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단 보

A Least Square Fit Analysis on the Earth's Polar Motion Time Series: Implication against Smylie's Conjecture

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지구의 극운동에 대한 최소제곱법 분석: 스마일리의 추측에 상반됨

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Abstract: From the Earth's polar motion time series (IERS 08 C04, since 1981), after removal of seasonal variation by band-pass filtering, we acquired Earth's free Eulerian motion (Chandler wobble) time series. By successive least square error fittings on it, we analyzed amplitude and phase variation of Chandler wobble. We attempted to identify any precursory behavior of the pole before large earthquakes but only to fail. Unlike Smylie's conjecture there was no appreciable motion of the Earth's pole detected at around the each times of recent six largest earthquakes of magnitude over 8.5.

Keywords: Polar Motion, Earthquake Precursor

요 약: 지구의 극운동 자료(IERS 08 C04, 1981년 이후)로부터 1 년 주기 성분을 제거한 뒤 얻어진 시계열에 대하여 최소제곱법을 적용하여 지구의 자유-오일러 운동(챈들러 워블) 시계열을 얻었으며, 이의 진폭과 위상 등의 변화를 조사하였다. 한편 대지진 발생 전의 전조현상으로서의 극의 움직임을 찾아보았으나 발견하지 못하였다. 스마일리의 추측과는 달리, 규모 8.5 이상의 최근 지진 여섯 개의 발생시점 부근에서 극운동의 특별한 징후가 없었다.

주요어: 극운동, 지진전조현상

Introduction

The Earth's spin rotation is quite stable: however, the pole shows ceaseless and complicated movement. The precession of the Earth, which is caused by luni-solar torque exerted on the Earth's equatorial bulge, exists in large amount. In fact, the magnitude of precession (50 arcsec per year) surpasses all other kinds of variations in the Earth's spin rotation. We hereby are concerned with the polar motion, which is torque-free motion aside from the forced precession and nutation, and refers to the slow relative change of the Earth's rotational pole with respect to the observer on the Earth itself. Chandler wobble and annual wobble, both of a few hundred milliarcsec radii, are the dominant periodic components of the Earth's polar motion, and they together show conspicuous beating of 6.4 year period (Fig. 1a-b). While annual wobble is a driven motion, Chandler wobble can be regarded as authentic oscillating mode of the spinning Earth, and its period is about 433 days. Aside from these periodic variations, there exists steady pole drift about 10 centimeters per year along 70W (Fig. 1a-b) due to 'glacial isostatic adjustment', which is also known as 'post glacial rebound.' It is obvious that seasonal variations of diverse processes of the Earth should be associated with the annual periodic components of the polar motion. Likewise there must be certain energy source to excite

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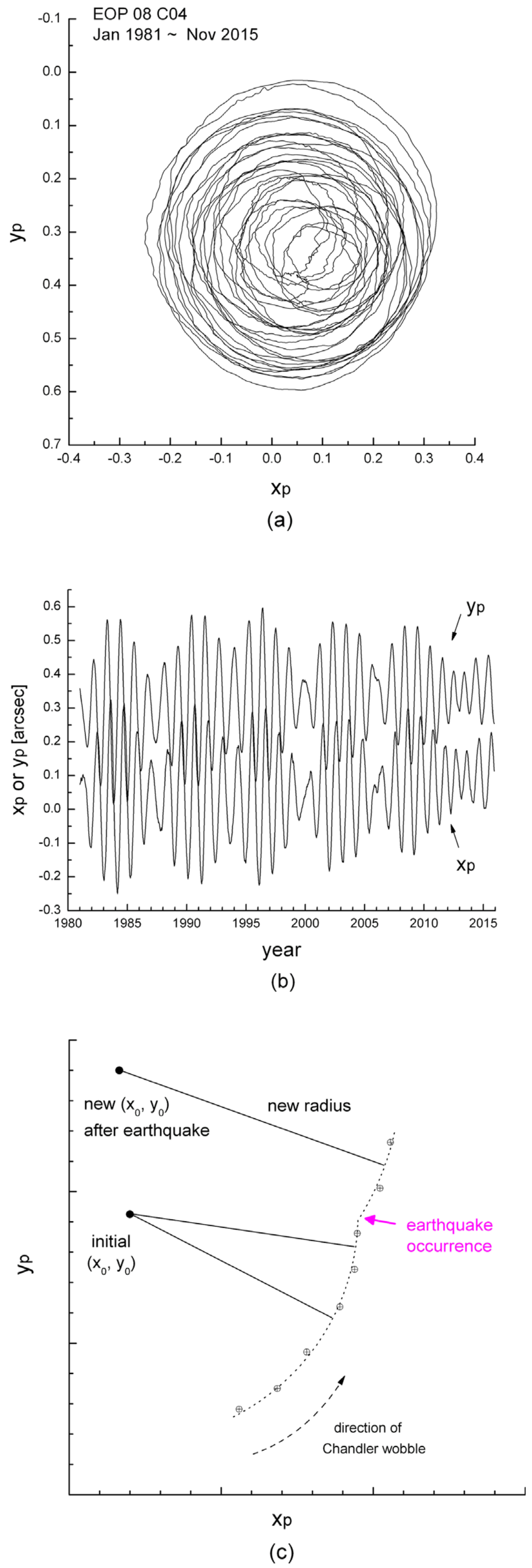

