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POSSIBLE PLANETARY EXCITATION OF EARTHQUAKES

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Several recent studies show the possibility of an important connection between the Earths rotational motion and the number of earthquakes (Stavinschi and Souchay 2001, Shanker et al. 2001). We discuss the long-term periodic variations (30 years and 60 years) in these two geophysical processes, as well in solar activity and the Suns celestial orbit. The similarities in such periodicities suggest that solar system dynamics may contribute to both solar and geophysical phenomena.

Keywords: earthquake; Earth's rotation; solar activity; solar system dynamic

1. Introduction

The spatial distribution of earthquakes is fairly well known but the temporal evolution of seismic activity is still quite unclear. The basic cause of earthquakes is the accumulated stress in tectonic plates. Several geophysical processes, e.g., air pressure difference on the two sides of a large tectonic plate or tidal forces (Steiner 1981) can trigger the release of the accumulated energy leading to an earthquake event. In this paper we present some similarities in the decadal variation of earthquakes and Earth's rotation, suggesting their possible connection. We argue that these two geophysical variable could be indirectly rather directly connected via the Sun's motion in the solar system, and possibly to solar activity. In the next section we discuss the data used. In section 3 we present our results on the earthquakes and the Earths rotation and on solar system dynamics. In section 4 we discuss the results and present our conclusions.

2. Data

The global seismological observatory network has been working quite accurately since the end of the 19th century. The time series used was compiled by the Earthquake Data Base System of the U.S. Geological Survey, National Earthquake Center. We have chosen 1900 as the starting date of our investigations of earthquakes, and taken into account only those earthquakes which have magnitude seven or greater. This is quite good an approximation of the total energy released by earthquakes

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since the earthquakes with magnitude seven or larger represent approximately 90% of the total energy.

Fluctuations in the Earth's rotation are introduced as a difference between the constructed uniform time scale, Terrestrial Time (TT) and the universal time (UT). The difference

$$\Delta T = \mathrm{TT} - \mathrm{UT} \tag{1}$$

is a measure of the cumulative time discrepancy due to the departure of the Earth from uniform rotation. Before 1956 the uniform time was estimated from the observations of the Moon and called Ephemeris Time (ET). Since 1956 atomic time scales (TAI) were available to determine the TT. The unit and origin of the TT scale are fixed relative to the TAI scale, as defined by Recommendation IV of the IAU Working Group on Reference Systems. The unit of the TT scale is the SI second and its origin is specified by

$$\mathrm{TT} = \mathrm{TAI} + 32.184 \text{ s} \tag{2}$$

at the epoch of January 1.0, 1977 (Jordi et al. 1993). The difference in time between the uniform time scale (TT) and rotational time UT1, the rotational motion corrected by the variation due to polar motion at a particular instant T is

$$(\mathrm{TT} - \mathrm{UT1})_T = \int_{T_0}^{T} \overline{\omega}(t)dt\,, \tag{3}$$

where T_0 is some arbitrary initial instant and $\overline{\omega}(t)$ is the variation in the rotational speed, at time t, relative to the standard length of exactly 86400 seconds (McCarthy and Babcock 1986). The so called length of day (l.o.d.) time series (in milliseconds per day) is equal to $-\overline{\omega}(t)$ (in milliseconds). Therefore, from physical point of view the l.o.d. time series is more useful than ΔT since it is directly proportional to the change in the angular momentum of the Earth. McCarthy and Babcock produced a time series of l.o.d. values each six month for 1860–1984.5 (McCarthy and Babcock 1986). Our analysis is based on this data. However, we use the first time derivative of l.o.d. series which is proportional to the rotational acceleration, because it gives the corresponding torque which causes the variation in rotation speed.

