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Regional atmospheric influence on the Chandler wobble

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Abstract

From the maps of regional contribution to atmospheric angular momentum (AAM) over the period 1948–2011 (NCEP/NCAR reanalysis data) time domain excitation in Chandler frequency band was extracted by Panteleev's filtering method. This permits us to investigate the evolution of the regional atmospheric influence on Chandler wobble. It appears that the temperate latitudes bring the strongest inputs. For pressure term they are limited to continents, and highlight the role of Europe. For the wind term they mostly result from ocean area, encompassing in particular North Atlantic. A quasi-20 year cycle is found in the regional patterns of the atmospheric excitation. The integrated AAM is finally compared with the geodetic excitation reconstructed from the observed polar motion.

Keywords: Earth rotation; AAM; Chandler wobble

1. Introduction

With an average amplitude of 0.2 arcsec Chandler wobble is the main component of the polar motion (PM). It is a resonant oscillation (Lambeck, 1980; Sidorenkov, 2009) but as the Earth is a viscous-elastic body, it should decay with a characteristic time of ~50 years in absence of excitation (Gross, 2000). The maintaining of the Chandler wobble amplitude can be explained by exchange of angular momentum between the solid Earth and the surface fluid layer composed of atmosphere and oceans (Brzezinski et al., 2002, 2012; Brzezinski and Nastula, 2002; Gross et al., 2003; Salstein, 2000). An additional input could come from hydrological processes (Liao et al., 2007; Nastula et al., 2007). A strong argument favouring the role of the surface fluid layer is the correlation noted between Chandler wobble amplitude variation and changeability found in the integrated effective atmospheric angular momentum (EAAM) and effective oceanic angular momentum (EOAM) (Bizouard et al., 2011) from 1950. Because of the proximity with the large annual excitation, it is a more difficult task to extract time domain Chandler excitation in both fluid layer angular momentum and geodetic excitation reconstructed from PM observations. The Chandler excitation reconstruction is an inverse problem. Different methods such as singular numbers truncation or Tikhonov regularization can be used to obtain a pseudo-solution of this problem (Zotov and Panteleev, 2012). To reduce the noise influence on the solution and to select the frequency band of interest, the Panteleev corrective filter was proposed in Panteleev and Chesnokova (2011) and was applied to PM in Zotov and Bizouard (2012) and Zotov (2010). Such a filter tapers the annual and other frequency components prior to the inversion. Zotov and Bizouard (2012) not only show the good agreement between surface fluid layer excitation and geodetic one (reconstructed from

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PM observations) over a 20-year time interval, but also put forward a modulation in Chandler excitation, synchronous with the 18.6-year Lunar tide.

In this paper we aim at localising the atmospheric sources of Chandler excitation by filtering regional AAM inputs in the Chandler frequency band. Like in Liao et al. (2007) and Nastula and Salstein (2012) we will determine the regional contribution to EAAM in Chandler band, but after having designed a narrow-band Panteleev filter as in Zotov and Bizouard (2012). Unlike Nastula et al. (2009, 2012, 2014), we do not calculate covariances between regional contribution to EAAM and excitation. We focus our study on filtered AAM fields in Chandler frequency band and their evolution: animated maps permit to track changes of the atmospheric excitation sources and their geographical location, Hovmoeller plots are used to characterise temporal evolution over latitude and longitude bands.

2. Initial data and method of processing

The Earth's polar motion is commonly modelled by the linear Euler–Liouville equation (Munk and MacDonald, 1960; Lambeck, 1980)

