters. The project involves four German institutions: GeoForschungsZentrum Potsdam (GFZ), Bundesamt für Kartographie und Geodäsie (BKG) in Frankfurt/Main, Institut für Geodäsie und Geoinformation, Universität Bonn (IGG) and DGFI. An overview about the project as well as the standards for modelling and parameterization used for the processing of the GGOS-D data are given in Rothacher et al., (2007). Table 2 shows the VLBI, SLR and GPS observation time series, which were provided as unconstrained datum-free normal equations (Krügel et al., 2007; Angermann et al., 2009a).

Table 2. GGOS-D input data used for the TRF computation.

Technique	Institutions	Software	Data	Time period
GPS	GFZ	Bernese	Daily NEQ	1994 – 2007
VLBI	IGG DGFI	CALC/SOLVE OCCAM	24 h session NEQ 24 h session NEQ	1984 – 2007 1984 – 2007
SLR	DGFI GFZ	DOGS EOPS	Weekly NEQ Weekly NEQ	1993 – 2007 1993 - 2007

Compared to the ITRF2005 input data, there are some major advantages: (1) The observation time series of the different space techniques were homogeneously reprocessed based on unified standards; (2) in case of GPS consistently reprocessed observation time series were used (see Steigenberger et al., 2006, Rülke et al., 2008); (3) the modelling of the observations was improved (e.g., absolute instead of relative phase centre corrections, the pole tide model was correctly applied in the VLBI software CALC/SOLVE); and (4) the type of input data is nearly identical to the original observation equations and is much more appropriate for the combination than for example loosely constrained solutions or solutions with removable mimimum constraints. Another advantage is, that the total number of discontinuities could significantly be reduced compared to the ITRF2005 computation (Krügel et al., 2007). This was mainly achieved by the homogeneously processed GGOS-D data sets and the implementation of absolute antenna phase centre corrections for the GPS processing.

The time series analysis has shown seasonal variations for many stations, especially in the height component. Fig. 3 shows the mean average shape of such annual variations for four GPS-VLBI co-location sites. These seasonal signals may be caused by atmospherical, hydrological and non-tidal oceanic loading effects, which are presently not reduced from the original observations. In other cases, instrumentation effects (rather than geophysical ones) may be also responsible for the observed signals.

A deficiency in the current reference frame computation is that the temporal variations of station positions are described only by constant velocities. Deviations of the station motions from a linear model (e.g., seasonal variations) will produce errors in the combination results. Seasonal variations will affect the velocity estimations, in particular for stations with relatively short observation time spans (i.e., < 2 years). The alignment of epoch solutions to a reference frame with positions and constant velocities is also affected by non-linear station motions. As shown in figure 3, the shape of these non-linear motions differs between stations. A suitable handling (parameterization) of the seasonal variations in station positions is a challenge for future ITRF computations.

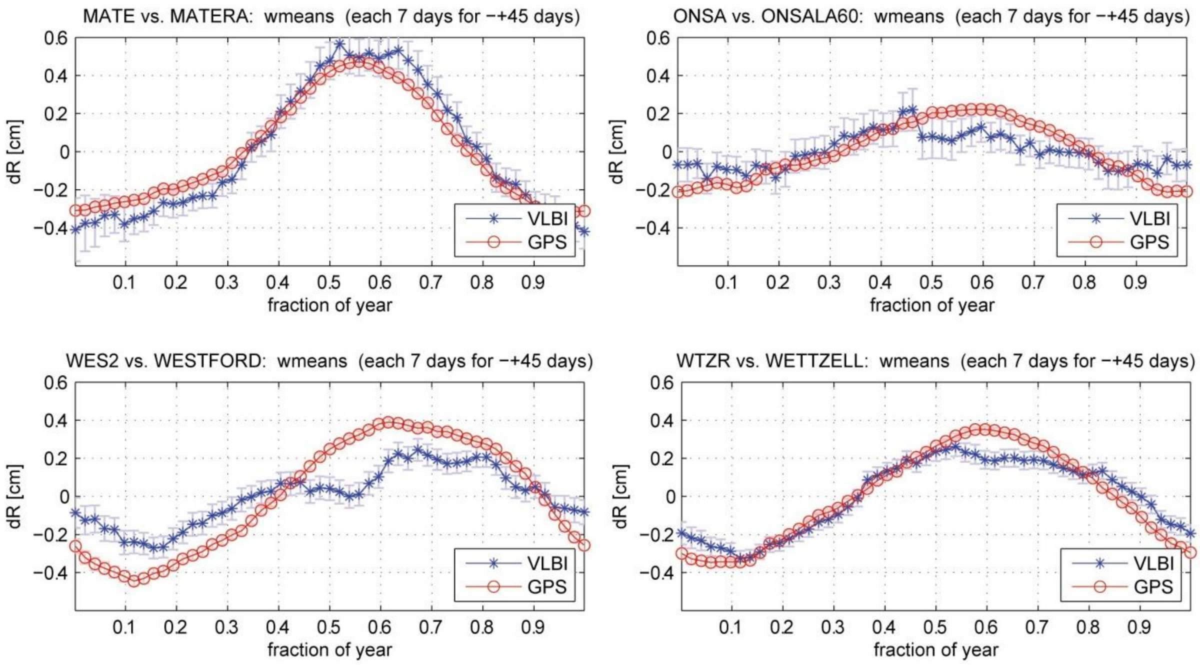

Figure 3. Mean annual behaviour of homogeneously processed VLBI (blue stars) and GPS (red circles) height time series at four co-location sites. The figures illustrate 90 days moving weighted means and their formal errors, computed each 7 days from the daily height estimates

6. Conclusions

The ITRF2005 results and in particular the inconsistency between the VLBI and SLR scale have stimulated intensive discussions within the space geodetic community. The combination strategies of the ITRS Combination Centres of IGN and DGFI were analysed and the differences were discussed. Also the technique centres (i.e. IGS, ILRS, IVS and IDS) have carried out various activities to study the existing inconsistencies and to perform investigations regarding modelling and parameterizations for the processing of the different space geodetic observations. As a result improvements have been achieved for all space techniques and reprocessed observation time series are available for the computation of the new ITRF2008, which is currently under examination.

Another objective was the identification of remaining deficiencies regarding terrestrial reference frame computations and the development of new concepts. A remarkable progress has been achieved within the GGOS-D project due to the generation of fully consistent and homogeneously processed observation techniques and due to the development of advanced combination methods. The results of the time series analysis have shown non-linear variations for most of the stations. Deficiencies regarding current reference frame computations are that the temporal variations are described only by constant velocities, and hence deviations of the station positions from a linear model (e.g., seasonal variations) will produce errors in the ITRF results. Thus, the handling and parameterization of non-linear station motions is a challenge for future TRF realizations.

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