3.6.2.8 Groupe de Recherches de Géodésie Spatiale (GRGS)

We present thereafter the status of the GRGS concerning the IERS Combination Pilot Project (CPP). We have demonstrated the possibility of deriving both station coordinates and Earth Orientation Parameters (EOP) based on weekly solutions on a regular basis since the beginning of 2005. Results are made available in the form of SINEX files at the IERS site (ftp <iers1.bkg.bund.de>) (Gambis et al., 2006a). However, before such products are adopted as references, different problems concerning the stabilization of the terrestrial reference frame have to be solved in addition to upgrade the individual techniques processing to the best level of accuracy. After a general presentation of individual technique processing we present the analyses concerning the combination procedures performed on two modes: the weekly mode and the long-term one over a full year (2005).

1 General approach

Observations of the different techniques (VLBI, SLR, LLR, DORIS and GPS) are processed separately using a unique software package: GINS/DYNAMO, developed and maintained at the GRGS (Groupe de Recherches de Géodésie Spatiale) since 1965.

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. This project, ambitious and too important to be run by a single analysis centre is distributed at different institutes where in addition the expertise can be found for the dedicated technique: GPS at Noveltis, Toulouse (S. Loyer), DORIS at CLS, Toulouse (L. Soudarin), SLR at the Observatoire de la Côte d’Azur, Grasse (P. 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 and T. Carlucci). In addition the expertise of Z. Altamimi concerning terrestrial frame is appreciated.

Data processing is performed using the GINS software with identical up-to-date models and standards (Figure 1).

2 The GINS/ DYNAMO package

The a priori dynamical and geometrical models are:

- A priori dynamical models are the GRIM5-C1 gravity field model and the three body point mass attraction from the Sun, the Moon (+ J2 Earth’s indirect effect) and planets, Mercury, Venus, Mars, Jupiter and Saturn.
  - Earth tide model according to IERS Conventions (2003)

