Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS28-P01 Room:Convention Hall Time:May 24 17:15-18:30

Secondary faulting behavior characterized by nondimensional parameters associated with damage evolution

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We construct a simple, unified model with nondimensional parameters to explain the diversity observed in secondary faulting development in terms of damage (microcrack) generation. Secondary faulting is defined here as the faulting around the main fault plane such as fault rock pulverization and branch development and have smaller scales than the main fault. This behavior is considered to occur as a consequence of damage evolution. They occur separately sometimes, while sometimes they are observed simultaneously. We employ the damage tensor D, which represents the damage state, and the energy release rate tensor Y for formulating mathematical framework to explain this diversity. A parameter Yc is also used in the present framework as the material yielding criterion assumed for Y; if the component of Y excesses Yc, the material is regarded to be yielded. We assume a two-dimensional fault.

There are two important nondimensional parameters consisting of three material parameters with a dimension of stress, eta2, eta4 and Yc, in the present framework; the parameter eta2 represents the effect of damage amount on a constitutive relationship, while the parameter eta4 represents the effect of damage orientation on the constitutive relationship. Therefore, the first nondimensional parameter gamma=eta4/eta2 determines how the microcrack distribution deviates from the isotropic one. It should be noted that eigenvalue for D stands for number density of microcracks whose normal orientation is in the direction of eigenvector for the eigenvalue. The analytical form of the damage tensor shows that the two eigenvalues for D are the same with the condition gamma=0. Microcracks with any orientation appear in this case and only the isotropic fault rock pulverization is expected regardless of the value of Yc*=Yc/eta2, the second nondimensional parameter and nondimensional yielding criterion. If gamma is not equal to zero, the two eigenvalues are different and normal orientations of microcracks tend to have similar directions with increasing gamma. In particular, if gamma increases infinity, one of the eigenvalues approaches zero and all the microcracks have the same normal orientation. The tendency for microcrack orientation is related to the branch development angle from the main fault plane. However, in intermediate cases for gamma, it should be noted that both isotropic fault rock pulverization and branch development can appear. If Yc* is selected appropriately, both phenomena are found to occur simultaneously. The parameter Yc* also plays an important role on determining the secondary faulting behavior in these cases.

Nondimensional parameters gamma and Yc* can be concluded to play important roles to determine how the secondary faulting behavior occurs: only isotropic pulverization, only branch development, and both. If the value of gamma is sufficiently small, only pulverization appears. On the other hand, if the value is sufficiently high, branch development occurs. These cases are classified only by gamma and Yc* does not affect the system behavior much. Combination of fault rock pulverization and branch development is characterized by both two nondimensional parameters.

Keywords: damage tensor, nondimensional number, pulverization, branch development

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BIEM simulation for dynamic earthquake rupture that intersects with a bimaterial interface

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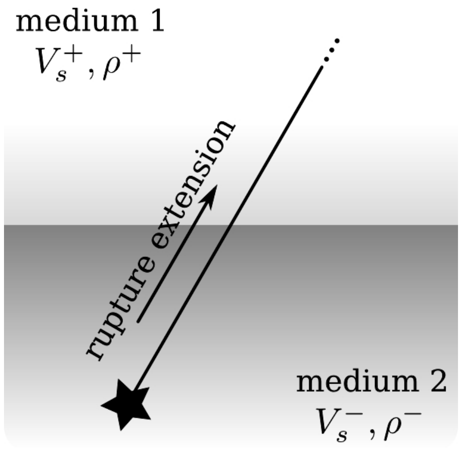
Recently, seismic observations are getting more precise and have revealed heterogeneous structure near faults. For example, Kato et al. (2006, JGR) imaged the seismic structure in the source region of the 2004 Chuetsu earthquake and concluded that faults of the main shock and some major aftershocks are located near of material interfaces where seismic wave velocities change discontinuity. Moreover, Naoi et al. (2011, BSSA) analysed dynamic behaviour of a M2 earthquake that occurred in 2007 near a pre-installed observational network at the deep gold mine of South Africa and concluded that rupture extension of its fault stopped at very close to a material interface. Considering heterogeneous structures that exist universally in the Earth's crust, dynamic earthquake rupture will be affected by the existence of material interface. If fault intersects with the interface during its growth, the effect of material interface will be significant. The observational studies described above might support them.

