Processing Situation after improvement of JMA's earthquake catalog

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Based on the policy of the Headquarters for Earthquake Research Promotion, Japan Meteorological Agency (JMA) collects the data of the high-sensitive seismographs nationwide, performs the processing of hypocenter determination centrally, and publishes the result as the earthquake catalog.
The earthquake catalog has been improved by JMA on April 1, 2016 (Japan Standard Time). The main improvement was application of PF method (Tamaribuchi, 2016) which was an automatic hypocenter determination technique, and raising detection capability and efficiency of the hypocenter determination processes.
Specifically, main improvements are as follows. Threshold of magnitude (Mth) for making a scrutinized analysis (picking P and S arrivals and maximum amplitudes at many stations) by analysts is set for each area and depth of the hypocenter. An earthquake which magnitude is equal or bigger than the Mth, the scrutinized analysis is made as same as before. If the magnitude is smaller than the Mth, parameters determined by the PF method are basically adopted and registered to the earthquake catalog. For detected earthquakes which locations have not been calculated by the PF method, analysts make simple analysis. Simple analysis means picking P and S arrivals and maximum amplitudes by analysts at most 10 stations. For shallow earthquakes occurred in inland, the Mth is M2. The Mth for earthquake occurred in sea area depends how far from the observation network in inland. The Mth is gradually raised as the distance from land, and the biggest Mth is M4.
As the PF method has been introduced to the JMA's procedure to make earthquake catalog, new flags which indicates the differences in analysis methods and the accuracy of the hypocenter have been added. JMA started to introduce these new procedures to make earthquake catalog on April 1, 2016. Total number of the hypocenters in the catalog has approximately doubled, and hypocenters which parameters are automatically calculated occupy approximately 60% of the catalog. For the Kumamoto earthquake and other big earthquakes occurred after April in 2016, by utilizing automatically determined hypocenters, JMA could successfully enhance documents for press release and contribute evaluation of seismic activity by the Earthquake Research Committee.
We would like to introduce processing situation of this new earthquake catalog including processing situation of the sequence of the 2016 Kumamoto Earthquake.

Keywords: Earthquake Catalog

Temporal change of stress field in forearc region after the 2011 Tohoku-Oki earthquake

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The 2011 Tohoku-Oki earthquake changed the stress field around its source region. Significant coseismic rotation of the principal stress axes was observed and it was suggested that almost all the accumulated shear stress was released on the ruptured plate boundary (Hardebeck, 2012; Hasegawa et al. 2011). Hardebeck (2012) showed that the directions of the principal stress axes returned to those before the Tohoku-Oki earthquake in 0.1 years after the earthquake. She argued that slight strain re-accumulation within short time period can account for the rapid restoration of the stress orientation after the complete stress release.

In this study, we inverted focal mechanism solutions of earthquakes in the Tohoku forearc for temporal changes of the stress field after the Tohoku-Oki earthquake. We analyzed GCMT solutions selected by almost identical criteria used by Hardebeck (2012), but added the solutions from 2012 –2016. When we inverted all the earthquakes at once, the postseismic restration of the stress axes, similar to that reported by Hardebeck (2012), was identified.

Next, we divided the forearc region into two sub-regions to take into account possible spatial heterogeneities of the stress state and performed the stress tensor inversion. In the analysis, one sub-region was set inside the large co-2011 earthquake slip distribution (Yagi and Fukahata, 2011) and another was set outside of it. In the sub-region of the large coseismic slip, normal-faulting aftershocks were extremely active, whereas reverse-faulting earthquakes were dominant in the surrounding sub-region. The difference in dominant focal mechanisms suggests significant difference in stress state between the two sub-regions. The stress axes obtained by the inversion in the large coseismic slip sub-region rotated greatly at the occurrence of the Tohoku-Oki earthquake, and they changed towards the directions before 2011 gradually. However, the amount of postseismic rotation was not as large as that reported by Hardebeck (2012) and the stress regime has never been resumed to the pre-2011 state. On the other hand, in the surrounding sub-region, the coseismic rotation of the stress axes was smaller than that in the large coseismic slip sub-region, and the temporal change after the earthquake was also very small. As a result of the present reanalysis considering spatial variation of the stress field, we suggest that the result given by Hardebeck (2012) may contain apparent temporal stress changes due to spatio-temporal variations of the seismicity in the area, which she did not take into account.

