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GIANT EARTHQUAKES ARE OCCURRING AT LUNAR PHASES SPECIFIC TO EACH SUBDUCTION ZONE

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ABSTRACT

Here, we statistically proved that giant earthquakes occur at lunar phases specific to each subduction zone. Enough attention during the lunar period, especially when seismicity is occurring, will significantly reduce damage from giant earthquakes. Two case studies in which giant earthquakes occurred after seismicity in dangerous lunar phases were discussed, and the mechanisms underlying why giant earthquakes occur around neap tide at some subduction zones were explained by prohibition of giant earthquake occurrences due to high strain rates at spring tides at N–S subduction zones. The prohibition was statistically proven for uniaxial creep tests on Inada granite with slight stress disturbances.

KEYWORDS

Giant earthquakes, Lunar phase, Subduction zone, Delay from spring tide, Statistical testing

INTRODUCTION

In previous studies, we showed that from 1900 to present, giant earthquakes ($M_W \geq 8$) have occurred at lunar phases specific to each subduction zone (Fujii & Ozaki, 2012; Ozaki & Fujii, 2012). Although we later proposed a possible reason for these occurrences, the study lacked statistical analyses (Fujii et al., 2013). Therefore, this paper shows the results of such statistical testing and presents case studies for the Tohoku 2011 and Chile 2014 events, thereby providing updated data on giant earthquakes through July 2014.

DANGEROUS LUNAR PHASES FOR EACH SUBDUCTION ZONE

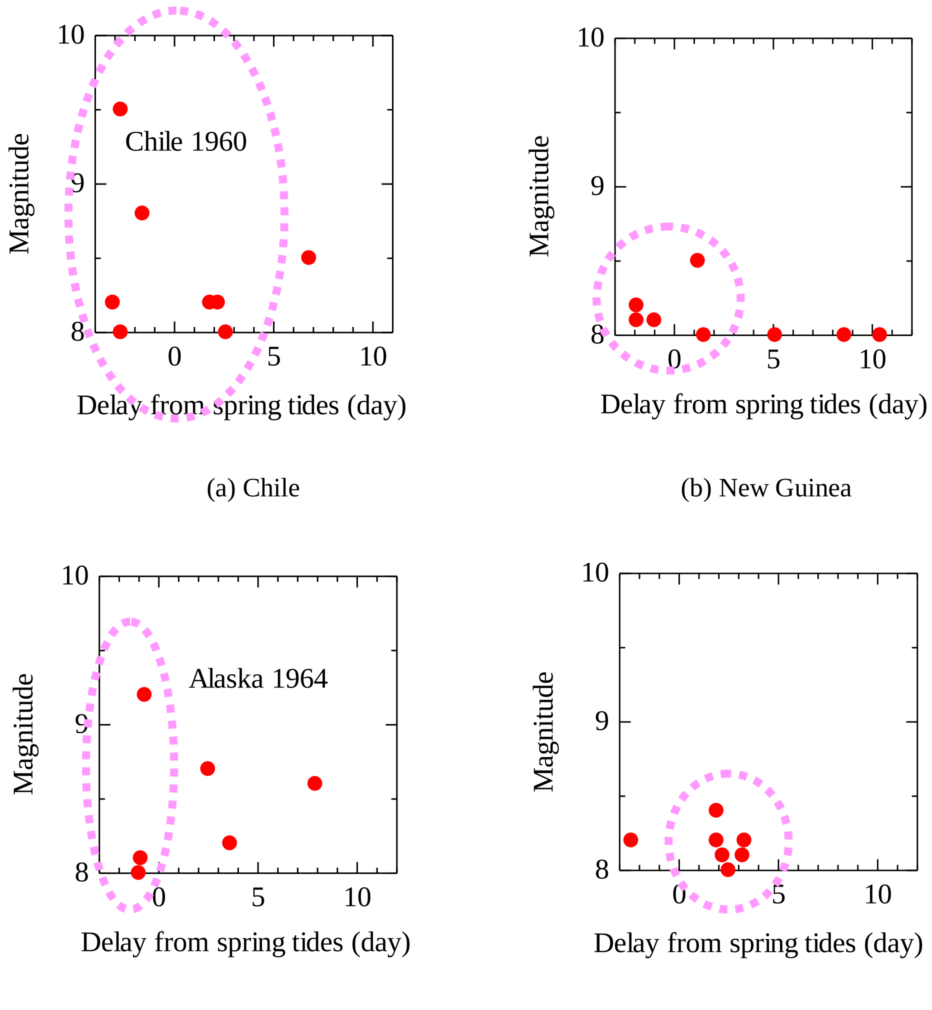
Most of the giant earthquakes ($M_W \geq 8$, source: USGS website) that occurred between 1900 and July 2014 at each subduction zone seem to have occurred during specific lunar phases, represented as delays from spring tides at each subduction zone (Figure 1). Assuming a random process for earthquake occurrences (random null hypothesis), the probability p that m earthquakes occur in a specific lunar phase is

