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

SCG74-P01 Room:Convention Hall Time:May 24 17:15-18:30

Perturbation of small repeating earthquake depending on frictional properties

ARIYOSHI, Keisuke[1*], MATSUZAWA, Toru[2], HINO, Ryota[2], HASEGAWA, Akira[2], KANEDA, Yoshiyuki[1]

[1]Japan Agency for Marine-Earth Science and Technology, [2]RCPEV, Tohoku University

Owing to recent development of seismological observation network, small repeating earthquake analysis has been confirmed as an effective approach to estimate slip history or coupling ratio on subduction plate boundaries, especially near source regions of megathrust earthquakes where inland GPS network would have difficulty estimating it with high precision. Some of repeating earthquake analyses shows that estimated slip amount tends to be smaller than that estimated from GPS analysis. This discrepancy is thought to be caused by failure in detecting non-similar earthquakes with low cross-correlation coefficient due to stress perturbation around the source regions. Ariyoshi et al. [2007 GRL] pointed out that slow slip events temporarily occur in the deeper source region of a repeating earthquake during the passage of large postseismic slip. However, this is only one example of non-similar earthquakes, and other types of them may occur with different conditions of effective normal stress or constitutive friction law. In order to investigate it, we perform numerical simulations of non-similar earthquake with stress perturbation.

In case of slowness-law, our simulation shows that slow slip events usually occur but regular earthquakes temporarily occur under the same frictional properties and lower effective normal stress due to shallower focal depth or higher pore pressure, which is the opposite result from Ariyoshi et al. [2007 GRL]. In case of moderate effective normal stress, repeating earthquakes usually occur and become temporarily active in the passage of large postseismic slip. In case of slip-law, similar characteristics are shown but its range of effective normal stress between regular and slow earthquake is significantly narrower than that of slowness-law. The temporary activation with moderate effective normal stress could not have been reproduced by many trial simulations we have done so far. For deeper focal depth, no slip events occur for a long period before and after a large interplate earthquake. We think that such differences come from the narrow range of effective normal stress generating slow earthquake for slip-law [Ampuero and Rubin, 2008 JGR], which would be applied to stress perturbation due to large postseismic slip.

Comparing with observational results, we think that actual condition of subduction zone of the Pacific plate may obey slowness-law or slip-law under moderate effective normal stress being nearly constant over a wide depth range. Considering the fact that repeating earthquakes occur three times just after the 2011 Tohoku-oki Earthquake, we conclude that slip-law can not be applicable to the actual plate interface. In this presentation, we will discuss the validity of several types of friction laws including composite-law [Kato and Tullis, 2001 GRL] or PRZ law [Perrin et al. 1995 JMPS] as well as slowness-law and slip-law, toward developing evaluation of crustal deformation accompanied by megathrust earthquakes such as the 2011 Tohoku-oki Earthquake by analyzing repeating earthquakes and numerical simulations based on the friction law.

Keywords: non-similar earthquake, slip estimation by repeating earthquake analyses, numerical simulation based on friction law, postseismic slip propagation, effect of geofluid and focal depth, interplate earthquake, interplate earthquake

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SCG74-P02 Room:Convention Hall Time:May 24 17:15-18:30

Current status and future plan of seafloor geodetic observation for 2011 Tohoku-oki earthquake

KIDO, Motoyuki[1*], OSADA, Yukihito[1], IINUMA, Takeshi[1], FUJIMOTO, Hiromi[1]

[1]RCPEV, Tohoku University

We have detected considerably large coseismic displacement associated with the 2011 Tohoku-Oki earthquake thorough GPS/acoustic geodetic surveys. Taken them together with those observed by Japan Coast Guard and wide-spread array of seafloor pressure gauges, the data definitely contribute to elucidate the coseismic slip distribution of the earthquake based on numerical inversion analysis, the result of which we did not expected with our knowledge before the earthquake, but is supported by many other observations after the earthquake. The unexpected feature is not only in the coseismic slip distribution but also in postseismic deformation. GSI has been monitoring the postseismic deformation using GEONET and reported reasonable slip distribution that compensates the coseismic slip of the main shock mainly in the western (and hence deeper) adjacent area. However, our repeated observations after the earthquake indicate complexity in the postseismic slip, including further slip even at the main coseismic slip area near the trench. In addition, the deformation seems to still continue with a considerable rate.

