VARIABLE PROCESSES IN POLAR MOTION AND LENGTH OF DAY

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ABSTRACT. Seasonal terms in the Earth rotation parameters (polar motion and length of day) are broad band processes. This denotes variability of their amplitudes in phase, probably associated with the underlying geophysical process. We show that the patterns of variability in the seasonal terms of the observed polar motion and lenght of day are well correlated with those found in the combined atmospheric-oceanic excitation. This result confirms the reliability of the oceanic angular momentum time series. However correlation between atmospheric-oceanic and observed excitation seems to be spoiled episodically by El Niño and La Niña events.

1. INTRODUCTION

The "fluid layers" of the Earth, the atmosphere, the oceans and the underground water present variable masse distributions, and for this reason exchange angular momentum with the solid Earth. It results considerable effect on the Earth's rotation, currently deduced from the estimates of the Atmospheric Angular Momentum (AAM) and Oceanic Angular Momentum (OAM) changes.

Whereas AAM series are routinely determined since 10 years, OAM series remain still sparse, and production of Hydrological Angular Momentum (HAM) has just started. The first OAM time series date back 1998. Longest official series spans over 1985-1998 (Ponte et al., 1998, 1999, 2000 ; Johnson, 1999).

As shown by recent studies (Brzezinski and Nastula (2000), Gross (2000)) the combined forcing of atmosphere and oceans better matches the observed polar motion (PM), especially the Chandler term. Mean effects of prominent harmonics are investigated in former studies, but spectral peaks reveal broad band processes associated with variable amplitudes and phases. We wonder to which extend pattern of variability in seasonal terms of the polar motion and lenght of day can be accounted for those found in the combined atmospheric-oceanic excitation.

2. GEOPHYSICAL AND GEODETIC EXCITATION FUNCTIONS

Easiest investigation of the atmoshperic/oceanic/hydrological effects on the Earth rotation is to compare the so-called geophysical excitation functions, to the "observed" excitation, which can be inferred from Earth Orientation Parameters (EOP). Geophysical excitation function are less-dimensional forms of the Atmospheric Angular Momentum (AAM) and Oceanic Angular Momentum (OAM).

Let be p the complex-valued coordinate of the Celestial Ephemeris Pole (CEP) in the terrestrial reference frame ($p = x - iy$) and ΔLOD the excess of length-of-day proportional to the time derivative of $UT1 - TAI$ (Universal time - Temps Atomique International). It can be shown (Barnes et al. 1983) that for processes at scales longer than a few days :

$$\chi_G = p + \frac{i}{\sigma_{\rm cw}} \frac{{\rm d}p}{{\rm d}t}$$

$$\chi_{G,3} = \frac{\Delta LOD}{LOD} = -\frac{d(UT1 - TAI)}{dt} \tag{1}$$

where $\sigma_{\rm cw} = \frac{1}{433}(1 + \frac{i}{2Q})$ is the complex-valued frequency of the Chandler Wobble, known as a damping process of frequency of 0.8435 cycles per year and quality factor Q=170 according to Wilson and Vicente (1990), and LOD is the nominal duration of the mean solar day (86400 s). The quantities χ_G and $\chi_{G,3}$ are the so-called geodetical excitation functions to be compared with the geophysical ones coming from the atmosphere χ_A and from the oceans χ_O.

Our basic data are the following :

- The AAM time series (1948-2001) are those of the NCEP-NCAR Reanalysis project, sampled at 0.25 day (Special Bureau for Atmosphere of the IERS : ftp://ftp.aer.com/pub/collaborations/sba/).
- Our OAM series (1985.0 - 1997.95, sampled at 5 days intervals) has been obtained by completing the Ponte's series (1985.0 - 1996.3, sampled at 5 days intervals) with the last years of the Johnsons series (1996.3-1997.95, sampled at 3 days intervals) (Special Bureau for Oceans of the IERS : http://euler.jpl.nasa.gov/sbo/). This complemention is the weak point of our study, in the sense that both oceanic series are unconsistent for some seasonal terms on their overlapping interval.
- The Polar motion-length (from 1958.0 to 2000.0) of the IERS combined series C04, sampled at 1 day, comprehending fluctuations from 6 days (Earth Orientation Center : http://hpiers.obspm.fr/eop-pc/).

We derived Geodetic (G), atmospheric (A) and oceanic (O) excitations sampled at 5 days and spanning 1985.0-1997.95. The effect of zonal tides is removed from UT1 and oceanic tidal effects are removed from PM (9.12, 9.13, 13.63, 0.52, 13.66, 27.56 days) (Gross, 1998).

