Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

SSS27-01 Room:103 Time:May 24 10:00-10:15

Statistical investigation of spatio-temporal densities of foreshocks to understand earthquake predictability

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The relation between the size of earthquake preparation zone and the magnitude of forthcoming earthquake is different between nucleation and domino-like cascade models. The former model indicates that the magnitude is predictable before the mainshock of the earthquake, because the preparation zone is proportional to the rupture area. One the other hand, the latter indicates that the magnitude is unpredictable, because the rupture consisting of sequence of tiny earthquakes is unknown to terminate. Since this issue is still controversial, we would like to verify the two models using the methodology proposed by Lippiello et al. (Scientific reports, 2012). In the analysis, spatial occurrence rates of the foreshock and the aftershock are statistically compared. The results show that both the rates are similar and the distribution of the rates versus the epicentral distance depends on the magnitude of the mainshock. From the interpretation of these results, the nucleation model seems reliable.

Keywords: Earthquake, Foreshock, Mainshock

SSS27-02 Room:103 Time:May 24 10:15-10:30

Proper scoring systems available for probability forecasts targeting rare phenomena

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Necessary conditions for ensuring that newly introduced method can improve forecast are, existing *proper* scoring system and that the new method marks better score than the present method do. Murphy and Epstein (1967) pointed out that "all proper scoring system should encourage the meteorologists to make his probabilities correspond with his true belief." Probability Score (Brier, 1950; hereinafter called BS), which is well used for evaluating such as probability of precipitation forecasts, satisfies the mathematical term of the *proper* scoring rule; but, information gain (Kullback and Leibler, 1951) does not. The effort to score high in an *improper* scoring rule does not mean honest activity aiming for a better forecast in general, because the rule do not ensure forecasters to get the highest score in case they make forecast with their true belief. Therefore, we should become very careful about interpretation of the measurement or comparison of the forecast based on various information criteria and other *improper* scoring rule, although they still are very widely performed especially in the field of earthquake prediction study.

BS is defined as the expectation of the mean square error between forecasted probability and the existence or non-existence of intended phenomenon. The existence and non-existence are equally weighted. On the other hand, the users tend to give importance to the forecasts of relatively high probability and the cases of the existence, if the intended phenomena of the forecast is rare. Proper scoring systems available for probability forecasts targeting rare phenomena like large earthquakes are discussed below.

Proper scoring rule have to satisfy E_s(x,c)=pS_1(x,c)+(1-p)S_0(x,c) (eq.1), and E_s(p,c)>E_s(x,c) for all x $\neq$ p (eq.2), where p, f, i, c, S_i, and E_s are probability based on true faith by a forecaster, forecasted value, existence (0) or non-existence (1), benchmark forecast such as a probability based on basic statistics, score, and expected score, respectively. The rule also have to satisfy fair condition from the viewpoints to give higher score for more difficult issue to forecast, *i.e.* S_0(c,f) $\equiv$ S_1(1-c,1-f) (eq.3), and $\partial S_1/\partial f|_{c=const}$>=0, $\partial S_1/\partial c|_{f=const}$<=0 (eq.4).

The solutions of eq.1 and eq.3 satisfies S_1(f,c)=-(i-f)B'(f,c)+(i-x)B'(x,c)-B(f,c)+B(x,c), A=d^2B/df^2 (eq.5), where A is any function.

A proper scoring system with suitable characteristics can be obtained after solving eq.5 in a certain boundary conditions and A, and if S_i satisfies eq.2 and 4.

For the first example, from the conditions about scores of benchmark forecast S_i(c,c) $\equiv$ 0, score of perfect forecast S_i(i,c) $\equiv$ 1, A=-2 and S_i(f)=1-$(i-f)^2$ (eq.6) are derived. 1-S_i(f) is BS.

For the other example, by using the boundary condition for expected score of the perfect forecast (f=i) $E_{s,p}$ $\equiv$ 1 instead, and assume that A is the expression of degree 0 of f, A=-2/c(1-c) and S_i(f,c)={(i-c)^2-(i-f)^2}/c(1-c) (eq.7) are derived. The fact (1-S_i(f))/4 is equivalent to BS in case of c=1/2 shows that eq.7 can be interpreted as an extended form of Brier's Score.

