Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SSS24-P01 Room:Poster Time:May 1 18:15-19:30

Seismic activity in eastern Japan and the source region after the 2011 off the Pacific coast of Tohoku earthquake

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Changes of seismic activity in eastern Japan and the source region were shortly reported after the 2011 off the Pacific coast of Tohoku earthquake (Toda et al., 2011; Kato and Igarashi, 2012). To clarify subsequent changes, we investigated seismic activity in the wide region for two and a half years since the 2011 Tohoku earthquake.

We examined a region in a range of 33.4-42N and 136-145E. The region was divided into small squares with a size of 0.2 degree, and in each square, we computed seismicity rates. First, as the background seismicity, we computed the average number of earthquakes per a year, based on seismic activity for nine years before the 2011 earthquake. Then, to obtain seismicity rates after the 2011 earthquake, we counted the number of earthquake during two periods, respectively, and computed the ratios against the background seismicity. The two periods are 0-1 and 1.5-2.5 years after the 2011 earthquake. We used hypocenters determined by JMA. In regions where large inland earthquakes occurred before 2011, the background seismicity was computed from a period excluding aftershocks. Finally, by plotting the resultant seismicity rates in maps, we searched regions where seismic activity significantly changed. By the same method, we also examined seismicity rates of interplate earthquakes in the source region of the 2011 Tohoku earthquake, based on data selected from the F-net CMT catalog.

Our results show that when two and a half years passed since the 2011 earthquake, seismicity of interplate earthquakes had been lower than the background, throughout the source region of the 2011 Tohoku earthquake except for a region off Iwata. High seismic activities for a year since the 2011 earthquake were found in Iwaki, the middle and northern parts of Akita, the southern part of the Kanto region, and also in regions near active volcanos (Bandai, Nikko-Shirane, Kusatsu-Shirane, Naeba, and Fuji mountains). When two and a half years passed, seismicity in many regions of eastern Japan had been lower than the background, including the activities near Bandai, Naeba, and Fuji mountains. However, activities in Iwaki, the middle and northern parts of Akita, the southern part of the Kanto region, and near Nikko-Shirane and Kusatsu-Shirane mountains continued to be high.

Furthermore, we carefully examined seismic activity in the regions where we detected significant changes of seismic activity. In many regions of eastern Japan, we found that locations of earthquakes and focal mechanisms were changed before and after the 2011 Tohoku earthquake.

Using JMA hypocenters, we also attempted to apply the modified Omori's law for seismic activity after the 2011 earthquake in the regions with significant changes of seismic activity. The modified Omori's law could roughly model the changes of seismic activity in many regions, even when a region is inland, away from the source region. The Omori's regression parameter, p, was estimated in a range from 0.2 to 1.1. The values ranged between 0.2 and 1.1 in the regions where seismic activity has been high for 2.5 years, whereas they were between 0.8 and 1.1 where high seismic activity for the first 1 year decreased in 2.5 years since the 2011 earthquake. In the southern part of the Kanto region, the value of p (0.2) was extremely low, compared to the other regions, which implies that the seismic activity decays very slowly. In the regions near active volcanos, the values of p tended to be high. In the source region of the 2011 Tohoku earthquake, we estimated the values of p in three regions; a whole source region, an afterslip region, and a region excluding the afterslip region. The values ranged from 1.0 to 1.1, and there was no significant difference in the three regions.

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SSS24-P02 Room:Poster Time:May 1 18:15-19:30

A statistical feature of anomalous seismic activity prior to large inland earthquakes in Japan

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To reveal the preparatory processes of large inland earthquakes, we systematically applied the pattern informatics (PI) method to earthquake data of Japan. We focused on 12 large earthquakes with magnitudes greater than M6.4 (based on the magnitude scale of the Japan Meteorological Agency) that occurred at depths shallower than 30 km between 2000 and 2010. We examined the relationship between the spatiotemporal locations of these large shallow earthquakes and the locations of PI hotspots, which correspond to grid cells of anomalous seismic activity during a designated time span. Based on a statistical test conducted using Molchan's error diagram, we investigated whether precursory anomalous seismic activity occurred in association with these large earthquakes and, if so, studied the characteristic time spans of such activity. Our results indicate that Japanese inland earthquakes with M $\geqq$ 6.4 are typically preceded by anomalous seismic activity in timescales of 8-10 years.

