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

SCG62-01 Room:303 Time:May 27 14:15-14:30

Repeating Shallow Slow-Slip-Events along the Block Boundary in the Northern Hokkaido

IKEDA, Shohei[1*] ; HEKI, Kosuke[2]

[1]Department of Natural History Sciences, Graduate School of Science, Hokkaido University, [2]Department of Natural History Sciences, Faculty of Science, Hokkaido University

In Northern Hokkaido, to the north of Rumoi, earthquakes larger than M6 class have not occurred for a few decades. However, a block boundary is considered to run N-S in this region with the E-W convergence rate of about 1 cm/year coming from the eastward movement of the Amurian Plate (Loveless and Meade, 2010). Ohzono et al. (2014) reported the shortening of the baseline between Horonobe and Nakatombetsu of about 1cm over 4 months period from 2012 summer to the early 2013 and they considered it an inland SSE (slow slip event).

In this study, we thought there might have been other SSEs at different segments along the block boundary, and analyzed time series of distances between GEONET GNSS points that cross this block boundary from Wakkanai (north) to Rumoi (south). The baseline between Nakagawa and Otoineppu, about 20 km to the south of Horonobe-Nakatombetsu, was found to have shortened by a few millimeters in the middle 2005 and middle 2007. We also found that the distance between Haboro and Horokanai, further south, also decreased in late 2002 and early 2004. All these contractions were a few millimeters and took 1-2 months. To detect changes objectively, we followed Nishimura et al. (2013), and monitored the differences in AIC (Akaike's Information Criterion) between the two cases, i.e. regression with SSE and without SSE. We considered an SSE occurred when AIC significantly decreased by assuming an SSE.

Shallow seismicity occurs along the N-S block boundary in the northern Hokkaido. The seismic zone bends and runs E-W at the latitude of Rumoi (44.1N), and is connected to the plate boundary along the eastern margin of the Japan Sea.In Rumoi, an M6 class earthquake occurred in December, 2004 with over twenty aftershocks larger than M3 (Takahashi and Kasahara, 2005). In this region, more earthquakes occur than in the region to the north. In conclusion, block convergence would take place as regular earthquakes in the region to the south of Rumoi. On the other hand, the convergence will be occurring as repeating SSE to the north of Rumoi.

Keywords: Northern Hokkaido, inland, SSE, GPS, GNSS

SCG62-02 Room:303 Time:May 27 14:30-14:45

Estimation of fault parameters of slow slip event, off the Kii Peninsula, detected by DONET

SUZUKI, Kensuke[1*] ; NAKANO, Masaru[1] ; HORI, Takane[1] ; TAKAHASHI, Narumi[1]

[1]JAMSTEC

The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) installed permanent ocean bottom observation stations named as Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET) off the Kii Peninsula to monitor earthquakes and tsunamis. We derived the component of sea floor change from the ocean-bottom pressure record, and we detected the ocean-bottom pressure changes, starting from February 2013, at a part of stations deployed to DONET (Suzuki et al., 2014). These pressure changes were synchronized with a decrease in the background seismicity within the area of a nearby earthquake cluster. Although we considered that these pressure changes show the vertical sea floor changes due to the crustal deformation caused by slow slip event (SSE), we did not estimate the fault parameters of SSE. Therefore in this study we tried to estimate the parameters of the fault slip that caused crustal deformation.

In this study we estimated the fault parameters of SSE by comparing the observed vertical displacements with ones calculated by the fault model using the dislocation source solutions (Okada, 1992). In Suzuki et al. (2014), we derived the vertical crustal deformations from the ocean-bottom pressure changes as described below. First we removed the tidal component from the ocean-bottom pressure records by BAYTAP-G (Tamura et al., 1991). Next we subtracted the average of pressure change taken over the records at stations connected to each science node from the records removed tidal component in order to remove the pressure changes due to atmosphere pressure changes and non-tidal ocean dynamic mass variation. Therefore in this study we subtracted the average changes from the each theoretical displacement when we calculated the theoretical displacements by using the fault model.

Although there are nine parameters in the fault model, we observed vertical displacements at only four stations. Therefore we cannot uniquely determine the fault parameters, and we need to constrain the fault parameters in the inversion process. In this study we supposed the plate boundary and splay fault in the sedimentary wedge as the fault that caused crustal deformation. In the plate boundary case, we fixed the strike, dip and rake, and estimated other parameters by grid search method. However we made the fault depth to be coincident with the plate boundary depth. On the other hand in the splay fault case, we estimated the fault depth and dip by the grid search method in addition to parameters estimated in the plate boundary case. However fault depth was constrained in the shallower part than the plate boundary depth.

Although we explain the relative vertical displacement pattern in the plate boundary case, the average displacement taken over the stations is large. If this large average displacement actually occurred, we could detect it from the pressure gauge records removed tidal component. Therefore it is difficult to explain the observed displacements by using the fault model along the plate boundary. On the other hand in the splay fault case, the average displacement is small and the calculated relative displacement pattern is coincident with observed one. Therefore the splay fault case is more reasonable to explain the observed vertical displacements. In the future we will consider the fault model having other type mechanisms and investigate the relationship between the fault slip and the seismicity change.

Keywords: DONET, ocean bottom pressure change, slow slip event, seismicity change

SCG62-03 Room:303 Time:May 27 14:45-15:00

Robust estimation of spatio-temporal distribution of slow slip event by switching model

ARAKI, Takamitsu[1*] ; OCHI, Tadafumi[1] ; MATSUMOTO, Norio[1] ; AKAHO, Shotaro[1]

[1]National Institute of Advanced Industrial Science and Technology

Short-term slow slip event (SSE) can be precisely captured by only highly sensitive instruments such as borehole strainmeter and tiltmeter, Meanwhile, since such sensitive instruments is affected by various external factors, the observed data contain large noise which has complicated structure in time.

