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An approach to the validation of thermal and electromagnetic earthquake precursors: Effects of earth tides

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ABSTRACT

It has been debated for years whether earth tides trigger earthquakes. A recent statistical study has proven the significance of earth tides in earthquake triggering. In this paper, we firstly show that large earthquakes in the region of the 2004 Sumatra earthquake (M9.0) occur largely during a specific phase of the Moon. Then, we show that the observed thermal/electromagnetic precursors of the outgoing long wave earth radiation and the VLF propagation anomaly (ionospheric perturbation) at the time of an earthquake are modulated by the tidal effect of the region. Finally, we propose a model to explain the observed behaviors of the thermal/electromagnetic precursors, and show that tidal stress can trigger earthquakes, leading also to thermal/electromagnetic signatures.

1. Introduction

The Earth travels around the Sun as a planet in the solar system, and the Moon orbits the Earth as a satellite. These movements cause changes in the seasons. They also produce changes in the apparent shape of the Moon and consequently produce periodic changes – rise and fall – in the level of seawater, which are called the ocean tides. The same mechanism operates on the Earth's body, and the solid Earth deforms like seawater. This phenomenon is called the earth tides, with which the Earth's surface moves like the surface of a sea, some 10 cm vertically. At the same time, the Earth's crust, which covers the Earth's surface, is expanded, contracted, and inclined, as is schematically illustrated in Fig. 1.

It has been debated for years whether earth tides trigger earthquakes (EQs). A recent statistical study has proven the significance of these earth tides in EQ triggering (Tanaka et al., 2004). Paying particular attention to specific fault structures, another study further reported the evidences of tidal effects in EQ triggering in three specific regions in Japan, such as the Sagami trough region (Sue, 2009).

EQs are definitely a mechanical phenomenon; therefore, it is not difficult to imagine that the earth tide is a possible candidate for triggering EQs when the focal zone is at a critical stage. Further, considerable evidences have been accumulated on the precursory electromagnetic (EM) phenomena of EQs (Hayakawa and Molchanov, 2002; Molchanov and Hayakawa, 2008). Hence, the purpose of this study is to find out any effect of earth tides in those precursory signals for the case of the 2004 Sumatra EQ and then to consider the possible theory behind them.

2. Analysis method

The earth tides produced by the gravitational action of the Moon and the Sun affect the occurrence of EQs. This is the phenomenon that occurs only when earth tides deform a fault in such a direction as to assist fault slipping. We would expect that earth tides may also affect the corresponding seismogenic behavior in the same manner. Therefore, we investigate if there are any effects of a specific lunar phase on EQ precursors.

The lunar phases are illustrated in Fig. 2. As an index of a lunar phase, it is possible to apply the ecliptic-longitude difference between the Moon and the Sun of the ecliptic coordinate system. This is the angle with a numerical value from 0° to 360°: the new moon at 0°, the first quarter moon at 90°, the full moon at 180°, and the last quarter moon at 270°. Since the Moon orbits the Earth in 29.5 days on average, the average traveling speed of the Moon is 12.2° per day. In this paper, by combining the two indicators: angle and day, we use the number of days with respect to such specific lunar positions as the new, first quarter, full, and last quarter moon as the indicator of lunar phase.

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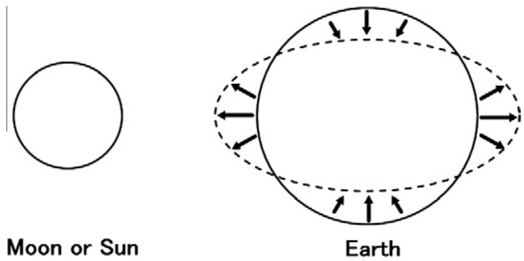

Fig. 1. Schematic picture of earth tides (expansion, contraction, inclination).

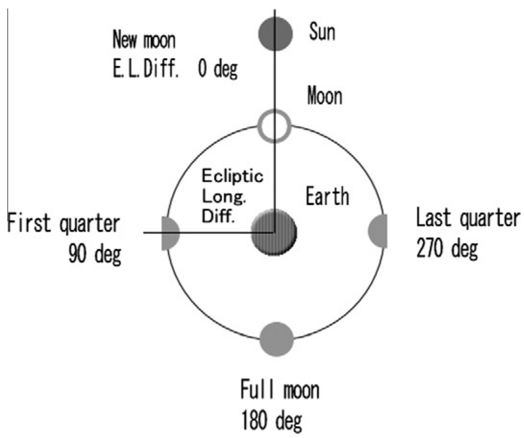

Fig. 2. Explanation of the lunar phases (0°, the new moon, 90°, the first quarter moon, 180°, the full moon and 270°, the last quarter moon).