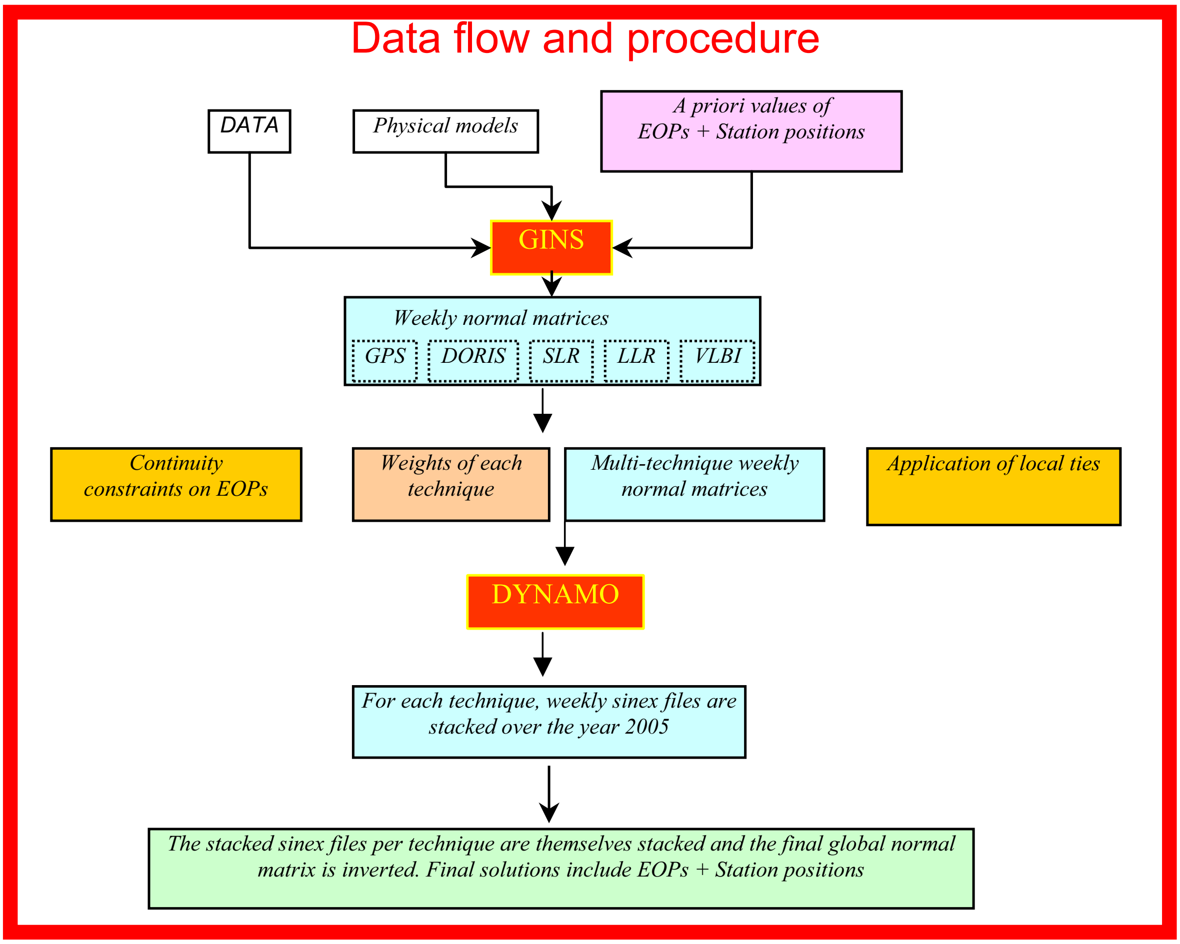


Fig. 1: Chart showing the organisation of the project and the data flow

  - FES-2004 ocean tide model
  - 6h-ECMWF atmospheric pressure fields only over continents (IB hypothesis)
  - DTM94bis thermospheric model
  - Albedo and Infra-Red grids from ECMWF (resolution of 4.5 degrees)
- A priori geometrical models :
  - Coordinates derived from ITRF 2000
  - A priori EOPs from IERS C04 series
  - Earth tide model according to IERS Conventions (2003)
  - Oceanic loading effect from FES-2004 ocean tide model
  - Atmospheric loading effect from 6h-ECMWF atmospheric pressure fields only over continents

3 Processing of individual techniques

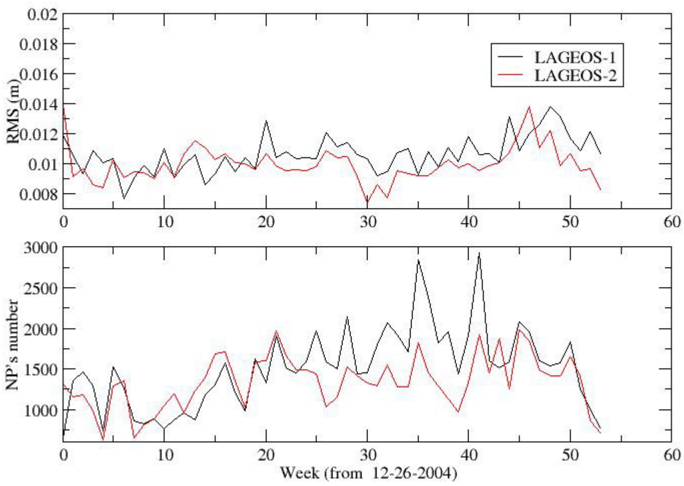
We present thereafter the main characteristics and recent improvements of the processing concerning the different techniques.

3.1 Satellite Laser Tracking (SLR)

Observations of LAGEOS 1 and 2 satellites have been processed over 9-day arcs with 2-day overlappings. The network comprises 31 observing stations with a number of normal points per week of respectively 1504 and 1338. The final RMS are respectively 1.06 cm and .99 cm for both satellites. Weekly normal matrices are derived relative to a range bias per week, per station and per satellite, station coordinates and EOPs at 6-hour intervals. Final results are obtained with a two week delay. Two modifications were recently implemented to improve results: taking into account the difference between the centre of reflection mass and centre of mass as dependant of the type and power of the laser and the application of the tropospheric correction derived from ECMWF meteorological models rather than state parameters at the ground level. Figures 2 and 3 present the SLR network and statistics concerning the normal point numbers and the final RMS of the fit.