We estimate the spatio-temporal distribution of SSE by analyzing noisy data such as strain data and tilt data. Conventionally, the Network Inversion Filter (NIF) has been widely used to estimate the spatio-temporal distribution of the larger SSE, e.g., long-term SSE, based on smaller noise data such as Global Navigation Satellite System (GNSS). However, since the NIF assumes the same dynamics of the noise and slip signals over the entire observation period, the NIF cannot eliminate the large noise signals from such noisy data. Therefore, the NIF cannot correctly estimate SSE from the entire period of the noisy strain and tilt data.

We propose the estimation method using the switching model that represents three forms in three periods. In the first period, the fault never slips, in the second period, the fault is slipping slowly, and in the third period, the fault is being at rest. The time points at which the model changes as well as the parameters of the switching model are estimated by the maximum likelihood method using the Expectation-Maximization (EM) algorithm. The EM algorithm maximizes the likelihood with little dependency on initial parameters and enables us to estimate the parameters stably. The spatio-temporal distribution of SSE is estimated using the Kalman filter, after the model changing time points and the parameters of the model are estimated. The strict and physically reasonable assumptions of the fault slip in first and third periods remove the almost noise signal in the periods, and lead to the stable estimate of the fault slip in the second period.

In order to compare the proposed method to the NIF, we applied the proposed method and the NIF to the noisy synthetic data and the strain data. The synthetic data were produced by the simulation of SSE and large noise signals, and the strain data were measured in the Tokai and Kii area, central Japan, on 2012. In the synthetic data, the fault slip estimated by the proposed method is much more accurate than that by the NIF. The proposed method also estimated the more reasonable SSE than the NIF in the strain data. It is important to detect the starting time point of SSE without any information, and the proposed method correctly detected the starting time point of SSE in both data sets, which the NIF could not capture.

Keywords: Slow slip event, Strain data, Switching model, Maximum likelihood method, Kalman filter

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

SCG62-04 Room:303 Time:May 27 15:00-15:15

An attempt to estimate duration for short-term SSEs in southwest Japan using the stacking method of GNSS data

NISHIMURA, Takuya[1*] ; MATSUZAWA, Takanori[2] ; KIMURA, Takeshi[2] ; OBARA, Kazushige[3]

[1]Disaster Prevention Research Institute, Kyoto University, [2]National Research Institute for Earth Science and Disaster Prevention, [3]Earthquake Research Institute, The University of Tokyo

Introduction

Short-term slow slip events (SSEs) with duration of several to ten days occur on a subducting plate interface in southwest Japan. Nishimura et al. (2013) and Nishimura (2014) suggest that short-term SSEs occur not only in a deep part (20 $\sim$ 40 km deep) from the Tokai region to the Bungo Channel but also along the Ryukyu trench from Hyuganada to the Yaeyama Islands. Because displacement signal caused by short-term SSEs is comparable to a noise level of GNSS data, Nishimura et al.(2013) assumed no duration of short-term SSEs and fitted an instantaneous step function with a linear trend to GNSS time-series to estimate a fault model. It is unclear how long the detected SSEs continue.

It is a gap of duration between short-term and long-term SSEs in southwest Japan. Intermediate-term SSEs with duration of one or two months have never been reported. This gap may be artificial due to less sensitivity of observation sensors including GNSS, strainmeters, and tiltmeters to the signal for those periods.

In this study, we try to estimate duration of short-term SSEs using a combination of the detection method of short-term SSEs using GNSS data (Nishimura et al., 2013) and the stacking method for the detection of crustal deformation (Miyaoka and Yokota, 2012).

Data and Analysis

The used data are daily GNSS coordinates (F3 solution) published by the Geospatial Information Authority of Japan. We detected short-term SSEs and estimated their fault models using the method of Nishimura et al.(2013) and Nishimura (2014). And then, we applied the stacking method (Miyaoka and Yokota, 2012) for GNSS time-series using the displacement calculated from the fault model. The detailed procedure of the stacking follows. First, we select a time window of 181 days centering a date of a short-term SSE in NS and EW components of GNSS time-series. We removed a linear trend and calculated RMS (Root Mean Square) using the data in the time window excluding the middle 60 days. The RMS is used as the noise level of the data and the time-series is normalized by the noise level. Next, we calculate signal to noise ratio (SNR) every component of GNSS stations using the noise level and the signal calculated from the fault model. Then, we stack the normalized time-series in order of SNR and calculate the noise level of the stacked time-series. We stop stacking when the SNR of the stacked time-series is the highest. Finally, we estimate the duration of the short-term SSEs by fitting a lamp-type function to the stacked time-series.

Result

Stacking 30 $\sim$ 100 time-series gives the highest SNR for the short-term SSEs along the Nankai Trough. Although it is difficult to recognize transient signals of SSEs in the original time-series, we can visually inspect duration of SSEs using the stacked time-series, which demonstrates effectiveness of the stacking method. The estimated duration for SSEs with good SNR time-series ranges several days to a month approximately. It is longer than that estimated in the previous studies (e.g., Sekine et al., 2010) in some cases. Although such a long duration can be explained by misrecognition for two succeeding SSEs with a short interval, the long duration may be real in some cases. We also report a regional feature of duration, comparison with an activity of low-frequency tremors and Hi-net tilt data by the National Research Institute for Earth Science and Disaster Prevention.

Acknowledgements We thank the Geospatial Information Authority of Japan for providing the daily coordinates of the GEONET stations (F3 solutions).

Reference

Miyaoka, K., and T. Yokota (2012), Zisin, 65, 205-218.
Nishimura, T., T. Matsuzawa, and K. Obara (2013) JGR Solid Earth, 118, 3112-3125.
Nishimura, T. (2014) PEPS, 1:22.
Sekine, S., H. Hirose, and K. Obara (2010) JGR Solid Earth, 115, B00A27.

