MONITORING GEOCENTER AND SCALE VARIATIONS USING DORIS DATA: MONTHLY AND WEEKLY COMPARISONS TOWARD ITRF REFERENCES

Pascal WILLIS, Patrick SILLARD, Institut Géographique National, ENSG/LAREG, Cité Descartes, 6-8, Avenue Blaise Pascal, 77455 Marne-la-Vallée, France

INTRODUCTION

Since 1992, the Institut Géographique National is using the GIPSY/OASIS II software, developped by the Jet Propulsion Laboratory, for DORIS data processing [Willis et al, 1994]. Main applications are precise geodetic positioning for the stations of the ground tracking network, precise orbit determination (Topex/Poseïdon) and also polar motion monitoring in the scope of the International Earth Rotation Service (IERS) [Willis 1996a; Willis 1997].

Within the Geocenter campaign organized by the IERS, IGN has derived monthly and weekly coordinates data sets from DORIS data analysis than can be used to estimate possible variationsin location of the geocenter. Several authors [Stolz 1976; Dong 1997] have shown, than due to geophysical changes in the geographical distribution of the Earth masses, the Earth center of mass should have some small variations mostly at an annual period.

The goal of this paper is to present the results obtained at IGN during this IERS Geocenter campaign, both for geocenter variations and also for scale factor variability.

DESCRIPTION OF THE DORIS DATA ANALYSIS

It must first be noted that the DORIS data are more inhomogeneous than for other space techniques, such as GPS or even SLR data. There is not a « DORIS constellation » of satellites as it exists for GPS. There are in fact several satellites carrying a DORIS receiver on-board, but the number of these satellites is changing in time, as described in the table below. There are then periods of time for which 3 DORISsatellites are available (March 1994 to September 1996) and other periods for which only one or two satellites are available. We should keep this in mind while analysizing the next results. It is not surprising that the results themselves will show some improvement during multisatellites period, as more data will be available for each DORIS tracking stations.

Period	DORIS satellites	Comments
April to June 1990	SPOT2	
January to March 1992	SPOT2	
January 1993 - February 1994	TOPEX	SPOT2 data existing but not yet available to IERS
March 1994 - September 1996	SPOT2+SPOT3+TOPEX	
October 1996 - December 1997	SPOT2+TOPEX	SPOT3 satellite lost in September 1996

Table 1: Description of the DORIS data analysed

For all the following DORIS processing, the GIPSY/OASIS II software, developped at JPL was used. One of its particularity is to use a filtering approach of the data, making it extremely easy to estimate stations coordinates in a so-called « free-network approach » [Heflin 1998]. In this case, all stations coordinates are estimated simultaneously with the orbital parameters and all the other parameters (Earth orientation parameters, tropospheric corrections, clock drifts offsets). In order to make the estimation problem non-singular, a priori standard deviation information are added to the filtering sequence for the stations coordinates parameters.

However, these a priori constraints are rather loose (typically 100 m for all three components). The terrestrial reference frame of the computations is then only loosely known. Daily computations are done for all DORIS satellites.

When two or more satellites are available, all data are processed in the same runs, making full profit of common parameters. This imposes that all common parameters have the same estimated value. This is true of course for external parameters such as the Earth orientation parameters (polar motion and UT1 - UTC rate). But this gives also additionnal constrained to parameters such as the tropospheric zenith delay. Even if the passes of the different satellites are not exactly simultaneous, this add some constraint between these parameters, as we impose a time-dependant constraint on this parameter due to the rather stable nature of the troposphere [Willis et al, 1998a].

In order to express the stations coordinates results in a well defined and well maintained in time reference frame, several steps are required, involving different processing techniques [Willis 1996; Dorie, 1997]:

- **combining** the daily DORIS coordinates data sets into weekly, monthly (or even longer period of time) using the full covariance matrix of the positions estimates.

- **projecting** the weekly (resp. monthly) global coordinates data sets solutions. This procedure project the full covariance matrix in a terrestrial reference frame for which the variance is minimum. It does not affect the coordinates of the stations themselves but only their estimated standard deviations, making them smaller (from about 10 m to a few mm), removing indetermination due to the fuzzy definition of the underlying terrestrial reference frame.

- **transforming** the obtained projected solutions in a unique terrestrial reference frame, realized by a global data set of stations coordinates and velocities used as reference, by estimating a 7-parameter transformation. It must be noted that the precision of the results is limited by two different sources of errors: the error coming from the DORIS estimation itself (limited by the number of DORIS measurement available, the DORIS data noise and the possible mismodelling errors in the DORIS measurements), but also from the reference itself which cannot be anymore considered as perfect at these level of precision.

It must also be noted that for this transformation, the reference solution has to be propagated in time to the mean epoch of the DORIS observations as all stations move towards one another due to geophysical considerations (plate tectonic). Any error in the velocity field of the reference solution will then propagate in the result of this transformation, making it difficult to differentiate between errors coming from the DORIS free-network solution itself (free of any terresrial reference farme error by construction) and errors coming from the reference.

The results of this last operation provides simultanesouly the coordinates (and its associated full-covariance matrix) and also the estimated 7-parameters of the transformation for which we will focus our discussion in this paper.

The 7 parameters correspond to:

- 3 **translations** (difference between the realized origin of the system that can be assimilated to the instantaneous center of mass of the Earth towards a conventional origin of the frame given in the reference),

- 1 **scale factor** (ratio between the realization of the meter value and its conventionnal value provided in the reference),

- 3 **rotations** (that are in a certain sense conventional) and which will not be discussed in this paper.

The first 4 parameters (translations and scale) have then a physical significance as they can provide information on possible physical variations of the geocenter (due to temporal changes in the Earth mass distribution) and also in the realization of the unit of length (meter) that is usually biaised by unmodelled effects such as propagation errors (ionospheric corrections).

