ATMOSPHERIC AND OCEANIC EXCITATION OF THE FREE CORE NUTATION: OBSERVATIONAL EVIDENCE

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ABSTRACT. The paper discusses the excitation of the observed free core nutation signal by the combination of atmospheric and oceanic processes. We compute the "geodetic" excitation from the time series of the celestial pole offsets and compare it to the subdiurnal estimates of the atmospheric and oceanic angular momenta. We find that during 1993.0 to 2000.5 the geophysical excitation contained more power at the FCN frequency, up to the factor of 10 to 30, than needed to explain the observed free motion. The cross spectral analysis shows that the observed and modeled excitations were coherent near the FCN frequency – the coherence magnitude estimates are between 0.7 and 0.8. But surprisingly, the geodetic and geophysical excitations are found to be out of phase at the FCN frequency.

1. INTRODUCTION

The celestial motion of the Earth's pole, that is precession-nutation, is dominated by the lunisolar effect which is expressed by the conventional model. The remaining part is driven by large-scale geophysical processes leading to the angular momentum exchanges between the solid Earth and its fluid environment including the dynamically coupled atmosphere-ocean system. A part of this geophysical component is the regular variation which can be expressed by the incremental amplitudes of the conventional precession-nutation model. This variation has been studied extensively by the use of the atmospheric and nontidal oceanic angular momentum (AAM, OAM) data with subdiurnal resolution by, e.g., Bizouard *et al.* (1998), Brzeziński *et al.* (2004). The remaining tiny part, below 1 milliarcsecond (mas), is the irregular fluctuation consisting of the free core nutation (FCN) and a broad-band variability with power concentrated mostly around the prograde annual frequency (Brzeziński *et al*, 2004).

Here we focus our attention on the atmospheric and oceanic excitation of the FCN signal seen in the time series of the celestial pole offsets determined from the very long baseline interferometry (VLBI) observations (Fig. 1a). Understanding the FCN and its excitation mechanism is needed for the following purposes: 1) further improvement of the conventional precession-nutation model – see (Dehant, this volume); 2) validation of the available time series of the VLBI celestial pole offsets; 3) constraining the atmospheric and oceanic global circulation models at diurnal periods.

It is commonly believed that the FCN signal is driven mostly by variability in the atmosphere and oceans associated with the daily solar heating cycle. Our earlier spectral estimation based

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on the first operational sets of 6-hourly AAM indicated that the matter term of AAM has enough power near the FCN resonant frequency to explain the observed free signal, while the contribution of the motion term is negligible (Brzeziński, 1994b). This conclusion was confirmed later on the basis of the reanalysis AAM series (Brzeziński *et al.*, 2002). A recent study based on the output of the barotropic ocean circulation model (Brzeziński *et al.*, 2004) demonstrated that adding the contribution from the nontidal OAM increased the FCN excitation power of the matter term but had a negligible contribution to the excitation by the motion term.

In this study our approach is similar to that applied successfully in the excitation study of the Chandler wobble (Brzeziński and Nastula, 2002) – from the selected series of the VLBI determinations of nutation we compute the corresponding excitation series, the "geodetic" excitation of nutation (Brzeziński, 1994a; Bolotin, this volume), which is then compared to the available subdiurnal estimates of the atmospheric and oceanic angular momentum functions. Comparison is performed in both the time domain – a sliding window correlation analysis, and in the frequency domain – the cross-spectral analysis in vicinity of the resonant FCN frequency.

2. DATA SETS AND COMPUTATIONAL PROCEDURE

Several time series of the celestial pole offsets are currently available, including individual solutions derived by different VLBI analysis centers and the combination series. Here we use the following 2 individual solutions which have been recommended by Bolotin and Brzeziński (2005) for investigations concerning the FCN signal: 1) GSF – series derived at the NASA Goddard Space Flight Center, USA, using the software CALC/SOLVE; 2) MAO – derived at the Main Astronomical Observatory of the National Academy of Sciences of Ukraine, using the software SteelBreeze. These series span the period 1979.0 to 2005.0 and are available from the International VLBI Service (GSF) or from S.B. upon request (MAO).

We use the same geophysical excitation series as Brzeziński *et al.* (2004). In case of the atmospheric excitation this is the AAM series based on results of the NCEP-NCAR reanalysis project (Kalnay *et al.*, 1996; Salstein and Rosen, 1997), available from the IERS Special Bureau for the Atmosphere. The series spans the period from 1948 to 2005 and is sampled 4 times daily. The AAM series consists of the wind (motion) and the pressure (matter) terms. In addition, there is the pressure term corrected for the ocean response using the inverted barometer (IB) model, further denoted AAMIB. The oceanic excitation is expressed by the OAM series derived from a barotropic ocean model forced by the NCEP-NCAR reanalysis fields (Ponte and Ali, 2002). The series consists of the motion and mass (matter) terms. It is sampled hourly and covers the period between 1993.0 and 2000.5. When considering the combined atmospheric and oceanic excitation this OAM series should be added to AAMIB.

