EOP Alignment Campaign, IDS/IGS/ILRS/IVS EOP Combinations, Systematic Errors

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1 Introduction

The combination of independent estimates of Earth Orientation Parameters (EOP), derived from global space geodetic observations, can be considered an ideal tool for investigating characteristics of the individual estimates (i.e. systematic and random errors) as well as stabilizing the results. As an attempt of a joint investigation into various aspects of combinations, the IERS has initiated a campaign of data analysis, combination and comparison of such EOP. In order to reduce the level of inflicting effects, these EOP had to be estimated on the basis of ITRF2000 station positions and velocities.

In parallel to the investigations of the IERS, the space geodetic services, IGS, IVS and ILRS, as well as the DORIS group have started their own analysis of (combined) EOP series. Special considerations taken into account by the different groups are summarized below.

2 International DORIS Service (IDS)

The recent launch of three new satellites (NASA-CNES's Jason 1 in late 2001, CNES's Spot 5 and ESA's Envisat in the first half of 2002) doubles the number of satellites carrying the DORIS navigation payload. The enhanced technology of the embarked new generation receivers, as well as the checking and upgrading of the network of terrestrial beacons that is well under way, will contribute to an increased interest in combinations.

Present status

The IDS products may be prepared under several forms, depending on their further use. The standard global geodetic solutions with variance-covariance information (SINEX files) are complete except for the orbits, which are available separately. In addition, it may be convenient to prepare time series of the parameters that vary in time.

In November 2001 the IDS Central Bureau initiated an analysis campaign that originally focused only on sets of station coordinates derived from the June 2001 observations of the Spot2, Spot4 and Topex/Poseidon satellites. The campaign objectives were set as follows:

- Check the level of consistency of results obtained using different software packages.
- Identify and analyze possible systematic discrepancies.
- Study the possibility of defining time series of sets of station coordinates as an IDS product.

- Initiate the process of combining DORIS results into unified IDS products.
- Check the consistency of the estimated time varying parameters (Geocenter, EOP) with the estimated reference frames (sets of station coordinates, ephemerides).

Responses were received from six Analysis Centers (IGN-JPL, INASAN, CSR, LEGOS-CLS, CNES/SOD, CNES-CLS/SSALTO), while others (IAA, St Petersburg; Geod. Obs. Pecny, Czech Rep.) expressed interest to participate at a later time. The content of the responses was larger than expected, in several ways: the data span covers several years, as compared to the single month originally requested, and the products span not only sets of stations coordinates, but also times series of the Earth's orientation parameters and of the geocenter location and orbits. The Central Bureau has started the analysis of the submitted solutions, with the technical support of the IERS ITRS Center. Results are presented at the 2002 IERS Combination Workshop.

Problems and deficiencies encountered

While the DORIS orbit computation activities are quite developed in the framework of the space oceanography missions, the activities devoted to the Earth's motions and to reference frames are still in a warming up phase. The latter topics are not central to the space altimetry groups. Therefore, new analysis centers are required. This evolution is taking place, in particular with new groups in Europe, but it is still too slow. As an example, only one DORIS solution could be provided for the IERS EOP alignment campaign (IGN-JPL). In addition, the open distribution of the observed data is not yet very smooth.

Goals and future steps for improvements

The future steps for improvement are both organisational and technical:

- Settle the organization of the data flow and the access to information on the DORIS system.
- Develop the Central Bureau combination capabilities, e.g. time series of SINEX-TRFs and corresponding EOPs and TRF origin motion ("geocenter").
- Encourage the development of new analysis centers and develop discussions and interactions.
- Check/update the local ties in the co-location sites involving DORIS.

Schedule of these next steps and recommendations

- The progressive upgrade of the stations and the checking of local ties is under way (IGN action).
- The data flow and information circulation system is under way and should be completed by the end of 2002. See http://lareg.ensg.ign.fr/IDS.
- An Analysis Workshop is planned in early 2003 in Paris to further discuss the combination results and prepare the definition of the future IDS products.

