PROCESSING DORIS DATA WITH THE GIPSY/OASIS II SOFTWARE: RECENT RESULTS FOR POINT POSITIONING AND ORBIT DETERMINATION

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BIOGRAPHY

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William I. Bertiger, received his Ph.D. in Mathematics from the University of California, Berkeley, in 1976, specializing in Partial Differential Equations. In 1985, he began work at JPL as a Member of the Technical Staff in the Earth Orbiter Systems Group focussing on the use of high precision GPS.

ABSTRACT

The french DORIS system, launched for the first time in january 1990 on the SPOT2 satellite has proved its capabilities for precise orbit determination and point positioning. Since then, two additionnal satellites are currently carrying a DORIS receiver (Topex/Poseïdon, since August 1992 and recently SPOT3, since September 1993).

The purpose of this paper is to present recent results obtained with the GIPSY/OASIS II software developped at JPL, and presently used at IGN/France. Several improvements have been done since the very beginning of the DORIS system: use of precise gravity fields models, such as JGM-2, determination of empirical accelerations for the satellite orbit, precise surface force modelling for T/P,...

Results will be showned for precise orbit determination in the case of the US-French Topex/Poseïdon oceanographic mission. Comparisons will be performed with the precise orbit obtained at JPL using the GPS data in the new reduced dynamic approach.

DORIS data were also computed for point positioning using the free network approach (using very low constraints on ground stations coordinates). It is now possible to obtain a 10-cm accuracy absolute positioning using only 1 day of data in most cases. Recent results will also be presented using broader time spans of DORIS data (typically months). Best solutions show now agreement with the IERS Terrestrial Reference Frame at the 2.1 cm level.

As a preliminary study, Earth Rotation Parameters were also estimated for 1-day DORIS data span, showing consistency at the 2 mas level with the IERS solution.

For each topic, orbit determination and point positioning, the strategy of the computation will be discussed and results will be presented.

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INTRODUCTION

DORIS is an acronym for Doppler Orbit determination and Radiopositioning Integrated on

Satellite. This system has been designed and developped by the CNES (french national Space Agency) for Precise Orbit Determination of low earth orbiting satellite (Nouel et al, 1988; Nouel et al, 1991; Cazenave et al, 1992).

The first satellite, SPOT-2 (a remote sensing satellite) has been launched in january 1990 and has been performing precise DORIS measurements since this epoch. In August 1992, another DORIS receiver has been put on-board the TOPEX satellite as the the french nominal tracking system for the US/French Topex/Poseïdon oceanographic mission. Another satellite (SPOT-3) has also recently been launched by the European Ariane carrier in september 1993.

This system is a precise Doppler dual-frequency radioelectric system (2 GHz and 400 MHz). For orbit determination's purposes, it has been conceived as an uplink system (meaning that, opposite to systems such as GPS, the ground stations are transmitting while the receiver is on-board the satellite). Consequently, the system is centralized. This is an important positive aspect for the DORIS system: all the data are easily available at the computing center in Toulouse without the usual significant cost for the data telecommunications.

A dense homogeneous tracking network has been deployed by IGN (Lansmann, 1993), in cooperation with CNES, relying on a large international scientific cooperation. Presently, 49 permanent DORIS stations are installed (allowing an almost continuous tracking of the satellites). As far as possible, these stations were collocated by IGN with the IERS network (International Earth Rotation Service). Presently, 17 permanent DORIS tracking stations are in collocations with the IERS sites.

The Jet Propulsion Laboratory and the Institut Géographique National have developped a fruitful cooperation in the scope of the Topex/Poseïdon mission, for scientific intercomparisons of the GPS and the DORIS system. In particular, this cooperation allowed us to use the GIPSY/OASIS software for DORIS data analysis.

The aim of this paper is to present some of the recent results obtained for either orbit computation or point positioning using the DORIS Topex/Poseïdon data or Earth rotation parameters.

PROCESSING STRATEGIES

All DORIS data processing described in this paper were realized at IGN using the GIPSY/OASIS II software developped at JPL (Wu et al, 1990) and slighly upgraded to take into account this new type of measurement (Willis et al, 1993b).

The general strategy is very similar to the one used by the JPL group to process GPS data (Melbourne et al, 1993; Bertiger et al, 1993a). The force models include the new JGM-2 gravity model (and its associated ocean tide model) obtained jointly by the Goddard Space Flight Center and the University of Texas (Lerch et al, 1993; Nerem et al, 1993), atmospheric drag, earth albedo, solar radiation pressure, and thermal radiation models (Marshall et al, 1992a; Marshall et al, 1992b; Yunck et al, 1990). In addition, an empirical acceleration (Kaplan, 1976) was estimated using the following formula:

$$\bar{a} = \bar{C} + \sum_{i=1}^{2} \bar{A}_i \cos \omega_i t + \bar{B}_i \sin \omega_i t$$

where $\bar{C}$, $\bar{A}_i$, and $\bar{B}_i$ are constant vectors in the coordinate system oriented in the nominal spacecraft along track, radial and cross track dirrections. In the case of DORIS, $\bar{C}$ was only estimated in the along track direction, while $\bar{A}_i$, and $\bar{B}_i$ were only estimated both in the along track and the cross track direction.

