Measuring the Electric Field of the Earth by an Ocean Bottom Instrument with a Long (10-100km) Cable

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***Abstract* – We newly developed an electric field observation system on seafloor by using a long ocean bottom cable. Such large-scale electric field includes signal from the earth's core. The system is designed to enable us to make an observation wherever we need. We successfully deployed the system on the seafloor off Daito-jima Island, Japan, with the cable extension of about 10 km length.**

I. INTRODUCTION

Electric field observations recorded by a long submarine cable is composed of three major signal sources (Fig. 1): the electric field of toroidal magnetic mode penetrated out of the outer core, the electromotive force induced by ocean current and the externally induced electric field that reflects electrical conductivity distribution within the Earth. Runcorn (1964) [1] suggested that the electric field of core origin could be detected as difference in ground voltages at two distant points on the Earth surface if one uses a cable of a planetary scale. Shimizu et al. (1998) [2] analyzed observed submarine cable voltages and obtained 0.1 mV/km as amplitude of electric field, assuming thirty-year period variation. Shimizu and Utada (2004) [3] confirmed that a kinematic dynamo with electrically conductive mantle can generate the observed amplitude of electric voltage variation.

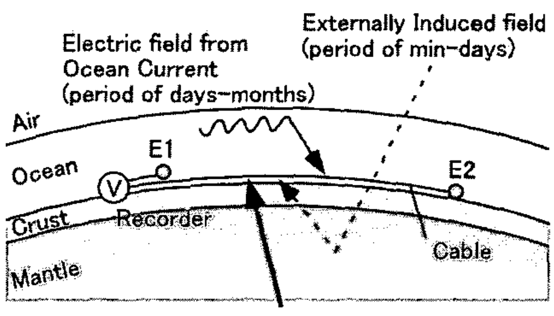

Fig. 1. Major signal source of semi-global scale electric field on the earth. E1, E2: electrodes. V: voltmeter.

In recent years, several attempts have been made to make a network of decommissioned submarine telephone cables to record the electric field of the Earth (e.g., Lanzerotti, et al., 1985 [4]). Long-term observation by using this network will be efficient, but can be performed only among North America, Europe and East Asia with a limited geographical coverage over the globe. Especially, electric field with N-S component is poorly recorded by the existing network. We need a new observation system with a long submarine cable deployed in an area where we want.

Although major purpose of large scale measurements of electric field is to detect signal of core origin, the measured electric field data can be also applied to other geophysical studies: especially on electrical conductivity structure in the earth and oceanographic studies. Koyama (2001) [5] estimated electromagnetic response functions from electric field variations measured by submarine cables and geomagnetic field variations, and obtained three-dimensional conductivity structure in the mid-mantle of the one-forth of the Earth beneath the north Pacific Ocean. Such a global conductivity structure can be used for estimating mantle temperature as shown in Fukao et al. (2003) [6]. Meanwhile, oceanographic studies have been made on sea water transportation with motional induced electric field by using cable potential measurements (e.g., Larsen and Stanford, 1985 [7]). Fortunately, three major electric fields with origins of core, ocean current and the external induction field are characterized by representative period bands (summarized in Fig. 1), so that the observed electric field is possibly decomposed into one from each signal source.

In this study, we introduce a new instrument to measure large-scale electric field in any ocean areas, and report the successful investigation to deploy it on the ocean bottom.

2. MEASURING SYSTEM

A new instrument called "Electric field Observation System (EOS)" consists of three components: electrodes, an anchor with electronics (e.g., voltmeter) and a long submarine cable of 10 km (such as shown in Fig. 1). System development has been made in a three-year project collaborated by JAMSTEC and the University of Tokyo. The system is designed to enable us, with the use of JAMSTEC's deep-tow technology, to make such an observation wherever we need. Our final goal is a system with 100 km long cable, which is supposed to be necessary length to detect the core signal as was estimated by our theoretical study (Shimizu and Utada, 2004 [3]). The instrument developed here has only 10 km long cable. Therefore it is not a final model, but should be regarded as a prototype for a long-term, in-situ test. This experiment is an important step toward the completion of system development.

