Hydrological and oceanic effects on polar motion from GRACE and geophysical models

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1. Polar motion excitation

The polar motion excitations can be expressed as an integral of gridded pressures and currents [e.g. *Eubanks*, 1993]:

$$c^{p} = c_1^{p} + i c_2^{p} = \frac{-1.0980\,\bar{R}^4}{g(C-A)} \iint p \sin j \cos^2 j \, e^{il} \, d l \, d j \quad (1)$$

$$c^{m} = c_1^{m} + i c_2^{m} = \frac{1.5913\,\bar{R}^3}{g\Omega(C-A)} \iiint (u \sin j + iv) \cos j \, e^{il} \, dp \, d l \, d j \quad (2)$$

where x^p and x^m are the pressure term and motion term of polar motion excitation, respectively, x_1 and x_2 are the polar motion *Px* and *Py* excitations, respectively, *g* is the gravitational constant, *R* and *O* are the mean radius and mean rotation rate of the Earth, respectively, *C* and *A* are the Earth's axial and equatorial principal moments of inertia, respectively,f , ?, and *t* are the latitude, longitude and time, respectively, and *u* and *v* are the eastward and northward motion velocities (e.g. wind or ocean current).

2. Data and Analysis

2.1 OBP and TWS from GRACE

The latest GRACE gravity field solutions (Release-04) are used from the Center for Space Research (CSR) at the University of Texas, Austin, which are available from the GRACE Tellus Web site (http://gracetellus.jpl.nasa.gov/data/mass). The data have been corrected and smoothed into monthly maps of TWS and OBP with a 300-km Gaussian smoothing [e.g. *Chambers*, 2007]. The TWS and OBP excitations to polar motion are calculated by using TWS and OBP (in appropriate units) in place of *p* in Eq.(1).

2.2 OBP, currents and TWS excitations from models

The atmospheric contributions can be estimated from 6-hourly excitation series based on the NCEP-NCAR reanalysis provided by the IERS Special Bureau for the Atmosphere (SBA). The ocean OBP and ocean current excitations are determined from the ECCO model kf066b provided by the IERS Special Bureau for the Oceans (http://euler.jpl.nasa.gov/sbo/). The hydrological excitations to polar motion have been estimated from global hydrological land surface discharge model (LSDM) with near real-time input data of daily Precipitation, Evaporation and Temperature from the European Center for Medium-Range Weather Forecasts (ECMWF) (6h ECMWF operational).

3. Results and Discussions

The purpose of this study is to evaluate the relative ability of OBP plus TWS from GRACE or models to close the budget OBM+HAM = GAM-AAM-OCM, where GAM represents the full geodetic polar motion excitations, AAM is the atmospheric portion, HAM (hydrological angular momentum) is the hydrological portion, OCM is the ocean current portion, and OBM is the portion related to ocean bottom pressure variations.

3.1 Seasonal polar motion

The annual and semi-annual variations of polar motion excitations from observations and models are analyzed (Fig. 1). For Px, the GRACE OBM+HAM excitations agree well with geodetic residuals at the annual period. The annual amplitude using GRACE OBM is closer to the observed residuals. However, for Py, the closest combination is for GRACE OBM + ECMWF HAM. Using the GRACE HAM results in an amplitude only half of that from GAM-AAM-OCM and a large phase shift. For the semi-annual component, however, the GRACE OBM+HAM combination is closer to GAM-AAM-OCM than any of the other combinations. These results suggest that the GRACE OBP data are significantly better at estimating seasonal polar motion excitations than the ECCO model.