To elucidate the complexity, Tohoku University and Nagoya University plan to drastically extend the seafloor geodetic survey sites along the Japan Trench by this summer under the accelerated project promoted and funded by MEXT. The total number of survey sites being planned is about 20, to be distributed mainly on deeper seafloor near the trench, in where the deformation cannot be inferred from onshore GPS network. The most of the survey sites consist of four transponders while some important sites consist of six transponders, which can effectively correct the effect of undesired spatial variation in sound speed in ocean. The new transponders are designed against long ranging over 10 km distant at depth and are compatible with both the systems of the university groups and Japan Coast Guard.

The other key of the project is the introduction of an autonomous moving buoy, which can navigate itself along programmed path or remotely operated on demand away from a research vessel. The utilization of this extra buoy will lead surveys to be more efficient or precise taken with an existing towing buoy simultaneously. The power for electronics and propulsion will be supplied by diesel oil lasting for at least two days per fuel. The autonomous buoy is an all-in-one system and the allover length is 3 m at most, which can be dealt with any researcher on any vessel. This promotes new research groups to begin their own GPS/acoustic survey. Systematic result of displacements in postseismic deformation will be obtained after the second time of survey to be conducted by the end of the fiscal year of 2012.

Keywords: 2011 Tohoku-Oki earthquake, seafloor crustal deformation, postseismic deformation, seafloor geodesy

SCG74-P03 Room:Convention Hall Time:May 24 17:15-18:30

Postseismic deformation following the 2011 off the Pacific coast of Tohoku earthquake and its mechanism

SUITO, Hisashi[1*], OZAWA, Shinzaburo[1], NISHIMURA, Takuya[1], TOBITA, Mikio[1]

[1]GSI of Japan

The postseismic deformation caused by the 2011 off Pacific coast of Tohoku earthquake exceeds 90 cm for 10 months after the main shock. The coseismic subsidence area begins to uplift except for the area in the Iwate prefecture. Estimated afterslip exceeds 3.0 m and extends to west, south and north of the coseismic slip area with a moment of 9.15 x 10^{21}Nm for 10 months. The area of the afterslip was extended westward and reaches a depth of approximately 90 km of the subducting plate. Northern and southern edges of the area of afterslip seems to be limited by the source region of the 1994 Sanriku-Haruka-oki earthquake and the north limit of the overriding Philippine Sea plates, respectively.

We report the latest status of the postseismic deformation and estimated afterslip model in the meeting. We also report the deformation due to the other mechanisms, such as viscoelastic and poroelastic rebound.

Keywords: 2011 off the Pacfic coast of Tohoku earthquake, postseismic deformation, afterslip, viscoelastic relaxation, poroelastic rebound

Japan Geoscience Union Meeting 2012
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SCG74-P04 Room:Convention Hall Time:May 24 17:15-18:30

Spatio-temporal distribution of afterslip due to the 2011 Tohoku-Oki earthquake from MCMC inversion

SUZUKI, Syota[1*], ITO, Takeo[1], HYODO, Mamoru[2], SATO, Kachishige[3], NOGUCHI, Takumi[4]

[1]Nagoya University, [2]JAMSTEC, [3]Tokyo Gakugei University, [4]Fluid Enginieering Co., Ltd.

INTRODUCTION

The 2011 off the Pacific coast of Tohoku Earthquake (Mw9.0) occurred at 5:46 a.m. on March 11, 2011 (UTC). In northeast Japan, an earthquake of magnitude 9 has first recorded in history. Moreover, the information of the huge earthquake is poor in the world. On the other hand, national GPS observation network (GEONET) observes detail of crustal deformation. GEONET observes eastward post-seismic displacements due to the Tohoku-Oki earthquake on the plate interface. We asuume that the post-seismic displacement is due to an afterslip. In order to understand earthquake, it is important to infer stress state and frictional behavior on the plate boundary from spatio-temporal distribution of afterslip (Hsu *et al.*,2006). Hence, we estimate spatio-temporal distribution of afterslip due to the 2011 Tohoku-Oki earthquake.

