Long-term Predictability for Repeating Earthquake using Standard Value of Lognormal Distribution

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Event numbers of sequential recurrent large/medium earthquakes listed in seismic catalog are frequently very small, because they recur at long intervals. Then it may be useful to adopt a standard value in some parameters which is commonly applied for such sequences in calculating the probability for the coming event. We are studying the predictability by two models, LN-NORM and LN-SST-Pin, involving those parameters. The standard values of σ_0=0.581 for standard deviation in log-normal distribution are determined from the 166 small interplate repeating earthquakes along the Japan Trench, which were used for the experiment of prospective forecasts from 2006 to 2010. Event data were taken in order from the last earthquake, with 3, 4, 5 and 5 or more. In 248 of 524 forecast sequences the repeater occurred during the forecast period.

(1) LN-NORM: Lognormal distribution model. The mean and variance parameters for each sequence are the sequential mean of logarithm of interval and the standard value squared, σ_0^2, respectively.

(2) LN-SST-Pin: Lognormal distribution model based on the idea of the small sample theory. The mean and variance parameters for each sequence is the same as LN-NORM and ((n+1)/n) σ_0^2, respectively.

(3) LN-Bayes: Lognormal distribution model with Bayesian approach. The parameter of the inverse gamma distribution, which is the prior distribution of σ^2, are ϕ=0.25 in shape and ζ=0.44 in scale (2006, 2008) or ϕ = 1.5, ζ = 0.15 (2009, 2010).

(4) LN-SST: Lognormal distribution model base on the small sample theory.

(5) Exp: Exponential distribution model. The parameter plugged is the sample mean.

(6)- (8) BPT-pin: BPT distribution models. The mean parameter for each sequence is the sequential mean of interval. And the parameter of coefficient of variation is the median of the values calculated from sequences of 4 repetitions, α_0=0.367, for model (6), the mean, α_0=0.52 for model (7), and the standard value by the Headquarters for Earthquake Research Promotion in Japan, α_0=0.24 for model (8), used in the long term evaluation of the large and great earthquake, respectively.

The "Mean log-likelihood" mentioned below are used to score the forecast results.
Mean log-likelihood (MLL): Average of Ev*ln (P) + (1-Ev)* ln (1-P)
Here P means forecast probability for event and Ev means presence (Ev=1) or absence (Ev=0) of the event. If the Mean log-likelihood is larger than those of the alternative, the model is considered to be superior to the alternative one.

The ROC (Receiver Operating Characteristic curve) is a diagram showing the relationship between "False Alarm Rate" and "Hit Rate" when the threshold value changes. It can be said that the model is better as the curve swells to the upper left side of the figure.

In Figure 1 the forecasts by six models become worse surely as the number of preceding events is smaller. When the number of event interval data is 2 or less, compared with the result of LN-SST-Pin model, the decline of the LN-NORM model is remarkable. The results of the LN-NORM model and the LN-SST-Pin model are inferior to those of the LN-Bayes model and the LN-SST model. When the LN-NORM model and the LN-SST-Pin model are predicted with 1 event data, the score is poor, and it is below the results of the probability of 0.5 (MLL=-0.693) for all case.

In Figure 2 the supplementation rate of the LN-Bayes model and the LN-SST model is superior to other models. And the supplementation rate of LN-NORM model and the LN-SST-Pin model is inferior to the 3 types of BPT model.

Keywords: Repeating earthquakes, Forecast, Log-normal distribution, Standard value, Mean log-likelihood, Receiver Operating Characteristic curve