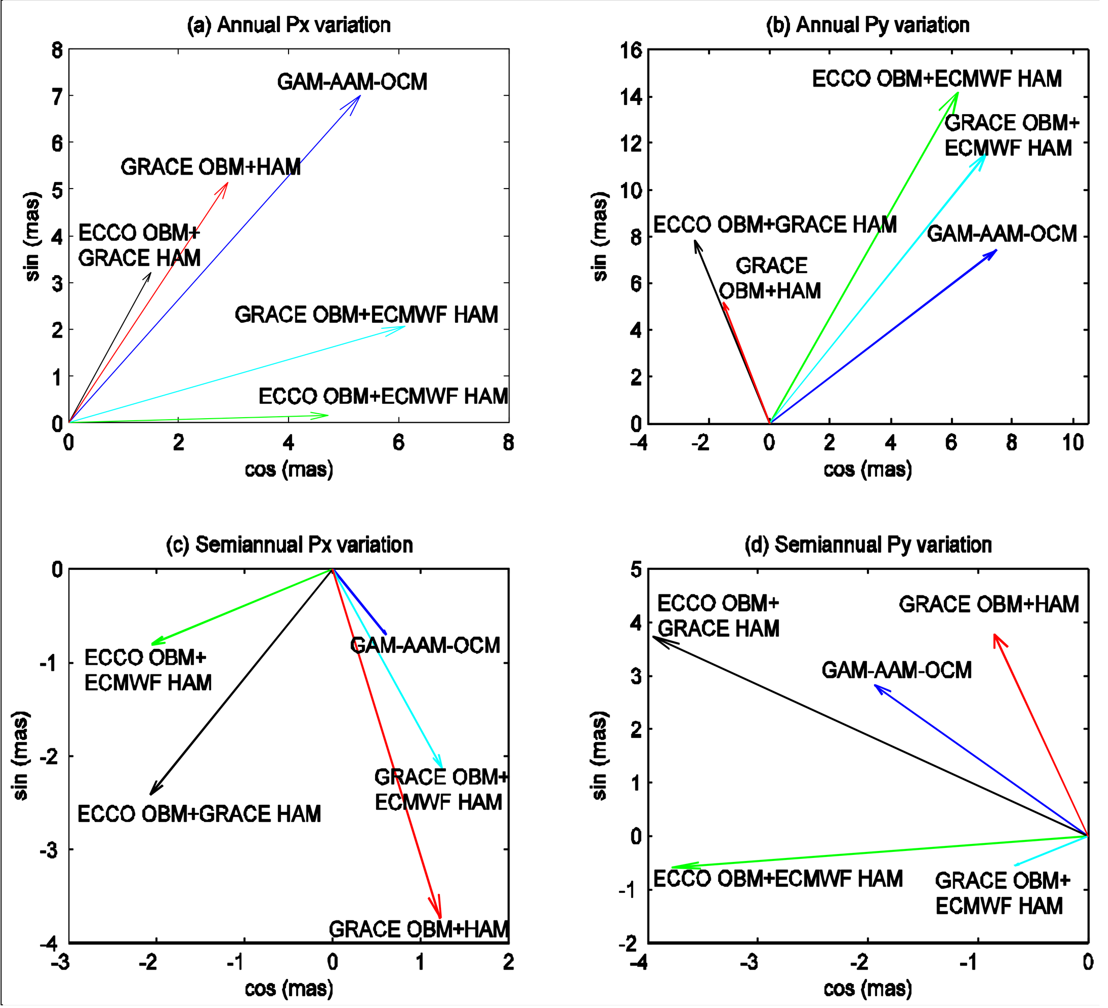

Fig. 1. Phaser plots of annual Px (a), annual Py (b), semi-annual Px (c), and semi-annual Py (d) excitation variations from geodetic observation residuals, GRACE and models

3.2 Intraseasonal polar motion

To quantify which combination agrees better with geodetic residual at non-seasonal periods, we have computed cross correlation coefficients (Table 1). The zero-lag correlation coefficient between GRACE OBM+ HAM and GAM-AAM-OCM is comparable to those of GRACE OBM+ECMWF HAM and ECCO OBM+ GRACE HAM, but all are smaller than that of models only combinations (ECCO OBM+ECMWF HAM).

Table 1. Cross-correlation coefficients at the zero phase lag and root-mean-square (RMS) of difference between intraseasonal geodetic polar motion (Px, Py) and excitations from models and GRACE.

	GAM-AAM-OCM			
	Px		Py	
Excitations	Coefficients	RMS	Coefficients	RMS
ECCO OBM+ECMWF HAM	0.60	3.55	0.53	5.68
ECCO OBM+GRACE HAM	0.49	4.73	0.49	7.25
GRACE OBM+ECMWF HAM	0.55	7.04	0.44	7.29
GRACE OBM+HAM	0.51	8.20	0.39	10.11

One can also use coherence analysis to study excitation series in the frequency domain. The estimates of the squared coherence of various excitation time-series show that the coherences between GAM-AAM-OCM and GRACE OBM+HAM in Px and Py are significantly less than that for the model estimates at most high frequencies (Fig. 3).

