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Co-seismic Earth's rotation change caused by the 2012 Sumatra earthquake

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Abstract: Earthquakes heavily deform the crust in the vicinity of the fault, which leads to mass redistribution in the earth interior. Then it will produce the change of the Earth's rotation (polar motion and length of day) due to the change of Earth inertial moment. This paper adopts the elastic dislocation to compute the co-seismic polar motion and variation in length of day (LOD) caused by the 2011 Sumatra earthquake. The Earth's rotational axis shifted about 1mas and this earthquake decreased the length of day of 1 μs, indicating the tendency of earthquakes make the Earth rounder and to pull the mass toward the centre of the Earth. The result of variation in length of day is one order of magnitude smaller than the observed results that are available. We also compared the results of three fault models and find the co-seismic change is depended on the fault model.

Key words: earthquake; Earth rotation; polar motion; variation in LOD

1 Introduction

The mass redistribution produced by earthquakes will disturb the Earth's inertial moments, hence exciting polar motion and variation in LOD (length of day). In last decades, many researchers have used different methods to estimate the effect of earthquakes on the Earth rotation. They need to compute the changes in Earth inertial moments firstly. Many researchers used different dislocation models to compute the effects[1-4], some people also used the free oscillation and normal mode method to compute the effects[5,6]. Lambeck[7] summarized the different time-scale geophysics phenomenon on Earth's rotation. Degryse and Dehant[8] put forward a polynomial approximation of depth functions which weren't given by Dahlen[1,2] and studied the problem about the effect of earthquakes on the free core nutation and the free inner core nutation. Then Gu[9] studied the accumulative earth rotation changes caused by earthquakes in period of 1977 – 1994. With the 2004 Sumatra earthquake happened, the rotation change caused by earthquake is still focused by scientists[10,11]. They used different methods to study the co-seismic rotation change. Kobayashi and Heki[12] also studied the effect of the 2011Tohoku event on Earth rotation and they concluded that polar shift has a strong tendency toward 140°E. Gross has reported the earthquake shortened LOD by 1.8 μs (http://www.jpl.nasa.gov/news/news.cfm?release=2011-080).

In this paper, the elastic dislocation is used to compute the co-seismic Earth rotation change due to the 2012 Sumatra earthquake (Mw8.6). Polar motion and variation in LOD (ΔLOD) are estimated by adopting three fault models and we compare it to the co-seismic earth rotation caused by the Tohoku event.

2 Theory and calculation method of co-seismic Earth rotation change

To elucidate the effects of earthquake parameters on ro-

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tation change, Dahlen's elastic dislocation theory is used to compute co-seismic rotation change. This method yields analytical expressions of Earth's inertia moment, which consist of functions of earthquake parameters and which are convenient to ascertain effects of different earthquake parameters on polar motion and ΔLOD. The method uses a SNREI Earth model and assumes the epicenter as a point source. We calculate polar motion and change in LOD, with evaluation of changes in Earth inertia moments, combining the excitation function of polar motion and ΔLOD.

2.1 Changes in Earth inertia moments

Based on Dahlen's[1,2] elastic dislocation theory, changes in Earth inertia moment components induced by earthquakes can be expressed as:

$$\Delta I_{13} = M_0 \sum_{i=1}^{3} \Gamma_i(h) g_i(\phi, \lambda, \delta, \alpha, \theta) \tag{1}$$

$$\Delta I_{23} = M_0 \sum_{i=1}^{3} \Gamma_i(h) h_i(\phi, \lambda, \delta, \alpha, \theta) \tag{2}$$

$$\Delta I_{33} = M_0 \sum_{i=1}^{3} \Gamma_i(h) j_i(\phi, \lambda, \delta, \alpha, \theta) \tag{3}$$

Therein, ΔI_{ij} signifies the change in inertia moments. M_0 denotes the seismic moment, and $M_0 = \mu(r)\Delta v A$. $\mu(r)$ is the elastic shear modulus at the epicenter. Also, Δv is the dislocation; A stands for the fault area. $\Gamma_i(h)$, which represents the function of the depth of earthquake epicenter h, depends on changes of the elastic modulus and density. g_i, h_i, j_i respectively stand for functions of latitude ϕ, longitude λ, azimuth angle δ, dip angle α and strike angle θ. We assume that α is measured counterclockwise from the North Pole and that λ is measured counterclockwise from horizontal direction on the fault plane.

To complete the theory of Dahlen[1,2], Degryse and Dehant[8] derived the expressions of $\Gamma_i(h)$ in the form of polynomial approximations.

$$\Gamma_1(h) = 0.549 + 5.981 \times 10^{-4} h \tag{4}$$

$$\Gamma_2(h) = -1.946 + 0.001h + 2.738^{-7}h^2 - 6.944 \times 10^{-10}h^3 \tag{5}$$

$$\Gamma_3(h) = -0.050 + 0.002h + 2.199 \times 10^{-5}h^2 - 9.246 \times 10^{-8}h^3 + 2.667 \times 10^{-10}h^4 - 1.063 \times 10^{-12}h^5 + 2.785 \times 10^{-15}h^6 - 3.426 \times 10^{-18}h^7 + 1.560 \times 10^{-21}h^8 \tag{6}$$

Some variables used there in g_i, h_i, j_i, are defined as shown below.