On the other hand, almost all dynamic rupture simulations for understanding fault mechanics are based on an assumption that rupture propagates in a homogeneous medium or along a material interface. That is to say, past studies have not treated intersection of dynamic rupture behaviour with material interfaces. This might be due to difficulty and immaturity of numerical techniques to simulate dynamic rupture behaviour. A front of dynamically extending fault radiates strong perturbation of stress, so that quite high accuracy is required for the simulation. Additionally, faults are sometimes non-planar and this should be taken into account. In a framework of elasticity, one of the best techniques that meets these requirements is the Boundary Integral Equation Method (BIEM) developed by Tada and Yamashita (1997, GJI). BIEM requires analytical expression of non-hyper singular response function of an ambient system generated by slip of each discretized fault element. Previous studies, however, have derived the response function only for an infinite homogeneous medium.

In this study, we consider the intersection of dynamic rupture behaviour with material interfaces. First, in order to do so, we derive the non-hyper singular response function of two welded elastic 2-D half-spaces, which is referred to as "bimaterial", due to an anti-plane dynamic crack. Difficulty of the derivation of response function is resolved by treating 2-D Green's function as complex function and using the Cagniard de-Hoop's method. This analytical solution can be considered as a response of bimaterial when uniform slip rate is given on a finite planar fault. Hence this solution itself can be employed as a benchmark for a numerical simulation of a fault with uniform slip rate embedded in bimaterial. Next, we actually execute BIEM simulation by using this solution. We find that a distinct phenomenon appears on the fault after the rupture front intersects with the interface. In other words, a significant slip rate change occurs at the intersection and it propagates back towards the rupture nucleation point. Especially, on the case that the rupture extends towards more rigid material from more compliant material, this perturbation can be seen as temporal reduction of slip rate. Considering velocity weakening friction law, this implies that fault behaviour could be complex because the reduction of slip rate generates increase of friction, so that slip may stop after the rupture front intersects with the interface.

Keywords: fault, dynamic rupture, bimaterial interface, Boundary Integral Element Method, numerical simulation


medium 1
V_s^+, ρ^+
rupture extension
medium 2
V_s^-, ρ^-

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Stress triggering with modified rate- and state-dependent friction law

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Rate- and state-dependent friction law (RSF) has been recently revised by Nagata et al. [2012]: its frictional parameters were replaced by experimentally corrected values in the constitutive equation and a shear stress weakening effect was incorporated in the state evolution equation. It can quantitatively simulate any kinds of rock friction data observed in hold-slide tests and velocity-step tests. Based on the revised RSF, we here re-investigated the mechanics of frictional slip on earthquake faults responsible for stress triggering because they might be wrongly inferred from the earlier flawed RSFs such as the slowness law.

Seismicity is considered as a sequence of earthquake nucleation events, which are controlled by loading history and fault frictional property. Dieterich [1994] modeled aftershock seismicity, a major part of earthquake clustering, based on the derived RSF. In his modeling, he consider an accelerating process of the slip on a fault caused by a spontaneous stress step and analytically derived time to instability. However, the aftershock productivity and duration predicted are much lower and much longer than those of observation.

Here we reconstruct the aftershock model by using the revised RSF recently proposed in order to examine how the defects in the original model are modified. Analytic derivation of the time to instability is not available in the revised RSF and we have to simulate slip acceleration process of fault population and measure the time from a stress step to instability.

Our simulation results show that the aftershock productivity with the revised RSF is around 2.0 times larger than the original, and the durations are 3 times shorter (stress step :10MPa). Our reconstruction with the revised RSF can not fill the gap between the theory and observation.

Keywords: aftershock, rate- state-dependent friction, triggering

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Estimation of fracture energies at the rupture nucleation points of large interplate earthquakes

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Numerical simulations of recurrence of large interplate earthquakes at a subduction zone are conducted by using a rate- and state-dependent friction law to estimate fracture energies at the rupture nucleation points of large interplate earthquakes. Shear stress is concentrated near the deeper edge of a locked zone of a plate boundary and seismic rupture occurs when the energy release rate by rupture extension becomes larger than the fracture energy. The stress concentration at the deeper edge is expected to increase with aseismic slip amount at the deep aseismic slip zone, and the aseismic slip amount at the occurrence of a large interplate earthquake is equal to $V_{pl}T_r$, where V_{pl} is the relative plate velocity and T_r is the recurrence interval of interplate earthquakes. The fracture energy G_c at the rupture nucleation point is measured for each simulated earthquake from the relation between shear stress and slip distance. Simulation results for various values of friction parameters and effective normal stress indicate that G_c is proportional to the square of $V_{pl}T_r$, suggesting that G_c of interplate earthquakes can be estimated from $V_{pl}T_r$. The fracture energy G_c at the rupture nucleation points of M8 class Nankai earthquakes, which took place along the Nankai trough, southwestern Japan, every 100 years, is estimated to be 0.1 to 1 MJ/m^2. This estimated value seems to be significantly smaller than the reported G_c values of large earthquakes in the literature. This is probably because the estimated G_c value in the present study is for the rupture nucleation point, while G_c has been estimated from dynamic modeling of developed rupture processes in many cases. The fracture energy may increase as rupture propagates because of off fault plastic deformation and/or secondary ruptures near the propagating crack tip. G_c of the 2011 Tohoku-oki earthquake of magnitude 9.0 is on the order of 10 MJ/m^2, which is much larger than that estimated for the Nankai earthquakes. The region with the large fracture energy controls a very long recurrence interval and enables the accumulation of large strain energy.