Spatial and temporal variations of seismic moment release before and after the 2011 Tohoku-Oki earthquake

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Seismicity is often changed significantly before and after a large earthquake, probably due to the change of stress distribution in and around its fault area. We examined seismic moment release for coseismic and adjacent areas before and after the 2011 Tohoku-Oki earthquake. We adopted not the number of events but the amount of seismic moments because we like to focus on large events that represents the stress states in the studied area. With the JMA catalog of event locations and magnitudes (m) from 1967 to 2016, we converted the seismic moment (M_0) in Nm by $\log M_0 = 1.5m + 9.1$. The area is divided into the segments based on the pre-2011 version of the evaluation of its major subduction earthquakes by the headquarters for earthquake research promotion. The area off the trench axis of the Pacific plate where outer-rise earthquakes occur is included. We further divided each segment into three depth levels based on its depth of the plate boundary: the shallow zone (i.e., in-land intra-plate events), the plate boundary zone defined by the depth range between 10 km and 20 km in shallow and deep sides, respectively, and the deep zone (slab intra-plate events).

The most outstanding contrast in terms of temporal change before and after the 2011 mega-event (hereafter called the main shock) is a decline of moment release in the off Miyagi segment versus a significant increase in the off Fukushima segment. In the former segment, there were many earthquakes even before the main shock, compared with other adjacent ones. Although there were intensive aftershock activities, the amount of moment release was not significantly amplified. In contrast, there were a few events in the off Fukushima segment prior to the main shock, particularly with the small amount of moment release, that is, only small events had occurred. After the main shock, not only the number but also the mount release rate was clearly increased, getting comparable to the active off Miyagi segment. The amount of slips in this segment was not large for the main shock. We may conclude that there were no stress or strain accumulated before the main shock and the coseismic slip in this segment might not have been spontaneous but rather associated with large slips in the off Miyagi segment, resulting in newly built-up stress that started inducing active seismicity there. A similar increased seismicity was found in the Kodiak segment after the 1964 Alaska earthquake (Doser et al., 2006).

In all the outer-rise areas, there were a few events before the main shock while seismic activities or moment releases were clearly enhanced after it, particularly in the off Miyagi and off Fukushima segments. This change seems to have been caused by the large coseismic slips on its adjacent plate boundary although the original stress was small.

Keywords: seismic moment release, the 2011 Tohoku-Oki earthquake, spatial and temporal variations of seismicity

Study on the plate model of the Pacific plate

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The Cabinet Office is conducting examination of the largest class earthquakes in the Japan Trench and the Kuril Trench in the “Council for studying megaquake models in the Japah trench and the Kuril trench (established in February 2015)". As a part of that, we examined the shape of the Pacific plate upper surface subducting beneath the Izu-Ogasawara Trench, Japan Trench and the Kuril Trench to create a plate model.
Several models are proposed for Pacific plate along the Japan trench and the Kuril trench, However, some of them are limited to the specific areas and are not consistent with the hypocenter distribution.
In this study, we created the plate model along the Izu-Ogasawara Trench, Japan Trench and the Kuril Trench based on the following data.

A) Location of the trench axis: We set the trench axis that is made by smoothly connecting the deepest part of the seabed topography data (provided by the Japan Coast Guard), and it was used as the boundary line between the plate upper surface and seabed topography.
B) Structure exploration data by JAMSTEC: We used depth data of the Pacific plate provided by JAMSTEC along MSC and OBS survey lines to constrain the shapes of shallow part of the Pacific plate upper surface.
C) Hypocenter Distribution: We used JMA Unified earthquake catalog, ISC catalog and EHB catalog to constrain shapes of the Pacific plate upper surface in the shallow and deep area.
D) Volcanic Front Position: We set the 100km depth of plate position based on the position of the volcano front for areas where the plate shape could not be determined due to low seismicity.

Using the above data, we set many cross sectional shapes of the upper plate surface approximately orthogonal to the trench axis. And a planar plate upper surface model was created by interpolating the cross section data.

Keywords: Pacific plate, plate model, fault model, earthquake hazard assessment

Spatiotemporal distribution of shallow seismic activity around Onikobe area, northeastern Honshu, Japan

