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

SSS27-P01 Room:Convention Hall Time:May 23 17:15-18:30

Attenuation measurements of ultrasonic wave in partially frozen unconsolidated sands

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Ultrasonic wave transmission measurements were conducted in order to examine the influence of ice-brine coexisting system grown in unconsolidated porous material on ultrasonic P- and S-waves. We observed the variations of a transmitted wave, changing its temperature from 25 degree C to -15 degree C and quantitatively estimated attenuation for unconsolidated porous material during the freezing of brine in porous material by considering different distances between the source and receiver transducers. This paper is concerned with attenuation at ultrasonic frequencies of 350-600 kHz for P-waves and 150-250 kHz for S-waves. The waveform analyses for P-waves indicate that the attenuation curves reach their peak at a temperature of freezing point and gradually decrease with decreasing temperature, which is interpreted as the increase of the ice fraction or the increase of the effective bulk modulus of the system. The waveform analyses for S-waves indicate that the attenuation decreases with decreasing temperature, which is interpreted as the increase of the effective shear modulus of the system due to the increase of cementation of ice in the frozen sand. The laboratory experiments of the present study demonstrated that ultrasonic waves with such a frequency range are significantly affected by the existence of a solid-liquid coexistence system in the porous material. From liquid phase to around the freezing point, the presence of a partially frozen brine increases both velocity and attenuation. Attenuation estimation for P-wave is repeatable and stable while that for S-wave is not. However, the frequency content of S-wave shifts to higher with decreasing temperature. This implies that the attenuation decreases with decreasing temperature. In terms of a plausible mechanism for attenuation, we must consider the physical interactions between pore fluid, sands, and ice, that is, the pore microstructure and permeability in such system is important. Furthermore, several considerations on velocities using some theoretical models are also demonstrated.

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SSS27-P02 Room:Convention Hall Time:May 23 17:15-18:30

Preliminary study to estimate elastic impedance in ground surface layer

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Dynamic response of structures during earthquakes depends on physical parameters in the ground due to the dynamic soil-structure interaction. The influence is complicated, but it is known that elastic impedance of ground layer associates with the radiation damping.

Normalized Energy Density (NED; Goto et al., 2011a) is a physical quantity related to wave propagation in multi-layered ground, and it becomes a constant value through each layer independent of how layer structure is. This characteristic enables us to directly estimate damping property of the layered ground when we observe NED in ground surface layer and NED in ground equivalent to the basement even we do not know concrete velocity structures of the layered ground (Goto et al., 2011b). NED is the function of elastic impedance in each layer. This means that it is necessary to measure the impedance in ground surface layer in order to calculate NED in ground surface layer.

In this study, we perform preliminary study by numerical experiment using finite difference method in order to consider a method of measuring elastic impedance in ground surface layer.

Hiroyuki Goto, Sumio Sawada and Toshiyuki Hirai: Conserved quantity of elastic waves in multi-layered media: 2D SH case -Normalized Energy Density-, Wave Motion, 48, pp.602-612, 2011.

Hiroyuki Goto, Sumio Sawada, Yuichi Kawamura, Toshiyuki Hirai and Takashi Akazawa: Definition of normalized energy density and its application to direct estimation of damping property, The 4th International IASPEI/IAEE Symposium on the Effects of Surface Geology on Seismic Motion, 2011.

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Performance tuning of the Seism3D, the seismic wave propagation code, for large-scale parallel simulation using K comput

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The "K computer" is the world's fastest super computer at present which has the maximum peak speed of more thatn 10 PFlops (Yonezawa et al., 2011). By using the huge computer resource of K, it is expected that there are massive improvements on numerical simulations such as seismic wave propagation or plate motion simulation in seismology. However, the K computer has more than 80,000 nodes (CPUs) that require us to highly tuned parallel computation. Additionally, the K's CPU has lower memory access speed relative to their flops. To overcome these technical difficulties, we measured the theoretical performance of our seismic wave propagation code "Seism3D" and did performance tunings from the aspects of the parallelization performance and single-CPU performance.