3 International GPS Service (GPS)

Within IGS, the combined station coordinates, EOP and apparent geocenter coordinates are generated using the Analysis Centers (AC) (COD, EMR, ESA, GFZ, JPL, NGS, and SIO) weekly SINEX solutions. This short report focuses on the pole position estimates. All the available covariance information provided by the ACs is used during the combination. A cumulative solution of station coordinates/velocities is also updated weekly. The AC coordi-

nator combines and aligns the orbit products to the weekly SINEX solution to ensure consistency of the IGS products. As part of the orbit combination process an independent combination of the EOP is also produced (igs95p02.erp) and used to quality control the SINEX EOP (accumulated in "igs00p02.erp"). All EOP estimates are provided for the middle of each day. All the solutions are aligned by an unweighted 7/14 parameters Helmert transformation using the current IGS realization of ITRF. More details about the IGS analysis procedure can be found in the annual and technical reports available at <[1]>.

Since February 28, 2000 (MJD 51602,GPS Wk 1051), the difference between the daily igs00p02.erp and igs95p02.erp X and Y pole estimates are –0.02 ± 0.05 mas and –0.01± 0.05 mas. The MIT Global Network Associate Analysis Center (GNAAC) has also computed independent weekly combinations of the AC SINEX solutions including EOP. The X and Y pole differences between "igs00p02.erp" and the MIT estimates since November 21, 1999 (MJD 51503, GPS Wk 1037) are –0.01± 0.04 mas and –0.01± 0.04 mas. More recently, since April 21, 2002 (MJD 52385, GPS Wk 1163), the GNAAC "NCL" also includes the AC daily EOP as part of its weekly SINEX combination; the results of the pole comparison with igs00p02.erp are –0.01± 0.02 mas and +0.02± 0.02 mas. These internal comparisons are on average consistent at the 0.02 mas level, with a noise level at or better than 0.05 mas. Routine external comparisons between igs00p02.erp and IERS Bulletin A show pole differences of 0.01±0.06 mas and 0.18±0.06 mas, suggesting a significant bias between the IGS pole position and the IERS Bulletin A.

The objective of the IERS Analysis Campaign was to better understand the stability, consistency and limitations of EOP alignment when using ITRF2000, with an accuracy goal of 0.1 mas. The test included all the IGS weekly solutions between February 27, 2000 and February 23, 2002. Those solutions contain weekly station coordinate estimates as well as daily EOP. The weekly solutions were constrained using the ITRF2000 as well as its IGS realization (IGS00). In both cases, the set of 54 reference frame stations currently used to realize ITRF2000 was used. The tests were also repeated using the most reliable stations available (154 for ITRF and 132 for IGS). The tests also included minimal and formal constraints on the network and heavy position weights. Heavy weights are 100 times the formal weights. In the case of minimal constraints, the weekly solutions were aligned to the reference frame realization of the epoch using a weighted 7-parameter Helmert transformation. Inner constraints were also applied in this instance to produce meaningful statistics. Note that in this procedure, the application of the inner constraints had no effect on the estimated parameters. In all cases, the noise level of the X & Y pole position differences with respect to the official IGS EOP time series "igs00p02.erp" always remained below 0.03 mas.

The effect of the alignment strategy on the EOP was also tested for the ACs. For all the network and weighting strategies, the average differences with respect to "igs00p02.erp" was at or below the 0.01 mas level for both pole axis when considering all the AC simultaneously. When considering the ACs separately, the average differences with respect to igs00p02.erp were generally below 0.04 mas, with occasional exceptions. For some ACs the Y pole component is more affected by network configuration and constraining strategy. Note that the AC network configuration varies and the number of stations processed vary between ACs.

There are still a few minor problems to resolve with some AC solutions, but those are not expected to significantly affect the results currently available. Those are dealt with, as they occur and as time permits.