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In order to elucidate the process of inland earthquake occurrence, it is necessary to consider the influence of the heterogeneous structure of the upper crust. In particular, examining the relationship between seismic activity and existing weak planes such as geological faults and caldera walls will be very important for the above understanding. In order to investigate the relationship between geologically heterogeneous structure and seismic activity, the best region will be where reliable geological data are available and the seismicity is high. In this study, we investigate the relation between the heterogeneous geological structure and the seismic activity in the Onikobe region located in the northernmost part of Miyagi prefecture because the region satisfies the above conditions.
This area is located in the backbone range, where many calderas exist. In this region, Umino et al. (1998) discussed the relationship between the caldera structure and large-scale earthquakes that occurred in the Onikobe region in 1996. After that, however, the earthquake activity in this area appears to change considerably after the 2008 Iwate-Miyagi Nairiku earthquake and the 2011 Tohoku-Oki earthquake. We investigate the temporal change in the seismic activity for about 20 years (1996-2015) in detail, and discuss the relation between the spatiotemporal change in the seismic activity and the caldera structure.
In order to elucidate the relation, we carried out 1) estimation of temporal change in the seismic activity, 2) hypocenter relocation, 3) fault type determination, and 4) stress field estimation. The results indicate that the earthquake fault-type distribution as well as the seismic activity and hypocenter distribution is affected by nearby large earthquakes. It is also suggested that the change in the hypocenter and fault-type distributions are controlled by the caldera wall distribution.
According to Terakawa and Matsu'ura (2010), this area is located in a reverse fault type stress field of east-west compression, but many strike-slip-fault type earthquakes have occurred and at least some of them appear to occur along steep caldera walls. We will discuss in detail the relation among the seismic activity which changed due to the stress disturbance caused by large earthquakes, the shape of the existing weak planes, and the background stress field.

Keywords: seismicity, focal mechanism, caldera

Seismogenic structures of the 2006 M_L4.0 Dangan Islands Earthquake offshore Hong Kong

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As a typical extensional continental margin, the intraplate seismicity in the coastal region of the northern South China Sea (SCS) is very active. Compared with the seismically active zones of NanAo Islands, Yangjiang, and Heyuan, the seismicity is relatively low in the Pearl River Mouth area. But, a M_L4.0 earthquake in 2006 has occurred near the Dangan Islands offshore Hong Kong, adjacent to the source of historical Dangan Islands earthquake in 1874 with about M5.8. In this study, we ascertained the locations of NW- and NE-trending faults in the Dangan Islands sea, and found that the NE-trending Littoral Fault Zone (LFZ) mainly dipped southeast at a high angle and cut through whole crust with an obvious low-velocity anomaly. The NW-trending fault dips northeast with similar high angle. The 2006 Dangan Islands earthquake is adjacent to the intersection of the NE- and NW-trending faults, which suggests the intersection of two faults in different directions could provide a favorable condition for the generation and triggering of intraplate earthquakes. Crustal velocity model showed that the high-velocity anomaly was imaged in the west of Dangan Islands, but a distinct entity with low-velocity anomaly at depth smaller than 10 km but high-velocity anomaly below depth of 10 km was found in the south of Dangan Island. Both 1874 (about M5.8) and 2006 (M_L4.0) Dangan Islands earthquakes occurred along the edge of above mentioned distinct entity, and the vertical cross-sections parallel and perpendicular to the LFZ revealed that there were good spatial correlations between the 2006 Dangan Islands earthquake and the prominent high-velocity body below 10 km depth in the distinct entity, which indicated that the high-velocity body might be rigid and capable to store strain energy and release it as a brittle failure, being considered as earthquake-prone area.

Triggered seismic activity in Yonezawa-Aizu area ―Space time change of focal mechanism―

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Triggered seismic activity started 7 days after the 2011 off the Pacific coast of Tohoku Earthquake. The activity still continues at present, though the revel is becoming lower. The northern extension of the Tanagura Tectonic Line is presumed to pass through this area. Its configuration, however, is not clear, because the Cenozoic igneous rocks cover the surface. In the present study, we tried to estimate the configuration (the strike and the dip) of the fault from focal mechanisms. Focal mechanisms were determined using the polarity of P-wave first motion for earthquakes with magnitude greater than 3.0 that occurred by Oct. 31, 2015 and were recorded at the Hi-net stations. We read the P-wave first motion on the display, and selected precise data. 100 mechanism solutions obtained with sufficient accuracy using more than 20 polarity data were used to estimate the fault configuration.

Most of the solutions were reverse fault or reverse with strike slip component types. We selected a nodal plane whose strike was close to that of the epicenter distribution or similar to adjacent events from a couple of nodal planes. In case of reverse faults, the plane with gentle dip was selected. We regarded the nodal planes thus selected as fault planes. The strike and the dip of the faults revealed the following characteristics. 1) The strike was NW-SE in the central part of the area (middle and the SW edge of the Otoge Caldera), and was N-S or NNE-SSW directions in other area. 2) From the center to the southern edge of the area, each hypocenter clusters had the predominant fault strike and the dip. 2)In the northern part of the area, the strike was similar, but the dip direction was different among events. These characteristics show that the strike of the faults is close to that of the Tanagura Tectonic Line in the center to the south part, and in the other part of the area is similar to the faults distributed over the Tohoku District.