The Seism3D is a numerical simulation code based on the staggered-grid, finite difference method (FDM) explicit solver of the equation of motion of elastic medium (Furumura and Chen, 2005). We have improved the code in several aspects. First, we substituted the constitutive equation between stress and strain from the liner elastic solid to the generalized Zenner body to take broadband intrinsic attenuation into account. Second, the split-PML technique is used for an absorbing boundary condition at the model edges. This choice also enables us to simulate coseismic deformation at the sea floor and/or ground surface in addition to the seismic waves. The code can be extended naturally by incorporating the gravity and equilibrium between gravity and pressure field (Maeda and Furumura, 2011).

Simulation using the Seism3D requires large amount of memory access for referring inhomogeneous earth medium and wave/stress field at each time step. However, recent supercomputers including the K have relatively lower memory access speed compared to their CPU speed. Therefore, the ration between amount of the computation and amount of the memory access determine the maximum performance of the Seism3D as about 16 %.

For massive parallel simulations based on the MPI we also investigated the parallel balance between computational nodes. We found that the horizontal 2D partitioning, not 3D, is best for the computational performance. The single node assigns a rectangular parallelepiped shape having extremely long in the vertical direction. To obtain better performance, we exchanged computational loops among space so that the computation along z-direction is in the innermost loop. By this change, the continuous memory access is assured.

The data read from the memory are placed on L1- or L2- cache temporally. Because the access speed to cache is far faster than that to memory, the effective use on cache is mandatory for effective computation. In this point of view, we also tuned the cache access up (Minami et al., 2012). The K computer share the L2 cache among 8 CPU cores inside the nodes. By using this characteristic, we re-arranged the openMP-based parallelization inside a node so that at least the neighbor core can reuse the data on cache.

As a result, we achieved the 16 % of the maximum performance, which is almost the maximum speed of the Seism3D theoretically, on the K computer by the abovementioned tuning on benchmark codes. We will present the technical detail and some example of large-scale simulation by using the K computer.

Acknowledgements
This study is supported by the SPIRE field 3, MEXT. Part of this result is obtained by early access to the K computer at RIKEN Advanced Institute for Computational Science.

Keywords: Seismic wave propagation, numerical computation, numerical simulation, parallel computation, tuning

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Influence of Antarctic ice sheet on seismic waveform observations at intra-Antarctic region

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Recently, a lot of temporal broadband seismic stations had been installed on the intra-Antarctic region by the projects related to the International Polar Year (IPY) 2007-2008. Antarctica is known as a window toward the Earth's deep interior since it is the seismically quietest location on the Earth, it has wide extent enough to cover large epicentral distances needed to detect various seismic phases, and seismic waves observed at Antarctica cross regions within the Earth that previously have been sampled only poorly. We have been working to construct an accurate and efficient technique to model global seismic wave propagation. Our numerical scheme solves wave equations in spherical coordinates using the finite-difference method (FDM) based on the "2.5-D approach" which calculates 3-D seismic wavefields on a 2-D cross section of the Earth (e.g., Toyokuni et al., 2005, *GRL*).

This time, our method is applied to investigate influence of Antarctic ice sheet on observed seismograms obtained at intra-Antarctic region. We calculate synthetic seismograms for both a spherically symmetric Earth model PREM (Dziewonski & Anderson, 1981, *PEPI*) and a laterally heterogeneous model with a simplified ice sheet. In order to reduce equations and calculate synthetics up to higher frequency, only SH wave is simulated by using a torque source assigned at a depth of 600 km. The ice sheet model has a constant thickness of 3 km and single values of the density (0.914 g/cm^3) and the S-wavespeed (2 km/s). In the presentation we will show several results obtained for source time functions with various pulse widths (4 s-30 s).