3. Results

3.1 Earthquakes and l.o.d.

Irregularities in the Earth's rotation arise from three different sources. Annual variation is probably due to the seasonal redistribution of air mass. Secular deceleration is due to tidal friction. The amplitude in secular time scales (hundreds of years) is several orders of magnitude smaller than the third source, the decadal fluctuation. According to conventional theory the decadal fluctuations in l.o.d. are caused by mass distribution and redistribution in the fluid outer core. Only the fluid outer core has sufficient large mass and mobility to modify the Earth's rotation with as large an amplitude as it is observed (Munk and McDonald 1960). However several recent results show that the decadal fluctuations in Earths rotation cannot be explained by only one exciting agent, but "by a more complicated geophysical phenomenon, i.e., it must be described by a system of exciting processes" (Greiner-Mai 1995).

Figure 1 shows the 11 year lowpass filtered curves of the time series of earthquakes and the first time derivative of l.o.d. The number of earthquakes seems to oscillate at about 30–35 years for the last 100 years with some indication for delayed correlation with l.o.d. time derivative. The correlation coefficient between the earthquake numbers and l.o.d. derivative is as high as 0.64 with eight years lag. However, one could expect that the period of effects (earthquakes) would be half of the period of torque changes. There are two possible solutions for this problem. If the dominant periodicity in l.o.d. time derivative is 60–70 years (Greiner-Mai 1995, Jin and Jin 1989), then the 30 year variation of earthquake could be related. On the other hand, a higher triggering effect arises from the increasing centrifugal force caused by the larger rotational speed (Shanker et al. 2001) the same periodicity would be evident. In view of the similar features of the curves of the two time series (see Fig. 1) this possibility seems viable.

3.2 Solar system dynamics

As mentioned above it has been suggested that the dynamical processes in the fluid outer core, the core-mantle coupling, cannot be assumed as a closed system and could be driven by some external physical phenomenon. These external sources are supposed to arise either from the Sun and/or from the solar system dynamics (Djurovic 1981, Georgieva 2002).

In a theoretical undisturbed case, the celestial orbit around an attractive body lies in one plane (XY-plane). In reality the planets do not orbit exactly in the same plane and every planet excerts some perturbation on all other planets (and on the Sun as well). It means that the gravitational and tidal forces act on the Earth also in the Z-direction. If we suppose as a first assumption that the ecliptic plane is equal to the X, Y-plane in the celestial co-ordinate system, the acceleration in the Z-direction arises from planetary perturbations.

We have calculated the celestial orbits (using the Floppy Almanac 2.00.88 program) in barycentric rectangular co-ordinates, where X, Y, and Z are measured

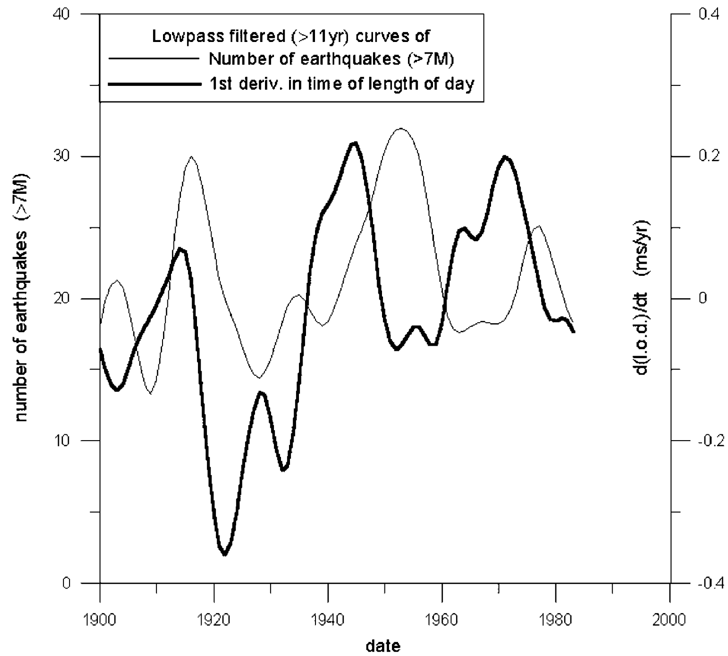

Fig. 1. Lowpass ($T > 11$ y) filtered number of earthquakes (thin line) and time derivative of l.o.d. Note that filtering distarts the phase at either end

