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Autoregressive Harmonic Analysis of the Earth's Polar Motion Using Homogeneous International Latitude Service Data

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The homogeneous set of 80-year-long (1900–1979) International Latitude Service (ILS) polar motion data is analyzed using the autoregressive method (Chao and Gilbert, 1980), which resolves and produces estimates for the complex frequency (or frequency and Q) and complex amplitude (or amplitude and phase) of each harmonic component in the data. Principal conclusions of this analysis are that (1) the ILS data support the multiple-component hypothesis of the Chandler wobble (it is found that the Chandler wobble can be adequately modeled as a linear combination of four (coherent) harmonic components, each of which represents a steady, nearly circular, prograde motion, a behavior that is inconsistent with the hypothesis of a single Chandler period excited in a temporally and/or spatially random fashion), (2) the four-component Chandler wobble model "explains" the apparent phase reversal during 1920–1940 and the pre-1950 empirical period-amplitude relation, (3) the annual wobble is shown to be rather stationary over the years both in amplitude and in phase, and no evidence is found to support the large variations reported by earlier investigations, (4) the Markowitz wobble is found to be marginally retrograde and appears to have a complicated behavior which cannot be resolved because of the shortness of the data set.

1. Introduction

The earth's rotational axis does not remain fixed relative to the body of the earth. Instead, the intersection of the axis with the surface of the earth (i.e., the pole) traces out a quasi-periodic path about some (slowly drifting) mean position on a scale ≤ 0.3 arc sec = 10 m. This motion is known as the polar motion of the earth. The polar motion in principle consists of a number of components arising from various dynamical processes [see, e.g., *Rochester*, 1973]. The most prominent ones (with amplitude above the 0.01 arc sec level, say) in the International Latitude Service (ILS) polar motion data include the annual wobble, the 14-month Chandler wobble, a "Markowitz wobble" with a period of about 30 years (first reported by *Markowitz* [1960] as having a period of 24 years), and a linear secular drift (or the polar wander) [see, e.g., *Wilson and Vicente*, 1980]. The present paper is aimed principally at a numerical analysis (rather than a geophysical interpretation) of the ILS data by means of the "autoregressive" method [*Chao and Gilbert*, 1980], which has been successfully applied to the analysis of data of earth's normal modes of free oscillations [*Chao and Gilbert*, 1980; *Masters and Gilbert*, 1983]. All of the four said motions will be studied, with emphasis on the Chandler wobble, whose mysterious behavior has defied an unambiguous analysis and has aroused a great deal of controversy.

One of the fundamental questions concerning the Chandler wobble is the following: Is the observed Chandler wobble the manifestation of a single decaying sinusoid excited more or less randomly in space-time by some yet unidentified source(s) or is it the consequence of a beating phenomenon of more than one component having close periods? In this paper, we show that the homogeneous set of 80-year ILS polar motion data is consistent with the multiple-component hypothesis. In fact, it is found that the ILS Chandler wobble can be adequately modeled as a linear combination of as many as four (coherent) sinusoidal components. However, first, let us be warned of the pitfalls in power spectral analysis, the technique commonly used in treating data of a periodic nature, such as the polar motion.

2. Some Notes on the Use of Power Spectra and Data Windows

Take a noisy time series containing a number of sinusoidal components (whether pure, decaying, or growing) that have different signal amplitudes and are very close together in frequency, with frequency difference of the order of 1/(total length), say. Suppose we hope to analyze each and every component. A common practice to obtain the frequency estimates is to calculate a discrete Fourier power spectrum (DFPS) and identify the spectral peaks. Unfortunately, in the present case, the DFPS is a "dangerous" frequency estimator. For one thing, if the DFPS is obtained through a fast Fourier transform (FFT) algorithm, the frequency resolution is generally inadequate to give satisfactory frequency estimates and may even lead to completely erroneous conclusions (for an example, see *Buland and Gilbert* [1978]). This can be easily remedied by directly interpolating around the spectral peaks using discrete Fourier transform (DFT) or, often more efficiently, by padding zeros at the end of the series (normally several times as long as the series itself) and then running the FFT to get a denser DFPS. However, a more serious problem arises from spectral leakage (manifesting itself as side bands around the spectral peaks) which, in turn, is caused by the end effects (or, equivalently, by the finiteness of the record length) of the time series. This interference can, and usually does, considerably bias the DFPS frequency estimates (for an example, see *Dahlen* [1982]) and may even introduce spurious peaks.

The latter problem can be greatly reduced by the technique of time-domain windowing, which will play an important role in our study to follow. A time-domain window, in a nutshell, is a bell-shaped taper to be multiplied into the time series under consideration prior to DFT in order to reduce spectral leakage. However, it does so at the expense of the sharpness of the spectral peaks; so a good window represents some optimum compromise (for a review, see, for example, *Harris* [1978]). Because of this, the windowed DFPS is, at its best, an un-

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