Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P01 Room:Convention Hall Time:May 26 14:15-16:15

Precursory VLF/LF Propagation Anomaly for the 2011/3/11 Earthquake

Masashi Hayakawa[1*]

[1]UEC

We have established a VLF/LF network in Japan, consisting of several observation points(Moshiri,Choufu,Kasugai,Tsuyama,Kochi). At each Station we receive simultaneously two Japanese transmitters (JJY,JJI) ans foreign transmitters (NWC,NPM,NLK). As for this earthquake, we have found no effect on the JJY-Moshiri path, but a significant anomaly on March 5 and 6 for the NLK-CHOFU path, which is considered to be a precursor to this earthquake.

Keywords: Earthquake, VLF/LF Propagation

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Is there any relationship between the 2011 Tohoku mega Earthquake and the geomagnetic field variations in Japan?

Kiyohumi Yumoto[1*], Emad Moris Henry Takla[2], Teiji Uozumi[1], Shuji Abe[1], Akihiro Ikeda[1]

[1]SERC, Kyushu Univ., [2]Earth&Planetary Sci. Dept., Kyushu Univ.

On 11 March 2011 at 05:46:23 UTC, a mega earthquake (EQ) with magnitude 9.0 [The 2011 Tohoku Earthquake] has occurred near the east coast of Honshu, Japan, as a result of thrust faulting on or near the subduction plate boundary between the Pacific and North American plates. Generally, anomalous geomagnetic variations observed by ground-based measurements in association with the earthquakes are generally accepted and many studies have reported precursory phenomena (a few nT's) associated with some earthquakes. Geomagnetic data from MAGDAS network, Geospatial Information Authority of Japan (GSI) and other geomagnetic observatories in Japan stations have been analyzed to examine the occurrence of any anomalous signature related to this massive earthquake.

Our results indicate an increase in the total magnetic field intensity (F) in the vicinity of the epicenter of the Tohoku EQ (38.322 N, 142.369 E), compared with other reference stations inside and outside the epicenteral region. Moreover, the annual range of the daily Z-component variations tends to decrease near the epicenter. In addition, the polarization ratio of Pc3 [Z/H] at Onagawa (ONW) station (about 80 km from the epicenter) shows a decrease a few weeks before the occurrence of the Tohoku EQ.

Keywords: total magnetic field intensity(F), daily Z-component variations, polarization ratio of Pc3 [Z/H]

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MIS036-P03 Room:Convention Hall Time:May 26 14:15-16:15

The Relative Quiescence and its Recovery of Seismicity Preceding 2011 M9.0 Earthquake in the east off Tohoku District

Ritsuko S. Matsu'ura[1*], Koji Iwasa[1]

[1]Earthquake Research Center, ADEP

The devastating M9.0 earthquake occurred on 11 March 2011 in the east off Tohoku district. Its hypocenter was located where M8-size earthquakes occurred in 1793 and 1897, which were destructive to the southern part of Tohoku district. In order to reveal the preparation process of a huge earthquake, we examined 126 years seismicity quantitatively with data of M6.0 and larger earthquakes in the area of east-off Tohoku district, Japan, by the point-process analysis. The area was chosen by the geological information to avoid some intentional or subjective selection of the examined area. The residuals from the ETAS model show the most significant decrease of the activity in the area from 1998 to 2002. The significant increase of the activity is only seen in 1938-1939 during 126 years, when the extraordinary swarm of six M>=6.9 earthquakes occurred off Shioyazaki promontory, Fukushima prefecture. These two significant activity changes are robust to selections of the term length of data to be used, and the window width for counting the residuals. The activity was restored to the normal level gradually until 2008. In order to explain the decrease then recovery of seismicity before a large earthquake, there should be some preparation process such as absorbing pore fluid in surrounding area should be antecedent to the pre-slip before a large main shock. Since the beginning and ending of this large relative quiescence could be detected a few years in advance, it can be utilized as one component for the long-term forecast.

Keywords: 2011 M9.0 East off Tohoku Earthquake, point process, residual analysis, precursor in seismicity before pre-slip, quiescence and its recovery

Japan Geoscience Union Meeting 2011
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Long-term seismic quiescence lasting 22 years before the 2011 off the Pacific coast of Tohoku earthquake (M=9.0)

Kei Katsumata[1*]

[1]Hokkaido University

A long-term seismic quiescence started 22 years before the 2011 off the pacific coast of Tohoku earthquake (M=9.0) is found by analyzing an earthquake catalog compiled by Japan Meteorological Agency (JMA). The catalog includes 5,770 earthquakes shallower than 60 km with M>=4.5. A detailed analysis of the earthquake catalog between 1965 and 2010 using a gridding technique (ZMAP) shows that the 2011 Tohoku earthquake is preceded by a seismic quiescence anomaly that starts in the middle of 1989, and lasts about 22 years, until the occurrence of the main shock. The quiescence anomaly area is located around the deeper edge of the asperity ruptured by the main shock, and the Z-value is +4.9 for a time window of Tw=15 years, using a sample size of N=150 earthquakes. The seismicity rate clearly decreases from 3.0 to 1.5 events/year (a drop of 50%). A hypothesis is presented in this study that seismic quiescences lasting more than 20 years are a long-term precursor to giant earthquakes (M ~ 9.0) in subduction zones.

Keywords: seismic quiescence, the 2011 Tohoku earthquake, JMA earthquake catalog, ZMAP, Z-value

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MIS036-P05 Room:Convention Hall Time:May 26 14:15-16:15

Foreshock activity before the 2011 Off-Pacific Tohoku earthquake: migrations and tidal responses

Aitaro Kato[1*], Kazushige Obara[1], Hiroshi Tsuruoka[1]

[1]ERI University of Tokyo

The 2011 Off the Pacific Coast of Tohoku Earthquake M9.0 ruptured nearly 500 km length and 200 km width of the fault off-shore of the Tohoku region along the Japan Trench subduction zone as a huge thrust earthquake at 14:46 (JST = UT + 9 hours) on March 11, 2011.

Before the earthquake, a M7.2 foreshock occurred to the approximately 30 north of the M9 initial rupture area on March 9. Following the M7.2 foreshock, the significant aftershock activity continued. It is very important to investigate a relationship between the aftershocks and M9.0 initial rupture stage. However, a significant portion of the aftershock events is missing in existing earthquake JMA catalogue. We searched missing events after the M7.2 foreshock, applying the matching filter technique (Shelly et al., 2007), and investigate detailed foreshock activity before the huge thrust earthquake.

Keywords: Foreshock activity, migrations, tide, preslip

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Tilt records prior to the 2011 Off the Pacific Coast of Tohoku Earthquake

Hitoshi Hirose[1]*

[1]NIED

The Off the Pacific Coast of Tohoku Earthquake on March 11, 2011 is an unexpected megathrust event with magnitude 9.0 along the Japan trench. I examine Hi-net tilt records prior to the great earthquake in order to see whether a precursory tilt change is observed for a short-term (days) and a medium-term (about a month) for confirming a preslip hypothesis and the effectiveness of an earthquake prediction method based on the hypothesis. For a quantitative reference to the observation, the detectability of the tilt observation for interplate slip on the subducting Pacific plate is also evaluated. In this study, no clear signal of preseismic tilt change or preslip is found in the records. This means that there is no preslip larger than moment magnitude (Mw) 6.2 on the deeper extension of the earthquake source area on the plate interface or larger than Mw 7.3 near the hypocenter.

Acknowledgments: Meteorological observation data were provided by Japan Meteorological Agency.

Keywords: The 2011 Off the Pacific Coast of Tohoku Earthquake, Preseismic crustal deformation, preslip, earthquake prediction, NIED Hi-net high-sensitivity accelerometers

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MIS036-P07 Room:Convention Hall Time:May 26 14:15-16:15

Possibility of Mw 9.0 mainshock triggered by diffusional propagation of after-slip from Mw 7.3 foreshock

Ryosuke Ando[1*]

[1]Geological Survey of Japan/AIST

In two days advance of the March 11, 2011 off the Pacific Coast of Tohoku, Japan, earthquake, a Mw 7.3 earthquake occurred at a location 40 km away toward northeast from the mainshock hypocenter. I investigated the spatio-temporal changes in seismicity from the Mw 7.3 foreshock, May 9 2011, 11:45, to the Mw 9.0 mainshock, May 11, 14:46 (Japan Standard Time). I found that seismic activities slowly migrated from the source area of the foreshock, which presumably reflected the propagation of after-slip. The mainshock rupture was initiated when the migration reached to the hypocentral location of the mainshock. It is also found that the migration slowed down as it expanded, where the migration distance was well fitted by a certain curve proportional to square root of duration, suggesting that the propagation was limited by diffusion with the diffusion coefficient of about 104 m2 s-1. This value of the diffusion coefficient is of the same order of magnitude with that reported for the migration of the deep non-volcanic tremor. These results appear to be compatible with a conceptual model that strongly coupled patches are separated by decoupled stable regions on this plate-interface, however these patches were not mechanically isolated and became interactive when they broke.

Keywords: Tohoku, Japan trench, foreshock, triggering, seismicity, afterslip

Japan Geoscience Union Meeting 2011
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Possible Prediction of 3.11M9.0 Gigantic Earthquake Based on Anomalous Aftershocks of 3.09M7.3 Miyagiken-oki Earthquake

Tomoki Hayashino[1*]

[1]RCNS, Tohoku University

(0) Before 3.11M9.0 gigantic earthquake(EQ), M7.3 EQ took place in the offing of Miyagi prefecture on March 9, which was almost officially recognized to be a pre-shock of the gigantic EQ after its occurrence.

In this poster, possibility of prediction for the 3.11M9.0 EQ is discussed based on analysis of anomalous aftershocks of 3.09M7.3 EQ.

(1) Employing database on EQ(1926-) in Japan archived by the Meteorological

Agency, the author has investigated all 30 interplate type EQs with magnitudes greater than 7.0 and seismic center depths shallower than 60km.

These 30 events are identified to be main shock.

The number of big aftershocks associated with the 30 EQs having dM=Mo-Mj<1.5(1.7) and dT=Tj-To<20hours are very small, only 0-2times (average 0.7) for dM<1.5 and 0-3times(average 1.1) for dM<1.7.

Here, Mo and Mj are magnitudes of main shock and aftershock respectively. To and Tj are occurance times of main shock and aftershock respectively. This means that one of the essential characteristics of main shock is rareness of big(dM<1.5 or 1.7) aftershocks.

(2) The statistical nature of the 30 events, i.e., the rareness of big aftershocks, described in (1) is expressed by the following formula,

(a) Uzu's formula(1969) log S = Mo - 3.7 (for 5.5<Mo<8.5)

(b) Seino's one(1984) log S = log N + Mj - 2.6

Here, S ; area of aftershocks in km2

N ; number of aftershocks with M>Mj (including main shock)

Combining (a) with (b), we get the formula,

(c) log N = Mo - Mj - 1.1 = dM - 1.1 (dM=Mo-Mj)

In this way, N scales in dM, which justifies dM parametrization in (1). Using (c), number of aftershocks(N-1) are calculated to be 1.5 and 3.0 for dM<1.5 and <1.7 respectively. These numbers are bit larger than (1), because they include aftershocks at T>20hours.

(3) On the other hand, real 3.09M7.3 EQ had shown remarkable excess of big aftershocks, i.e., 7 times for dM<1.5 and 8 times for dM<1.7 at T<20hours. It had 6 big aftershocks even for dM<1.3.

(4) Here, it is important to point out that giant "Miyagiken-oki" EQ is supposed in near future and 3.09M7.3 EQ was immediately interpreted not to be the supposed one. So that, "supposed one" remains to take place in near future.

Therefore, it would be not so difficult to consider a possibility that the prominent excess of big aftershocks of 3.09M7.3 EQ can be related to the mechanism which will cause forthcoming big event.

(5) In this way, on March 10, scientist could and should dispatch a warning message to society. If such warning was given in appropriate way, a great many human lives will be saved.

Keywords: Prediction of Earthquake, The Meteorological Agency Database on Earthquake, Regularity of Aftershock, Main Shock Characteristics, Anomalous Aftershocks, Warning to Society

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Huge seafloor movements associated with the 2011 off the Pacific coast of Tohoku Earthquake

Tadashi Ishikawa[1*], Mariko Sato[1], Naoto Ujihara[1], Shigeru Yoshida[1], Masashi Mochizuki[2], Akira Asada[2]

[1]JHOD, [2]IIS, Univ. of Tokyo

A mega-thrust earthquake took place on March 11, 2011, off the coast of northeastern Japan, resulting in catastrophic disaster. In Japan crustal movements have been estimated by the nation-wide GPS network on land, but large subduction-zone earthquakes occur in ocean areas. Therefore we have developed a GPS/acoustic seafloor geodetic observation system and we had five reference points above the source region of this huge event.

Here we report on unprecedentedly large seafloor movements associated with this event. Comparison of the positions estimated before and after the earthquake revealed a co-seismic displacement of about 24 m toward ESE and about 3 m upward at the reference point located above the hypocenter. At the reference points located 40 km and 120 km away from epicenter, co-seismic displacements were about 15 m and 5 m toward ESE, respectively. These results are extremely useful to understand what happened in the subduction zone.

Keywords: seafloor geodetic observation

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Huge crustal displacements just above the source region of the Tohoku earthquake observed by GPS/acoustic survey

Motoyuki Kido[1*], Yukihito Osada[1], Hiromi Fujimoto[1], Ryota Hino[1], Yoshihiro Ito[1]

[1]RCPEV, Tohoku Univ.

The 2011 off the Pacific coast of Tohoku earthquake brought devastating damage to Tohoku region especially due to unexperienced large tsunami. Such a large tsunami must be originated in large vertical deformation of seafloor and hence significant horizontal displacement should be accompanied. Actually the largest co-seismic displacement observed on land exceeds 5 meters in horizontal, which suggests much larger displacement on seafloor close to the source region. On April 11, just a month after the earthquake, we have conducted GPS/acoustic survey to measure the positions seafloor benchmarks, GJT3 and GJT4, installed just on the source region. GJT4 is located roughly the middle between the Tohoku shoreline and the trench axis while GJT3 is located in much more trench side. Since the survey is urgent using chartered ship and operation is limited in daytime to avoid crush with numerous driftage originated in the tsunami destruction, total ship time to assigned to GPS/acoustic survey was 4 hours at GJT3 and 3 hours at GJT4. Although our basic survey style is ”stationary”, keeping a surface buoy at the center of seafloor transponder array, we conducted moving survey because we have to reconfigure the exact shape of the transponder array to assess its distortion due to strong ground motion generated by the earthquake and succedent possible local landslide other than regional crustal deformation. It found that 3 out of 5 transponders in GJT4 were not responded or lost after the earthquake, while all 6 transponders were survived in GJT3. Stationary survey is no longer make sense in GJT4 because the total number of transponder is less than 3. Therefore we concentrated on a single transponder as a target and made moving survey quickly so as not to change the sound speed with a path as even as possible. Then the final horizontal accuracy in positioning reached to less than 1 m, while the vertical accuracy is limited to 2 m. The final solution of the co-seismic displacement is 15 m in horizontal (ESE) and 3.5 m in vertical (UP). For GJT3, we made 3 hours of moving survey and an hour of stationary survey. Comparing relative difference in traveltime residual to each transponder before and after the earthquake, we can evaluate relative motion among transponders exited by strong ground motion of the earthquake at least in ”line of sight” direction. Roughly 30 cm of relative motion can be detected. These small change in the relative position indicates no local landslide occurred beneath GJT3. From the stationary survey compared past survey before the earthquake, we obtained 31 m (ESE) horizontal displacement. While 5 m (UP) vertical displacement from moving survey. For GJT4, no information of relative motion can be obtained due to the lost of 3 transponders. The reason of the lost of the is questionable. GJT4 installed fairly flat seafloor. One possibility is just a lifetime of internal battery. Investigation using ROV is desired. The huge eastward displacement and uplift at GJT3 indicates large slip on the fault is extended to up-dip close to the trench.

Keywords: seafloor geodesy, GPS/acoustic, crustal deformation, Tohoku earthquake

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The 2011 off the Pacific coast of Tohoku earthquake recorded by offshore seismic/geodetic observation network

Ryota Hino[1*], Yoshihiro Ito[1], Kensuke Suzuki[1], Syuichi Suzuki[1], Daisuke Inazu[1], Takeshi Iinuma[1], Hiromi Fujimoto[1], Tomoaki Yamada[2], Masanao Shinohara[2], Kazuo Nakahigashi[2], Toshihiko Kanazawa[2], Masao Abe[3], Yoshiharu Kawaharada[3], Yohei Hasegawa[3], Kenji Hirata[4], Yojiro Yamamoto[5], Shuichi Kodaira[5], Yoshiyuki Kaneda[5]

[1]Tohoku University, [2]ERI, University of Tokyo, [3]Japan Metrological Agency, [4]Meteorological Research Institute, [5]JAMSTEC

A megathrust earthquake of M=9.0, the 2011 off the Pacific coast of Tohoku earthquake, occurred along the Japan Trench subduction zone to cause devastating damage to the Pacific coast of northeastern Japan. The rupture of the earthquake started at the central part of the subduction zone, where interplate earthquakes of M ˜ 7.5 have occurred along the subducting plate boundary repeatedly at about 40 years intervals, so-called Miyagi-Oki earthquakes. Since 2002, we have maintained a seismic and geodetic observation network in the source area of the earthquakes by repeating deployment and retrieval of ocean bottom off-line recording instruments.

The network of ocean bottom seismometers (OBSs) successfully observed detailed spatio-temporal variation of microseismicity before and after the occurrence of the M9 earthquake as well as two large (M>7) earthquakes occurred within the source region of the M9 event, one in 2005 and another on two days prior to the mainshock. In this paper, we will review the seismicity and stress field after the 2005 earthquake, and 3D seismic velocity structure around its rupture area and also give a preliminary result of hypocenter location of the foreshocks, mainshock, and aftershocks of the 2011 M9 earthquake. The relocated hypocenter locations will be discussed in terms of relevance to the seismic velocity structure along the plate boundary.

The ocean-bottom pressure data have also been recorded in the rupture area to detect vertical movement of the seafloor. Our bottom pressure gauges (OBPs) detected secular vertical seafloor motion due to strong interplate coupling prior to the M9 earthquake. More than 10 OBPs were in place at the occurrence of the mainshock to provide co- and postseismic seafloor motion.

Keywords: the 2011 off Pacific coast of Tohoku earthquake, ocean bottom seismic observation

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In-situ observation of ocean-bottom pressure in the source region of the 2011 off the Pacific coast of Tohoku Earthquake

Yoshihiro Ito[1*], Yukihito Osada[1], Daisuke Inazu[1], Ryota Hino[1], Hiroaki Tsushima[2], Yusaku Ohta[1], Motoyuki Kido[1], Hiromi Fujimoto[1]

[1]Tohoku University, [2]Metrological Research Institute

The 2011 off the Pacific coast of Tohoku Earthquake of March 11, 2011 killed more than 25,000 people living near the coast off Tohoku Japan. The earthquake generated a tremendous tsunami; the tsunami height near the coast reached over 10 m. The highest impulsive crest of the sunami was generated near the trench [Hayashi et al., 2011]. Tsunami generation by an earthquake in a subduction zone is generally modeled by water surface displacement identical to the vertical deformation of ocean bottom, especially inner trench slope near a trench due to the earthquake. Here we show an uplift of five meters near the toe of the inner slope along the Japan Trench; the uplift is caused by the M9.1 event. The pressure gauge also recorded an uplift of 20 mm accompanied with the M7.3 foreshock of March 9, 2011, which is well consistent with the calculated uplift from the model reconstructed by landward GPS data. The pressure gauge could record continuous data for a year with a logging interval of 30 s. The sensors were recovered by a pop-up system after the mainshock. After the earthquake, large disturbance appear it may be caused surrounding environmental change by ground shaking. The distincit negative offsets clearly appear the between before and after the foreshock and the mainshock. The negative pressure changes represent uplift of the observation point. The calculated pressure change reached 2 and 500 hPa (20 and 5000 mm), respectively. The pressure gauge was located near the source area of the impulsive tsunami accompanied with the mainshock. We successfully obtained the in-situ pressure change that is accompanied with the megathrust event and related to the tsunami generation.

Keywords: seafloor geodecy, ocean bottom pressure

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Crustal deformation of the 2011 off the Pacific coast of Tohoku Earthquake detected by SAR interferometry

Taku Ozawa[1*]

[1]NIED, Japan

On 11 Mar. 2011, Mj9.0 great earthquake occurred off the Tohoku district where the Pacific plate is subducting beneath the North American plate. To investigate crustal deformation associated with this earthquake, we applied SAR interferometry technique to ALOS/PALSAR data. Now we analyzed strip-map mode data for seven ascending and three descending orbit paths, and obtained clear fringes over the land area. Fringe configuration for ascending orbit was roughly half circles, which centered the epicenter of the mainshock, meaning that large dislocation occurred there. This slant-range change is consistent with the thrusting of the plate interface.

Crustal deformations associated with inland shallow earthquakes that occurred after the Mj9.0 earthquake were also obtained. Around the epicenter occurred in the Nagano Prefecture (2011/3/12, Mj6.7), slant-range change of 10cm was obtained, indicating that the fault dips to southeast. Furthermore slant-range change by another small fault was found. In the northern area of the Ibaraki Prefecture, slant-range change due to the earthquake occurred in 2011/3/19 (Mj6.1) was found, and it indicates that the fault dips to southwest. In the eastern area of the Fukushima Prefecture, slant-range changes due to earthquakes occurred in 2011/3/23 (Mj6.0) and 2011/4/11 (Mj7.0) were found. It indicates that the fault of the 2011/3/23 earthquake dips to west. For the 2011/4/11 earthquake, the obtained interferogram shows that crustal deformation concentrated along the Yunotake Fault and the Idosawa Fault.

Keywords: the 2011 off the Pacific coast of Tohoku Earthquake, crustal deformation, SAR, interferometry, InSAR

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Tsunami inundation associated with AD 869 Jogan tsunami and fault modeling

YUKI SAWAI[1*], Masanobu Shishikura[1], Yuichi Namegaya[1]

[1]AIST

The written history of tsunamis near Sendai begins with a possible predecessor of the 2011 extraordinary large tsunami which was over 1,000 years ago. It is known from series of historical documents (Nihon Sandai Jitsuroku) for the Heian era (AD 794-1192). The documents mention a large earthquake and a tsunami on July 9, AD 869, in the Julian calendar. In these seven years, we carried out geological research to reconstruct inundation area associated with the Jogan tsunami, its predecessors, and theri recurrence intervals.

Tsunami deposits were identified based on litho- and bio-stratigraphy. Tsunami deposits are shown by poorly-sorted and graded sand sheets interbedded with swamp/marsh peat and mud. The sand deposits include many marine and brackish diatoms. They can be traced continuously landward over a few kilometers from the present coast using a key bed of historical volcanic ash (To-a, AD 915), and the distributions are extensively larger than the recent tsunamis (e.g. 1933 Showa Sanriku tsunami, 1960 Chile tsunami, and other 20thcenturyMiyagi-oki tsunamis) and historical and recent storms. These marine-originated, continuous and widespread sand sheets were regarded as tsunami deposits associated with tsunamis.

Radiocarbon ages and tephrochronology can correlate a sand sheet with a tsunami in AD869. deeper part of the cores record that usually large tsunamis repeatedly inundated Miyagi and Fukushima prefecture in the late Holocene. Recurrence intervals were estimated a range between 450-800 years on the basis of a computer program OxCal using radiocarbon ages of samples from 3-4 m geoslicers in Sendai, Yamamoto, and Minami-Soma sites.

Tsunami inundation area was examined by computer simulations. Satake et al. (2008) and Namegaya et al. (2010) tested several types of tsunami source models. They show that tsunami source of the Jogan tsunami was extraordinary larger than usual Miyagioki (off Miyagi prefecture) earthquake (refer Namegaya's presentation in this AOGS meeting).

It requires at least Mw 8.4 (interplate earthquakes with length of 200 km, width of 100 km, upper depth of 15 km or 31 km, and the slip amount of 7 m) to explain tsunami inundation based on distribution of sand sheet. We assumed 14 fault models of the Jogan earthquake (Satake et al., 2008 and Namegaya et al. 2010, ARAFPR). They include outer-rise normal fault, tsunami earthquake, interplate earthquakes with various fault depth, width, length, and slip amounts. In addition, an active fault in Sendai bay is modeled. Tsunami inundation areas in Ishinomaki plain, Sendai plain, and Ukedo river-mouth lowland were computed from these models. The computed areas were compared with the distributions of the Jogan tsunami deposit in each area. As a result, two fault models are selected as possible models; interplate earthquakes with length of 200 km, width of 100 km, upper depth of 15 km or 31 km, and the slip amount of 7 m (Mw 8.4). The 2011 source area includes these source areas, but much wider with larger slip amount.

Keywords: Jogan tsuanmi, tsunami deposit, tsunami model, Japan Trench

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Proposal of Real-time Monitoring System of Strong Earthquake Motion and Tsunami based on GPS

Tetsuya Iwabuchi[1]*

[1]GPS Solutions

We propose a real-time monitoring system for strong earthquake motion and tsunami based on GPS with real-time data streaming. The system makes it possible to monitor real-time crustal deformation and tsunamis with latency of a second. The GPS coordinate solutions help to improve the accuracy of fault model of strong earthquake and tsunami model which is needed to issue urgent and accurate warnings as soon as possible after the occurrence of strong earthquakes.

Fast and accurate estimation of the magnitude of the 2011 Tohoku earthquake was difficult because seismometers were saturated with strong motion of the seismic wave of the earthquake (Wright et al., 2011). High-rate (1Hz or more) GPS observations have been used as complementary observation to the seismometer for strong earthquakes (i.e., Miyazaki et al., 2004). In Japan, we have a dense GPS network called GEONET deployed by GSI, and it stream 1-Hz data in real-time. However, the current operational processing system focuses only on near real-time processing (latency of several hours or more) or post-processing.

We demonstrated that our GPS processing system based on precise point positioning (PPP) strategy with the RTNet software (developed by GPS Solutions and Hitachi Zosen) succeeded to detect seismic wave and deformation of crust with real-time in the event of the 2011 off the Pacific Coast of Tohoku Earthquake with real-time streaming data of GEONET (http://rtgps.com/rtnet_pppar_honshu hereafter rtgps site). In an additional experiment with post-processing of GEONET 1Hz data in real-time mode (satellite orbit and clock were estimated in real-time by the Veripos APEX system), we showed that we could detect propagation of seismic waves for the earthquake (see rtgps site).

The tsunami induced by the earthquake inflicted significant damage in the port cities along the coast of the Pacific ocean in Tohoku. We processed GPS buoy data at Hiratsuka-oki operated by Tokyo university with RTNet and APEX, and showed that coincide motion of buoy with the arrival of seismic waves and the subsequent tsunami wave signal (see rtgps site). The facts suggest that we can monitor tsunami signal with real-time with PPP strategy based on real-time satellite products and if real-time communication between GPS processing system and buoy were available.

Based on the facts above, we propose (1) real-time monitoring system of motion and deformation of crust, and (2) GPS buoy network in the off-shore and corresponding real-time monitoring system. Both systems would mitigate disaster due to earthquake and tsunami for future strong earthquakes.

(1) There are multiple services which provide real-time satellite orbit and clock based on global GPS (GNSS) networks. Such products are superior to corrections from regional networks because multiple reference station in the regional network could move or fail during strong earthquakes. Currently, an accuracy of a few cm in the horizontal and better than 10 cm in the vertical component, is achievable with the products. The system is also helpful to monitor ongoing slow slip.

PPP-AR (PPP with ambiguity resolution, Mervart et al., 2008) can provide more accurate coordinate solutions. For this application we propose to process multiple networks of reference stations to avoid offset due to movement of coordinate of the reference stations during earthquakes. We plan to demonstrate the proposed system in rtgps site in the near future.

(2) We need to deploy tsunami GPS buoy system in more off-shore of about 100-200km (currently 20 km) from the coast to allow for more time for evacuation. We propose that the GPS buoy system is used as multi-purpose observing system during periods without tsunami. One application is water vapor monitoring based on tropospheric delay processed in GPS for weather forecast. Another one is GPS wave observation for fisheries and ocean engineering. The systems could be deployed for all nations which need such monitoring systems.

Keywords: GPS, Real-time, Earthquake, Tsunami, PPP, Monitoring

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P16 Room:Convention Hall Time:May 26 14:15-16:15

Why does the northeastern Pacific coast of Japan subside?

Teruyuki Kato[1*]

[1]Earthq. Res. Inst., Univ. Tokyo

There is a long standing problem as to the crustal deformation along the northeastern Pacific coast of Japan. While the geodetic data shows stationary subsidence along the pacific coast with several to 10mm/yr, late quaternary deformation suggests that the coast line shows a slight upheaval of 0.3-0.5mm/yr. Therefore, there should be some rebounding mechanism of the subsidence along the coast. A simple thought may be that a repeating large interplate earthquakes rebound the subsidence. However, this is not the case because the seismogenic zone is too far from the coast and all of upheaval area is in the ocean and the coast is rather residing in the subsidence area. Some researchers postulated that there would occur a super large earthquake of M9 among some repeated interplate large earthquakes of M8 and rebounds the subsidence. However, the 2011 Tohoku earthquake denied this possibility. Sawai et al. (2004) hypothesized, on the other hand, that a large transient uplift would occur after a large interplate earthquake. We will see if such a large post-seismic slip that extend downward of the seismogenic zone would occur in the coming days and uplift the Pacific coast of Tohoku significantly.

There are some other factors that may be responsible for such recovery uplift; high-angle reverse faulting that branches from the main plate interface, and visco-elastic stress re-adjustments in the upper mantle. First, such branching faults would play some role for the uplift. A part of the Solomon earthquake that occurred on April 1st 2007 (Mw8.1) would be one of such branching earthquake. The Inomisaki fault at the time of 1946 Nankai earthquake or the Patton Bay fault at the time of 1964 Alasuka earthquake would be other examples of such branching faulting. However, the region of crustal deformation would be much localized than the area that subsided due to the M9.0 earthquake.

Visco-elastic deformation due to stress re-adjustment around the source area was first modeled for the 1946 Nankai earthquake. The crust and the upper mantle was assumed to be a Maxwell body for which an elastic spring (crust) and a dash-pot (upper mantle) are connected in a series manner. This model has been successfully applied to some other earthquakes to interpret a part of post-seismic crustal deformations. However, neither high-angle reverse faulting nor the visco-elastic readjustment can solely resolve the inconsistency between geodetic and geological deformations. Synthetic role of these possible causes ? namely, post-seismic deeper slip, high-angle reverse faulting and visco-elastic stress re-adjustment - may fulfill the inconsistency between geodetic and geological strain rates. Quantitative evaluation of contribution of each these factors is required for solving this long standing problem.

Keywords: Tohoku earthquake, Crustal movement, Pacific coast

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Detailed deformation associated with the 2011 off Pacific coast of Tohoku earthquake from a dense regional GPS network

Mako Ohzono[1], Yusaku Ohta[2*], Takeshi Iinuma[2], Satoshi Miura[3], Kenji Tachibana[2], Tomotsugu Demachi[2], Toshiya Sato[2]

[1]ISV, Hokkaido University, [2]RCPEV, Tohoku University, [3]ERI, University of Tokyo

Our original continuous GPS network, which consists of 60 sites, observed large coseismic displacement field due to the 2011 off Pacific coast of Tohoku earthquake, Japan. Two nearest GPS sites from the epicenter recorded 5.6m of horizontal displacement directing ESE, and 1.2m of subsidence from both static daily coordinate analysis and high-rate kinematic precise point positioning (PPP) analysis. This is the largest value among whole GPS sites in Japan. The high-rate kinematic PPP results clearly suggest the coseismic rupture characteristics. Static coseismic displacement field, which is estimated form with our GPS network and GEONET, shows E˜ESE directing horizontal displacement, and subsidence along the mainly coastline. The simple rectangular fault model on the plate interface approximately explains the data well. Our original GPS network has been revived and accumulating data after the mainshock. These data will provide us important information to understand the postseismic deformation process and the earthquake cycle process at this region.

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Coseismic and postseismic slip for the 2011 Tohoku earthquake inferred from inversion of GPS data

Jun'ichi Fukuda[1*], Yosuke Aoki[1], Teruyuki Kato[1]

[1]ERI, University of Tokyo

We used GPS data recorded by the continuous GPS network, GEONET, to estimate spatial distribution of coseismic slip and afterslip for the 2011 M=9.0 Tohoku earthquake. We analyzed the GPS data on March 11, 2011, using the GIPSY-OASIS software to estimate station coordinates every 300 seconds. This analysis allows us to separate coseismic displacements due to the mainshock from coseismic displacements due to large aftershocks and early postseismic deformation. The coseismic displacements due to the mainshock were inverted for spatial distribution of slip on the plate interface. Our result shows that the mainshock ruptured primarily the shallower part of the plate interface than asperities of historical M=7-8 earthquakes, where interseismic slip deficit rate was inferred to be low. The estimated maximum slip is 33.6 m and the moment magnitude from the estimated slip distribution is Mw=8.9.

We also analyzed GPS data after March 11 with the GIPSY-OASIS software to estimate daily station coordinates. The daily GPS time series show significant postseismic deformation. We inverted the data for distribution of afterslip on the plate interface. The inferred afterslip is mainly located in the deeper and southern parts of the coseismic rupture region. As of April 2, 2011, the estimated maximum afterslip is 0.9 m and the moment magnitude from the estimated slip distribution is Mw=8.2.

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Co-seismic displacement of 2011 Off Tohoku Earthquake (M9.0) observed by GEONET and IGS networks applying GAMIT program

Seiichi Shimada[1*], Thomas A Herring[2]

[1]NIED, [2]MIT

Co-seismic displacement of 2011 Off Tohoku Earthquake (M9.0) observed by GEONET and IGS GPS network is obtained applying GAMIT/GLOBK 10.4 program (Herring et al., 2011). For the fiducial sites, we adopt 15 IGS network sites in eastern Asia, Pacific, and North America, whose ITRF2005 coordinates (Altimimi et al., 2007) are tightly constrained. We adopt IGS final orbit as precise ephemeris.

We divide nationwide GEONET sites and domestic IGS sites (TSKB and USUD) into regional 39 groups, obtain one-day GAMIT solutions of each group with IGS fiducial sites using RINEX data, and combine all the regional GAMIT solutions to one nationwide GEONET and IGS site coordinates solutions applying GLOBK program (Ito et al., 2009).

For the period before the earthquake, for four-day period during March 7 and 10UT, 2011, we combine every daily (24-hourly) solutions into one GEONET and IGS site coordinates solution applying GLOBK program. For the period after the earthquake, we analyze the RINEX data for the periods during 05:50 and 23:59UT on March 11 and 24 hour on March 12 (UT), 2011, applying GAMIT program and obtain daily GAMIT solution, then we combine two daily solutions into one GEONET and IGS site coordinates solution applying GLOBK program. Finally we obtain the co-seismic displacement subtracting post-seismic site coordinates from pre-seismic coordinates. Thus the displacements caused by the largest aftershock (M7.7) occurred off Ibaraki 29 minutes after main shock and other aftershocks occurred within two days after main shock may be contaminated in the co-seismic displacement.

In the resultant co-seismic displacement, for the horizontal movements, coastal area from Iwate to Ibaraki near the main shock generating fault, displacements directed eastward to eastern northeastward are significant. Moreover even by the sites in Kyushu Island in western Japan displacements directed eastward to eastern northeastward are detected. In the western part of Hokaido, southern southeastward displacements are observed. For the vertical movements, in the coastal area from Iwate to Ibaraki near the main shock generating fault, significant subsidence is observed, and around the subsidential area seen the uplift area, consistent with the displacement calculated by the dislocation theory of the reverse type fault. In the western part of Hokkaido uplift area observed, and in the eastern part of Hokkaido subsidence area are widely seen. For the west of epicentral area, in the Izu Peninsula and the coastal area of central Shizuoka subsidence area are seen, and the other part of the western Japan are observed uplift area.

Keywords: 2011 Off Tohoku Earthquake, Co-seismic displacement, Global Positioning System, GEONET, IGS, GAMIT program

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Post-seismic displacement during 30 days just after 2011 Off Tohoku Earthquake observed by GEONET and IGS networks

Seiichi Shimada[1*]

[1]NIED

30-days post-seismic displacement just after the occurrence of the 2011 Off Tohoku Earthquake (M9.0) observed by GEONET and IGS GPS networks is obtained applying GAMIT/GLOBK program 10.4 (Herring et al., 2011). For the fiducial sites, we adopt 15 IGS network sites in eastern Asia, Pacific, and North America, whose ITRF2005 coordinates (Altimimi et al., 2007) are tightly constrained. For the analysis of the GPS data of the pre-seismic period we adopt IGS final orbit as precise ephemeris, and for the analysis of data of the 30days after the main shock we adopt IGS rapid orbit as precise ephemeris.

We divide nationwide GEONET sites and domestic IGS sites (TSKB and USUD) into regional 39 groups, obtain one-day GAMIT solutions of each group with IGS fiducial sites using RINEX data, and combine all the regional GAMIT solutions to one nationwide GEONET and IGS site coordinates solutions applying GLOBK program (Ito et al., 2009).

For the period before the earthquake, for four-day period during March 7 and 10UT, 2011, we combine every daily (24-hourly) solutions into one GEONET and IGS site coordinates solution applying GLOBK program. For the period just after main shock, we analyze the RINEX data for the periods during 05:50 and 23:59UT on March 11 and 24 hour on March 12 (UT), 2011, applying GAMIT program and obtain daily GAMIT solution, then we combine two daily solutions into one GEONET and IGS site coordinates solution applying GLOBK program (Shimada and Herring, 2011). For 30-days after the main shock, we analyze the 24-hourly RINEX data for April 9 and 10 (UT), 2011, applying GAMIT program and obtain daily GAMIT solutions, then we combine two daily solutions into one GEONET and IGS site coordinates solution applying GLOBK program. Finally we correct co-seismic displacements from the site coordinates solution of the 30-days after the main shock, and compare with the site coordinates solution of the pre-seismic period and obtain the 30-days post-seismic displacement just after the main shock. Thus the displacements may include the co-seismic displacements caused by the aftershocks occurred during the day after the main shock and 30 days after the main shock.

In the resultant post-seismic displacement, for the horizontal movements, coastal area from Iwate to Ibaraki near the main shock generating fault, displacements directed eastward to eastern southeastward are significant. Especially comparing with the co-seismic displacement distribution, the region from Ibaraki and the northern part of the Boso Peninsula eastern southeastward movement is relatively significant. In the western Japan, eastward to eastern northeastward displacement is seen to the sites in Kyushu Island as well as the co-seismic motion. In Hokkaido, the east part moves northwestward, anti-clockwise rotating to the southward displacements in the western part are observed. For the vertical movements, in the coastal area in Iwate near the main shock generating fault, significant subsidence is observed, however in the coastal area from Miyagi to Ibaraki the uplift area widely seen, possibly indicating the co-seismic motions of the aftershocks. Around the uplift area, in the marginal area of the subsidence area in the co-seismic motion, subsidence is widely seen, except the area from Niigata to Nagano where uplift is seen. In the far west of the epicental area, the uplifting and subsidence sites are contaminating in the Izu Peninsula and the coastal area of central Shizuoka, and also the same for the western Japan area.

Keywords: 2011 Off Tohoku Earthquake, 30-days post-seismic displacement, Global Positioning System, GEONET, IGS

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Crustal Deformation and Fault Model of The 2011 off the Pacific coast of Tohoku Earthquake

Mikio Tobita[1*], Misao Ishihara[1], Tetsuro Imakiire[1], Shinzaburo Ozawa[1], Tomokazu Kobayashi[1], Hisashi Suito[1], Akira Suzuki[1], Takuya Nishimura[1], Yuko Noguchi[1], Basara Miyahara[1], Hiroshi Munekane[1], Masayuki Yamanaka[1], Hiroshi Yarai[1], Mariko Sato[2], Tadashi Ishikawa[2]

[1]GSI of Japan, [2]Hydrogr. and Oceanogr. Dept. of Japan

The 2011 off the Pacific coast of Tohoku Earthquake caused large crustal deformation of the Japanese Islands, observed by a permanent GPS array "GEONET" and ALOS PALSAR. The maximum horizontal displacement reaches 5.3 m in the Oshika Peninsula along the Pacific coast of northeastern Japan. It is the largest coseismic displacement measured by GEONET since 1994. The subsidence up to 1.2 m was observed in the Pacific coastal area. The postseismic displacement exceeds 0.4 m in one month after the earthquake. We estimated the distribution of the coseismic and the postseismic slip on the subducting Pacific plate from the GPS data.

Acknowledgments

This work was conducted as a collaborative research project between GSI and JAXA. PALSAR data were analyzed by GSI from the ALOS raw data provided by JAXA and METI.

Keywords: crustal deformation, fault model, GEONET, postseismic displacement, sea-floor crustal deformation

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Coseismic slip distribution of the 2011 Off the Pacific Coast of Tohoku Earthquake estimated based on GPS data

Takeshi Iinuma[1*], Mako Ohzono[2], Yusaku Ohta[1], Satoshi Miura[3]

[1]Graduate School of Science, Tohoku Univ., [2]Graduate School of Sci., Hokkaido Univ., [3]Earthq. Res. Inst., Tokyo Univ.

The 2011 Off the Pacific Coast of Tohoku Earthquake (M9.0) occurred on 11 March 2011 off the Pacific coast of Tohoku district, northeastern Japan, where the Pacific plate is subducting at a rate of about 8 cm/year beneath the overriding continental plate. Various studies on major interplate earthquakes around this area have revealed that some of those events can be regarded as recurrent ruptures of asperities, which are defined by distributed patches showing large coseisimc slip. The rupture area of the 2011 earthquake includes several asperities M ˜ 7 earthquakes.

Earthquakes with magnitudes of about 7.5 or larger have repeatedly occurred on the plate boundary east off Miyagi Prefecture (Miyagi-oki) with an interval of about 37 years. The most recent one took place in 1978 (M7.4). Based on historical records of these recurrent earthquakes, the Headquarters for Earthquake Research Promotion stated that the next Miyagi-oki earthquake will occur with a probability of about 70 % in the next 10 years from 1 January 2011.

On August 16, 2005, an interplate earthquake with magnitude 7.2 occurred. Okada et al. (2005) carried out the relocation of aftershocks of the 1978 and 2005 events to reveal that the aftershock area of the 2005 event is overlapped only with the southeastern part of the 1978 source area. Yaginuma et al. (2006) performed the seismic waveform inversion for the 2005 event to estimate the coseismic slip distribution and found that it also corresponds to the southeastern part of the 1978 rupture area. The northern and southwestern parts of the rupture area of 1978 earthquake did not slip aseismically after the 2005 earthquake (Miura et al., 2006; Iinuma et al., 2011). Therefore, we had regarded that the remaining asperities of the 1978 Miyagi-oki earthquake had not been ruptured and had been accumulating strain energy since 1978 for the next Miyagi-oki earthquake, until the 2011 M9.0 earthquake occurred.

Thus, we tackled the problem whether the remaining asperities of the 1978 Miyagi-oki earthquake were ruptured with the 2011 off the Pacific Coast of Tohoku Earthquake or not based on land GPS observation data. In the present study, we applied GPS data to estimate coseismic slip distributions on the plate boundary by means of a geodetic inversion method.

The results show that the significant large slip area is divided into two areas. One is the main rupture area on the plate interface shallower than 30 km in depth where the subducting plate contacts with the crust of the continental plate. Another one locates at Miyagi-oki region where the asperities that caused the 1978 Miyagi-oki earthquake are distributed. We can conclude that tremendous slip in the crust-crust contact zone on the plate boundary mainly caused the 2011 off the Pacific coast of Tohoku Earthquake, and that the boundary between the continental crust and mantle on the hanging wall side of the plate interface fault might prevent the main shock rupture from propagating into the crust-mantle contact zone along the plate interface. Miyagi-oki, however, is an exceptional region where the coseismic slip also occurred on the plate interface under the continental mantle. The material heterogeneity of the mantle wedge might control this slip distribution.

Whole estimated slip distribution suggests that the main shock rupture did not propagate into the brittle-ductile transition zone along the plate interface. Igarashi et al. (2001) pointed that there is a clear boundary of the distribution of the interplate earthquakes in this region, and no slip is estimated at the plate interface deeper than this border. However, week interplate coupling is estimated in the deeper plate boundary based on interseismic crustal deformation data. Thus, postseismic slip is expected to occur in the plate interface deeper than this border in order to release the cumulative strain energy due to the interplate coupling.

Keywords: The 2011 Off the Pacific of Tohoku Earthquake, Miyagi-oki Earthquake, Coseismic Slip Distribution, GPS

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Coseismic fault models for the March 9 2011 event (M7.3) and April 7 2011 event (M7.1) based on the geodetic data

Yusaku Ohta[1*], Mako Ohzono[2], Takeshi Iinuma[1], Satoshi Miura[3], Ryota Hino[1], Yoshihiro Ito[1], Yukihito Osada[1], Junichi Nakajima[1], Daisuke Inazu[1], Saeko Kita[1], Tomotsugu Demachi[1], Kenji Tachibana[1], Akira Hasegawa[1], Norihito Umino[1]

[1]RCPEVE, Tohoku University, [2]ISV, Hokkaido University, [3]ERI, The University of Tokyo

We propose coseismic fault models based on the geodetic data for the March 9 2011 earthquake (M7.3) and April 7 2011 (M7.1) one.

A large earthquake of M 7.3 occurred at the subducting Pacific plate interface on March 9, 2011, 51 hours before the M 9 huge off the Pacific coast of Tohoku Earthquake. We propose a simple rectangular fault model of the March 9 event based on a dense GPS network and one OBP (Ocean Bottom Pressure gauge) site. The coseismic displacements are estimated by baseline analyses. The rectangular fault was estimated by non-linear inversion approach. The simple rectangular fault model can explain observations including the vertical displacement based on tha OBP data. The amount of moment release is equivalent to Mw 7.17. The spatio-temporal aftershock distribution of the March 9 earthquake shows the clear migration to the southward of the estimated our coseismic fault plane. We suggest that the possibility of afterslip occurrence after the March 9 earthquake until the occurrence of the March 11 Mw 9 earthquake. The aftershocks may be triggered by afterslip. The afterslip generates strain concentrated in particularly edge areas of the afterslip region. It is important results for the understanding of the nucleation process of the M 9 huge off the Pacific coast of Tohoku Earthquake.

We also propose a source fault model for the 2011 April 7 earthquake (M7.1) deduced from a dense Tohoku University GPS network and GEONET data. The coseismic displacements estimated by GPS data clearly show the intraslab earthquake characteristics of not only horizontal components but also vertical ones. The rectangular fault was estimated by non-linear inversion approach. The results indicate that a simple rectangular fault model can explain the observations. The amount of moment magnitude was estimated to be Mw 7.16. The Japan Meteorological Agency hypocenter depth of the main shock is slightly deeper than the neutral plane between down-dip compression (DC) and down-dip extension (DE) stress zone of the double-planed deep seismic zone. This suggests that the depth of the neutral plane was deepened by the large slip of the 2011 M9.0 Tohoku earthquake, enabling to initiate the rupture of the thrust fault type M7.1 April 7 earthquake, although more investigations are required to confirm. The estimated fault plane has an angle of 50-60 degree from the surface of subducting Pacific plate. It is consistent with the hypothesis that intraslab earthquakes are thought to be reactivation of the preexisting hydrated weak zones made in bending process of oceanic plates at outer-rise regions.

Keywords: GPS, fore shock, intraslab earthquake

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Strain seismograms of the 2011 off the Pacific coast of Tohoku Earthquake recorded by high-sampling rate borehole strain

Naoto Takeda[1*], Kazutoshi Imanishi[1], Yuichi Kitagawa[1]

[1]Geological Survey of Japan, AIST

Coseismic strain steps and groundwater changes, associated with the 2011 off the Pacific coast of Tohoku Earthquake, were observed at observatories of Geological Survey of Japan, AIST in Tokai and Southwestern Japan (Itaba et al., and Kitagawa et al., in this session). Our borehole strain observation is performed at a high sampling rate of 20Hz or higher, so we could record strain seismograms caused by this gigantic thrust earthquake with a high signal-to-noise ratio. Here we introduce these strain seismograms recorded by our high-sampling rate borehole strain meter array.

Okubo et al. (2004) indicate that borehole strain seismograms show very similar waveforms with broadband seismograms at the range of a flat response of broadband seismometer. By comparing two-hours long section (14:00-16:00 on March 11, 2011) of strain seismograms with those of NIED F-net broadband seismometers, we found that they are similar each other at a period shorter than 100 sec.

