SIT36-01 Room:102A Time:May 25 09:00-09:15

Penetrate across the mantle, and light up the heart of the Earth

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ACROSS is an active tomography method, in which highly accurate oscillators radiate designed wave. So far, we have studied elastic wave and electromagnetic diffusive wave. The latter is not mentioned here. Underlying physics may differ from one problem to another, but the procedure of operation and data processing is common. Suppose an ACROSS hardware is given, we first define, corresponding to the desirable frequency range of recording, a unit time interval. Next, we define a wave form over this unit interval; this is the unit waveform and the oscillator simply repeats this. Obviously, the waveform of the input electricity into the actuator is not same to that of the actuator's motion; the actuator's physics and the soil-structure interaction intervene. After intensive stacking, we transform the data into the frequency domain. The result is just a spectrum of the <frequency comb>type; it consists of distinct signal channels and noise channels. Thus signal and noise have been intrinsically separated. The <frequency comb>also allow us run many ACROSS sources simultaneously.

The first generation of the elastic wave sources, have a rotary mass. Rotational frequencies are around several ten Hz. They have been used for two decades without serious troubles. Their achievement proved a remarkably high performance of commercially available inverter motors, which use angular position control by means of encoders. However, rotary sources have one weak point, frictional loss. The second generation source that is under feasibility study aims at lower frequency range (less than several Hz), and linear motion of heavy mass is used. Preliminary estimation of the performance of the new model is telling so far that its range covers the heart of the Earth.

In the long run, we will apply the new ACROSS to the whole-globe exploration. But at first, we target the D" layer of the mantle and the inner core. Recently, remarkable experimental data about D" materials as well as tomography evidence of heterogeneity of D" were reported. D" is thus one of the hottest spots within the globe, and ACROSS may get useful data for calibration. Historically, ACROSS efforts first started as an attempt to provide with tools for the earthquake prediction research program. The first generation ACROSS thus focused on the exploration of shallow crust. While some results were obtained, it was also revealed that earthquake prediction will take still a long way to go. But trial of ACROSS to the deep Earth will bear a lot of lessons.

During the course of development of ACROSS, we kept a collaborative basis of science and engineering, avoiding hasty unification of separate disciplinary biases, different ways of thinking and knowledge. Which existing disciplines are effective for analysis of ACROSS data? The global seismology will be a good candidate. It is widely known that the American global seismology, its great progress since 1970s above all, is one of the major successors of the American space engineering, which accomplished the Apollo project in 1960s. Engineering mind, together with technologies, sciences and expertise, span out from NASA and developed a new horizon of global seismology. This antecedent is encouraging the ACROSS enterprise.

Keywords: ACROSS, active monitoring, dlobal seismology, D", ST collaboration

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State of the art and future direction of ACROSS at Volcanoes

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Introduction Temporal variation of seismic propagation property in volcanoes has important information to monitor the subsurface volcanic activity, such as magma intrusion, pressure change or vesicular state in magma chamber, hydrothermal or gas activity and stress change. Though seismic interferometry and seismic anisotropy with natural seismic vibration are often used to detect temporal variation, little effort has been made on the usage of artificial sources, which has an advantage in the resolution of temporal change.

Seismic source Rotation sources that have been used for seismic ACROSS have some serious disadvantage for practical use. They use relatively large bearing, which requires high cost in case of trouble and produces large heat. Yamaoka et al. (2014) designed a new-type across to overcome such shortcomings with a combination of small unit sources. Yamaoka et al. (2011) tested a linear-motion type seismic source, which is commercially available, for the operation in lower frequency range as the rotation source can produce only small force in lower frequency. It can produce a sinusoidal wave with overtone distortion of 5%.

The borehole seismic source will be also useful for monitoring the deep part of volcanoes apart from meteorological effects. Linear motion source along the axis of borehole is useful for low-frequency operation, whereas rotation source is useful for high-frequency operation. Yokoi et al. (2014) designed a prototype of borehole type linear moving source that can drive small electric power.

Sakurajima We have started an experiment of seismic ACROSS at Sakurajima volcano in 2012 (Yamaoka et al. 2014). We deployed rotary-type ACROSS sources with vertical axis, which are reliable after long-term test for practical use in Toyohashi, Japan. Deploying ACROSS source at a volcano is our first challenge that we may face some difficulty. Actually unstable electric power condition in summer season often stop the ACROSS source, which have been overcome in the collaboration with local university of Kagoshima. A careful analysis on the data to correlate with the activity of Sakurajima revealed the temporal change associated with the explosions (Maeda et al., 2014).

Keywords: Volcano, Monitoring, subsurface structure, temporal variation, magma, hydrothermal system

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Seismic time-lapse imaging of subsurface

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1. Introduction

The imaging of the Earth has been carried out by the passive method using natural earthquakes. When we use natural earthquakes, it is difficult to select source positions and ray paths. Although seismic interferometry technique acts as virtual sources, it seems difficult due to less excitation on refracted and reflected waves. The control sources are complementary to the natural earthquakes.

