# The ILRS contribution to the development of ITRF2013

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**Abstract**

Satellite Laser Ranging (SLR) data have been fundamental over the past three decades for the realization of the International Terrestrial Reference Frame (ITRF), which is based on an inter-technique combination of the geodetic solutions obtained from an intra-technique combination strategy performed at each IAG Technique Centre. This approach provides an opportunity to verify the internal consistency for each technique and a comparison of Analysis Center (AC) adherence to internal procedures and adopted models.

The International Laser Ranging Service (ILRS) contribution is based on the current IERS Conventions 2010 as well as on internal ILRS ones, with a few documented deviations.

The main concern in the case of SLR is monitoring systematic errors at individual stations, accounting for undocumented discontinuities, and improving the satellite target signature models. The SLR data re-analysis for ITRF2013 extends from 1983 to the end of 2013 and was carried out by 8 ACs according to the guidelines defined by the ILRS Analysis Working Group (AWG). These individual solutions have been then combined in the official solution by the ILRS Combination Center.

This work allows point-wise monitoring of the quality of the SLR contribution and a thorough investigation on the time behaviour of its characteristic products, i.e. origin and scale of ITRF. The stability and consistency of these products are discussed for the individual and combined SLR time series. The critical issues from this analysis will be presented to highlight the key points that SLR should take into account to contribute in the best possible way to the present and future ITRF realizations.

**Introduction**

For the realization of the next ITRF, the IERS Technique Centers of the four space geodetic techniques (SLR, VLBI, GNSS, DORIS) were requested to provide official single-technique solution, merging in an optimal way all of the available AC solutions.

The role of SLR in the realization of the ITRF is fundamental, both for its temporal data coverage, starting at the beginning of the eighties, and its specific sensitivity to the terrestrial origin and scale. As in the case of ITRF2008, it is expected that SLR will realize the ITRF origin and along with VLBI the ITRF scale.

The official ILRS (Pearlman et al. 2002) contribution to the new ITRF2013[(1)] is generated by the Primary ILRS Combination Center (CC) at the Space Geodesy Center of the Italian Space

[1] At the time of the IWLR 2014, the ITRS Call for Participation for ITRF2013 was still valid. The decision to extend the series through 2014 and go for the realization of ITRF2014, came later. The description of the ILRS contribution is applicable to ITRF2014 with the extension of the series to 2014.

Agency (ASI/CGS) and is designated as ILRSA. A backup solution time series (named ILRSB) is computed at the Goddard Earth Sciences and Technology Center (GEST/UMBC), the backup CC.

The ILRS contribution to ITRF2013 is a time series of weekly station coordinates and daily EOPs: X-pole, Y-pole and excess Length-Of-Day (LOD), estimated over 7-day arcs aligned with calendar weeks (Sunday to Saturday) from January 1993 to December 2013. For the earlier period, January 1983 to December 1992 15-day arcs had to be used generating station coordinates as biweekly averages and EOP estimated as 3-day averages since the network size and the data from a single satellite do not allow stable solutions with the higher resolution. Both the individual and combined solutions follow strict standards agreed upon within the ILRS AWG to provide products of the highest possible quality.

## Individual solutions

The individual solutions are computed by the official ILRS ACs (see Table 1) using the SLR data acquired from the worldwide network that observed the satellites LAGEOS, LAGEOS-2, Etalon-1 and Etalon-2. From 1983 to 1992 the dataset made up of LAGEOS data only is called from now on the "historical period". This dataset is complemented with the LAGEOS-2 and ETALON satellites starting from 1993. The amount of the ETALON data is roughly one tenth of the data from the two LAGEOS, and have a practically negligible impact on the results.

| | | |
|---|---|---|
| ASI | Agenzia Spaziale Italiana | Italy |
| BKG | Bundesamt für Kartographie und Geodäsie | Germany |
| DGFI | Deutsches Geodätisches Forschungs Institut | Germany |
| ESA | European Space Operation Center | Europe |
| GFZ | GeoForschungsZentrum Potsdam | Germany |
| GRGS | Groupe de Recherche de Géodésie Spatiale – Observatoire de la Cote d'Azur | France |
| JCET | Joint Center for Earth Systems Technology – NASA&UMBC | USA |
| NSGF | NERC Space Geodesy Facility | UK |