Keywords: seismology, synthetic seismogram, finite-difference method (FDM), global modeling, IPY2007-2008, Antarctica

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Effect of complex surface topography on the distortion of the apparent S-wave radiation pattern

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Introduction

In the high frequency (f > 1 Hz), the observed maximum amplitude pattern don't show clear four-lobe pattern expected from a double-couple source [e.g. Liu and Helmberger, 1985; Takemura et al., 2009]. By analyzing a large number waveform data, Takemura et al. (2009) concluded that the main reason of such distortion is the seismic wave scattering due to small-scale velocity fluctuation in the medium. However, the resent studies revealed that the scattering due to irregular topography is also important for the propagation of high-frequency seismic waves. In order to clarify the effect of irregular surface topography on the distortion of the apparent S-wave radiation pattern, we conduct FDM simulations of seismic wave propagation in the model including topography.

FDM Simulation including heterogeneous topography

Our simulation model covers a zone 128 km by 128 km by 64 km, which has been descretized with grid size 0.1 km in horizontal direction and 0.05 km in vertical direction. In order to conduct such large scale simulations, we use a parallel staggered-grid FDM simulation technique. We assume the heterogeneous surface topography model provided by Geospatial Information Authority of Japan. In order to achieve precise simulation of high-frequency wave propagation, we employ the suitable boundary condition at the free surface [e.g. Okamoto and Takenaka, 2005; Maeda and Furumura, 2011].

We also assume the stochastic random heterogeneity characterized by exponential auto-correlation function with correlation distance a = 5km and rms value e = 0.05 and compare scattering properties of both heterogeneities. We assume a pure-strike slip at the center of model, depth h = 5 km, and so expected apparent S-wave radiation pattern at the free surface is a four-lobe shape

Simulation results

We conduct FDM simulation of seismic wave propagation in the three models, 1) uniform velocity structure model with surface topography, 2) flat surface model with stochastic random velocity fluctuation and 3) uniform back ground velocity model with both heterogeneities. We examine the maximum amplitude pattern of mean square envelopes for the sum of three components in frequency band of 2-4 Hz.

In the model 1, the amplitude pattern shows the four-lobe pattern maintains a four-lobe pattern, although the amplifications due to topography occur at the mountain regions. On the other hand, in the model 2, the effects of diffraction and scattering due to velocity fluctuation are accumulated during propagation and at larger distance (D> 30 km) the amplitude pattern is clearly collapsed from four-lobe pattern. In the model 3, the distortion become 11% stronger compared with the model 2 which is including velocity fluctuation alone.

Takemura et al. (2009) estimated the parameters of velocity fluctuation in the southwestern Japan by comparison of observation and simulation including velocity fluctuation alone. Therefore the estimation of velocity heterogeneities may be overestimated by the effect of irregular topography. We may be able to estimate the velocity fluctuation more precisely by considering the effects of irregular topography.

Acknowledgement

The computations were conducted on the Earth Simulator at the Japan Marine Science and Technology Center (JAMSTEC).

Keywords: Seismic wave propagation, Seismic wave scattering, Small-scale heterogeneity, topography, numerical simulation

SSS27-P06 Room:Convention Hall Time:May 23 17:15-18:30

Lateral structure beneath the Izu-Nankai collision zone: Implication of a plate split in the subducting Philippine slab

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On July 5, 2011, an earthquake with a magnitude of 5.5 occurred off the Kii Peninsula in the northern Wakayama Prefecture in southwest Japan within the subducting PHS plate at depth of around 10 km. The earthquake caused strong shaking in the area near the epicenter. We analyzed the waveforms from this earthquake recorded at Hi-net and F-net stations in Japan. Such waveform analyses exhibit most of the earlier observations like dominance of low-frequency ($f < 0.25$Hz) onset and following high-frequency ($f > 2$Hz) energy with long coda due to the stochastic waveguide effect of the subducting plate, proposed earlier by Furumura and Kennett (2005). Interestingly, we observed a clear difference in wave propagation pattern between east and west of the epicenter. For example, the waveforms for eastern part show S-coda are depleted with high frequency energy as compared to the western part. The duration of S-coda varies alternatively between high and low from east to west through center of the epicenter. The central stations show loss of low-frequency precursor to P-waves and presence of converted phases in P-coda. Such complexities in the observed waveforms are difficult to explain due to the radiation pattern of P- and S-waves and/or by anomalous propagation of seismic waves in existing plate model, indicating sudden lateral change in the wave guiding properties of the subducting slab, such as caused by the splitting of the slab as proposed by Ide et al. (2010).