Fig. 1. Earth's polar motion. (a) 35-years locus of Earth's polar motion data (IERS 08 C04), (b) two components x_p and y_p. of the polar motion data shown in (a), (c) a hypothetical Chandlerian motion of the Earth's spin rotational pole before and after earthquake (after Smylie group).

the Chandler wobble. Nowadays, the fluid parts of the Earth - atmosphere, ocean and the outer core are thought responsible for most of all the Earth's polar motion except the slow drift associated with glaciers (Gross, 2009).

Smylie and his group have pursued for years to find evidence of earthquake to excite Chandler wobble. Smylie and Zuberi (2009) reported that the path of polar motion was found to be shifted 10 days before the 2004 Sumatra earthquake. A schematic illustration following their idea is given in Fig. 1c, where the two different paths of the Earth's pole of spin rotation before and after large earthquake are shown. The procedures of their investigation can be summarized as follows: (i) after filtering out of annual wobble component, the Earth's polar motion should be mainly of Chandler wobble, (ii) a smooth idealistic Chandler wobble path would be attained by least square fitting, (iii) the Chandler wobble path would remain as a circle unless certain disruption, (iv) (they claimed) the pole path was apparently changed 10 days ahead of the 2004 December 26 Sumatra earthquake, (v) (they argued) the shift was caused by the prior deformation in the crust ahead of the failure. In this report we partly adopted their procedures; (i) and (ii) as above. In fact, Smylie and Manshina (1968) had advocated seismic activity being the energy source of Chandler wobble. On the contrary, other investigators found that seismic events yield only small excitations to the Earth rotation compared with atmosphere/oceanic excitations (see for example, Chao and Gross, 1995; Gross, 2009 and references therein), although they agreed that earthquakes do a small role to increase the Earth's spin. Since 2004 Sumatra earthquake, there occurred five more earthquakes of magnitude larger than 8.5. Thus recent space geodetic measurements having unprecedented accuracy may detect some change in about the Earth's rotational state. We hereby consider whether Chandler wobble has been enough affected by large earthquakes to noticeably change its characteristics (center or radius of wobble or others) with successive Chandler wobble fittings on the filtered data.

Earth's Polar Motion and Large Earthquakes: Data

International Earth Rotation and References Service (IERS) provides daily position of the Earth's pole (now called as Celestial Intermediate Pole) on its surface and the Earth's spinning rate in several different formats, and EOP 08 C04 is regarded as the most accurate one (Bizouard and Gambis,

Table 1. World largest earthquakes since 1960.

Date	Location	Magnitude
1964 Mar 27	Alaska	9.2
1965 Feb 04	Alaska	8.7
2004 Dec 26	Sumatra	9.1
2005 Mar 28	N. Sumatra	8.6
2007 Sep 12	Sumatra	8.5
2010 Feb 27	Chile	8.8
2011 Mar 11	Japan	9.0
2012 Apr 11	N. Sumatra	8.6

2009). Although C04 dataset is available since 1962, only those after 1981 were used for this study because of its renowned quality after employment of space geodetic measurements in the 80s (Fig. 1a-b). It is noted here that the direction of x and y axes were taken along the Greenwich meridian and 90W for convenience, so that the y-axis is the opposite of common right-handed coordinate system.

There were recorded eight earthquakes having their magnitudes larger than 8.5 on the globe since 1960 (Table 1). After two large earthquakes of Alaska in 60s, no such ones occurred until 2004. Six large ones occurred between 2004 and 2012. All these eight world-largest earthquakes were concentrated on the Circum-Pacific zone.

