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Quality and possible improvements of the official ILRS products

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Abstract.
In this paper we are looking for some possible improvements to the official ILRS products. These combined products are already of good quality but a few changes can help to get better results. We are investigating the data handling, especially the range biases and the possible use of LARES as an additional target in space.

Introduction

The Analysis Working Group (AWG) of the ILRS (Pearlman, 2002) is providing various products for the international community. Seven analysis and two combination centers take care of the quality of resulting products such as station coordinates, Earth Orientation Parameters (EOPs) and satellite orbits. Daily and weekly products are provided by the ILRS data centers.
One aspect to improve station coordinates is the consistent handling of station biases and the station coordinates used for processing. Biases and station coordinates are correlated and especially the height component of a station depends on the range bias estimated. EOPs depend on a homogeneous distribution of observations along the orbit. Especially Etalon is poorly tracked with presently 150 to 200 observations per week only and hence has only little influence on the ILRS products.
Furthermore, we were investigating the use of the new satellite LARES as an additional target or as replacement for Etalon tracking. The orbit perturbations of this satellite can easily be modeled since he combines a heavy weight with a small diameter. Due to the orbit characteristic LARES can also improve the sky coverage over stations. Besides, this satellite can be used to improve the low degree harmonics of the Earth's gravity field. These coefficients up to degree and order four to six are not well defined by the present gravity missions GOCE and GRACE.

Quality assessment

It is not easy to investigate the quality of a unique product. The weekly and especially the daily solutions are combined by two different combination centers. ILRSA is a combination of loose constrained solutions, whereas ILRSB is a combination of free normal equations. To evaluate their quality, we analyzed the differences of similarity transformation parameters between the two combined solutions using the ILRS core stations. The transformations parameters are small (Figure 1), in general a few millimeters, as well as the resulting coordinate differences for the core stations. However, if we look at the non-core stations, differences up to one meter exist (Figure 2). In our analysis we identified the main reason for that as a difference in the handling of the bias parameters for non-core stations and the different approaches of the two combination centers. Not all analysis centers use the same set of bias parameters they solve for. This aspect cannot be neglected, especially if the SLRF2008 coordinates for a station are not correct, either due to earthquakes or if the station is new and has preliminary coordinates and especially velocities. The ILRS data handling file

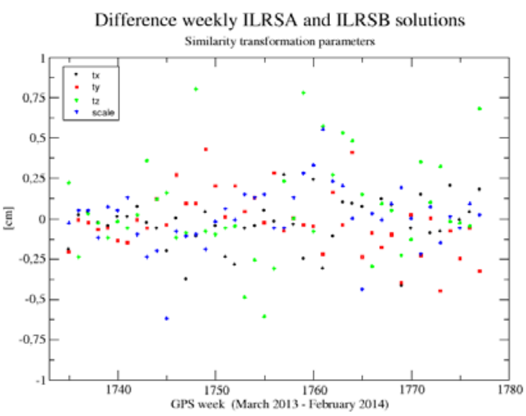

Figure 1: Parameter of similarity transformation between ILRSA and ILRSB weekly solutions, using core stations.

(1) summarizes all actions to be applied to the data. This file is mandatory to all analysis centers. Besides all analysis centers have to use the IERS 2010 standards for their analysis and should analyze all observations to LAGEOS 1/2 and Etalon 1/2.

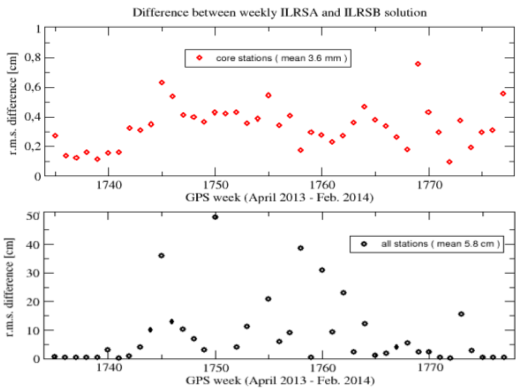

Figure 2: Station residuals after similarity transformation.

Station Biases

Biases are still a critical aspect in SLR processing and have to be taken into account for a few stations. Either by deleting the data, by applying a previously estimated common range bias or by solving for a solution dependent range bias. Figure 3 shows the range biases for the station San Juan (7406) for the period between July 2011 and February 2014 from the DGFI quality analysis.