Keywords: earthquake cycle, fracture energy, interplate earthquake, stress concentration

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A scaling approach and a phase map of the large deviation function for frequency in a simple model of earthquakes

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Statistical indices for characterizing earthquake are important for understanding the mechanism of earthquakes. The Gutenberg-Richter (GR) law for the earthquake magnitude is well established in seismology and it is well known that the b-value depends on time and space. However in the tail part of the distribution which corresponds to large magnitudes, the functional form is still a subject of concern not only because we want to know how frequent the large earthquakes occur but also because we have insufficient data of large earthquakes. Moreover, the estimation of frequency or probability of rare events like disastrous earthquakes is a big concern from the hazard assessment point of view.

To study further the frequency of large earthquakes, we adopt a large deviation function (LDF). The LDF is related to the probability of rare events which constitute the tail part of the distribution. In addition to the practical usefulness similar to that of log scale, the LDF is universal in the sense that it is an asymptotic form whenever the number of elements is large. In general it is difficult to calculate the exact form of the LDF. Recently, a population Monte Carlo method has been introduced to obtain the LDF of some cellular automaton models. Among those simple models, we adopt an one-dimensional forest-fire model, which can be understood as one of minimalist models for earthquakes. Recently, the configuration of ignition sites (trigger sites) is investigated in the 2D forest-fire model by Tejedor et.al.[1] where they limit and fix the trigger sites to represent various heterogeneous faults. They found that there exist some asperity regions where large earthquakes tend to occur in their models. The power-law line of the frequency distribution (GR law) is adopted as criterion for the definition of phases which are classified as subcritical, critical or supercritical.

In this study we numerically calculate the LDF for frequency in the 1D forest-fire model. The configuration dependence is examined by introducing four models of different numbers of trigger sites. A mean frequency distribution is calculated to make a phase map analogous to the one by Tejedor et.al. Among various earthquakes that occur in the model, for practical reasons, we focus on the characteristic earthquake which is the earthquake that break all the area. Next we numerically calculate the LDF for frequency of the characteristic earthquake. In all cases, the LDF display a peak structure around the mean frequency. Whether the scaled data of the LDF by the mean frequency fall on to a curve or not depends on parameters such as the number of trigger sites and the ratio between loading rate and triggering rate. When the scaling do not collapse, the system size dependence of the symmetric part differs from that of the anti-symmetric part in some region. We draw a phase map by comparing the LDF of the present model to that of the Poisson process. Finally we calculate the LDF from the real seismic catalogs and find that the LDF is different from that of the Poisson process.

[1] A.Tejedor, J.B.Gomez and A.F.Pacheco, Phys.Rev.E. 79 (2009) 0461021

Keywords: The Gutenberg-Richter law, Simulations, Scaling

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Rotational asymmetry of shear zone in brittle/ductile regime

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In the deep crust, the rocks taken stress deform ductile, and form a ductile shear zone. As a general deformation of ductile shear zones, proposed by Ramsay & Huber(1983) is that mainly in area that is taken the strongest deformation and in other areas, deformation is spread wide on both sides of an has been accepted. However, in many ductile shear zones in natural, deformations are spread on both sides of the areas are not necessarily dominated by deformation. Then, this paper call ductile shear zone having feature like that, having no axis for a rotational symmetry twice on the plane on which rock took the most prominent deformation, "asymmetric" shear zone. Ductile shear zones having asymmetry even being in the same parent rock is expected to include information on the formation of ductile shear zones. But quantitative discussion has not been made for asymmetry. In this study, ductile shear zone asymmetry is quantitatively discussed by defining "Degree of deformation asymmetry".

Keywords: shear, asymmetry, deformation

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Interpretation of the G-R law using an arithmetic dynamical system

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The G-R law is known as an empirical law about the magnitude and frequency of earthquakes. In seismic hazard assessment, background seismic activity models that assume the G-R law and a Poisson process have been conventionally used. As critical phenomena, it is well known that earthquakes follow a power law represented by the GR law and phenomenological interpretation have also been made. On the other hand, the attempt to derive the GR law on the basis of dynamical systems is very few.

