POLAR MOTION INTERPRETATION USING GRAVIMETRIC OBSERVATIONS

L. SEOANE, C. BIZOUARD, D. GAMBIS
Observatoire de Paris, SYRTE, UMR 8630/ CNRS,
61 avenue de l'Observatoire, 75014 Paris, France.
e-mail: lucia.seoane@obspm.fr; christian.bizouard@obspm.fr; daniel.gambis@obspm.fr

ABSTRACT. Polar motion is interpreted as the effect of i) the Earth's inertia moment changes associated with the so-called mass term of the Earth's angular momentum ii) the Earth's relative angular momentum in the terrestrial frame. Thanks to the GRACE mission and in a lesser extent to LAGEOS missions, the mass term is determined since 2002, independently from any geophysical model. Besides the modeled excitations of the polar motion, *i.e* the atmospheric angular momentum (AAM), the Oceanic Angular Momentum (OAM), the Hydrological Angular Momentum (HAM), this gravimetric mass term is a new kind of information which can be matched to the observed excitation of the polar motion after removal of the effect of the relative angular momentum, mostly caused by the wind and the oceanic currents. Such comparison, already performed by various authors, is updated for the last releases (RL04) of the gravity field changes *i.e.* those of the GFZ, CSR, JPL and explored for the mixed LAGEOS-GRACE solution of the GRGS. We confirm that a fair general agreement, especially for the y-component of the equatorial excitation. After removing the modeled oceanic and atmospheric excitations from the signals, we obtain the non-modeled excitation, mostly of hydrological nature; this allows us to compare them to the existing hydrological models, differences might comes from others Earth's phenomena, for example, earthquakes.

1. INTRODUCTION

The primary cause of the Earth's polar motion is the mass transport occurring in the Earth. In the terrestrial frame (Oxyz) off-diagonal inertia moments (I_{xz}, I_{yz}) of the Earth undergoes permanent changes, and relative motion takes place. Thus a time-variable equatorial angular momentum is created, composed by a *matter term* $\Delta\underline{\overline{I}\omega}$ where $\underline{\omega}$ represents the terrestrial components of the Earth's angular velocity vector, and a relative angular momentum (*motion term*). But according to the angular momentum conservation, that increment is balanced by motion of the rotation pole with respect to the crust. By estimation of the matter term and relative angular momentum, it is possible to provide an interpretation of the polar motion. So far those quantities are determined partially and commonly approached by ground observations, especially for the atmosphere and the oceans, which are known as the main source of angular momentum changes at seasonal and sub-seasonal scale. The assimilation of ground pressure and wind into Global Circulation Model allows to estimate the atmospheric angular momentum (AAM) on a routine basis. The determination of the oceanic angular momentum (OAM) is less easy, because oceanic observations are not so widespread. Whereas AAM explains 90% of the length-of-day variations at seasonal and sub-seasonal scales, combined AAM and OAM series fit up to 80% of the excitation found in polar motion at those periods. That might be due to the defect of OAM model or to the neglect of some other geophysical excitation, like the one linked to hydrological processes.

The advent of the Gravity Recovery and Climate Experiment (GRACE) mission shed light on the polar motion excitation. It has been monitoring the variability of the gravity field with unprecedented accuracy and spatial resolution since March 2002. As the inertia moments (I_{xz}, I_{yz}) are directly related to the spherical harmonics coefficients C_{21} and S_{21} of the geopotential, we can assume that GRACE mission permits to observe the equatorial part of the variable matter term, independently from any geophysical model. The GRACE's matter term has to be compared to the excitation found in the observed polar motion, mainly at seasonal and sub-seasonal time scales, since we have at hand 4 years of observations. It is interesting to know to which extent mass redistribution observed by GRACE is compatible with the Earth's rotation observations.

Such study has already be initiated by Chen and Wilson (2003), Chen et al. (2004), and revisited by

Nastula et al. (2007) for the previous GRACE products releases. We shall reproduce their study for the updated release, and complete it by an analysis of the hydrological signal. We shall see that our results differ significantly.

