3.6.2.7 Groupe de Recherches de Géodésie Spatiale (GRGS)

Abstract

A rigorous approach to simultaneously determine both a terrestrial reference frame (TRF) materialized by station coordinates and Earth Orientation Parameters (EOP) is now currently applied on a routine basis in a coordinated project of the Groupe de Recherches de Géodésie Spatiale (GRGS). To date, various techniques allow the determination of all or a part of the Earth Orientation Parameters: Laser Ranging to the Moon (LLR) and to dedicated artificial satellites (SLR), Very Large Baseline Interferometry on extra-galactic sources (VLBI), Global Positioning System (GPS) and more recently DORIS introduced in the IERS activities in 1995. Observations of these different astro-geodetic techniques are separately processed at different analysis centres using unique software package GINS DYNAMO, developed and maintained at GRGS. GPS at CLS, Toulouse (S. Loyer) and NOVELTIS (T. Lalanne), Doris at CLS, Toulouse (L. Soudarin), SLR at the Observatoire de la Côte d'Azur, Grasse (F. Deleflie, Ph. Bério), LLR at CNES, Toulouse (J. Ch. Marty) and at the Observatoire de Paris (G. Francou), VLBI at the Observatory of Bordeaux (G. Bourda, P. Charlot).

The final combination as well as the validation and various post analyses are performed at the Observatoire de Paris (D. Gambis, T. Carlucci, J.Y. Richard). An exhaustive description can be found in Gambis et al. (2008). In the following sections, each component is presenting a general description of its procedures as well as recent significant improvements.

1 Analyses of the Observations of the various techniques using GINS

1.1 Satellite Laser Ranging (SLR), OCA/GEMINI, Grasse (*F. Deleflie, P. Bério, D. Feraudy*)

Observations of LAGEOS 1 and 2 satellites have been processed over 9-day arcs with 2-day overlaps. The network comprises about 30 observing stations. The final RMS values are in the range of 1 cm for both satellites. Weekly normal equations are derived relative to a range bias per week, per station and per satellite, station coordinates and EOP at 6-hour intervals, in addition to empirical dynamical parameters, following ILRS recommendations. Final results are obtained with a three week delay. Two modifications were recently implemented: the use of the difference between the centre of reflection and the centre of mass as dependant of the type and power of the laser and the use of the tropospheric correction derived from ECMWF meteorological models. In addition, SLR observations are currently processed in an operational way, at GEMINI/OCA in Grasse, France, which became an official ILRS AC at the end of 2007. Some differences exist between the two parameterisations; in particular atmospheric loading is accounted for the CRC project, but is not included in products delivered to ILRS, affecting the geocentre motion.

1.2 DOPPLER Orbitography and Radiopositioning Integrated by Satellite (DORIS), CLS, Toulouse (*L. Soudarin*)

A new processing chain including several evolutions has been set up in 2007. Its main characteristics are a new set of models was defined for the orbit computation. The GRACE-derived gravity model EIGEN-GL04S which includes annual and semi-annual terms of the low degree coefficients (up to 50), ITRF2005 and an a priori tropospheric zenith delays, derived from ECMWF meteorological model. In addition an updated version of the software is used (GINS 7.2). The data processing is now fitted for a weekly delivery of the products requested by IDS and CRC. The analysis of the data from Jan. 2007 is performed using this new chain. Satellites processed are SPOT2, SPOT4, SPOT5 and ENVISAT. These evolutions lead to improvements of the determination of the coordinates times series, EOP, scale factor, geocentre. For example, the precision of the weekly positioning estimated from 2-year coordinate time series is now in a range of 6 to 18 mm for all the stations (weighted 3D rms).

1.3 Global Positioning System (GPS), CLS (*S. Loyer, H. Capdeville, L. Soudarin*)

The period 2007–2008 is associated with the intensification of the operational activities in delivering weekly NEQ to the CRC Combination Centre in Paris and solutions to IGS (including EOP, Orbits and stations coordinates). The weekly solutions were delivered for evaluation during a period of 8 months and at the end of May 2008 the group was officially labelled Analysis Centre of the IGS.

The significant improvements are the automatic processing activities as well as the development of a new pre-processing program called "Prairie" able to take in charge the Glonass data. The routinely processed network by the CNES-CLS IGS Analysis Centre contains now around 85 GPS sites. The latency of the processing is now 10 days.

