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A study of atmospheric influence from earthquake statistics

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Abstract

We analyze daily variation in earthquake (EQ) occurrence to try to find a correlation with atmospheric tide whose basic period is 24 h exactly. In selection of earthquake ensembles we use a specially developed index of seismic activity. In this way we present statistics of earthquakes in Kamchatka during the last 40 years, in Japan during the last 7 years and in California during the last 72 years, which shows a weak but recognizable effect. We explain it by tidal modulation of the earthquake instability process.

Keywords: Earthquake triggering; Atmospheric tide

1. Introduction

There are many evidences that atmospheric perturbations are related to seismic activity. Effects of VLF subionospheric signal changes in amplitude and phase (Hayakawa et al., 1996; Molchanov and Hayakawa, 1998), seismo-induced scattering of HF signals (e.g. Fukumoto et al., 2002), preseismic LF anomalies (e.g. Biagi et al., this issue), modification of the ionospheric turbulence (Molchanov et al., 2004) can be mentioned as such examples. The conventional explanation is reduced to the assumption on seismo-induced water or gas eruptions, which produce acoustic or atmospheric gravity waves and consequent plasma density variations in the upper atmosphere and ionosphere.

However there is a possibility that atmospheric perturbations like large tidal circulations and typhoons can also influence seismic activity itself. Tides in the Earth are produced by Moon and Sun gravitation and lead to regular oscillation of the ground or ocean surface height (Ht) with periods about 12.5 h (sectorial tides), about 25 h (tesserial tides) and zonal tides with period about 14 days (e.g. Melchior, 1996). Unlike them tidal variations in the atmosphere are produced by solar heating and have basic periods 24 h, harmonic periods 12, 8, 6 h and they probably induce the so-called planetary waves with periods about 2, 5, 10 days (Murgatroyad, 1970; Venne, 1989; Tiwari et al., 1994). In the first sight a possibility of tidal influence on earthquakes looks incredible because tide perturbation creates too small strains and stresses inside the ground medium in comparison with those produced by the EQ. Indeed conventional EQ strain change is $\Delta\varepsilon \sim 10^{-4}$, whereas gravitational tides in the ground produce strain change $\Delta\varepsilon \sim 10^{-7}$ and solar-induced atmospheric perturbations lead to similar or even less ground strains (see estimations in Section 3). Nevertheless there are many statistical studies that have reported a positive correlation between the earth or ocean tides and EQ occurrence (see e.g. review in the paper by Tsuruoka et al., 1995). So it is not worthless to try to find a similar correlation related to atmospheric tides, which have exact 24 h variation. In other words we are going to analyze daily variation in EQ occurrence.

2. Results

An important problem is the selection of appropriate EQ ensemble. Assuming that atmospheric influence is more

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or less a local effect, we include in our consideration EQs with value of seismic index $K_s > 1$, where K_s is an index defined as follows (Molchanov et al., 2005):

$$K_s = \sqrt{(\Delta E_s/\Delta E_s^*)} = K_0 \cdot 10^{0.75M} \Phi a/R \qquad (1)$$

where ΔE_s is seismic energy input at the distance R (in km) and ΔE_s^* is the corresponding threshold level of seismic energy input. $\Phi a \ (1+2R/\mathrm{La})^{-2.5}$ is the attenuation function and K_0 is a constant ($K_0 = 0.1$) but with the dimension of km. And, $\mathrm{La} \cong QL \cong 2 \times 10^{M/2}$ (km), where $Q \cong 100$ is elastic quality and L is average size of the seismic source (Aki and Richards, 1980).

First of all we present in Fig. 1 daily variation of EQ occurrence for the area near our Karimshino station (Kamchatka peninsula, Russia). It is evident that the distribution is inhomogeneous even after long-time (40 years) averaging. This inhomogeneity can be hardly explained by statistics incompleteness as it is demonstrated in Fig. 1b, where statistics on several 10-year periods is shown. Daily distribution varies probably due to slow change in tectonic activity, however some peculiarities are found to repeat. Especially indicative is an increase of EQ occurrence in the local time sector 21–24 LT. Then we produce the similar computations for the data in Japan (around the station of Tarumizu) using JMA catalog in Figs. 2 and 3 illustrates the corresponding results for USA (around Los Angeles area), using SCSN catalog. Once again the stability of latter statistics is checked by division by four 18-year intervals and some features are seen to keep as in the case of Karimshino; for example weak EQ activity in the sector 09–12 LT.