In order to know the behavior of critical phenomena in the system that a boundary conditions is added, phenomenological interpretation is carried out only for the phenomenon under no boundary condition. If we construct a dynamical system that can produce the G-R law, we expect that we can consider behavior of critical phenomena in systems that boundary conditions are added.

In the following, we consider that we model seismic activity by using the distribution of prime numbers.

Let p_i be i-th prime. M(p_i) = p_i - p_i-1. Then, M(p_i) can be interpreted as magnitude. The behavior of the number of occurrences M(p_i) follow a power law. A problem that the seismic activity model can be parameterized using a prime number is raised.

On the other hand, in recently, in the field of mathematical physics, as part of the study of noncommutative geometry, so called Bost-Connes system has been studied. As a feature of Bost-Connes system, it is known that the partition function of the system becomes the Riemann zeta-function. By applying the Mellin transform on the Reimann zeta-function, we can obtain the explicit formula on the distribution of prime numbers. By using the explicit formula and zeros of the Riemann zeta-function, the nature of the distribution of prime numbers can be described.

If we can associate a occurrence field of earthquakes with the Bost-Connes system and we can capture the time evolution of the system by variable transformation for the partition function, we may get a dynamical system that can explain seismic activity that produces the G-R law.

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Keywords: G-R law, Reimann zeta-function, explicit formula, Bost-Connes system, partition function, prime

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The rupture process of M5-6 earthquakes after the 2011 Tohoku earthquake in the focal area of the off-Kamaishi repeaters

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For more than 50 years from 1957, earthquakes of M~4.8 have repeatedly occurred on the plate boundary off Kamaishi, NE Japan with the recurrence interval of about 5.5 years (the repeating earthquakes off Kamaishi). Previous studies reported that the repeating earthquakes have been caused by repeated ruptures of the same asperity (Matsuzawa et al, 1999, 2002; Okada et al., 2003; Uchida et al., 2007; Shimamura et al. 2011a). Moreover, no earthquakes of M5 or larger have occurred around the off-Kamaishi repeaters since at least 1957. Nevertheless, after Tohoku earthquake of M9.0 on 11 March, 2011, events of M5-6 occurred with the interval of a few days to a few months in vicinity (1-2km in JMA catalogue) to the repeating events off Kamaishi (Uchida, 2011; http://www.aob.geophys.tohoku.ac.jp/info/topics/20110311_news/index_html). Generally, the extent of rupture areas of the M5-6 earthquakes is from a few km to 10 km, thus, it is possible that these M5-6 event ruptured the asperity of the repeating earthquakes off Kamaishi.

In this study, in order to investigate the relation of the M5-6 earthquakes to the repeating earthquakes off Kamaishi, we conducted hypocenter relocation and seismic waveform inversions. Here, among the M5-6 events, for the event on 20 March 2011 (M5.9) we reported the results of analyses of the event on 20 March 2011 (M5.9) in SSJ FALL MEETING 2011 (Shimamura et al., 2011b, in Japanese) and those of the events on 20 March (M5.9), 1 April (M6.0), 13 April (M5.5), and 29 April 2011 (M4.8) in AGU FALL MEETING 2011 (Shimamura et al., 2011c). In this study, we analyzed the events on 5 May (M5.3), 11 July (M5.0), and 23 September, 2011 (M5.0) in addition to the events mentioned above.

Except the event on 1 April (M6.0), the following results are commonly obtained: 1) Hypocenters of the M5-6 events are located within only 1-2km from those of the repeating earthquakes off Kamaishi before 2011. 2) The M5-6 events ruptured the asperity of the off-Kamaishi repeating events and areas around (mainly east of) it. These results are basically the same as those reported by Shimamura et al. (2011b, 2011c).

In previous studies, for example Uchida et al. (2005), a velocity-weakening region corresponding to the asperity of the off Kamaishi events is considered to be located in a velocity-strengthening region where two plates slip aseismically. However, this model cannot explain our result that the area around the off-Kamaishi asperity also slipped seismically during the M5-6 events. In order to explain the results, we infer that conditionally stable areas (e.g., Scholz, 1990; Boatwright and Cocco, 1996) are located near the off-Kamaishi asperity. A conditionally stable area has velocity-weakening nature but the frictional parameter a-b is nearly equal to zero. Such a conditionally stable area slips aseismically in usual. However, if a large stress perturbation is applied to the conditionally stable area, it might slip seismically (Kato, 1996). In the model proposed here, the conditionally stable areas around the off-Kamaishi asperity slipped seismically during the M5-6 events only. Actually, large afterslip of the Tohoku earthquake was estimated (Ozawa et al., 2011; GSI, 2011) in the area and it is supposed that stress perturbation caused by the large afterslip forced the conditionally stable area to slip seismically.

