

Development of a Seafloor Acoustic Ranging System (SeaFAR): Preliminary results of long term trial experiment

Tetsuichiro Yabuki*, Yoshiharu Nagaya*, Akira Asada*, Fusakiti Ono** and Katsuyuki Tajiri***

* Hydrographic Department, Maritime Safety Agency

** Sena Inc.

*** Nichiyu Giken Kogyo Co., Ltd.

1. Introduction

The plate boundaries are mainly on the deep sea bottom; spreading centers, subduction zones, and transform faults, along which many crustal dynamic episodes are occurring. Then, the researches of sea bottom crustal episodes are one great target in the earth science. However, these episodes have not been directly observed in the human history. We have been remotely experienced them through some kinds of low-resolution propagating phenomena generated by the dynamic events; for example tsunamis, earthquake motions and so on. Therefore, it is an important frontier for the earth science to observe the crustal deformation directly at the seabottom.

There are two difficulties for the observations of the sea bottom episodes. One is that we cannot stay at the deep sea bottom to monitor those events by ourselves. And the other is that the electromagnetic wave, which is a very nice tool for the remote sensing, do not transmit into the sea water. Against the first difficulty, the development of underwater vehicles is an answer of human technology. And against the second difficulty, we can use the acoustic wave instead of electromagnetic wave.

Acoustic techniques have already been used as a ranging technique in the sea water; for example, the underwater positioning tools and remote sensing tools of seafloor. Then, we have already known the possibility of acoustic techniques as the method for the geodetic observation in the sea water (Spiess, 1980, 1985;

Fujimoto, 1995). However, in order to observe the crustal deformations and plate motions on the sea bottom, high precision and high long-term stability is necessary. And we have a few experience to use the acoustic techniques for the precise geodetic method (Spiess & Hildebrand, 1995; Fujimoto et al., 1995).

In this report, we introduce an recent activity at the Hydrographic Department of Japan for the development of an observation system of seafloor crustal movements (Yabuki et al., 1994; Nagaya et al., 1996). We call this observation system SeaFAR (Sea Floor Acoustic Ranging system). The purpose of the development of SeaFAR is the assessment of acoustic technique as the method of precise ranging on the sea bottom. And, as one goal, we aim the detection of plate spreading at the super-fast spreading plate boundary at the southern East Pacific Rise.

2. Development of SeaFAR

Our strategy for the observation of sea floor crustal movements is to measure the travel time of acoustic signal between two points precisely (Fig.1). We think that the repeatedly measured data can reveal the temporal changes of baseline length, and therefore, we may detect the crustal movements. In our plan, we prepare twin units; unit I and unit II. Measurement is done at the baseline between unit I and unit II.