In Fig. 2, parts of polar motion are illustrated with dots indicating the occurrences of the six largest earthquakes after 1981. Polar motions in Fig. 2a-c appear as left-handed spirals with much irregularities so that it is hard for naked eye to discern whether the pole paths were really altered in any amount due to the earthquakes or not.

Chandler Wobble: Filtered Data and Least Square Error Fit Model

In this study we partly adopted the methodology of Smylie (2004, 1968) to investigate the possibility of the Earth's polar motion to be affected by large earthquakes. First, annual wobble component was removed from the polar motion time series through band pass filtering in the frequency domain. Its linear trend was removed as well. Then, the center and radius of Chandler wobble were found by least square error fitting. In Fig. 3a-b, the acquired polar motion time series after band pass filtering (excluding annual wobble component and linear drift) is illustrated. Evidently the amplitude of Chandler wobble has been changing in much amount, and was, in fact, only about

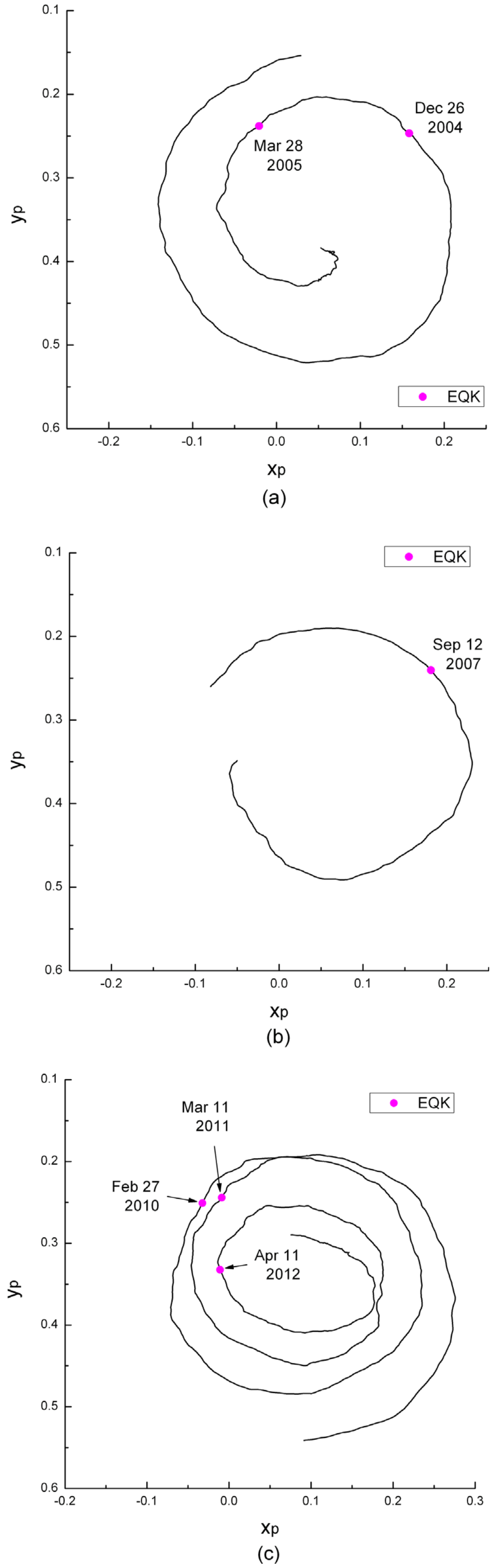

Fig. 2. Parts of the Earth's polar motion near the epochs of six largest earthquake occurrences. The pole locations at the six event dates are marked by circular dots.

