THE EFFECT OF EARTHQUAKES ON THE ERP DURING 1977-1985

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ABSTRACT. The effect on the Earth Rotation Parameters (ERP) of all the large earthquakes that occurred during 1977-1985 is evaluated. It is found that they cannot have caused the variations observed in the ERP during this time period.

1. INTRODUCTION

The Earth is observed to nonuniformly rotate about an axis whose position is everchanging. The observed variations in the Earth's rate of rotation, commonly known as changes in the length-of-day (l.o.d.), are classified according to the period of the variation. The long period variations, including the secular change and the decade fluctuations, are thought to be caused by, respectively, dissipation of tidal energy and by, more speculatively, core-mantle interactions. The short period fluctuations have been shown to be dominantly produced by seasonal and tidal effects. The fluctuations of intermediate period, the interannual variations, are also thought to be caused by meteorological effects. For a review of this subject see Lambeck (1980).

The observed variations in the position of the rotation pole with respect to some axis tied to the solid earth, commonly known as polar motion, consist principally of a secular drift, an annual term thought to be a forced motion of the pole driven by seasonal meteorological events, and the Chandler wobble, whose excitation mechanism is currently unknown. Various geophysical mechanisms have been proposed as candidates for the source of this excitation of the Chandler wobble; the two most studied candidates being meteorological variations and seismic events. Again, for a review of this subject see Lambeck (1980).

Recently, Gross (1986) and, independently, Souriau and Cazenave (1985) have restudied the earthquake excitation of the Chandler wobble by applying the results of Dahlen (1973) to 1287 earthquakes that occurred during 1977-1983. The purpose of the present paper is to extend this study to include the effect of these earthquakes not only on the Chandler wobble but also on the length-of-day. Since the results of Dahlen (1973) cannot be directly applied to obtain the influence of earthquakes on the length-of-day, the normal mode approach of O'Connell and Dziewonski (1976) is used herein.

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2. THEORETICAL INFLUENCE OF EARTHQUAKES ON THE ERP

The equation governing the motion of the rotation pole is obtained by linearizing the Liouville equation in a uniformly rotating reference frame (e.g., Lambeck 1980):

$$\psi_1 + i\psi_2 = (m_1 + im_2) + \frac{i}{\sigma_0}(\dot{m}_1 + i\dot{m}_2) \quad ; \quad \dot{\psi}_3 = \dot{m}_3 \tag{1}$$

where σ_0 is the complex-valued (thereby including damping) frequency of the Chandler wobble and the m_i give the small departure of the rotation vector from its initial state of uniform rotation about the $\hat{z}$-axis. The ψ_i are known as the excitation functions and are the terms in equation (1) that are responsible for generating the observed changes in the m_i (i.e., in the ERP). For earthquake excitation, the ψ_i have the functional form (e.g., Gross 1986):

$$\psi_1 + i\psi_2 = \frac{1.61}{I_{zz} - I_{xx}}(\Delta I_{xz} + i\Delta I_{yz}) \quad ; \quad \psi_3 = -\frac{\Delta I_{zz}}{I^M_{zz}} \tag{2}$$

where the I_{ij} are components of the Earth's inertia tensor and I^M_{zz} is the mantle's polar principal moment of inertia. Thus earthquakes influence the Earth's rotation by changing its inertia tensor.

The change in the inertia tensor of some body of initial density $\rho_0(\mathbf{r})$ due to some small earthquake-induced displacement field $\mathbf{u}$ is given, to first order in $\mathbf{u}$, as:

$$\Delta \mathbf{I} = \int \rho_0(\mathbf{r})\ [2(\mathbf{r}\cdot\mathbf{u})\mathbf{1} - (\mathbf{ru} + \mathbf{ur})]\ dV \tag{3}$$

where the integration is over the undeformed state of the body. By taking a normal mode approach, it can be shown (e.g., Gilbert 1970) that the earthquake-induced static displacement field is given by:

$$\mathbf{u}(\mathbf{r},\infty) = \sum_k \frac{1}{\omega_k^2} \mathbf{M}:\mathcal{E}_k(\mathbf{r}_0)\ \mathbf{u}_k^*(\mathbf{r}) \tag{4}$$

where ω_k and $\mathbf{u}_k(\mathbf{r})$ are the eigenfrequency and eigenfunction, respectively, of the k^{th} normal mode, $\mathcal{E}_k(\mathbf{r}_0)$ is the strain tensor for the k^{th} normal mode evaluated at the earthquake source location $\mathbf{r}_0$, and $\mathbf{M}$ is the seismic moment tensor.