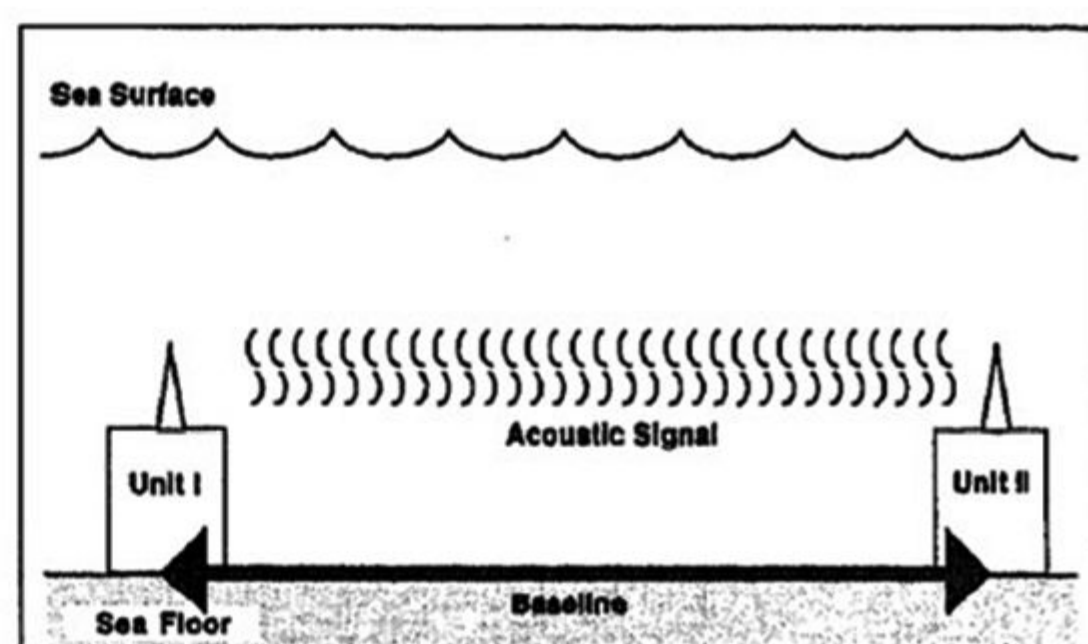


Figure 1: Schematic view of the acoustic ranging of the sea bottom baseline

Unfortunately, the velocity of acoustic wave is not constant; it depends on temperature, salinity and pressure, and varies temporally and spatially. However, the environment at the deep

seabottom is rather invariant compared with that in the shallower layers; shallower than 1000 meters (Urlick, 1983). Therefore, repeated measurements at the deep seabottom has the possibility to show us the baseline length, changes, if we obtain sufficient precision and accuracy.

In order to obtain sufficient resolution and accuracy in the travel time measurement, we employ the following three plans (Nagaya et al., 1996). Firstly, the target resolution of baseline length measurements is about 1 centimeters or less. In order to realize this resolution, we have to measure the travel time of acoustic signal with the resolution of less than 7 micro-second. Then, we use rather high frequency acoustic wave, frequency is from 30 to 50 kilo Hertz, although this signal is not appropriate for the ranging of long baselines because of high attenuation. We think that the limitation of baseline length for the SeaFAR is about 1.5 kilo-meters. Secondly, to get high signal-to-noise ratio, we digitize the output of hydrophone and calculate the cross-correlation with the transmitted signal. By using this technique, the signal to noise ratio is expected to increase ten or more times. Thirdly, the measurements is done in two-way, in order not only to cancel the effects of water flow but also to cancel the ambiguity that stems from unknown time lag between two local clocks in unit I and unit II.

The observation scenario by using SeaFAR is as follows. The twin units; unit I and II are deployed on the seabottom. At a predefined moment, each unit transmits the signal and, typically one second later, receive the signal from the partner unit. The received signal is digitized and stored in the memory. Cross-correlation is computed and the arrival time of signal is identified. The time difference between signal transmission and signal arrival from partner unit is not the true travel time. It is the pseudo travel time because which include the time lag between two local clocks. After the repeated measurements of typically one years, we recover two units and extract the pseudo travel time data. By summing up of two pseudo travel time for each epoch, we obtain the time series of measured two-way travel times. Two-way travel time is free completely from unknown clock lag and is free approximately from the effects of seabottom water flow (Yabuki et al, 1994).

3. Sea Trial and Preliminary Results

We have done several trial experiments of SeaFAR at the Sagami Bay (Nagaya et al., 1996). In this report, we presents some results of the experiment from August through October in 1996. Fig.2 is the location map of that experiment. The baseline length was about 760 meters. The water depth was about 1240 meters. More than 1000 times measurements were done every one hour for forty three days. Fig.3 is an photo of a unit of SeaFAR, just before the free fall from the ship. The topography of the field experiments was chosen carefully. Two units were placed on the slopes of a valley so that the baseline cross the axis of valley. The reason of this careful choice is to ensure the acoustic visibility between two units.

