THE RELATIONSHIP BETWEEN THE GLOBAL SEISMICITY AND THE ROTATION OF THE EARTH

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ABSTRACT. Possible relationship between seismicity and the length of day (LOD) variation was investigated for a single seismic event and in global case.

1. On the basis of a theoretical model investigation it was found, that even in case of the largest instrumentally recorded earthquakes, the amplitude of the generated LOD variation is below the associated accuracy of the observations.

2. The latitude distribution of the seismic energy and the number of the earthquakes of magnitude (M) equal or greater than seven are maximal for latitudes around 48.2°. It was shown by model calculations that this phenomenon takes place when the variation of geometric flattening of the Earth, due to the changes in rotation speed, occurs. Significant correlation was found in the course of the XXth century between the changes in LOD and the annual number of M*geqslant*7 seismic events. It is therefore likely, that the variations of LOD have some significant influence on seismic activity.

1. INTRODUCTION

The connection of the Earth rotation vector and the earthquakes up to now were firstly discussed in relation of polar motion (PM). For a review see Lambeck (1980). May 22, 1960, occurred a giant earthquake in Chile (M=9.5) from far the largest seismic event in terms of magnitude for which records exist. Study of the PM excitation caused by this event was based initially on polar motion derived from International Latitude Service (ILS) database (e.g. Slade & Yoder, 1989). For later seismic events different attempts were carried out to use space-based techniques, unfortunately for time-intervals where there was no earthquakes able of significant effects in Earth rotation, even using these most sophisticated techniques (e.g. Souriau and Cazenave, 1985; Gross 1986; Chao and Gross 1987). The second largest recorded earthquake, the Alaskan event of 1964 produced only (20-30) % of energy of the Chilean one. All earthquakes after the earthquake in Alaska produced only ~1 % of the energy of the Chilean event. The length of day (LOD) is less affected by seismic influences. This is so first of all because the rotation energy is far the biggest component of energetic household of our planet and its yearly variation is somewhat bigger than the seismic energy annually released (Table 1). In spite of this circumstance, Chao and Gross (1995) has shown the connection of changes in the Earth's rotational energy and seismic activity. They arrived to the conclusion that the seismic activity has a tendency to increase the Earth's spin energy.

Annual variations		**Energies**	
Solar energy received	$\approx 2.1 \times 10^{24}$ J/a	Rotation energy	$\approx 2 \times 10^{29}$ J
Atmospheric circulations	$\approx 6.3 \times 10^{22}$ J/a	Earth core rotation energy	$\approx 3 \times 10^{24}$ J
Loss by heat flow	$\approx 1.0 \times 10^{21}$ J/a	Magnetic field of the core	$\approx 8 \times 10^{22}$ J
Oceanic circulations	$\approx 3.2 \times 10^{19}$ J/a	Mantle magnetic field	$\approx 4 \times 10^{18}$ J
Rotational energy	$\approx 1.6 \times 10^{19}$ J/a		
Energy of earthquakes	$\approx 9.5 \times 10^{18}$ J/a		
Vulcanic energy	$\approx 2.0 \times 10^{18}$ J/a		
Geomagnetic storms	$\approx 3.2 \times 10^{13}$ J/a		

Table 1: Energetic budget of the Earth

2. SOME BASIC INFORMATION ON THE SEISMICITY OF THE EARTH

The energy released during the unique Chilean seismic event was $1.1 \cdot 10^6$ TJ. The second and third largest earthquakes happened in Alaska (Prince William Sound 1964.03.28., M=9.2 and Andrean of Islands, 1957.03.09., M=9.1) which produced energy $4 \cdot 10^5$ TJ and 2.8·10 TJ respectively. During the history of instrumental seismology, what means practically during the XXth century, there were only 10 seismic events, which had $M \geqslant 8.5$. As far as the annual distribution of the seismic events is concerned annually there is on the average one seismic event with $M \geqslant 8$. The order of seismic events during a year with magnitudes $7 \leqslant M \leqslant 8$ is 10^1, $6 \leqslant M \leqslant 7$ 10^2, $5 \leqslant M \leqslant 6$ 10^3, $4 \leqslant M \leqslant 5$ 10^4 etc. It is important to notice here that if M is increased by 1.0 the energy of the earthquake is magnified by a factor of $10^{1.5}$, i.e. approximately 32 times. The annual seismic energy release is of the order of 10^6 TJ (see Table 1). From energetic point of view it can be concluded that earthquakes with $M \geqslant 8$ are responsible for the 49 % of the annual seismic energy, the events $7 < M \leqslant 7.9$ for 43 % and $6 < M \leqslant 6.9$ for 4 % respectively. This means that seismic events $M \geqslant 7$ represents 92 % of the annual seismic energy budget.