We then performed a semblance analysis to determine a spatio-temporal distribution of long-period radiation energy using 5 GSJ borehole strain meters located at Kii peninsula, incorporating nearby 6 NIED F-net broadband seismometers. We focus on a period shorter than 100 sec, on the basis of the above consideration. The semblance analysis revealed that the seismic radiation migrates from north to south during the mainshock faulting, which is consistent with other studies. In addition, we detected seismic radiations caused by large-scale aftershocks at appropriate locations. It is noted that the spatio-temporal resolution is significantly improved if we combine the strain meters with F-net borehole seismometers.

Reference

Okubo, M., Y. Asai, H. Ishi, and H. Aoki, Earth Planets Space, vol. 57, pp. 303-308, 2004.

Acknowledgement. We used F-net broadband seismograms operated by NIED.

Keywords: strain seismogram, array analysis, semblance analysis

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The fault model of the 2011 Off the Pacific Coast of Tohoku Earthquake from the coseismic strain steps

Satoshi Itaba[1*], Norio Matsumoto[1], Yuichi Kitagawa[1], Naoji Koizumi[1]

[1]Geological Survey of Japan, AIST

The 2011 off the Pacific Coast of Tohoku earthquake, whose moment magnitude is 9.0, occurred. The fault slip of this earthquake caused the coseismic strain steps of 10^{-7} in the Tokai, Kii Peninsula and Shikoku, which were observed by the borehole strainmeters of Geological Survey of Japan, AIST. Using these strain steps, we estimated the fault model of the earthquake on the boundary between the Pacific and North American plates. According to the fault model, the moment magnitude of the earthquake is 8.7. Our model is almost consistent with the fault models estimated from the data of GPS and seismic waves. This shows that the array of precise borehole strainmeters can be useful for rapid estimation of faults of gigantic earthquakes.

Keywords: strain step, crustal movement, fault model, magnitude, The 2011 Off the Pacific Coast of Tohoku Earthquake

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Examination concerning source time function and permanent stress by using data observed by borehole stress meter

Hiroshi Ishii[1*], Yasuhiro Asai[1]

[1]TRIES

Tono Research Institute of Earthquake Science (TRIES) developed borehole stress meter. The instrument installed in 500m depth borehole observed stress seismograms caused by Tohoku district off Pacific Ocean Earthquake (M9.0). We derived source time function and permanent principal stress by analyzing the wave form. We present examined results.

Keywords: source time function, borehole stress meter, applied permanent stress, stress seismograms, M9.0 earthquake

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The 2011 off the Pacific coast of Tohoku Earthquake inferred from TRIES observation network

Makoto OKUBO[1*], Atsushi Saiga[1], Tadayoshi Nakashima[1]

[1]TRIES

In 11th March 2011, huge earthquake occurred at northeast part of Japan, named ”The 2011 off the Pacific coast of Tohoku Earthquake.” This earthquake was the largest earthquake in observational recorded history in Japan. In Tono area, which located approximately 600km away from the epicenter, large ground acceleration (maximum seismic intensity 4) and large dynamic strain (10^{-5} strain; approximately 1000 times larger than the tidal change) was observed. In this paper, we inferred the rupture process of the 2011 off the pacific coast of Tohoku earthquake from the ground acceleration and dynamic strain.

We have been operating some crustal activity observatories with in deep borehole strainmeters (BYB, TRIES, and TOS) at the Tono area, Gifu prefecture, central Japan. We used the dynamic strain records, which obtained by the The 2011 off the Pacific coast of Tohoku Earthquake, in order to estimated the rupture process. In the analysis, at first, we determined the the principal stain azimuth with from four horizontal strain records for each frequency by using the Fourier Strain Analysis (Okubo, 2007). The results of the principal strain azimuth changes and the distance inferred from the principal strain amplitude derived that the strain release source gradually moved from off Miyagi to off Ibaraki. In addition, we assumed that the longest period of the principal strain azimuth with small analytical errors (˜ 2.5degrees) means the rupture duration of earthquake. We derived the results that the rupture continued over a period of approximately 180 seconds after initial arrival and revealed that total has been released seismic moment equivalent to M_W8.7. Seismic moment that we obtained from the dynamic strain is smaller than the JMA reported moment (M_W9.0).

On the other hand, we have been also operating the more than 50 seismic stations (ground acceleration) in the Tono area. Tono area observed seismic intensity 4 by mainshock. we obtained more than 30 seismic intensity distribution records, which caused by induced earthquake and subsequent aftershocks, in about a month after the earthquake.

Keywords: dynamic strain, acceleration, Seismic Intensity, Source process

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Release of absolute elastic strain due to the 2011 Tohoku-oki earthquake and its geophysical implication

Yukitoshi Fukahata[1*], Yuji Yagi[2]

[1]DPRI, Kyoto University, [2]University of Tsukuba

The earthquake releases elastic strain accumulated on a fault, but only a part of it is released usually. So, absolute level of stress and strain have been very difficult to estimate, because seismic data only allow us to determine the stress drop of an earthquake. The 2011 Tohoku-oki earthquake appears to have exceptionally released all the accumulated elastic strain, as suggested from very long duration of slip-rate function, extensional aftershocks in a previously compressional stress regime, and so on. The earthquake provides us a precious opportunity to estimate the absolute level of stress and strain. Exceptional weakening of the fault strength seems to be due to some non-linear process, such as thermal pressurization. If so, the nonlinear nature of weakening would make prediction of the next big event very difficult.

Keywords: 2011 Tohoku-oki earthquake, absolute strain, absolute stress, earthquake cycle

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Modeling the source process of the 2011 off the Pacific coast of Tohoku earthquake using the 1-Hz GPS data

Masayuki Kano[1*], Shin'ichi Miyazaki[1], Yusuke Yokota[2]

[1]Geophys., Kyoto Univ., [2]ERI, Tokyo Univ.

High-rate GPS data can record ground displacement as a seismometer. Previous studies demonstrated that high-rate GPS data show good agreement with strong motion waveforms for M8 class large earthquakes, e.g., the 2002 Denali Fault earthquake (Larson et al. 2003), and the 2003 Tokachi-oki earthquake (Miyazaki et al. 2004), as well as the medium-sized earthquakes, e.g., the 2008 Iwate-Miyagi Nairiku earthquake (Yokota et al. 2009). Strong motion records must be integrated twice to obtain static displacement, resulting in amplifying noise. On the other hand, the high-rate GPS waveforms contain not only dynamic process but static displacement of the ground surface. Using this advantage of high-rate GPS data, GPS waveforms recorded during an earthquake were inverted to infer slip distribution (e.g., Miyazaki et al. (2004) and Yokota et al. (2009)). For example, Miyazaki et al. (2004) estimated the spatio-temporal evolution of fault slip during the rupture of the 2003 Tokachi-oki earthquake and demonstrated the ability to infer source process of earthquakes solely from high-rate GPS data. In this study, we first analyze 1-Hz GPS data in Tohoku and northern Kanto area for the 2011 off the Pacific coast of Tohoku earthquake. Then we perform a waveform inversion for the rupture process of the earthquake and finally compare theoretical GPS waveforms with observed strong motion waveforms.

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Source process of the 2011 off the Pacific coast of Tohoku Earthquake determined from seismic waveform and geodetic data

Hisahiko Kubo[1*], Yasumaro Kakehi[1]

[1]Kobe University

In this study, Source process of the 2011 off the Pacific coast of Tohoku Earthquake is estimated from the inversion of seismic waves and geodetic data.

We assume a curved fault model for the fault plane source model of source process inversion. This fault model is consisted of three planar segments with gradually changing dip angles, based on the plate boundary by Miura et al. (2005). The lengths (along-dip direction) of three segments are all 480km. The widths (along-dip direction) of three segments are 60km, 60km and 90km. The dip angles of the three segments are 9 deg, 11 deg and 23 deg. Each fault segment is divided into 30km-30km subfaults for the inversion. The rupture starting point location is (38.1035 deg, 142.1035 deg, 17.8km), which is the epicenter determined by JMA and the depth of the plate boundary modeled by Miura et al. (2005). The strike angle of 201 deg is used based on Global CMT solution.

For the inversion of seismic waves, waveforms of teleseismic P-waves at 42 IRIS (Incorporated Research Institutions for Seismology) stations with epicentral distance 50-100 deg are used. In order to cover the long duration of source process of the huge earthquake, P-wave part of vertical displacement waveform with time length of 180 s (beginning 10 s prior to the P-wave onset) is basically used. For the 6 stations with epicentral distance 60-70 deg and for the 8 stations with epicentral distance 50-60 deg, shorter time lengths of 160 s and 140 s are used, respectively. This is for avoiding PP phase coming into the time length for inversion analysis. Displacement waveforms are bandpass ?ltered from 10 s to 100 s and resampled with 0.5 s sampling interval.

Theoretical waveforms from a point source located in the center of each subfault are calculated using the program by Kikuchi and Kanamori. In the calculation, we use the structure model referred to Miura et al. (2005). The waveform inversion is done using multiple time-window analysis. The number of time windows is 14. Each time window has duration of 8.0 s, and one time window is put after the previous one with a time lag of 0.5 s. Rake angles of the subfaults are variable within 85 deg +- 45 deg, where central angle 85 deg is adopted from Global CMT solution. Smoothing constraint is given in the spatial and temporal distribution of slip. Weight of smoothing constraint is determined using minimum ABIC condition.

In the model by the waveform inversion, the total seismic moment is $1.9*10^{22}$ N*m, and the maximum slip is 18.1 m. Variance reduction is 79 % and waveform fitting is good. Large slip area is seen in shallow part.

The geodetic data consist of horizontal ground displacement at stations from GEONET GPS data (F3 solution processed by GSI). Theoretical internal deformations from a point source located in the center of each subfault are calculated using the program by Okada (1992). In the waveform of geodetic data, rake angles of the subfaults are variable within 85 deg +- 45 deg, where central angle 85 deg is adopted from Global CMT solution. Smoothing constraint is given in the spatial distribution of slip. Weight of smoothing constraint is determined using minimum ABIC condition.

In the model by the geodetic inversion, the total seismic moment is $2.05*10^{22}$ N*m, and the maximum slip is 28.0 m. Overall, the slip is smoother than that of the seismic wave model.

Acknowledgments: The authors are grateful to the following organization and people. We used the program of Kikuchi and Kanamori (1982) and Okada (1992) for calculating the Green functions of telesesimic body waves and internal deformation. Seismic waveform recorded by Incorporated Research Institutions for Seismology, geodetic data recorded provided by the Geographical Survey Institute and the hypocenter data provided by the Japan Meteoroloical Agency were used for the analysis.

Keywords: The 2011 off the Pacific coast of Tohoku Earthquake, Source process, Seismic waveform, Geodetic data

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Rupture process of the 2011 Tohoku-oki earthquake obtained by tele-seismic body wave

Yuji Yagi[1*], Yukitoshi Fukahata[2]

[1]University of Tsukuba, [2]DPRI, Kyoto University

We estimated the rupture process of the 2011 off the Pacific coast of Tohoku earthquake using waveform inversion of tele-seismic body wave. In principle, we can never know the true Green's function, which is a major error source in seismic waveform inversion. Due to the propagation law of errors, the uncertainty of Green's function results in a data covariance matrix with significant off-diagonal components, which naturally reduce the weight of observed data in later phases. To estimate stable and detailed rupture process of mage-thrust earthquake, we introduced uncertainty of Green's function into waveform inversion analyses. Tele-seismic P-wave data recorded at FDSN network stations and Global Seismograph Network stations were retrieved from IRIS-dmc. 53 stations were selected from the viewpoint of data quality. Form observed waveform, three noticeable wave packets exhibit azimuthal dependence in the arrival times, which implied rupture propagated asymmetric bilateral manner. From obtained seismic source model, we found repeated slips around the epicentral area, which led to a large maximum slip (29 m).

Keywords: 2011 Tohoku-oki earthquake, seismic source process, uncertainty of Green's function

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Source processes of the 2011 Tohoku-Taiheiyo-oki earthquake inferred from teleseismic body waves

Yoshiko Yamanaka[1*], Masahiro YOSHIMOTO[1]

[1]Nagoya Univ.

On March 11, 2011, a huge earthquake with a magnitude of 9.0 occurred along the Japan Trench off Iwate-Miyagi-Ibaragi, Japan. We investigated the source process by using teleseismic P- and SH-wave data. This earthquake was an interplate earthquake associated with the subduction of the Pacific plate, and consisted of some asperities. The asperity near the Japan Trench might have behaved like the tsunami earthquake.

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Source process of the 2011 off the Pacific coast of Tohoku Earthquake

Yasuhiro Yoshida[1*], Hiroshi UENO[2], Daisuke Muto[2], Shigeki Aoki[1]

[1]MRI, [2]JMA

We analyzed the source process of the 2011 off the Pacific coast of Tohoku Earthquake using teleseismic body wave or strong motion data.

1. Source process determined by teleseismic waveform

Spatio-temporal distribution of slip is analyzed by broadband data with UD-components of teleseismic P-waves using Kikuchi and Kanamori (2003)'s program. The data are integrated to displacement and band-pass filtered between 0.002 to 1.0 Hz. The size of fault plane is assumed to be 480 km x 240 km by the aftershock distribution and the assumed strike and dip angles of fault are fixed to be 203 and 10 degrees referred to the low-angle nodal plane of the JMA CMT solution. Optimal maximum rupture velocity is selected to 1.8 km/s to minimize residuals between observed and synthetic waveforms by trial and error. We get following results. Total seismic moment is 4.0×10^{22} Nm (MW9.0). There are three large slip stages (asperities). The three asperities are ruptured at about 20-40 s, 40-90 s, and 100-160 s after the initiation of rupture, respectively. First and second asperities are located near the hypocenter and last one in southern part. The variance reduction is about 76% and the overall fitting between observed and synthetic data is well.

2. Source process determined by strong motion waveform

23 strong motion seismograms of K-NET and KiK-net stations deployed by NIED and JMA stations, are used in this analysis. Acceleration seismograms are integrated to velocity. The data are band-pass filtered between 0.01 to 0.15 Hz, and decimated to 0.5 Hz. The fault size is assumed to cover the aftershock distribution. The fault is divided into subfaults with a size of 25x25km. We use the linear multiple time window inversion method with constraints on the smoothness of spatio-temporal slip distribution selected to minimize ABIC. Total seismic moment is 3.4×10^{22} Nm (Mw9.0). Large slip area extends from hypocenter to the shallower part of the fault plane. The maximum slip amount exceeds 30 m. We get 3 asperities, which have almost the same temporal and spacial distribution obtained by teleseismic waveform analysis. The comparison of observed and synthetic waveforms at the stations is quite well.

3. Discussion and Conclusion

We get almost consistent results by teleseismic waveform and regional strong motion waveform analysis. But slip distribution in southern part is not identical with teleseismic and regional analysis. This suggests the larger location error compared to that in northern part, but the slip amount is necessary to explain the strong waveform peaks at stations in Kanto area. The sources of high frequency energy radiation were roughly estimated using the modified Source-Scanning Algorithm [Aoki et al., 2011]. Five high-frequency radiation sources (HFS) were imaged during this event. The HFSs are generally located just rim of the slip patch. The moment release by 2nd stage is very large and maximum slip amount exceeds 30m. It is relatively large value compared to the maximum slip for another huge earthquake such as the 2004 off Sumatra event and the 2010 Chile event, which is about 15m [USGS, 2004, 2008]. The rupture duration is long (~80 s) at the hypocentral region. This long duration produces very large slip amount and may generate large tsunami. This large asperity coincides with the large co-seismic slip area obtained by GPS analysis [GIJ, 2011] except near trench area, where small co-seismic slip is estimated by GPS. The difference is partly because the resolution near the trench is poor in GPS analysis. The region, where tsunami back propagation curves of initial crests were concentrated [Hayashi et al., 2011], is just above the large slip area obtained by this study.

Acknowledgement

Strong motion seismograms of K-NET and KiK-net deployed by NIED, and of JMA network are used in this study. Teleseismic seismogram are distributed by IRIS DMC. We use teleseismic body-wave inversion program developed by Kikuchi and Kanamori (2003).

Keywords: source process, the 2011 off the Pacific coast of Tohoku Earthquake, teleseismic seismogram, strong motion seismogram

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Source process of the 2011 Tohoku earthquake

Yusuke Yokota[1*], Kazuki Koketsu[1]

[1]ERI, University of Tokyo

We examined the source process of the 2011 Tohoku earthquake, which occurred in the subduction zone off the coast of Japan. We analyzed the source process of this earthquake using several data sets. We reported the results using strong motion data.

First, we carried out point source analysis [Kikuchi and Kanamori, 1991] and W-phase inversion [Kanamori and Rivera, 2008] using teleseismic waveforms. In the results, the rupture was generated in large areas off the coast of Miyagi. Next, we performed waveform inversion [Yoshida et al., 1996] using strong motion data. We considered the analyses using teleseismic waveform data and aftershock distributions and the rectangle of 480 x 150 km^2 was adopted with a strike of 200^o and a dip of 12^o to model the source fault of the mainshock. Green's function was calculated using Kohketsu [1985]. We used a layered velocity structure constructed by the JIVSM [Japan Integrated Velocity Structure Model; Koketsu et al., 2008].

We obtained the source model with a seismic moment of 3.4 x 10^{22} Nm (Mw ~ 9.0) and a maximum slip of about 30 m. This slip distribution recovered at the regions off the coast of Miyagi and Fukushima.

Acknowledgment: The GPS data were recorded by NIED and IRIS.

Keywords: 2011 Tohoku earthquake, source process, strong motion

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Source Modeling of the 2011 Tohoku-Chiho Taiheiyo-Oki Earthquake (Mw9.0)

Hidenori Kawabe[1*], Katsuhiro Kamae[1], Hirotoshi Uebayashi[1]

[1]RRI, Kyoto University

The Tohoku-Chiho Taiheiyo-Oki Earthquake (Mw9.0) on March 11, 2011, which occurred near the east coast of Tohoku district, Japan, resulted from thrust faulting on the subduction zone plate boundary between the Pacific plate and North America plate. The observed acceleration waveforms in Miyagi and Iwate prefectures display two remarkable phases of ground motion. The waveforms in Fukushima prefecture display many phases, and the waveforms in Ibaraki prefecture display one remarkable phase. These observed records suggest a very complex source process. It is very important for the strong ground motion prediction of the future subduction zone earthquakes, such as the Tonankai and Nankai earthquake, to estimate the source process of this earthquake.

We tried to construct the source model by the forward modeling approach using the empirical Green's function method. We use the observed records of two earthquakes, which are Mj6.3 earthquake on October 19, 2005 and Mj6.4 earthquake on March 10, 2011, as the empirical Green's functions. In this study, our target frequency band of the observed records is from 0.1 to 10.0Hz. Finally, we proposed the source model composed of five asperities on the subduction zone plate boundary. The synthetic waveforms using this source model well explain the observed waveforms.

Acknowledgment: We thank the National Institute for Earth Science and Disaster Research (NIED), Japan for strong motion records, and the Japan Meteorological Agency (JMA) for the source data.

Keywords: 2011 Tohoku-Chiho Taiheiyo-Oki Earthquake, strong ground motion, source model, asperity, empirical Green's function

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Characteristics of the 2011 Tohoku-oki earthquake revealed by the seismograph networks operated by NIED

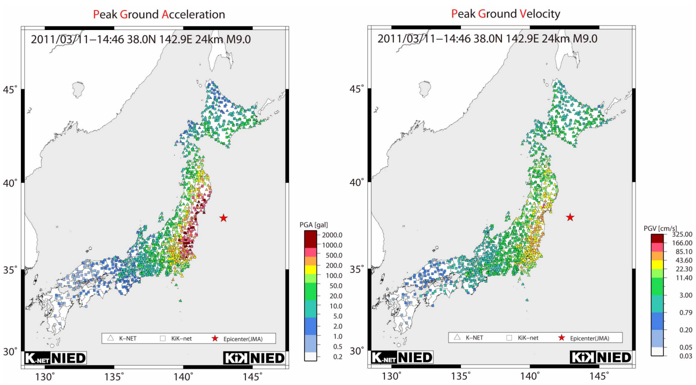
Shin Aoi[1]*, Takashi Kunugi[1], Wataru Suzuki[1], Nobuyuki Morikawa[1], Hiromitsu Nakamura[1], Nelson Pulido[1], Youichi Asano[1], Katsuhiko Shiomi[1], Hiroyuki Fujiwara[1]

[1]NIED

An Mw 9.0 megathrust earthquake attacked the Tohoku region of March 11, 2011 and strong shaking (MMI>10) was observed in a wide area across East Japan. This earthquake is the first M9-class earthquake that is closely recorded by dense seismograph network. In this paper we describe the characteristics of the earthquake observed by the seismograph network (K-NET, KiK-net, Hi-net and F-net) which are managed by the National Research Institute for Earth Science and Disaster Prevention (NIED).

The earthquake was recorded by nearly 1200 K-NET and KiK-net stations with peak ground accelerations of 2933 gal and more than 1g at 20 stations. The waveforms ordered by latitude from north reveal a very complex source process; An initial strong phase originating near the hypocenter is clearly observed. A subsequent seismic phase uniformly delayed by approximately 40 s suggests a second event at nearly the same location. A later seismic phase is strongly observed to the south 100 s after the first phase. This phase suggests that a third strong event took place of shore of Fukushima-Ibaraki. The rupture of an asperity at this location would be in agreement with the strong shaking observed in this region.

Applying a multi-line linear waveform inversion method to the 33 strong-motion waveforms, we obtained a moment magnitude of 9.0 and a peak slip of 33m. The estimated model has one large slip area which extends from the area near the hypocenter to the shallow part of the fault plane, located far off the coast of Miyagi prefecture. The estimated slip time functions at the largely slipped area have two peaks and these peaks are corresponding to the two remarkable phases observed on the record. Though aftershocks having various types of focal mechanisms are widely distributed from off Iwate to off Chiba, few interplate aftershocks with thrust focal mechanisms occurred within the large slip area but occurred in its surroundings.



Keywords: 2011 Tohoku-oki earthquake, megathrust earthquake, K-NET, KiK-net, Hi-net, F-net

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2011 Tohoku megathrust earthquake revealed by high-frequency strong ground motions

Hiroyuki Kumagai[1*], Nelson Pulido[1], Shin Aoi[1], Eiichi Fukuyama[1]

[1]NIED

A megathrust earthquake that struck the Tohoku region, Japan, on 11 March 2011 was closely observed by dense seismic networks. Strong-motion waveforms clearly indicated that distinct sub-events successively occurred during the earthquake. To investigate source processes of the earthquake, we utilized a source location method using high-frequency seismic amplitudes, which enables us to locate sources of continuous signals. We estimated source locations in successive time windows using strong-motion waveforms from the KiK-net, in which a frequency band of 5-10 Hz and a Q factor of 300 were used. We detected three main sub-events during total source duration of 150 s. The sources of these sub-events were located in a region near the Japan Trench off Miyagi and Fukushima Prefectures. The first two sub-events were determined in very similar locations. The peak ground velocities at stations of KiK-net and K-NET showed strong shaking in Miyagi, Fukushima, and Ibaraki Prefectures, which is in agreement with the location of our estimated source area of high-frequency seismic radiations.

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Imaging of the high-frequency energy radiation sources of the 2011 off the Pacific coast of Tohoku Earthquake

Shigeki Aoki[1*], Yasuhiro Yoshida[1], Mitsuyuki Hoshiba[1], Akio Katsumata[1]

[1]Meteorological Research Institute

We report the preliminary results of imaging of the high-frequency energy radiation sources (HFSs) of the 2011 off the Pacific coast of Tohoku Earthquake (PcT Eq.) using the Source Scanning Algorithm (SSA) [Kao and Shan, 2007, GJI]. In SSA, normalized amplitude of RMS envelope observed at each seismic station is back-projected with the correction of the S-wave travel time and stacked at a grid point in potential 3D source volume. The stacked value is called a brightness. The image of the brightness of all grid points illuminates the locations and timings of seismic rupture (e.g. HFS). Aoki et al. [(2010, SSJ), (2011, this meeting)] succeeded in depicting the rough image of rupture of the 2003 off Tokachi Earthquake using regional strong motion data.

The PcT Eq. was a Mw 9.0 undersea mega-thrust earthquake with the fault area of 450km x 200km [Yoshida et al, 2011, submitted to EPS]. The grid points are arranged in and around the aftershock area (4 to 80km in depth) with 4km interval. Owing to the gigantic fault, we introduce two modifications to the method used by Aoki et al. (2010). One is limitation to epicentaral distance from a grid point to a station (150km in this study; however, if the number of stations is not enough, the limitation distance is gradually modified up to 300km). Another is the introduction of the azimuthal weighting in order to reduce the effect of the unbalanced station distribution.

We used the EW component accelerograms of K-NET and KiK-net accelerometer networks installed by the National Research Institute for Earth Science and Disaster Prevention (NIED). The accelerograms are integrated to velocity, and are band-pass filtered with a frequency band of 4.0 - 8.0 Hz. Then the RMS envelopes are computed. The features of envelopes are as follows: Two distinct peaks are observed at the stations in Miyagi prefecture and northward, and one distinct peak is observed at the stations in Ibaraki prefecture and southward.

In SSA, the grid point with higher brightness is considered to be a candidate of the HFS. Our results show there are at least three stages of the high-frequency energy radiation in the PcT Eq. In this analysis, the relative maximum point (RMP) of brightness appears around the actual HFS. However a ghost peak of brightness tends to move greatly from east to west via the actual HFS due to a gap of station distribution. Therefore we mainly explain the locations and timings of RMP of the brightness in the following.

1st stage: The RMP appears at 38s from initial ruputure, and is located approximately 40km north-east from the Oshika Peninsula. If the S-waves radiate from this point, the travel times almost correspond to the first peak of the envelopes observed in Miyagi and northward. These also correspond to the expansion of the high seismic intensities of real-time manner in the Tohoku district.

2nd stage: Two RMPs are included in this stage. One appears at 57s, and is located 20km east from the epicenter. The other appears at 74s, is located 55km west from the epicenter. The S-wave travel times from these points correspond to the second peak of the envelopes in Miyagi and northward. High seismic intensities are observed at some stations in the southern Tohoku district under the influence of this stage.

3rd stage: Two RMPs are included in this stage. One appears at 105s, is located 85km off the coast of southern Fukushima prefecture. The other appears at 130s, and is located 25km off the coast of northern Ibaraki. The S-wave travel times from these points correspond to one distinct peak of the envelopes in Ibaraki and southward. These also correspond to the expansion of the high seismic intensities in the Kanto district.

In this study, we found three stages of the high frequency energy radiation in the PcT Eq. These may show that the gigantic earthquake of Mw 9.0 is interpreted as a superposition of successive occurrences of some giant earthquakes during about 160s.

Keywords: The 2011 off the Pacific coast of Tohoku Earthquake, High-frequency energy radiation sources, Distribution of the seismic intensity, Source process

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Direct observation of rupture propagation during the 2011 off the Pacific coast of Tohoku earthquake using a small array

Hisashi Nakahara[1*], Haruo Sato[1], Takeshi Nishimura[1], Hiroyuki Fujiwara[2]

[1]Tohoku University, [2]NIED

A great earthquake of Mw 9.0 took place on March 11, 2011 at the plate boundary between the Pacific plate and the North-American plate off the coast of Tohoku and Kanto region, Northeast Honshu, Japan. Strong ground motions from the earthquake were recorded at 4 stations of a small seismic array, which is located at about 120km to the westward north west of the epicenter. The seismometers of the array are deployed with an aperture of about 500m, and a seismogram at a station is correlated well to those at the other stations in frequencies lower than 2 Hz. Two prominent bursts and at least two following smaller bursts can be identified on the strong-motion records which lasted for longer than 200s. Peak ground acceleration exceeds the full scale of a seismometer of 2 *g* on the horizontal components, and is larger than 1 *g* even on the vertical component. We perform semblance analysis to estimate rupture propagation during the earthquake using coherent seismograms in frequencies of 0.5-2Hz. According to the results, the rupture during the earthquake seems to consist of at least four stages. Rupture propagated to the north or north-west from the epicenter in the beginning 50s forming the first burst, then proceeded to the southwest from around the epicenter in the next 50s during the second burst. The rupture farther extended southwestward in the following 40s, and finally migrated to the south for about 30s. This is a *direct* observation of rupture propagation during the earthquake, because no assumptions are made on the earthquake source process. Projecting the rupture propagation to a linear fault, we have estimated apparent rupture velocity to be about 2km/s on average for the initial 100s of the rupture.

Acknowledgments:
We are very grateful to Mr. Tokushichi Ito and Mr. Keiki Kuchiki for providing us with part of their pasture for our seismic array observation. Part of this observation was supported by the global COE program "Global Education and Research Center for Earth and Planetary Dynamics" of Tohoku University. We thank research center for prediction of earthquakes and volcanic eruptions, Tohoku University for supporting data retrieval after the earthquake. We appreciate continuous encouragement from Prof. Shigeo Kinoshita, Yokohama City University since the beginning of our observation. We used the integrated event catalogue compiled by the Japan Meteorological Agency and the Ministry of Education, Culture, Sports, Science and Technology in Japan. We would like to offer our deepest condolences to the victims of the earthquake and tsunami.

Keywords: The 2011 off the Pacific coast of Tohoku earthquake, rupture propagation, array, semblance

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Source process and broadband waveform modeling of 2011 Tohoku earthquake using Spectral-Element Method

Seiji Tsuboi[1]*, Takeshi Nakamura[1]

[1]JAMSTEC

We have calculated broadband synthetic seismograms for Mar. 11, 2011 Tohoku earthquakes using the Spectral-Element Method. We use finite source models by using a set of sub-events distributed along the fault surface, retrieved by inversion of body waves (Nakamura et al, 2010). The finite source model used in this simulation estimates Mw to be 9.1. The fault dimension is 460 km times 240 km with the source duration time of 150 sec. We use the Earth Simulator2 of JAMSTEC to calculate preliminary synthetic seismograms for this finite source model. We used 726 processors of the Earth Simulator 2, which should provide synthetic seismograms that are accurate up to about 5 second and longer. The comparison of the synthetic seismograms with the observation for this event, at teleseismic stations, shows that synthetic P-waveforms model the observed seismogram quite well, reflecting that the finite source model is quite precise.

The stations along the Pacific coast of Tohoku region show near field displacement with eastward horizontal movement and subsidence of the ground, which matches with the observed crustal deformation. This source model shows that the maximum slip occurs at depth of 20 km and propagates to shallower region, which is consistent with the fact that the tsunami excitation was significant for this event. Azimuthal dependence of misfits of synthetic waveforms and observation, especially for surface waves, may reflect the discrepancies of three-dimensional mantle structure used in this simulation with the actual Earth.

Keywords: 2011 Tohoku earthquake, earthquake rupture process, broadband seismograph, theoretical waveform, Spectral-Element Method

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Source Model for Generating Strong Ground Motions during the 11 March 2011 off Tohoku, Japan Earthquake

Kojiro Irikura[1*], Susumu Kurahashi[1]

[1]Aichi Institute of Tecnology

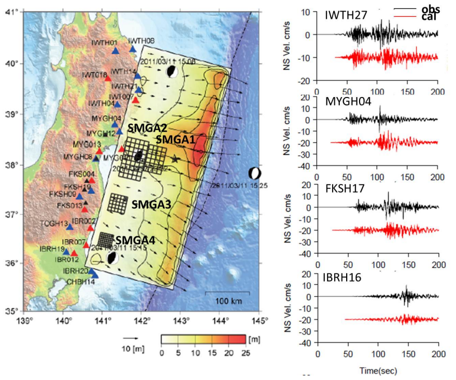
1. Introduction : This event occurred on the boundary between the Pacific and the continental plates. The focal mechanism showed a reverse fault with a compression axis in a WNW-ESE direction. The source fault roughly 400 km long and 200 km wide with strike of 193deg and dip 10deg from aftershock distribution within 24 hours and CMT solution by Japan Meteorological Agency (JMA). Strong ground motions at more than 1000 stations of K-NET and KiK-net belonging to NIED and other organizations were widely observed all over Japan including near-source areas along the Pacific coast of Tohoku. Inland areas from Miyagi to Tochigi were struck by very large ground motions as high acceleration of more than 1000 gals were recorded at 20 stations (NIED, 2011).

2. Strong ground motions simulation : We try to estimate a source model for generating strong ground motions from this earthquake from a comparison of the observed records of the mainshock and synthesized motions based on the characterized source model using the empirical Green's function method. The characterized source model consists of several strong-motion-generation-areas (SMGA) with large slip velocity or high stress drop, in entire rupture area of the earthquake. First, we specify the locations of the SMGAs by the back-propagation method by Kurahashi and Irikura (2010). The acceleration records at stations around a line from north to south show several isolated wave-packets arriving from different origins on the source fault. Such origins are considered to be the strong motion generation areas (SGMA). We identified four wave-packets in the observed seismograms, which were arriving from four SMGAs on the source fault. The onsets of the wave-packets are found to propagate with a certain velocity. We can estimate roughly the locations of the SMGAs based on the onset times of the wave-packets at many stations.

The synthetic seismograms from each SMGA are calculated, by specifying the area and starting point of the SMGA using the empirical Green's function method (Irikura, 1986). To calculate ground motions from each SMGA, the area of the SMGA is divided into equal-sized square subfaults, the area of which is set to be the same as the aftershock area. We assumed that the strong ground motions are generated only from the SMGAs and not from the background area because we are concerned primarily with the acceleration and velocity motions, which are predominantly controlled by short-period motions from the SMGAs. The ground motions from the source area of the mainshock are calculated summing those from the SMGAs considering the rupture velocity from the hypocenter to the starting points of the SMGAs.

The best-fit characterized source model consisting of four SMGAs (SMGA 1, SMGA 2, SMGA 3, and SMGA 4) is obtained as shown in the left of Figure 1. The area and starting point of each SMGA is shown by rectangle shape and star mark, respectively. The observed and synthetic ground motions at IWTH27, MYGH04, FKSH19 and IBRH16 from the best-fit source model are shown in the right of Figure 1. The agreement between the observed and synthetic ones is satisfactory at all of stations.

3. Dissection : The slip distributions from the waveform inversion using the long-period (8 s to 50 s) motions of the strong motion data are shown together with SMGAs in the left of Figure 1. There extend main slip distribution east of the hypocenter toward the Japan Trench zone, consistent with the slip distributions from the tsunami data. However, short-period ground motion simulation in this method shows large amplitude in forward rupture direction because of directivity effect, but less amplitude in backward rupture direction. This is the reason why the SMGAs have only source areas west to the starting point of each SMGA. Therefore, the areas of the SMGAs in this analysis should be examined more carefully if the strong motion data were available in the offshore east to the source fault.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IWT007
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MYGH04
SMGA2
MYGH12
SMGA1
MYG013
MYGH08
FKS004
FKSH19
FKSH09
FKS013
SMGA3
2011/03/11 15:25
TCGH13
IBR002
IBR007
SMGA4
IBRH19
IBR012
IBRH20
CHBH14
100 km
41°
40°
39°
38°
37°
36°
35°
139°
140°
141°
142°
143°
144°
145°
10 [m]
[m]
0 5 10 15 20 25
IWTH27
obs
cal
MYGH04
FKSH17
IBRH16
NS Vel. cm/s
Time(sec)

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P42 Room:Convention Hall Time:May 26 14:15-16:15

Source modeling of the 2011 off the Pacific Coast of Tohoku earthquake using the empirical Green's function method

Kimiyuki Asano[1*], Tomotaka Iwata[1]

[1]DPRI, Kyoto Univ.

A great subduction-zone earthquake of Mw 9.0 occurred along the Japan Trench off the east coast of east Japan on March 11, 2011. Strong ground motions from this event were densely observed by the strong motion networks all over Japan. It is quite important to analyze this rich data set for studying the detail structure of the source rupture process in terms of strong motion generation from such a great subduction earthquake. Aligning ground motion acceleration or short-period (<10s) velocity time-histories, which are strongly related to earthquake ground motion disaster, observed by the K-NET and KiK-net of NIED, Japan along the coast, several remarkable wave packets were captured. In Miyagi and Iwate prefectures, which were close to the northern part of the source fault, two remarkable wave packets (S1 and S2) propagating from the north part of the source region were observed, and these two wave packets are separated about 45-50s. In Fukushima and Ibaraki prefectures, which are close to the southern part of the source fault, another distinctive wave packets (S3) propagating from south part of the source region was observed. Using the observed travel time of these three wave packets that is related to damage by strong motions, the location of the rupture starting point of each strong motion generation area (SMGA) is estimated. The S1 and S2 are located west of the hypocenter off Miyagi prefecture, and those are located close to each other. The third one is located near the coast between Fukushima and Ibaraki prefectures. We modeled strong ground motions from this event using the empirical Green's function methods, and determined the source parameters (size, stress drop, rise time) of three SMGAs corresponding to three pulses S1-S3. Observed strong ground motions are reproduced well. Those SMGAs seem not to overlap the large slip area estimated by teleseismic, geodetic and Tsunami inversions. The sum of seismic moment of three SMGAs is only 2-3% of total seismic moment, which is comparable to Mw8.0 event.

Acknowledgments: The strong motion data from K-NET and KiK-net, NIED are used in this study.

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Rupture process of the 2011 off the Pacific coast of Tohoku earthquake derived from strong-motion data

Wataru Suzuki[1*], Shin Aoi[1], Haruko Sekiguchi[2], Takashi Kunugi[1]

[1]NIED, [2]DPRI, Kyoto Univ./NIED

We derive the rupture process of the 2011 off the Pacific coast of Tohoku earthquake using the strong-motion data recorded by K-NET and KiK-net. We employ the multi-time-window linear waveform inversion method. Our fault model is a rectangle plane, length and width of which are 510 km along the Japan Trench and 210 km along subducting direction of the Pacific plate. Projection of the fault plane extends from the trench line to the coastal line of northeast Japan. The subfault size is 30 x 30 km and the slip history of each subfault is represented by 25 time windows having a duration of 6 seconds separated by 3 seconds. The derived rupture model has one main large slip area extending from the area near the hypocenter to the shallow part of the fault plane, located far off Miyagi prefecture. Seismic moment of the estimated model is 4.24 x 10^{22} Nm (M_w9.0). There are two events that ruptured the main slip area at 20-45 seconds and at 65-95 seconds after the rupture initiation. This is consistent with the fact that the two wave groups separated by 40 seconds propagated along north-south direction with the stations of the similar latitude at the head. Our rupture model may give an important clue to understanding the generation mechanism of the shallow large slip during the Tohoku earthquake, which may be responsible for the catastrophic tsunami.

Keywords: The 2011 off the Pacific coast of Tohoku earthquake, Rupture process, strong-motion data

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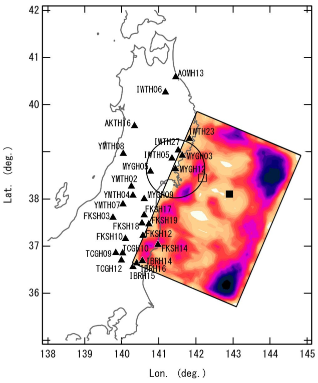
Rupture process of the 2011 Tohoku, Japan, earthquake estimated by waveform inversion with empirical Green's functions

Atsushi Nozu[1]*

[1]Port and Airport Research Institute

Ground motion records from the December 17, 2005 earthquake (MJ=6.1) (EQ1) were used as empirical Green's functions. The conventional least-squares linear waveform inversion (Hartzell and Heaton, 1983) was adopted. A fault plane with a dimension of 390km x 270km was assumed, whose strike and dip angles were set to be 203 and 10 degrees, respectively. The fault was divided into 39 times 27 fault elements. The rupture front is assumed to start from (38.1N, 142.9E, depth=24km) and to propagate radially at a constant velocity of 2.6km/s. Each fault element is allowed to slip 12 times in 6.0 seconds after passage of the rupture front at equal time intervals. The moment release of each slip relative to the moment of EQ1 was determined through the inversion. Conventional corrections for the geometrical spreading and time shifts (Irikura, 1983) were applied to the empirical Green's functions to represent arrivals from each fault element. The shear wave velocity in the source region was assumed to be 3.9km/s. Absolute time information for both the mainshock and the aftershock recordings was used.



Keywords: the 2011 off the Pacific coast of Tohoku, Japan, earthquake, rupture process, waveform inversion, empirical Green's function, Fourier phase, asperity

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Nonlinear source inversion analysis for the 2011 Tohoku Mw 9.0 earthquake based on strong-motion records

Yoshiaki Shiba[1*], Sadanori Higashi[1], Hiroaki Sato[1], Masayuki Kuriyama[1], Shinako Noguchi[1]

[1]CRIEPI

The Tohoku earthquake of Mw 9.0, which occurred on 11 March 2011, is estimated to occupy almost 500 km long and 200 km wide for its source rupture area in the plate boundary between the North American and the Pacific plates, based on the moment tensor solution and the aftershock distribution. Several source slip models have been presented for the main shock using teleseismic data, and many of these show large slip area in shallow area along the trench axes which is considered to be the source of the huge tsunami striking the eastern coast area of the Tohoku and Kanto district. On the other hand the strong-motion records observed in Japan also exhibited large peak amplitudes particularly in Miyagi Prefecture such as Tsukidate, Kurihara city where observed peak ground acceleration exceeded 2.7 g in NS component, though the asperity of the main shock is estimated to be far from the land. To reveal the contribution of the source effect to such large ground motions during the main shock the source model based on the broadband strong-motion records should be examined. In this study we applied the source inversion method using the empirical Green's function to the strong-motion records of the 2011 Tohoku earthquake and estimated the source model.

We adopted the foreshock of M 6.8 occurring on 10 March as the element event for the empirical Green's function method. The fault plane of the main shock is divided into 25 times 10 sub-faults based on the fault size of the element event. The moment density, rise time and rupture time at each sub-fault is searched during the inversion procedure with the simulated annealing. Strong-motion records at 15 stations are used for the inversion analysis. They are band-pass filtered in the frequency range from 0.05 to 0.5 Hz (2 to 20 seconds) and converted to displacement motions by the numerical integration. The data length of each component is 170 seconds after S-wave arrival.

The estimated source model for the main shock shows a large slip around the hypocenter. The area of asperity is about 100 to 150 km long and wide and the peak slip reaches 28 m assuming the rigidity as 48 GPa. The total moment release is 2.7E+22 Nm and the moment magnitude is 8.9, which is slightly smaller than other earlier reports based on the teleseismic data. This might be due to the limited frequency band of the empirical Green's functions used in the inversion. The average rupture velocity is about 1.8 km/s. During the inversion analysis the total moment, the asperity size and the largest slip are stably estimated independence from the initial values for generation of random numbers used for the simulated annealing, however the location of the asperity fluctuates around the hypocenter with different initial parameter settings. In future work we will correct such fluctuations and try to apply the inversion process to more broadband strong-motion data.

Keywords: 2011 Tohoku earthquake, source process, inversion analysis, strong motion, empirical Green's function

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Source Process of the 2011 Tohoku Earthquake Inferred from Waveform Inversion with Long-Period Strong-Motion Records

Kunikazu Yoshida[1*], Ken Miyakoshi[1], Kojiro Irikura[2], Anatoly Petukhin[1]

[1]Geo-Research Institute, [2]Aichi Institute of Technology

We have investigated the rupture process of the 2011 Tohoku earthquake by the multi-time-window linear waveform inversion method using the long-period strong-ground motion data.

We used the strong-motion data obtained from 30 stations of F-net and KiK-net, and 1 station (MYR) of Hokkaido University. These stations are located on relatively hard rock. It is expected that the broadband seismometers, used for F-net and MYR, accurately recorded very long-period strong motion excited by this M9 earthquake.

We assumed a single planar fault model of 475 km in strike and 225 km in dip. We assume N193E and 14 degrees for the strike and dip angles, respectively, referring to the USGS W-Phase moment solution. The rupture starting point is located at the hypocenter determined by USGS: 38.322.N, 142.369.E, 24.4 km.

Theoretical Green's functions are calculated using the discrete wavenumber method (Bouchon, 1981) and the Reflection/Transmission coefficient matrix method (Kennett and Kerry, 1979) using a stratified medium. We use the same structure model for all stations, because the stations used in the inversion are located on hard rock, so it is expected that the observed seismograms are not affected by local site effects in the long-period range.

We use multi-time-window linear waveform inversion procedure (e.g., Hartzell and Heaton, 1983) in which the moment-release distribution is discretized in both space and time. For discretization in space, we divide the fault plane into 38 columns in the strike direction and into 18 rows in the down-dip direction (making a total of 684 subfaults with area of 12.5 km x 12.5 km). We use 8 smoothed ramp functions with duration of 16 seconds separated by 8 seconds interval to represent the slip history of each subfault. In order to limit the rake-angle variation, non-negative constrains (Lawson and Hanson, 1974) are also adopted. The rake angles are allowed to vary within 45 degree centered at 90 degree. We use the first time window triggering velocity (FTWTV) as 2.2 km/s.

Total moment release of the inverted source model is 3.07×10^{22} Nm (Mw8.9). Overall matching between the synthetics and observed ones is very good. The inverted slip distribution shows a large slip area with a maximum slip of 29 m which is located on the shallower part of the fault plane. Large moment there was released at 60-80 s from the rupture started. The rupture velocity was inferred to be slower than 2.2 km/s (FTWTV) at early stage of the rupture process. The peak moment rate distribution indicates two high peak moment rate areas. One is the identical area with the large slip area. Another one is located on the southern part of the fault plain.

The synthetics calculated from the northern part of the fault model explain the largest amplitude of waves observed at the northern and near-epicentral stations. However, largest ones at the southern stations is explained by the synthetics calculated from the southern part of the fault model. In the southern part of the fault plane, the final slip is not large, but the relative high peak moment rate area is recognized. This relative high peak moment rate suggests making the peak of the waveform observed at the southern stations.

Keywords: 2011 Tohoku earthquake, Long-period ground motion, Strong motion, Source process

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Broadband back projection images of the Pacific coast of Tohoku Earthquake revealed from MeSO-net

Ryou Honda[1*], Yohei Yukutake[1], Masatake Harada[1], Hiroshi Ito[1], Tamotsu Aketagawa[1], Akio Yoshida[1], Shin'ichi Sakai[2], Shigeki Nakagawa[2], Naoshi Hirata[2], Kazushige Obara[2], Hisanori Kimura[3]

[1]Hot Springs Research Institute, [2]Earthquake Research Institute, [3]NIED

The most powerful earthquake after modern seismological network had been developed, hit eastern Japan and caused huge Tsunami damages. Strong ground motions from the 2011 off the Pacific coast of Tohoku Earthquake were recorded over such a long time extending 500 seconds or more by a dense and wide-span seismic network, Metropolitan Seismic Observation Network installed around Tokyo. We tried to reveal rupture process of the giant earthquake by performing semblance enhanced stacking analysis on the waveforms. By projecting the power of the stacked waveforms onto an assumed fault plane, asperities that generated significant pulses were successfully separated. Overall, strong seismic energy was found to have been generated from the areas off Miyagi and off Fukushima Prefectures. The shallow part of the fault plane off Miyagi prefecture released strong energy which caused gigantic tsunami, whereas contributions from those area off Ibaraki are not so large. Focal areas of the expected Miyagi-oki earthquake and those of historical earthquakes occurred off the coast of Fukushima Prefecture in 1938 are considered to have been broken.

Keywords: Broad band image, Source process, Back projection, MeSO-net

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Analysis of the 2011 Tohoku-oki earthquake sequence using the back-projection technique and the data from North America

Miaki Ishii[1*], Eric Kiser[1]

[1]Harvard University

There are a variety of slip models of the Mw 9.0 Tohoku earthquake available, but the slip distribution differ significantly from one model to another. This type of difference between models produced by different groups has been observed in the past, and one of the main reasons is the type of assumptions made to constrain the slip inversion. We use a back-projection method that requires very little a priori input to image the rupture process and area of the mainshock, foreshock, and a sequence of events that followed the mainshock.

At the time of this earthquake, the transportable component of the USArray project in the United States was, fortunately, still at a teleseismic distance that allowed good P-waveform recordings. We take advantage of this dense, broadband array in the back-projection analysis, and combine it with other stations in North America (including Canada) to expand the distance and azimuthal coverage of our data set.

The results of the back-projection analysis show that the area that ruptured during the foreshock sequence on March 9th does not overlap significantly with the rupture area of the mainshock. In addition, there is a discrepancy between the region defined by the aftershocks and the mainshock rupture area. The aftershock distribution is better reconciled when rupture areas of events subsequent to the mainshock are included, i.e., these events are occurring on plate interface that did not rupture during the mainshock. The cascading failure of the plate interface suggests that the earthquake magnitude could have been larger if the entire area slipped during a single event.

