Station Positioning and the ITRF

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Abstract

The International Terrestrial Reference Frame (ITRF) as a realization of the International Terrestrial Reference System is one of the scientific products of the International Earth Rotation and Reference Systems Service (IERS). The ITRF is the standard frame recommended for a variety of applications, from surveying to the very fine studies in Earth Sciences. In order to satisfy science requirements, the ITRF should be accurate, reliable and internally consistent over time with unambiguously specified datum definition (origin, scale, orientation and their respective time evolution). Starting with the ITRF2005, the input data requested for the ITRF construction are under the form of time series of station positions and Earth Orientation Parameters (EOPs). Such data do not only allow an appropriate evaluation of the frame accuracy and internal consistency, but also are adequately suited to measure the positioning performance of space geodesy techniques. This paper attempts to review the positioning performance of space techniques via the analysis of the submitted time series to ITRF2005. A special focus will also be given to address the current accuracy level of the ITRF datum definition.

Introduction

The concept of reference systems and frames is one of the fundamental mathematical foundations of modern geodesy with the advent of space techniques since the early eighties. We refer to the pioneering work by a certain number of geodesists and astronomers in (Kovalevsky et al., 1989) who established the foundation of the concept of reference systems and frames followed and used as a basis for the ITRF derivation. Indeed, it is fundamental to adopt that clearly defined concept which distinguish between the system as a theoretical inaccessible mathematical model and the frame as the numerical realization of the system. Moreover, the frame is not only accessible to the users but it is also by essence perfectible, being based on and derived from space geodesy observations.

Using the commonly accepted model of 7(14)-parameter euclidian similarity (also known as Helmert or Bursa-Wolf parameters), it becomes then straightforward to estimate discrepancies between solutions over the frame physical parameters. This is the case for instance where large translation components are often found between SLR on one hand and GPS or DORIS solutions on the other hand. Less scattered temporal behavior of the SLR translation components (as seen from time series analysis), compared to GPS or DORIS, leads to privilege SLR for the ITRF origin definition. Regarding the scale, it is of course admitted that from the theoretical and technology point of view, VLBI and SLR techniques should agree on the TRF scale. However, because we have the possibility to check for their scale consistency (or inconsistency), then when comparing their respective solutions, the possible inconsistency is obviously due to some systematic errors that should be investigated.

The ITRF Product Center hosted by the Institut Géographique National, France, together with the contribution of the ITRF combination centers (DGFI and NRCan) released the ITRF2005 solution in October 2006. Contrary to previous ITRF versions, the ITRF2005 integrates time series of station positions and daily Earth Orientation Parameters (EOP's). The ITRF2005 input time-series solutions are provided in a weekly sampling by the IAG International Services of satellite techniques: the International GNSS Service-IGS (Dow et al. 2005), the International Laser Ranging Service-ILRS (Pearlman et al., 2002) and the International DORIS Service-IDS, (Tavernier et al., 2006), and in a daily (VLBI session-wise) basis by the International VLBI Service-IVS (Schlueter et al., 2002). Each per-technique time-series is already a combination, at a weekly basis, of the individual Analysis Center (AC) solutions of that technique, except for DORIS where two solutions are submitted by two ACs, namely the Institut Géographique National (IGN) in cooperation with Jet Propulsion Laboratory (JPL) and the Laboratoire d'Etudes en Geophysique et Oceanographie Spatiale (LEGOS) in cooperation with Collecte Localisation par Satellite (CLS), designated by (LCA).

Reasons for which it was decided to use time series of station positions and EOPs as input to ITRF2005 include:

- monitoring of non-linear station motions and all kinds of discontinuities in the time series: Earthquake related ruptures, site instability, seasonal loading effects, etc;
- rigorously and consistently including EOPs in the combination and ensuring their alignment to the combined frame;
- examining the temporal behavior of the frame physical parameters, namely the origin and the scale;
- assessing space geodesy positioning performance, through the estimation of the weekly (daily) Weighted Root Mean Scatter (WRMS) with respect to the long-term solution resulting from the stacking of the time series.

In the following sections we will primarily focus on two main issues: the positioning performance of space geodesy techniques and the temporal behavior of the SLR origin and the scale and the VLBI scale of the contributed solutions to the ITRF2005.

