ESOC IGS, IDS, and ILRS (Re-) processing

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Abstract

This paper gives an overview of the processing and reprocessing activities at the European Space Operations Centre (ESOC) of the European Space Agency (ESA). Within ESOC the navigation support office (OPS-GN) is since many years an analysis centre of the International GNSS Service (IGS). Enabled by enhancements of the Napeos software package the OPS-GN analysis capacities and activities have been expanded significantly since 2008. Thanks to these enhancements OPS-GN is now capable to contribute to the international services for all three satellite geodesy techniques: IDS, IGS, and ILRS. Besides an overview this paper shows selected results of the ongoing processing activities.

Introduction

Early in 2008 ESOC has replaced its old GNSS analysis software with its new software, called ***Napeos***. One of the key design criteria of this new ESOC GNSS analysis software was the reduction of processing time! The software, now fully operational, allows generating a 1-day IGS final solution using 150 stations within 60 minutes on a single core of a Linux PC using the Intel Fortran compiler. On a "quad-core" CPU four jobs can be run simultaneously without any performance loss, meaning that we are able to process 96 days of IGS data per day (24 hours x 4 cores). With this performance, rapid reprocessing of decades of IGS data becomes possible. On a single PC reprocessing of a full year of IGS data takes less than 4 days, so reprocessing 10 years of data will take about 40 days on a single quad-core PC.

Besides efficient GNSS analysis, the Napeos software is also fully capable of processing DORIS and SLR observations. ESOC recently joined the reprocessing activities of the International Doris Service (IDS), and is joining the ILRS reprocessing activities. Our aim is to contribute to all three space geodesy technique services: IGS, IDS, and ILRS with fully reprocessed time series. In our opinion a contribution from one software to all three techniques is unique and of significant value for the next ITRF combination. Our IDS, IGS and ILRS reprocessing has been completed. Only for the ILRS the acceptance of the solution is still pending.

At ESOC the reprocessing of the three individual techniques is considered a ***first step***. Our ***ultimate*** goal is to do a fully combined analysis of the data of all three techniques, and in the future even 4 techniques when adding VLBI. In such a combined analysis the strength of each technique may be used to overcome the weaknesses in the other techniques. In this combination of techniques SLR plays a crucial role as it is the only technique that provides (in principle) unbiased range measurements. Thus SLR is the only technique that provides direct access to the scale of the terrestrial reference frame. In addition SLR is extremely important in validating the orbits of both the IGS and the IDS.

Here will show the status and some selected results from our different reprocessing solutions and provide an overview of our future plans regarding the fully combined reprocessing.

IGS processing

ESOC OPS-GN has been a full analysis centre of the International GNSS Service (IGS) since its very beginning in 1992. In January 2008 a switch to the new ***Napeos*** software was made which gave rise to a significant improvement of the ESOC GNSS processing, both in quality and in speed. The two aspects combined enabled ESOC to participate in the IGS reprocessing. With Napeos the reprocessing of 1 day of IGS data using 150 stations and 32 satellites can be done within 60 minutes on a single core of a Linux PC. Thus on a single "quad-core" machine four jobs can be run simultaneously without any loss of performance. For the reprocessing this means that the reprocessing can advance by 96 days of IGS data per day. With this performance the reprocessing of the full IGS data set from 1994 to 2008 took only 53 days.

ESOC reprocessed all days from 1994 to the end of 2007. The results from 1994 were omitted since the IGS tracking network suffered some severe problems early in this year when "anti-spoofing" was turned on. So ESOC finally submitted only the results from 1995 until the end of 2007 to the IGS. Before submission our products were carefully validated. One important quality measure in the validations was the agreement of the orbit at the day boundary. The ESOC reprocessed orbits are generated using 24 hour arcs. So the difference at the day boundary gives a "worst case" estimate of the satellite orbit quality. Figure 1 shows the results of this day boundary check in the radial direction for each of the years. A steady improvement of the orbit overlap is observed going down to the 20 mm level. This is an excellent result for the overlap of two independent orbit arcs at their arc boundary!