**Table 1** Current ILRS Analysis Centers

The measurements are processed in intervals of 7 days (15 days in 1983-1992) to generate a loosely-constrained solution for station coordinates and EOP. The EOPs ($X_p$,$Y_p$ and LOD) are all computed as daily averages since 1993 and as 3-day averages when only LAGEOS data are available during the "historical period". Daily UT parameters are also solved for, but they are of course considered as weakly-determined parameters by any satellite technique and are not included in the analysis product that is submitted to the combination centers.

The product quality is affected by different factors including the adopted conventions, application/estimation of systematic errors, applied satellite center-of-mass (CoM) corrections, data coverage and hidden constraints. These factors were addressed in the past years within the ILRS AWG in order to give the ACs some guidelines. Analysis contributors are generally free to follow their own computation model and/or analysis strategy, but a number of constraints must be followed for consistency:

## ILRSA intra-technique combination

The first step in the combination process is the rigorous check of each individual AC time series in terms of looseness in the applied constraints, the application and/or estimation of systematic corrections for the set of sites over specific periods, the deletion of data when they are not recoverable, all according to the adopted AWG guidelines. This phase is in general time consuming, requiring a close interaction between the ACs and the CCs, and can take several months especially when reprocessing of the time series is required.

Once the input AC solutions are fully checked, the CCs are ready to start the final combination process. The official ILRS combined solution is produced by the Primary Combination Center, ASI/CGS, and named ILRSA; a backup combined solution (ILRSB) is computed at GEST/UMBC, the backup CC.

The ILRSA solution has been obtained by a direct combination of the loosely constrained solutions, taking advantage of the fact that loosely constrained solutions, although they possess an ill-defined datum, they still preserve the relative geometry of the station polyhedron figure.

The combination is based on the method described in (Davies and Blewitt 2000) and allows handling input solutions easily, with no inversion problems for the solution variance-covariance matrix, no need to know a priori values for the estimates and no need to estimate or remove relative rotations between the reference frames before combining the solutions.

Each contributing solution (and related variance-covariance matrix) is treated as an 'observation' whose misclosure with respect to the combined solution must be minimized in an iterative Weighted Least Square approach. Each solution is stacked using its full covariance matrix rescaled by an estimated scale factor. A scaling of the covariance matrix of the *i*-th solution is required because the relative weights of the contributing solutions are arbitrary. Imposing $\chi^2=1$ for the combination residuals and requiring that each contribution to the total $\chi^2$ is appropriately balanced, the relative scaling factors ($\sigma_i$) are estimated iteratively together with the combined solution.

The scale factors for each contributing AC are reported in Table 1 as mean value and standard deviation over the period 1993-2013 when the solutions are more stable with the complete 4 satellites configuration. Five ACs have similar scale factors (between 4 and 5) while 3 ACs need higher scale factors to achieve a balanced contribution in the combination, which means that they have higher residuals with respect to the combined solution.

**Table 1** Scaling factors applied to the individual AC solutions' covariance

| | ASI | BKG | DGFI | ESA | GFZ | GRGS | JCET | NSGF |
|---|---|---|---|---|---|---|---|---|
| Mean | 4.3 | 4.9 | 11.6 | 3.9 | 7.6 | 4.7 | 5.4 | 10.6 |
| Standard deviation | 2.7 | 4.1 | 5.5 | 1.7 | 5.4 | 2.9 | 3.5 | 6.0 |

A rigorous editing (Brockmann 1996) has been introduced to eliminate outliers with respect to the combined solution following a 5σ criterion.

## ILRSA assessment

The internal precision of the ILRSA solution is checked through the computation of the weighted root mean square (wrms) over the time series of the coordinate residuals of each input solution with respect to the combination. Thus, a cumulative 3-dimensional value of the wrms (3D wrms) is computed for each solution using the coordinate residuals in all three components, of all the sites contributing to each solution. The time series of the 3D wrms for each AC are illustrated in Fig. 1 as a yearly running average, from 1993 to 2013, in order to make more evident their mean value and their trend. The internal "agreement" is roughly 4 mm over the last years, with a higher value for three input solutions, as mentioned above.