With the use of empirical equation (Kasahara, 1981) the after shock area (A) is

$$\log A \ (\mathrm{km}^2) = 1 + 1.02 \cdot M$$

This way for

$$M = 9 \quad A = 1.5 \cdot 10^5 \ \mathrm{km}^2$$

$$M = 8 \quad A = 1.4 \cdot 10^4 \ \mathrm{km}^2$$

$$M = 7 \quad A = 1.4 \cdot 10^3 \ \mathrm{km}^2$$

$$M = 6 \quad A = 1.3 \cdot 10^2 \ \mathrm{km}^2$$

It is generally accepted in seismology that the area of aftershocks coincides with the source area.

3. SEISMOLOGICAL AND LENGTH OF DAY DATA BASES

Earthquake catalogs are primary data sources for the characterization of seismicity behaviour and testing hypotheses. The completeness and accuracy of earthquake catalogues vary in time and depend on earthquake depth and tectonic, but first of all due to density and resolution of worldwide seismograph network. One can observe monotone increase of global annual number of seismic events if the catalog consists earthquake 4.0⩽M⩽9.5 since the beginning of XXth century up to present. The list of seismic events consists in different sudden jumps of annual number of observed earthquakes. The most "dramatic" one reflects the starting of the World Wide Seismic Standard Seismograph Network in 1963. From statistical viewpoint, since about that time the list of worldwide seismic events is complete for M⩾(6.0-5.5). Recently the best catalogues are reasonably complete with the magnitude M⩾5.4. The global catalog of shallow (depth <70 km) and large M⩾7 earthquakes shown to be complete during the whole XXth century (Kagan, 2003). The seismic moment and consequently the energy release are predominantly connected to subduction zones of convergent tectonic plates. The (80-90) % of seismic moment release is connected to large shallow earthquakes. To Chile event of 1960 belong (30-45) % of the total seismic moment observed during the XXth century (Pacheco & Sykes, 1992). Due to above described situation for the purposes of present study the M⩾7 events were collected from the data base of National Oceanic and Atmospheric Administration (NOAA) almost for the whole XXth century.

The LOD data were taken form the IERS EOP CO4 record, which is given at one-day intervals. CO4 is free from tidal effects. The oscillations in UT and duration of the days due to zonal tides for periods under 35 days, as well as the fortnightly terms are present in full size in the series. The EOP (IERS) CO4 is slightly smoothed by Vondrak (1977) algorithm in order to remove the high frequency noise.

4. POSSIBLE INFLUENCE OF A SINGLE EARTHQUAKE ON THE LOD

The influence of the elastic stress accumulation or release on the LOD can be described with the use of Love-Shida theory. For our calculations it was supposed that at the surface of the Earth or at certain depth a normal stress builds up strains, which generates surface vertical displacements. For the modeling it was supposed that the Earth's mantle is elastic and has radial symmetry. The loaded spherical surface can be characterised by an angle $\Delta\alpha = \sqrt{\frac{\Delta\phi+\Delta\lambda}{\pi}}$ (ϕ and λ are the geographical coordinates) and the vertical surface displacements (D)are given in function of ψ angular distance measured from the centre of the loaded area. The theoretical details of the calculations carried out are given in Varga (1987), Varga & Grafarend (1996). For model calculations it was supposed that an anomalic normal stress with a magnitude of 10^7 N $\cdot$ m^2 (which is of the order of maximal stress drops in the case of largest seismic events) acts on spherical surfaces $10° \times 10°$ ($\sim 10^6$ km^2), $1° \times 1°$ ($\sim 10^4$ km^2) and $0.1° \times 0.1°$ (10^4 km^2) Calculations were performed for the surface of the Earth and for the relative depths $r/a = 0.99$, 0,98, and 0.96 (a - is the Earth's radius, r is the radial distance from the Earth's centre). It was found that the vertical displacements are occurring on areas six times bigger than the area of stress accumulation. If $\rho(r)$ is the density function the variation of the polar momentum of inertia due to the layer occupying a spherical layer of thickness D is

$$\Delta C = \int_r^{r+D} \int_{\phi_1}^{\phi_2} \int_{\lambda_1}^{\lambda_2} \rho(r) r^4 \cos^3\phi \, dr \, d\phi \, d\lambda =$$

$$= \frac{(r+D)^5 - r^5}{5} \rho(r)\Delta\lambda[(\sin\phi_2 - \sin\phi_1) - \frac{1}{3}(\sin^3\phi_2 - \sin^3\phi_1)]$$