GPS DATA

In this study, we used daily coordinates of GPS station (F3 solution), which is observed by GEONET and analyzed by Geospatial Information Authority of Japan (GSI). The period of observation is from 1996 to now. In this period, the time series of crustal deformation include a liner trend, annual variations, and co- and post-seismic deformations. They can be modeled by a linear, trigonometric, Heaviside-step and logarithmic functions, respectively. We estimate these model parameters using least square method for linear part and the interior-reflective newton method for non-linear part (Coleman *et al.*, 1996). We extract the post-seismic displacements due to the Tohoku-Oki earthquake through a modeling of time series of crustal deformation.

INVERSION METHOD

We use a method based on a Markov chain Monte Carlo (MCMC) Method to estimate the spatiotemporal distribution of afterslip. The conventional inversion method, such as least squares method, estimates one solution for each unknown parameter. On the other hand, MCMC method estimates probability density functions (PDFs) of each unknown parameter. Especially, MCMC method represents an under-determined problem as the correlation between each solution. To estimate afterslip distribution, the observation equation, representing a relation between observed data and the afterslip distribution, is written as $\mathbf{d} = \mathbf{G}\,\mathbf{m}$. Here, $\mathbf{d}$ is an observation data, $\mathbf{m}$ is afterslip of every sub-fault in strike and dip directions, and $\mathbf{G}$ is a Green function that is the coefficient matrix which defines a relation between $\mathbf{d}$ and $\mathbf{m}$, and including the coefficient of Laplacian smoothing parameter. In this study, we use a Green function considered a 3-dimensional heterogeneous structure in northeast Japan, which is produced by 3D Finite Elements Method. In the smoothing parameter, we employ weighted Laplacian smoothing regularized by scale of the Green function. The sampling method of MCMC is Metropolis-Hastings algorithm. In order to enhance computational speed, we use GPU (Graphics Processing Unit), because MCMC method needs large amounts of calculations.

RESULTS

Mainly afterslip locates in depth range between 25 and 35 km, and in width range of 400km, which is below the co-seismic slip distribution (Simons *et al.*, 2011). The peak of afterslip is about 3m in Fukushima-Oki after 7 months from the Tohoku-Oki earthquake. This area agrees with the area of the 1983 Fukushima-Prefecture-Oki earthquake. For the temporal change of afterslip, the large afterslip started at off the Fukushima prefecture. After then, afterslip move to off the Iwate prefecture. Furthermore, the spatial distribution of residual is similar pattern of interseismic strain concentration area.

Keywords: Tohoku-Oki earthquake, afterslip, Malcov chain Monte Carlo method, Green function using FEM

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SCG74-P05 Room:Convention Hall Time:May 24 17:15-18:30

Temporal changes of Toki ACROSS signal induced by the 2011 off the Pacific coast of Tohoku Earthquake

KUNITOMO, Takahiro[1*]

[1]Takahiro Kunitomo

Temporal changes of waveform and travel time of Toki ACROSS signal observed by Hi-net induced by the 2011 off the Pacific coast of Tohoku Earthquake (2011 Tohoku Earthquake as follow) are repored. At Toki station, the current specifications of seismic signal being transmitted since Mar. 2007 (ongoing for ˜ five years) are as follows: FM signal with a carrier frequency of 13.005 Hz, modulation period 50s in the frequency range 10.245-19.445Hz and ˜2700N in spectrum amplitude. The signal and operational mode of rotary transmitter with the vertical rotation axis are optimized for acquiring the accurate tensor transfer function data in frequency domain and Green's function in time domain between the source and receivers located anywhere.

The major results observed at Hi-net Yaotsu (11.3km form Toki station) are as follows:

1) Difference waveforms between daily stacked waveforms and a reference waveform stacked one year data (Apr. 2008 to Mar. 2009) show notable changes of P and S wave later phases after March 11, 2011. These changes are decaying as the month move on, but waveforms do not return to its former state as at December 2011. These changes are thought to be due to groundwater fluctuation induce by the 2011 Tohoku Earthquake.