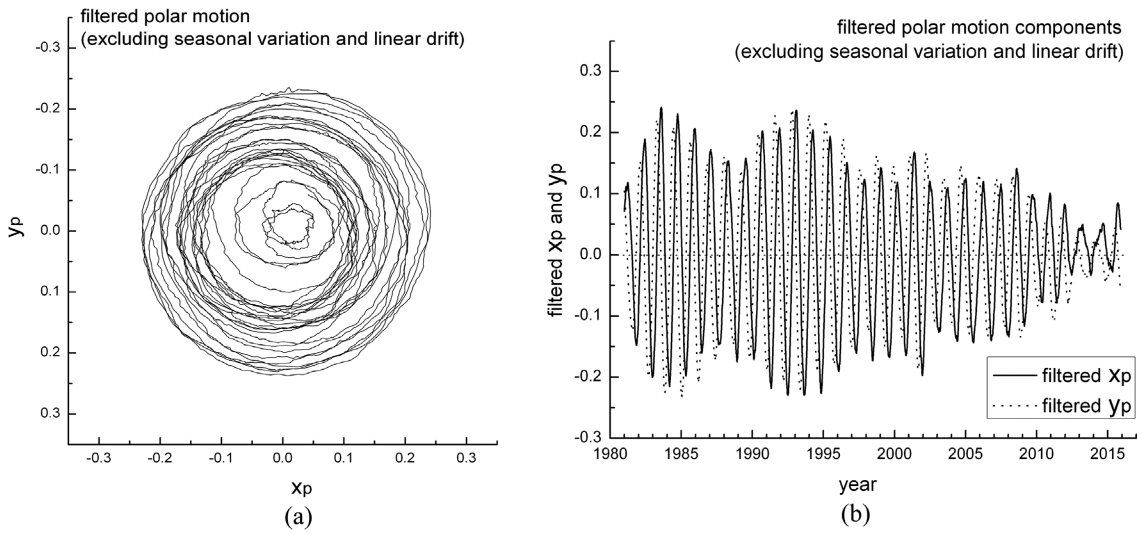

Fig. 3. Filtered polar motion devoid of annual wobble component and linear drift trend. (a) The locus of filtered polar motion on the Earth's surface, (b) Its two components x_p and y_p.

