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A geomagnetic triggering of Chandler wobble phase jumps?

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[1] Taking advantage of a longer series of polar motion data, we investigate again the existence of phase jumps in the Chandler wobble [*Gibert et al.*, 1998]. We point out one more phase jump in 1990, and find again that geomagnetic jerks are followed by phase jumps in the Chandler wobble within at most 3.5 years. *INDEX TERMS:* 1507 Geomagnetism and Paleomagnetism: Core processes (8115); 1530 Geomagnetism and Paleomagnetism: Rapid time variations; 1223 Geodesy and Gravity: Ocean/Earth/atmosphere interactions (3339); 1239 Geodesy and Gravity: Rotational variations

1. Introduction

[2] The Chandler wobble is an excited resonance of the Earth's rotation having a period of about 14 months [*Lambeck*, 1980; *Wahr*, 1988]. Although it has been under investigation for more than a century, its excitation mechanism has long remained elusive. Many mechanisms have been evaluated as possible candidates (atmospheric processes [*Wahr*, 1983], core–mantle interactions [*Hinderer et al.*, 1987], earthquakes [*Dahlen*, 1973; *Gross*, 1986], . . .). It has been admitted for a few years that the Chandler wobble is maintained by a combination of atmospheric and oceanic processes. The demonstration seems rather convincing, as exposed in *Gross* [2000]. Nevertheless, to our knowledge, if it does seem possible that the external excitation does maintain the wobble on a long term, some particular features of the wobble series are not yet interpreted individually. Such is the case of phase jumps in the series. The most notorious is the 1926 phase change [*Guinot*, 1972], up to 180 degrees in less than 2 years. *Gibert et al.* [1998] found, by a wavelet analysis, about ten phase jumps for the 1900–1997 period, and noticed that they appear to correlate with the geomagnetic jerks. It stands to reason that, if confirmed, such a correlation would give new constraints on the geomagnetic jerks mechanism [*Bellanger et al.*, 2001] and new informations on core dynamics. This leads us to test whether or not the most recent jerk is followed by a phase jump in the Chandler wobble.

[3] *Mandea et al.* [2000] proposed that a new jerk probably took place at the end of the 20th century; it is a little too early to ascertain its existence, although the last data from magnetic observatories tend to confirm it. In the same paper, we made some bold related predictions based on the observation of a new jerk at the very end of the last century and revisiting the 1990 one: that the Earth rotation rate will decrease in less than 10 years, and that a phase change in the Chandler wobble is now taking place or will take place within a few years. The lack of hindsight does not give us any chance to confirm these predictions, but the same considerations urge us to study the possible effect of the 1990 jerk [*Macmillan*, 1996] on the Chandler wobble, following *Gibert et al.* [1998] *modus operandi*. In their 1998 paper, the time series of polar motion was too short to permit any firm analysis of the possible phase change following the 1990 jerk. In 2001, it has become possible, despite a persisting edge effect.

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2. Wavelet Analysis of Polar Motion

2.1. Method of Analysis

[4] The theoretical background is identical to the one described by *Gibert et al.* [1998] and the reader is referred to that paper for a full description of wavelet analysis applied to phase jump detection. Theory of wavelet transform from a general point of view can be found, for instance, in *Meyer* [1990] and *Holschneider* [1995].

[5] The X and Y components of the polar motion (the X axis coincides with the Greenwich meridian while the Y axis is on the 90° meridian) are used to form the complex signal $m(t) = X(t) - \mathrm{i}Y(t)$ [*Gibert et al.*, 1998] which is first analyzed with a progressive Morlet's wavelet in order to extract the Chandler component centered on the frequency 0.840 cycle per year (c.p.y.). Next, the prograde wavelet transform of the reconstructed Chandler component is computed with the finest time resolution, and the ridge function — as the set of points where the instantaneous phase velocity of the wavelet coefficients equals the central frequency of the dilated wavelet — is extracted. For a signal with a slowly varying instantaneous phase velocity the ridge follows the instantaneous frequency modulations; and for sudden phase jumps the ridge function presents troughs or peaks (whether phase jumps are positive or negative) whose depths depend on the amplitude and duration of the phase jumps.

[6] The ridge function of the prograde Chandler wobble computed from the International Earth Orientation Service (iers) polar motion data (eopc01 series, http://hpiers.obspm.fr) is displayed on Figure 1.

