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

SSS31-01 Room:304 Time:May 25 14:15-14:30

Seasonal load variations, cGPS displacements, and crustal rigidity in Iceland

DROUIN, Vincent[1] ; HEKI, Kosuke[2*] ; SIGMUNDSSON, Freysteinn[1] ; HREINSDOTTIR, Sigrun[1]

[1]University of Iceland, [2]Dept. Nat. Hist. Sci., Hokkaido Univ.

Annual-cycle displacements can be seen directly on the cGPS network in Iceland. Every year, the country is subject to heavy snowfalls during winter times. The snow accumulates mainly over the five ice-caps and the highland in the central part of the island before melting during spring. This snow is expected to apply an important load on the crust. Other load like atmospheric load and water reservoir load are also subject to annual variations. Previous studies have shown that the crust has an elastic response to these loads.

We analyzed the time-series of 110 cGPS Icelandic stations processed using over 100 worldwide reference stations. We de-trended the data from its secular trends, mainly caused by plate spreading and glacial isostatic adjustments. Signals associated with earthquakes or volcanic activities were also removed. The annual and semi-annual components of the signal were estimated by finding their best fit to a sinusoid using least-square adjustments. In the end, only the stations with a good estimate of these components were kept.

Each of the three coordinates (East, North and Up) of the GPS time-series were analyzed. It appears that the Up coordinate is one with the clearer signal. It is also showing the biggest annual signal amplitude and is thus the more sensitive to annual load changes. By looking at it, we found that almost all cGPS stations show largest subsidence in April. The stations close to ice caps or to the central part of Iceland tends to have their maximum subsidence later than the station further away. It is also clear that the amplitude of the signal gets bigger the closer the station are to ice caps or to the central part of Iceland. These are indications that the snow load is the dominant load in the annual cycle in Iceland.

These data were inverted using the Green function assuming the Preliminary Reference Earth Model (PREM) to get a time-series of the load distribution. As expected, we found that load accumulate on the ice-caps especially on Vatnajokull, the biggest one.

We also had atmospheric pressure data, reservoir water-level data and an estimation of the snow load from a weather model. Using the same model as the inversion but in the direct way, we estimated the contribution of each of the load. We found that the atmosphere has a fairly homogeneous effect in Iceland with the maximum vertical amplitude of 2-3 mm and insignificant horizontal displacements. The reservoir water-level changes are only affecting nearby stations. The snow load data is in agreement with the inversion results: it is the main contributor to annual crust deformation in Iceland.

Having both the load data and the deformation data, we are also expecting to be able to get more information on the Icelandic crust rigidity. We will be able to find out if there is any relevant change in the crustal strength near the plate boundary or the center of the Iceland hot spot.

Keywords: GNSS, GPS, annual crustal deformation, seasonal changes, snow load, crustal rigidity

SSS31-02 Room:304 Time:May 25 14:30-14:45

Fault source modeling of the October 28, 2008 earthquake sequence in Baluchistan, Pakistan, using ALOS/PALSAR InSAR data

USMAN, Muhammad[1*] ; FURUYA, Masato[1]

[1]Hokkaido University

The Quetta Syntaxis in the western Baluchistan, Pakistan, is formed as a result of oroclinal bend of the western mountain belt and serves as a junction for different faults. As this area also lies close to the left lateral strike slip Chaman fault, which is supposed to be marking the boundary between Indian and Eurasian plate, the resulting seismological behavior of this regime becomes even more complex. In the region of Quetta Syntaxis, close to the fold and thrust belt of Suleiman and Kirthar ranges and on 28 October 2008, there stroke an earthquake of magnitude 6.4 (Mw) which was followed by a doublet on the very next day. In association with these major events, there have been four more shocks, one foreshock and three aftershocks that have moment magnitude greater than 5.Here we use ALOS/PALSAR InSAR data sets from both ascending and descending orbits that allow us to more completely detect the deformation signals around the epicentral region. On the basis of these data sets, we propose a four-faults model that consists of two left lateral and two right lateral strike slips that also include some thrust slip. We have thus confirmed the complex surface deformation signals even from the moderate-sized earthquake. Intra-plate crustal bending and shortening seem to be often accommodated as conjugate faulting without any single preferred fault orientation. We also discuss two possible landslide areas along with the crustal deformation pattern.