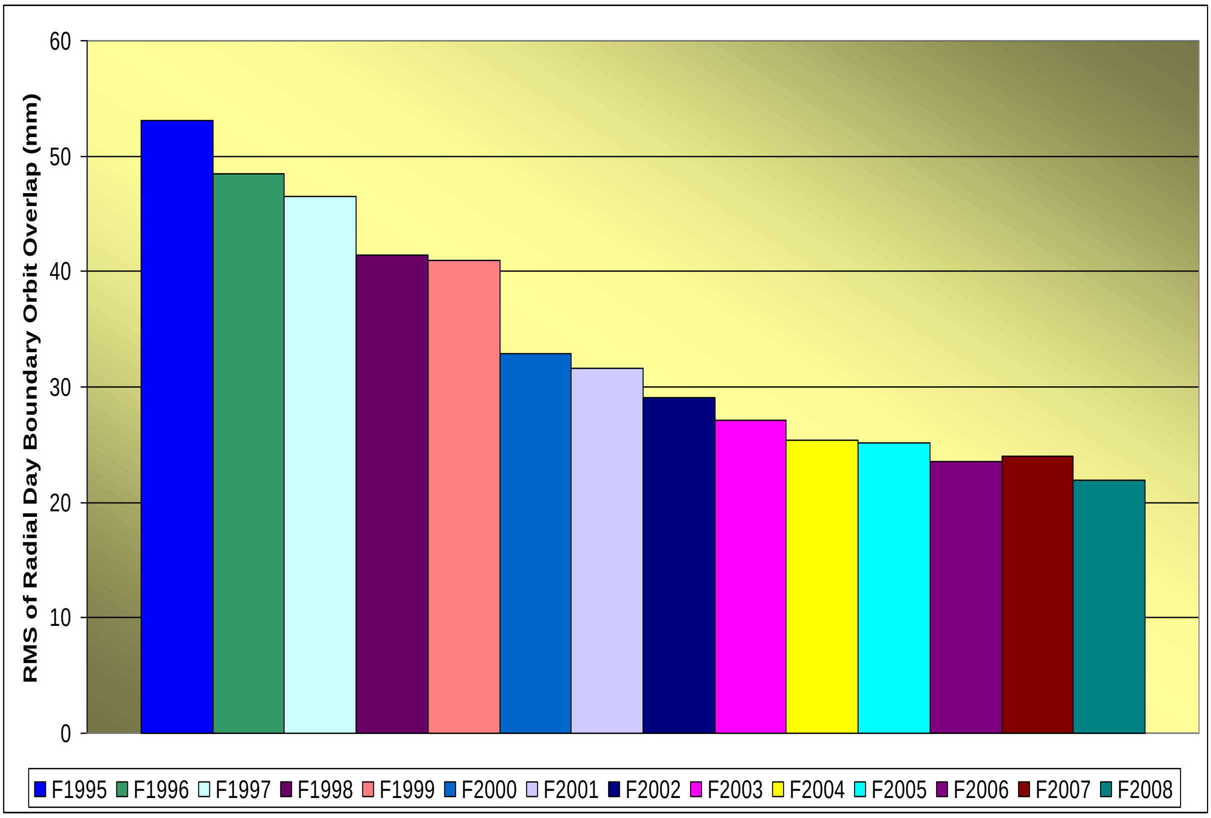

Figure 1. Statistics of Radial Orbit Differences at the Day Boundaries of the ESOC reprocessed IGS orbits for each individual year over the timeframe from 1995 to 2008

Another quality control step was the validation of the orbits against the SLR observations from the GPS satellites 35 and 36 (PRN 5 and 6). The mean and the sigma of this GNSS-orbit versus SLR-observation validation are given in Figure 2.