$$p = h^{m-1}(1-h)^{n-m} \times {}_{n-1}C_{m-1} \tag{1}$$

where n is the total number of earthquakes, h is the probability of an earthquake occurs in the specific lunar phase and equals the length of the specific lunar phase divided by the length of one lunar month (29.53 days). The random null hypothesis was statistically rejected for all of the subduction zones, because the probabilities were less than 5% (Table 1). This means that the statement “giant earthquakes occur at lunar phases specific to each subduction zone” is statistically meaningful. Thus, paying sufficient attention to foreshocks and various precursors that occur during the dangerous lunar phase of each subduction zone (Table 1; Figure 2) is a very effective way of reducing damage from giant earthquakes.

Table 1 – Dangerous lunar phases, number of giant earthquakes within the dangerous period/total giant earthquakes, and the probability of the random null hypothesis

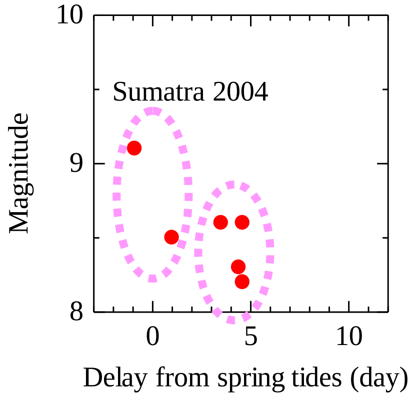
Subduction zone	Dangerous lunar phase or phases (delay from spring tide, days)	Number of earthquakes in the period/total	Probability of random null hypothesis (%)
Chile	-3.1 to 2.6	7/8	1.40
Alaska	-1 to -0.7	3/6	0.39
New Guinea	-1.9 to 1.5	5/8	4.5
Peru	1.9 to 3.3	6/7	0.0041
Indonesia	-0.9 to 1.0 and 3.5 to 4.6	6/6	0.169
Tonga	5.3 to 6.7	4/5	0.31
Japan	3.6 to 7.7	5/6	2.1
Kuril	-1.8 to 2.3 and 8.8 to 10.5	9/9	0.142



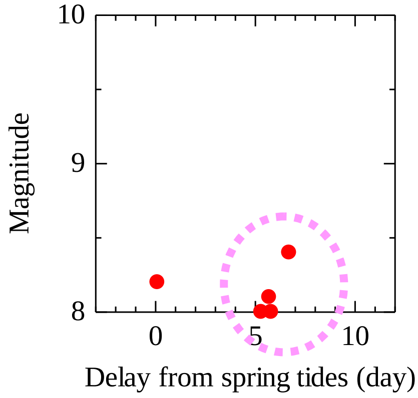
(a) Chile (b) New Guinea

(c) Alaska (d) Peru

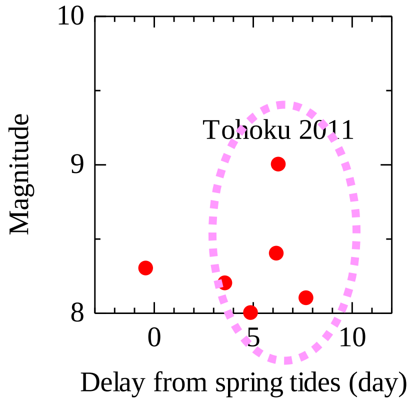
Figure 1 – Lunar phase in delay from the spring tide, and magnitude of giant earthquakes for each subduction zone