2.2. Ridge Function Fitting

[7] Following *Gibert et al.* [1998], we model the experimental ridge function with a small number of phase jumps. The model signal is given by,

$$m_s(t) = A_a(t)\exp[2\mathrm{i}\pi \mathrm{t}] + A_c(t)\exp[\mathrm{i}\phi_\mathrm{c}(\mathrm{t})], \tag{1}$$

where $A_a(t)$ and $A_c(t)$ are the envelopes of the prograde annual and Chandler components reconstructed from the data, and

$$\phi_c(t) = \frac{2\pi t}{T_0} + \sum_{n=1}^{N} \frac{\phi_n}{2}\left[\mathrm{erf}\left(\frac{\mathrm{t}-\mathrm{t_n}}{\sqrt{2}\mathrm{T_n}}\right) + 1\right], \tag{2}$$

where the time unit is the tropical year. T_0 is taken equals to 434 mean solar days. The amplitudes ϕ_n, the dates t_n, the durations T_n of the phase jumps and their number N are adjustable parameters of the model. Both $m(t)$ and $m_s(t)$ are analyzed through the same procedure and the best model is the one which reproduces the experimental ridge function with the smallest number of phase jumps.

[8] The best fit to the ridge function is obtained, Figure 2, using 10 phase jumps for the period 1900–2000. Their characteristics are given Table 1 (left side).

2.3. Comparison with the Previous Model

[9] We emphasize that the analyzed polar motion series is not the one used by *Gibert et al.* [1998]. Indeed, the eopc01series, provided by the IERS, is regularly recomputed. In

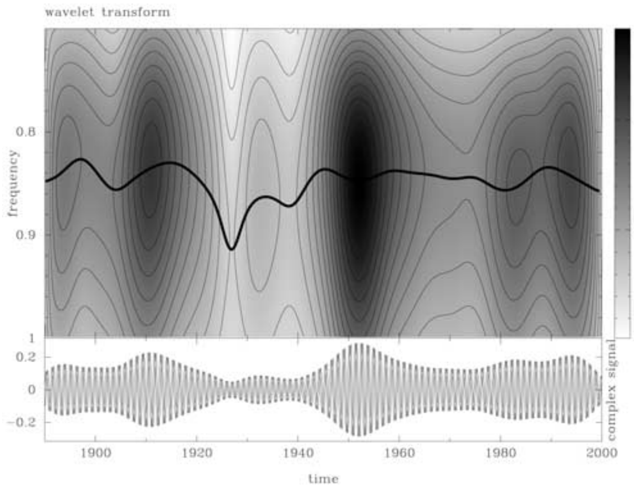

Figure 1. Ridge function and prograde wavelet transform of the reconstructed Chandler component.

Table 1. Phase Jumps for the Ridge Function Model

This Study			Previous Model (*Gilbert et al.*, [1998])		
t_n	ϕ_n	T_n	t_n	ϕ_n	T_n
1903.8	28	1.2	1905.2	29	1.0
1913.7	−26	0.9	1912.0	−24	1.6
1926.7	142	1.8	1926.8	164	1.8
1937.0	132	5.0	1932.8	48	1.5
1945.0	−32	3.0	1940.0	77	1.5
1952.0	12	0.9	1952.3	47	2.2
1959.0	−9	0.6	1953.0	−140	15.0
1973.0	10	1.0	1961.0	17	1.0
1981.0	34	1.5	1969.9	28	1.0
1990.4	−10	1.0	1980.2	44	1.5

t_n are the dates, ϕ_n the amplitudes in degrees and T_n the durations in years of phase jumps.

particular, the Kiev observatory series for the 1900–1961 period has been recently replaced by the more precise and less filtered Vondrak solution [*Vondrak et al.*, 1995]. This updating has a major consequence on the model: a slow phase variation with a duration of about 15 years centered in 1953 (see the seventh phase jump of the previous model, right-hand side of Table 1) is not required anymore. Also, the series used in the present paper is long enough to allow detecting a new phase jump in 1990.

[10] Except for the two phase jumps just noticed, we can observe that both models (Table 1) give approximatively the same dates for the phase jumps, with a maximum time lag of 5 years, more often 1 or 2 years. The sign of ϕ_n is sometimes reversed for the phase jumps contaminated by the slow phase variation considered in the previous model. The good accordance between both models proves the robustness of the analysis method, even if we are not considering the same data and the same non-stationary filtering.