Previous studies suggest that the flow of fluid may be the cause of the triggered activity. If there is a flow of fluid or a change of fluid pressure, the focal mechanisms are expected to change. We checked a temporal change of focal mechanisms in the area of 37.76-37.78°N, 139.97-40.02°E, where earthquakes continually occur. We read the polarity of P-wave first motion for the events with magnitude larger than 2.0. The area was divided into four regions, and the polarity data were plotted on one focal sphere projection for each region for every month. The distribution of polarity data mostly corresponded to the reverse fault type, and the change of polarity distribution was small in the western region. On the other hand, in the eastern regions many of monthly polarity distributions indicated strike slip fault with NW-SE tension, and the distribution sometimes changed to reverse fault type, suggesting the change of fluid condition.

Keywords: triggered earthquake, focal mechanism, Tanagura Tectonic Line

Aftershock observation and their source parameter analysis of the 2016 Gyeongju earthquake

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The 12 September 2016 Gyeongju earthquake (5.8) occurring at 11:32:54 (UTC) is the largest instrumentally recorded event in the southern Korean Peninsula and it is followed by thousands of aftershocks. For monitoring the aftershocks, a temporary seismic network of 27 stations was installed in a few days and operated for several months. From regional seismic networks and the temporary network, we detected P/S phase arrival-times and associated them by a series of automatic procedures. With a 1-D velocity structure and the associated arrival times, locations of the aftershocks were initially determined by an iterative linear method. To observe the detailed pattern of the hypocenters, initial hypocenters were relocated by the double difference method using the waveform cross-correlation. With the hypocenter distribution, the focal mechanism analysis of specific events was then operated by measuring the first P-wave motions. Our detection algorithm observed over a thousand events and their locations are mainly clustered between two regional fault lines. Our result indicates that the distribution of the aftershocks and the fault plane solutions obtained from the focal mechanism analysis are not matching with the surface traces of two regional faults, suggesting a complex geometry of faulting system beneath the Gyeongju area can exist.

Keywords: Gyeongju earthquake, aftershock monitoring, Yangsan Fault system

Time evolution of the 2016 Kumamoto Earthquakes II

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Matched filter technique (Gibbons and Ringdal, 2006; Shelly et al., 2007) was used to detect events of earthquake swarms. We applied to the data recorded during the 2016 Kumamoto earthquakes and investigate the time evolution of seismic activities.
In this study, we checked the effect of data that were recorded near source region. We compared the average cross correlation value of each station for detected events. We found that the values of the stations within about 10km from template events were larger than that of other stations. This indicated that these data ware important to distinguish the events from continuous records.

Acknowledgement
In this study, we used the seismic observation data recorded by various organizations, including the Japan Meteorological Agency (JMA), National Research Institute for Earth Science and Disaster Prevention (NIED), Kyushu University, and Group for urgent joint seismic observation of the 2016 Kumamoto earthquake.

Keywords: the 2016 Kumamoto earthquake

Rupture properties of the 2016 Kumamoto Earthquake sequence based on seismicity data analyses

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The Kumamoto Earthquake sequence occurred on April 14, 2016 for the foreshock (Mw 6.2) and on April 16, 2016 for main shock (Mw 7.0) in the Kumamoto area of Kyushu. The earthquake sequence was derived from fault ruptures of the Futagawa and Hinagu Fault zones. The rupture directivity was just northeast. Furthermore, the earthquake sequence dominantly affected the northeast region, and M ˜6 earthquakes are triggered around the Oita area (Uchida et al., 2016). On the other hand, the southwestern parts of the Hinagu Fault zone were not ruptured. The purpose of the study is to examine what is a factor for controlling seismic properties of the earthquake sequence.
We used earthquake data that occurred from October 24, 1997 to July 31, 2015 in the JMA catalog to grasp the seismic activity around the source faults: Futagawa and Hinagu Fault zones. We applied the fault model which was proposed by HERP [2013] to the analysis. According to some previous research results, the dip angles of the Futagawa and Hinagu Fault zones are set up to be 60º in northwest and 90º, respectively. Then, we define the analytical area of the Futagawa Fault zone as the region of 10 km in the northwest direction from the surface trace. For the Hinagu Fault zone, the area is defined as 5 km on either side on the surface trace.
We recognized a remarkable seismic gap in the Hinagu Fault zone based on seismicity data before the Kumamoto Earthquake sequence. The fault rupture of the Kumamoto Earthquake sequence was probably arrested at the seismic gap, however the southern part of the Hinagu fault zone is within positive stress change. The aftershocks of the foreshock do not propagate in the seismic gap, however, those of the main shock distribute over a seismic gap; propagating to the southern part of the Hinagu Fault zone.
Here, we focused on two Mw ˜5 earthquakes happened in 2000 and 2005 on Hinagu Fault zone. The analysis results show the 2005 earthquake maybe is related to the 2000 earthquake: a delayed earthquake. Therefore, the analysis of the seismic sequence probably provides useful information to evaluate seismic condition of the Hinagu Fault zone after the Kumamoto Earthquake sequence. The seismic scale of the Kumamoto Earthquake sequence is far bigger than the 2000 earthquake, and the aftershock activity propagated up to the southern part of the Hinagu Fault zone. Therefore, the Hinagu Fault zone has a potential to cause some delayed earthquakes.