Combination Methodology

The approach that is currently adopted for the combination of various TRF solutions provided by a single or several space geodesy techniques is built on the construction of a unique (combined) TRF, making use of the mathematical (7)14-parameter euclidian similarity. It considers defining the combined TRF at a given (arbitrary) reference epoch and adopting a TRF time evolution law that is supposed to be linear (secular). Consequently, 14 degrees of freedom are always necessary to completely ensure the TRF datum definition: 6 for the TRF origin and its rate (time derivative), 2 for the scale and its rate and 6 for the orientation and its rate. The inclusion of EOPs into the combination requires additional equations where the link between the TRF and EOPs is ensured via the 6 orientation parameters. The combination model considered by the ITRF Product Center allows the estimation of station positions and velocities, transformation parameters of each individual TRF solution with respect to the combined TRF and, if included, consistent series of EOPs. The input solutions usually used in this kind of combination are either (1) time series of station positions and EOPs or (2) long-term solutions composed by station positions and velocities and EOPs. In the first case where the combination amounts to rigorously stacking the time series, the un-modeled non-linear part of geodetic parameters are implicitly embedded in the combination output: possible seasonal (e.g. annual or semi-annual) station or/and geocenter motions are respectively left in the output time series of station residuals and the transformation parameters. For more details, regarding the combination methodology the reader may refer to (Altamimi et al. 2007a, 2007b).

Positioning Performance

When stacking station positions time series (weekly for satellite techniques and daily for VLBI), global WRMS per week (day) is computed, that is to characterize the internal precision and repeatability over time of each individual position time series. Figure 1 illustrates the WRMS per week (day) for each one of the 4 technique time series over the horizontal and vertical components and Table 1 summarizes the WRMS range. It is to be noted that the WRMS values do not qualify the techniques, but rather the solutions of the techniques which were submitted to the ITRF2005, and they are highly dependent on the quality of each station/instrument. Other factors are also important such as the number of the satellites available, e.g. in case of DORIS it was shown (Altamimi et al. 2006) that the quality (WRMS) improves when the number of satellites increases. However, from Figure 1 and Table 1, we can postulate that the current positioning performance for the best cases is around 2 mm for the horizontal component and around 5 mm for the vertical component.

