HIGH FREQUENCY FLUCTUATIONS OF POLAR MOTION DURING IGS'92 CAMPAIGN

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ABSTRACT. During IGS'92 Campaign seven PM(Polar Motion) series provided by GPS Processing Centers are analysed in this paper. Some similar high frequency fluctuations in these PM series are detected by using spectral analyses, least square adjustment and F-test as follows: there are short periodic fluctuations of 27.0, 16.5, 13.4, 10.4 day in X direction; and of 10.0, 20.5, 15.8 day in Y direction. And there are similar systematic deviations derived from the comparison of each series with EOP(IERS) 92 C 04. The main cause of these systematic deviations is that the rotation between the reference frames of these series and ITRF91 exists. As for the reason, the coordinates of stations are not fixed (or partly fixed only) when solving X and Y with GPS data. The high frequency fluctuations of polar motion are explained to some extent by the excitation of atmospheric angular momentum.

1. Introduction

With the improvement of GPS observational precision and the increase of the observations, especially due to its convenience and cheapness, GPS has become an important technique for geodesy and geodynamics. GPS Coordinating Centre was set up by IERS at 1989. Some scientific results have been attained from the GIG'91 Campaign (Jan.22- Feb.13,1991) which is the first attempt at coordinating on an international basis and is the efforts of a number of participants in deploying a globally distributed network of GPS tracking stations\textsuperscript{[1]}. IGS'92 Campaign completed its scientific task during Jun.21-Sep.22,1992. More than six hundred stations took part in EPOCH'92 (Jul.26-Aug.8) in which VLBI, SLR and LLR were also adopted in order to compare various techniques. Shanghai Observatory(China) attended this Campaign, and has processed global GPS data. There is now a total of eight GPS analysis centers contributing on a regular basis their EOP(Earth Orientation Parameters) and TRF(Terrestrial Reference Frame)results to the IERS Central Bureau and sub-Bureau for rapid service and predictions. During IGS'92 Campaign, some polar motion series accumulated by these centers are analysed and compared in this paper.
2. Materials and data used

Six polar motion series discussed in this paper are obtained from IGS'92 Earth Orientation Bulletin (Table 1).

<table>
<thead>
<tr>
<th>No.</th>
<th>Series</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>EOP(CSR) 92 P 01</td>
<td>27 Jun. - 5 Sep. 1992</td>
</tr>
<tr>
<td>3</td>
<td>EOP(JPL) 92 P 02</td>
<td>27 Jun. - 5 Sep. 1992</td>
</tr>
<tr>
<td>4</td>
<td>EOP(SIO) 92 P 03</td>
<td>27 Jun. - 5 Sep. 1992</td>
</tr>
<tr>
<td>5</td>
<td>EOP(ESOC) 92 P 01</td>
<td>27 Jun. - 5 Sep. 1992</td>
</tr>
<tr>
<td>6*</td>
<td>EOP(GFZ) 92 P 01,02</td>
<td>27 Jun. - 5 Sep. 1992</td>
</tr>
<tr>
<td>7</td>
<td>EOP(SHA) 92 P 01</td>
<td>24 Jul. - 10 Aug. 1992</td>
</tr>
<tr>
<td>8**</td>
<td>EOP(COM.) 92 P 01</td>
<td>27 Jun. - 5 Sep. 1992</td>
</tr>
</tbody>
</table>

* Because EOP(GFZ) 92 P 01,02 is not in the same series, we do not use this series for the following analyses.

A new combined EOP(COM.) 92 P 01 series marked on "* *" at above table is obtained from series No.1,2,3,4,5 in order to compare with AAM instead of each series in section 5 this paper. For this series the weight is considered as follow:

\[ p_{ij} = \left( e_i^{-2} / \sum_{i=1}^{5} e_i^{-2} \right) \cdot \left( u_{ij}^{-2} / \sum_{j=1}^{5} u_{ij}^{-2} \right) \]

So

\[ r_{cj} = \sum_{i=1}^{5} r_{ij} \cdot p_{ij} / \sum_{i=1}^{5} p_{ij} \]

where for ith series

- \( e_i \) estimated uncertainty (from Table 4 cited in [3])
- \( r_{ij} \) value of X,Y at epoch j
- \( u_{ij} \) observational error
- \( r_{cj} \) combined value of X,Y at epoch j
- \( n_i \) number of observational data of the ith series

In 1992, a software SHAGAP was developed in Shanghai Observatory. Using this program, the global GPS observational data during EPOCH'92 were processed and many scientific results were obtained. The series of polar motion EOP(SHA) 92 P 01 is one result.

