COMPARISON OF POLAR MOTION EXCITATION FUNCTIONS COMPUTED FROM DIFFERENT SETS OF GRAVIMETRIC COEFFICIENTS

J. NASTULA[1], M. WIŃSKA[2], M. BIRYŁO[3]
[1] Space Research Center Polish Academy of Sciences
Bartycka 18A, 00-716 Warsaw, POLAND
e-mail: nastula@cbk.waw.pl
[2] Warsaw University of Technology, Faculty of Civil Engeneering
Al. Armii Ludowej 16, 00-637 Warsaw, POLAND
e-mail: m.winska@il.pw.edu.pl
[3] University of Warmia and Mazury in Olsztyn
ul. Michala Oczapowskiego 2, 10-719 Olsztyn POLAND
e-mail: monika.sienkiewicz@uwm.edu.pl

ABSTRACT. Since its launch in February, the Gravity Recovery and Climate Experiment (GRACE) has been source of data of temporal changes in Earth's gravity field. These gravity fields can be used to determine the changing mass field of the Earth caused by redistribution of the geophysical fluids, and from that excitations of polar motion. The so-called Level 2 gravity field product are available, in the form of changes in the coefficients: C_{nm}, S_{nm}. Since 2002 until the present time there are still attempts to better process these data. In this study we estimate gravimetric excitation of polar motion using a recent series of C_{21}, S_{21} coefficients. In our calculations we use several series developed by different centers. Firstly, we compare these gravimetric functions with each other. Then we examine the compatibility of these functions with hydrological signal in observed geodetic excitation function. We focus on seasonal and subseasonal time scales. The main purpose is to explore which from these several solutions are closed to observation.

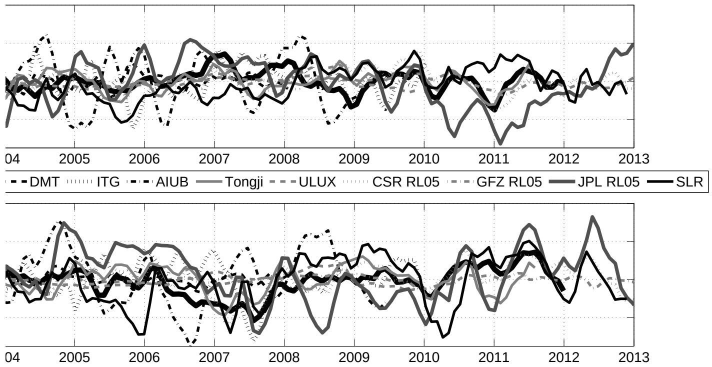
1. RESULTS AND ANALYSIS

In recent years many studies on the impact of land hydrology and Hydrological Angular Momentum (HAM) on the polar motion were carried on (Shuanggen et al., 2010; Brzeziński et al., 2009; Chen and Wilson, 2005; Nastula et al., 2007; Seoane et al., 2009).
Investigations of influence of HAM on the polar motion in different part of spectra show that consideration of the HAM data not improve significantly an agreement of the geophysical excitation of polar motion (atmosphere, oceans and hydrology) with geodetic excitation function GAM (Brzeziński et al., 2009; Chen and Wilson, 2005; Nastula and Kolaczek, 2005; Nastula et al., 2011; Shuanggen et al., 2010).

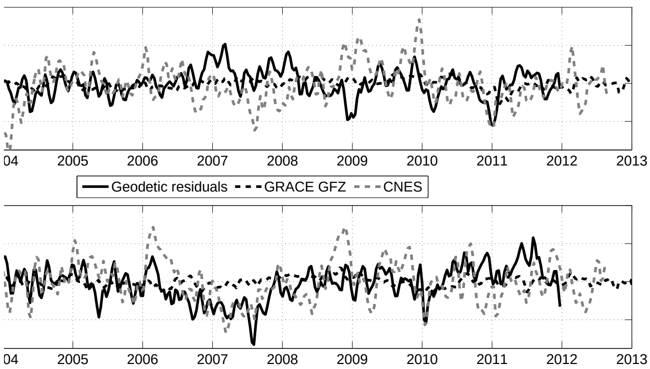
Here gravimetric HAM functions were estimated from several gravimetric monthly GRACE/CHAMP solution data: ITG-GRACE2010 gravity field model, DMT-1 (DEOS Mass Transport Model), AIUB - multi - annual mean gravity field GRACE03S, Tongji - GRACE monthly solution from the Tongji University, ULUX - monthly CHAMP solution from the university of Luxembourg, CNES/GRGS solution determined by a combined analysis of LAGEOS and GRACE observations, from GRACE monthly solutions from the three processing centers CSR, GFZ and JPL from RL05 series, from GRACE weekly solutions: GFZ Release 05 and from SLR solution obtained from the analysis SLR data to five geodetic satellites LAGEOS 1 and 2, Starlette, Stella and Ajisai. The gravimetric data are available in ICGEM - International Center for Global Gravity Field Model.
The gravimetric HAM functions were computed from harmonic coefficients of the Earth gravity field, based on formulae (Chen and Wilson, 2005):