1.4 Very Long Baseline Interferometry (VLBI), Observatoire de Bordeaux (*G. Bourda, P. Charlot*)

VLBI data acquired on a regular basis by the International VLBI Service for Geodesy and Astrometry (IVS) are processed using the GINS software in order to estimate the Earth Orientation Parameters (EOP) and station positions. These include both IVS inten-

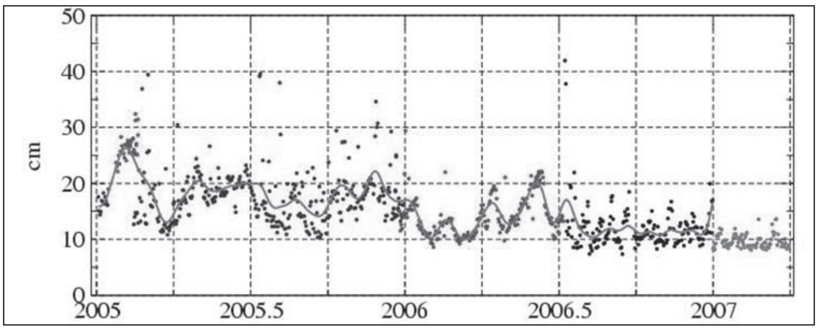

Fig. 1: Internal orbit overlappings (non weighted 3D RMS).

Table 1: GPS products quality compared to IGS combined solution.

<u>Orbits vs IGS Combined orbit:</u> TX = 2 +/- 1.5 mm ; TY = 0.3 +/- 1 mm ; TZ = -2 +/- 3 mm RX = -17 +/- 35 μas ; RY = -75 +/- 65 μas ; RZ = 38 +/- 60 μas Scale = 1 + /- 0.05 ppb ; WRMS3D : 3.2 +/- 0.35 cm
<u>Stations vs IGS05 (bias + rms)</u> Nord = 0 +/- 2.5 mm ; Est = 0 +/- 1 mm ; Up = 0 +/- 6 mm
<u>Pole vs IGS solution (bias + rms)</u> Xp = 5 +/- 25 μas ; Yp = 43 +/- 30 μas ; LOD = -1.5 +/- 32 μs Xp_rate = -56 +/- 90 μas/day ; Yp_rate = -6.5 +/- 90 μas /day

sive sessions (i.e. daily one-hour long experiments) and the so-called IVS-R1 and IVS-R4 sessions (i.e. two 24-hour experiments per week). Based on these data, weekly normal matrices are produced for combination with the data acquired by the other techniques (SLR, GPS, DORIS). The free parameters include station positions and the five EOP along with clock and troposphere parameters. The clocks are modelled using piecewise continuous linear functions with breaks every two hours. The tropospheric zenith delays are modelled in a similar way except that breaks are applied every hour. The a priori terrestrial reference frame used in 2007 is ITRF2005 (Altamimi et al. 2007) while the celestial frame is fixed to the ICRF (Ma et al. 1998, Fey et al. 2004). Overall, a total of 20 stations have been used in such sessions. The final post-fit weighted rms residuals for the VLBI time delay is of the order of 30 picoseconds (i.e. about 1 centimetre) for the IVS-R1 and IVS-R4 sessions, and less for the intensive ones. Comparison of the EOP results with those published by the IVS indicates an agreement at the 0.2 mas level.

2 Combination procedure using DYNAMO at Paris Observatory (*J.Y. Richard, D. Gambis, T. Carlucci*)

The datum-free normal equations (NEQs) weekly derived from the analyses of the different techniques are collected and stacked at Paris Observatory to derive solutions of station coordinates and Earth Orientation Parameters (EOP). Two approaches are made: the first one consists in accumulating normal equations derived from intra-technique single run solution in a single run combined solution; the second one leads to weekly combinations of NEQs. Results are made available at the IERS site (ftp <iers1.bkg.bund.de>) in the form of SINEX files. The strength of the method is the use of a set of identical up-to-date models and standards in unique software for all techniques. In addition the solution benefits from mutual constraints brought by the various techniques; in particular UT1 and nutation offsets series derived from VLBI are densified and complemented by respectively LOD and nutation rates estimated by GPS. The analyses we have performed are extending over 2005–2008. They show that the accuracy and stability of the EOP solution are very sensitive to a number of critical parameters mostly linked to the terrestrial reference frame realization, the way that minimum constraints are applied and the quality of local ties. We present thereafter the procedures which were applied, recent analyses and the latest results obtained. For an exhaustive presentation, refer to Gambis et al. (2008).