[11] The main conclusion of *Gibert et al.* [1998] was that phase jumps in the Chandler wobble follow geomagnetic jerks. *Alexandrescu et al.* [1996] identified 7 worldwide jerks in 1901, 1913, 1925, 1932, 1949, 1970 and 1980. *Macmillan* [1996] and *Alexandrescu et al.* [1997] observed a jerk in 1990. *Golovkov et al.* [1989] and *McLeod* [1989] pointed out another jerk event in 1939 and 1940, respectively. The phase jumps characteristics and the jerks dates are reported in Figure 3. We observe that the 9 geomagnetic jerks are followed by a phase jump (detected automatically and blindly by the wavelet analysis) within at most 3.5 years. The 1959 phase jump is not associated with a jerk, but almost coincides with the merging of two different series of polar motion data in 1962, and thus can be due to the readjustment of time–series (note also that *Golovkov et al.* [1989] and *Jackson* [1997] list a jerk in 1958, but *Alexandrescu et al.* [1996] did not find any conclusive evidence for it). Satisfactorily, large phase jumps occur during periods where the wobble amplitude is small (Figure 3), since it is all the more

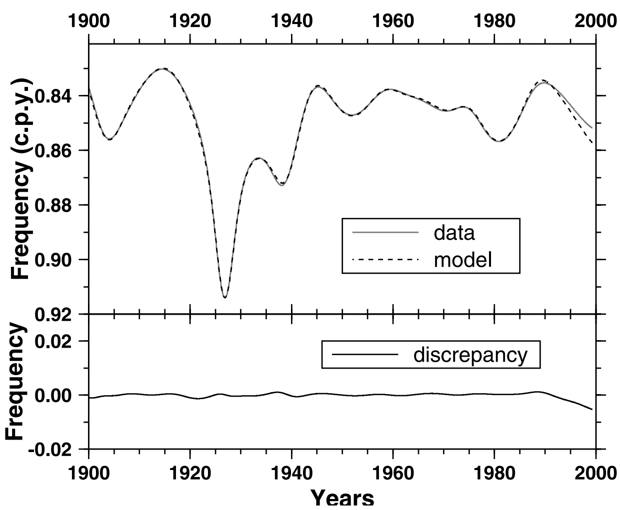

Figure 2. Experimental and synthetic ridge functions (top). Discrepancy (bottom).

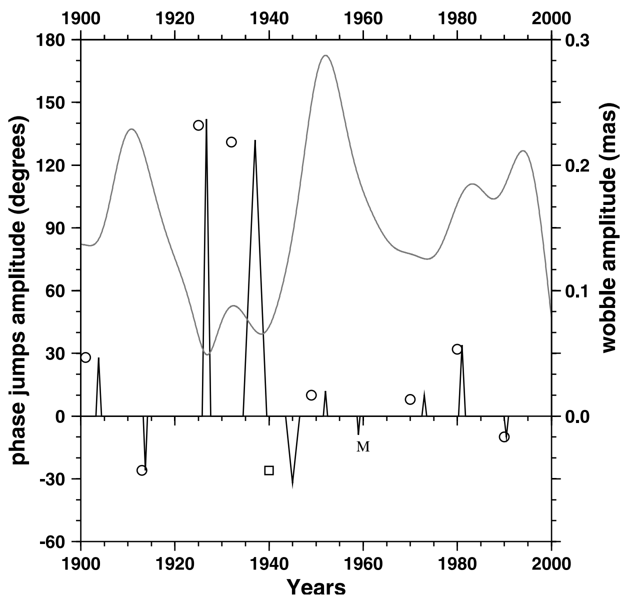

Figure 3. Dates and characteristics of phase jumps (black peaks), dates of jerks (8 circles and 1 square for the jerk reported by *Golovkov et al.* [1989] and *McLeod* [1989]) and amplitude of the wobble (gray line, right scale). The black peaks give the amplitude of the jumps (left scale), the jumps duration, as defined by *Gibert et al.* [1998], is given by the width of the peaks. Letter M denotes the merging of *Vondrak et al.* [1995] series with previous IERS series (see text).