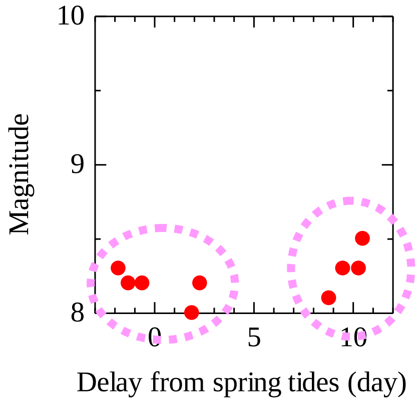
(e) Indonesia



(f) Tonga



(g) Japan



(h) Kuril

Figure 1 – Continued

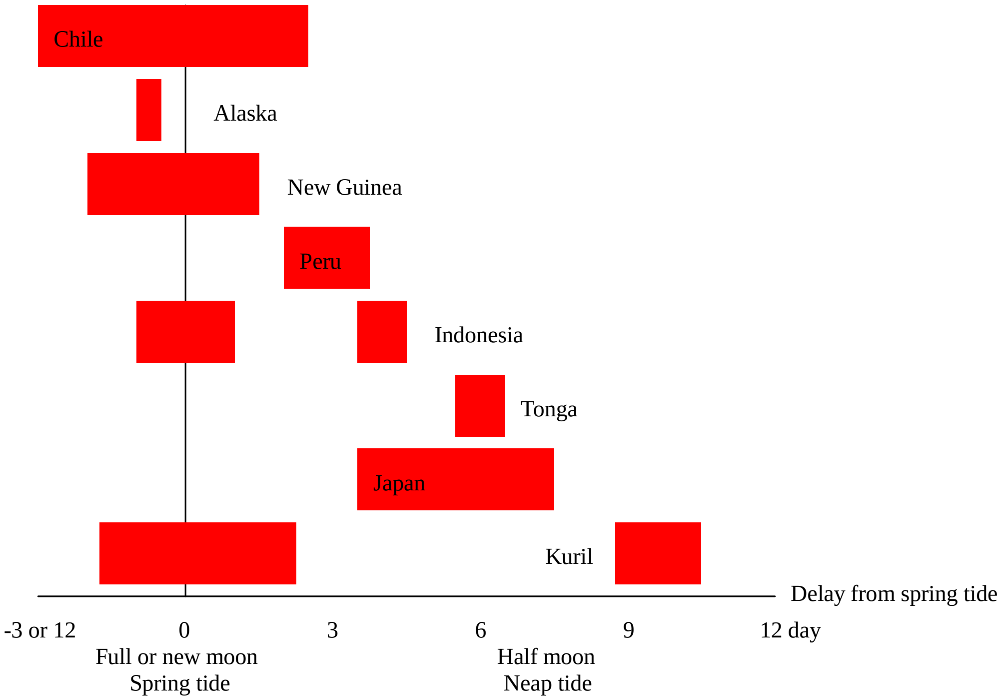


Figure 2 – Dangerous lunar phase in delay from the spring tide for each subduction zone

CASE STUDIES

Tohoku 2011

For the Japan Trench, the dangerous lunar phase is 3.6 to 7.7 days from the spring tide (Table 1). On March 9, 2011, a M_W 7.2 foreshock occurred during the dangerous lunar phase (Figure 3). A tsunami watch ($\leq$ 0.5 m) was issued and then lifted (Table 2). Subsequently, another foreshock (M_W 6.6) occurred. A tsunami watch was again issued and lifted. However, small foreshocks continued to occur, and the mainshock occurred 28 h later, still in the dangerous lunar phase. The seismicity pattern before the mainshock appeared to be similar to the preceding gas outbursts from deep coal mining. If people had known that there was a dangerous lunar phase, and had remained evacuated for only another 28 h, the number of victims would have been greatly reduced.