In the computations we assume that only the matter term of the excitation functions (pressure term of AAM, mass term of OAM) influences the FCN signal, that is we neglect the motion term; see (Brzeziński, 1994a; Bolotin, this issue) for justification.

We process the input time series in the following way. First, we remove from the VLBI data corrections to the conventional precession-nutation model and derive the corresponding (geodetic) excitation of nutation. Then, we extract from each geophysical excitation series (AAM, AAMIB, OAM) the diurnal retrograde component by complex demodulation at -1 cycle per sidereal day (cpsd). Each demodulated excitation series is reduced by removing the best least squares fit of the model consisting of a sum of first-order polynomial and sinusoids with periods ± 1, $\pm 1/2$, $\pm 1/3$ yr. After smoothing all the series with cut-off period of 2 months, we compare the VLBI-inferred excitation to the combined atmospheric/oceanic excitation assuming three different models of the ocean response to the atmospheric forcing: 1) rigid ocean response with the aggregated excitation represented just by AAM, 2) inverted barometer response, with excitation expressed by AAMIB, and 3) dynamic response, with excitation AAMIB+OAM.

3. RESULTS AND CONCLUSIONS

From Fig. 1a it can be seen that the input VLBI data sets do not differ significantly. However, after computing the corresponding excitation functions (Fig. 1b) the differences between series became more visible. All comparisons illustrated in Figures 2 to 4 and discussed below concern only the VLBI nutation series MAO.

The time domain comparison done in Fig. 2a shows a rough agreement in size of the excitation inferred from VLBI data and the geophysical excitations AAM, AAMIB+OAM, while the variability of AAMIB is considerably lower. Overall correlation between geodetic and geophysical excitations shown in Fig. 2a is rather low: for χ_1 it is -0.206, 0.232, 0.132, for χ_2 it equals 0.068, 0.221, 0.141, where the subsequent numbers refer to AAMIB, AAM and AAMIB+OAM, respectively. The sliding-window correlation analysis (Fig. 3) reveals periods with high correlation, up to 0.8, but also periods with significant negative values.

Comparison of the power spectral densities done in Fig. 2b shows that geophysical excitation functions contain more power at the FCN frequency than the geodetic excitation, by the factor of about 10 for AAMIB and AAM, and as much as about 30 for AAMIB+OAM. But the time interval 1993.0–2000.5 used to estimate the power spectra at the FCN period of 1.18 years is relatively short. When considering the atmospheric excitation over the entire period 1984–2005 with the VLBI data (see the PSD in Fig. 1b), the discrepancy of power almost disappears. The integration of cross-power spectrum in the vicinity of the FCN frequency, yields a high coherence magnitude, between 0.7 and 0.8, for all 3 geophysical excitation series (Fig. 4). But surprisingly, the estimated argument of coherence is close to 180°, that is the geodetic and geophysical excitations are out of phase. Extending interval of comparison to 1984–2000 decreases coherence to 0.3 for AAM and to 0.2 for AAMIB, and changes the argument to about $-90°$.

In conclusion we should say that the reported results though promising in several aspects nevertheless have to be treated as preliminary. Such investigations should be continued using alternative subdiurnal estimates of the atmospheric and oceanic excitation of Earth rotation.

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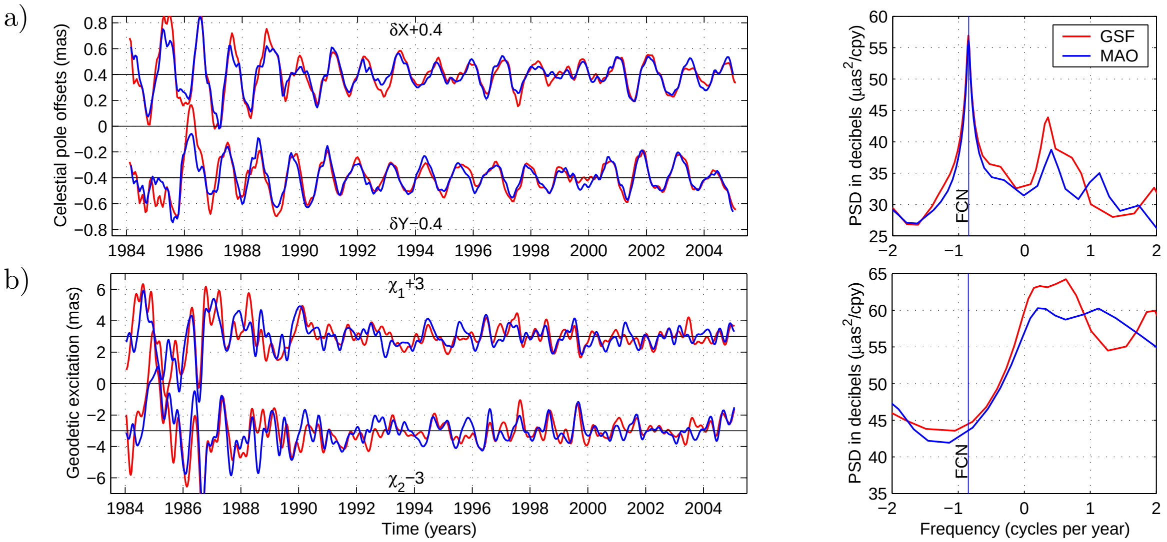