The transformation operation also provides a estimate of the goodness of the fit: the root mean square (RMS) of the stations coordinates. Figure 1 shows the evolution in time of this statistical estimator.

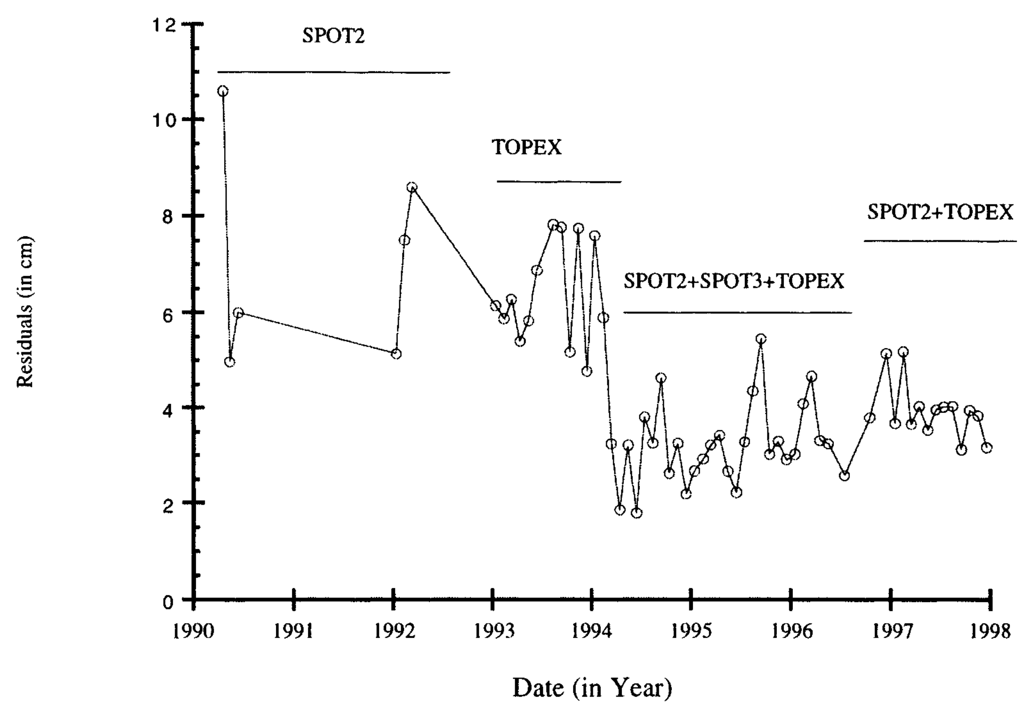

Figure 1: Monthly DORIS stations coordinates residuals (towards DORIS/IGN reference IGN98D01)

In this comparison, we have used our own DORIS-derived solutions transformed in rotation only to be expressed in the ITRF96 reference frame (IGN98D01 DORIS solution presently submitted to the IERS Central Bureau for the ITRF97 realization).

Several important results can already be obtained from this single plot. First of all, the number of available satellite clearly improves the consistency of the results. The first months before March 1994 corresponding to only one satellite (SPOT2 and then TOPEX/POSEÏDON) are effectively not as well consistent with the reference as the period corresponding to the 3-satellite period (March 1994 - August 1996, see table 1). On the other hand, the period after August 1996 corresponding to a dual satellite mode after the loss of the SPOT3 satellite can be considered as an in-between result between those two extremes.

In figure 1, we can also see a degradation in time during the 3 satellite period. This is certainly due to possible errors (or imprecisions due to the lack of long-term DORIS data history for some tracking station) in the DORIS velocities given in the reference. As this reference was established using all the DORIS data set available, the best coordinates can be obtained for the mean observation time of the stations. Before 1990 and after 1996 (last epoch for which some DORIS data was included in the ITRF96 realization [Boucher et al, 1998]), the coordinates are