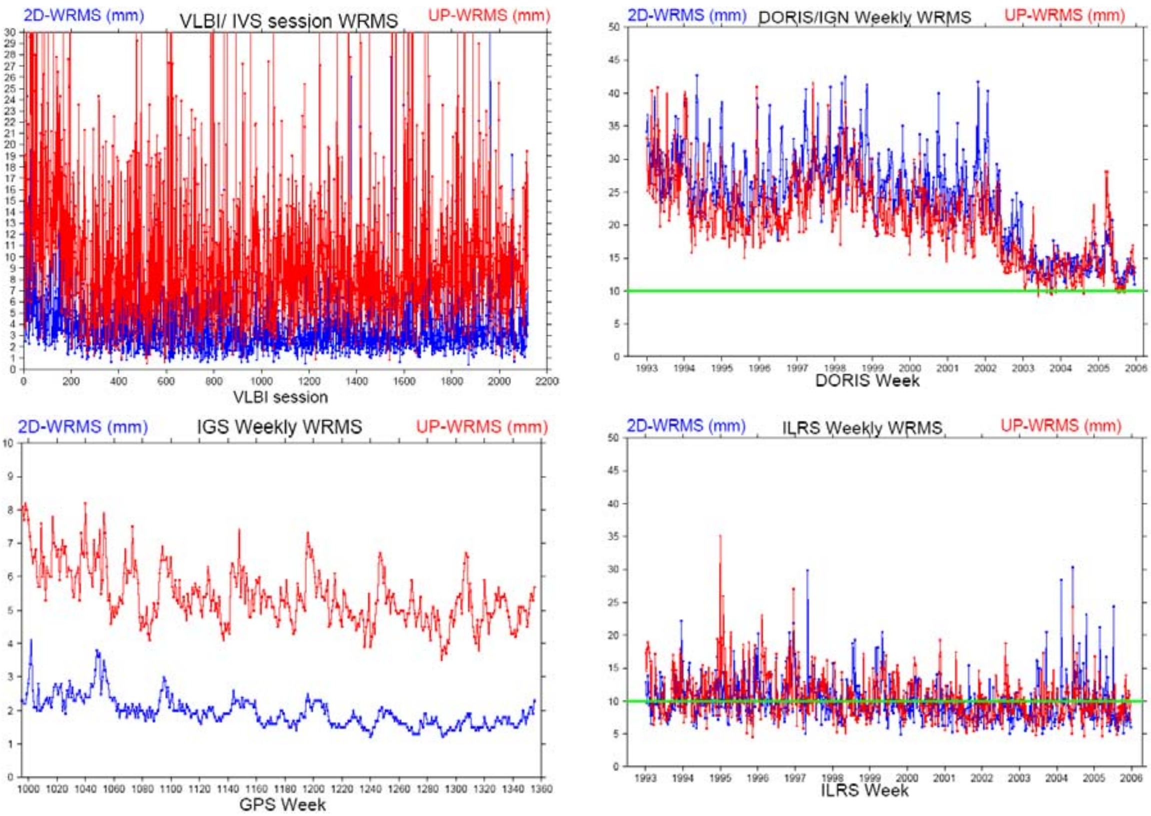

Figure 1*. Weekly (daily) WRMS as results from the time series stacking.*

Accuracy of the ITRF Origin and Scale

The Origin

Although it is hard to assess the origin accuracy of the single ILRS solution that is submitted to ITRF2005, we attempt however to evaluate its consistency with respect to ITRF2000. Figure 2 shows the 3 translation time variations with respect to ITRF2000, using a reference set of 12 stations. Given their observation history and good performance, these are the only stations that are usable to link the combined

Table 1. *WRMS range per technique*

Solution	2-D WRMS mm	Up WRMS mm
VLBI	2-3	5-7
SLR	5-10	5-10
GPS	2-3	5-6
DORIS	12-25	10-25

SLR TRF resulting from the stacking of the time series to the ITRF2000 frame. Because the estimated transformation parameters are heavily sensitive to the network geometry, the distribution of the reference set of 12 stations is far from being optimal; only two of them are in the southern hemisphere (Yaragadee, Australia, and Arequipa, Peru). Apart from the seasonal variations that could be estimated over the translation parameters, the linear trends are of great importance to the ITRF origin stability over time. From Figure 2 we can easily see that the most significant trend is that of the Z-translation component, being of the order of 1.8 mm/yr. This bias will therefore exist between ITRF2000 and ITRF2005, and could be regarded as the current level of the origin accuracy as achieved by SLR. From that figure we can also distinguish a "piece-wise" behavior of the Z-translation: between respectively 1993-1996; 1996-2000 and 2000-2006. In our opinion, this is completely related to and correlated with the change of the ILRS network geometry over time. In order to illustrate that effect, we plotted on Figure 3 the number of SLR stations available in each weekly solution. From this plot, one can easily see the decreasing tendency of the number of stations, starting around 2000, which should be correlated with the Tz component that starts to significantly drifting at this same epoch (see Figure 2). In addition, among the approximately 80 SLR stations available in the ITRF2005, approximately 20 of them have sufficient time-span of observations to be considered as core stations for useful and comprehensive analysis.

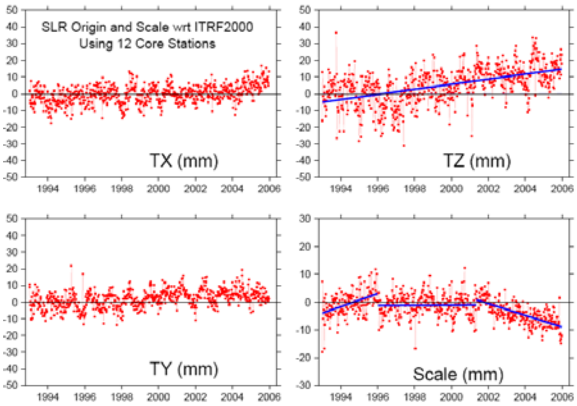

Figure 2*. Translations and scale variations with respect to ITRF2000 of the ILRS SLR time series submitted to ITRF2005.*

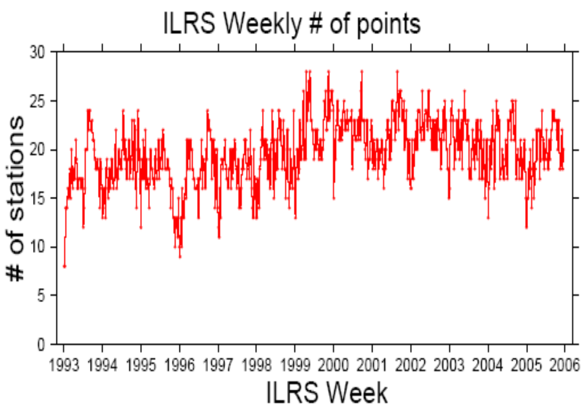

Figure 3*. Number of stations included in the weekly ILRS SLR time series submitted to the ITRF2005.*