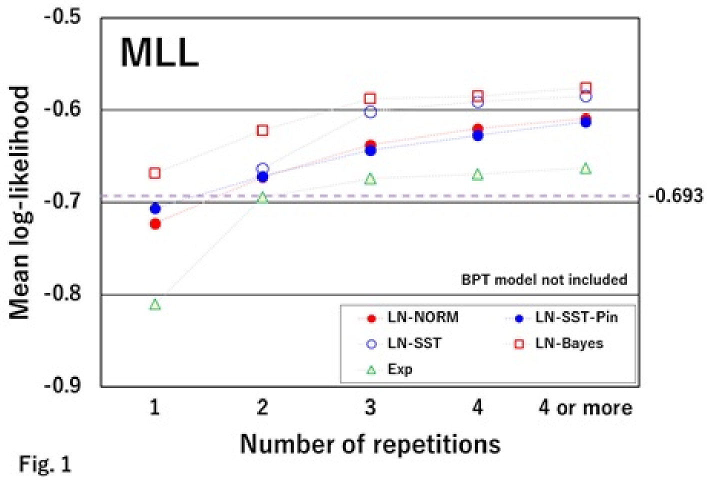

Fig. 1

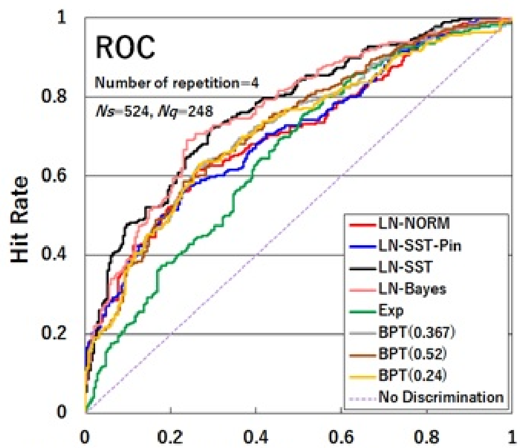

Fig. 2

Has the stress over the focal region of the 2011 Tohoku-Oki *M*9 earthquake recovered to the pre-earthquake state?

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When the logarithm of the number of earthquakes equal or above a magnitude *M* is plotted against *M*, the frequency distribution is well represented by a line in a magnitude range where almost all earthquakes are detected. In the linear distribution known as the Gutenberg-Richter law, the *b* value (slope of the line), has been pointed out to relate to the stress in the seismogenic region: the *b* value is small in a high stress area such as fault patches, while it is large in a region under low stress condition, for example, in high-pore-pressure zones. Based on the empirical knowledge, Tormann et al. (2015), having obtained a result that the distribution of the *b* value in recent years in the focal region of the 2011 Tohoku-Oki *M*9 earthquake is similar to that at pre-earthquake times, considered that the stress over the focal region has already recovered to the state before the earthquake occurrence. Then, they suggest that the renewal process of large earthquake occurrence along the subduction zone is described by a stationary Poisson process, i.e., a similar size megathrust event is potentially possible to occur in overlapping volumes sooner than expected from estimated mean inter-event times of past events. Is that true? If this is the case, we have to re-consider the basic method of long-term earthquake prediction taken by the Earthquake Research Committee of the Headquarter for Earthquake Research Promotion, Japan. This is a serious problem. Here we investigated spatio-temporal change in the *b* value over the foal region of the 2011 Tohoku-Oki *M*9 earthquake in detail. The method of our analysis is basically almost the same as that taken by Tormann et al. (2015), but we improved the analysis somewhat by separating earthquakes in the sea region into two groups, those along plate boundary and such ones that occur above the plate boundary, and by taking temporal variation of spatial distribution of earthquakes into consideration.

Our main results are as follows: The *b* value in the large slip area at the 2011 Tohoku-Oki *M* 9 earthquake has not yet returned to the small value just before the megathrust event elucidated by Nanjo et al. (2012). The *b* value had been becoming small before the 2011 Tohoku-Oki *M* 9 earthquake in the focal region of the 1987 Miyagi earthquake (*M*7.4). The *b* value in the sea region off northern Sanriku has been notably small since the time before the megathrust event and the area of the low *b* values seems to have been expanding to the west. The northern part of this low *b* value area overlaps with the starting point of the rupture of the 1944 offshore Sanriku earthquake (*M*7.5), but the southern part of the area does not overlap with any focal region of past large earthquakes.

In general, our results show that the *b* value over the focal region has not yet returned to the value before the 2011 Tohoku-Oki *M* 9 earthquake, inconsistent with Tormann et al. (2015). We think that it is necessary to monitor the progress of the low *b* value area off northern Sanriku, considering a possibility of occurrence of a large earthquake in the near future.

Keywords: the 2011 Tohoku-Oki earthquake , stress recovery, the Gutenberg-Richter law

Recent seismic activity in Italy and seismic gaps

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After the 1908 M7.1 Messina earthquake, Omori(1909) pointed that there were two seismic gaps along the Montes Appenninus seismic belt. The M7.0 Avezzano earthquake occurred at the one of them in 1915. So, the seismic gap is the one of important information to predict the place of the future earthquake. But there was no earthquake in the other seismic gap until now.
Recently destructive earthquakes occurred at the middle part of the Montes Appenninus. These were M6.1 eq in 1984 April, M6.0 eq in 1984 May, M6.4 eq in 1997, M6.3 eq in 2009, M6.2 eq in 2016 August, M5.9 eq in 2016 Oct., and M5.9 eq in 2017. The source areas were estimated by one month aftershock(M>=2.5) distributions. Italian Seismic Instrumental and parametric Data-base(ISIDe) by Institute of National Geophysics and Volcanology(INGV), Quick Epicenter Determinations by USGS and Catalog of Damaging Earthquakes in the World by Utsu(http://iisee.kenken.go.jp/utsu/index_eng.html) were used.
There are some seismic gaps along the Montes Appenninus seismic belt. One is a small seismic gap between the 1984 M6.1 eq and 1997 M6.4 eq. The area between 2009 M6.3 eq and 1984 M6.0 eq is large, but the 1915 M7.0 Avezzano earthquake occurred in this area. There is a possibility to exist a small seismic gap. Additionally, the area between 1984 M6.0 eq and 1980 M6.9 eq may be other seismic gap.