Fig. 2: SLR core stations network

Fig. 3: RMS and normal points number



3.2 DORIS

Analyses were performed from January 2005 (GPS week 1304 day 0) to the end of 2005 (GPS week 1355 day 6). Satellites processed are SPOT2, SPOT4 and SPOT5. Recently the upgrading of the GINS allows processing ENVISAT observations with the right centre of phase correction as well as Jason's, the effect of the South-Atlantic Anomaly was introduced as a model. Residuals are in the range of 0.4 mm/s.

Arc lengths extend over 3.5 days starting on Sunday 0:00 or Wednesday 12:00 (between 1 and 3.5 days in case of orbit correction manoeuvres or data lacks) .

Fitted parameters are orbital elements, drag and solar pressure coefficients, tropospheric zenithal bias, frequency bias and Hill parameters. The application of the tropospheric correction derived from ECMWF meteorological models has lead recently to the suppression of the abnormal scaling factor in the network. Figure 4 shows the DORIS network.

Fig. 4: Network of DORIS stations

3.3 GPS

The recent improvement concerns the implementation of the undifferenced measurements on an operational mode. The comparison of the satellite orbits and IGS ones show differences of about 10 to 15 cm with a small radial bias. Final results are obtained with a delay of 3 to 9 weeks. One recent implementation concerns the double differences mode taking into account integer ambiguities in the data processing. Another improvement should come from the introduction of empirical corrections during eclipses. Figures 5 and 6 show respectively the network of participating stations and the number of stations involved in the solution and the phase residual in mm.