Keywords: Slow Slip Event, GNSS, Southwest Japan, Duration

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

SCG62-05 Room:303 Time:May 27 15:15-15:30

Slow slip event within a gap between tremor and locked zones in midwestern Shikoku

TAKAGI, Ryota[1*] ; OBARA, Kazushige[1] ; MAEDA, Takuto[1]

[1]Earthquake Research Institute, UTokyo

Episodic tremor and slip (ETS), a slow slip phenomenon on the plate interface, occurs at downdip region of seismically locked zone in the Nankai subduction zone. The locked zone has potential to be ruptured by great earthquakes. However, there is a gap between ETS and the locked zones. In the present study, we detected a slow slip event (SSE) within the gap from GNSS data by subtracting steady state component and postseismic effect of large earthquakes.

We analyzed GNSS daily coordinates at GEONET stations in southwest Japan provided by GSI. After removing offsets due to large earthquakes and equipment repairs, we applied the spatial filtering proposed by Nishimura et al. (2013) to reduce spatially coherent noise. Then, we estimated trend and seasonal components from the displacement time series during two years from 2007 to 2008, and subtracted those from entire time series. The displacement field after 2011 contains short wavelength variation at midwestern Shikoku in addition to long wavelength variation due to the postseismic effect of the 2011 Tohoku-Oki earthquake. Thus, we estimated the long wavelength variation from the displacement data without midwestern Shikoku by assuming the long wavelength variation as a bivariate quadratic function of horizontal space. Finally, subtracting the estimated long wavelength variation from displacement filed, we extracted the short wavelength variation.

The short wavelength variation in midwestern Shikoku shows displacements toward southeast and it may be attributed to a thrust fault slip in the plate convergence direction. Modeling with a rectangle fault using the equation by Okada (1992) reveals that a dip slip of 2 cm/year within the gap between ETS and the locked zones well explains the observed displacements. The dip slip event lasts at least 1.5 years. The rectangle faults estimated from annual displacements for the periods starting from Apr. 2011, Oct. 2011, Apr. 2012, and Oct. 2012, are located between mid Shikoku and the Bungo channel with dimensions of 150-180 km length and 20-40 km width. The strikes of the faults are almost parallel to isodepth contours of the subducting plate. A similar SSE is detected in 2004 and 2005, which was partly reported by Kobayashi (2010), while the fault length of the 2004-2005 event is shorter than that of the 2011-2012 event. These SSEs within the gap follow the 2003 and 2010 long-term SSEs in the Bungo channel and are located just east of the long-term SSEs. Therefore, after the long-term SSEs in the Bungo channel, the slip may migrate east and small slip last within the gap between ETS and the locked zones.

Tremor in western Shikoku occurs at intervals of about a half years, and migrates along the strike direction with durations of a few days to a week. After 2011, the migration pattern has been changed. Some episodes show migrations with length longer than 120 km, while such long migration has not been observed before 2011. Since the long-term SSE detected by the present study is located shallow part of the tremor episodes with the long migration, it is suggested that the shallower long-term SSE facilitates the migration of the deeper short-term SSEs.

In Cascadia subduction zone, there is also a gap between ETS and locked zones. Understanding slip behavior in the gap zone is of importance for estimating downdip limit of grate earthquake rapture (Hyndman, 2013) and understanding stress accumulation for great earthquake (Wech and Creager, 2011; Yokota and Koketsu, 2015). In the present study, we detected the long-term SSE within the gap from GNSS data by removing trend components and postseismic effects of large earthquakes. We suggest that, between ETS and the locked zones, the long-term SSE slowly releases accumulated strain due to plate convergence.

Keywords: slow slip event, slow earthquake, GNSS, non-volcanic tremor, subduction zone

SCG62-06 Room:303 Time:May 27 15:30-15:45

The properties and variations of repeating slow slip events near Hateruma Island, southwestern Japan

TU, Yoko[1*] ; HEKI, Kosuke[1]

[1]Department of Natural historical sciences, Hokkaido University

Slow slip events (SSEs) are a kind of transient motion related to slow fault rupture at the plate interface (Heki and Kataoka, 2008). These events are classified into slow earthquake series due to their long periods than regular earthquakes. SSEs are usually detected on intensely coupled plate boundaries such as Cascadia subduction zone (Dragert et al., 2001), Alaska (Ohta et al., 2007) and central Japan (Ozawa et al., 2002, 2003). For this reason, SSEs are considered to relate to large thrust earthquakes and can be evidence for seismic coupling on subduction zones. However, in the southwestern Ryukyu trench where most researchers believe that it should be a creeping and aseismic plate boundary. Nevertheless, Heki and Kataoka (2008) identified more than 20 SSEs near Hateruma Island using ten-yrs GNSS (Global Navigation Satellite Systems) data and found that repeated intervals are approximately 6 months regularly. Moreover, the events occurred at a fault patch that is as deep as 20 to 40 km, and their release seismic moments are Mw 6.6 on average. In addition, Nakamura (2009) identified a slow crust deformation near Yonaguni Island that was induced by an Mw7.1 earthquake, and the duration of this event is longer than 5 yrs. These phenomena describe that the southwestern Ryukyu subduction zone could be a coupled plate boundary and have potentials to cause large thrust earthquakes.

In order to understand the properties and variations of SSEs in this area, GEONET GNSS daily coordinate solutions of 16-yrs (1997-2014) are used in this study. During this period, a total of 33 SSEs are identified from Hateruma station through visual inspection. The average recurrence interval (6.3 mos) and the average release seismic moment (Mw 6.6) consistent with the results of Heki and Kataoka (2008). However, the interval and slip of SSEs vary in a short time. For instance, from 2005 to 2007, the interval decreases suddenly from 6 to 4.5 mos without specific causes, and then turns back to the previous level. Moreover, the slip rate (cumulative slip/ lapse time) of SSEs in this area is 8 cm/y on average. From 1997 to 2001, the slip rate is 10 cm/y; and during 2003 to 2006, the slip rate increases slightly to 11 cm/y. Afterward, between 2007 to 2013, it drops remarkably to 6 cm/y, and then increases again to 12 cm/y near the end of 2013.