The index "i" depends on the possible choice taken for the relevant frequencies (once per rev., twice per rev.,...). In our case, the only empirical acceleration estimated was at the orbital period of the satellite.

Table 1 displays the adjusted parameters in the DORIS runs. It should be pointed out that this correspond really to dynamic orbit computation, by opposition to the reduced dynamic approach (Yunck et al, 1993; Bertiger at al, 1993b). Three different processing strategies were used, defining differently the a priori weight of the stations coordinates:

- the fixed network approach: the a priori error on the station coordinate is assume to be 0.1 mm, meaning that the station coordinates are basically fixed in the estimation. This is the usual approach used for Precise Orbit Determination by most of the orbit POD groups in the world. When a DORIS tracking station does not appear in the coordinate data set (e.g. newly installed DORIS tracking station), an a priori error of 10 m is assumed. In this case, we also use some DORIS data to estimate its a priori position to 1 m (or better).

- the free network approach (Blewitt et al, 1992): the a priori station coordinate error is then assumed to be 10 m, meaning that the stations coordinates are basically entirely estimated in the run. The choice of 10 m instead of 1 km, is an attend to try avoiding non linearity when DORIS data are very sparse. There is also presently a 10 cm contraint (which does not affect the results) on only one station longitude, for the same reason . This is the usual approach for GPS Precise Point Positioning at JPL (non-fiducial estimation).

- the constrained approach: the a priori error is assumed to be the one given in the input coordinate data set. The specific interest of this approach expresses itself when some ground stations are not determined at the same level of quality in the input coordinate set as the others (reliability of the local tie, new station,...). This is presently our usual approach for DORIS Precise Orbit Determination. When, a DORIS tracking station does not appear in the coordinate data set, the same approach used for the fixed network solution is taken.

Adjusted Parameters and A Priori Errors	
Satellite state vector Along-track Constant Acceleration Once/rev Along-Track and Cross-Track Accelerations Ground station frequency offset Zenith tropospheric delay	1 km; 1 m/s, each component 10^6 nm/s^2. 10^6 nm/s^2, each component 1 km/s, each station (reset by pass) 50 cm, each station (reset by pass)
Ground stations location	0,1 mm, each component (fixed network) given in the coordinate set (constrained network) 10 m, each component (free network)

TABLE 1: Summary of DORIS data processing using the GIPSY/OASIS II software

If not estimated (see later on), the Earth Rotation Parameters (polar motion and UT1-UTC) have been fixed to their corresponding IERS circular B values (final values), as given regularly by the IERS Central Bureau at the Paris Observatory (Charlot et al, 1993).

Topex/Poseïdon DORIS data where processed on a daily basis:

- using 24 h data span for point positioning (to limit the amount of data processing)

- using 30 h data span for precise orbit determination (as usually done for GPS data analysis). In this case the data start at 9:00pm the day before and stop at 3:00am the day after.

ORBIT OVERLAP AGREEMENT

From one day to another, there is consequently a 6 hour overlap period (from 9:00pm to 3:00am, centered around midnight) allowing internal quality tests.

As a preliminary test, we have compared the level of internal agreement between two consecutive days. During this 6-hour overlap period, we have compared (at every minute), the two estimated positions of the satellite. Using these minute by minute differences, as elementary "measurements, we have computed for each couple of consecutive days a daily RMS overlap (without, of course, substracting any mean value). This value gives us then a daily estimate of the orbit internal consistency (during the overlap period).

Figure 1 displays those daily orbit overlap RMS for the radial component of the Topex satellite during a five months period (January to June 1993). This figure clearly shows that the internal consistency of the radial component of the orbit is well within 2 cm. These results were obtained using the constrained network approach and the J7 coordinate data set, which combinaison, as we shall see later on, seems to give the better results.

Taking now these daily overlap RMS as a new statistical population, we can compute, for this new data set, the corresponding mean values and standard deviations over this 5-month period of time. Table 2 shows these more synthetic quality control estimations, using three different DORIS tracking stations data sets and different period of time:

- JCOD4 and JCOD5 correspond to different versions of the nominal IGN reference for the DORIS tracking stations (Fagard, 1993; Boucher et al, 1993a).

- J7 corresponds to our estimated coordinate data set obtained using only several months of DORIS data in a free network adjustment (in this case using 5 months of recent DORIS Topex/Poseïdon data).

For all these solutions, our results show an internal consistency of 2 cm or better (table 2). The best solutions is obtained with our J7 solution, showing internal consistency at the 1.7 cm level for the radial component.

