GEOCENTER VARIATIONS DERIVED FROM 5 YEARS OF DATA OF THE DORIS SPACE SYSTEM. COMPARISON WITH SURFACE LOADING DATA

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ABSTRACT – The Earth centre of mass plays a crucial role as the origin of the terrestrial reference system. Because of surface mass redistribution, its position varies with respect to the centre of figure, the geocenter. Space techniques are now precise enough to allow geocenter motion determination. Here we present estimates of geocenter coordinate time series over five complete years (1993-1997) from DORIS data on SPOT2, SPOT3 and TOPEX/POSEIDON. Amplitude and phase of the DORIS-derived annual cycle for each geocenter coordinate have been compared to surface mass redistribution at the Earth surface estimated from different geophysical sources.

INTRODUCTION

The DORIS space system has been developed in France in the early 90s to become the nominal tracking system of the TOPEX/POSEIDON altimeter satellite launched in 1992. Prior to TOPEX/POSEIDON, DORIS had been placed on board the remote sensing satellite SPOT2 for a test mission of 6 months. SPOT2 was launched in January 1990. Nearly 8 years later, the DORIS instrument on board SPOT2 is still operationally functioning. DORIS was also onboard the SPOT3 satellite which worked from September 1993 until November 1996. The Groupe de Recherche de Géodesie Spatiale (GRGS) is currently involved in DORIS data analysis on the three satellites SPOT2, SPOT3 and TOPEX/POSEIDON for the determination of 3-D absolute coordinates and velocities of the permanent DORIS network station.The analysis is based on the GRGS's GINS/DYNAMO software developed for precise orbitography and geopotential modeling. There are now 52 permanent DORIS stations in operation throughout the world. Some of them are collocated with GPS, VLBI and SLR stations. Recently, we have attempted to determine the motion of the geocenter. In fact, analyses of satellite tracking data have provided persuasive evidence that the reference frame formed by the tracking stations attached to the Earth's crust moves relative to the Earth's centre of mass. This translation motion, when viewed from a crust-fixed reference frame, is known as « geocenter motion » and is caused by the mass redistribution of the fluid enveloppes, primarily the atmosphere, oceans and continental ground waters. Here, we present time series of the three geocenter components derived from DORIS as well as a comparison with the contributions estimated from variations in atmospheric surface pressure, ocean, land water storage and snow/ice cover.

GEOCENTER VARIATIONS FROM DORIS

The analysis of DORIS data on SPOT2, SPOT3 and TOPEX/POSEIDON has been performed over 5 complete years (January 1993 to December 1997). The approach is a geometrical one, consisting of computing the translation parameters of an Helmert transformation between successive monthly coordinate solutions of the global DORIS network and a multi-year reference solution. The DORIS station coordinates define the reference system and its centre is the centre of figure whose position from one month to

another varies. These variations measured relative to an empirically defined reference position, are interpreted as the geocenter motions.
To determine the geocenter coordinates, a reference solution over the 5 years has been computed as well as monthly coordinate solutions. The method of analysis used to obtain the coordinate solutions is detailed in Cretaux et al. (1998). Differences between each monthly solution and the 5-year solution have been minimized through a least squares process by adjusting classical translation, rotation and a scale factor parameters. Time variations of the translation parameters are interpreted as the geocenter motion during 1993-1997 relative to a mean position over that period. Fig.1 shows the time evolution of the 3 geocenter coordinates (units are in millimeter) with an annual cycle adjusted for each component. The X and Y coordinates show a clear seasonal signal. Annual amplitudes are 4.59 mm, 4.06 mm and 3.93 mm for X, Y and Z components respectively.