Since $(r+D)^5 - r^5 = r^5\left[\left(1+\frac{D}{r}\right)^5 - 1\right] \approx 5r^4D$, the ΔC can be written in the following form

$$\Delta C \approx r^4 D\rho(r)\Delta\lambda[(\sin\phi_2 - \sin\phi_1) - \frac{1}{3}(\sin^3\phi_2 - \sin^3\phi_1)]$$

If an extreme case of the load is considered (the loaded area is $1° \times 1° \approx 10^4$ km^2 and the vertical displacement is $D = 1.0$ cm over an area $6° \times 6° \approx 3.6 \cdot 10^5$ km^2) the anomaly $\Delta C = 7.80 \cdot 10^{27}$ kgm^2 gives with $C = 8.04 \cdot 10^{37}$ kgm^2

$$\Delta LOD = LOD \cdot \frac{\Delta C}{C} \approx 8 \text{ microseconds}$$

Due to the fact that the accuracy of the ΔLOD observations is ~ 10 microseconds it can be concluded that the seismic events are not able to produce any realistic, observable changes in LOD. To similar conclusion arrived, on the basis of modeling viscoelastic Earth, in case of PM Soldati & Spada (1999) and Soldati et al (2001).

5. TEMPORAL DISTRIBUTION OF PLANETARY SEISMICITY AND VARIATIONS OF LOD

The despinning of the acceleration of the angular rotation of the Earth modifies the flattening of the Earth. Amalvict and Legros (1996) have derived sets of formulae for incremental lithospheric stresses. Their results confirm and extend earlier results of Melosh (1977) and express the variation of stress tensor components due to angular speed induced geometrical flattening variations Δf:

Meridional stress	$\sigma_{\phi\phi} = -\frac{\mu \Delta f}{11}(5 - 3\,cos\,2\phi)$	
Azimuthal stress	$\sigma_{\lambda\lambda} = \frac{\mu \Delta f}{11}(1 + 9\,cos\,2\phi)$	(μ is the sheer modulus)
Stress difference	$\Delta\sigma = \sigma_{\phi\phi} - \sigma_{\lambda\lambda} = -\frac{\mu \Delta f}{11}(6 + 6\,cos\,2\phi)$	

It is important to mention that the stress pattern described by above equations is symmetric to the equator and has inflection points around $\phi = 45°$ (the critical latitude is 48.2°), where the stress derivatives along ϕ - which are proportional to the corresponding force components F_ϕ and F_λ - have their maxima. This phenomenon - related to ΔLOD - should be expressed in the seismicity of the Earth. The latitude distribution of the number of M⩾7 earthquakes (Fig.1) have maxima close to the critical latitudes 48.2°. (In the southern hemisphere the maximum is missing because the most of the significant seismic regions of the world are in the northern hemisphere).

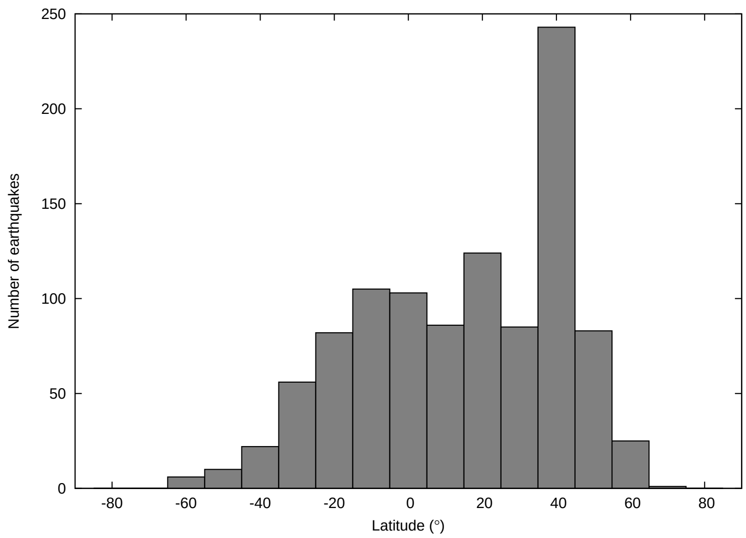

Figure 1: Distribution of M⩾7 earthquakes along the latitude.