This approach of running back-projection on continuous data also demonstrates that some early aftershocks following large earthquakes are missed by conventional source-location algorithms. In the case of 2011 Japanese earthquakes, many events are missing from the JMA catalogue immediately following a large earthquake. The back-projection analysis using high-quality data can, therefore, contribute to improving the catalogue completeness following giant earthquakes.

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Short-period seismic wave radiation zones of the great 2011 Tohoku-oki earthquake and historical earthquakes

Katsuhisa Kanda[1*], Masayuki Takemura[1]

[1]Kobori Research Complex Inc.

Seismic intensity inversion analysis was carried out to obtain short-period seismic wave radiation zones in the fault of main shock and major aftershocks of the great 2011 Tohoku-oki (Mw9.0) earthquake. The short-period seismic wave represents shorter than about one second. The seismic intensity data were corrected by site factor related to local soil amplification of ground motions. The distance attenuation curves for inversion analysis was evaluated using measured seismic intensity of aftershocks. The short-period seismic wave radiation zone of the main shock was separated into two areas, Miyagiken-oki and Fukushimaken-oki. It is indicated that these areas were located at the rupture end of asperities showing large slip area, compared to the slip distribution by the existing research. Those of four M7 class major aftershocks were located at the edges of large aftershock area.

The short-period seismic wave radiation zones of the main shock and aftershocks were compared to those of historical earthquakes. Those of the so-called Miyagiken-oki earthquake in 1861, 1897, 1936 and 1978 were located on the west of Miyagiken-oki main shock area. Those of the 1763, 1856 and 1968 Tokachi-oki and the 1994 Sanriku-Haruka-oki earthquakes were located in the north and did not overlapped in space. Furthermore, those of the bunch of the 1938 Shioyazaki-oki earthquakes overlapped a little and fill in the space of the West and North regions of the main shock Fukushimaken-oki area.

Keywords: seismic intensity inversion, Miyagiken-oki earthquake, Shioyazaki-oki earthquake, Tokachi-oki earthquake, historical earthquake, short-period seismic wave

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Stress before and after the 2011 Mw9.0 East off Tohoku earthquake

Keisuke Yoshida[1*], Akira Hasegawa[1], Tomomi Okada[1], Yoshihiro Ito[1], Takeshi Iinuma[1], Youichi Asano[2]

[1]RCPEV, [2]NIED

Temporal change in the stress field before and after the 2011 Mw9.0 East off Tohoku earthquake was observed by stress tensor inversion analyses of earthquake focal mechanisms of events near the source region. Focal mechanism data are those estimated from moment tensor inversions of broadband seismic waveforms. The maximum principal stress axis before the earthquake has a direction toward the plate convergence, dipping oceanward at an angle of about 25-30 degree. Its dip angle significantly increased by 30-35 degree after the earthquake, and the maximum principal stress became to intersect with the plate interface at a very high angle of about 80 degree. The observed 30-35 degree rotation of the maximum principal stress axis was used to estimate the ratio of mainshock stress drop to the background deviatoric stress to be 0.9-0.95. This shows that the shear stress on the plate interface causing the Mw9.0 earthquake was mostly released by the earthquake, or the stress drop during the earthquake was nearly complete. Adopting the average stress drop obtained by GPS observation data, the deviatoric stress magnitude is estimated to be as low as 22MPa, suggesting that the plate interface is weak. The nearly complete stress drop by the earthquake caused by a high dip angle(~60 degree) of the maximum principal stress axis, which is the reason why not a small number of normal fault type aftershocks have occurred after the present earthquake, despite the predominance of thrust type earthquakes there in the pre-mainshock period.

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Modeling generation processes of off the Pacific coast of Tohoku earthquake by considering fault lubrication

Bunichiro Shibazaki[1*], Takanori Matsuzawa[2], Yushiro Fujii[1]

[1]IISEE, BRI, [2]NIED

We investigate the generation process of the 2011 off the Pacific coast of Tohoku earthquake (M9) on the basis of recent experimental results for fault frictional behavior at low to high slip rates. According to the result of tsunami waveform inversion (Fujii and Satake, 2011), large slips have occurred near the trench off Miyagi and off Fukushima. The maximum slip was estimated to be over 30 m. This result indicates that significant stress drop occurred in this region. Recent experimental studies on friction indicate that fault lubrication occurs at high slip rates and results in a significant decrease in the frictional coefficient (e.g., Di Toro et al., 2011). Therefore, it is considered that fault lubrication occurred in the area with the largest slip in the case of the 2011 off the Pacific coast of Tohoku earthquake.

In this study, we propose a rate- and state-dependent friction law with two-state variables that shows velocity weakening or velocity strengthening with a small critical displacement at low to intermediate slip rates, but strong velocity weakening with a large critical displacement at high slip rates. We use this friction law for quasi-dynamic 2D modeling of earthquake cycles. We consider two asperities where velocity weakening occurs at low to intermediate slip rates, in the region close to land and close to the trench considering the off-Miyagi region. Ruptures of asperities occur at intervals of several ten to one hundred years. On the other hand, large events occur at intervals of several hundred to thousand years. In the case of such an event, ruptures occur in the regions where velocity strengthening occurs at low to intermediate rates since the slip rate becomes enough high that velocity weakening occurs.

Next, we perform 3D quasi-dynamic modeling of earthquake cycles. We consider asperities off Miyagi, off Fukushima, and off Ibaraki and a large asperity close to the trench off Miyagi and off Fukushima. A relatively small rupture occurs repeatedly at the asperities off Miyagi, off Fukushima, and off-Ibaraki. When a rupture occurs at a large asperity close the trench, it grows a very large earthquake by rupturing the surrounding stable regions and some asperities. Very large earthquakes close to M9 occur at intervals of 400-800 years. Based on our numerical results, we propose the following scenario for the 2011 off the Pacific coast of Tohoku earthquake: (1) large slips occurred at the large asperity close to the trench off Miyagi and off Fukushima, (2) the rupture propagated to the region of the velocity strengthening at low to intermediate slip rates but velocity weakening at high slip rates, and (3) then several ruptures of asperities occurred off Fukushima and off Ibaraki.

Keywords: the 2011 off the Pacific coast of Tohoku earthquake, Earthquake cycles, quasi-dynamic modeling, fault lubrication, rate- and state-dependent friction

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Two faces of the Great Tohoku Earthquake: Shallow Dynamic Overshoot and Energetic Deep Rupture

Satoshi Ide[1*], Annemarie Baltay[2], Shintaro Tamura[1], Gregory C. Beroza[2]

[1]Dept. EPS, Univ. Tokyo, [2]Stanford University

We use empirical Green's function-based finite-source imaging and energy estimates to study rupture evolution of the Mw 9.0 Great Tohoku earthquake. We find that the earthquake consists of: a small initial phase, deep rupture up to 40 s, shallow large rupture at 60-70 s, and deep rupture lasting over 100 s. The ratio of seismic energy to seismic moment is within the normal range for earthquakes, but we find that deeper parts of the rupture radiated strongly at high frequencies; whereas, shallower parts of the rupture radiated only weakly at high frequencies despite prodigious total slip. Extremely large values of shallow slip near the trench would have been responsible for the extremely large tsunami and may have been facilitated by a combination of a shallow dipping fault and a compliant hanging wall. Reversed-mechanism (normal faulting) aftershocks suggest complete dynamic overshoot to the point of failure in the opposite direction.

Keywords: Tohoku-Oki earthquake, slip model, dynamic overshoot, seismic energy

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How did the 2011 Tohoku Earthquake start and grow up? -Role of dynamic weakening and conditionally stable area-

Yuta Mitsui[1*], Yoshihisa Iio[2]

[1]Sci., Hokkaido Univ., [2]DPRI, Kyoto Univ.

The 2011 Off the Pacific Coast of Tohoku Earthquake broke the huge area from Miyagi-Oki to Ibaraki-Oki. Such the large-scale rupture on the plate interface was the first observation off the Pacific Coast in Japan. Why did such the giant M9-class earthquake occur? To consider its generation mechanism, we construct a preliminary model of the mechanical system of the M9-class earthquake based on geophysical observation.

We consider the generation mechanism of the 2011 Tohoku Earthquake as follows: In the restoration period of the interplate locking after the active period of M7-class earthquakes and afterslip, one M7-class earthquake off Miyagi occurred and triggered the 2011 Tohoku Earthquake as the model proposed by Matsuzawa et al. (2004). Although the rupture initiation was similar to the M7-class earthquakes around this area, certain dynamic-weakening mechanism such as thermal pressurization of pore fluid promoted the rupture propagation. In particular, extremely large slip occurred in the region on the east of the hypocenter without strong wave radiation in short period. Then the rupture propagated southward through a barrier-like region with slower slip velocity and large amount of slip, and extended to the southern part.

As a part of the above scenario, we perform a preliminary simulation using a connected spring-slider system, to present that the extremely large slip in the northern part could cause rupture propagation southward without large-scale nucleation over the whole fault. The slip behavior of the barrier-like region is well explained by the “conditionally stable” condition of frictional instability. Furthermore, we try to show that the thermal pressurization around the hypocenter could cause the extremely large slip within the northern part using a three-dimensional elastodynamic system.

Keywords: Thermal pressurization, Conditionally stable, Earthquake cycle, Giant earthquake

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East Japan Super Earthquake as Tectonic Process in East Japan

Nobuaki Niitsuma[1*]

[1]Nobuaki Niitsuma

East Japan consists of Kitakami-Abukuma Mauntains, Kitakami-Abukuma Lowland, Backbone range, Intramountain basins, and coastral plains, parallel to Japan Trench. Upper and lower deep sea terrace develop between coast line and Japan Trench. The large scale topography has been formed as anticlinrium and syclinrium by East Japan Tectonics since Neogene. Because the Japan Trench is characterized as margin of subduction of Pacific Plate in Plate Tectonics, the subduction of Pacifi Plate directly controls the East Japan Tectioncs Process.

The subduction of Pacifi Plate induced the East Japan Super Earthquake of 11st March 2011, which can be concerned as one of the processes of the East Japan Tectonics.

Inversed S type Japan Trech can be divided into 3 segments, strait northern part from junction with Kuril Trench, circular middle part centered in Mogami, and circular southern part centered in Pacific include junction with Izu Trench. The radii of the circular shape were calculated ca. 400km, which assumed to be related with minimum curvature of Pacific Plate (Niitusma, 1996). Seismic Tomography (Zao, 2009) shows that Pacific Plate with 100km thickness bends along concentric circle, of which radius calculated as 375km, similar to inverse S type shape.

The slip fault planes caluculated by Geographical Survey Institute based on GPS crustal movement observations. Hypocenter and focal mechanism of earthquakes are routinely reported by Meterorological Agency.

The afershocks are characterized by the forcal mechanism and the position of hypocenter relating to the concentric circular bending surface of Pacific Plate and the fault plane. The three layer structure for the aftershocks can be recognaized, normal fault type aftershocks in upper hanging wall of faults and lower circular bending Pacific Plate and inverse fault type aftershock in middle footwall of faults.

The three layer structure can be observed typically in middle segment where hypocenter of main shock locates. Inverse fault type aftershocks occurred in the three layers of the north segment where locate mainly outside of the fault plane area, because the main shock has not release the compressonal stress. Rare normal fault type aftershocks and inverse fault type aftershocks dominates in middle layer and also in lower Pacific Plate in the south segment, where partially outside of fault area. The inverse fault type aftershocks in Pacific Plate indicate the conpressional stress still remaining accompanied with footwall of fault and large scale earthquake can be estimating such as the earthquake M 8.0 off Kanto just after 1677 Sanriku Tsunami Earthquake.

Inverse fault type aftershocks dominate along the western margin of the fault planes, where consectric circlar bending Pacific Plate rebend into flat plane. The Mantle sitting on the bending Pacific Plate surface should collide to the gate of flat subduction. The collision induces compressional stress and M 7.1 off Miyagi (7 Arpril) such as Off Sendai Earthquake in the same year of 1986 Meiji Sanriku Tsunami Earthquake which develop forearc basin, and aftershocks of Chuetsu M 6.7 & 5.9 (12 March) and Akita M 5.0 (1April) such as Uetsu Earthquake in Akita just after 1896 Meiji Sanriku Tsunami Earthquake, which develop the folding structure of backbone range and intramountain basin.

Tentional stress is induced at the top of the gate and normal fault type aftershock occurs since 19 March including M 7.1 (11 April) on Iwaki plane such as 1900 North Miyagi Earthquake after 1986 Meiji Sanriku Tsunami Earthquake which develop coastral plane and Kitakami-Abukuma Lowland.

Keywords: East Japan Super Earthquake, Tectonics, Pacific Plate, decending slab, Focal Mechanism, concentric circluar bend

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Multi-scale dynamic rupture modelling for the 2011 Tohoku earthquake: from foreshocks to mainshock

Hideo Aochi[1*], Satoshi Ide[2]

[1]BRGM, Orleans, France, [2]Graduate School of Science, Univ. Tokyo

We present conceptual dynamic rupture models for the 2011 Tohoku earthquake based on the multi-scale heterogeneity in fracture energy. Regardless of frequently occurring M7.5 events in this area, it is crucial that a large scale fault heterogeneity corresponding to a M9 event had not been clearly recognized until this earthquake. We show that the largest heterogeneity having high fracture energy is consistent with relatively slow rupture propagation of the Tokoku earthquake. The large gap in fracture energy explains the separation of two groups of waves clearly visible in observed ground motions. Our simulations prefer a cascading rupture that begins from a medium heterogeneity and then progresses over larger scale heterogeneity. We also find that the existence of foreshocks helps the rupture to grow up during the mainshock.

Keywords: dynamic rupture, multi-scale heterogeneity, Tohoku earthquake, fracture energy

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2011 Megathrust Earthquake that Revealed the Existence of Two Types of Great Earthquakes

Junji Koyama[1*], Kazunori Yoshizawa[1], Kiyoshi Yomogida[1], Motohiro Tsuzuki[1]

[1]Hokkaido Univrsity

A megathrust earthquake of magnitude (Mw) 9.0 hit the Tohoku-Kanto district of Japan, on 11 March 2011. This earthquake ruptured almost all of the seismic segments between the Pacific coast of the Tohoku district and the Japan Trench, causing devastating tsunamis. How did this event grow to such a scale? The prime factors that had not been recognized before are the double seismic segmentation along the Japan Trench and its strong initial break induced the secondary rupture during the earthquake. We show the similarity between this earthquake and the 1964 great Alaska earthquake, in terms of seismic activities both before and after the events, together with their asperities in each initial rupture region. Based on these characterizations, we suggest that these earthquakes belong to a new type of great earthquakes distinct from the 1960 Chile and 2004 Sumatra earthquakes, which mainly extended laterally along their trench axes.

Keywords: 2011 Megathrust Earthquake in Japan, Mechanism of Great Earthquakes, 1964 Alaska Earthquake, 1960 Chile Earthquake, 2004 Sumatra Earthquake

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Some hints hidden in the 1964 Alaska earthquake for the 2011 off the Pacific coast of Tohoku earthquake

Kiyoshi Yomogida[1*], Kazunori Yoshizawa[1], Junji Koyama[1], Motohiro Tsuzuki[1]

[1]Grad Sch Science, Hokkaido University

We present a variety of similarities between the 2011 off the Pacific coast of Tohoku earthquake and the 1964 Alaska earthquake. They have very different characteristics from standard megathrust earthquakes, such as the 1960 Chile and the 2004 Sumatra-Andaman earthquakes, which we call here single segmentation. Their dominant focal process is a unilateral rupture propagation along a trench axis.

The fault geometry of the Tohoku earthquake is wide but short, compared with much elongated for the standard ones of single segmentation. While a unilateral long rupture propagation along a trench dominates in the standard megathrust earthquakes, there are no specific migrations of moment release during the 2011 Tohoku earthquake. Large slips estimated from teleseismic body waves are estimated to be a very limited single region within their entire faults, that is, near the epicenters, for both the 1964 Alaska and 2011 Tohoku earthquakes.

The seismicity prior to a megathrust earthquake is generally very weak, forming a relatively clear seismic gap, but there are seismicities with either repeated large earthquakes or minor earthquakes in all the segments of the 2011. Instead, there is a shallow and long zone of virtually no seismicity close the trench. We can recognize these features similar to those of the 1964 Alaska earthquake. The similarities are extremely surprising because they exhibit strong contrast with the other famous examples, the 1960 Chile and the 2004 Sumatra earthquakes.

In addition, the characteristic of seismogenic segments adjacent to the epicenter (i.e., a segment of large coseismic slips) stongly implies its weak plate coupling in contrast to very stong coupling at the segment with the epicenter for either of double-segmentation earthquakes. In the case of the 1964 Alaska earthquake, there are several earthquakes of maginitude 7 in the southwestern segment around Kodiak Island and they are normal-fault events within the subducting Pacific plate (Ratchkovski and Hansen, 2001). In the Tohoku case, a series of five similar earthquakes occurred in 1938 in the Shioya-Oki or Fukushima-Oki segment in the south of the Miyagi-Oki segment (Abe, 1977). Since plate coupling appears to be very strong in all the segments along a trench for single-segmentation megathurst earthquakes, the above contrast of two adjacent segments (strong and weak couplings) strongly distinguish double-segmentation earthquakes from them.

The existence and major role of shallow segments (calling it double segmentation) associated with the 2011 and the 1964 earthquakes make them different from the other megathrust earthquakes. The recognition of these two types, particularly the similarity between the two earthquakes should help our understanding of megathrust earthquakes occurring in the future.

Keywords: megathrust earthquake, double segmentation, interrelation of segments, 2011 Tohoku earthquake, 1964 Alaska earthquake

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Bathymetric feature around Japan Trench obtained by JAMSTEC multi narrow beam survey

Yukari Kido[1*], Toshiya Fujiwara[1], Tomoyuki Sasaki[2], Masataka Kinoshita[1], Shuichi Kodaira[1], Mamoru Sano[1], Yuji Ichiyama[1], Yasunori Hanafusa[1], Seiji Tsuboi[1]

[1]JAMSTEC, [2]AORI, Univ Tokyo

Bathymetric map covered with Northeast Japan, off Sanriku and Japan Trench area are compiled by JAMSTEC cruise data. Data source are SeaBeam2100 and 2112 series, SeaBat 8160 and HS10 multi-narrow beam bathymetry by JAMSTEC research vessels obtained since 1997 through 2010. Japan500m_mesh bathymetric dataset compiled by Japan Hydrographic Department, Maritime Safety Agency, which is 500m by 500m-gridded data, cover the loss of multi-narrow precise survey area. These datasets were smoothly merged using weighted means and simple averages by Generic Mapping Tools (GMT) software (Wessel & Smith, 1995).

These mappings are basic knowledge of bathymetric features before gigantic earthquake.

Since June 2008, JAMSTEC data search portal and research cruise data sites are available as shown below for general public.

http://www.jamstec.go.jp/e/database/index.html

http://www.godac.jamstec.go.jp/dataportal/index_eng.html

http://www.godac.jamstec.go.jp/cruisedata/e/

Keywords: Japan Trench, Multi-narrow beam bathymetry, JAMSTEC data search portal, JAMSTEC cruise database

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Submarine landslides of trench landward slopes in the Japan Trench before the earthquake

Kiichiro Kawamura[1*], Tomoyuki Sasaki[2]

[1]Fukada Geological Institute, [2]Ocean Engineering & Development Co.,Ltd.

In this presentation, a detailed bathymetric map of the Japan Trench land ward slope before the NE Japan great earthquake and the submergence record by the submersibles are shown.

The sea geographical features data were obtained by acoustic device SeaBeam2112 equipped with cruises of JAMSTEC research vessels from 1998 to 2007. In the area from the coast of Hachinohe of the latitude 41 degree to the coast of Fukushima of the north latitude 37 degree, the range covers east longitude 145 degree from east longitude 143 degree that places Japan Trench. The scanning zone of the data interval is appropriately set because it becomes oversampling in shallow level and undersampling in deeper level in water depth. In this bathymetric map, the large-scale collapse geographical features scooped out like the circular arc of width tens of the km in each place is admitted. The ruggedness of geographical features with the possibility of the block that slipped and fell by such a collapse of the slope is admitted.

The topography of the seabed announced here will become a critical data set in considering the topography of the seabed and the dive investigation record after the earthquake that will be acquired in the future. However, these landslides-like circular arc geographical features might be formed with the geological time scale.

Keywords: submarine landslide, submersible, bathymetric map, seabeam

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Geophysical survey around the rupture zone of the 2011 off the Pacific Coast of Tohoku Earthquake by R/V KAIREI

Tetsuo No[1*], Yuka Kaiho[1], Narumi Takahashi[1], Seiichi Miura[1], Mikiya Yamashita[1], Yasuyuki Nakamura[1], Jin-Oh Park[2], Takeshi Tsuji[3], Koichiro Obana[1], Gou Fujie[1], Takeshi Sato[1], Yojiro Yamamoto[1], Toshiya Fujiwara[1], Kazuhiko Kashiwase[1], Kazuo Nakahigashi[4], Masanao Shinohara[4], Ryota Hino[5], Shuichi Kodaira[1], Yoshiyuki Kaneda[1]

[1]JAMSTEC, [2]AORI, Univ. of Tokyo/JAMSTEC, [3]Kyoto Univ./JAMSTEC, [4]ERI, Univ. of Tokyo, [5]Tohoku Univ.

On March 11, 2011, the Pacific Coast of Tohoku Earthquake, occurred with a magnitude of M_J9.0 beneath the landward slope of the Japan Trench, where large interplate thrust earthquakes are frequently generated. The magnitude of the main shock was the largest in Japan. As a result, the earthquake caused very strong vibrations, large tsunamis, and extensive damage around the Tohoku and Kanto areas. Immediately after the earthquake, we conducted a geophysical survey around the rupture zone of the earthquake using R/V Kairei of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). The operations included the deployment of ocean bottom seismographs (OBSs) [JAMSTEC, the University of Tokyo, Tohoku University], the retrieval of OBSs and ocean bottom pressure (OBP) [Tohoku University], a multi-channel seismic reflection (MCS) survey, and topography measurements by a multi-beam echo sounder. We deployed 42 OBSs for aftershock observations around the rupture zone in the offshore area from Iwate to Ibaraki prefectures. Moreover, 6 OBSs and 3 OBPs were successfully recovered. This survey is a part of the program launched following the "2011 off the Pacific coast of Tohoku Earthquake" and is assisted by a grant-in-aid for special purposes from the Ministry of Education, Culture, Sports, Science and Technology, Japan.

The MCS survey data were acquired along two lines (TH03 and TH04) in the offshore area of Miyagi prefecture and estimated at the maximum slip in the earthquake from the various analyses of some institutes. Because we carried out the survey of line TH03 in the same line as the 1999 survey (Tsuru et al., 2002), it could be possible to perform a time-lapse seismic reflection analysis using these data. However, we faced two difficulties in performing time-lapse seismic reflection analyses using these data: first, the data for the two surveys were obtained using different data acquisition systems of R/V Kairei, and second, the data quality in this survey was severely affected by the aftershocks, which were very frequent and had large magnitudes. Despite the difficulties in carrying out the time-lapse analyses, it could be possible to determine the nature of the coseismic change in the bathymetry and the crustal structure to study not only MCS data but also topographic data.

In the survey, we used an air-gun array with a spacing of 50 m. The total capacity of the array was 7800 cu.in. (130 liters; a tuned air-gun array consisting of 32 guns). The standard air pressure was 2,000 psi (approximately 14 MPa). During the operation, we towed a 444-channel hydrophone streamer cable with a 5700-m maximum offset, and the group interval was 12.5 m. The towing depth of the air-gun array and the streamer cable was maintained at 21 m below the sea surface. The sampling rate was 2 ms, and the recording length was 18 s.

In this study, we present an outline of the survey and the preliminary results of seismic reflection data and geophysical data.

Keywords: The 2011 off the Pacific Coast of Tohoku Earthquake, Ocean Bottom Seismograph, Multi-channel seismic reflection survey, Bathymetric survey, Time lapse survey, Ocean bottom pressure

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Fault System of the 2011 Off-Tohoku Earthquake; Insight from Seismic Reflection Data and Seafloor Observations

Takeshi Tsuji[1*], Yoshihiro Ito[2], Motoyuki Kido[2], Yukihito Osada[2], Hiromi Fujimoto[2], Juichiro Ashi[4], Masataka Kinoshita[3], Toshifumi Matsuoka[1]

[1]Kyoto University, [2]Tohoku University, [3]JAMSTEC, [4]University of Tokyo

Faults related to the tsunamigenic 2011 off-Tohoku earthquake (Mw 9.0) were investigated by using multi-channel seismic reflection data acquired in 1999 and submersible seafloor observations from 2008. The shallow fault geometries as well as submarine slide are important to reveal mechanisms of the huge tsunami generation. On the reflection seismic profile, we identified three predominant faults; (A) backstop reverse fault working as a boundary between seaward accreted sequence and landward consolidated sequence, (B) a branch fault constructing the seafloor slope break, and (C) vertical fault extending toward a seafloor ridge. Several imbricate thrusts are developed within the accreted sequence seaward of (A) backstop reverse fault. Between (A) the backstop reverse fault and (B) the branch fault, underplating structures are identified on the profile. Displacement along (C) the vertical fault has offset a Cretaceous sequence surface by ~800 m. The location of these faults interpreted in the seismic reflection profile is distributed around the area with largest slip and tsunami induction of the 2011 event. Cold-seep communities and a high scarp observed at these fault traces suggest current activity on these faults. We interpret the fault system in the seismic profile as a shallow extension of the seismogenic fault that may have contributed to induction of the huge tsunami.

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Environmental fluctuation observed on deep seafloor off Tokachi in Hokkaido and off Hatsushima Island in Sagami Bay

Ryoichi Iwase[1*], Ichiro Takahashi[2]

[1]JAMSTEC, [2]Marine Works Japan, Ltd.

When the 2011 off the Pacific Coast of Tohoku Earthquake of JMA magnitude 9.0 occurred at 14:46 JST on March 11th 2011, tsunamis whose amplitudes were about 20 - 80 cm were observed with JAMSTEC's cabled observatories deployed on deep seafloor off Hokkaido, in Sagami Bay, off Muroto Cape in Kochi and DONET. Among those observatories, at the deep seafloor observatory off Hatsushima Island in Sagami Bay and at the observatory off Kushiro-Tokachi in Hokkaido, the observation with several other sensors, such as CTD (conductivity, water temperature and water depth) sensors, current meters, TV cameras and so on, have been conducted besides seismometers and tsunami pressure gauges. Water depth of cable end stations of the observatories to which those multidisciplinary sensors are attached are 1175 m off Hatsushima Island and 2540 m off Tokachi, respectively. At 22:31 JST on March 15th 2001 the Eastern Shizuoka Prefecture Earthquake of JMA magnitude 6.4 occurred in north-west of off Hatsushima Island observatory. In this presentation environmental fluctuation on deep seafloor observed with those two observatories will be reported.

When the off the Pacific Coast of Tohoku Earthquake occurred on March 11th, the pressure gauge of CTD at the off Kushiro-Tokachi observatory detected the beginning of pressure increase associated with tsunami at 15:07. It increased up to about 60 cm in water height at the period between 15:12 and 15:18. The electro-magnetic current meter whose sampling rate is 2 Hz detected northward bottom water current at the same time. Considering background current, current velocity increase associated with the tsunami is estimated about 2 cm/s. In water temperature, conductivity and echo intensity of ADCP (Acoustic Doppler Current Profiler), significant fluctuations were not observed.

At off Hatsushima Island observatory, decrease of water pressure associated with the tsunami began at 15:32. It decreased about 80 cm in water height at 15:48, then began to increase about 160 cm from the minimum at 16:17 and degreased again to the same level of 15:48 at 16:55. The fluctuation of water pressure has continued until March 15th. Significant fluctuation of water current was not observed with ADCP whose sampling interval is 1 minute. However, echo intensity of ADCP, which corresponds to the amount of suspended materials, increased up to about 13 dB at 15:23 and then decreased to usual level at 17:00. After that it began to increase again at 01:17 on March 12th and it increased larger than ever up to about 18 dB at 01:37. Those echo intensity increases indicate regional land slide occurred in Sagami Bay, considering that the occurrence of submarine telecommunication cable trouble was reported by KDDI, although mudflow or strong water current was not observed at the observatory.

When the Eastern Shizuoka Prefecture Earthquake occurred, unfortunately ADCP and some other equipment were stopped because of scheduled blackout conducted by TEPCO just before the earthquake occurred. Nevertheless, the CTD sensor worked at that time and water temperature increase of 0.3 degree whose pattern was characteristic to mudflow was observed. Gamma ray intensity fluctuation was also observed, though it can be affected by sedimentation of suspended materials associated with biological spring bloom on sea surface.

In summary, as deep-sea environmental fluctuations besides bottom water pressure fluctuation caused by tsunamis, bottom water current fluctuation associated with tsunami caused by off the Pacific Coast of Tohoku Earthquake was observed on deep seafloor off Tokachi and increase of suspended materials which indicates landslides or mudflow associated with both earthquakes were observed on deep seafloor off Hatsushima Island.

Keywords: the 2011 off the Pacific Coast of Tohoku Earthquake, the Eastern Shizuoka Prefecture Earthquake, deep-sea environmental fluctuation, off Hatsushima Island in Sagami Bay, off Tokachi in Hokkaido, bottom water current

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Quasi real time estimation of coseismic displacement field based on the RTK-GPS time series ?Applied to the 2011 off the

Tatsuya Kobayashi[1*], Yusaku Ohta[1], Satoshi Miura[2], Hiromi Fujimoto[1]

[1]RCPEVE, Sci., Tohoku Univ., [2]ERI, The University of Tokyo

The Mw 9.0 earthquake, the 2011 off the Pacific coast of Tohoku Earthquake on March 11, 2011 (hereafter PCTE) generated a large tsunami, which caused a devastating disaster including the loss of more than 12,200 lives up to April 7. It is the extremely important for the rapid-determination of the earthquake size for disaster prevention and tsunami early warning system. Kobayashi et al. (2011) developed the rapid permanent displacement estimation method based on the RTK-GPS time series. In this study, we applied this newly developed method to the PCTE event.

The GEONET Oshika (0550) site is, which the close to the epicenter of the PCTE event, recorded huge coseismic displacement. Ohzono et al. (in this meeting) shows the detail coseismic displacement field based on the daily analysis. The estimated coseismic displacement reached 5.19 m (Eastward), 1.46 m (Southward), and 1.16 m (downward), respectively. For rapid-determination of the coseismic displacement fields, we applied our newly developed method (Kobayashi et al. (also this meeting)) to the RTK-GPS time series. In Oshika site, we succeed to determine the coseismic displacemet 2 minutes 28 seconds after the mainshock occurrence. The estimated coseismic displacement amount is 5.20 m (Eastward), 1.50 m (Southward), and 1.49 m (downward), respectively. It is almost consistent with the daily coordinate analysis. When we applied the same procedure to the all GEONET sites of the Tohoku and Kanto region, the coseismic displacement estimation finally finished after the approximately 4 minutes after the mainshock. Our result suggests that we can start the coseismic fault estimation after the 4 minutes after the mainshock. We will show the more detail discussion including rapid determination of the coseismic fault model in this meeting.

We thank GSI for providing GPS data. We thank Mr. T. Takasu for providing the GPS analysis software, 'RTKLIB ver.2.4.0'.

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Spatial distribution of foreshocks and aftershocks of the 2011 Tohoku earthquake and their focal mechanisms

Youichi Asano[1*], Tatsuhiko Saito[1], Yoshihiro Ito[2], Katsuhiko Shiomi[1], Hitoshi Hirose[1], Takumi Matsumoto[1], Tomotake Ueno[1], Bogdan Enescu[1], Tomoe Kazakami[1], Takeshi Kimura[1], Hisanori Kimura[1], Tetsuya Takeda[1], Sachiko Tanaka[1], Takanori Matsuzawa[1], Hirotoshi Matsubayashi[1], Takayuki Miyoshi[1], Yoshikatsu Haryu[3], Shin Aoi[1], Sadaki Hori[1], Shoji Sekiguchi[1]

[1]NIED, [2]RCPEV, Tohoku Univ., [3]ADEP

We estimated centroid moment tensors of foreshocks and aftershocks of the 2011 megathrust earthquake in eastern Japan with Mw 9.0. Obtained result shows that foreshocks were basically interplate earthquakes with thrust type focal mechanisms and those were distributed in a localized area off Miyagi. The mainshock hypocenter is located in the southwestern edge of this foreshock area. Aftershocks are widely distributed from off Iwate to off Chiba and have various types of focal mechanisms. Interplate aftershocks with thrust focal mechanisms have not occurred within the larger coseismic slip area inferred from tsunami data and have occurred in its surroundings. We interpreted that this larger coseismic slip area can no longer slip as aftershocks due to plenty stress release during the mainshock rupture and aftershocks in its surroundings were caused by stress concentration mainly by the larger coseismic slip area in the mainshock asperity. Normal fault type aftershocks were widely distributed in the overriding plate and the outerrise of the Pacific plate. These aftershocks may be due to tensional stress change caused by the coseismic slip. Trust fault type aftershocks in the subducting Pacific plate are also interpreted to be induced by compressional stress change by the coseismic slip.

Keywords: foreshock, aftershock, centroid moment tensor, focal mechanism

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Magnitude of the 2011 Off the Pacific Coast of Tohoku Earthquake from HFER duration and displacement amplitudes

Tatsuhiko Hara[1*]

[1]IISEE, BRI

We determined magnitude of the 2011 Off the Pacific Coast of Tohoku Earthquake using durations of high frequency energy radiation (HFER) and the maximum displacement amplitudes of tele-seismic P waves. The estimated HFER duration and magnitude are 170.5 s, and 8.96, respectively. Compared to the December 26, 2004 Sumatra earthquake (Mw 9.0), the HFER duration of this event is shorter, while the displacement amplitude is larger. We discuss the relation between HFER duration and displacement amplitude for other large shallow earthquakes in the presentation. The azimuthal dependence of HFER durations indicates the rupture propagation in the southwest direction. We measured time differences between P-wave arrivals and the times at which absolute amplitudes of high bandpass filtered P-waves became the largest. Most of the time differences normalized by the centroid time shift are in the range between 50 and 80 per cent, which is consistent with the frequency distribution that we obtained for large shallow earthquakes previously.

Keywords: high frequency energy radiation, magnitude

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Earthquake Early Warning and Observed Seismic Intensity

Mitsuyuki Hoshiba[1], Kazuhiro Iwakiri[1*], Yasuyuki Yamada[2], Naoki Hayashimoto[1], Toshihiro Shimoyama[2]

[1]Meteorological Research Institute, [2]Japan Meteorological Agency

The strong ground motions were recorded at wide area of north eastern Japan. Just before the strong ground motion hit cities around Tohoku district, Japan Meteorological Agency (JMA) issued the Earthquake Early Warning (EEW) to general public at the district. Eventually seismic intensity of 7 (JMA scale) was observed, which is the 2nd experience since JMA had introduced instrumental measurement for the intensity observation in 1996. Seismic intensities of 6-upper and 6-lower were also widely observed at Tohoku and Kanto districts. In this paper, we will report the outline of EEW, and its observation focusing on the seismic intensity for the Mw9.0 earthquake.

The JMA EEWs are divided into two grades; that is ”forecast” and ”warning”. ”Forecast” is issued to advanced users when estimating M3.5 or larger, or expecting seismic intensity equals to 3 or greater. In the ”forecast”, the regions are particularly specified where intensity 4 or larger is expected. When intensity is expected to be 5-lower or greater at any observation stations of the intensity networks, ”warning” is issued to general public at the regions where intensity 4 or larger is expected. The ”warning” is broadcasted though various methods such as TV, radios and cellular phone mails. JMA EEWs are updated as available data increases with elapsed time. Accordingly EEWs are issued repeatedly with improving the accuracy.

JMA EEW system was triggered for the Mw9.0 earthquake when station OURI detected the initial P wave at 14:46:40.2, March 11. The first ”forecast” was issued 5.4s after the P wave detection. At the 4th ”forecast”, 8.6s after the first trigger, the magnitude was estimated to be 7.2, and seismic intensity was expected to be 5-lower for central Miyagi Prefecture (around Sendai city), then the 4th ”forecast” was issued as ”warning”. The ”waning” was issued to general public at Tohoku district, and then automatically broadcasted using TV, radios and cellular phone mails. It was earlier than the S wave arrival (observed intensity was at most 2), and also 15s earlier than the strong ground motion (intensity 5-lower) hit the closest station to the epicenter. The ”forecast” was updated up to the 15th issue, 116.8s after the first trigger, in which magnitude was estimated to be 8.1. The estimated magnitude is almost the upper limit of JMA magnitude because of the saturation of JMA magnitude vs. Mw for events of $M>8$. Note that the magnitude derived from maximum amplitude is 8.4 in the unified hypocentral catalog of JMA.

The area of 6-upper and 6-lower is widely distributed from Tohoku to Kanto district, approximately in the area of 400 km x 100 km. The long duration is also another characteristic of the event. At OURI, two peaks are apparent in the acceleration envelope, which is probably due to the complicated source process. At IYASAT, strong ground motion were apparent at later phase, which is much later than direct S phase, and it took 80s to increase from intensity 1 to 5-lower.

EEW system expected intensity to be 4 in the 12th to 15th (final) issues for Tokyo region, which was underestimation as compared with actual observation (5-upper; larger than the criterion of ”warning”). The underestimation is probably due to the large extent of fault rupture.

After the mainshock, the operation of EEW did not work well. For several days, because some earthquakes occur simultaneously at the wide source region, the system confused, and did not always determine the location and magnitude appropriately. After the mainshock to March, 29, 2011 (19 days), JMA appropriately issued ”warning” for 15 out of the 22 events for which seismic intensity 5-lower or greater was actually observed. On the other hand, for the period of 19 days, 45 ”warnings” were issued expecting intensity 5-lower or greater, but actual observed intensity was not larger than 2 at any observation stations for 11 out of the 45 events.

Acknowledgement: We used waveform of K-NET, and KiK-net of NIED.

Keywords: The 2011 off the Pacifc coast Tohoku earthquake, Earthquake Early Warning, Seismic Intensity

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Deviation from empirical relations - Initial several seconds and strong ground motion: tau_c, Pd, and spectrum -

Mitsuyuki Hoshiba[1*], Kazuhiro Iwakiri[1]

[1]Meteorological Research Institute

The strong ground motions were recorded at wide area of north eastern Japan. The amplitude of the Mw 9.0 is quite small for first several seconds, and its spectrum contains strong high frequency waves. For research of Earthquake Early Warning (EEW), several empirical relations are has been proposed, but large deviation is found from the empirical relations for the Mw 9.0.

Amplitude of initial several to several tens second: Pa, Pv and Pd are the maximum absolute amplitude of acceleration, velocity, and displacement, respectively, for the range between tp and tp+ tN, where tp is P wave onset time for each waveforms. For tN, 3, 4, 5, 10, 20 and 30s are used in this analysis. For tN=3-5s, Pa, Pv and Pd of the Mw9.0 are comparable to or even smaller than those of not only the Mw7.3 but also the Mw6 class earthquakes. This indicates that the initial amplitude do not suggest the large magnitude event.

Pd-PGV: Wu and Kanamori(2008) showed the correlation of Pd of first 3 sec and PGV(peak ground velocity), and proposed to use it for EEW. However, because the Pd of the first 3 sec is quite small for the Mw 9.0, it is difficult to anticipate the large PGV for the first several seconds.

tau_c-M relation: New algorisms, called tau_c, were proposed for estimates of eventual magnitude from the very early portion of waveforms using the frequency contents, and has been widely investigated by many researchers. Most of them concluded that the frequency contents are more sensitive to the magnitude than the ground motion amplitude in the initial several seconds of the P wave, and also claimed that the sensitivity is appropriate for EEW and it is possible to determine the eventual size of the events from the initial several seconds. However, there are some counterarguments against them. Discussion of the validity of the new algorisms of tau_c for estimates of magnitude is not yet well settled. tau_c of the Mw9.0 is comparable to or even smaller than that of not only the Mw7.3 but also the Mw6 class earthquakes for initial several seconds. This suggests that it is difficult to recognize to be larger than the Mw7.3 from only tau_c for initial several seconds.

Spectrum of waveform: Spectrum of Mw9.0 earthquakes contains strong high frequency waves, which is flat to the frequency of anti aliasing filter, and clear fmax is not found. Spectrum ratio of the Mw9.0 to the Mw7.3 foreshock shows that the dominant frequency is higher for the Mw9.0 than for the Mw7.3. This high frequency is the reason of the contrary to the expectation that tau_c increases with increasing magnitude.

Estimation of source rupture extent: Irikura et al.(2010) proposed a method to estimate the source rupture extent using "more than 150cm/s/s for vertical component", and Yamada(2010) also a method based on a criterion depending on "f=4.36logPa+5.69logHv-19.97, in which f>0 corresponds to near source region". For the Mw9.0, these indexes are satisfied for wide area of inland region of Tohoku and Kanto.

Summary: Our analysis indicates that updating procedure is necessary using ongoing waveforms for EEW, and we believe that the EEW should be robust even for the extraordinary case, especially for larger events.

Acknowledgement: We used waveform of K-NET, and KiK-net of NIED.

Keywords: The 2011 off the Pacific coast Tohoku Earthquake, Earthquake Early Warning, empirical relations, tau_c, Pd-PGV, Intitial several seconds

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Static and dynamic earthquake triggering associated with the 2011 Tohoku earthquake

Bogdan Enescu[1*], Youichi Asano[1], Shinji Toda[2], Zhigang Peng[3], Shin Aoi[1], Wataru Suzuki[1], Takanori Matsuzawa[1], Kazushige Obara[4], Sachiko Tanaka[1], Katsuhiko Shiomi[1], Tetsuya Takeda[1], Takeshi Kimura[1]

[1]NIED, [2]DPRI, Kyoto University, [3]Georgia Institute of Technology, [4]ERI, University of Tokyo

The 2011 Tohoku earthquake (M9.0) was followed by large aftershocks and seismicity activation at locations up to several hundred kilometers away from the mainshock. Our present study is divided into two parts. In the first part we analyze the effect of static stress changes due to the 2011 Tohoku event on the occurrence of relatively large aftershocks, using their CMT focal mechanism solutions. In the second part, we investigate the possible role of both dynamic and static stress transfer mechanisms on the occurrence of remote seismicity.

a) Static stress changes resolved on the nodal planes of large aftershocks.
We used the Tohoku slip distribution of Suzuki et al. (2011) and the CMT focal mechanism solutions of aftershocks determined by Asano et al. (2011). The aftershocks (M >= 3.8) are located in an area of slightly larger extent compared to the fault plane of the mainshock and the depth ranges between 0 and 60 km. We divide the focal mechanisms into two groups: consistent (i.e., thrust faulting) and non-consistent (mainly normal faulting) with the mainshock focal mechanism, based on the rotation angle defined by Kagan (1991). We resolve the Coulomb static stress changes on both aftershock nodal planes and select the nodal plane with the largest stress change as the likely fault plane. We show that 71% and 78% of earthquakes from the two groups, respectively, occur at locations of increased stress. To test the statistical significance of this result, we have selected 1800 F-net focal mechanisms for earthquakes occurred in the same region as the analyzed aftershocks, before the occurrence of the Tohoku earthquake (2003.01.01 - 2011.03.11). The percentage of earthquakes that occur at locations of increased stress is about 46%. Several other slip models for the Tohoku mainshock produce similar results. This indicates a high correlation between the occurrence of the aftershocks and the co-seismic static stress changes.

b) Triggering of remote seismic activity.
The 2011 Tohoku earthquake was followed by an unprecedented increase of seismicity at remote locations (i.e., at distances up to several hundred kilometers away from the mainshock). Examination of Hi-net waveform data and the JMA earthquake catalog reveals triggered local events in southern Kyushu, close to the Ibusuki volcanic field, at about 1000 km from the southwestern edge of the Tohoku fault. The onset of increased seismic activity correlates very well with the arrival of the surface waves. We detect local, high-frequency tremor-like signal (i.e. not clearly defined P- and S-arrivals) correlated with the arrival of the mainshock surface waves at several Hi-net seismic stations in Shikoku region, at distances of about 700 km from the SW edge of the Tohoku fault. We also detect a rather clear correlation between the arrival of the surface waves and the seismicity increase close to Yakedake volcano, in Hida Mountains, at about 300 km from the fault edge. A cluster of seismicity close to the Hakone geothermal area and in the northwestern part of the Miyakejima volcano could be explained by both static (Coulomb stress changes of about 0.2-0.3 Bar) or dynamic stress changes. The 15th March 2011, M6.4 Shizuoka Prefecture earthquake occurred in an area of static stress change of about 0.4 Bar. In contrast, there was no clear activation of seismicity on the nearby Tokai subduction zone, where the static stress changes resolved on the plate interface show values of less than 0.1 Bar. The passage of surface waves from the Tohoku mainshock appears to be responsible for the activation of seismicity in some volcanic and geothermal areas, however it is more difficult to detect or confirm such a correlation at other locations.

Keywords: 2011 Tohoku earthquake, stress triggering, seismicity activation, aftershocks, focal mechanisms

MIS036-P69 Room:Convention Hall Time:May 26 14:15-16:15

Characteristics of initial P-wave of extremely large earthquakes

Shunta Noda[1*], Shunroku Yamamoto[1], Naoyasu Iwata[1], Masahiro Korenaga[1]

[1]Railway Technical Research Institute

In this study, we indicate the facts described below by analyzing K-NET and KiK-net data.

1) In M6-7 events, there is no difference in the initial P-wave from the onset to 2-3 seconds.

2) In M8-9 events, the initial P-wave from the onset to 5-6 seconds is getting larger very slowly compared with the M6-7 events. This fact is confirmed in the frequency range between high value and 1Hz, and not influenced by the difference of radiation pattern.

From these result, the occurrence of extremely large earthquake can be found compared with the present EEW system.

Keywords: P wave, initial phase, initial rupture, Earthquake Early Warning, EEW

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(May 22-27 2011 at Makuhari, Chiba, Japan)

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Estimation of crustal deformation due to the 2011 off the Pacific coast of Tohoku Earthquake

Takashi Hirai[1*], Nobuo Fukuwa[1], Masafumi Mori[1]

[1]Environmental Studies, Nagoya University

1. Introduction

The 2011 off the Pacific coast of Tohoku Earthquake was the greatest earthquake in Japan as the magnitude of 9.0. Analysis of GPS network, such as GEONET by Geospatial Information Authority of Japan, has revealed the crustal deformation due to the earthquake. On the other hand, the crustal deformation can be estimated from the displacement waveform calculated by integrating the accelogram observed by strong motion seismometer. This method would be used complementary with GPS analysis. In this study, we calculated the crustal deformation due to the 2011 off the Pacific coast of Tohoku Earthquake from the accelograms recorded on strong motion observation network KiK-net by National Research Institute for Earth Science and Disaster Prevention.

2. Method

All KiK-net observatories have seismometers both on basement and ground surface. Both accelograms were used in order to compare the results from basement accelogram and that from surface accelogram in this study. The displacement waveform was calculated by applying the baseline adjustment and the linear acceleration integral method to the span 0 ? 150 s of the accelogram. For the accelogram seemed to change the baseline during recording, baseline change was corrected before integration.

3. Result and discussion

The crustal deformation at KiK-net observatories in Fukushima, Miyagi and Iwate prefectures calculated by integrating basement accelogram are shown in Fig. 1. This result agrees with the result by GPS network GEONET [1] mostly. By comparison between the result from basement accelogram and surface accelogram, the former provides more stable result. Thus, it is found that the basement accelogram does not contain the amplification effect by surface soil layer so that it reflects the deformation of crust more purely. Displacement waveform at several KiK-net observatories, such as KiK-net Tajiri (MYGH06), agreed with that from high rate GPS analysis [2] mostly as shown as Fig. 2.

4. References

[1] Geospatial Information Authority of Japan, Crustal deformation due to the 2011 off the Pacific coast of Tohoku Earthquake, http://www.gsi.go.jp/chibankansi/chikakukansi_tohoku.html (2011.4.27).

[2] Research center for Earthquake Prediction, Disaster Prevention Research Institute, Kyoto University, Coseismic displacement by high rate GPS analysis,
http://www.rcep.dpri.kyoto-u.ac.jp/events/110311tohoku/gps_1s/index.html, (2011.4.27).

Acknowledgment

We used the KiK-net seismograms by National Research Institute for Earth Science and Disaster Prevention.

