Japan Geoscience Union Meeting 2014
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SSS33-01 Room:315 Time:April 30 09:00-09:15

Spatio-temporal afterslip distribution of the 2011 Tohoku-Oki earthquake considering visco-elastic response

SUZUKI, Syota[1] ; ITO, Takeo[1*] ; SATO, Kachishige[2] ; HYODO, Mamoru[3]

[1]Graduate School of Environmental Studies, Nagoya University, [2]Faculty of Education, Tokyo Gakugei University, [3]Japan Agency for Marine-Earth Science and Technology

1. Introduction

The 2011 off the Pacific coast of Tohoku Earthquake with a moment magnitude (Mw) of 9.0 occurred at 5:46 (UTC) on March 11, 2011 along the boundary between the subducting Pacific Plate and the overlying plate. Since large earthquake are likely to produce stress concentrations in neighboring region along the plate boundary, the mainshock might have been trigger afterslip. It is very important to determine the detail of spatio-temporal distribution of afterslip, in order to understand the characteristic of friction relationship on the plate boundary. In this study, we estimate spatio-temporal afterslip distribution using visco-elastic Green's function (GF).

2. Method

We make GF using 3D finite element method (FEM) with a grid model for the Hokkaido and Tohoku regions. The model space and assumed subsurface structure for the 3D-FEM have a dimension of 2600 km (in the ESE direction) x 1500 km (in the NNE direction) x 400 km (depth) and typical subsurface structure consist of four sub-regions, i.e., upper crust, lower crust, upper mantle, and Pacific plate. The numbers of node and cell of 3D-FEM mesh are 3,205,950 and 3,121,200, respectively. For the calculation, we use the Pylith version 1.9.0, which is designed for simulating lithospheric deformation. In order to estimate the distribution of afterslip, we assume subfaults on the plate interface in and around the co-seismic slip zone of the 2011 Tohoku-Oki event. In inversion, we impose the smoothness constraint on the slip distribution. We estimate co-seismic and spatio-temporal distributions at the same time, considering visco-elastic response, derived from GEONET and seafloor observations.

3. Results and discussion

We obtain the co- and post-seismic slip distributions. The maximum slip of the 2011 event is about 60 m close to the Japan Trench. Estimated afterslip distribution is complementary to co-seismic slip distribution and also historical source regions. Amount of afterslip is about 2m, and the cumulative seismic moment is 8.06, considering visco-elastic response during 2.5 years after event. In case of only considering elastic response, amount of after slip is about 4m. There is no slip off Fukushima prefecture only considering visco-elastic response. And, our result can explain seabottom observations. i.e., Miyagi-Oki1 site move to west about 38 cm during 2 years after event. The effect of visco-elastic response is too large. In inversion for afterslip distribution from geodetic data, it must be consider to visco-elastic response due to relaxation in upper mantle.

Keywords: Afterslip, Visco-elastic response, FEM

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SSS33-02 Room:315 Time:April 30 09:15-09:30

Vertical displacement in Naruko Volcano area following the 2011 Tohoku earthquake deduced from precise leveling survey

TSUKAMOTO, Yuya[1*] ; SUGIYAMA, Kenichi[1] ; FUJITA, Wakana[1] ; WATANABE, Keitaro[1] ; WATANABE, Kosui[2] ; TAKAHATA, Akihiro[2] ; MATSUOKA, Moe[2] ; GOTO, Akio[3] ; OHTA, Yusaku[2]

[1]Fac. Sci., Tohoku University, [2]Grad. School Sci., Tohoku University, [3]CNEAS, Tohoku University

Large subsidence accompanied the 11 March 2011 Great East Japan Earthquake along the Pacific coast. GEONET data have indicated that the subsidence goes down westward (http://www.gsi.go.jp/common/000059956.pdf). In a summer field seminar by the Division of Earth and Planetary Material Science, Tohoku University, we made precise leveling survey for 10km on the second-order leveling route along the National Route 47 (from benchmark number 047-064 to 047-074; hereafter indicated as BM64, BM74 etc.) which locates along the east to west in Naruko area, Miyagi prefecture, to detect the vertical crustal deformation of this area. We performed the leveling twice (23-28 August, 2011 and 19-25 August, 2013) using bar-code leveling rods (Leica CPCL3) and an electronic digital level (Leica DNA03). By comparison with the data by Geospatial Information Authority of Japan in 2009, we acquired the change of difference in elevation at each benchmark against the westernmost BM64. We conducted round-trip survey between each benchmark and re-measured when the residual error did not meet the first-order leveling, except the segments between BM66 and BM68 in 2011 and between BM72 and BM74 in 2013 due to the fixed seminar schedule.