Coordinate data set	Orbit overlap	
	Mean of daily RMS (cm)	Mean of daily Stddev (cm)
JCOD4 (Oct-Dec 1992)	1.88	0.74
JCOD5 (Oct-Dec 1992)	2.01	0.85
J7 (Oct-Dec 1992)	1.69	0.66
J7 (January-June 1993)	1.58	0.61

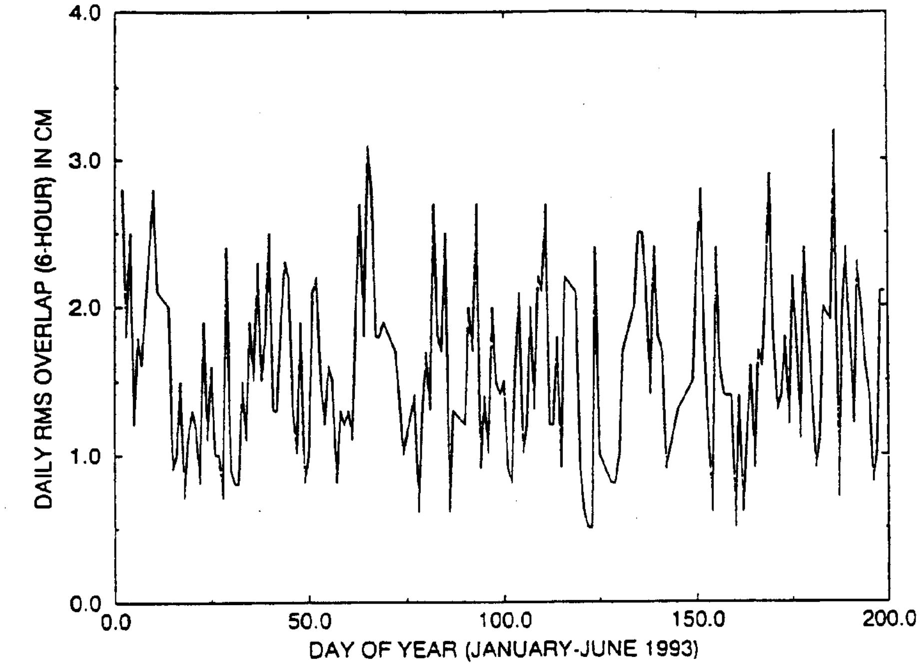
TABLE 2: DORIS Topex/Poseïdon orbit overlap comparisons

We can also see that these three coordinates data sets give rather similar results, showing that the major part of the orbital error may not still come anymore from errors in the tracking stations coordinates. It should also be stressed again, that in such tests, reference frame errors (significant 7-parameters transformation with regards to ITRS) would never be seen.

We have focused our discussion on the radial component only of the satellite position, because this

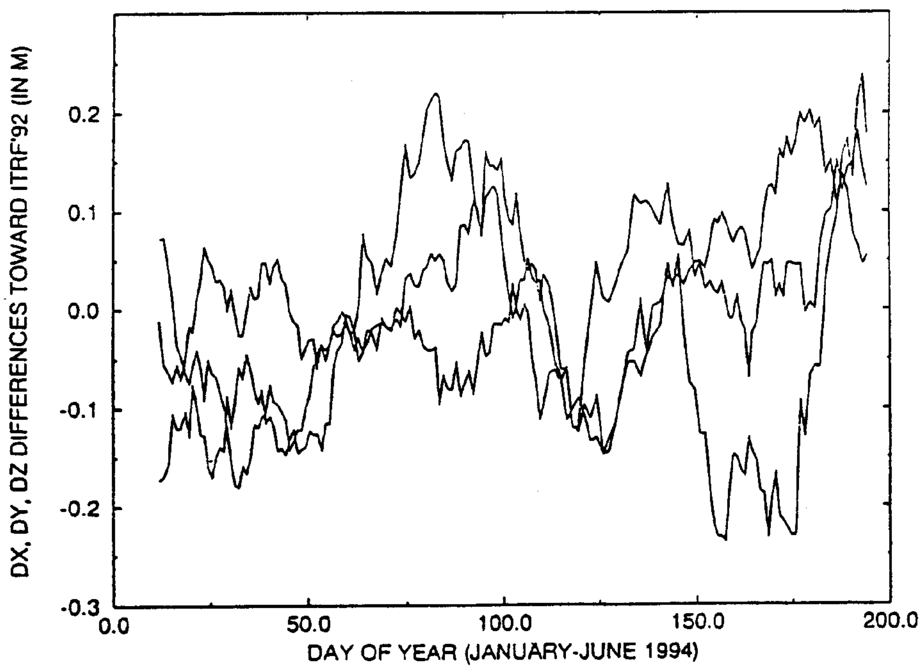
DORIS/TOPEX PRECISE ORBIT DETERMINATION

FIGURE 1: DAILY RMS OVERLAP (J7 CONSTRAINED)



DORIS/TOPEX RELATIVE POSITIONING: TOULOUSE-YELLOWKNIFE (6600 KM)

FIGURE 2: 10-DAY RUNNING AVERAGE SOLUTIONS



is the critical orbit result for the oceanographers. Any error in this component would affect directly the altimetric information, and would then disturb or bias their geophysical investigations.

