GLOBAL COMBINATION FROM SPACE GEODETIC TECHNIQUES

D. GAMBIS , R. BIANCALE, J.-M. LEMOINE, J.-C. MARTY, S. LOYER *,
L. SOUDARIN **, T. CARLUCCI, N. CAPITAINE, PH. BÉRIO, D. COULOT,
P. EXERTIER, P. CHARLOT AND Z. ALTAMIMI
Groupe de Recherche de Géodésie Spatiale, FRANCE
* Noveltis, Ramonville St-Agne, FRANCE
** CLS, Ramonville St-Agne, FRANCE

ABSTRACT. We have demonstrated the possibility of deriving both station coordinates and Earth Orientation Parameters (EOP) using weekly normal equations derived from the processing of different space-geodetic techniques: VLBI, SLR, LLR, DORIS and GPS. The work is performed in the frame of a joint project within the GRGS, Groupe de Recherches de Géodésie Spatiale, federation of French institutes. Observations of the different techniques: VLBI, SLR, LLR, DORIS and GPS are processed separately at the different institutes where in addition expertise can be found for the specific technique. Before such products are adopted as references, different problems concerning the stabilization of the terrestrial reference frame have to be solved in addition to upgrading the individual techniques processing to the best possible level of accuracy.

1. INTRODUCTION

Earth Orientation Parameters (EOP) provide the transformation between the International Terrestrial Reference Frame (ITRF) and the International Celestial Reference Frame (ICRF). The reference EOP series computed at the Earth Orientation Centre at Paris Observatory is obtained from the combination of individual EOP time series derived from the various astro-geodetic techniques: Laser Ranging to the Moon (LLR) and to dedicated artificial satellites (SLR), Very Large Baseline Interferometry on extra-galactic sources (VLBI) and more recently from GPS and DORIS systems.

Although the current determination of reference frames and EOP temporal series are both derived from the same observations processing, the rigorous approach allowing a simultaneous determination of station coordinates and EOP is not currently applied. This is however more satisfactory to ensure consistency between the EOP system and both reference frames. Different approaches are now carrying out within the IERS. The first one is based on combination of SINEX matrices derived from the various techniques (Altamimi et al, 2002; Altamimi et al., 2005). An alternative approach is the combination at the observation equation level. Observations of the different techniques are processed separately by the unique software package: GINS/DYNAMO. The normal matrices derived from the analyses of individual techniques are stacked to give both the terrestrial frame materialized by station positions and Earth Orientation Parameters (EOP). The project started in January 2005 on an operational mode. Results are available on the ftp/Web of the IERS Central bureau (http://www.iers.org).

The a priori dynamical and geometrical models used in the GINS DYNAMO package include: GRIM5-C1 gravity field model and the three body point mass attraction from the Sun, the Moon (in addition J2 Earth's indirect effect) and planets. A priori models include: Earth tides, FES-2004 ocean tide, 6h-ECMWF atmospheric pressure fields. DTM94bis thermospheric model, albedo and infra-red grids from ECMWF, station coordinates derived from ITRF 2000, EOP from IERS C04 series.

DYNAMO is a set of numerical codes used for normal equations handling: permutation, solving, and stacking. It also can generate a normal equation matrix from a set of constraint parameters.

2. CONSTRAINTS

When solving for parameters, i.e. EOP and station coordinates, the normal equation matrices might not be invertible; it is then necessary to apply constraints. Two kinds of constraints can be applied in the procedure:

II- 1 - Minimum constraints:

Minimum constraints concern transformation parameters: translation, rotation parameters and a scale factor. Their application allows to inverse normal equations matrices suffering from rank deficiencies, which is initially not invertible.
The basic expression used in the transformation of two reference frames X1 and X2 can be written as:

$$X_2 = T + \lambda R X_1,$$

where T is the vector translation $T = (T_x, T_y, T_z)$, R the vector rotation $R = (R_x, R_y, R_z)$ and λ a scale factor.

The minimum constraints applied in the present analysis are translations in X, Y, Z for the VLBI and rotation in Z for the satellite techniques GPS, SLR and DORIS. For more details about minimum constraints, see Sillard and Boucher (2001).

II-2 - Local ties constraints

The combination of EOP and station coordinates derived from the various techniques requires a good link between the terrestrial reference frames. This link is brought by local surveys at collocation sites where two or more techniques are simultaneously observing. Classical surveys are usually direction angles, distances, and levelling measurements between reference points of the instruments or geodetic markers. This is commonly referred to as local ties (3D coordinate differences between the reference points). Adjustments of local surveys are performed by national geodetic agencies operating space geodesy instruments to provide local ties connecting the collocated instruments. An accuracy level of 1-2 mm is required for reference frames combination, however real estimates can reach several centimetres. A local tie file is derived from the computation of the ITRF (Altamimi et al, 2002). DYNAMO allows generating a normal equation matrix from such a local ties file. 23 local ties constraints (ITRF2000 file) were used in the present analyses i.e. 3 SLR-VLBI, 6 SLR- GPS, 6 SLR-DORIS, 1 GPS-VLBI and 7 GPS-DORIS stations.