Contrary to our expectation before the leveling, we found all benchmarks subsided against BM64 and the degree of subsidence increases westward. At the 2011 leveling 5 months after the earthquake, benchmarks BM66, 68, 70, 72, and 74 subsided 13.0mm, 21.4mm, 81.7mm, 91.1mm and 113.9mm, respectively. This subsidence continued further with decreasing the amount, 8.5mm, 16.2mm, 23.7mm, 41.9mm and 46.2mm between 2011 and 2013, respectively. Obtained displacement pattern along the leveling survey between 2011 and 2013 is almost similar pattern with the 2009 and 2011 one.

Ozawa and Fujita (2013) and Takeda and Fukushima (2013) showed local depressions on some major volcanic areas in Tohoku region by In-SAR analysis. They explained the depressions by the east-west extension of hot and soft medium under the volcanoes. Our research route locates on one of that volcanic area and our leveling result is consistent with their previous studies. In contrast, their analysis just focused on the coseismic displacement. In our analysis, we found not only subsidence during the coseismic stage but also the subsidence in the postseismic stage. Particularly, it is worth noting that the subsidence increases remarkably between BM68 and BM70, which is inferred to cross the rim of Naruko caldera.

Acknowledgement
We appreciate Ryohei Kobayashi and Emi Hara who joined the leveling survey in 2011.

Keywords: Great East Japan Earthquake, Naruko caldera, precise leveling survey, subsidence

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SSS33-03 Room:315 Time:April 30 09:30-09:45

Postseismic gravity changes after the 2011 Tohoku earthquake recorded by superconducting gravimeters

IMANISHI, Yuichi[1*] ; TAMURA, Yoshiaki[2] ; NAWA, Kazunari[3] ; IKEDA, Hiroshi[4]

[1]ERI, The University of Tokyo, [2]NAOJ, [3]AIST, [4]University of Tsukuba

Continuous gravity monitoring by means of superconducting gravimeters is revealing significant effects of the 2011 Tohoku Earthquake on surface gravity in Japan. Two stations of superconducting gravimeters, Matsushiro and Kamioka, both in the main island of Japan (Honshu), are indicating gravity decreases at similar rates of approximately 10 microgal per year after the 2011 event, and this trend is still going on. Since Matsushiro and Kamioka are relatively far from the earthquake source region (epicentral distances being 420 km and 490 km, respectively), the postseismic crustal uplifts of the stations recorded by GPS are too small to account for the observed gravity decreases. Therefore, the observed gravity changes are likely to reflect ongoing changes in the density of the earth material, maybe associated with a viscoelastic flow of the asthenosphere. Data from Mizusawa, another SG station in Honshu, will also be presented in the paper.

Keywords: superconducting gravimeter, 2011 Tohoku earthquake, postseismic gravity changes, viscoelasticity

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SSS33-04 Room:315 Time:April 30 09:45-10:00

Pressure Source Model Inferred from Crustal Deformaton Preceeding Seismic Swarm in 2013 beneath Tarumae Volcano

KOSHIROMARU, Takuma[1] ; MURAKAMI, Makoto[1*]

[1]ISV, Hokkaido University

Tarumae-volcano is an active volcano with an altitude of 1,041 m located in the southwestern part of Hokkaido. In past 350 years, three major magmatic eruptions occurred, i.e. Plinian eruptions in 1667 and 1739 and dome forming eruption in 1909. Volcanic activity in recent years is restricted to gas emission or volcanic earthquake activity at the shallow part of the volcano. A spherical source model for inflation/deflation sequence is inferred at shallow depth beneath the summit dome by campaign GPS observations by the Meteorological Agency. No sign of crustal deformation is found at the deeper depth of the volcano by continuous GPS observation in a regional scale either by the Geographical Survey Institute nor the Meteorological Agency. Thus, until now, a crustal deformation which suggests fluid activity beneath the Tarumae-volcano at deeper depths had not been detected.

In July, 2013 swarm seismic activity started at the depths of between 2-5 km about 2 km to the west of summit dome. In addition a crustal deformation preceding the swarm was identified at several observation sites. The size of the change was at about 1 micro radian or micro strain level. Because the change appeared commonly at several stations around the volcano, it is highly likely that the strain and tilt change is resulting from a activity of a source at a depth beneath the volcano. A spherical inflation source was inferred from the observation data. The estimated position is at the m.s.l. depth of 4.2 km and about 1.3 km to the NNW of the summit horizontally with inflation volume of 3.4×10^5 m^3.

Since the position and time of activation of the source are close to those of seismic activity, it is likely that there is some geodynamic relationship between swarm seismicity and crustal deformation. In our presentation we also discuss possible relationship between them.