At this stage, we should not be too hasty and confuse these preliminary results of 1.7 cm (radial RMS) with an estimation of orbit accuracy, as several systematic errors may still remain undetected by such statistical tests (gravity field errors, reference frame realization).

ORBIT COMPARISONS

Another important test is to really try to assess the accuracy of our DORIS orbit by comparing to the precise orbits, delivered to the scientific community by the Topex/Poseïdon Project. These precise orbits are computed by two different scientific groups: the CNES in France and the NASA/GSFC group in the US. Both precise orbits are now computed using simultaneously the data of the two nominal tracking systems (DORIS and SLR). Thhose two orbits are distributed by cycle (about 10 days) to the Topex/Poseïdon scientific community.

In a first step, we have combined daily orbit solutions using the strategy described above for the constrained network approach (using J7 as a priori coordinate data set for the tracking stations coordinates).

In a second step, we have combine our daily solutions using a sine-cosine smoothing, to create 10-day orbits in the so-called POE format.

We have then compared these 10-day orbits with the NASA/GSFC orbit taken as reference. These comparisons were jointly performed in the inertial true of date reference frame (table 3) and in the earth fixed reference frame (table 4). RMS differences were computed for 6 cycles separately (spanning basically from january to march 1993).

Cycle	RMS Differences		
T/P	Radial (cm)	Along-Track (cm)	Cross-Track (cm)
11	2.5	15.2	10.3
12	2.2	8.6	11.8
13	1.8	10.9	11.7
14	2.0	11.3	14.1
15	1.9	10.8	13.4
16	1.9	8.0	15.2

TABLE 3: SLR/DORIS NASA/GSFC orbit comparisons with the DORIS IGN/JPL solution (in orbital frame)

Table 3 presents the agreement between the NASA/GSFC DORIS/SLR orbit (taken as reference) and our DORIS orbit for the radial, along-track and cross-track component. This table shows that our difference is also around 2 cm (in the RMS sense). The differences between those two different orbi: over 6 Topex cycles scatter between 1.8 cm and 2.5 cm.

This is a better test for orbit accuracy, because in this specific test: the data are somehow different (DORIS vs DORIS/SLR), the software are different (even if the mathematical models are close) and the processing strategies are also slightly different.

The other two orbital components stay around 10 cm, which is also encouraging result, as we have not used exactlly the same tracking stations coordinates. So, part of these 10 cm discrepancies may well still come from terrestrial reference frame inconsistency (or similarly from Earth rotation parameters) between the two groups.

Topex/Poseïdon Cycle	X (cm)	Y (cm)	Z (cm)
11	0.6	0.0	-1.0
12	0.1	-0.3	0.5
13	-0.2	-0.3	0.9
14	0.0	-0.2	0.1
15	-0.2	-0.1	0.0
16	-0.2	0.2	0.2

TABLE 4: Mean coordinates differences between the SLR/DORIS NASA/GSFC orbit and the DORIS IGN/JPL solution (Earth fixed)

When looking at these orbits differences in the pseudo-Earth fixed X, Y, Z coordinates (table 4), no actual systematic data can be found. The mean offset between our DORIS dynamical orbit and the NASA/GSFC orbit is at the sub-centimetric level in all three components (maximum of 1.0 cm for cycle 11).

CROSSOVER ANALYSIS

We could also try to estimate the quality of our DORIS by doing crossover analysis. In this kind of test, the radar atimetric data are used. The principle is rather simple: we compare the sea surface height at some specific points obtained at different epoch. The sea surface height is easily derived from the satellite altitude (orbit) and the altimetric measurement.

In fact, as these comparisons are not considered at the same epoch, we need to properly model the sea surface height variations due to ocean and solid tides during this time span (typically several days). Remaining errors will also come from changes in ocean currents, local or temporal sea height variability and modelling errors in tidal models.

Table 5 gives crossover comparisons derived from the Topex/Poseïdon US altimeter data. In this table, we show comparisons obtained with different types of orbits. CNES and NASA correspond to the nominal T/P orbits delivered by the project to the scientific community (Nouel et al, 1993c). IGN/JPL orbits correspond to our own solutions obtained using three different coordinates data sets for the DORIS tracking stations: JCOD4, JCOD5 and J7, as described previously.