To explain the observations, we employ two-dimensional finite-difference method (FDM) simulations of complete high-frequency P-SV wave propagation taking thinning of the PHS slab into account. In the plate model we included stochastic random heterogeneities described by von Karmann distribution function with a longer correlation length of 10 km in horizontal direction and much shorter correlation length of 0.5 km in depth and standard deviation from background P- and S-wave velocities of 5% following the study of Furumura and Kennett (2005). We expect that the observed guided wave energy decouples from the waveguide where the slab is split. Low frequency energy leaks out of the slab in the low velocity mantle surrounding the slab. Taking into account the distribution of seismicity and focal mechanisms (Ide et al., 2010), and receiver function analyses (Shiomi et al., 2004) in the PHS plate, we expect a local velocity discontinuity or splitting of the plate at least to a depth of 30 km. Such a split in the PHS plate structure could also be manifested as non-volcanic tremor sources in the southwest Japan (Obara, 2002). The preliminary results, which suggest that the Philippine Sea slab is strongly split or partitioned beneath the Izu-western Nankai Trough in southwestern Japan, is the cause of the complicated waves from shallow inslab events. These effects need to be tested further with a 3-D FDM simulation employing high-performance computers with a variety of possible slab geometries. We finally discuss the implications of the new split plate model on the seismogenic potential of the area and the dynamics of the Nankai subduction in southwest Japan.

Keywords: philippine sea plate, wave propagation, numerical simulation, coda

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Ambient noise tomography in the eastern margin of the Japan Sea, NE Japan

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Seismic inteferometry has been used to estimate subsurface structure. Seismic inteferometry is based on the fact that cross-correlation function of random wavefields observed at a pair of stations contains Green's function between the two stations. Recently, seismic interferometry has been applied for ambient noise to estimate velocity structure, called ambient noise tomography. In this study, we applied this method for data of a dense seismic network in the region of the eastern margin of the Japan Sea. We estimated group velocity under the Sea of Japan and the western part of Tohoku region.

Date are vertical component of continuous record observed at 90 seismic station of Hi-net, JMA, Tohoku University, and temporary seismic stations installed for 'Multidisciplinary research project for high strain rate zone' promoted by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan. Time period of data is 10 months from January 2009 to October 2009.

First, we calculated daily cross-correlation function for each pair. We divided day-long data into 287 segments with a length of 10 minutes and with an overlap of 5 minutes and downsampled the data with a sampling with a sampling frequency of 20 Hz. Then we corrected instrument response. In order to avoid contamination of outliers such as natural earthquakes and packet deficits due to error of data transfer, we did not use the segments that include outliers. Determination of the earthquake was carried out automatically by using a root-mean-square value of the amplitude. After these procedures, we applied a fast Fourier transform for data segments and multiply the spectrum of the first segment with the complex conjugate of the second spectrum. The cross-spectra is normalized by spectral amplitude of both segments. We computed averaged cross-spectra over all segments. The daily cross-correlation function is obtained by applying invert Fast Fourier transform for the averaged cross-spectra. Finally, we stacked all available cross-correlations functions for each station-pair during 10 months.

We applied band-pass filter for the cross-correlation functions with three periodic bands 2-5 sec, 5-10 sec, and 10-20 sec. Line up of the cross-correlations in order of separation distance between the two stations shows clear seismic wave propagation with an apparent velocity of 3 km/s, which corresponds to the fundamental mode of Rayleigh wave. We estimated group velocity in the period of 5-10 sec, which the peaks emerge. Group velocity between two stations is calculated by dividing the separation distance by the peak time of envelope function. As a first step, we averaged group velocities between certain station and all the other stations and estimated average velocity for each station. The average velocity of each station is about 2.5-3.5 km/s.