Keywords: Crustal Deformation, Active Volcano, Swarm Earthquake, Tarumae Volcano

SSS33-05 Room:315 Time:April 30 10:00-10:15

Campaign GPS for detection of the volcanic deformation on and around Mt.Meakan and Mt.Tokachi

WADA, Sayaka[1*] ; MORI, Hitoshi, Y.[1] ; OKUYAMA, Satoshi[1]

[1]Hokkaido University, Institute of Seismology and Volcanology

Mt. Meakan is an active volcano located in the eastern Hokkaido, Japan. It made phreatic eruptions in 1996, 1998, 2006 and 2008. Mt. Tokachi is one of the famous active volcanoes sits in the central Hokkaido. In the recent 100 years, three major magmatic eruptions took place in 1926, 1962 and 1988-1989.

In this presentation, we will discuss the results of the campaign GPS on and around Mt. Meakan and Mt. Tokachi. Each broad area GPS observation had begun at Mt. Meakan in 2006 and at Mt. Tokachi in 2007, respectively. The campaign GPS observations have made for several days to weeks in each year for Mt. Meakan at 8 sites, and that for Mt. Tokachi at 12 sites.

We used the data of our campaign observations after the 2008 eruption for Mt. Meakan and since 2007 for Mt. Tokachi. We also used the data of several sites operated by JMA (Japan Meteorological Agency) at the same time. Analyzing these data, annual movements at those points were estimated. These movements included deformations of the regional tectonic moving, and of the coseismic step of Tohoku-oki earthquake on March 11, 2011. For making corrections of these non-volcanic deformations, we used the continuous data of GEONET sites by Geospatial Information Authority of Japan (GSI) around the volcanoes. Using the GEONET data from 2007 to 2013, the regional tectonic and the seismic deformations were estimated by linear approximation in space. To elucidate the volcanic deformation, seasonal variations should be taken into consideration. The discussion about estimated volcanic deformation will be made, with the corrections about the regional deformation, the coseismic step and the after slip of 2011 Tohoku-oki earthquake, and the seasonal change.

Acknowledgements

In this study, JMA, Sapporo District Meteorological Observatory furnish their observation data to us. We would like to express our gratitude to them. Also, we used the data of GEONET sites of GSI with thanks.

Keywords: campaign GPS observation, volcanic crustal deformation, Mt. Tokachi, Mt. Meakan

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SSS33-06 Room:315 Time:April 30 10:15-10:30

Crustal deformation associated with the unrest of Zao Volcano

MIURA, Satoshi[1*] ; NISHIMURA, Takeshi[1] ; OHTA, Yusaku[1] ; YAMAMOTO, Mare[1] ; DEMACHI, Tomotsugu[1] ; TACHIBANA, Kenji[1] ; OHMI, Katsuya[2] ; SHINOHARA, Eiichiro[2]

[1]Graduate School of Science, Tohoku University, [2]Sendai District Meteorological Observatory

Mt. Zao (1,841 m) is an active volcano located in northeastern Japan and having histories of phreatic or phreato-magmatic eruptions in the last 2 ka. Unrest of Zao volcano started in January, 2013 with a volcanic tremor (JMA, 2013) followed by activated seismicity mainly in the lower crust and very ?long-period seisimic events (VLP) up to today. Since the number of volcanological observatories within a distance of 10 kilometers from the volcano was limited at the time of beginning of the unrest; two continuous GPS sites and two sites equipped with borehole seismometers and tiltmeters, Tohoku University has built up 4 sites with broadband seismometers, 5 sites with continuous GPS, 1 site with shallow borehole tiltmeter, and 2 sites with a Proton magnetometer.

Using the new broadband network, we detected some VLPs with dominant period of about 10 sec, and revealed the source of the VLPs is located at a depth range of 2?4 km beneath the crater lake, from where the recent eruptions occurred since ~600 years ago. There were, however, no significant surface phenomena such as steam explosion, ash effusion, and so on associated with the VLPs, except for precursory tilt signals about 5 minutes preceding a few major events.

We deployed dual-frequency GPS receivers at 5 new stations and the data are transmitted to the university using cellphone network for continuous observation (Demachi et al., 2011). The data are processed using the precise point positioning strategy (Zumberge et al., 1997) of GIPSY-OASIS II ver. 6.1.2 with IGS08 precise ephemerides and GMF mapping functions (GMF, Boehm et al., 2006). Since the wide area of northeastern Japan still suffers the long lasting postseismic deformation following the 2011 Tohoku-oki earthquake (M9.0), we try to extract volcanic deformation related to the unrest of the volcano using spatial and temporal filtering. Even though no distinct deformation has been recognized in the continuous GPS and tiltmeters at present, we may detect cm level variation of the shape of the mountain.

Reference
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Zumberge et al. (1997), JGR, 102, 5005-5017.