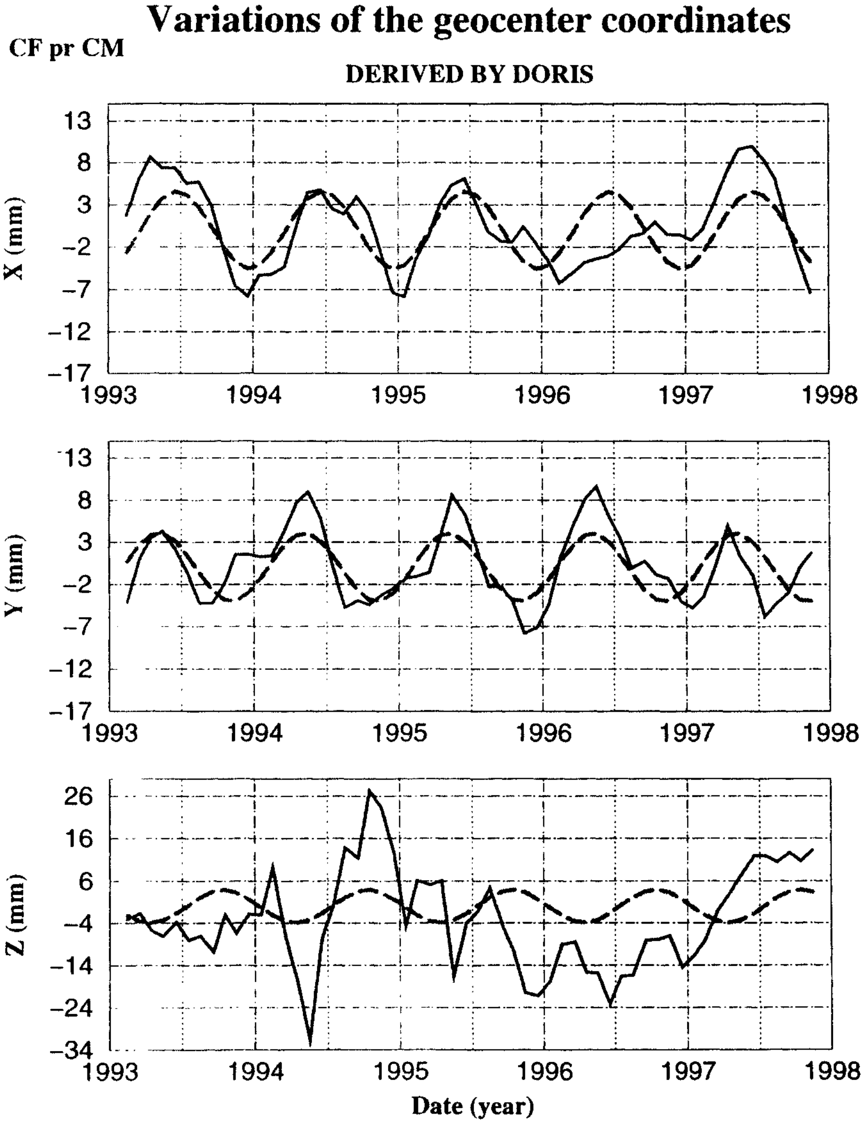

Fig.1 : Geocenter motion determined by DORIS over 1993-1997. The adjusted annual harmonic is superimposed for each coordinate.

The DORIS–derived geocenter variations have been compared to other determinations based on different methods or different space systems (e.g., SLR or GPS). We note a good agreement with recent laser determinations from the Texas group, in particular for the Y component. The agreement is less good for X and rather bad for Z. We note that there is still large discrepancies between the various solutions, an indication that more work is needed to get reliable geocenter coordinates.

GEOCENTER VARIATIONS FROM SURFACE MASS LOAD

Global mass redistribution alters the Earth rotation, produces temporal variations of the gravitational field, and also shifts the position of geocenter. The estimated geocenter variations from surface mass redistribution can be directly compared to the DORIS-derived geocenter variations. Below are discussed geocenter variations arising from surface loads such as atmospheric pressure, ocean and surface ground waters.

Atmospheric loading contribution

Atmospheric mass redistribution is classically deduced from atmospheric surface pressure variations. We used ECMWF gridded surface pressure fields given every 6 hours for the period 1988-1996. Monthly averaged values have been first computed and harmonic expansion has been performed for each monthly grid. Over the oceans, an inverted barometer response has been assumed. The degree 1 coefficients of the spherical harmonic expansion of surface pressure have been transformed into degree 1 coefficients of the gravitational potential using the well known relation :

$$\begin{pmatrix}\Delta C_{nm}\\ \Delta S_{nm}\end{pmatrix} = \frac{(1+k'_n)}{(2n+1)}\frac{R^2}{M}\int_S \Delta q(\varphi,\lambda)\begin{pmatrix}\cos\\ \sin\end{pmatrix}(m\lambda)P_{nm}(\sin\varphi)\,dS \qquad (1)$$

with $\Delta q = \dfrac{\Delta p}{g}$

Δp : *Surface pressure variation*

R, M : *Radius and mass of the Earth*

g : *Mean surface gravity*

k'_n is the load Love number of degree n.