$$\begin{bmatrix} \chi_1^{mass} \\ \chi_2^{mass} \end{bmatrix} = -\frac{1}{(1+k_2')\sqrt{\frac{3}{5}}\frac{C-A}{1.098R_e^2M}} \begin{bmatrix} \Delta C_{21} \\ \Delta S_{21} \end{bmatrix} \tag{1}$$

where M and R_e are the mass and mean radius of the Earth, respectively, C and A are the Earth's principal moments of inertia, is the degree–2 Love number (−0.301) accounting for elastic deformational effects on gravitational change. ΔC_{21}, ΔS_{21} are Stokes coefficients of the gravity field.
The gravimetric excitation functions of polar motion (HAM) were compared with the so-called geodetic residuals series G-A-O computed by removing atmospheric (Atmospheric Angular Momentum-AAM) and oceanic (Oceanic Angular Momentum-OAM) contributions from the GAM series (Nastula et al., 2011). In this study we used the geodetic time series estimated by the International Earth Rotation and Reference System Service (IERS) from C04 series of the pole coordinates (Bizouard and Gambis, 2009). The atmospheric excitation function AAM were derived from time series of NCEP/NCAR reanalysis data (Salstein et al. 1993). The oceanic excitation function OAM including bottom pressure and currents term were computed on the basis of ECCO-JPL ocean model (Gross et al. 2003).



(a) Gravimetric excitation functions vs. GAO (30 days step)



(b) Gravimetric excitation functions vs. GAO (10 days step)

Figure 1: Comparison of components of the gravimetric excitation functions, χ_1 and χ_2, of polar motion from different gravimetric data and of the geodetic residuals G-A-O being the difference between the geodetic excitation function and sum of the atmospheric and oceanic excitation function of polar motion. All the data were smoothed with a step of 30 days (top panel) and 10 days (bottom panel), FWHM=60 (top panel) and FWHM=20 (bottom panel). The 365.25, 180.0 and 120.0 days oscillations were removed from the time series.

Comparison of the equatorial components of the gravimetric excitation polar motion functions (monthly and 10 days sampling) with the geodetic residuals excitation function G-A-O are shown in Fig. 1. Tables 1 compares variances of the series. One can see that gravimetric excitation functions are not consistent with each other and with geodetic residuals. However, the agreement between geodetic residuals and gravimetric excitation function determined from CNES/GRGS data is quite good, especially for χ_2 equatorial component of polar motion. Next the comparison of the geodetic residuals and the HAM were carried out in two ways: through the determination of annual oscillation parameters (see Table 3) and the computation of correlation coefficients of non-seasonal variations of the series obtained subtracting a seasonal signals model (365 days, 181 days, 121, days) from the time series (Table 2), using LSQ method (Brzeziński et al., 2009). The correlation coefficients, computed for non-seasonal variations of all considered gravimetric time series, indicated generally better agreement between χ_2 component than χ_1 of

Variances of HAM		
Excitation functions	$\chi_1[mas^2]$	$\chi_2[mas^2]$
G-A-O	28.3	57.1
DMT	11.9	9.1
ITG	95.8	104.0
AIUB	179.7	221.7
Tongji	29.9	51.3
ULUX	28.1	11.3
GRACE CSR	33.0	60.8
GRACE GFZ	6.9	4.6
GRACE JPL	166.3	211.1
SLR	65.8	145.5
GFZ (10 days)	8.5	6.4
CNES (10 days)	121.6	119.09

Table 1: Variances of global geodetic and gravimetric excitation functions of polar motion; geodetic residuals are calculated as differences between GAM (C04 series) and sum of AAM (NCEP/NCAR model were used) and OAM (ECCO model were used).

Correlation coefficients Geodetic residuals vs. HAM		
Geodetic residuals vs.	χ_1	χ_2
CSR RL05 (monthly)	0.24	0.69
GFZ RL05 (monthly)	0.30	0.37
JPL RL05 (monthly)	0.25	0.29
ITG (monthly)	0.24	0.14
DMT (monthly)	0.02	0.26
AIUB (monthly)	0.18	0.15
SLR (monthly)	0.10	0.46
ULUX (monthly)	0.33	0.00
Tongji (monthly)	0.35	0.60
CNES (10 days)	0.30	0.52
GRACE GFZ (10 days)	0.24	0.26

Table 2: Correlation coefficients between global geodetic and gravimetric excitation functions of polar motion calculated after removing annual signals from time series; geodetic residuals are calculated as differences between GAM (C04 series) and sum of AAM (NCEP/NCAR model were used) and OAM (ECCO model were used); statistical significance $p = 0.3$.