The analysis of GRACE satellites data is carried out by four centres: the Centre for Space Research (CSR), the GeoForschungsZentrum (GFZ), the Jet Propulsion Laboratory (JPL) and the Groupe de Recherche de Géodésie Spatiale (GRGS). Each Centre has provided updated solutions in several releases, not only the time span lengthens, but the data processing, especially the background models are revised. Recently, in April 2007, CSR, GFZ and JPL have updated their GRACE products in the Release 04. Our investigation uses this latest version of the gravity field solution in the form of normalized spherical harmonic coefficients for each centre.

2. METHOD

Polar motion excitation is deduced from the relation between the (2,1) Stokes coefficients of the gravity field and off-diagonal inertia moments of the Earth in the terrestrial frame. We have used Chen et al. (2003) formulation for computing excitation from GRACE solutions. For each Centre we have time series of the (2,1) normalized spherical harmonic coefficients of the gravity field $\Delta\overline{C}_{21}$ and $\Delta\overline{S}_{21}$ are tide free and also corrected from non tidal atmospheric and oceanic effects using ECMWF model and OMCT baroclinic model respectively, except for the GRGS that uses a barotropic ocenic model, MOG2D (Biancale et al. 2007). The degree 2 coefficients of the GRGS solution are determined by a combined analysis of the LAGEOS and GRACE observations. The non-tidal models have to be added back, in order to compare C_{21} and S_{21} variations to polar motion excitation deduced from Earth rotation observations.

The International Earth rotation and Reference systems Service (IERS) provides combined time series of the Earth Orientation Parameters (EOP) at daily interval (Gambis 2004, Bizouard and Gambis 2007), in particular the pole coordinates x and y, which allows us to compute the "geodetic" polar motion excitation according to:

$$\chi_G = \chi_1 + i\chi_2 = p + i\frac{\dot{p}}{\sigma_c} \tag{1}$$

where $p = x - iy$ is the complex pole coordinate and σ_c is the Chandler pulsation ($2\pi/433$ rad/days) with an adopted quality factor of 175. Geodetic excitation are corrected from oceanic tides using FES-2004 model (Lefevre et al. 2005).

GRACE or LAGEOS excitation only reflects mass redistribution, we have then to remove the motion part from the geodetic excitation associated with atmospheric winds and ocean currents. Wind term is computed by the National Center for Environmental Predictions (NCEP) (Salstein et al. 1993) and provided by the IERS Special Bureau for Atmosphere (SBA); current term is computed from ECCO model (Gross et al. 2003) provided by the IERS Special Bureau for Oceans (SBO).

On the other hand latitude-longitude grids providing the charge of continental water by surface unit at monthly intervals are available for the period 2002-2006. By integrating the grids of the CPC hydrological model we have reconstituted the hydrological excitation function or hydrological angular momentum - HAM - reduced to its mass term. Adding the HAM to the mass term of the atmospheric and oceanic excitations computed from NCEP and ECCO series we obtain an Earth's modelled mass redistributions that we labelled PAOH.

Time series of the CSR, GFZ and JPL solutions present common sampling of about 30 days, but the GRGS solution is given at approximately 10-day intervals. On the other hand our geodetic excitation function presents variations up to 2 days. Applying Vondrak smoothing (Vondrak 1977), which transmits 95% of the signal at 121 days (1% transmitted at 34 days, 22% transmitted at 60 days) we make both GRGS, geodetic series and modelled mass excitation spectrally consistent with the CSR, GFZ and JPL solutions. All those solutions are then interpolated at common dates at 30 day intervals.