Keywords: prediction, seismic gap, Italy

Long-term increasing and decreasing changes in groundwater temperature in the Tokai region

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Stress concentration due to deformation of the crust may generate highly compressed fluids within cracks in the rocks. Those fluids tend to migrate upwards through crack system in the crust. The intrusion of water with high temperature into a shallow water layer results in an increase in the temperature of the shallow water. An increasing trend in water temperature is found since the beginning of the observation in December, 2003 at a depth of 30m in an observation well, in Yaizu City. The increasing rate is 23m degree/year. At an artesian well in Shizuoka, where we set thermometers at depths of 5 m and 30m, we found an increasing rate of 34m degree/year since March 29, 2006. However, the rate changed up to 67m degree/year around February in 2007 and turned to decrease down to 14m degree/year in September. After September, 2008, the temperature is decreasing with a rate of -40 m degree/year. This change of long-term trend is a possible precursor for the Aug. 11, 2009 Suruga Bay earthquake of M6.5. Including aftereffects , the volumetric strain meters deployed by JMA could not detect the trend changes. Recently, the Shizuoka water temperature shows another change of decreasing trend. The recent increasing and decreasing trends with impulsive events in groundwater temperature in the Tokai region is possibly due to increasing and decreasing compressional stresses deep underground, indicating a sign of the preparation process of the impending Tokai or Tonankai earthquake.

Keywords: crustal movement, earthquake prediction, groundwater temperature

A fault model of the 1946 Nankai earthquake estimated from the survey on sea level Changes

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For the Kii peninsula, we have already proposed the fault model of the 1944 Tonankai earthquake and the 1946 Nankai earthquake, respectively (Umeda & Itaba, 2016). In this study, based on the survey value of the hydrographic bureau (Fig.1), the fault model of the 1946 Nankai earthquake was estimated from the Kii Peninsula to Shikoku (Fig. 2).

Keywords: 1946 Nankai earthquake, sea level change, fault model

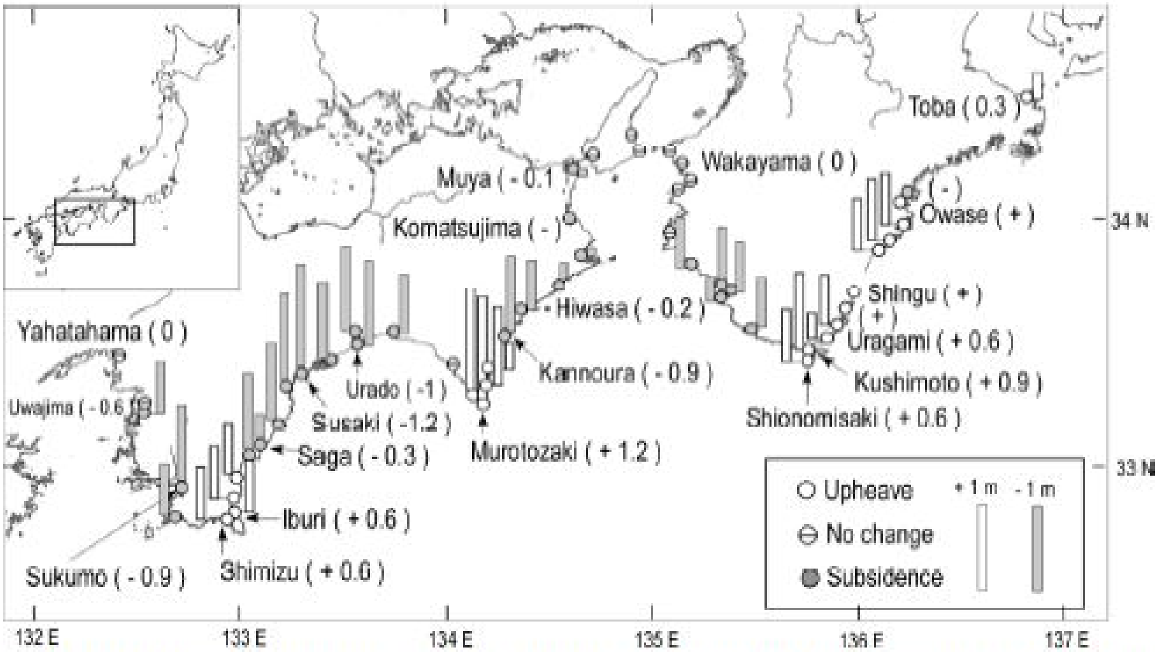

Fig.1 Co-seismic vertical variations of 1946 Nankai earthquake. Variation was obtained from the change of the sea level before and after the earthquake (Hydrographic bureau,1948). An upheaval area is seen on the east coast of the Kii peninsula.