$$\frac{i}{\sigma_c}\frac{dp(t)}{dt} + p(t) = \chi^{tot}(t), \qquad (1)$$

where the complex Chandler angular frequency $\sigma_c = 2\pi f_c(1 + i/2Q)$ depends on real Chandler frequency f_c and quality factor Q. In the dynamical system (1) the complex PM trajectory $p = p_1 + ip_2$ forms an output, which depends on the total input excitation $\chi^{tot} = \chi_1^{tot} + i\chi_2^{tot}$. Large part of this excitation is caused by the atmosphere. It can be described by the EAAM functions $\chi = \chi_1 + i\chi_2$, which can be calculated from the meteorological observations (Brzezinski et al., 2012; Zhong et al., 2002). The χ_1 component is the projection along the x axis of the terrestrial reference frame (TRF), and χ_2 along its y axis. Each of EAAM projections has two components – pressure (mass) χ^P and wind (motion) χ^W. The first one is related to the moment of inertia changes, the second one to the changes of atmospheric momentum with respect to the solid Earth. These one-dimensional time series $\chi^{P,W}$ provided by IERS Global Geophysical Fluids Centre (http://www.iers.org/IERS/EN/DataProducts/GeophysicalFluidsData/geoFluids.html) are usually analysed and compared to the geodetic excitation.

The EAAM functions χ are obtained through integration of regional contribution $X^{P,W}(\lambda,\phi)$ all over the globe (over all the longitudes and latitudes)

$$\chi^{P,W} = \iint X^{P,W}(\lambda,\phi)\,d\lambda d\phi. \qquad (2)$$

So, EAAM includes the sum of inputs of atmospheric variability from different regions of the globe. The fields of $X(\lambda,\phi)$ representing regional contributions to EAAM are called just AAM (without E) throughout this paper.

We used data from NCEP/NCAR reanalysis project, obtained through meteorological data processing with use of numerical weather modelling. The interpolated fields of wind and pressure all over the globe are available since 1948 with 6-h step. The data for different heights (pressure levels) can be found at http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html.

These data were processed and converted to AAM maps at the Center for Astro-geodynamics of Shanghai Astronomical Observatory. For every geographical point of the longitude-latitude grid the regional pressure component was calculated according to the expression

$$\begin{aligned} X^P(\lambda,\phi) &= X_1^P + iX_2^P \\ &= \frac{1.11R^4}{(C-A)g} p_s(\lambda,\phi)\sin\phi\cos^2\phi e^{i\lambda}, \end{aligned} \qquad (3)$$

and the wind component – according to

$$\begin{aligned} X^W(\lambda,\phi) &= X_1^W + iX_2^W \\ &= \frac{1.57R^3}{\Omega(C-A)g}\int (u(\lambda,\phi,p)\sin\phi \\ &\quad + iv(\lambda,\phi,p))\cos\phi e^{i\lambda}dp, \end{aligned}$$

where R and Ω are mean Earth radius and angular velocity; A, C are the principal moments of inertia of the Earth; g is the gravitational acceleration; λ and ϕ are longitude and latitude at a given grid point; p_s is surface pressure; and u, v are zonal and meridional wind velocities. The pressure term was calculated by assuming the Inverted Barometer (IB) hypotheses, i.e. the pressure compensation over water by the changes of its level (Zhou et al., 2006).

The AAM field with 6 h step and 2.5° × 2.5° angular resolution were obtained. Every day has 4 maps and every map has $73 \times 144 = 10{,}512$ longitude-latitude points. In every point we have a time series, which are filtered in the Chandler frequency band by applying the Panteleev band-pass filter (Zotov and Bizouard, 2012). The filter's impulse response is given by

$$h(t) = \frac{\omega_0}{2\sqrt{2}} e^{-\left(\frac{\omega_0|t|}{\sqrt{2}} - i2\pi f_c t\right)}\left(\cos\frac{\omega_0 t}{\sqrt{2}} + \sin\frac{\omega_0|t|}{\sqrt{2}}\right) \qquad (4)$$

with the parameter $\omega_0 = 2\pi f_0$. The filter parameter (defining its width) was selected to be $f_0 = 0.04\ \mathrm{yr}^{-1}$ (see below). The transfer function of the filter (4) in frequency domain is given by expression

$$L_h(f) = \frac{f_0^4}{(f - f_c)^4 + f_0^4}. \qquad (5)$$

It is centred on the Chandler frequency $f_c = 0.8435\ \mathrm{yr}^{-1}$ and does not change the phase of the signal. The filter (5) for the selected f_0 and non-zero f_c is a narrow-band filter. The time-window (4) of ~40 year length corresponds to it. Filtered AAM data thus undergo edge effect. This forces us to remove 20 years of data at the beginning and the end of