The benefit to use control sources is that we can get detailed information on the source signatures. Knowing the precise source signature, we can estimate the temporal changes of transfer functions between source and receiver.

To determine the location causing temporal change it is necessary to know the 3D seismic structure in details. Once we identify the ray path and travel time of the seismic wave concerning the target area, continuous monitoring using only a few receivers might be possible. To monitor the wider area and know the spatial distribution of changing zone, the time-lapse imaging is demanded.

2. Time-lapse Imaging

If numbers of sources and receivers are not so dense, the resolution of subsurface imaging will be limited. To enhance the resolution we can increase number of sources or receivers. In the field of the most recent seismic exploration surveys the number of receivers reaches to 10,000 with receiver spacing of 25-50 m. We might be possible to increase the density of receivers.

In the time lapse study of the subsurface, it is likely to exploit the temporal changes of waveforms. By use of residual waveforms and the reciprocal relation between source and receiver, we can do back-propagation of the residual waveforms from the receivers to focus to the location of temporal change.

3. Effects of near surface, weather conditions and rain falls

Through our knowledge of the seismic time lapse studies, the travel time changes of first arrivals are not large compared to the coda parts. One of the reasons for this is that we tend to observe the fastest arrivals and it is difficult to identify arrivals through a slower region. By use of the waveform residuals we might reduce this effect.

The temporal change in near surface layer strongly affects to observed waveforms. Without the consideration of near surface effects the results might lead to wrong answer. We will show some examples obtained in Awaji Island and a quarry field. Rainfalls and change of moisture contents due to weather conditions could be the most significant. The experimental observation of the time lapse in a quarry filed showed changes the residual waveforms day by day. The frozen of ground soil changes the waveforms during a day. We think that in the volcanic area the moisture contents in lava might strongly affect to the estimation of volcanic activity.

The effects of ground coupling of source can be eliminated by use of heavy concrete basement as in the installation of ACROSS sources.

The heterogeneity and anisotropy of the near surface layer might also affect to the paths of seismic waves and electromagnetic waves. This has to be considered.

4. Discussion and conclusions

Use of active source for the structural imaging could improve the resolution of blind parts of Earth's interior and possibly provide the time-lapse image. However, there are important factors that we should consider. The 3D structure is needed to evaluate the correct location of the temporal change. The backpropagation of residual waveforms from dense receivers gives better image of temporal changes if we properly evaluate the effects of near surface, heterogeneity and anisotropy. One of the ways to minimize the effects of near surface and weather condition on the time lapse is to place source(s) and receiver(s) in the ground.

The EM time lapse has similarity as the seismic one.

Keywords: Time-lapse, ACROSS, Seismic imaging, back-propagation, residual waveform, near-surface effect

SIT36-04 Room:102A Time:May 25 09:45-10:00

Surface Wave Analyses for Observing 3-D Crustal Deformation and its Application to Long-period Excitation Sources

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We propose an analysis method of ACROSS data to reveal 3-D crustal deformation, that should be crutical for understanding mantle convection and earthquake generations. Details are shown at the time of the presentation.

Keywords: Earth's internal structure, surface wave

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Toward an Innovation for Large Scale Data Analysis in EM-ACROSS

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As presented by Kumazawa et al., Ogawa et al. and Fujii et al. in this session, we are planning to restart a development study of EM-ACROSS in collaboration with Earth-Life Science Institute and Volcanic Fluid Research Center of Tokyo Institute of Technology. This presentation re-evaluates an observation scheme and data analysis procedures in EM-ACROSS by reference to a trial data obtained from a preliminary test at Shizuoka University. The main purpose of this study is to obtain valuable knowledge about the processes of extracting transfer function with noise level information from very large scale raw data with noise, bias and missing data.

The preliminary test was conducted from 2007 to 2012. Source signal was transmitted from an electric current dipole located in the Suruga campus of the university, and its response was observed at three sites; Shimizu-hokubu site (electric field, distance of 17km from the source), Tawaramine site (magnetic field, 18km) and Asahata site (magnetic field, 7km). Observation period is a maximum of 5 years while missing periods exist due to blackouts and mechanical failures, and the whole data size is dozens of terabytes.

A specific subject of this study is an elimination of irrelevant variation in the observed data caused by an environmental change near the surface of the ground. Since such variation greatly influences resulting transfer functions, a refined data stacking method and a data correction method by auxiliary information (micro earthquake, meteorological data, etc.) are indispensably required. Furthermore, a use of current dipole transmission by a pair of ground electrode is considered as a reason of the variation. To quantitatively assess its instability and to obtain valuable knowledge for improvements are also required.

Keywords: ACROSS, Electromagnetic sounding, Volcano, Big data

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Reviews and future perspectives of studies on temporal resistivity change

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3D magnetotelluric (MT) modeling is now in practice and is becoming a routine. It is time to start challenges on temporal changes of resistivity structures for active volcanoes or crustal-scale temporal resistivity changes.