Keywords: pattern informatics, seismic quiescence, seismic activation, Molchan's error diagram, stress accumulation, inland earthquake

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Coulomb stress change inverted from the seismicity rate change in southern 2011 Tohoku earthquake's source region

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By using the analysis of seismicity rate change, we estimated spatio-temporal evolution of Coulomb stress around the upper boundary of the Pacific plate (PAC) and Philippine Sea plate (PHS) in and around the southern edge of the rupture zone of the 2011 Pacific coast of Tohoku earthquake (Mw=9.0). We used hypocenter catalog of the Japan Meteorological Agency (JMA) for the period between 1998/1/1 and 2013/3/31. Estimated stress change became large just after the 2011 Tohoku earthquake in most of rupture zone. The large stress change estimated from the seismicity reached the southern outside of the contact zone of the PHS and the PAC, while this area is located at outside of the source fault of the 2011 Tohoku earthquake. Moreover, in the October 2011 Boso slow slip event (SSE) initiation area, stress change remained large value after the 2011 Tohoku earthquake.

To estimate the effect of the mainshock and largest aftershock in our inversion result, we calculated Coulomb stress change by simulating the mainshock, afterslip and Mw7.9 aftershock for the 2011 Tohoku earthquake in an elastic half space. From similarity between the result from seismicity rate change and result of forward modeling, most of the stress change pattern in and around mainshock rupture zone after the 2011 Tohoku earthquake might be explained by the effect of the 2011 Tohoku earthquake mainshock, afterslip and the largest aftershock. On the other hand, since the result from seismicity rate change didn't correspond to the result of forward modeling in the October 2011 SSE area, this region was possibly affected by other event or closeness to break strength.

Keywords: stress change, 2011 Tohoku earthquake, aftershock, slow slip

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SSS24-P04 Room:Poster Time:May 1 18:15-19:30

Spatial distribution of earthquakes off the coast of Ibaraki and the Boso Peninsula after the 2011 Tohoku Earthquake

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The 2011 off the Pacific coast of Tohoku Earthquake occurred on March 11, 2011, off shore of the northeast Japan region. Many aftershocks occurred following the mainshock. To obtain a precise aftershock activity is important for understanding the mechanism of earthquake generation, and the recovery of plate coupling at a ruptured plate boundary. In order to study the aftershock activity, we had deployed 66 long-term ocean bottom seismometers(LTOBS) off the coast of Ibaraki and the Boso Peninsula from October 2011 to November 2012.

For hypocenter determination, we selected 1606 events whose epicenter catalog which the Japan Meteorogical Agency for hypocenter determination.P- and S- wave arrival times were manually picked using the WIN system (Urave and Tsukada, 1991).Hypocenters were determined by the maximum-likelihood estimation technique (Hirata and Matsu'ura, 1987). The hypocenter location program used in this study is based one-dimensional structure with constant Vp/Vs ratio of 1.73. Because a sedimentary layer below the sea floor generally has a large Vp/Vs value, an adjustment of the station corrections is needed. To obtain the station correction, we used the following method. First, we located the hypocenter using the P- and S-wave arrival times with the assumed station correction values for the velocity structure used. The averaged differences between observed travel time and estimated travel times (O-C times) for each station were then calculated. The averaged O-C times were added to the previous station correction values, and the hypocenters were relocated. We repeated this procedure eleven times. After this procedure, the averaged O-C times were less than 0.1 s for both the P-wave and S-wavesWe estimated 458 hypocenter locations with an error of less than 5 km in the horizontal direction and less than 3 km in depth by using LTOBS data.

Most of the hypocenter locations have a depth shallower than 40km. The earthquakes form a plane dipping landward in the study area. Comparing the hypocenter locations with crustal structures obtained by active seismic studies (e.g. Miura et al., 2003). Many events occurred along the plate boundary. We also compared the hypocenter locations with aftershock distribution of the seismic observation conducted immediately after 2011 Tohoku Earthquake (Shinohara et al., 2012). Shinohara et al., (2012) reported that the low seismicity region has seen at the shallow part of the plate interface in the off-Fukushima. On the other hand, our results showed the seismicity is not low at the same region. This difference may reflect the change of stress fields at a ruptured plate boundary.

