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

SCG74-01 Room:IC Time:May 24 13:45-14:00

Coseismic displacement of the 2011 Tohoku-Oki earthquake detected by repeated multi-narrow beam bathymetric surveys

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After the 11 March 2011 Tohoku-Oki earthquake, we carried out bathymetric surveys using the R/V Kairei in the rupture zone across the Japan Trench. Some survey tracks were aligned along the tracks obtained before the earthquake, and we analyzed the difference in bathymetry before and after the earthquake. Although the results may incorporate errors of several meters in vertical displacement and ˜20 m in horizontal displacement, the extraordinary coseismic displacement caused by the 2011 earthquake was detected by the bathymetric surveys.

Off the coast of Miyagi in the Tohoku district, the R/V Kairei surveys had been conducted in 1999 and 2004 [e.g. Tsuru et al., 2002 JGR; Ito et al., 2005 GRL; Miura et al., 2005 Tectonophys.]. For analysis, we used only the data obtained by beams within a 45^o swath width (3-6 km) because these inner beam soundings have higher accuracy and less effects of errors in water column sound velocity. Direct comparisons of absolute values of soundings were hampered by the differences of sound velocities used to calculate the depths and by the uncertainty of ship position. The apparent offsets were examined on the seaward side, because the seaward was thought to have suffered little change from the earthquake. For the 38^{o}N track, there were large relative differences landward extended up to the trench axis (˜144^{o}00'E, water depth ˜7600 m), suggesting the earthquake fault rupture reached the trench axis. The 2011 seafloor is shallower throughout the landward side. Notably, on the outermost landward slope, the 40 km wide area between the slope break (water depth 3700 m) and the trench axis, the difference between the 1999, 2004, and 2011 data shows the seafloor is ˜11-16 m shallower on average. Furthermore, locally upward and downward changes in seafloor elevation of +/-50 m are evident at the axial seafloor. These changes are likely due to seafloor deformation at the place of the plate boundary fault reaching the seafloor. Comparison of the 1999 and 2004 data obtained before the 2011 earthquake indicated no clear difference between the two sides of the trench axis.

The observed seafloor elevation change on the outermost landward slope corresponds to a sum of vertical displacement and additional uplift for the sloping seafloor due to horizontal displacement. We estimated the horizontal displacement by calculating the offset distance to maximize the cross-correlation of bathymetry. The estimated displacement is ˜50 m in the east-southeast toward the trench. After restoring the horizontal displacement, the average elevation change became ˜7-10 m in comparison between the 1999, 2004, and 2011 data. We interpret these to represent vertical displacement, from the fault motion along the subducting plate and uplift from other unknown processes such as inelastic deformation.

For the 38.5^{o}N track, bathymetric data comparison shows the same trend, and there are relative differences landward extended up to the trench axis (˜144^{o}05'E). Though, change in seafloor elevation along this track is smaller than that along the 38^{o}N track.

Combined with results of coseismic displacements determined at GPS/acoustic seafloor geodetic stations and other ocean-bottom instruments deployed off Miyagi [Ito et al., 2011 GRL; Kido et al., 2011 GRL; Sato et al., 2011 Science], our study demonstrates the coseismic displacement increasing toward the trench. This large horizontal displacement and the steeply sloping seafloor on the outermost landward slope having an average inclination of 5^o produced large additional uplift by ˜4-6 m in addition to the vertical displacement. This uplift was likely an important factor contributing to the generation of the massive pulsating pattern of tsunami waves observed by cabled seafloor pressure gauge [e.g. Maeda et al., 2011 EPS].

The 2011 survey, part of the program launched following the earthquake, was supported by a Grant-in-Aid for Special Purposes of the MEXT and a contribution from JAMSTEC.