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An application of seismic interferometry for DONET data

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From 0.05 to 0.2 Hz, background surface waves, known as microseisms, are dominant, and they mask seismic signals of earthquakes. The microseisms are excited by oceanic-swell activities at random. Recently using their random excitation properties, researchers have developed ambient noise tomography (e.g. Shapiro et al., 2005). The group velocity anomaly of Rayleigh wave is shown by cross-correlation functions between pairs of stations. The measurements by modern dense networks of broadband seismometers reveal fine tomographic images. There is an application of seismic interferometry for data of ocean bottom seismometers [e.g. Harmon et al, 2007, Yao at al., 2011], but investigations of their propagations are still ongoing in particular in high frequency (>0.1 Hz). In this study, we will clarify properties of wave propagation using a dense network on the sea floor. We analyzed vertical components of broad band seismometers (Guralp CMG3T) and pressure (absolute pressure gauge of Paroscientific inc.) from 2011/7/19-7/29 at 18 stations of Dense Ocean floor Network System for Earthquakes and Tsunamis (DONET), which consists of 5 sub arrays. We divided the records into segments of 409.6 s, and we discarded transients such as earthquakes and local noises. We calculated their normalized cross-spectra between all pair of stations. Corresponding cross-correlation functions (CCFs) of vertical components show clear Rayleigh wave propagation below 0.1 Hz. Because observed Rayleigh waves have sensitivity to accretionary wedge from 0.1 to 0.5 Hz, their waveforms are distorted with long coda parts. Above 0.5 Hz, Scholte waves, which are boundary waves between a fluid layer and a solid layer [e.g. Yao et al., 2011], become dominant. Their phase and group velocity is around 1.5 km/s. CCFs of pressure gauge also show similar features except for those at stations above thick accretionary wedge. At the stations from 0.2 to 0.5 Hz, fundamental Rayleigh waves are dominant in vertical components, whereas first overtones are dominant in pressure records. We estimated dispersion curves from CCFs, based on Aki's SPAC method. In regions of thick accretionary wedge, fundamental Rayleigh waves are not clear from 0.2 to 0.5 Hz in vertical components. Their phase velocity is about 500 m/s, whereas phase velocity in other regions is about 1000 m/s. Observed frequency is consistent with results of CCFs. In future studies, we will invert the phase velocity into local 1-D structure beneath each sub-array.

Keywords: seismic interferometry, surface wave

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Seismic velocity changes due to the 2005 Miyagi-Oki Earthquake revealed from auto-correlation analysis of ambient noise

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We show temporal changes of auto-correlation functions (ACFs) calculated from ocean bottom records accompanied with the occurrence of a large interplate earthquake.

Seismic intererometry is one of techniques used to estimate the detailed properties of the Earth interior using a number of seismic records; a pair of seismic traces is correlated with one another to estimate a Green's functions as a response of subsurface elastic properties (e.g. Campillo and Paul, 2003). Some previous works for the seismic interferimetry of ambient noise showed that ACFs and cross-correlation functions have temporal changes associated with strong motions due to local large earthquakes (e.g. Wegler et al., 2009).

The 14 ocean bottom seismometers (OBSs) were deployed off Miyagi before the 2005 M7.2 Miyagi-Oki Earthquake. All of the OBSs used in this study were a free-fall/pop-up type with a vertical component geophone. We computed ACFs with time-window length of 120 s. Filtered one-hour traces at the frequency band of 0.5?2 Hz were used to compute correlation by the one-bit correlation technique. By taking ensemble average of ACFs among 24 hours, one-day ACFs were computed for several months including the Miyagi event at each station. The ACFs showed some common coherent phases throughout observing period. We assumed that computed the ACFs reflected subsurface structure just below the OBSs networks.

We investigated temporal variations of the ACFs during observed periods. Some distinguished coherent phases at lag times were delayed or changed after the 2005 Miyagi-Oki Earthquake. Furthermore, we investigated a dependence of a delay or change upon a lag time during the whole ACFs. We consequently found two factors for time-delay and change on ACFs due to the occurrence of the large earthquake. One is due to a decrease in seismic velocity around the stations owing to strong motions. The other is due to a local velocity change. If a local velocity change was observed by backscattered P waves, this change probably occurred at depths of ~30 km near the plate interface.