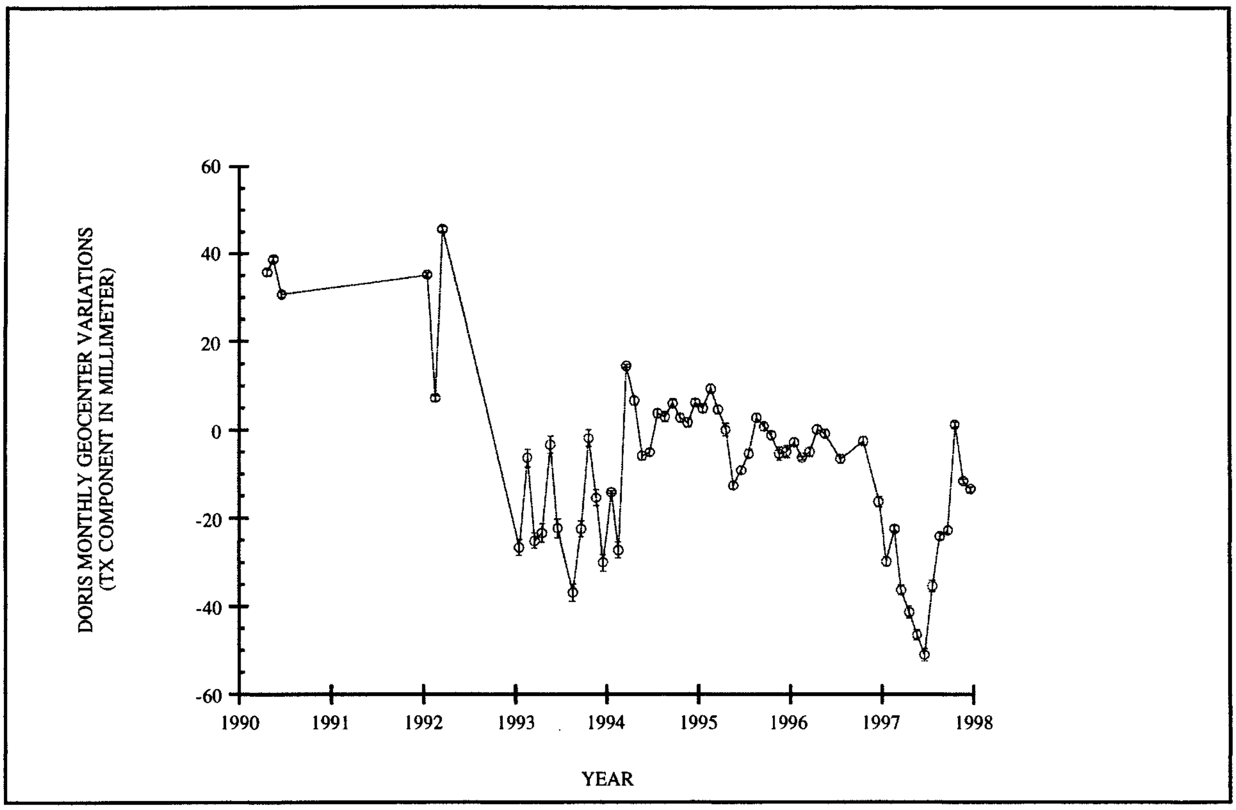

Figure 2: Monthly geocenter variations (TX component)

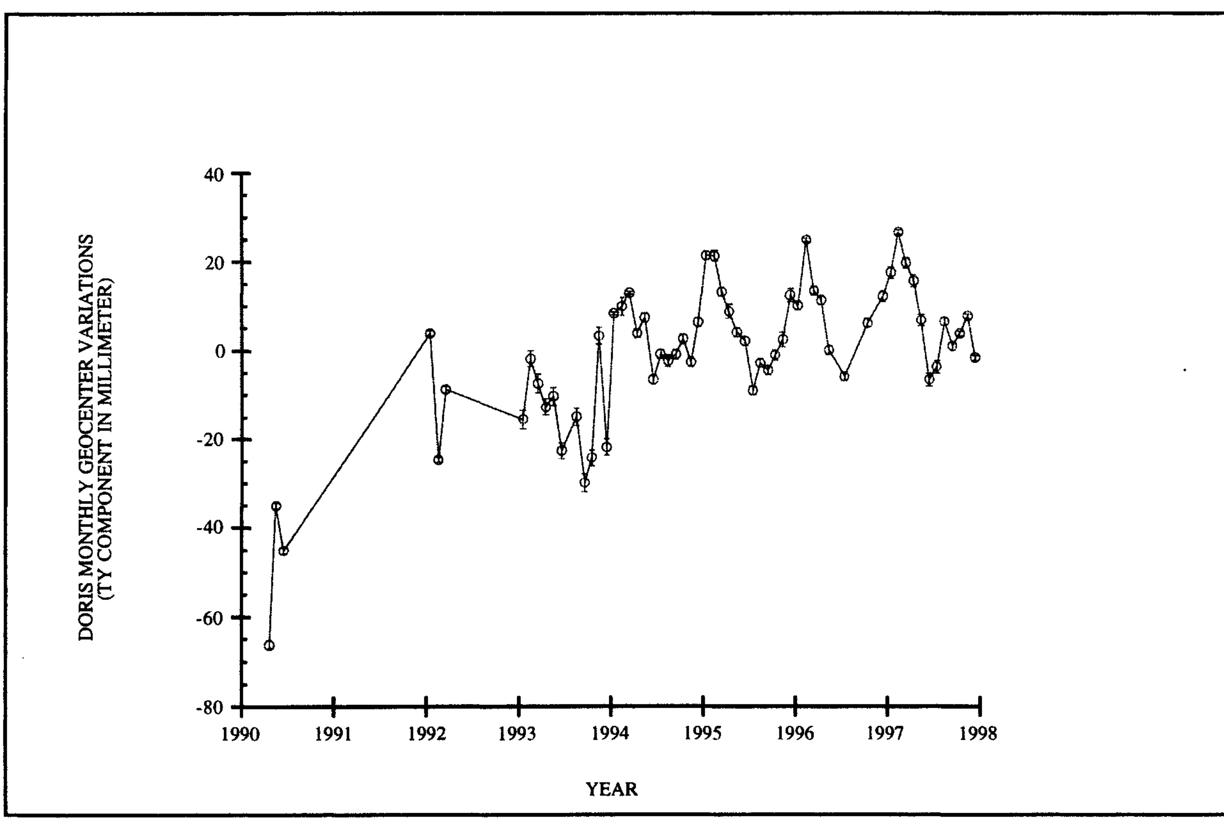

Figure 3: Monthly geocenter variations (TY component)

in fact extrapolated from the DORIS data and their accuracy is more and more affected by the reliability of the velocities given in the reference file.

The gaps that can be seen in this plots correspond to data that are not yet available to the DORIS/IERS analysis groups. In fact, these data exist and for technical reasons has not yet been formated and distributed to the IERS groups. In the future, it is expected to get a complete series of measurements that could then lead to a continuous time series from January 1990.

No bias in X,Y or Z are visible for these (internal) comparisons.

MONTHLY GEOCENTER VARIATIONS

In order to give possible intercomparisons with other space techniques within the IERS geocenter campaign, DORIS monthly solutions were obtained and compared toward and ITRF reference [Boucher et al, 1994; 1996; 1997; 1998] . In fact, all available DORIS/IERS data were processed and not only the data during the period selected for the IERS geocenter campaign.