3. MEAN SEASONAL EFFECTS AND TREND

Seasonal terms and trend (annual, semi-annual and ter-annual) are the most prominent features of the excitation functions. They have been estimated by a least-squares fit on the whole data span 1985-1998.

For this purpose any equatorial excitation function is modelled as the sum of circular and linear terms :

$$\begin{aligned} \chi_1 &= \textstyle\sum_i \ A_i^{(ip)} \cos(\omega_i t) - A_i^{(op)} \sin(\omega_i t) + at + b \\ \chi_2 &= \textstyle\sum_i \ A_i^{(ip)} \sin(\omega_i t) + A_i^{(op)} \cos(\omega_i t) + ct + d \end{aligned} \tag{2}$$

where $A^{(ip)_i}$ is called the "in-phase" amplitude and $A^{(op)_i}$ the "out-of-phase" amplitude with respect to the reference epoch J2000.0 (1 january 2000, 12h UTC). The ω_j, j=1,2,3 are the frequencies associated with the following circular periodic terms : annual prograde and retrograde terms (-1,1 cpy), semi-annual prograde and retrograde terms (2, -2 cpy), ter-annual prograde and retrograde (3, -3 cpy).

The axial excitations are modeled by :

$$\chi_3 = \sum_i B_i^{(ip)} \cos(\omega_i t) + B_i^{(op)} \sin(\omega_i t) + et + f \tag{3}$$

For equatorial components, adding OAM brings significant improvement of the balance between geodetic and geophysical excitations, except for the semi-annual (both prograde and retrograde) oscillation. The prograde annual term of the atmospheric excitation exhibits too much power with respect to the observed excitation, but the oceanic forcing reduces the relative offset from 30% to 10%. The annual retrograde amplitude undergoes even better change : from 90% to 16%. In all cases the phases are considerably closer to those of the geodetic excitation. This effect of OAM contribution is particularly significant for 1 cpy, -3 cpy, and 3 cpy. These results confirm the influence of the oceanic angular momentum variations on polar motion.

For axial component the OAM does not have significant effect.

4. TIME EVOLUTION OF THE COHERENCE

We have computed the mean coherence function associated with two frequency bands over a sliding window of 2 years. The frequency bands are the "seasonal" ones from -4 cpy to 4 cpy, and the "overall" one including all components from -36 cpy to 36 cpy. Results are displayed in Fig. 1 and Fig. 2 for both axial and equatorial components. The bottom graphics shows that the oceans globally improve the overall coherence, except for some limited periods. In the upper graphics are displayed both the coherence in seasonal band between χ_{A+O} and χ_G and the Southern Oscillation Index (SOI), which quantify the global pressure inhomogeneity over south pacific. The agreement at seasonal frequencies seems to be blurred during the strong minima and maxima of the SOI, that corresponds respectively to El Niño and La Niña events. This is striking for axial and equatorial excitations at the beginning of the year 1987 (maximum of El Niño) and beginning of the year 1989 (maximum of La Niña).