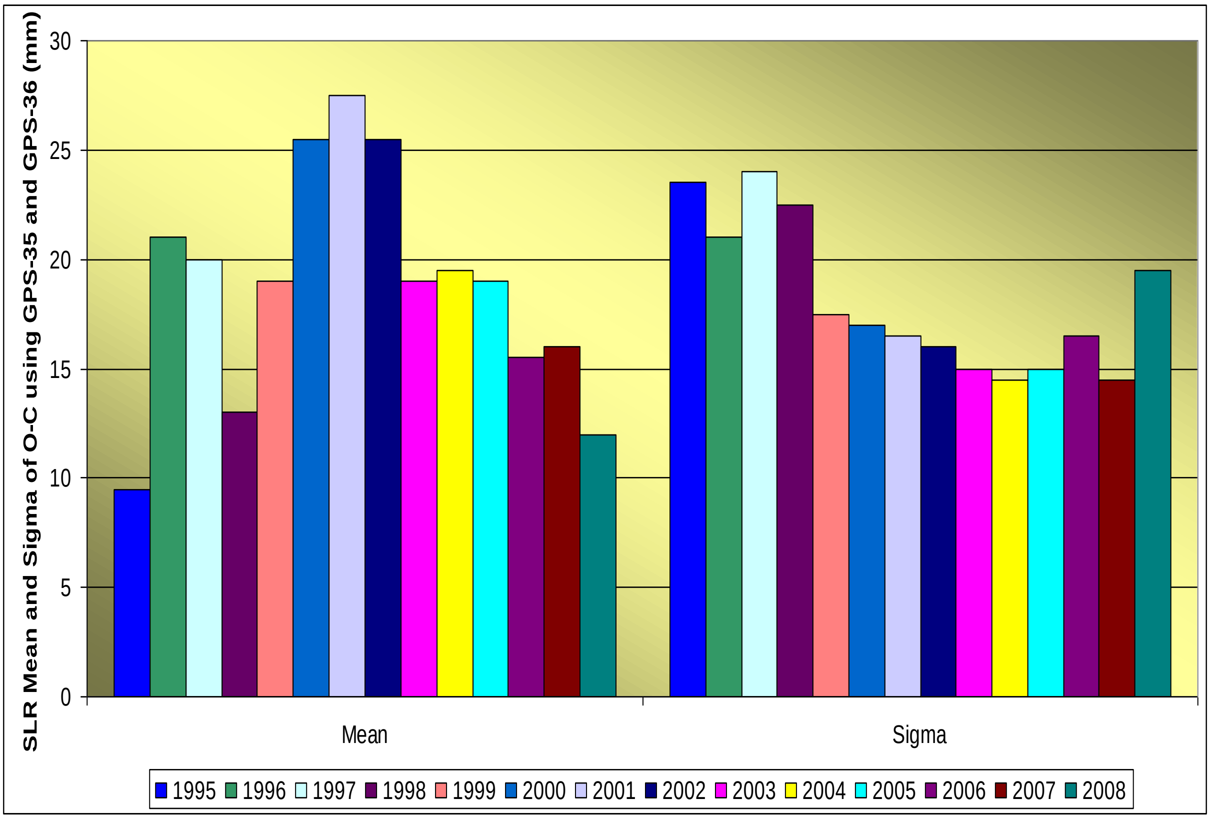

Figure 2. SLR validation of the ESOC reprocessed IGS orbits for each individual year over the timeframe from 1995 to 2008.

Figure 2 shows that the average mean bias between the GPS-orbits and the SLR observations is now at the level of 15 mm whereas the sigma is at a similar level. The agreement between time series of the radial orbit overlap and the sigma of the SLR residuals is quite good. However, the somewhat "erratic" behaviour of the mean of the SLR residuals indicates that for the early years, 1995 to 1998, there may be some biases in the SLR observations. Also the rather high sigma for 2008 may be related to not properly accounting for some of the biases present in the SLR observations.

Another interesting way to look at the SLR residuals it to plot the residuals as function of the latitude and elevation of the Sun with respect to the orbital plan of the satellites, as was done by Flohrer (2008). The results are shown in Figure 3. The figure nicely shows the eclipse period of the satellites, the dark circle in the middle. The reason for this pronounced eclipse effect is mainly because we did not account for the correct attitude of the GPS satellites. Thus the attitude error coupled with the eccentric position of the laser reflector array gives a significant signal for the eclipse phase. Outside the eclipse very little signal may be observed although in the centre of the figure, around 180 degrees latitude, there seem to be more positive residuals whereas around 90 and 270 degrees latitude there seem to be more negative residuals. This could be an indication for a twice per revolution signal. Unfortunately there is little data around 0 and 360 degrees latitude because this reflects the point where the satellite is in full sunlight and thus would require daylight tracking. Most of the ILRS stations are incapable of daylight tracking of the GPS satellites.