from the solar system barycenter. The XY-plane is the mean equator of J2000.0 (Julian date), the Z-axis points toward the mean north celestial pole of J2000.0, and X-axis points towards the mean equinox of J2000.0. The longer period fluctuations in the calculated Z-acceleration of the Sun and Earth are equal and in phase, after the Earths annual motion around the Sun was filtered. Therefore, to make the data analysis easier we used the Suns Z-acceleration series in the following calculations. Jupiter has the strongest effect on the motion leading to a strong ~ 11.8-year variation. We used 23.5-year (twice the Jupiter period) lowpass filtering to reject Jupiters effect. The Z-acceleration together with Earths rotation acceleration is shown in Figs 2, 3, depicting the common approximately 30-year fluctuation obviously due to Saturn (orbital period 29.5 years). The anti-correlation is rather high, reaching nearly -0.7 with a few years lag.

We have extended this investigation since 1800 in Figs 4, 5. The l.o.d. has a visible 60-year fluctuation (Kahle and Ball 1969, Jin and Jin 1989) which is seen as alternatingly higher and lower 30-year peaks in Fig. 4. The smoothed Z-acceleration seems to have a dominant $\sim$ 30-year variation which is roughly in phase with the rotational acceleration for almost 200 years. There is also indication of a 60-year variation, which raises and lowers every second 30-year cycle peak. This is possible due to the 60-year orbital phase of the Jupiter-Saturn system.

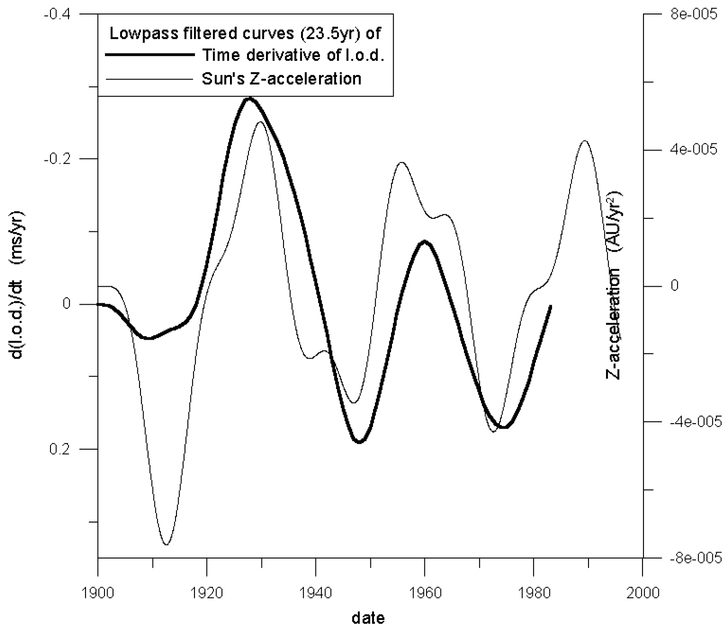

Fig. 2. Lowpass ($T > 23.5$ y) filtered orbital acceleration of the Sun (similar to the Earth) perpendicular to the ecliptic plane (Z-direction) and l.o.d. time derivative

