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ON THE EXCITATION OF THE EARTH'S POLAR MOTION

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Abstract. One of the conclusions reached by recent studies of Barnes et al. and later Hide was "that atmospheric excitation alone was sufficient to account for the observed polar motion over (the studied) period, that there is apparently no need to invoke substantial excitation either by the fluid core or . . . earthquakes." The purpose of the present paper is to point out that their argument that led to the above conclusion is unjustifiable (hence whether the conclusion is in reality true or not is still an open question). I demonstrate this through a physical "thought" experiment and a numerical simulation. In essence, they show that if we want to compare a geophysically observed excitation function $\psi_a(t)$ with the excitation function deduced (via deconvolution) from the polar motion observation $m(t)$, we should do so directly (the "direct approach"). To compare $m(t)$ with the polar motion computed (via convolution) from $\psi_a(t)$ (the "integration approach"), as Barnes et al. and Hide did, is misleading.

Introduction

The motion of the Earth's rotation axis with respect to the geographical reference frame, known as the polar motion, has been observed for nearly a century now. It consists mainly of an annual wobble and a 14-month Chandler wobble. The annual wobble is a forced motion believed to be caused by seasonality in the atmosphere and hydrosphere. The Chandler wobble is a mode of the Earth's free oscillation which has been, and is being, continually excited. The evidence is two-fold: (i) without excitation the Chandler wobble would have died away a long time ago due to energy dissipation in the Earth, and (ii) the observations do show changes in the amplitude and phase of the Chandler wobble. However, despite decades of effort by many investigators, the major excitation source(s) for the Chandler wobble still remain a mystery.

In a recent study, Barnes et al. [1983] made, among other things, a detailed comparison of the polar motion with global meteorological data for the period 1/1981 - 4/1982 (about 1.1 Chandler periods in length). One of the main conclusions they reached was "that atmospheric excitation alone was sufficient to account for the observed polar motion over that period, that there is apparently no need to invoke substantial excitation either by the fluid core or . . . earthquakes" (henceforth referred to as the CONCLUSION). Hide [1984] later extended this analysis to include 12/1979 - 2/1984 (about 3.6 Chandler periods in length), endorsing the same CONCLUSION. The importance of these work is quickly being recognized. Unfortunately, due to a stumble in their reasoning, the CONCLUSION is unjustified. My argument is as follows.

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A "Thought" Experiment

Let us consider the following "thought" experiment. Suppose we place two identical, heavy pendulums some distance apart in a turbulent wind. We set the pendulums in motion starting from the same initial conditions and record their motions $m_1(t)$ and $m_2(t)$ for a few cycles. Upon close examination, we notice that the two functions $m_1(t)$ and $m_2(t)$ are not exactly the same — they have been perturbed by "random" excitation fucntions $\psi_1(t)$ and $\psi_2(t)$ of the wind, respectively. Yet by and large $m_1(t)$ and $m_2(t)$ look rather alike (and incidentally, rather smooth). Can we then conclude that the two excitation functions $\psi_1(t)$ and $\psi_2(t)$ are the same, at least approximately? The answer, of course, is "no" because the observed motions $m_1(t)$ and $m_2(t)$ are predominantly a free motion set off by the initial conditions. As long as the initial conditions are the same, we will always have $m_1(t) \simeq m_2(t)$ regardless of how different $\psi_1(t)$ an $\psi_2(t)$ are. In other words, the observed motion $m(t)$ is insensitive to the excitation function $\psi(t)$. Mathematically, $m(t)$ is the convolution of $\psi(t)$ with the pendulum's free motion $m_o(t)$. No matter how "rugged" $\psi(t)$ is, its convolution with $m_o(t)$ will yield a rather smooth $m(t)$ which, within a few cycles at least, does not differ much from $m_o(t)$ itself (for details see discussions pertaining to Equation 1 below). With known $m_o(t)$, we can recover $\psi(t)$ from $m(t)$ via deconvolution. The point here is that if we want to compare $\psi_1(t)$ with $\psi_2(t)$, we should do so directly. Comparing $m_1(t)$ and $m_2(t)$ instead is, to say the least, misleading.

Back to Polar Motion

The swing of the pendulums in the above example is physically analogous to the Earth's polar motion. The latter is being excited (by some unknown means) just as the pendulums were perturbed by the turbulent wind. The only (formal) difference is that the functions are now complex-valued functions reflecting the 2-dimensional nature of the polar motion. To be more specific, the observed polar motion $m(t)$ can be expressed [c.f. Munk & MacDonald 1960, p. 46] as the sum of an "initial condition" term (see below) and the convolution of some (unknown) excitation function $\psi(t)$ with the free Chandler wobble $m_o(t)$, which is the impulse response of the Earth filter:

$$m(t) = m(0)exp(i\sigma t) + \psi(t) * m_o(t). \qquad (1)$$

where $m(0)$ is the initial position $m(t)$ at $t=0$, $\sigma = 2\pi/(435\text{days})$ is the Chandler frequency, and the asterisk denotes temporal convolution. Note that for simplicity we have taken σ to be real-valued since the energy dissipation within a few cycles is