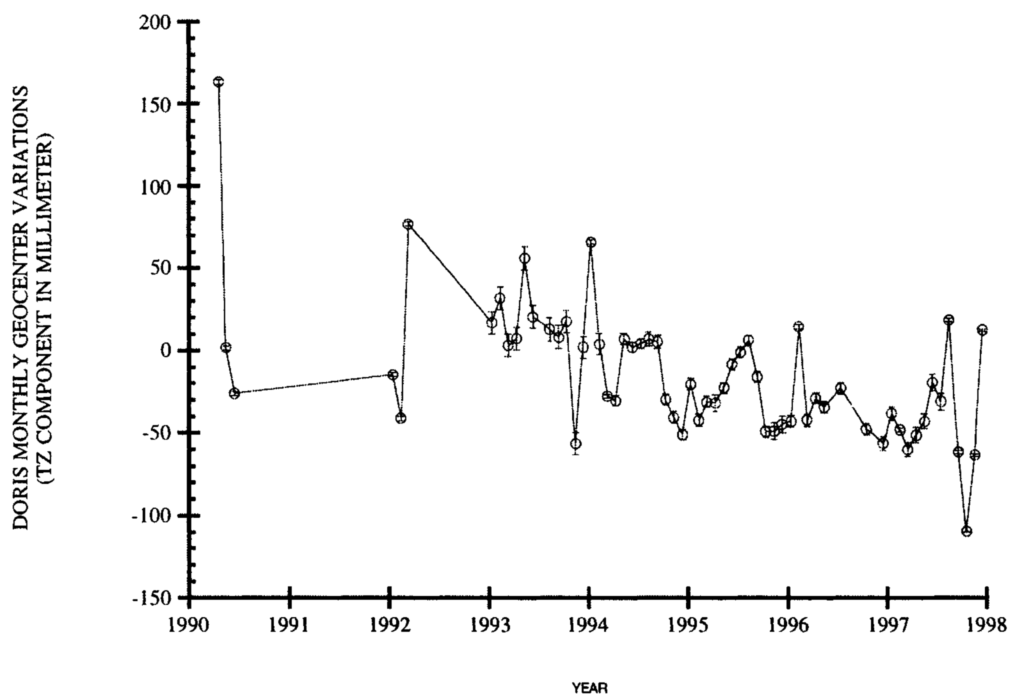

Figure 4: Monthly geocenter variations (TZ component)

Figure 2 to 4 shows results obtained for the geocenter variations in the 3 components X, Y and Z. In these plots, it is clear that systematic biases can be found between 1 and 3 satellites period. During the 3 satellite period, resulkts seem to be less noisy and appear to show an annual signal. Curiously, the Y component seem to show a drift also that is probably coming from the noisier 1990 SPOT2 data at the start of the observation period. The Z component show variations with a larger amplitude as it is often the case in satellite geodesy.

WEEKLY GEOCENTER VARIATIONS

As a test, we also derive weekly DORIS solutions for test purposes [Willis et al 1998]. To be compatible with the equivalent GPS weekly series derived from the IGS (International

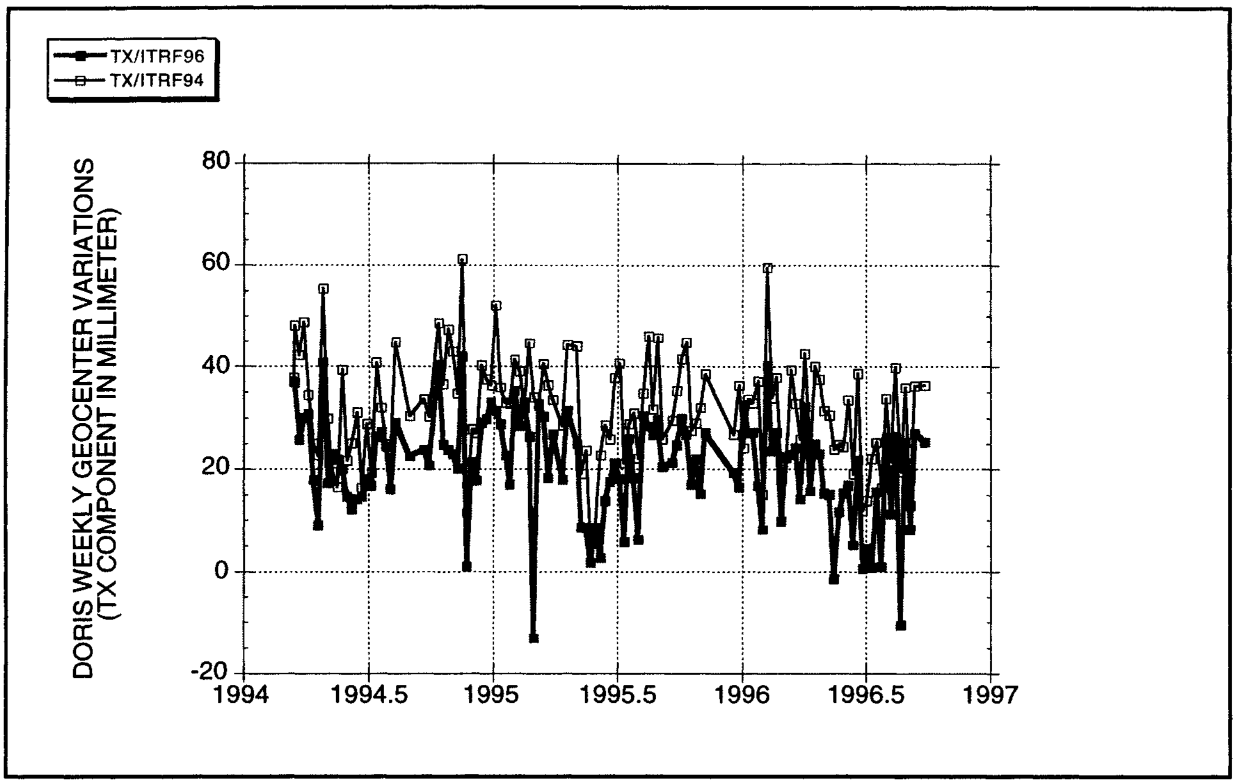

Figure 5: Weekly geocenter variations (TX component) compared to ITRF94 and ITRF96 references

