Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

SEM33-01 Room:102A Time:May 26 09:00-09:15

Electromagnetic waves radiated from the ground

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We have been observing electromagnetic (EM) pluses excited by earthquakes. Recently we have confirmed that the detected EM waves were co-seismic ones which were readily generated by piezo-electric effect in earth crusts by vibrations of seismic waves [1]. In order to inspect behaviors of the excited EM pulse, we prepared two sensor systems consisting of tri-axial magnetic search coils. One was inserted into a deep bore hole of 100 m in depth and another was installed on the ground. When an earthquake (M2.7) occurred at just below (at the depth of 11 km) the EM observation site, we simultaneously captured waveforms of an EM pulse in the borehole and on the ground. From the waveforms of magnetic north-south and east-west components detect by the both sensor systems, we obtained their wave polarizations in horizontal plane. Their results are shown in Figure 1. As shown in the figure, the wave above the ground shows elliptic polarization whereas that in the earth shows linear polarization. This means that the wave was propagating from the deep earth to the air region passing through the ground surface which is interface of two media with different refractive indices. We found that almost all of seismic waves can excite EM waves, and they were radiated out of the ground surface. This is a reason why co-seismic signals were often detected by MT method.

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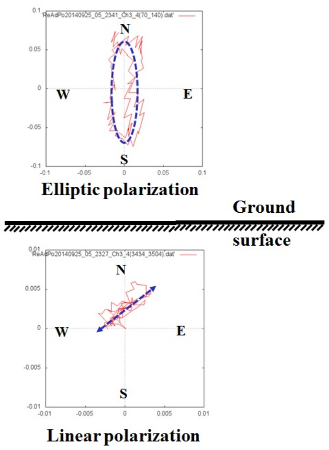
[2] M. Tsutsui, T. Nakatani, M. Kamitani and T. Nagao, Polarization and propagation property of electromagnetic pulses in the earth, in Proc. IGARSS, 2011, pp. 838-841.

Keywords: observation of electromagnetic pulses, polarization analysis, radiation from the ground



SEM33-02 Room:102A Time:May 26 09:15-09:30

Three-dimensional forward calculation of magnetotelluric responses using a mesh-free particle method.

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Accurate forward calculation of electromagnetic induction in the earth is essential for quantitative modeling of subsurface resistivity structure. The expression of complicated topography and bathymetry in the three-dimensional (3D) model should be carefully handled for accurate numerical calculations, but frequently ignored, unfortunately. For example, a widely-used 3D inversion code of magnetotelluric (MT) data is based on the finite difference method (FDM), in which the 3D model consists of assembly of rectangular blocks. Therefore, a smooth relief on the ground can be expressed as stair-like hills and valleys. Previous studies indicated that such step-wise approximation of topography yields large calculation error of MT responses. The finite element method (FEM) can include the smooth topographic relief in the 3D model, while the selection of proper mesh configuration for FEM is a hard task for users.

In this research, I developed an new 3D MT forward calculation method with the MPS (Moving Particle Semi-implicit) method, one of the mesh-free calculation methods. The main purpose is the proper expression of topography / bathymetry in the 3D resistivity model. The MPS method is a particle method and is developed for the simulation of incompressible flow by Koshizuka and Oka (1996), and has been applied for the one and two-dimensional MT problems. I use the MPS method for the 3D simulation of electromagnetic induction in this study. In the forward calculation, electric and magnetic fields can be defined at each particle in a calculation model. Then, MT responses are calculated on an arbitrary point in the 3D model (on the surface, on the seafloor, and even in the earth). The results of MT forward calculation indicate enough accuracy, implying capability to application to the inversion procedure of MT responses with complicated topography.

Keywords: particle method, magnetotellurics, forward calculation, numerical calculation, mesh-free

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SEM33-03 Room:102A Time:May 26 09:30-09:45

Accuracy evaluation of MT response calculated with Particle Method

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MT(magnetotelluric) method ,one of the electro-magnetic(EM) sounding methods, is considered as a technique in practice for the exploration of hydrocarbon resources.Conventionally, the finite difference method and the finite element method are often used as a numerical calculation of the electromagnetic field below the surface for the forward and inverse problem of the MT method (e.g.,Baba and Seama,2002; Minami and Toh, 2012).