For the analysis, the big values are unproblematic since these data are eliminated. However, this station has from time to time also small range biases in the 10 - 20 cm level, which are not easy to detect (mainly in automatic processes) and might lead to different coordinates. To have a reliable estimate of the range biases it is necessary to use accurate a priori coordinates. In Figure 4, the biases estimated for Altay Mountain (1879) with the recent (wrong in SLRF2008) coordinates and velocities and a new set, computed by DGFI, are shown. The influence of the wrong set of coordinates, especially the wrong velocity, can easily be seen in the big values and variations of the range biases computed with the old set. Additionally, the range biases provided in the weekly JCET solutions are shown.

Since the data handling file does not include the information to solve for a range bias for this station, resulting station heights vary between centers solving for biases and those not solving for. The unequal combination strategies also lead to different coordinates. The same behavior can also be seen for some other stations.

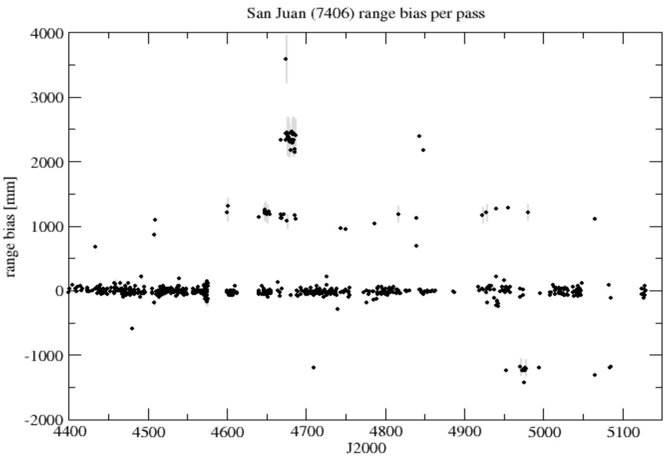

Figure 3: Range biases per pass for stations San Juan (7406) from DGFI quality analysis.

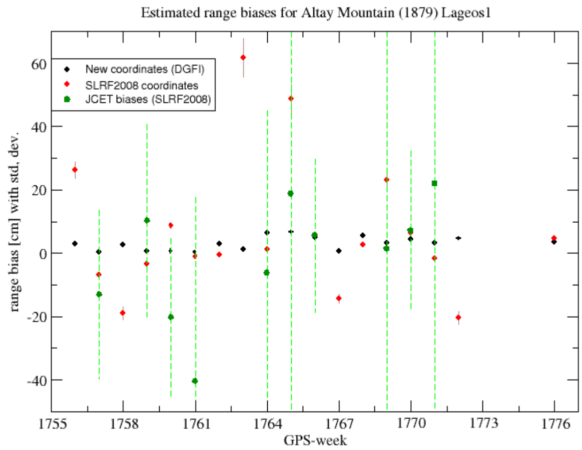

Figure 4: Estimated range biases for Altay Mountain (1879) with different sets of station coordinates.

New station coordinates

To reduce the influence of incorrect station coordinates, a new set was computed by DGFI and ASI and will be adopted into the new SLRF2008 version, used for the processing of the ITRF2013 reference frame. For the station Altay Mountain (1879), the station velocity published in SLRF2008 is wrong by about one order of magnitude and hence the extrapolated coordinates are getting worse with time. The stations Concepcion (7405), San Juan (7406), Koganei (7328), Tanegashima (7358), Kunming (7820) and Simosato (7838) were affected by earthquakes close to the station and need new coordinates and velocities. The weekly coordinates of Concepcion show the relaxation after the big earthquake with an offset of more than 3 meters. Other stations like Svetloe (1888) and Badary

(1890) in Russia are new and need new coordinates and especially new velocities. In order to get reliable station velocities, observations for about 2.5 years are required (Blewitt and Lavallée, 2002). In the appendix, weekly time series processed at DGFI using the DOGS software are included. For a few stations, weekly coordinates and fitted velocities (blue dots and lines) together with discontinuities and SLRF2008 velocities (red lines) are shown.