2) Daily travel time changes of maximum amplitude phases (including direct P wave, direct S wave and these later phases) were calculated using the cross-spectral method. Travel time changes up to 2 msec delay was detected at March 11, 2011. This changes are decaying as the month move on, but travel times do not return to its former state as at December 2011.

Acknowledgement: Hi-net data are provided by National Research Institute for Earth Science and Disaster Prevention, Japan (NIED). Toki ACROSS transmitting station is managed by Japan Atomic Energy Agency (JAEA).

Keywords: travel time change, crustal movement

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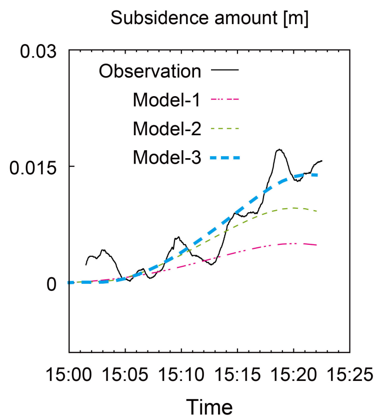
Detection of tsunami-induced deformation caused by the 2011 Tohoku earthquake using on-land GPS network

MITSUI, Yuta[1*], HEKI, Kosuke[1]

[1]Sci., Hokkaido Univ.

The 2011 Tohoku earthquake on March 11 caused massive tsunami. We first detect a land-deformation signal due to the tsunami using on-land GPS network. We focus on GPS stations along the Sanriku coast, and stack the GPS data at seven coastal stations and seven landward stations respectively. The data show that relative subsidence at the coastal stations to the landward stations had occurred on the order of 1 cm until almost 30 minutes after the Tohoku earthquake. We check whether the subsidence signal corresponds to simulated land deformation based on a tsunami simulation model, and confirm the tsunami hypothesis for the subsidence. We find that a popular elastic model with a stratified velocity structure (Gutenberg-Bullen earth model) for the Green's function leads to underestimation of the subsidence amount about 1/2-1/3. Effect of compliant materials near the surface may be important to estimate tsunami-induced land deformation.

Keywords: The 2011 Tohoku earthquake, tsunami, load deformation, comparison between observation and simulation



SCG74-P07 Room:Convention Hall Time:May 24 17:15-18:30

Gravity changes due to the 2011 Tohoku earthquake recorded by superconducting gravimeters

IMANISHI, Yuichi[1*], TAMURA, Yoshiaki[2]

[1]ERI, The University of Tokyo, [2]NAOJ

The 2011 Tohoku earthquake caused large scale crustal deformations, both coseismic and postseismic, in a wide area of the Japanese islands. As a result, surface gravity must have indicated not only coseismic changes but also long-term changes. In addition, secular changes due to the viscoelastic properties of the crust and the mantle may be observed in gravity recordings.

This earthquake is the first event in which three superconducting gravimeters (Mizusawa, Matsushiro and Kamioka) were in operation not far from the source region of an M9 class earthquake. Although these gravimeters suffered from severe disturbances due to the main shock and the aftershocks, they have been producing almost continuous recordings of gravity. As the data are accumulated, crustal deformations as seen from gravity may be revealed by long term gravity observations with the superconducting gravimeters. We are working on separation of the signals by making corrections for the atmospheric and hydrological effects on gravity.

Keywords: superconducting gravimeter, 2011 Tohoku earthquake

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Mechanism of induced earthquakes of the 2011 Off Pacific coast of Tohoku Earthquake according to aftershocks activity

KAWABE, Takayuki[1*], NAKANO Keiji[2]

[1]Faculty of Education, Art and Science, Yamagata University, [2]Terra-Fluid Systems

Many induced earthquakes occurred after the Off the Pacific coast of Tohoku Earthquake in 2011. According to the GPS-network measurement, the Northeast Japan expanded more than 5m to the east. This means that a tensional stress affected to the upper crust and the stress field of the upper crust of Northeast Japan would be reduced. So, the fuluids occured in the lower part of the upper crust, and uplifted into the upper part of the upper crust. This is causing the induced earthquakes.