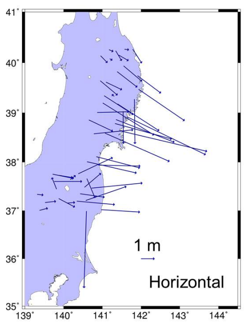

Fig. 1 Crustal deformation calculated from KiK-net accelogram

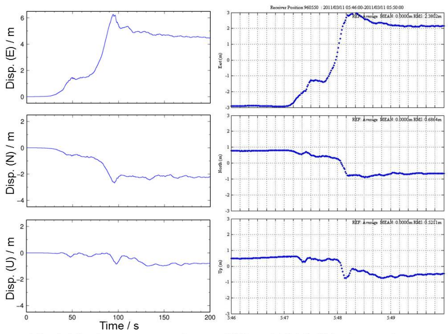

Fig. 2 Displacement waveform at KiK-net Tajiri (left) by integrating accelogram (right) by high rate GPS analysis (ref.[2])

Keywords: the 2011 off the Pacific coast of Tohoku Earthquake, crustal deformation, permanent displacement, strong motion seismogram

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MIS036-P71 Room:Convention Hall Time:May 26 14:15-16:15

Response Duration Time Spectra of Ground Motions in Tokyo during The 2011 Off the Pacific Coast of Tohoku Earthquake

Toru Ishii[1*]

[1]Shimizu Corporation

The 2011 off the Pacific coast of Tohoku earthquake (2011.3.11 14:46, Mw 9.0) was the largest of the earthquakes observed in and around Japan. In Tokyo, the duration time of the ground motion became very long and many kinds of damages were generated; ex. indoor damages of high-rise buildings, damages of weak structures or members, soil liquefaction, etc. The foreshocks, many aftershocks, and many other earthquakes induced by the huge main shock have occurred.

In this study, the response spectra and the response duration time spectra of the horizontal and vertical ground motions which were recorded at the engineering bedrock at Etchujima in Tokyo, during the 2011 off the Pacific coast of Tohoku earthquake, its foreshock, aftershocks, and triggered earthquakes, are calculated and investigated. Each record was separated from the ones of the other aftershocks, and was selected on the condition that its noise was less and its duration was long enough. The noises in the frequency components higher than 10 Hz were removed from the record by using the high-cut filter. Then the velocity response spectra Sv [cm/s] and the velocity response duration time spectra TSv [s] of the ground motions were calculated in the period range between 0.1 and 20 seconds, with the damping coefficient h=0.05, the parameters p1=0.03 and p2=0.95.

The fault plane of the main shock expanded enormously along the Pacific coast of Tohoku district and the Japan trench, from the area off Iwate prefecture to the one off Ibaraki prefecture. Sv of the horizontal motions reached 20 to 50 cm/s for the periods longer than 2 seconds. TSv of the motions exceeded 200 seconds (exceeded 3 minutes) for the periods longer than 3 seconds, and TSv of the EW motion exceeded 600 seconds (exceeded 10 minutes) for the period of 10 seconds. In comparison with the previous study on the ground motion in Tokyo after the 1923 Kanto earthquake (1923.9.1, M 7.9) , Sv for the Kanto earthquake was 1.5 times as much as the one for the Tohoku earthquake, however TSv for the Tohoku earthquake became much more than the one for the Kanto earthquake for the periods longer than 7 seconds.

Keywords: huge earthquake, Tohoku, Tokyo metropolitan area, earthquake ground motion, duration time, response

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MIS036-P72 Room:Convention Hall Time:May 26 14:15-16:15

Strong-motion characteristics in Sendai during the 2011 off the Pacific coast of Tohoku Earthquake and its aftershocks

Susumu Ohno[1*], Masato Motosaka[1]

[1]DCRC, Tohoku University

1. Introduction

Since 2004 we have been operated the strong-motion observation network in Sendai (Ohno et al., Annual Meeting of AIJ, 2004). Based on the observation records by this network, we report summary of the strong-motion characteristics in Sendai during the 3/11/2011 off the Pacific coast of Tohoku Earthquake as well as in its aftershocks.

2. Strong-motion observation

Before 2004, there were two major strong-motion networks in Sendai: Sendai Strong-motion Array by BRI/Tohoku Univ. and 'Small-Titan' network by Tohoku Institute of Technology. Our network, composed of ETNA and QDR seismometers, were installed in order to spatially supplement these two networks. Also, SSA-1 was installed at the Sumitomo-Seimei building, central Sendai, where the strong-motion record was obtained during the 6/12/1978 Miyagi-oki earthquake (M7.4). A total of 19 stations were operated but only 13 records were obtained at the 2011 mainshock. The major reason of losing records is probably due to QDR memory initialization by the long-term blackout after the mainshock. Still, the Higashi-Rokugou station was located in the inundated area but the mainshock record remained in the ETNA's memory.

3.Strong-Motion Characteristics in Sendai

The major strong-motion characteristics in Sendai estimated from the observation records are summarized as follows.

1) At the Sumitomo-Seimei building, central Sendai, the strong-motion duration of the 2011 mainshock (M9.0) is about 3 minutes, which is quite longer than 30 seconds of the 1978 Miyagi-oki earthquake (M7.4). In response spectrum at periods of 0.02-10sec, the 2011 mainshock amplitude is averagely 1.3 times larger than the 1978 earthquake's amplitude and more than twice of the amplitudes of the 2005 Miyagi-oki and the 2008 Iwate-Miyagi Nairiku earthquakes.

2) During the M9.0 mainshock of 3/11, PGA ranged about 300-800Gal in Sendai. Maximum PGA was 840 Gal at the Shogen-Chuou elemental school. PGV ranged about 30-80cm/s; maximum PGV was 86cm/s at the Matsumori elemental school. Also, during the M7.1 aftershock of 4/7, PGA ranged about 170-750Gal; maximum PGA was 767 Gal at the Matsumori elemental school. PGV ranged about 15-75cm/s; maximum PGV was 76cm/s also at the Matsumori elemental school.

3) These maximum values were obtained at the northern part of Sendai. Compared with the central part of Sendai, spectral amplitudes at periods shorter than 1-sec were larger at the northern part. On the other hand, spectral amplitudes at periods not only shorter than 1-sec but also about 3-sec were larger at the southern part of Sendai. Also, long-period later phases can be seen on the velocity traces at the southern part of Sendai. Such regional differences in Sendai have been commonly observed over the 2011 fore, main, and aftershocks as well as in the past disastrous earthquakes in the Tohoku region.

4) At the southern part of Sendai, 3-sec spectral peaks commonly appear in almost all earthquakes, while the spectral peaks at periods shorter than 1-sec have clear amplitude dependencies, probably due to the effect of non-linear response of surface soil.

We will investigate the strong motion characteristics in Sendai in more detail by adding records from the other networks, and will also investigate the relationships between strong-motion characteristics and building damages.

Keywords: The 2011 off the Pacific coast of Tohoku Earthquake, Strong-motion record, Sendai

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MIS036-P73 Room:Convention Hall Time:May 26 14:15-16:15

Estimation of velocity discontinuities in sediment of Yokohama for the 2011 Off the Pacific Coast of Tohoku earthquake

Makiko Takagishi[1*], Shigeo Kinoshita[1]

[1]Yokohama City University

Acceleration seismograms were recorded at 62 stations in the Yokohama dense strong motion array (the Yokohama array) for the 2011 Off the Pacific Coast of Tohoku earthquake (Mw=9.0). We conducted the estimation of velocity discontinuities in a sedimentary layer of the Yokohama region by applying nonstationary ray decomposition method (NRDM) to the seismograms obtained in Yokohama. According to Japan Meteorological Agency, size of the fault was estimated about 450km long and 200km width. Therefore, it is difficult to apply the ordinary NRDM to the records obtained for this earthquake because of the hard identification of constitutive phases in S-wave. Thus, in this study, we conducted the NRDM in a statistical way. We analyzed the data following procedures.

We divided the S-wave data into a set of data window with a length of 20 s. After converting the acceleration data to velocity by numerical integration, we estimated transverse component wave which was treated this as SH-wave. Using this SH-wave, we calculated instantaneous power associated with rays in a homogeneous half space. The instantaneous power is represented as a function of lapse-time and the travel time towards depth-direction; depth-time in the (t, tau) space. We estimated local instantaneous power as a function of depth-time by integrating the instantaneous power along lapse-time. Then, we normalized the local instantaneous power using the global instantaneous power which was calculated by integration in the whole (t, tau) space. We applied the procedures to each data window, and then estimated the average local instantaneous power as a function of depth-time. We could obtain the velocity boundaries by using the local maxima of the power above.

Though we usually had to analyze numerous strong motion data to estimate the velocity discontinuities in a basement ? sedimentary layer system by using the ordinary NRDM, we think that we can estimate it using only a strong-motion data recorded at each site for this earthquake. It will make the ordinary NRDM much convenient.

Keywords: nonstationary ray decomposition, The 2011 off the Pacific Coast of Tohoku earthquake, Yokohama array, sedimentary layer, instantaneous power

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P74 Room:Convention Hall Time:May 26 14:15-16:15

Characteristics of Long-Period Ground Motions in Osaka Basin by the 2011 off the Pacific Coast of Tohoku Earthquake

Takashi Akazawa[1*]

[1]G.R.I.

During the 2011 off the Pacific coast of Tohoku Earthquake (3/11 14:46 ; Mw9.0), the Committee of Earthquake Observation and Research in the Kansai Area (CEORKA), which is arraying stations throughout the Kansai district, obtained the records at the all stations. In this study, the characteristics of long-period ground motions in Osaka basin was examined using the records. The response spectra of records obtained in Osaka basin predominated at the period of 5 - 6 seconds in horizontal components and 3 second in vertical one. These predominant periods are same as the one of the main shock of the 2004 off the Kii Peninsula earthquake (9/5 23:57 ; MJ7.4). This result supports that these predominant periods characterizes the long-period ground motions in Osaka basin.

Acknowledgements. The used records were obtained at the seismic stations of The Committee of Earthquake Observation and Research in the Kansai Area (CEORKA) network.

Keywords: The 2011 off the Pacific coast of Tohoku Earthquake, Long-Period Ground Motion, Osaka Basin

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P75 Room:Convention Hall Time:May 26 14:15-16:15

Three space geodetic signals left by the 2011 off the Pacific coast of Tohoku Earthquake

Koji Matsuo[1*], Yuta Kobayashi[1], Kosuke Heki[1]

[1]Dept. Natural His. Sci., Hokkaido Univ.

The M9 massive earthquake hit offshore Tohoku region on March 11th 2011 causing widespread destructions and catastrophic damages to east Japan. This is the largest earthquake in Japan and the fifth in the world over the course of recorded history. Earthquake is a result of a fault dislocation under the ground, i.e. sudden deformation of surficial or inner structure of the earth. Therefore, such process leaves three kinds of space geodetic signatures, i.e. crustal deformations, gravity change, and polar motion. In this study, we derive fault parameters of this earthquake based on surficial displacement data by dense GPS network (GEONET), and perform numerical simulation on the extent of crustal deformation, gravity change, and polar motion under the realistic earth. In addition, if the data would be released on time, we will do comparative discussion using the actual observed data, such as the gravity change from GRACE and the excitation pole of Y axis from VLBI.

Keywords: The 2011 off the Pacific coast of Tohoku Earthquake, Space geodesy, Crustal deformation, Gravity change, Polar motion

Japan Geoscience Union Meeting 2011
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MIS036-P76 Room:Convention Hall Time:May 26 14:15-16:15

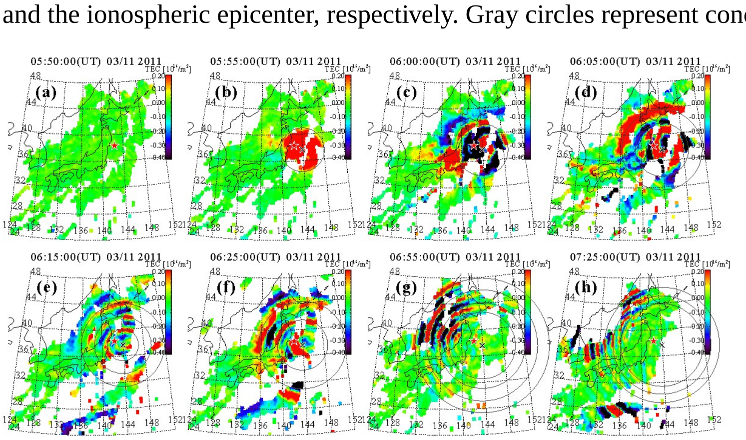
Ionospheric disturbances detected by GPS total electron content observation after the 2011 Tohoku earthquake

Takuya Tsugawa[1*], Akinori Saito[2], Yuichi Otsuka[3], Michi Nishioka[3], Takashi Maruyama[1], Hisao Kato[1], Tsutomu Nagatsuma[1], Ken T. Murata[1]

[1]NICT, [2]SPEL, Kyoto University, [3]STEL, Nagoya University

All the details of the commencement and evolution of ionospheric disturbances after the 2011 off the Pacific coast of Tohoku Earthquake were firstly revealed by the high-resolution GPS total electron content observation in Japan. The initial ionospheric disturbance appeared as sudden depletions by ˜6 TEC unit (20%) following small impulsive TEC enhancements around 05:54UT, about seven minutes after the earthquake onset, near the epicenter. At 06:00UT, zonally extended enhancements of TEC appeared in the west of Japan, and traveled to the southwest direction. From 06:00UT to 06:15UT, large-scale circular waves with two peaks propagated in the radial direction in the propagation velocity of 3,457 m/s and 783 m/s for the first and second peak, respectively. Following the large-scale waves, medium-scale concentric waves appeared to propagate at the velocity of 138?423 m/s after 06:15 UT. In the vicinity of the epicenter, short-period oscillations with period of ˜4 minutes were observed after ˜06:00 UT for 3 hours or more. We focus on the the circular and concentric waves in this paper. The circular or concentric structures of the large- and medium-scale waves indicate that these ionospheric disturbances had a point source. The center of these structures was located around 37.5 deg N of latitude and 144.0 deg E of longitude, 170 km far from the epicenter to the southeast direction. We termed this center of the coseismic ionospheric variations as "ionospheric epicenter". According to the propagation velocities, the large-scale waves would be caused by the acoustic waves generated from the propagating Rayleigh wave for the first peak and from the sea surface near the epicenter for the second peak. The wavelength and the propagation velocity of the medium-scale concentric waves tended to decrease with time. This characteristic is consistent with the result of a numerical model of the coseismic atmospheric wave, indicating that these medium-scale waves were caused by the atmospheric gravity waves. The amplitude of the large- and medium-scale circular waves were not uniform depending on azimuth of their propagation direction, much larger in the north and west directions than other directions. This directivity could not be explained by the previously proposed theory.

∗ Figure shows two-dimensional maps of the detrended TEC with ten-minute window from 05:50UT to 07:25UT on March 11, 2011. The interval of figures (a-d), (d-f), and (f-h) is 5, 10, 30 minutes, respectively. Star and cross marks represent the epicenter and the ionospheric epicenter, respectively. Gray circles represent concentric circles with the ionospheric epicenter.



Keywords: Ionosphere, Earthquake, Tsunami, GPS, TEC, Japan

Japan Geoscience Union Meeting 2011
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MIS036-P77 Room:Convention Hall Time:May 26 14:15-16:15

Acoustic resonance and plasma depletion detected above the epicenter of the 2011 Tohoku earthquake

Akinori Saito[1*], Takuya Tsugawa[2], Yuichi Otsuka[3], Michi Nishioka[3], Toshihiko Iyemori[4], Mitsuru Matsumura[1], Susumu Saito[5], Chia Hung Chen[1], Yukari Goi[1]

[1]Kyoto University, Dept. Geophysics, [2]National Institute of Information and Co, [3]Solar-Terrestrial Environment Laboratory, [4]DACGSM, Kyoto University, [5]Electronic Navigation Research Institute

Two-dimensional structures of the ionospheric variations generated by the acoustic resonance, and plasma depletion were firstly observed above the epicenter after the M9.0 Tohoku earthquake on March 11, 2011. A short period oscillation of total electron content was observed by a GPS receiver array after the earthquake for four hours in the vicinity of the epicenter. The frequency of the dominant mode of the oscillation was 4.5mHz, 222 seconds of period, while there were minor oscillations whose frequency were 3.7mHz and 5.3mHz. These periods are consistent with the periods of the acoustic resonance between the ground surface and the lower thermosphere, predicted by a numerical model. The amplitude of the TEC oscillation showed gradual change of the amplitude. This would be generated by the beat of two modes of the resonance. The two-dimensional distributions of TEC variations generated by this resonance showed wave frontal structures that stretched from northwest to southeast, and traveled to the southwest direction. Besides the oscillation, plasma depletion was observed above the epicenter after the earthquake. The earliest variation was observed about seven minutes after the earthquake. The amplitude of the depletion was several TEC unit, and continued for longer than 60 minutes. The area of this depletion was centered the epicenter but larger than that of the resonant oscillation. The ionospheric variations above the epicenter after the earthquake will be presented.

Keywords: Ionosphere, GPS, TEC, Acoustic wave, Atmospheric gravity wave, Earthquake

Japan Geoscience Union Meeting 2011
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MIS036-P78 Room:Convention Hall Time:May 26 14:15-16:15

Comparison between ionospheric TEC perturbations observed after the earthquake and simulated atmospheric oscillations

Mitsuru Matsumura[1*], Akinori Saito[1], Takuya Tsugawa[2], Hiroyuki Shinagawa[2], Toshihiko Iyemori[1], Yuichi Otsuka[3], Michi Nishioka[3], Chia Hung Chen[1]

[1]Graduate School of Science, Kyoto Univ., [2]NICT, [3]STEL, Nagoya University

Numerical simulations are performed to simulate periodic structures observed at ionospheric heights just after the 2011 off the Pacific coast of Tohoku earthquake. A two and three-dimensional, non-hydrostatic, compressible and neutral numerical model is developed to reproduce the atmospheric oscillations. An impulsive upward surface motion is used as the source. Simulated atmospheric oscillations at 300 km altitude show remarkable agreement with the observed TEC oscillations. In the vicinity of the source, the fast waves with high frequencies are dominant. They have three dominant frequencies for the interval between 20 and 60 min after the impulsive input. The oscillation that has the maximum amplitude is the mode of 4.4 mHz. The others are the two minor modes of 3.6 and 5.4 mHz. These modes correspond to the acoustic resonance modes between the ground-surface and the lower thermosphere. The wave packets with about 0.7mHz frequency are also seen. They are considered as the beat due to the dominant modes. In the distance, the slow waves with low frequencies are dominant. The horizontal phase velocities are about 220 to 450 m/s, and the horizontal wavelengths are about 200 to 600 km. Waves with longer wavelengths have larger phase velocities. These waves correspond to the gravity modes. The good agreement between the simulation and the observations indicates that ionospheric perturbations observed after the earthquake are mainly due to the motion of the neutral atmosphere. In addition, the region where the acoustic waves pass is dependent on the aria of the source. This shows that the area of the uplifted sea surface, the supposed actual source can be estimated from the observed acoustic wave region.

Keywords: acoustic wave, gravity wave, TEC, earthquake

Japan Geoscience Union Meeting 2011
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MIS036-P79 Room:Convention Hall Time:May 26 14:15-16:15

Ionosphere disturbances observed by the Hokkaido HF radar after the 2011 Off the Pacific Coast of Tohoku Earthquake

Nozomu Nishitani[1*], Tadahiko Ogawa[2], Yuichi Otsuka[1], Keisuke Hosokawa[3], Tomoaki Hori[1]

[1]STEL, Nagoya Univ., [2]NICT, [3]UEC

Ionospheric responses to the 2011 Off the Pacific Coast of Tohoku Earthquake are studied using the SuperDARN Hokkaido radar, which is located at (43.5 N, 143.6 E) in geographic coordinates and monitoring the ionosphere over the wide horizontal area. The radar observed oscillation of the vertical motion of the ionosphere with the period of a few minutes. The disturbance propagated northward, away from the epicenter with the velocity of about 3.5 to 4.5 km/s. This value is consistent with the propagation of the earth's surface waves reported in several previous studies.

Keywords: SuperDARN, Hokkaido HF radar, 2011 Off the Pacific Coast of Tohoku Earthquake, ionospheric disturbance, Rayleigh waves, acoustic waves

Japan Geoscience Union Meeting 2011
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Magnetic signals from 2011 Tohoku earthquake tsunami observed at Chichijima magnetic station of JMA

Yozo Hamano[1*], Takafumi Kasaya[1], Hiroshi Ichihara[1], Hidee Tatehata[2]

[1]IFREE, JAMSTEC, [2]JMA

Magnetic fields generated by tsunami from 2011 Tohoku earthquake are observed at the magnetic station on Chichijima, 1200 km south of the epicenter. Vertical component of the magnetic field show a periodic signal with periods of about 20 minutes, lasting more than several hours. The signal starts at 6:55 UTC and the amplitude of the first wave is 1.5 nT. Sea level change recorded at the tide station on Chichijima indicates that the arrival time of the tsunami was 7:15 UTC and the amplitude of the first wave is about 1m. The sea level change is also periodic. The 20 minutes delay of the first arrival of tsunami compared to the magnetic signal can be attributed to shallow water depths around Chichijima, whereas the magnetic change reflects water flows in a wide area around the island. By using the formula by Tyler (2005), the ratio of the magnetic change to the sea level change indicates that the average water depth responsible for the magnetic field is about 1500 m.

Although the dynamo effect of ocean flow is well known and the effects by tidal flow have been frequently observed, observation of the tsunami-induced magnetic field had to be waited until very recently. Seafloor measurement of the induced magnetic field from 2006 and 2007 Kuril island earthquakes were first recorded by the seafloor electro-magnetic observatory (SFEMS) located at North-West Pacific (Toh et al., 2011), and the seafloor geophysical network in the French-Polynesia observed the magnetic fields generated by tsunami from 2010 Chilian earthquake (Hamano et. al, 2011). As for land measurement, magnetic signal from the above Chilean tsunami was detected by the magnetic observatory on Easter island (Manoj and Maus, 2011). Accumulation of these data sets of tsunami-induced magnetic field is very important not only for understanding electromagnetic induction effect of tsunami, but also for monitoring the tsunami propagation and for designing next-generation tsunami-warning systems.

Acknowledgement

The geomagnetic data used in this study are provided by Kakioka magnetic observatory of Japan Meteorological Agency, which operate the magnetic station on Chichijima. Sea level data is measured by the tide station on Chichijima operated by Japan Meteorological Agency.

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Keywords: tsunami, magnetic observatory, oceanic dynamo effect, geomagnetic variation, Chichijima

Japan Geoscience Union Meeting 2011
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MIS036-P81 Room:Convention Hall Time:May 27 14:15-16:15

Co-seismic Groundwater level changes associated with the 2011 off the Pacific coast of Tohoku Earthquake

Yasuhiro Asai[1*], Hiroshi Ishii[1]

[1]TRIES, ADEP

The co-seismic groundwater level changes associated with the 2011 off the Pacific coast of Tohoku Earthquake (M9.0; JMA) were observed at Togari (TGR350), Syobasama (SBS110), Shizubora (SN-1 and SN-3) in the Tono region, central Japan (Hypocentral Distances are approximately 560km; Seismic Intensities are from 2 to 3).

We will present the details of these groundwater level changes.

Keywords: Co-seismic groundwater level changes

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P82 Room:Convention Hall Time:May 27 14:15-16:15

Groundwater changes associated with the 2011 Off the Pacific Coast of Tohoku Earthquake (M9.0)

Yuichi Kitagawa[1*], Naoji Koizumi[1]

[1]AFERC, GSJ, AIST

The 2011 off the Pacific Coast of Tohoku earthquake (M9.0) occurred on March 11, 2011. At many of groundwater observatories of Geological Survey of Japan, AIST in Tokai, Kinki and Shikoku, changes in groundwater level, groundwater pressure or groundwater discharge rate were observed associated with the earthquake. Most of the changes were drops and they were consistent with the static coseismic strain changes due to the fault slip of the earthquake. On the other hand, some of them were rises and they were not consistent with the static strain changes. This suggests that the rises were caused by dynamic strain changes.

Keywords: the 2011 off the Pacific Coast of Tohoku earthquake, groundwater level, groundwater pressure, discharge rate, volumetric strain

Japan Geoscience Union Meeting 2011
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MIS036-P83 Room:Convention Hall Time:May 27 14:15-16:15

Coseismic hot spring water changes of the 2011 Tohoku earthquake at the observation stations in San-in district

Yuichi Kuwano[1*], Tatsuya Noguchi[1], Kagawa Takao[1], Nishida Ryohei[2], Watanabe Kunihiko[3], Koizumi Naoji[4]

[1]Tottori University, [2]The Open University of Japan, [3]Seminar for Earthquake Information, [4]AIST

Coseismic temperature changes due to several earthquakes were observed at the hot springs in San-in district where we maintain observation network consist of 8 sites. After the 2011 off the Pacific coast of Tohoku earthquake, the water temperature rapidly increased by 1.86 degrees at Iwai station, by 0.23 degrees at Okutsu station, by 0.18 degrees at Yudani station and by 0.28 degrees at Yoshioka station,and the water temperature rapidly decreased by 0.23 degrees at Saginoyu station. After water temperature rapidly changes, water temperature gradually increases at Iwai station, at Saginoyu station and at Yudani station and water temperature gradually decreases at Yoshioka station. Until 4/28 from rapid water temperature changes, water temperature increases by 0.47 degrees at Iwai station, by 1.07 degrees at Saginoyu station, by 0.51 degrees at Yudani station and by -0.79 degrees at Yoshioka station and water temperature do not change at Okutsu station. At Iwai station, temperature has changed from a decreasing tendency into a increasing tendency three days before the earthquake occurred.

Keywords: hot spring, temperature changes, San-in district, the 2011 Tohoku earthquake

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(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P84 Room:Convention Hall Time:May 27 14:15-16:15

Discharge changes of geothermal wells related to the geologic structure and shocks of the 2011 large earthquake

Takayuki Kawabe[1*], Keiji Nakano[2]

[1]Yamagata University, [2]Terra-Fluid Systems

Water lebel and its temperature are changed at some geothermal wells situated in Yamagata, southern Fukushima and northern Ibaraki Prefectures just after the 2011 off the Pacific coast of Tohoku Earthquake.

Such hange of geothermal wells beared in fractures by large earthquake is known at previous large earthquakes.

Water level and its temprature increase when the secondary stress by a deformation of the surface of the crust by the quake effects compressionally to the fractures, and they decrease when the secondary stress effects reratively tentionally to the fractures.

Change of water level and its temprature at the 2011 off the Pacific coast of Tohoku Earthquake should be caused by the secondary stress change to the fractures bearing geothermal wells.

Keywords: discharge changes, geothermal well, fracture system, stress change

Japan Geoscience Union Meeting 2011
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MIS036-P85 Room:Convention Hall Time:May 26 14:15-16:15

Earthquake prediction from peak gust(6)-The 2011 off the Pacific coast of Tohoku Earthquake-

Takao Saruwatari[1*]

[1]none

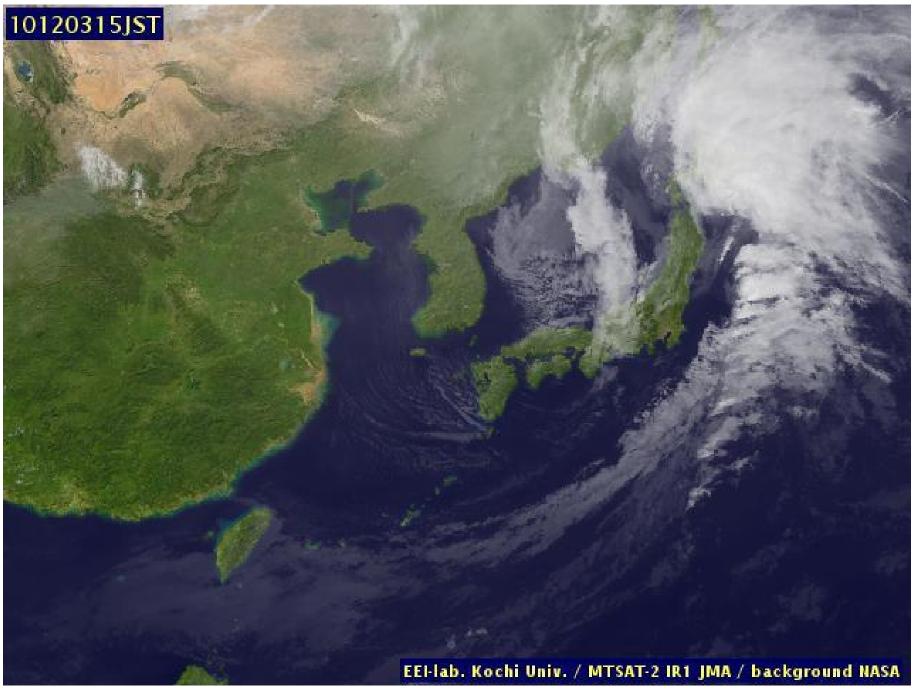

Fig.1. **The 2011 off the Pacific coast of Tohoku Earthquake is shown in the satellite image of 15:00 on December 3, 2010.**
The tip of the dry slot shows the epicenter.
The width of the dry slot shows the length of the focal region.
The direction of the wind shows the focal mechanism axis.

1.Process

The seismology is based on the hypothesis with "Energy is liberated when the energy of the swerve accumulated in the plate by the mantle convection exceeds a certain limit and the earthquake occurs". It thought being not able doing the earthquake prediction for the problem to exist in this hypothesis.

Because there was many earthquake outbreak, after the typhoon passage, I paid my attention to the wind velocity / the direction of the wind of the epicenter.

The maximum instantaneous wind speed of the epicenter neighborhood understood that it was a record of the maximum instantaneous wind speed for the first time in several years from several months. Furthermore, the direction of the wind understood that I agreed in a pressure axis or the pulling axis in the transcurrent fault in the normal fault in the reverse fault in the pulling axis in the pressure axis. This is that a course of the power accords with the direction of the wind and shows that the velocity of the wind is the cause of the earthquake not mantle convection. And foretelling an earthquake is possible using time lag.

However, it is necessary to identify it in the smaller place because the range of the prediction of the epicenter is too wide. Therefore as a result of having examined energy of the wind, I understood that a downdraft was necessary so that wind affected the earth crust. The downdraft is seen as a dry slot in the meteorology conspicuously for time and the development period to turn into an extratropical cyclone from a typhoon of the low pressure and is related to the maximum instantaneous wind speed.

As a result of I thought that I might pinpoint the epicenter on a satellite image from a dry slot, and having analyzed a satellite image about the cause of the major earthquake after 2000 and a large low pressure thought about, I understood that I could identify the epicenter.

1) The place where the maximum instantaneous wind speed for the first time in several years was recorded in the occurring place from several months is very likely to be the epicenter. The tip of the dry slot as for the epicenter of major earthquakes more than M6.5.

2) The volume of earthquake relates to strong winds level more than the threshold with the maximum instantaneous wind speed.

3) Outbreak time: From one week to seven months later (three months on the average)

(It has announced in JPGU and Seismological Society of Japan)

2. The prediction of the 2011 off the Pacific coast of Tohoku Earthquake

As had spoken on the top, it pays attention when it changes from the typhoon into the extratropical cyclone and the low-pressure develops. A low pressure of October 31 and December 3 falls under it. A major earthquake was expected distance offing Tohoku by the weather charts, but did not analyze it in detail concerning the distance offing. I analyzed it after an earthquake . (The analysis of the low-pressure on December 3 is recorded here.)

1)March 9, 2011 11:45 Sanriku-oki Earthquake (M7.2 P:WNW-ESE reverse fault)

http://www.data.jma.go.jp/fcd/yoho/data/hibiten/2010/201012.pdf

http://weather.is.kochi-u.ac.jp/sat/gms.fareast/2010/12/04/fe.10120402.jpg

The dry slot point shows the epicenter. The wind direction of the WNW is corresponding to P axis of the mechanism solution.

2)March 11, 2011 14:46 The 2011 off the Pacific coast of Tohoku Earthquake (M9.0 P:WNW-ESE reverse fault)

http://weather.is.kochi-u.ac.jp/sat/gms.fareast/2010/12/03/fe.10120315.jpg Fig.1

The dry slot of the satellite image is seen conspicuously at 15:00 from 13:00. Width of the tip of the dry slot accords with the length of the focal region. The others are the same as 1).

Keywords: peak gust, earthquake prediction, dry slot, downdraft, satellite image

Japan Geoscience Union Meeting 2011
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MIS036-P86 Room:Convention Hall Time:May 27 14:15-16:15

Groundwater flow evaluation in the whole Fukushima Prefecture and around the Fukushima Daiichi Nuclear Power Plant

Atsunao Marui[1*], Narimitsu Ito[1], Masaru Koshigai[1], Naoki Kohara[1]

[1]AIST, GSJ

Groundwater flow simulation was conducted to contribute the reconstruction from the disaster by the 2011 off the Pacific coast of Tohoku Earthquake. Wide and detailed 3D hydro-geological models were built for the saturated and constant simulation of whole Fukushima Prefecture and around the Fukushima Daiichi Nuclear Power Plant. The dataset of geologic basement depth in the whole Japan (Koshigai et al., submitting), which is one of the AIST's DB of geology and groundwater in the whole Japan, was used to set the depths of layers for the wide model. This dataset includes the depths data of four formations in Quaternary (H, Q3, Q2, Q1) and three in the Neogene (N3, N2, N1) compiled by krigging using more than 12,000 logging data.

Two layers were extracted for the wide model which represent the Quaternary and Neogene. The hydraulic conductivities were defined as 10^{-4} and 10^{-6} [m/s] in horizontal and vertical directions of the Quaternary, and homogeneously 10^{-6} [m/s] in the Neogene, referred from the internal information of previous groundwater flow research in the closed coal mine in Fukushima Pref. The boundary conditions set the hydraulic heads fixed with the elevation around the model and a constant recharge to the surface The constant recharge was given from the dataset of submarine groundwater discharge in the Japan Islands (Ito and Marui, 2010) which is also one of the AIST's DB, as 833[mm/yr] from the average in the year of 1993 - 2002 on Abukuma River basin, which locates in the center of Fukushima Pref. The simulated groundwater flow directions are shown in Fig.1. More outward groundwater flows are represented from the west and south than the north around the zone of radius 30 km of Fukushima Daiichi Nuclear Power Plant. It indicates some risk to make influence to the domestic water of city area in Koriyama and Iwaki when reaching the polluted water. In these cities, deep wells may strengthen the water supply system to avoid pollution risk, because deep groundwater has little influenced from surface pollution.

The detailed model, which has an approximate same range with the radius 10km of Fukushima Daiichi Nuclear Power Plant, has three layers which equal to the Quaternary, the upper and lower of Neogene. The hydraulic conductivities were defined homogeneously as 10^{-5}, 10^{-7}, and 10^{-6} [m/s] in each layer respectively, from the previous report by the local government (Tohoku Agricultural Bureau, 1979). The boundary conditions fix the hydraulic head of rivers, lakes, and ponds with the elevations, and the sea area with 0m. Result showed the groundwater flows into the sea with the flux of 0.01 [m/d] in the top Quaternary which has 5m width. In the upper and lower Neogene, which has 20m and 200m width, the fluxes were calculated around 0.00001 and 0.0001 [m/d]. It means the pollutants can flow out through the Quaternary into the sea by relatively fast groundwater flux, as the main facilities of the power plants are built on the Quaternary. Additionally, it is difficult to infiltrate the pollutant into the Neogene by the low permeability.

Reference

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Tohoku Agricaltural Bureau Planning Department (1979): Report of land subsidence in the district of Haramachi (in Japanese).

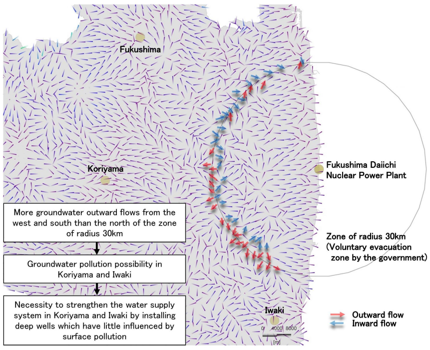

Fig.1 Groundwater flow directions around the radius 30km of Fukushima Daiichi Nuclear Power Plant

Keywords: Fukushima Daiichi Nuclear Power Plant, radiation protection, pollution of surface soil, outward flow, domestic water, deep well

Japan Geoscience Union Meeting 2011
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MIS036-P87 Room:Convention Hall Time:May 27 14:15-16:15

Proximity of the lunar days for the devastating earthquakes in the off-Sanriku region: the effects of earth tides

Yoshiki Sue[1*]

[1]No institution affiliation

It is known that earth tides, which are the effects of gravitational pulls by the moon and the sun, have an influence on earthquake occurrences. For details, there is an apparent increase in occurrence of earthquakes, when earth tides so work on faults or plate boundaries that change of stress on them assists fracturing (e.g., Tanaka et al., 2004). Regarding the moon, the sun and the earth on such an occasion, on the other hand, a specific positional relationship producing the change exists. This positional relationship can be identified by "the ecliptic longitude difference between the moon and the sun (ELDMS, 0-360 degrees)". It can also be determined by the day of the lunar calendar (1-29 or 30th), or days from/to such specific positions of the moon as New, First quarter, Full and Last quarter moon. They are accessible indexes, although the amount of error may increase.

The off-Sanriku region is the region where large earthquakes often occur. Even in the recent times, the 1896 Meiji Sanriku EQ(M8.5) and the 1933 Showa Sanriku EQ(M8.1) occurred. For this region and neighboring the off-Miyagi Pref. region, special occurrence patterns depending on earth tides are reported (Sue, 2007 and Sue, 2008). At 14:46 on March 11, 2011 (JST), an earthquake of M9.0 occurred and created huge damages in this region, therefore such tendency is investigated. An earthquake of M7.3 occurred near the focal region two days before the main shock and the earthquake is also investigated, because the earthquake can be a foreshock. A large aftershock of M7.4 occurred again on April 7, almost one month later. And this earthquake is also added to the investigation.

Date	Name	M	ELDMS (deg.)	L. cal. (day)	Casualties (abt.)
1896/6/15	Meiji Sanriku	8.5	50	5th	22,000
1933/3/3	Showa Sanriku	8.1	71	8th	3,000
2011/3/9	Off-Sanriku	7.3	46	5th	-
2011/3/11	Main shock	9.0	70	7th	26,000
2011/4/7	Off-Miyagi P.	7.4	44	5th	-

(Main shock: 2011 Japan's tohoku earthquake)

It is known that the earthquakes of March 9 and 11 occurred under close lunar conditions with those of the 1896EQ(M8.5) and the 1933EQ(M8.1) respectively. In addition, the earthquake of April 7 occurred also under close lunar conditions as those for the 1896EQ(M8.5) and the March 9 EQ. Therefore remarkable concentration of occurrences for the ELDMS of 40-70 degrees is observed. This is consistent with the report that there is concentration of occurrence to the ELDMS of 20-80 degrees for the earthquake in this region (Sue, 2008). As for the month of occurrence, by taking other earthquakes in this region into account, from March to July seem to have much occurrence of large earthquakes. This can be regarded as solar contribution to the earth tides, while it needs future examination.

As reported here, the large earthquakes occurred under influence of the earth tides in specific ways to the region, and this means that earthquakes occur at the similar ELDMS, or on the same days of the lunar calendar. This further implies that earthquakes have been occurring on the same lunar days in each region from the past. Furthermore, there may be certain tendency on months of occurrence. These understandings may be similar to ""The nature" is faithful to old customs." by the renowned physicist Torahiko Terada (Tsunami and humankind, 1933). The understanding on these phenomena should help prevention or mitigation of disasters.

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Keywords: earthquake, earth tides, Sanriku

Japan Geoscience Union Meeting 2011
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Anomalous variations of geomagnetic intensity possibly induced by the 2011 off the Pacific coast of Tohoku Earthquake

Yasuhiro Minamoto[1*], Nobuyuki Yamazaki[1], Toshiaki MISHIMA[1]

[1]Kakioka Magnetic Observatory, JMA

Anomalous variations of geomagnetic field possibly induced by the 2011 off the Pacific coast of Tohoku Earthquake (M9.0) are obtained from one-minute total intensity data atsites operated by Kakioka Magnetic Observatory, Japan Meteorological Agency (JMA).

Differences between the geomagnetic total intensity obtained at Iwaki (IWK), which located approximately 210 km from the epicenter and that at the reference point, Memambetsu (MMB), located approximately 650 km from the epicenter, decreased in 7.2 nT from 14:39 JST to 15:01 JST, and increased in 6.4 nT from 15:01 JST to 15:14 JST. As occurrence time of the earthquake is 14:46 JST after JMA, the decrease at IWK is preceding the earthquake.

On the other hand, at Kakioka (KAK) and Kitaura (KTR), both are located approximately 300 km from the epicenter, variations of the total intensity at these sites with reference to MMB decreased in 2.2 nT and 2.9 nT respectively from 14:52 JST to 14:55 JST, and recovered by about 15:00 JST. However, the preceding variation detected at IWK was not observed at KTR and KAK.

Keywords: 2011 off the Pacific coast of Tohoku Earthquake, geomagnetic, total intensity

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MIS036-P89 Room:Convention Hall Time:May 27 14:15-16:15

Urgent aftershock observation of the 2011 Tohoku earthquake using ocean bottom seismometer network

Masanao Shinohara[1*], Tomoaki Yamada[1], Kazuo Nakahigashi[1], Shin'ichi Sakai[1], Kimihiro Mochizuki[1], Kenji Uehira[2], Yoshihiro Ito[3], Ryosuke Azuma[4], Yuka Kaiho[5], Tetsuo No[5], Hajime Shiobara[1], Ryota Hino[3], Yoshio Murai[4], Hiroshi Yakiwara[6], Toshinori Sato[7], Yuya Machida[1], Takashi Shinbo[1], Takehi Isse[1], Hiroki Miyamachi[6], Koichiro Obana[5], Narumi Takahashi[5], Shuichi Kodaira[5], Yoshiyuki Kaneda[5], Kenji Hirata[8], Sumio Yoshikawa[8], Kazushige Obara[1], Takaya Iwasaki[1], Naoshi Hirata[1]

[1]ERI., Univ. Tokyo, [2]ISV, Kyushu Univ., [3]Sci., Tohoku Univ., [4]ISV, Hokkaido Univ., [5]JAMSTEC, [6]Sci., Kagoshima Univ., [7]Sci., Chiba Univ., [8]MRI, JMA

The 2011 off the Pacific coast of Tohoku earthquake occurred offshore of northeast Japan region on March 11, 2011. Knowledge of precise aftershock distribution is inevitably important to understand the generation mechanism of this large earthquake. In addition, this kind of information provides useful constraints for studies of rupture in such wide source region. In order to study the aftershock activity of this event, we started deployment of seventy-three ocean bottom seismometers (OBSs) four days after the mainshock. Consequently, we observed the aftershocks at 121 sites including the pre-installed OBS sites in total. Deployed OBSs after the mainshock are being recovered after one-month observation. The observation area is 500 km x 200 km and has a high aftershock activity, which is estimated from the land seismic network. The spatial interval of OBS is approximately 25 km to cover the whole source region. We use various types of the digital recording OBS system. Most of OBSs have both vertical and horizontal velocity sensitive electro-magnetic geophones with a natural frequency of 4.5 Hz. This 4.5Hz OBS are equipped with a glass sphere pressure vessel with the recording period of 1-3 months. Some OBSs use three-component velocity sensitive electro-magnetic geophones with a natural frequency of 1 Hz. The 1Hz OBS uses glass sphere or titanium sphere as a pressure vessel. The others use broadband seismic sensor or accelerometer as a seismic sensor. The OBS with titanium sphere pressure vessel has the longest recording period of 1 year. The resolution of the A/D conversion is 16 bits or 24 bits. Accurate timing is provided by a precise crystal oscillator. All the OBSs are of a pop-up type with an acoustic release system. The recovered OBS position at the sea floor was estimated by using acoustic ranging and ship GPS positions.

In south of the source region, thirty-four long-term OBSs (LT-OBSs) had been deployed before the occurrence of the mainshock, and we recovered three LT-OBSs to clarify the depth distribution of aftershocks. Using the data of OBSs, 99 aftershocks were located. Most of the aftershocks were located in a depth range of 5 - 30 km and concentrate in the plate boundary region. In addition, aftershocks occurred within the subducting oceanic crust and the 6.2-km/s layer of the landward plate. No aftershocks were found in the mantle of the subducting plate. From the results of previous seismic survey using OBSs and controlled sources, the subducting Philippine sea plate is estimated to be contact with the subducting Pacific plate. The southern end of the seismic activity region of the aftershocks corresponds to the region of two subducting plate contact. We infer that the propagation of the rupture during the mainshock sequence was terminated at the contact point with two subducting oceanic plate.

Keywords: The 2011 Tohoku earthquake, aftershock, subduction, ocean bottom seismometer

Japan Geoscience Union Meeting 2011
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The M9.0 earthquake off the east coast of Honshu, Japan and related seismicity

Yuzo Ishikawa[1]*

[1]GSJ, AIST

The huge thrust earthquake occurred between the NE Japan micro plate and the Pacific plate on March 11, 2011. It followed a lot of aftershocks and many earthquakes in Japan. The first one is the aftershocks next the north of the mainshock source fault. The Mw7.4 earthquake occurred on March 11th 15:08. The second is the aftershocks next the south of the mainshock source fault. The Mw7.8 earthquake occurred on March 11th 15:15. The third is the seismicity in outer rise of the Pacific plate. The Mw7.6 earthquake on March 11d 15:26 occurred in outside of the Japan trench. The forth is the intra-plate events in the Pacific slab. The Mw7.2 earthquake on April 7th 23:32 occurred. The fifth is the intra-plate events in NE Japan micro plate. The Mw7.0 earthquake occurred on April 11th in south of Fukushima prefecture. It was the normal fault. The sixth is the seismicity along the plate boundary between the NE Japan micro plate and Amurian plate. The M6.7 earthquake on March 12th 03:59 occurred in the Niigata-Nagano border. The seismicity in some regions of the NE Japan micro plate were changed. The seventh is the seismicity in Hokkaido, the north American plate. The seismicity in the south Hakkaido increased just after the maishock occurrence. The eighth is the seismicity in Izu region in Philippine Sea plate. The ninth is the seismicity in Chubu and west Japan. The seismicity was increased in some region, but the other region decreased. The seismic gaps were pointed in some regions.

Keywords: seismicity, induced earthquake, NE Japan earthquake, Off the east coast of Honshu, aftershock

Japan Geoscience Union Meeting 2011
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MIS036-P91 Room:Convention Hall Time:May 27 14:15-16:15

The 2011 off the Pacific coast of Tohoku Earthquake; seismicity and tsunami

Erika Hayami[1*], Kenji Nakata[1], Tomoaki Ozaki[1], Yuji Usui[1], Takahiko Yamauchi[1]

[1]Japan Meteorological Agency

At 14:46 JST on March 11th 2011, The 2011 off the Pacific coast of Tohoku Earthquake (Mw9.0) occurred at the depth of 24 km in off Sanriku. The maximum seismic intensity (JMA's seismic intensity scale) of 7 is observed at Kurihara (Miyagi prefecture) and 6 lower to 1 at quite large area from Hokkaido to Kyusyu. This earthquake also caused tsunami. The very high tsunami are observed along the Pacific coast of northeast Japan. More than 9.3 m high tsunami is observed at Soma (Fukushima prefecture). The ground motion and tsunami of this earthquake caused a great disaster. We report about the seismic activity, the tsunami warning and advisory by JMA, and the observed height of the tsunami.

1. Seismicity

Around the hypocenter of The 2011 off the Pacific coast of Tohoku Earthquake, earthquakes which magnitudes are more than 5.0 often occurred (ex. Mj5.5 earthquake on February 16th 2011), and sometimes, earthquakes which magnitudes are more than 6.5 occurred (ex. Mj6.8 earthquake on October 31st 2003). Mj7.3 and Mj6.8 earthquakes occurred 2 and 1 day before the Mw9.0 earthquake.

After The occurrence of 2011 off the Pacific coast of Tohoku Earthquake, the seismicity in and around the source region became high. The all mechanisms of the Mw9.0 earthquake and two earthquakes (Mj7.3 and Mj6.8) occurred on March 9th and 10th are thrust fault, and they occurred at the plate boundary. However, after the Mw9.0 earthquake on March 11th, high seismicity regions are also found in outer rise and in the crust of the upper plate, and not only thrust earthquakes but also many normal-fault-type earthquakes occurred in the aftershock region (in and around the source region). For example, Mw7.5 earthquake occurred at 15:25 JST on March 11th in outer rise, and in the crust of the upper plate, Mj7.0 earthquake occurred at 17:16 JST on April 11th in Hamadori (Fukushima prefecture).