2.1 First step: intra-technique solution

The combination is performed in two steps. Weekly NEQs derived by the dedicated analysis centres have been cumulated for each technique over 2005–2008 to derive a single run solution. Stations minimum variances are applied. The mean measurement residuals lead to the determination of the weight of each technique in the global combination. The weighting procedure is based on the variance component estimation method as suggested by Helmert and described in Sahin et al. (1992). The weights determined in these analyses have been fixed in the operational combinations. The relative weights are used in the matrices combinations. They should be carefully considered since contributions to EOP and station coordinates are different according to techniques. For instance, VLBI is the only technique to determine both UT1 and nutation offsets whereas satellite techniques can only bring some information on their respective rates. GPS-derived polar motion is more accurate. SLR brings a constraint in the long-term stability of the latter components. In addition, changes in the weights of the respective tech-

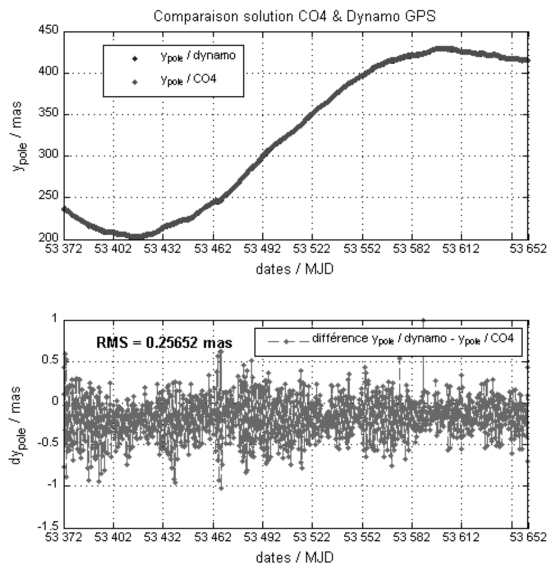

Fig. 2: Y pole 40 cumulated GPS weeks compared to IERS EOP CO4.

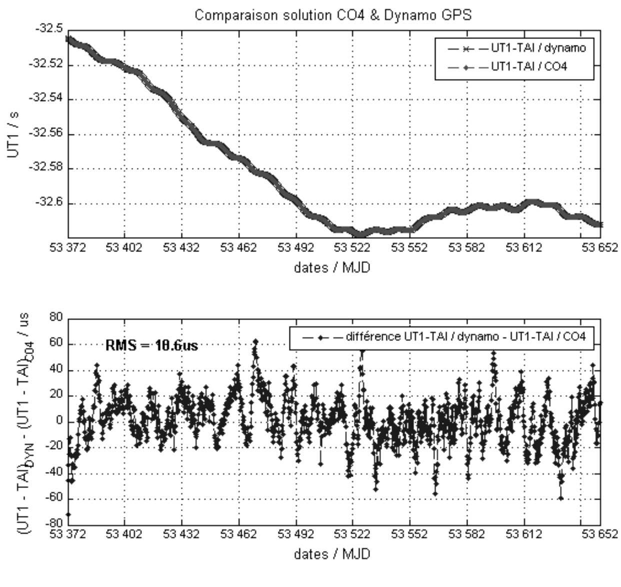

Fig. 3: UT1–TAI 40 cumulated GPS weeks compared to IERS EOP C04.

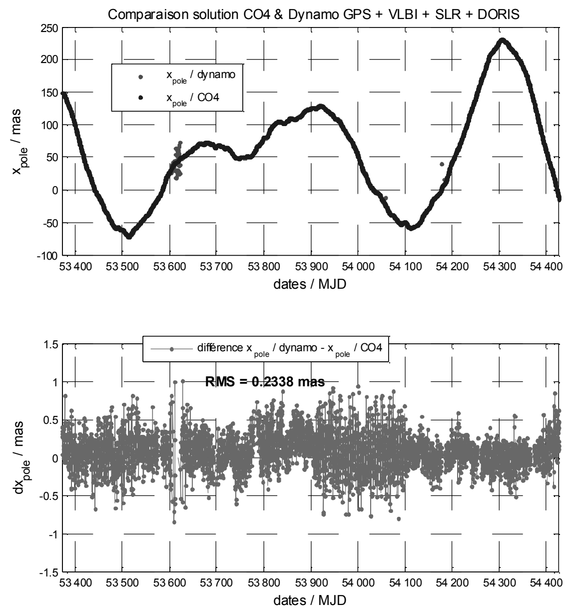

Fig. 4: X pole compared with IERS EOP CO4, residuals rms = 234 µas over 2005–2007.