LARES, a new target in orbit

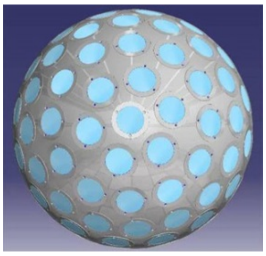

Figure 5: Drawing of LARES (source: ilrs.gsfc.nasa.gov)

In February 2012, the new LARES satellite (Figure 5), equipped with reflectors, was launched and is tracked by the ILRS network. This satellite has a very small area-to-mass ratio (weight: 386.8 kg, diameter: 36.4 cm). Therefore, the impact of the surface forces is small and it is not necessary to use drag models for the high atmosphere. In general, it is sufficient to use a simple empirical model to approximate the along-track acceleration as for LAGEOS 1/2 and Etalon 1/2. Since LARES has a small orbit altitude, it allows to improve the low degree harmonics of the Earth's gravity field up to degree and order 4 or even 6. For these coefficients, the specialized gravity missions like GRACE and GOCE are not very sensitive (Bloßfeld et al., 2014) since their mission priority is to observe time-variable or small wavelengths of the gravity field.

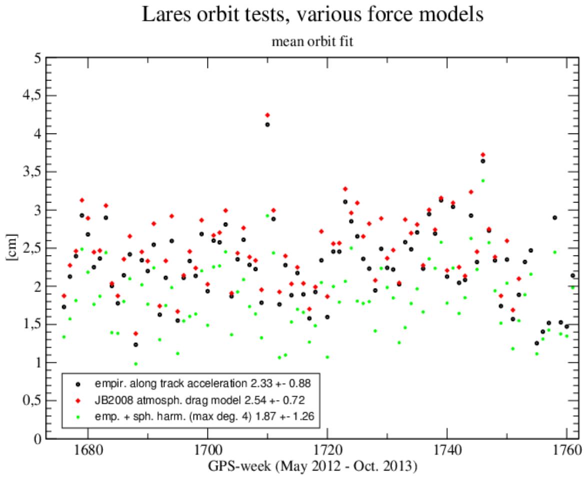

Figure 5: Weekly LARES orbit fit using different force models.

Since LARES is an easy target, many SLR passes are available (around 150 per week with 1700 normal points). In contrast to this, both Etalons have 28 passes per week with 150 observations in the same time period. The low number of observations makes it difficult to compute stable orbits which could contribute to the overall product. LARES orbits are well tracked and therefore might contribute to the ILRS products even without solving for spherical harmonics significantly. In Figure 6, the weekly orbital fits for different force models used in the LARES processing are summarized. The main advantages of including LARES into the processing would be the improved sky coverage and better global distribution.

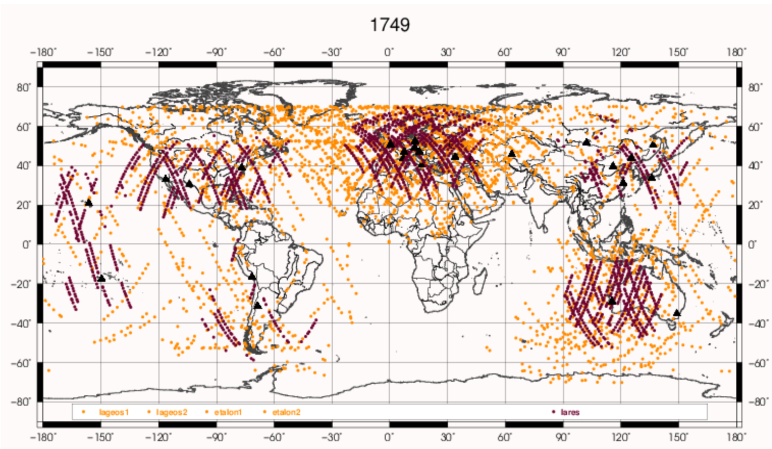

Figure 7: Global coverage of observations GPS-week 1749, LAGEOS 1/2, Etalon 1/2 and LARES.

Figure 7 shows the global distribution of observations for the GPS-week 1749 (mid of July 2013) with the LAGEOS 1/2 and Etalon 1/2 observations as bright (orange) dots and the additional LARES observations as dark (red) dots. The better global distribution stabilizes the estimation of polar motion and length of day (Bloßfeld et al., 2014). More evident is the improvement of the sky coverage over stations with only few observations.