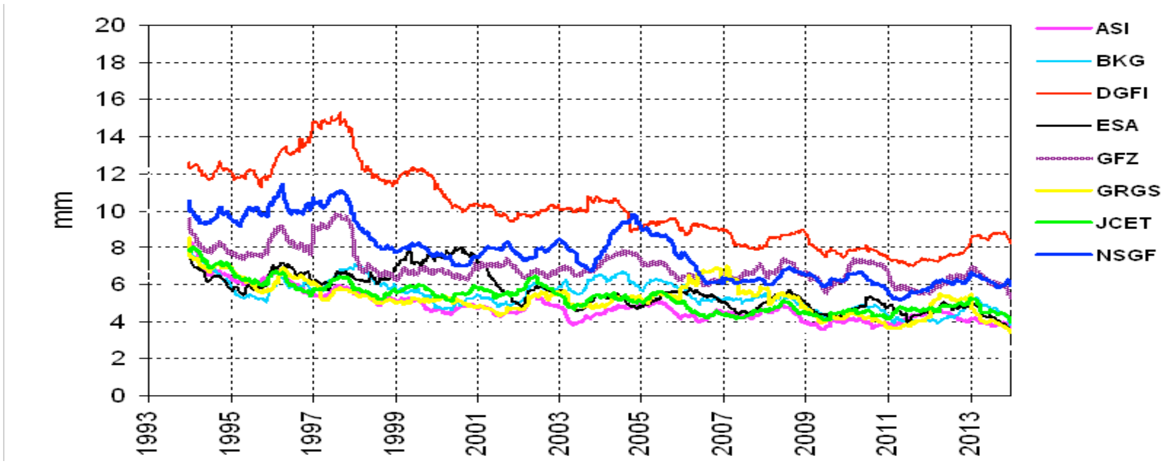


**Fig. 1** WRMS of the coordinate residuals with respect to ILRSA (yearly running average)

The external precision is checked comparing the ILRSA solutions with SLRF2008 in terms of:

- mean of the 3D wrms of the site coordinate residuals w.r.t. SLRF2008
- translation and scale offsets of ILRSA with respect to SLRF2008.

and the EOPs with respect to the USNO final daily values (derived primarily from GNSS data). The initial decade of the solution time series, the "historical period", (1983-1992) consists of less precise estimates. However, the old portion of the series is a valuable and unique contribution of the SLR technique to the long-term Terrestrial Reference Frame definition, contributing a number of sites from the early stages of space geodetic networks.

Fig. 2 shows the 3D wrms values for the input solutions as well as the ILRSA combination, where each dot is the value of the single solution using a subset of "core sites" and the black line is a polynomial fit that highlights the trend of the ILRSA combination.