Table 2. shows latitude dependence of seismic energy calculated from surface wave magnitudes (M⩾7.5) for the time interval 1950-2000. It can be concluded that the seismic energy is predominantly connected with shallow focus events.

Latitude - $\phi(°)$	Total seismic energy (in 10^{18} Joule)	Events with intermediate[1] and deep[2] focus (in 10^{18} Joule)	Events with shallow[3] focus (in 10^{18} Joule)
0	2.40	0.41	1.99
15	2.16	0.42	1.74
30	2.29	0.68	1.61
45	2.74	0.27	2.47
60	1.64	0.09	1.55
75	0.00	0.00	0.00
Total	11.230 (100%)	1.87 (16.7%)	9.36 (83.3%)

Table 2: Distribution of seismic energy along latitude for 1950-2000 (earthquakes M⩾7.5).

Practically no seismic events M>7.5 occurs above the latitudes $\phi > 65°$. Between $\phi = \pm 50°$ and the poles only shallow focus great seismic events were observed. And - what is the most important for the research described in present study - the earthquake energy release has maximum at the critical latitudes $\phi = \pm 48.2°$. This way it can be concluded that the seismicity of the Earth- through the stress variations caused by changes in rotation speed- is related to the ΔLOD. Fig.2. shows the LOD variations and the yearly number of the earthquakes with M⩾7.0 on the basis of the NOAA earthquake catalogue.

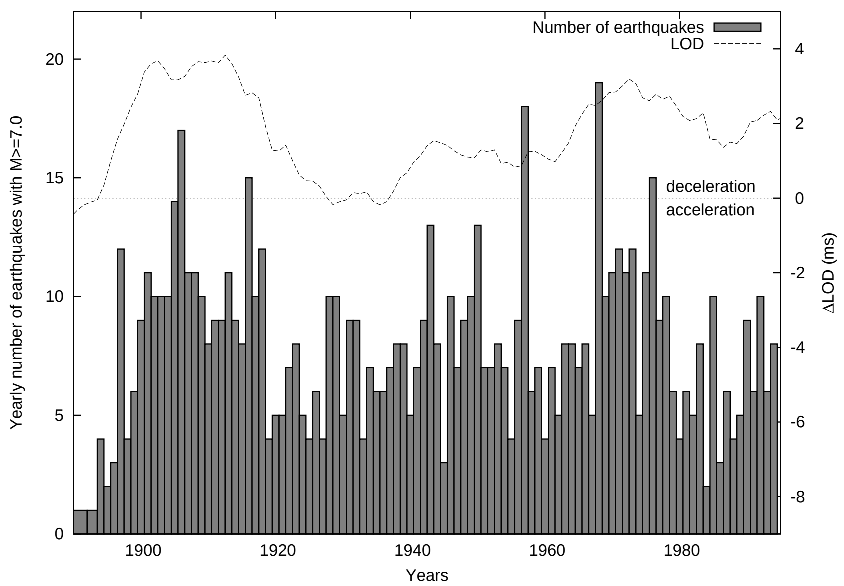

Figure 2: Annual number of seismic events M⩾7 and the LOD variations during the XXth century.

The correlation during the XXth century between these two phenomena was well expressed:

[1]Intermediate earthquakes (hypocentral depth between 70 and 300 km).
[2]Deep earthquakes (depth>300 km).
[3]Shallow earthquakes (depth<70 km).

when the axial rotation decelerates the annual number of M⩾7 earthquakes has its maximum.

6. CONCLUSIONS

With the use of model calculations, it was found that a seismic event (even the biggest one) is not able to influence the rotation speed of the Earth. The variation of rotation speed through stress caused by the corresponding flattening variations is related to the longitudinal distribution of seismicity and seismic energy. It is likely that the seismicity does not generate ΔLOD anomalies. On contrary: the variations of LOD have influence on seismic activity. This fact is expressed by the correlation between the annual number of the earthquakes with M⩾7 and LOD.

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