Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SSS02-01 Room:201B Time:May 21 09:00-09:15

Short-term earthquake forecasting experiment before and during the L'Aquila seismic sequence of April 2009

Jiancang Zhuang[1*], Rodolfo Console[2], Maura Murru[2], Giuseppe Falcone[2]

[1]Institute of Statistical Mathematics, [2]Istituto Nazionale di Geofisica e Vulcanologia, Italy

In this study, we compare the forecasting performance of several statistical models, which are used for describing the occurrence process of earthquakes, in forecasting the short-term earthquake probabilities during the occurrence of the L'Aquila earthquake sequence in central Italy, 2009. These models include the Proximity to Past Earthquake (PPE) model and two versions of the Epidemic Type Aftershock Sequence (ETAS) model. We used the information gains corresponding to the Poisson and binomial scores to evaluate the performance of these models. It is shown that both ETAS models work better than the PPE model. However, when comparing between the two types of the ETAS models, the one with the same fixed exponent coefficient ¥alpha=2.3 for both the productivity function and the scaling factor in the spatial response function (Model I), performs better in forecasting the active aftershock sequence, than the other model with different exponent coefficients (Model II) even though Model I is a subclass of Model II; Model II performs only better when a lower magnitude threshold of 2.0 and the binomial score are used. The reason is found to be: the catalog does has an event of similar magnitude as the L'aquila mainshock in the training period, and ¥alpha-value is under estimated and thus the forecasted seismicity is underestimated when the productivity function is extrapolated to high magnitudes. These results suggest that the training catalog used for estimating the model parameters should include earthquakes of similar magnitudes as the mainshock when forecasting seismicity in the duration of an aftershock sequences.

Keywords: earthquake forecast, probability forecast, ETAS model, information gain, 2009 L'aquila earthquake

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SSS02-02 Room:201B Time:May 21 09:15-09:30

Forecasting Moderate Seismicity by Using the Moment Ratio Method

Abdelhak Talbi[1*], Mohamed Hamdache[1], Mourad Mobarki[1]

[1]Centre de Recherche en Astronomie Astrophysique et Geophysique (CRAAG)

Abstract. Recently, we introduced a new alarm-based forecasting model for earthquakes, called moment ratio (MR) model. In this model, the ratio of the mean inter-event time over the variance is used as a precursory alarm function to forecast future earthquakes in a given region. In a former study, this model was successfully tested in forecasting large earthquakes with magnitude M >= 7, occurred in Japan. As a first step towards testing the applicability of our model in forecasting earthquakes in moderate seismicity areas as Northern Algeria, the MR model is tested on target earthquakes with magnitude M >= 5. For this purpose, a composite catalog covering all Japan within the period 679-2011 is used. This catalog was compiled using the Japan Meteorological Agency (JMA) catalog for the period 1923-2011 and the Utsu historical seismicity records for the period 679-1922. Time periods used in training and testing are selected by taking into account the completeness of the magnitude. Molchan error diagrams are used to evaluate the forecasting performance of the MR method in a series of retrospective tests applied at short, intermediate and long-term. Then, MR forecasting maps are obtained based on minimizing miss and alarm rates. The limitations of the MR model are discussed focusing on cases of poor catalog data with epicenter location errors. The applicability of the Collaboratory for the Study of Earthquake Predictability CSEP prospective tests to the MR method is discussed by tuning different free parameters of the model. Results show that the minimal inter-event time sample size used to calculate the moment ratio together with the size of inter-event time sampling area shape the study region, and play important role in the calibration of our model to CSEP 'rules of game'. Finally, we discuss the impact of the MR forecasts on seismic hazard assessment in a given region.

