Japan Geoscience Union Meeting 2014
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SSS33-P01 Room:Poster Time:April 30 18:15-19:30

Post-seismic crustal movements of the 11 April Mw6.6 Fukushima Hamadori earthquake based on GPS observations

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Tohoku earthquake on March 11, 2011 (Mw9.0) was accompanied by a vigorous aftershock activity. One of the aftershocks occurred on April 11, 2011, nearby Iwaki city, Fukushima Prefecture, and was called as Fukushima-Hamadori earthquake (Mw6.6; Depth=5km). The focal mechanism of the earthquake was a normal fault. Co-seismic crustal movements due to the earthquake observed by GPS observation was amounted to about 30cm to northeast direction at Iwaki site.

Crustal deformations associated with the Fukushima-Hamadori earthquake is obtained by InSAR and the data were used to construct detailed fault slip models by the previous studies (Kobayashi et al.,2013 : Fukushima et al.,2013). However, it has not been possible to measure the postseismic deformations using the SAR because the ALOS satellite has terminated its operation in immediately after the Fukushima-Hamadori earthquake. Thus, the postseismic crustal movements has been observed only by the GPS observations. Therefore, we aim to elucidate the mechanism of postseismic deformations due to the Fukushima-Hamadori earthquake using the GPS data in this study.

In this study, it was assumed that postseismic crustal deformations were caused by a slip in the vicinity of the fault. We used earthquake fault geometries employed by previous studies (Kobayashi et al.,2013 : Fukushima et al.,2013). As the GPS data is including large postseismic displacements due to the main shock since the March 11, first, we removed the postseismic transient displacements from GPS data using a postseismic slip model of the main shock (Fukuda et al., 2013). The obtained residual displacements after April 11, 2011, are considered as postseismic displacements due to the Fukushima-Hamadori earthquake. We, then, estimated slip distribution on the fault plane based on the residual displacement field. We will discuss estimated results in our presentation.

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Coseismic slip distribution for the 2011 Tohoku-Oki earthquake with topographic corrections

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Seismological study (Ide et al., 2011) revealed that the rupture of the 2011 Tohoku-Oki earthquake extended to the Japan Trench (i.e. free surface). Since the depth of the trench is about 8km, it is not appropriate to use green functions for elastic half-space media as given by e.g., Okada (1992). When we employ green functions for the half-space, it is not possible to satisfy the following two conditions simultaneously; (1) the updip limit of the rupture is ~8km deeper than the ground surface, and (2) the rupture extends to the free surface (i.e. the trench). If the condition (1) is satisfied, the rupture extends to ~8km at depth, not to the free surface. On the other hand, if the condition (2) is satisfied, the depth of the trench must match to the ground surface. The maximum discrepancy in between predicted ground displacements for the condition (1) and (2) is 5% in horizontal, and 15% in vertical component. Thus, it may be important to take the topography into account in green functions.

In this study we applied the topographic correction on green functions as proposed by Williams and Wadge (2000). Segall (2010) suggests that this method is applicable to approximately incorporate the earth sphericity into green function for observation sites within about 600km from the dislocation. Combining those two corrections, we are able to calculate corrected green functions for spherical earth with topography. Although this method gives only approximate green functions, it helps us to investigate the dependence of green functions on topography and fault geometry.

Then we use the corrected green functions for the inversion of coseismic slip distribution for the 2011 Tohoku-Oki earthquake. In the invsersion we use the following data set: GEONET F3 solutions obtained by the Geospatial Information Authority of Japan (GSI), the ocean bottom deformation data by the Japan Cast Guard (Sato et al., 2011), and that of Tohoku University (Kido et al., 2011; Ito et al., 2011). Then the inversion result is compared with the half-space solutions.

Keywords: crustal deformation, the 2011 Tohoku-Oki earthquake, topography, sphere

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Secular change of permeability estimated by using the variations of groundwater discharge

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Secular change of permeability causes the variation of the atmospheric pressure admittance of groundwater discharge. We estimated the permeability of the surrounding crust by using the groundwater discharge observed at Rokko-Takao station during 12 years from 2001 to 2012. The estimated secular change of permeability contained the short term variations for about a year as well as the gradual decrease. It is considered that the gradual decrease of permeability was caused by the closure of the cracks, which were opened in the 1995 Hyogoken Nanbu earthquake, due to the accumulation of mud and the crustal stress. On the other hand, the short term variations of permeability suggest the temporary re-open of the cracks due to the earthquake ground motions.

