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The mantle rotation pole position. A solar component

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ABSTRACT

The direction of the Earth's rotation axis with respect to the mantle has been studied for more than a century. The time variation of this direction is generally considered to be the sum of three components: the annual wobble, forced by the atmosphere, the Chandler wobble, a free oscillation with a period of 435 days, and the so-called drift of the mean pole. In the present paper, applying the singular spectrum analysis (SSA) technique, we uncover two more components, with smaller amplitude than the three first ones, but well identified, periodic with periods of 11 and 5.5 years, respectively, undoubtedly linked to solar activity. We interpret them tentatively as the result of an exchange of kinetic angular momentum between the atmosphere, in which a flow would be generated by solar activity, and the mantle. The order of magnitude of the required mean winds in the atmosphere computed in the frame of a schematic model is 1 ms^{-1}, compatible with the observed values of the meridional mean circulation.

1. Introduction

The Earth's rotation axis, close to the polar inertia axis, presents, with respect to the mantle, variations at different time scales, from daily to secular. The trace of the rotation axis at the surface of the Earth is generally considered to be the sum of three components: the annual wobble, a forced oscillation due to an atmospheric excitation, the Chandler wobble, a free oscillation with a period of 435 days, whose maintaining mechanism is not yet fully understood, and the so-called drift of the mean pole (*e.g.*, Chandler, 1891a; Chandler, 1891b; Gibert and Le Mouël, 2008; Hulot et al., 1996; Lambeck, 2005). In the present paper, we will add a fourth periodic component, that we attribute to solar activity.

In 1967, Karklin (1967) analyzed the International Latitude Service data from 1900 through 1959, and found variations in the amplitude of both the Chandler and the annual oscillations with decadal periods (*e.g.*, 10.3, 12.3, 17.7 years for Chandler) and amplitudes of a few 10^{-2} arcsec (1 arcsec $\sim 4.85 \cdot 10^{-6}$ rad) that he attributed to Solar activity. Jady (1970) estimated the torque exerted by the solar wind on the Earth's magnetic dipole, $\vec{M}$, using a simplified model of magnetosphere (a thin planar, perfectly conducting sheet). He found that the magnitude of the torque ($1.1 \cdot 10^{16}$ J) was smaller than that required to account for the change in the length of the day (l.o.d), but comparable to the lunar tidal torque ($2.7\ 10^{16}$ joules). It seems that this mechanism has not been considered further since then.

2. The SSA analysis of the series of pole positions

We will use here the series of pole positions produced and issued by the International Earth Rotation Service (IERS; web site: http://www.iers.org/IERS/EN/Science/EarthRotation/EarthRotation.html) in the form of a yearly report (EOPC01); the 2015 EOPC01 report is considered. m_x

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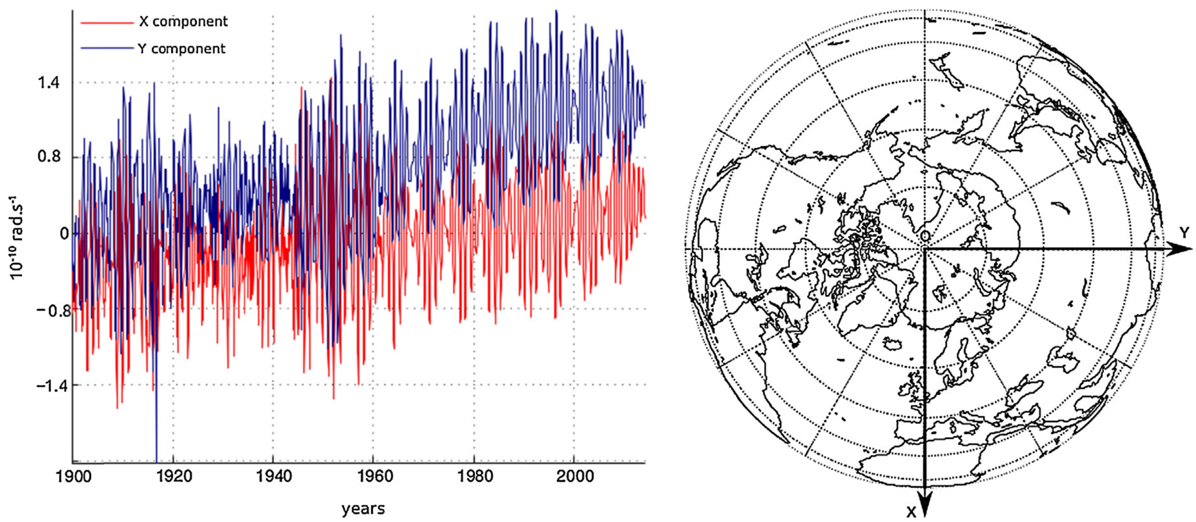