3. High frequency fluctuations and systematic deviations of polar motion

3.1. METHODS
Fig. 1 High-pass-filtered Polar Motion

Y Coordinates

X Coordinates

( \text{X-axis units: m/s} )
Fig. 2 Spectra of Polar Motion

CSR_X

CSR_Y

CODE_X

CODE_Y

JPL_X

JPL_Y

SIO_X

SIO_Y

ESOC_X

ESOC_Y

COM_X

COM_Y
In order to analyse the high frequency variations of X and Y, it is necessary that the part of low frequency of above series should be removed and the parts of high frequency were reserved. Firstly, the part of low frequency (longer than 35 day) for EOP(IERS) 90 C 04 is obtained by using Vondrak low-pass-filter (filter factor $c = 3d^{-5}$). Secondly, the parts of high frequency (sub-35 day) of above series are derived after reduction of the part of low frequency of EOP(IERS) 90 C 04 from each series (Fig.1). Finally, the spectra of each series (Fig.2) were processed by maximum entropy method, and simultaneously, some periodic fluctuations $P_i$ (day), amplitude $A_{m_i}$ (mas) and bias $a$ (mas) of each series (Table 2) are fitted by least square adjustment and tested by F-test, where the bias $a$ is the systematic deviation between each series and IERS. Because the interval of EOP(SHA) 92 P 01 is too short (18 day only) to make spectral analyses, the systematic deviation $a$ is obtained only.

<table>
<thead>
<tr>
<th>Series</th>
<th>$a$ * (mas)</th>
<th>$P_1$ (day)</th>
<th>$A_{m_1}$ (mas)</th>
<th>$P_2$ (day)</th>
<th>$A_{m_2}$ (mas)</th>
<th>$P_3$ (day)</th>
<th>$A_{m_3}$ (mas)</th>
<th>$P_4$ (day)</th>
<th>$A_{m_4}$ (mas)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSR</td>
<td>1.2</td>
<td>27.5</td>
<td>1.3 ± 0.3</td>
<td>16.4</td>
<td>0.9 ± 0.3</td>
<td>13.0</td>
<td>0.8 ± 0.3</td>
<td>9.4</td>
<td>0.4 ± 0.2</td>
</tr>
<tr>
<td>CODE</td>
<td>0.8</td>
<td>27.4</td>
<td>1.3 ± 0.2</td>
<td>16.8</td>
<td>0.7 ± 0.2</td>
<td>12.3</td>
<td>0.4 ± 0.2</td>
<td>10.2</td>
<td>0.3 ± 0.2</td>
</tr>
<tr>
<td>JPL</td>
<td>1.5</td>
<td>27.2</td>
<td>1.2 ± 0.7</td>
<td>17.3</td>
<td>0.5 ± 0.1</td>
<td>12.5</td>
<td>0.5 ± 0.1</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>SIO</td>
<td>2.0</td>
<td>27.2</td>
<td>0.8 ± 0.2</td>
<td>16.5</td>
<td>0.8 ± 0.2</td>
<td>/</td>
<td>/</td>
<td>10.4</td>
<td>0.4 ± 0.2</td>
</tr>
<tr>
<td>ESOC</td>
<td>2.7</td>
<td>26.9</td>
<td>1.2 ± 0.2</td>
<td>16.2</td>
<td>0.7 ± 0.1</td>
<td>13.4</td>
<td>0.4 ± 0.1</td>
<td>10.4</td>
<td>0.3 ± 0.2</td>
</tr>
<tr>
<td>COM.</td>
<td>5.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHA</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Series</th>
<th>$a$ * (mas)</th>
<th>$P_1$ (day)</th>
<th>$A_{m_1}$ (mas)</th>
<th>$P_2$ (day)</th>
<th>$A_{m_2}$ (mas)</th>
<th>$P_3$ (day)</th>
<th>$A_{m_3}$ (mas)</th>
<th>$P_4$ (day)</th>
<th>$A_{m_4}$ (mas)</th>
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<tr>
<td>CSR</td>
<td>3.8</td>
<td>10.0</td>
<td>1.1 ± 0.3</td>
<td>20.6</td>
<td>0.6 ± 0.3</td>
<td>22.8</td>
<td>0.6 ± 0.3</td>
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<td></td>
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<tr>
<td>CODE</td>
<td>1.0</td>
<td>10.0</td>
<td>0.8 ± 0.2</td>
<td>20.5</td>
<td>0.5 ± 0.2</td>
<td>13.8</td>
<td>0.7 ± 0.2</td>
<td></td>
<td></td>
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<tr>
<td>JPL</td>
<td>2.1</td>
<td>9.9</td>
<td>0.9 ± 0.2</td>
<td>/</td>
<td>/</td>
<td>15.9</td>
<td>0.5 ± 0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SIO</td>
<td>2.7</td>
<td>9.7</td>
<td>0.9 ± 0.2</td>
<td>19.2</td>
<td>0.4 ± 0.2</td>
<td>15.8</td>
<td>0.5 ± 0.2</td>
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<tr>
<td>ESOC</td>
<td>0.9</td>
<td>9.9</td>
<td>0.6 ± 0.3</td>
<td>20.0</td>
<td>0.9 ± 0.3</td>
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<td>/</td>
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</tr>
<tr>
<td>COM.</td>
<td>2.7</td>
<td>10.0</td>
<td>0.7 ± 0.2</td>
<td>20.5</td>
<td>0.5 ± 0.2</td>
<td>15.3</td>
<td>0.4 ± 0.2</td>
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<tr>
<td>SHA</td>
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</tr>
</tbody>
</table>