The degree 1 terms have been further expressed in terms of geocenter coordinates X, Y, Z, as written below :

$$\begin{aligned} X &= RC_{11}\\ Y &= R\,S_{11}\\ Z &= RC_{10} \end{aligned} \qquad (2)$$

The atmospheric contribution computed in this study agrees quite well with that of Dong et al. (1997) based on another data set.

Ocean loading contribution

The ocean contribution to the geocenter variations has two components : (1) water mass redistibution due to regional change of the ocean circulation and (2) global sea level change. For the first contribution, we used geocenter variations estimated by Dong (see Dong et al., 1997) who based their computations on two ocean general circulation models. (ISO and MOM). The ocean has the biggest contribution in the x component with 1.05 mm for the annual term. The latter contribution is small but easy to estimate. We computed the seasonal change in the global mean sea level using altimeter data of the TOPEX/POSEIDON satellite (see Minster et al., 1998 for details). The observed mean sea level has been corrected for steric effects and the contribution to the geocenter computed as explained in Chao and O'Connor (1988). At the annual frequency this effect is quite small, less than 0.2 mm in amplitude.

Continental waters

Continental water storage varies over the year in response to annual changes in precipitation, evapotranspiration, snowcover and river runoff. We used the continental water climatology of Wilmott and co workers (Wilmott et al., 1985), distributed by the National Centers for Environmental Predictions (NCEP). This climatology provides monthly grids of soil moisture and snow load. These gridded data sets have been developed into spherical harmonics. The degree 1 coefficients have been transformed into geopotential coefficients and further expressed in terms of geocenter coordinates as explained above for the atmospheric contribution. For snow cover participation in geocenter motion , we have also estimated a geocenter motion with snow cover data from The International Satellite Land Surface Climatology Project (ISLSCP). Our results can be compared with those obtained from Willmott climatology with a difference in amplitude for the z component. This could be explained by a lack of snow cover data in Willmott climatology in some areas like Greenland, North of China and Antarctica. Whereas, the snow accumulation in these regions should influence a geocenter motion in the North-South direction.

COMPARISON BETWEEN DORIS-DERIVED AND SURFACE LOAD DERIVED GEOCENTER VARIATIONS

The sum of surface mass load contributions which induce geocenter variations can be compared in amplitude in phase with the DORIS-derived geocenter variations. Fig. 2 presents a comparison the DORIS-derived geocenter variations and the geophysical estimates. For the latter we have considered the atmosphere and continental waters as explained above. We also added the ocean contribution given in Dong et al. (1997), due to ocean circulation changes and in addition our estimation of geocenter variations from sea level change. Each geophysical contribution as well as their sum are shown in Fig.2 superimposed on the DORIS-derived geocenter coordinates. For Y and Z, the sum of the geophysical effects agree reasonably well with the observed variations. The snow contribution accounts for almost all observed signal in Z. For the X component, the total geophysical signal appears rather different from Doris estimation and the reason is unclear. It is unlikely that some missing signal would be able to explain such a difference. Further investigation is needed to understand this discrepancy. A comparison is also made with geocenter motion prediction made by Dong et al. (1997). Their results coincide rather well with geocenter variations derived with Doris data. Our geophysical prediction is not finished yet because soil moisture data which have been used from Willmott climatology are not optimal. Anyway, this good agreement with geophysical predictions in geocenter motion obtained by Dong shows that Doris results are satisfatory.

