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

SCG63-P01 Room:Convention Hall Time:May 20 15:30-17:00

Non-volcanic low frequency tremors at Kii channel detected by vertical seismic array network (VA-net)

TAKEDA, Naoto[1*], IMANISHI, Kazutoshi[1]

[1]Geological Survey of Japan, AIST

In 2007, Geological Survey of Japan has started an integrated borehole observation (water levels, strains, seismic waves etc.) in southwest Japan for forecasting the Tonankai and Nankai megathrust earthquakes. At present, 14 stations are in operation. Each site has three level vertical seismic array. We developed a high sensitive detection method (Vertical Seismic Array Detection: VSAD) of non-volcanic low frequency tremors (NVTs) using the three level vertical seismic array network, VA-net, and demonstrated that the method enables us to detect minor NVTs which cannot be identified by a conventional envelope cross-correlation method (Imanishi et al., 2011).

The spatial distribution of the NVTs in southwest Japan is not uniform and has some clear gap areas of activities (e.g., Obara, 2010). On the basis of the VSAD method, Takeda et al. (2011) succeeded in detecting NVTs in Ise Bay, which is one of major gap regions of NVT activities. In this study, we report the NVT activities in another major gap region, Kii Channel, that was detected by the VSAD method.

We analyzed vertical seismic array waveforms of our observatory in Anan city of Tokushima prefecture, which faces Kii Channel. The VSAD method was applied over the last three and a half years. It is noted that large activities of long duration were not recognized, while small activities lasting a few minute were frequently detected. We determined epicenters of these NVTs by using manually picked S-wave arrival times and found that these events are located to the northeast of Anan city.

References:

Imanishi, K., N. Takeda, Y. Kuwahara, and N. Koizumi (2011), Enhanced detection capability of non-volcanic tremor using a 3-level vertical seismic array network, VA-net, in southwest Japan, Geophys. Res. Lett., 38, L20305, doi:10.1029/2011GL049071.

Obara, K. (2010), Phenomenology of deep slow earthquake family in southwest Japan: Spatiotemporal characteristics and segmentation, J. Geophys. Res., 115, B00A25, doi:10.1029/2008JB006048.

Takeda, N., K. Imanishi, and N. Koizumi (2011), Non-volcanic low frequency tremors only detected by vertical seismic array network (V-net), Japan GeoScience Union Meeting 2011, SCG058-P03.

Acknowledgements: We use seismic waveform data provided by National Research Institute for Earth Science and Disaster Prevention (Hi-net), JMA and University of Tokyo.

Keywords: vertical seismic array, VA-net, Non-volcanic low frequency tremor, Kii channel

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SCG63-P02 Room:Convention Hall Time:May 20 15:30-17:00

P- and S-wave detection of the low frequency earthquakes (LFE) using 3D array (3)

SUZUKI, Sadaomi[1*], OKUBO, Makoto[1], IMANISHI, Kazutoshi[2], KITAGAWA, Yuichi[2], TAKEDA, Naoto[2]

[1]TRIES, [2]AIST

Tokai area is the eastern side of Southwest Japan subduction where great earthquakes and deep low-frequency earthquakes (LFEs) occur along the convergent plate boundary.Researching the relationship between the great interplate earthquakes and activity of LFEs, Tono Research Institute of Earthquake Science (TRIES) installed two seismic arrays at Shimoyama in Tokai area. The first was a small-aperture array (six stations in the area of 120m diameter) with short-period velocity type seismographs. The second was a middle-aperture array (four stations in the area of 4 km diameter) with high-sensitive acceleration type seismographs. Geological Survey of Japan (AIST) also installed a seismic array of three borehole-type instruments with high-sensitive seismographs at three depths of 50m, 200m, and 600m at Shimoyama.We used seismic data of those three arrays and SMYH station of Hi-net array of National Research Institute of Earth Science and Disaster Prevention (NIED) as 3D array data for investigating LFEs. Using the 3D array (total 14 stations), we observed a remarkable activity of LFEs occurring in Tokai area in November 10-30, 2010. We analyzed the 3D array data to pick out direct P and S-waves propagating from LFE origins by using the semblance method. Assuming a homogeneous half space model with Vp=4.5 km/s and Vs=2.2 km/s,we obtained a semblance distribution for each component depending on the three factors of time, back-azimuth and incident angle of seismic waves. The maximum semblance point in each component shows a direct P-wave in UD, and S-wave in NS and EW, respectively. Incident angles and back-azimuths are compared with theoretical ones calculated by using JMA hypocenter data. Using the estimated S-P time of the LFE, we recalculated the depth of its hypocenter. The LFE locates near the interface of the Philippine Sea Plate subducting under Tokai area.

