Parameter variability of the observed periodic oscillations of polar motion with smaller amplitudes

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Received: 26 August 2002 / Accepted: 27 May 2003

Abstract. Compared to the Chandler and annual wobbles, the higher-frequency components of polar motion (PM) have substantially smaller amplitudes. Therefore, their study has had to wait until higher-quality time series with high temporal resolution, as measured by space geodetic techniques, have become available. Based on the combined Earth orientation series SPACE99 computed by the Jet Propulsion Laboratory (JPL) from 1976 to 2000 at daily intervals, the periodic PM terms, in particular at the quasi-biennial, 300-day, semi-Chandler, semi-annual, 4-month, 90-day, 2-month and 1.5-month periods, have been separated by band-pass filtering and it has been found that the persistence of oscillations becomes less with increasing frequency. In order to quantify and better describe the parameter variability of these PM components over time, the radii, direction angles and period lengths were computed from the periodic terms filtered out from the time series. The results clearly show the characteristics and time evolution of the periodic PM components. The largest elliptic oscillation is the semi-annual wobble with a maximum semi-major axis of up to 13 mas (milliarc seconds). The other wobbles are smaller. They have maximum semi-major axes of between 3 and 8 mas. If the oscillations have period lengths of 4 months and less, then they are elapsed not only progradly, but also retrogradly.

Keywords: Polar motion – Periodic components – Parameter (radii, directions, period lengths) – Variability

1 Introduction

Variations in the Earth’s rotation relative to the terrestrial body-fixed reference frame are measured by polar motion (PM) and changes in the length of day (LOD). The theoretical foundations for such phenomena, especially PM, were derived between the mid 18th and mid 19th centuries (Euler 1758; Lagrange 1788; Poinsot 1834; Peters 1844). In order to confirm the existence of the PM of the Earth in terms of latitudinal variations, intensive efforts were undertaken at several observatories towards the end of the 19th century. This was finally achieved by Küstner (1888) in observations carried out between 1884 and 1885 at the Berlin Observatory.

In 1899, the Central European Arc Measurement (i.e. the forerunner of the International Association of Geodesy, IAG) established the International Latitude Service (ILS) as the first permanent worldwide scientific cooperation in order to monitor the motion of the Earth’s pole of rotation (Helmert and Albrecht 1899). In 1962, since the PM was derived from both latitude and longitude variations, the ILS was renamed the International Polar Motion Service (IPMS). Since the mid 1970s, precise space geodesy techniques such as VLBI (very long baseline radio interferometry), LLR (lunar laser ranging) and SLR (satellite laser ranging) have been used, while since 1992 GPS (global positioning system) and DORIS (Doppler orbit determination and radiopositioning integrated on satellite) have come into use. In 1988, the IPMS was discontinued with the commencement of the International Earth Rotation Service (IERS). For details on the history of the study of PM see, for example, Höpfner (2000) and the references therein. An overview of the historical and scientific problems of PM can be found in Dick et al. (2000).

PM data is available from the mid 19th century to the present. Based on the measurements of the Earth orientation parameters by optical astrometry, there are a number of PM solutions in terms of ILS and non-ILS time series. A review of these PM time series can be found in Höpfner (2000). Compared to the earlier PM data, the combined Earth orientation series based on the precise space geodetic measurements has a higher accuracy and a higher temporal resolution.

Recent studies dealing with the substantially smaller PM components are those of Kołaczek (1992, 1993), Kołaczek and Kosek (1993), Höpfner (1995, 1996), Kosek et al. (1995), Kosek and Kołaczek (1997) and
Kolacze et al. (2000). Some details of these studies should be noted.

Kolacze (1992, 1993) studied the short-periodic oscillations of PM and found that those with periods ranging from 50 to 120 days are the most energetic components after the Chandler and seasonal wobbles. In order to explain the origin of these oscillations, correlations of them with such oscillations of atmospheric angular momentum variations were determined and studied by Kolacze and Kosek (1993). Based on the combined time series EOP(IERS)C04 from 1976.5 to 1988.0, Höpfner (1995, 1996) computed the parameter of the semi-annual and semi-Chandler wobbles, together with those of the annual and Chandler wobbles for the trigonometric, exponential and elliptic representations. Using the time series of atmospheric angular momentum variations, the atmospheric excitation portions at annual and semi-annual frequencies were also determined. Kosek et al. (1995) investigated the variability of oscillations of PM with periods from 20 to 150 days between 1979 and 1991. Kosek and Kolacze (1997) studied the semi-Chandler and semi-annual oscillations. In particular, the pole paths of both wobbles were displayed for 1983–1992. Kolacze et al. (2000) investigated the sub-seasonal oscillations, in particular those with periods of 120, 62 and 49 days, and found maximum correlation coefficients between geodetic and atmospheric excitation functions of the order of 0.6–0.8.