Keywords: Seismic interferometry, auto-correlation function, ocean-bottom seismometer, ambient noise, velocity change

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Fractional velocity changes in Japan Islands related to the 2011 Tohoku-Oki Earthquake

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Using the Passive Image Interferometry (PII) method we investigated the temporal changes of the fractional velocity, dv/v, before and after the 2011 M9.0 Tohoku-Oki earthquake. Recently an increasing number of studies have documented abrupt dv/v changes after large earthquakes, swarms, and volcanic activities. We therefore considered that a huge earthquake, like the 2011 Tohoku event, could produce temporal changes of dv/v that can be found all over Japan. Our purpose is detecting the dv/v temporal change during the earthquake and investigating the relationship between such changes and other geophysical observations, in order to clarify the underlying physical mechanisms.

We applied the PII method to vertical-component continuous waveforms recorded during 2010 and 2011 by the Hi-net system (100 Hz sampling, with a natural frequency of 1 Hz). We divided the continuous record into segments of one hour length, removed the mean and trend and applied 1-3 Hz band-pass filtering and one-bit normalization. Auto-Correlation Functions (ACFs) were calculated for the one-hour segments and stacked for time intervals of one week to obtain good stability. We employed the mean ACFs in 2010 as a reference ACF to calculate phase shifts for daily ACFs. Since the fractional velocity, dv/v, can be estimated by using the phase shift between the reference ACF and the daily ACFs, we could monitor the dv/v before and after the 2011 Tohoku earthquake. We quantified the temporal changes of dv/v by calculating the difference between the mean dv/v for the month before and the one after the Tohoku earthquake, using a bootstrap resampling method. To investigate the cause of the temporal changes, we compare them with the volumetric strain, calculated using source models of the huge earthquake, or Peak Ground Acceleration (PGA), recorded by KiK-net, whose seismometer is installed at the same borehole of Hi-net.

From the comparison of the time periods before and after the Tohoku earthquake, we have obtained a velocity decrease in the Tohoku, Kanto and eastern Chubu regions, as well as in the western part of the Hokkaido district. In contrast, a velocity increase was obtained in eastern Hokkaido, western Chubu, Kinki and Chugoku district, although it was slightly weak. Comparing these dv/v changes with the volumetric strain, calculated using source models of the large earthquake, we have found that the dv/v clearly decreases more than 10-6 in strain. The dv/v also changes in the area where moderate and large PGAs (more than 10 gal) were observed.

Our results suggest that the strain changes in the crust, caused by the huge earthquake, correlate with the dv/v temporal variations. Especially the relationship between the dv/v decrease and the positive volumetric strain appears to be clear. This result was also obtained during the eastern Izu Peninsula swarms. For the area of the dv/v increase, the volumetric strain was less than 10-7 and shows an unstable pattern of compression/extension: compression in the eastern Hokkaido and extension in the west of Chubu district. Furthermore, it is complicated to infer the dv/v increase from PGA data of large earthquakes.

Keywords: seismic interferometry, The 2011 Tohoku-Oki Earthquake, temporal changes

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Temporal seismic velocity changes associated with the 2011 Tohoku Earthquake from repeating earthquakes analyses

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Recent studies using seismic wave interferometry for ambient noise report temporal changes of about a few percentages in seismic velocity of the structure associated with occurrences of large earthquakes and volcanic activities. These studies generally analyze surface waves with a period of about 1-10 s, hence the structures changing seismic velocity are considered to be quite shallow, about a few hundred meters to 1 km. In the present study, seismic velocity changes associated with the 2011 off Pacific ocean of Tohoku earthquake (M9) are reported based on analyses of similar earthquakes occurring before and after the earthquake.