General solution for proper scoring systems, and particular solutions, so-called extended Brier's Score, available for probability forecasts targeting rare phenomena like large earthquakes are mathematically derived as I discuss above.

In the meeting, the author would like to introduce the details of derivation of equations and to discuss on the problem for the practical application of the scoring systems. Besides, mathematical solutions of proper scoring rules for warnings, which is a kind of binary forecast, has already been discussed based on expected-utility theory (Hayashi, 2014, JpGU).

Keywords: benchmark forecast, earthquake prediction, extended Brier's score, information gain, probability forecst, proper scoring rule

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SSS27-03 Room:103 Time:May 24 10:30-10:45

Physical interpretation and detection of anomalies associated with crustal processes leading to large earthquakes

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Based on a cellular automata earthquake model proposed by Sacks and Rydelek (1995), we propose an observational approach to the problem of earthquake prediction (short-term). This approach is different from the detection of pre-seismic slip. We propose to revisit the dilatancy model. Previously reported magnitude dependent seismic quiescence (e.g. 1982 Urakawa-OKi earthquake, 1994 Northridge earthquake, 2008 Wenchuan earthquake) can be interpreted as a manifestation of the dilatancy hardening process. By incorporating this process, our model explains the magnitude selectivity. This information may be useful for raising awareness. We note that this phenomenon is not confined to the eventual earthquake zone but covers much wider area. If we advance this line of thinking, dilatancy breakdown can be expected before the eventual large faulting, which should result in fluid diffusion into cracks opened by dilatancy. Mature faults are known to have high permeability and may act to accelerate the process and lead to observable anomalies. Our model needs to include this phase to provide quantitative direction for detection. We propose that the observation of vertical strain will complement the existing multiple-parameter observations to provide useful data related to fluid distribution changes as a short-term precursor.

Keywords: seismic quiescence, dilatancy, cellular automata earthquake model

SSS27-04 Room:103 Time:May 24 11:00-11:15

Predicting changing rates of swarm activity by volumetric strain

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Near the eastern coast of Izu peninsula is an active submarine volcanic region in Japan, where magma intrusions have been observed many times. The forecast of earthquake swarm activities and eruptions are serious concern particularly in nearby hot spring resort areas. It is well known that temporal durations of the swarm activities have been correlated with early volumetric strain changes at a certain observation station of about 20 km distance apart. Therefore the Earthquake Research Committee (2010) investigated some empirical statistical relations to predict sizes of the swarm activity. Here we looked at the background seismicity rate changes during these swarm periods using the non-stationary ETAS model (Kumazawa and Ogata, 2013, 2014), and have found the followings. The modified volumetric strain data, by removing the effect of earth tides, precipitation and coseismic jumps, have significantly higher cross-correlations to the estimated background rates of the ETAS model than to the swarm rate-changes. Specifically, the background seismicity rate synchronizes clearer to the strain change by the lags around a half day. These relations suggest an enhanced prediction of earthquakes in this region using volumetric strain measurements. Hence we propose an extended ETAS model where the background rate is modulated by the volumetric strain data. Here we have also found that the response function to the strain data can be exponential functions with the same decay rate, but that their intersects are inversely proportional to distances between the volumetric strain-meter and the onset location of the swarm. Our numerical results by the same proposed model show consistent outcomes for the various major swarms in this region.

Keywords: nonstationary ETAS model, background seismicity, swarm, volumetric strain, prediction

SSS27-05 Room:103 Time:May 24 11:15-11:30

Seismo-ionospheric precursor monitoring system based on near-real-time spaceborne and ground GPS observation

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Recently, the global ionosphere map (GIM) has been used to study the seismo-ionospheric precursors (SIPs) intensively. In order to shorten the data latency, an SIP monitoring system is built up based on the near-real-time GIM processing. The GIM data is derived from the combination of the ground-based and spaceborne total electron content (TEC) observation by means of the spherical harmonic function, where the data is retrieved from a global GPS observational network and the FORMOSAT-3/COSMIC radio-occultation (RO) experiments. The temporal statistical analysis is developed to detect the SIPs at several important metropolitans such as Tokyo. Some new finding and results are to be further discussed. The spatial analysis will be introduced to finding the repeat, duration and distribution of worldwide SIPs to estimate the possibility of forthcoming large earthquakes in the future.