* $a$ is systematic deviation

3.2. RESULTS

As shown in Fig.2 and Table 2, similar fluctuations exist in the above series. In X direction, there are fluctuations with periods of 27.0, 16.5, 13.4 and 10.4 day and its maximum amplitude is 1.2 mas (27.0 day). In Y direction, there are of 10.0, 20.5, 15.8 day, the maximum amplitude is 0.9 mas (10.0 day). And there are also systematic deviations for combined series. They are about 2.1 mas (X) and 2.7 mas (Y).

4. Systematic deviation and reference frame

In processing GPS data, in order to set up a reference frame, it is usual to fix the coordinates of some stations (theoretically more than three) with high precision as fiducial stations which are not considered in the adjustment. But there are two problems. One is that there are no or few stations satisfying the demand of precision of fiducial station[5] (i.e. better than 2 cm). For example, when GPS data observed during EPOCH’92 Campaign
are processed in Shanghai Observatory, the criterion of fiducial station is the priori error of station coordinates smaller than 2 cm. As a result, there are about twenty coordinates (no height) fixed, and they are mostly coordinates of American sites. The other problem is that the selected fiducial stations may altogether locate at one region (i.e. American or European). That is to say, they may not be well-distributed globally. And even if there are a few fiducial stations meeting the need, from the point of view of the effect to fix reference frame, these stations are of little use. The direct result of these two problems is that the reference frame is not perfectly fixed as need (i.e. fixed at ITRF91), it has a rotation relative to ITRF, so the solved station coordinates and polar coordinates have a rotation too. As a result, the rotation induces the systematic deviations between various series and IERS as mentioned above.

For example, EOP(SHA) 92 P 01 is taken to study the relation between its reference frame (named TRF(SHA)) and ITRF91.

Among the twenty-four stations of TRF(SHA), just seven station coordinates are given directly in Table T-3 cited in [1] in which station coordinates in the ITRF91 are listed, and similarly, there are twenty-one stations are listed in ITRF92 Table T-3 cited in [6]. And noted that there is not rotation between ITRF91 and ITRF92[6], so ITRF92 are used to compare with TRF(SHA) instead of ITRF91. These twenty-one stations are well-distributed globally, they are: ALBH, ALGO, DRAO, DS10, DS60, FAIR, GRAZ, HART, JPL1, KOSG, MASP, METS, ONSA, PAMA, PIN1, SANT, STJO, TAIW, USUD, YAR1 and YELL.