Keywords: Earthquake forecasting, Inter-event times, Alarm function, Molchan diagram

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SSS02-03 Room:201B Time:May 21 09:30-09:45

Identification of the Nucleation Stage of Natural Earthquakes by Monitoring Microcracks

Motoki Fujii[1*], NODA, Yoichi[2], TAKAHASHI, Kozo[3], KOBAYASHI, Masaji[4], TAKAMTSU, Kenichi[5], NATSUMEDA, Jiro[5]

[1]Fujinawa Earthquake Res. Inc., [2]Tierra Tecnica Corp., [3]Communication Res. Lab., [4]Real-time Earthquake Information Cons., [5]OKI Engineering Co. Ltd

Identification of precursory phenomena is essential to the development of a method for forecasting earthquakes (Scholz, 2002). For the imminent forecasts, however, no confirmative phenomena have been identified which might be practically applied. There are numerous approaches to identifying the nucleation stage through seismic, electromagnetic, geodetic, and hydrologic approaches. Especially, the foreshock or acoustic emission have been taken to be most plausible phenomena on the basis of investigation of seismic activities (e.g., Jones and Molnar, 1979; Maeda, 1999) and rock rupture experiment (e.g., Yoshida et al, 1998). However, we have no knowledge to define the nucleation phase in the preparatory process of the natural earthquake.

The acoustic emission technique has been widely used in the geotechnical engineering field. Concerning natural earthquakes there are only several pioneering studies to investigated field acoustic emission activities (Hattori, 2003). Those researches indicate that the activity is high about a half-day both before and after the earthquake occurrence, but detailed characteristics defining the nucleation phase has not yet been obtained.

We have been observing electric field variations to find anomalous phenomena for prediction. The detection sensor is to measure vertical components of electric field by a special antenna made of a casing pipe ranging 100- 1,800 m deep. The system has been proved to be highly robust to both meteorological and urban noises. Among various kinds of variations, the particular pulse-like variations similar to the time evolution of geyser (GUV) have been almost always detected in association with seismic swarms, volcanic eruption near the observation points (Fujinawa et al., 2001). The signals have never been detected in a normal state. And the phenomena are suggested to be induced by an electro-kinetic effect (e.g., Mizutani et al., 1976).

The new detector has higher dynamic ranges in frequency bands of DC (0-1.45 Hz) and AC (1.45 Hz- 9 kHz) and in signal strength. The observation started on 3, March 2011 at Hasaki in the Ibaraki Prefecture about 300 km south of the epicenter of the Tohoku Earthquake.

Here we show that there are typical pulse-like waveforms associated with cracks just before and after the Great Tohoku Earthquake on March 11, 2011. Those variations are grouped by time constants: A type with duration of several to several ten minutes same as the GUV (Fig. 1a), B of several ten milliseconds, and C of several hundred micro seconds (Fig.1e). The B- type variations are sub-grouped into three by waveform: B-1 of similar to the GUV but in the stepped decay in relaxation phase (Fig. 1b), B-2 of wave packet similar to seismic wave (Fig.1c), and B-3 of a combination of B-1 and B-2 (Fig.1d). Different types of electric waveforms are suggested to be corresponding to crack rupture modes of tensile and shear, and to be generated by induced confined water movement through the electro-kinetic effects (e.g., Mizutani et al., 1976) on the ground of previous investigations on laboratory experiments.

Before the Tohoku earthquake there appeared 163 type B variations except one events of A type, and type A and C events after the earthquake. The number of B type events started to increase on the 7th, had a prominent peak on the 9th, a pronounced lull on the 10th, and recovered considerably on the morning of 11th. This time evolution had a strong similarity with that of acoustic emissions just before rupture in the rock experiment and the averaged evolution for many cases of the pre-shocks (Varnes, 1989). In the DC range only one A-type appeared during the preparation stage: almost all occurred after the main shock.

The shorter period variation of Type B is suggested to be a key phenomenon to identify the nucleation stage. The signal can be detected for natural earthquake by monitoring vertical components of electric fields using special deep long antenna.