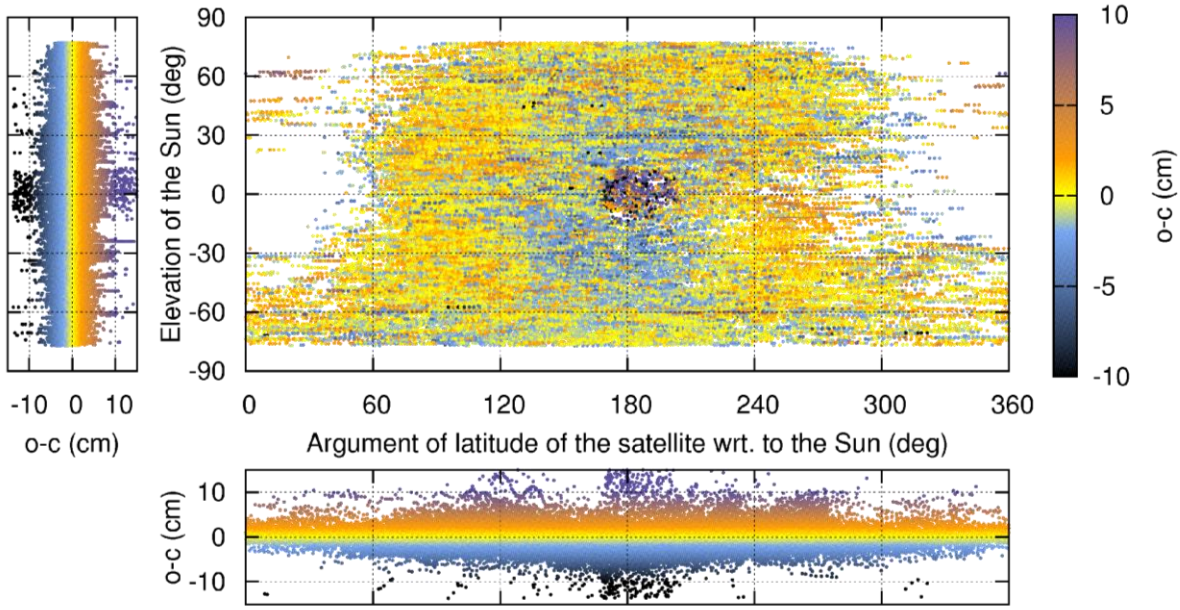

Figure 3. SLR residuals of the GPS satellites as function of latitude and elevation of the Sun with respect to the Orbital Plane, using all SLR observations from the GPS satellites from 1995 to 2008.

The pronounced eclipse effects may also be an explanation for the variability of the mean and the sigma observed in Figure 2. We will have to regenerate the statistics either whilst excluding the eclipse phases of the satellites or whilst correctly accounting for the attitude of the satellites.

IDS processing

The key enablers for ESOC to participate in the DORIS reprocessing were:

- Many years of experience in routine processing of the DORIS data of the ESA ENVISAT mission
- Efficient software, Napeos, including
  - Excellent modelling capability for LEO satellites, and,
  - All tools for generating the required IDS products, e.g., SINEX.

The key challenges in IDS reprocessing are the station and satellite equipment changes. Many stations were refurbished over time because of hardware improvements. However, this leads to discontinuities in the station coordinates. Secondly, there are only few satellites equipped with a DORIS instrument and thus the addition and/or removal of a satellite from such a small constellation has noticeable effects. The positive effect of the hardware changes, or rather improvements, can be observed clearly in Figure 4 which shows the evolution of the residual RMS of the DORIS observations over the entire reprocessing period of 1992 to 2008. The downward trend of the DORIS residual RMS from 1992 to 2006 is mainly caused by hardware improvements of the system. The small jump of the ENVISAT residual RMS around 2005 is an artefact of the increase of the integration time. Furthermore, the increase of the residual RMS since 2006 is caused by the degradation of the accuracy of the station positions. In this analysis the station coordinates were fixed to the ITRF2005 values. Imperfections of the velocities and a number of new sites thus have a significant effect on the residual RMS. At the same time the figure shows appearance and disappearance of the satellites equipped with DORIS receivers.