The Rokko-Takao station is located in Kobe, the southern Hyogo prefecture, and passes through the fracture zone of Manpukuji fault. At this station, the significant increase of groundwater discharge was observed just after the 1995 Hyogoken Nanbu earthquake (Fujimori et al., 1995). This suggested that the many cracks were opened in the fracture zone around the station by the ground motion of the earthquake. Mukai and Otsuka (2009) estimated the elastic properties by using the tidal strains observed at the station and reported that the Young's modulus of the surrounding crust showed the secular increase. This suggested that a part of cracks were closed by the crustal stress and the accumulation of mud and the strength of the fracture zone had been recovering.

Mukai and Otsuka (2013) estimated the variations of permeability due to the 2011 Tohoku earthquake by using the atmospheric pressure admittances of the groundwater discharge observed at the station under the assumption of one-dimensional model about groundwater migration. The permeability just after the earthquake increased by about 1.9 times just before the earthquake and decreased to the level about 1.3 times just before the earthquake in 10 months. This suggested that even the small ground motions due to the teleseismic waves could cause the outflow of the mud and the temporary re-open of the cracks in the fracture zone.

In this study, we estimated the secular change of permeability around the station during 12 years from 2001 to 2012 by using the procedure of Mukai and Otsuka (2013). The permeability estimated by using the atmospheric pressure admittances of the groundwater discharge showed the secular decrease by about 50% in 12 years. This result agrees to the secular increase of Young's modulus estimated by using the tidal strain and is considered that the gradual decrease of permeability was caused by the recovering of the fracture zone, in which the cracks were opened in the 1995 Hyogoken Nanbu earthquake.

Keywords: fracture zone, permeability, groundwater discharge, strain change

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Vertical crustal deformation in Boso Peninsula from 1966 to 2001 deduced from leveling and sea level data

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Leveling data and sea level data for the period from 1966 to 2001 in Boso Peninsula, Japan, were investigated to characterize unsteady vertical deformation. We estimated the steady vertical deformation rate at each GEONET GNSS station using the daily coordinates for the periods from January 1997 to January 2011 avoiding the period of the large earthquakes.

First-order leveling surveys have been conducted repeatedly every one or several years since 1966 in Boso Peninsula. We determined crustal displacements by comparing leveling data from successive surveys. We subtracted subduction-related steady component derived by the GNSS from the distribution of vertical crustal displacements during periods between leveling surveys. If any episodic events have not occurred, they should show little spatial variation around zero vertical displacement. Unsteady vertical deformation was not seen in the period from 1966 to 2001 except the land subsidence by pumping industrial water and natural gas brine.

Keywords: Boso Peninsula, crustal deformation, leveling, sea level

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2014 Boso slow slip

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Introduction

The GPS network detected transient crustal deformation on the Boso peninsula in 1996, 2002, 2007, and 2011. The detected transient displacements subsided for approximately 10 days. Rupture process and slip area are similar among the past four Boso SSE. The recurrence intervals of Boso SSE are 6.4, 4.9, 4.2 years from 1996. Under this circumstance, the anticipated slow slip event started from January 1 2014. This recurrence interval of 2.2 years is the shortest one compared with the previous 4 slow slip events. In this research, we estimate spatio-temporal evolution of the 2014 Boso slow slip and compare it with those in 1996, 2002, 2007, 2011.

Data and analytical procedure

Trend and annual components which are estimated for the period between 2009 and 2011 are removed from the raw time series. The detrended crustal deformation in 2014 shows southeastward movments with 1 cm maximum movement in the Pacific coastal area.

We employed time dependent inversion to the detrended crustal deformation associated with the 2014 Boso SSEs. We used EW, NS, and UD components of crustal deformation at approximately 40 GPS sites relative to Yasato station. The plate geometry of the upper surface of the Philippine Sea plate is based on Nakajima and Hasegawa [2006]. The fault geometry is composed on the B-spline and slip on the fault is also composed of superposition of B-spline function. As a boundary condition, we set 0 slip on the edge of the fault geometry.

