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Tidal triggering of earthquakes in Japan related to the regional tectonic stress

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We observe a correlation between the Earth tide and earthquake occurrence that is closely related to the regional tectonic stress. We investigate the direction of the tidal compressional stress using shallow earthquakes occurring in 100 subregions of Japan for nearly five years. The azimuthal distribution of the compressional stress obtained for the observed earthquake data is compared with that synthesized for random earthquake occurrence. Statistical analysis confirms a significant difference between the observed and random catalogs for 13 subregions, which include the areas where unusual seismic activities took place recently, and where the possibility of future large earthquakes has been argued. For these subregions, earthquakes preferentially occur when the tidal compressional stress is near the dominant direction of P-axes of focal mechanisms obtained in the corresponding subregions. This suggests that the tidal stress may encourage earthquake occurrence when it acts in the direction to increase the regional tectonic stress.

Key words: Tidal triggering of earthquakes, tectonic stress, statistical test.

1. Introduction

The tidal force produces periodic stress variations of the order of 10^3 Pa in the Earth. This stress change is much smaller than the typical stress drop of earthquakes, but its rate is generally larger than that of tectonic stress accumulation. Therefore the tidal stress could trigger an earthquake when the stress in the focal region is close to the critical level to release an earthquake. Accordingly, many studies have investigated the correlation between the Earth tide and earthquake occurrence (e.g., Emter, 1997; Glasby and Kasahara, 2001).

In order to physically investigate the relation between the Earth tide and fault rupture, recent studies have examined stress components resolved on the fault plane by using the focal mechanism solution (Tsuruoka *et al*., 1995; Vidale *et al*., 1998; Wilcock, 2001; Tanaka *et al*., 2002a, b). Some of these studies have also examined the trace of the stress tensor, which is invariant with coordinate rotation and corresponds to the confining stress (Tsuruoka *et al*., 1995; Wilcock, 2001; Tanaka *et al*., 2002b). Through the analysis of this component, Tanaka *et al*. (2002b) suggested that earthquake occurrence is encouraged when the tidal stress acts in the same sense as the tectonic stress. They analyzed earthquakes of $M_w \geq 5.5$ that had focal mechanisms in the Harvard catalog.

In this paper, we further explore the relation between the tidal effect on earthquake occurrence and the tectonic stress field by using a large number of shallow earthquakes occurring in Japan. These earthquakes include small ones for which focal mechanisms are not available, so we instead focus on the direction of the tidal compressional stress to assess the possible tidal effect.

2. Data

From the earthquake catalog of the Japan Meteorological Agency (JMA) for the period from October 1997 to May 2002, we use the origin times and hypocenters of shallow earthquakes (focal depth $\leq$ 70 km, $M_{\mathrm{JMA}} \geq 2.0$) occurring in Japan. Clustered events are removed following the method of Reasenberg (1985). Dividing the whole of Japan into $1^\circ \times 1^\circ$ subregions, we select 100 subregions for the analysis, each of which includes at least 200 earthquakes. These subregions are indicated by small squares in Fig. 1. A total of 89,504 earthquakes is used in this study.

3. Method of Statistical Test

We investigate the correlation between the Earth tide and earthquake occurrence by statistically comparing the azimuthal distribution of a tidal stress component obtained for the observed earthquake occurrence with that synthesized for random earthquake occurrence. The random occurrence data are generated by randomly assigning 100 origin times for each hypocenter.

For the tidal azimuth, we use the horizontal projection of the maximum principal axis (maximum compression) of the tidal stress tensor considering that the horizontal compression is dominant in the Japan region. The tidal stress tensor is theoretically calculated at the origin time and the hypocenter of each earthquake for the Preliminary Reference Earth Model (Dziewonski and Anderson, 1981) following the method of Tanaka *et al*. (2002b). This calculation includes both the direct solid Earth tide and indirect term due to the ocean loading by using the ocean tide model NAO.99b (Matsumoto *et al*., 2000; Takanezawa *et al*., 2001). From the tidal stress tensor thus calculated, we obtain the azimuth of

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