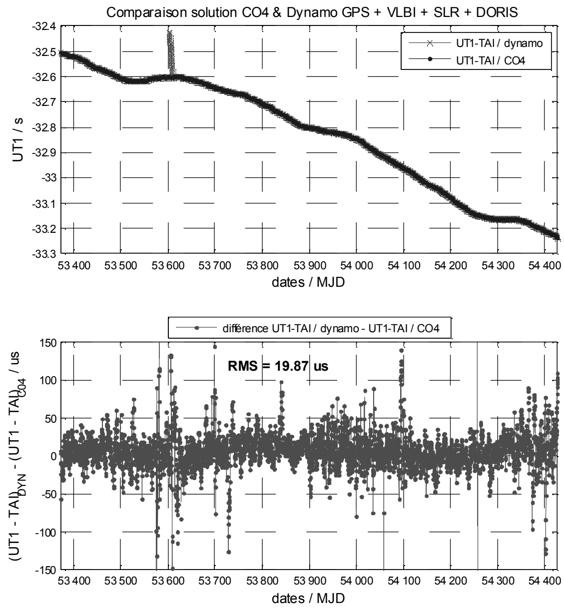

Fig. 5:UT1–TAI compared with IERS EOP C04, residuals rms = 19.9 µs over 2005–2007.

niques can have significant effects on the final estimation quality. Figures 2 and 3 show the X pole and UT1 dynamo solutions over forty weeks of 2005 cumulated using only GPS observations. Continuity constraints are fixed to 2 mas for X and Y poles and 30 µs for UT1.

2.2 Second step: inter-technique combination

The four intra technique NEQs derived over the three years are then accumulated into a single NEQ containing EOP at six-hour intervals. In this process local ties associated with ITRF2005 were considered. A global reference frame consistent with ITFR2005 is obtained, station positions rates being fixed to ITRF values in the process. Figure 4 and 5 show results with combination of the four techniques GPS, VLBI, DORIS, and SLR. The weighting set are for GPS = 5.212, SLR = 1.709, VLBI = 1.927, and DORIS = 1.102. The continuity constraint on Earth parameters are weak, 2 mas for X pole and Y pole and 20 ms for UT1.

3 Assessment of the EOP solutions derived

EOP are computed with respect to the IERS EOP C04 (Gambis, 2004) used as the reference and corrected by the diurnal and sub diurnal model (Ray et al., 1994). Station position corrections are computed with respect to ITRF2000 positions (Altamimi et al., 2002) corrected with models from the IERS conventions (McCarthy and Petit, 2004). As previously mentioned, station velocity rates are held fixed to ITRF2000 values. This appears not to be critical over time intervals limited one year. Polar motion and UT1 are derived at 6-hour intervals whereas pole offsets are derived on a 12-hour basis. For the sake of comparisons, EOP sub-diurnal values are mod-

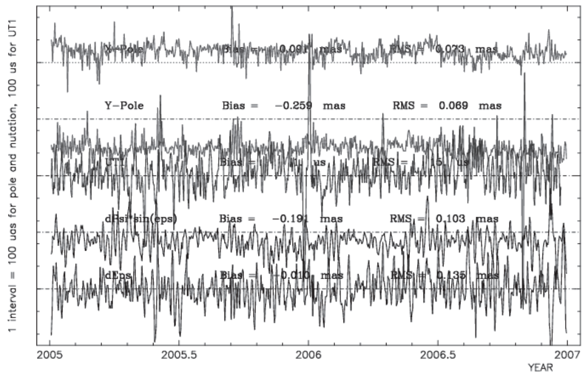

Fig. 6: EOP: differences of GRGS solution with 05C04 over 2005–2006. From top to bottom: X and Y-pole, UT1 and nutation offsets. RMS are about 0.070 mas for pole and 12 microseconds for UT1.