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Spatial distribution of earthquakes off the coast of Fukushima deduced from a one-year OBS observation in 2013

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The 2011 Tohoku earthquake (M9.0) vastly changes stress field around the rupture zone, and many aftershocks and other related geophysical phenomenon such as geodetic movements have been observed. The seismicity not only keeps still high rate compared with that before the 2011 earthquake but is important to figure out the time-spacious distribution during the relaxation process for understanding the giant earthquake cycle. Many studies using ocean bottom seismometers (OBSs) [e.g. Shinohara et al,, 2011, Nakahigashi et al., this meeting] have been doing since soon after the 2011 Tohoku earthquake in order to obtain aftershock activity precisely. Here we show one of the studies at off the coast of Fukushima which is located on the southern edge of the rupture zone of the 2011 Tohoku earthquake. 12 short-period type [Lennartz 3Dlite] OBSs (SOBS) and 4 broadband type [Guralp CMG 3T] OBSs (BBOBSs) in Auguest 2012 were installed. 20 SOBSs and 4 BBOBSs attached with absolute pressure gauge [Paroscientific Model 8B] were added in November 2012. After one year continuous recording, 36 OBSs were recovered in November 2013. We selected characteristic 1,000 events in the vicinity of the OBS network based on a hypocenter catalog publish by the Japan Meteorological Agency, and extracted the events' data from all available OBS data after time corrections caused by each internal clock. Each P and S wave arrival times, P wave polarity and maximum amplitude were picked manually on a computer display using the WIN system [Urabe and Tsukuda, 1991]. We assumed one dimensional velocity structure that is modification of the result from an active source experiment close to our network, and applied time corrections every station which were estimated from differences from theoretical and observational travel times for removing ambiguity of the assumed structure. Then we adopted the maximum-likelihood estimation technique [Hirata and Matsu'ura, 1987] and calculated the hypocenters. Preliminary results show that intensive activity near the Japan trench can be seen while there was a quiet seismic zone between the trench zone and landward high activity zone.

Keywords: off Fukushima, Aftershock activity, Long-term OBS

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Relation between Seismicity and Stress Change Associated with Interplate Slips off Boso Peninsula: Part 2

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Hirose & Maeda (2012, 2013, JpGU; 2013, SSJ) investigated a relation between temporal variation of seismicity rate or b-value of the G-R law (Gutenberg and Richter, 1944, BSSA) and stress change associated with slow slip events (SSEs) around Boso peninsula. For example, there are three characteristic stages about seismicity: (S-1) activation during SSE, (S-2) quiescence before 2002 and 2007 SSE, and (S-3) seismicity rate increases after 2007 SSE. On the other hand, b-value repeats a cycle as follows: (b-1) small during and just after SSE, (b-2) gradually increases up to the next SSE.

By considering the correlation of seismicity rate with stress increase and inverse correlation of b-value with stress obtained in laboratory experiments (Dieterich, 1994, JGR; Scholz, 1968, BSSA), they interpreted their result as follows: for (S-1, b-1) during SSE, the slip rate at the edge of SSE on the plate boundary where is seismically active becomes higher (We can confirm it from the distribution of slip deficit and SSE estimated by GNSS data). Then because a strain accumulation rate increases, the stressing rate increases. Thus, seismicity rate increases, and b-value decreases at the same time. On the other hand, for (S-2, b-2) in SSE interval, because the slip rate on the plate boundary becomes lower than that during SSE, the seismicity rate decreases, and b-value increases at the same time. For (S-3) seismicity rate increases after 2007 SSE, the distribution of slip deficit after 2007 SSE is not much different from that before SSE. When we consider a frame of Dieterich (1994), only steady slip rate should become higher without changing of slip deficit rate so that seismicity rate changes under this situation because slip deficit on the plate boundary is independent of the value of steady slip rate (Savage, 1983, JGR). That means the drop of the coupling rate on plate boundary (slip deficit rate / steady slip rate). Therefore, the temporal change of the seismicity and b-value is comprehensively consistent with the perturbation of the slip rate on the plate boundary.

By the way, Boso SSEs had occurred every 4-7 years, but the latest interval of occurrence has a shorter period because those occurred in the end of 2011 and early in 2014. It is considered that the shortening of interval is mainly caused by the influence of the 2011 off the Pacific Coast of Tohoku Earthquake (Mw9.0, hereinafter Tohoku earthquake). We extended data period and investigated whether the same characteristics as before are also seen for the 2014 SSE. As a result, it showed such the same characteristics that (S-1) activation during SSE, (S-3) seismicity rate increases after 2007 SSE, (b-1) small during and after SSE, and (b-2) gradually increase up to the next SSE. On the other hand, (S-2) quiescence before SSE was not recognized because the perturbation of stress caused by the Tohoku earthquake may affect the seismicity.