Keywords: ALOS/PALSAR data, Earthquake, Crustal Deformation, Source Modeling, Conjugate Faulting

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

SSS31-03 Room:304 Time:May 25 14:45-15:00

Possible repeating slow slip events beneath the Bonin Islands

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

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

Continuous global navigation satellite system (GNSS) data including the global positioning system (GPS) is one of the most powerful tools available for observation of Earth's surface deformation. In particular, coseismic, postseismic, slow transient, and interseismic deformation have all been observed globally by GPS over the past two decades, especially in subduction zones.

Here, we are using the deformation data from GPS observations to understand the deformation due to the earthquakes, afterslip and slow slip events in subduction zones around Japan, where geodetic data coverage is particularly dense. We are focusing on Bonin (Ogasawara) Islands Arc to understand its characteristic, especially the possibility of repeating Slow Slip Events (SSE). Global positioning system (GPS) time series in Bonin Islands Arc reveal the possible existence of slow slip events (SSEs) at the boundary between the Philippine Sea plate and Pacific plate.

Using data from this dense geodetic network operated by GSI, there are several possible events look like SSE that have one-year recurrence, detected by stations in Hahajima and Chichijima islands. These SSEs were identified from January 1996 to October 2014 by GNSS time series offset monitoring and rupture modeling with a rectangular fault located on the subducting Philippine Sea Plate. The detected SSEs were found to have a variety of characteristic recurrence intervals, magnitudes, durations, and coincide or relate with other seismic activities.

Time-decaying constant of these slow slips are first estimated to obtain the northward, eastward and vertical components of the ground deformation. Several methods are used to estimate the fault parameter including depth, dip, slip, strike, and width to understand its consistency with the fault boundary geometry. This process is followed by modeling the rupture area during the events and calculating the magnitude of these events based on geodetic approach.

These results lead us to further understanding about sequence of slow slip events in Bonin Islands Arc as a part of Philippine Sea plate.

Keywords: Slow Slip Event (SSE), Bonin Islands Arc, Ogasawara, GNSS, GPS

SSS31-04 Room:304 Time:May 25 15:00-15:15

Plate Convergent Process and Block Motions in Mindanao, the Philippines

SHIOMI, Masahiko[1*] ; TABEI, Takao[2] ; OHKURA, Takahiro[3] ; KIMATA, Fumiaki[4] ; ITO, Takeo[5]

[1]Grad. School Int. Arts Sciences, Kochi Univ., [2]Fac. Science, Kochi Univ., [3]Aso Volcanological Laboratory, Kyoto Univ., [4]Tono Research Institute of Earthquake Science, [5]Earthquake and Volcano Research Center, Nagoya Univ.

Tectonics of the Philippine Archipelago is characterized by westward subduction of the Philippine Sea plate (PHS) at the Philippine Trench in the east, eastward subduction of the Sunda plate (SUP) in the west, and left-lateral strike-slip movement of the Philippine fault inland. Ohkura et al. (2015) used GPS campaign measurement data spanning 2010-2014 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. The displacement rate field with respect to SUP shows that west-northwestward motions are dominant due to the convergence of PHS from the east but their spatial decay with increasing distance from the trench is not significant. Elastic deformation caused by a strong coupling at the PHS interface can not explain the observed displacement rates. Thus, they needed to introduce translations of multiple crustal blocks to interpret the observed deformation pattern. However GPS data in Mindanao are too sparse to conduct geodetic inversion analyses.

In this study, we introduce a Markov Chain Monte Carlo method (MCMC) into the simultaneous estimation of slip deficit distribution on the PHS interface, lateral slip along the Philippine fault and translations of multiple crustal blocks. MCMC can get posterior probability density function of unknown parameters from enormous number of forward calculations. In the modeling we represent configuration of the plate interface and fault segments of the Philippine fault by 64 and 4 rectangular elements, respectively. Slip deficit rates, lateral fault slip rates and block translation rates are searched by MCMC while the direction of slip deficit is fixed to that of the PHS-SUP relative motion.