Keywords: GPS, Ground Tilt, Volcanic deformation, Volcanic activity

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SSS33-07 Room:315 Time:April 30 10:30-10:45

The acceleration episode of the back-arc rifting in the Izu-Bonin Arc possibly triggered by a remote earthquake in 2004

ARISA, Deasy[1*] ; HEKI, Kosuke[1]

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

The Izu-Ogasawara (Bonin)-Mariana Island arc lies along the convergent boundary between the subducting Pacific plate (PA) and the overriding Philippine Sea plate (PH) in the western Pacific. Nishimura (2011) found that the back-arc rifting goes on behind the Izu arc by studying the horizontal velocities of GNSS stations on the Izu Islands. Here we show that this rifting has accelerated in 2004 using GNSS data at stations such as Aogashima, Hachijojima, Mikurajima, Shikinejima, and Nijima (we excluded stations in the Miyake Island because of the volcanic deformation).

The back-arc rifting behind the Izu islands can be seen as the increasing distance between stations in the Izu Islands (they are located to the east of the rifting axis) and stations located in the stable part of PH, e.g. Minami- and Kita-Daito islands. We found that their movement showed clear acceleration around the third quarter of 2004. Such an accelerated eastward movement could be interpreted not only as the acceleration of the back-arc rifting, but also as the trenchward movement of the arc due to a slow slip episode at the PH-PA boundary.

We first rule out the second possibility by constraining the onset time of the acceleration episode, and by correlating it with other inter-plate earthquakes in the PH-PA boundary. There was an inter-plate earthquake occurred on May 29, 2004 (M6.5) at the PA-PH boundary just to the south of the Boso-oki triple junction. However, the time series clearly lacked the jump which should mark the onset of the eastward slow movement. Moreover, the additional velocity vectors do not converge to the epicenter, and the onset time that minimizes the post-fit residual is significantly later than May. We therefore conclude that the accelerated eastward movement started in 2004 was not due to the afterslip of the interplate earthquake in May.

We found that the onset time coincides with the occurrence of the September 5, 2004, Kii-Hanto-oki, September 5, 2004, earthquake (M7.4), which occurred in the PH slab subducting at the Nankai Trough off the Kii Peninsula. We found that the accelerated movement vectors of these islands are almost parallel with each other, and perpendicular to the rift axis. We hypothesize that the seismic wave radiated from the epicenter of this earthquake dynamically triggered the acceleration of the back arc opening in the Izu Arc.

Keywords: GPS, GNSS, Izu-Bonin Arc, time series, back-arc opening, acceleration

SSS33-08 Room:315 Time:April 30 11:00-11:15

Subsurface structure and slip pattern of the Median Tectonic Line, SW Japan inferred from GPS displacement rate field

EDAGAWA, Nobuko[1] ; TABEI, Takao[1*] ; ICHITANI, Shozui[2] ; NAKAMURA, Yasuhiko[2]

[1]Fac. Science, Kochi Univ., [2]Grad. School Int. Arts Sciences, Kochi Univ.

The Median Tectonic Line (MTL) is the longest arc-parallel fault system in southwest Japan. Its right-lateral strike-slip motion is originated from oblique subduction of the Philippine Sea plate at the Nankai Trough, separating the Nankai forearc sliver (the outer zone) from the inner zone of southwest Japan. The deformation of the forearc sliver is characterized by interseismic contraction in the direction of the plate convergence (NW-SE) and long-term westward block movement along the MTL. In addition the MTL itself has a potential to generate a large inland earthquake in the future. Therefore it is important to understand subsurface structure and current slip/locking pattern of the MTL fault plane.

From dense GPS campaign measurements along a traverse line across the MTL, we have made it clear that a transition zone of the relative motion between the outer and inner zones is located 20-30 km north of the surface trace of the MTL (Tabei et al., 2002). To interpret the transition zone, we used a northward-dipping MTL fault plane which was revealed by seismic reflection survey (Ito et al., 1996) and assumed that its upper part was locked and a stationary right-lateral slip was occurring at depth. However, the concept of a pure strike-slip on an inclined fault plane seems somewhat unrealistic. In addition linear distribution of earthquakes aligned 20-30 km north and parallel to the MTL seems inconsistent to the hypothesis of the dipping MTL fault plane because most of them show a right-lateral slip on a nearly vertical fault plane. Unfortunately station distribution of the nationwide continuous GPS network is rather sparse in the north of the MTL because of the existence of the Seto Inland Sea. In this area we have deployed supplementary three GPS stations and collected continuous data since November 2010.

We propose a kinematic model of the transition zone. The model consists of several vertical right-lateral faults in a hanging wall above the northward-dipping MTL fault plane, which are close and parallel to each other. Distributed slip deficits on this parallel fault system may block the relative motion between the outer and inner zones and act as s broad shear zone as a whole. In this study we assume four parallel faults with different widths and depths from surface. Integrated displacement field from relative block motion and slip deficits on these faults is consistent with that derived from a strike-slip on an inclined fault.