Keywords: earthquake precursor, nucleation stage, microcrack, electric phenomena, confined water

SSS02-03 Room:201B Time:May 21 09:30-09:45

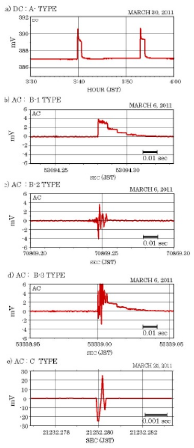


Figure 1

a) Waveform of the pulse-like particular signals in the DC band (type A). Type A has a duration of several tens of seconds to several tens of minutes, and a height of about 2–3 mV. The form was first identified by the temporally rapid recording at the time of volcanic eruption activities in 1990 at Izu-Oshima (Fujinawa *et al*, 2001). Afterward, we detected similar signals at almost cases of nearby volcanic eruption and seismic swarms (11).

(b) Type B-1 waveform of the pulse-like signals in the AC band. The form is very similar to type A except that it is of smaller duration (several tens of ms) and shows several steps in the process of relaxation.

(c) Type B-2 waveform of the pulse-like signals in the AC band similar with a wave-packet. There is no coda phase, in contrast to seismic waves. A similar pattern was detected in the case of wetted granite specimens with a dominant frequency of 500 kHz (Yoshida *et al,* 1998). The S-P time was about 30 ms, suggesting an epicentral distance of 270 m. Several examples of events having P,S phases can be seen. The absence or very slight appearance of a P-phase indicates an epicentral distance larger than a few km.

(d) Type B-3 waveform in the AC band with a waveform compounded by type B-1 and type B-2.

(e) Type C waveform in the AC band. The waveform is the same as type B-2, but its amplitude is very large: 20–30 mV, with some 10 times larger than those of type A and B.

SSS02-04 Room:201B Time:May 21 09:45-10:00

Physical properties of laboratory faults inferred from seismic event statistics during stick-slip experiments

Thomas H. W. Goebel[1], Danijel Schorlemmer[2*], Thorsten W. Becker[1], Charles Sammis[1], Georg Dresen[2]

[1]University of Southern California, [2]GFZ German Research Centre for Geosciences

Seismicity contains information about the in-situ faulting process from the plate boundary scale down to the scale of individual asperities. In this study, we consider the possibly smallest, seismically recordable earthquakes: those generated during stick-slip experiments, a laboratory analog to earthquakes. In the laboratory, seismic energy, radiated from brittle micro-cracking in form of acoustics emissions (AEs), has successfully been used to monitor the initiation and propagation of intact-rock failure. In contrast to much of the previous work, we concentrate on AEs that occur within or close to laboratory-created fault zones.

We present results from experiments on complex faults that were created by initial sample fracture. The fracture surfaces evolve due to successive stick-slips until they exhibit many of the hallmarks of upper crustal faults after the experiments. The structure of laboratory faults can be categorized into a gouge layer containing localized shear zones and a broader damage zone that marks the transition to the country rock. The transitional damage zone is generally associated with high AE activity that decreases as a power-law at larger fault-normal distances. The exponent of this power-law is connected to the roughness of the fault as revealed by saw-cut experiments with specific, pre-defined roughness.

We examined along-strike fault heterogeneity in X-ray computer tomography (CT) scans and spatial maps of AE statistics. We performed a detailed spatial analysis of event clusters before and after stick slip events, primarily focusing on b value, seismic moment release and AE event density. AE hypocenter distributions showed a high degree of spatial clustering close to low b value regions. Slip events and the connected acoustic emission 'aftershocks' nucleated within or at the periphery of areas of low b. To identify larger scale geometric asperities we combined fault structural information from post-experimental CT-scans with AE statistics. Asperities were connected to low b value regions, high moment release and areas of large AE event density gradients. The faults were anomalous thin in these areas.

Rough fracture surfaces during laboratory experiments, strongly favor the creation of spatial and temporal distinct AE clusters which have similar characteristics to seismicity observed on crustal scales. Specific seismicity anomalies may be an expression of fault heterogeneity and mark areas of larger seismic hazard.