Keywords: deep low-frequency earthquake, 3D array, P- and S-waves, semblance, plate boundary

Japan Geoscience Union Meeting 2012
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SCG63-P03 Room:Convention Hall Time:May 20 15:30-17:00

Multiple Seismic Array Observations of Non-volcanic Deep Tremor in Western Shikoku (Part2)

TAKEDA, Tetsuya[1*], MATSUZAWA, Takanori[1], SHIOMI, Katsuhiko[1], OBARA, Kazushige[2]

[1]NIED, [2]ERI, Univ. of Tokyo

Deep non-volcanic tremors become very active during episodic slow-slip events in western Japan and Cascadia. Detailed tremor activity are important to understand the mechanism of tremor and the relationship between tremor and SSEs. However it is difficult to determine the location of tremors with high accuracy because tremors show faint signals and make the identification of P/S-wave arrivals difficult. The Envelope Correlation method (Obara, 2002) and the Hybrid method (Maeda and Obara, 2009), which are focusing on energy temporal change and excluding phase information, were developed. Seismic array analysis (e.g. Ueno et al., 2010, Ghosh et al., 2010), which is focusing on phase information, is also useful to evaluate tremor activity, especially to estimate the arrival direction of seismic energy, as it can distinguish multiple tremor sources occurring simultaneously. Here, we have conducted seismic array observation and analyzed seismic data during tremor activity by applying the MUSIC method to trace tremor location and its migration in western Shikoku.

We have installed five seismic arrays in western Shikoku since January 2011. One of the arrays contains 30 stations with 3-component seismometers with a natural frequency of 2 Hz (Type-L array). The array aperture size is 2 km and the mean interval between stations is approximately 200 m. Each of the other arrays (Type-S array) contains 9 seismic stations with the same type of seismometers of the Type-L array, and is deployed surrounding the Type-L array. The small array aperture size is 800 m and its mean station interval is approximately 150 m. All array stations have recorded continuous waveform data at a sampling of 200Hz.

We have installed five seismic arrays in western Shikoku since January 2011. One of the arrays contains 30 stations with 3-component seismometers with a natural frequency of 2 Hz (Type-L array). The array aperture size is 2 km and the mean interval between stations is approximately 200 m. Each of the other arrays (Type-S array) contains 9 seismic stations with the same type of seismometers of the Type-L array, and is deployed surrounding the Type-L array. The small array aperture size is 800 m and its mean station interval is approximately 150 m. All array stations have recorded continuous waveform data at a sampling of 200Hz.

In May 2011, an episodic tremor and a short-term slip event occurred for the first time during the observation period. We could retrieve the array seismic data during the whole tremor episode. The analysis of data from the type-L array confirms concentrated seismic energy arriving from the anticipated direction of tremor which is located by the Hybrid (Maeda and Obara, 2009; Obara et al., 2010). Most of the arrays could detect the arrival direction; the Type-L array could also estimate the slowness with an adequate accuracy. We converted from slowness to location (latitude and longitude) in MUSIC spectrum by assuming tremor occurs on the plate boundary and compared with results of the Hybrid method. The MUSIC spectrum peak approximately is consistent with the epicenter of the Hybrid method. But spectrum peak concentration that the Hybrid method cannot detect is also observed. This is an advantage of the seismic array analysis that also uses phase information.