Keywords: Kumamoto Earthquake sequence, seismic gap, delayed earthquake

Seismic observation on northern Ryukyu Trench subduction zone

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The Ryukyu Trench is a plate convergence zone whose total length of about 1,300 km, and its northern end borders on the western end of the Nankai Trough. Due to the subduction of Philippine Sea plate in northwest direction, active seismicity was observed in the forearc region of Ryukyu arc. In addition, occurrence of large earthquakes was well known; for example, 1911 off-Amami (M8.0), 1923 near Tanegashima (M7.1), and 1774 Yaeyama (M7.4) earthquakes. On the other hand, both detection capacity and location accuracy of earthquakes in this region were not enough to discuss the detailed seismicity pattern and plate geometry, since the seismic network is limited on sparse-distributed islands. To know the seismicity, lithospheric structures and plate geometry, Japan Agency for Marine-Earth Science and Technology (JAMSTEC) launched a series of seismic observations and active-source seismic surveys at the Ryukyu arc from 2013, as a part of research project funded by Ministry of Education, Culture, Sports, Science and Technology, Japan.

In FY2016, we have conducted a passive source observation in the northern Ryukyu forearc region. We have deployed 47 seismic stations including 43 ocean bottom seismographs (OBS) and 4 onshore stations. All OBSs are equipped with short period (4.5 Hz) geophones. Onshore stations are deployed at Tanegashima (two stations), Nakanoshima, and Akuseki-Jima, composed of broadband and/or 2 Hz seismometers. The average separation of seismic network is about 30 km, and covered the area of 250 km and 160 km in trench parallel and normal directions, respectively. The observation period of OBS is about 4 months, from September to December 2016. From the continuous seismic record, we have detected more than three-times the number of events identified from Japan Meteorological Agency (JMA) catalogue. We also confirmed that almost all our seismic stations recorded the seismic signal when the JMA magnitude of event located within our network is larger than 2.5. In this presentation, we will show the preliminary result of hypocenter relocation analysis.