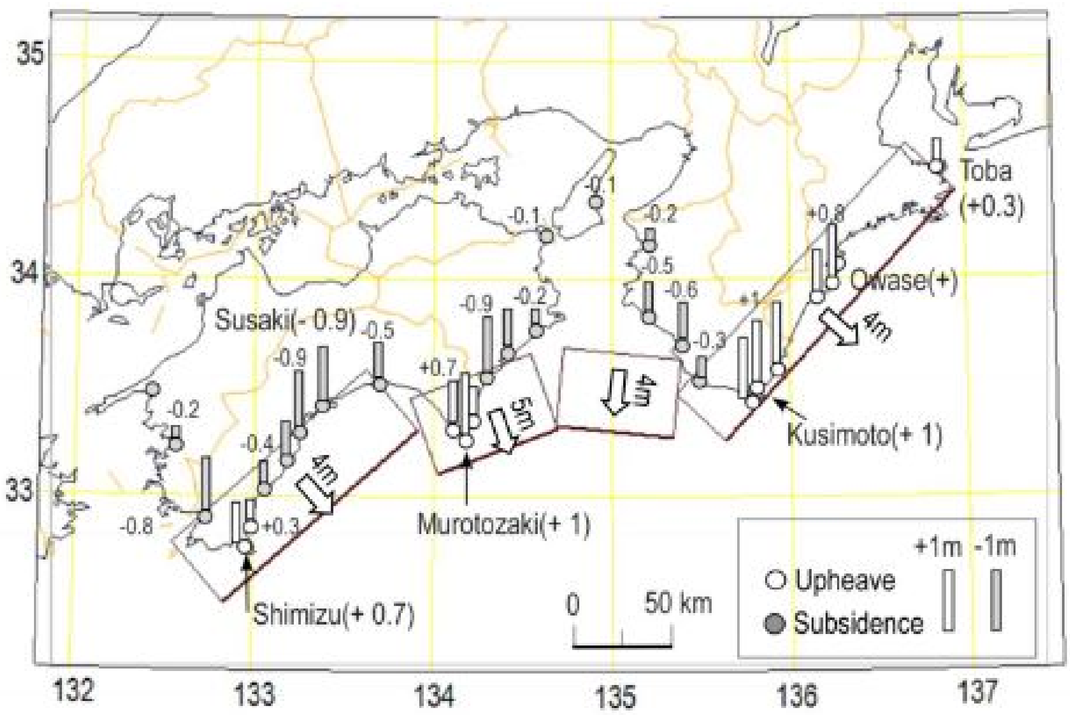

Fig.2 Four assumed faults and displacements of the 1946 Nankai earthquake. Vertical bars indicate the calculated value of upheave and subsidence. The fault extends to the east coast of Kii peninsula and the southwest of cape Ashizuri (Shimizu).

On Statistical Hypothesis Testing of Earthquake Precursory Phenomena

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There are wide variety of phenomena which possibly precede large earthquakes. Physical mechanism between these phenomena and earthquakes are often unclear, but if the link between them were statistically strong, these phenomena could be utilized in practical earthquake forecast. In this talk, we argue that statistical tests have been misused in some of the previous studies on possible precursory phenomena. We present examples from electromagnetic studies, but the lessons would be applied to other observations as well.
We argue two improper statistical hypothesis testing methods, "data snooping" and multiple testing. As Love and Thomas [2013] pointed out, we are obliged to have statistical inference before looking at the data in statistical testing. When statistical inference is set after looking at the data, this test is never validated, and such inference is referred as data snooping. Unless the hypothesis is tested with another set of data, we should refrain from making conclusive statements on its statistical significance.
Type I error is so-called "false positive", in which a true null hypothesis is incorrectly rejected. We set significance level to a small number to reduce such possibility. When we perform large number of statistical test concurrently, the expected value that we encounter Type I error increases proportionally. As Love and Thomas [2013] showed, when physical mechanism between the phenomena and earthquakes is not known, we are forced to use many sets of parameters and repeat tests. Proper corrections, such as Bonferroni correction, will reduce occurrence of Type I error, but often are not used in previous publications of precursory phenomena. Additionally, when specific combination of parameter is used without theoretical basis or strong rationale, it could be safe to assume that use of multiple testing is properly documented in such publications so that possibility of false positive remains regardless of their conclusion.

Keywords: Earthquake Precursory Phenomena