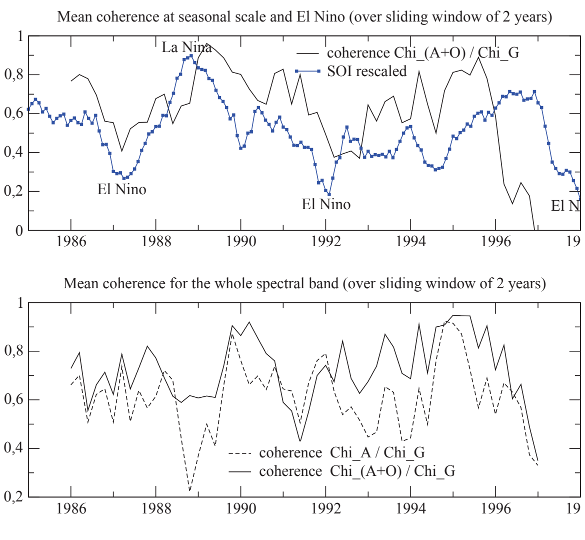

Figure 1: Mean coherence between equatorial excitation functions

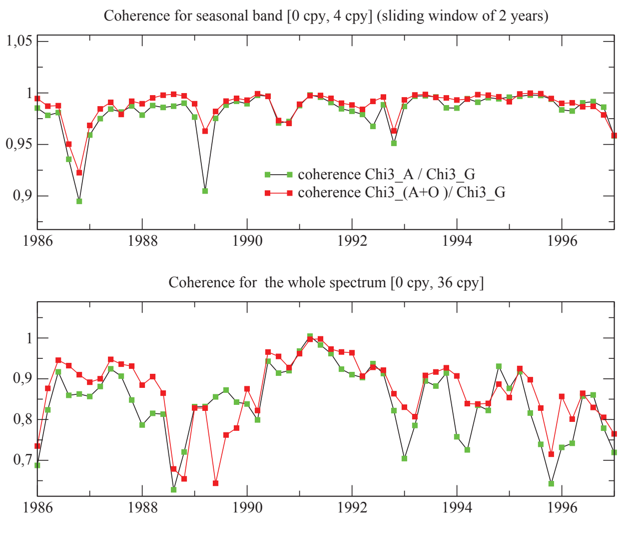

Figure 2: axial excitation functions over 2-year sliding windows

The bottom graphics gives the coherence between χ_G and χ_A or χ_{A+O} over the whole spectrum, the upper ones are restricted to the seasonal bands [-4 cpy, 4 cpy], and shows the rescaled SOI.

5. LEAST-SQUARES ESTIMATION BY SLIDING WINDOW

Time local features in the seasonal band can be determined by least-squares estimations of in-phase and out-of-phase terms restricted to smaller sliding windows.

This procedure has been applied to the excitation functions for the periods of which the amplitude is greater than 4 mas (*i.e.* at least 2 times the rms of the spectrum). The amplitudes are estimated from the residuals, *i.e.* the original signal where the mean periodic effects and the trends have been removed. The model used for least-squares estimation is given by Equations (3) and (3) where the trend is not estimated. The sliding window length is 2 years and the window is shifted by 0.5 year.

Polar motion. For the seasonal components of the equivalent polar motion ($p(\sigma) = \chi(\sigma)/(1 - \sigma/\sigma_{CW})$) results of the least-squares analysis are plotted on Figure 3. The formal error on the estimates is about 4 mas for the annual term, and is below 0.5 mas for the other terms.

Globally the time variations of the amplitude of the seasonal terms on the observed polar motion are well explained by the combined action of the atmosphere and the oceans. Adding the contribution of the oceans makes the value closer to the observation (see Figure 3) and the similarity of the shape of the curve is very strong. The best improvements are encountered for the prograde semi-annual (in-phase and out-of-phase), the prograde annual (out-of-phase) and the prograde ter-annual (out-of-phase) terms for which the correlation grows up very significantly and is then very close to 1.

Nevertheless, for the retrograde annual (out-of-phase), the retrograde semi-annual (in-phase), the prograde ter-annual (in-phase) and the retrograde ter-annual (in-phase) terms, the correlation was close to 1 with the atmospheric effect alone. Adding the oceans does not bring anything or deteriorates the value of the correlation.

For the other seasonal terms, the correlation is made better, but still remains below 0.5 : prograde and retrograde annual terms (in-phase), retrograde semi-annual (out-of-phase) and retrograde ter-annual (out-of-phase) terms.

The ratios of the associated standard deviations are also closer to 1, except for the retrograde semi-annual (out-of-phase) and the retrograde annual (in-phase) terms for which they are deteriorated. Except for the prograde annual component and the ter-annual (out-of-phase) components, the ratios remain around 0.6 even if they are improved by the addition of the oceans.

These small inconsistencies in correlation and standard deviation for seasonal terms are reflected in time domain when the geophysical equivalent polar motion does not agree with the observed polar motion. For example : during the years 1988-1990 in the in-phase terms for +1 and -1 cpy, and around 1994 on the same plots, or 1988-1990 in the out-of-phase term for 3 cpy. On several spans, neither the atmospheric contribution nor the oceanic one are sufficient to explain the observed polar motion. It is the case during the year 1994 on the out-of-phase term for 1 cpy where the addition of the oceanic contribution does not bring anything. The amplitude in the fluid layers is too much important compared to the polar motion, and this result had already been noticed using the wavelet method. The same remark can be done for the out-of-phase term at -2 cpy : around 1993, the polar motion is higher than the predicted effect of the fluid layers and just after 1994, the phenomenon is inverted.

Lenght-of-day. The variability of the seasonal terms is identical in shape both in length-of-day and axial atmospheric excitation. Oceans do not bring significant improvement. However the power of the atmospheric excitation is significantly lower than that on observed in the LOD.