Keywords: 2011 Tohoku-Oki earthquake, multi-narrow beam bathymetry, coseismic displacement, tsunami, sub-marine landslide

SCG74-02 Room:IC Time:May 24 14:00-14:15

Seafloor movements associated with the 2011 Tohoku Earthquake detected by GPS/acoustic geodetic observation

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The Hydrographic and Oceanographic Department, Japan Coast Guard, have been developing precise seafloor positioning systems using the GPS/acoustic combination technique under technical cooperation with the Institute of Industrial Science, the University of Tokyo and carrying out campaign observations along the major trenches in the Pacific Ocean, such as the Japan Trench and the Nankai Trough. The primary purpose of these observations is to detect and monitor the crustal deformation caused by the subduction of the oceanic plate near the plate boundary where huge earthquakes repeatedly occur.

On 11 March 2011, a large interplate earthquake [Mw = 9.0] occurred at the plate boundary off Miyagi Prefecture, northeastern Japan. Various studies have been under way to understand the mechanism of occurrence of this earthquake. For example, the Geospatial Information Authority of Japan (GSI) has reported coseismic displacements on land, on the basis of the dense GPS network. The largest displacement has been detected at the Oshika peninsula, amounting to about 5 m toward ESE and about 1 m downward.

Because the Oshika peninsula is located about 130 km away from the epicenter of the earthquake, it is preferable to measure crustal movements closer to the focal regions, that is, on the seafloor, to better constrain the focal mechanism of the event.

In order to monitor crustal movements offshore, we have been carrying out seafloor geodetic observations. Five sea-floor reference points were installed off the Tohoku region between 2000 and 2004 with campaign observations carried out three times a year on average. After the event, we conducted observations at these sites. Comparison between before and after the event yielded coseismic displacements of 5 to 24 m toward ESE and ?0.8 to 3 m upward. In particular, at reference point near the epicenter, we detected a huge coseismic displacement of about 24 m toward ESE and about 3 m upward. This is more than four times larger than that detected on land.

These results suggest that slip on the plate boundary near the trench exceeded the 20- to 30-m level estimated as a maximum by the terrestrial data, because slip on the plate boundary should be much larger than displacement of the sea floor.

With only five observation sites, we may not be able to constrain the detailed feature of focal mechanism, but we believe that the coseismic displacements obtained offshore in this study will provide far better constraints than only the terrestrial data in inferring a fault model for this event.

Keywords: Seafloor geodetic observation, the 2011 Tohoku earthquake

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SCG74-03 Room:IC Time:May 24 14:15-14:30

Seafloor vertical displacements related to the 2011 Tohoku-Oki earthquake observed by ocean bottom pressure gauges

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Seafloor vertical displacements related to the 2011 Tohoku-Oki earthquake were directly observed by in-situ ocean bottom pressure (OBP) measurements using autonomous gauges. In the vicinity of the hypocenter of the earthquake within a distance of 100 km, eight OBP gauges recorded OBP during several months including the time of the occurrence of the earthquake. In addition, we carried out several-months OBP observations after the earthquake at five sites on a landward slope of the Japan Trench between Miyagi and Aomori. The OBP observations starting before the Tohoku-Oki earthquake revealed coseismic seafloor vertical displacements of the mainshock (Mj9.0, 5:46 UT, 11 March), the largest foreshock (Mj7.3, 2:45 UT, 9 March), and the second largest foreshock (Mj6.8, 21:24 UT, 9 March), and associated slow displacements including postseismic displacements. This presentation summarizes these observational evidences. The observed coseismic displacements were meters, tens of centimeters, and centimeters for the mainshock, the largest foreshock, and the second largest foreshock, respectively. Detecting slow seafloor vertical displacements from OBP records seems difficult because OBP signals related to the slow displacements are contaminated by ubiquitous oceanic variations. The authors developed an ocean model based on a numerical simulation, and corrected the OBP data. As a result, a slow vertical displacement of centimeters was evident at a time from the largest foreshock to the mainshock. The postseismic displacements after the mainshock were evident as a subsidence at most sites near the hypocenter region. The subsidence was large at landward sites, and reached several tens of centimeters during several months. The OBP records starting after the earthquake will be examined considering a separation of postseismic displacements and instrumental drifts.