Keywords: Earthquake Physics, Statistical Seismology, Laboratory Experiment, Seismic b-Value, Seismic Hazard

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SSS02-05 Room:201B Time:May 21 10:00-10:15

Analysis of Induced seismicity after the 2011 Tohoku-Oki earthquake by non-stationary ETAS models

Takao Kumazawa[1*], Yosihiko Ogata[1]

[1]The Institute of Statistical Mathematics

The epidemic-type aftershock sequence (ETAS) model is a stationary point process, and provides a good fit to an ordinary seismic activity. Its poor fitting suggests that the earthquake mechanisms are affected by changes in geophysical factors. Fault strength is one of the fundamental factors in a seismogenic zone, and its temporal change can induce nonstationary seismicity. Although changes in fault strength have been suggested to explain various phenomena, such as the remote triggering of seismicity, there has been almost no means of quantitatively monitoring this property in situ. For this purpose, we extend the ETAS model for non-stationary cases. This allows the parameters to be time-variant, which then describes anomalous features of the seismic activity. We prepare Bayesian models, and apply them to the data from inland seismic swarm activities that have been induced by the 2011 Tohoku-Oki earthquake of M9.0.

Keywords: ETAS model, non-stationary model, Bayesian smoothing, Tohoku-oki earthquake, pore fluid pressure

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SSS02-06 Room:201B Time:May 21 10:15-10:30

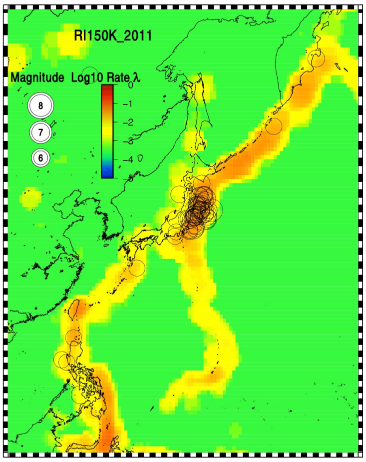
An earthquake forecast experiment in the northwest Pacific using RI model

Hiroshi Tsuruoka[1*], Naoshi Hirata[1]

[1]ERI, The University of Tokyo

The Collaboratory for the Study of Earthquake Predictability (CSEP) has been conducting a prospective earthquake forecast experiment in the northwest Pacific from 2009. This test region includes 2011 Tohoku Earthquake, So, it is very important to evaluate testing results before and after this event. The northwest Pacific test region covers the longitude rand between 109.75 and 170.25 and then latitude range between -0.25 and 60.25. This region is gridded into cells of 0.5 by 0.5 degree and depth H <= 70.0 km is considered (Eberhard et al., GJI 2012). Forecast models define earthquake rates for each magnitude bin in magnitude range 6.0 <= M <= 9.0 (0.1 magnitude unit steps) at each node for consecutive 1-year time windows. The first forecast time stars at 1st JAN 2009. The GCMT catalogue was used for both model building and evaluation. CSEP testing centers (also CSEP-Japan) now use various tests to determine which models fit the observed data and which models forecast the distribution of seismicity best. For this study, we used the consistency tests of N, L, CL, S-tests developed by CSEP. For model comparison, we used the L-test's log likelihood. For this study, relative intensity (RI) model was used to get earthquake forecasts. We evaluated the test results of smoothing radii of RI models of 50km, 75km, 100km, 150km, 200km, 300km, 400km, 500km and 1000km. We summarize the testing results as follows. (1) For 2009-2010 and 2010-2011 forecasts, All RI models passed all consistency tests. (2) For 2011-2012 forecasts, All RI models passed S and CL tests. (3) Uniform model didn't pass S-test for all 3 rounds. (4) Comparing log likelihood, the RI model with the smoothing radii of 150 km showed the best performance of forecast in all 3 rounds.