*Acknowledgement: In this study, we used data of K-NET and KiK-net operated by NIED.

Keywords: repeating earthquakes, the 2011 Tohoku earthquake

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Seismic activity of medium-scale characteristic earthquakes after the 2011 off the Pacific coast of Tohoku Earthquake

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Medium-scale characteristic earthquakes around Japan have been detected on the basis of regularity, geographical proximity, magnitude, correlation coefficient and coherence. It has become clear that among 31 detected groups in eastern Japan, 9 groups had the newest earthquake after the Great East Japan Earthquake on March 11, 2011, on the basis of the digital wave data of 87-type strong motion seismometer and 95-type seismic intensity meter of JMA. Correlation coefficients and coherences were used. The 9 groups are the East off Shimokita Peninsula M5.0, Group A and B of off Taneichi M5.7, off Kamaishi M5.1, off the Ojika Peninsula M5.1, off Iwaki M5.6, Hitachi M4.8, off Ibaraki M7.7, Katori M5.4. These suggests that characteristic earthquakes triggered by the great earthquake need two things, short distance from the hypocenter area of the great earthquake and enough time from the last event in order to accumulate strain to occur an earthquake.

Keywords: Characteristic earthquake, Recurrent earthquake, Correlation coefficient, Coherence, Off Taneichi, the Great East Japan earthquake

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Characteristic Earthquake Sequences off Taneichi after the 2011 off the Pacific Coast of Tohoku Earthquake

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The earthquakes clusters of the middle-scale characteristic earthquakes had been detected off the pacific coast of Tohoku in Japan, where the 2011 off the pacific coast of Tohoku earthquake with M9.0 occurred on March 11. Characteristic earthquake is distributed in the same region. Seismic activity of characteristic earthquakes off Taneichi which is in the eastern Japan after the 2011 off the pacific coast of Tohoku earthquake has been investigated. In this area, there are 2 characteristic earthquakes called group A and group B, the magnitude of these groups is around M6.0 and the strain of the group B has been thought to be fully accumulated. The events of group B occurred in 1960, 1976, 1993 had been recognized. In this region, a new event (M5.7) occurred on May 8, 2011. To examine whether the event is the members of the group B, correlation coefficient were computed with waveforms. The data of waveforms of 1960, 1976, 1993 were recorded on the smoke paper. The smoke paper records at Morioka and Hachinohe stations were picked by hand and converted the analog waveforms to digital waveforms. In result, the events of group B and the 2011event show high correlation coefficient from0.72 to 0.92. This suggests that the last event (M5.7) occurred on May 8, 2011 was the newest member of the group B after the 2011 off the pacific coast of Tohoku earthquake.

By the way, the correlation coefficient at Hachinohe between group A and group B also were very high, from 0.75 to 0.85, and this had made difficult to distinguish 2 groups. The reason is estimated that the direction of the destruction of earthquakes of group A and B are to the Hachinohe station. In fact, the waveforms of Hachinohe station contain high frequency component more than that of in Morioka station. The after slip of the 2011 off the Pacific Coast of Tohoku Earthquake seems to influence the magnitude. The coupling rates of group B seems to be smaller after suffering the after slips of near larger earthquakes and the magnitudes became smaller. The group B is estimated to include the co-seismic slip area and aseismic slip area, and the aseismic slip area would be expanded because of the influence of the after slip. Therefore, co-seismic slip area would become smaller.

The next group B earthquake will occur from October 2026 to May 2029 with 70% probability, using the small-sample theory with a log-normal distribution model. The occurrence of the next group B event may be accelerated by the after slip of the 2011 off the Pacific Coast of Tohoku Earthquake, on the other hand, after slip effect on only expanding of the aseismic area which would cause smaller magnitude than the average of the member of the group B.

Keywords: Characteristic Earthquake, the 2011 off the Pacific Coast of Tohoku Earthquake, after slip, probability, off Taneichi, correlation

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Investigation of repeating and recurrent earthquakes in the Kinki, Chugoku and Shikoku districts

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Conducted a survey of repeating and recurrent earthquakes in the Kinki, Chugoku and Shikoku districts, 16 groups of earthquakes have been extracted as candidates for repeating and recurrent earthquakes. Among all groups, 6 groups had digital wave data. Although coherences were calculated for these groups, these values were all less than 0.9. As a result, repeating and recurrent earthquakes were not detected.