$$\begin{aligned} g_1 &= \alpha_1 \sin 2\phi \cos\lambda - a_2 \cos\phi \sin\lambda \\ g_2 &= a_3 \sin 2\phi \cos\lambda \\ g_3 &= a_4 \sin 2\phi \cos\lambda + a_5 \cos\phi \sin\lambda \end{aligned} \tag{7}$$

$$\begin{aligned} h_1 &= \alpha_1 \sin 2\phi \cos\lambda + a_2 \cos\phi \sin\lambda \\ h_2 &= a_3 \sin 2\phi \cos\lambda \\ g_3 &= a_4 \sin 2\phi \cos\lambda - a_5 \cos\phi \sin\lambda \end{aligned} \tag{8}$$

$$\begin{aligned} j_1 &= 3a_1 \cos 2\phi \\ j_2 &= a_3 \left(\frac{3}{4}\sin 2\phi - \frac{1}{4}\right) \\ j_3 &= -\frac{3}{2} a_4 \sin 2\phi \end{aligned} \tag{9}$$

Furthermore, the following definitions are used.

$$\begin{aligned} a_1 &= \sin 2\alpha \sin\delta \cos\theta + \frac{1}{2}\cos 2\alpha \sin 2\delta \sin\theta \\ a_2 &= \sin 2\alpha \sin 2\delta \sin\theta - 2\cos 2\alpha \sin\delta \sin\theta \\ a_3 &= -\sin 2\delta \sin\theta \\ a_4 &= \cos\alpha \cos\delta \cos\theta - \sin\alpha \cos 2\delta \sin\theta \\ a_5 &= \sin\alpha \cos\delta \cos\theta + \cos\alpha \cos 2\delta \sin\theta \end{aligned} \tag{10}$$

For given earthquake parameters, equations (1) – (10) are used to compute the change in inertial moments.

2.2 Excitation of polar motion and ΔLOD

The change of Earth inertia tensor parameters engenders Earth's inertia moment change. Subsequently, Earth's rotation parameters change, which alters Earth's rotation change with the following relation.

According to the theory of Earth rotation, the excitation of polar motion caused by earthquakes can be expressed as the function of the principal moment of Earth inertia and inertia tensor components[6,13].

$$\psi = \frac{1.61}{C-A}(\Delta I_{13} + i\Delta I_{23}) \quad (11)$$

In that equation, A and C are the equator and polar principal inertial moments of the Earth: $A = 8.0177 \times 10^{37}$ kgm^2, and $C = 8.0438 \times 10^{37}$ kgm^2.

The ΔLOD produced by earthquakes can be derived using the following expression[6].

$$\Delta LOD = \frac{LOD}{C_m}\Delta I_{22} \quad (12)$$

therein, C_m is the polar principal inertial moment of the mantle, and the fluid core is decoupled from the elastic mantle on a short time scale. $C_m = 7.1242 \times 10^{37}$ kgm^2, $LOD = 86400$s. Therefore, we can calculate Earth's inertial tensor components as ΔI_{13}, ΔI_{23}, ΔI_{33} in accordance with expressions (1) - (3). Then we take the three components into (11) and (12). We can obtain the co-seismic polar motion and ΔLOD.

3 The results of different fault models

The 2012 earthquakes off the west coast of northern Sumatra, Indonesia, occurred as a result of strike-slip faulting within the oceanic lithosphere of the Indo-Australia plate.

Using the fault plane parameters from USGS centroid moment tensor solution (Tab. 1), we compute the co-seismic Earth rotation change. And we also use two finite fault models provided by Hayes et al[14] and Shao et al[15] respectively and estimate the effects. The results are listed in table 2. Shao et al[15] presented a finite fault model (called the UCSB model) consisting of 19 × 8 sub-faults (20 km × 5 km cell size) with the strike angle of 20° and dip angle of 80°. The Hayes' model (called the USGS model) comprises 25 × 8 sub-faults (15 km × 5 km cell size) with the strike angle of 198.87° and the dip angle of 79.95°.

From the results, we can know that this seismic event are not able to produce the observable change in Earth's rotation, but the results agree well with each other. Numerical results show that this earthquake resulted in a displacement to the Earth's pole of 0.868 mas and a decrease to the LOD of 1.08 μs from the CMT solution. The results of finite fault model are different from the result using mean fault model and they are numerically larger than the result using mean fault model. The values of polar motion are 0.941 mas and 1.175 mas respectively and the values of ΔLOD are -1.035 μs and -1.401 μs. Because the mean fault model can not represent the real distribution of mass migration and the density change, which will lead to a great error in the co-seismic Earth rotation change, the finite fault model is closer to the real situation.

4 Conclusions and discussion

The co-seismic Earth rotation induced by the 2012 Sumatra earthquake is estimated in accordance with the method given by Dahlen based on the elastic dislocation theory. Because the mean fault model can't represent the real distribution of density changes, the co-seismic rotation change has a great error and it can't represent the true value of rotation change. The modern observation technique can not detect the co-seismic ΔLOD signal, because the co-seismic rotation change

Table 1 The parameters from USGS centroid moment tensor solution

Latitude	Longitude	Height	Moment	Strike	Dip	Slip
2.350°S	93.039°E	40 km	0.85×10^{26} N/m	201°	75°	6°

Table 2 The results of different fault models

Fault model		Amplitude of polar motion (mas)	Variation in length of day (μs)
Mean fault (USGS CMT)		0.868	-1.081
Finite fault model	200 sub-faults[14]	0.941	-1.035
	152 sub-faults[15]	1.175	-1.401

is one order of magnitude smaller than the accurate. But the co-seismic polar motion from this event should be observed.

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