We check the effect of the 2011 Tohoku-Oki earthquake on the deformation field of southwest Japan. We compare two displacement rate fields before (Jan. 2006 - Dec. 2009) and after (Mar. 2011 - July 2013) the earthquake. After the earthquake, additional wide-area displacements of 1-4 cm/yr trending to the source region (extension) have been superposed on the original compressional deformation field due to the subduction of the Philippine Sea plate. No significant change has been recognized in the latter.

Keywords: Median Tectonic Line, Nankai Trough, GPS, Deformation

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Continuous GPS observation in northern part of Nansei Islands

NAKAO, Shigeru[1*] ; YAKIWARA, Hiroshi[2] ; HIRANO, Shuichiro[2] ; GOTO, Kazuhiko[2]

[1]GSSE, Kagoshima Univ., [2]NOEV, Kagoshima Univ.

GEONET, which is a nationwide GPS observation in Japan cover on all over Japan. However, there is a GEONET site in Toshima-mura which is located in northern part of Nansei Islands. This region is defined the boundary between Northern and Central part of Ryukyu arc (Nishimura et al., 2004). It is not clear that where is the boundary because there is almost no GPS site. Goto (2013) concluded that the great earthquake occurred in 1911 is the interpolate event in this region. We set up the continuous GPS in islands of this region due to observe crustal deformation in this region.

In Akuseki Island (AKSK), Takarajima (TAKR) and Kuchinoshima (KCHI), continuous GPS (CGPS) observation started in March 2007, July 2007 and September 2010, respectively. CGPS set up on Gajyajima (GJYA) and Ujishima (UJIS), where is a deserted island, in May 2009. CGPS in Yokoatejima (YKAT) started in September 2013. Data is recorded at CGPS sites. Electric power system at GJYA, UJIS and YKAT is composed of batteries and photovoltaic cells.

Bernese GPS Software ver. 5.0 are used with IGS precise ephemerides and IERS rotation parameters. We also estimated tropospheric delays every hour and their horizontal gradients every six hours.

The short-term repeatabilites are from 1.6 to 3.0 mm in horizontal component and from 6.5 to 7.9 mm in vertical components. These observation is expected to make contribution to resolve rigid movement and crustal deformation in this region.

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The detection of crustal deformation associated with earthquake swarm in Tanzania observed by SAR

HIMEMATSU, Yuji[1*] ; FURUYA, Masato[1]

[1]Graduate School of Science, Hokkaido University

The East Africa Rift Valley is one of the divergent plate boundaries can be seen on the land surface. The area undergoes middle-class earthquakes and eruptions due to the existing faults and volcanoes.

An earthquake swarm occurred in the Northern Tanzania in July 2007 including the largest earthquake with Mw5.9 and lasted for approximately two months. According to the Global CMT solution, eight M>5 earthquakes occurred during the earthquake swarm and all of them were reported to be caused by normal fault. One week after the start of the swarm, an effusive eruption began at Mt. Oldoinyo Lengai located near the epicentral region, and a major ash eruption was observed by the time when swarm was terminated.

Biggs et al. (2009, 2013) also detected the crustal deformation associated with the earthquake swarm and Mt. Oldoinyo Lengai eruption, using mainly ENVISAT/ASAR C-band SAR data. In these interferograms, however, the ground displacements at some deforming areas were uncertain because of the difficult of phase-unwrapping. Also, these datasets were acquired only along the descending track, and the 3D deformation fields were unclear. Therefore, we used the L-band ALOS/PALSAR data obtained at both ascending and descending track to detect the detailed crustal deformation.

The purpose of this paper is to elucidate the mechanism of crustal deformation associated with the earthquake swarm in Tanzania in 2007 by interferometric synthetic aperture radar (InSAR).

By using InSAR data for ascending and descending track and the azimuth-offset data, we determined the 3D displacement. The results show a subsiding region along the NE-SW direction that are sandwiched by two horizontally deforming regions toward NW and SE directions. These spatial variation patterns are consistent with the expected direction, where the East Africa Rift Valley is expanding. In addition, the azimuth-offset data reveals slightly southward displacement in sediment area.

The ground at the subsiding region indicated ~62 cm subsidence and ~33 cm horizontal displacement toward SSE. The two-lobe pattern in eastern and western half each moved several centimeter upward and ~50 cm in NW-SE direction horizontally.