Keywords: Low frequency tremor, Multiple seismic array

Japan Geoscience Union Meeting 2012
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SCG63-P04 Room:Convention Hall Time:May 20 15:30-17:00

Resolving slip evolution of deep tremor in western Japan

OHTA, Kazuaki[1*], IDE, Satoshi[1]

[1]EPS, Univ. of Tokyo

Recent studies have shown that deep tectonic tremors in many subduction zones consist of numerous low-frequency earthquakes (LFEs) that occur as shear slips on the plate interface. LFE hypocenters are determined relatively accurately, and in western Japan, they are concentrated in a narrow zone around the anticipated plate interface [Ohta and Ide, 2011]. Therefore, the location of LFEs may constrain the instantaneous location of tremor sources and illustrate its migration behavior, as demonstrated by a matched filter analysis with template LFEs [Shelly et al., 2007]. Nevertheless, it is yet unclear whether tremor occurs at exactly the same location as LFEs. Since tremor behavior on the plate interface are various and spatially characteristic [Ide, 2010], there might be some tremor activity undetectable using template LFEs. Moreover, while the previous method using matched templates has achieved to draw the discrete picture of the slip behavior of potential tremor, it is not sufficient to explain the entire rupture process. To understand the underlying physics of tremor and other slow earthquakes, it is essential to highly resolve the spatial and temporal behavior of the rupture of these events.

This study determines spatiotemporal slip distribution associated with deep tremor in western Japan, without the spatial limitation of template LFEs. We first estimate the location of the plate interface based on the precise hypocenter locations of LFEs in a target region and prepare "synthetic template waveforms" by stacking the seismograms of these LFEs at every grid point arranged on this interface. These synthetic template waveforms can be used in a matched filter analysis to continuous waveforms, to grasp a crude image of tremor source. Furthermore, we use the synthetic waveforms as substitute of Green's functions, and invert continuous tremor waveforms by a non-linear slip inversion method.

We apply the method to 3600 s continuous velocity seismograms recorded at Hi-net stations in the western Shikoku, on 16 March, 2008 from 23:00-24:00, to obtain the detailed slip history of about 1200 s tremor sequence. The slip episode migrates from south to north and consists of three stages: (1) the southern part for 80 s, (2) the central part for several hundred seconds, and (3) the northern part for 60 s. Average migration velocity is between 10-50 m/s, and the first and third stages correspond to unknown VLF events, whereas the second stage includes a much longer slip episode. These differences may be associated with the heterogeneities of material properties on the plate interface.

Keywords: deep tremor, slow earthquake, subduction zone, Nankai Trough, slip distribution

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SCG63-P05 Room:Convention Hall Time:May 20 15:30-17:00

Triggered low frequency tremors in Tonankai accretionary prism, by the 2011 Tohoku-Oki earthquake

TO, Akiko[1*], OBANA, Koichiro[1], TAKAHASHI, Narumi[1], FUKAO, Yoshio[1]

[1]Japan Agency for Marine-Earth Science & Technology

There have been many reports of triggered tremors and micro-earthquakes, by the 2011 Tohoku-Oki earthquake, most of which are based on land observations. Here, we report that numerous low frequency tremors are recorded by broadband ocean-bottom seismographs of DONET, a network of cabled observatory systems deployed in the Tonankai accretionary prism of the Nankai trough. Ten stations were in operation at the time of the earthquake. The tremors are observed at five of the stations, which are located on the landward slope of the Nankai trough. On the other hand, the signals are weak at stations near the coast, which are placed on the Kumano Forarc basin.

The tremors are dominant in a frequency range of 1-10Hz. Their duration ranges from tens of seconds to a few minutes. More than 20 events per hour can be detected in the first few days after the earthquake. The activity continues about one month with a decrease in the frequency of occurrence.