The normal mode eigenfunctions used in this study are those computed for the spherically symmetric, non-rotating, elastic and isotropic (SNREI) Earth model 1066B by Gilbert and Dziewonski (1975). The moment tensors used in this study are those produced at Harvard University via the centroid-moment tensor technique (Dziewonski, et al. 1986 and references therein). They have produced estimates of the

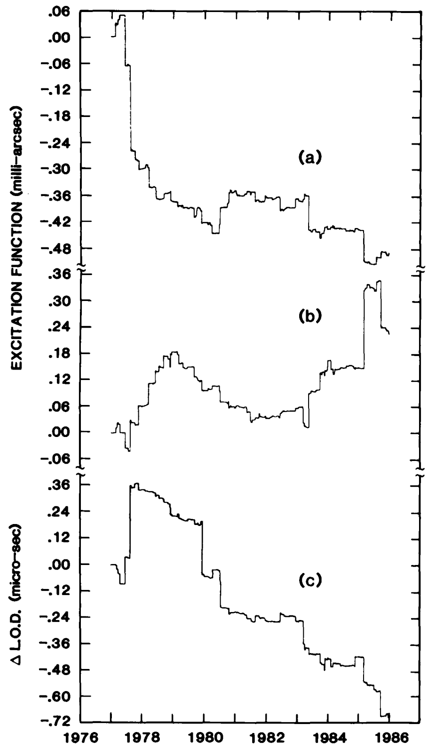

Figure 1. Theoretical effect of earthquakes on a) the x-component of the excitation function, b) the y-component of the excitation function and c) the length-of-day.

hypocentral locations and moment tensors for some 2657 events that occurred during 1977-1985.

Figure 1 shows the cumulative effect of these 2657 earthquakes on the ERP. The results for the polar motion (Figures 1a and 1b) are virtually identical to those obtained via a completely independent technique by Gross (1986) and Souriau and Cazenave (1985). This similarity is a strong validation of these results.

3. OBSERVATIONS OF THE ERP

The observations of the ERP used in this study consist of two different solutions generated at the University of Texas at Austin of the LAGEOS laser-ranging data. The series designated ERP(CSR)81 L 01 in the Bureau International de L'Heure (BIH) Annual Report for 1983 (Schutz, et al. 1984 and references therein) was used during 1977-1982 and during 1983-1985 it was the BIH designated series ERP(CSR)84 L 02 (BIH Annual

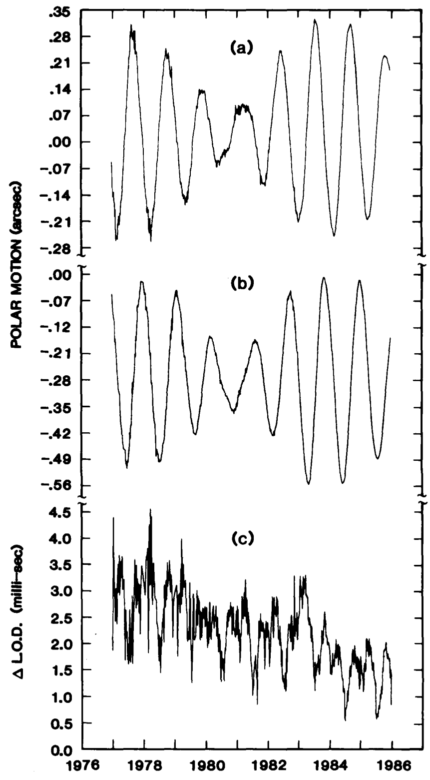

Figure 2. LAGEOS derived observations of a) the x-component of polar motion, b) the y-component of polar motion and c) the length-of-day. Note that the sign of the y-component of the polar motion has been reversed from the published values.

Report for 1985, p. D-65 and references therein). These two series were simply combined with the result shown in Figure 2. As can be seen, there is no evidence of any discontinuity in the ERP values at 1983.0.