2. Tsunami

At 14:49 JST, 3 minutes after the occurrence of The 2011 off the Pacific coast of Tohoku Earthquake, JMA issued 'tsunami warning (major tsunami)' to Iwate, Miyagi and Fukushima prefecture, and issued 'tsunami warning (tsunami)' and tsunami advisory to many other coast of Japan. At 15:14 JST, based on the observed height of offshore GPS buoy (received from Ports and Harbours Bureau, MLIT), JMA increased the tsunami warning and advisory. JMA kept watching the tsunami height and increased the tsunami warning and advisory several times. At 03:20 JST on March 12th, JMA issued tsunami warning and advisory for all tsunami forecast regions. After that, kept watching the tsunami height, JMA started decreasing tsunami warning and advisory. At 17:58 JST on March 13th, all tsunami warning and advisory are lifted.

JMA use observed tsunami height at 183 tsunami station in Japan. However, for some stations, because of power outage or drifting of the stations themselves, the real-time observed tsunami heights were not available. Later, some of the data could be collected, and it became clear that the highest height of tsunami were observed since the observation at tsunami stations started; the tsunami height was over 9.3 m at Soma (Fukushima prefecture), over 8.5 m at Miyako, over 8.0 m at Ofunato (Iwate prefecture), over 7.6 m at Ayukawa (Miyagi prefecture). The tsunami of this earthquake are also observed at oversea tsunami stations.

Keywords: The 2011 off the Pacific coast of Tohoku Earthquake, mechanism, tsunami, tsunami warning

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Forecast test for major aftershocks of the 2011 off the Pacific coast of Tohoku earthquake

Ken'ichiro Yamashina[1*]

[1]Earthquake Research Institute

After the occurrence of the 2011 off the Pacific coast of Tohoku earthquake at 14:46 on 11 March, aftershock activity was tried to forecast. As a result, among 15 alarms for major aftershocks up to the end of April, 9 were succeeded by aftershocks with a size of just assumed within the alarmed period.

In the present forecast, an alarm is based on the magnitudes of 10 aftershocks that occurred immediately before the time of the prediction (Yamashina, Abstract of the 2008 meeting of the Seismological Society of Japan). That is, when the mean magnitude of those 10 aftershocks is equal to or less than Mmin+0.4, then major events with magnitudes of Mmax+0.6(+/-0.5) are expected to occur. Here, Mmin and Mmax are the lower threshold of magnitude (assumed to be around 5.3, considering the magnitude difference from the main shock and the detectability of the available aftershock list) and the largest magnitude among 10 events paying attention to, respectively. Time period of the alarm was taken to be 2.2 times of the period between the first and the 10-th events (the factor was slightly extended from 2.0 which had been assumed before, because the time difference of the first and the 10th events are not the period in which 10 events are expected to occur but 9 on the average).

After testing the applicability of the present hypothetical method, the prospective forecast was started at 22:00 on 11 March. The first alarm was 'Possibility of M7.0+/-0.5 by around 24:00 on the same day (expected probability: 20-30%)'. Although this resulted in false, an aftershock with a magnitude of 6.6(?) did occur only 13 minutes after this alarm period. Hereafter, alarms of the similar form were repeated. For example, the 11th alarm at 17:00 on 3 April was 'Increased probability of M6.7+/-0.5 by around 06:00 on 11 April (50%)', which actually forecast the event of M7.1(?) at 23:32 on 7 April. In spite of several false alarms, 2/3 of whole alarms were proved to be successful in the present experiment.

A possible new alarm may be generated at every opportunity when an aftershock with a magnitude of Mmin or greater occurs. However, the expected ranges of magnitude and time period may overlap with each other. In the case that a new alarm nearly overlapped with a previous one, it was neglected in the present experiment. Since the procedure was made by hand, it was sometimes not in time for the occurrence of major aftershocks.

Although the present rule of forecast was obtained empirically in 2008 for the Iwate-Miyagi inland earthquake, it seems to be supported by the Omori-Utsu and the Gutenberg-Richter laws at least to some extent. The factor of 2.0-2.2 to determine the length of the alarm period is considered to correlate with the features of those relations. As shown in the results, there is a limitation of the reliability of the present method of forecasts. However, such an effort is expected to help the better understanding on the situation of the aftershock activity.

Keywords: Off the Pacific coast of Tohoku, aftershock, forecast, alarm, Omori-Utsu law, Gutenberg-Richter law

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P93 Room:Convention Hall Time:May 27 14:15-16:15

Seismic activities of eastern Japan increased by the 2011 off the Pacific coast of Tohoku Earthquake

Yoshiro Masuda[1*]

[1]Japan Meteorological Agency

The 2011 off the Pacific coast of Tohoku Earthquake (Mw9.0) occurred on March 11, 2011 off eastern Tohoku, Japan. After the main shock, seismic activities increased in many regions of eastern Japan far from the aftershock region. Earthquakes with a seismic intensity of a lower 5 or greater was observed in the eastern part of Shizuoka prefecture, the border between Nagano and Niigata prefectures, Akita prefecture, and so on. Small earthquakes also clustered after the main shock in several regions along the volcanic front.

Many triggered seismic activities in regions far from main shock was reported, which thought to be caused by dynamic stress change related to arrival of seismic wave and static stress change related to faulting of main shock. In the meeting, I will present the relationship between the seismic activities of eastern Japan increased after the 2011 off the Pacific coast of Tohoku Earthquake and the static stress change caused by the main shock.

Keywords: The 2011 off the Pacific coast of Tohoku Earthquake, Seismic activity, Coulomb Failure Function, Stress changes

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Inland earthquakes induced after the 2011 off the Pacific coast of Tohoku Earthquake

Tetsuya Takeda[1*], Hisanori Kimura[1]

[1]NIED

The 2011 off the Pacific coast of Tohoku Earthquake at 14:46 on 11 March 2011 was so gigantic event of Mw 9.0, having induced many inland earthquakes away from the focal area just after the mega-earthquake. The inland earthquake locations were widely spread, and large events over M_{JMA} 6.0 occurred at least Nagano-Niigata prefecture boundary on 12 March, the East Shizuoka prefecture on 15 March, the North Ibaraki prefecture on 19 March, and the East Fukushima prefecture on 23 March, 11 April, and 12 April. Here we introduce each feature of the induced earthquakes.

Keywords: the 2011 off the Pacific coast of Tohoku Earthquake, induced earthquake, inland earthquake

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Seismicity and stress/strain changes in central Japan after the 2011 off the Pacific coast of Tohoku Earthquake

Satoru Nagai[1*], Kazuhiro Ozawa[1], Takeo Ito[1], Keiichi Tadokoro[1]

[1]RSVD, Nagoya Univ

The 2011 off the Pacific coast of Tohoku Earthquake (M 9.0) occurred at 14:46 of March 11, 2011(JST). Seismicity, including tremor activity, has been activated worldwide after this 2011 Tohoku Earthquake. In this study, we focused on seismicity change in central Japan, mainly before and after the 2011 Tohoku earthquake. And then we infer stress and strain change from seismicity rate change and compare them with ones from other analyses (e.g. GPS observation).

It is considered that Seismicity is very sensitive to stressing rate change related with them. Seismicity can be used as remote-sensing stress meter, as suggested by Dieterich et al. [2000] and Dieterich [1994]. Through investigating seismicity change, we want to understand stressing rate change in central Japan and relationship between spatio-temporal variations of seismicity and strain rate.

We use the Japan Meteorological Agency (JMA) unified earthquake catalog to calculate seismicity rate change. As a magnitude threshold to make a complete earthquake catalog form JMA catalog, we use a value of 1.5. Using this magnitude threshold and focal depths, we have selected earthquake catalog occurred in crust. We have calculated spatio-temporal variations of seismicity rate. And also, we have calculated Z-value, b-value, and related parameters using software ”ZMAP”. Calculations have gone on to increase a number of earthquakes and to include ones occurred in recent days as possible.

We report spatio-temporal variation of seismicity, seismicity rate changes and stressing rate changes inferred from them, strain rate differences inferred from GPS before and after the 2011 Tohoku Earthquake. And also, we show some results related on the 2011 Tohoku Earthquake.

Acknowledgement: We thank the Japan Meteorological Agency for the earthquake catalog. And also, we thank Drs. Stefan Wiemer, Max Wyss, and Ramon Zuniga for providing us their software ”ZMAP” via website.

Keywords: seismicity, seismicity rate chanege, stress/strain change, z-value, b-value

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Spatial and temporal variation of b-value off northeastern Japan

Fuyuki Hirose[1*], Kenji Maeda[1]

[1]Meteorological Research Institute

1.Introduction

Hirose et al. (2002, 2006) estimated the spatial distribution of the b-value beneath the subduction zone in the Pacific off northeastern Japan. They reported that asperities estimated by Yamanaka and Kikuchi (2004, JGR) are distributed to avoid high b-value areas. Furthermore, they also reported that b-value in and around asperities decreases before a mainshock occurs. In this study, we extended the period of seismic data and thus improved the spatial resolution of b-value. Then we compared the spatial distribution of b-value with the slip distribution of the mainshock of Mw9.0, and investigated the temporal variation of b-value just before the mainshock in the area foreshock activity was eminent.

2.Data and Method

Spatial variation

We used the JMA catalogue in the period from January 1, 1990 to February 28, 2011 (M?3.0, Depth?90 km), and extracted earthquakes which occurred in the Pacific interplate region and the upper part of double-planed deep seismic zone in the Pacific plate from the catalogue taking into consideration the tectonic conditions by using REASA (Aketagawa et al., 2007).

We estimated the spatial distribution of b-value by using the computer program ZMAP (Wiemer, 1996).

We set grids with a spacing of 0.05 degrees in latitude and longitude over the northeastern Japan in the Pacific and selected the nearest 200 events from each grid. Then lower limit magnitude Mc in each grid was estimated by the method of Wiemer and Wyss (2000, BSSA). We estimated the b-value for events larger than Mc by the maximum likelihood method (Utsu, 1965, Hokkaido Univ.). Note that when there are less than 50 events over Mc, b-value is also not estimated.

Temporal variation

We used the JMA catalogue in the period from January 1, 1990 to April 20, 2011 (M?2.0, Depth?90 km). We estimated the temporal variation of b-value by using REASA (Aketagawa et al., 2007). We set 300 events as the calculation unit in order to estimate the temporal variation of b-value and shifted them at every 50 events. Note that we divided a period into two on March 11, 2011 when the mainshock occurred. Mc in the calculation unit was estimated by the method of Wiemer and Wyss (2000, BSSA), and we estimated the b-value for events larger than Mc by the maximum likelihood method (Utsu, 1965, Hokkaido Univ.). Mc was estimated as 2.0-2.1.

3.Result and Discussion

The following results are obtained, which is almost the same as Hirose et al. (2002, 2006) in spite of the difference of the data period.

1)Estimated b-value increases with the increase of depth.

2)Areas with anomalously high b-values are not intruded by asperities.

3)Temporal variation of b-value shows a remarkable decrease just before the mainshock and increase after it.

These observations suggest that b-value reflects the stress change occurring in the vicinity of the asperities (Scholz, 1968, BSSA).

The main cause that b-value became small just before the mainshock was due to the foreshock activity. Seismic activity including an event of M5.5 started one month before the mainshock, and it continued for two weeks at northeastern adjacent area of 50 km away from the epicenter of the mainshock. Furthermore, the foreshock activity with the largest event of M7.3 (Mar. 11, 2011 11:45 JST) started at the same area two days before the mainshock and the aftershock area spread around the epicenter of the mainshock. It was pointed out that foreshock activity is remarkable in this region (Maeda, 1996, BSSA). In 1981 there occurred a mainshock of M7.0 which was preceded by foreshock activity with the largest event of M6.1 about eight and half an hour before the mainshock. Unfortunately, we were not able to estimate b-value for this activity because the detection ability of the earthquakes in that time was low.

Keywords: The 2011 off the Pacific Coast Tohoku Earthquake, b value, Spatial and temporal variation, Subduction zone, Asperity,

Stress

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Shallow inland earthquakes in NE Japan possibly triggered by the 2011 Off the Pacific Coast of Tohoku Earthquake

Tomomi Okada[1*], Keisuke Yoshida[1], Sadato Ueki[1], Junichi Nakajima[1], Naoki Uchida[1], Toru Matsuzawa[1], Norihito Umino[1], Akira Hasegawa[1], Group for the aftershock observations of the 2011 Tohoku Earthquake[2]

[1]RCPEV, Grad. Sch. of Sci., Tohoku Univ., [2]Group for the aftershock observations

After the occurrence of the 2011 Mw 9.0 Off the Pacific Coast of Tohoku Earthquake, not only aftershocks near the source fault along the plate boundary, but also many shallow earthquakes occurred at several locations in the overriding plate. It is important to understand the cause of this distinctive seismicity change. We precisely relocated earthquake hypocenters for several earthquake sequences that occurred just after the Tohoku earthquake by the double-difference method. The obtained hypocenter distributions were used to discriminate the fault plane from the auxiliary plane of the focal mechanisms for those earthquake sequences. Some of them in the central part of NE Japan are the strike-slip type with steeply (dip angle $>$ 60 degrees) dipping fault planes and NE-SW oriented P-axes. Then, we calculated coulomb stress change on those fault planes caused by the 2011 Mw9 earthquake. In all cases, the estimated coulomb stress changes at the plausible fault planes for those post-mainshock sequences are positive. The positive coulomb stress change is mainly due to the reduction of normal stress on the steeply dipping fault plane of the earthquake sequences which are located to the west of the large reverse-fault source area of the 2011 Mw9 earthquake. The present observations suggest the static stress transfer possibly triggered those post-mainshock earthquake sequences.

We also find that the post-events tend to be distributed above the edge of the seismic low-velocity zone in the lower crust. This suggests that inhomogeneous structure of viscoelastic structure and fluid distribution in the lower crust are spatially related with the spatial distribution of the post- events.

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Change in seismic activity in the northern part of Tohoku district after the 2011 Off the Pacific Coast of Tohoku Earthq

Masahiro Kosuga[1*]

[1]Fac. Sci. Tech., Hirosaki University

We have investigated the seismic activity in the northern part of Tohoku district after the 2011 Off the Pacific Coast of Tohoku Earthquake on the basis of our manually picked locations. In the inland area the seismicity increased drastically but the activity is limited in some small clusters. The previously known active zones of seismicity are mostly inactive after the mainshock. This quiescence seems consistent with the Coulomb stress change due to the rupture of mainshock. Focal mechanisms for three major inland earthquakes in Akita prefecture are of strike-slip type, and an earthquake in the eastern part of Aomori prefecture is a type of normal faulting. These focal mechanisms are different from the typical mechanisms in the active zones before the mainshock. This suggests that the stress state within the inland crust has changed so that the previously common reverse faulting is unfavorable to a new state.

Keywords: 2011 Off the Pacific Coast of Tohoku Earthquake, hypocenter distribution, aftershock activity, focal mechanisms, stress change

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Increase of seismic activity along the Hida mountain range after the 2011 off the Pacific coast of Tohoku earthquake

Shiro Ohmi[1*], Hiroo Wada[1], Youichiro Takada[1], Yuki Hamada[1]

[1]DPRI, Kyoto University

Seismic activity along the Hida mountain range, central Japan, intensively increased soon after the occurrence of the mainshock of the 2011 off the Pacific coast of Tohoku earthquake. Around 10 minutes after the mainshock, two M4.5 class earthquake took place along the Hida mountain range and seismic activity increased since then. In this paper, we will focus on the activity in the vicinity of the Mt. Yake (Yake-dake) volcano. An M4.8 event occurred at 2011/3/11 14:57 (JST), which is 11 minutes after the mainshock of off Tohoku, at the northern flank of the Mt. Yake volcano followed by intense swarm activity. This activity is declining at the end of April, 2001. No temporal migration of the hypocenters has been observed. Focal mechanism of larger earthquakes exhibit reverse fault type with NW-SE compression stress field, which corresponds to the regional stress field. The former observation indicates that no magma transport is seen, and the latter indicates that local stress field is not disturbed by the volcanic activity, both of which show that this seismic activity is likely not related to the volcanic activity of the Mt. Yake in this stage.

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Seismicity activity in Hakone volcano remotely trigged by the 2011 Off the Pacific Coast of Tohoku Earthquake

Yohei Yukutake[1*], Ryou Honda[1], Masatake Harada[1], Tamotsu Aketagawa[1], Hiroshi Ito[1], Akio Yoshida[1]

[1]Hot Springs Research Institute, Kanagawa

Seismic activity in Hakone volcano at an epicentral distance of 450 km was remarkably activated just after the 2011 Off the Pacific Coast of Tohoku Earthquake. More than 1600 events were observed in the caldera of Hakone volcano, in the period from 15:00 on March 11 to 12:00 on April 2. To clarify the relationship between the occurrence of the main shock and the induced activity in Hakone volcano, we investigated the spatial distribution of hypocenters and temporal changes of the seismicity, and we examined seismographs of the main shock to find small local events during the passage of the surface waves. Hypocenters determined with the double-difference method mostly distribute in the N-S direction, showing several clusters of the seismicity. Focal mechanisms of major earthquakes are dominantly strike-slip having the P axis in the NNW-SSE direction. These features about the hypocenter distribution and the focal mechanisms are consistent with those of the earthquakes that occur ordinarily in Hakone volcano. The onset of local event was initiated during the Love and Raleigh waves from the main shock, suggesting that large dynamic stress changes of 0.6 MPa dominantly contributed to initiate a sequence of the seismic activity.

Keywords: triggered earthquake, Hakone volcano

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MIS036-P101 Room:Convention Hall Time:May 27 14:15-16:15

The volcanic activity change associated with the 2011 off the Pacific Coast of Tohoku earthquake

Toshikazu Tanada[1*], Hideki Ueda[1], Yuhki Kohno[1], Eisuke Fujita[1], Tomofumi Kozono[1], Masashi NAGAI[1], Tetsuya Takeda[1], Takanori Matsuzawa[1], Youichi Asano[1], Hisanori Kimura[1], Tetsuya Jitsufuchi[1], Taku Ozawa[1], Motoo Ukawa[1]

[1]NIED

With the occurrence of the 2011 off the Pacific Coast of Tohoku earthquake, it found that seismic activity rose up in 20% of active volcanos with 108. At present, there is no erupting case. But it is necessary to gaze at the volcanic activity with the aftershock and the induced earthquake of the 2011 off the Pacific Coast of Tohoku earthquake.

In this urgent session, we introduce the volcanic activity of Mt.Fuji(especially 2011 Shizuoka pref. Earthquake(Mjma6.4)), Izu-Oshima, Miyakejima, Mt.Nasu, Iwo-tou etc.

Keywords: the 2011 off the Pacific Coast of Tohoku earthquake, volcano, seismic activity, Fuji volcano

Japan Geoscience Union Meeting 2011
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Disturbance on magma system of Mount Fuji by the induced earthquake Mjma6.4 at eastern Shizuoka prefecture

Eisuke Fujita[1*], Tomofumi Kozono[1], Hideki Ueda[1], Taku Ozawa[1], Shoichi Yoshioka[2], Norio TODA[3], Aiko KIKUCHI[3], Yoshiaki Ida[3]

[1]NIED, [2]Kobe University, [3]Advance Soft Corporation

The Mjma6.4 earthquake at eastern Shizuoka prefecture on March 15 is considered to be the induce earthquake by the 2011 off the Pacific coast of Tohoku earthquake. This earthquake occurred beneath the south flank of Mount Fuji and may affect on the magma plumbing system. We applied numerical simulation to estimate the stress change quantitatively and studied the possibility the induced eruption of Mount Fuji. By the analysis of crustal deformation, GPS and tiltmeter data around Mount Fuji, of Mjma6.4 earthquake, the seismic fault is inferred to be almost strike slip of 86 centimeters, and strike, dip and rake are 24, 80 and 20 degrees, with the size of 6 kilometers x 6 kilometers at 7 kilometers depth (top position). The location of magma reservoir of Mount Fuji is not clear but estimated about 15 ? 25 kilometers depth by seismic tomography (Nakamichi et al, 2007) and hypocenter distribution of deep long period events. In this paper, we calculated stress field change caused by Mjma6.4 earthquake and evaluated the disturbance loaded on the magma reservoir. Our result clearly suggests that upper western area is compressed and upper eastern part is depressed. The possibility to squeeze magma and to cause an eruption depends on not only stress perturbation but also on the intrinsic potential of magma to erupt, e.g., gas component, heat, etc.

Keywords: The 2011 off the Pacific coast of Tohoku earthquake, Mount Fuji, Stress change, magma reservoir, FEM, infinite boundary

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The Earthquakes around Northern part of Ibaraki Prefecture and Coastal Area of Fukushima Prefecture

Daisuke Muto[1*], Hiroshi UENO[1], Koji Tamaribuchi[1], Koji SAKODA[1], Yuji USUI[1], Takahiko YAMAUCHI[1]

[1]JMA

The seismicity around northern part of Ibaraki Prefecture and Coastal Area of Fukushima Prefecture made active right after "the 2011 off the Pacific coast of Tohoku Earthquake". It occurred on an earthquake with JMA magnitude 6.1 on March 19, those of M6.0 and M5.8 on March 23, that of M7.0 on April 11 (hereinafter shortened to '4th large shock') and that of M6.4 on April 12 (likewise '5th large shock'). Earthquakes have occurred actively and the number of earthquakes with magnitude of 3.0 or more was over 700 until April 21.

We relocated their hypocenters with accuracy by Double Difference Method and solved CMT about some large earthquakes. In addition, we solved source process about the above 5 earthquakes using K-NET and KiK-net strong motion waveforms by NIED. These analyses revealed:

1) Hypocenter distributions are separated certain seismic zone. Specially, the hypocentral distributions around the areas of aftershocks of 4th and 5th large shocks are separated into upper and lower zones.

2) Focal mechanisms of most of large earthquakes were normal fault mechanisms with strikes of about N-S direction. It is worth notice because, in the eastern Japan, most of major earthquakes occurred in recent or geological age had reverse fault mechanisms. On the other hand, the mechanism of 5th large shock had reverse fault mechanism.

3) Slip areas of principle 5 earthquakes have filled in the area where earthquakes have occurred frequently by degree. Slip by 5th large shock filled only northern part of the lower seismic zone. Therefore the strain may remain on the southern part of it.

The active fault called 'theIdosawa Fault' is located around the aftershock area of 4th and 5th large shocks. We will show the relation between this activity and the fault on the session. In addition we will try to do the result why the earthquake with reverse fault mechanism occurred one day after the large earthquake with normal fault mechanism.

Keywords: source process, Double Difference Method, the Idosawa Fault, the 2011 off the Pacific coast of Tohoku Earthquake, aftershocks activity

Japan Geoscience Union Meeting 2011
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Surface earthquake fault due to the earthquake in the Fukushima prefecture on 11th of April, 2011

Norio Shigematsu[1*], Takashi Azuma[1], Tadashi Maruyama[1], Eiji Saito[1], Makoto Otsubo[1], Kaoru Taniguchi[1], Masayuki Yoshimi[1], Kazutoshi Imanishi[1], Miki Takahashi[1], Ryosuke Ando[1], Koichiro Fujimoto[2], Tomoyuki Ohtani[3]

[1]Geological Survey of Japan, AIST, [2]Tokyou Gakugei University, [3]Gifu University

While total displacement along an earthquake fault can be measured after the earthquake, the trajectory of the fault movement is recoded as fault striae on the fault plane. Surface earthquake fault appeared due to the M7.0 earthquake in the Hamadori district of the Fukushima prefecture on 11th of April, 2011. In this study, we measured the total displacement along the earthquake fault and the orientation of the fault striae, to reveal the fault motion during the earthquake.

(1)Attitudes of striae and total displacement

The attitude of the fault plane at an outcrop located at 36^{o}58.4'N, 140^{o}41.9'E is N15W78W, and the vertical, strike-slip, and horizontal total displacements are 1.72 m, 0.19 m, and 0.36m, respectively. Dogleg shaped striae are clearly developed on the fault plane and those plunge 77^o to south at the upper part and 70^o to north at the lower part. Considering the dogleg shape of the striae, the attitude of the striae is concordant with the total displacement. This is also the case at many of other localities. There is, however, a discrepancy between the measured total displacement and the attitude of the striae at one locality. Further study is necessary.

(2) Heterogeneous slip

The displacement along the earthquake fault is heterogeneous. Although most of the striae plunge to south, some plunge to north. Furthermore, dogleg shaped striae are sometimes observed. These observations suggest that not only the amount of the total displacement but also the direction of fault motion was temporally and spatially changed during the rupture of the earthquake.

(3) Overlapping of the striae

While striae caused by the present earthquake are clearly developed on the earthquake fault plane, several older striae which are overprinted by striae of this time are found. These striae may have been formed during the Quaternary period, because they develop in clayish fault gouge zones, suggesting a possibility that directions of fault motion of past earthquakes are different.

Keywords: the Hamadori district of the Fukushima prefecture, earthquake fault, total displacement, fault striae

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Tectonic setting of coseismic surface rupture associated with the 2011 Iwaki earthquake (M7.0)

Tatsuya Ishiyama[1*], Hiroshi Sato[1], Nobuhiko Sugito[2], Tomoo Echigo[3], Tanio Ito[4], Naoko Kato[1], Toshifumi Imaizumi[5]

[1]ERI. University of Tokyo, [2]Nagoya University, [3]Geo-Research Institute, [4]Teikyo Heisei University, [5]Department of Science, Tohoku University

M 7.0 intraplate normal fault earthquake occurred on April 11, 2011 near Iwaki city, Fukushima Prefecture. Based on basic field reconnaissance from April 12 to 15, we recognized coseismic surface ruptures, presumably associated with the main shock. Coseismic surface ruptures extend NNW for about 11 km in a right-stepping en echelon manner. Geomorphic expressions of these ruptures commonly include WWS-facing normal fault scarps and/or drape fold scarp with open cracks on their crests, on the hanging wall sides of steeply west-dipping normal fault planes subparallel to Cretaceous metamorphic rocks. Highest topographic scarp height is about 2.3 m. Both right-stepping en echelon patterns of the fault scarps or open cracks and striations observed at several outcrops suggest left lateral components of slip, though much smaller than vertical components of slip estimated by topographic relief of coseismic fault scarps. This normal fault earthquake is in contrast to compressional stress regime in Tohoku region and may reflect enhanced extensional stress on the hanginwall block induced by M~9 earthquake.

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Preliminary report on slip distribution of surface rupture associated with the 2011 Iwaki earthquake

Nobuhiko Sugito[1*], Tatsuya Ishiyama[2], Tomoo Echigo[3], Hiroshi Sato[2], Naoko Kato[2], Toshifumi Imaizumi[4]

[1]Nagoya Univ., [2]Tokyo Univ., [3]Geo-Research Institute, [4]Tohoku Univ.

We identified normal-fault surface rupture associated with the 2011 Iwaki earthquake that extends NNW for about 11 km (from Tsunagi to Kamihiraishi) along the Shionohira fault, with maximum vertical offset of c.a. 2.3 m. Based on results of our field mapping and leveling surveys, including data using handy GPS and total station, we present locations and slip amounts of the surface rupture observed at Tsunagi, southwest of Uekida, east of Saibachi, Saido to Shionohira, Sukeuemonzawa, and Kakehashi to Kamihiraishi.

Keywords: off the Pacific coast of Tohoku earthquake, Fukushima Hamadori earthquake, surface rupture, slip distribution, active fault, normal fault

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MIS036-P107 Room:Convention Hall Time:May 27 14:15-16:15

Surface slip vectors along the Yonotake fault during the April 11, 2011 earthquake of Mj 7.0 at eastern Fukushima

Yasuo Awata[1*], Kyoko Kagohara[1], Yuichi Sugiyama[1], Toshikazu Yoshioka[1], Takashi Azuma[1], Ryosuke Ando[1], Tadashi Maruyama[1]

[1]Geological Survey of Japan, AIST

A Mj 7.0 (Mw 6.8) earthquake on April 11, 2011 at east Fukushima Prefecture, NE Honshu, Japan caused surface ruptures along the Idosawa and Yunotake faults. We investigated the distribution of slip vectors along the Yunotake fault. The rupture is a normal fault and linearly extend for 15.6 km between 37 3.94 N, 140 40.59E and 36 59.16N, 140 49.91E. Slip vectors along the 10 to 14 km-long central section of the main strand are almost constant. The hangingwall (SW) side moves 40-60 cm vertically and 30-50 cm horizontally toward S30-45W relative to the footwall (NE) side along the section. There is a gap of 800 m long in the southeastern part of the main strand. Tow subsidiary strands, which branches toward the northeast from the main strand on both side of the gap, forms a depression on the footwall side.

Keywords: east Fukushima earthquake of April 11, 2011, surface rupture, Yunotake fault, slip distribution, slip vector

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A generation mechanism of normal-faulting earthquakes in northeast Japan, activated after the 2011 Tohoku earthquake

Kazutoshi Imanishi[1*], Ryosuke Ando[1], Yasuto Kuwahara[1]

[1]National Institute of Advanced Industria

After the occurrence of the 2011 Mw 9.0 Off the Pacific Coast of Tohoku Earthquake, shallow normal-faulting earthquake sequence occurred near the Pacific coast at the Ibaraki-Fukushima prefectural border. We investigated why normal-faulting earthquakes were activated in northeast (NE) Japan, which is characterized by E-W compression. Focal mechanisms of microearthquakes that occurred before the 2011 Tohoku earthquake have been determined from P-wave polarity data as well as body wave amplitudes. We found that earthquakes occurring in the studied area are characterized by normal faulting, strike-slip faulting and a mixture of both the two components. A stress tensor inversion reveals that the pre-shock stress field in the area shows a normal-faulting stress regime in contrast to an overall reverse-faulting regime in NE Japan. We then computed stress changes due to the mainshock, in which calculations were made in an elastic half-space by assuming a shear modulus of 32 GPa and a Poisson's ratio of 0.25. The stress changes produced normal faulting stress fields with E-W extension over a wide region including the target area. We estimated that the E-W extensional stress with a few MPa was added to the target area. These results suggest that the 2011 Tohoku earthquake could trigger the normal-faulting earthquake sequence in combination with the estimated pre-shock normal-faulting stress regime. In other words, the stress changes alone could not trigger this sequence if this area was in the ambient reverse fault regime, because the horizontal compressional stress could be comparable to 100 MPa simply assuming Byerlees's friction law under the lithostatic pressure. We also explore why the normal-faulting stress field can exist at a specific area at convergent plate boundary.

Acknowledgements. We are grateful to JMA for earthquake catalogue. Seismograph stations used in this study include permanent stations operated by NIED (Hi-net), JMA, and Tohoku University.

Keywords: 2011 Tohoku earthquake, normal-faulting earthquake, induced earthquake

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MIS036-P109 Room:Convention Hall Time:May 27 14:15-16:15

Strain inhomogeneity of the crust induced by the great earthquake east off NE Japan

Yasuo Yabe[1*], Mako Ohzono[2], Takeshi Iinuma[1], Yusaku Ohta[1]

[1]Tohoku University, [2]Hokkaido University

We evaluated inhomogeneity of crustal strain in NE Japan associated with a step-wise stress change induced by the great earthquake of M9.0 east off NE Japan. The earthquake ruptured the plate interface of as long as about 500km, from off Iwate to off Ibaraki. The observed eastward coseismic displacements of GPS stations were relatively uniform in the central NE Japan. This suggests that the induced stress change in this area should be uniform. The inhomogeneity of crustal strain, therefore, should reflect inhomogeneity of rheological characteristic of the crust.

The observed deformation was dominated by E-W extension. Crustal deformation predicted from a source model consisting of two rectangle faults was subtracted from the observed crustal deformation to depict deformation anomaly. It was found that the E-W extension in the Ou-backbone range was smaller than the predicted extension. This evidence strongly supports a hypothesis that viscosity of the lower crust beneath the Ou-backbone range is low.

Keywords: strain concentration zone, structual inhomogeneity

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Alteration of stress field due to the occurrence of the 2011 Off the Pacific coast of Tohoku earthquake (Mw9.0)

Shinya Hiratsuka[1*], Tamao Sato[1]

[1]Hirosaki University

A giant earthquake of Mw 9.0 took place off the Pacific coast of Tohoku on March 11, 2011. It caused a large tsunami of 10-20 m and wrought devastation in northeast coastal Japan. An interplate earthquake of Mw 7.5-8.0 had been anticipated off the Pacific coast of Miyagi in the near future, and yet an earthquake as large as Mw 9.0 had not been regarded as impending. Since this earthquake is so huge that the stress field in and around the source region has been disturbed immensely. In this paper, we look at the change in stress field brought about by this earthquake through the change in the Coulomb Failure Function (dCFF), and discuss its effect on aftershocks and future earthquake probabilities in the surrounding region.

The geometry of the fault is based on the configuration of upper plate interface of the subducted Pacific plate determined by Takeuchi et al. (2008). The coseismic slip distribution is given with reference to that estimated by the Geospatial Information Authority of Japan (GSI). The top of fault is placed at a depth of 6.5 km along the axis of the Japan Trench. The attitude of each fault segment is fitted to the local strike and dip of the plate interface. Along the dip direction, the segments are divided by their depths down to 50 km at a depth interval of 10 km. The slip amplitudes are more than 20 m over the segments off the Pacific coast of Miyagi. Given a rigidity of 40 GPa, this fault model constitutes a Mw 8.9 earthquake. The horizontal displacements calculated for the fault model agree with the ones observed at the GPS sites of GEONET operated by GSI. A good agreement between the observed and calculated displacements provides a rationale for using the fault model to evaluate the stress change due to the earthquake. The source code developed by Okada (1992) is used to calculate the displacements and strains, assuming a half-space medium with a Poisson's ratio equal to 0.25. The internal friction coefficient is assumed to be 0.4. Here we restrict the target area to northeastern Japan. Based on the general feature of focal mechanisms in northeastern Japan and the focal mechanisms of aftershocks determined by the F-net of NIED, we selected several types of target earthquakes.

The results suggest that the increased activity of normal-fault earthquake after the main shock is explained by a large positive dCFF of 1-5 MPa prevailing over a vast area in and around the source region. The areas adjacent to the northern and southern borders of the source region where another large interplate earthquakes might occur are occupied by a positive dCFF of 0.1-1.0 MPa. The dCFF for the reverse faults in the shallow crust suggests that the future probability of reverse fault earthquake will be decreased in the land area of Tohoku, with notes that the Rikuu earthquake occurred soon after the 1896 Meiji Sanriku earthquake that may have transferred a similar stress change to the land area.

Keywords: Off the Pacific coast of Tohoku earthquake (Mw9.0), giant earthquake, Coulomb Failure Function, subduction zone, induced seismicity, interplate earthquakes

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Change in seismicity beneath the Tokyo metropolitan area due to the 2011 off the Pacific Coast of Tohoku Earthquake

Takeo Ishibe[1*], Kunihiko Shimazaki[1], Kenji Satake[1], Hiroshi Tsuruoka[1]

[1]ERI. Univ. of Tokyo

We forecasted the seismicity rate changes in the Tokyo Metropolitan area due to the 2011 off the Pacific Coast of Tohoku Earthquake, by calculating the static changes of the Coulomb Failure Function (dCFF) on a nodal plane of focal mechanisms of past earthquakes. Among 30,000 previous events in this region with various depth and focal mechanism, almost 17,000 indicate significant increase of the dCFF while about 7,000 show significant decrease.

Increase in seismicity is predicted in southwestern Ibaraki prefecture and northern Chiba prefecture where intermediate-depth earthquakes occur, and in shallow crust of Izu-Oshima and Hakone. A comparison of seismicity before and after the 2011 event shows that the seismicity in the above regions indeed increased. This study successfully predicts the seismicity rate changes after the mainshock.

This study is based on the assumption that the focal mechanisms of the past and future events are similar. Thus, if earthquakes with unknown mechanisms occur, our method cannot forecast such an activity. For example, earthquake cluster took place in northern Ibaraki prefectures, where shallow crustal activity was very low and information of receiver fault mechanism was unavailable. The focal mechanisms in this cluster are dominantly a normal-type with T-axis in E-W direction, presumably induced by the extension of the upper plate of the gigantic thrusting. The dCFFs calculated on those focal mechanisms are significantly positive. Accumulation of focal mechanisms for small-magnitude earthquakes will enable us more reliable forecast.

When the spatial correlation between the dCFF due to large earthquakes and the subsequent aftershock distribution is discussed, two types of receiver faults have been assumed: a specified receiver fault and an optimally oriented receiver fault. However, the dCFF assuming receiver fault mechanisms generates large errors under a complex stress field in which various types of earthquakes occur (e.g. Toda, 2008; Ishibe et al., 2011). This study substantially reduced this uncertainty by using focal mechanisms of past earthquakes as receiver faults.

For the source fault, the variable slip model of the 2011 off the Pacific Coast of Tohoku Earthquake (Ozawa, personal communication) based on continuous Global Positioning System (GPS) observation, was used to calculate the dCFF. As the receiver faults, we used the 30,099 focal mechanism solutions determined from initial motion by the National Research Institute for Earth Science and Disaster Prevention (NIED) from July 1979 to July 2003 (Matsumura and Observation and Research Group of Crustal Activities in the Kanto-Tokai District, 2002). The Preliminary Determined Earthquake (PDE) catalog from February 1, 2011 to April 1, 2011 provided by JMA on April 2 was used to examine whether or not forecasted seismicity changes actually take place.

Our results are based on a preliminary source model and earthquake catalog. Various fault models based on tsunami waveform, far-field body waves, and strong motion seismographs are now being proposed and updated. In addition, the progress of significant afterslip is suggested from GPS observations. The PDE catalog of JMA that is used for post-mainshock seismicity will be revised later. Therefore, the correlation between the dCFF and changes in seismicity rate should be re-examined using final catalog and updated fault models.

Acknowledgments

We used variable slip model of the 2011 off the Pacific coast of Tohoku Earthquake provided by Dr. S. Ozawa of Geospatial Information Authority of Japan, preliminary determined earthquake catalog by JMA, and focal mechanisms by NIED. We also used the program by Okada (1992) for calculating dCFF. We thank all of these organizations and individuals. This study is supported by the Special Project for Earthquake Disaster Mitigation in the Tokyo Metropolitan Area from the Ministry of Education, Culture, Sports, Science, and Technology of Japan.

Keywords: the 2011 off the Pacific Coast of Tohoku earthquake, the static change of the Coulomb Failure Function (dCFF), Tokyo Metropolitan Area, seismicity

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InSAR analysis on inland crustal activities induced by the 2011 off the Pacific coast of Tohoku earthquake

Youichiro Takada[1*], Yo Fukushima[1], Manabu Hashimoto[1]

[1]DPRI, Kyoto Univ.

We detected local crustal deformations induced by the 2011 off the Pacific coast of Tohoku earthquake on March 11 (Mw9.0) by interferometric synthetic aperture radar (InSAR) analysis. We used ALOS/PALSAR images acquired before and after the earthquake and processed with the GAMMA software suite. We used the digital elevation models of the Geospatial Information Authority of Japan and hole-filled SRTM to remove topographic fringes.

First of all, we created interferograms in which large wavelength phase changes are dominant by far. To detect local signals, next, we determined coefficients of the bi-quadratic function, which well represents the large wavelength phase change, and subtract the modeled phase change from observed phase change. With this procedure, we succeeded in detecting many local signals induced by this large earthquake.

Some of the detected local signals clearly correspond to large and shallow inland earthquakes: an earthquake at northern Nagano pref. on March 12 (M6.7) and April 12 (M5.8), at eastern Shizuoka pref. on March 15 (M6.4), etc. Among all, we detected large phase changes due to large normal fault earthquakes along the Pacific coast in the northern Ibaraki and the southern Fukushima prefectures. In this region, the local fringes match the local topographic expression (active faults, steep slopes, rivers, etc.) implying that the normal fault motions have been accumulating over geologic time scale. Seemingly, reported earthquake hypocenters and mechanisms in this region cannot explain the detected phase changes.

Local crustal deformations are likely to be induced in and around the volcanic and/or geothermal area. We found signals in Mt. Fuji, Mt. Azuma, near the Naruko caldera, Nikko area, etc. However, we should be careful of atmospheric phase delay because the amplitude of the detected signals is not large.

Acknowledgements:
PALSAR Level1.0 data belongs to the Japan Aerospace and Exploration Agency (JAXA), and the Ministry of Economy, Trade, and Industry (METI). The original images were provided by JAXA through the Earthquake Working Group.

Keywords: InSAR, Triggering, Local crustal deformation

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Comparison of the long-term crustal movement deduced from the Quaternary landforms with co-seismic crustal movement of t

Takehiko Suzuki[1*], Mamoru Koarai[2], Amao KASAHARA[1], Takayuki Kawai[1]

[1]Tokyo Metropolitan Univ., [2]GSI

We considered the relationship between the long-term crustal movement deduced from the Quaternary landforms and co-seismic crustal movement of the 2011 off the Pacific coast of Tohoku Earthquake, together with the geodetic data. Altitude of paleo-shoreline of the marine formed during the MIS (marine isotope stage) 5.5 represents the long-term uplift of 0.2-0.8 mm/y along the Joban Coast (Hamadori in Fukusima to Northeast of Ibaraki Prefecture). On the other hand, the geodetic survey conducted by the Geospatial Information Authority of Japan (GSI) shows two periods characterized by the subsidence (1984/85-1994, 1994-2002) and one by the uplift (1978/79-85). Co-seismic crustal movement of the 2011 off the Pacific coast of Tohoku Earthquake along the Joban Coast is characterized by the subsidence 30-50 cm. Development and changes in heights of MIS 5.5 marine terrace cannot be explained by the interseismic crustal deformation observed in last ca. 25 years and the co-seismic crustal movement of the 2011 off the Pacific coast of Tohoku Earthquake. This suggests presence of the interseismic crustal deformation with uplifting along the Joban Coast and/or presence of the co-seismic crustal movement by different type of the 2011 off the Pacific coast of Tohoku Earthquake causing uplifting.

Keywords: Marine terrace, MIS5.5, Abukuma Highlands, 2011 off the Pacific coast of Tohoku Earthquake, Geodetic data

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Tsunami source area of the 2011 off the Pacific Coast of Tohoku Earthquake by back-propagation from offshore stations

Yutaka Hayashi[1*], Hiroaki Tsushima[1], Kenji Hirata[1], Kazuhiro Kimura[1], Kenji Maeda[1]

[1]Meteorological Research Institute

On 11th March, the largest earthquake (Mw 9.0 by JMA) since the recorded history of Japan occurred; JMA named it the 2011 off the Pacific coast of Tohoku Earthquake. Subduction zone along the Japan Trench have source areas on the plate boundary of several series of repeating large earthquakes. This paper determines the tsunami source area due to this huge earthquake by using tsunami arrival times detected by various offshore observatories (coastal wave gauges, RTK-GPS buoys, cabled deep ocean bottom pressure gauges, DART buoys) installed off Tohoku and its neighbor districts, and then determines which segments of repeating earthquakes are included. Although TM1-2 (cabled ocean bottom pressure gauges off Kamaishi) and seven GPS buoys stopped observation due to the tsunami or ground motions, most of them successfully detected tsunami arrivals before possible destruction of their inland facilities. Tsunami travel times are modified as much as 1 min corresponding to 150km distance from the epicenter, in order to consider difference of timing of tsunami source generation. Determined tsunami source area is approx. 2x10**2 km in width and 5.5x10**2 km in length; the area includes following segments of repeating large earthquakes, which are identified by Earthquake Research Committee, along the further side from the trench [last event]: southern half of Off Northern Sanriku [1968 M7.9], Off Central Sanriku [unknown], Off Southern Sanriku [1897 M7.7], Off Miyagi [1978 M7.4], Off Fukushima [1938 M7.5,7.3,7.4] and at northern half of Off Ibaraki [2008 M7.0]. In addition, it also includes center part of the area from off Sanriku to off Boso along the nearer side of the trench, where historically tsunami earthquakes [e.g. 1896 Mt8.2] have been generated. However, it suggested that the main shock did not rupture half part of Off Northern Sanriku and Off Boso nearer side of the Japan Trench [1677 Mt8.0].

Acknowledgements. Observation data distributed by MLIT (coastal wave gauges and RTK-GPS buoys), JAMSTEC (KPG-1, 2), ERI, Univ. Tokyo (TM-1, 2), JMA (Boso-2, 3), NOAA (DART 21413, 21418), and RFERHR (DART 21401) were engaged in this study.

Keywords: RTK-GPS buoy, cabled ocean bottom pressure gage, DART buoy, tsunami travel time, tsunami source area, multi-segment earthquake

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Experimental tsunami forecasting of the 2011 off the Pacific coast of Tohoku Earthquake from offshore tsunami data

Hiroaki Tsushima[1*], Kenji Hirata[1], Yutaka Hayashi[1], Yuichiro Tanioka[2], Kazuhiro Kimura[1], Shin'ichi Sakai[3], Masanao Shinohara[3], Toshihiko Kanazawa[3], Ryota Hino[4], Kenji Maeda[1]

[1]Meteorological Research Institute, [2]Hokkaido University, [3]ERI, Univesity of Tokyo, [4]RCPEV, Tohoku Univerisity

We retroactively applied a method of near-field tsunami forecasting to the offshore tsunami data of the 2011 off the Pacific coast of Tohoku Earthquake (Mw 9.0). The tsunami with height of more than 10 m at the coastal tide stations damaged people and infrastructure along the Pacific coasts of Japan Island. The tsunami was observed at many offshore tsunami observatories deployed around Japan, such as cabled ocean bottom pressure gauges (OBPGs) and Real-Time Kinematic GPS (RTK-GPS) buoys, ~10 minutes earlier than at the coastal tide stations nearest the source. In the present study, we carried out an experimental forecasting of the disastrous tsunami using the offshore tsunami data. We applied a method of near-field tsunami forecasting developed by Tsushima et al. (2009). In the method, offshore tsunami waveform data are inverted for distribution of initial sea-surface height within a tsunami source region, and coastal tsunami waveforms are synthesized by using the estimated source and the pre-computed tsunami Green's functions. The successive calculation of tsunami forecasting can be accomplished within one minute. We carried out the calculation of the forecasting using the tsunami data observed at nine offshore stations (four OBPGs and five GPS buoys) from the origin time of the earthquake to 20 minutes; these valuable offshore tsunami data were provided by the University of Tokyo, JAMSTEC, MILT, and PARI. Assuming realistic situation of the earthquake, we used only data that were actually available at the time. As a result, tsunamis with heights of 6-14 m were forecasted at the coastal tide stations Miyako, Kamaishi, and Ofunato nearest to the source where the sea-level elevation due to the tsunami reaches 1 m after elapsed time of 25 minutes. The result suggests a possibility that the method can contribute to issuance of reliable tsunami warning for M9 earthquakes.

Keywords: the 2011 off the Pacific coast of Tohoku Earthquake, real-time tsunami forecasting, ocean bottom pressure gauge, GPS bouy

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Tsunami source of the 2011 off the Pacific coast of Tohoku, Japan earthquake

Yushiro Fujii[1*], Kenji Satake[2], Shin'ichi Sakai[2], Masanao Shinohara[2], Toshihiko Kanazawa[2]

[1]IISEE, Building Research Institute, [2]ERI, University of Tokyo

Tsunami waveform inversion for the 11 March 2011 off Pacific coast of Tohoku earthquake (M 9.0) indicates that the source of largest tsunami was located near the axis of the Japan trench, while the deeper interplate fault in Sanriku-oki and Miyagi-oki regions also slipped. Ocean bottom pressure and GPS wave gauges recorded gradual increase of water level (~ 2 m) followed by an impulsive tsunami wave (3 to 5 m). The slip distribution estimated from 33 coastal tide gauges, offshore GPS wave gauges and bottom pressure gauges show that the large slip, more than 30 m, was located along the trench axis. This offshore slip, similar but much larger than the 1896 Sanriku "tsunami earthquake," is responsible to the recorded large impulsive peak. In addition, large (> 10 m) slip on the plate interface at Sanriku-oki and Miyagi-oki around the epicenter, similar to the previously proposed fault model of the 869 Jogan earthquake, is responsible to the initial water rise and presumably large tsunami inundation in Sendai plain. The interplate slip is ~ 4 m in Fukushima-oki, and less than 2 m in Ibaraki-oki region. The total seismic moment is estimated as 3.2 x 10^{22} Nm (Mw = 8.9).