Preliminary results show that southern portion of the PHS interface is strongly locked. But its contribution to the displacement rate field is as small as 29% of the observation at the maximum and the rest can be attributed to the translation of crustal block. Along the Philippine fault that is the major boundary between forearc and backarc blocks, slip rate changes from south to north even in Mindanao. While stronger locking is estimated in the southern segment, clear creep motion is detected in the north. Creep rate in the northern Mindanao is comparable to that detected in Leyte Island just north of Mindanao. Some segments of the Philippine fault are estimated to release strain stationary.

Keywords: MCMC, Philippine fault, Philippine Trrench, Mindanao, GPS observation

SSS31-05 Room:304 Time:May 25 15:15-15:30

Aseismic strike slip associated with the 2007 dike intrusion episode in Tanzania

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

[1]Graduate School of Science, Hokkaido University

In July 2007, an earthquake swarm initiated Northern Tanzania near Lake Natron and lasted for about two months. Mt. Oldoinyo Lengai, which located near the seismicity, began to erupt effusively before about a month later, and increased eruption intensity on September when the swarm almost ceased. The explosive eruption continued until April 2008.

Calais et al. (2008), Baer et al. (2008), and Biggs et al. (2009) have already reported the deformation associated with the swarm using InSAR. However, they mainly used ENVISAT/ASAR(C-band) images and only used images acquired from descending pass. We use both ascending and descending passes of ALOS/PALSAR (L-band) images. In addition to InSAR data, we also employ the offset-tracking technique to detect the signals along the azimuth direction. Using InSAR and offset-tracking, we could obtain the full 3D displacement field associated with the swarm.

The inferred full 3D displacement indicates that the graben-like-subsiding zone was horizontally moving by ~48cm toward SSW. To our knowledge, the horizontal movement at the subsidence zone has never been identified. To explain the displacement, we performed the fault source modeling. The fault slip distribution indicates that the ratio of strike slip component is about 20% of total moment release. Aseismic strike-slip creep motion might have also been responsible for the horizontal motion area and the swarm activity. We also confirmed that the stress changes due to the dike intrusion were consistent with the inferred fault slip distributions.

Keywords: InSAR, dike intrusion, aseismic slip, East African Rift valley, relay ramp

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

SSS31-06 Room:304 Time:May 25 15:30-15:45

Permeability change estimated by using frequency property of the atmospheric effect on groundwater discharge

MUKAI, Atsushi[1*] ; OTSUKA, Shigeaki[2] ; FUKUDA, Yoichi[3]

[1]Nara Sangyo University, [2]Kobe Gakuin University, [3]Graduate School of Science, Kyoto Univ.

The Rokko-Takao station in the southern Hyogo prefecture passes through the fracture zone of Manpukuji fault. Groundwater discharge about 550ml/s regularly takes place at this station. The groundwater discharge showed rapid changes due to earthquakes, as well as seasonal changes due to precipitation. For example, the groundwater discharge increased by about 50% just after the 2011 off the Pacific coast of Tohoku Earthquake. Mukai and Otsuka (2014) constructed one-dimensional groundwater migration model, in which groundwater flows in the confined aquifer from a source to the station, and estimated permeability change due to the 2011 Tohoku earthquake by using the observational data of groundwater discharge and pore pressure. The permeability just after the earthquake was about 20% higher than that before the earthquake. It was considered that the increase of permeability due to the earthquake was caused by the seismic motion that loosed or swept mud in the crack in the surrounding crust.

Permeability change is expected to have influences on the atmospheric effect of groundwater discharge as well. In this study, we constructed one-dimensional groundwater migration model with periodic atmospheric loading on the confined aquifer, and estimated secular change of permeability by applying the model to the atmospheric effect of groundwater discharge observed at the Rokko-Takao station. The atmospheric effect admittance of groundwater discharge is expressed to be 'a$*\sqrt{}$ (f)' when the atmospheric pressure varies with the frequency 'f'. Coefficient 'a' in this equation is proportional to ' $\sqrt{}$ (k$*$S)' that is square root of permeability 'k' and storage coefficient 'S'. Therefore, we can estimate permeability change by investigating the frequency property of the atmospheric effect for various periods.