3. The 2004 Sumatra EQ (M9.0)

This EQ occurred on December 26, 2004 at 7:58 AM (local time) off the west coast of Northern Sumatra. The magnitude of the EQ is about 9.0, though there are several calculations. This is the fourth largest EQ in the world since 1900, having produced an enormous number of casualties. Therefore many studies have been conducted on it, including those on the tidal effect, which are enumerated below.

A statistical analysis on tidal triggering of EQs shows that a high correlation between the earth tides and the EQs existed in the area around the initial rupture point for about 10 years preceding the occurrence of this EQ (Tanaka, 2006).

The frequency of EQ incidence along the Andaman/Sunda/Java Trench plate-boundary region for the ten-lunar-month period encompassing the EQ shows that variations in EQ activity correlate with the tidal-force cycles: maxima in EQ activity occur around the times of new and full moons, typically lagging by 0–3 days, and this relationship is consistent with EQ inducement via ocean tidal loading (Crockett et al., 2006). However, Cochran and Vidale (2007) have raised questions on the method used by Crockett et al. (2006) and have pointed out that the results contradict nearly all previous studies and theoretical expectations.

Therefore, we firstly investigate whether the EQs occurring in this region have any relationship to the lunar phase. We used the unbiased data provided by Bell et al. (2005), which are shown in Fig. 3. We set the study region as the one that surrounds the first rupture point of the EQ, where the Indo-Australian plate subsides below the Sunda (or Eurasian) plate, causing reverse-type EQs. Table 1 lists the EQs in the study region with the corresponding lunar phases. Fig. 4 shows the plot of the EQs against the lunar phase. Although the EQ number in the region is small, it can be observed that the EQs occurred largely on a full moon and shortly thereafter. There are also some occurrences before a first quarter moon, after a last quarter moon, and before a new moon. As for the result of the analysis, we consider the regional tidal response, like the evidences shown by Sue (2009).

The huge EQs with a magnitude greater than 7.5 in the study region only occurred from November to March, and this suggests possible seasonality in EQ occurrence. Such seasonality is also observed in the Southern Japan region (Ohtake and Nakahara, 1999).

4. Thermal and EM measurements

4.1. Thermal anomalies

Ouzounov et al. (2007) have reported that the analysis of the continuous outgoing long wave earth radiation (OLR) indicates anomalous variations prior to a number of medium to large EQs. The OLR anomaly corresponds to a large area of ground coverage and coincides with the main epicentral zone. They have found the OLR anomalous values within the epicentral area on December 21, 2004, i.e., 5 days before the event.

Fig. 5 shows the further analysis on the lunar phases of the obtained results. The presence of several peaks and valleys implies the existence of several phases in the measurement, while we pay special attention to full moons according to the characteristic of the region. The occurrence of the EQ was on a full-moon day, hence the full-moon days of 1 and 2 months before the EQ in addition to the new-moon days between them are added to the original figure. As a result, the maxima near full-moon days as well as minima between them, which are shown by the red arrows, are identified. The black arrows indicate that the OLR value assumed a maximum several days prior to the full-moon day 2 months before, assumed a minimum, again assumed a maximum on several days after the full-moon day 1 month before, assumed a minimum, and finally assumed the largest maximum on 5 days before the EQ. After assuming the last and the largest maximum, the value decreased and the EQ occurred. Thus, the OLR shows an iteration of the maximum–minimum–maximum pattern for the duration of 2 months before the EQ, possibly due to the reason of modulation by earth tides.

4.2. EM anomalies

The seismo-EM anomaly was also observed on the data of VLF transmission between the NWC station in Australia and the sites in Japan. Fig. 6 shows the temporal evolution of the VLF amplitude nighttime fluctuation (dA^2) at three observing sites; namely, Chofu (Blue), Chiba (Black), and Kochi (Red) in Japan for the period encompassing the Sumatra EQ (Horie et al., 2007). The EQs with a magnitude greater than 6.0 are also shown. The nighttime fluctuation (defined in Horie et al., 2007) is plotted for the three sites. The three lateral lines indicate $m + 2\sigma$ (where m is the mean and σ is the standard deviation) at the corresponding sites. On December 8, 2004, we notice a significant enhancement at Chiba, exceeding $m + 2\sigma$, which is shown by a downward black arrow. Considering that the anomaly is only at the Chiba site, it is concluded that the anomalous state occurred significantly only on the NWC-Chiba path rather than all the paths. A geomagnetic storm was found to have occurred before this VLF anomaly, so that this anomaly might be related to the geomagnetic storm. Then, from December 21, 2004 (5 days before the EQ) to January 2, 2005, there are prolonged periods of amplitude fluctuation for all sites, which imply that the fluctuation is global; therefore, all the NWC-Japan propagation paths are strongly disturbed (Horie