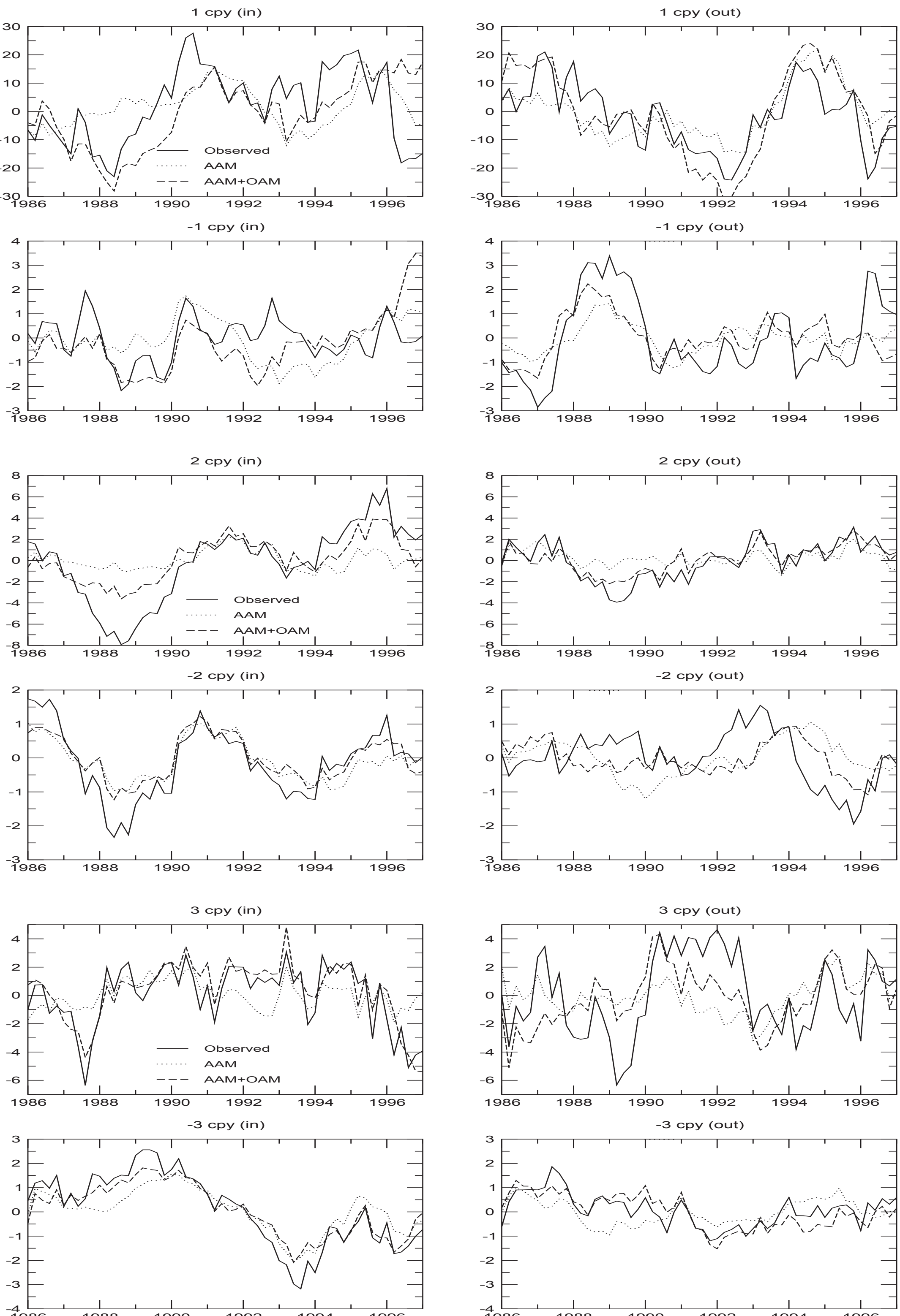

Figure 3: Time variability of prograde and retrograde seasonal terms in the polar motion (full line), the atmosphere (dotted line) and the fluid layers (dashed line) using least-squares estimates and a sliding window. In-phase and out-of-phase terms are defined by Expression (3). The quantity plotted is the equivalent polar motion computed from the excitation.

6. CONCLUSION

Combined atmospheric and oceanic forcing almost well explain the time variability of prominent periodic terms in polar motion. This is a postive test for the reliability of the OAM series. Oceans take a minor part in the axial excitation. Moreover coherence seems to be decreased when El Niño and La Niña present their maximum of activity. This is probably due to the mismodeling of the oceanic and atmospheric circulation during such events.

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