In order to describe the ground displacement in detail, we estimated a fault source model assuming slip distribution in a homogeneous elastic half-space. Considering the complexity of the fault geometry, we derive a non-planar fault source model with triangular dislocation elements. Based on the result captured by InSAR and the observed area is in tension field, we propose two fault segments. The model indicates dip-slip and strike-slip displacement with maximum slip of about 1 m and 75 cm at 2-4 km depth.

Derived slip distribution can well explain the spatial variation pattern acquired by InSAR. The amount of moment release inferred from the model (Geodetic Moment: GM) exceeds that of the earthquake swarm (Seismic Moment: SM), and the ratio (SM/GM) is 37.2 percent. The ratio indicates that significant aseismic crustal deformation contributes to GM.

Some interferograms also detected the crustal deformation associated with Mt. Oldoinyo Lengai eruption during the earthquake swarm. We will also discuss the relationship between the earthquake swarm and the volcanic eruption of Mt. Oldoinyo Lengai.

Keywords: InSAR, Crutal deformation, East Africa rift valley, Earthquake swarm, Continental techtonics, Tanzania

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Coseismic Deformation Detected by SAR and Fault Source Modeling of the 2009 Cinchona Earthquake (Mw6.1), Costa Rica

UMEMURA, Shutaro[1*] ; FURUYA, Masato[1]

[1]Department of Natural History Sciences, Hokkaido University

A shallow earthquake with magnitude 6.1 (Mw) occurred in Costa Rica, Central America, on 8 January 2009. This earthquake, called Cinchona earthquake, accompanied with many landslides and caused around 20 fatalities. In the proximity of epicenter, there is the Angel-Vara Blanca fault that has a strike NNW-SSE. Montero et al. (2009) inferred the fault as the earthquake source fault. After 4 days of the earthquake occurrence, Poas volcano located 6 km to the west of the epicenter erupted (Volcanic Explosivity Index 1) after a quiescence of one year. This volcano had remained dormant for a decade after 1996 and became active since 2006. As the 1st step to study the possible relationship between earthquake and volcanic eruption, we detected the coseismic deformation by using the ALOS/PALSAR data and created fault models to explain the data.

In this study, we used ascending (path 162, frame 190) and descending (path 465, frame 3410) data of ALOS/PALSAR. To correct for the topography effect, we used the digital elevation model of ASTER GDEM. We analyzed the SAR data with GAMMA software. In the interferogram processing, we removed the atmospheric noise. We calculated the Green's function by triangular dislocation elements using Meade (2007) scripts.

The detected interferogram indicated that the maximum coseismic LOS (Line of Sight) changes were 20cm for ascending and 22cm for descending track, respectively. We derived the fault source model that could explain the LOS changes by trial-and-error approach. The estimated strike/dip angle of the fault were 133/65, and the rake angle at the center of fault was -163 degree. The difference of fault parameter from Angel-Vara Blanca fault suggested that the previously unknown fault worked. We calculated the pressure change caused by fault movement. This indicated positive change (compression) under the Poas volcano.

Keywords: InSAR, Coseismic Deformation, Fault Source Model, Costa Rica

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An acceleration event of creeping slip detected by precise leveling survey at the central part of the Longitudinal valle

MURASE, Masayuki[1] ; MATSUTA, Nobuhisa[2*] ; LIN, Cheng-hong[3] ; CHEN, Wen-shan[4] ; LIN, Jui-jen[3] ; NISHIKAWA, Yuka[4] ; WADA, Erika[1] ; KOIZUMI, Naoji[5]

[1]Department of Geosystem, College of Humanities and Sciences, NIHON University, [2]Graduate School of Environmental Studies, Nagoya University, [3]Institute of Earth Sciences, Academia Sinica, [4]National Taiwan University, [5]The National Institute of Advanced Industrial Science and Technology

Precise levelling surveys were conducted across the central Longitudinal Valley Fault, eastern Taiwan, to understand the deformation of the transition zone between the stable fault creep area and the locked area, which maybe correspond to an asperity. In order to investigate the surface relationship between the fault creep area and the geological condition of the transition zone, we established levelling routes in the Yuli, and Chike-san areas. The Yuli area forms the geological boundary of the Lichi Melange Formation, which is composed of chaotic mudstones containing numerous exotic blocks of various sizes and lithologies. Along the Yuli route, located on the Lichi Melange, an uplift rate of 30 mm/yr was detected during the period 2010-2013, suggesting that aseismic fault creep might be continuing with long-term stability. Along the Chike-san route, located on no Lichi Melange, a vertical deformation rate of 8 mm/yr, 40mm/yr, and 20mm/yr were detected in the period 2010-2011, 2011-2012, and 2012-2013, respectively.