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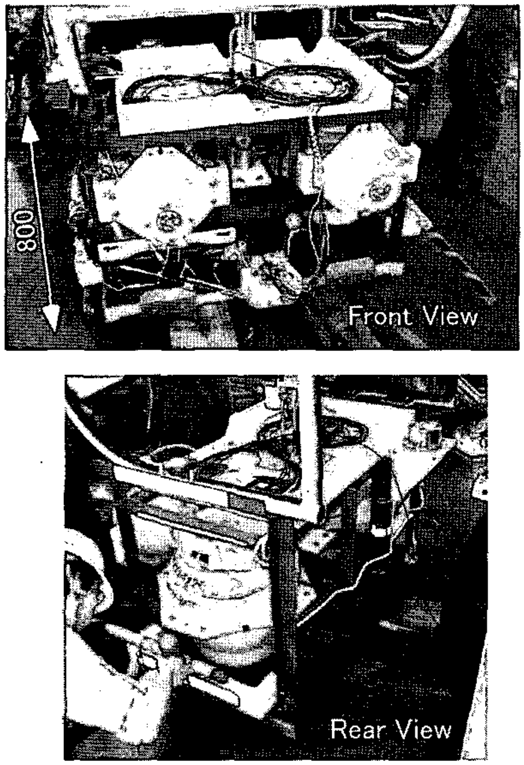

Photo 1. Anchor for the EOS.

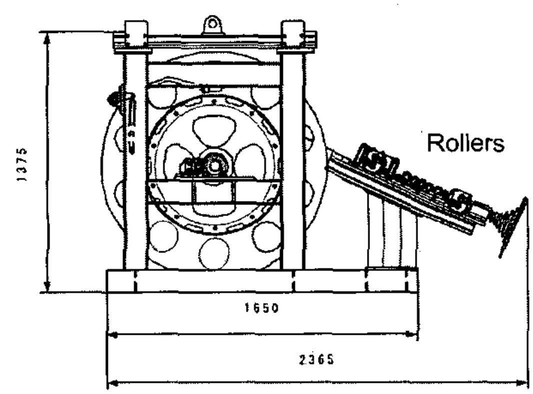

Fig. 2. Bobbin for a long (10 km) cable.

For electrodes, long Ag-AgCl wires with each length of 3m were used. The electrodes are originally made from silver wires. After deployment of the EOS, they are electroplated in the sea water, and covered by silver chloride. The noise level of the long Ag-AgCl electrodes was checked by test electrodes with shorter length of 10 cm in room temperature. The noise level was less than 0.4 mV, close to the minimum recording resolution of the EOS (0.1mV). Longer electrodes with more stable temperature environment will make much lower noise level.

The anchor unit consists of an aluminum frame, a basement with heavy weight, a transducer and glass spheres (Photo 1). The total weight is about 80 kg in water and about 230kg in air, respectively. A low-noise amplifier for measuring electric field, a recording system and an acoustic transponder are installed in the glass spheres. The dynamic range of the voltage measurement is 20 V p-p with 0.1 mV resolution. The sampling period is 10 seconds and a continuous recording for 2.5 years is achieved. The transponder is used for acoustic ranging to decide the seafloor location of the anchor. It can also receive a release signal of the heavy weight, and then anchor can pop up by its buoyancy.

The 10km cable is specially designed for the EOS. A copper wire with diameter of 0.5 mm is surrounded by a SUS pipe and a two-layered polyethylene sheath, and total diameter of the cable is 4.5 mm. The weight is about 7kg/km in water and 23 kg/km in air, respectively. The maximum strength of the cable is about 1200N. The cable was wounded on a bobbin (Fig. 2). The cable is extracted through rollers attached at the rear of bobbin.

The way of cable extension for the EOS is basically same as the expandable deep seafloor monitoring system (Kawaguchi et al., 2002 [8]), but is slightly modified because of the thinner and longer cable. The schematic diagram for the cable extension is summarized in Fig. 3.