However,using the finite difference method has a difficulty of including complicated shape in the model like the topography and underground heterogeneous structure.

For overcoming the weak point, the particle method attracts attention of MT users recently.The particle method is one of the techniques to make a model discretization with particles not aligned along lattice or mesh. It is easy for particle method to include any complicated shapes in the model.However, early researches have not discussed the calculation conditions and setting of the parameter which is thought to contribute.For example, the influence radius , one of the parameters in the particle method is important to be adjusted for keeping high accuracy of calculations beforehand in the particle method.

In this study,we performed examination about the better setting of the influence radius to achieve the high accuracy when we use the particle method for the analysis of the electromagnetic field in the MT method.

In our numerical results, the trend is obvious that the calculation error at high frequency was small enough if the influential radius was small.We also found that a relation between the degree of the electric field attenuation and the influential radius which can adjust the calculation error to be smaller.Influence radius and weight in particle method should be optimize.

Keywords: MT, Particle Method

SEM33-04 Room:102A Time:May 26 09:45-10:00

3-D forward calculation and inversion of magnetotelluric data using the meshes including the actual topography

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The author developed a 3-D MT inversion code using unstructured tetrahedral elements and a tool to make computational meshes including the actual topography from digital terrain data.

It is important to consider topographic effects in interpreting observed data of magnetotelluric (MT) method. Without ignoring these effects, it is, therefore, possible to misinterpret subsurface structures because the observed data from MT surveys can be strongly affected by the topography around the survey area. The most straightforward way to take account of these effects is to incorporate the topography explicitly in the computational grid used in forward calculation and inversion, and this method can be applicable to a wider range of surveys.

Among space discretization methods, the finite element method using the unstructured tetrahedral element is considered to be one of the most effective method to include topography in computational grids, because it can represent topography precisely without using too many elements, and a number of robust meshing algorithms have been proposed such as Delaunay triangulation method and the advancing front method.

The forward part of the developed inversion code uses the edge-based tetrahedral element to calculate the electromagnetic field on the earth's surface. The inversion code can use the impedance tensor, the vertical magnetic transfer function and the phase tensor as observational data, and it estimates the subsurface resistivity values by updating them using Gauss-Newton method.

To make 3-D computational mesh of model, the tetrahedral mesh generator TETGEN (Si 2007) was used. This program constructs a tetrahedral mesh by the constrained Delaunay triangulation method from an inputted piecewise linear complex (PLC). Thus, in order to make a 3-D mesh containing topography, the author developed the program which makes the PLC including the topography. First, this program makes the 2-D mesh including land-sea boundaries by the 2-D constrained Delaunay triangulation method from the data of coast lines. Next, the altitude of the water depth of each node of the mesh is interpolated from topographic data by the inverse distance weighting method, and then outputs the 3-D PLC containing the topography.

With the aid of the inversion code and the meshing tool, the author will perform forward calculation and inversion using the mesh including actual topography to evaluate the topographic effects precisely and interpret subsurface resistivity structures accurately.

SEM33-05 Room:102A Time:May 26 10:00-10:15

3D Electrical Resistivity Imaging beneath Kyushu by Geomagnetic Transfer Functions and Network-MT Response Functions

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The Kyushu Island in the Southwest Japan Arc has many Quaternary active volcanoes, which exist along the volcanic front of N30^{o}E-S30^{o}W, in relation to the subduction of the Philippine Sea Plate (PSP). The volcanoes are located in northern and southern regions of the island, and no volcano is located in the central region between the two volcanic regions of the island. We have performed three-dimensional (3-D) inversion analyses to obtain a lithospheric-scale electrical resistivity structure (model) beneath the entire Kyushu Island by using a data set of Network-Magnetotelluric (MT) response functions [*Hata et al.*, 2015]. One of two major findings from a distribution of conductive anomalies in the model is that the volcanoes in the northern and southern volcanic regions have two different origins bordering the non-volcanic region at deep depths. Secondly, the degrees of magmatism and the relative contributions of slab-derived fluids to the magmatism vary spatially in the one non-volcanic and two volcanic regions.