Keywords: CSEP, NW-Pacific, forecast, GCMT catalogue



Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SSS02-07 Room:201B Time:May 21 10:30-10:45

Estimating statistical models of seismicity under incomplete detection of earthquakes

Takahiro Omi[1*], Yosihiko Ogata[2], Yoshito Hirata[3], Kazuyuki Aihara[3]

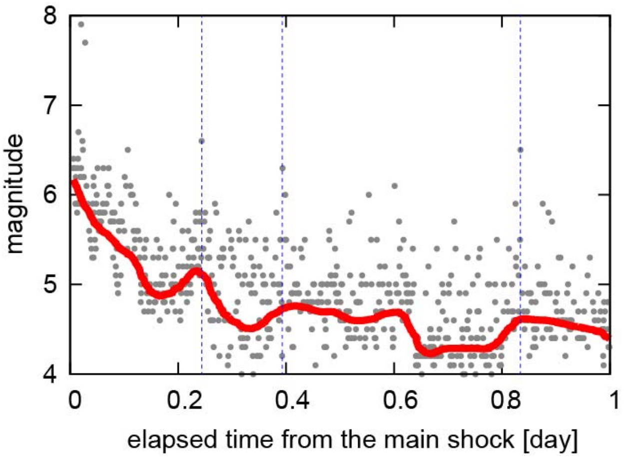
[1]FIRST Aihara Project, Japan Science and Technology Agency, [2]The Institute of Statistical Mathematics, [3]Institute of Industrial Science, the University of Tokyo

After a large earthquake, a vast number of aftershocks follow. The clustering property of earthquakes is commonly modeled by the Omori-Utsu formula of aftershock decay or Epidemic type aftershock sequence (ETAS) model. Usually, these statistical models have been directly fitted to the observed data above cut-off magnitudes enduring complete detection. On the other hand, it is well known that early aftershocks are substantially missed from seismic records because of overlaps of seismic waves caused by the main shock and congested aftershocks. In other words, earthquakes catalogues are highly incomplete during the early stages immediately after large earthquakes. Previous studies have applied the models to the datasets either avoiding the early part of the observed period of aftershock activity or taking a higher cut-off magnitude throughout whole period, so that such incompleteness of the data can be mitigated by an adjusted c-value of the Omori-Utsu formula or the ETAS. Nevertheless, such direct analysis of the catalogues may still produce some biased estimate. Also, we need to apply the ETAS model for a long period where the detection rates of earthquakes vary in time due to the development or reduction of seismic networks in and near focal seismogenic region.

Here we present a method for fitting the statistical models by considering the incompleteness of the catalogues. To do this, we developed a method to estimate non-stationary detection rate, based on the state-space model. This model can capture even irregular oscillation of the time-variation of the detection rate (Fig. 1). Then this model is combined with the Omori-Utsu formula of aftershock decay or the ETAS model.

Acknowledgement: This research is supported by the Aihara Project, the FIRST program from JSPS, initiated by CSTP.

Figure 1:Time-dependence of the magnitude of 50% detection rate (red line) for the observed afterhocks (closed circle) by PDE/NEIC, which occurred within one day from the 2011 Tohoku-Oki earthquake of M9.0 The estimate shows oscillating behaviour. The steep rise is accompanied with large aftershocks.



Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SSS02-08 Room:201B Time:May 21 11:00-11:20

Research towards practical earthquake forecasting

Yosihiko Ogata[1]*

[1]Institute of Industrial Science, University of Tokyo, [2]The Institute of Statistical Mathematics

Earthquakes occur because of abrupt slips on faults due to accumulated stress in the Earth's crust. Because most of these fault and their mechanisms are not readily apparent, deterministic earthquake prediction is difficult. For effective prediction, complex conditions and uncertain elements must be considered, which necessitates stochastic prediction. In particular, a large amount of uncertainty lies in identifying whether abnormal phenomena are precursors to large earthquakes, as well as in assigning urgency to the earthquake. Any discovery of potentially useful information for earthquake prediction is incomplete unless quantitative modeling of risk is considered. Therefore, this talk aims the prospect of earthquake predictability research to realize practical operational forecasting in the near future. More specific summaries are as follows:

To predict the future under complex and diverse earthquake generation process, the probability forecasting cannot be avoided. The likelihood (log-likelihood) is rational to measure the performance of the prediction. To provide a standard stochastic prediction of seismic activity in long term and short term, it is necessary to construct proper point process models and revise them that conform to each region.