Keywords: The Ryukyu Trench, Seismicity, Philippine Sea Plate

An overview of the seismic activity and gaps in the Marmara Sea area

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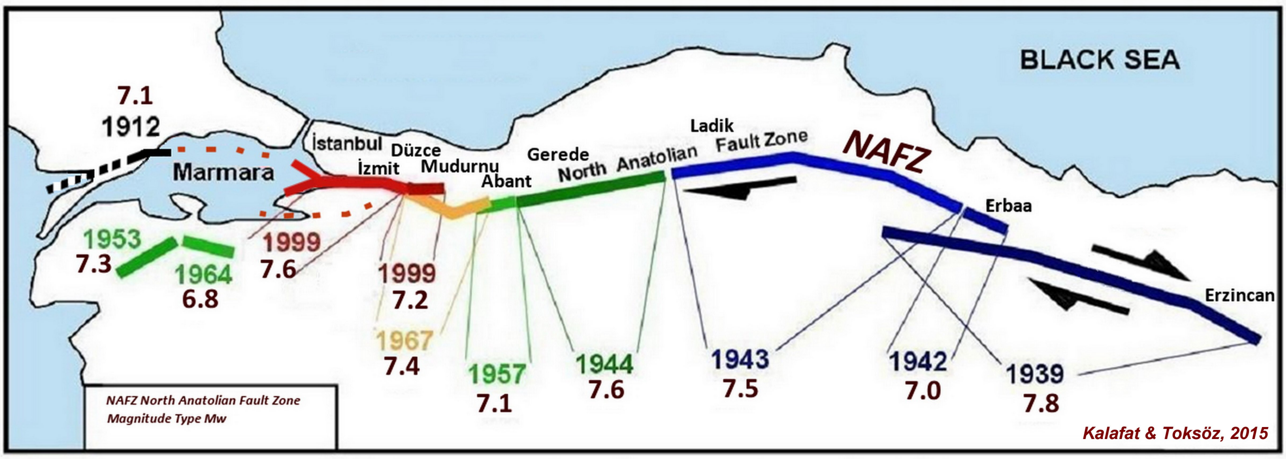
Turkey and its surrounding region comprise one of the most rapidly deformation parts of Alpine-Himalayan mountain belt, because the country is located at the junction of the three main tectonic plates. Global kinematic models based on the analysis of oceanic spreading, fault system, and earthquake slip vectors indicate that Arabian plate is moving in the north-northwest direction relative to Eurasian at an average rate of about 25 mm/yr. The westward escape of Anatolian plate by right lateral strike-slip motion produces major earthquakes along the North Anatolian Fault Zone and this causes an important role on the tectonic evolution of the Marmara Sea region. Eventually, the Marmara Sea region is one of the most seismic active region, because the Marmara Sea region is at a triple junction between the Turkish, Aegean and Eurasian Plates in a complicated area of small block structures, and an understanding of the behaviour of the Marmara Sea area is very important in the interpretation of the tectonics evolution of the entire region.
Active tectonics in the region has strike-slip, normal and some reverse of dip-slip (oblique) faulting types. Especially western part of the latitude 30°E, fault mechanisms changed via normal faulting and oblique faulting types. Another indicator, the Marmara Sea region is a kind of mixed place of changing of fault mechanisms and rotation of dominant T stress axes directions in the NAFZ.
In this study, we present seismicity and briefly presented the fault mechanism characteristics of the Marmara Sea region. On the other hand, we try to understand seismic gaps along the Marmara region. Recent crustal deformation and seismicity provide about seismic gaps in the region for future earthquakes.

Keywords: Marmara Sea, seismicity, fault mechanisms



The westward migration earthquakes since 1939 along the North Anatolian Fault

Very Long Period Seismic Signals at Cotopaxi Volcano-Ecuador.

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This work identifies seismic events with very long period (VLP) content that occurred at Cotopaxi volcano (Ecuador) between June 2010 and October 2014. In order to do this, it was necessary to study the spectral content of the signals by decomposing them into their constituent frequencies, done using a discrete Fourier transform.

The existence of a single family, containing half of the recorded VLP events, was recognized by performing cross-correlations between them. The remaining events could not be grouped into families due to the small signal amplitudes, having been considerably influenced by microseismicity. No other patterns of similarity were found between these events.

Each signal was then integrated and filtered to locate the source using P wave polarization analysis, specifically the particle motion method.

Finally, the possible source mechanism of the event family was identified through the comparison and cross correlation with those studied in previous woks at Cotopaxi volcano. The proposed mechanism would be that of a crack model, located to the north of the crater at a depth between 2 and 4 km. It is proposed that this crack generated the recorded events between 2006 and 2014 and that it is independent of the resonator which was activated between 2002 and 2014. Both systems would represent a region filled with magmatic fluids that, depending on its volume, suggest a possible renewal of volcanic activity.

Keywords: VLP seismicity, particle motion, source mechanism

Rupture process of the 1979 Tumaco, Colombia, earthquake and rupture characteristics along the Ecuador-Colombia subduction zone

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The 1979 Tumaco earthquake was the second largest earthquake in the Ecuador-Colombia subduction zone after the 1906 Ecuador-Colombia earthquake. However, previous studies of the 1979 event only estimated the seismic moment and the rupture velocity from surface-wave records [Kanamori and Given, PEPI, 1981] and the source duration from P-wave records [Beck and Ruff, JGR, 1984]. In order to evaluate the risk of earthquake and tsunami in this region, it is important to estimate the spatial and temporal slip distribution of the 1979 earthquake and its relationship to the 1906 earthquake.
We inverted teleseismic P-waves at WWSSN stations to investigate the rupture process of the 1979 Tumaco earthquake. We calculated Green’s functions using the method of Kikuchi and Kanamori [BSSA, 1991] and applied the waveform inversion scheme of Kikuchi *et al.* [EPS, 2003] to image the spatio-temporal slip distribution. Our inversion results indicated that the large slip of the 1979 event occurred in the northeastern part of the source region. The average plate coupling ratio in the 1979 earthquake source region was estimated to be only 30 % [White *et al.* EPSL, 2003]. From this coupling ratio and the average slip of 2.4 m in our slip model, the recurrence interval of the 1979 earthquake was estimated to be 174 years. This suggests that the 1906 Ecuador-Colombia earthquake did not rupture the source region of the 1979 Tumaco earthquake. This interpretation is consistent with that the tsunami source model of the 1906 event proposed by Yoshimoto and Kumagai [AGU fall meeting, 2016].