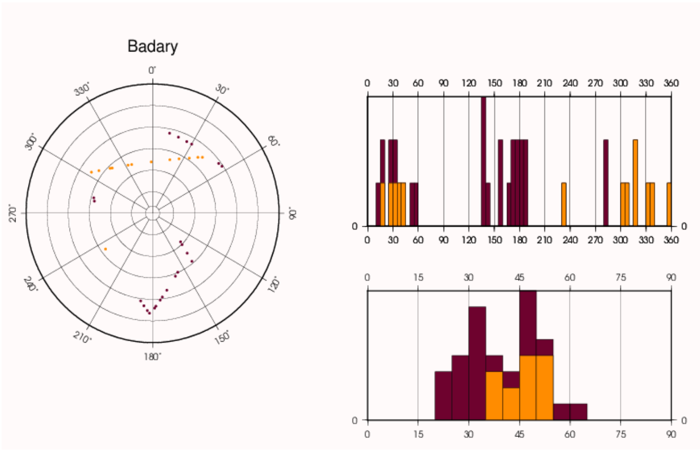

Figure 7: Sky coverage, azimuth and elevation of observations for station 1890.

In Figure 8, the sky plot for the Russian station Badary (1890) shows the improvement of the observation coverage in azimuth and elevation (during the same GPS-week as in Figure 6) when using the LARES observations. The improved coverage leads to better weekly station coordinates. The remaining position residuals of this station to SLRF2008 after similarity transformation are reduced from 10.9 cm North, 6.3 cm East and -10.2 cm in Height to 2.6 cm 3.0 cm and 0.9 cm by using the LARES observations of this week.

The overall quality of the weekly stations coordinates improve with LARES added to the combination.

Figure 8 shows mean remaining station residuals of the weekly DGFI solutions from April 2012 to the end of 2013 in North, East and Height. For this plot, the official ILRS solution setup (LAGEOS 1/2 and Etalon 1/2 observations, blue) is compared to a solution using in addition LARES observations (red) and using observations to up to 11 spherical passive satellites (green).

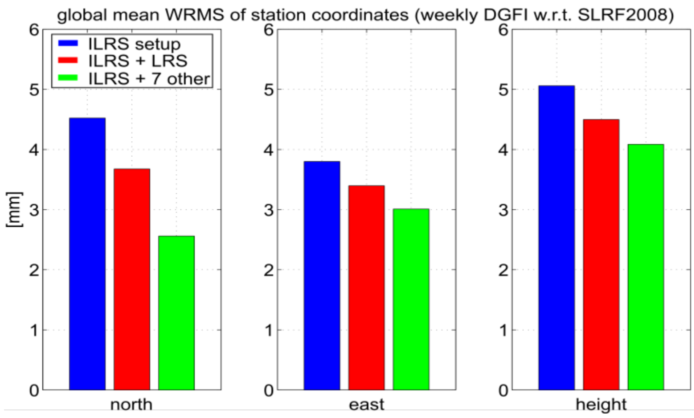

Figure 8: Global WRMS of weekly DGFI station coordinates w.r.t. SLRF2008.

Conclusion

The standard ILRS products are high quality products which could be further improved by possibilities shown in this paper. First, a unique modelling of the reference frame and the force models used for computation is essential. Second, a unification of the data handling, including bias modelling and eventually a unification of data editing is necessary. Furthermore, the use of ranging data to LARES would improve the overall product. In this context, an inclusion of the low degree spherical harmonics of the Earth's gravity field to the list of official ILRS products would be fruitful. This possibility is currently investigated by the ILRS AWG and a pilot project within the ILRS AWG is in preparation. This is necessary in order to ensure that all analysis centers can solve for spherical harmonics correctly.

References

1) ILRS data handling file: http://ilrs.dgfi.badw.de/data_handling/ILRS_Data_Handling_File.snx

Pearlman M. R., Degnan J. J. Bosworth J. M., *The International Laser Ranging Service*, Adv in Space Res, 30(2), pp 135-143, DOI:10.1016/S0273-1177(02)00277-6, 2002

Blewitt G., Lavallée D, *Effect of annual signals on geodetic velocity*, J Geophys Res 107(B7), DOI: 10.1029/2001JB000570, 2002

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Appendix:

Time series of weekly station coordinates computed at DGFI and adopted to the updated SLRF2008 frame. Left the difference of the weekly solution to a mean value, and the newly estimated velocities, compared to the SLRF2008 solution (red). Right the difference between the weekly solution and the SLRF2008 coordinates of Dec. 18, 2012. The wrong velocity for Altay Mountain in y-direction is clearly indicated. For Concepcion the nonlinear behavior after the big earthquake can be seen especially in the x-component. Coordinates of San Juan suffer after 2010 from the unsolved range biases.