THE SOURCE OF THE VARIABLE CHANDLER WOBBLE

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In the absence of forcing, the Chandler wobble (CW) would have a period of 430.3 days, and would lose most of its energy after a few decades because of dissipation in the mantle and in the oceans. Observation of the Earth's polar motion, however, reveals a prograde oscillation of which pseudo period can be as far as 20 days from the above value (Vondrak 1988). It gains energy at some epochs (Danjon & Guinot 1954) so that it never disappears. The CW excitation is accounted for, on average, by the atmosphere and oceans (Gross 2000, Brzeziński & Nastula 2002), but its variability is so far poorly explained. We attempt to interpret it as consequence of the hydro-meteorological forcing, as suggested by Plag (1997), Celaya et al. (1999), and Seitz & Schmidt (2005). At periods larger than 2 days and for a deformable Earth surrounded by fluid layers, the time evolution of the complex pole coordinates $p = x - iy$ is given by Barnes et al. (1983):

$$p + i\frac{\dot{p}}{\sigma_c} = \frac{1.02c}{(C-A)\Omega} + \frac{1.43h}{(C-A)\Omega} \tag{1}$$

where $\sigma_{\rm c} = \sigma_0(1 + i/2Q)$ is the Chandler frequency, $c = c_{13} + ic_{23}$ and $h = h_1 + ih_2$ are respectively the off-diagonal moment of inertia and the equatorial relative angular momentum of the fluid layer, and A and C are respectively the mean equatorial and axial moments of inertia of the Earth. The LHS of (1) is referred to as the geodetic excitation $\chi_{\rm g}$, while the RHS $\chi_{\rm f}$ is referred to as the geophysical (or fluid) excitation. The theoretical computation of $\sigma_{\rm c}$ leads to a period of 430.3 days and a quality factor of $Q = 88$ (Mathews et al. 2002). Those values are consistent with estimates based on analyses of polar motion time series.

The most common approach to explain the Chandler wobble excitation by external fluid layers consists in computing $\chi_{\rm g}$ from observed pole coordinates, and comparing it against $\chi_{\rm f}$ directly given by fluid layer angular momentum time series. Conversely a modeled polar motion obtained by time integration of (1) can be directly compared with the observed pole coordinates:

$$p_{\rm f}(t) = p_0(t_0)\mathrm{e}^{i\sigma_{\rm c}(t-t_0)} - i\sigma_{\rm c}\mathrm{e}^{i\sigma_{\rm c}t}\int_{t_0}^{t}\chi_{\rm f}(t')\mathrm{e}^{-i\sigma_{\rm c}t'}\mathrm{d}t', \tag{2}$$

where t_0 is the time origin of the integration. The first term represents a damped, free wobble of relaxation time $2Q/\sigma_0 \sim 40$ years for $Q = 100$. This progressive damping is not observed, but balanced by the integral expressing the forced polar motion. The latter term mainly contains the effects of the seasonal forcing and an oscillation emerging in the Chandler signal.

We used the pole coordinates of the combined C 01 series, computed at the International Earth Rotation and Reference Systems Service Earth Orientation Parameter Product Center (EOP PC 2010). We considered the geophysical forcing made up of (i) atmospheric angular momentum (AAM) as given by the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis project (SBA 2010), and (ii) oceanic angular momentum (OAM) output from the ECCO model in a near-global domain (SBO 2010). The model is forced by NCEP/NCAR reanalysis products.

Using (2), we computed the modeled polar motion $p_{\rm f}(t)$ from the geophysical excitation by a trapezoidal integration. The value of the observed CW at t_0 was taken as initial condition. Doing so, we assumed that the atmosphere and the oceans are the only sources of the observed CW, thus neglecting the contribution of continental waters. The CW was extracted from the observed and modeled polar motions by singular spectrum analysis, a technique that allows one to isolate quasi periodic modes without any assumption on their periods. We chose a covariance lag close to 6.4 years in order to separate the CW from the annual oscillation of which amplitude is of the same order of magnitude (Fig. 1a). We repeated the integration of the geophysical data sets and the comparison with observed polar motion using different values for Q and computed the regression coefficient between the observed and modeled

(a) Amplitude and phase variations (b) Regression coefficient as function of Q

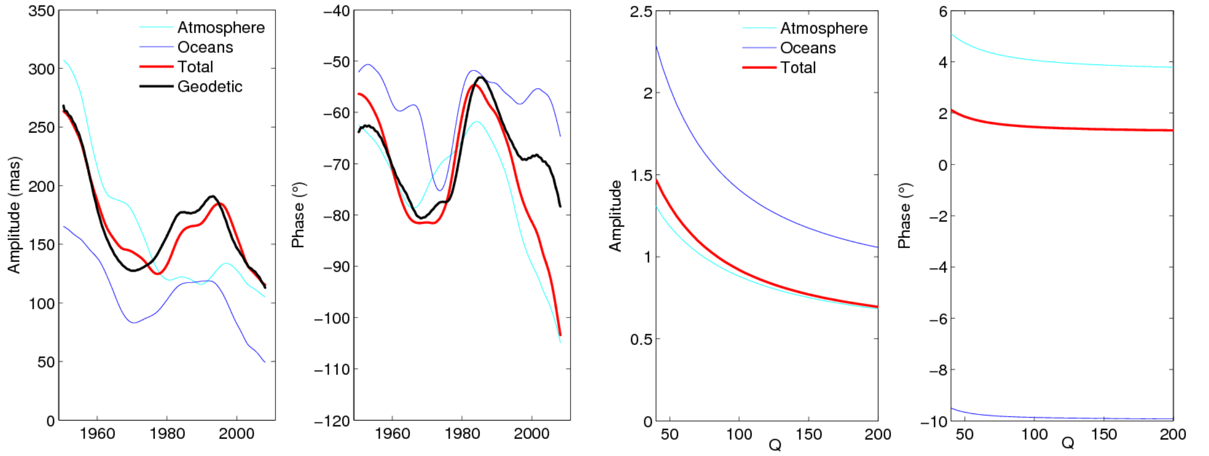

Figure 1: Variability of the observed and modeled Chandler mode: (a) amplitude and phase variations (b) regression coefficient as a function of Q

Chandler modes (Fig. 1b). The value $Q \sim 84$ produces an optimal regression. The amplitude and phase of the observed and modeled CW obtained with $Q = 84$ are displayed in Fig. 1. The regression coefficient between the observed and modeled CW is $1.001 + 0.027\,i$. The atmosphere alone poorly accounts for the CW irregularities. Though it explains the large amplitude before 1960, the minimum around 1970 and the bump in 1980–1990 is mainly due to the oceans. The atmospheric contribution remains stable within the same period. Similar remarks can be made for the phase variations before 1995. Around 2000, the phase of the observed CW presents a bump around $-70°$. The phase shifts of the CW are equivalent to variations of the observed Chandler period that can reach 33 days, corresponding to the period for which the forcing exhibits maximal energy in the vicinity of the eigenperiod. We repeated the integration using different starting epochs t_0, and we computed the regression coefficient between the observed and modeled Chandler modes. The combination of the atmosphere with the oceans generally drew the amplitude of the regression coefficient towards unity and the phase closer to zero.

Our results show that the integration of the NCEP/NCAR reanalysis project's atmospheric data, combined with the ECCO oceanic data, explain most of the observed variations in the CW amplitude and phase since the middle of the twentieth century. The integration approach therefore constitutes a valuable alternative method, which has the advantage of being more intuitive from the point of view of the astronomer who directly observes the position of the pole.

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