Keywords: 1979 Tumaco earthquake, rupture process, Colombia

On the hypocentral distribution considered to be double seismic zone obtained by pop-up ocean bottom seismometers at the area around Ogasawara

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The Meteorological Research Institute conducted observation for about 3 months by pop-up ocean bottom seismometers (OBS) from July to October 2015 for the purpose of improving hypocenter determination accuracy around the Ogasawara area. The observation network was set to cover this area at about 50 km intervals at 8 stations of OBS and 2 stations of existing Chichijima and Hahajima in total 10 stations. Analysis of this observation data showed that the hypocenters determined by OBS observation was located about 50 km west from the Seismological Bulletin of Japan (the unified seismic catalog) (Nakata et al., 2016, JpGU).
This analysis reveals the hypocenters, which is thought to be an intraslab earthquake of the Pacific plate subducting from the Izu-Ogasawara trench. Especially, hypocenter distribution of two planes, the upper plane and lower plane, can be seen from a depth of about 70 km to 200 km. The distance between the upper plane and lower plane is about 35 km, and the both planes can not be separated from each other at about 200 to 250 km. An active region of cluster-like seismic activity can be seen around the depth of 60-80 km. The cluster is scattered to run parallel 80 - 90 km east of volcano front including Nishinoshima. This may correspond to the upper plane seismic belt pointed out by Kita et al. (2006, GRL). In this way, the features obtained in the Ogasawara area are similar to those of the double seismic zone reported in various parts of the world including Tohoku Japan. Regarding the distance between double planes in other areas, it is about 20 km in Aleutian, about 30 km in Hokkaido Japan, about 35 km in Tohoku Japan, about 30 km in Kanto Japan, about 25 km in Mariana, about 20 - 25 km in central Chile (Reyners & Coles, 1982, JGR; Hosono & Yoshida, 2001, Volcano (in Japanese); Yoshida & Hosono, 2002, Volcano; Shiobara et al., 2010, GJI; Marot et al., 2013, JGR).

Keywords: Izu-Ogasawara trench (Izu-Bonin trench), double seismic zone

Smaill repeating earthquakes beneath the Tokai region detected by NIED Hi-net

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1. Introduction
Small repeating earthquakes (SRQs) occur around the quasi-static slip region at the plate boundary (Igarashi et al., 2001; Uchida et al., 2003). Matsubara and Obara (2006) found the SRQ at the upper boundary of the Philippine Sea (PHS) plate with the data of Kanto-Tokai seismic network operated by National Research Institute for Earth Science and Disaster Resilience (NIED). In this study, I analyze data in Tokai region of the high-sensitivity seismograph network (Hi-net) operated by NIED.

2. Data and Method
Target region is 136.4-139E, 34-36N, and 0-500 km depth. The number of earthquakes with magnitude equal or larger than 1.5 satisfying the Gutenberg-Richter magnitude-frequency relation is 20331. I compare waveforms of an event to those of events within the 0.1 degree from the event since I focus on the events beneath the land area. I compare the band-pass filtered waveforms with 1-4 Hz on vertical component from P onset to five seconds after the S-wave arrival time. I defined the SRQ whose waveforms with at least three seismic stations within the 100 km from the event.

3. Result
The number of group of the SRQs is 1194 with 4697 events. I defined the burst-type SRQ with the total period from the first event to the last event within a group. The number of the group of the SRQs is 341. SRQs with low-angle lower thrust occur at depths of 18-27 km beneath the Fujieda region with 11 groups and at depths around 23 km beneath the Mori Town with 3 events. I estimated the plate slip rate using the relationship estimated by Nadeau and Johnson (1998). The slip rate at the upper boundary of the PHS plate is 1.5 cm/year.
SRQs within the PHS plate occur on the north of the Lake Hamana. There are three clusters of SRQs. The slip rate is approximately 0.8-1.2 cm/year.
There are many SRQs deeper than 35 km, however the focal mechanism of those events are strike-slip or normal fault. These events are located within the PHS plate.
SRQs accompanied with the subducting Pacific plate occur at depths deeper than 100 km. The focal mechanisms of those events are mainly reverse fault with strike-slip component or strike-slip type. There is no SRQ at the upper boundary of the Pacific plate beneath the Tokai region.