The creep slip distribution was estimated by using a two-dimensional single-fault model proposed at Chike-san in the period 2012-2013. Large slip rates were estimated at 4-5 km of the fault plane. At the previous periods 2010-2011 and 2011-2012, relatively large slip rates were estimated at two parts of the fault plane-one at a depth of about 1.5 km and another at a depth of 4-5 km-. We believe that the acceleration event of creeping slip was continued at the depth of 4-5 km in the period 2012-2013. The northern limit of the stable creep area may be the Yuli area. The episodic creep event occurred in the transition zone between the stable fault creep area and the asperity area. The boundary between the stable creep area and the episodic creep area is consistent with the geological boundary of the Lichi Melange Formation.

Keywords: Taiwan, Longitudinal valley fault, precise leveling survey, aseismic creep motion

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Internal stress changes due to point dislocations in a spherical earth

TAKAGI, Yu[1*] ; OKUBO, Shuhei[1]

[1]Earthquake Research Institute, The University of Tokyo

A simple and complete theory about internal deformations due to point dislocations in a homogeneous half-space was proposed by Okada (1992). This theory has been used by many researches to estimate Coulomb stress changes due to an earthquake and has contributed to understanding of seismology. Although a homogeneous half-space is a first approximation of the earth, global deformation like broad stress changes due to a great earthquake have to be calculated in a more realistic earth model, spherically symmetric earth model. Sun and Okubo (1993) succeeded in calculating surface displacements and gravity changes due to point dislocations in a spherically symmetric earth model. However, internal stress changes and displacements have never been calculated because there exist some difficulties to realize the calculation in spite of early proposal of a fundamental method (Takeuchi and Saito, 1972). In this research, we propose a strategy to realize the calculation of internal deformations and present some computational results.

We shall

i) outline the strategy to calculate internal deformations,

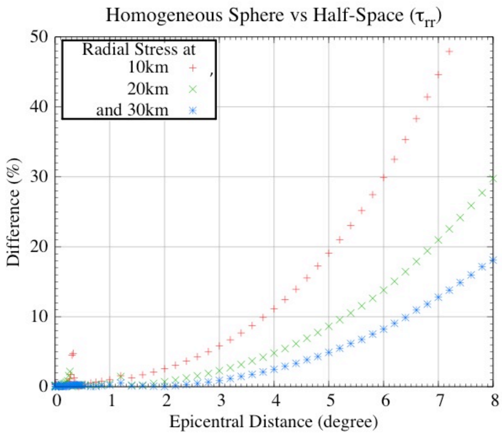
ii) compare the stress changes in a homogeneous sphere with those in a half-space which were already solved and

iii) show the results in a stratified earth model such as PREM.

Our study shows that significant difference between a homogeneous sphere and a half-space model occurs when epicentral distance exceeds several hundreds kilometers. For example, epicentral distances at which difference of radial stress changes in two models reach 10% are 4, 5 and 6.5 degrees at observation depth at 10, 20 and 30, respectively (Figure). Angular distance of 4 degrees, which is 400km, roughly equals the length of fault that is thought to have slipped in the 2011 Tohoku-Oki earthquake.

Figure. Difference of radial normal stress changes due to a vertical-strike slip at depth of 32km in two models, a homogeneous sphere and a half-space.The horizontal axis is epicentral distance and vertical axis is difference between the two models in percentage. Red, green and blue points indicate observation depth of 10, 20 and 30km, respectively.

Keywords: internal stress change, spherically symmetric earth, point dislocation, stratification



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

SSS33-14 Room:315 Time:April 30 14:15-14:30

Continuous measurements of ocean bottom crustal movements based on GPS-acoustic system using GPS buoy

IMADA, Naruyuki[1*] ; TERADA, Yukihiro[2] ; SAKAUE, Hiromu[3] ; TADOKORO, Keiichi[4] ; KATO, Teruyuki[5]

[1]Hitachi Zosen Corporation, [2]Kochi National College of Technology, [3]None, [4]Graduate School of Environmental Studies, Nagoya University, [5]Earthquake Research Institute, the University of Tokyo

We report the results of experiments of continuous measurements of ocean bottom crustal movements using GPS buoy and acoustic system.

We have developed a GPS buoy system for the early detection of tsunami. The system uses a buoy that is freely floating on the sea, tied to the sea bottom using an anchor, equipped with a GPS sensor at the top of the buoy. The system enables us to estimate the position of the buoy in a few centimeter accuracy.

On the other hand, Spiess (1985) and other researchers have developed the GPS-acoustic system for estimating the ocean bottom position in sub-decimeter accuracy. However, these systems have used owned or chartered vessels to measure the position of ocean surface, so that the measurements have been only intermittent. After the 2011 Tohoku-oki earthquake of Mw9.0, it has been recognized that continuous monitoring of ocean bottom crustal deformation is very important. Thus, we got an idea in that the GPS buoy could be used for the continuous monitoring of the ocean bottom crustal movements, if an acoustic system is equipped at the GPS buoy.