Keywords: ocean bottom pressure, seafloor vertical displacement, coseismic slip, slow slip, postseismic slip

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SCG74-04 Room:IC Time:May 24 14:30-14:45

Evolution of the postseismic slip associated with the 2011 Tohoku Earthquake based on land and seafloor geodetic data

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On 11 March 2011, the 2011 off the Pacific coast of Tohoku earthquake (M 9.0) has occurred on the plate boundary between the subducting Pacific and continental plates. This huge earthquake has been associating postseismic deformations as well as past large earthquakes that occurred around the Japanese Islands. Especially, the postseismic slip events that were associated with recent interplate earthquakes in the northeastern Japan subduction zone, such as 1993 Sanriku-Haruka-Oki (Mw 7.6) and 2005 Miyagi-Oki (Mw 7.2) earthquakes, released moments as large as the seismic moments that were released by their mainshocks (e.g., Heki et al., 1997; Miura et al., 2006). Ozawa et al. (2011) have already reported the postseismic slip associated with the 2011 off the Pacific coast of Tohoku earthquake based on the terrestrial continuous GPS observation performed by means of a nationwide GPS array, "GEONET." The postseismic slip has been still continuing at present, but the released moment is still relatively small (< Mw 8.6 according to GSI, 2012, http://www.gsi.go.jp/cais/topic110314-index.html) comparing with the seismic moment of the mainshock, M 9.0. Therefore, we expect that the postseismic slip will continue for a while. However, we can not estimate postseismic slip at the very shallow portion on the plate interface precisely based only on the terrestrial GPS data, because such offshore areas are too far from the coast of the northeastern Japan.

Thus, We investigated the spatial and temporal evolution of the postseismic slip on the plate interface based not only on the terrestrial GPS data but also on the seafloor geodetic data such as crustal movements measured by means of GPS/Acoustic ranging and vertical displacements observed by using Ocean Bottom Pressure gauges. We estimated displacements due to large aftershocks based on their CMT solutions, and subtracted them from the original displacement time series data. A time-dependent inversion method devised by Yagi and Kikuchi (2003) is applied to estimate the postseismic slip distributions. Usages of the seafloor geodetic data significantly improve the spatial resolution of the slip distribution near the Japan Trench as well as the coseismic slip distribution.

Preliminary result shows following features; 1) Large postseismic slip has been occurring at the very shallow (< 20 km in depth) portion on the plate interface off Ibaraki, Fukushima and Iwate prefectures where huge (~50 m) coseismic slip did not occurred, 2) Significantly large slip is distributed at the deep (> 50 km in depth) plate interface beneath Miyagi prefecture where no seismic event occurs, and 3) No postseismic slip may occur at the asperities in Miyagi-Oki region that ruptured during the Miyagi-Oki earthquake in 1978 and the M 9.0 mainshock in 2011.

We will present the latest result in the meeting.

Keywords: 2011 off the Pacific Coast of Tohoku Earthquake, Crustal Deformation, Ocean Bottom Pressure, GPS/Acoustic ranging, GPS, Postseismic Slip

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SCG74-05 Room:IC Time:May 24 14:45-15:00

Temporal evolution of afterslip following the 2011 Tohoku-oki earthquake

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We use GPS data recorded by the continuous GPS network, GEONET, to investigate afterslip following the March 11, 2011, Tohoku-oki earthquake (Mw 9.0). We analyzed GPS data after March 11 with the GIPSY-OASIS II software to estimate daily station coordinates. The daily GPS time series show large-scale postseismic deformation. The observed postseismic deformation is assumed to result from aseismic afterslip on the subducting Pacific plate interface and temporal evolution of afterslip distribution is estimated using a time-dependent inversion method. In the inversion, the curved plate interface is approximated with collection of many triangular dislocation elements. The Network Inversion Filter [Segall and Matthews, 1997] is applied to the GPS time series from March 11 to October 17, 2011, to estimate temporal variation of afterslip distribution. Our inversion analysis shows that afterslip is concentrated downdip of the coseismic rupture off Sanriku, off Miyagi, and off Fukushima. We find another afterslip patch that is adjacent to the rupture area of the largest aftershock off Choshi. Our analysis does not show significant temporal variation of spatial pattern of afterslip, indicating that afterslip propagated within a few days after the mainshock. As of October 17, 2011, the maximum cumulative afterslip is 2.79 m and the moment magnitude from the estimated afterslip distribution is Mw=8.52. Residuals between the observed and predicted displacements show a systematic pattern that is consistent with postseismic viscous relaxation.