4. Discussion
SRQs at the upper boundary of the PHS plate beneath Fujieda region are also found by Kanto-Tokai seismic network by Matsubara and Obara (2006). The average slip rate from 1980 to 2004 was 0.9 cm/year and it is 1.4 cm/year in this study. Both slip rates are smaller than the slip rate 4.0 am/year estimated by geodetic data (Seno et al., 1993).

5. Conclusion
I analyzed the NIED Hi-net data beneath the Tokai region from 2000 to 2015. The SRQs at the upper boundary of the PHS plate occur beneath Fujieda city and Mori Town. Many SRQs are selected within the inland crust, PHS plate, Pacific plate with focal mechanism of strike-slip or normal fault.

Keywords: repeating earthquake, Tokai, Philippine Sea plate

Controls of repeating earthquakes’ location from a- and b- values imaging

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To explore where earthquakes tend to recur, we statistically investigate repeating earthquake catalogs and background seismicity from different regions. We show that the location of repeating earthquakes can be mapped by the spatial distribution of the seismic a- and b-values obtained from the background seismicity. With statistical significance confirmed by Molchan’s error diagram, repeating earthquakes are found to occur within the areas with higher a-values (2.8-3.8) and b-values (0.9-1.0) on both strike-slip and thrust fault segments (Parkfield, Hayward, Calaveras, and Chihshang faults). The significant association however, does not hold true for fault segments with more complicated geometry or wider areas with a complex fault network. The productivity of small earthquakes that is responsible for both high a- and b-values, therefore, is likely the most important factor that controls the location of repeating earthquakes. Since such condition is commonly found in creeping fault, we propose that it requires a specific fault property for the repeating earthquakes to show a universal association with a- and b-values.

Keywords: repeating earthquake, a-value, b-value, creeping fault, California, Taiwan

The first research on seismic interferometry in the region of induced earthquakes of Song Tranh Dam, Vietnam

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Vietnam is located in South East Asia and bounded by the Pacific and Mediterranean-Himalaya seismic belts on its eastern, western and southern sides, respectively. The dynamic tectonic processes in this region cause the territory of Vietnam and adjacent areas to have intensive differential movement, making the regional tectonic structure very complicated. The tectonics have led this territory to have moderate seismic activity and complicated geological structures, such as the Lai Chau-Dien Bien fault zone, Red River fault zone, and others. Southern Vietnam was considered to be a region with low seismicity, compared to the North. However, the sequence of earthquakes that occurred at Song Tranh Dam during the last several years surprised many scientists because the southern region of Vietnam was not expected to have major tectonic activity. This region where many induced earthquakes are now occurring is associated with the filling of a new reservoir. There have been four M4 earthquakes (maximum earthquake was 4.7 in November, 2012), so it is one of the most active induced earthquakes examples in the world. It is important to determine the strong motion attenuation relations for this area since damaging earthquakes may be expected in the near future. We collect and process data from 10 seismic stations around Song Tranh dam, include 5 years continued data in Song Tranh dam.
Traditional methods of imaging the Earth’s subsurface using seismic waves require an identifiable, impulsive source of seismic energy, for example an earthquake or explosive source. Naturally occurring, ambient seismic waves form an ever-present source of energy that is conventionally regarded as unusable since it is not impulsive. As such it is generally removed from seismic data and subsequent analysis. A new method known as seismic interferometry can be used to extract useful information about the Earth’s subsurface from the ambient noise wavefield. Consequently, seismic interferometry is an important new tool for exploring areas which are otherwise seismically quiescent, such as the Song Tranh Dam region in which there are relatively thousands of induced earthquakes. Here we provide a review of seismic interferometry and show that the seismic interferometry method which have agreeable results within the Song Tranh dam region.
One of the possible applications of seismic interferometry is ambient noise tomography (ANT). ANT is a way of using interferometry to image subsurface seismic velocity variations using seismic (surface) waves extracted from the background ambient vibrations of the Earth. Today, ANT has been used successfully to image the Earth’s crust and upper-mantle on regional and continental scales in many locations and has the power to resolve major geological features such as sedimentary basins and igneous and metamorphic cores. In future study we will do some advance research on ANT in Song Tranh Dam region and make comparison between Northern and Southern of VietNam (especially Moho layer).

Keywords: Seismic Interferometry, Song Tranh Dam, Ambient Noise Tomography