We conducted frequency analysis by applying FFT to the groundwater discharge observed at the Rokko-Takao station and the atmospheric pressure observed at the Kobe local meteorological office in the range from 2001 to 2013, and calculated the atmospheric effect admittance of groundwater discharge with frequency domain. In this calculation, we obtained the frequency properties for 348 windows with size 2048 data (85.3 days), and the window was shifted from the former one by 240 data (10 days). After then, coefficient 'a' was estimated by applying the equation ' $\sqrt{}$ (f)' to the frequency property of the atmospheric effect admittance in the periodic band from 0.5 to 7 days, because there is high correlation between the groundwater discharge and the atmospheric pressure in that periodic band. The coefficient 'a' just after the 2011 Tohoku earthquake increased twice as high as that before the earthquake. This agrees to the conclusion of Mukai and Otsuka (2014) of based on time domain analysis. We could find the increase of the coefficient 'a', or permeability increase, after the great earthquake such as the 2004 off Kii Peninsula earthquake as well.

Precipitation as well as earthquakes have the influences on the coefficient 'a', which shows positive correlation with the seasonal change of accumulated precipitation during the almost period since 2011. It might be considered that pore pressure increase due to precipitation causes looseness or outflow of mud in the crack and permeability increase.

Keywords: permeability, groundwater discharge, atmospheric effect

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

SSS31-07 Room:304 Time:May 25 15:45-16:00

How much was the interseismic strain released by the 2011 Tohoku-oki earthquake?

OHZONO, Mako[1*] ; HASEMI, Akiko[1]

[1]Faculty of Science, Yamagata University

In order to estimate the value of released strain at the 2011 Tohoku-oki earthquake with respect to interseismic accumulated geodetic strain in northeastern Japan, we analyze daily coordinates (F3 solutions) obtained from GEONET, operated by GSI. During the interseismic period, northeastern Japan had been under the EW contractional field with the order of ˜0.1 ppm/yr, affected by interplate coupling between Pacific plate and Okhotsk plate. On the other hand, the 2011 Tohoku-oki earthquake released these accumulated strain generating mainly EW extentional field. The value ran to several 10 ppm near the hypocenter. We assumed that the period between 1996 and 2002 is interseismic period and its strain rate reflects stable state. Then, we compared this maximum principal strain rate to coseismic released strain toward to interseismic principal strain axis at each area. Around the eastern Pacific coast, the coseismic strain released accumulated interseismic strain of 500-100 years. Back-arc region and northern part of central Japan are released the interseismic strain of 50-100 years and several-several decades by the coseismic event, respectively. In spite of the extentional field at almost all are at the earthquake, some local areas show contraction toward the interseismic principal axes. This is caused by the difference of the direction of interseismic principal axis and coseismic extensional direction, and this may imply a possibility that this strain field change triggered seismic activity in inland after the 2011 Tohoku-oki earthquake. As an example, Yonezawa area in Yamagata prefecture, which is activated seismicity after the 2011 event, became contractional field by the coseismic strain with respect to interseismic principal strain axis. Consideration of this strain change is important to consider the strain accumulation process for the next inland earthquakes in the future. In addition, this geodetic approach will provide independent information to the discussion of stress field change by the seismological data.

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

SSS31-08 Room:304 Time:May 25 16:15-16:30

Characteristics of viscoelastic relaxation caused by the 2011 off the Pacific coast of Tohoku earthquake

SUITO, Hisashi[1*]