Keywords: 2011 Tohoku earthquake, Tsunami source, Tsunami waveform inversion, Ocean bottom sensor, GPS buoy, Tide gauge

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Infrasound signals excited by uplift and subsidence of ocean surface during the tsunami genesis in 11 March event

Nobuo Arai[1*], Takahiko Murayama[1], Makiko Iwakuni[1], Mami Nogami[1]

[1]Japan Weather Association

Observed infrasound records at IMS (International Monitoring System for CTBT verification regime) stations in East Asia relating to the disastrous tsunamigenic earthquake occurred at Mar. 11, 2011 in Japan have been analyzed. Long period acoustic signals which might be excited by the uplifting and subsiding ocean surface during the tsunami genesis were detected in the records observed at IS30 (Japan), IS34 (Mongolia) and IS45 (Russia). The on-set time of these signals coincided with the time predicted based on the distance between the tsunami source region and each station, and the shape of these signals also coincided with the water level changes of the tsunami source estimated by the fault model of the event. IS34 and IS45 are located in the direction along the fault width, and IS30 is located in the direction along the fault length. Infrasound signals observed at both IS34 and IS45 have relatively shorter wave-lengths than the signal at IS30. It also coincided with the geographical relation between the tsunami source and stations.

Keywords: Infrasound, Tsunami source, International Monitoring System

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Tsunami source of the 2011 off the Pacific coast of Tohoku earthquake estimated from tsunami back propagation

Toshihiro Ueno[1*], Kenji Satake[1], Shin'ichi Sakai[1], Masanao Shinohara[1], Toshihiko Kanazawa[1]

[1]Earthquake Research Institute

We estimate the tsunami source of the 2011 off the Pacific coast of Tohoku earthquake (M9.0) by using tsunami back propagation. As a result, tsunami source is about 400km long along the Japan trench, and almost reach the trench axis. The tsunami source of highly characteristic tsunami have great amplitude (about 5m with 1618m water depth) and short cycle (about 10 minute) is estimated off Miyagi, near trench area.

The tsunami caused by 2011 off the Pacific coast of Tohoku earthquake immensely damaged Pacific coast of Japan. Highly characteristic tsunami is observed at Ocean bottom tsunamimeter off Kamaishi (Tokyo University) and GPS wave gauge (MLIT) off pacific coast of Iwate. The records showed large amplitude (about 5m with 1618m water depth) and short cycle (about 10 minutes) wave came after long cycle (several tens of minutes) wave. we estimate tsunami source by tsunami back propagation from Ocean bottom pressure gauge data (NOAA and JAMSTEC) and tide gauge data (JMA , JCG and GSI) in addition to these Ocean bottom tsunamimeters data and GPS wave gauges data . Tsunami back propagation is drawing wavefronts propagate from observation station from arbitrary time back to origin time of earthquake. 40 obsevation stations we use surround the hypocenter.

First, we estimate length and width of the tsunami source by using tsunami back propagation from first break. Estimated tsunami source is about 400km long and almost reach the Japan trench axis. However, in north part of tsunami source area, back propagation wavefronts showed complicated pattern. More detailed investigation is needed to estimate the north edge of the tsunami source.

Next, We estimate the source of highly characteristic tsunami by using tsuami backpropagation from first break and end of characteristic tsunami. As a result, the source of characteristic short cycle tsunami is located off Miyagi, near trench area. From tsunami phase velocity (200m/s) in this area and period(5 minute) from start to end of characteristic tsunami, we estimate horizontal scale of the characteristic tsunami source is about 60km.

Keywords: tsunami, the 2011 off the Pacific coast of Tohoku earthquake, back propagation

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Run-up height distribution of tsunami caused by the 2011 Mw 9.0 Off Pacific Coast of Tohoku earthquake and its seismic i

Aiming Lin[1*], Gang Rao[1], Ryoya Ikuta[2]

[1]Graduate School, Shizuoka University, [2]Faculty of Science, Shizuoka University

On 11 March 2011, at 02:46:23 PM local time 2011, a moment magnitude 9.0 earthquake (called 2011 Off Pacific Coast of Tohoku Earthquake) occurred in the off shore of the northeast Japan, resulting in extensive damage throughout east-northeast Japan, including more than 14,100 deaths and 13,500 missing and ~5,000 injured.

The epicenter is located on the on the off shore near the plate boundary between the Pacific plate and the North American plate, 130 km east of Sendai City, Miyagi Prefecture, northeast Japan. Seismic inversion analyses reveal that a maximum thrust slip of >20 m occurred on a 500-km-long fault plane (USGS, 2011; Yagi and Nishimura, 2011). Such large thrusting slip along the plate boundary between the Pacific plate and the North American plate resulted in an enormous tsunami that caused great damage along the north-south striking coast parallel to the plate boundary.

It is reported that the tsunami-induced inundation areas are distributed in a wide corridor along the coast with the tsunami wave height of >35 m, resulting in serious secondary damage after the main shock, however, the tsunami run-up height distribution and its relations with coseismic slips remain unclear. In the present study, we report the analytical results of tsunami run-up height using high-resolution remote sensing imagery data, including ALOS and Google images and aerial photographs, acquired before and after the 2011 earthquake and digital elevation data, and calculated coseismic slips on the fault palne. Based on the analytical results, we conducted fieldworks in the early April to validate the interpretations and compared the run-up heights with the GPS observations and calculated seismic slips on the fault plane.

Analytical results and field investigations reveal that the run-up heights are up to >20-30m in Ishinomaki-Miyako areas and decreases south- and northward gradually. The distribution pattern of run-up heights is consistent with that of ground displacements indicated by GPS observations and calculated coseismic slips on the fault plane along the plate boundary. The findings indicate that the run-up height is closely related to the coseismic slip on the source fault along the plate boundary between the Pacific plate and the North American plate.

We thank JAXA for providing the ALOS imagery data and Geospatial Information Authority of Japan for providing the aerial photographs and 25,000 topographical maps and digital elevation data timely. This work was supported by the Center for Synthesis Disaster Prevention, Shizuoka University and a Science Project (Project no. 23253002 for A. Lin) of the Ministry of Education, Culture, Sports, Science and Technology of Japan.

Keywords: Off Pacific Coast of Tohoku earthquake, tsunami, run-up height, seismic slip, plate boundary, ALOS image

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High resolution survey results for the inundation limit and height of the 2011 Tohoku earthquake tsunami

Ikuo Abe[9], Tomoya Abe[10], Kazuno Arai[7], Koji Fujima[3], Shigehiro Fujino[8], Hideomi Gokon[1], Kazuhisa Goto[2], Kenji Harada[6], Tsuyoshi Haraguchi[5], Kentaro Imai[1], Fumihiko Imamura[1], Shunichi Koshimura[1], Yoichi Murashima[11], Hajime Naruse[7], Shuji Seto[4], Yoshinori Shigihara[3], Daisuke Sugawara[1], Tomoyuki Takahashi[4*], Ryota Tsudaka[3], Shota Yamashita[7]

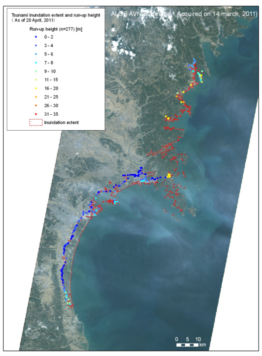
[1]Tohoku University, [2]Chiba Institute of Technology, [3]National Defense Academy of Japan, [4]Kansai University, [5]Osaka City University, [6]Shizuoka University, [7]Chiba University, [8]University of Tsukuba, [9]Fuji Tokoha University, [10]Nagoya University, [11]Kokusai Kogyo Holdings Co., LTD.

An earthquake of magnitude 9.0 occurred off the Pacific coast of Tohoku, Japan, on March 11, 2011. The tsunami devastated the northeast coasts of the Tohoku district and the maximum run-up height was measured nearly 39 m at Sanriku area. The remarkable feature of this tsunami was the range of inundation areas. In fact, on the Sendai plain, the tsunami inundated more than 5 km inland. Emergency field surveys were conducted by many Japanese groups in the devastated area and they measured the inundation depths or building damages near the shore. Satellite and aerial photographs were studied by multiple societies, universities and companies, and inundation limit was estimated from such photographs immediately after the tsunami. We also measured the inundation limit of the northeast coast of the Tohoku district by the analysis of the ALOS AVNIR2 image that was taken on 14th March.

In order to validate the results of the satellite image analysis and to confirm the maximum inundation limit in the wide area, we organized a research group and conducted high-resolution surveys of the inundation limit and height in the few-centimeter accuracy by using GPS measurement system (Promark3) in Miyagi, Iwate, and Aomori prefectures. The horizontal measurement interval is ranging from approx. 500 m to few kilometers and we measured nearly 300 sites until the end of April.

We preliminarily confirmed that the inundation limit estimated from the satellite image is well consistent with the field measurement results at most places, although there are some exceptions that might have not been interpreted from the satellite images. We still continue our survey to cover whole devastated area before the tsunami watermarks were removed or washed away in the rainy season.

This research is funded by Tohoku University. The survey team member is listed in an alphabetical order.



Keywords: The 2011 Tohoku tsunami, Field survey, Tsunami inundation extent, GPS measurement

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Preliminary result of field survey on the 2011 Tohoku earthquake tsunami along the Pacific coast of Hokkaido

Yuichi Nishimura[1*], Yugo Nakamura[1], Ioki Kei[1], Purna Putra[1], Aditya Gusman[1]

[1]Hokkaido University

The 2011 Tohoku earthquake accompanied huge tsunami that caused severe damage along the Pacific coast of Hokkaido, Tohoku and Kanto districts. To understand the tsunami disaster and behavior, post tsunami field surveys were carried out by the 2011 Tohoku Earthquake Tsunami Joint Survey Group along the comprehensive coastal region in Japan. We worked as a part of the team and measured the tsunami heights at 43 sites in Hokkaido and 36 sites in northern Tohoku. Evidences for the tsunami inundations we traced were water marks on buildings, broken trees and debris on trees, and surface erosion and debris left on land. For most of the sites, we could understand the tsunami behavior on land based on these evidences. Then, the tsunami heights around Erimo Peninsula were 5-6 m, while the other sites along Hokkaido coast were 2-4 m. Tsunami heights along the Misawa coast, Aomori prefecture, were 5-10 m. The tsunami attacked the sawtooth coastline of Sanriku and invaded along the steep coastal valleys. For some sites, the tsunami heights were more than 30 m and the inundation distances were more than 1km from the beach. We also investigated coastal erosion and deposition processes by the tsunami at the Misawa coast and typical sawtooth coasts in Iwate prefecture.

Keywords: Tohoku tsunami, tsunami evidence, tsunami deposit, runup height, flow height

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Comparison of tsunami inundation limit between the 869 Jogan earthquake and the 2011 Tohoku earthquake

Masanobu Shishikura[1*], YUKI SAWAI[1], Yuichi Namegaya[1], Koichiro Tanigawa[1]

[1]Active Fault Earthq. Res. Ctr., AIST/GSJ

To confirm the deference between tsunami inundation limit and distribution limit of sandy deposit transported by tsunami of the 2011 Tohoku earthquake, we conducted post-tsunami survey, and compared the sandy deposit limit with the 869 Jogan earthquake. Our survey results show that magnitude of tsunami inundation seems to be roughly same between two events.

Keywords: 2011 off-Tohoku earthquake, 869 Jogan earthquake, tsunami deposit, tsunami inundation area, Sendai Plain, Ishinomaki Plain

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(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P123 Room:Convention Hall Time:May 27 14:15-16:15

Tsunami deposits associated with the 2011 off the Pacific coast of Tohoku earthquake -examples from Miyagi and Chiba-

Koichiro Tanigawa[1], YUKI SAWAI[1*], Masanobu Shishikura[1], Yuichi Namegaya[1], Haruo Kimura[1], Kyoko Kagohara[1], Yukari Miyashita[1], Yushiro Fujii[2], Osamu Fujiwara[1]

[1]AIST, GSJ, [2]Building Research Institute

We observed tsunami deposits in Sendai Plain, City of Hitachi, City of Kashima, and Hasunuma coast of Chiba Prefecture, associated with the 2011 off the Pacific coast of Tohoku earthquake.
In Sendai Plain, we observed sedimentary structure and thickness of tsunami deposit along leveled transect of Isohama and Ushibashi (Town of Yamamoto). The deposits show landward thinning and fining. In City of Hitachi, the tsunami deposit shapes a fan and the sand thins toward its fringe. Surface sediment has ripples and the direction of the current shows toward outside. In City of Kashima and Hasunuma coast, extensive sand and mud sheet distribute on paved road near the sea.
We made diatom analysis on samples from tsunami deposits of Hitachi, Kashima, and Hasunuma.

Keywords: Tsunami deposit, 2011 off the Pacific coast of Tohoku earthquake, Sendai Plain, Ibaraki, Chiba

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Urgent survey of the tsunami of "The 2011 off the Pacific coast of Tohoku Earthquake" on the Pacific coast of Hokkaido

Satoshi Ozawa[1*], Noritoshi Okazaki[1], Kenji Nishina[1], Gentaro Kawakami[1], Sunao Ohtsu[1], Takahiro Suzuki[1], Makoto Tamura[1], Yusuke Morino[1], Tomo Shibata[1], Wataru Hirose[1], Ryo Takahashi[1], Satoshi Ishimaru[1], Yasuyuki Kakihara[1], Tagiru Ogino[1], Masahiro Yahata[1], Jun Tajika[1]

[1]Geological Survey of Hokkaido

The strong ground motion, caused by "The 2011 off the Pacific coast of Tohoku Earthquake" on 11 March 2011, according to Japan Meteorological Agency (JMA), registered 7 on the seismic intensity scale in Kurihara city of Miyagi Prefecture. And that recorded an upper 6 on the seismic intensity scale in a large area of Miyagi, Tochigi, Ibaraki and Fukushima prefecture. In Hokkaido prefecture, the ground motion recorded 4 on the seismic intensity scale in maximum, in a wide area on the coast of Pacific Ocean. The tsunami of this earthquake caused extensive and severe damage in a wide area on the coast of Pacific Ocean in Tohoku region and Kanto region near the epicenter, also in parts of the coast of Hokkaido. In Hokkaido, according Hokkaido local government (summary 11 April 2011), this tsunami caused damages such as casualties (1 death, 3 minor injured), house damage (294 flooded above floor level, 435 flooded under floor level), fishery damage (148 fishing ports & fisheries, 318 fisheries facilities, 768 fishing boats . 16 fish farms).

Geological Survey of Hokkaido organized a tsunami research group immediately after the earthquake. Then, in cooperation with Institute of Seismology and Volcanology of Hokkaido University and Sapporo District Meteorological Observatory, the tsunami research group urgently had survey for the purpose of measurement of the height (elevation) of the tsunami traces which were left in coastal ports and rivers and beaches, and also the purpose of observation of tsunami sediments. As the first survey, 3 teams (3/14 - 3/16, 7 people in total) surveyed 3 regional areas of south Hokkaido area, central Hokkaido area and east Hokkaido area. Then, the second survey (1 team: 3/17 - 3/18, 2 people) and the third survey (2 teams: 3/24 - 3/24, 2 people; 3/23 - 3/26, 2 people) were conducted for the purpose of supplemental and targeted survey.

We mainly used GPS survey equipment to measure the ground elevation of the survey site. And hand level equipment was also used to measure the height of the tsunami traces from the ground elevation. In addition some sites, we measured the height of the tsunami traces from the elevation basis such as tidal elevation, using hand level equipment. In addition, we calculated the tsunami height from tidal level using tidal observation data of JMA.

Tsunami height survey results, although there is variation with the influence of coastal topography, as general tendency, the tsunami height is estimated to become highest in the region between Cape Erimo and Shiranuka town. In there, tsunami height is estimated to 3 to 5 meter high (maximum 5.7 meter at Kinashibetsu in Onbetsu-cho Kushiro city). In the west (Hakodate city - coast along Uchiura bay - Tomakomai city - Urakawa town), the tsunami height is estimated to 1 to 3 meter high. In the east (Kushiro city - Nemuro city), the tsunami height is estimated to 1 to 4 meter high, and become lower towards east.

In addition, we offers the results of Tsunami survey from Web-GIS site. Please visit "http://webgis.gsh.hro.or.jp/tsunami/".

Keywords: tsunami height, tsunami sediments, The 2011 off the Pacific coast of Tohoku Earthquake, Hokkaido

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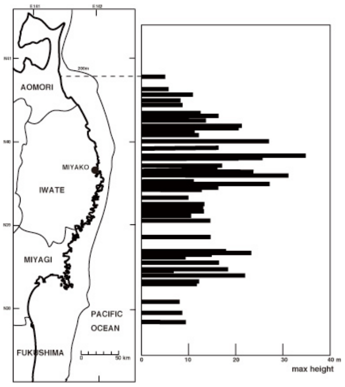
Characteristic maximum heights observed in the 2011 Tohoku Earthquake Tsunami

Kuniaki Abe[1*]

[1] Junior College at Niigata, NDU

Field surveys were carried out to detect the maximum tsunami heights of the 2011 off the Pacific coast of Tohoku Earthquake. The heights were obtained at 56 points distributing from Misawa fishing port in Aomori prefecture to Soma port in Fukushima prefecture, as shown in Fig.1. Maximum and minimum values in them are 36.4m and 5.6m, respectively, and the average is 14.6m. We noticed two important facts. One of them is a water height increase at V shaped valleys and another is a moderate height at the heads of long bays. The former is characteristic to a short-period wave and the latter is to a long-period wave. Such a double-period wave is attributed to tsunami formation from a large-scaled fault of about 200 km in width under a deep sea of about 3000m.



Keywords: the 2011 off the Pacific coast of Tohoku Earthquake, tsunami, field survey, V shaped valley, bay

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MIS036-P126 Room:Convention Hall Time:May 27 14:15-16:15

Multiscale Tsunami Simulation of Tohoku Earthquake

David Yuen[1*]

[1]University of Minnesota

Multi-scale Tsunami Simulation of Tohoku Earthquake

David L. George, USGS , Vancouver, Washington, U.S.A.
David A. Yuen, and Erik O.D. Sevre ,
Dept. of Geology and Geophysics, University of Minnesota, Minneapolis, MN 55455-0219, U.S.A.
Shigenori Maruyama, Dept. of Earth and Planetary Sciences, Tokyo Institute of Technology, 153, Tokyo, Japan
Y. Yanai and Atshushi Utsunomiya , Japan Geocommunications Co. Ltd, Shinjuku , Tokyo, Japan

The recent M 9.0 Tohoku earthquake has dealt northeastJapan a great blow and the resultant tsunami waves have caused great destruction and loss of lives. We have employed state-of-the-art numerical methods to study the tsunami run-up problem by means of a high-resolution finite volume method with special focus on the inundation problem. The Riemann solver under the auspices of th GEOCLAW package is applied to the nonlinear shallow-water equations that works robustly with fine-scale seafloor bathymetry and dry states associated with the land and the buildings. Very high- resolution bottom seafloor topography near the Japanese coast, less than 100 meters , was employed in this study

We have employed the adaptive mesh refinement (AMR) method to study this multi-scale phenomenon of tsunami waves interacting with the coast. Grid sizes vary greatly by more than two-orders in magnitude allowing for multi-resolution capability. We are particularly interested in the waves coming toward the nuclear plant at Fukushima and to study the maximum height of the waves leaping over the building structures along the coast. The influences of high-resolution bathymetry on amplifying the run-up waves will be emphasized

Keywords: tsunami, riemann solver, run-up waves, adaptive mesh refinement

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Characteristics of the recent onshore tsunami deposits in coastal lowland, Wakabayashi-ku, Sendai plain, eastern Japan

Yasuhiro Takashimizu[1*], Atsushi Urabe[1], Koji Suzuki[1]

[1]Niigata University

Sedimentary characteristics of the tsunami deposits caused by the 2011 off the Pacific coast of Tohoku Earthquake in coastal lowland of Wakabayashi-ku in Sendai plain were summarized as follows;

1) The area of coastal dune and beach were widely eroded by tsunami waves.
2) The sediments derived from coastal dune and beach area were distributed in inside area of coastal dunes.
3) The tsunami deposits show a fining- and thinning-landward trend.
4) Internal structures of tsunami sediments were mainly parallel lamina or massive structure. Cross-lamination structures were sometimes shown in uppermost part.
5) The tsunami deposits shown in seaward area include mud clast in the basal part, which interpreted as these formed by intensive tsunami current
6) Mud-drape layer is commonly observed in these deposits and indicates a calm period during tsunami currents and/or after tsunami.
7) The deposits from return flows of tsunami were rare in this survey.

Keywords: tsunami deposits, Sendai, The 2011 off the Pacific coast of Tohoku Earthquake

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Preliminary results for the inundation heights, current velocities, and deposits of the 2011 Tohoku tsunami

Kazuhisa Goto[1*], Catherine Chague-Goff[2], James Goff[2], Bruce Jaffe[3], Witold Szczucinski[4], Shigehiro Fujino[5], Daisuke Sugawara[6], Yuichi Nishimura[7], Bruce Richmond[3], Rob Witter[8], David Tappin[9], Eko Yulianto[10]

[1]Chiba Institute of Technology, [2]University of New South Wales, [3]US Geological Survey, [4]Adam Mickiewicz University, [5]University of Tsukuba, [6]Tohoku University, [7]Hokkaido University, [8]DOGAMI Coastal Field Office, [9]British Geological Survey, [10]Indonesian Institute of Science

The 11 March 2011 MW 9.0 Tohoku megathrust earthquake off the coast of Japan was one of the largest events in the history of Japan. The huge tsunami inundated a large area on the northeast coast of Japan, and resulted in widespread devastation. Remarkable feature of the Tohoku region is the abundance of available historical and geological records for the past earthquakes and tsunamis. Based on the 1200 years historical records and 2800 years geological records, tsunami disaster mitigation countermeasures were prepared to the Pacific coasts of the Tohoku region. Hence, the Tohoku region is one of the best prepared regions against the tsunami in the world. This event is a very important opportunity to test the validity of a previous methodology for the tsunami risk assessment using the historical and geological records. In addition, there are many video footages for the 2011 event and hence the sedimentation process can be linked to the flow characteristics (e.g., inundation height and current velocity) of the tsunami. In order to study the inundation heights, current velocities, and their relationships to the erosion and sedimentation by the tsunami, we organized an international team of scientists and undertook a post-tsunami survey in May 2011 that focused on the area close to the Sendai megacity and the Sendai airport near the Natori to Iwanuma cities.

The field observation was conducted along transects established on a grid extending few kilometers inland near the north of Sendai airport. We conducted high resolution sampling at each pit to study the vertical and horizontal variation of the grain size for understanding the sedimentary process and for performing the inversion modeling. Geochemical analyses are also performed for the environmental assessments. We also studied the paleo-tsunami deposits such as the 869 Jogan tsunami in order to compare the sedimentary characteristics to the 2011 tsunami deposits. We also used video footages at the Natori city and at the Sendai Airport and estimated the current velocity of the tsunami. Our preliminary analysis revealed that the wave front of the run-up wave of the tsunami was moved about 3 m/s on land, whereas it was about 6.5 m/s in the Natori River.

In our presentation, tsunami inundation heights and current velocity will be linked to the sedimentary process of the tsunami deposits by using the forward and inversion modeling results.

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Inundation area by the 2011 Tohoku earthquake tsunami in Sendai plain: comparison to the 869 Jogan earthquake tsunami

Daisuke Sugawara[1*], Fumihiko Imamura[1], Kazuhisa Goto[2], Hideaki Matsumoto[3], Koji Minoura[4]

[1]Tohoku University, [2]Chiba Institute of Technology, [3]Tohoku Gakuin University, [4]Tohoku University

The 2011 off the Pacific coast of Tohoku Earthquake and following tsunami, occurred on 11 th March, affected widely to east Japan. The tsunami caused serious damages in particular to Iwate, Miyagi and Fukushima prefectures. According to the analysis by USGS, the moment magnitude is estimated at 9.0, which is the largest value among the observed earthquakes in Japan and 4 th largest event in the world. In Sanriku coasts, maximum run-up heights reached up to 40 meters (JSCE). Tsunami heights on the coasts in Sendai and other flat coastal plains are estimated around or more than 10 m. In addition, tsunami inundation in the coastal lowlands extended around several kilometers from the coast due to the large-scale tsunami and coseismic subsidence (GSJ).

In Sendai City, tsunami height of around 10 m near the coast was measured at Arahama, Wakabayashi Ward (JSCE). Post-tsunami survey by Research group of Tohoku University clarified that inundation depths reached around 2.8 meters in the areas 2 km from the coast. Although slopes of Sendai East Expressway prevented the tsunami inundation in the inland area, the tsunami run-up passed through underpath and elevated bridges of the expressway. Post-tsunami survey by Tohoku University clarified that traces of tsunami inundation exist at Kasuminome, Wakabayashi Ward, which is located landward of the elevated bridges and apart more than 5 km from the coast. The result is roughly consistent with the estimated inundation area from the satellite images and aerial photographs (GSJ). Therefore, inundation area could have reached around 5 km from the coastline through entire Sendai plain, if the expressway did not exist.

Like the 2011 event, the 869 Jogan earthquake has been known as one of the major historical earthquake that caused a large-scale tsunami in Tohoku region like the 2011 event (Watanabe, 2001). Deposits by the Jogan tsunami are distributed in the coastal plains of Ishinomaki, northern coast of Sendai Bay, Sendai and neighboring areas (Minoura & Nakaya, 1991; Sugawara et al., 2001; Sawai et al., 2007; Shishikura et al., 2007). In Sendai Plain, the Jogan tsunami deposit extends up to 3 km from the paleo-coastline, which is located around 1 km inland of the present beach (Sugawara et al. 2011). They estimated the hydraulic character of the Jogan tsunami based on the distribution and sedimentological feature of the deposit and reconstructed numerically the inundation area of the tsunami. Inundation area by an earthquake with a magnitude of 8.35 (fault length = 200 km, width = 85 km, displacement = 6.1 m) reaches around 3.5 km from the paleo-coastline. This is consistent with the distribution and character of the deposit. According to the calculation, tsunami height is estimated around 7 m near the coast and 2.5 m in lowlands around 2 km from the coast.

Based on the results from Sendai Plain, the inundation area (inundation distance) by the 2011 event is 2 km greater than that by the Jogan event. Tsunami height is around 3 m higher near the coast and several tens of centimeters higher in the inland area.

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Keywords: Inundation area, Jogan tsunami, tsunami deposit

Japan Geoscience Union Meeting 2011
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Field surveys of tsunami heights and inundation area in Ibaraki and Chiba, generated with the 2011 Tohoku earthquake

Yuichi Namegaya[1*], Masanobu Shishikura[1], Yuki Sawai[1], Osamu Fujiwara[1], Kyoko Kagohara[1], Haruo Kimura[1], Junko Komatsubara[2], Yukari Miyashita[1], Yushiro Fujii[3], Yasuo Okuda[4], Koichiro Tanigawa[1]

[1]AFERC, GSJ, AIST, [2]IGG, GSJ, AIST, [3]IISEE, BRI, [4]DSE, BRI

We conducted field surveys of tsunami heights and inundation area in Ibaraki and Chiba prefectures, just after the 2011 off the Pacific coast of Tohoku earthquake. In the surveys, we tried to find evidences which indicate the tsunami heights, for examples, watermarks on walls and debris on the ground. Witness accounts about the tsunami heights were also obtained. Then, tsunami inundation heights (above the sea level), run-up heights (the height of inundation limit above the sea level), and flow depth (above the ground) were measured based on the evidences by using a total station (electronic/optical instrument). Along the Kujukuri beach, Chiba prefecture, inundation area was intensively surveyed. Locations of the most-inland debris and/or locations which inhabitants pointed out as the inundation limit were measured by using GPS receivers.

The results were briefly shown as follows. The tsunami inundation heights were measured to be 3.3-3.6 m (above the sea level at 17:20 on 14 March, 2011) in Hitachi-naka city, Ibaraki prefecture, 4.4-4.8 m (above the sea level at 15:29 on 14 March) in Oarai town, more than 7.5 m in Kamisu City, 3.8 m (above the sea level at 15:18 on 13 March)in Kujukuri town, Chiba prefecture. The flow depths were also measured to be more than 3.5 m just behind the most-seaward beach ridge in Sanmu city. The estimated inundation area indicates that the tsunami basically inundated up to several hundred meters inland from the coast line. Around ditches, some places were inundated about 1.5 km from the coast line. In the south part from Katagai village of Kujukuri town, the tsunami barely inundated over the Kujukuri toll road, which runs parallel to the coast line. That means that the toll road might behave as breakwaters.

Keywords: the 2011 off the Pacific coast of Tohoku earthquake, tsunami height, tsunami inundation area, field survey, Ibaraki prefecture, Chiba prefeture

Japan Geoscience Union Meeting 2011
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Tsunami simulation for the 2011 Tohoku earthquake using long-period source model

Anatoly Petukhin[1*], Kunikazu Yoshida[1], Ken Miyakoshi[1], Kojiro Irikura[2]

[1]Geo-Research Institute, [2]Aichi Institute of Technology

On March 11, 2001, M9.0 earthquake has occurred east off the Pacific coast of Tohoku, as a result of thrust faulting on the interface of plate boundary between the Pacific and North American plates. This earthquake generated tsunami of 20-30m high and strong ground motions up to 1000gal and more. This is one of the best geophysically-recorded great earthquakes and due to this numerous source models were generated using teleseismic, GPS, strong ground motion and tsunami data. The question we addressing here is the possibility of evenly good simulation of observed ground motions and tsunami using the same source model.

Here we used rupture process of the 2011 Tohoku earthquake inverted by the multi-time window linear waveform inversion method using the long-period (20s and more) strong-ground motion data (Yoshida et al., 2011, EPS submitted). A single planar fault model of 480 km in strike and 160 km in dip is assumed. The rupture velocity inferred to be slower than 2.2 km/s at early stage of the rupture process. The inverted slip distribution shows a large asperity with a maximum slip of 29 m which is located on the shallower part of the fault plane, slightly north of epicenter. This is consistent with the tsunami source model of Fujii and Satake(2011). But in contrast to the Fujii and Satake(2011) source model the slip distribution is small on the fault plane south of epicenter.

We simulated tsunami using Bousinessq type model of Watt et al. (2003), and source model of Yoshida et al. (2011) and compared it with observation data and with results of simulation using other source models. Without any asperity on the fault plane south of epicenter, we have simulation results that fit observation tsunami data on the coast of the Iwate and Miyage prefectures. On the coast of Fukushima prefecture, south of epicenter, simulated amplitudes are smaller than observed ones. Source models having asperity in southern part of source (including model of Fujii and Satake,2011) produce tsunami that could better fit observations. In order to get model that describes both long-period strong ground motions and tsunami amplitudes similarly good, by try and error method we modify model of Yoshida et al.(2011).

Keywords: 2011 Tohoku earthquake, tsunami simulation, long-period ground motion, earthquake source model

Japan Geoscience Union Meeting 2011
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The tsunami wave was amplified at bays in the ria-coast ? ?amplification of tsunami in the bay?

Mamoru Nakamura[1*], Shoichi Yoshioka[2], Kazuomi Hirakawa[3], Yuka Nishikawa[4]

[1]Faclty Science, University Ryukyus, [2]RCUSS, Kobe University, [3]Hokkaido University, [4]National Taiwan University

We investigated the tsunami amplification of the 2011 Tohoku earthquake at the bays in the ria-coast of Sanriku area, northeast Japan. The amplification of tsunami wave in the ria-coast type bay occurs by the concentration of tsunami wave, and by the oscillation in the bay as a result of the periodic arrivals of the tsunami waves. The amplification factor, which is the ratio of the wave height at the head of the bay to wave height at the bay mouth, depends on the oscillation of bay and the period of tsunami wave (Abe, 2005). The amplification factor at the long-period oscillation type bays (>30 minutes) was in the range of 0.3?0.5 for the 1896 Sanriku tsunami and 1933 Sanriku tsunami. These reached at the range of 2?3 for the 1960 Chilean tsunami. The amplification factors of the short-period type bays were at the range of 1?3 for those tsunamis.

We observed the inundation heights at the bays from south of Iwate prefecture to north Miyagi prefecture on April 20-23, 2011. The oscillation period of the bays were classified to long-period type (Ohunato bay (46 minutes), Hirota bay (52 minutes), and Kesennma bay (52 minutes)) and short-period type (Kippama bay (12 minutes) and Okirai bay (10 minutes)) (Abe, 2005). We measured the inundation height at the steep slope to avoid the effect of runup and estimate the heights of tsunami wave.

The observed amplification factors were at the range of 1.5?2.0 at the short-period type bays (Okirai bay and Yoshihama bay). Those were almost 1.0 at the long-period bays (Ohunato bay, Hirota bay, and Kesennuma bay).

The obtained results are consistent with those of the previous tsunami at the short-period bays, although these are inconsistent with those at the long-period bays. The no amplification at the long-period bay would be caused by the near-field magnitude 9 earthquake: the long wave periods of tsunami (about 40 minute from the GPS tsunami measurement system at Kamaishi) and prominent wave height of the first wave (6.5m for the first wave, and two meter for the later waves).

Keywords: tsunami, 2011 Tohoku Earthquake

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Preliminary report on the bedforms of the tsunami deposits form the 2011 off the Pacific coast of Tohoku Earthquake

Osamu Fujiwara[1*], YUKI SAWAI[1], Masanobu Shishikura[1], Yuichi Namegaya[1], Haruo Kimura[1], Kyoko Kagohara[1]

[1]Geological Survey of Japan, AIST

Tsunami from the 2011 great Tohoku earthquake formed tsunami deposits on throughout the Kujukuri coast, East Japan. Land survey performed immediately after the tsunami revealed various forms of tsunami deposits, such as the variation of thickness, grain size and bedforms of the deposits. These sedimentological data will contribute to understand the tsunami sedimentation process, and also improve our skill to identify the tsunami deposits from the storm deposits, which is indispensable knowledge in the paleo-tsunami researches.

Observation sites and tsunami: 1) Hasu-numa, San-mu City, Chiba Prefecture, where the tsunami partly washed over the coastal dunes with height of ~4-5 m and inundated inland ~1 km (1.8 m in height) from the coast line along the a paved road. 2) Katakai fishing port, Kujukuri Town, Chiba Prefecture, where the tsunami height was 3.77 m above sea level of 15:18 PM, March 12 and flooded from the quay to the vacant land and road.

Tsunami deposit in the Hasu-numa coast
The 2011 tsunami eroded the sandy coast and sand dunes, then transported the eroded materials mainly inland and formed tsunami deposit. The tsunami deposit was mainly distributed behind the dunes (with patchy distribution on the sea-side area of the dunes) and generally tapered landward direction. The maximum thickness is ~15cm. According to the observation along a road in coast-normal direction, the tsunami deposit was mainly composed of well sorted fine sand within ~600m from the coast-line, and then the more it was distributed inland the more it became muddy. Finally the trace of the tsunami was marked by debris (mainly plant fragments) concentrated lines near its inundation limit.
Bedforms characterizing the tsunami deposit is ripples with various size and shape. Many of them are current ripples with a wavelength ranging from several cm to 10cm, which suggest a uni-directional current. Flow-directions reconstructed from the ripples were mainly landward (tsunami run-up) within ~500m from the coastline, however, more inland area, seaward directed flow (tsunami back wash) was dominant. Thin film of mud (mud drape) resulted from the suspension fall out during the slack water condition (after the flooding) often covers the ripples.
Interference ripples showing honeycomb pattern characterized the slopes connecting the sidewalk and roadway. As interference ripples are formed by the interaction of two-directional current, they suggest that the flooded water on the sidewalk concentrated in the slopes from landward and seaward and collided each other there, and then was drained to the roadway.

Tsunami deposit at the Katakai fishing port
Tsunami deposit at this site was also characterized by fine-grained sand bed with current ripples, ranging from 8 to 12 cm in thickness. Probable source of the current ripples ornamenting the surface of the tsunami sand bed is tsunami backwash. The vertical section of the tsunami deposit was characterized by the fine alternation of sand sheets and mud drapes, and suggests the repeated occurrence of the tsunami flooding intercalating the slack water periods. At least four tsunami flooding (sand sheets) and three slack water periods (mud drapes) were recognized here.

Keywords: 2011 Tohoku Earthquake, Tsunami, Tsunami deposit, Kujukuri

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Characteristics of surface erosion and sedimentation by the 2011 Tohoku Tsunami

Yugo Nakamura[1*], Yuichi Nishimura[1]

[1]ISV, Hokkaido University

Distribution, thickness, and geological features of tsunami deposits formed by the 2011 Tohoku Tsunami were investigated on natural coasts in Aomori and Iwate prefectures, northeastern Japan. Tsunami inundation distance and deposit thickness varied along the coast. For some sites, the tsunami heights were more than 30 m above the sea level and the inundation distances were more than 1 km from the beach. On gentle topography, the tsunami left continuous sand deposits on the surface. The thicknesses of the deposits are less than 20 cm and it thicker where large dune or sandy beach exists at the valley mouth. For most of the cases, the deposit thickness tends to decrease with distance from the sea. Near to the inundation boundary, only sand particles are scattered on land. The tsunami deposition was patchy in areas without eroded landforms. The deposits are composed mainly of sand, and their particle size gradually decreases in a landward direction. Thickness and grain size of the tsunami deposits seem unrelated to wave heights.

Keywords: Tsunami deposit, Landform, Erosion, the 2011 Tohoku Tsunami

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ALOS Observation Results of the 2011 Magnitude-9.0 Earthquake off the Pacific coast of Tohoku-Kanto District, Japan

Yosuke Miyagi[1*], Masuo Takahashi[1], Masanobu Shimada[1]

[1]Japan Aerospace Exploration Agency

At 5:46 on March 11, 2011 (UTC), a magnitude 9.0 huge earthquake occurred off the Pacific coast of Tohoku-Kanto district of Japan (38.32N, 142.37E, 32 km in depth; hypocenter information from USGS Web site), accompanied by a massive tsunami. The earthquake and tsunami caused severe damage in many cities, and more than 20 thousand people were killed and lost their homes. After the main shock, many aftershocks or induced earthquakes have occurred in various places in Japan. The Japan Aerospace Exploration Agency (JAXA) has performed emergency observations since the occurrence of the earthquake, using three sensors (PALSAR, AVNIR-2, and PRISM) installed on the Advanced Land Observing Satellite (ALOS). Using optical images or PALSAR amplitude images acquired before and after the earthquake, we detected tsunami inundation areas, and monitored a transition of the area after the earthquake. Next, we detected extensive crustal deformation associated with the M9.0 earthquake, using the differential interferometric SAR (DInSAR) technique. In the resultant interferograms, there are so many obvious color fringes over almost whole area in the eastern and the northeastern Japan. The maximum displacement in the interferograms was estimated to be more than 4m at the tip of Ojika Peninsula relative to the tip of Tsugaru Peninsula, from an ascending orbit. Considering a mechanism of this earthquake, the color pattern which means deformation away from the satellite indicates a subsidence or eastward displacement in the coast area. Moreover, we can find several local fringes that are obviously different from the surrounding fringe pattern. These show the crustal deformation associated with shallow inland earthquakes (e.g. M6.1 earthquake in the northern Ibaraki Prefecture on March 19; M7.0 earthquake in Hamadori of Fukushima Prefecture on April 11). In this presentation, we introduce several ALOS observation results of the 2011 M9.0 earthquake and tsunami, and of several inland earthquakes. Other ALOS observation results are shown in EORC/ALOS web page of JAXA.

http://www.eorc.jaxa.jp/ALOS/en/index.htm

Keywords: ALOS, Earthquake, Tsunami, Crustal Deformation, Remote Sensing

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

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Earthquake damage tracking using multi platform satellite images and simulation analysis of eastern Japan

Noritoshi Kamagata[1*], Yukio Akamatsu[1], Yoichi Murashima[1], Sakae Mukoyama[1]

[1]KOKUSAI KOGYO CO., LTD.

In March 11, 2011, at 2:46 p.m., a great earthquake with a magnitude of 9.0 hit eastern Japan and caused unprecedented damages. It was reported that the hypocenter of this earthquake was located at 38.0 degrees north in latitude, 142.9 degrees east in longitude, and at a depth of approximately 24 km. Tsunamis that were generated by this great earthquake also caused great damage to an approximately 700 km of areas between Aomori and Chiba prefectures on the Pacific coast.

Remote sensing technology plays a powerful role to investigate damages of the disaster. The great earthquake and tsunamis devastated a wide range of region. It is certain that a fair amount of time will be required to conduct an aerial survey of the widespread disaster region. Further, due to influences of serious damages to the Fukushima nuclear plants, no-fly zone was enforced, and an aerial survey is not allowed in some regions. On the other hand, satellites can make observations for a wide range of region and remain unaffected by the flight ban. Therefore, remote sensing technology using satellites play a critical role to quickly monitor a wide range of damaged area and uncover the whole truth of the great disaster. Since the earthquake occurrence, a wide range of the devastated area has been observed using many earth observation satellites. It is important to select a combination of satellite resources that are appropriate for various conditions such as elapsed time after the disaster occurrence and surveyed types of damage and areas after giving adequate consideration to features of each satellite and sensor.

Simulations are also useful in the damage investigations. Generally, it is difficult to monitor situations in the event of tsunamis generated by the earthquake and figure out areas of inundation damages where outflows of property did not occur in a timely manner and in time series using the remote sensing technology. In addition, due to unfavorable weather conditions, observations using high resolution optical satellites, which are needed to monitor in-depth disaster situations, are commonly delayed in many regions. On the other hand, simulations can estimate a range of disaster areas, and make it possible to understand circumstances of tsunamis' arrival, as well as tsunamis and inundations height without satellite data or airborne data of damaged areas. Therefore, the combination use of the estimation of a range of inundation area using tsunami simulations and the satellite data analysis results will play a important role to gather accurate data early and provide appropriate information in a timely manner.

It was implemented to monitor the situation of the disaster using the multi platform optical and SAR satellites and estimate a range of damaged area by the tsunami simulation. The combination use of these satellites enabled for quasi-real-time, accurate data acquisition and analysis about situation of the damage. The combination use of these satellites also enabled for putting the whole picture together and understanding details of the damage quickly and accurately. This situation also made it possible to provide appropriate information to related organizations or agencies in a timely manner. It is critical to continue to gather relevant data and provide appropriate information using the geospatial information technology and help the re-establishment of the disaster area.

Keywords: Multi platform satellite images, Simulation analysis, Earthquake damage tracking, Optical imagery, SAR imagery

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TerraSAR-X based monitoring over Sendai plain inundated by the tsunami

Takashi Shibayama[1*], Kazuo Yoshikawa[1], Yuki Okajima[1], Katsu Kato[1]

[1]PASCO CORPORATION

The massive tsunami caused by the 2011 off the Pacific coast of Tohoku Earthquake that occurred at 14:46 on March 11, 2011 brought the great damage in the Pacific coastal area between Aomori and Chiba.

The tsunami reached at from the shore the range of approximately 6 kilometers on the plains of Soma city, Fukushima from Matsushima of Miyagi in particular, and a wide area was flooded. Because the area consists of low flat topography, the flooded situation had been continued.

It was urgent issues to carry out efficient and effective drainage measures, and therefore it was necessary to monitor the change of the inundation range continuously to push forward the restoration of the stricken area.

Earth observing satellite is suitable for regional monitoring. Above all, the synthetic aperture radar (SAR) can observe the surface of the earth regularly because its microwave penetrates a cloud regardless of the night and day and the expectation of SAR for the practical use in disaster prevention has been rising recently.

Imageries acquired by TerraSAR-X were utilized for the monitoring of the flooded area. TerraSAR-X is a synthetic aperture radar satellite developed and operated under Public-Private Partnership (PPP) of German aerospace center (DLR) and EADS Astrium affiliated with European aerospace company EADS.

A SAR image consists of backscattering intensity of the specified microwave. The backscattering intensity depends on the land cover/use and the topography. For example, in the city area where the building crowds, strong backscattering is often provided by multiple scattering. On the other hand, the backscattering becomes relatively weak on the smooth road or surface of the water because specular scattering excels on such smooth surface.

The monitoring utilizing TerraSAR-X was implemented from March 13, 2011 just after the earthquake to April 4. In addition, the image of October 21, 2010 before the disaster was referred.

A comparison of the image acquired on March 13, 2011 just after the earthquake with the image of October 21, 2010 before the disaster clearly showed the inundation caused by the tsunami in a wide area.

Image acquisition was carried out continuously for the Sendai plain. 18 times of acquisition were carried out from March 13 until the morning of April 4. In other words, the acquisitions were carried out at the frequency once in approximately 1.3 days. During this period, a total area of approximately 120,000 square kilometers at the coast between Hokkaido and Chiba including Sendai plain was captured.

In addition, the extraction analysis of the flooding range and the exhibition in the web site from images was completed in about less than 24 hours because time required for the data acquisition is shortened to perform down-link in a domestic receiving station.

It is difficult to determine flooding area where dense and strong scatterers exist, such as in a city area, but it is thought that an advantage of the satellite-borne SAR was shown as means to grasp the inundation damage over the wide area immediately.

Keywords: earth observation satellite, synthetic aperture radar, TerraSAR-X, inundation area, backscattering intensity

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Low altitude aerial photographs of March 2011 tsunami damaged areas in Minamisanriku Town, Miyagi Prefecture, Japan

Hiroshi Inoue[1*], Hiroshi Imai[1], Hitoshi Taguchi[1]

[1]NIED

We took low altitude aerial photos of the tsunami damaged areas in Minamisanriku Town in Miyagi Prefecture as a part of Tsunami Damage Record and Archive Project under ALL311 project coordinated by NIED. The purpose of the photographing is to record all of the disaster, studying damages of structures, tsunami inundation mapping, and providing materials to assist recovery and restoration of the cities.

Photographs taken from low altitude (up to 100m) provides more details of the objects as compared with ordinary aerial photos from 300 m or above in inhabited areas. It also gives overall images of the objects or the areas unavailable by pictures from the ground. We used a radio controlled helicopter, waterproof fish-eye full HD camera, GPS logger, and compass. We also tried to take photos from 4m high camera attached to the vehicle, and 10m high camera attached to a rod.

Photographs were taken in tsunami damaged areas all over Minamisanriku Town in about ten days. Images of completely demolished areas, half-damaged RC and steel buildings, road bridges and railroad trucks were taken from unique view angles. Several tens of thousands of the photos were obtained. We provide them to researchers and communities using the e-Community Map by NIED and those available on Google Map, ih consideration of privacy of the suffered people as close-up photos of the residential houses are included.

We will continue the photographing in Kesennuma City and others, but the whole area is too wide to cover by out team. It would therefore be needed to cooperate other groups, using also simpler devices like kites and balloons with standardized procedures to collect the images of the whole suffered areas in timely manner.

志津川地区 Shizugawa area

歌津地区 Utatsu area

航跡図 Flight tracks

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A field survey of coastal disaster in South Fukushima and Ibaraki by the 2011 off the Pacific Coast of Tohoku Earthquake

Shinya Shimokawa[1*], Satoshi Iizuka[1], Tomokazu Murakami[1], Yasuaki Nohguchi[1], Takahiro Kayahara[1], Naoki Sakai[1]

[1]NIED

We conducted a field survey of coastal disaster from South Fukushima to Ibaraki by the 2011 off the Pacific Coast of Tohoku Earthquake. Focusing damage due to Tsunami and liquefaction, we did it from Itako, Ibaraki to Hitachinaka, Ibaraki on 1 April, and from Yotsuura, Fukushima to Takahagi, Ibaraki on 8 April.

The large damaged regions in Fukushima are Yotsukura, Usuiso, and Onahama, and those in Ibaraki are Nakaminato, Ooarai, Kyouchigama, and Kashima (from north to south in order). The Maximum wave heights in Fukushima are about 5-10 meters, and those in Ibaraki are about 3-8 meters.

The most damaged region due to Tsunami is Usuiso, Fukushima. The damage was caused mainly by levee crevasse. However, the neighboring region, Tomigami had small damage. The amount of damage is considered to be decided by local topography and Tsunami direction. Similar tendency can be seen in the regions neighboring the other large damaged regions.

The most damaged region due to liquefaction is Kashima, Ibaraki. Although Kashima is located in the southernmost on the surveyed area, therefore, the maximum wave height of Tsunami is inferred to be the smallest, liquefaction caused a destructive damage in Kashima. On the other hand, damages due to liquefaction are small in the north of Ooarai. The amount of damage is considered to be decided by firmness of the ground.

In the presentation, we will show the summary of another field survey (on 14 and 15 April) of coastal disaster in Iwate by the 2011 off the Pacific Coast of Tohoku Earthquake.