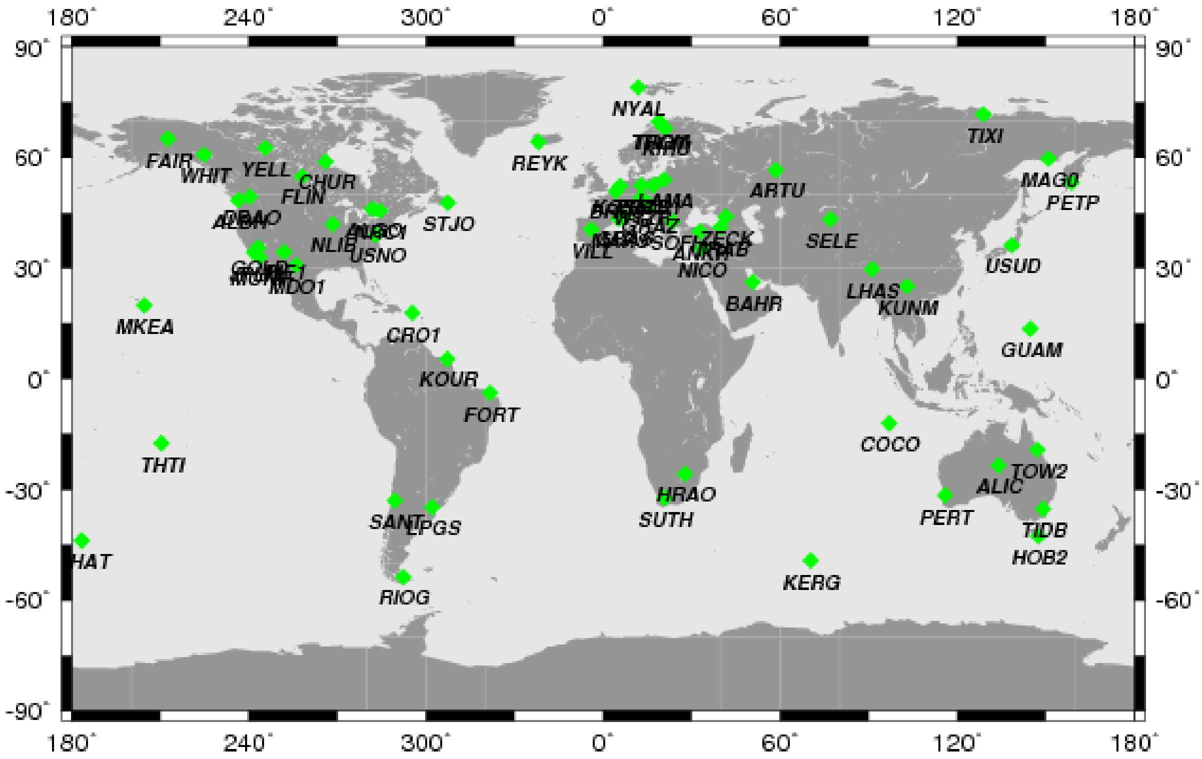


Fig. 5: Network of participating GPS stations in the GRGS project

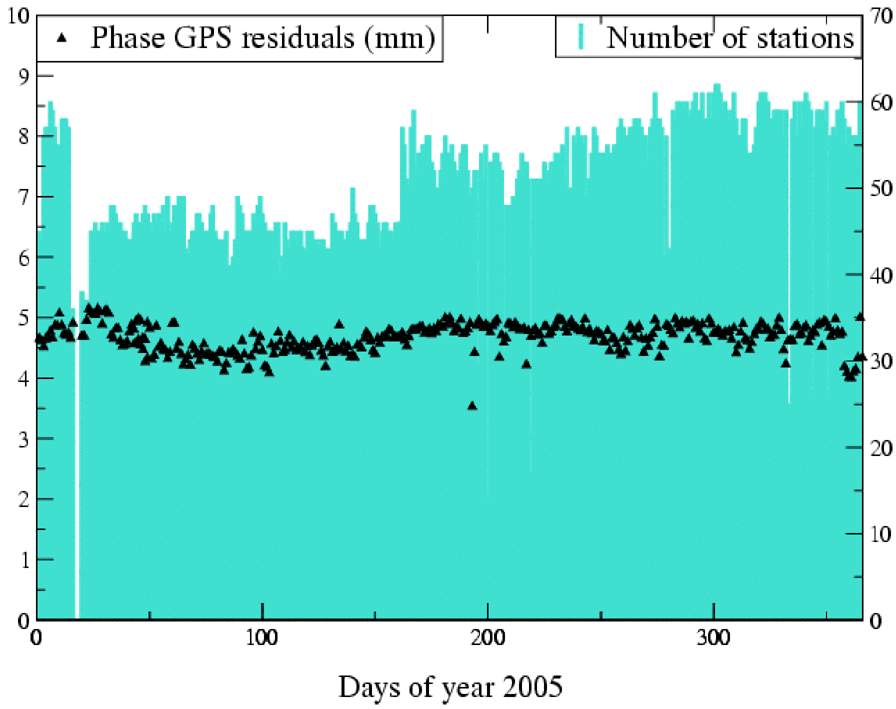


Fig. 6: Number of stations involved in the GPS solution and phase residual in mm

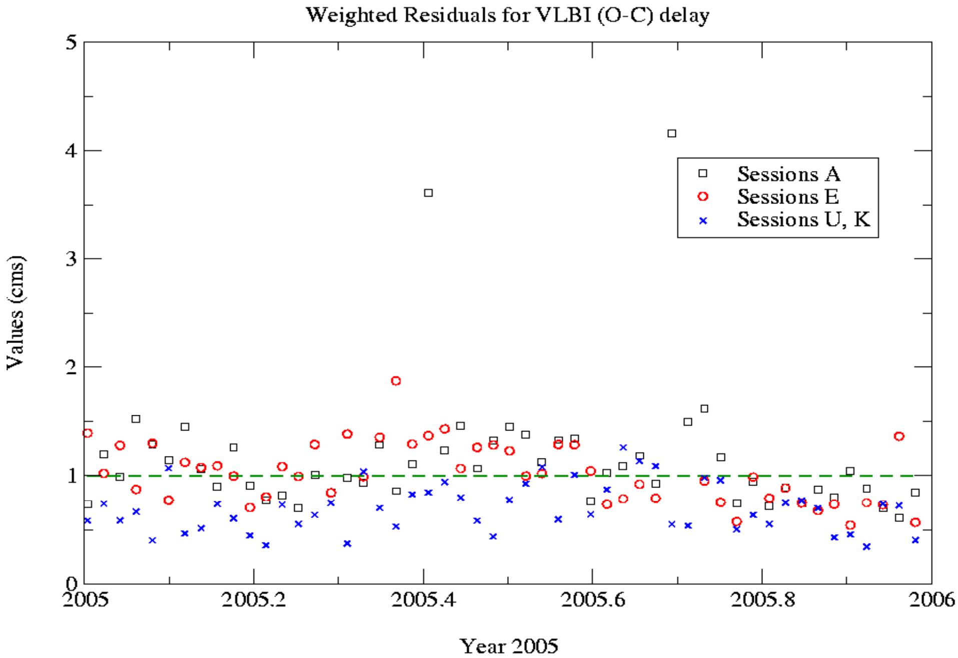


Fig. 7: Weighted residuals for A,E, U and K sessions

3.4 Very Long baseline Interferometry (VLBI)

R1, R4 and the intensive sessions are computed using the software GINS, for each week of 2005. The a priori terrestrial reference frame VTRF2005 is used (Nothnagel 2005). Two series of computations were performed:

- R1 and R4 IVS sessions (also called A and E), one time bias parameter over 2 hours, and one zenithal tropospheric bias parameter over each hour are fitted
- Intensive sessions (called U and K), the determination concerns a value and a trend per session (which lasts more or less one hour) for the time bias and the zenithal tropospheric bias parameters.

Comparisons made between two different softwares GINS et MOD-EST show a good agreement, i.e. about 8 mm on data residuals in the barycentric system. It is also important to check the compatibility between nutation models, i.e. IAU 1980 and 2000.

Residuals of processings over 2005 on sessions A and E are in the range of 1 cm (Figure 7).

3.5 Lunar Laser Ranging (LLR)

The LLR observation equations were implemented in the GINS software based on 6 hour lunar ephemeris as well as libration parameters series derived from the CAROLL software of the Paris Observatory. However the LLR station has now been stopped to be upgraded in the T2000 program. The analyses of Grasse and MacDonald observations over the previous years show residuals with an RMS of about 13 cm.

4 Combination process and validation

The optimal relative weights between techniques were obtained by using the Helmert's optimal variance-covariance method. The global final solution is derived from the stacking of the technique normal equations relative to EOP and station coordinates. In the processing of GPS and VLBI, pole components and UT1 are estimated at 6 h intervals whereas nutation corrections in obliquity and longitude are obtained every 12 hours. In the multi-technique combination a daily solution is derived applying a piece-wise linear function over the 6h estimates. Solutions were stabilized applying minimal constraints through the classical Helmert's transformation on stations coordinates in order to constrain the whole network to stay close to the ITRF2000 reference system.