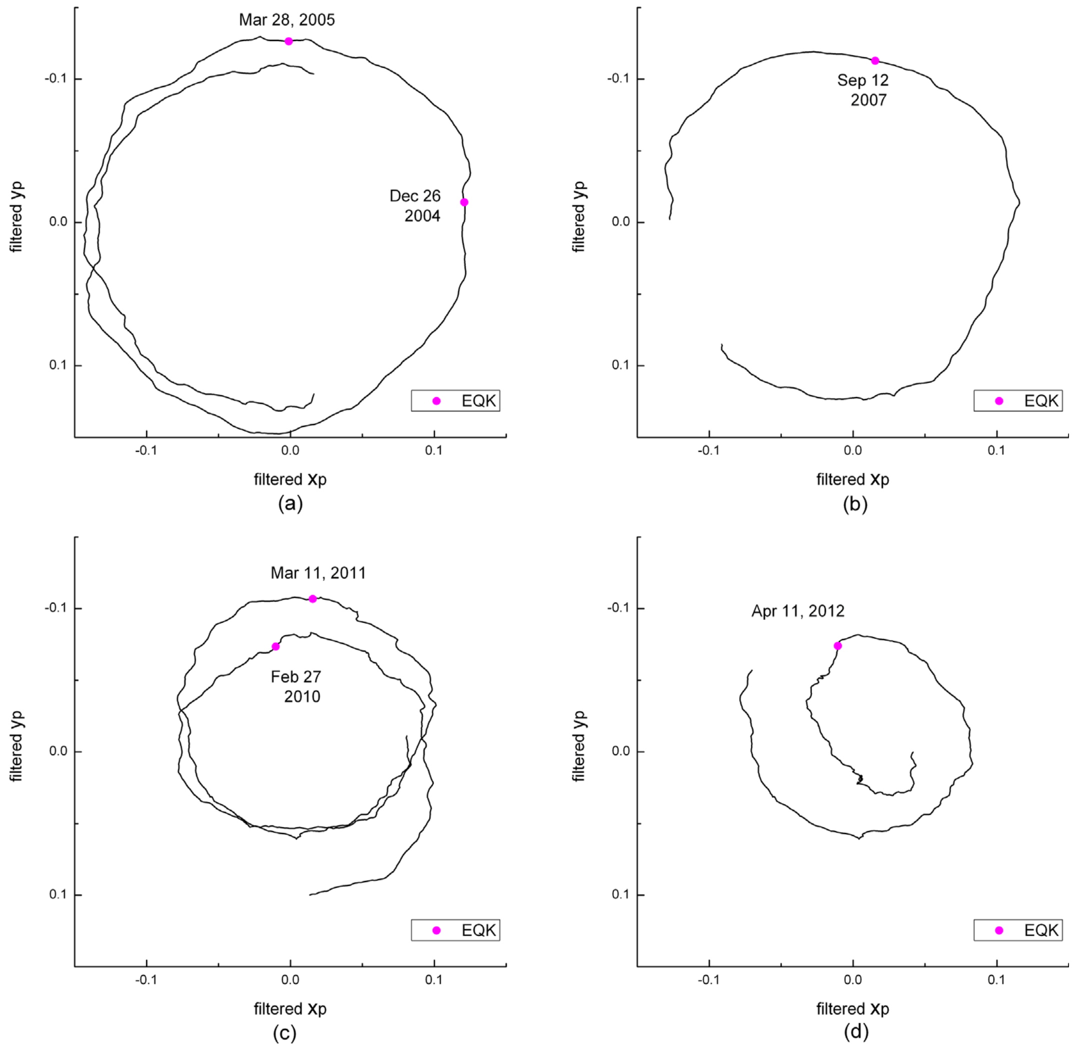

Fig. 4. Parts of the Chandler wobble near the epochs of six largest earthquake occurrences. The pole locations at the six event dates are marked by circular dots.

fifty milli-arcsec during 2012 ~ 2015 (hereafter we regard the filtered polar motion simply as Chandler wobble, although certain small amount of other components, such as the semi-annual polar motion, are included in it). The earthquake occurrences are once again shown on the filtered polar motion (Fig. 4a-d).

In Fig. 5a-b, the filtered polar motion for the first 433-day time span since Jan 1st 1981 is illustrated with its least square