Keywords: recurrent earthquake, repeating earthquake, coherence, Kinki district, Chugoku district, Shikoku district

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Estimation of areas with a large slip of the next a large earthquake from the stress drop of small earthquakes

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Stress drop of earthquakes is one of the physical parameters that reflects the difference of the fault strength and the dynamic frictional stress level. It is reported that the stress drop of small earthquakes occurred in the source region of the 2004 Parkfield earthquake (Mw6.0) were relatively large [Allmann and Shearer, 2007] and that small earthquakes in and around large slip patches of the 2006 Kihoro Bay earthquake (Mw6.7) had larger stress drops [Yamada *et al.*., 2010]. These results suggest that the region with a large slip in large earthquakes permanently have large difference of strength and the dynamic frictional stress level and that it would be able to predict large slip areas by analyzing the stress drop of small earthquakes.

Large earthquakes occurred repeatedly about every 50 years; 1915 (M7), 1952 (Mw7.8), and 2003 (Mw8.0) [e.g., Yamanaka and Kikuchi (2003)] off the south-east of Hokkaido (Tokachi-oki region), Japan. The 2003 Tokachi-oki earthquake had two characteristics, which were that the slip area of the 2003 Tokachi-oki earthquake was the deeper half of the source area of the 1952 Tokachi-oki earthquake [e.g., Yamanaka and Kikuchi (2003)] and that significant afterslip was observed at adjacent areas to the coseismic rupture zone [Miyazaki *et al.* (2004)]. We analyzed the stress drop of small earthquakes in the source region of the 2003 Tokachi-oki earthquake and investigated the special distribution of the values.

We estimated stress drops of 423 small earthquakes ($4.0 < M < 5.0$) occurred from June, 2002 to December, 2010. First, we calculated empirical Green's functions from waveforms of smaller earthquakes and estimated corner frequencies from spectra of the velocity seismograms by assuming the omega-squared model of Boatwright (1978). We then calculated stress drops of the earfthquakes by using the model of Madariaga (1976). Most of the values were around 3MPa, while some earthquakes had stress drops with an order of 0.01MPa and 100MPa. We are going to examine each seismogram carefully and compare the special pattern of the stress drop of small earthquakes with the slip distribution and the afterslip of the 2003 Tokachi-oki earthquake.

Acknowledgments
We used Hi-net waveform data (http://www.hinet.bosai.go.jp/) .

Keywords: stress drop, area with a large slip, small earthquake

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Rupture process of the 1952 and 2003 Tokachi-oki earthquakes (2)

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Along the Kuril Trench of the Pacific side of Hokkaido, many destructive earthquakes have occurred. Among those, the hypocenter of the 1952 Tokachi-oki earthquake (41.706^{o}N, 144.151^{o}E, depth: 52 km, JMA) and the 2003 Tokachi-oki earthquake (41.778^{o}N, 144.078^{o}E, depth: 45 km, JMA) were very close and it is highly possible that those two events were reccurent plate-boundary earthquakes.

In our previous study, we performed teleseismic waveform inversion of the 1952 and 2003 events using the inversion code of Kikuchi *et al*. (2003). We showed that the 1952 event had a larger M_w than that of the 2003 event, and rupture processes of those two events were slightly different from each other. In this study, we added some new waveform data of the 1952 event to the dataset and preformed teleseisemic inversion with the method of Yoshida *et al*. (1996). Moreover, we checked whether the estimated fault plane corresponds to the plate boundary of the JIVSM (Koketsu *et al*., 2008). We used strike=230^o, dip=20^o, initial rupture depth=21 km for the 2003 event, and strike=238^o, dip=20^o, initial rupture depth=17 km for the 1952 event. The assumed fault planes consist of 17x14 subfaults at intervals of 10 km.

For the waveform dataset of the 1952 event, we collected the copies of historical seismograms which were recorded by the seismographs in those days. We digitized them and then resampled them at 0.5 s. Thereafter, we removed the instrument response of the seismograph from the resampled waveforms and bandpass-filtered at 0.01 (or 0.02) ~ 0.2 Hz to obtain the wavesform data to be used for the inversion. We used P-waves of 19 components of 11 stations. For the 2003 event, we used the dataset from the IRIS DMC. When we selected the stations, we took care to include the stations which are near to those of the 1952 event. 34 P and SH components of 30 stations were used.

Our source inversions incidate that the 1952 event had M_w =8.3 with maximum slip 6.2 m and the 2003 event, M_w =8.2 with maximum slip 7.0 m. The place with maximum slip is almost the same each other. However, the 1952 event showed some slips at shallow part of the Kushiro-oki region where the 2003 event had little slip. This can be seen in the slip distribution of the tsunami waveform inversion (Satake *et al*., 2006). This result suggests that the 1952 Tokachi-oki earthquakes included the rupture area of the 2003 Tokachi-oki earthquake as well as the shallow part of the Kushiro-oki region; this shallow slip may have contributed to tsunami generation.