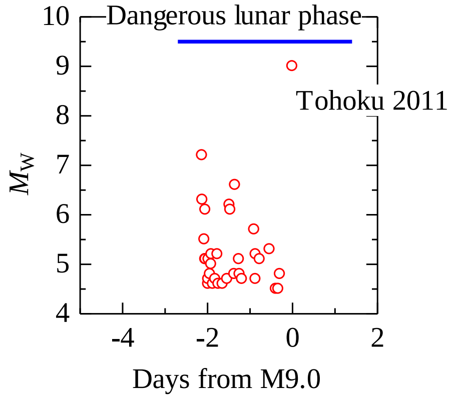


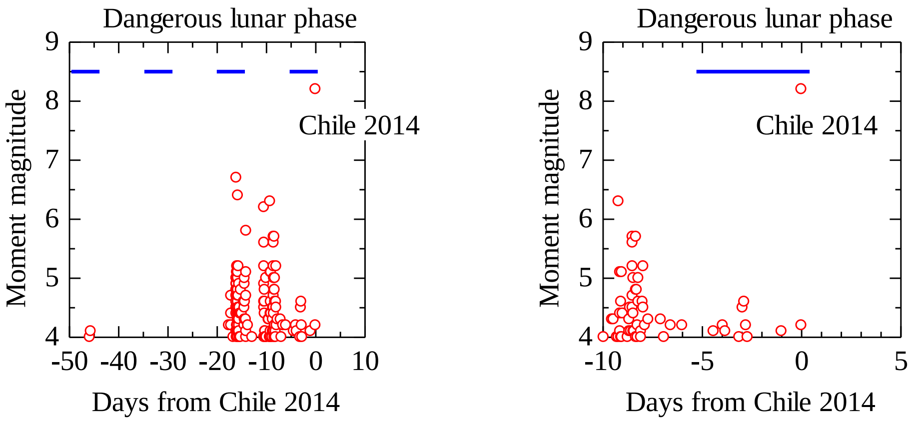
Figure 3 – Foreshocks and mainshock of the Tohoku 2011 event (source: JMA web site)

Table 2 – Tsumani watches immediately preceding the Tohoku 2011 event (UTC 2:46, March 11, 2011)

Date (UTC)	Time (UTC)	Event
March 9, 2011	2:45	M_W 7.2 foreshock
	2:48	Tsunami watch is issued
	5:50	Tsunami watch is lifted
	21:24	M_W 6.6 foreshock
	21:28	Tsunami watch is issued
	22:30	Tsunami watch is lifted

Chile 2014 (23:46, Apr. 1, 2014)

Active seismicity began approximately 2 weeks before the 2014 Chile event during the dangerous lunar phase for the Chile Trench (Figure 4a, b). The seismicity became inactive once, and then began again approximately 10 days before the mainshock, although not in the dangerous lunar phase. Then it became inactive and the lunar phase advanced into the dangerous period. Small foreshocks continued, and the Chile 2014 mainshock occurred at almost the end of the dangerous lunar phase (Figure 4b). In this case, the earthquake damage could also have been significantly reduced if people had known that there was a dangerous lunar phase for the Chile Trench, and had continued to pay sufficient attention until the dangerous period had ended.



(a) Two-month period (b) Magnified plot

Figure 4 – Chile 2014 event and earthquakes within 120 km from the mainshock epicenter that occurred before the mainshock (source: USGS web site)

WHY NEAP TIDES?

It is natural that giant earthquakes occur around the spring tide in Chile, Alaska, New Guinea, Indonesia, and Kuril, because the tidal forces from the sun and moon combine. On the other hand, it seems strange that giant earthquakes would occur at times other than around spring tides, such as around neap tides in Peru, Indonesia, Tonga, Japan, and Kuril.

Fujii et al. (2014) showed that the strike of a subduction zone affects the amplitude of the theoretical solid tidal stress, thereby causing a slip at the reverse fault in the subduction zone. The amplitude of the nearly N–S subduction zones, at which giant earthquakes occur around the neap tide, was much greater than that for nearly E–W subduction zones at which they occur around the spring tide (Figure 5). It is well known that rock strength becomes larger under larger strain rate as Equation 2.

$$\sigma_{max} = A\dot{\varepsilon}^{\frac{1}{n+1}} \tag{2}$$

where σ_{max}, A, $\dot{\varepsilon}$ and n are the peak stress, a constant, the strain rate and the stress corrosion index, respectively. It was therefore assumed that greater strain rate caused by the greater tidal stress during the spring tide prohibited giant earthquake occurrences at nearly N–S subduction zones.

A series of uniaxial compression creep tests were carried out on Inada granite to examine the assumption. UCS of the rock is around 200 MPa (Fujii et al., 1998) but creep stress was not fixed because strength may vary between specimens. Instead, creep control (simulating the neap tide) was started when circumferential strain reached -0.1% to make sure that specimen did not break before the creep control but break within several days. Then slight stress disturbances were applied repeatedly to simulate spring tides at N–S subduction zones. 8.3 MPa or 0.83 MPa disturbance was used as a first step of investigation. 8.3 MPa is impossibly larger than tidal stress including ocean loading of 0.05 MPa and only for comparison.