[1]GSI of Japan

We are developing a 3-D viscoelastic model using the Finite Element Method to describe the postseismic deformation following the 2011 Tohoku-oki earthquake. A purpose of this presentation is to describe the characteristic of the viscoelastic relaxation. Our model is composed of an elastic crust and subducting plate, plus a linear (Maxwell) viscoelastic upper mantle wedge and mantle beneath the slab (oceanic mantle). The viscoelastic relaxation strongly depends on the viscosity of the upper mantle. The viscoelastic relaxation at oceanic mantle produces westward displacements and subsidence. On the other hand, the viscoelastic relaxation at mantle wedge produces eastward displacements and uplift. Therefore, observed westward displacement and subsidence at sea area are probably produced by the viscoelastic relaxation at oceanic mantle, and eastward displacement at the land area and uplift at the Pacific side are produced by the viscoelastic relaxation at mantle wedge. If the viscosity of the oceanic mantle is smaller than that of the mantle wedge, westward displacement and subsidence are dominant. On the other hand, if the viscosity of the oceanic mantle is larger than that of the mantle wedge, eastward displacement and uplift are dominant. Hence, the ratio of the viscosity between mantle wedge and oceanic mantle is important to quantitatively explain the observed displacements.

Keywords: Tohoku-oki Earthquake, Postseismic deformation, Viscoelastic relaxation

SSS31-09 Room:304 Time:May 25 16:30-16:45

Crustal tectonic stress and poroelastic relaxation of the Mw 9.1 tohoku earthquake

PANUNTUN, Hidayat[1*] ; MIYAZAKI, Shinichi[1]

[1]Graduate School of Science, Kyoto University

The Mw 9.1, Tohoku-oki earthquake has been investigated by many scientists. This earthquake produces changes in the state of strain and stress in the surrounding rupture area. Postseismic deformation following large earthquake including afterslip, viscoelastic relaxation, and pore fluid flow, further modify strain and stress near a fault. The migration of fluid after earthquake from high-pressure area to low-pressure area modify stresses and pore pressure near fault and cause pore pressure changes in the surrounding rocks. This pore pressure changes are a part of coulomb stress calculation for fault interaction analysis.

By using various input of slip model, we calculate undrained coseismic pore pressure and coulomb stress change due to the earthquake (King, Stein, & Lin, 1994; Cocco & Rice, 2002) and its poroelastic relaxation by using green's function proposed by (Kalpna & Chander, 2000). The strain and stress due to slip on the fault are calculated by using analytical expression of (Okada, 1992) and consider stress-strain relation for an isotropic form of Hooke's law, respectively. We find that pore pressure changes following the tohoku-oki earthquake is increased through relaxation in the dilatation region which further modified coseismic coulomb stress in surrounding region. We estimates the pore pressure variation from the first 50 days following the tohoku earthquake has change from 7.08 MPa to 2.62 MPa in the dilatation region, and in the compression region, it change from -9.37 MPa to -3.46 MPa.

Keywords: pore pressure, poroelastic relaxation, coulomb stress

SSS31-10 Room:304 Time:May 25 16:45-17:00

Change of groundwater behavior caused by 2011 Tohoku earthquake detected from pore pressure and gravity

KINOSHITA, Chihiro[1*] ; KANO, Yasuyuki[2] ; TAMURA, Yoshiaki[3] ; IMANISHI, Yuichi[4] ; IKEDA, Hiroshi[5] ; ITO, Hisao[1]

[1]Graduate School of Science, Kyoto University, [2]Reserch Center for Earthquake Prediction,Disaster Prevention Research Institute, Kyoto University, [3]National Astronomical Observatory of Japan, Mizusawa VLBI Observatory, [4]Earthquake Research Institute,The University of Tokyo, [5]Cryogenic Division Research Facility Center, University of Tsukuba

At the Kamioka mine, Gifu prefecture central Japan, several kinds of apparatus, such as seismometer, strainmeter, tiltmeter and laser extensometer, have been installed. We have been monitoring pore pressure and barometric pressure at this mine. Pore pressure remarkably decreased at the time of the earthquake, although the hypocentral distance of 2011 Tohoku earthquake is 528 km. This reduction of pore pressure was equivalent to 2-3 m decrease of groundwater level. It was the largest response during the observation period. The pore pressure reduction had continued for a few days. We anticipated the causes of the reduction were creation of new water path or permeability increase. We focused on Earth tide which can be assumed that it's effect is almost constant. We extracted Earth tidal response of pore pressure by the tidal analysis program BAYTAP-G (Tamaura et al., 1991). We compared it before and after the earthquake and the amplitude of M2 constituent reduction was seen from 22 to 16 Pa. O1 constituent also slightly responded to the Tohoku earthquake and these results indicate the rock property change. We estimated the hydraulic diffusivity to evaluate permeability of rock. From the analysis, adopting theory of linear poroelasticity and diffusion equation, we found that diffusivity increased about two fold after the Tohoku earthquake (Kinoshita et al., 2015). If these results are real, other instruments should also capture the change of diffusivity and groundwater behavior induced by earthquake.