SCG74-06 Room:IC Time:May 24 15:00-15:15

Co- and post-seismic slips of the 2011 Tohoku-oki Earthquake sequence from EOF analysis of GPS kinematic time series

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GPS kinematic time series are analyzed to estimate slip distributions for the M 9.0 2011 off the Pacific coast of Tohoku Earthquake sequence. Empirical orthogonal function (EOF) analysis is employed to enhance the signal-to-noise ratio of the original time series. The coseismic and subsequent postseismic deformations of the foreshock can be described by a single mode, suggesting that the extent of the source for both events must be similar. The total moment magnitude of the afterslip following the foreshock is estimated to be M 7.1 with a decay time of 0.63 days. The magnitude of the afterslip was larger for the duration than was anticipated by the scaling law for a typical slow earthquake, although two previous earthquakes in the adjacent regions showed the same tendency as that in the present case. No acceleration of quasistatic slip that may hint at the occurrence of a future mainshock was detected. The pattern of slips of the mainshock and the subsequent afterslips and aftershocks indicates that each slip occurs in a region adjacent to that of the previous slips in a complementary manner. Finally, in the course of the EOF analysis, the modes representing the thermal expansion of the GPS pillars are clearly identified.

Keywords: Kinematic GPS, Empirical Orthogonal Function, Coseismic slip, Afterslip

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SCG74-07 Room:IC Time:May 24 15:30-15:45

The 2011 Tohoku-oki Earthquake: Total Recovery of the Slip Deficit Accumulated in a Basement Asperity

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The Mw9.0 off northeast Japan (Tohoku-oki) earthquake occurred on March 11th of 2011 at the interface between the North American (NA) and Pacific (PA) plates. The occurrence of interplate earthquakes can be regarded as the sudden release of tectonic stress accumulated by the interseismic gradual increase of slip deficit in source regions. To obtain precise slip-deficit rate distribution on the NA-PA plate interface, Hashimoto et al. (2009) have analyzed GPS velocity data for the interseismic calm period of 1996-2000 with a unified inversion formula for Bayesian models with direct and indirect prior information (Matsu'ura et al. 2007). In this analysis, however, the updip limit of the model region is set to 4 km on the basis of geohydro-chemical studies for the strength of subduction zone plate boundaries, and so the inversion result might be biased especially in the shallow part of the plate interface. In the present study, to obtain unbiased slip-deficit rate distribution, we reanalyzed the same interseismic GPS velocity data with the same inversion procedure but without setting any updip limit of the model region. The result of the inversion analysis clearly shows the existence of five remarkable slip-deficit zones distributed on the NA-PA plate interface along the southern Kuril-Japan trench. We also analyzed coseismic GPS displacement data for the Tohoku-oki earthquake with the same inversion method, and obtained the bimodal distribution of coseismic slip spreading over the southern two, Miyagi-oki and Fukushima-oki, interseismic slip-deficit zones. The maximum slip is 32 m for the Miyagi-oki slip-deficit zone but only 7 m for the Fukushima-oki slip-deficit zone. The extraordinarily large coseismic slip in the Miyagi-oki slip-deficit zone, where ordinarily large earthquakes with about 3 m coseismic slips have repeated every 40 years in the past two centuries, suggests the total rupture of a 300-km-long basement asperity underlying much smaller-scale local asperities.