A shallow depth resolution of the lithospheric-scale resistivity model, however, was too low to examine small-scale resistivity structures of the crust because of the period range between 480 and 40,960 s of the Network-MT data. Thus we have started to perform 3-D inversion analyses by using a data set of geomagnetic transfer functions whose period range is from 20 to 960 s to obtain a resistivity structure model, in which we can examine smaller-scale structures. The geomagnetic transfer functions were determined at 167 sites in the Kyushu district. Original raw data sets for the geomagnetic transfer functions were measured at the entire Kyushu island and several islands off the western coast of Kyushu from 1980's to 1990's [e.g., *Handa et al.*, 1992; *Shimoizumi et al.*, 1997; *Munekane et al.*, 1997]. In this presentation, we will show a new electrical resistivity model, which is obtained through a two-stage inversion process as follows. We determine a resistivity structure mainly at a shallow depth by applying 3-D inversion analyses for the geomagnetic transfer functions of 20-960 s first and then determine a lithospheric-scale resistivity structure by applying 3-D inversion analyses for the Network-MT response functions of 480-40,960 s, which is based on values of the previous resistivity model determined by using the geomagnetic transfer functions. In the two-stage inversion process, we use two types of DASOCC inversion code [*Siripunvaraporn et al.*, 2004; *Uyeshima et al.*, 2008; *Siripunvaraporn and Egbert*, 2009].

SEM33-06 Room:102A Time:May 26 10:15-10:30

Temporal Resistivity Change of Crustal Resistivity Structure Before and After the 2011 Tohoku Earthquake

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The NE Japan was under the EW compression and localized strain distributions were observed along the Ou backbone ranges, which were responsible for generating the large inland earthquakes. The coseismic displacement of the 2011 off the Pacific Coast of Tohoku Earthquake (M9) released EW compressional strain and generated EW extension over the region. This earthquake had a great influence crustal dynamics in NE Japan. In particular, the seismicity around the Naruko area has sharply decreased. The GPS displacement show extension deficit (Ohzono et al, 2012), i.e. the Ou backbone rage shows less EW extension compared to the surroundings, because of the anomalous viscosity under the Ou backbone range. InSAR detected the subsidence of the geothermal regions around the Naruko area (Takada and Fukushima,a 2013). These suggest existence and migration of crustal fluids after the M9 earthquake.

MT is suitable to detect the fluid migration in the crust, as the resistivity is sensitive to the existence an connectivity of fluids, although they are minor components in the fluid bearing rocks. The previous profile MT dataset over Naruko volcano were obtained in 2003 (Asamori et al., 2010) and we tried to repeat MT measurements at the same places in 2013. Altough we tried to measure at the same spots, the locations are not exactly the same. In particular, we worry about the difference in the near surface local structures of the 2003 and 2013 sites. To overcome this difficulty, we used phase tensor (Caldwell et al, 2004) as response functions, which are insensitive to galvanic distortions of the near-surface local structure. To evaluate the temporal changes, it is important to show the errors of the phase tensors. For this, we used boot-strap method with 1000 realizations. We compiled the difference of α, β, ϕmax, ϕmin with error bars for all the period range. We found some consistent differences in the phase tensor parameters.

Keywords: resistivity, temporal variation, magnetotellurics, phase tensor, fluid

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SEM33-07 Room:102A Time:May 26 11:00-11:15

Electrical conductivity imaging of "Normal Oceanic Mantle"

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[1]Earthquake Research Institute, The University of Tokyo, [2]Japan Agency for Marine-Earth Science and Technology, [3]Tongji University

Horizontal flow zone between up-welling and down-welling of the mantle convection, which occupies large portion of the ocean floor, is thought to represent "normal" mantle that is away from tectonic activities. The research group of Normal Oceanic Mantle Project consists of researchers in Earthquake Research Institute (ERI), The University of Tokyo, and Japan Agency for Marine-Earth Science and Technology (JAMSTEC) have investigated normal oceanic mantle by means of marine geophysical observations to elucidate two fundamental questions of the Earth Science; 1) What is the physical condition for the lithosphere-asthenosphere boundary (LAB)? 2) Is the mantle transition zone (MTZ) a major water reservoir of the Earth? We set the target field to two areas, which are northwest (Area A) and southeast (Area B) of Shatsky Rise in the northwestern Pacific, and have carried out seafloor electromagnetic (EM) surveys using ocean bottom electromagnetometers (OBEMs) and electric field observation systems (EFOSs) since 2010. Total 36 OBEMs were deployed at 17 sites in Area A and 8 sites in Area B through this project.