Keywords: Boso peninsula, slow slip event, b value, stress, temporal change

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Microseismicity around the Nankai trough south off the Kii Peninsula

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The seismicity around the Nankai trough axis and its southern area, south off the Kii Peninsula, was not well understood, because most previous ocean bottom seismograph observations had been performed at landward from the trough axis. In order to investigate the seismicity around the region, Meteorological Research Institute conducted ocean bottom seismograph observations at around the Nankai trough axis and its southern area from 2005 to 2008, cooperated with Seismology and Volcanology Department, Japan Meteorological Agency (JMA). We conducted four observations, which period was approximately three months, using about ten pop-up type ocean bottom seismographs. As a result, we could detect a microseismic activity, which were not listed in the earthquake catalogue by JMA, around the trough axis.

The features of the microseismic activity are as follows. The depth of the hypocenters distributes around 10km to 25km. Since the depth of hypocenters determined by JMA at the region distributes around 30km to 40km, the true depth of the earthquakes is considered about 20km shallower than that of the JMA. There is a clear lower limit plane of hypocenters, and little earthquakes occur deeper than 25km. As a general tendency, the microseismic distribution has south incline at seaward from the trough axis, north incline at landward. The distribution of the hypocenters is not uniform, and we can detect some seismic clusters, liner arrangements and several seismic gaps of the 20km to 30km in diameter. It seems that seismic segment structures are formed within the Philippine Sea plate.

In general, seismic activity around a trough axis is causes by bending of oceanic plate. Moreover, the activity is affected by somewhat change of interplate coupling status at subduction zone. For instance, it is pointed out that the focal mechanism at outer rise region changes from compressional to tensional tectonic field by occurrence of large interplate earthquakes at subduction zone. We propose a possibility that the temporal change of the microseismic activity around the Nankai trough axis reflects a temporal change of the plate motion or a somewhat change of plate coupling conditions.

Keywords: ocean bottom seismograph, Tonankai earthquake, Nankai earthquake, Nankai trough, microseismicity, Philippine Sea plate

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Repeating earthquake activity along the Izu-Bonin and Ryukyu trenches

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There are several subduction systems near the Japanese islands. The 2011 Mw9.0 Tohoku-oki megathrust earthquake occurred at the northeastern Japan subduction zone and revealed a complementary relation between the slip areas for huge earthquakes and small repeating earthquakes (REs). Investigations of REs in other subduction zones and their comparison with Tohoku area are important for revealing generation mechanism of megathrust earthquakes.

We use seismograms from the High Sensitivity Seismograph Network (Hi-net) and Japan Meteorological Agency (JMA)'s permanent seismograph stations from 8 May 2003 to 31 December 2012. We detect RE along the Izu-Bonin and Ryukyu trenches, using similarity of seismogram pairs.

Although, Igarashi (2010) and Yamashita et al. (2012) have already examined RE activity in this region, we mainly follow the method of Uchida et al. (2010) to compare with the REs at Tohoku area. In the method, pair with coherence larger than 0.95 at multiple stations is considered to belong to a repeating earthquake group. We apply this method to the earthquakes along the Ryukyu trench. Along the Izu-Bonin trench, however, the signal-to-noise (S/N) ratios of the waveforms are not so good because of the limited seismic stations at sparsely distributed islands. Therefore, we adopt a coherence threshold of 0.8 and even if S/N ratios of the waveform are good at only one station, earthquake pairs that satisfy the threshold in multiple components are considered as candidates of REs along the Izu-Bonin trench.

Along the Ryukyu trench, we find RE distribution shows two dense bands parallel to the trench axis. This feature is similar to the northeastern Japan subduction zone. We consider the regions between the two bands of REs may have strong interplate locking as suggested at Tohoku.

Along the Izu-Bonin trench, in spite of the non-strict coherence threshold, we find much fewer REs than that in northeastern Japan. Our result suggests that REs are relatively rare along the Izu-Bonin trench and they mainly occur at the shallow part where the Pacific plate contacts with the crust of the Philippine Sea plate.