Keywords: global ionosphere map, seismo-ionospheric precursor, total electron content

Japan Geoscience Union Meeting 2015
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SSS27-06 Room:103 Time:May 24 11:30-11:45

Long-term groundwater temperature change at a hot spring preceding the 2014 Nagano-ken Hokubu earthquake of M6.7

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On November 22, 2014, an large earthquake of M6.7 took place at the Kamishiro fault in Hakuba Village in the northern Fossa Magna region, central Japan. The Hakuba earthquake was predicted in a long-term basis: a historical earthquake, the Kamishiro active fault, accumulation of crustal strains, etc(Association for the Development of Earthquake Prediction, 1990). To clarify how large earthquakes are generated, we should closely observe changing signals associated with their preparatory process underground. For the purpose of monitoring the preparation process of large earthquakes, various kinds of surveys and nearby observations have been being conducted in the Hakuba Village region around the northern Fossa Magna. Affiliated organizations are Shinshu University, Toyama University, Tokyo Metropolitan University, Tokai University, Nagasaki University, and others. Among them, the observation of water temperature has been conducted at a hot located just west of the Kamishiro fault, since October 1998. The temperature has been slightly decreasing with a rate -0.17 degree/year before around 2009, whereas the rate grew more than before during recent five years as -1.5 degree/year, indicating that dilatation processes in the subsiding region on the footwall side of the fault had been going on before the earthquake.

Keywords: the 2014 Nagano-ken Hokubu earthquake of M6.7, earthquake prediction, precursor, water temperature, dilatation, contraction

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SSS27-07 Room:103 Time:May 24 11:45-12:00

Empirical forecast of mainshocks based on foreshock activities - Application to the north-central Nagano prefecture -

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1. Introduction

An earthquake with magnitude (M) 6.7 occurred on November 22nd, 2014 in the northern Nagano prefecture and it caused many injuries and housing damages. According to JMA, about four days before the mainshock, a pronounced foreshock activity that includes more than 40 small earthquakes with M less than 3.0, had been observed at the very near location of the mainshock. However, it is quite difficult to distinguish foreshocks from background seismicity before a mainshock occurs because we have not yet elucidated the physical process that associates foreshocks with a mainshock. Even though the situation is not easy, empirical approach is one of the realistic ways to use foreshock activity as a precursor of a mainshock. We have been investigating probabilistic features of empirically defined foreshocks and searching for the best parameters to define foreshocks which present relatively high performance to predict large earthquakes. Maeda (1996) and Maeda and Hirose (2012, 2014) proposed a foreshock definition which gives the highest performance to predict large earthquakes along the Japan trench and the Izu region. In this study we basically apply the same method to the seismicity in the north-central Nagano prefecture where foreshock activities are relatively higher than those in other inland regions of Japan. Then we estimate the best parameters to define foreshocks which give good performance of predicting mainshocks in the region.

2. Method

The method to search for parameters for foreshocks that present high prediction performance consists of four steps. 1) To eliminate small aftershocks from the original data. 2) To define foreshock candidates satisfying the condition that the number of Nf earthquakes with magnitude >= Mf occur during the period of Tf days in the segment of the size of D x D degree (latitude x longitude). 3) To set the alarm period of Ta days during which a mainshock is expected to occur after a foreshock candidate is found. 4) To search for the values of D, Mf, Tf, Nf and Ta which give high prediction performance by the grid search method. The prediction performance is measured mainly by dAIC that is defined as the difference of AIC for a stationary Poisson model and a model based on a foreshock activity, and additionally by alarm rate (AR: the fraction of mainshocks alarmed), truth rate (TR: the fraction of foreshock candidates followed by a mainshock), and probability gain (PG: the ratio of mainshock occurrence rate in the predicted space-time to background occurrence rate).