The Scale

The ITRF2005 combination (making use of local ties in co-location sites) revealed a scale bias of 1 ppb between VLBI and SLR solutions at epoch 2000.0 and a scale drift of 0.08 ppb/yr. VLBI scale selected to define that of ITRF2005 is justified by (1) the availability of the full VLBI history of observations (26 years versus 13 for SLR) embedded in the submitted time series and (2) the the non-linear behavior (discontinuities) observed in the ILRS scale (see Figures 3). In order to illustrate more the inconsistency between the two scales, Figure 4 displays both scales with respect to ITRF2005, showing a clear bias both in the offset and the linear trend.

The accuracy assessment of the ITRF scale is not easy to evaluate, being dependent on several factors, as for instance, the quality and distribution of the local ties, the SLR range bias effect, the tropospheric modeling in case of VLBI and other possible systematic errors of the two techniques. However, given the level of consistency mentioned above between VLBI and SLR scales and despite the optimistic accuracy estimate of the ITRF2000 datum definition as stated in (Altamimi et al., 2002), and to be more conservative, we can postulate that the current level of accuracy of ITRF scale is around 1 ppb and 0.1 ppb/yr.

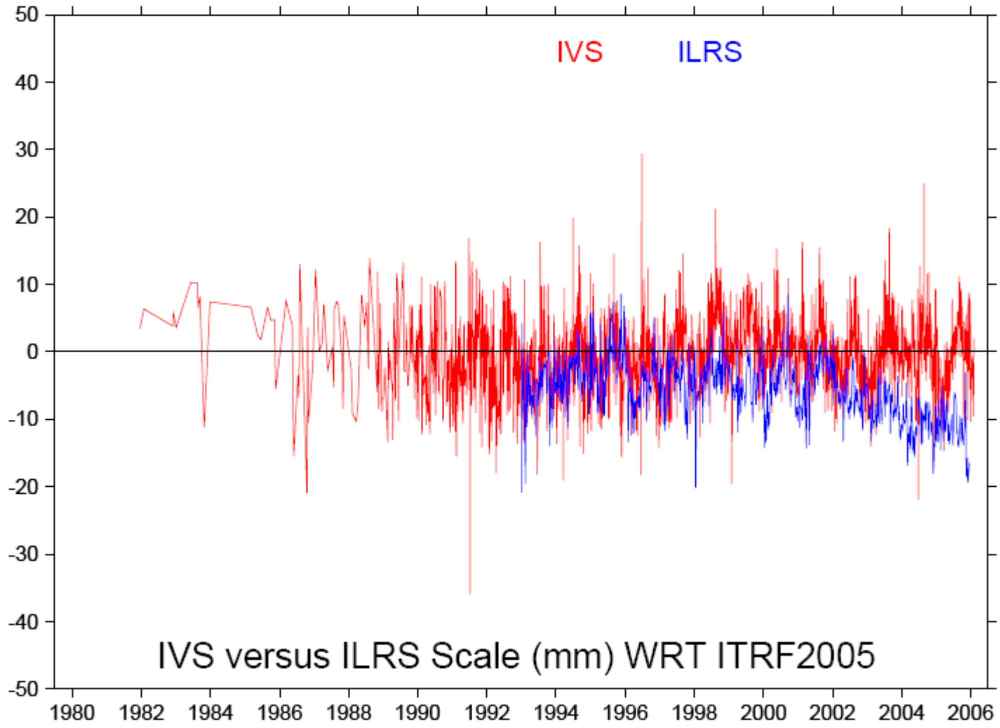

Figure 4. *VLBI and SLR Scale factor variations with respect to ITRF2005.*

Conclusion

The ITRF2005 experience, using time series as input data, showed how sensitive the frame parameters are to the network geometry and in particular in case of SLR and VLBI and their co-locations. The scale bias between VLBI and SLR solutions revealed by the ITRF2005 combination is most probably due to multiple reasons that include poor VLBI and SLR co-locations, local tie uncertainties, systematic errors and possible differences in correction models (e.g. troposphere, SLR range bias, relativity) employed in the data analysis of both techniques. As results from the ITRF2005 analysis, the positioning performance at the weekly/daily basis, range between 2 to 25 mm, depending on the measurement technique, the instrument quality or station performance.

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