Keywords: induced earthquake, mechanism, hipocentral distribution, geologic structure, reduced stress, uplifting by fluid

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Geomorphologic analysis of the co-seismic deformation of the seabed in the tsunami source area of the Tohoku Earthquake

BAO, Badalahu[1*], Akira Takeuchi[2]

[1]Graduate School of Science and Engineer, University of Toyama, [2]Faculty of Science, University of Toyama

Abstract
The 2011 off the Pacific coast of Tohoku Earthquake happened on March 11, 2011, generated huge tsunamis and caused many fatalities and missing in the Hokkaido, Tohoku and Kanto regions.

According to Japan Agency for Marine-earth Science and Technology, JAMSTEC, seabed topography in off the coast of Tohoku deformed at the giant earthquake event by active faults along the Japan Trench.

We identify a series of faults from bathymetric data obtained before and after the giant event. Bathymetric data after the earthquake had acquired by KH11-7 cruise of the JAMSTEC R/V Hakuho-maru and YK11-E06 cruise of the JAMSTEC R/V Yokosuka in 2011, and the data before earthquake were acquired and compiled by Japan Coast Guard.

By deciphering and comparing the coseismic deformation of the seabed in both map view and vertical sections, we confirmed the location and attitude of the active faults that caused great slip at the shallow tip of the plate boundary.

The resultant slip model corresponds to the relationship of seabed topography with tsunamigenic displacement in the tsunami source region.

The rises located in the center of the trench bottom are asymmetric in profile, the landward side dips gentle and the seaward side is steeper. They are chained almost north-southerly, in the trench floor from 38o02' to 38o05'N, about 5.5 km.

Examined the correspondence between the results of geomorphlogical analysis and the slip distribution models, the distribution of asymmetric ridges formed by the earthquake is ristricted in the area 143o57'˜144o03E', and 38o00'˜38o07'N and almost coincide with large displacement area in slip distribution model in Iinuma et al.(2011).

The trench floor west of the anticlinal ridges and the lower landward trenchslope display apparent uplift by about 50 m, while no significant change was detected in the seaward.

From this we can consider that, the asymmetric ridge is caused by reverse faulting of the plate interface, and the layers of trench floor sediment were deformed in a style of detachment fold.

The fault scarps distributed on the landward trench-slope before the earthquake were disappeared after the earthquake. This is because the hanging wall of a spray fault might be raised to caused the giant tsunami.

In the landward trench-slope many new landslides and fault scarps were formed. Numbers of small landslides appeared along the fault scarps. Some of them are accompanied by sedimentary terraces.

Consequently, we estimated the trench floor and the landward trench-slope were uplifted and displaced seaward by the coseismic slippages of the decollement surface and splay faults during the giant earthquake. Such seafloor deformation conformed by this study might explain the reason of the sharp peak wavelet of the giant tsunami.

Those changes in seafloor topography due to large slip of the decollement surface and the splay faults during the earthquake, we may provide one of criteria in screening of slip distribution models.

Keywords: Off Tohoku Earthquake, Geomorphological Change, Morphological survey, The KH11-07 Cruise, Japan Trench, Seafloor Faults

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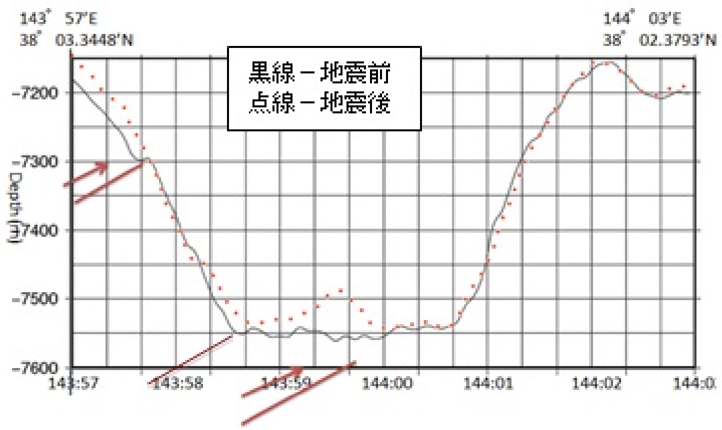