Results and Discussion

The results show that the slow slip started offshore of the Boso peninsula and expanded to the south over time. The estimated moment magnitudes are 6.4, while those area 6.4 in 1996, 6.5 in 2002, 6.5 in 2007 and 6.6 in 2011. The 2014 Boso SSE ruptured an area similar to those of the four Boso SSEs. The recurrence interval is 6.4 year from 1996 to 2002 events, 4.9 years from 2002 to 2007 events, 4.3 year from 2007 to 2011, and 2.2 years from 2011 to 2014 events. The five events do not seem to be slip predictable nor time predictable. Though the 2011 event shows the largest magnitude among four cases, recurrence interval from 2007 event is the shortest. We cannot rule out a possibility that the Tohoku earthquake may have affected the occurrence of the 2011 event. In fact, dCFF increased near the rupture area of the Boso peninsula from the Tohoku earthquake [Hirose et al. 2012]. However, it remains unclear the reason why recurrence interval change drastically from 4.2 to 2.2 years for the 2011 and 2014 events, since dCFF does not change so much from 2011 and 2014. Another interpretation of shortening of recurrence interval is based on a scenario proposed by several simuylation studies in which recurrence interval of slow slip events become shorter as occurrence of large earthquake nears. If this is the case, it is quite important to monitor crustal deformation on and around the Boso peininsula..

Keywords: Boso peninsula, slow slip

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Estimation of frictional parameters in afterslip areas by assimilating GPS data :The 2003 Tokachi-oki earthquake

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Seismological and geodetic observations have revealed that various aspects of fault slips are determined by frictional properties on the interface. Kano et al. (2013) developed an adjoint data assimilation method to estimate frictional parameters from synthetic in-situ slip velocity data and found by numerical experiments that all frictional parameters are constrained if both acceleration and deceleration phases are observed. Additionally, we found that synthetic surface displacement data also have the ability to constrain frictional parameters in the areas where slip is well resolved. Following their study, we then applied the method to an actual case of the 2003 Tokachi-oki earthquake. Given reasonable initial conditions of simulation variables, estimated frictional parameters are well constrained if two conditions above are satisfied. Our results imply that the adjoint method we developed is useful to investigate and understand fault frictional properties.

Keywords: afterslip, adjoint method, frictional parameters, GPS, earthquake cycle

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Crustal deformation of the northeastern margin of the Izu Collision Zone inferred from GPS observations

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Izu Collision Zone is characterized by the collision between Izu Peninsula and Tanzawa Mountains, and Philippine Sea Plate also subducts beside this zone. Because of these complicated plate geometries, a number of historical earthquakes occurred in the northeastern margin of this zone. Additionally, there are a lot of active faults in the marginal area of the collision zone.

It is important to describe the steady state of crustal deformation in the Izu Collision Zone, in order to clarify mechanisms of earthquakes occurring in this area. In this study, we examined crustal deformation of the northeastern margin of Izu Collision Zone by using the datasets of GEONET sites (coordinate F3) and our original GPS sites.

Based on the displacement velocity vector diagram and profile, we can point out the following characteristics of crustal deformation there.

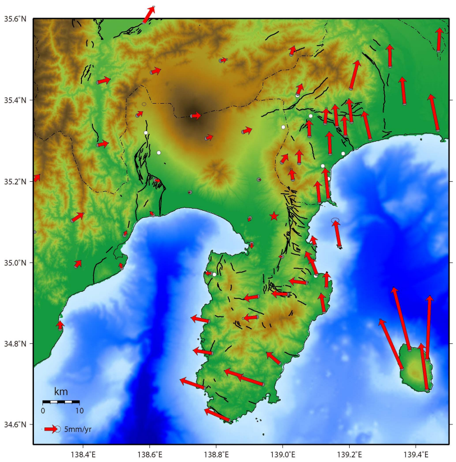
1) Remarkable northward crustal displacement vectors were observed in the eastern area of the Kita-Izu fault zone.

2) A shear zone with North-South trend was detected in the area between Kita-Izu fault zone and Ashigara Plain. Width of its zone was estimated about 15-20 km. Average shear strain rate in this zone was about 0.47 micro-strain per year.

3) Such remarkable crustal displacement vectors were not observed in the western area of the Kita-Izu fault zone.

This shear zone may be a transition zone between the collision and the subduction blocks on the Philippine Sea Plate, caused by the displacement gap between the blocks.