By the appearance of the anomaly, we need to evaluate the probability that it will be a precursor to a large earthquake. Namely, we need to forecast that the probability in a space?time zone will increase to an extent, relative to those of the reference probability. For this, we make use of a point process model for the causality relationship. Thus it is desired to search any anomaly phenomena that enhance the probability gain that is ratio of the predicted probability relative to the baseline earthquake probability. A comprehensive physical study between precursory phenomena and earthquake mechanisms is essential for composing useful point process models. These elements must be incorporated to achieve predicted probability exceeding predictions of typical statistical models.

The key for progress of research for practical probability earthquake forecasting is to make use of multiple prediction formula that is derived through the Bayes formula. According to the formula, total probability gain is approximately the product of individual probability gains. The probability gain for an individual anomaly to be a precursor is basically its success rate divided by the precursor time. The success rate can only be determined from the accumulation of data with actual earthquakes. In this talk, I would like to start with the important suggestions by Utsu (1979) and Aki (1981), and then to provide some examples toward better probability gain modeling.

Furthermore, numerous research examples on earthquake processes must be accumulated. On the basis of these examples, probable prediction scenarios must be presented. Furthermore, to adapt well to diversity of earthquake generation, it is useful to adopt hybrid predictions taking account of period- and region-specific models.

My experiences thus far confirm that the method of statistical science is essential to elucidate movement leading to prediction of a complex system of global phenomena. There is a need for development of a forecasting model that reflects diversity of the vast amount of information on the basis of seismicity of various data by incorporating a hierarchical Bayesian model. Space?time models for seismicity have become increasingly complicated. A similar evolution is required for statistical models of geodetic GPS data. Thus, I believe that statistical seismology is essential for the study of complex systems of Earth. Moreover, educating citizens on understanding the forecast probability of complex phenomena is also the duty of researchers and practitioners who engage in statistical science.

Keywords: probability forecast, probability gains, multiple prediction formula, point process models, space-time models, hierarchical Bayesian models

SSS02-09 Room:201B Time:May 21 11:20-11:40

Testability of maximum magnitude estimates

Danijel Schorlemmer[1*], Robert A. Clements[1], Alvaro Gonzalez[1]

[1]GFZ German Research Centre for Geosciences

Disasters caused by unexpectedly large earthquakes illustrate the need for reliable estimates of the maximum possible magnitude M (also known as M_{max}) at a given fault or in a particular zone. Such estimates are essential parameters in seismic hazard assessment, but their accuracy remains untested. In fact, whether M can be tested or not is still uncertain. In this study, we discuss the testability of M and the limitations that arise from testing such rare events. We use a simple extreme value theory approach to derive the sampling distribution for the maximum magnitude, i.e. the probability distribution for the maximum of a sample of earthquake magnitudes, and propose a straightforward hypothesis test for M. The test is based on the largest magnitude observed in the sample. If it is larger than the estimate of M, or it is too unlikely, given the assumed magnitude probability density function, the estimate of M is rejected. We then perform a sensitivity analysis to identify which parameters have the most influence on this sampling distribution and conduct a power analysis for the test. Our results suggest that the sampling distribution is relatively insensitive to the overall M, except when the b-value of the Gutenberg-Richter distribution is low and the size of the sample is high. Consequently, the power of the test is high only under optimal conditions, such as when the hypothesized value of M is grossly different than the true M, or when the seismicity rate is very high. Finally, we discuss that these limitations, in practice, may imply that a wrong maximum magnitude estimate can rarely be falsified, and express our concern about the use of these unfalsifiable estimates in seismic hazard assessment.