These varieties in the RE occurrences suggest different interplate locking patterns along these subduction systems.

Keywords: subdection zone, repeating earthquake, Izu-Bonin, Ryukyu, interplate locking

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Ocean bottom seismic observation in the Hikurangi subduction zone offshore the North Island of New Zealand

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The Hikurangi Plateau which has ~12 km thick crust subducts under the Australian plate
in the Hikurangi subduction zone offshore North Island, New Zealand. The plate interface is relatively shallow so that geometry of the plate interface has been revealed in detail by high quality seismic reflection data collected along dense profiles along the margin [Bell et al. 2010]. Distribution of interseismic plate-coupling has been estimated and series of slow slip events (SSEs) have been detected at around the lower limit of the coupling region due to recent installation of dense GPS network over the North Island. In the northern part, along-strike coupling region is narrow and the upper limit extends to near the trench axis and the lower limit is shallow at ~15 km depth. Most of the region of strong interplate coupling is under the sea. We need to conduct seismic observation using ocean bottom seismometers (OBSs) to understand seismicity and hypocentral distribution in detail. SSEs occur at much shallower depth than other subduction zones.

We conducted a passive seismic observation using OBSs for the first time offshore Gisborne to reveal seismisity and low-frequency events accompanying SSEs. We deployed four OBSs in April 2012 and recovered all instruments after 11 months of observation. The northern two instruments were a broadband type and the other southern two were equipped with 1Hz seismometers. Although the recorder of one of the broadband type OBSs recorded only intermittently, good data were obtained from the others. An earthquake swarm occurred to the north of the array in September to November 2012. A large SSE occurred around the Hawke's Bay to the south of the array from mid-February 2013. At first we apply STA/LTA algorithm to this data to detect seismicity. The result shows seismicity was activated accompanying both the earthquake swarm and the SSE. We tried to determine the hypocenters of these events using 4 OBSs and some GeoNet onshore seismometers. We could detect more offshore events than are listed in the GeoNet catalogue owing to higher Signal-to-Noise ratios of the OBS data while most events occurred beneath the seafloor.

Keywords: seismicity, Hikurangi, OBS

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Greenland Ice Sheet Dynamics and Glacial Earthquake Activities

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The Greenland ice sheet and its response to climate change have potentially a great impact upon mankind, both through sea-level rise and modulation of fresh water input to the oceans. Monitoring a dynamic response of the Greenland ice sheet to climate change is a fundamental component of long-term observations in global science. Glacial earthquakes have been observed along the edges of Greenland with strong seasonality and increasing frequency in this 21st century by the data from Global Seismographic Network (GSN). During the period of 1993-2006, more than 200 glacial earthquakes were detected, but more than 95% have occurred on Greenland, with the remaining events in Antarctica. Greenland glacial earthquakes are considered to be closely associated with major outlet glaciers at the margins of the continental ice sheet. Temporal patterns of these earthquakes indicate a clear seasonal change and a significant increase in frequency after 2002. These patterns are positively correlated with seasonal hydrologic variations, significantly increased flow speeds, calving-front retreat, and thinning at many outlet glaciers. These long-period surface waves generated by glacial earthquakes are incompatible with standard earthquake models for tectonic stress release, but the amplitude and phase of the radiated waves can be explained by a landslide source model. The seismicity around Greenland including tectonic/volcanic events was investigated by applying a statistical model to the globally accumulated data. Calculated b values, the Magnitude-frequency-dependence parameter, indicated a slight increase from 0.7 to 0.8 in 1968-2007, implying that the seismicity including glacial events around Greenland become slightly higher during the last four decades. The detection, enumeration, and characterization of smaller glacial earthquakes were limited by the propagation distance to globally distributed stations of the GSN. Glacial earthquakes have been observed at stations within Greenland, but the coverage has been very sparse. In order to define the fine structure and detailed mechanisms of glacial earthquakes, a broadband, real-time network needs to be established throughout the ice sheet and perimeter. The International Polar Year (IPY 2007-2008) was a good opportunity to initiate the program with international collaboration. Then, the Greenland Ice Sheet Monitoring Network (GLISN) was initiated for the purpose of identifying the dynamic response of the Greenland ice sheet to climate change.

Keywords: Greenland, global warming, glacial earthquakes, broadband seismometer, monitoring