\( r_{SHA} \) is the average position during EPOCH'92 at epoch MJD48835.5, so the coordinates of the twenty-one stations of ITRF92 should be transferred from epoch 1988.0 (MJD47160) to MJD48835.5. Here the plate motion is considered only and the equation for this transfer will be as follows:

\[
\vec{r}_{iERS} = \vec{r}_{iERS} + \vec{V} \cdot (t - t_0)
\]

so observational equation is

\[
\vec{r}_{SHA} = \vec{r}_{iERS} + \vec{i} + \Theta \vec{r}_{iERS} + \vec{\varepsilon}
\]

where

\[
\vec{i} = (t_1, t_2, t_3)^T
\]

\[
\Theta = \begin{pmatrix}
D & -R_3 & R_2 \\
R_3 & D & -R_1 \\
-R_2 & R_1 & D
\end{pmatrix}
\]

\(
\vec{\varepsilon} = \text{accidental error}
\)

equation can also written as

\[
L_{63 \times 1} = \Theta_{63 \times 7} \vec{X}_{7 \times 1} + \vec{\varepsilon}_{63 \times 1}
\]

the least square solution will be

\[
\vec{X} = (\Theta^T \vec{p} \Theta)^{-1} \Theta^T \vec{p} \vec{L}
\]
where weight $\bar{P}$ are calculated from the precision of $\vec{P}_{SHA}$

$$p_i = \sigma_i^{-2} / \sum_{i=1}^{n} \sigma_i^{-2}$$

thus, the transfer parameters from TRF(SHA) to ITRF92 are solved:

$$t_1 = -18.4 \pm 1.7 \text{cm}$$
$$t_2 = -13.3 \pm 1.8 \text{cm}$$
$$t_3 = 2.7 \pm 1.5 \text{cm}$$

$$D = (-1.08 \pm 0.22) \times 10^{-8}$$

$$R_1 = 2.67 \pm 0.75 \text{mas}$$
$$R_2 = 5.14 \pm 0.63 \text{mas}$$
$$R_3 = 8.87 \pm 0.52 \text{mas}$$

Using these transfer parameters, polar coordinates of EOP(SHA) 92 P 01 are transferred from TRF(SHA) to ITRF92, then, the average difference between them and the polar coordinates of IERS in eighteen days are obtained, they are about 4.92mas (X) and 3.46mas (Y). And they correspond to the solution derived in section 2 ($\Delta X_p = 5.7 \text{mas}, \Delta Y_p = 3.5 \text{mas}$).

These results have shown that the systematic deviations of series are mainly induced by the rotation of terrestrial reference frames of series which are not completely fixed on ITRF91(or ITRF92) during the processing of GPS data.

So, it is recommended that it should have more and globally well-distributed stations possibly fixed at ITRF91 or ITRF92 when X and Y are solved, or the rotation parameters be given and the influence of them be considered.

5. High frequency fluctuation in X and Y and the excitation of Atmospheric Angular Momentum(AAM)

The correlation between the variation of earth rotation and the atmospheric excitation has been studied by many authors[7], who explained well that the variations of Length Of Day(LOD) from irregular short periodic (40-50 day) to years are caused by the exchange of angular momentum between the Earth and atmosphere, and the sub-daily variation of LOD is due to ocean and tide[8][9]. But the explanation of variation of polar motion caused by atmosphere is not as good as that in LOD.

Taking EOP(COM.) 92 P 01 as an example, the correlation between the polar motion during IGS’92 Campaign and the AAM-induced polar motion is studied in this section.