Existing gaps in the above ERP data were filled by linear interpolation. A mean, a trend and an annual term were then least-squares fit and removed from the polar motion observations leaving the Chandler wobble time series. The excitation function is obtained by deconvolving the Chandler wobble time series. The technique used here has been thoroughly described by Gross and Chao (1985) with Figures 3a and 3b showing the resulting "observed" excitation function.

In order to compare the theoretical effect of earthquakes with the observed l.o.d. variations we first remove a mean, a trend, an annual and a semi-annual term from the observations. The resulting residual l.o.d. time series is shown in Figure 3c. A variation in amplitude having a period of approximately 4 years is seen to linger in these residual l.o.d. values and is presumably due to an incomplete removal of the decade fluctuations which have been modelled here as a trend.

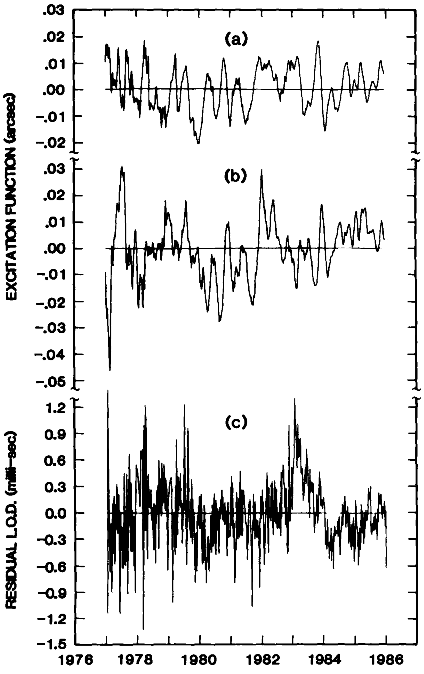

Figure 3. The x-component (a) and y-component (b) of the "observed" excitation function and the residual length-of-day (c). The horizontal lines in these plots are, to scale, the corresponding theoretical earthquake-induced values shown in Figure 1.

4. COMPARISON OF THEORY WITH OBSERVATIONS

The horizontal lines shown in Figure 3 are the theoretical effect of earthquakes on the Chandler wobble's excitation function and residual l.o.d. drawn to the same scale as the "observed" quantities. As can be seen, earthquakes have not materially influenced either the l.o.d. or the Chandler wobble during 1977-1985. The largest earthquake-induced change in the l.o.d. shown in Figure 1c is 0.33 μsec due to the Sumba earthquake of August 19, 1977 (m_b = 7.0, $M_0 = 3.6 \times 10^{28}$ dyne-cm). The great 1960 Chilean and 1964 Alaskan earthquakes are similarly found to have changed the l.o.d. by -8.4 μsec and 6.8 μsec, respectively. Thus, even the greatest earthquakes appear to affect the l.o.d. by at most 10 μsec. Since the standard error in the recovery of the l.o.d. from the LAGEOS laser-ranging data is currently about 100 μsec it is clear that there is currently no possibility of detecting earthquake-induced changes in the observed l.o.d. values.

For the Chandler wobble, the comparison between theory and observations should ideally be done in the frequency domain in order to isolate the Chandler frequency band (Gross 1986). However, lack of space prevents this frequency domain comparison to be presented in this study. Instead, a time domain comparison will be made similar to that done above for the length-of-day. The largest earthquake-induced change in the excitation function shown in Figures 1a and 1b is of amplitude 0.2 milli-arcseconds and is also due to the Sumba event. The 1960 Chilean and 1964 Alaskan earthquakes are similarly found to have induced changes of amplitude 23 milli-arcseconds and 7 milli-arcseconds, respectively, in the Chandler wobble's excitation function. The standard error in the recovery of the polar motion from the LAGEOS laser ranging data is currently about 2 milli-arcseconds. Thus even though earthquakes have not had an observed influence on the Chandler wobble during 1977-1985, it is probable that the next truly great earthquake to occur will have a measurable effect on the Chandler wobble.

In conclusion, earthquakes, via the static displacement field generated by them in a SNREI earth model, have not had a measurable influence on the ERP during 1977-1985. The influence of even the greatest earthquakes on the l.o.d. cannot be currrently detected but they should have an observed effect on the polar motion when one next occurs.

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