Data	Prograde annual		Retrograde annual	
	Amplitude	Phase	Amplitude	Phase
ULUX	14.5	-53.9	14.9	128.9
Tongji	1.8	11.7	4.0	139.6
ITG	4.2	-60.1	8.5	-100.9
SLR	15.0	-89.3	18.3	-118.7
DMT	0.4	-3.6	2.9	72.0
CNES 10 days	2.6	-171.0	3.2	-74.4
AIUB	10.9	-76.6	4.4	-61.3
CSR RL05	2.8	-2.0	3.1	138.7
GFZ RL05	3.6	-14.3	4.5	130.2
JPL RL05	4.6	-5.8	5.9	11.2
GFZ Weekly	3.7	-27.5	4.8	137.7
G-A-O	6.4	-53.5	3.5	120.8

Table 3: Amplitudes and phases of the of the prograde and retrograde annaul oscillations of the residuals of the geodetic excitation function (G-A-O) and of the different gravimetric excitation functions by using Last Square Method. The fitted and removed from the time series data model comprises the order polynomial and a sum of complex sinusoids with periods 365.25, 180.0, 120.0 days. Analysis is done over the period 2003.0 to 2009.5.

these gravimetric excitation functions (see Table 2). The highest value, equal to 0.69, of the correlation coefficient was reached, when to estimate of gravimetric computation the CSR RL05 data were used. Amplitudes and phases of these annual oscillations are presented in Table 3. It can be concluded, that the annual oscillations of the gravimetric excitation functions have different amplitudes and phases, furthermore, only ITG function is close to the geodetic residuals in prograde oscillations and only GRACE GFZ RL05 and GRACE CSR RL05 vectors are close to the geodetic residuals in retrograde oscillations.

2. CONCLUSIONS

GRACE is a powerful tool to determine time-variable geophysical mass fields, and in particular that of the changing land-based hydrology, which is estimated otherwise only with complex hydrological models. We found that these gravimetric-hydrological excitation functions, obtained by the several processing centers, still differ significantly. One difference is that a greater degree of smoothness is exhibited by GFZ than the other products. Analyses show that the use of these new data to compare with GAO does not bring significant new results from to previous studies (Seoane et al., 2009, 2011; Nastula et al., 2011), though confirms the current extent of the differences among the series. The best agreement between gravimetric-hydrological excitation functions and geodetic residuals was obtained for the χ_2 component of gravimetric excitation function computed from the CSR, Tongji and CNES data series, and this may be due to some positive attributes in the processing, like its increased background resolution.

Acknowledgements. This work was supported by the National Science Centre contracts 2012/07/N/ST10/03275 and 2012/05/B/ST10/02132.

3. REFERENCES

Bizouard, C., Gambis, D., 2009, "The combined solution C04 for Earth orientation parameters consistent with international terrestrial reference frame 2005", In: H. Drewes (ed.), Geodetic Reference Frames, Proc. IAG Symp., Munich, Germany, October 9-14, 2006, Springer, Berlin, pp. 265–270.

Brzeziński, A., Nastula, J., Kołaczek B., 2009, "Seasonal excitation of polar motion estimated from recent geophysical models and observations", J. Geodyn., 48, pp. 235–240.

Chen, J.-L., Wilson, C.R., 2005, "Hydrological excitation of polar motion, 1993–2002", J. Geophys. Int. 160, pp. 833–839, doi: 10.1111/j.1365-246X.2005.02522.x.

Nastula, J., Kołaczek, B., 2005, "Analysis of Hydrological Excitation of Polar Motion", In: Proc. Workshop: Forcing of polar motion in the Chandler frequency band, a contribution to understanding interannual climate variations. Centre Europeen de Geodynamique et de Seismolgie, Luxembourg, pp. 149–154.

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

Nastula, J., Paśnicka, M., Kołaczek, B., 2011, "Comparison of the geophysical excitations of polar motion from the period: 1980.0–2009.0", Acta Geophysica, 59(3), pp. 561–577, doi: 10.2478/s11600-011-0008-2.

Salstein, D.A., Kann, D.M., Miller, A.J., Rosen, R.D., 1993, "The subbureau for atmospheric angular momentum of the international Earth rotation service: A meteorological data center with geodetic applications", Bull. Am. Meteor. Soc. 74, pp. 67–80, doi: 10.1175/1520-0477(1993)074<0067:TSBFAA>2.0.CO;2.

Seoane, L., Nastula, J., Bizouard, C., Gambis, D., 2009, "The use of gravimetric data from GRACE mission in the understanding of polar motion variations", Geophys. J. Int., 178(2), pp. 614–622, doi: 10.1111/j.1365-246X.2009.04181.x.

Shuanggen, J., Chambers, D.P., Tapley, B.D., 2010, "Hydrological and oceanic effects on polar motion from GRACE and models", J. Geophys. Res., 115, B02403, doi: 10.1029/2009JB006635.