3. Data and Results

By applying the above method to the earthquakes with M >= 1.0 and depth <= 30 km cataloged by JMA during the period from 1998 through 2014 in the north-central Nagano region (35.6N-37.1N, 137.2E-139.0E), we obtained the best parameters for foreshocks as D=0.1 degree, Mf=2.0, Tf=1 day, Nf=5, and Ta=5 days to predict mainshocks with M>=5.0 among 45000 combinations of parameters of D(0.1, 0.2, 0.3), Mf(1, 1.5, 2, 2.5, 3), Tf(1, 2, 3, 5, 10), Nf(1, 2,...,20), and Ta(1, 2,...,30). The prediction performance is expressed as dAIC=66, AR=45% (=5/11), TR=12% (=8/69), and PG=333. If we use these parameters to define foreshocks, the 2014 Nagano earthquake mentioned at the opening sentence comes to be predicted by the foreshocks. Therefore we can say that a seismic activity such that observed about four days before the 2014 Nagano mainshock would be followed by a mainshock of M>=5.0 with about 12 % possibility, and to the contrary a mainshock with M>=5.0 would be preceded by a foreshock activity such that observed before the 2014 Nagano mainshock with about 45 % possibility. The value 12 % of TR is relatively low if compared with that for the specific region in the Japan trench (TR=30%) and for the Izu region (TR=23%) where we know the prediction performance is considerably high. This suggests that the prediction performance based on foreshock activities is largely different among regions.

Keywords: earthquake prediction, performance, foreshocks, Nagano prefecture, statistics, empirical relation

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SSS27-08 Room:103 Time:May 24 12:00-12:15

Estimation of inelastic displacement of a fault zone during an earthquake cycle

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1. Introduction: A damage zone/asperity model of faults was proposed to interpret the source parameters of an earthquake in terms of the physical properties of a fault zone (Yamamoto & Yabe, 2003, 2006 in SSJ meeting). In this model, the apparent fracture energy was calculated by assuming the complete elastic behavior of asperities in fracturing process. Further, the displacement vertical to a fault surface, which is produced by rotation of the damage zone, was calculated by first-order approximation. This approximation was found to cause an over-estimation of the apparent fracture energy. Here, the vertical displacement has been re-calculated by a more exact manner, taking account of inelastic displacement of asperities. Based on the results, the total slip accompanying an earthquake at plate boundary and the relationship between magnitude and recurrence time is examined.

2. A damage zone/asperity model: In this model, a fault zone means the damage zone including asperities. The fault surfaces are the boundaries between the fault zone and the host rocks outside of the fault zone. An asperity fractures at the time that the relative displacement between the surfaces reaches to $u*_c$, $u*_c$=u_c+u_{fc} = t(e_c+e_{fc}), Here u_c and u_{fc}, respectively, are elastic and inelastic components of $u*_c$. t denotes the thickness of the fault zone. The displacements respectively correspond to the strains e_c and e_{fc}. u_c is called the critical displacement. After an asperity has fractured, the displacement between the fault surfaces is newly produced by u_b, which generates seismic waves. The fracturing produces the slip plane in the fault zone. The displacement on the slip plane is expressed by u_c+u_b. This means that the displacement seismological estimated is not equal to the displacement on the slip plane.

The vertical displacement v is produced by rotation of the damage zone accompanying slip-plane propagation. The vertical displacement acts against the normal stress on the fault plane. The apparent fracture energy is almost equal to the work of v acting against the normal stress. The density of the work per unit area w is written by w=(s_nv)}≈s_n(1+2a)$e_c$$u_c$/2, where s_n is the normal stress, and a is the ratio of e_{fc}/e_c. Assuming that s_n is equal to the litho-static pressure and the rigidity of asperities is 30GPa, e_c≈0.01 is estimated for the depths from 10 to 20 km. For e_c=0.01, it is found that the data of apparent fracture energy versus critical displacement summarized by Ohnaka and Matsu ura (2002) are almost explained for (1+2a)/2?1. This means that the inelastic strain amounts 1/2 of elastic strain at the fracture of an asperity.