[1] http://igscb.jpl.nasa.gov/overview/pubs.html

4 International VLBI Service

The VLBI technique has the great advantage that all observing sessions, even the oldest ones, can be re-analyzed in a single run using the same reference frames and models available at that time. It is, therefore, no big effort to re-analyze all geodetic VLBI sessions since the advent of the high precision Mark III system in late 1979. From January 1, 2002 onwards all submissions of EOP series from IVS Analysis Centers have been based on the ITRF2000 reference frame either fixed or constrained to it. The IVS EOP series are, thus, ideally linked to ITRF2000 in a consistent way from the first data points onwards. The accuracy of the combined EOP series as deduced from the post-fit residuals and verified by comparisons with the IGS pole series is in the range of 100 microarcseconds in the x and y pole components and 15 microseconds in UT1.

On the research side the IVS Analysis Coordinator has issued a call for the Second IVS Analysis Research Project soliciting submissions of special EOP series from IVS Analysis Centers in the summer of 2001. The data was limited to all VLBI sessions of the so-called NEOS series in the period January 1, 1999 to December 31, 2000. This series was observed once per week with a 5-station network thus providing 104 EOP data points. The EOP had to be estimated on the basis of ICRF radio source positions (International Celestial Reference Frame) and ITRF2000 station coordinates and velocities. Ten submissions have been received in addition to the six regular contributions in late 2001 providing ample material for a detailed investigation.

The EOP series resulting from the routine IVS combination has an accuracy of about 100 microarcseconds and can, thus, be used as an accurate and reliable reference series. Weighted RMS differences of seven of the series submitted for the Second IVS Analysis Research Project with respect to this reference series range from 37 to 108 microarcseconds in the x and y pole components and from 2.3 to 7.4 microseconds in UT1. Biases between 11 and 157 microarcseconds in x and y pole and between 0.5 and 7.6 microseconds in UT1 have been taken into account.

Although these results have demonstrated the good agreement of the different analyses it has to be noted that the EOP are based on observations of almost identical networks throughout the series. As further investigations have shown, the effects of different network configurations are quite severe. VLBI EOP results of series of two separate networks observing on the same day do show systematic differences of up to 130 microarcseconds (MacMillan and Ma 2000). The origin of these have been investigated extensively but convincing explanations are still missing.

From the beginning of 2002 IVS has added a second session of routine EOP observations per week with the same rapid turn around policy as the old NEOS session. Now networks with varying configurations regularly observe on Mondays and Thursdays. The impact of the variations in the network configurations are still being studied in view of the problems incurred at the time when different networks observed in parallel.

In the future, the impact of VLBI network configurations on the EOP determinations will receive high priority within the IVS' investigations. All IVS Analysis Centers are asked to concentrate their efforts on this topic and actively participate in the investigations. The cause or the causes of the discrepancies between different networks will certainly permit a deeper insight into systematic errors inherent in the VLBI technique and will eventually lead to higher accuracy of the results.

5 International Laser Ranging Service (ILRS)

In October 2002, the ILRS has organized one of their bi-annual Analysis Working Group (AWG) meetings. The AWG has a number of so-called pilot projects in development, each aimed at specific results.

In the ILRS Pilot Project called "benchmarking", the ILRS AWG has defined a reference set of observations and computation model elements, with the aim of producing analysis results that should be 100% compatible. The goal is not to reach the best possible fit to the observations (indeed, that does not happen) but to determine errors in the various software programs and in handling procedures. During the October AWG meeting the first results were reported (it was the first meeting after the definition of this pilot project), and a number of items have been identified where the analysts can fine-tune the results and come up with better agreements (depending on the product that is looked at, the internal consistency may range from dm to sub-mm). This project is considered an essential stepping-stone towards individual and combination solutions with the best possible quality.