Results in the form of Earth Orientation Parameters and stations coordinates are available in SINEX files in the IERS database. Different tests have been performed, taking into account or not the critical parameters, i.e. the local ties, minimal constraints on stations, EOP continuity constraints as well as the weighting of the different techniques. The effects of the choice and the tuning of these parameters are exhaustively discussed in Gambis et al. (2006b).

4.1 Weekly process

Normal equations derived from the different techniques are cumulated on a weekly basis. Minimal EOP continuity constraints, local ties (ITRF2000) are used; piece-wise linear fits are applied over 6 h time intervals for pole components. Figure 8 gives the differences between this multi-technique combined solution, referred as EOP (GRGS) and the IERS C04 with the corresponding statistics, i.e. biases and RMS. We can note the significant jumps in the pole components, up to 150 µas. These jumps are due to inconsistencies between the realisations of the successive weekly station coordinates solutions, to the poor accuracy of the local ties and possibly to the values of minimal constraints adopted. We expect that the complete local ties associated to the forthcoming ITRF2005 will partly solve this problem. Results concerning the reference frame are not presented here.

4.2 Multi-technique combined solution over a full year analysis (2005)

Intra-techniques solutions are firstly independently cumulated over the year 2005. The 4 matrices are then stacked to derive the global multi-technique solution. Stations coordinates offsets are given for the whole year. Stations rates have been set to their ITRF2000 values. Minimal constraints, EOP continuity constraints and local ties (ITRF2000) are applied. A piece-wise linear fit was not applied over 6h estimates for pole components. This might be the cause of the significant short-periodic oscillation appearing in the beginning of 2005. Figure 9 shows differences between the combined solution and the IERS C04 used as the reference. The EOP solution is more