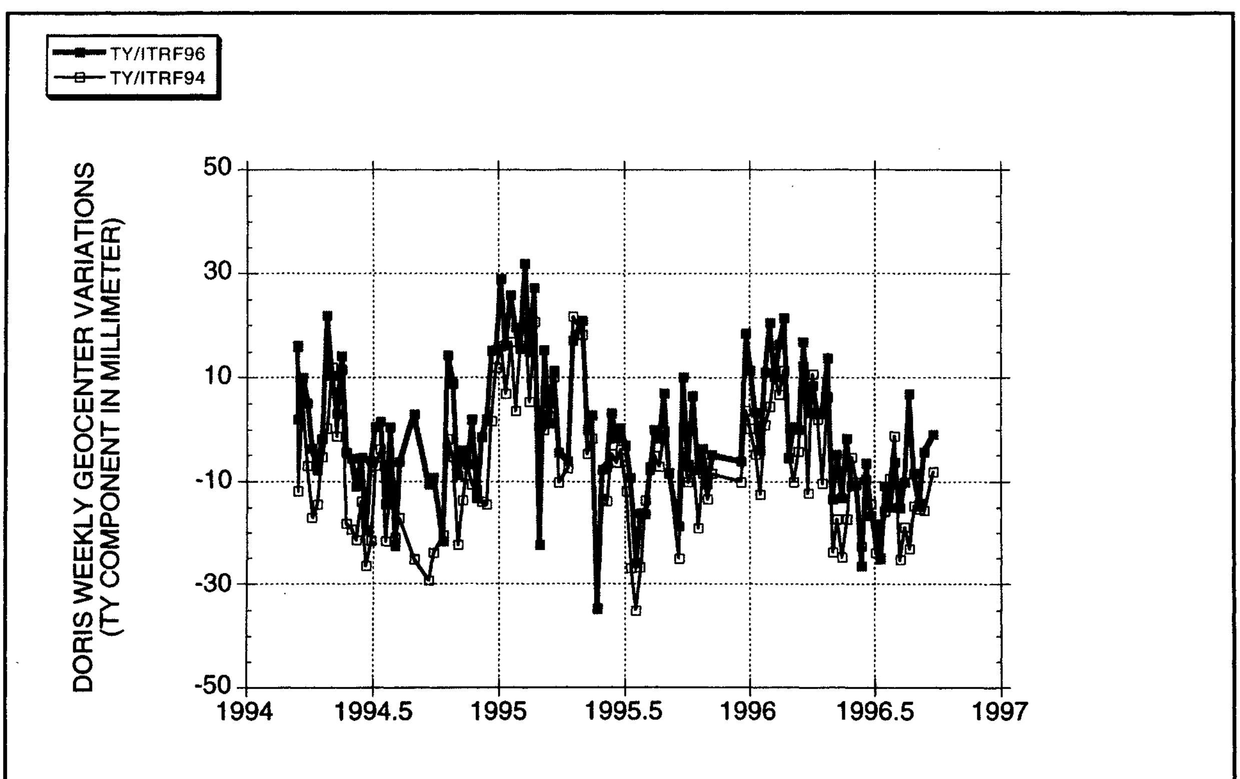

Figure 6: Weekly geocenter variations (TY component) compared to ITRF94 and ITRF96 references

GPS Service [Beutler et al, 1995]) groups, the week conventionnaly starts on a sunday and finishes on the following saturday. It is also expected that these weekly time series of DORIS derived coordinates could be used in the future, in combination with these already available IGS/GPS weekly time series to ITRF combinations.