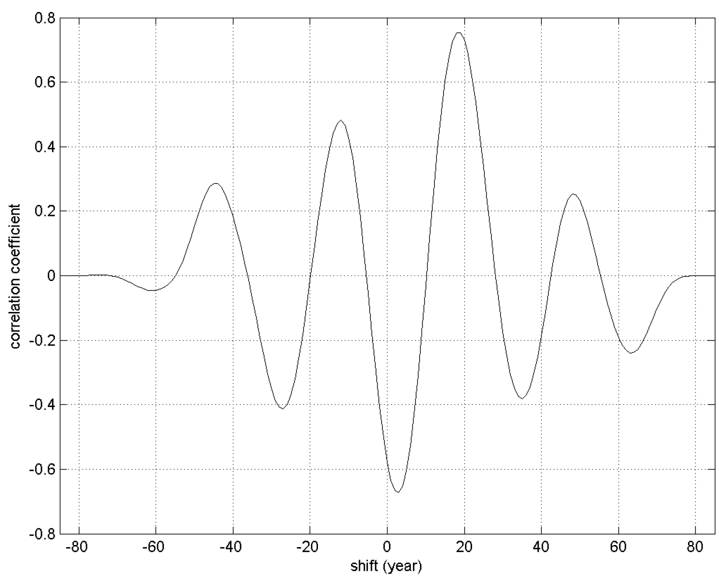

Fig. 3. Cross-correlation function between the Sun's Z-acceleration and the Earths rotation acceleration in 1900–1985

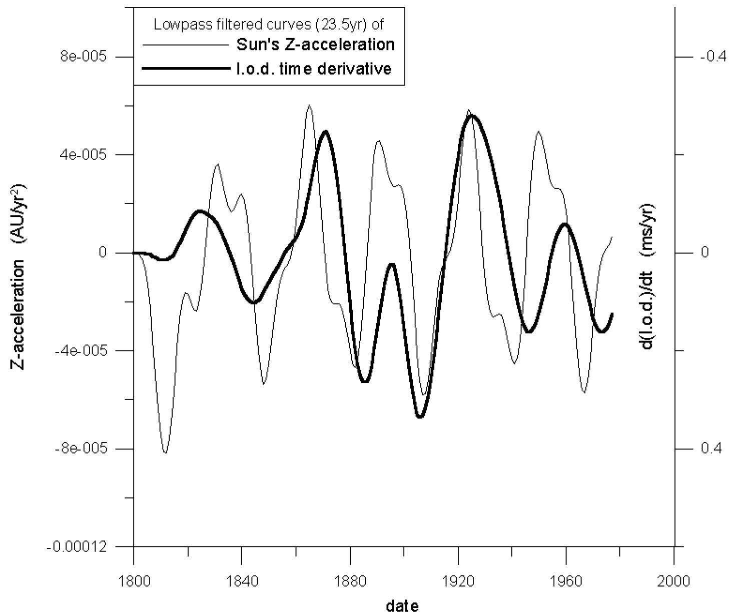

Fig. 4. Lowpass ($T > 23.5$ y) filtered curves of the orbital acceleration of the Sun perpendicular to the ecliptic plane (Z-direction) and l.o.d. time derivative since 1800

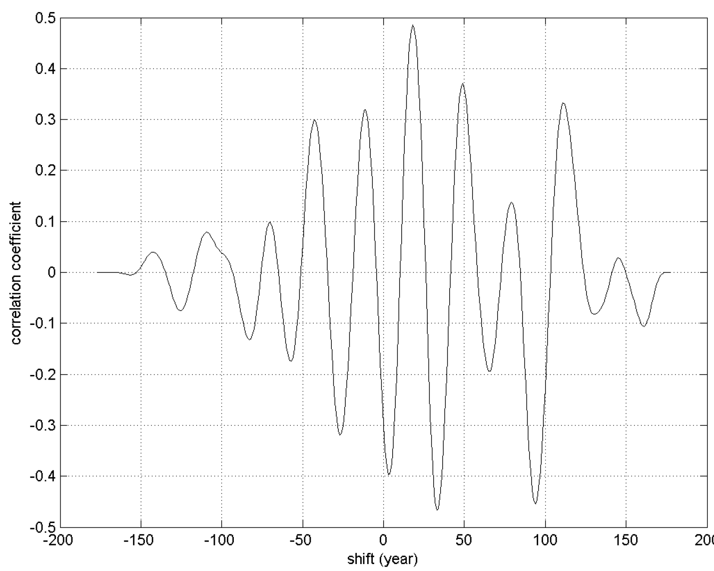

Fig. 5. Cross-correlation function between the Sun's Z-acceleration and the Earth's rotation acceleration in 1800–1985