For Case 10s, in which stress disturbances were under 8.3 MPa, specimens failed under a stress larger than the average value (Figures 6 and 7) Assuming a random process for specimen breakage (random null hypothesis), the probability p that m specimens break in a specific period is calculated substituting the total number of specimens n, the probability of a specimen breaks in the specific period h

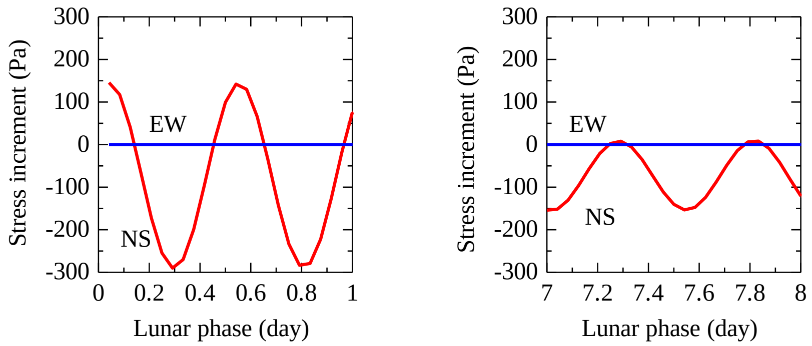
which equals the length of the specific period (2 min. for larger stress or 4 min. for creep control) divided by the length of one cycle (8 min.) of creep control and slight disturbances into Equation 2.

$$p = h^m (1-h)^{n-m} \times {}_n C_m \tag{3}$$

The degree of freedom in Equation 3 is different from that in Equation 1 because the time period is not arbitrary chosen for this case. The random null hypothesis was rejected (Table 3). This means of course that the larger stress is the reason of the specimen breakage.

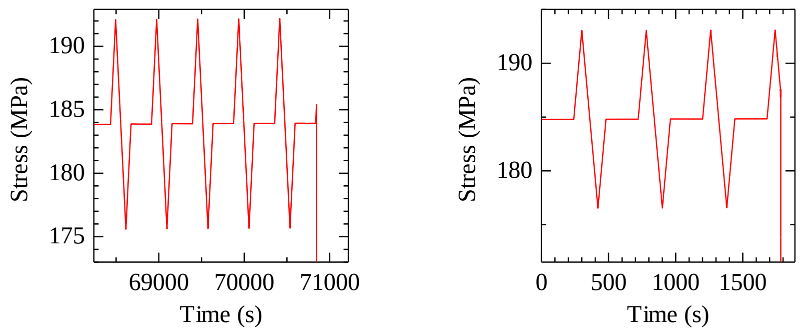
For Case 1+, in which stress disturbances were under 0.83 MPa, 3/5 of the specimens failed when the stress value was larger than the average (Figure 8). This was a random process as the probability of the random null hypothesis was 8.8% (Table 3), and this means that the small stress amplitude did not affect specimen failure.

For Case 1-, under the same stress amplitude but beginning from the decrease in stress, all five specimens failed under creep control (Figure 9). The probability of the random null hypothesis was 3.1% (Table 3), and the hypothesis was rejected. The reason for this must be the low strain rate under creep control. This result supports the assumption that the larger strain rate during spring tide prohibits giant earthquake occurrences at nearly N–S subduction zones.



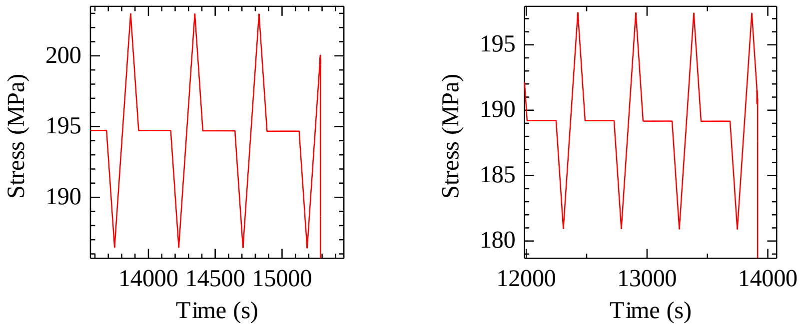
(a) Spring tide (b) Neap tide

Figure 5 – Examples of theoretical solid tidal stress for N–S and E–W subduction zones



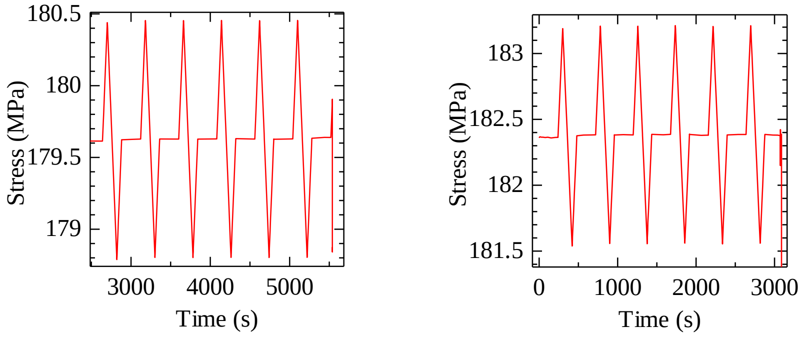
(a) Failed when stress was increased (b) Failed when stress was decreased