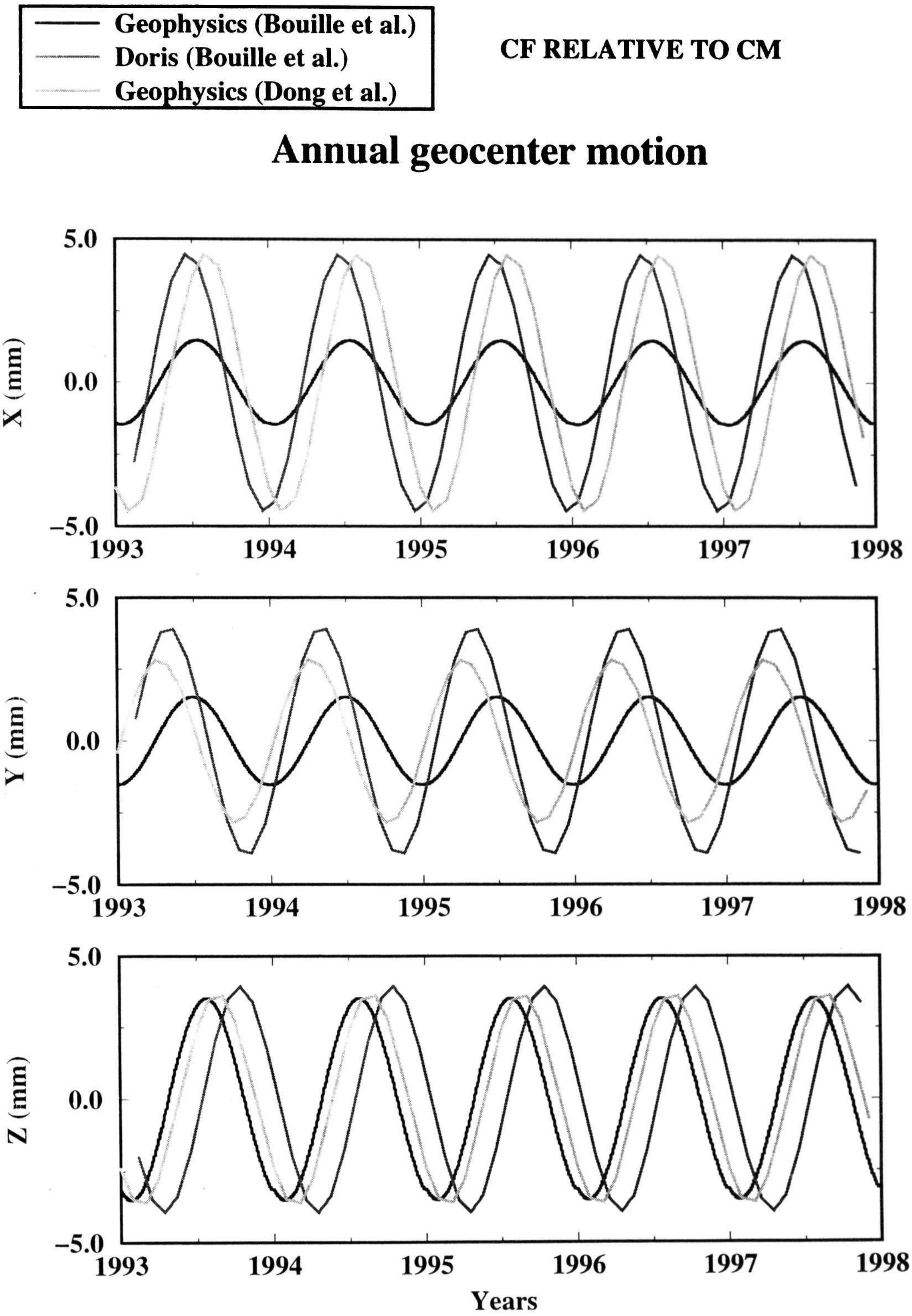

Fig.2 : DORIS-derived geocenter coordinates and sum of the geophysical effects. A comparison is also made with geocenter motion predicted by Dong et al. from other geophysical data.

CONCLUSION

Owing to its global an well distributed station network, the DORIS system is quite suitable for measuring the geocenter motion. As for other space-derived solutions, the precision of the geocenter coordinates will increase as the time series lengthen.
In March 1998, another DORIS receiver has been placed in orbit, on the SPOT4 satellite. Early 2000, JASON 1 and ENVISAT will carry second generation DORIS receivers with lower instrumental noise. Thus we can reasonably hope improving the geocenter determination. Moreover, as now done for space-derived tectonic motions, combined solutions obtained from different space techniques will be computed. In addition to providing constraints on the still poorly known hydrological contribution at the annual frequency, measurements of interannual variations of the geocenter may be of great interest for global sea level changes derived by satellite altimetry since in this case measured sea surface height is referred in principle to the centre of mass.

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