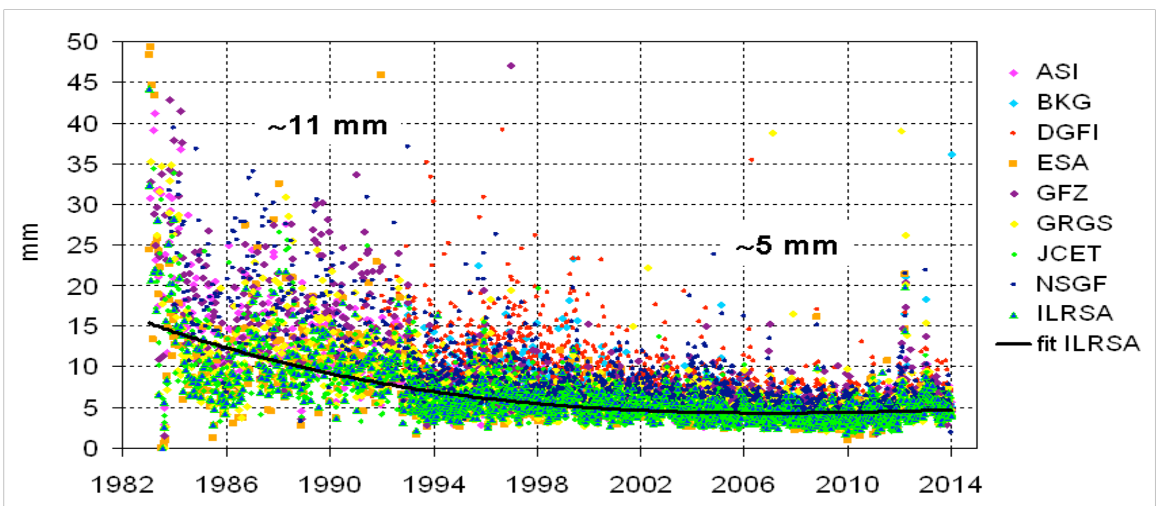


**Fig. 2** 3D WRMS of the core site coordinate residuals with respect to SLRF2008

The datum stability of the ILRSA combination is assessed through the estimation and analysis of the translation and scale offsets with respect to SLRF2008. The translations shown in Fig. 3 are relative to the 1993-2013 time-span.

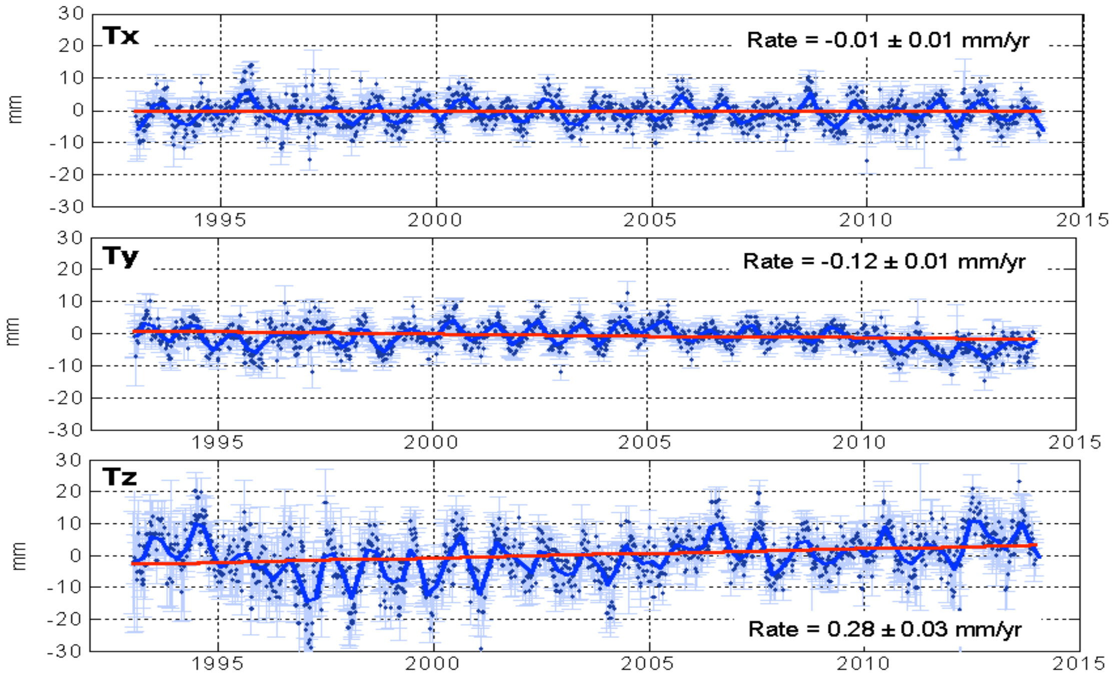


**Fig. 3** ILRSA translation offsets with respect to SLRF2008

Very small offsets and drifts are visible (Table 2) while, as expected, significant seasonal variations are present. A small deviation from the trend is visible in Ty after 2010; this signature is present in all the input time series, but the reason for the deviation is not clear. Tz is noisier, as expected, and a change of slope occurs around 1997, already present in previous solutions (Altamimi et al. 2011).
The linear fit on the scale (Fig. 4) time series indicates clearly a negative slope (-0.37 mm/yr). The yearly running average over the time series highlights a change of slope around 1997 and an anomalous signature around 2010 (similar and contemporary with what we see in Ty), unexplained at the moment.