Keywords: GPS, crustal deformation, Izu Collision Zone, Kita-Izu fault zone



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The wind velocity correction of the precipitation to use for the rainfall correction of the volumetric strainmeter

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The rainfall correction of the volumetric strainmeter has the sensitivity that can judge quality of the precipitation data.(Kimura et al., 2013) In the observation of the rain gauge, it is well known that a capture rate of the rainfall decline at the time of a strong wind. We try the ranfall correction of the volumetric strainmeter in consideration of wind velocity dependence. As a result, the strainmeters at the slope of the big mountain or near the river where had a long basin area is improved the rainfall correction. This is not influence of the capture rate of the rain gauges, it is caused by the fact that altitude dependence of the precipitation is remarkable as a strong wind.

For the rainfall correction of the crustal movement data such as the volumetric strainmeter, it is necessary to consider it about the rainfall at high altitudes in addition to the precipitation around the observation station.

Keywords: strainmeter, rainfall correction, wind velocity, altitude dependence of the precipitation

SSS33-P09 Room:Poster Time:April 30 18:15-19:30

The change except the sudden contraction of the Higashiizu staraimeter with the seismic activity east off Izu Peninsula

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The sudden contraction strain change of the Higashiizu staraimeter with the seismic activity east off Izu Peninsula is well known. These changes were clear for anyone, but the Higashiizu staraimeter couldn't detect the long-term change that Murakami(2006) pointed out by the GNSS data until now. However we became able to remove the seasonal change by the rainfall from the strainmeter data by using the rainfall correction(Kimura et al., submitted). After reviewing the Higashiizu strainmeter data using the rainfall correction, this data detect the interesting change with the seismic activity east off Izu Peninsula.

Keywords: Strainmeter, seismic activity east off Izu Peninsula, Higashiizu

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Characteristic strain distribution following the 2011 Tohoku earthquake based on the kinematic PPP analysis

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The 2011 off the Pacific coast of Tohoku Earthquake (March 11, 2011, M 9.0) generated widespread coseismic deformation. The slip on the plate boundary is larger than the 10 m in widely (e.g. [1]). Ohzono et al [2] found inhomogeneous strain distribution caused by the coseismic step of the 2011 Tohoku earthquake. They extracted the residual strain distribution, which is estimated by comparison between the expected coseismic displacement by a simple rectangular faults model and the observed coseismic displacement in the Tohoku area. Ozawa and Fujita [3] found the local deformation around the Akita-Komagatake, Kurikoma, Zao, Azuma, and Nasu volcanoes caused by the 2011 Tohoku earthquake based on the ALOS/PALSAR and GPS data. They suggested that the coseismic extensional deformation concentrates in the soft medium under a volcano and that this deformation has caused local deformation with subsidence based on the FEM modeling. These previous studies , however, used the daily coordinates time series of the GPS observation. Thus, these previous studies result might be contained early postseismic displacement following the 2011 Tohoku earthquake. Based on these backgrounds, we tried to extract the pure coseismic deformation by the kinematic Precise Point Positioning (kPPP) approach.

We estimated every 1 seconds coordinates time series of the 1,208 GEONET by the GIPSY-OASIS II software version 6.1.2. We defined the " pure " coseismic displacement, which is coordinate difference between just before the origin time and 600 seconds after the event. We averaged from 500 to 700 seconds after the event for eliminating short-term fluctuation of the time series. Based on the estimated " pure " coseismic displacement, we estimate the dilatation strain distribution by method of the [4]. We also estimated strain distribution in the early time period after the 2011 Tohoku earthquake, which estimated coordinate difference between coseismic displacement by the daily coordinate (e.g. difference between 10 to 12th March, 2011) and " pure " coseismic displacement by the kPPP analysis.

As a result, we found the characteristic local expansion in and around the Mt. Gassan, which located in Yamagata prefecture. We also found the characteristic contraction in and around Mt. Zao even though this obtained strain amount is smaller than the noise level determined by the kPPP time series. We also estimated strain distribution of early postseismic between mainshock and 15th March for the understanding the spatiotemporal development of strain distribution. The area of the expansion is clearly larger than the 12th March in and around the Mt. Gassan. Furthermore, the contraction area around the Mt. Zao clearly changed to expansion between just after the mainshock and 15th March.

In the presentation, we will discuss more detail characteristics and its interpretation of the obtained strain distribution.