Analysis Center	Tracking Data	Points	Mean (cm)	RMS (cm)	Var. (cm^2)
CNES Precise Ephemerides	DORIS+SLR	12384	1.42	9.71	92.32
NASA Precise Ephemerides	DORIS+SLR	12384	0.72	9.69	93.36
IGN/JPL (JCOD4)	DORIS	12384	0.33	9.56	91.33
IGN/JPL (JCOD5)	DORIS	12384	0.19	9.54	90.99
IGN/JPL (J7)	DORIS	12384	0.25	9.56	91.43

TABLE 5 : Topex/Poseïdon Altimeter Crossover Statistics (cycle 2 to 6)

In this table, the number of points correspond to the actual number of crossovers taken into account in this analysis. It is exactly the same for all the orbits because we have preselected only the common points. It is extremely important that such intercomparisons tests be performed using the same statistical processing and the same croosover populations (exact same time). A prefit editing has been done, based on geophysical, instrumental and environment parameters (but not the orbit fit). In this study, no geographical editing was done (Bertiger at al, 1993b).

We would like to point out first that the reader should be very careful in interpreting these results because most of the errors may still come from ocean height variations and/or oceanographic mismodelled effects (Bertiger et al, 1993b).

However, our results yield somehow lower residuals, the difference being small but visible. This effect is seen specially in the mean value and therefore in the total RMS evaluation.

From table 5, it is reasonnable to conclude that our DORIS orbits are at least at the same level accuracy (or slightly better) as the CNES or the NASA/GSFC precise orbits delivered by the project.

This is particularly interesting because, in our case, no SLR data was actually used, showing the potentiality of the DORIS system by its own. From our point of view, this is due to quality of the DORIS Doppler measurements but also to the almost continuous tracking of the satellite and the quality of the reference coordinates of the DORIS network.

The second interesting aspect is that the choice of the coordinates data set does not influence much the output of this test. To us, this means that the quality of the DORIS tracking stations coordinates is probably not anymore a major source of error for precise orbit determination. Another possibility is that the orbit quality of all these orbits is too good to be put in default by such a basic crossover testing technique. It must also be noted that, for obvious reasons, a possible reference frame misalignement would not be visible at all in such crossover analysis.

DORIS GLOBAL POSITIONING

Another important application of the DORIS system is the possibility to perform precise absolute positioning.

For this purpose, daily free network solutions were obtained using all the available Topex/Poseïdon DORIS data (24-hour data span). In this type of computation, both the orbit and the station coordinates are estimated simultaneously in a dynamic orbit adjustment.

These daily stations coordinates solutions were then combined using their full variance matrices in a mathematically correct adjustment. Combined solutions were then obtained on a monthly basis (or multi-months basis).

In order to check of the quality of our DORIS positioning, we have first compared them (see table 6) to the newly available ITRF'92 reference frame computed at IGN by the IERS central Bureau (Boucher et al, 1993c).

Table 6 displays the estimation of a 7-parameter tranformation between the ITRF'92 and several of our DORIS free network solutions. These parameters were well determined, in terms of a posteriori standard deviation: 1.4 cm (resp. 0.7 cm) in translation for monthly solutions (resp. 5-months solution), 2 10^{-9} (resp. 10^{-9}) for the scale factor and 0.4 mas (resp. 0.2 mas) for the rotations.

In these solutions, few DORIS data were available in March for the Ottawa station, which was then worsly determined (only 6 passes available in March for all this 5 months period). This station was then disregarded in a this analysis to test really the DORIS capability in "regular" conditions of utilization.

From table 6, we can also see that the agreement, over the 16 IERS stations in collocation between the IERS and the DORIS network, is around 5 cm for a DORIS monthly solution (in 3-D weighted RMS) and at the 2.1 cm level for a 5-month DORIS solution