Another pilot project, that has been in development for quite some time now, is on "positioning and Earth orientation". The AWG has gone through a long process here, involving issues like formats, definition problems and such. Also the question on a representative (good) analysis product for Earth orientation has been on the table for some time. A conclusion has been reached now and as a result a Call for Participation for contributions to an official ILRS analysis product on station coordinates and EOPs (with the IERS Bulletin A as a customer for the latter) has been released in November 2002. A good number of reactions to this invitation has been received, and a full-scale test phase has been scheduled for the first months of 2003. If everything goes OK, the analysis system can be operational around the time of the 2003 EGS meeting (or shortly thereafter). This will produce daily solutions for x- and y-pole and LOD, and a full set of global station coordinates. Before submitting the EOP solutions, they will be converted to the ITRF2000 reference frame first.

6 IERS Alignment Campaign

In September 2001 the IERS Analysis Coordinator presented the 'IERS Analysis Campaign to align EOPs to ICRF / ITRF2000' as proposed by J. Ray. The intention of the IERS Alignment Campaign is to create EOP series with the highest possible consistency with ICRF and ITRF2000. The aim of this project is to achieve an overall accuracy of 0.1 mas. This will lead to an intermediate solution until a rigorous combination of EOP together with ITRF / ICRF is possible. Therefore we have to analyse and understand the origin of systematic errors belonging to the reference frame.

At the end of September 2001 the IERS Alignment Campaign was started with an initial call for participation. The Campaign is subdivided into two parts. In a first step the Technical Centers were asked to produce EOP series with a reference frame fixed to the ITRF2000 / ICRF at the level of uncertainty. In addition they were asked to produce solutions with different constraints on ITRF2000 (ICRF). The second step consists of the analysis of the submitted EOP series by comparison with the official annual solutions 2000 and by study the consistency against each other. The final results should be recommendations for future realizations of reference frames.

Until May 2002 21 proposals were presented, see also the web pages <[1]>. 12 of them contributed to the first step and produced more than 40 EOP series from all techniques with various constraints to realize the ITRF2000 reference frame. The series are stored and are publicly available from ftp archive <[2]>. In addition to each series a description file about the constraints, the reference frame, the reference sites and the combination approach used is available. In the second step 12 participants are now analysing the submitted EOP series.

The analyses have to deal with many special problems coming from the pooling of EOP series from different techniques. In order to compare the series they need to be reformatted and resampled in one common format. Problems occur with data gaps, different interpolation schemes and different signs. In a first comparison of the EOP series against each other, three EOP parameters (X_{pol}, Y_{pol}, UT1–UTC) were studied by a simultaneous estimation of offset, drift and a scale factor. Additionally possible time lags (shift in time) were detected. In polar motion (X_{pol}, Y_{pol}) most series agree within ±0.5 mas in offset and almost no drift, except IGN 01 (DORIS) and ASI 01 (≈ 1.5 mas/a). Drifts are mainly observed between the long VLBI series (IAA, GAUS, GSFC) where the ITRF2000 velocities are used over long time intervals. The VLBI series show also a good accordance in UT1–UTC, < ± 1 ms. The comparison with the satellite techniques is a known problem. Until now there is no significant indication that fixed constraints are better than loose constraints, only the ASI 01 series differs from the other series, maybe due to the loose constraints conditions used. After identifying the great differences and removing all error sources like interpolation and sampling errors, further investigations will concentrate on the smaller differences between the EOP series. The analysis of the remaining residuals should help to detect systematic errors. Final results are expected until the end of the year 2002.

Recommendations:

- Solve problems occurring from reformatting, resampling and interpolation
- Create a new database with comparable EOP series until end of the year 2002
- Analyse offsets and drifts in X_{pol}, Y_{pol}; find relations to the ITRF-realization
- Develop strategies to combine / compare UT1 and LOD of satellite techniques and VLBI
- Call analysis groups finish their studies until February 2003
- Conclusion and presentation of final results during the EGS General Assembly, April 2003

References

MacMillan D., C. Ma: Improvement of VLBI EOP Accuracy and Precision; Vandenberg and Baver (eds.), IVS 2000 General Meeting Proceedings, NASA/CP-2000-209893, Greenbelt (MD), 2000

[1] http://alpha.fesg.tu-muenchen.de/iers/
[2] ftp://alpha.fesg.tu-muenchen.de/iers/eop/