From the hypocenter data base of JMA, we select earthquakes with magnitude of about 4 and find earthquake groups in which hypocenters of several earthquakes are located within a distance of about a few kilometers. Then, calculating the cross-correlation coefficients for the waveforms for about 30 s from the P-waves, we select similar earthquakes. By applying cross-spectrum method to direct P- and S-waves for a pair of the selected similar earthquakes, travel time differences of P- and S-waves for the two earthquakes are calculated The results obtained from the analyses of 8 pairs of similar earthquakes occurring at depth of 40 - 60 km show following characteristics. Travel time differences of P-waves are quite small, almost less than 0.01 s. On the other hand, significant changes are observed in the travel time differences of S-waves: Tohoku region where the M9 faults are closely located show travel time increases of about 0.01-0.06 s while Kanto, Chubu and Hokkaido regions do not show significant velocity changes. Travel time differences of S-waves detected in the east-west component are slightly larger than those in the north-south direction. Travel time differences are not observed both for P- and S-waves for the pairs of similar earthquakes occurring before M9 earthquakes. Therefore, the travel time increases of S-waves observed around Tohoku regions are caused by the occurrence of the M9 earthquake.

Seismic velocity decreases, that correspond to travel time increases, are often discussed with reduction of the rigidity of the shallow structure that are damaged by strong motions. The travel time increases observed in the present study may be explained by this mechanism. In such cases, the stations characterized by low S-wave velocity at shallow parts are expected to observe large travel time differences. But, the spatial distribution of shallow S-wave velocity measured in boreholes is not well correlated with the distributions of travel time differences. This inconsistency may suggest that some deeper regions decrease the S-wave velocity.

Keywords: Temporal seismic velocity change, The 2011 off the Pacific Coast of Tohoku Earthquake, crustal structure, repeating earthquake

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Detecting temporal changes in shallow subsurface structures by auto correlation analysis of coda waves

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Seismic interferometry using ambient noise records has been successfully used to detect temporal changes in a subsurface velocity structure. So far, velocity changes have been found to be associated with large earthquakes and volcanic eruptions [e.g. Sens-Schoenfelder and Wegler (2006); Brenguier et al. (2008)]. Though coda waves, which may contain more body waves than ambient noises, will be better to detect reflected waves from interfaces at depths, we can not help waiting earthquakes. But at regions with high seismicity, it may be possible to monitor subsurface structures. Though seismic interferometry using downhole array records is very efficient to detect temporal changes in shallow subsurface [e.g. Sawazaki et al., (2009)], it requires borehole records. In this study we propose to use auto-correlation function of coda waves recorded at surface receivers to detect subsurface velocity structures. And we apply this method to the 2011 Tohoku-Oki earthquake, with which velocity changes have been reported to be associated by Wu and Peng (2011) and Nakata and Snieder (2011). So the purpose of this study is to validate the auto-correlation analysis of coda waves for monitoring.

We use KiK-net stations in the Pacific side of Northern Honshu (from Aomori to Chiba). At each station, records from earthquakes of M smaller than 7.0 which occurred at depths of 20-60km off Pacific region in 2010 and 2011. Two horizontal component acceleration records at the surface are used. In the frequency range of 1-20Hz, normalized auto correlation function of the record is calculated for a 10.24 s?long coda waves starting from the 1.5 times the direct S-wave travel time. We repeat such calculations 20 times by sliding time windows by 1 s. Normalized auto correlation functions are stacked with respect to different time windows. Aligning the stacked normalized auto correlation functions along time, we try to find changes in arrival times of phases in the auto correlation functions. Focusing on shallow depths, we deal with phases in lag times of less than 1s. According to the results, temporal variations are found at some stations. Especially, clear phase delays are found at stations along the coast in Iwate and Ibaraki. And this change is associated with the mainshock. Amounts of phase delays are in the order of 10% on average with the maximum of 30%. This method seems to have an accuracy of about a few percent, which is much larger than methods using earthquake doublets [e.g. Poupinet et al. (1984)]. So this method might be applicable to detect larger changes. In spite of these disadvantages, this method is still attractive because it can be applied to records on the surface without boreholes.

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Keywords: seismic interferometry, auto correlation function, coda wave