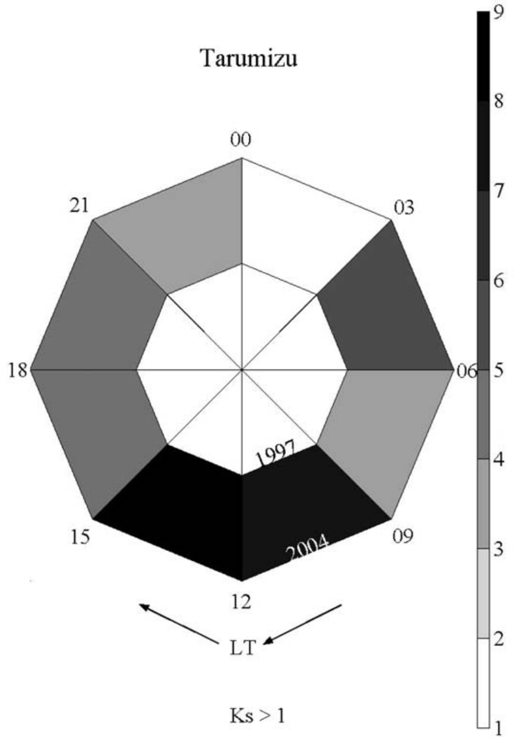

Fig. 2. Daily variation in EQ occurrence for 7-year period near the station of Tarumizu (Japan).

In conclusion we produce conventional estimation of our result reliability assuming 95% probability and binomial data. It is presented in Fig. 4.

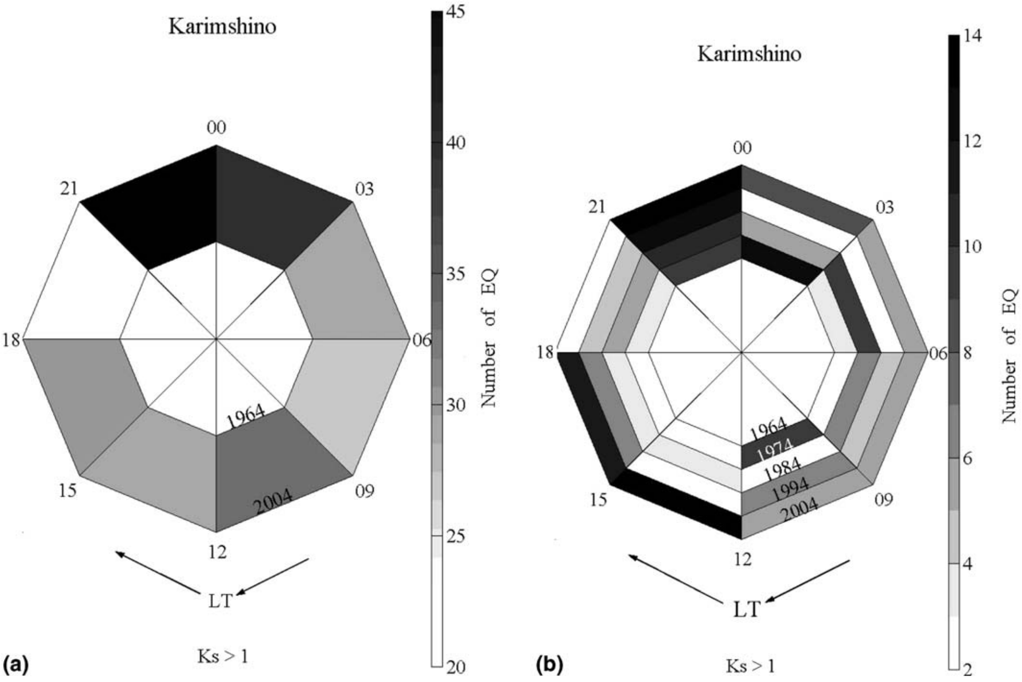

Fig. 1. Daily variation of EQ number with $K_s > 1$ during the last 40 years in the Kamchatka area (around Karimshino station) in eight 3-h sectors. (a) Statistics for a whole period and (b) statistics for the four successive periods of 10-year duration.