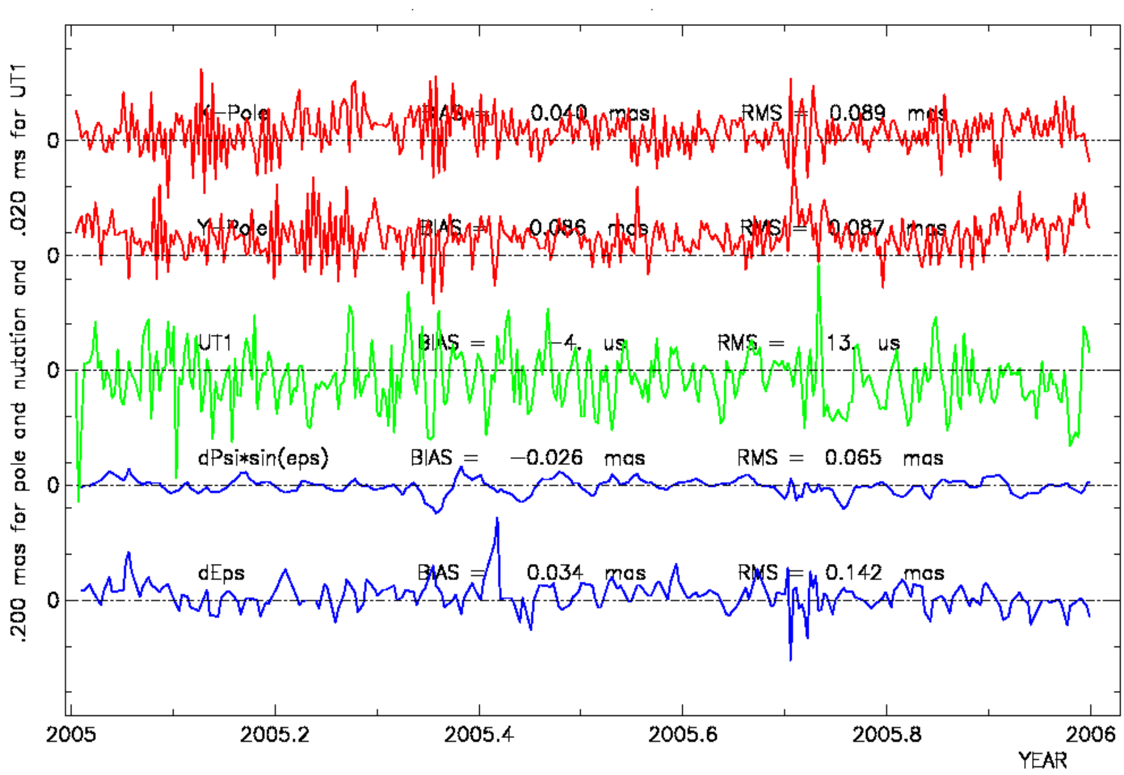


Fig. 8: Differences for X- and Y-Pole, UT1 and nutation offsets between the combined solution obtained from the successive weekly solutions and the IERS C04 used as the reference