Figure 1: (a) Celestial pole offsets observed by VLBI and (b) the corresponding excitation function. The right-hand side plot show the maximum entropy method power spectra of the complex combinations $P = \delta X + i\delta Y$ and $\chi = \chi_1 + i\chi_2$.

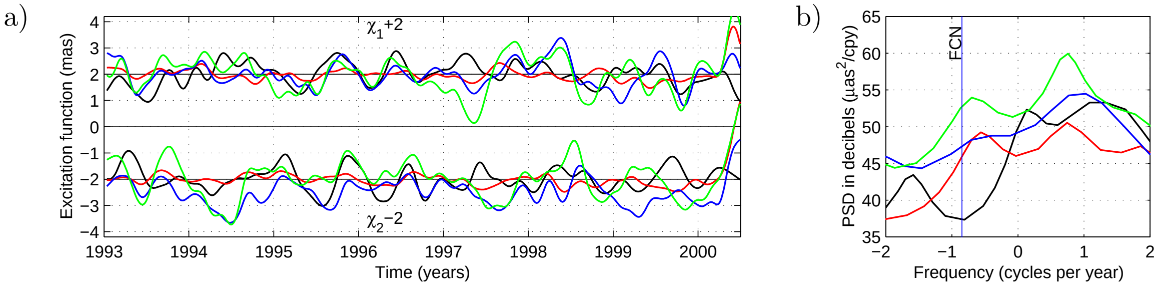

Figure 2: Comparison of the geodetic excitation of nutation (black) with geophysical excitations AAMIB (red), AAM (blue), AAMIB+OAM (green), in (a) time domain, (b) frequency domain.

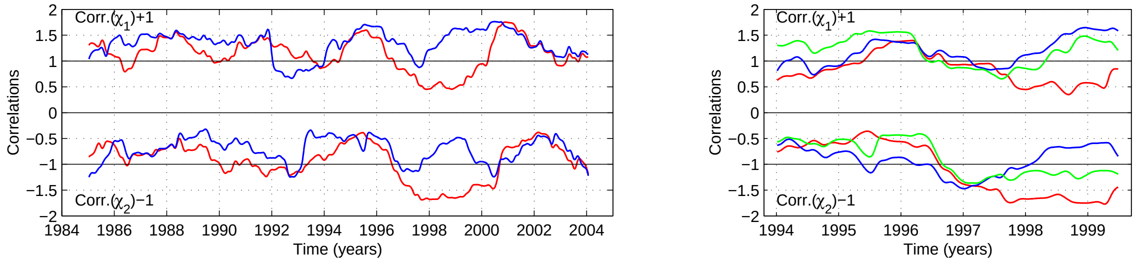

Figure 3: Sliding-window correlation between geodetic and geophysical excitations of nutation: AAMIB (red), AAM (blue) and AAMIB+OAM (green). Window length is 2 years.

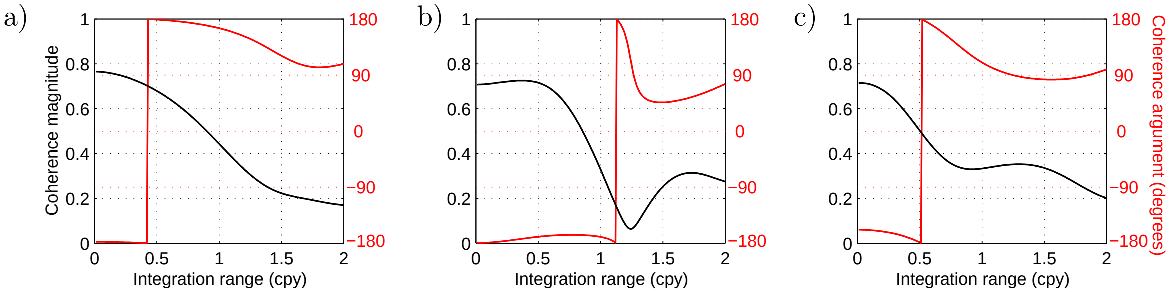

Figure 4: Coherence at the FCN frequency between geodetic and geophysical excitations of nutation (a) AAM, (b) AAMIB, (c) AAMIB+OAM, shown as a function of the length of the cross-power spectrum integration interval. Data span: 1993.0–2000.5.