Using the combined Earth orientation series SPACE99, as computed by the Jet Propulsion Laboratory (JPL) from 1976 to 2000 with 1-day sampling (Gross 2000), we have studied the dominant components of PM, including the low-frequency component (the secular drift of the Earth’s pole) and the Chandler and annual wobbles, focusing on quantifying their temporal variability (Höpfner 2001a). The remaining motions, after removing the major terms from the PM coordinates of the time series SPACE99, were analysed with respect to the PMs with smaller amplitudes (Höpfner 2001b). In this study, we continue our previous PM investigations, the objective being to quantify and better describe the parameter variability of substantially smaller PM components over time.

### 2 Fundamentals

In order to study the behaviour of variable oscillations over time it is suitable to separate them by using filters. Therefore, linear transversal band-pass filters with the form of a moving weighted average have been designed for separating the PM terms from daily values at the quasi-biennial, 300-day, semi-Chandler, semi-annual, 4-month, 90-day, 2-month and 1.5-month periods. In particular, the filters have a cosine shape modified over four periods as weight function, except for the quasi-biennial filter with two periods. The characteristics of the filters are given in Table 1, and their amplitude characteristics are shown in Fig. 1. Note that the amplitude characteristic for the quasi-biennial filter is similar, but is not shown here.

As seen in Fig. 1, the response functions of the semi-Chandler and semi-annual filters partially cover each other. The same is the case for the 2- and 1.5-month filters. Therefore, in order to derive optimal solutions for the semi-Chandler and semi-annual oscillations as well as for the 2- and 1.5-month oscillations, we made use of recursive band-pass filtering; for more details, see Höpfner (2001a,b).

We need to use the polar coordinate system to quantify and better describe the parameter variability of the periodic oscillations of PM over time. Therefore, we compute the radii (amplitudes), their direction angles and the period lengths for the different components.

For each periodic oscillation of PM

\[ x_f(t) = x_{1,f}(t) + i x_{2,f}(t) \]  

with a frequency \( f \) and the time variable \( t \), the radii (amplitudes) \( r_f(t) \) and direction angles \( \gamma_f(t) \) are expressed as

\[ r_f(t) = |x_f(t)| = |x_{1,f}(t) + i x_{2,f}(t)| = \left( x_{1,f}(t)^2 + x_{2,f}(t)^2 \right)^{\frac{1}{2}} \]  

and

\[ \gamma_f(t) = \arctan \frac{x_{2,f}(t)}{x_{1,f}(t)} \]  

Concerning an elliptic motion, the maxima of the radii (amplitudes) \( r_f(t) \) are the semi-major axes \( a \) at the times \( t_a \) and the minima the semi-minor axes \( b \) at the times \( t_b \)

\[ a = r_f(t_a) = \max \{ r_f(t) \} \]
\[ b = r_f(t_b) = \min \{ r_f(t) \} \]  

while the pertinent direction angles \( \gamma_f(t) \) are their directions \( \gamma_a \) and \( \gamma_b \)

\[ \gamma_a = \gamma_f(t_a) \]
\[ \gamma_b = \gamma_f(t_b) \]  

Note that the semi-major and semi-minor axes and their directions are determined for actual time points of a periodic oscillation in the polar coordinate system.

<table>
<thead>
<tr>
<th>Filter</th>
<th>Number of points used in each filtering</th>
<th>Related edge effect: points lost at either end</th>
<th>Half-power points of the filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quasi-biennial</td>
<td>1645</td>
<td>822</td>
<td>572 and 924</td>
</tr>
<tr>
<td>300-day</td>
<td>1225</td>
<td>612</td>
<td>249 and 324</td>
</tr>
<tr>
<td>Semi-Chandler</td>
<td>925</td>
<td>462</td>
<td>188 and 245</td>
</tr>
<tr>
<td>Semi-annual</td>
<td>787</td>
<td>393</td>
<td>160 and 208</td>
</tr>
<tr>
<td>4-month</td>
<td>525</td>
<td>262</td>
<td>107 and 139</td>
</tr>
<tr>
<td>90-day</td>
<td>395</td>
<td>197</td>
<td>80 and 104</td>
</tr>
<tr>
<td>2-month</td>
<td>263</td>
<td>131</td>
<td>53 and 69</td>
</tr>
<tr>
<td>1.5-month</td>
<td>199</td>
<td>99</td>
<td>43 and 55</td>
</tr>
</tbody>
</table>