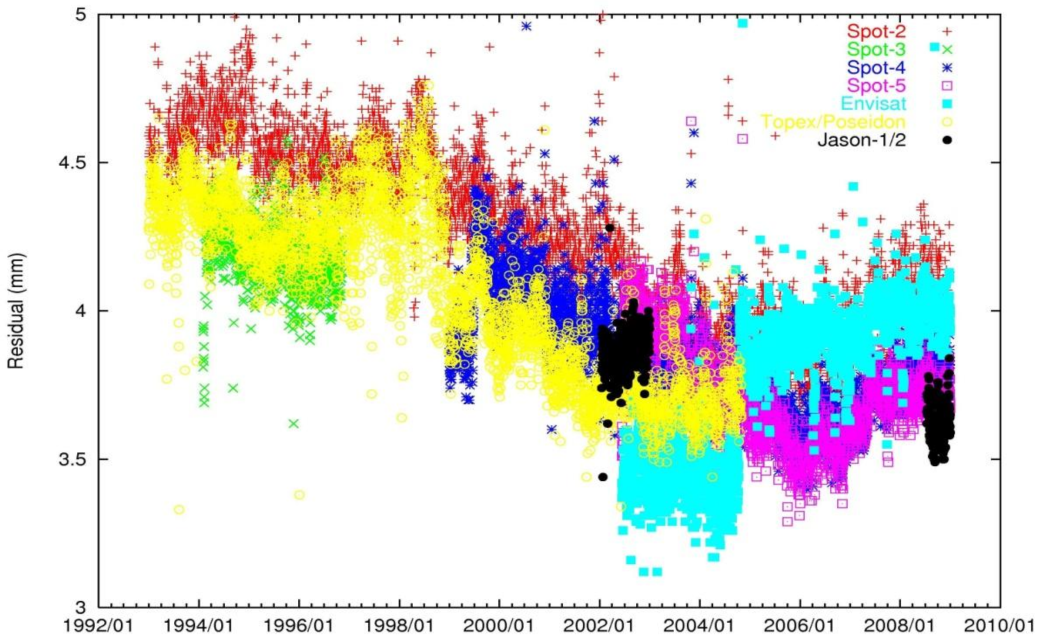

Figure 4. Time Evolution of the DORIS Residual RMS.

ILRS processing

The key enablers for ESOC to participate in the ILRS reprocessing were:

- Many years of experience in routine processing of the SLR data of the ESA missions
    - ERS-1, ERS-2, and ENVISAT
- Experience with processing SLR from GNSS targets
- Efficient software, Napeos, including:
    - Excellent modelling capability for LAGEOS and ETALON targets
    - All tools for generating the required ILRS products, e.g., SINEX files
- ILRS associate analysis centre with as key activities:
    - Prediction centre for several satellites, e.g., Giove-A, Giove-B
    - Analysis of ENVISAT, ERS-1 and ERS-2

The main challenges for ILRS reprocessing are gathering the information regarding the different possible instrumental biases. It has become clear that even for our relatively simple SLR validation of the GNSS satellite orbits, taking into account the different instrumental biases of the ILRS stations is an absolute must. The results in Figure 2 give some indication regarding the importance of this. Given the fact that the GNSS orbit were generated fully homogenously in terms of modelling and reference frame the significant variation of the observed mean differences must, at least in part, be caused by not properly accounting for the observation biases. After accounting for the observation biases the analysis of the Lageos and Etalon data is actually not very time consuming. Thus ESOC is planning to become a full analysis centre of the ILRS. The benchmark test has been performed and submitted in May 2009. In addition, a full reprocessing of all ILRS historic data since 1993 of both Lageos and both Etalon satellites has been performed. Figure 5 shows the time evolution of the ESOC weekly reference frame solution compared to the ITRF2005 (courtesy of Zuheir Altamimi). The results are very encouraging although the individual station residuals indicate that some station biases were not yet properly accounted for.