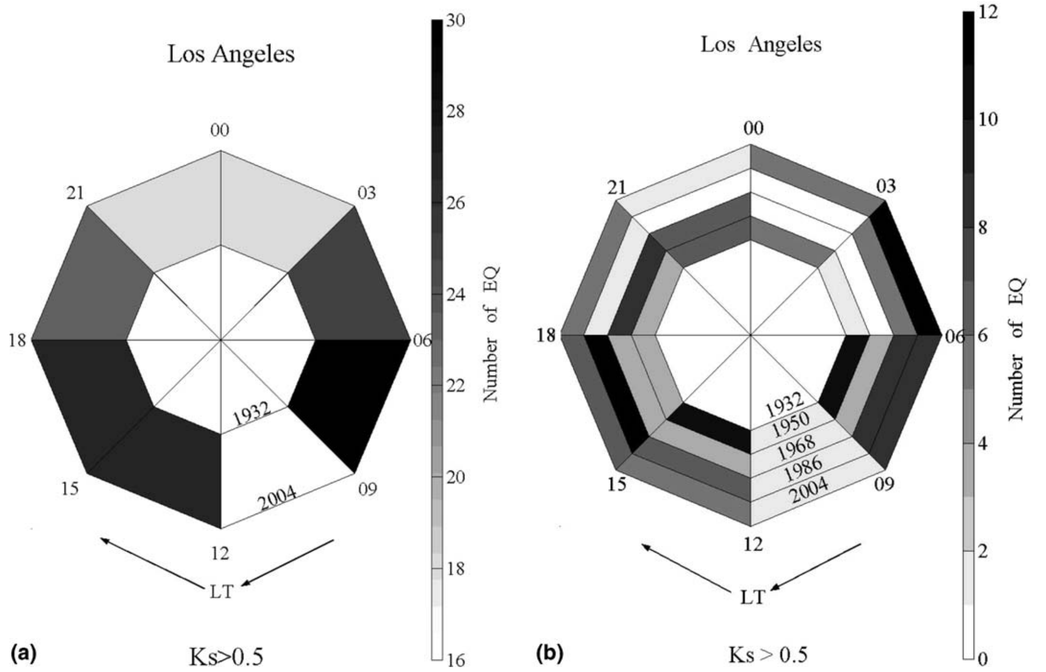

Fig. 3. Daily variation of EQ occurrence in the area of Los-Angeles (USA) since 1932 till 2004: (a) for all the period and (b) for four 18-year periods.

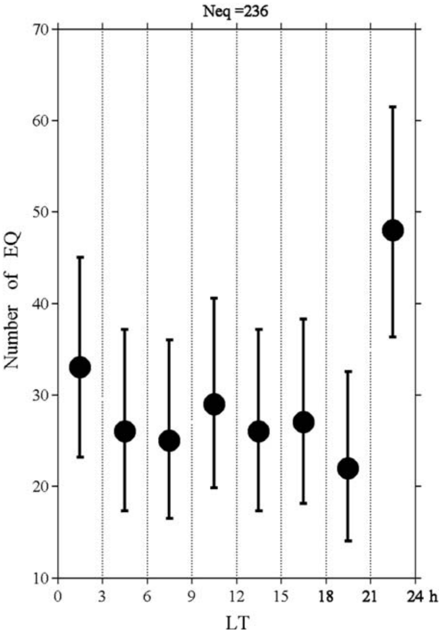

Fig. 4a. Estimation of 95% confidence intervals of daily variation in a case of EQ occurrence near the Karymshino station during 40 years.

3. Discussion

At least as for the Kamchatka region our results look as reliable. For other regions we can find only some tendency. It means that atmospheric influence exists but not very efficiently.

As mentioned above it is not easy to find explanation of the results. One of the simplest idea is that EQ process is connected not with strain change itself but with strain derivative $d\varepsilon/dt$. So both fast tidal influence and slow tectonic activation are comparable in magnitude (Tsuruoka et al., 1995). However, this idea cannot help in explaining why regular tidal variations are efficient only sometimes. The recent SOC (self-organized criticality) concept leads to a possibility of EQ triggering because "complex system has a tendency to evolve into a critical state, where minor disturbances may lead to events, called avalanches, of all sizes"(Bak, 1997). Due to it, a behavior of the complex system element is unpredictable, but this is in clear contradiction with the existence of precursors like seismic foreshocks. Nevertheless, one of the SOC statements concerning critical state and possibility of triggering of EQ "avalanche" (fracture or slip instability in classic mechanisms) is probably true; i.e., the strength–stress difference $\Delta\sigma^*$ required to launch EQ instability could be less than the stress drop $\Delta\sigma \approx (0.3\text{–}1)10^6$ Pa. In other words, $\Delta\sigma^*$ is not much more as in the classic theories (e.g. Mjachkin et al., 1975) and $\Delta\sigma^* \neq 0$ as in the SOC concept. Calculated maximum variation of the gravitation tidal height Ht is 0.78 m (in a model of liquid Earth) and 0.51 m in reality (Melchior, 1996). Rough estimation of the extension strain change by tides is $\delta\varepsilon \approx \mathrm{Ht}/R_\mathrm{E} \approx 0.8 \times 10^{-7}$, where $R_\mathrm{E} \approx 6 \times 10^6$ m is the earth radius. Hence maximum tidal stress variation is$\delta\sigma \approx \delta\varepsilon\mathrm{E} \approx (3\text{–}4) \times 10^3$ Pa ≈ 30–40 mBar. Such pressure variations are usual for large atmosphere circulations and typhoons, but they are much less than the stress inside the crust, which varied from 10^5 Pa to about 3×10^8 Pa, and of course $\delta\sigma \ll \Delta\sigma$. When the static stress difference $\Delta\sigma^* < \Delta\sigma$, an additional energy input is necessary in order to compensate energy consumption in fracturing