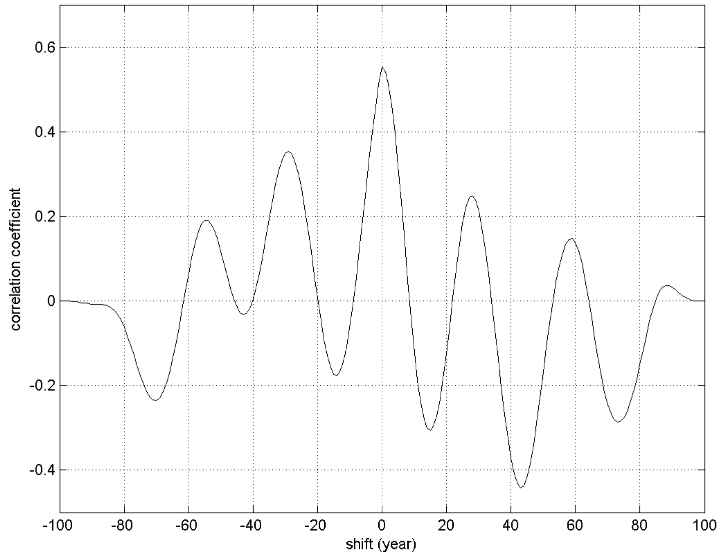

Fig. 6. Cross-correlation function between the north-south sunspot asymmetry (Sa) and the Sun's Z-acceleration in 1874–1976. Both time series were lowpass filtered above 23.5yr

4. Discussion and conclusions

Assuming a direct planetary coupling whereby Saturn could affect the mass flow in the outer core, changing the rotation speed, would imply that we would have to allow a strong effect of the extremely small tidal force of Saturn on the Earth. It is therefore more probable to suppose an indirect planetary effect on the Earths rotation and thus, on the fluctuation of earthquakes.

Although the conservation of orbital angular momentum is a fundamental assumption, in the case of Sun some special conditions "may be sufficient to allow exchange of momentum between Sun's orbit and spin to help conserve the total angular momentum of the solar system" (Juckett 2000). These conditions are the Sun's relative closeness to the barycentre, the Sun's bulge shape and the tilt of the Sun's rotation axis with respect to the normal of the solar system plane.

If the Sun's orbit and rotation are partly coupled, the periods in solar system dynamics can appear in solar rotation and also in solar activity. Therefore we have used the north-south asymmetry of sunspots (Sa) between the Suns two hemispheres as a sign of solar activity which could be affected by the fluctuations in Suns rotation. The cross-correlation function between Sa and the Sun's Z-acceleration is shown in Fig. 6. The roughly 30-year celestial period, which was earlier found in the temporal variation of the number of earthquakes and the time derivative of l.o.d., is also present in the Sa time series and the phase with the Sun's Z-acceleration.

Although earlier theories about the decadal fluctuation in l.o.d. did not take into account external sources because they were assumed negligibly small (Munk and McDonald 1960), it seems that these assumptions underestimate the level of external modulation in the Earths rotation. Recent studies show that the decadal changes in l.o.d. are a complex phenomenon (Greiner-Mai 1995, Djurovic 1981) and that the core-mantle coupling is probably affected by solar activity modulated by planetary influence (Georgieva 2002). Our results are in an agreement with these studies and show that solar system dynamics can modify the Earths rotation, but probably not directly but via driving solar activity. Moreover, the temporal evolution of large earthquakes (magnitude 7 or larger) seems to be modulated by solar system dynamics. Since the orbital motion of the planets (and Sun) can be calculated for decades in advance quite accurately, the evolution of earthquakes may be predicted. Of course, this connection is not able to predict the location of earthquakes at a certain time or even the spatial distribution of earthquakes. Moreover, we do not yet have a good quantitative physical model to explain the empirically found relations. Despite this incompleteness, our results may help in better understanding the processes leading to earthquakes and show a new direction for future investigations. Moreover, the suggested connection can be proved on disproved by the improved, continuous monitoring of earthquakes, Earth rotation and solar activity within a couple of decades, at the latest.

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