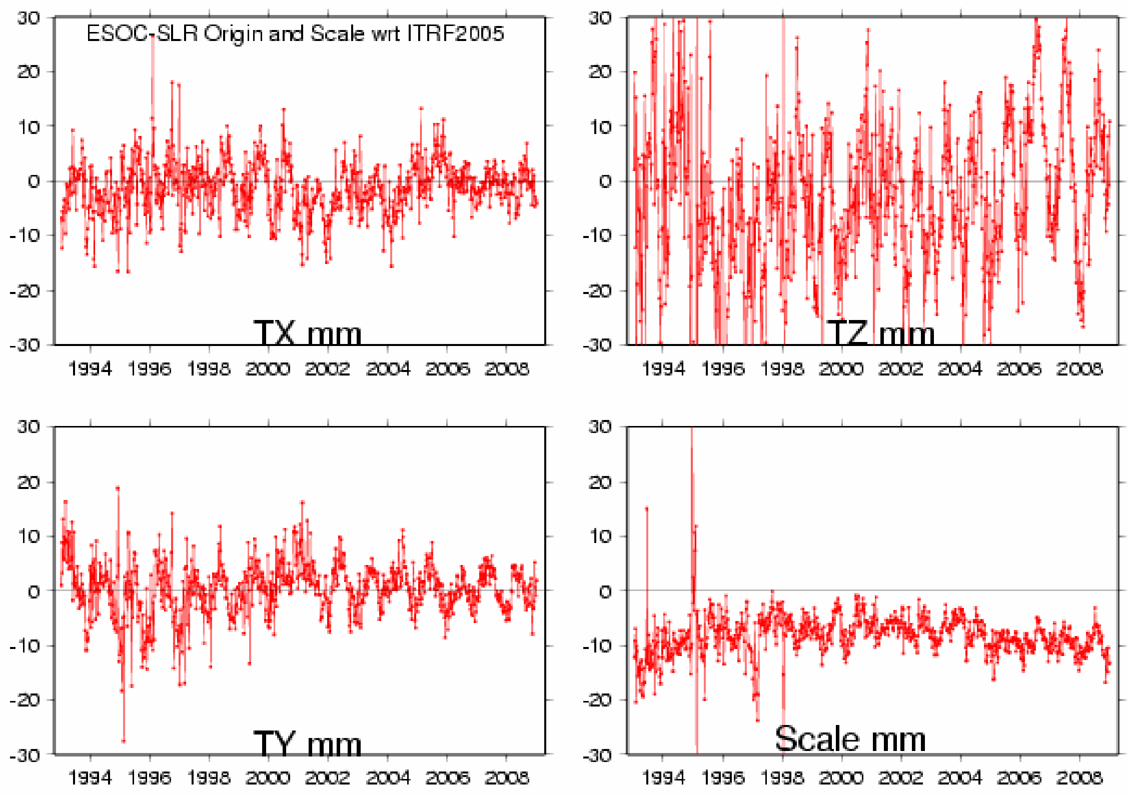

Figure 5. Time Evolution of ESOC ILRS Reference Frame Solutions from 1993 to 2008 (courtesy of Zuheir Altamimi)

Conclusions

ESOC has re-analyzed the historic data of all three satellite geodetic techniques, IDS, IGS, and ILRS using one single piece of software. The results of the ESOC IDS and IGS reprocessing will contribute to the realization of the ITRF2008. Due to the "infamous" ILRS bias issues and the lengthy process of being accepted as an ILRS analysis centre the ESOC ILRS reprocessing results will not be used for the ITRF2008 realization. For future ITRF updates we are convinced that we will contribute to all three space geodetic techniques using our Napeos software.

References

Flohrer, Claudia, *Mutual Validation of Satellite-Geodetic Techniques and its Impact on GNSS Orbit Modelling,* PhD Thesis, Bern, Switzerland, May 2008.