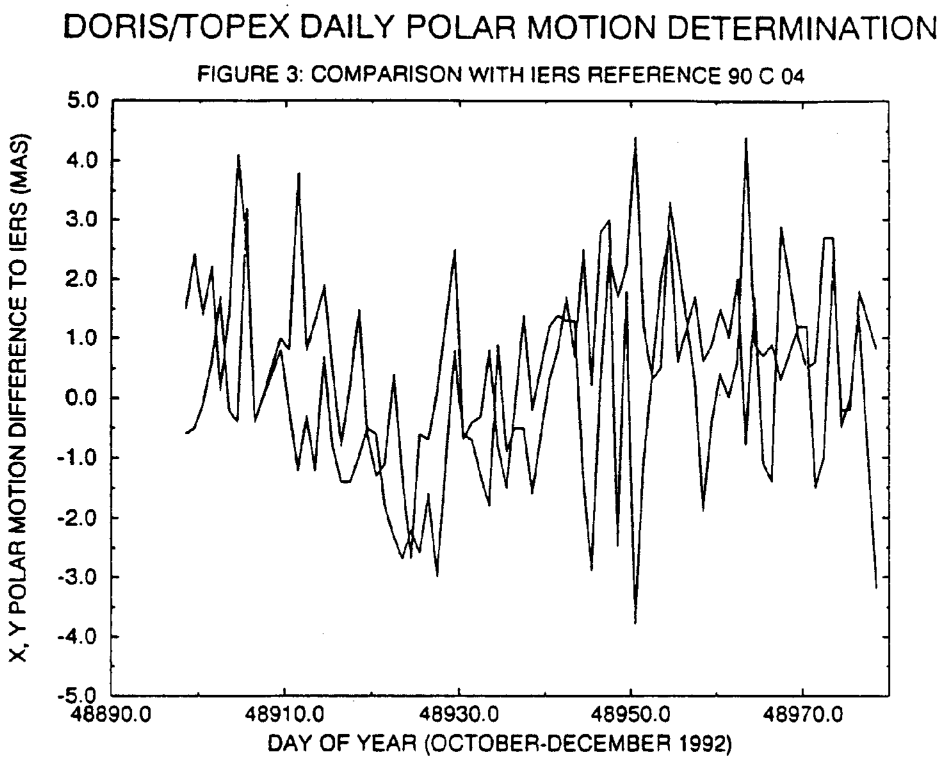


TABLE 6 : Comparisons between several T/P solutions and ITRF'92

T/P DORIS solution	Common Points	Transformation Parameters (from DORIS to the ITRF'92)				Weighted 3-D RMS
		Tx (cm)	Ty (cm)	Tz (cm)	D 10^{-8}	(cm)
January 1993	16	1.3 ±1.4	-0.1 ±1.3	-7.2 ±1.4	0.19 ±0.21	4.5
February 1993	16	5.4 ±1.8	1.9 ±1.7	-8.9 ±1.8	0.11 ±0.27	5.9
March 1993	16	2.0 ±1.5	1.9 ±1.4	2.5 ±1.5	0.48 ±0.22	4.8
April 1993	16	2.9 ±1.5	0.6 ±1.4	9.0 ±1.5	0.48 ±0.23	4.9
May 1993	16	4.8 ±1.2	0.2 ±1.2	5.6 ±1.3	0.05 ±0.19	4.1
January to May 1993	16	3.3 ±0.7	1.2 ±0.6	0.0 ±0.7	0.29 ±0.10	2.1

(including only Topex/Poseïdon data). This can be taken as a rather good agreement, because this error comes from our DORIS solutions but also from incertainty in local ties and also, at a lower level, to errors in the ITRF92.

These results show that the agreement with the ITRF'92 is almost two times better with a DORIS 5-month solution (by comparison with monthly solutions). This means that most of the discrepancies found in the monthly solutions do not come mainly from systematic biases. In fact, in those single satellite DORIS solutions, very few data are available for each stations (few passes per day) by comparisons to techniques such as GPS. This means also that DORIS multisatellites solutions may well provide the same type of accuracy (around 2 cm) but within a short period of observation.

Extensive comparisons, were also done at IGN (Boucher et al, 1993b) by comparing the IERS Terrestrial Reference Frame reference to several DORIS solutions obtained by all scientific groups studying the DORIS data: University of Texas (Watkins et al, 1992), GRGS/Toulouse (Cazenave et al, 1992; Soudarin et al, 1992).

DORIS RAPID POSITIONING

For test purposes, we have also tried to determine the potentiality of DORIS rapid positioning using only days of DORIS data.

Figure 2 shows the repeatability of DORIS free network solutions obtained using a 10-day running average. These results are shown as relative positioning for an intercontinental baseline (Toulouse-Yellowknife) of about 6,600 km.

Table 7 gives the repetability and the difference toward the IERS refernce. These rapid DORIS positioning solutions, using only Topex/Poseïdon data, already achieve an 8 to 13 cm repeatability in all components, equivalent to a 1.5 10^{-8} repeatability over an intercontinental baseline.

	X	Y	Z
Mean (cm)	-3.5	0.1	1.1
Stdev (cm)	12.6	7.8	7.4

TABLE 7 : DORIS Topex/Poseïdon baseline repeatability (Toulouse-Yellowknife 6600 km) using 10-day running free network solutions (January to June 1993)

Even more rapid solutions (e.g. daily solutions) could be obtained (Willis et al, 1993c), but in this case, taking into account the small amount of DORIS satellite available by station in one day, multi-satellites may again be of great interest. This type of combined adjustment presently under investigation. As they are presently three DORIS satellite in activity, this study presents a important interest.

DORIS ERP ESTIMATIONS

As a preliminary test, a first serie of Earth Rotation Parameters were estimated from the Topex/Poseïdon DORIS data using the GIPSY/OASIS II sofware.

These computations were very similar to the precise orbit determination runs (using the constrained network approach and the J7 coordinate data set as a priori for the tracking stations coordinates). The only difference in processing was that we simultaneously adjusted polar motion and UT1-UTC rate (with large a priori errors).

Daily solutions, centered at noon were obtained using 30-hour of DORIS data. A first 3-month period was analysed (October 1992 to December 1992) by the IERS Central Bureau.

Figure 3 displays the difference in Polar Motion (X and Y-component) between our DORIS Topex/Poseïdon solution and the IERS reference (90 C 04 serie).