We will perform joint inversion of strong-motion and teleseismic waves to investigate more detailed rupture process.

Keywords: source process, inversion, the 1952 Tokachi-oki earthquake, the 2003 Tokachi-oki earthquake, recurrent earthquakes

SSS28-P14 Room:Convention Hall Time:May 24 17:15-18:30

Comparison of the ratio of maximum displacement amplitude to HFER duration to the slowness parameter

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Hara (2007, EPS, 59, 561-565) suggested a possibility to distinguish tsunami earthquakes using the ratio of the contribution of the maximum displacement amplitude (with distance correction) in the magnitude formula of Hara (2007, EPS, 59, 227-231) to that of high frequency energy radiation (HFER) duration. In this study, we calculate common logarithms of ratios of maximum displacement amplitudes of teleseismic P waves (with distance correction) to their HFER durations for a set of large shallow earthquakes. Then, we compare them to the slowness parameters, which are defined by common logarithms of ratios of radiated seismic energy to seismic moment (Newman and Okal, 1998, JGR, 103, 26,885-26,898), determined by Newman and Okal (1998), Lomax et al. (2007, GJI, 170, 1195-1209), and Lomax and Michelini (2009, GJI, 176, 200-214). We find a good correlation between these two ratios. Since the slowness parameter is demonstrated to be effective to identify tsunami earthquakes (i.e., the slowness parameter is deficient for tsunami earthquakes), the ratio of the maximum displacement amplitude to its HFER duration for teleseismic P waves is useful to distinguish tsunami earthquakes.

Keywords: high frequency energy radiation duration, tsunami earthquake, slowness parameter

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Rupture propagations inferred from HFER durations for the 1994 far east off Sanriku and 2003 Tokachi-oki earthquakes

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Hara (2011, EPS, 63, 525-528) showed a clear azimuthal dependence of high frequency energy radiation (HFER) durations measured from teleseismic P waves for the 2011 off the Pacific coast of Tohoku Earthquake. He suggested that it reflected the rupture propagation that generated high frequency energies. In this study, we investigated whether such azimuthal dependences were observed for the 1994 far east off Sanriku earthquake (Mw 7.7) and the 2003 Tokachi-oki earthquake (Mw 8.3). We applied the measurement procedure of high frequency energy radiation duration of Hara (2007, EPS, 59, 227-231) to these earthquakes, and found their azimuthal dependences. We calculated high frequency energy radiation durations referring to previous rupture process models of these earthquakes, and compared them to the observed high frequency energy radiation durations. For the 1994 far east off Sanriku earthquake, we found a good correlation between them. For the 2003 Tokachi-oki earthquake, although the observed azimuthal dependence is consistent with the direction of the rupture propagation, there is a substantial difference between their absolute values, which needs further detailed analyses.

Keywords: high frequency energy radiation duration, rupture propagation, azimuthal dependence

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Initial rupture of the 2011 Suruga-bay, Japan, earthquake (M6.2)

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The 2011 Suruga-Bay, Japan, earthquakes (6.2) occurred two years after the 2009 Suruga-Bay earthquakes (6.5). This area, where the two earthquakes occurred, is located at the eastern tip of the Supposed Tokai earthquake source area. In this study, we estimate source process at the initial stage of the 2011 earthquake. The P-wave portion of records at local stations shows about one seconds of small but increasing amplitude arrival (so-called ”initial rupture phase”) followed by the onset of the main energy release (so-called ”main rupture phase”). We estimated the focal mechanisms of the events corresponding to these phases. We found that the initial rupture has a mechanism of strike-slip fault, while the main rupture has a reverse-fault one. We also determined the relative time and location between the initial and the main ruptures.

Keywords: initial rupture, main rupture, source process, 2011 Suruga-bay earthquake

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Rupture Process of Torishima-Kinkai Earthquake(M7.0) on 1 January, 2012 by Back Projection Method

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It is occurred M7.0 earthquake (maximum seismic intensity was 4) in plate near Torishima Island on 1 January, 2012. The hypocenter located by JMA is at 31.256^{o}N 138.339^{o}E and a depth of 397km. The focal mechanism is pressure axis in the direction of a type that has the Philippine Plate is subducting Pacific Plate, and the fracture occurred in Pacific Plate. It is not occurred earthquake of M7-class in the fault after 1970 . By using of teleseismic body-wave waveform inversion method(JMA), the fault is about the length of 25km, the width of 20km, the strike of 6^o, the dip of 84^o and the angle of -73^o. The maximum slip is about 1.0m. The duration time is 15 seconds. The main rupture process is located deeper than the starting point. In the fault plane can be seen two large slip.