Aizawa et al. (2011) made continuous MT measurements at two stations around the Sakurajina volcano and found that the apparent resistivities decrease after the onset of tilt measurement. They interpreted that the volatiles from the magmatic gas may decrease the resistivity of ground water. Honkura et al. (2013) analyzed the array MT data over the North Anatolian Fault during the 1999 Izmit earthquake and found the abrupt coseismic resistivity change at the fault zone.

Peacock et al. (2012, 2013) used MT method to monitor the temporal change of fluid distribution during the fluid injection for enhanced geothermal system. They used phase tensor (Caldwell et al., 2004) in order to avoid effect of temporal change of shallow local structure. MacFarlane et al. (2014) tried to explain the temporal change of phase tensor by two-dimensional resistivity model with anisotropy.

Saito et al. (2015) focused on the crustal resistivity change before and after the Tohoku-Oki earthquake. He used a profile MT data in 2003 passing through Naruko volcano (Asamori et al., 2010) and another repeated profile MT data in 2013. He also used phase tensor to detect the significant resistivity change. MT monitoring has an intrinsic problem of noise contaminations and unstable signal strengths, although it does not require any artificial sources.

Shallow resistivity monitoring by DC resistivity methods is well known. Izu-Oshima eruption in 1986 was successfully monitored by the apparent resistivity change using two sets of dipole-dipole array over the edifice (Yukutake et al., 1990). Although this experiment was successfully detected the rising magmatic melt at the vent, imaging the time-dependent structure was only possible by forward modeling with a priori volcanic knowledge (Utada, 2003)

Smaller scale 4D resistivity monitoring at Onikobe Geyser was successfully performed using multiple-source, multiple-receiver pole-pole method. Kouda (2009) report the case of time switching the current poles, but Jinguuji et al. (2012) report the case with multi-low-frequency current injection at different current poles. The latter has an advantage of continuously monitoring the 3D structure.

Volcano monitoring using controlled source electromagnetic induction is in practice at Izu-Oshima and Aso volcano using ACTIVE system (Utada et al., 2007). They use electrical grounded dipole with step waveform and measure vertical magnetic sensors at many locations. This has an advantage of covering a large area and wide frequency range. Theoretically, multiple sources are recommended, as the response functions are functions of resistivity structures including the transmitter and the receivers. Coincident loop system (VOLCANO LOOP) at the volcanic crater is proposed to monitor the phreatic eruption at Kusatsu-Shirane volcano (Hino, 2014). This has an advantage of an easy installation without digging and burying current or potential electrodes and monitoring the structure directly below the loop. However, the monitoring area is limited. The merit of the system is the detection of the secondary field when the primary source field is absent.

EM ACROSS (Kumazawa et al., 2015) is a frequency domain technique. The frequency domain techniques measures primary and secondary fields together and care must be taken when the source receiver distance is smaller than the skin depth, where primary field dominates. Tensor measurements using multiple sources will be important.

Keywords: resistivity, temporal variation, monitoring, natural signal, artificial controlled signal

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Integrated Frequency Comb Spectroscopy by ACROSS: Active Monitoring by Use of Elastic and Electromagnetic Waves

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In 1994, we started to develop an active method of observing the Earth's interiors by means of stationary transmission of accurate sinusoidal signal of elastic and electromagnetic waves. Original idea was quite naive in a sense that signal is a sinusoid with one spectral line, whereas we were confident that this type of frequency domain approach is definitely promising in future on the basis of its principle itself. Later developmental works made by many colleagues have been made to introduce a variety of new ideas, new theories and new technologies both in hardware and supporting theory. Koshun Yamaoka, Junzo Kasahara and their colleagues have been accumulating a large amount of applications. Now we are confident that this frequency domain approach is essential after 20 year effort on the developmental works for this methodology.

Now we claim that a new era has come to study the physics of the whole Earth's interiors by using an active method of physics instead of passive phenomenological approach. Pressure and temperature range of laboratory experiments on the materials has been extended to the bottom of the mantle, the first principle computation of physical properties has been realized, and numerical simulations of a variety of dynamic processes have come to be made, whereas the observation on the real nature has been made only passively so far without sufficient resolution and reliability yet.

We have apparently two major targets of the new observation technology:

(1) Active observation of the whole mantle, the inner core and also their boundary layers to provide much reliable data on the structure and their temporal variation with higher resolution to study the dynamics of the whole Earth. This target demands the installation of powerful transmitters distributed over the different continents, so that international corporation is demanded.

(2) Qualified system for monitoring the volcanic and earthquake fields can be now designed and proposed: implementation of denser array of both electromagnetic and elastic ACROSS of wider frequency range to acquire the detail physical states at the target sites. Special emphasis is placed on the physical studies of anisotropy and other structure-sensitive properties of the materials. The primary importance is to be placed on the study of the material physics through the qualified observations combined with laboratory experiments and material physics, which are essential for the background of future prediction research works on the disastrous events.

This presentation is an introduction to the forthcoming works directed to the "Integrated Frequency Comb Spectroscopy by ACROSS" for geophysical researches.

Keywords: ACROSS, frequency comb, monitoring observation, whole Earth