The atmospheric data are from NMC(USA) and JMA(Japan). In NMC, the data of effective excitation functions $\tilde{X}(x_1, x_2, x_3)$ cover whole year of 1992 and are given at two points each day. There are wind component in southern and northern hemisphere $x_w, x_n$ (limit to 50 mb and to 100mb) and pressure component $x_p, x_{np}$ (No Inverter-Barometer(N.I.B.) and With I.B.(W.I.B.)). In JMA $\tilde{X}$ data have four points each day during Jun.21-Sep.30,1992 and there are wind component $x_w$ and pressure component $x_p$(N.I.B. and W.I.B.). Then
effective excitation functions are expressed as the following formulam:

\[ \ddot{X} = \dot{X} + \dot{Y} + \dot{Z} + \dot{W} \]

In this paper, wind component is limited to 50 mb, and pressure component (W.I.B.) is used. PM reduced by \( \ddot{X}_{ig} \):

\[ \ddot{m}(t) = e^{i\sigma t}[\ddot{m}(0) - i\sigma(1 + \sigma/\Omega) \int_0^t \ddot{X}(\tau)e^{-i\sigma \tau}d\tau] - (\sigma/\Omega)[\ddot{X}(t) - e^{-i\sigma t}\ddot{X}(0)] \]

where, \( \sigma = 2\pi/435 \text{day}^{-1} \), the mean rotation rate of the solid earth \( \Omega = 7.29 \times 10^{-5} \text{s}^{-1} \)

\( \ddot{m}(t) \) depends on initial value \( \ddot{m}(0) \), but \( \ddot{m}(t) \) will rapidly tend to be stable after calculation several times repeatedly. In this paper, \( \ddot{m}(0) \) is adopted from EOP (IERS) 90 C 04. And using one-degree integration approach:

\[ \int_0^t f d\tau = \frac{1}{2}(f + f')t \]

In order to compare with the high frequency fluctuation of PM of EOP (COM.) 92 P 01, it is necessary to filter \( \ddot{m} \) induced from atmospheric data of NMC and JMA as done in section 3.1 for keeping the fluctuation of sub-35 day (\( \epsilon = 3.\text{d-5} \), Fig.3). In plot, the X and Y coordinates of EOP (COM.) 92 P 01 move downwards with a constant i.e. their systematic deviations:

\[ X = x - 2.1\text{mas} \]
\[ Y = y - 2.7\text{mas} \]

As shown in Fig.3, there are some similar trends between X and m1, but it does not happen between Y and m2.

In Table 3 the correlation coefficients between PM of EOP (COM.) 92 P 01 and AAM-induced PM of two meteorological centers, JMA and NMC are given.

| Table 3 Correlation between GPS-observed and AAM-induced Polar Motion |
|-------------------|-------------------|
|                  | NMC   | JMA   |
| X                 | 0.70  | 0.81  |
| Y                 | 0.10  | 0.21  |

From Fig.3 and Table 3, some results can be obtained:
(1) The amplitudes of X and Y are larger than those of m1, m2, and the high frequency variation in X can be explained partly as the results of excitation of AAM;
(2) Due to the growth in number of observations and the improvement of the observational precision during EPOCH'92 (MJD 48828-48840), X and Y are well consistent with m1, m2;
(3) The systematic deviations of X and Y are confirmed again.

6. Summary
Fig. 3. Polar Motion of high frequency
(1) There are similar high frequency fluctuations among the series of Polar Motion during IGS'92 Campaign. In X direction, the fluctuations have periods of 27.0, 16.5, 13.4, 10.4 day, of which the maximum amplitude is 1.2 mas (27.0 day), and in Y direction, the fluctuations are of 10.0, 20.5, 15.8 day, of which maximum amplitude is 0.9 mas (10.0 day).

(2) There are also systematic deviations with the same sign between above series and EOP(IERS)92 C 04, which values are about 2.1 mas in X and about 2.7 mas in Y while they are 5.7 mas in X and 3.5 mas in Y reduced in Shanghai Observatory. The main reason of these systematic deviations is that there is rotation between the reference frame of these series and ITRF91 (or ITRF92). The station coordinates are not fixed (or are partly fixed only) when solving X and Y with GPS data so the rotation exists.

(3) The high frequency fluctuations of polar motion can be explained partly as the result of excitation of atmospheric angular momentum. And the systematic deviations are confirmed again.

Acknowledgement We thank IERS for disturbuting the EOP series from six analysis centers, thanks to Dr. Richard S. Gross and David A. Salstein for their kindness to offer us the atmosphere data of JMA and NMC, and special thanks are due to Professor Dawei Zheng for his help on many details.

Reference