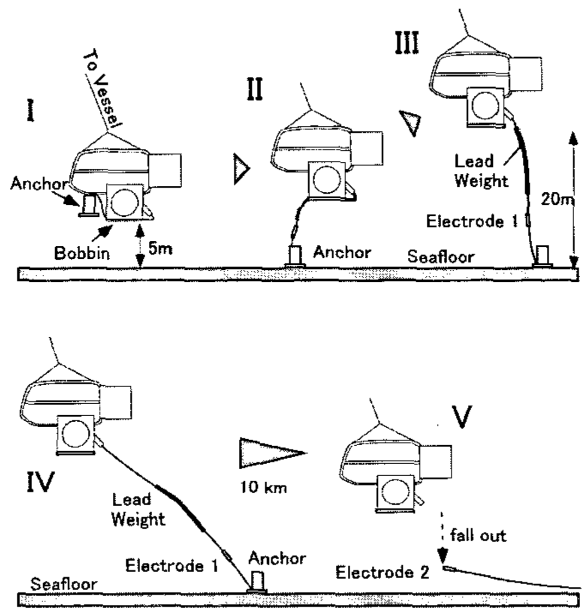

Fig. 3. Schematic views of the deployment of the EOS.

3. Deployment of the EOS

We installed the prototype EOS to make a long term test for about a year. A research cruise named NT04-04 on JAMSTEC R/V "Natsushima" with the 4000m deep-tow system (DT-4000) was carried out from May 4 to 15, 2004. Prior to the test cruise, a similar test experiment was made in last year by a cruise on R/V Natsushima named NT03-05 (May 19-30, 2003). On NT03-05, the cable was unexpectedly cut at the beginning of installation. Through this experiment, we found out a number of important and significant problems to be solved. Large improvement has been made to the system before and on the NT04-04 cruise as follows:

1) Break strength was set as 35 kgf before rotation and 10-15 kgf after.
2) Friction of the cable holder was made much weaker than the break strength.
3) Cable was rolled on the bobbin with a tension control at 20 kgf.
4) The anchor weights 80 kg in the seawater.
5) Cable outside the bobbin at the initial setting was made heavy by putting lead weight (Fig. 3).

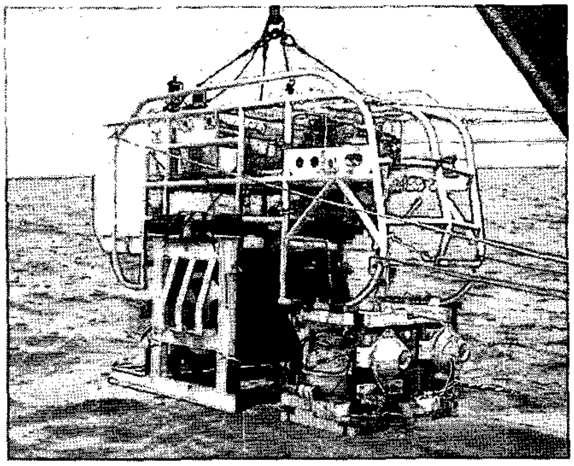

Photo 2. DT-4000 with the Electric field Observation System (EOS).

The EOS was successfully deployed on the ocean bottom at about 100 km east off the Daito-jima Islands, Japan (Fig. 4 and Photo 2). First, the anchor was deployed at about 3300m deep seafloor, then 9.3 km long cable was installed in S40E direction. This direction is almost parallel to the TPC-2 submarine cable, used for voltage measurements between Guam and Okinawa, so that we can make direct comparison of the electric field. It took about 7.5 hours for expanding the cable near the seafloor with towing speed of 0.5-1.0 knots. The total operation time was 10 hours including ascending and descending time of DT-4000. The weather is calm during the operation with state of S-4 (Moderate breeze).

We also deployed an Ocean Bottom Electro-Magnetometer (OBEM) in the same area. The OBEM is a kind of self pop-up instruments with an acoustic unit, and has a three-component magnetometer and a voltmeter with two electric dipoles of 5m length. Simultaneous electromagnetic data recorded by the OBEM can help us to discuss the externally induced component in the observed electric field recorded by the EOS.