We have reported preliminary analysis of part of the data and 1-D electrical conductivity structure models for Area A and Area B, before. We have conducted new trial for the seafloor measurement in 2012-2014, that the sampling intervals were switched between 10 and 60 seconds by timer during the observation (60 seconds were conventionally used). This procedure expects that we can obtain the MT impedance for the periods shorter than conventional approach and we can consume the battery more efficiently. We used BIRRP (Chave and Thomson, 2004) for the MT response estimation. We could not obtain good MT responses for the period shorter than several hundred second by the conventional application of BIRRP. However, BIRRP yielded better result with the option of two-stage processing. We obtained good MT responses down to about 50 seconds for 9 sites in Area A and 1 site in Area B. Also, We found that the MT responses obtained by 60 second sampling data produce downward bias in the apparent resistivity for the period shorter than about 400 seconds. Then, we used the MT responses obtained by 10 second data for the periods shorter than 400 seconds, and those obtained by 60 second data for longer periods for the following analysis.

We have averaged MT responses for Area A and Area B, respectively, and then estimated 1-D conductivity structure correcting the effect for the land-ocean distribution and seafloor topography. For Area A, the conductivity of the upper most lithosphere (crust) was constrained much better than the previous analysis. This must be because of the extension of the periods in the new MT response. For Area B, 10 second data were available for only one site so that we analyzed the MT responses obtained from 60 second data for the periods down to 480 seconds to produce the average response. As the result, new 1-D model does not show a strange curve at 50-100 km depths and high conductivity peak at about 170 km depth, which were seen in the old model. These features are thought to be fakes due to smoothness constraint of the inversion and downward biased apparent resistivity at periods shorter than 400 seconds. The thickness of highly resistive layer, which is thought to be cool lithospheric mantle, is similar with the previous results. It tends to be thinner for Area A compared with Area B and significantly thinner than Area C (off the Bonin Trench).

The crustal age for the Areas A, B, and C are about 130, 140, and 147 Ma, respectively. Based on plate cooling with age, the age difference cannot produce significant difference in the thermal structure. Consequently, the difference in the electrical conductivity of the upper mantle for the three areas cannot be explained by the simple cooling process of homogeneous mantle.

Keywords: oceanic upper mantle, northwestern Pacific, ocean bottom electromagnetometer, magnetotellurics, electrical conductivity structure

SEM33-08 Room:102A Time:May 26 11:15-11:30

Electromagnetic investigation into the mantle transition zone in the Normal Oceanic Mantle project

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We report a preliminary analysis of marine electromagnetic field data that were obtained under the Normal Oceanic Mantle project for elucidating an electrical conductivity structure of the mantle transition zone in the northwest Pacific. A primary aim of this study is to answer one of fundamental questions in the solid earth science "Is the mantle transition zone a major water reservoir of the Earth?" from observations for the electrical conductivity structure with our new and latest instruments. To elucidate the electrical conductivity structure of the mantle transition zone, periods of electromagnetic response functions should be long as more than 10^5 s (approximately 1 day) due to the response sensitivity to plausible electrical conductivities of the mantle [Fukao et al., 2004]. The electric field observation system (EFOS) has achieved better signal-to-noise ratio at the target long period range than the ocean bottom electromagnetometer (OBEM) in measurement of voltage difference variation with its long electrodes separation of almost 2 km [Utada et al., 2013]. In addition to utilizing the EFOS, multi-year observations with EFOSs and OBEMs were conducted (up to 2 years for EFOS and up to 4 years for OBEM) to obtain data for estimation of electromagnetic response functions at the long period range with high accuracy.