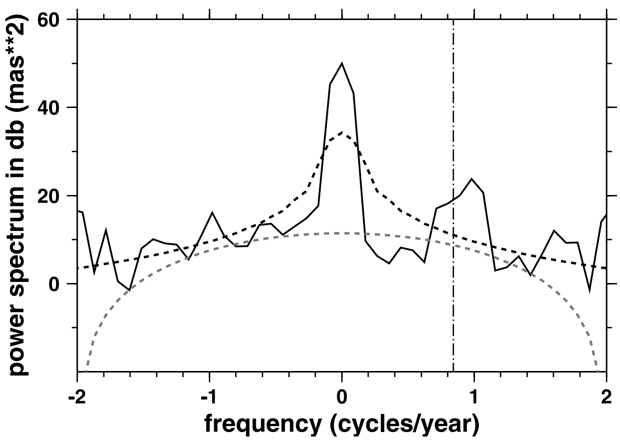

Figure 4. Power spectra of polar motion excitation series spanning 1985–1996: (a) the observed polar motion excitation function (solid curve), (b) the excitation function due to a step of amplitude $5 \cdot 10^{-7}$ (black dashed curve) and (c) the excitation due to a step of finite duration of amplitude $2 \cdot 10^{-7}$ (gray dashed curve). The vertical dashed–dotted line indicates the Chandler frequency.

difficult to change the phase of a pendulum as its amplitude is larger [*Gibert et al.*, 1998].

3. Discussion

[12] Recently *Gross* [2000] and *Aoyama and Naito* [2001] convincingly argued that the Chandler wobble is excited by both atmospheric and oceanic processes, and it seems difficult not to admit that external sources (we mean atmosphere and ocean) maintain the wobble. However that does not preclude perturbations from other transient mechanisms. For instance, the beating of an old–fashioned clock with a pendulum is maintained by the weight mechanism and can nevertheless be temporarily slowed down with a finger. Let us put it into equation:

$$\frac{i}{\sigma_w}\frac{\mathrm{dm}}{\mathrm{dt}} + m(t) = \chi(t) = \chi^e(t) + \sum_{i=1}^{N} \chi_i^c(t), \qquad (3)$$

where N is the number of jerks, and σ_w is the complex Chandler frequency including dissipation. χ, χ^e and χ^c respectively represent the total, external and core–driven excitation functions. For the 1985–1996 period retained by *Gross* [2000], a single core excitation χ^c would take place in 1990. For a step–like $\chi^c(t) = \Psi_0\mathcal{H}(t - 1990)$, the phase change can be generated with $\Psi_0 \simeq 5 \cdot 10^{-7}$ [*Bellanger et al.*, 2001] while for a rectangular excitation $\chi^c(t) = \Psi_0\mathcal{H}(t - 1990)\ \mathcal{H}(1990.5 - t)$, $\Psi_0 \simeq 2 \cdot 10^{-7}$ is enough. The energy spectra of these χ^c models are shown in Figure 4 together with the experimental excitation function computed for the 1985–1996 period using the same parameters as *Gross* [2000] (*i.e.* period 433.0 days and quality factor Q = 179. See also *Dickman and Nam* [1998] for constraints on Q).We can observe that the energy level of the step–like χ^c excitation exceeds the total χ energy in wide frequency intervals. On the contrary, the energy level of the rectangular excitation almost remains at or below the χ energy level. In the Chandler wave–band, the energy of both excitation models is much lower than the χ one, leaving the possibility for a large external excitation χ^e as evaluated by *Gross* [2000].

4. Conclusion

[13] To our knowledge, no particular behavior of the atmosphere and oceans can explain the observed phase jumps in the Chandler wobble. *Gibert et al.* [1998] proposed a correlation between phase jumps and geomagnetic jerks. This argument can be regularly buttressed up: each jerk occurrence should be followed by a phase jump in the Chandler wobble. Taking advantage of a longer series, we performed the analysis used by *Gibert et al.* [1998] in order to see whether or not the 1990 jerk precedes a phase change. We insist on the fact that phase jumps are detected blindly and that dates of geomagnetic jerks are not used as an a priori information: the only hypothesis is that phase variations in the Chandler wobble can be explained by phase jumps which number, dates, durations and amplitudes are free parameters. It appears that a phase change, of modest amplitude is indeed located in 1990.

[14] The proposed correlation between the dates of geomagnetic jerks and those of the Chandler wobble phase jumps gives new constraints on geomagnetic jerks mechanism. The fact that the jerks lead the phase jumps strongly suggests that changes in the fluid flow at the core-mantle boundary (CMB) generate additional core-mantle torques which are responsible for the phase jumps. On one hand, an abrupt (of time constant short compared with 434 days) and strong torque is needed to generate phase jumps, and on the other hand, the magnetic field (and hence the velocity at the CMB, under the frozen flux hypothesis) seems to evolve too smoothly. The problem raised by these apparently irreconcilable observations, derived from the analysis of rotation and geomagnetic data, requires, to be solved, to revisit the physics of the fluid flow at the top of the core and its action on the mantle's rotation; a first attempt was made in [*Bellanger et al.*, 2001].

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