Keywords: Maximum Magnitude, Seismic Hazard, Seismic Risk, Statistical Seismology, Earthquake Forecasting

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SSS02-10 Room:201B Time:May 21 11:40-11:55

An earthquake forecast testing experiment with statistical seismology in Japanese earthquake prediction research program

Naoshi Hirata[1]*

[1]Earthquake Research Institute, the University of Tokyo

The current Japanese national earthquake prediction program, which inherits its essential observational network from all the previous programs, emphasizes the importance of modeling as well as monitoring for a sound scientific development of earthquake prediction research. Also, one major focus of the current program is to move toward creating testable earthquake forecast models. For this purpose, we joined the Collaboratory for the Study of Earthquake Predictability (CSEP) and installed, through an international collaboration, the CSEP Testing Centre, an infrastructure to encourage researchers to develop testable models for Japan and to conduct verifiable prospective tests of their model performance. In 2009 we started the 1st earthquake forecast testing experiment for the Japan area within the CSEP framework .

The experiment consists of 12 categories, with 4 testing classes with different time spans (1 day, 3 months, 1 year and 3 years) and 3 testing regions called All Japan, Mainland, and Kanto. A total of 203 models, as of November 2012, were submitted, and are currently under the CSEP official suite of tests for evaluating the performance of forecasts. I will give an idea how good results we will have. Also, we have conducted retrospective earthquake forecast experiments for aftershocks of the 2011 Tohoku-oki earthquake and 3-D seismicity in Kanto region. Our aim is to describe what has turned out to be the first occasion for setting up a research environment for rigorous earthquake forecasting in Japan.

Keywords: Earthquake Prediction Reserah, Earthquake Forecast, Statistical seismology, CSEP

SSS02-11 Room:201B Time:May 21 11:55-12:10

Contribution of Coulomb stress changes by the 2011 Tohoku-oki earthquake on seismicity rate change in the Kanto region

Takeo Ishibe[1*], Kenji Satake[1], Shin'ichi Sakai[1], Kunihiko Shimazaki[1], Hiroshi Tsuruoka[1], Shigeki Nakagawa[1], Naoshi Hirata[1]

[1]Earthquake Research Institute, the University of Tokyo

Abrupt changes in seismicity rate after the 2011 off the Pacific coast of Tohoku earthquake (MJMA 9.0) on March 11, 2011 are basically well explained by the static changes in the Coulomb Failure Function (dCFF) imparted by the gigantic thrusting. This suggests that changes in seismicity rate are sensitive for small changes of Coulomb stress (dCFF $<$ 1.0 bar), and accurate evaluation of Coulomb stress changes may improve the performance of earthquake forecasting after large earthquakes.

In the source region of gigantic event and its neighboring regions, the drastic changes in both hypocentral distributions and focal mechanism solutions were clearly observed. For example, in Tohoku region, focal mechanisms of earthquakes after the megathrust event are dominantly strike-slip type in the region where the thrust-type was dominant before the mainshock.

We examined a relationship between the dCFF due to the Tohoku earthquake and the seismicity rate change in Tokyo Metropolitan area following March 11. Because various types of earthquakes with different focal mechanisms occur in the Kanto region, the receiver faults for the calculation of dCFF were assumed to be two nodal planes of small earthquakes.

The computed dCFF shows positive values, which predicts seismicity rate increase, at intermediate depth in southwestern Ibaraki and northern Chiba prefectures and in shallow crust of the Izu-Oshima and Hakone regions. In these regions, the seismicity rate has actually increased since March 2011 with respect to the Epidemic Type Aftershock Sequence (ETAS) model, suggesting that the rate change was due to the stress increase by the Tohoku earthquake. The activated seismicity in the Izu and Hakone regions rapidly decayed following the Omori-Utsu formula, while the seismicity rate in the southwestern Ibaraki and northern Chiba prefectures is still increasing.

The observed temporal changes in focal mechanism distributions are well correlated with calculated dCFF. For example, thrust-type focal mechanisms (typical dCFF values ~ +1-2 bars) relatively increased in an earthquake cluster in southwestern Ibaraki after March 11, whereas normal-fault type earthquakes (typical dCFF values ~ -0.5 bars) relatively decreased compared to before March 11. The dCFF values calculated for focal mechanisms of the earthquakes after March 11 show more positive values than those before March 2011, supporting a hypothesis that the 2011 Tohoku earthquake triggered the seismicity changes in the Kanto region, whereas some other possible factors (e.g., dynamic stress changes, excess of fluid dehydration, post-seismic slip, large aftershocks, or viscosity) may also contribute the rate changes.