	Bias (mas)	RMS (mas)
X-comp.	-1.1 ± 0.2	1.6
Y-comp.	-2.1 ± 0.4	2.3

TABLE 8: DORIS T/P daily Polar Motion Determination (by comparison to the IERS 90 C 04 reference)

Table 8 shows, for each Polar Motion component, the bias found with the IERS serie and the RMS. A small bias was estimated of 1-2 mas, meaning that the terrestrial reference system used can be considered as aligned with the IERS (within the actual uncertainties).

Table 8 also shows an excellent agreement between the DORIS polar motion serie and the IERS reference (1.6 and 2.3 mas for X and Y polar motion). Further investigation are obviously needed to ascertain these results on more than 3-months of data, but are already a real improvement on previous determination by other authors in the past. As already discussed, most of these discrepancies should decrease when using DORIS multisatellites solutions.

DISCUSSION AND CONCLUSIONS

As it has been shown in this paper, DORIS is an excellent geodetic tool for precise orbit determination or for point positioning.

Orbits obtained in the case of the Topex/Poseïdon mission, using the DORIS data alone show daily repeatabilities better than 1.7 cm (radial RMS). They also compare well with the NASA/GSFC SLR/DORIS precise orbits at the 2 to 3 cm level.

Precise point positioning showed agreement with the ITRF'92 solution at the 2.1 cm level for a 5-month solution (using only Topex/Poseïdon DORIS data). Further investigation should now be done to obtain annual or plurial annual DORIS solutions, but also DORIS multi-satellite point positioning.

Monthly DORIS free network solutions provide a 5 cm accuracy (with regards to the ITRF'92). More rapid DORIS point positioning can also be obtained (8-10 cm repeatability over a 6600 km baseline) for a 10-day observation period.

Polar Motion were also estimated using the DORIS Topex/Poseïdon data. Daily solutions showed agreement at the 2 mas with the IERS reference.

DORIS is still a "recent" space geodetic system and new improvement on these results should be obtained in a near future.

REFERENCES

W. Bertiger, S.C. Wu, T. Yunck, R. Muellerschoen, P. Willis, Y. Bar-Sever, A. Davis, B. Haines, T. Munson, S. Lichten, R. Sunseri, Early results from the Topex/Poseïdon GPS precise orbit determination demonstration, AAS/AIAA Spaceflight Mechanics Meeting, Pasadena, USA, February 1993.

W.I. Bertiger, Y.E. Bar-Sever, E.J. Christensen, E.S. Davis, J.R. Guinn, B.J. Haines, R.W. Ibanez-Meier, J.R. Jee, S.M. Lichten, W.G. Melbourne, R.J. Muellerschoen, T.N. Munson, Y. Vigue, S.C. Wu, T.P. Yunck, B.E. Schutz, P.A.M. Abusali, H.J. Rim, N.M. Watkins, P. Willis, GPS Precise Tracking Of Topex/Poseïdon: Results and Implications, Journ. of Geophys. Res., Topex/Poseïdon, Special Issue, November 1993.

G. Blewitt, M. Heflin, W. Bertiger, F. Webb, U. Lindqwister, R. Malla, Global coordinates withn centimeter accuracy in the International Terrestrial Reference Frame using GPS, Geophys. Res. Lett., 19, 853-856, 1992.

C. Boucher, J.P. Dufour, P. Willis, The JCOD5 station coordinates solution of the DORIS network, Techn. Rep., Groupe de Recherche de Géodésie Spatiale, n° 11, June 1993

C. Boucher, J.P. Dufour, Etude de la qualité du positionnement DORIS par intercomparaisons et combinaisons globales, Journée Localisation DORIS du CNES, Toulouse, IGN CC/G n° 585, June 1993.

C. Boucher, Z. Altamimi, L. Duhem, ITRF'92 and its associated velocity field, IERS Techn. Note, 15, Paris Observatory, October 1993.

A. Cazenave, J.J. Valette, C. Boucher, Positioning results with DORIS on SPOT2 after a first year of mission, J. Geophys. Res., 97, 7109-7119, 1992.

P. Charlot, Earth Orientation, Reference Frames and Atmospheric Excitation functions submitted for the 1992 IERS Annual Report, VLBI, LLR, SLR and AAM, IERS Tech. Note, 14, Paris Observatory, October 1993.

H. Fagard, JCOD4: a combined Set of Coordinates for the DORIS Orbitography Network, IGN, March 1993.

M.H. Kaplan, Modern Spacescraft Dynamics and Control, John Wiley and Sons, 1976.

M. Lansmann, État du réseau d'orbitographie DORIS, IGN/SGN, CM-RP-968-IGN, 10th Ed., March 1993.

F. Lerch, R. Nerem, J. Marshall, B. Putney, E. Pavlis, S. Klosko, S. Luthcke, G. Patel, N. Pavlis, R. Williamson, J. Chan, B. Tapley, C. Shum, J. Ries, R. Eanes, M. Watkins, B. Schutz, Gravity model improvement for Topex/Poseïdon, EOS Tran. of AGU, 74, 16, 96, April 1993.