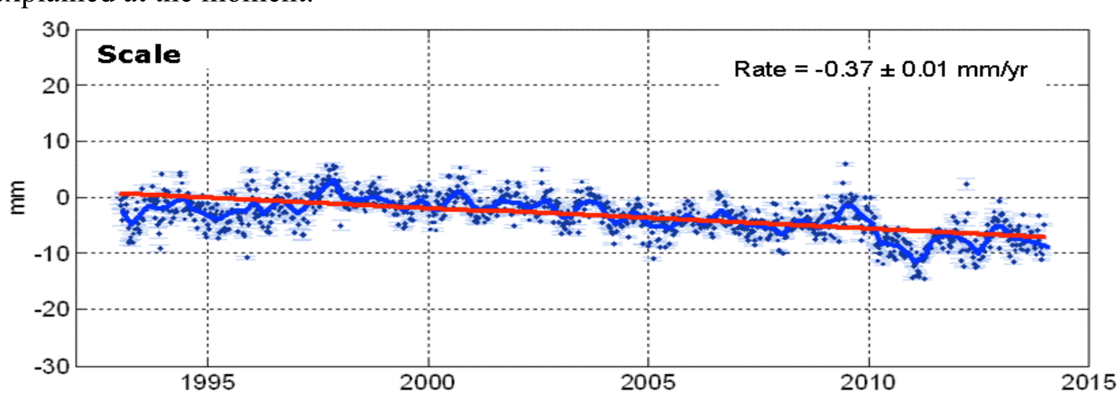


**Fig. 4** ILRSA scale factor with respect to SLRF2008

It seems that the anomaly in 2010 is due to an isolated event at that time, with the subsequent part of the time series continuing with the same linear trend observed over the main part of the series. As in the case of the translations, all the input AC solutions show the same behavior and a much more extensive investigation will be undertaken to resolve it. A summary of the Helmert transformation parameters linear trend is in Table 2.

**Table 2** Translation and scale with respect to SLRF2008

| | $T_X$ | $T_Y$ | $T_Z$ | SCALE |
|---|---|---|---|---|
| Offset @ 2005.0 (mm) | -0.3±0.1 | -0.7±0.1 | 0.7±0.2 | -3.76±0.08 |
| Slope (mm/y) | -0.01±0.01 | -0.12±0.01 | 0.28±0.03 | -0.37±0.01 |

As stated above, another external comparison is made for the EOPs with the USNO final daily values. The comparison is performed in terms of wrms of the residuals and the results agree in general with what is expected from the SLR technique: 167 μas for the X-component, 190 μas for the Y-component and 32 μs for LOD.

## Conclusion

The ILRS contribution to the next ITRF has been delivered following the guidelines of the ITRS Call for Participation. The eight ILRS Analysis Centers produced time series of station coordinates and EOPs ($X_p$, $Y_p$ and LOD ) over the period 1983-2013 under the constraints agreed within the ILRS Analysis Working Group. The ILRS Combination Centers delivered the official ILRSA combined time series and the backup series ILRSB.

The internal and external precision of the combined time series has been evaluated through the comparison between the input individual series and the combined one, between the combined and SLRF2008 a priori, and for the EOPs, with the USNO time series.

These comparisons show good performance of the quality parameters (site coordinates WRMS, Helmert transformation parameters time series) for the final combined solution and a remarkable coherence for the single AC solutions: the 3D WRMS of the Core Site residuals with respect to SLRF2008 reaches 5mm in the last years, the Helmert transformation parameters time series (origin and scale) show coherence over time and very limited noise, allowing the detection of small secular and periodic components, with only Tz slightly noisier, as expected. A signature starting around February 2010 is visible in the Ty and scale series and will be further investigated as to its origin and possible remedy.

As requested by the IERS ITRS centre, the ILRS time series will be extended to include 2014; the network will benefit by a considerable number of new stations, mainly Russian, but the quality of the ILRS contribution is not expected to be substantially affected.

## References


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