An intriguing feature of the observed tremors is that some of them are associated with a very low frequency (VLF) component, most clearly visible between 0.02 and 0.05 Hz. We found 74 such events within 5 days after the great earthquake. The VLF signals of the 72 events are observed at stations located above the shallowest part of the splay fault, and the remaining at a station above the up-dip toe of the main thrust. The instrument-corrected seafloor displacement corresponds to a subsidence of up to 0.04 mm with a rise time of 10-20 s. For each event, the VLF signal is detected only at one station in contrast to the high frequency signal (1-10Hz), which can be observed at more than a few stations. The disappearance of the large VLF signal at neighboring stations located only ~20km away indicates that the station which recorded this signal is well within the near field of the source.

In the presentation, we discuss the spacial and temporal variation of the triggered low frequency tremors during one month after the great earthquake.

Keywords: low frequency tremor, Ocean bottom seismometer, 2011 Tohoku-Oki earthquake

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SCG63-P06 Room:Convention Hall Time:May 20 15:30-17:00

A new detection method for very low-frequency earthquakes in southwest Japan

NIZATO, Taro[1]*, SUDA, Naoki[1]

[1]Hiroshima Univ.

Very low-frequency earthquakes (VLF) have been detected along with deep non-volcanic tremors in southwest Japan (Ito et al., 2007, 2009; Takeo et al., 2010). In these studies, it has been shown that the fault strike and dip angles of VLF events reflect the upper surface geometry of the subducting Philippine Sea plate and the slip angles are consistent with the motion of the subducting plate. These studies, however, simply applied methods of grid moment-tensor analysis for ordinary earthquakes to the VLF detection, so that a considerable number of small VLF events might be missed. In this study, we have developed a new method specialized to the detection of VLF events. In this method, VLF events are assumed to occur at grid points on the subducting Philippine Sea plate interface, having source mechanisms predetermined from the subducting plate surface geometry and the plate motion. By using this method, it is expected that we are able to detect smaller VLF events missed in the previous analyses. To evaluate availability of our method, we conducted numerical simulations in which we analyzed synthetic waveforms calculated using the observed VLF source parameters. As a result, our method was able to detect VLF events at the nearest grid points in most cases, indicating availability of our method to the VLF detection. In the presentation we will show the result of real data analysis.

Keywords: very low-frequency earthquake, slow earthquake, grid MT method, automatic detection

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SCG63-P07 Room:Convention Hall Time:May 20 15:30-17:00

Distinguish between very low frequency earthquakes and landslides signal.

TU, Yoko[1]*, ANDO, Masataka[1], LIN, Cheng-Horng[1], KUMAGAI, Hiroyuki[2]

[1]Inst.Earth Science,Academia sinica, [2]National Research Institute for Earth sc.

Almost every year, large typhoons strike Taiwan, which bring a huge rainfall sometimes up to 4000 mm in a few days. Such enormous rainfalls induces large landslides and submarine slumps in and around Taiwan. A series of landslides and submarine slumps due to the Typhoon Morako were identified and located by Lin et al. (2010) using band-pass filtered (0.02-0.05Hz) seismograms recorded at broadband stations of the BATS. This technique can be applicable to a real-time monitoring of landslides and submarine slumps. However, east of Taiwan and south of Ishigaki and Yonaguni islands near the trench axis of the Ryukyu subduction zone, a number of very low frequency earthquakes (VLFEs) occur at shallow depths (Ando et al., 2012) where 600-700 VLFEs occur every year and recorded at broadband even at the BATS stations. Although VLFEs have not been found beneath Taiwan, there is a possibility that VLFEs occur there from the point of view of tectonic situations. Nevertheless, the bandpass filtered (0.02-0.05 Hz) waveforms of the landslides and VLFEs are quite similar; both contain a spectral peak between 0.03 and 0.08 Hz. It is very hard to distinguish the two different phenomena on the seismograms alone. To distinguish landslide events from VLFEs and ordinary earthquakes, we take a method to identify landslides as follows: 1) Applying a bandpass filter (0.02 -0.05Hz) to raw broadband seismograms. 2) Picking up low frequency events from the filtered seismograms, 3) Removing ordinary earthquakes using an identification technique of P and S waves and surface waves, and hypocenter catalogues unless it is a real-time determination. 4) Locating the events with an inversion technique. 5) If the location of the event is at shallow depths beneath Taiwan or in submarine valleys, and if heavy rain-fall happened over the days, we assume the events a landslide. Our experiment with this method is still preliminary and further studies are required.