Keywords: the 2011 Tohoku-oki earthquake, GPS data inversion, interseismic slip deficit, coseismic slip, basement asperity

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SCG74-08 Room:IC Time:May 24 15:45-16:00

Accelerated subduction of the Pacific Plate

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In NE Japan, GPS stations move landward, and the velocity gets faster as the inter-plate coupling becomes stronger (interseismic crustal deformation). Once an interplate earthquake occurs, coseismic trench-ward movements occur and subsequent slow movements continue while the afterslip lasts. We divide the plate boundary in NE Japan into three segments, i.e. (1) Tokachi-oki, (2) Aomori-oki and Rikuchu-oki, and (3) Miyagi-oki and Fukushima-oki, from north to south. There relatively stable and uniform interseismic deformation continued in 1996-2003. Since 2003 autumn, however, these three segments have been in different situations. Here we study time evolution of plate coupling in these segments from a macroscopic viewpoint.

The figure shows the trench-ward (N110E) movements of the three GPS stations in Taiki (Hokkaido), Kuji (Iwate) and Soma (Fukushima), which reflect coupling in the segments (1), (2), and (3), respectively, from the F3 solution of GEONET. Long-term trends inferred from pre-2003 data are removed to isolate changes in trend after 2003. Large coseismic movements of the 2003 Tokachi-oki (Mw8.0) and the 2011 Tohoku-oki (Mw9.0) earthquakes are removed for visual simplicity.

In Taiki, afterslip of the 2003 earthquake is obvious, and the time series after that suggests that the coupling in (1) has not completely recovered till now (positive slope still remains). Similar decoupling is seen also in the segment (3). There, the coupling seems to be progressive weakening since 2003 (positive slope gradually increases). Microscopic inspection reveals that this comes from a series of M7 class earthquakes, i.e. the 2003, 2005, 2011 Miyagi-oki events (M6.8, 7.2 and 7.3), the 2008 Ibaraki-oki event (M6.9), and the 2008, 2010 Fukushima-oki (M6.7, 6.2) events, and their disproportionally large afterslips. From macroscopic point of view, however, these earthquakes could also be interpreted as ruptures of relatively small asperities occurred as parts of a huge slow earthquake that started in 2003 and continued until the 2011 Tohoku-oki earthquake.

In the segment (2), no large interplate events occurred during this period. The Kuji GPS station, in northern Iwate, showed a sudden increase of coupling (almost double) in 2003 September as seen by a clear break in slope. It is unlikely that interplate friction suddenly increased by nearby earthquakes. Here we hypothesize that this rather reflects the accelerated subduction and consequent apparent strengthening of the coupling in the segment (2).

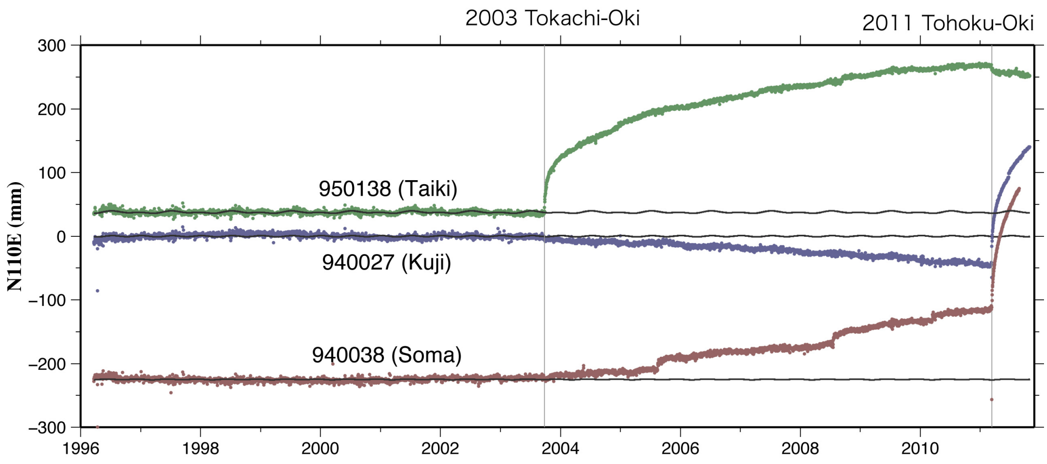
When a large interplate earthquake decoupled the plate interface, subducting slab would be temporarily accelerated. This, however, will not enhance the slip deficit of the adjacent segment, i.e. decoupling in the segment (1) would not accelerate the landward movement of Kuji. If the entire slab spanning from (1) to (3) behaved like a coherent body, the segment (2) would follow the acceleration of the other segments.