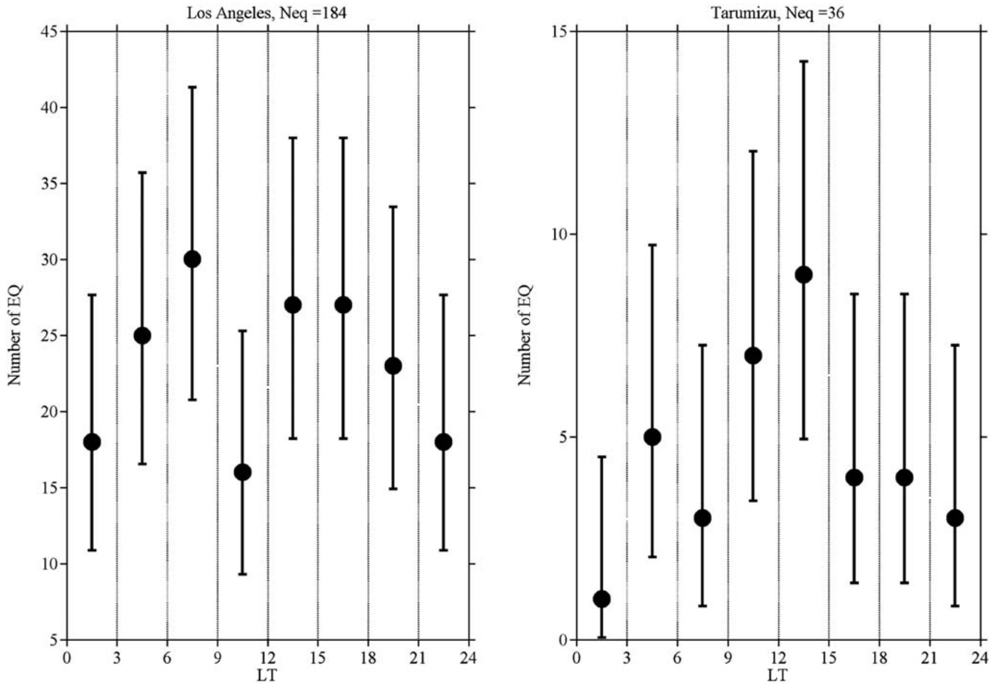

Fig. 4b. The same estimation as in Fig. 4a for California region (left) and Japan (to the right).

and in overcoming of strength barriers during fracture junctions. Simple estimation shows that energy input from tides is not sufficient. In our opinion the main triggering agent is upward fluid migration as described and modeled in the papers by Iudin et al. (2002) and Korovkin et al. (2002). In this theoretical scheme a perturbation of internal heating flux provides an energy input and we have no problem with energy resource. One of the simplest way to check the pre-seismic fracture instability development is the registration of seismo-acoustic emission (SAE) or high-frequency seismic noise (HSFN). Saltykov et al. (2006) reported on the stabilization of phase between HSFN variation and gravitation tidal variation with period of 25. 82 hours in time interval about one month before several large EQs in Kamchatka. It is probably evidence that tides can modulate EQ fracture instability. Observation results by Gorbatikov et al. (1999) on the correlation between SAE and atmospheric planetary waves can be also mentioned in this connection. Coming back to observation results of this paper we emphasize that many years averaging excludes a possibility to find influence of the gravitation tides, but weak influence of atmospheric tide with period of 24 h is more or less recognizable. Taking into account theoretical discussion above and supposing fracture instability duration of several weeks we believe that atmospheric tide cannot excite the instability itself but it can a little bit change exact time of the instability termination, main shock (approximate or delay it) in dependence of atmosphere induction phase. It means there is a real lithosphere–atmosphere coupling with corresponding feedback.

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