Although the slip rate significantly increases in 2002 and 2013, the mechanisms of the variations are still uncertain. For this issue, Heki and Kataoka (2008) indicated the slip rate variation of SSE in 2002 could relate to nearby large earthquakes (Mw $>$7). Subsequently, Nakamura (2009) calculated the $\triangle$CFS on the fault of SSEs and proposed the slow crust deformation near Yonaguni Island induced by one thrust earthquake might affect the slip rate variation. However, above idea cannot explain the slip rate change in 2013, since no significant earthquake occurred near the southwestern Ryukyu trench in this period. On the contrary, one earthquake swarm activity in the Okinawa trough, approximately 50km north of the SSE fault patch, started simultaneously. On the basic of displacement data of Yonaguni and Hateruma stations, we infer that the earthquake swarm was generated by a dyke intrusion which relates to the Okinawa trough spreading. Through Coulomb failure stress calculation, the positive $\triangle$CFS confirms the dyke intrusion triggered the slip rate change of SSEs in 2013.

Keywords: SSEs, Hateruma Island, variations, Ryukyu subduction zone

SCG62-07 Room:303 Time:May 27 15:45-16:00

The Apr 2013 earthquake swarm and dyke intrusion in the Okinawa trough

ANDO, Masataka[1*] ; IKUTA, Ryoya[2] ; TU, Yoko[3] ; CHEN, Horng-yue[4] ; LIN, Cjeng-horng[4]

[1]Center for Integrated Research and Education of Natural Disasters, [2]Graduate School of Science, Shizuoka University, [3]Department of Natural Historical Sciences, Hokkaido University, [4]Institute of Earth Sciences, Academia Sinica

In April 2013, a shallower earthquake swarm occurred in the Okinawa trough, 50 km NNE of Yonaguni Island, following more than 10 yrs of seismically quiet period in the area. The major seismic activity decayed within a week. During the period, 28 earthquakes of Mw >4.5 (max Mw 5.2) occurred. The sum of all seismic moments is equivalent to Mw 5.7. GPS data from seven stations from GEONET and three from Taiwan are used over a sufficient long interval of dataset. During the active period, crustal displacements reached 4.7 cm in SSW direction on Yonaguni Island, 1cm in the E direction on Iriomote, sub-cm on Ishigaki and other islands and no noticeable displacements at stations in Taiwan.

A kinematic GPS analysis of theses data reviles that this deformation started at the time of the earthquake swarm and slowly continued over two days. During the period no step-like movements exceeding a threshold level occurred, suggesting the absence of sudden slips at the earthquake source area. We propose two source models to interpret these GPS data, 1) a normal fault of Mw 7.0 and 2) a magma intrusion with the thickness of 3 m. These models cannot be distinguished from the GPS data alone.

Prior to the earthquake swarm, the GPS velocity vector at Yonaguni is 6.5 cm/yr in the SSE direction but that increases at 8.4 cm/yr after the earthquake swarm and furthermore 9.5 cm/yr throughout 2014. The long-lasting and accelerating GPS displacements suggest a strong preference for the dyke intrusion model.

A question may arise whether such magma intrusion causes the rifting of the Okinawa trough and hence the southward migration of the Ryukyu arc. To solve the question, the data from the baseline of Iriomote and hateruma islands is critical. This baseline is aligned perpendicular to the general trend of the western Ryukyu trench. The baseline of 40 km between the two islands shows a constant extension of 1 mm/yr from 2001 to 2015. The long-term and steady extension of the baseline suggests that rifting of the Okinawa trough is caused by the retreat of the Ryukyu trench due to a rollback of the Philippine Sea plate in the western Ryukyu trench.

Keywords: earthquake swarm, normal fault, Okinawa trough, back-arc rifting, dyke intrusion, Ryukyu trench

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

SCG62-08 Room:303 Time:May 27 16:15-16:30

Correlation of activity of very low frequency earthquakes with tide in the Ryukyu Trench

NAKAMURA, Mamoru[1*] ; KAKAZU, Keito[1]

[1]Faculty of Science, University of the Ryukyus

Recently, very low frequency earthquakes (VLFEs) were observed in the shallow part of the Ryukyu subduction zone (Ando *et al.*, 2012; Asano *et al.*, 2013, 2014, 2015; Nakamura and Sunagawa, 2015). Since the stress drop of the VLFEs are very small comparing with that of ordinary earthquake (Ito and Obara, 2005), the VLFEs would be activated by small stress change such as tidal stress. Then we investigated the activation of the VLFEs by earth tide.

We used the events (Mw>3.5) which occurred from January 1, 2002 to December 31, 2014. We employed the VLFE catalogue which is determined by manually-picking method (Nakamura and Sunagawa, 2015). We employed the ocean-tide data at Naha, Ishigaki, and Naze which is installed by Japan Meteorological Agency. Then we computed the theoretical horizontal strain by the earth tide and ocean loading using GOTIC2 (Matsumoto et al., 2001) to compare the theoretical strain and activity of the VLFEs.

First we selected five areas along the Ryukyu Trench where the VLFEs are clustered, then we counted the number of VLFEs as a function of the phase of ocean tide. The VLFEs had been activated at low tide, and they had been quieted at high tide in all areas excluding southwest of Ryukyu. Moreover, the activation occurred on the compressional stage by the earth tide and ocean loading, and quiescence occur on the tensional stage. The VLFEs were activated when the shear stress on the plate interface reached maximum.