Three EFOSs were deployed in September 2012 and were recovered in September 2014. One EFOS recorded excellent data for full two years, and the other two EFOSs recorded good data for one year in total. The sampling rate of the EFOSs was 1 s, and clock drift of each EFOS, which was less than 120 s, was corrected for the subsequent data analysis. MT response functions were estimated by using the processed EFOS electric field data and OBEM magnetic field data obtained at the same site, and GDS response functions were estimated by using OBEM magnetic field data (Baba et al. in the same session will present details on OBEM data). These response functions were estimated mainly at the period range of 10^5 - 10^6 s. MT responses were estimated at 3 sites in Area A (northwest of the Shatsky Rise), and GDS responses were estimated at 15 sites in Area A and at 7 sites in Area B (southeast of the Shatsky Rise).

The estimated response functions were compared with predictions from a known semi-global 1-D electrical conductivity model of the north Pacific with land-ocean conductance distribution in a surface layer [Shimizu et al., 2010]. The comparison done so far suggests that the mantle transition zone may be more resistive than the reference 1-D model and a north-south variation in electrical conductivity of the mantle transition zone may be none or weak under Area A. A further data analysis is ongoing, and the result of the analysis and an interpretation of the result on the thermal and geochemical state of the mantle transition zone will be presented.

Keywords: mantle transition zone, electrical conductivity structure, northwestern Pacific

SEM33-09 Room:102A Time:May 26 11:30-11:45

Development of geomagnetic total force models by applying Natural Orthogonal Component (NOC) method

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Geospatial Information Authority of Japan (GSI) has conducted nationwide continuous geomagnetic field vector observations since 1997. By utilizing these continuous data, we developed 2 types of geomagnetic total force models by applying Natural Orthogonal Component (NOC) method. One model is constructed from continuous total force observation data of proton and overhauser magnetometers. The other model is constructed from continuous 3-component geomagnetic vector observation data of fluxgate magnetometers. We call the models "scalar model" and "vector model" respectively. We developed the scalar model from total force observation data of 17 observatories operated by the GSI, Japan Meteorological Agency (JMA) and Earthquake Research Institute (ERI) and additional 2 observation stations operated by the ERI. We evaluated accuracy of the model by Leave-One-Out Cross-Validation (LOOCV), and the model reproduces total magnetic forces at the observatories and stations with the consistency of a standard deviation of 2.6nT. On the other hand, the vector model is developed from vector observation data of 17 observatories operated by the GSI, the JMA and the ERI. The model reproduces total magnetic forces at the observatories with the consistency of a standard deviation of 3.7nT. In order to remove a long wavelength trend of total geomagnetic force from total force observation data time series around a large volcano, we reproduced time series of total magnetic forces around Mt. Fuji and removed them from total force observation data at four observation stations around Mt. Fuji. The detrending revealed that detrended time series of one of the stations, Fujishi, contain clear seasonal variation with amplitude of 2nT. Time series of another station, Fuji-no-miya, also contain a clear step down which might be caused by piezomagnetic effect with an earthquake in the eastern part of Shizuoka Prefecture on March 15, 2011.

Keywords: Principle Component Analysis, Geomagnetic total force model, Natural Orthogonal Component, Geomagnetic charts

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SEM33-10 Room:102A Time:May 26 11:45-12:00

A method of representing standard secular variations around such as Japan

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Geomagnetic reference field models are mathematical or numerical expression of the geomagnetic field or its secular variation at a specific point (and a time). Geomagnetic reference field models aiming at representing only a specific region is sometimes called regional geomagnetic reference field models. Determining procedure of geomagnetic field models from a discrete set of data is regarded as an interpolation. Also, it is regarded as a high-cut filtering when the model is expressed by a combination of analytical functions. Many procedures have been used to determine geomagnetic field models. A classical method is using polynomial functions. In Japan, Tazima et al. (1976) reported. Sumitomo, 19xx. Ji et al. (2006) published an example of around Japan by using Spherical Cap Harmonic Analysis (SCHA). Recently, revised SCHA (R-SCH) was proposed and applied to several regions in the globe (Thebault et al., 2006).