Figure 6 – Examples of the results for Case 10+



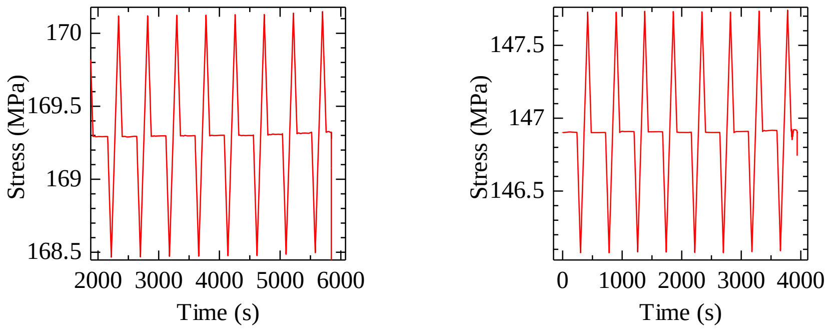
(a) Failed when stress was increased (b) Failed when stress was decreased

Figure 7 – Examples of the results for Case 10–



(a) Failed when stress was increased (b) Failed under creep control

Figure 8 – Examples of the results for Case 1+



(a) Failed under creep control (b) Failed under creep control

Figure 9 – Examples of the results for Case 1–

Table 3 – Probability of the random null hypothesis for the timing of rock failure

Case	Stress state	Number of rock failures in the period/total	Probability of random null hypothesis (%)
10+	Larger than average	5/6	0.49 (rejected)
10–	Larger than average	5/7	1.15 (rejected)
1+	Larger than average	3/5	8.8 (accepted)
1–	Creep control	5/5	3.1 (rejected)

CONCLUDING REMARKS

Here, we statistically proved that giant earthquakes occur at lunar phases specific to each subduction zone. Enough attention during the lunar period, especially when seismicity is occurring, will significantly reduce damage from giant earthquakes. Two case studies in which giant earthquakes occurred after seismicity in dangerous lunar phases were discussed, and the mechanisms underlying why giant earthquakes occur around neap tide at some subduction zones were explained by prohibition of giant earthquake occurrences due to high strain rates at spring tides at N–S subduction zones. The prohibition was statistically proven for uniaxial creep tests on Inada granite with slight stress disturbances.

Examining additional case studies to show the effectiveness of the dangerous lunar phase concept, and performing triaxial compression tests to examine the timing of failure on rock that composes fault asperities, such as basalt under high temperature and high confining and pore pressures, are required for further advancement.

REFERENCES

Fujii, Y., Kiyama, T., Ishijima, Y. and Kodama, J. (1998), Examination of a Rock Failure Criterion Based on Circumferential Tensile Strain, *Pure and Applied Geophysics, 152(3)*, 551-577.

Fujii, Y. and Ozaki, Y. (2012), Date, Lunar Phase and Time of Giant Earthquakes might be Specified for Each Subduction Zone, *Seismological Research Letters, 83(2)*, 456 (Seismological Society of America 2012 Annual Meeting, Apr. 19, San Diego, US).

Fujii, Y., Ozaki, Y., Fukuda, D. and Kodama, J. (2013), Why Do Giant Earthquakes Occur at Lunar Phases Specific to Each Subduction Zone? *RS2013-1021, 6th Int. Symp. on In-situ Rock Stress*, 20-22 August 2013, Sendai, Japan.

JMA Web Site (in Japanese), http://www.data.jma.go.jp/svd/eqev/data/index.h.tml

Ozaki, Y. and Fujii, Y. (2012), *Characteristics of Date, Time and Lunar Phase of Giant Earthquakes for Each Subduction Zone*, SSS25-05, Japan Geoscience Union Meeting 2012, May 20, Makuhari, Japan.

USGS Web Site, http://earthquake.usgs.gov/earthquakes/eqarchives/year/mag8/magnitude8_1900_date.php, http://neic.usgs.gov/neis/eq_depot/mag8.html, http://earthquake.usgs.gov/earthquakes/search/