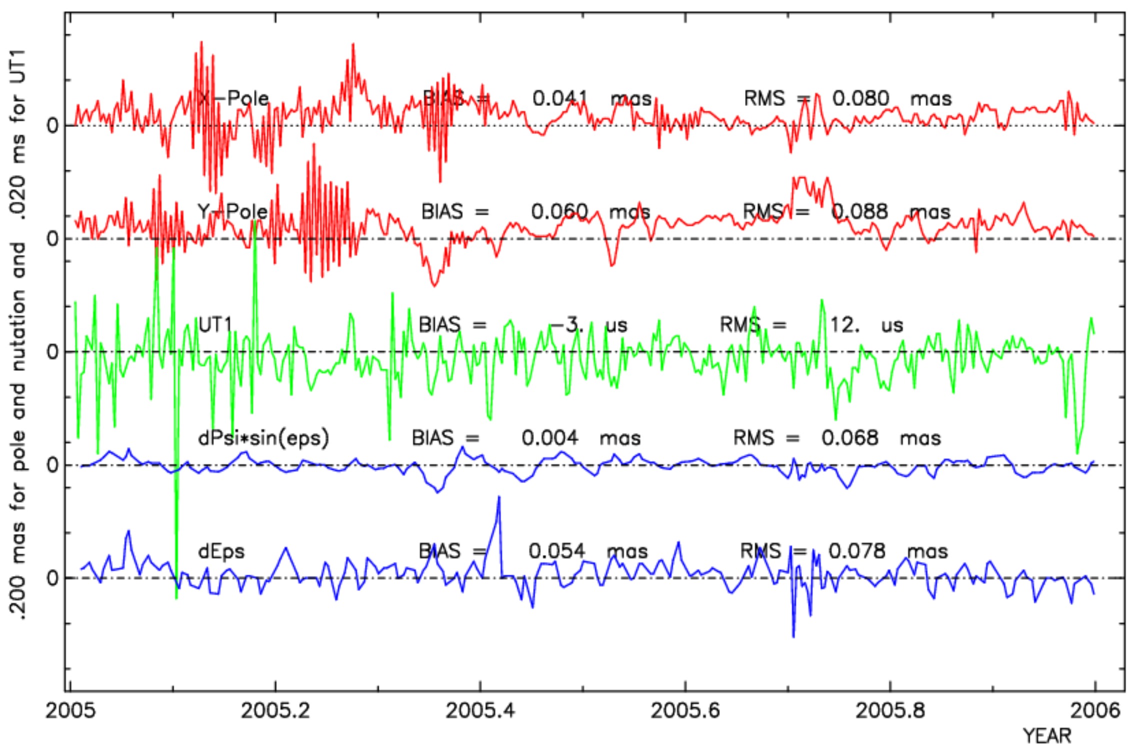


Fig. 9: Differences for X- and Y-Pole, UT1 and nutation offsets between the combined solution derived over the full year 2005 and the IERS C04 used as the reference

Table 1: RMS of the difference between individual technique solutions and IERS C04

	DORIS only	SLR only	GPS only	VLBI only	Multi-technique GRGS	Best current solution
X-Pole in µas	176	136	91	156	80	34 (IGS)
Y-Pole in µas	150	133	73	167	88	30 (IGS)
UT1 in µs				13	12	11 (IVS)
$D\psi.\sin\varepsilon$ in µas				65	68	21 (IVS)
$D\varepsilon$ in µas				70	78	37 (IVS)

homogeneous than the weekly solution one although RMS are larger. We can note that including the intensive VLBI sessions densifies UT1 series to one-day intervals.

Table 1 shows the comparison, i.e. the RMS of the differences between the individual intra-technique solution on one hand and the combined final multi-technique solution "GRGS" on the second hand and the IERS C04 used as the reference. It appears that the multi-technique solution is not better than individual technique solutions. This is assumed to be mainly due to the terrestrial reference frame instabilities.

The effect on the combined UT1 of LOD derived GPS is not clear since this quantity is affected by a significant bias due to errors propagated by mismodelling in the ascending node of satellites orbits (Gambis, 1996, Ray 1996, Gambis 1997). This should be carefully investigated.

For comparison purpose, the last column gives the current best solution accuracy yielded by international services, IGS for pole components and IVS for UT1 and nutation offsets.

Table 2: Reference frame solution: 7-parameter transformion with respect to ITRF2000

	Tx cm	Ty cm	Tz cm	Scale cm	Rx cm	Ry cm	Rz cm
DORIS	1.2	1.3	2.3	–1.4	0.0	–0.6	–0.6
GPS	0.9	1.0	4.0	0.3	–0.2	0.0	0.0
SLR	0.1	–0.4	–1.3	0.4	–0.2	0.4	–0.6
VLBI	0.0	0.8	0.0	0.5	–0.4	0.2	0.6
COMBINED	0.6	0.5	0.8	0.5	0.0	0.0	–0.9

Table 3: Accuracy of individual reference frame solution with respect to ITRF2000

		Bias/RMS in mm		
	Nb of stations	dX	dY	dZ
GPS	55	0/1	0/1	0/1
SLR	28	0/1	0/1	0/1
VLBI	15	0/3	0/4	0/3
DORIS	52	-11/23	-14/36	-21/27
COMBINED	150	-8/13	-4/17	2/15

Table 2 to Table 4 show the statistics concerning the transformation between individual reference frames per technique and ITRF2000. Table 2 gives the 7-parameter transformation, rotation, translation and scaling factors between each individual terrestrial frame and ITRF2000 for the various techniques; we note an abnormally high estimate for the scaling factor derived from DORIS. In recent analyses where the tropospheric correction derived from ECMWF meteorological models is applied, this scaling factor decreases significantly.