Since the VLFEs in the Ryukyu Trench are thrust type or reverse fault type (Ando *et al*., 2012), the VLFEs would be activated in the compressional shear stress stage. This suggests that the activity of the VLFEs is triggered by stress change by the earth tide. The amplitude of the shear stress on the plate interface is large in the central and north Ryukyu Trench but it is small in the southwestern Ryukyu Trench because of the strain by the ocean loading and strike of the Ryukyu Trench. This generates the difference in activation of VLFE by the ocean tide along the north-central and southwestern Ryukyu Trench.

Keywords: very low frequency earthquake, tide, Ryukyu Trench

SCG62-09 Room:303 Time:May 27 16:30-16:45

Tidal sensitivity of tectonic tremors in subduction zones

YABE, Suguru[1*] ; TANAKA, Yoshiyuki[2] ; HOUSTON, Heidi[3] ; IDE, Satoshi[1]

[1]EPS, UTokyo, [2]ERI, UTokyo, [3]ESS, Univ. of Washington

Tectonic tremor, which is one of slow earthquakes occurring in subduction zones, have been known to be triggered by small stress perturbation such as passing surface wave from distant earthquake and tidal stress. Tidal sensitivity of tremors can be detected by investigating the frequency of tremor catalog, but more quantitative comparison gives us useful information. By comparing tremor activity with calculated tidal stress on the plate interface, some previous studies estimate frictional property on the plate interface, such as frictional parameter in rate and state friction (Tanaka et al., 2008), friction coefficient (Thomas et al., 2012; Houston, 2015). Furthermore, recent studies reveal the relation between tremor rate and tidal stress is exponential (Ide and Tanaka, 2014, Houston, 2015), which would represent the frictional property of plate interface. However, the analyses of previous studies are limited to specific places in subduction zones. Hence in this study, we try to estimate the spatial variation of tidal sensitivity in Nankai, Cascadia and Mexican subduction zones.

Tidal stress calculation includes both body tide and ocean tide. Tidal stress is converted to normal stress and shear stress on the plate interface based on the local plate model and plate movement.

Tremor catalog is from Yabe and Ide (2014). We calculate tremor rate at each tidal stress level following Ide and Tanaka (2014) and Houston (2015). Tidal sensitivity is calculated from this data using maximum likelihood method. The uncertainty of estimated parameter is assessed as well.

In this study, we categorize tremors in the catalog into four types. Tremors occurring between major ETS episodes are categorized into inter-ETS events. Tremors in ETS events are categorized into three categories (”early”, ”front”, and ”later” as Houston, 2015). Spatial variations of tidal sensitivity for each type of tremors are estimated. Nankai and Cascadia subduction zones have both ETS tremors and inter-ETS tremors, while tremors in Mexican subduction zone do not show significant along-strike migration, and all tremors are categorized into inter-ETS tremors.

As for tremors in ETS, early tremor and later tremor show high sensitivity in Nankai subduction zone, while front tremor does not. In Cascadia, only after tremor does show tidal sensitivity. The absence of tidal sensitivity in early tremor in Cascadia is considered to be due to the smaller amplitude of tidal stress and/or stronger coupling of slow earthquake region. In the front period, stress perturbation due to SSE slip would be larger than tidal stress, and tidal sensitivity disappears. After the SSE front passes, plate interface get weakened, and strong tidal sensitivity will appear. Comparing with the amplitude of tremors estimated by Yabe and Ide (2014), tidal sensitivity tends to increase from early tremors to later tremors where the amplitude of front tremors is large. Because the amplitude of tremors is proportional to moment rate (Ide and Yabe, 2014), this observation is consistent with the interpretation presented above. Tidal sensitivity also tends to be higher in shorter duration tremors, which is defined as the half value width of tremor envelope. Considering the tremor model by Ando et al. (2010, 2012) and Nakata et al. (2011), shorter duration might imply smaller tremor patch, which would not endure higher strain accumulation than larger tremor patch, resulting in higher tidal sensitivity.

Keywords: Tectonic Tremor, Slow Earthquake, Subduction Zone, Tidal Sensitivity, Rate and State Friction Law

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

SCG62-10 Room:303 Time:May 27 16:45-17:00

An estimate of fluctuating plate subduction velocities caused by tidal modulations and decadal variations in the ocean

TANAKA, Yoshiyuki[1*] ; YABE, Suguru[2] ; KIKUCHI, Ryosuke[2] ; IDE, Satoshi[2]

[1]ERI, Univ. Tokyo, [2]Department of Earth and Planetary Science, Univ. Tokyo

Non-volcanic tremors and slow slip events have been detected in plate subduction zones. The source areas of these events are distributed in the transition zone located below the seismogenic zone, where high-pressure fluids supplied from the dehydration of the subducted slab are decreasing the effective normal stress. Consequently, extremely small external stress disturbances can trigger such events. Actually, variations in the tremor rate synchronized with diurnal and semi-diurnal tides have been observed. In our previous study, a model to predict long-term variations in the tremor rate was constructed by considering modulations of diurnal and semi-diurnal tidal amplitudes in decadal time scales. Tremors and slow slips arise from slips on a plate boundary, so long-term variations in the occurrences of these events generate a fluctuation of a plate subduction velocity. By applying the model to the Nankai area in Japan, it was found that the calculated tremor rate well corresponded to the long-term seismicity. However, in their model, tidal and non-tidal ocean effects were not separated because observed tidal levels were used. Some past studies estimated such non-tidal climatic effects on the seismogenic zone and concluded that the stress changes were insufficient to trigger earthquakes. However, if considering the high sensitivity of the transition zone, smaller stress changes can fluctuate a subduction velocity, which may eventually trigger earthquakes. In this study, employing an ocean model developed by the Japan Meteorological Agency, the effects of non-tidal ocean variations on such a fluctuation of slip rate are estimated for the first time. The result indicates that the non-tidal effects are larger than the tidal effects in some regions. The fluctuation of slip rate computed for a frictional parameter determined by observations of tremors exceeds 1 mm/yr at annual average in decadal scales, and periods with faster rates agree with some variations in seismicity. To quantitatively confirm if such slip variations are sufficient to trigger large earthquakes, incorporating the stress disturbances into numerical simulations of earthquake cycles is necessary.