Keywords: the 2011 off the Pacific Coast of Tohoku Earthquake, Tsunami, Liquefaction, Field survey, Fukushima, Ibaraki

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Tsunami flow on the Sendai and Ishinomaki plains in relation to their geo-environment

Masatomo Umitsu[1*], Kyouhei KITAMURA[1], Masahiro SUGIMOTO[1], Kenya TAMURA[1]

[1]Nara University

Mapping on aerial photos taken just after the tsunami disaster shows characteristics of tsunami flow on two coastal plains: the Sendai and the Ishinomaki plains in northern Japan. Landforms of the plains are characterized as the strand plain with several rows of beach ridges. The run-up tsunami flow invaded into the plains about 4?5 km from the coast. Strong tsunami flow severely washed the villages located along the coast and damaged the area further inland. The tsunami inundation spread out over the plains with the depth of 4?5 m along the coast and 1-2 m even in the area about 2-3 km from the coast. In the southern part of the Sendai plain, direction of the back wash flow is almost towards the coast and perpendicular to the coastline. But the directions of the back wash flow in the central and northern part of the Sendai plain were various, whereas the run-up flow direction was almost perpendicular to the coastline. The direction of the back wash flow might be controlled by the regional topography and structures on the region.

In the Ishinomaki coastal plain, directions of the back wash flow were indicating mostly towards the southeast and east. There is not many places where the direction of the back wash flow were towards the direction of perpendicular to the coastline. This extraordinary direction of the back wash flow might be related with the tsunami waves in the Ishinomaki Bay.

Keywords: Tsunami flow, Sendai Plain, Ishinomaki Plain, Landforms, Geoenvironment

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Tsunami inundation, inundation height, and run-up elevation between southern part of the Sanriku and the Sendai Plain

Satoshi Ishiguro[1*], Kazuaki Hori[1], Masatomo Umitsu[2], Nobuhisa Matsuta[1], Nobuhiko Sugito[1], Toyohiko Miyagi[3], Kenya Tamura[2]

[1]Nagoya University, [2]Nara University, [3]Tohoku Gakuin University

A huge tsunami generated by the 2011 off the Pacific coast of Tohoku Earthquake brought a large-scale flood to the Pacific Ocean coast especially from the Tohoku to Kanto regions. Because the damage extended the large area, maps of tsunami inundation area were made and published based on the satellite image analysis or air photograph interpretation by the Geospatial Information Authority of Japan, academic societies, and spatial information consultancies immediately after the earthquake. Moreover, the tsunami heights along the coasts have been reported based on field investigation by many researchers. We conducted a field survey about inundation area, inundation height, and run-up elevation between the southern part of Sanriku coast and Sendai coastal Plain by using the tsunami inundation map published by the Tsunami Disaster Mapping Team, Association of Japanese Geographers.

Field survey was conducted at the Sendai and Ishinomaki coastal plains characterized by low-lying coasts and Onagwa Town located along the Rias coastline of the southern Sanriku coast between April 22th and 24th, 2011. We established transects almost perpendicular to the coastline, confirmed the tsunami trace, and obtained the inundation height. Because the damage was especially large in the south of the Hiyoriyama, which is a very low mountain located near the mouth of the right bank of the Old Kitakami River, we also surveyed the lowland surrounding this mountain. Moreover, the limit of tsunami inundation that had been shown in the map was confirmed by observation and interviews with local people.

The tsunami reached approximately 4 km from the coastline around Arahama in the Sedndai coastal Plain. The limit of tsunami inundation was relatively correlated well with that of the map. Inundation heights between Arahama and the Sendai Toubu Highway were about 10 m at the coast, 5 to 6 m behind the coast, and decrease to 4 m near the highway.

It was flooded to the vicinity of the JR Senseki Line that runs 2 to 3 km inland from the coast on the western side of the Ishinomaki Port in the Ishinomaki Plain. Inundation height was ca. 7 m near the coast. The inundation heights were 3 to 4 m between ca. 1 and 3 km inland from the coast. The inundation height reached more than 7 m in the south of the Hiyoriyama where severe damage had occurred. On the other hand, the height tends to decrease landward.

East side of Onagawa Town faces the sea, and the most part of the settlements mainly located in three valley plains received catastrophic damage from the tsunami. According to the map, the distribution of the severe damaged settlements roughly corresponds to the inundation area. Inundation heights exceeded 15m near the coastline. The heights approximately 15 to 18 m were also recorded along the valley plain. Therefore, tsunami inundation occurred partially even on uplands.

There is a possibility of causing a large margin of error when we estimate the run-up elevation at the valley plains where both sides face to steep slope like Onagawa by using the computerized map, because the map represents the limit of the run-up by the polygon. The accuracy would be checked by comparing the map with empirical field data.

Keywords: Tsunami, Inundation, Run-up height, GPS, GIS

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Flooded area and run-up height of tsunami triggered by the 2011 off the Pacific coast of Tohoku Earthquake

Yasuhiro Kumahara[1*], Mitsuhisa Watanabe[2], Takashi Nakata[3], Naoto Koiwa[4]

[1]Gunma University, [2]Toyo University, [3]Professor Emeritus, Hiroshima University, [4]Hirosaki University

We survey the flooding area and run-up height of tsunami triggered by the 2011 off the Pacific coast of Tohoku Earthquake by short-term fieldwork. Prior to field work, we interpreted air photos of post-tsunami disasters to select the sites for fieldwork, where the run-up heights of tsunami are much higher than those in other areas. In fieldwork we recognize upper limit of flooding area by witness of local people or by clear signs on surface such as disturbance of soil or the remaining floating matters.

The maximum run-up heights of tsunami are 30m over, 34.7m, 27.5m, 37.3m, 24m in Matsutsuki, Otonobe, Shigetube, Koboriuchi and Mizusawa respectively. Leveling along the low-land in valley behind the bay shows that run-up height along the valley is higher toward inside gradually in Matsutsuki, and that is almost horizontal from the mouth to inside of the valley in Shirasaki.

It is clear by fieldwork that run-up heights of tsunami and longitudinal profile of its heights in each bays close to each other is different due to difference of topography of coastal submarine and land or trending of the bay. In presentation we will show the factor of difference of run-up heights of tsunami in each bays.

Keywords: Off the Pacific coast of Tohoku Earthquake, Tsunami, Run-up height, airphoto, Sanriku coast

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Estimation for tsunami height of 11 March 2011 along the Japan trench, based on the analysis of digital elevation model

Hideaki Goto[1*], Nobuhiko Sugito[2], Masatomo Umitsu[3], Takashi Nakata[1], Tsunami Damage Mapping Team[4]

[1]Hiroshima University, [2]Nagoya University, [3]Nara University, [4]The Association of Japanese Geographer

Tsunami damage area maps of 11 March 2011 with scale of 1:25,000 were made by means of interpretation of the aerial photographs taken just after the earthquake by Geospatial Information Authority of Japan (GSI). We estimated distribution of run-up height by combining tsunami damage maps and Digital Elevation Model (DEM) of GSI. Run-up elevation of Sendai and Ishinomaki coastal plain tends to be smaller than that of the Sanriku coast.

Based on the analysis of 2m-mesh DEM derived from scanning airborne lidar system, the run-up maximum elevation reached more than 10m in the southern part of Hamadori district where people are prohibited to enter, because of the accident of the Fukushima nuclear power plant. It is similar value in the northern part of Hamadori district.

Keywords: Tsunami, DEM, 11 March 2011 Tohoku earthquake, aerial photograph

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Maps of the Area hit by the Tsunami of 11 March 2011, Northeast Japan - Southern area between Tagajo and Asahi

Nobuhisa Matsuta[1*], Hideaki Goto[2], Kazuaki Hori[1], Yasuhiro Suzuki[1], Daisuke Hirouchi[3], Masatomo Umitsu[4], Kenya Tamura[4], Nobuhiko Sugito[1], Tsunami Damage Mapping Team, Association of Japanese Geographers[5]

[1]Nagoya University, [2]Hiroshima University, [3]Shinshu University, [4]Nara University, [5]None

A giant tsunami caused by the Great East Japan Earthquake inundated Pacific Ocean coasts especially from the Tohoku to Kanto regions. Disaster headquarters of the Association of Japanese Geographers started a work team that examines the tsunami damage. The team made the tsunami inundation map with a scale of 1 to 25,000 by interpreting aerial photographs and published the map through the Internet on March 29, 2011. The purposes of this work are to provide data and information useful for quick understanding of the damaged area, relief efforts, and developing a reconstruction plan and to offer the base map for field investigation into tsunami run-up and inundation and clarifying the regional characteristics of the damage.

Approximately 3,000 aerial photographs taken by the Geospatial Information Authority of Japan after the earthquake were used to construct the map. We hypostatized the photographs, cross-checked interpretation each other, fixed the final draft, and computerized it. Single image on Google Earth was interpreted for a part of Fukushima Prefecture in which the aerial photographs were not taken. Tsunami inundation area and heavily damaged residential area were shown on the map. Additionally, the distribution chart of tsunami run-up height was made by combining the map and 10mDEM. This paper reports the regional characteristics of the damage between Tagajo City, Miyagi Prefecture and Asahi City, Chiba Prefecture.

Natural levees are distributed along the Nanakita, Natori, and Abukuma rivers and three beach-ridge sets develop almost parallel to the coasts in the Sendai coastal Plain (Matsumoto, 1977). Intervals between the beach ridges are small in areas south of Abukuma River where the width of the plain becomes small. Tsunami inundated several kilometers and reached even or immediately before the most landward beach-ridge set. Especially, settlements located on the most seaward beach-ridge set had received catastrophic damage. Rice straw distributed on the rice field around the limit of tsunami inundation was often swept in the corner of the field. Moreover, there was a settlement that had escaped flooding probably because it is located on natural levee and defended by the embankment in the Abukuma River.

In the Hamadori district, hills, fluvial terraces, and Holocene alluvial lowland occur in the east-west direction along rivers, which originate in the Abukuma Mountain and empty into the Pacific coast (Suzuki, 2005). Marine terraces are also found along the coast. Holocene alluvial lowland and valley plains dissecting the hills and terraces were severe flooded by the tsunami. Inundation area was small along the coasts of Ibaraki Prefecture relative to the Sendai coastal Plain and Hamadori district.

Run-up elevation of the study area tends to be smaller than that of the Sanriku coast. Moreover, the elevation is below 5 m asl in the Sendai coastal Plain characterized by the beach-ridge plains with several kilometers wide. On the other hand, the elevation reached 10 m asl or more at the Hamadori district where the lowlands extend in a direction perpendicular to the coast. Therefore, it is necessary to clarify the relationship between the run-up elevation and geographical features in detail.

We are indebted to students of Nagoya University and Nara University for the arrangement of the aerial photographs and the work of the computerization. The map is open to the public on the following web sites.

http://danso.env.nagoya-u.ac.jp/20110311/index.html

Keywords: Tsunami, Inundation area, Aerial photograph, Coastal plain, Topography, Geography

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Maps of the Area hit by the Tsunami of 11 March 2011, Northeast Japan - Nothern area between Hashikami and Shiogama -

Yasuhiro Suzuki[1*], Mitsuhisa Watanabe[2], Takashi Nakata[3], Hideaki Goto[3], Masatomo Umitsu[4], Tsunami Damage Mapping Team, Association of Japanese Geographers[1]

[1]Nagoya Univ., [2]Toyo Univ., [3]Hiroshima Univ., [4]Nara Univ.

Tsunami damage area maps with scale of 1:25,000 were made by interpretation of the aerial photographs taken just after the earthquake by Geospatial Information Authority of Japan. The purpose of this mapping is to promptly provide basic information about extent of tsunami invasion and distribution of devastated area for the all people taking counter-measures against the disaster.

Red line indicates limit of tsunami invasion, and portion colored blue shows heavily damaged residential area.

The data can be provided on the 'Digital Japan Web System' or the 'e-comi map', in addition to the JPEG files.

Keywords: The 2011 off the Pacific coast of Tohoku Earthquake, Tsunami, Geography

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Preliminary results for the topographic change by the 2011 Tohoku tsunami at the Arahama area in Sendai City

Tomoya Abe[1*], Kazuhisa Goto[2], Tsuyoshi Haraguchi[3], Daisuke Sugawara[4], Shigehiro Fujino[5]

[1]Nagoya University, [2]Chiba Institute of Technology, [3]Osaka City University, [4]Tohoku University, [5]University of Tsukuba

A Great Tohoku Earthquake(Mw9.0)occurred on 11th March, 2011 (hereinafter the 2011 Tohoku Earthquake). The earthquake triggered huge tsunami, and the tsunami damaged to the wide range of the coastal areas in the northeast Japan. The Sendai City was also damaged by the tsunami and the earthquake, and at least 859 people died or were missing, and 3190 houses were fully destroyed according to the report of the Miyagi Prefecture on 28th April.

We conducted field survey to explore a topographic change by the tsunami flow and ground subsidence before and after the 2011 Tohoku Earthquake, and to explore the effect of liquefaction.

We set 4 km long transect until the inundation limit perpendicular to the coastline at Arahama area in the Sendai City, one of the most severely damaged area by the tsunami in the city, on the early April. Sampling of the tsunami deposits were performed every 100 m along the transect. We also studied damages and inundation heights of the Tsunami, and conducted kinematic GPS measurement by using Promark3 in order to study the topographic change before and after this earthquake. In addition to the field survey, we analyzed several satellite images, aerial photographs, and topographic maps to estimate the large scale topographic change by the tsunami as well as the seismic subsidence in the area, and distribution of liquefaction. Moreover, we compared topographic data before (5 m DEM, provided by The Geospatial Information Authority of Japan: GSI) and after the 2011 Tohoku Earthquake.

High-resolution topographic profiles before and after the 2011 Tohoku Earthquake revealed approximately 30-40 cm subsidence in this area. The result is consistent with the shifting of the electric reference points.

Field survey results show different grain size and thickness of the tsunami deposit at each pit with distance from the coastline. In the beach area (0-150 m from the coastline), tsunami impact is minor and, in fact, even the offshore breakwater had not been damaged. Moreover, beach sands seem to have not been moved significantly. On the other hand, in the coastal forests behind the onshore wave breaker (150-700 m from the coastline), most of the trees were devastated landward by the run-up wave. The thickness of the tsunami deposit is less than 12 cm, and mostly it is less than 3 cm. Moreover, its grain size is medium to course sand. Current ripples are usually observed on top of the deposits. In the rice field (700-4000 m from the coastline), there are many traces of the liquefactions and sand boil is frequently observed. Clay to very coarse sand layers with less than 27 cm in thickness were deposited on the rice paddy. However, these sand layers were locally deposited and we interpreted that sources of the sands are probably the beach/sea or liquefaction. Maximum extents of the sandy tsunami deposits and the tsunami inundation are approximately 3500 m and 4000 m, respectively.

Our observations of the various images and topographic maps revealed that most of the telegraph-poles and coastal trees located in about 150-700 m from the coastline were broken landward by the run-up flow. The backwash flow was concentrated in an old channel near the beach and eroded this channel. As a result of this erosion, the coastline was cut immediately after the tsunami, but it has been recovered quickly at least until 24th March.

Keywords: the 2011 Tohoku Earthquake and the tsunami, topographic change, liquefaction, tsunami deposit

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Application of chemical analysis to measurement of tsunami inundated area

Takumi Yoshii[1*], Masafumi Matsuyama[1], Masahiro Imamura[1], Toshinori Sasaki[1], Shunichi Koshimura[2], Masashi Matsuoka[3], Erick Mas[4], Cesar Jimenez[5]

[1]CRIEPI, [2]Tohoku University, [3]AIST, [4]Tohoku University, [5]Universidad Nacional Mayor de San Marcos

Quasi-periodic occurrence of earthquake keeps coastal cities under threat of tsunami hazard. Tsunami has caused catastrophic damage to coastal regions many times in history. Fortunately, since a period of earthquake occurrence can be estimated from historical records, the time of the next earthquake and its magnitude are roughly estimated. Therefore, accumulation of field survey data and knowledge is the most basic but steady way to prep for future tsunamis. Numerous field surveys have been conducted after tsunami occurrences. The measured tsunami run-ups were utilised as a validation data for numerical simulations and contributed to improvement of the models. Moreover, the obtained data set of tsunami run-ups and the record of tide gages enabled an inference of size of earthquakes and its seismic parameters. However, field survey points on tsunami disaster, especially in tsunami run-up height and tsunami inundation height, are limited since it depends on visual evidences and witnesses. Thus, in this paper, we validated the applicability of chemical analysis of soil to field survey on tsunami inundated area to obtain more objective and reliable data set.

The field survey on the disaster damages due to the tsunami was conducted near Talcahuano in Chile after the severe earthquake of Mw 8.8 occurred on 27 Feb. 2010 at the center of Chile. The soil samples were obtained from both the inundated and the non-inundated position. The stirred solution was made by the soil and ultrapure water, then, the content of water-soluble ions, electric conductivity (EC), and pH were measured. The soil obtained in the tsunami inundated area contains much water-soluble ions (Na^{+}, Mg^{2+}, Cl^{-}, Br^{-}, $SO_4{}^{2-}$) compared to the samples obtained in the non-inundated area. The discriminant analysis of the tsunami inundation was conducted using the amount of ions in the soil. High discriminant accuracy (over 90%) was obtained with Na^{+}, Mg^{2+}, Cl^{-}, Br^{-}, $SO_4{}^{2-}$ and EC. Br^{-}, Cl^{-}, Na^{+} are believed to be suitable for the discriminant analysis about tsunamis considering the contaminant of these ions in the soil and in the sea water.

In the presentation, we are planning to show the preliminary survey results conducted after the 2011 Japan earthquake and discuss the applicability of this method and the task for the future.

Keywords: tsunami, soil, water-soluble ion, inundated area, tsunami deposits

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P148 Room:Convention Hall Time:May 27 14:15-16:15

Distribution and properties of geo-hazards along road-slope and river levee by the 2011 off the Pacific coast of Tohoku

Yasuhito Sasaki[1*], Ken-ichi Asai[1], Shunsuke Shinagawa[1], Katsuhito Agui[1], Kazumi Yasumoto[1], Hiroyuki Hayashi[1]

[1]Public Works Research Institute

Distribution and properties of geo-hazards such as landslides and liquefaction along road slope and river levee by the 2011 off the Pacific coast of Tohoku Earthquake were investigated due to official data and our original field investigation.

Density of these disasters is higher on the soft rock region than on the hard rock region. Several big landslides have occurred along national roads, in which unstable topographical properties are clearly recognized.

Keywords: earthquqke, road slope, river levee, slope failure, landslide, liquefaction

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P149 Room:Convention Hall Time:May 27 14:15-16:15

Structural Damages on Artificially Modified Hills around Sendai Caused by Earthquakes in 1978 and 2011

Yoshiyuki Murayama[1*], Shin-ichi Hirano[2], Hiroshi Yagi[1], Noriyuki Chiba[3], Akihiro Shibayama[2]

[1]Yamagata University, [2]Tohoku University, [3]Tohoku Institute of Technology

Hills are typically modified by cutting the ridges and filling the valleys, thereby creating a flat terrain with least transport of soil. Most heavily affected houses are often located on the boundary between land cut and fill or on the land filled sites. The damages on houses on artificially modified hills were also prevalent in previous earthquake in recent Japan, after the 1978 Miyagi-ken Oki Earthquake (Murayama, 1980). The following is an early result of the preliminary fieldworks conducted in and around Sendai.

1) The contrast of damages between on the fill or on the cut/fill boundary and on the cut is very clear, as same as recent earthquakes in Japan.

2) The severest damages to houses and housing lots were caused by slide or subsidence (differential settlement) on the fill or on the cut/fill boundary. Those damages are observed more in the housing estates developed before 1970s, than in those developed after 1970s.

3) Some housing estates modified with shallower fills are damaged more than those with deeper fills. The tendency is observed in the housing estates developed before 1970s.

4) There are many cases that have damage both in 1978 and in 2011, and most of the cases have severer damage in 2011 than in 1978. Slaking of the filled material should be considered.

5) Newly built RC retaining walls (small walls around housing plots) are stronger than walls by CB or by stones.

6) Newly built houses with RC basement are tough, and they stay undamaged even against small ground failure on the housing lots.

Keywords: The 2011 off the Pacific Coast of Tohoku Earthquake, The 1978 Miyagi-ken Oki Earthquake, artificially modified land, ground damage, building damage

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P150 Room:Convention Hall Time:May 27 14:15-16:15

Landslide surface deformation of hilly area in Sendai City, Japan

Hiroshi, P. Sato[1*], Takayuki Nakano[1]

[1]GSI of Japan

The 2011 off the Pacific coast of Tohoku Earthquake triggered landslide surface deformation in hilly area, Sendai City, Japan; such the deformation damaged residential districts. We focused Midorigaoka district (ca.1.2km^2), where were damaged by 1978 Miyagiken-oki earthquake and this earthquake, and investigated surface deformation (e.g., open crack and shortening of asphalt pavement). The total number of the field survey sites was 149, and mapped 77 deformation and 72 no-deformation sites. Next, we mapped earth filling and cut earth area distribution using two kinds of 5-m-digital elevation model (DEM, as of 1951 and 2000). Finally, we overlaid total 149 sites on the distribution map. As a result, average thickness of earth filling was 0.8m (SD: 5.4m) and 6.7m (SD: 4.7m) on no-deformation and deformation sites, respectively. It was found that there is the dendency that filling earth is thicker on deformation sites than on no-deformation sites. Furthermore, we tried sliding and no-sliding simulation for the main earth filling sites, considering seismic shaking and length of side and base of the cross section on the earth fillig sites. We will also report the result of the simulation.

Here, the DEMs were given by courtesy of Prof.Miyagi, Tohoku Gakuin Univ.

Keywords: landslide, residencial district, damage, earth filling, cut earth, earthquake

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P151 Room:Convention Hall Time:May 27 14:15-16:15

Relationship between Quaternary system and damage from eathquake in center of Fukushima

Tatsuya Kobayashi[1]*

[1]The University of Tokyo

The largest earthquake broke out in East Tohoku region, Japan, at 11, March, 2011. Fukushima prefecture is damaged many houses and a lot of roads by this earthquake, too. Fukushima prefecture lies about 200 kilometer northward distant from Tokyo. So, there coast is located Fukushima nuclear power plants.

I researched in center of Fukushima prefecture. The Abukuma River flows in center of Fukushima prefecture. Center of Fukushima lies between the Abukuma Mountains and the Ouu Mountains. Center of Fukushima formed by Quaternary system (Pleistocene Series and Holocene Series).

It turned out that relationship between Quaternary system and damage from earthquake in center of Fukushima.

The fast, Center of Fukushima was once large lake. This lake called Ko-Koriyama-ko(Lake Old Koriyama). So, overlap with damage area from earthquake and this Lake Old Koriyama area. This area is Koriyama city, Sukagawa City, Kagami-ishi town, Yabuki town and parts of Tamakawa village.

The second, many houses damaged area is Koriyama Uplands formed lacustrine sediment.

The third, of all others, concentration area is old river channel, periphery the pond, reclaimed pond on the Koriyama Uplands. And, reclaimed pond occurred liquefaction.

The fourth, on the Holocene Series (alluvial plain) is damaged smaller than Koriyama Uplands (Pleistocene Series). Because, Gravel underneath the alluvium.

The fifth, the other hands, there is almost no damaged by earthquake in neighboring area (Abukuma Mountains, Ouu Mountains and Sirakawa city).

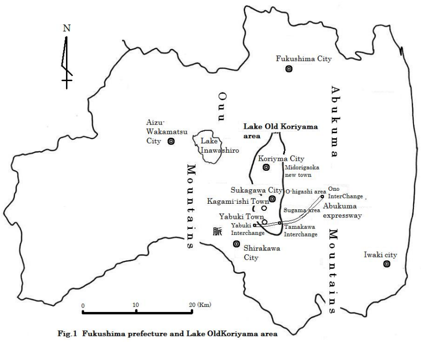

Fig.1 Fukushima prefecture and Lake OldKoriyama area

Keywords: Lake Old Koriyama, Koriyama lacustrine sediment, slough, old river channel, pond, decrepit building

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P152 Room:Convention Hall Time:May 27 14:15-16:15

The damage caused by the 2011 off the Pacific coast of Tohoku Earthquake in Ibaraki Prefecture

Masatoshi Motoki[1*], Koji Ishizuka[1]

[1]Tokiwa University

The magnitude 9.0 earthquake occurred on 11 March 2011, off the pacific coast of the northeastern part of Tohoku region and Kanto district, causing devastating damages.

This massive earthquake occurred on our country serious damage centering on East Japan, such as an accident of tsunami, liquefaction, and a nuclear power plant. Especially Iwate, Miyagi, and Fukushima prefectures suffered serious damage, and were reported greatly. About Ibaraki Prefecture, there was not much news in the media. But, Ibaraki Prefecture suffered heavy damage like Tohoku.

The purpose of this study is to show the perspective generally what kind of damage occurred because of this earthquake disaster in Ibaraki Prefecture.

Keywords: off the pacific coast of tohoku earthquake, Ibaraki Prefecture, damage, tsunami, earthquake disaster

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P153 Room:Convention Hall Time:May 27 14:15-16:15

Observation of the damages of buildings and ground surfaces caused by the tsunami and liquefaction in Kamisu city, Ibara

Takushi Koyama[1*]

[1]Graduate Student, Meiji Univ.

The 2011 off the Pacific coast of Tohoku Earthquake with a magnitude of 9.0 occurred on March 11, 2011. It caused the tsunami and liquefaction in Kamisu city, Ibaraki Prefecture. And they made severe damages on buildings and ground surfaces in Kamisu city.

The liquefaction damages were concentrated in the residential areas constricted on former marsh lands.

Keywords: The 2011 off the Pacific coast of Tohoku Earthquake, liquefaction, tsunami, damages of buildings and ground surfaces, Kamisu city, Ibaraki Prefecture

Japan Geoscience Union Meeting 2011
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MIS036-P154 Room:Convention Hall Time:May 27 14:15-16:15

Distribution of housing damage around Tsukuba and Tsuchiura cities using Google Earth images

Shinsuke Okada[1*], Kentaro Sakata[2], Yosuke Nakamura[1], Junko Komatsubara[1], Tomonori Naya[1], Susumu Tanabe[2], Hideaki Nagamori[2], Tsutomu Nakazawa[2], Taku Komatsubara[1], Kiyohide Mizuno[1]

[1]GSJ, AIST (Geology and Geoinformation), [2]GSJ, AIST (Geological Museum)

On March 11, 2011, the intensities 6 lower were recorded around Tsukuba and Tsuchiura cities due to the 2011 off the Pacific coast of Tohoku earthquake. To reveal the relationship between the damage and the geological conditions, we carried out the mapping of roofing tile damage (based on the presence of tarpaulin on the roof) using the Google Earth images, then we clarified the distribution of housing damage around Tsukuba and Tsuchiura cities.

The damage distribution map shows that the damage around the Tsuchiura, Arakawa-oki, and Ushiku stations was severe. The Hojo area, the area from Imakashima to Hakke, and the Yatabe area in Tsukuba City were also severely damaged. These areas are not situated only on Sakuragawa Lowland (alluvial plane) but also on the Sakuragawa Terrace (lower terrace) and the Joso Terrace (middle terrace). Therefore, we interpret that the earthquake damage in the study area were not depend solely on the surface geology and topography. Hence, we need a consideration of subsurface geology (ex. Middle Pleistocene buried valley and pre-Neogene basement morphology)

Keywords: 2011 Off the Pacific Coast of Tohoku Earthquake, Google Earth image, damage of roofing tiles, Tsukuba City, Tsuchiura City

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P155 Room:Convention Hall Time:May 27 14:15-16:15

Flash report of the housing and ground damage around Tsukuba and Tsuchiura cities due to the 2011 Off the Pacific Coast

Yosuke Nakamura[1*], Kentaro Sakata[2], Shinsuke Okada[1], Ayako Funabiki[3], Yuki Sawada[4], Junko Komatsubara[1], Tomonori Naya[1], Susumu Tanabe[2], Hideaki Nagamori[2], Tsutomu Nakazawa[2], Taku Komatsubara[1], Kiyohide Mizuno[1]

[1]GSJ, AIST (Geology and Geoinformation), [2]GSJ, AIST (Geological Museum), [3]Nihon University, [4]Fukuyama City University

The 2011 off the Pacific coast of Tohoku Earthquake (Mw 9.0) caused severe damage to housing and ground in the urban area of Tsuchiura. In order to clarify the relationship between the damage and the geological conditions, we have made an investigation on (1) damage of roofing tiles, (2) damage of outer walls, (3) collapse of fences and garden lanterns, (4) sand boils and (5) land subsidence and cracks, 6) others (e.g. landslides) in the Tsuchiura-Tsukuba area of which detailed geologic map (Unosawa et al., 1988) was published.

Our investigation reveals that damage on the Sakuragawa Lowland (alluvial plain) was the most severe in the study area. The Sakuragawa Terrace (lower terrace) which is underlain by sand and pebble was less damaged, but the widespread Joso Terrace (middle terrace) composed of sand and mud was severely damaged as well as the Sakuragawa Lowland. Consequently, the most of the terrace areas, generally known as earthquake-resistant topography, were likely to tremble furiously during the earthquake, as well as the alluvial plains.

In the reclaimed areas around the Tsuchiura Port, we recognize some sand boils, but housing damage was not salient.

Keywords: 2011 Off the Pacific Coast of Tohoku Earthquake, Tsukuba City, Tsuchiura City, damage of roofing tiles, sand boils

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

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Some cases of liquefaction in the central Kanto plain caused by the 2011 Off Pacific Coast of Tohoku earthquake

Masayuki Seto[1*], Toshikazu Tamura[2], Takahisa Machida[3]

[1]Saitama University, [2]Rissho University, [3]Graduate student of Rissho University

1. Preface

The Off Pacific Coast of Tohoku earthquake in 2011 induced liquefaction in lowland areas extending over the eastern side of northeast Honshu, including not only coastal reclaimed lands but also inland low plains. We report a few cases of them appeared along the mid-Tone river in the central part of the Kanto Plain. We investigated the liquefaction in Watarase flood prevention reservoir and the Minamikurihashi district on April 4, 2011, we report it. Watarase flood prevention reservoir and the Minamikurihashi district are located in the central part of Kanto basin and hit a middle part of Tone river.

2. Watarase flood prevention reservoir

The Watarase flood prevention reservoir is composed of Yanaka lake and the first adjustment pond, the second adjustment pond, the third adjustment pond.Liquefactions occurred in a exercise park located north end of first adjustment pond.At the time of the investigation, there were eruptive sand around some cracks.The grain size is medium or fine. As for the width of the crack, 3 to 5 cm, depths are 20 to 30 cm and length is 20 to 30 m or more.A large quantity of eruptive sand flowed into the gutter of the ground side. In addition, there were erupted sand at the joint of pavement of the road in this park. At the part of covered with lawn, we recognized erupted sand.The tennis court where certain pavement was given an earth surface was within the park, crack and erupted sand were not recognized.

3. Minamikurihashi district

The Minamikurihashi district is a residential area developed around Tobu Railway Nikko Line Minami-Kurihashi Station. Because the opening of business of the station is August, 1986, it seems that it was prepared land near this year. Judging from a figure of aerial photo (1947) of the United States Armed Forces photography and topography classification of Hirai (1983), the topography is a former river channel and wetland. This district is estimated that which is composed of old valley at the period of the lowest sea level and that was flood plain and wetland during the Holocene. In the Kanto earthquake of 1923, many cracks were formed in the right bank of Nakagawa river near this district (Kadokura, 1925). There are records of erupted sand in the West Saitama earthquake of 1931 in Sakurada village (Kumagaya Meteorological Observatory 1932).

Liquefaction occurred around exercise ground in southwestern residential area and the land developed for housing which were not sold in lots. The subsidence of the wooden house and damage of water supply and sewage equipments occurred. Restorations are not completed at the time of the investigation.

4. Conclusion

The central part of the Kanto Plain where many rivers are concentrated contains extensive areas which tend to be affected by liquefaction. Although similar events as previously occurred in big earthquakes take place in the present event again, it is quite different that a part of this area was urbanized in recent several tens of years. The facts seem to be remarked in land-use planning in future.

Keywords: 2011 Off Pacific Coast of Tohoku earthquake, Kanto plain, liquefaction

Japan Geoscience Union Meeting 2011
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Liquefaction damage in the Tone river basin

Nobusuke Hasegawa[1*], Hiroyuki Fujiwara[1], Takahiro Maeda[1], Hiroki Azuma[1], Asako Iwaki[1], Shinichi Kawai[1], Ken Xiansheng Hao[1], Nobuyuki Morikawa[1], Shigeki Senna[1]

[1]NIED

By the 2011 off the Pacific coast of Tohoku Earthquake, a large number of liquefaction occurred in the Tone river basin. By this liquefaction, serious damage including the cutoff of the lifeline, the destruction of the house basics and the nonequivalent subsidence occurred. The liquefaction damage taken up by the news was a small portion. Then we carried out field investigation for the purpose of catching perspective of the liquefaction damage in the Tone river basin.

Investigation areas are Kamisu, Kashima Itako, Namegata, Ryuugasaki, Kawachi, Tone, Toride, Tsukubamirai, Moriya, Joso, Shimotsuma, Yachiyo, Chikusei, Bando, Sakai, Goka, Koga, Yuuki (in Ibaraki Prefecture), Choshi, Tohnosho, Katori, Kozaki, Narita, Sakae, Inzai, Abiko, Kashiwa (in Chiba Prefecture), 28 city areas in total. We carried out the investigation in two days from April 7, 2011 to 8th. After having collected information about the liquefaction at the local government office of each city, the investigation carried out photography, sampling of the sand which spouted out by liquefaction, the hearing to inhabitants in the field.

We divided the Tone river basin into three areas. The characteristics of liquefaction in each area are as follows.

1. Pacific coast area (Kamisu, Kashima, Choshi)
Intense liquefaction was seen in the artificial ground such as the backfill of gravel pit, the backfill of pond. And, intense liquefaction was seen in the dune which was the natural ground, too.

2. Lower part of the Tone river basin (Itako, Namegata, Tohnosho, Katori, Kozaki, Kawachi, Tone)
It was almost the artificial ground where filled up pond and river that intense liquefaction was seen. Liquefaction might occur on the natural ground, but was not reported to local government office.

3. Middle part of the Tone river basin (other cities)
It was almost the artificial ground where filled up pond and river that intense liquefaction was seen. And the liquefaction was seen on the natural ground. But the liquefied area was almost the area of ruins of rice field, and of the topography to gather the water such as small valley region or the exit part of valley.

In addition, by the hearing to inhabitants, the testimony that a intense spout of sand was seen in at the time of the aftershock at 15:15 in comparison with the main shock at 14:46 on March 11 was provided. This suggests the possibility that strong earthquake ground motion occurred at a short interval was promote liquefaction damage.

Keywords: the Tone river basin, liquefaction damage, field investigation

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Analytical result based on liquidizing investigation of the 2011 off the Pacific coast of Tohoku Earthquake

Shigeki Senna[1*], Hiroyuki Fujiwara[1]

[1]NIED

In the 2011 off the Pacific coast of Tohoku Earthquake, the ground hazard by a lot of liquidizing was generated in the Kanto region. The ground hazard by liquidizing was known from of old. It was recognized again to cause an extensive ground hazard by liquidizing in this earthquake.

It is thought that liquidizing is generated by the earthquake in the future again.

Specific and the verification of the liquidizing region generated in the large area due to this earthquake are indispensable.

In this study, the liquidizing region chiefly generated in the Tone river area in Ibaraki Prefecture and Chiba Prefecture was surveyed, and the problem and the technique of the analytical result were examined.

Keywords: Liquidizing, Nonlinear, Strong Ground Motion, Structure Model, Geomorphologic Condition

Japan Geoscience Union Meeting 2011
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Investigation of the liquefaction along Tone river after the 2011 off the Pacific coast of Tohoku Earthquake

Hideaki Shinohara[1*], Syunichirou Ohta[1], Yasuhiro Kaida[1], Syunpei Manabe[1], Hiroyuki Fujiwara[2], Shigeki Senna[2], Nobusuke Hasegawa[2], Yoshiaki Inagaki[1], Shunichi Azuma[1]

[1]OYO Corp., [2]NIED

We have investigated the liquefaction along the Tone river, Kanto district, immediately south-western portion of the focal region of the 2011 off the Pacific coast of Tohoku Earthquake.
We confirmed the liquefaction at the following places.

1)The left bank of the river : from Yotsuya, Inashiki-city , via Yatabe,Kamisu-city, and Hinode, Itako-city
2)The right bank of the river : Minamikurihashi, Kuki-city, Miyako, Abiko-city, Nakatani and Manaitanabekoshinden, Sakae-town, Kouzakihonshuku and Matsuzaki Sawara, Kouzaki-town, Omigawa and Sawara, Katori-city.

The liquefaction areas were concentrated at areas where abandoned river channels and marshes were filled up.

Japan Geoscience Union Meeting 2011
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Correlation of the distribution of liquefied sites in the Tone River lowland and land use change since the Meiji era

Masafumi Aoyama[1*], Takushi Koyama[2]

[1]Japan Map Center, [2]Graduate school, Meiji University

The occurrences of liquefaction damage were observed in many places in the Tone River lowland induced by the 2011 off the Pacific coast of Tohoku Earthquake. On the basis of the old edition maps which have been surveyed and published since the Meiji era, a large number of these sites are located on former river channel, recently filled or reclaimed land, backfilled land of canal, natural levees and backmarsh.

Keywords: Liquefaction damage, Land use change, Old edition map, Tone River lowland, The 2011 off the Pacific coast of Tohoku Earthquake

Japan Geoscience Union Meeting 2011
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MIS036-P161 Room:Convention Hall Time:May 27 14:15-16:15

Distribution of liquefied sites on reclaimed lands in Tokyo during the 2011 off the Pacific Coast of Tohoku Earthquake

Koichiro Inoue[1*]

[1] none

The 2011 off the Pacific Coast of Tohoku Earthquake on March 11,2011,with magnitude 9.0, caused serious damage at the coastal areas in eastern Japan. After the earthquake, liquefaction phenomena of the ground occurred in various parts of flood plains and artificial ground such as reclaimed lands and/or landfills in eastern Japan. The reclaimed lands along Tokyo Bay in Koto city were within the zones seismic intensity 5+ in Japan Meteorological Agency scale, so the author identified total of 198 traces of liquefaction such as sand boiling and/or floating up of buried structures on the reclaimed lands in Koto city; Toyosu, Shinonome, Ariake, Shiohama, Tatsumi and Shin-Kiba.

The hazard map for liquefaction of the ground during the earthquakes, published by the Civil Engineering Center of Tokyo Metropolitan Government in 1987 and 1991, classifies the areas in Tokyo lowlands into three types based on the probability of occurrence of liquefaction; high probability of occurrence, low probability of occurrence and rare occurrence. In order to verify the utility of the hazard map for liquefaction, the author made a comparison between the anticipated areas by hazard map for liquefaction and the liquefied sites observed in this survey. As a result,in 198 traces identified as liquefaction, only 5 % of traces of liquefaction correspond to the areas estimated ”high probability of occurrence,” and 68 % of traces and 27 % of traces of liquefaction correspond to the areas estimated ”low probability of occurrence,” ”rare occurrence,” respectively. Recently each reclaimed land in Koto city has developed rapidly, so its land use has changed markedly. More than twenty years have passed since the hazard map above was released, therefore, the contents of the hazard map for liquefaction need to be reexamined in order to reduce serious damage during future earthquakes.

Japan Geoscience Union Meeting 2011
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Soil Liquefaction caused by the 2011 off the Pacific coast of Tohoku Earthquake at Tokyo Bay reclaimed land

Tomoko Nagao[1*]

[1]Tokyo Jogakkan Schools for Women

The 2011 off the Pacific coast of Tohoku Earthquake hit off the coast of Tohoku in The Pacific. In the area that left the epicenter of the earthquake, Soil Liquefaction occurred on reclaimed lands and alluvial plane in Tokyo and Chiba and Kanagawa and Ibaragi prefectures.The characterization and distribution of sand boiling at Tokyo Bay reclaimed land are reported in this study.Especially large amounts of sand boil occurred at Koto,Edogawa,Urayasu,Itikawa,Funabasi,Makuhari,Chiba city and distributed extending linearly along the coast.

The Tokyo Bay reclaimed land that liquefied is at least 40 square km, and a record-high scale all over the world.

Many kinds methods for the prediction of the occurrence of liquefaction have been developed from 1964.These methods have been introduced in seismic design code.However,there are still several problems to be solved.One of them is the estimation of liquefaction potential under large-scale earthquakes.Duration and amplitude of the big earthquakes must be considered carefully in the estimation for liquefaction.The other problem is the evaluation of liquefaction-induced deformation of structures. Performance-based design methods for liquefaction must be introduced in seismic design codes.

By this earthquake,disasters happened in areas outside of the Hazard map (liquefaction).We have necessity to reexamine an anti-liquefaction measure.

Keywords: the 2011 off the Pacific coast of Tohoku Earthquake, Tokyo Bay, soil liquefaction

Japan Geoscience Union Meeting 2011
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Ground Damage on Man-made Land caused by Mega Earthquake -Characteristics of Ground Disaster due to the Quake-

Shigeo Higuchi[1*], Masashi HIGASHI[2], Akira INADA[3], Akihide ITO[4], Hiroshi IWAMOTO[5], Satoshi KAMIKASEDA[6], Kenichi KAWASAKI[7], Kazuyuki SUENAGA[8]

[1]Waseda Univ., [2]JAPEX, [3]., [4]Chiba-kita Hi., [5]Kanto Natural Gas Development Co., Ltd., [6]NTC Consaltants Co., Ltd., [7]Funabashi-higashi Hi., [8]Earth System Science Co., Ltd.

Objective of the survey is how the ground damage caused by the Mega-earthquake was happened, especially on man-made land. In this case both source and site characteristics of the earthquake should be noticed as follows: its magnitude was 9.0 (JMA); fault plane size was calculated as 510kn(length) by 210km(width) (Natl. Res. Inst. for Earth Sci. and Disaster Prevention, 2011); this tele-seismic earthquake was long-period component rich, and had very long duration time, i.e. more than 10 minutes (Natl. Res. Inst. for Earth Sci. and Disaster Prevention, 2011). Problem is how the man-made ground responded under these conditions.

Survey was held at (1) Kaihin-makuhari Mihama-ku in Chiba city, Chiba prefecture (next two cities also belonged in the same prefecture), (2) Horie, Fujimi, and Higashino area in Urayasu city, (3) Hinode, Akemi, and Takasu area in Urayasu city.

As a result (above-mentioned number(1),(2), and(3) corresponds here and next), (1) the distribution of liquefaction phenomena etc. was revealed. On the other hand almost no distribution was found in limited area. One fault of 120m in length was distributed at Kaihin-makuhari park at 1 Hibino Mihama-ku Chiba city, and the other fault of 190m in length was distributed at Hanamigawa-ryokuchi at 3 Utase Mihama-ku Chiba city. These faults (open sense) was happened at gradual slope between 3.4m-3.6m high at street and 6m-6.4m high at park area (mound-top). And these accompanied with flow-out of big amount of sand, and heaving of manhole etc. was observed, and was 100-200m, 50m far from each fault respectively. (2) The ground damage was rare on land consisted from natural Holocene sediments, whereas the damage was very severe on land reclaimed after 1962. (3) The phenomena of liquefaction was distributed complicated and random on the most newly (after 1971) reclaimed land. The way of 'discrete sampling of ground damage' (Higuchi, 2011) was used here. Approximately 300 manholes of drainage system were observed, described, and measured. Damage was observed at approximately 40% of these locations. But its distribution pattern shows irregular.

Consequently, inexperienced ground damage due to the Mega-earthquake was observed and described. (1) Two cases of fault on gradual slope area, where is park area, were supposed one kind of phenomena in liquefied zone. No liquefied zone was observed. It is concerned with soil improvements (Kamura, 2000). (2) Relatively simple distribution was investigated. (3) Why complicated distribution was shown? Because one of the reason was the way of reclamation by hydraulic filling work, with this work silty sand of sea floor was deposited randomly. Moreover it constructed with soil improvements in any case.(Kamura, 2000). Above-mentioned methodology was tried in this survey. It was effective. Also now many scientific and social support is expected these disaster area.

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Photo: Fault (approximately 190m in length and approximately 70cm in throw; open sense) in liquefied zone at Hanmigawa-ryokuchi, 3 Utase Mihama-ku Chiba city, Chiba pref.

Keywords: the 2011 off the Pacific Coast of Tohoku Earthquake, Ground Disaster, Liquefaction, Reclaimed land, Chiba city, Urayasu city

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P164 Room:Convention Hall Time:May 27 14:15-16:15

Distribution of Geological Disaster by Liquefaction-Fluidization Phenomena on Boso peninsula -Urayasu area-

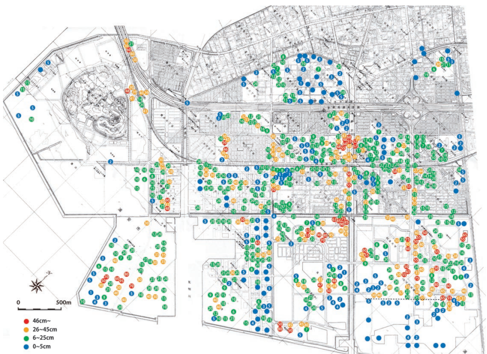
Atsushi Kagawa[1*], Osamu Kazaoka[1], Kunio Furuno[1], Takashi Kusuda[1], Yutaka Sakai[1], Takeshi Yoshida[1], Akiko Kato[1], Mari Yamamoto[1]

[1]R.I. Environmental Geology, Chiba

The 2011 off the Pacific coast of Tohoku Earthquake resulted in destructive damage to the eastern margin of the East Japan. Many cities of the Kanto Plain are built on soft sediments deposited in deltaic and ragoonal environments along the Tokyo Bay. Industrial and urban area were extended by reclaimed land along the ancient coast. In Urayasu City, reclaimed lands are expanding by overpopulation and industrialization since 1960s.

Large scale Liquefaction-Fluidization was caused by the earthquake in the coastal reclaimed land areas. Ground sinkage and ejection of sandy water caused sand flooding. The boiled sand was composed of reclaimed materials which are fine sand and shell flakes. The underground lifeline suffered serious damage due to upward displacement of the piled buildings. Many of the houses were inclined and subsided. The water supply pipelines and other underground lifelines used for residence were cut due to differential subsidence. Many underground emergency water tanks were broken by floating. In the outer edge of the reclaimed land, a partly of the banks were inclined and subsided.

These phenomena were caused by large scale Liquefaction - Fluidization with long period ground motion. Most buildings were existing in the residence area, however, comfortable life are destroyed. Liquefaction subsidence is an exceptional event, however, it is a big problem for low lying and reclaimed land areas because of the immediate heavy damage caused.