3. RESULTS

The correlation coefficients between each "gravity" excitation and the geodetic excitation computed labelled here-after "G-WC" (that is from geodetic excitation with winds and currents effects removed) are reported in table 1. Also we shows correlation between the modeled mass excitation "PAOH" and the geodetic excitation. There is generally a good correlation for the component χ_2 (0.8-0.9). In the case of χ_1 function, which is mainly associated with mass transport over oceanic regions, correlation drops to 0.4-0.6. That points out the defect of the modelling of the coupled oceanic-atmospheric influence on the oceans. We also compare the standard deviation of the GRACE excitation with that one of the geodetic excitation (restricted to its mass term). As shown also in table 1 there is globally more power in GRACE excitation (0%-50% more) for χ_1 component, and less power in GRACE excitation for χ_2 component (10-20% less). As for correlation the agreement in standard deviation is globally better for χ_2 component. Generally modeled mass excitation are better correlated with geodetic excitation than gravimetric excitation. But series are short, only 39 points, according to Nastula et al. (2007) formulation 90% significance level of correlation for 39 points is 0.26 and only a difference of 0.24 in the correlations is significant.

	Standard deviation ratio		Correlation			
					$\chi_1 + i\chi_2$	
	χ_1	χ_2	χ_1	χ_2	Magnitude	Phase degree
CSR/G – WC	1.6	0.9	0.6	0.8	0.8	7
GFZ/G – WC	1.5	0.9	0.4	0.8	0.8	-1
JPL/G – WC	1.9	1.0	0.6	0.9	0.8	14
GRGS/G – WC	1.6	0.9	0.4	0.8	0.7	-11
PAOH/G – WC	0.8	0.9	0.8	0.9	0.9	1

Table 1: Correlation coefficients between the *gravimetric* excitation (CSR, GFZ, JPL, GRGS, GRGS) and the mass term of the *geodetic* excitation, labelled G-WC. Also the table shows the correlation between the modeled mass excitation PAOH computed from geophysical fluids models (NCEP, ECCO, CPC) and the *geodetic* excitation.

From the GRACE solutions we remove the modeled influence of the atmosphere and the oceans using NCEP data and ECCO. Hence those signals should reflect the mass term of “exotic” nature, like the one caused by hydrological processes and geodynamic processes like earthquakes. Therefore we have also a precious information on the non-modeled causes of the polar motion. That residual excitation can be compared to the geodetic excitation, after removing not only the motion term but also the mass term caused by the atmosphere and the oceans.

They are large discrepancies in time timing, and amplitudes (up to 10 mas) which are also reflected by the spectra shown in Figure 1. Corresponding correlation coefficients up to 0.7 and standard deviation ratios are given in table 2. Residual geodetic excitation G-WC-PAO is also compared to hydrological excitation computed from CPC model. Correlation is better what shows that the models seems to better reflect the hydrological angular momentum than the GRACE observation. Note that the solutions are all referred to the same atmospheric data (NCEP) and oceanic model (ECCO).

	Standard deviation ratio		Correlation			
					$\chi_1 + i\chi_2$	
	χ_1	χ_2	χ_1	χ_2	Magnitude	Phase degree
CSR – PAO/G – WC – PAO	1.9	1.3	0.5	0.4	0.4	5
GFZ – PAO/G – WC – PAO	1.9	1.8	0.3	0.7	0.5	-3
JPL – PAO/G – WC – PAO	2.3	1.0	0.4	0.5	0.4	8
GRGS – PAO/G – WC – PAO	1.9	1.3	0.2	0.4	0.3	-18
CPC/G – WC – PAO	0.4	1.2	0.7	0.7	0.7	-24

Table 2: Correlation coefficients between the hydrological excitation from *gravimetric* data (CSR, GFZ, JPL, GRGS, GRGS) or models (CPC) and hydrological signal from geodetic data. Note that atmospheric and oceanic effects are removed: motion term is labelled “WC” and mass term is labelled “PAO”.