Based on this idea, we started experiments using our GPS buoy, which is located off Muroto Peninsula, western Japan, in the year of 2013. After a preliminary experiment in March 2013, we made an experimental observation from August to October of 2013. Three transponders were placed around the buoy and the equipment of sound sender/receiver at the side surface of the buoy. The water depth of the site is about 700meter and the ocean bottom transponders are placed so that the distances among these are in the same scale. We will report the results including noise characteristics of data, daily repeatability of estimated ocean bottom position, effects of swinging buoy, etc.

Currently, 15 GPS buoys have been established around the Japanese coasts. Augmentations of the acoustic system in these GPS buoy network will provide a powerful tool of monitoring ocean bottom crustal movements as well as tsunamis. Further requirements to GPS buoys are to be placed farther offshore, say, more than 100km from the coast. Recent developments of the GPS buoy system, including a newly developed algorithm, PPP-AR (precise point positioning with ambiguity resolution), clarified this requirements. However, still another problem of how data at the buoy placed far offshore is transmitted to land in real-time manner is still to be solved. For such problem of a newly designed high capacity data transmission system using a dedicated satellite system will be necessary. Our current experiment will provide an important data for designing a specification of such satellite system.

Spiess, IEEE Trans. Geosci. Remote Sens., 23, 502-510, 1985

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Movement of a fault arised by a pumping or a spring water and its understanding by poroelasticity -a case of NNW fault-

ISHII, Hiroshi[1*] ; ASAI, Yasuhiro[1]

[1]TRIES, ADEP

Tono Research Institute of Earthquake Science (TRIES) has developed a borehole stress meter for continuous observation and multi-component borehole instruments. At the present time about 15 borehole stations are in operation. We have investigated crustal movements and behavior of underground water by using data obtained from borehole observations. The depth of the deepest borehole is 1030 m.

Near TRIES, JAEA (Japan Atomic Energy Agency) is constructing deep boreholes with diameters of 4m and 6.5m. And depth is about 500m at the present time. The boreholes are 40m apart and connected by stages. NNW fault is running beside the 6.5m borehole. We are investigating a relationship between water flow and geophysical observations by using experiments of pumping water and spring water.

The main results obtained are as follows:

1. Water level of TGR350 borehole station decreases by pumping water and spring water. Data of the strain meters installed at 350m depth indicate right lateral movements of NNW fault.

2. Data of the strain meters installed at 350m depth indicate left lateral movements of NNW fault in case of recovery of water level.

3. Strain meters installed shallower depth (165m) and extensometers installed in sedimentary layer do not indicate such fault movements.

4. We have considered a mechanism explaining the phenomena by using poroelastic understanding.

We will present the details of observations and analyses.

Keywords: Deep borehole observation, Fault movement by spring and pumping water, Groundwater flow, Understand by poroelasticity, Continuously observable stressmeter

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Construction of Syobasama crustal activity observatory ?Installation of Ishii-type borehole stressmeter?

ASAI, Yasuhiro[1*] ; ISHII, Hiroshi[1]

[1]Tono Research Institute of Earthquake Science, Association for the Depvelopment of Earthquake Pred.

Large changes in the pore pressure in Toki granite have produced by the excavation of underground facilities of Mizunami Underground Research Laboratory (MIU) and drilling well for hydraulic tests in MIU (e.g. Asai and Ishii, JpGU2013). We have observed remarkable stress/strain/tilt variations associated with the pore pressure changes at borehole observation site TRIES, STG300 (on the north-east side of the fault), Togari(TGR350/TGR165), STG100, STG200 (south-west side), respectively within 500m of the MIU.

In this area the NNW trending sub-vertical (normal) fault is exists (e.g. JNC, 2003 and 2004). Pore pressure changes occurs in the south-west side of the fault, its impact were observed in water level/pressure record of the same side, and were also observed in stress, strain and tilt record. On the other hand, its impact were not seen in the water level/pressure record of the north-east side of the fault, but its impact were observed on stress, strain and tilt record. Pore pressure change occurs in the north-east side of the fault are similar to those of the south-east side. This observation results indicate that fault has impermeability and elastic deformation of the rock caused by pore pressure change extends over the fault.

In order to clarify the relationship of groundwater level changes to crustal strain changes at Syobasama observation site which is located approximately 1km northwest of MIU, Tono Research Institute of Earthquake Science has constructed the new borehole depth of 110 m and installation of Ishii-type borehole stress meters is scheduled in February 2014. We will present the details of construction of Syobasama observatory, and result of continuous stress observation with groundwater records.

Keywords: Pore pressure change, Elastic deformation, Mizunami Underground Research Laboratory, Ishii-type borehole stress meter