Keywords: VLFEs, landslides, broadband seismic system

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SCG63-P08 Room:Convention Hall Time:May 20 15:30-17:00

Along-strike variations in relationship among slow slip events, low-frequency tremor and very low-frequency earthquakes

KIMURA, Takeshi[1]*, HIROSE, Hitoshi[2], MATSUZAWA, Takanori[1], KIMURA, Hisanori[1], TANAKA, Sachiko[1], OBARA, Kazushige[3]

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

In southwest Japan the Philippine Sea Plate is subducting beneath the continental plate. Dense and high-quality observation networks such as NIED Hi-net have revealed that various types of slow earthquakes have occurred repeatedly on the plate interface. In the case of western Shikoku, simultaneous occurrences of the short-term slow slip event [SSE; Obara et al., 2004] with the magnitude of about 6.0, the nonvolcanic deep tremor [Obara, 2002] and the very low-frequency earthquake [VLFE; Ito et al., 2007] have been observed. In this study, we compare the slip process of short-term SSE with the tremor and VLFE activities which occurred from December 23, 2011 to January 10, 2012 around western Shikoku. This short-term SSE, whose magnitude is estimated to be 6.2 by a preliminary analysis assuming a rectangular fault with a uniform slip, is one of the largest events in western Shikoku. Moreover, this is the first case that an episode of tremor activity and short-term SSE occurs in a wide area from Bungo channel to central Shikoku.

In order to estimate the detailed slip process of this SSE, we apply a time-dependent inversion method [Segall & Matthews, 1997; Hirose & Obara, 2010] to a set of ground tilt data recorded by Hi-net high-sensitivity accelerometers (tiltmeters). From the hourly-resampled ground tilt data, tidal and atmospheric pressure effects are removed using the BAYTAP-G program [Tamura et al., 1991]. The plate interface configuration in the target area is modeled by placing 17 x 7 subfaults with the size of 10 x 10 km^2, referring to Shiomi et al. [2008].

The estimated cumulative slip distribution shows two separate areas with the large slip in western and mid Ehime prefecture and a gap area with the small slip between them. The location of the large slip area in western Ehime prefecture coincides with the area where the large slip occurs when the short-term SSEs occur repeatedly at approximately 6-month interval [Hirose & Obara, 2010]. After January 3, a large slip of the SSE developed beneath western Ehime prefecture and then the slip area jumped to mid Ehime prefecture while the tremor activity migrated from western Ehime to mid Ehime continuously. As a result, in two large slip areas, the slip and the tremor activity occurred simultaneously, and in the gap area, the tremor activity increases without the large slip. In the case of the VLFEs, some VLFEs occurred when slip occurred in the large slip area in western Ehime, and a VLFE occurred in the other large slip area. In the gap area, VLFEs were not detected.

In the episode of slow earthquakes from December 2011 to January 2012, we can show that the relationship among the slip of the SSE, tremor activity and very low-frequency earthquakes varies along the strike of the subducting Philippine Sea slab. In most of the tremor activities and short-term SSEs in western and central Shikoku, the migration of the source area stopped when the source area reached to the gap area. Moreover, only two and no VLFEs have been detected in the large slip area in mid Ehime prefecture and in the gap area, respectively, while many VLFEs have occurred in the other large slip area. Therefore, the along-strike variation in the relationship among three types of the slow earthquakes during the target episode would be caused by a spatial difference in the slip property on the plate interface.