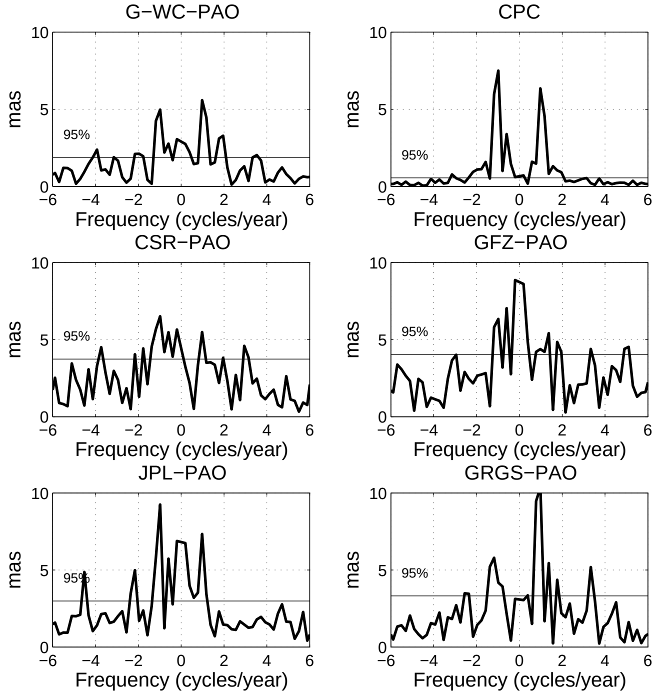

Figure 1: Spectrum of complex residual excitation functions computed from gravimetric data (JPL,CSR,GFZ,GRGS) and geodetic data by removing the atmospheric and oceanic signals, and also from global water storage model (CPC)

4. REFERENCES

Biancale, R., Lemoine, J. M., Balmino, G., Bruinsma, S., Perosanz, F., Marty, J.C., Loyer, S., Bourgogne, S. & Gégout, P., 2007. 4 years of gravity variations from GRACE and LAGEOS data at 10-day intervals over the period from July 29th, 2002 to October 25th, 2006, http://bgi.cnes.fr:8110/geoid-variations/README.html.

Bizouard, C. & Gambis, D., 2007. The combined solution C04 for Earth Orientation Parameters consistent with International Terrestrial Reference Frame 2005, Technical Note of IERS Earth Orientation Center, http://hpiers.obspm.fr/iers/eop/eopc04_05/C04_05.guide.pdf.

Chen, J.L. & Wilson, C.R., 2003. Low degree gravitational changes from earth rotation and geophysical models, Geophys. Res. Lett., 30(24), 2257, doi:10.129/2003GL018688.

Chen, J.L., Wilson, C.R., Tapley, B.D. & Ries, J.C., 2004. Low Degree Gravitational Changes from GRACE: Validation and Interpretation, Geophys. Res. Lett., 31, L22607,doi:10.1029/2004GL021670.

Gambis D., 2004. Monitoring Earth Orientation at the IERS using space-geodetic observations, J. of Geodesy, 78, pp 295-303, state-of-the-art and prospective, J Geod 78(4-5):295-303, doi: 10.1007/s00190-004-0394-1.

Gross, R.S., Fukumori, I. & Menemenlis, D., 2003. Atmospheric and oceanic excitation of the Earth's wobbles during 1980-2000. J. Geophys. Res., 108(B8), 2370, doi:10.1029/2002JB002143.

Lefevre, F., Letellier, T. & Lyard, F., 2005. FES2004 Model (realization FES2004_r190105).

Nastula, J., Ponte, R.M. & Salstein, D.A., 2007. Comparison of polar motion excitation series derived from GRACE and from analyses of geophysical fluids, J. Geophys. Res. vol. 34, L11306, doi: 10.1029/2006GL028983.

Salstein, D. A., Kann, D. M., Miller, A. J. & Rosen, R. D., 1993. The sub-bureau for atmospheric angular momentum of the International Earth Rotation Service: A meteorological data center with geodetic applications, Bull. Am. Meteorol. Soc., 74, 67-80.

Vondrak, J., 1977. Problem of smoothing observational data II, Bull. Astron. Inst. Czech, 28, p. 84-89.