II-3 -EOP continuity constraints

In addition, to stabilize the EOP time series and remove the short-term noise, continuity constraints on EOP have to be applied. This leads to smooth the corresponding time series. Piece-wise linear fits are applied over 6 h time intervals for deriving daily pole components.

3. WEEKLY COMBINATION PROCESS, ESTIMATION AND VALIDATION

Normal equations derived from the different techniques are stacked on a weekly basis over the six first months of 2005. The constraints previously presented are applied: minimum variance, EOP continuity constraints, local ties (ITRF2000); piece-wise linear fits are applied over 6 h time intervals for pole components in order to derive a daily estimates. The mean measurement residuals lead to determine the weighting of each technique in the global combination (Table 1).

The weighting procedure is based on the variance component estimation method as suggested by Helmert (Sahin et al., 1992). The relative weights are used in the matrices combinations. They should be carefully considered since contributions to EOP and stations coordinates are different according to techniques. Changes in the weights can have significant effects on the final estimation quality.

	Number of observations per week	Mean measurement residuals	Weighting (expressed in measurement units)
GPS (phase)	600 000	4.5 mm	6.8 mm
SLR	1500 - 4000	1.0 cm	1.3 cm
DORIS	100 000	0.40 mm/s	0.27 mm/s
VLBI	2000 - 5000	1.5 - 3.5 cm	1.0 cm
LLR	0 - 20	11. cm	46. cm

Table 1: Statistics concerning the processing of the various techniques

III-1 - Multi-technique EOP combined solution EOP are computed with respect to the IERS EOP C04 (Gambis, 2004] corrected with 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 of IERS conventions Table 2 gives for pole components and UT1 the differences between this multi-technique combined solution, referred as EOP (GRGS) and the IERS C04 with the corresponding statistics, biases and RMS. External results derived from the different techniques also referenced to IERS C04 are also given. RMS values are good compared to the various international services contributions but are so far not at the level of accuracy of these solutions. This comes from the fact that individual techniques observations processed by GINS need to be improved to match the best products given by GPS for polar motion and VLBI for UT1.

III-2 - Assessment of the quality of the global reference frame derived
Weekly sets of station coordinates are expressed in a frame consistent with the ITRF2000 used as the reference. Levels of 3-5 mm in positions and 3-8 mm in the height component are reached with fair time stability.

The quality of the multi-technique combined terrestrial reference frame (GRGS) depends on the relative qualities of the contributing solutions per technique as well as on the combination strategy which is applied. The overall quality indexes of the individual solutions included in the GRGS combination is given via the transformation components: translation and scale.

Table 3 represents the transformation between these reference frames expressed in the form of translation, rotation and scale factor parameters. It gives the accuracy of the origin and scale. All results and in particular those relative to the multi-technique combination show a general fair stability of terrestrial reference frames compared to ITRF2000. We can note that SLR results present some significant discrepancies larger than one centimetre in the translation components.

	Bias			R M S		
	X_p (μas)	Y_p (μas)	$UT1$ (μs)	X_p (μas)	Y_p (μas)	$UT1$ (μs)
IGS	-31	320		36	31	
IVS	-221	231	1	195	122	8
ILRS	-226	242		180	213	
IDS	21 265	14 657		459	744	
GRGS	-21	30	1	73	74	15

Table 2: Earth rotation parameters: differences of the global combined solution referred as to GRGS with IERS C04 used as the reference. Comparisons with solutions derived from International Services are also given

	T_X (mm)	T_Y (mm)	T_Z (mm)	Scale (ppb)	R_X (mm)	R_Y (mm)	R_Z (mm)
GPS	6	7	-4	11	-3	-1	-3
SLR	-14	-11	-21	1	-6	7	-7
VLBI	1	-3	-1	2	-1	0	2
DORIS	3	30	31	-8	-7	2	10
GRGS	-7	6	-4	6	-3	0	1

Table 3: Reference frame solution: 7-parameter transform / ITRF2000 translation and rotation components in mm. Scale factors are in ppb (6 mm in station heights)

4. CONCLUSIONS

The combination process is performed on a routine basis since the beginning of 2005 in the frame of GRGS. We already demonstrated the good quality of the results for EOP as well as station coordinates. Better results are expected after the improvement in the processing of the different techniques. It appears that the EOP and station coordinate solutions are sensitive to a number of critical parameters mostly linked to the terrestrial reference frame realization i.e. station minimum constraints, local ties, EOP continuity constraints for the Earth Orientation Parameters. Before EOP and station coordinates be derived on an operational basis with an optimal accuracy different problems have to be studied and solved. Another critical point which needs to be carefully studied concerns the optimization of the weighting of the different techniques using the Helmert's method. Other improvements will likely come from the upgrade in the processing of the various techniques such as the use of GPS double differences with integer ambiguities resolution, the use of JASON DORIS data taking care of SAA correction, the homogenization of tropospheric corrections per site using dry and wet delays derived from ECMWF. We also expect to be able to reduce the delivery delay to less than 8 weeks.

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