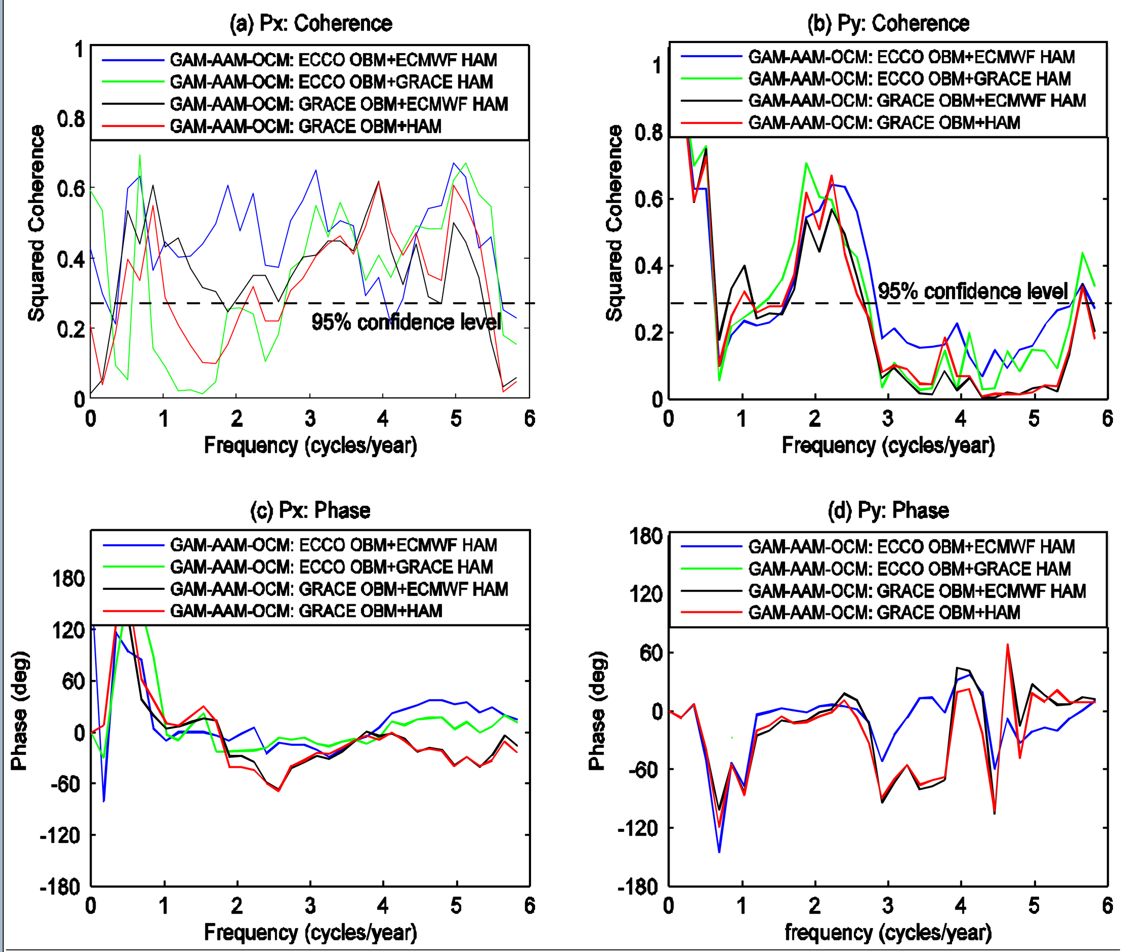

Fig. 2. Magnitude and phase of the squared coherence of GAM-AAM-OCM with GRACE and model excitations. Annual, semi-annual and periods longer than 1-year have been removed from all time series by least squares fitting and high-pass filter.

3.3 Interannual polar motion

In addition, significant interannual fluctuations are found (Fig. 5). The GRACE OBM+HAM time-series for Px matches the GAM-AAM-OCM residuals remarkably well in 2006. None of the model combinations, however, captured the large 2006 anomaly. The Py time-series have larger variations than Px, as well as more consistency between the geodetic residuals and the various combinations. The combinations with GRACE OBP are both slightly closer than the combinations with ECCO OBP.

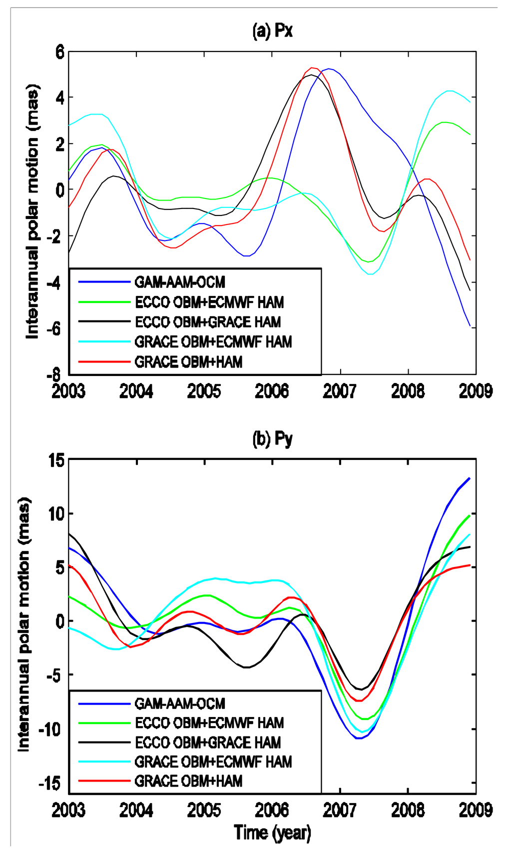

Fig. 3. Residual interannual excitations in *Px* (a) and *Py* (b) after removing seasonal variations and smoothing over 1-year.

4. Conclusion

Hydrological and oceanic mass excitations to polar motion are investigated using monthly terrestrial water storage (TWS) and ocean bottom pressure (OBP) derived from the GRACE, the ECMWF model and the ECCO model for January 2003 until December 2008. Results show that the GRACE-derived OBP and TWS better explain the geodetic residual polar motion excitations for the Px component at the annual period, while the GRACE OBP and ECMWF hydrological angular momentum agree better with the geodetic residuals for the annual Py excitation. GRACE ocean and hydrology excitations better explain the geodetic residuals for the semi-annual Py excitation. However, the JPL ECCO and ECMWF models better explain the intraseasonal geodetic residual of polar motion excitation in the Px and Py components.

Reference

Jin, S.G., D.P. Chambers, and B.D. Tapley (2010), Hydrological and oceanic effects on polar motion from GRACE and models, J. Geophys. Res., 115, doi: 10.1029/2009JB006635.