J.A. Marshall, S.B. Luthcke, P.G. Andtreasian, G.W. Rosborough, Modelling Radiation Forces Acting on Topex/Poseïfdon for Precise Orbit Determination, Journ. of Spacescraft and Rockets, 1992.

J.A. Marshall, S.B. Luthcke, P.G. Andreasian, G.W. Rosborough, Modeling radiation forces acting on Topex/Poseïdon for precision orbit determination, NASA Techn. Memo. 104564, June 1992.

W.G. Melbourne, B. Tapley, T. Yunck, The GPS flight experiment on Topex/Poseïdon, Geophys. Res. Lett., 1993.

R.S. Nerem, F.J. Lerch, J.A. Marshall, E.C. Pavlis, B.H. Putney, J.C. Chan, S.M. Klosko, S.B. Luthcke, G.B. Patel, N.K. Pavlis, R.G. Williamson, B.D. Tapley, R.J. Eanes, J.C. Ries, B.E. Schutz, C.K. Shum, M.M. Watkins, R.H. Rapp, R. Biancale, F. Nouel, Gravity model development for Topex/Poseïdon: Joint Gravity Model 1 and 2, submitted to Journ. of Geophys. Res., Topex/Poseïdon Special Issue, November 1993.

F. Nouel, J. Barding, C. Jayles, Y. Labrune, B. Truong, DORIS a precise satellite positioning Doppler system, Astrodynamics, 1987, 65, Adv. Astron. Sci., J.K. Solers et al (eds), 311-320, 1988.

F. Nouel, J.P. Berthias, P. Broca, M. Deleuze, A. Guitart, P. Laudet, C. Pierret, A. Piuzzi, C. Valorge, Precise Orbit Determination of the SPOT platform with DORIS, AAS/AIAA, Astronomics Specialist Conference, Colorado, USA, 1991.

F. Nouel, J.P. Berthias, M. Deleuze, A. Guitart, P. Laudet, A. Piuzzi, D. Pradines, C. Valorge, C. Dejoie, M.F. Susini, D. Taburiau, Precise CNES orbits for Topex/Poseïdon, submitted to Journ. of Geophys. Res., Topex/Poseïdon Special Issue, November, 1993.

L. Soudarin, A. Cazenave, Global Geodesy using DORIS data, Geophys. Res. Lett., 1992.

B. Tapley, J.C. Ries, G.W. Davis, R.J. Eanes, C.K. Shum, M. Watkins, A. Marshall, R.S. Nerem, B.H. Putney, S.M. Klosko, S.B. Luthcke, D. Pavlis, R.G. Williamson, N.P. Zelenski, Precision orbit determination for Topex/Poseïdon, submitted to Journ. of Geophys. Res., Topex/Poseïdon Special Issue, November, 1993.

M. Watkins, J.C. Ries, G.W. Davis, Absolute positioning using DORIS tracking of SPOT2 satellite, Geophys. Res. Lett., 19, 2039-2042, 1992.

P. Willis, C. Boucher, J.P. Dufour, Intercomparaisons GPS et DORIS dans le cadre de la mission océanographique TOPEX/POSEÏDON, Résultats préliminaires, Journée de la recherche de l'IGN, IGN CC/G n° 586, March 1993.

P. Willis, W. Bertiger, recent DORIS data processing results using the GIPSY-OASIS II software, JPL Interoffice Memorandum, 335.8-93-005, April 1993.

P. Willis, W. Bertiger, B. Haines, R. Muellerschoen, T. Yunck, C. Boucher, J.P. Dufour, H. Fagard, Processing DORIS data with the GIPSY/OASIS II software for Precise Point Positioning and Orbit Determination: First results and Intercomparaisons, XXth IAG General Meeting, Beijing, China, August 1993.

S.C. Wu, Y. Bar-Sever, S. Bassiri, W.I. Bertiger, G.A. Hajj, S.M. Lichten, R.P. Malla, B.K. Trinkle, J.T. Wu, Topex/Poseïdon Projet, Global Positioning System (GPS) Precision Orbit Determination (POD) Software Design, JPL D-7275, March 1990.

T.P. Yunck, S.C. Wu, J.T. Wu, C.L. Thornton, Precise Tracking of Remote Sensing Satellites withe the Global Positioning System, IEEE Trans. Geoscience and Remote Sensing, 28, 1, 108-116, January, 1990.

T. Yunck, W.I. Bertiger, S.C. Wu, Y. Bar-Sever, E.J. Christiansen, B.J. Haines, S.M. Lichten, R.J. Muellerschoen, Y. Vigue, P. Willis, First Assessment of GPS-Based reduced dynamic orbit determination on Topex/Poseïdon, Geophys. Res. Lett., 1993.