The two opposite forces are exerted on the slab near a trench, i.e. slab-pull in the down-dip direction, and friction caused by interplate coupling in the up-dip direction (the latter is visible as the slip deficit with GPS). Their balance maintains stationary subduction. Once a certain segment is decoupled, the slab pull temporarily exceeds the friction and would let the slab accelerate until the increased coupling realizes a new equilibrium. The time series of the Kuji station suggests that such an adjustment occurs in a relatively short time, say a few days.

(Figure)
Trench-ward (N110E) movement of the three GPS stations in Taiki (Hokkaido), Kuji (Iwate) and Soma (Fukushima), detrended using data before 2003. Large coseismic movements are removed for visual clarity. In response to the decrease of the coupling (trend becomes upward) at Taiki and Soma, coupling increases (trend becomes downward) in Kuji.

Keywords: Northeast Japan, GPS, Interseismic crustal deformation, Pacific plate, acceleration, 2003 Tokachi-Oki earthquake

SCG74-08 Room:IC Time:May 24 15:45-16:00



SCG74-09 Room:IC Time:May 24 16:00-16:15

Post-seismic vertical crustal movements due to the Tohoku-Oki earthquake of 11 March 2011

KATO, Teruyuki[1*], FUKUDA, Jun'ichi[1], TANAKA, Yoshiyuki[1], AOKI, Yosuke[1]

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This presentation reports the progress of investigations on the vertical crustal movements due to the 11 March 2011 Tohoku-oki earthquake (Mw9.0), northeastern Japan. Nationwide GPS array showed more than 1m of co-seismic land subsidence along the pacific coast of the Tohoku district. While the coast was not uplifted by the co-seismic slip, it was expected that the coastal subsidence before the earthquake together with co-seismic subsidence could be recovered by the post-seismic uplift due to combined effects of a slow slip at the deeper extension of the plate interface and subsequent visco-elastic stress adjustment in the crust and the upper mantle. For example, post-seismic crustal deformations in the southern Shikoku after the 1946 Nankai earthquake had been interpreted by this mechanism.

Time series of coordinates of GEONET array after the 2011 earthquake during the first several months after the earthquake showed slight uplift of the Sanriku coast and they were assumed to be due to the slip along the deeper plate interface along the Sanriku coast (Fukuda et al., AGU Fall meeting 2011). The maximum slip amounted to about 2.5m. However, the slip is not reaching deep enough to uplift the coast efficiently. The uplift of the coast in the first half year after the main shock has been only a few centimeters. A simple extension of the transient displacements with a logarithmic function suggests that the coast will never recover the co-seismic subsidence in the coming decades of years.

Visco-elastic adjustment using a model that assumes elastic crust and a visco-elastic upper mantle, predicts a little more complicated progress of vertical motions in the area (Tanaka et al., AGU Fall meeting 2011). Though it suggests some recovery uplift, in particular, in the southern part of the source area, the whole coast will subside in the coming 1000years or longer. Such visco-elastic process may continue for more than several thousand of years and might converge to slight subsidence compared with that before the earthquake. Considering that the super large earthquake may repeat in 1000 years or so, integrated effects of visco-elastic stress adjustments may accumulates subsidence in longer time elapse, which seem to contradict with a geomorphological evidence.