Keywords: tides, slow slip, tremors, earthquake, seismicity, subduction zone

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

SCG62-11 Room:303 Time:May 27 17:00-17:15

Tremor activity and slip modes controlled by the permeability of the megathrust boundary

NAKAJIMA, Junichi[1*] ; HASEGAWA, Akira[1]

[1]Graduate School of Sci. Tohoku Univ.

Tremor activity in southwest Japan shows a sharp variation along the strike, but factors controlling such variation remain largely unknown. We carry out seismic tomography using a large number of arrival time data to characterize seismic properties around tremor activity, and find a close link between tremor activity and seismic properties above the plate interface. Tremor is active underneath the moderate- to high-velocity overlying plate, while it is absent in areas overlain by distinct low-velocity materials. High permeability along the plate interface enhances metamorphism of the overlying plate and prevents pore-fluid pressures from reaching near-lithostatic values. As a result, the plate interface is somewhat strengthened and slow slip no longer occurs at short intervals. Our hypothesis explains the occurrence of long-term slow slip, instead of short-term slow slip, along the inferred high-permeable plate interface in the Kii channel and eastern Kyushu.

Keywords: permeability, Philippine Sea plate

SCG62-12 Room:303 Time:May 27 17:15-17:30

Seismic explosion survey on the episodic tremor and slow slip area in western Shikoku

TAKEDA, Tetsuya[1*] ; SHIOMI, Katsuhiko[1] ; UENO, Tomotake[1]

[1]NIED, Japan

Recently the Japanese Cabinet Office proposed the source model that would generate an anticipated maximum size mega-thrust earthquake along the Nankai trough. The down-dip limit of this model was based on the source regions of slow earthquakes occurring along the subducting Philippine Sea plate. However, the relationship between the mega-thrust earthquake and slow earthquakes has not been clear yet. Since the generation of slow earthquakes is strongly related to dehydration, there might be some characteristic structure around the source region of slow earthquakes.

To delineate the spatial geometry between slow earthquakes and plate boundary, and to investigate the structural variation along the plate boundary, we conducted a seismic explosion survey in western Shikoku. The seismic line was aligned in the direction of NNW-SSE, passed through above one of dominant tremor clusters. We deployed 180 temporary stations with spacing of 450 m along the line. 300 kg dynamite was exploded as one shot on the midnight of 11th Dec, 2014.

We obtained good quality seismograms including many later phases. Two distinct phases with large amplitudes are identified around 11-12 sec and 14 sec in two-way travel time, respectively. The former phase is expected to be reflections from the plate boundary in comparison to previous studies. The reflection would come from around the area where high pressure fluid would exist, which was suggested by Shelly et al. (2006). We have a plan to work on the analysis to understand the accurate location and the physical property variation of the plate boundary.

Acknowledgements: We thank the local governments along out survey line for cooperating our survey. The part of this study is sponsored by ”Research project for earthquake disaster mitigation along the Nankai trough”.

Keywords: Seismic survey, Nankai trough, Plate boundary

SCG62-13 Room:303 Time:May 28 09:15-09:30

Recurrence interval modulation of slow slip events by two types of earthquake loading

MITSUI, Yuta[1*]

[1]Institute of Geosciences, Shizuoka University

Geodetic studies have discovered recurrent spontaneous slow slip events (SSEs) at major faults. The SSE recurrence intervals should reflect mechanical states at the faults, including load effects of large earthquakes in neighboring areas. Here, we focus on temporal changes of the SSE recurrence intervals. We perform numerical model experiments with the rate- and state-dependent friction to simulate the SSE recurrence interval changes by the earthquake loading effects. One result is gradual shortening of the SSE recurrence intervals owing to nucleation process of nearby earthquakes, as revealed by several previous studies. When the distance between the SSE and earthquake areas is almost zero, a short-term further decrease of the SSE recurrence intervals precedes the earthquake occurrence ($\sim$ by a decade). The other result is that external stress perturbation, as large as 0.1 MPa, can reduce the SSE recurrence intervals to a similar extent. Furthermore, the interval modulation by the stress perturbation continues for a prolonged period until the occurrence of the adjacent earthquake. Both effects may be observable, as is advancing at the Boso zone, Japan, but their separation is difficult under the present circumstances.

Keywords: Slow slip events, Stress perturbation, Rate- and state-dependent friction law, Earthquake preparatory process

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

SCG62-14 Room:303 Time:May 28 09:30-09:45

Frictional properties of materials along the plate boundary of Tohoku subduction zone: implications for slow slip events

SAWAI, Michiyo[1*] ; NIEMEIJER, Andre[2] ; HIROSE, Takehiro[3] ; PLUMPER, Oliver[2] ; SPIERS, Christopher[2]

[1]Hiroshima University, [2]Utrecht University, [3]Kochi / JAMSTEC

Episodic tremor and slip occurred just before the 2011 Tohoku-oki earthquake on a shallow portion (less than 20 km depth) in the Tohoku subduction zone (Ito et al., 2013). The area where slow slip occurred overlapped with the seismogenic zone. To understand such diverse slip behaviour around the Japan Trench, not only the major earthquakes but also the slow slip events, it is essential to reveal the frictional properties of rocks distributed at the Tohoku subduction zone. We thus conducted friction experiments using a rotary shear apparatus on powders of blueschist (probably distributed at hypocenters at major Tohoku earthquakes) and smectite-rich pelagic sediments (distributed along the shallow portion of the Tohoku plate boundary (Chester., et al 2013)). Simulated gouges were sheared at temperatures of 20-400^{o}C, and effective normal stresses of 25-200 MPa and pore fluid pressures of 25-200 MPa. We conducted velocity-stepping sequences (0.1 to 100 micron/s) to determine the rate and state parameter (a-b) and investigated the effects of temperature, effective pressure and slip rate on slip stability.