3. The recurrence of large earthquakes at plate-boundaries: Two large earthquakes are known to have occurred in the regions along the Sagami Trough. One is the 1703 Genroku earthquake and the other is the 1923 Kanto earthquake (Mw 8.0). The magnitude of the 1703 earthquake ranges from 7.9 to 8.5 depending on researchers. The displacement and the critical displacement of the 1923 earthquake are estimated at about 5.1m and 2.56 m, respectively. The convergence rate of inter seismic period is obtained as about 11.6 mm/year. This estimation is carried out on the assumption that asperities are elastic. Here, the deformation of an asperity, no matter how small asperity, is assumed to contain inelastic component of 0.5 times of the elastic deformation at fracturing. In this assumption, the total rate is 17.4 mm/year. This is almost equal to the inter-seismic slip rate along the Sagami trough presented by Loveless, J.P. and Meade, B.J. (2010).

If this rate of 11.6mm/year is constant at the plate boundary, the potential magnitude of an earthquake, of which recurrence time is 400 years, is estimated at about M8.5. The fault length is about 288 km. This length is almost equal to the length of the Sagani trough.

Keywords: damage zone/asperity model, inelastic displacement, fracture energy, critical displacement, 1923 kanto earthquake, plate boundary

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Euler Rotation of Focal Mechanism to determine the main shock of the East Japan Super Earthquake, March 2011

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Focal mechanism is most important information on the stress field. The focal mechanism is presented by the azimuth and dip of the princepal axes, P, T and N. The changes in the focal mechanism with the 6 parameters can be described by Euler pole and rotation, because the angular distances between pricepal axes are constantly 90^o (http://www.niitsuma-geolab.net/ Special Report 4).

CMT focal mechanism by Japan Meteorological Agency for the earthquakes in the main shock area of 2011 East Japan Super Earthquake are using for this analysis.

The Euler pole and rotation angle can be calculated for the three pairs of princepal axes, PT, TN and NP, on two earthquakes under the adjustment of the hand system. The calculated three Euler poles and rotation angles do not completely agree, because the azimuth and dip of princepal axes are presented with degree unit. Because the rotation angles around the Euler pole should same for the used pair of the princepal axes, the Euler pole is selected with the minimum difference in the rotation angles for the used pair of the princepal axes. The selected minimum differences are generally within 0.1^o.

The Euler rotation analysis is calculated from the main shock of East Japan Super Earthquake to the other earthquakes in this study. In the case of the position of the Euler pole locates on the southern side of the perpendicular line to the trench axis, the top of coordination system for princepal axes rotates toward island arc, and locates on the northern side, rotates toward trench. The rotation angle around Euler pole is defined with sign, positive toward island arc and negative toward trench.

All of 18 fore shocks, started by 16 February 2011, have positive rotation angles within 25^o. All of 35 after shocks have negative rotation angles smaller than -25^o. The complete separation of the sign of Euler rotations demonstrates that the Euler rotation of focal mechanism can be used for determination of main shock.

The positive rotation of fore shocks and the negative rotion of after shocks can be explained as follow. The stress field on the plate boundary along the Japan Trench is controlled by a resultant of shear stress and normal stress along the plate boundary and the compressional principal P axis dips toward trench. Fore shocks occurs by less fracture stress with less normal stress which has shallower dip of P axis than the main shock (36^o). After shocks occurs in the stess field controlled by mainly lithostatic stress with vertical P axis without shear stress which is released by the main shock.

The maximum fore shock M7.3 of 9 March 2011 with $+2.0^o$ of Euler rotation angle induced disorder by misjudgement as main shock, but the Euler rotation quantitically indicate to be fore shock and 7 earthquakes M5.2-6.8 in the next day 10 March 2011 had also positive rotation within $+25^o$.

Keywords: Euler pole, rotation angle, focal mechanism, hand system, determination of main shock, East Japan Super Earthquake