One of applications of geomagnetic reference field models is extracting the crustal geomagnetic field. Given that spatial scales of variations in the crustal geomagnetic field are considered to be smaller than those represented by geomagnetic reference field models, differences between observed values and predicted values by a model are regarded as the crustal field.

However, conventiomnal models are unsatisfactory, at least when our purpose is on extracting crustal field for several region such as Japan. Two horizontal components (i.e. B_X and B_Y) represented by polynomials do not always satisfy the irrotationality condition: $\partial B_X / \partial Y$ - $\partial B_Y / \partial X$=0, which should be satisfied in a region with no electric currents. Quantitative relationship between the order of polynomials and the precision of the model is also unsure. SCHA and R-SCHA are designed for a region with a shape of a sperical cap, which is considerably different from Japan islands. The difference in shape yields instability in determining model parameters. Indeed, results presented in Ji et al. (2006) demonstrate unnaturally large secular variations at marginal regions of their analysis.

In this presentation, the author propose a method of representing the regional reference field around Japan using conventional Spherical Harmonic (SH) Functions. To reduce a number of SH functions for representing the spatial distribution, the Principal Component Analysis is applied to SH functions after restricting the variables' range of position to Japan Islands. Obtained major components of the Principal Components are used as the basis functions for representing spatial distribution. This method have three advantages compared with conventional methods. First, the obtained field model automatically satisfies Laplace's equation. Second, we can stably determine corresponding model parameters because orthogonality of basis functions over the target region is assured. Third, truncation errors can be evaluated by assuming an experimental spectrum law of Gauss's coefficients.

Keywords: geomagnetic secular variation, regional geomagnetic field model, spatial distribution, Spherical Harmonic Functions, Principal Component Analysis

SEM33-11 Room:102A Time:May 26 12:00-12:15

Total Magnetic Field Changes associated with the 2010-2011 seismo-volcanic crisis at Taal Volcano (Philippines)

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A mechanical model was presented which caused the 2010-2011 seismo-volcanic crisis of Taal Volcano, when the total evacuation of the inhabitants was conducted at the initial stage of the crisis in 2010. The model explains the observed magnetic changes as due to the piezomagnetic effect, in which a large hydrothermal reservoir repeated inflation and deflation. This implies that the hydrothermal reservoir plays the most important role in the activity of Taal Volcano.

Keywords: Taal Volcano, 2010-2011 seismo-volcanic crisis, Total Magnetic Field Change, Hydrothermal Reservoir, Curie Point Isotherm, Piezomagnetic Effect

SEM33-12 Room:102A Time:May 26 12:15-12:30

A Comparison Evaluation of Geomagnetic Observation Signal Using HTS-SQUID Magnetometers at Iwaki Observation Site

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This study addresses a comparison evaluation of high-resolution geomagnetic field observation systems using HTS-SQUID (high-temperature-superconductor based super conducting quantum-interference-device) magnetometers.

Our research group reported successful observation of ”co-faulting” Earth’s magnetic field changes, whose sources are the earthquake piezomagnetic effects, in 2008 Iwate-Miyagi Nairiku earthquake of M7.2 (2011 Okubo et al.). Then, an important finding is that the geomagnetic variation signal accompanying fault movement is very small; therefore development of a high-sensitive magnetometer system is very significant.

To solve this problem, since March 2012 we have introduced long-term precise geomagnetic observations using high-temperature-superconductor based superconducting-quantum-interference-device (HTS-SQUID) magnetometer system Unit No.1 (mark I) at Iwaki observation site (IWK) in Fukushima, Japan. The observation clock has been synchronized by use of GPS signals. An high-resolution accelerometer is also installed at observation point.

Moreover, since October 2014, we have also introduced the new HTS- SQUID magnetometer system Unit No.2 (mark II). In this study, we make a comparison evaluation of the geomagnetic field observation systems, and then we estimate the performance of our HTS-SQUID magnetometer systems for geomagnetic observation.

Keywords: HTS-SQUID Magnetometer, Geomagnetic Observation, earthquake piezomagnetic effect