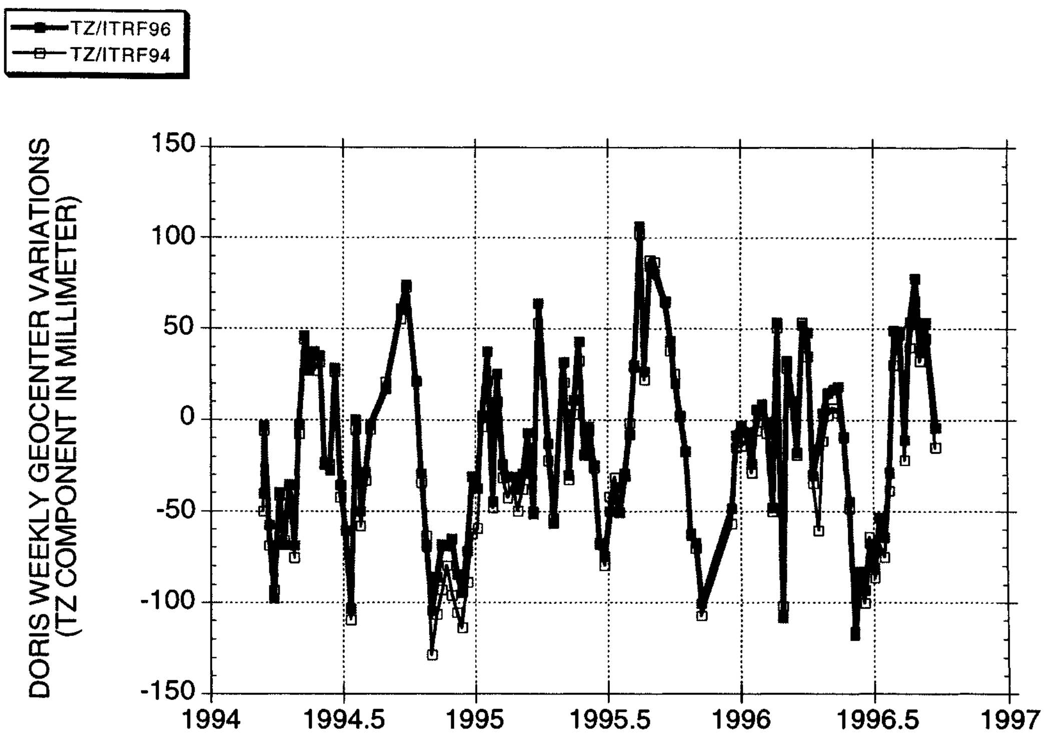

Figure 7: Weekly geocenter variations (TZ component) compared to ITRF94 and ITRF96 references

Figure 5 to 7 shows weekly geocenter variations determined with DORIS during the 3 satellite period. As it was also shown for monthly solutions, the Z-component is noisier than the other 2 component X and Y.

By opposition with the monthly comparisons for which we have compared our monthly results with our own DORIS-derived reference frame solution (IGN98D01), we have tried to compared our weekly solutions directly to the ITRF reference. In order to look for possible errors in the reference itself, we have done in fact these comparisons twice (toward the ITRF94 reference and towards the ITRF96 reference).

Figure 5 shows a possible systematic error in the X translation of about 2 to 3 cm (see also table 2). This bias is curently found in all our results and seem to come from a systemetic offset found in the UTCSR and IGN solutions (using 2 different software, GIPSY/OASIS and respectively UTOPIA). There is no detectable bias for the Y component and the Z component is too noisy to make any further investigation. No really convincing explanation has been found yet for this effect (larger than the estimated variations of the geocenter due to geophysical phenomenon).

From these plots an annual signal can be seen and is more visible in the Y component which is noisier. Howver the data span of observations seem really too limited to try to estimate a meaningful amplitude or even phase of this signal.

Table 2 summarizes the bias observed toward the ITRF94 and ITRF96 solutions. The standard deviation of the results among this mean is smaller for ITRF96 compared to ITRF94, showing that ITRF96 is more compatible with our new DORIS solution.

Reference	TX (bias) (in mm)	TX (standard deviation) (in mm)	TY (bias) (in mm)	TY (standard deviation) (in mm)	TZ (bias) (in mm)	TZ (standard deviation) (in mm)
ITRF94	31.9	10.4	-7.7	12.4	-22.1	50.3
ITRF96	20.4	10.3	-0.6	13.0	-15.8	49.0

Table 2: Weekly translations comparisons between DORIS solutions and different ITRF realizations (ITRF94 and ITRF96)

MONTHLY SCALE FACTOR VARIATIONS

The stability of the scale is also an important parameter that needs to be monitor as it is an estimator of the stability of realization of the unit of length (meter SI). Figure 8 shows the variations observed in the monthly scale using the DORIS data.

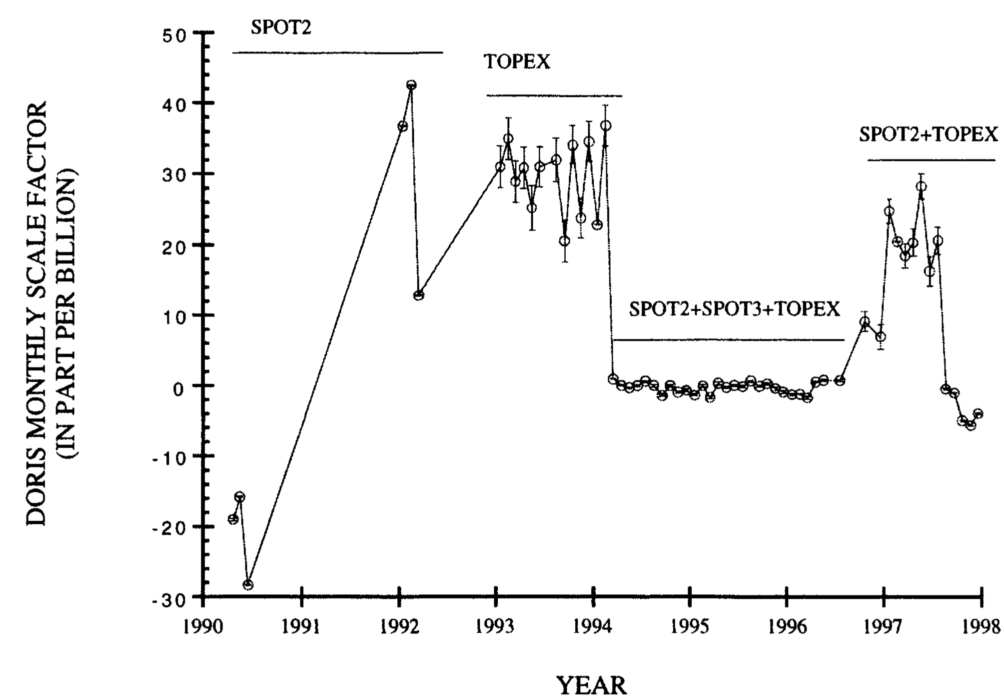

Figure 8: Monthly scale factor variations compared to ITRF94 and ITRF96 references

One more time, it is obvious from this plot that the number of available DORIS satellite is a critical issue to get precise scientific results from this system. It can be seen that with only one satellite, variations can be found at levels up to 40 ppb (part per billion), equivalent to a global heigth increase of all the stations of 24 cm! However, when 3 satellites are available, such as in the 1994-1996 period, variations are much less, up to 1 to 2 ppb, equivalent to 5 to 10 mm in heigth variations.