[1] Iinuma et al., (JGR, 2012), [2] Ohzono et al., (EPS, 2012), [3] Ozawa and Fujita, (JGR, 2013), [4] Shen et al., (JGR, 1996)

Keywords: strain, 2011 Tohoku earthquake, postseismic deformation, kinematic PPP

SSS33-P11 Room:Poster Time:April 30 18:15-19:30

Convergence of the Philippine Sea Plate in Mindanao, the Philippines

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Tectonics of the Philippines Archipelago is characterized by westward subduction of the Philippine Sea plate at the Philippine Trench in the east (5.8 - 7.0 cm/yr), eastward subduction of the Sunda plate at the Manila Trench in the west (3.3 - 3.6 cm/yr), and left-lateral strike-slip movement of the Philippine fault inland. Under the SATREPS project ”Enhancement of earthquake and volcano monitoring and effective utilization of disaster mitigation information in the Philippines” we have conducted yearly GPS campaign measurements in the eastern part of Mindanao since March 2010. The main purpose of the observation is to make clear the plate locking distribution at the Philippine Trench and slip/locking pattern of the Philippine fault in order to estimate earthquake generation potential in Mindanao.

We occupied 15 sites in the eastern Mindanao and collected continuous data for successive three to six days on March 2010-2013. Collected data were processed with Bernese software ver.5.0 together with the data from global IGS station (PIMO near Manila) to obtain coordinates and displacement rates based on ITRF2008. The displacement rates were then converted to those with respect to the Sunda plate. Moreover we used previous displacement rate data obtained in the central and western Mindanao from the 1997-2003 campaign measurements to cover the whole of Mindanao.

The resulted displacement rate filed shows that west-northwest motions are dominant due to the convergence of the Philippine Sea plate from the east but their spatial decay with increasing distance from the trench is not significant. Even the full locking of the Philippine Trench plate interface down to the depth of 80 km can explain only 29 percent of the observed displacement rate at the maximum. Thus we need to introduce remarkable rigid block rotations to interpret the deformation pattern of Mindanao. As a result of the estimate of pole position and angular velocity of the block rotation, deformation field of Mindanao cannot be reproduced by a rotation of single block. Considering the Philippine fault as a block boundary, it is natural to introduce multiple blocks into Mindanao. Unfortunately current station coverage and density are not enough to resolve elastic deformation due to plate locking at the trench and rigid motions due to multiple block rotations.

Keywords: Philippine Trench, Philippine fault, GPS observation, Mindanao

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Slip deficit rate distribution and its temporal changes along the Japan islands

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The Japan islands are located along several plate boundaries, where the oceanic plates are subducting beneath the continental plates. Due to this subduction, slip deficits are being generated and strain is being accumulated in coupled zones of the plate boundary so that many large earthquakes have occurred. Therefore, in order to reveal the generation mechanism of large earthquakes at the plate boundaries, it is necessary to clarify slip deficit rate distributions. In addition, as seen in long-term slow slip events, there are significant temporal changes in the slip deficit rate distributions. In this study, we determined the slip deficit rate distribution along the whole Japan islands for each year from 1996 to 2010 (the observation period of GEONET operated by GSI before the 2011 Tohoku earthquake) using the inversion method, and compared each other to investigate their temporal changes.

For calculating the deformation fields in Japan, we used the daily coordinates of F3 solutions. We obtained daily time series data considering the movements of the continental plates against reference frame and removing the offsets and postseismic effects due to nearby earthquakes. We then derived horizontal rate fields in Japan for each year by least-squares fittings. For reflecting the geometry of the plate boundaries, we used the plate model (Baba et al., 2005) incorporated in JIVSM (Koketsu et al., 2012). The Green's functions were calculated using the frequency-wavenumber method (Zhu and Rivera, 2002). We performed slip deficit inversions using the method of Yoshida et al. (1996).

The slip deficit rate distributions derived from the inversions were consistent with the previous study and the plate convergence rates. In addition, known long-term slow slip events were found in the temporal changes of the slip deficit rate distributions. Furthermore, we can see the temporal changes in the Hokkaido and Kanto regions, which suggest variations of plate coupling in these regions. The zones of large slip deficit rate in the distributions look corresponding to the source regions of past megathrust earthquakes. These correspondences are significant not only in Earth science but also in seismic hazard assessments.

Acknowledgement: We would like to thank Geographical Survey Institute for geodetic data recorded by GEONET.

Keywords: the Japan islands, crustal deformation, GPS, slip deficit, megathrust earthquake