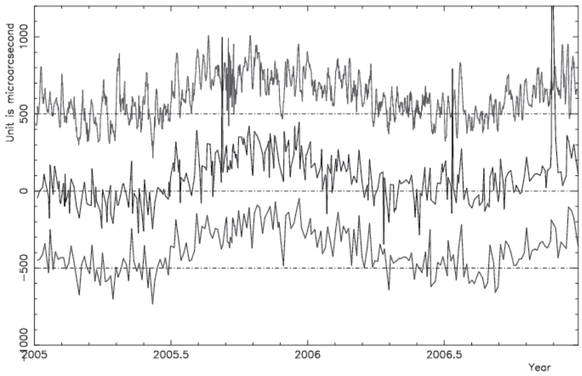

Fig. 7: Plots showing the differences between the GRGS combined solution and combined intra-technique solutions IVS, LRS and IGS for X-pole component over 2005–2006.

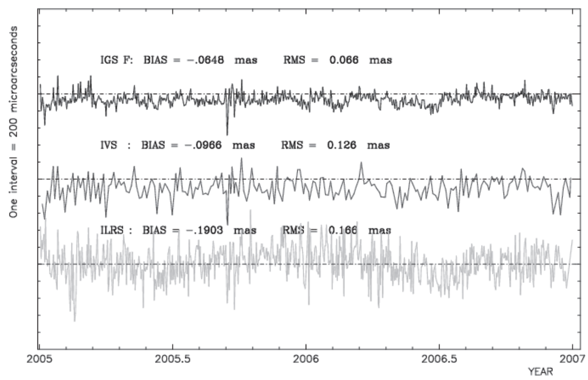

Fig. 8: Nutation offset dx relatively to the IAU 2000 nutation model. Nutation drifts derived from GPS analyses at 12 h-intervals allow to densify nutation series derived from 24-h VLBI sessions. From top to bottom, GRGS combined, GSFC and IAA solutions.

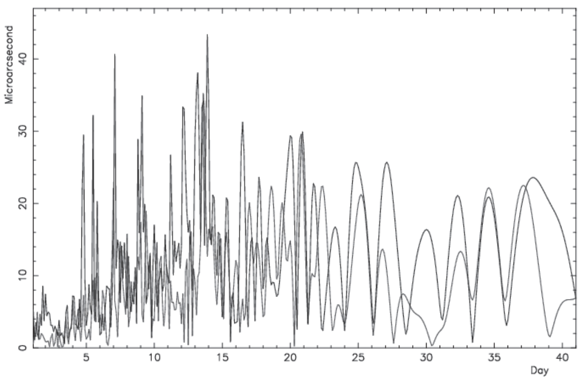

Fig. 9: LSQ periodogram of nutation offsets dx (blue) and dy (red) relatively to MHB2000 nutation model. Significant peaks appear in particular at 7 days and at fortnightly time scales.

elled by a piecewise linear fit to yield values at 0:00 hour. Figure 6 shows the difference of this combined solution with C04 used as the reference and their RMS. The values obtained show the good quality of the results obtained. Note the significant bias in Y pole due to the current inconsistency between the C04 and the ITRF2000. This inconsistency was removed by the realignment of the 05C04 respectively to ITRF2005 system.

4 Conclusion

The combination process based on datum-free NEQ is now done on a routine basis since the beginning of 2005 in a coordinated project within the frame of GRGS. The project is still in a research phase for the processing of individual techniques as well as for the final combination. We already demonstrated the good quality of the results for EOP as well as for station coordinates. The global combined solution benefits from the mutual constraints brought by the different techniques. Better results are expected after the improvement in the processing of the individual techniques. The strength of the method is the use of a set of identical up-to-date models and standards in unique software. In addition the solution benefits from mutual constraints brought by the various techniques; UT1 and nutation offsets derived from VLBI are constrained and complemented by respectively LOD and nutation rates estimated by GPS. Before EOP and station coordinates be derived on an operational basis with an optimal accuracy different problems have to be studied and solved. It appears that the EOP and station coordinate solutions are sensitive to a number of critical parameters linked to the terrestrial reference frame realization mostly local ties whose errors propagate in an unpredictable way in the station coordinates and EOP series. We are here in a context of service oriented researches. This implies that we have to find and apply the optimal values for the critical parameters involved, minimum constraints for stations, EOP continuity constraints and techniques weights. This "tuning" is essential to provide to the community, consistent, accurate and stable products.

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