Keywords: subduction zone, slow earthquake, short-term slow slip event, deep low-frequency tremor, deep very low-frequency earthquake, tilt change

SCG63-P09 Room:Convention Hall Time:May 20 15:30-17:00

Short-term slow slip event monitoring by joint analysis of crustal strain, tilt and groundwater changes

ITABA, Satoshi[1*], MATSUMOTO, Norio[1], KITAGAWA, Yuichi[1], KOIZUMI, Naoji[1], MATSUZAWA, Takanori[2]

[1]Geological Survey of Japan, AIST, [2]NIED

National Institute of Advanced Industrial Science and Technology (AIST) and National Research Institute for Earth Science and Disaster Prevention (NIED) have been exchanging crustal strain data of AIST and crustal tilt data of NIED since 2011. We developed a joint analysis method using crustal strain and tilt, and estimated fault models of short-term Slow Slip Events (S-SSE) [Itaba et al., 2011]. We can detect S-SSEs of about Mw5.5 or more by this joint analysis within the wide range in Shikoku, Kii Peninsula and Tokai.

The space density of Aichi Prefecture and Shizuoka Prefecture is low though AIST has a strain observation network in Shikoku, Kii peninsula, and Tokai. On the other hand, Japan Meteorological Agency has many strain observatories in Tokai. Moreover, in recent years, the groundwater changes associated with S-SSEs are observed at the groundwater observation network of AIST. Consequently, we developed a new joint analysis method of crustal strain, tilt and groundwater changes.

In this presentation, we will introduce this joint analysis method, detectability of S-SSE and the example of joint analysis.

Keywords: short-term slow slip event, tremor, strain, tilt, groundwater, crustal movement

SCG63-P10 Room:Convention Hall Time:May 20 15:30-17:00

Monitoring of small short-term SSEs in southwest Japan based on GEONET data

FUJITA, Akio[1*], SATOMURA, Mikio[2], IKUTA, Ryoya[2], SHIMADA, Seiichi[3], KATO, Teruyuki[4]

[1]Graduate School of Science, Shizuoka University, [2]Department of Geosciences, Faculty of Science, Shizuoka University, [3]National Research Institute for Earthsicence and Disaster Prevension, [4]Earthquake Prediction Research Center, Earthquake Research Institute, The University of Tokyo

In south-western part of Japan, there occur episodic tremors and slips beneath Nankai trough(Obara 2010). These short-term slow slip events(S-SSEs) especially in Tokai region are known to be very small and hard to detect by GPS. Our study is a trial for monitoring these S-SSEs around south-west part of Japan, including Tokai region, by geodetic inversion method using GPS data.

The data used inversion was F3 solution for 15 years from1996 to 2011 which were provided by Geospatial Information Authority of Japan (GSI) in south-west of japan. The procedure is followings :

1.Correction of offset in the GPS time series by earth quakes and antenna maintenance.

2.Principal component analysis(PCA) of the time series to remove the 1st principal component as common mode error between all the site.

3.Taking differences between two 10 days-averages with 1 week interval, which is done for all the data with 1 day shift.

4.Adopting Bayesian inversion method proposed by Yabuki and Matsuura [1992] ro above data.

Solving this inverse problem, we adopted a priori information which suppressed the slips on the fault surface without enough solvability. The slip axis was limited in the direction of the plate convergence of N45W but both polarities were allowed. In this study, we added two new conditions, one is that back slip rate must not exceed the convergence rate of Philippines sea plate, another that is the slip rate is zero in deeper position than 60km.

In our previous study, in which the two were not applied, we found unrealistic back and forward-slip in the deeper part where no coupling is expected because of the high temperature. We fixed the problem of the unrealistic slips by new conditions and then detectability of S-SSEs is better than that by the old method.

GPS is proofed to be a good tool to monitoring very small inter-plate slip.

Acknowledgement: In this study, we use GEONET data provided by GSI, and hypocenter data proposed by Japan Meteorological Agency.

Keywords: slow slip, deep low-frequency tremor, GPS, inversion

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Long-term slow slip events around eastern Shikoku and Kii Channel

KOBAYASHI, Akio[1*], YARAI, Hiroshi[2]

[1]Meteorological Research Institute, [2]Geospatial Information Authority of Japan

Long-term slow slip events around eastern Shikoku and Kii Channel are investigated using the GEONET GPS data. We estimated the steady deformation rate at each GPS station from the daily coordinates for the period from January 2006 to December 2009. Then the steady deformation rates were subtracted from all the coordinate data. The artificial offsets of the coordinate were corrected using data set shown on the homepage of the Geospatial Information Authority of Japan. We can see south-eastern displacements of a little less than 1 cm at GPS stations in eastern Shikoku from April 2001 to April 2003. These unsteady displacements are also seen in the time series of coordinate and the baseline length. Moreover, the change of the baseline length is also seen in 1996.