In this study we applied the back projection method to teleseismic body waveforms recorded USArray. The USArray consists of about 400 broadband stations in the United States. We obtain an image of the rupture process of the Torisima-Kinkai earthquake by back projection method in consideration of three-dimensional fault plane.

Keywords: back projection method, rupture process, Torishima-Kinkai Earthquake

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New back-projection method to use depth phases' information

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The Back-projection method has been applied to large, shallow earthquakes since success in imaging the 2004 Sumatra-Andaman earthquake (Ishii et al., 2005). Many researchers have analyzed the 2011 Tohoku-Oki earthquake by the back-projection method and detected huge seismic energy radiation from around the hypocenter and Ojika Peninsula (0-90 sec) and southward movement of the wave source (90-160 sec). On the other hand, the conventional back-projection method could not resolve rupture propagation pattern in early stage of mega-thrust earthquake detected by probable waveform inversion (e.g. Yagi and Fukahata, 2011). It seems difficult to discuss the mechanisms of some large, shallow earthquakes using the conventional back-projection method.

In the conventional back-projection method of tele-seimsic P-waves, overall observed waveforms are interpreted as direct P-wave and are projected to the seismic source region. Therefore, in case of analysis of shallow thrust faults, huge reflected phases (e.g. sP) should contaminate the rupture image. In this study, we propose new method to project cross-correlating functions between theoretical Green's functions and observed waveforms to the seismic source region. Using the new method, the source grids radiating waves would be detected more robustly and less affected by depth phases.

We applied the new method to the Tohoku-Oki earthquake waveforms recorded on 88 broadband stations of FDSN and GSN. The conventional method and the new method are carried out upon the same condition, and it is revealed that wave sources detected by the new method are smaller in time and depth than those by the conventional method. Resolution in depth progresses because depth phases specify depth of rupture areas. Moreover, radiated energy function by the conventional method is 10-20 seconds later compare to that by the new method, and the projected energy peak by the conventional back-projection (50-100 sec) swerves to near Ojika Peninsula. The results suggest that the conventional method projects not only P but also sP. Indeed, the rupture image with the new method is well consistent with the slip model proposed by Yagi and Fukahata (2011), especially early episode (0-50 sec) of mega-thrust earthquake.The new method seems to overcome weakness of the conventional back-projection method and provides rupture process more objective and higher-resolution. This hopeful method will be applied to verify the validity of slip models obtained by other methods.

Keywords: back-projection, rupture process, depth phase, the 2011 Tohoku-Oki earthquake, cross correlation

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Basic study on downscaling of a slip distribution by using multifractal

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We are planning to apply multifractal model for downscaling of a slip distribution. First, we tried to confirm whether or not slip distributions are (mono or multi) fractal fields, by using spectral analysis. However, we cannot distinguish multifractal field (measure) and monofractal field (geometry) by the spectral analysis alone. Then we used DTM (double trace moment) method proposed by Lavallee(1991). Data analyzed are 10 models of KyogoKen-Nanbu Earthquake. Results show that slip distributions are multifractal fields and suggest that we can downscale slip distributions by using multifractal simulations.

Keywords: slip distributution, multifractal, scaling, double trace moment, spectral analysis, downscaling

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Coseismic hot spring water temperature changes of the Tohoku earthquake at the observation stations in San-in district

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Coseismic temperature changes due to several earthquakes were observed at the hot springs in San-in district where we maintain observation network consist of 8 sites. After the 2011 off the Pacific coast of Tohoku earthquake, the water temperature rapidly increased by 1.86 degrees at Iwai station, by 0.23 degrees at Okutsu station, by 0.18 degrees at Yudani station and by 0.28 degrees at Yoshioka station,and the water temperature rapidly decreased by 0.23 degrees at Saginoyu station. After water temperature rapidly changes, water temperature gradually increases at Iwai station, at Saginoyu station and at Yudani station and water temperature gradually decreases at Yoshioka station. The maximum value of changes in water temperature increases is by 2.40 degrees at Iwai station, by 1.32 degrees at Saginoyu station, by 0.81 degrees at Yudani station, by 0.28 degrees at Yoshioka station and by 0.11 degrees at Okutsu station. At Yosioka station and Yudani station,temperature has changed from a decreasing tendency into a constant tendency two months before the earthquake occurred.

Keywords: hot spring, temperature changes, San-in district, the 2011 off the Pacific coast of Tohoku earthquake