Blueschist gouges show a friction coefficient of about 0.75 and positive (a-b) values which decrease to become negative with increasing temperature. At 200oC, the behavior is velocity weakening and shows negative (a-b) values with a background friction of ˜0.75. At 300oC, friction is ˜0.65 and the gouges show neutral to positive values of (a-b), showing larger (a-b) values than at 200 oC. (a-b) values slightly decrease at 400oC with a background friction of ˜0.7. There is also effective normal stress dependence: even at temperature conditions where (a-b) tends to be positive, (a-b) values are negative at low effective pressure and increase to positive with increasing effective normal stress. This suggests that increasing pore pressure is a possible factor causing unstable slip, leading to slow slip events.

Smectite-rich pelagic sediments show that at low temperatures of 20 and 50oC, the simulated gouges exhibit negative values of (a-b) with a background friction coefficient of 0.38, except at the highest slip rate of 0.1 mm/s. However, the gouges show neutral to positive values of (a-b) at temperatures of $>$100oC with the same background friction coefficient as at lower temperatures. In addition, the value of parameter (a-b) depends significantly on slip rates: at temperatures of 20 and 50^{o}C it increases from negative to neutral (or slightly positive at 20^{o}C) with increasing slip rates to 0.1 mm/s, whereas it tends to decrease with increasing slip rate at temperatures higher than 100^{o}C. The downdip temperature limit of the slow slip events at Japan Trench (Ito et al., 2013) seems to be in the range between 100 to 150^{o}C. The transition in (a-b) value from neutral to positive, particularly at lower slip rates, occurs at the same temperature range. Hence, this could correspond to the observed downdip limit of the slow slip events.

SCG62-15 Room:303 Time:May 28 09:45-10:00

Precise observation of migration of non-volcanic low frequency tremors by using dense seismic array

TAKEDA, Naoto[1*] ; IMANISHI, Kazutoshi[1] ; UCHIDE, Takahiko[1] ; MATSUMOTO, Norio[1]

[1]GSJ, AIST

Non-volcanic low frequency tremors (NVTs) in several major plate boundaries migrate with wide velocity range from 10 km/d to over 50 km/h. The NVTs migrations are characterized by the velocity and direction. The fastest NVTs migration of the velocity over 50 km/h is in either updip or downdip direction parallel to the slip direction of subducting plates [e.g. Ghosh et al., G3, 2010; Ide, JGR, 2012]. Since March 2011, Geological Survey of Japan, AIST, performed the observation by a dense seismic array in Mie prefecture. In this area, the active NVTs occur at intervals from 3 months to 6 months. Then, the seismic array records of over 10 times of major NVTs events were obtained to date. In this presentation, we located NVTs hypocenters by an analyzing procedure same to the method of Ghosh et al. [G3, 2010] using our dense seismic array.

A sensitivity of the NVTs detection by using the seismic array is higher than a conventional envelope cross-correlation method. However, the detection capability decreases, when the NVTs occurs roundly, as same as the case of the envelope cross-correlation method [Takeda et al., JpGU, 2014]. Furthermore, the location accuracy is influenced by a distance and a velocity structure between the NVTs hypocenter and the array.

Our observation infers that all the fastest NVTs migration around the array (within 25 km of epicentral distance) is in the almost same direction during these three and half years. The migration direction is almost parallel to the slip of the subducting plate, while some of events migrate in different directions. Furthermore, in some case, the direction changed temporary in the same event.

To confirm a relation between these differences of migration directions and the detailed location of NVTs is future work.

Keywords: non-volcanic low frequency tremor, seismic array, Kii Peninsula

SCG62-16 Room:303 Time:May 28 10:00-10:15

Activities about non-volcanic tremor beneath the Yatsushiro fault zone

MIYAZAKI, Masahiro[1*] ; MATSUMOTO, Satoshi[2] ; SHIMIZU, Hiroshi[2]

[1]Grad. Sch. Sci., Kyushu Univ., [2]SEVO, Kyushu Univ.

Non-volcanic tremor induced by dynamic stresses has been detected in the Hinagu fault zone (Chao and Obara, 2012, SSJ). We notice that the tremor occurred at the deep extension of the fault zone (Miyazaki et al., 2015, submitted). In addition, from the velocity structure estimated by sismic tomography (Matsubara and Obara, 2011), there are low P-wave velocity zone at the deep part of the source region and high P-wave velocity anomaly in the shallow seismogenic zone. Therefore, the resolution is not sufficiently enough, the tremor occurred in the brittle-ductile transient zone.

Investigating the stationary activities of non-volcanic tremor is important to reveal the crustal deformation process in the fault zone. We performed the matched filter analysis (Gibbons and Ringdal, 2006) and detected the events (Miyazaki et al., 2014, SSJ). However, most detected events were difficult to distinguish between signals and noises. In this study, we test the detectability of small-scaled template events in the continuous seismic records including ambient noises using the same way conducted by Shelly et al. (2006). We confirm that the scaled template events comparable to ambient noise level are detectable with same magnitude of summed correlation coefficients as threshold values. This implies that a non-volcanic tremor without a disturbance occurred at the deep extension of the Hinagu fault zone has very small magnitude.