5 Conclusions

Different approaches are carried out to deliver robust solutions concerning both station coordinates and Earth Orientation Parameters. One uses SINEX files derived from the analysis of observations of the various techniques processed by independent softwares like the ITRF2005 (Altamimi, 2006). Our approach within the GRGS (Groupe de Recherches de Géodésie Spatiale, federative organism involving different French institutes) is to use a single software/package, the GINS/DYNAMO developed and maintained at the CNES/GRGS. The advantages of this method come from the fact that all constants and models are identical for the analyses of the different techniques and in addition in assuming that the final combined solution will be reinforced by the strengths of the complementary aspects of these techniques.

We are combining both stations coordinates and Earth Orientation Parameters at the normal equation level. Observations of astro-geodetic techniques, VLBI, GPS, SLR, LLR and DORIS are processed at different dedicated analysis centres. Normal equations derived are thus processed and stacked at Paris Observatory. Two main approaches have been carried: the first one made on a routine basis leads to a weekly solution of both EOP and station coordinates. The second one gives a homogeneous solution over a full year, i.e. 2005. The analyses we have performed show that the EOP solution is sensitive to a number of critical parameters mostly linked to the terrestrial reference frame realization that need to be carefully tuned in order to regularly deliver an accurate and stable

Table 4: 3-D comparison of individual solutions with respect to ITRF2000. For VLBI the initial reference frame is VTRF2005 (Nothnagel, 2005)

	SLR	DORIS	GPS	VLBI
3-D difference with ITRF2000	1.6 cm	5.7 cm	1.7 cm	1.4 cm

solution. These parameters are station minimal constraints, local ties, EOP continuity constraints, piece-wise linear fitting for the Earth Orientations Parameters. Another critical point concerns the weighting of the different techniques by the Helmert's method.

References

Altamimi, Z. (2006), The ITRF2005, to be issued in Summer 2006, personal communication.

Gambis, D., 1996, Multi-technique Earth Orientation Parameters combination, Proc. International IGS Workshop, Silverspring, USA, March 19–21, R. E. Neilan, P. Van Scoy, and J. F. Zumberge (eds.), pp. 61-70.

Gambis, D., 1997, Monitoring Earth Rotation using various techniques, current results and future prospects, Dynamics and astrometry of natural and artificial celestial bodies, Proc. of IAU Colloquium 165, I.M. Wytrzyszczak, J.H. Lieske, and R.A. Feldman (eds.), Kluwer Academic Publishers, p. 475.

Gambis, D.; Biancale, R.; Carlucci, T.; Lemoine, J.M.; Marty, J.C.; Altamimi, Z.; Bério, P.; Bourda G., Charlot, P.; Loyer, S.; Soudarin, L., 2006, Global combination of a terrestrial frame and Earth Orientation Parameters at the observation level, in: EGU General Assembly, Vienna, Austria, 2–7 April 2006, Geophys. Res. Abs., Vol. 8, 07768, 2006 SRef-ID: 1607-7962/gra/EGU06-A-07768.

Gambis, D.; Biancale, R.; Carlucci, T.; Lemoine, J.M.; Marty, J.C.; Altamimi, Z.; Bério, P.; Bourda G.; Charlot, P.; Loyer, S.; Soudarin, L., 2006b, Global Multi-technique combination of Earth Orientation Parameters and stations coordinates at the observation level, in preparation.

Nothnagel, A., 2005, VTRF2005: A Combined VLBI Terrestrial Reference Frame, in: Proceedings of the 17th Working Meeting on European VLBI for Geodesy and Astrometry, held at Noto, Italy, May 21–22, 2005, M. Vennebusch and A. Nothnagel (eds.), pp. 118–124.

Ray, J., 1996, Measurements of length of day using the Global Positioning System, J. Geophys. Res., 101(89) , 20141–20149

Daniel Gambis, Richard Biancale, Teddy Carlucci, Jean Michel Lemoine, Jean Charles Marty, Philippe Bério, Géraldine Bourda, Patrick Charlot, Sylvain Loyer, Laurent Soudarin, Zuheir Altamimi