Keywords: seismicity rate change, Kanto region, Coulomb stress change, focal mechanism

SSS02-12 Room:201B Time:May 21 12:10-12:25

Impact of the 2011 M=9.0 Tohoku-oki earthquake on increased seismic hazard for greater Tokyo

Shinji Toda[1*], Stein, Ross S.[2]

[1]International Research Institute of Disaster Science, Tohoku University, [2]U. S. Geological Survey

The Kanto seismic corridor surrounding Tokyo has hosted 4-5 damaging M>=7 earthquakes in the past 400 years, and 55 M>=3 shocks per year were recorded in the decade before the Tohoku-oki earthquake. Both observations would indicate a 1.0-1.4% annual M>=7 probability, or 5-7% for 5 yr. Immediately after the Tohoku-oki earthquake, the seismicity rate in the corridor jumped ten-fold, while normal and strike-slip focal mechanisms all but ceased. The seismicity rate then decayed for less than a year, after which the rate steadied at three times the pre-Tohoku rate. The seismicity rate jump and decay to a new rate, as well as the shutdown of non-thrust mechanisms, can be explained by static Coulomb stress imparted to faults 40-80 km beneath the Kanto plain by the Tohoku rupture and postseismic megathrust creep. We fit the observations with a rate/state model, which we use to estimate the time-dependent probability of future large earthquakes in the corridor. Although it is possible that the increased Kanto seismicity accompanies accelerated creep that is shedding -rather than accumulating- the stress imparted by Tohoku-oki, the ratio of small to large shocks was not changed by the Tohoku-oki mainshock, and so the simplest assumption is that the probability of large shocks has climbed with the increased rate of small ones. Thus, for a b-value of 0.9, we estimate a 17% probability of a M>=7.0 shock over the 5-year prospective period, 11 March 2013 to 10 March 2018, two-and-a-half times the probability before the Tohuku-oki earthquake.

Keywords: Tohoku-oki earthquake, seismicity, Coulomb stress change, seismic hazard, earthquake probability

SSS02-13 Room:201B Time:May 21 12:25-12:40

M=9.0 Tohoku Earthquake and tsunami; a new interpretation

Shigenori Maruyama[1*], Toshikazu Ebisuzaki[2]

[1]Earth-Life Science Institute, Tokyo Institute of Technology, [2]RIKEN

M=9.0 Earthquake

A M=9.0 earthquake occurred on March 11, 2011, with its unusually large magnitude drawing our attention. Here, I propose a process different from that of the Benioff-plane origin, one that involves a spray-fault that periodically destroys the fore-arc region. This process involves tectonic erosion, which includes the collapse of the hanging wall of the overriding lithosphere, as well as transport of the collapsed materials into the deep mantle, presumably as far as the mantle transition zone, a process that contributes to the formation of the 2nd Continents through time.

The origin of spray faults is a manifestation of the physically unstable triangular region between the material boundary (trench) and the physical boundary (spray fault). The tightly connected Benioff thrust dragged down the frontal part of overriding plate to reactivate the spray fault, triggering the M=9.0 earthquake.

Tsunami

The spray fault occurs right below the trench-slope break which is a turning point of slope change from the shallow to the deep trench inner wall. Right above the fault, a sedimentary basin is present. Spray faulting resulted in a huge-scale submarine landslide, which led to the collapse of a huge volume of basin sediments, triggering the tsunami off Sendai.

The river drainage system on Northeast Japan is remarkably different from Southwest Japan. Two major rivers, one from the north and the other from the south, transport eroded sediments into the ocean, which contribute to the formation of the sedimentary basin off Sendai. This basin periodically collapses, approximately every 1000 years, causing the ruinous tsunami.