This plot shows also a clear anti- correlation with the TX monthly geocenter variations. This point is not completely well understood and is presently attributed to a possible error for one (or several) tracking stations coordinates. Further investigations are obviously needed to clarify and understand this effect often called « network effect ».

WEEKLY SCALE FACTOR VARIATIONS

The same study was aplied to the weekly solutions, but only in the 1994-1996 period for which 3 DORIS satellites are constantly available. It can be seen that variations are now extremely small (up to 4 ppb, equivalent to 2,4 cm in heigth).

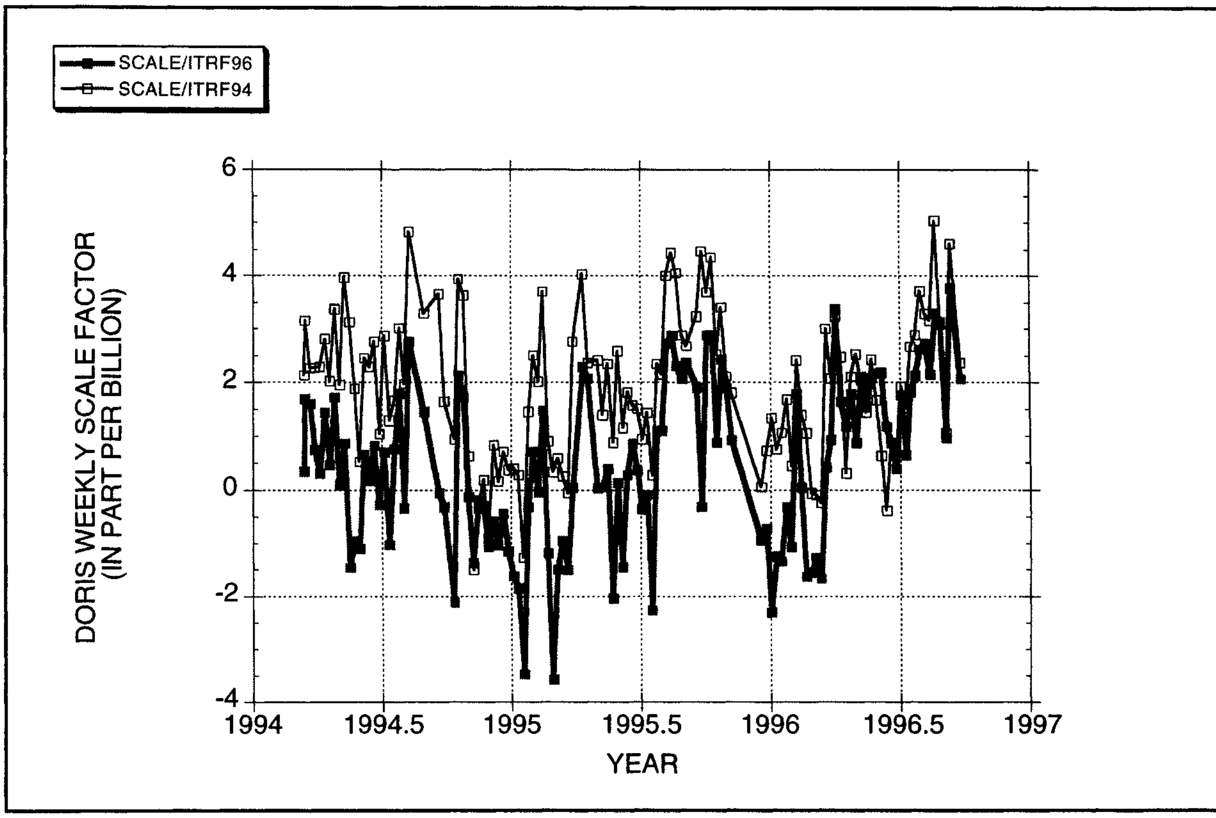

Figure 9 : Weekly scale factor variations compared to ITRF94 and ITRF96 references

To be consistent, we have compared this scale to the ITRF94 and also to the ITRF96 scale (which is supposed to be the same by construction). It can be seen that the two comparisons are very similar (by oppositions to the results found for the geocenter determination in this paper.

A annual signal is also visible. However, the data span seems to be too limited (less than two year) to estimate significant phase and amplitude parameter of the signal.

Reference .	Scale (bias) (in ppb)	Scale (standard deviation) (in ppb)
ITRF94	1.9	1.4
ITRF96	0.5	1.5

Table 3: Scale factor comparisons between DORIS solutions and different ITRF realizations (ITRF94 and ITRF96)

The scale is well aligned with the ITRF scale (it is even true for the latest ITRF96 realization) showing no systematic difference in time at the 1 ppb level of precision. Table 3 summarizes these results in term of systematic bias and standard deviation towards this mean.

IMPORTANCE OF GEOCENTER VARIATIONS AND SCALE FOR DORIS DATA PROCESSING

Main objectives of DORIS data processing are precise orbit computation and precise geodetic positioning of the tracking network.

In the case of precise orbit determination (for possible scientific uses in satellite altimetry, eg Topex/Poseïdon mission), an error in the origin of the frame or in the scale would propagate in the orbit parameters. This would create systematic errors for future oceanographic investigations. Presently, the variations shown in this paper seem to be small (few mm for the geocenter and a couple of part per billion for the scale)/ However, future altimetric mission, such as the JASON mission have a more drastic goal of 1-cm accuracy for the orbit determination. In this case, all the above errors should be taken into account by providing a realistic model which is one of the scientific goals of the IERS Geocenter campaign.