One question we may have to raise, given this consequence, is that the pre-seismic subsidence along the Sanriku coast would be due not to the coupling of the plate interface but to the visco-elastic effects by one or multiple super large earthquakes that have ever occurred in the past hundreds or thousands of years. More detailed investigations will be needed to confirm the mechanism.

Keywords: GPS, Tohoku-oki earthquake, post-seismic crustal movement, crustal movement, visco-elastic adjustment

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SCG74-10 Room:IC Time:May 24 16:15-16:30

The inter-, co- and post-seismic crustal deformation in the Tohoku region by the kinematic earthquake cycle model

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The Northeast Japan arc is a typical arc formed by the subduction of the Pacific plate beneath the North American plate. The interplate earthquake has been considered to be of M7 at the maximum. However, after Mw 9.0, the 2011 off the Pacific coast of Tohoku earthquake, tectonics of the Tohoku region of the northeast Japan should be reexamined under the environment of great earthquake cycles.

From geological observations, the Northeast Japan arc is considered to be under east-west compression. The late Quaternary vertical deformation is estimated to be uplift in the whole Tohoku region, revealed from the distribution of marine and river terraces. On the contrary, geodetic observation of the recent 100 years shows subsidence up to 5˜10 mm/yr particularly on the Pacific coast. In terms of long-term balance, great uplift is expected at the great earthquake. In fact, GPS observation shows further subsidence at the 2011 off the Pacific coast of Tohoku earthquake. Therefore, it is necessary to reveal the stage of the earthquake cycle where the deformation turns to uplift, and its mechanism. On the other hand, seismicity of inland area of Tohoku is mostly reverse fault of east-west compression before the great earthquake. However, this type of earthquakes is notably decreased.

As is stated, the crustal deformation and the pattern of inland earthquake reflecting the regional stress fields are variable at each stage of the earthquake cycle. Because each of them is caused by the plate subduction and associated earthquake cycles, we should construct the model to explain these features in the big picture. One of the models is the plate subduction model with the elastic dislocation theory. In this study, we examine the temporal variation of subsidence in the later stage of the earthquake cycle, subsidence at the time of the earthquake, and long-term uplift.

In this study, we take the two-dimensional geometry of the plate interface from the vertical section of the CAMP model near the epicenter of the Tohoku earthquake. The slip on the plate interface is decomposed into 3 components: steady slip on the whole plate interface (steady subduciton), increase of slip deficit in the locked region (interseismic locking) and periodic seismic slip. We give plate relative velocity (10 mm/yr) as steady slip and assume that fracture occur each 1000 years on the locked region of the horizontal 500-km width extending to 40-km depth. In the long-term deformation model, it is necessary to consider viscoelasticity in the asthenosphere. Here, we assume elastic surface layer over viscoelastic half-space as lithosphere-asthenosphere system.

First, long-term deformation is affected only by the effect of steady subduciton, regardless of the coseismic slip. The deformation shows subsidence at the trench and uplift in the arc region, which agrees with the long-term uplift in Tohoku. The coseismic deformation shows uplift at the upper edge of the slip region and subsidence at the lower edge and inland area.

The interseismic deformation clearly depends on the extent of fracture in the elastic lithosphere. In the case of the earthquake dividing the lithosphere entirely (lithospheric thickness H = 40 km), the arc region uplifts due to the effect of the interseimic locking. In the case of the introduction of steady slip region below the coseismic slip (H = 50 km), the inland region uplifts in the 200 years after the earthquake. On the other hand, 400 years before the earthquake, inland region turns to subsidence. This result is consistent with the subsidence in Tohoku in the later stage of the earthquake cycle.

In the earlier stage, the effect of viscoelastic response to the coseismic slip is dominant and in the later stage, the intersesmic locking. The results also show the importance of the observation of the long-term deformation in the ocean area of the Pacific coast, because the vertical deformation pattern strongly depends on the distance from the trench axis.

Keywords: 2011 off the Pacific coast of Tohoku earthquake, Crustal deformation, Earthquake cycle, Viscoelasticity, Steady subduction, Tectonics