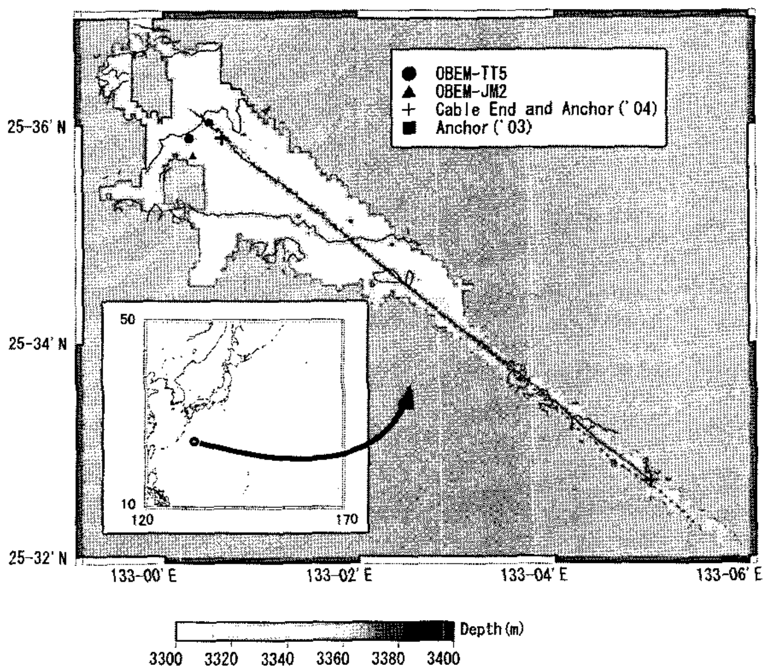

Fig. 4. Tracks of the DT-4000 (a dashed line) and R/V Natsushima (a solid line) at the cable extension, respectively. The locations of the OBEM deployed in 2003 (TT5) and 2004 (JM2) and the anchor deployed in 2004 are also shown. Bathymetric data obtained by a multibeam echosounder of R/V Natsushima is shown as a contour map (gray zone: no data).

4. Summary

We developed a new instrument to measure the electric field on the ocean bottom by using a long cable. Although the cable length is limited with 10 km, the instrument is a prototype to be used for one-year test on the ocean bottom. We conclude that the NT04-04 cruise was successfully carried out to deploy the instrument, and made a significant contribution for the system development by the present investigators toward a system with a 100 km cable. This success is based on various tests prior to the cruise, but is also due to the calm weather at cable extension. Our experiences indicate that tension control is the most important factor for successful cable extension. In future, much refinement should be required on the tension control even under less calm weather and sea conditions.

The recorder on the anchor will obtain continuous data of the electrical potential for a year till it is retrieved by JAMSTEC ROV "KAIKO 7000" in 2005. Then the 9.3 km long cable with a ROV connector will stay on the seafloor for further geophysical experiments. After recovery of the anchor with the recorder and retrieve of the OBEM, we will discuss on the noise level of the electric field recorded by the EOS in the real ocean bottom environment, and will decompose the observed data into signals come from external induction, ocean current and dynamics of the earth's core.

Acknowledgments

We would like to express our sincere thanks to Mr. M. Ishiwata, the captain at the NT04-04 cruise and Mr. S. Ryono, the captain at the NT03-05 cruise. We are grateful for officers, engineers, all the crew of R/V Natsushima, and marine technicians of Nippon Marine Enterprises, Ltd. and Marine Work Japan, Ltd. The prototype system could not be installed successfully without their great efforts.

Dr. K. Asakawa in JAMSTEC, Dr. J. Kasahara in Japan Nuclear Cycle Development Institute, Dr. Y. Ejiri, Kokusai Cable Ship Co., Ltd. gave us useful comments on refinement of the cable extension system. Ocean Cable & Communications Co. and Tierra-Technica Co. helped us to refine hard and software of the EOS. Dr. W. Siripunvaraporn and Dr. Shi, X. M., ERI, Univ. Tokyo, helped onboard operations. Dr. N. Hibiya, Graduate School of Science, Univ. Tokyo, and Dr. M. Uyeshima, ERI, Univ. Tokyo, supported us on land. Also we are grateful to JAMSTEC for providing us ship time to carry out the deployment. This work is partially supported by JSPS grant in aid for scientific research (#14204041).

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