On the other hand, these variations affect also the geodetic positioning results. In the combination of the daily coordinate data sets results, it is assumed in the model that the origin is unique. This point is not true anymore if we assume that the roigin of the frame in the daily solution is related to the center of mass which have some seasonnal variations towards a conventionnal origin. It would then be important in the future to have access to a new model, correction this effect in the DORIS measurement, allowing to express naturally the daily coordinates results (reference frame realization) toward a convetionnal origin. However, as it is also shown in this paper, DORIS derived geocenter and scale variations show an annual signal but also show some other systematic effects that would not be corrected by such a model. Furthermore, it must also be proved that the variations seen using the DORIS system are coherent in amplitude and also in phase with the variations derived from other systems (SLR, GPS).

CONCLUSIONS

In conclusion, the DORIS system is able to provide useful information about possible variations of the geocenter. Results presented in this paper show that an annual signal can be visible in the DORIS results (monthly and weekly solutions). No semi-annual signal seems to be visible. However, when only one DORIS satellite was used, results are much more noisier showing the need for a real DORIS constellation of satellites (at least 3 or 4!). As several DORIS satellites should be launched in the next future (ENVISAT, JASON, SPOT5), it is then expected that these results will be confirmed and ameliorated soon.

On the other hand, the two IERS reference used in these tests (ITRF94 and ITRF96 realizations) show inconsistency at the 2-3 cm level for the X component of the origin. This result has been verified by other authors [Sillard 1998] and can probably be attributed to the lesser accuracy level of the ITRF94 solution, being the first ITRF realization to incorporate DORIS stations coordinates and velocities, the DORIS observation data span may not have been sufficient to obtain precise velocities estimates.

The periodic term of the geocenter variation is at the 1 cm level and then needs to be corrected in the future. Otherwise, DORIS results (monthly, weekly) would suffer from this mismodelling. This point is also true for global solution incoporating several months of DORIS solutions and should be treated with great care in the near future. It is exepected than the IERS Geocenter campaign will help to define a reference model, at least for the annual variations of the geocenter.

Stability of the scale factor derived from the DORIS solutions is around 1-2 ppb, equivalent to a global indetermination of the heigths of the DORIS tracking network of 5-10 mm. These variations can certainely be explained from mismodelling in the ionospheric (or tropospheric) correction. However, the differences towards the ITRF94 and ITRF96 realization are exteremely small are very much comparable with results obtained by otherspace techniques within the International Earth Rotation Service.

Even if these variations are extremely small (even smaller when more DORIS satellites are available), they need additionnal scientific investigation. As a matter of fact, such systematic errors in the scale factor would affect directly the estimated radial component of the orbit component. In the case of oceanographic mission (eg Topex/Poseïdon), this could then lead to noisier geodynamic data leading to less precise scientific products (mean sea level rise, ocean currents, tides,...).

REFERENCES

Beutler G., R. Neilan, I.I. Mueller, The International GPS Service for Geodynamics (IGS), the story, *Proceed. IAG Symp. 115, GPS Trends in Terrestrial, Airborne and Spaceborne applications*, Ed. Springer-Verlag, pp. 3-13, (1995)

Boucher C., Z. Altamimi, M. Feissel, and P. Sillard, Results and analysis of the ITRF94, *IERS Techn. Note n°20*, (1994).

Boucher C., and Z. Altamimi, International Terrestrial Reference Frame, *GPSWorld*, 7, 9, pp. 71-74 (1996).

Boucher C., Z. Altamimi, and P. Sillard, The ITRF96 realization of the International Terrestrial Reference System, *Proceed. of the IAG Scientific Assembly*, Rio de Janeiro, in press (1997).

Boucher C., Z. Altamimi, P. Sillard, Results and analysis of the ITRF96, *IERS Techn. Note n°24*, in press (1998).

Dong D., J.O. Dickey, Y. Chao, and M.K. Cheng, Geocenter variations caused by atmosphere, ocean and surface ground water, *Geophys. Res. Lett.*, 24, pp. 1867-1870 (1997).

Dorie, O., Recherche d'une procédure optimale pour transformer les coordonnées mensuelles DORIS dans un système de référence mondial maintenu de manière fiable dans le temps, Rapport de stage de DEA, Astronomie Fondamentale, Mécanique Celeste et Géodésie, Observatoire de Paris, IGN/LAREG MS6 (1997).

Heflin M., Pers. Comm., 1998.

Sillard P., Les variations du géocentre déterminées par DORIS et les autres techniques de géodésie spatiale, *Proceed. DORIS Day 1998 symposium*, Toulouse, France (1998).

Stolz A., Changes in the geocenter due to variations in sea level, *Bull. Geod.*, 50, pp. 159-168 (1976).

Willis P. and W. Bertiger, Processing DORIS data with the GIPSY/OASIS II software: Recent results for point positioning and orbit determination, *Proceed. of the Institute of Navigation*, National Technical meeting, Navigating the Earth and Beyond, San Diego, USA, pp. 615-624 (1994).

Willis P., Définition d'une procédure de tests visant à définir une procédure optimale pour obtenir des coordonnées DORIS mensuelles dans un système de référence maintenu de manière fiable dans le temps, IGN/LAREG SP3 (1996)

Willis P., Le système DORIS: Présentation rôle et recherches menées à l'IGN, *Revue Internationale de Géomatique*, 6, 2-3, pp. 289-304 (1996a).

Willis P. Applications scientifiques du système DORIS, *Revue XYZ*, 73, 4, pp. 67-74 (1997).

Willis P., and P. Sillard, Weekly DORIS solutions for stations coordinates: early results and perspectives, *Proceed. DORIS Day 1998 symposium*, Toulouse, France (1998).

Willis P., Y. Bar-Sever, E. Doerflinger, J. Zumberge, Using DORIS data for estimating the tropospheric delay, Implications on climatology and meteorology, *Proceed. DORIS Day 1998 symposium*, Toulouse, France (1998a).