The value of liquefaction land subsidence in Urayasu area

Keywords: Liquefaction - Fluidization, reclaimed land, land subsidence

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P165 Room:Convention Hall Time:May 27 14:15-16:15

Distribution of Geological Disaster by Liquefaction-Fluidization on Boso peninsula and northern Tokyo bay reclaimed land

Osamu Kazaoka[1*], FURUNO Kunio[1], KAGAWA Atsushi[1], KUSUDA Takashi[1], SAKAI Yutaka[1], YOSHIDA Takeshi[1], KATO Akiko[1], YAMAMOTO Mari[1], TAKANASHI Yuji[2], NIREI Hisashi[3]

[1]Res. Inst. Env. Geol. Chiba, [2]Chiba Pref. Env. Res. Center, [3]officer of IUGS-GEM

Outline of liq-flu (liquefaction-fluidization) phenomena on Boso peninsula and characteristics of liq-flu disaster on southern Chiba city in Tokyo bay reclaimed land area by the earthquake are reported in this paper. The geological environment is different on Tokyo bay reclaimed land area, Kujyukuri plain area, Tonegawa river lowland area and Shimousa upland area. [OUTLINE OF LIQUEFACTION-FLUIDIZATION PHENOMENA ON BOSO PENINSULA]: 1) Liq-flu disaster distribute on artificial formation. 2) Liq-flu phenomena distribute mainly on northern Boso peninsula. Because the strength of shake increase to north of Boso peninsula. 3) Liq-flu disaster are more serious and widely at this earthquake than at 1987 east off Chiba prefecture earthquake. Houses and buildings with shallow depth foundation, block walls and electric poles submerged and tilted. Ground subside few ten centimeter and waved. Underground pipeline, tap water pipe and sewage pipe, were torn off. 4) 4 type sand volcanoes are recognized. 5) Seriousness of damage by liq-flu are different in reclaimed land. 6) Liq-flu phenomena distribute little on artificial formation with some preventive measure for liquefaction. [CHARACTERISTICS OF LIQUEFACTION-FLUIDIZATION DISASTER ON SOUTHERN CHIBA CITY IN TOKYO BAY RECLAIMED LAND]: 1) Liq-flu damage zones with few hundred meters wide distribute on this reclaimed land. Large part of the damage zones distribute on the thick part of the Holocene formation. 2) Liq-flu disaster distribute on sandy strata of Artificial formation, but the disaster distribute little on muddy strata of the formation (Kazaoka et al.,2000). Difference of few tens meter order seriousness of liq-flu disaster may depend on the litho-facies lateral change of Artificial formation and soil improvement. 3) Large amount of jetted coarse silt to fine sand poured into sewage pipe and drainage ditch. The drainage systems had been stopped up by the fine sediments. 4) Jetted sand distribute on 2 meter height, from road surface, in artificial hill. This shows the groundwater table to rise to 2 meters height from road surface. 5) Jetted sand distribute on corner of building and side of electric pole. 6) Strong shaking might decrease on liq-flu part, because tall furniture toppled little in there. Same phenomena happened at the 1995 Hanshin-Awaji Earthquake (Nirei et al.,1996). [SURVEY POINT FROM NOW]: It is very important the next surveys for urban planning against liq-flu disaster. 1) Recognition of lateral change of seriousness of damage and road deformation by liq-flu. 2) Recognition of lateral change and vertical change of litho-facies and groundwater flow in the Holocene formation and Artificial formation. 3) Recognition of correlation between amplification characteristic of shaking and geological structure.[FOR FUTURE RESTORATION AND RECOVERY]: 1) Against liq-flu damage: It is very important to prevent liq-flu on major road where emergency car goes through and lifeline lays under. It is consider that a drainage method of construction is suitable to prevent liq-flu on this reclaimed land because of flowing groundwater (Nirei,2003). It is necessary to consider as follows on damage control, damage situation of this earthquake, land use, geological environment, decrement effect of sheer wave by liquefaction. 2) Importance of groundwater: It is necessary to use daily the disaster prevention well and to monitor groundwater table and quality of the well. 3) Continuous landsubsidence after jetted sand. 4) Disaster education: Most of disaster is earth science field of the science. It is necessary to teach Artificial formation, the Holocene formation and the Neogene strata which disaster occur often on, and to teach geological disaster, Earthquake, Landsubsidence, Slope failure and Geo-pollution. Further it is necessary to teach sustainable use of Geo-resources, such as Land and Groundwater.

Keywords: Liquefaction-Fluidization, Boso peninsula, Artificial formation, Environmental Geology, Tokyo bay reclaimed land

Japan Geoscience Union Meeting 2011
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MIS036-P166 Room:Convention Hall Time:May 27 14:15-16:15

Distribution of Geological Disaster by Liquefaction-Fluidization Phenomena on Boso peninsula at The 2011 off the Pacific

Kunio Furuno[1*], Osamu KAZAOKA[1], Atsushi KAGAWA[1], Takashi Kusuda[1], Yutaka SAKAI[1], Takeshi YOSHIDA[1], Akiko KATO[1], Mari YAMAMOTO[1], Yuji TAKANASHI[1]

[1]Kunio FURUNO

The 2011 off the Pacific coast of Tohoku Earthquake and the aftershock caused Liquefaction-Fluidization phenomenon in many places in Boso Peninsula. The distribution and characteristic of the low land area around Tone River down stream on Chiba prefecture. seem to be as follows.

Liquefaction-Fluidization damage is seen in the reclaimed land where was the past water area around the former river channel and pond. The same phenomenon was occurred at the 1987 East Off Chiba Prefecture Earthquake. In this area, the liquefaction-fluidization phenomena occurred more extensive than the 1987 East Off Chiba Prefecture Earthquake. Also the liquefaction-fluidization hazards were more serious. It is often accompanied by big subsidence of the ground. Liquefaction-Fluidization phenomenon is seen in more wider area than a former river channel. But the degree of the damage varies by location. It is considered the impact of the differences of the strata of the shallow part of the area, such as the artificial layer and alluvial deposit.

The Liquefaction-Fluidization phenomenon was seen in low land area around Tonegawa down stream in Chiba prefecture such as Noda city, Abiko city, Inzai city, Sakae town, Narita city, Katori city.

Keywords: Liquefaction-Fluidization Phenomena, sand volcano, the 1987 East Off Chiba Prefecture Earthquake, the 2011 off the Pacific coast of Tohoku Earthquake

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P167 Room:Convention Hall Time:May 27 14:15-16:15

Distribution of Geological Disaster by Liquefaction-Fluidization on Boso peninsula at The Earthquake - Kujukuri plain

Takashi Kusuda[1*], Osamu KAZAOKA[1], Atsushi KAGAWA[1], Kunio FURUNO[1], Yutaka SAKAI[1], Takeshi YOSHIDA[1], Akiko KATO[1], Mari YAMAMOTO[1], Yuji TAKANASHI[2]

[1]Re. Insti. Envir. Geol. Chiba, [2]Envir.Re. Lab. Chiba

Kujukuri Plain characterized over ten of sand dunes are distributed in Kujukuri Plain. Marshes and ponds distributed between the dune lines were filled by fine grained sand of dune sand and the Shimosa Group collecting for houses lots. Along the coast, sand dune was dug for iron sand. Then the sites were filled up again by the iron removed sand.

In past this area suffered the liquefaction-fluidization hazards caused by earthquake at December 17, 1987. These artificial beds also liquidized by the 1987 East Off Chiba Prefecture Earthquake (Nirei, et al., 1990).

The hazards were more extensive than that of the past same scale earthquakes (Nirei, et al., 1990).

The liquefaction-fluidization hazards caused by the 2011 off the Pacific coast of Tohoku Earthquake, on the northern part Kujukuri plain seen more widely and seriously than the 1987 East Off Chiba Prefecture Earthquake. But the phenomena could not observe southern part of Togane city.

In Asahi city, located northern part of Kujukuri plain, the liquefaction-fluidization phenomena occurred more extensive than the 1987 East Off Chiba Prefecture Earthquake. Also the liquefaction-fluidization hazards were more serious. But the degree of damage varies by location. It is considered the impact of the differences in the thickness of the soft sand. Along the coast, sand dune was dug for iron sand. Then the sites were filled up again by the iron removed sand from many local residents - there was testimony that the liquefaction-fluidization hazards occurred.

At Komatsu/ Hasunuma-Hira, Sanmu city, located near the Kido-gawa river mouth, the severe liquefaction-fluidization hazards occurred. It is considered the impact of the differences in the thickness of the Holocene sediments and to configure the type of strata.

Keywords: Liquefaction-Fluidization Phenomena, Kujukuri plain, sand vocano, sand dune was dug for iron sand, the 1987 East Off Chiba Prefecture Earthquake

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P168 Room:Convention Hall Time:May 27 14:15-16:15

Liquefaction-Fluidization Phenomena in northern east coast of Tokyo bay at The 2011 off the Pacific coast of Tohoku Eart

Takeshi Yoshida[1*], Osamu Kazaoka[1], Takashi Kusuda[1], Atsushi Kagawa[1], Kunio Furuno[1], Yutaka Sakai[1], Akiko Kato[1], Mari Yamamoto[1], Yuji Takanashi[1]

[1]Research Institute of Environmental Geol

March 11, 2011, the earthquake with a Magnitude 9 directly hit east Japan. Chiba prefecture is suffering from damages of Tsunami and Liquefaction-Fluidization Phenomena by the earthquake.

We describe damages of Liquefaction-Fluidization Phenomena on man-made strata in northern east coast of Tokyo bay.

Area and damege

Sodegaura, Narashino city : large quantities of sand volcano and quick sand, crack (Bump:20-40cm; length: 50m), lean of houses and utility poles, warp in road. The sewer is stopped up.

Kasumi, Narashino city : large quantities of sand volcano and quick sand, lean of houses and utility poles, warp in road. The sewer is stopped up.

Akitsu, Narashino city : small quantities of sand volcano. The sewer is stopped up.

Akanehama, Narashino city : large quantities of sand volcano and quick sand, collapse of river-levee protection, warp in road. The sewer is stopped up.

Shibazono, Narashino city : large quantities of sand volcano and quick sand, , warp in road. The sewer is stopped up.

Yastu-higata, Narashino city : no sand volcano in natural tidal flat, warp in road. The sewer is stopped up.

Makuharinishi, Mihamaku, Chiba city : small quantities of sand volcano, warp in road.

Makuharicho, Hanamigawaku, Chiba city : very small quantities of sand volcano.

Keywords: Liquefaction-Fluidization, land subsidence, sand volcano, warp in roak, lean of utility poles

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P169 Room:Convention Hall Time:May 27 14:15-16:15

Preliminary report on damage to Central Kanagawa, Japan caused by the 2011 off the Pacific coast of Tohoku Earthquake

Hiroo Nemoto[1*], Kiyokazu Kawajiri[2], Nobumitsu Aihara[3], Setsuo Fujimoto[4], Kenichi Shinohara[5], Mikiko Kashiwagi[5], HIRATSUKA-BOUSAI-MACHIDUKURI-NO-KAI[5]

[1]J.F.Oberlin Unibersity, [2]Sagamihara City Museum, [3]Nippa Upper Secondary School, [4]Hadano City Kuzuhanoie, [5]HIRATSUKA-BOUSAI-MACHIDUKURI-NO-KAI

The purpose of this presentation is to provide a preliminary report on the damage caused to Central Kanagawa Prefecture by the 2011 off the Pacific coast of Tohoku Earthquake. Kanagawa Prefecture is located to the south-west of Tokyo and covers an area of about 2,415.85 square kilometers. It has a population of about 9 million people. The topography of the prefecture consists of alluvial lowland, upland, hills, and mountains such as Tanzawa Mountains.

This prefecture is located about 400 km from the epicentre, and about 150km from the southern edge of the source region of the earthquake. The distribution of the JMA (Japan Meteorological Agency) seismic intensity scale in Kanagawa Prefecture owing to the mainshock ranged from 2 and 5 upper. The number of those killed and injured within the prefecture by the mainshock was 4 and about 130 persons, respectively. Moreover, 200 or more houses, buildings, bridges, roads, agricultural facilities, and so forth received major or minor damage caused by the effects of the strong ground motion such as liquefaction, however this damage was largely localized in the middle of the prefecture.

It is necessary to study the reason why the damage caused was so localized. The subsequent results of the study will provide useful information to the prefecture to help prepare for any future earthquake to hit, which may strike with even greater strong ground motion.

In this presentation, we will report the preliminary results in detail, looking at such areas as the relationship among damage, topography and geological setting, as well as clarify remaining problems in future.

Keywords: the 2011 off the Pacific coast of Tohoku Earthquake, Kanagawa Prefecture, Central Kanagawa Prefecture, damage, topography, urban geosciences

Japan Geoscience Union Meeting 2011
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MIS036-P170 Room:Convention Hall Time:May 27 14:15-16:15

Preliminary report on damage to the northern Kanagawa, Japan, by the 2011 off the Pacific coast of Tohoku Earthquake

Kiyokazu Kawajiri[1*], Hiroo Nemoto[2], Nobumitsu Aihara[3], Setsuo Fujimoto[4], Sagamihara Geology Research Group[5]

[1]Sagamihara City Museum, [2]J.F.Oberlin Unibersity, [3]Nippa Upper Secondary School, [4]Hadano City Kuzuhanoie, [5]Sagamihara Geology Research Group

The purpose of this presentation is to provide a preliminary report on the damage caused to the northern part of Kanagawa Prefecture by the 2011 off the Pacific coast of Tohoku Earthquake. Kanagawa Prefecture is located to the south-west of Tokyo and covers an area of about 2,415.85 square kilometers. It has a population of about 9 million people. The topography of the prefecture consists of alluvial lowland, upland, and mountains such as Tanzawa Mountains. The earthquake struck just under 400 kilometers the northern part of Kanagawa Prefecture located in the Kanto region and hit between 4 and 5 lower on the Japan Meteorological Agency seismic intensity scale.

Slight damages such as the fall of roof tiles, fissures of water pipes, collapse of concrete-block walls and so forth were caused by the earthquake in this area.

We will report the preliminary results of the investigation, and especially describes the relationships among topography, geology and the situation of damages.

Keywords: the 2011 off the Pacific coast of Tohoku Earthquake, the northern part of Kanagawa, damage, topography, geology

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P171 Room:Convention Hall Time:May 27 14:15-16:15

High school student recognition report on the 2011 of pacific coast of Tohoku earthquake(prompt report)

Nobumitsu Aihara[1*]

[1]Nobumitsu Aihara, [2]Setsuo Fujimoto, [3]Kenichi Shinohara, [4]HIRATSUKABOUSAI-MACHIDUKURI-NO-KAI

1.Introduction

Do a preliminary survey of high school students in the Kanagawa Prefecture of Northeast Regional Pacific earthquake in this presentation. March11,14:46minutes from disaster at the time of many high school after end of the test after grade school, and at home, traveling or was in extracurricular activities. That lacks the means of transport to their home for their home and they come. I think this earthquake-tsunami disaster and the long-period ground motion to stay as well as getting a good opportunity to think about the impact on society of natural disasters in school education.

In the new high school curriculum beginning with fiscal year 200324 not just geology, geography, home economics, health and physical education, including in the development of disaster prevention education is considered. Learning about disaster in preparedness of external forces (magnitude of natural disasters) and social relations is important. Force is greater than the ability of the society and become a disaster. To increase the ability and ingenuity to minimize damage to you should be. Able to identify problems and realities of high school students about the siting when considering disaster prevention should be knowledgeable in recognition to improve disaster prevention education in the science of teaching very seriously and we have a

2.Map making community disaster walking

Announces investigation of damage of Hiratsuka City County Central (isehara plateau of the Northwest and Western consists of oiso hills, alluvial plains of the Sagami River flows through the Central of Kanagawa, Japan, and Central) and its causal factors about study. There are local damage due to liquefaction in the soft soil of the Valley Plains, House, building, roads, irrigation facilities, such as in Hiratsuka city. To reveal the cause why local in damage was caused, or, on the measures of future strong tremor-stricken does matter. Introduces initiatives to consider taking measures assumed regional (City) location (building strength and debatable) of any damage was going to happen, and collaborating with regional residents to reduce accidents ”in the eyes of disaster prevention matiaruki”.

3.How to investigate

(1) Research and practices

In the study, an established high school students. 2011 4 During the month of the season after also currently in progress.

(2) Questions

In the questionnaire, prepared topics: a-k’sconsciousness on environment, such as the following questions.

a.Knowledge of respondents information coming from junior high school
b.Residential environment (close to the River near the sea, on the Hill Clough)
c.Knowledge of ground on firm ground with exposed bedrock, somewhat stiff soil such as volcanic ash, and wetlands in loose soil or not)
d.Evacuation Area(name, walking distance)
e.Communication with family f.care recognition
g.Shout of disaster drills h.Initial tremors of those who feel i.Onsets of action
j.Action after that k.Learned from earthquake action

Keywords: the 2011 off the Pacific coast of Tohoku Earthquake, Kanagawa Prefecture, recognition report, ground disaster, education for disaster prevention, map making community disaster walking

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P172 Room:Convention Hall Time:May 27 14:15-16:15

How to evacuate from huge tsunami. Preliminary report based on eyewitnesses in Rikuzen-Takata

Yoshinari Hayashi[1*], Chiharu Mizuki[2], Masataka Ando[3], Mizuho Ishida[4], Shoichi Yoshioka[5]

[1]Faculty of Safety Science, Kansai Univ., [2]Graduate School of Environmental Science, [3]Institute of Earth Sciences, Academia Si, [4]Japan Agency for Marine-Earth Science an, [5]Research Center for Urban Safety and Sec

The 2011 off the Pacific coast of Tohoku Earthquake caused huge damage in eastern part of Japan. More than 99% of death and missing persons are concentrated in Fukushima Iwate and Miyagi. Currently, we have less information about Earthquake damage, preparetion against earthquake and tsunami and evacuation process during the tsunami. In this study, we clarified the actual situation of the human individual evacuation process by interviews.

In the survey, we used a technique that hearing the event by event after the earthquake. We carried out survey around Rikuzen-takata, Iwate from April 21th to 23th, 2011.

All interviewee have experienced strong shake. But their and neighborhood houses are not damaged by the quake to interfere for their evacuation actions. Almost respondents have a perception of the evacuation points, and they went to that point by themselves. But the evacuation places did not have adequate elavation for the tsunami. Many refugees have lost their lives.The most of survived persons have moved to higher place after watching the killer tsunami or hearing radio broadcat about tsunami over seaside bank.

Keywords: Tsunami, The 2011 off the Pacific coast of Tohoku Earthquake, evacuation, evacuation point, Hazard map, Damage estimation of tsunami

Japan Geoscience Union Meeting 2011
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MIS036-P173 Room:Convention Hall Time:May 27 14:15-16:15

A study of evacuation activities of the residents in Hidaka and Tokachi Coast on the Great East Japan Earthquake-Tsunami

Chiharu Mizuki[1*], Kazuomi Hirakawa[1], Teiji Watanabe[1]

[1]Hokkaido University

The 3.11 Tsunami attacked also the Pacific coast of Hokkaido. Although the tsunami had been 3-3.5 m in wave height, it had locally run up to the height of 6-9 msl. People had been expected to evacuate, according to the Great Tsunami Warning. How had the people living along the coast responded as the evacuation activity? We have carried out the hearing survey to 259 residents, using questionnaire in some selected villages and towns. Below are major key issues obtained from this survey.

1. Individual evacuation activity of each residents:
 Evacuated: mostly judged from TV news (live broadcasting from Tohoku)
 Not evacuated: judged from the 1952-, 2003-Tokachioki Tsunami.
2. The evacuation mark indicating the route and distance and the evacuation facilities are problematic in most cases.
3. Understanding the topographic condition against the tsunami, where each village or town is located: almost no knowledge
4. Understanding the Tsunami Hazard Map prepared by the Administrative Bureau: mostly poor

Keywords: Questionnaire, Evacuation Activities, Hidaka- Tokachi Coast

Japan Geoscience Union Meeting 2011
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Kyoshin monitor spreads to the people through Aftershocks and Induced earthquakes

Hiroki Azuma[1*], Shin Aoi[1], Takashi Kunugi[1], Hiromitsu Nakamura[1], Toshihiko Hayakawa[2], Hiroyuki Fujiwara[1]

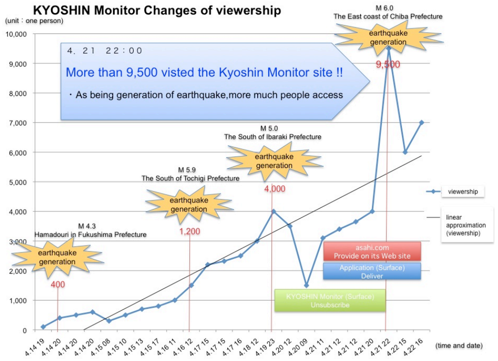
[1]NIED, [2]Mitsubishi Space Software Co,. Ltd.

1. Summary
In NIED (National Research Institute for Earth Science and Disaster Prevention), we provide realtime strongmotion seismic information from seismometer network called KiK-net through CGI web service (CGI below) from August, 2008. Thus, after 3.11 2011 off the Pacific coast of Tohoku Earthquake, it overloaded by too many accesses that increase while aftershocks and induced earthquakes occur. To solve this problem, We decided to deliver that KYOSHIN-Monitor by Ustream and we got huge number of views and some perceptions for the future services.

2. Hypothesis and Techniques
KYOSHIN-Moniter (CGI) was planned for the expert uses. In the other hand, KYOSHIN-Monitor in Usteream (UST) is expected as a dynamic counterplan for enormous amateur access because of the reason below.
- Cloud live delivering services would support distribution of access and let us deliver in fewer costs.
- Ustream enables to provide for Smartphone through their original application.
In addition, to maximize the effect of UST, we shape the followings.
- We selected 2sec refresh rating for UST delivering while CGI is 5sec.
- We opened social stream using Twitter and Facebook as a set, We get announcing easily and spreading effect.

3. Result
Many users - about 1.27 million people accessed uniquely and 4 thousand users monitoring on the steady basis. We got 1st in ranking domestically and 2nd in rank of the Ustream all over the world. We picked up some reactions of users below.
3.1. Opposition plans to earthquake intoxication and earthquake psychoneurosis.
3.2. Measures of false report of real-time earthquake information.
And merits for information distributor (us) are below.
3.3. Cost reductions.
3.4. Got a lot of visibility.

4. Conclusion
It can be said that this example is an epoch-making case in the meaning of having enabled the offer of about 20 times access escaping from such excessive protection though it tends to put an excessive security network restriction on the information infrastructure when a lot of research laboratories and municipalities, etc. deliver information so far. It becomes possible to correspond to a lot of accesses without multiplying the substantial cost in shifting to cloud services of the mutual operation type excluding the case where a very large, clear disadvantage exists the inconvenience and the dissatisfaction of the users who pays a surplus cost to the conventional type information security that cannot completely exclude the personal risk. It is necessary to provide service that is solider (Do not fall) so that the severe earthquake monitor is accepted as a society's infrastructure by a lot of users, and it is necessary to grope low latency and high stability in cooperation with stronger cloud services.



Keywords: KYOSHIN-Monitor, Aftershock, Induced Earthquakes, Bosai-Education, Cloud service, access distribution

Japan Geoscience Union Meeting 2011
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MIS036-P175 Room:Convention Hall Time:May 27 14:15-16:15

High school students' recognition on earthquake and earthquake research(prompt report)

Norihito Kawamura[1*], Akihiko Naiki[2], Nobumitsu Aihara[3]

[1]Akita Univ., [2]Mita High School, [3]Nippa High School

Japanese abstract only.

Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS036-P176 Room:Convention Hall Time:May 27 14:15-16:15

Surface peels of the cross section of sand cones formed soil liquefaction and use as a teaching material

Tomohiro Kasama[1*], Saeko Ishihama[1], Shuichi NIIDA[1]

[1]Kanagawa prefectural museum

The reclaimed land around the Tokyo Bay, for example Urayasu, Chiba, was damaged by soil liquefaction of the 2011 off the Pacific coast of Tohoku Earthquake. Damage of soil liquefaction also occurred on the schoolyard. But the schoolyard is the important evacuation area in every school. There needs measures of soli liquefaction in the future.

Surface peels of cross section of boiling sand cones formed by soil liquefaction were made in the school yard of grade school at Mihama, Chiba on April 1. Almost of the sand cones formed along the fissure like scoria cones along the fissure eruption. The section was made in a right-angled direction to the fissure. The schoolyard was dug down a little, and the section in the boiling sand cone was made. Domestic adhesives of the spraying type, G17 and Z2 by Konishi Co., Ltd, was painted on the section. The cloth was put on the adhesive. The cloth was peeled off. The cross section of sand cone was on the cloth. The widths (or diameters) of the sand cones are several centimeters to tens of centimeters. These heights are several centimeters to about twenty centimeters. These widths (or diameters) of the vent of boiling sand are several centimeters to thirty centimeters. These boiling sand cones are smaller than Ishiga et al. (2001) of Tottori-seibu earthquake. The boiling sand cones are made of medium or fine sand containing shell fragments, and these surface are covered by very fine sand or silt. This fining upward unit is repeated twice or more, showing several boiling event. Some surface peels was donated to the grade school where surface peels was collected. These surface peels will be used as a teaching material of earthquake of sixth grader. We will search for the use method as the teaching material of the sand cone while confirming the children's reactions and report later.

Keywords: surface peel, boiling sand cone, teaching material

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MIS036-P177 Room:Convention Hall Time:May 27 14:15-16:15

Sedimentation in Oarai Sun-beach attacked by the 2011 off the Pacific Coast of Tohoku Earthquake 2011

Yasuhiko Makino[1*]

[1]Faculty of Education, Ibaraki Univ.

The Oarai Sun Beach in Ibaraki Pacific coast was attacked by the tsunami which was happened by the 2011 off the Pacific Coast of Tohoku Earthquake. This flat beach is 1km wide and 400m long in the land-seaward direction. This beach consists of very fine and fine sand, and is a prograding coast. After the earthquake, at first, high-energy currents of the tsunami attacked the coast to N-NNE direction. Subsequently return flows form erosional depressions. T

Keywords: the 2011 off the Pacific Coast of Tohoku Earthquake, tsunami sedimentation, Oarai Sun-beach, Ibaraki Prefecture

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comprehensive study of the distribution of radioactive materials released from the Fukushim Daiichi nuclear power plant

Mitsuru Ebihara[1*]

[1]Grad. Sch. Sci. Eng., Tokyo Met. Univ.

A huge earthquake (M 9.0) and coupled tsunami on March 11, 2011 yielded enormous damage in the area from north Kanto to whole Tohoku district. Besides direct disaster caused by earthquake and tsunami, equally severe accident happened at Fukushima Daiichi nuclear power plant of Tokyo Electric Power Company. By this accident, nuclear power reactors couldn't been controlled properly and eventually radioactive materials were released from the building to house nuclear power reactors and dispersed over rather wide area. Consequently, agricultural materials, drinking water and food were contaminated with radioactive nuclides, for which public people worried. Therefore, it is un urgent ask to settle such uneasiness for public people and objectively predict the possible influence caused by radioactive material over agricultural products for people engaging in agriculture. To grapple with this task promptly as well as effectively, scientists belonging to Geochemical Society of Japan, atmospheric and oceanic section of JpGU and Japan Society for Nuclear and Radiochemical Sciences were allied and presented a proposal for comprehensive and systematic survey of radioactive materials in the environment. In this project, samples are to be collected for atmosphere, rain, soils and nderground water as systematically as possible and as wide as possible for the sampling area. After sampling, samples are to be subjected to precise measurement of radioactivity under controlled counting protocol and data thus obtained are to be opened to the governmental sector as well as public promptly. At the same time, scientific meaning and information derived from such data are to be reported openly to appropriate academic societies as well as to the public.

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Radiological measurements in Iwaki City and along Joban Express highway by Geiger counter

Hirokuni Oda[1*], Isoji MIYAGI[1], Goto Hideyuki[2]

[1]Institute of Geol. Geoinfo., AIST, [2]Tsukuba Branch, Shorinji Kempo

We report radiological measurements in Iwaki City and along Joban Express Highway with Geiger counter on 17th April. Fukushima Daiichi nuclear plant released radioactive nuclides several times after Great East Japan Earthquake and Disaster on 15th March. 131-I, 134-Cs, 137-Cs,132-Te, 89-Sr, 90-Sr etc. might be expected according to the previous reports of MEXT etc. The measurements were conducted with Inspector+ Handheld Digital Radiation Alert Detector (S.E. International Inc.), which can detect alpha, beta and gamma emissions.

Keywords: Geiger counter, Iwaki City, Joban Express Highway, Radiation dose rate, Radiological Measurement, Beta disintegration

Japan Geoscience Union Meeting 2011
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On site measurement of radiation dose around the radiation-contaminated surface soil

Katsumi Marumo[1*], Yoshinori Hosokawa[2], Nobuhiko Wada[3], Shingo Itonaga[4], Noboru Narisawa[5], Naoki Ishiyama[6], Masahiro Ono[7], Shin-ichi Atsuta[4], Shunsuke Kawashima[8]

[1]AIST, [2]X-ray Precision Inc., [3]Environmental Consultant of Geology & Gr, [4]Taiseikisosekkei Co.,Ltd., [5]Japan Gas Appliances Inspection Associat, [6]Nihon Environmental Services Co.,Ltd., [7]Sumiko Resources Exploration & Developme, [8]Earth-Appraisal Co., Ltd.

On site measurement of radiation dose is a useful tool for mineral exploration of uranium resources. Based on the contribution airborne and carborne mapping, many world-class uranium mineral deposits were discovered in north America and Africa.

We attempted to measure radiation dose around the radiation-contaminated surface soil, caused by the nuclear accident at the TEPCO Fukushima No.1 nuclear Power Plant. Four nuclear reactors went out of control and caused large scale radioactive pollution. The measurements were performed on March 26th and April 2nd,2011, based on the idea that the radiation dose caused by Iodine-131(half-life 8 days) will be the best radionuclide tracer for mapping of radiation-contaminated surface soil.

We used Geiger-Muller counter, Cesium iodide (CsI) scintillation counter, ionization chamber type survey meter, and gamma-ray spectrometer, for measuring radiation dose around the radiation-contaminated surface soil at service areas (SA) and parking areas (PA) along Jyo-ban highway (from Chiyoda PA to Yotsukura PA) and Ban-etsu highway (from Sashio PA to Abukuma-kogen SA).

The radiation dose increased with approaching the TEPCO Fukushima No.1 nuclear Power Plant. The radiation dose of March 26th around the surface soil at Hitachi-chuo PA (98km away from the Fukushima No.1 nuclear Power Plant) were 5.3 microSV/hour and 1.7 microSV/hour by the ionization chamber type survey meter and Cesium iodide scintillation counter, respectively. Meanwhile, their radiation dose of April 2nd were 2.7 microSV/hour and 0.8 microSV/hour, respectively. The radiation dose of March 26th around the surface soil at Yunotake PA (49km away from the Fukushima No.1 nuclear Power Plant) were 40.4 microSV/hour and 7.8 microSV/hour by the ionization chamber type survey meter and Cesium iodide scintillation counter, respectively. Meanwhile, their radiation dose of April 2nd were 22.2 microSV/hour and 3.6 microSV/hour, respectively. The radiation dose measured by the ionization chamber type survey meter is significantly higher than the Cesium iodide scintillation counter, because the ionization chamber type survey meter is capable to measure both beta and gamma rays, whereas the Cesium iodide scintillation counter can monitor only gamma rays.

These data suggest that the radiation came mainly from the beta and gamma rays caused by the disintegration of Iodine-131. The gamma ray spectral graph obtained by the 2 inch NaI(Tl) scintillation gamma-ray spectrometer also suggest the gamma rays of Iodine-131 is the major source of the gamma rays.

The radiation dose of April 2nd around the surface soil at the Usuishi elementary school playground in Iitate village, Fukushima prefecture were extremely high (93.3 microSV/hour) by the ionization chamber type survey meter, suggesting the radioactive contamination of the rainwater made surface soil radioactive.

Keywords: Fukushima No.1 nuclear Power Plant, Geiger-Muller counter, Cesium iodide scintillation counter, ionization chamber type survey meter, gamma-ray spectrometer, radiation-contaminated surface soil

Japan Geoscience Union Meeting 2011
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The distribution map of radiation levels by grid survey in Fukushima prefecture

Kotaro Hirose[1]*, Fukushima University Radioisotope Distribution Research Team[1]

[1]Fukushima University

Grid radioactive survey was performed to obtain sufficient information for the fast estimation of dynamism of radionuclides released from the Fukushima Daiichi Nuclear Power Plant following a dysfunction of the cooling systems caused by the Tohoku - Pacific earthquake and subsequent tsunami. The surveys were performed between March 25th and March31st, 2011 at 372 locations in each 2 km grids of areas deemed critical within the 20-70 km range of the nuclear power plant. Measurements were conducted by surveyors who were standing at the edge of asphalt-paved roads while holding detectors aligned parallel to the road approximately one meter above ground level.

Two areas with higher rates are shown evidently on the map. One extends northwestward in a narrow angle over 20-30 km from the nuclear power plant with rates above 0.02 mSv/h. This distribution is found to be consistent with the model prediction by SPEEDI and aerial monitoring USDOE. Another area, which extends from Koriyama city to Fukushima city, is located between west of the Abukuma mountain district and east of the Ou mountain district with rates around 0.002-0.004 mSv/h. The distribution of this area is not consistent with model prediction or aerial monitoring. These two higher rates areas look to be contentious. However, relatively lower dose area extends between these higher dose areas, east of Fukushima city.

The present result clarified extensive and detailed distribution of radiation levels on the affected areas, and will contribute to politics providing basic information to verify the model prediction of dynamism of radionuclides, to assess the effect of radionuclides to human, other living things, or soil conditions, which are crucial for aquiculture or livestock industry.

Fukushima University Radioisotope Distribution Research Team: Asada T., Ikuta H., Kanazawa H., Kawatsu K., Kimura K., Hirose K., Koyama Y., Kurosawa T., Nagahashi Y., Nanba K., Nittono O., Oyama D., Sakai M., Shibasaki N., Shinoda N., Tai M., Takagai Y., Takahashi T., Takase T., Tanaka A., Tsutsumi T., Watanabe A., and Yamaguchi K.

Keywords: radiation level, distribution map, grid survey, Fukushima Daiichi Nuclear Power Plant, the Tohoku - Pacific earthquake

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Regional map of radioactive Cs in the agricultural soils affected by the accident of Fukushima nuclear power plant

Haruo Tsuruta[1*], Yousuke Sato[1], Makiko Hashimoto[1], Teruyuki Nakajima[1]

[1] AORI, The University of Tokyo

To clarify the effect of radioactive substances emitted by the accident of the Fukushima Nuclear Power Plant on agro-ecosystems, the surface soils of 0-15cm in depth were collected at rice paddy fields and upland fields in 10 prefectures from the end of March to early April 2011, and their Cesium (Cs) radioisotope concentrations were analyzed by National Institute of Agro Environmental Sciences and other analytical centers. After those data were published on the website of each prefecture, we collected those published data to make a map for the regional distribution of Cs radioisotope concentrations in south Tohoku, Kanto, and Hokuriku area. In this report, a preliminary result by the analysis of the map is summarized for a distinctive feature of regional distribution of Cs radioisotope concentrations.

Keywords: accident of Fukushima nuclear power plant, agricultural soil, Cesium radioisotope, regional distribution

Japan Geoscience Union Meeting 2011
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Building Resilience and Reducing Vulnerability to Tsunami Affected Paddy Fields in Nagapattinam District, India

Takashi Kume[1*], Chieko Umetsu[1], K.Palanisami[2]

[1]RIHN, [2]IWMI

Seawater inundation and deposition of marine sediment during the 2004 Indian Ocean tsunami caused salinization of soil and groundwater in coastal agricultural areas. These areas are sensitive to natural hazards like tsunamis; therefore, building resilience and reducing vulnerability are needed to minimize damage from unexpected disasters and aid recovery. To examine the engineering resilience of agricultural fields, we analyzed post-tsunami recovery of the soil?groundwater system and vegetation in the Nagappatinam district, Tamil Nadu, India, from 2004 to 2007, and we examined linkages among resilience, vulnerability, and hydrological regimes. Salinity measurements and monitoring using NDVI vegetation index data derived from satellite observations showed that the fields recovered from salinization to pre-tsunami levels within one and a half years. This rapid desalinization was due to the northeast monsoon rainfall leaching salt from the highly permeable soils in the area. From these results, engineering resilience of the ecosystem, expressed as recovery time, can be estimated at one and a half years. Although this region suffered from the 2004 tsunami, agricultural fields in the area can be characterized as highly resilient to tsunamis because monsoon rainfall enables rapid recovery from the salinization caused by seawater inundation. The same factors that make this coastal area highly vulnerable to damage from flood operate favorably in the case of tsunamis. The results of our study imply that the region's hydrological regime must be considered as a factor maintaining and building resilience to disasters like the 2004 tsunami.

Keywords: Indian Ocean Tsunami, Paddy Fields, Resilience, Vulnerability, Salinization

Japan Geoscience Union Meeting 2011
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Short-period spectral levels for aftershocks and foreshocks of the 2011 off the Pacific coast of Tohoku earthquake

Toshimi Satoh[1*]

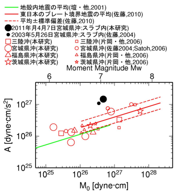
[1]Shimizu Corporation

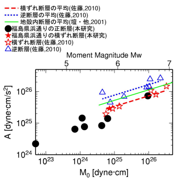
We estimate short-period spectral levels of acceleration source spectra for aftershocks and foreshocks of the 2011 off the pacific coast of Tohoku earthquake and previous earthquakes in this region by a spectral inversion method. We use two sets of data, that is, subduction-zone earthquakes off the Pacific coast and normal-faulting crustal earthquakes around the Fukushima coast.

The subduction-zone earthquakes are 10 interplate earthquakes with MJ 6.4 -7.7 and depth less than 60 km from October 2003 to March 28, 2011 and an intraplate earthquake occurred off Miyagi prefecture on April 7, 2011. The short-period spectral level of each earthquake is estimated using Q-value and empirical amplification factors estimated by a spectral inversion method (Satoh and Tatsumi, 2002) and strong motion records at K-NET and KiK-net stations. We also estimate short-period spectral levels of 7 normal-faulting crustal earthquakes with MJ 4.7 -7.0 and one strike slip crustal earthquake with MJ5.0 around the Fukushima coast by a spectral inversion method using K-NET and KiK-net (borehole) records with hypocentral distances less than 60 km. In the spectral inversion, one-dimensional amplification factor for S-wave at FKSH19 (Miyakoji) calculated using inverted soil constants from the seismic bedrock to the surface is used as a restricted condition. Q-value for path is represented as 70f{sub}0.9{/sub} using frequency f.

In a figure we show the relations between the short period spectral level A [dyne-cm/s/s] and the seismic moment M0 [dyne-cm]. The upper is for subduction-zone earthquakes and the lower is for crustal earthquakes. The short period spectral level (1.49e+27dyne-cm/s/s) of the intraplate earthquake occurred off Miyagi prefecture on April 7, 2011 is larger than that of the intraplate earthquake occurred off Miyagi prefecture on May 26, 2003 (MJ7.1). The short period spectral level of the interplate earthquake occurred off Miyagi prefecture on March 9, 2011 (MJ7.3) is a little smaller than that the interplate earthquake occurred off Miyagi prefecture on August 16, 2005(MJ7.1), but has the same scaling as the interplate earthquake occurred off Miyagi prefecture in 1978 (MJ7.4) and corresponds to the average + standard deviation of the empirical relation for interplate earthquakes occurred off the Pacific coast of east Japan derived by Satoh (2010). On the other hand, the short period spectral levels of the interplate earthquake occurred off Iwate prefecture at 15:8 on March 11, 2011(MJ7.4) and the interplate earthquake occurred off Ibaragi prefecture at 15:15 on March 11, 2011(MJ7.7) are 3.35e+26 dyne-cm/s/s and 6.19e+26 dyne-cm/s/s, respectively and lie between the average and the average-standard deviation. The short period spectral levels of the biggest normal-faulting crustal earthquake(MJ7.0) is 7.34e+25 dyne-cm/s/s and corresponds to the average of the empirical relation for strike-slip crustal earthquakes derived by Satoh (2010). The short period spectral levels of the second and the third biggest normal-faulting crustal earthquakes are smaller than the average of the empirical relation for strike-slip crustal earthquakes. This result that short period spectral levels for normal-faulting earthquakes are smaller than those for strike-slip earthquakes is the same result pointed by Satoh(2003) and is consistent with NGA (New Generation Attenuation) relations for response spectra.

Acknowledgements: This research was supported by the Ministry of Education, Science, Sports and Culture, Grant-in-Aid for Scientific Research (A), 21241044. Strong motion records observed at K-NET and KiK-net, and the PS-logging results by NIED are used. The fault mechanisms by F-net of NIED and hypocenter information by Hi-net of NIED and Japan Meteorological Agency (JMA) are also used.





Keywords: hort-period spectral level, the 2011 off the pacific coast of Tohoku earthquake, aftershock, foreshock, subduction-zone earthquake, normal-faulting crustal earthquake

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Tsunami situation of Chiba Prefecture Sanmu City due to the 2011 off the Pacific coast of Tohoku Earthquakethe.

Masatsune Hatakeyama[1*], Tamano Omata[2], Yasushi Obi[3], Fuminaga Noumi[4], Satoshi Miyajima[5], Nobumitsu Aihara[6], Susumu Yamaga[7]

[1]Seiko gakuin secondary school, [2]Jamstec, [3]Sagamihara Seiryo upper secondary school, [4]Saitama Omiyaminami lower secondary sch., [5]Fukayadaiichi upper secondary sch., [6]Nippa upper secondary school, [7]Azabu secondary school

This presentation is to provide a preliminary report on the tsunami of Chiba prefecture Sammu city due to the 2011 off the Pacific coast of Tohoku earthquake.

Sammu city is a city with the main seaside resort in the Hasunuma beach as for the corner of the Kujukuri coast.

One dead and 35 households in the house are completely destroyed in this city. The tsunami goes back the river and the waterway, and has caused the damage of the house destruction with the flood by the overtopping. This report looks at the realities of the flood on the coastal area, and the method of confirming the attainment point and the maximum height.

Keywords: The 2011 off the Pacific coast of Tohoku earthquake, Chiba prefecture, Sammu city, Tsunami, Tsunami attainment point, damage

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Structure of the rock failure toe slid on the snow surface induced by the Northern Nagano Prefecture Earthquake

Hidehisa Nagata[1]*

[1]Fu Sui Do co. ltd.

Many landslides and snow avalanches were occurred around the boundary between Nagano and Niigata Prefectures induced by the Northern Nagano Prefecture Earthquake (M 6.6) on March 12, 2011. Structure of the rock failure toe occurred at Tatsunokuchi, Tsunan Town, Niigata Prefecture is described here. The failure has the long runoff, which is a type of landslide to take care in the snow covered area.

The failure occurred right below at the western ridge of Mt. Eboshigatayama. The dimensions of about 100 m wide and 10 to 20 thousand cubic meters in volume are estimated from aerial photograph interpretation. The failure mass flowed down 700 m and buried Funetsunagigawa River and Route 353. The apparent friction angle is 20 degree, that indicates the fluidity of the mass was high.

Most sections of the toe show the stratigraphy of in situ snow cover, snow debris by the full-depth snow avalanche, and rock debris in ascending order. The snow debris including small amount of sandy or cohesive soil derived from cultivation has no snowfall structure, is brecciated, and is hardened. Rock debris including little amount of snow blocks is mainly composed of weathered mudstone in the lower or outer part, and of sandstone in the upper or inner part.

Such observation indicates that the moving mass was not simply formed by the mixture of the snow cover and rocks. It is likely that the full-depth snow avalanche involving surface soil and vegetation occurred before the rock failure. The following rock mass probably slid on the snow surface. High fluidity of the moving mass can be explained by this mechanism.

Keywords: rock failure, snow avalanche, Northern Nagano Prefecture Earthquak, Tsunan Town

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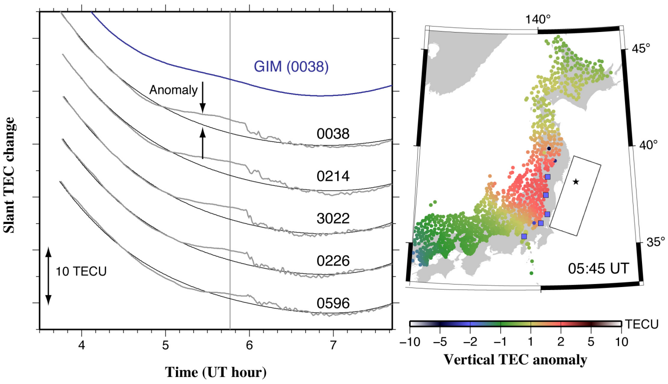
Ionospheric electron enhancement immediately before the 2011 NE Japan earthquake

Kosuke Heki[1*]

[1]Natural History Sci., Hokkaido Univ.

The 2011 March 11 earthquake in NE Japan (Mw9.0) caused vast damages to the country. Large events beneath dense observation networks could bring breakthroughs to seismology and geodynamics, and here I report one such finding. The Japanese dense network of Global Positioning System (GPS) detected clear precursory positive anomaly of ionospheric total electron content (TEC) over the region within 200-300 km from the focal region. It started ˜40 minutes before the earthquake and reached nearly ten percent of the background TEC. It lasted until atmospheric waves arrived at the ionosphere. Similar preseismic TEC anomalies, with amplitudes dependent on magnitudes, were seen in the 2010 Chile earthquake (Mw8.8), and possibly in the 2004 Sumatra-Andaman (Mw9.2) and the 1994 Hokkaido-Toho-Oki (Mw8.3) earthquakes. The ionospheric electrons might have been attracted by the positive electric charges appeared above the faults during the nucleation stage. The claim that earthquakes are inherently unpredictable may not be true at least for M9 class earthquakes.

The left panel of the figure shows the change of slant TEC observed with the satellite 15 at five GPS stations (their sub-ionospheric points are shown as blue squares in the right panel). The curvature of the time series comes mainly from the change in the satellite elevation. The vertical TEC was modeled with a cubic function of time as shown by black smooth curves, and the departures of the observed TEC from the models are defined as anomalies. Positive TEC anomalies are seen to grow immediately before the earthquake at GPS points close to the epicenter. Such positive TEC anomalies disappear after the passage of acoustic waves from the epicenter (i.e. the occurrence of coseismic ionospheric disturbances ˜10 minutes after the earthquake). The geographical distribution of these anomalies at 05:45 UT (1 minute before the earthquake) was plotted in the right panel. Latitudinal extent of the positive anomaly (shown in red) approximately overlaps with the ruptured fault. The blue curve in the left panel was drawn using a Global Ionospheric Map (GIM) downloaded from the University of Berne.



Keywords: TEC, GPS, 2011 Tohoku Earthquake, precursor, 2010 Maule Earthquake, 2004 Sumatra Earthquake

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Relocation and fault planes of the 2011 off the Pacific Coast of Tohoku and 1933 Sanriku earthquakes

Nobuo Hurukawa[1*]

[1]Building Research Institute

We relocated foreshocks, mainshock, and aftershocks of the 2011 off the Pacific coast of Tohoku earthquake (Mw 9.1) using the modified joint hypocenter determination (MJHD) method in order to obtain their accurate hypocenters and to identify fault planes of larger earthquakes. We used P-wave arrival times at stations worldwide reported by the U. S. Geological Survey (USGS). We confirmed by relocated hypocenters that the mainshock and aftershocks had occurred along the plate boundary between the North American and Pacific plates. We also confirmed that the Mw 7.5 foreshock, which occurred two days before the mainshock, and the largest aftershock (Mw 7.9), which occurred a half hour after the mainshock, are thrust earthquakes along the plate boundary. The second largest aftershock (Mw 7.6), which is a normal-faulting earthquake, occurred at outer rise of the Japan Trench and was well relocated with its aftershocks. We found that its fault plane is dipping westward with N-S strike. This implies that the western side of the fault plane had subsided and it leads to the westward plate subduction.

The 1933 Sanriku earthquake (M 8.4) and its aftershocks, of which epicentral area is located NE of the epicentral area of the 2011 event, were also relocated by the MJHD method. The relocated hypocenters indicate that the fault plane of the 1933 Sanriku earthquake dips westward with an angle of ˜30o.

Keywords: off the Pacific Coast of Tohoku earthquake, 1933 Sanriku earthquake, relocation, fault plane, joint hypocenter determination

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Active Faults along the Japan Trench and Large Earthquakes

Takashi Nakata[1*], Hideaki Goto[1], Mitsuhisa Watanabe[2], Yasuhiro Suzuki[3], Azusa Nishizawa[4], Noriaki Izumi[4], Koji Ito[4]

[1]Hiroshima University, [2]Toyo University, [3]Nagoya University, [4]Japan Coast Guard

It is very much regretful that we could not start our project on submarine active faults along the Japan trench before the devastating 311 Earhtquake. Fundamental information for prediction of large earthquakes such as the detailed distribution of active faults was not well known mainly due to lack of data regarding submarine topography. To make a more precise submarine active fault map along the trench, we have made detailed a submarine topographic images based on 0.002 degree (about 200m) DEM processed from the original data obtained by Japan Coast Guard.

Then we have made stereo-pair copies of topographic images for interpretation of active faults, similar in manner to how we use air-photo stereo sets for inland active fault interpretation.

Active fault distribution along and around the Japan trench is rather simple compared with that of the Nankai trough or/and the southwestern part of the Kuril trench. As mapped by a previous work (Research Group for Active Faults of Japan, 2001), there are trench-parallel north-dipping thrusts. One of the extensive thrusts extends from off-Sanriku to off-Ibaraki for over 500km, and is probably related to the source fault of the 311 Earthquake. source fault for Meiji Sanriku earthquake may be related to a 200km-long active fault along the trench off Sanriku.

Numerous normal faults are depicted on the outer-rise slope and they are generally short, and may cause M7 class earthquakes. The 1933 Sanriku earthquake is believed as one of the outer-rise earthquakes, but around the presumed source area we do not find any long normal fault that matches to a M8 class earthquake. One of the aftershocks of the 311 Earthquake probably took place along a long NNE-SSW normal fault on the outer rise off Fukushima. Normal faults densely distributed on the uplifted zone by extensive thrusting along the west of the trench, may suggest the site of asperity on the thrust.

Keywords: Japan trench, submarine fault, active fault, large earthquake