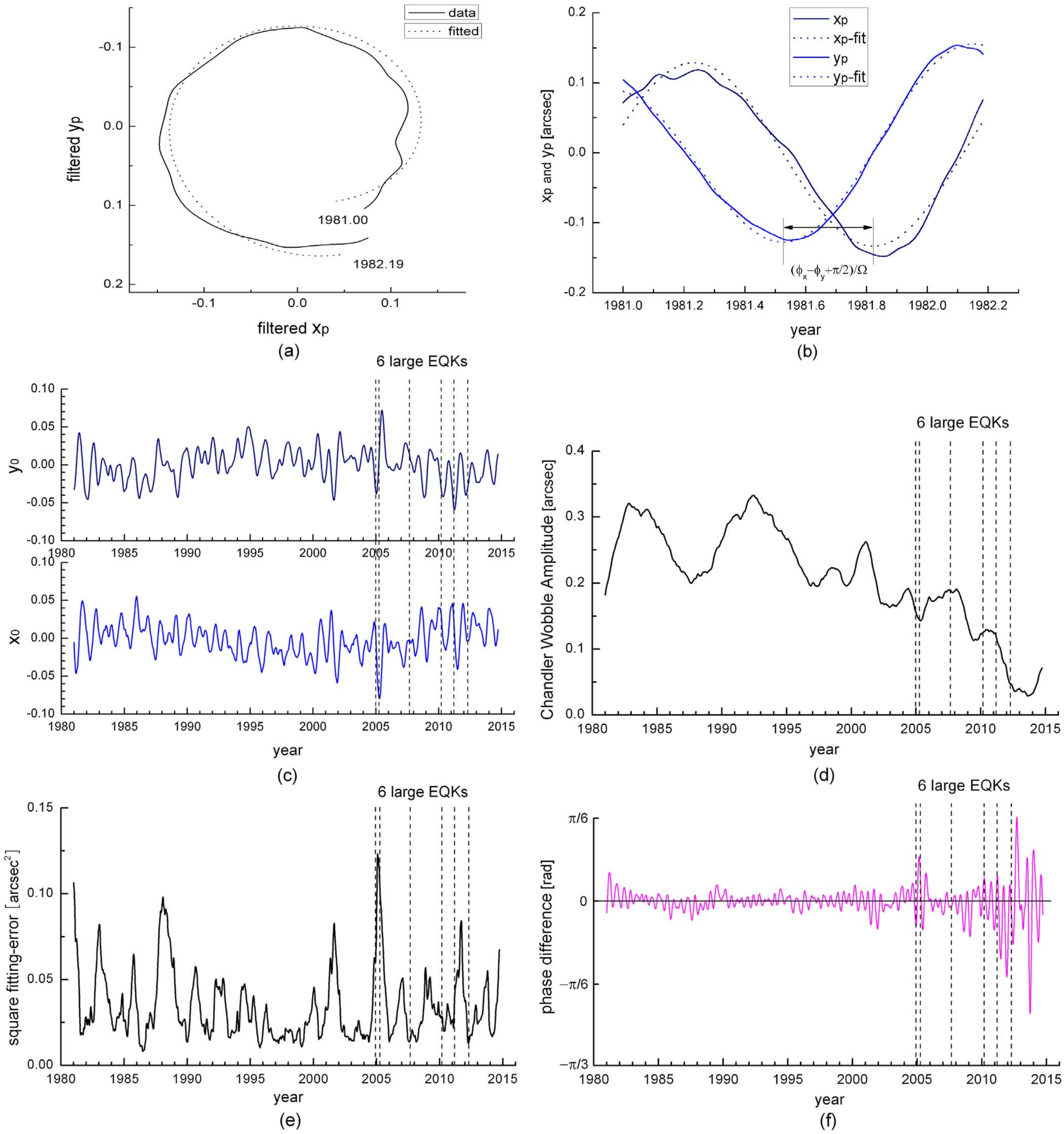

Fig. 5. Result of least square error fitting of Chandler wobble time series: (a) filtered polar motion for the 433-day time span starting Jan 1, 1981 and its least square error fit, (b) x_p and y_p components of the data and fit model in (a), (c) migration of the center of Chandler wobble as acquired by successive fittings (unit: [arcsec]), (d-f) the corresponding time variations of the radius, sum of square fit error, and phase difference $\phi_x - \phi_y$ of the each fit models acquired by successive fittings (total 12,320 least square error fittings of 433-day length each).

error fit. Both components of the Chandlerian motion were modeled as follows.

$$x(t) = x_0 + \dot{x}(t - t_0) + A\cos[\Omega(t - t_0) + \phi_x]$$
$$y(t) = y_0 + \dot{y}(t - t_0) - B\sin[\Omega(t - t_0) + \phi_y] \quad (1)$$

where Ω is the Chandler wobble frequency (in this study the Chandler period was taken as 433.5 days) and (x_0, y_0) is the center of the pole locus. The radius of Chandler wobble can be determined as $R = \sqrt{A^2 + B^2}$, and evidently the amplitude A is close to B. Likewise the phase ϕ_x and ϕ_y should not differ much from each other. Successive fittings with same length (433 days) of filtered polar motion shifted by integral multiple days each (totally 12,320 sets) have been carried by the same way, and their features are summarized in Fig. 5c-f.

Migration of the wobble center (x_0, y_0) is shown with indications of the six earthquake occurrences in Fig. 5c, while the wobble radius variation is shown in Fig. 5d. Time variation of the difference between the filtered polar motion and each fitted models (square error sum) is shown in Fig. 5e, and that of the difference between the two phases ϕ_x and ϕ_y is shown in Fig. 5f.

Discussion and Conclusion

Because the amplitude of Chandler wobble decreased (with fluctuation) since 1995 as shown by the successive fitting result (Fig. 5d), it is evident that the six largest earthquakes did not provide energy to maintain Chandler wobble. Neither the wobble's center movement (Fig. 5c) was caused by the earthquakes. This is inferred by the fact that the movements of (x_0, y_0) before 2005 have been almost as vigorous as those in the latter period of the six earthquakes. Suppose the pole path would be altered by large earthquake occurrence, then error in the fitting should be relatively larger for about a year before the event and should be much reduced after it (we hereby refer the head date of each 433 day-long segment of the filtered polar motion time series). However, such variation cannot be found (Fig. 5e). Likewise, if the pole path would be altered by large earthquake, then the deviation $\phi_x - \phi_y$ from its nominal value (zero) should also show corresponding variation around each large earthquake occurrences. However, the result (Fig. 5f) does not show such variation, but only larger fluctuations around 2005 and after it - which is probably due to the reduction of wobble radius.

Unlike Smylie, who claimed existence of a break in the pole path of Chandler wobble ten days prior to the 2004 Sumatra earthquake (Smylie and Zuberi, 2009) and similarly had asserted the role of earthquakes maintaining Chandler wobble (Smylie and Manshina, 1968), we could not find any appreciable evidence of alteration in Chandler wobble motion prior or after the times of six largest earthquakes including the 2004 event. We speculate that preceding deformation before large earthquake does possibly occur as well as co-seismic and post-seismic deformations (latter-ones are relatively larger), however, all their effect to change the whole Earth's wobbling motion is just too small to be isolated.

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