The superconducting gravimeter have been installed at the same mine. This observation started in 2004 which is located 2.5 km apart from our pore pressure monitoring point. We analyzed gravity data by the same method as used for the pore pressure analyses. We suppose that if permeability of rock increases, gravity should be changed because gravity reflects the density of underground. The tidal response of gravity is clearer than that of pore pressure and we can compare the other constituents (Q1, M1, N2 constituents). While gravity analysis has difficulty because of large disturbance caused by heavy snow around this region in winter in the case of the Kamioka mine. Imanishi et al. (2014) indicates that the data of gravimeter has decreased after the Tohoku earthquake and it could not be explained only by the crustal deformation. It implies that the density change occurred. We will show the tidal analysis results of pore pressure and superconducting gravimeter, and report the hydraulic parameter change after the Tohoku earthquake.

Keywords: pore pressure, superconducting gravimeter, Tohoku earthquake, Earth tide

SSS31-11 Room:304 Time:May 25 17:00-17:15

Postseismic deformation of the 11 April 2011 Fukushima Hamadori (Mw=6.6) earthquake inferred from GPS observations

HORI, Kayako[1] ; AOKI, Yosuke[2] ; KATO, Teruyuki[2*] ; MIYASHITA, Kaoru[1]

[1]Graduate School of Science and Engineering, Ibaraki University, [2]Earthquake Research Institute, University of Tokyo

The 2011 Fukushima Hamadori earthquake (Mw=6.6) is one of aftershocks of the 2011 Tohoku-oki earthquake (Mw=9.0). While the coseismic deformation field due to the Fukushima Hamadori earthquake is derived from InSAR measurements, leading to detailed slip distribution (Kobayashi et al., 2012; Fukushima et al., 2013), SAR data is not available to decipher postseismic deformation because the ALOS satellite terminated its operation right after the Fukushima Hamadori earthquake. GPS observations are thus the only way to delineate postseismic displacements of the earthquake. Here we try to detect the postseismic deformation of the Fukushima Hamadori earthquake and investigate the mechanism of it.

We assumed that the observed displacements are a combination of 1) rigid plate motion, 2) postseismic deformation of the Tohoku-oki earthquake, and 3) the triggered afterslip of the Fukushima Hamadori earthquake that results from fault creeps around the hypocenter of the mainshock, all of which are simultaneously estimated by solving an inverse problem. Because the postseismic deformation of the Tohoku-oki earthquake has prominent long-wavelength features compared with the spatial scale of this study, we approximated the deformation by either linear, quadratic, cubic, or quartic function. A statistical assessment indicates that the postseismic deformation of the Tohoku-oki earthquake is most appropriately represented by a cubic polynomial.

Our results indicate that, in the first six month, the afterslip is concentrated at the deeper and horizontal extension of the mainshock rupture and the shallowest part of the mainshock rupture. Of these, location of the slips in the horizontal extension of the mainshock rupture depends on the size of the fault we assume probably because of insufficient coverage of GPS sites.

We found that the observed displacement field during the first 12 months is inconsistent with the afterslip, invoking the need for assessing a contribution of viscoelastic relaxation. A preliminary analysis with a viscoelastic halfspace overlaid by a 25-km thick elastic layer indicates that a viscosity of 1×10^{18} Pa s, a very low value for a upper mantle viscosity, seems to be consistent with the observed postseismic displacements.

Keywords: Crustal deformation, GPS, Postseismic deformation, Normal faulting earthquake