Fig. 1. Polar motion data series (EOPC01) provided by the International Earth Rotation Service. The X and Y components, m_x, m_y, correspond to the red and blue lines respectively. m_x and m_y are given in rad·s^{-1}.

and m_y are the components of the pole position in a tangent plane Oxy at the north pole (or in the equatorial plane). O is a conventional origin, the axis Ox is in the Greenwich meridian, the axis Oy is in the 90°E meridian; the sampling interval is 0.6 month. Data m_x and m_y cover a period from 1900 to 2015 (see Fig. 1); they will be counted in rad·s^{-1}, like the Earth's spin itself. We analyze those series through singular spectrum analysis SSA (Vautard and Ghil, 1989) (see Appendix). The components of the pole motion extracted by SSA are ranked according to their "importance" (that is their amplitude, in a broad sense): first the annual oscillation (SSA component 1, prograde and retrograde), then the Chandler term (SSA component 2, wobble), then with the same "importance" the trend $y_t(t)$ that can be seen as the component of the mean pole drift (SSA component 3). Two other components, with an "importance" two times smaller, are identified mainly along the axis m_y (they are smaller, by about one order of magnitude, along the axis m_x):

- an oscillating component with segments containing quasi-pure sinusoidal variations with a 11-year period and a characteristic amplitude of ~0.5·10^{-12} rad·s^{-1}, which we note m_y^{11}, and a central segment presenting a sine variation with a 22-year period; the amplitude of the latter component is ~1.4·10^{-12} rad·s^{-1}; we note it m_y^{22} (SSA component 4, see Fig. 2). During the reconstruction process of each component obtained with SSA, we regroup them according to the magnitude of their associated eigenvalues (see Appendix). That is why, in this specific case, an oscillating variation composed of two distinct periods is reconstructed;
- a $m_y^{5.5}$ component with a smaller characteristic amplitude (~4·10^{-13} rad·s^{-1}), displaying 5.5-year modulated periodic sine oscillations (SSA component 5, see Fig. 3).

3. A tentative interpretation

We consider here that the periodic oscillations (with periods 22 years, 11 years and 5.5 years) detected in the series of pole positions are manifestations of solar activity for lack of any reasonable alternative. In this short note – devoted essentially to unveiling these periodicities – we do not attempt to propose a full explanation of their presence in the rotation pole series, but only to evoke some elements of a possible mechanism. First, a direct electromagnetic torque exerted by the solar wind on the Earth's main magnetic field, *i.e.* on the conducting core (the dipole according to Jady, 1970), transmitted to the mantle through some kind of core–mantle coupling (*e.g.*, Jackson, 1997; Jault and Le Mouël, 1991) could be envisioned. We have mentioned in the introduction the first attempt made by Jady, concerning l.o.d., but this process appears to lead to insufficient torques. A second mechanism, which we now elaborate somewhat further, involves an action of solar activity on the atmosphere, resulting in flows, or winds, and a transfer of angular momentum from the atmosphere to the mantle.

3.1. Schematic atmospheric flows

Since the vertical component of large scale winds in the atmosphere is small compared with the horizontal one, and the thickness of the different layers is small compared with the Earth's radius r, we assume velocities $\vec{u}$ to be purely horizontal and adopt a thin layer approximation (Chedin et al., 1982). A layer of thickness h, between radii a and b, is replaced by a surface layer of density $H = \int_a^b \rho(r)\mathrm{d}r$ (kg·m^{-2}). The horizontal divergence-free velocity field $\vec{u}_H(\theta, \varphi, t)$ can be represented by an expansion in elementary toroidal vectors,

$$\vec{u}_H(\theta,\varphi,t) = \sum t_n^{m,c}(t)\vec{\theta}_n^{m,c} + t_n^{m,s}(t)\ \vec{\theta}_n^{m,s} \tag{1}$$

with:

$$\vec{\theta}_n^{m(c,s)} = \vec{OP} \wedge \vec{\nabla}_H P_n^m(\cos m\varphi, \sin m\varphi) \tag{2}$$

$\vec{OP} = \vec{r}$ (O the Earth's center), $P_n^m(\cos\theta)$ is the associated Legendre function of the first kind. The t_n^m are coefficients