Keywords: non-volcanic tremor, Yatsushiro, Hinagu, active fault

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

SCG62-17 Room:303 Time:May 28 10:15-10:30

Temporal variation of crustal resistivity in western Shikoku revealed by continuous MT observations

YAMASHITA, Futoshi[1] ; HONKURA, Yoshimori[1*]

[1]NIED

Various kinds of slow earthquakes such as deep low frequency tremors (Obara, 2002, Science), deep very low frequency earthquake (Ito *et al*., 2007, Science), and slow/long-term slow slip event (Hirose *et al*., 1999, GRL; Obara *et al*., 2004, GRL) are observed in western Shikoku, Japan. In the lower crust of this area, existence of a characteristic low-resistivity structure was revealed by Magneto-telluric (MT) survey (Yamashita and Obara, 2009, AGU fall meeting). Since the low-resistivity structure would be derived from fluids dehydrated from the subducting Philippine Sea plate, continuous MT observations are being carried out to investigate relationship between the fluids and the activity of the slow earthquakes in this region. Since we succeeded to detect significant changes in the crustal resistivity by conducting careful data analyses, here we report the results. The continuous MT observations were carried out in two observational sites KBN and SGW in Ehime prefecture from September, 2008 to March, 2010. One MT observational system was moved from SGW to a new observational site IKT in April, 2010 and the observations are now continuing. To obtain highly reliable result by mitigating effects of noises, we followed the analytical method of Honkura *et al*. (2013, Nature Communications), in which we used only data whose coherency between electric and magnetic fields was larger than a threshold. Using the data, we calculated daily averages of apparent resistivity and phase. We further calculated moving average of them over 31 data points to reduce data scattering, which intrinsically arises in the MT method. Since the apparent resistivity shows annual variation due to atmospheric temperature variations, we removed it by using atmospheric temperature data obtained in Kuma observational site of Meteorological Agency. Number of analyzed frequencies of the MT data is nine between 0.00055-0.141 Hz. As a result of analysis, we successfully detected temporal variations which satisfy the following three conditions: (1) The apparent resistivity and the phase vary with antiphase at the same time. (2) The variations of (1) are similarly seen over several frequencies. (3) Similar variations are seen in two observational sites at the same time. From these results, we considered that the temporal variations of the apparent resistivity and the phase are originated from changes in the crustal resistivity. We then made a one-dimensional resistivity structure model based on the two-dimensional model revealed by Yamashita and Obara (2009), and compared an observational change with the simulated one by forward modeling. The result shows that the resistivity change in the depth between 20 and 25 km can approximately produce the observational changes in the apparent resistivity and the phase. We will further simulate how structural change can produce the observed variation based on the two-dimensional resistivity structure and also investigate the relationship between the observed resistivity variation and the activity of the slow earthquakes.

Keywords: Crustal resistivity, Magneto-telluric method, Slow earthquake, Subduction zone

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

SCG62-18 Room:303 Time:May 28 10:30-10:45

Seismic activity and velocity structure in the Hikurangi subduction zone offshore the North Island of New Zealand

HAIJIMA, Daisuke[1] ; MOCHIZUKI, Kimihiro[1*] ; HENRYS, Stuart[2] ; SHIOBARA, Hajime[1] ; YAMADA, Tomoaki[1] ; SHINOHARA, Masanao[1] ; FRY, Bill[2] ; BANNISTER, Stephen[2]

[1]Earthquake Res. Inst., Univ. of Tokyo, [2]GNS Science

The Hikurangi Plateau which has anomalously thick (~12 km) oceanic crust subducts under the Australian plate along the Hikurangi subduction zone offshore the North Island, New Zealand. The plate interface is shallow and we can identify the structure of plate interface in detail on the seismic reflection sections obtained by seismic surveys in the region [e.g., Bell et al. 2010]. Some topogrphic features on the plate interface such as seamounts and high-amplitude reflectivity zones have been identified. The onshore GPS network has been develped since 2000 in the North Island, and the mechanical coupling coefficient along the plate interface has been estimated along the Hikurangi subduction zone. In its northern part (north of -40 degrees), the coupling region is narrow and the down-dip limit is shallow at about 10 km depth. Although almost all of the coupling region is under the sea, ocean bottom seismic observation had not been conducted. Therefore, seismicity and hypocenter distribution in detail has not been well understood. SSEs (Slow slip events) have been observed along the down-dip limit of the coupling region. They occur at much shallower depths than other subduction zones. Tremors and swarms accompanying these events were also reported [Kim et al., 2010; Delahaye et al., 2009].

Marine seismic observation was conducted for the first time offshore Gisborne to observe earthquakes and low-frequency events accompanying SSEs. Four OBSs were deployed in April 2012 and recovered after a year-long observation. The northern two instruments were a broadband type and the other southern two were equipped with 1Hz seismometers. Although the data recorder of one of the broadband type OBSs recorded only intermittently, good data were obtained from the others. During the observation period, two major seismic events occurred around the OBS array. One of the events is a large SSE around the Hawke's Bay to the south of the array from mid-February 2013. First, I extracted event waveforms by applying the STA/LTA event-detection algorithm, and determined hypocenters using manually picked P- and S-wave arrival times. Waveforms of these events were, then, used as templates, and more events were detected by employing a Matched-filter technique. Differential arrival times were calculated by taking cross-correlation of waveforms of paired events. I applied double-difference tomographic analysis (TOMODD [Zhang and Thurber, 2003]) to both absolute and differential travel time data. Focal mechanisms were also calculated using P-wave polarity data. As a result, I successfully detected a number of events that were not observed by the onshore seismic network, and determined their hypocenters. Although few events occurred on the seamounts and HRZs along the plate interface, hypocenters are concentrated on the margin of the HRZ. In velocity structure analysis, I could resolve structure under the offshore region where previous studies using data from onshore stations could not have resolution. However, these velocity structure models are in good agreement in the region where both results have resolved. Quite a few earthquakes accompanying SSEs were observed. Seismic swarms which accompanied the past SSEs in this region occurred in the areas of stably high seismicity. Small coupling regions which are caused by irregular topography of the plate interface may exist in these ares.

Keywords: seismicity, slow slip, plate interface, structure