We estimated slip distribution on the plate boundary, assuming the unsteady displacements were caused by the slip on the plate boundary. The estimated slip is distributed from eastern Shikoku to the Kii channel. Non-volcanic deep low-frequency tremors are distributed belt-like along the Nankai trough. However, the active tremor is not observed in the Kii channel. It may provide important information about the condition of the plate interface that the long-term SSEs are seen in the region where the active non-volcanic deep low-frequency tremor is not seen.

Keywords: long-term slow slip, GPS, crustal deformation, eastern Shikoku, Kii Channel

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Strain data obtained in a vault near the Bungo Channel, above an epicenter area of long term slow slip events

YAMAZAKI, Ken'ichi[1*], TERAISHI, Masahiro[1], KOMATSU, Shintaro[1]

[1]Disaster Prevention Research Institute, Kyoto University

We have observed changes in strain using extensometers in a vault at Sukumo site near the Bungo channel, beneath which long-term Slow Slip Events (SSE) have repeatedly occurred. Earlier reports on strain data claimed that SSE has successfully recorded SSEs beneath the Bungo channel. However, data at Sukumo are highly affected by distortions due to changes in temperature. By referring temperature data obtained near the Sukumo site, secular variations in temperature possibly explain reported anomalies in strain data. This result implies that we cannot interpret recorded anomalies in strain data directly correspond to SSEs.

Keywords: extensometer, vault, slow slip event, Bungo Channel, changes in temperature

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SCG63-P13 Room:Convention Hall Time:May 20 15:30-17:00

Modeling of the Boso slow slips and effects of the 2011 off the Pacific coast of Tohoku Earthquake on the slow slips

YAMAZAKI, Takafumi[1*], SHIBAZAKI, Bunichiro[2], SATO, Toshinori[1], HASHIMA, Akinori[1], HIROSE, Hitoshi[3]

[1]Chiba Univ, [2]BRI, [3]Graduate School of Science, Kobe University

1. Introduction

Slow slip events (SSEs) off the Boso peninsula have occurred at intervals of about 5-6 years. The Boso SSEs are characterized by occurrence at depth 10-20km on the seismogenic zone. In this study, we model the SSEs using rate- and state- dependent friction law with aging law and investigate value of parameters of friction constitutive law to simulate observed feature of the SSEs. Such a parameter study is important to identify the reason the Boso SSEs occur on the seismogenic zone and to estimate materials and states at the SSEs area. We also research effects of the 2011 off the Pacific coast of Tohoku Earthquake on the Boso SSEs.

2. Methods

In our modeling, the region of the Boso SSEs is set on the basis of an inversion analysis of Hirose et al. (2008). Since the SSEs occur spontaneously, we set velocity weakening ($a\text{-}b < 0$) in the SSEs area and velocity strengthening ($a\text{-}b > 0$) out of the area. We assume that effective normal stress (Sn) increases with depth, and is set to 5-7 MPa at the SSE area. We run simulations with various parameters of a-b, Dc only in the SSEs area. To investigate the effects of the 2011 Tohoku Earthquake, we include changes of shear and normal stresses on the plate interface due to the coseismic slip of the earthquake.

3. Results

The parameter study reveals that parameter sets which can simulate the Boso SSEs are limited. The parameter set of Sn = 5-7 MPa, a-b = -0.004, Dc = 1.0cm can simulate observed interval, duration, and Mw of the Boso SSEs. The study with the effects of the 2011 Earthquake shows shortening of intervals with about 0.5 yr. This result may explain the shortening of intervals from 58 months (2002-2007) to 50 months (2007-2011).

Keywords: slow slip, parameter study, 2011 Tohoku Earthquake