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The Great Eastern Japan Earthquake 2011 and Its Mechanisms According to the Theory of Solid State Lithologic Flow

MADO, Shinichiro[1*]

[1]Mado Research Office of Sciences and Arts

1. Introduction

The Great Eastern Japan Earthquake, hit Tohoku and Kanto districts in Japan on March 11th 2011, was estimated 9.0 in its magnitude. It is the greatest earthquake which Japanese have ever experienced. However, it brought us very curious evidences to reconsider the orthodox theory about mechanisms of great earthquakes. Especially, the key for understanding seems to be the theory of solid state lithologic flow. Therefore, we discuss it in this paper.

2. A question about mechanisms of great earthquakes

The orthodox theory about mechanisms of great earthquakes was based upon plate tectonics and thermal mantle convection. However, the theory of solid state lithologic flow also explains that. Althogh it appears as if the two theories were able to explain the same phenomena, **the primal difference between them lies on the force which causes the crustal movements**.

3. Orthodox theory

The orthodox theory explains the great earthquakes with plate tectonics. The theory premises on thermal convections within mantle. This theory also premises that **the internal thermal energy in the Earth creates the force to drive convections**. To the east of Japan there is Japan Trench. The Pacific Plate lies under the bottom of the Paciphic Ocean east of Japan Trench. The orthodox theory supposes that there is a current of thermal mantle convection that flows under Japan Trench from the Paciphic Ocean side, and that the mantle convection drag the Paciphic Plate into the layer under Japan. Therefore, the Japan Islands are gradually subsiding with the Paciphic Plate. However, because the specific gravity of the continental Plate including the Japan Islands is smaller than the Paciphic Plate, the buoyancy makes a sudden rise after a while. At that sudden rise, a great earthquake and a great tsunami occur. **Nevertheless, coast subsidences were observed instead of coast upheavals.** This fact is enough for us to doubt the orthodox theory.

4. Mechanisms of the earthquake based on the theory of solid state lithologic flow

Please look at the figure.

A) As if it were a glacial flow, the solid state lithologic flow from higher places to lower places is made by gravity.

B) Since the Japan Trench is a very low place, the solid state lithologic flow flows into the trench. Therefore, there is the forefront of the flow on the trench.

C) The forefront of the flow run into the lithologic plate of the bottom of the Pacific Ocean. Then, it run over the plate.

D) It is the heavy weight of the forefront of the flow running over the Pacific plate, that push the Pacific plate into the Earth.

E) The lithologic plate of the bottom of the Pacific Ocean is gradually pushued deep into the Earth.

The causal chain of working force is following: **A->B->C->D->E**.

There is nothing but gravity to work. Thermal mantle convections have no place in this theory.

Since the movement C is a very sudden phenomenon, the great earthquake and tsunami occur.

The phenomena occur in the reverse order: **E->D->C->B->A**, because it is a repeated current.

5. The comprehension with the theory of solid state lithologic flow

It is possible for us to take one set understanding of these two phenomena: (1) the 5.3m movement toward the east and (2) the 1.2m subsidence of the sea coast (Both are observed at Ojika Peninsura).

These phenomena gave us evidences to understand the movement of the Japan Islands as a solid state lithologic flow. It flows from higher places to lower places. It flowed 5.3m to the east horizontally while it flowed down 1.2m vertically (Denoted by A).

It is possible for us to understand these movement as a movement of the whole Japan Islands with a current of solid state lithologic flow.

This explanation based on the new theory, which takes the lithologic flows as same as glacial flows, gives us very clear understanding without any difficulty.

Probably the sharply pointed shape of Ojika Peninsura has been created by repeated diastrophism like this time.

Keywords: Diastrophism, Earthquake, The Great Eastern Japan Earthquake 2011, Tsunami, Solid State Lithologic Flow, Gravity

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