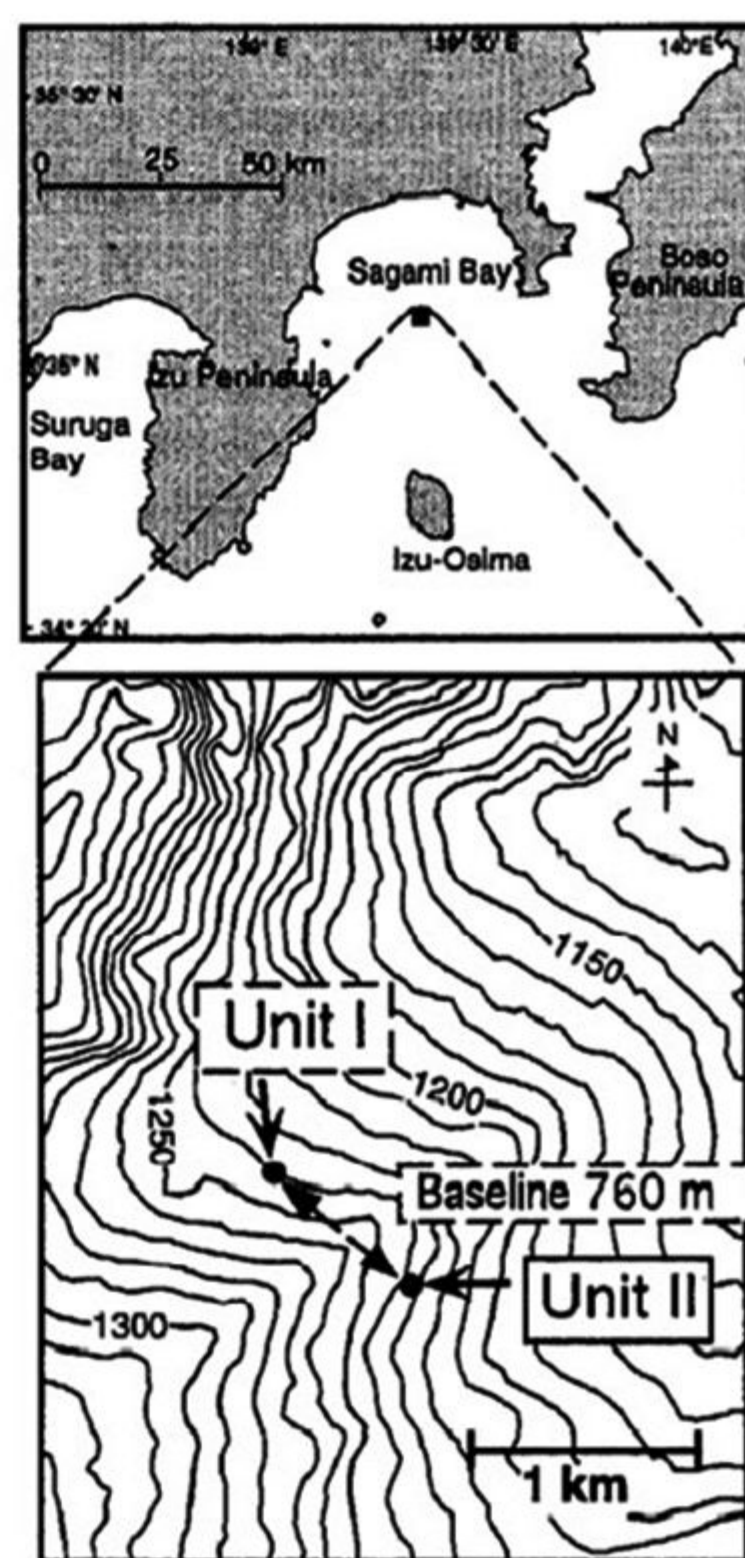


Figure 2: Location maps of the trial experiment of SeaFAR from August to October in 1996. In the bottom map, seafloor topography is shown by the isodepth contour. Contour interval is 10 meters.

In this experiment, we used the chirp signal for the range measurement. It sweeps from 30 kHz to 50 kHz linearly for 5 milli seconds.

Fig.4(a,b) are an example of the received signal form for an epoch. The background noise level is very small. The wave forms are distorted because of the overlapping of lately arrived signal. This overlapping means the existence of multi path. By storing the waveform data for each measurement, we can recognize the effects of multi path in the post-processing of data. Therefore, we hope that the analysis of waveform prevents ourselves from the misunderstanding in the detection of baseline length changes. Fig.4(c,d) are cross-correlations between the received waveform and transmitted signal (chirp signal). It seems that a rather large secondary signal arrives about 100 micro second later from the arrival of first wave. Some weak later signals are found.

Fig.5 is the preliminary result of 990 times two-way travel time measurements for 43 days. Epoch interval is one hour. Fig.6 shows the observed water temperature at a point for the same period. Thermometer is deployed at the point of 12.5 meters height from the seabottom and close to the middle point of the baseline with the depth of about 1260 meters. From these figures, we can understand the high cross-correlation between the travel time changes and water temperature changes. It is obvious that the variation of travel time is mainly caused by

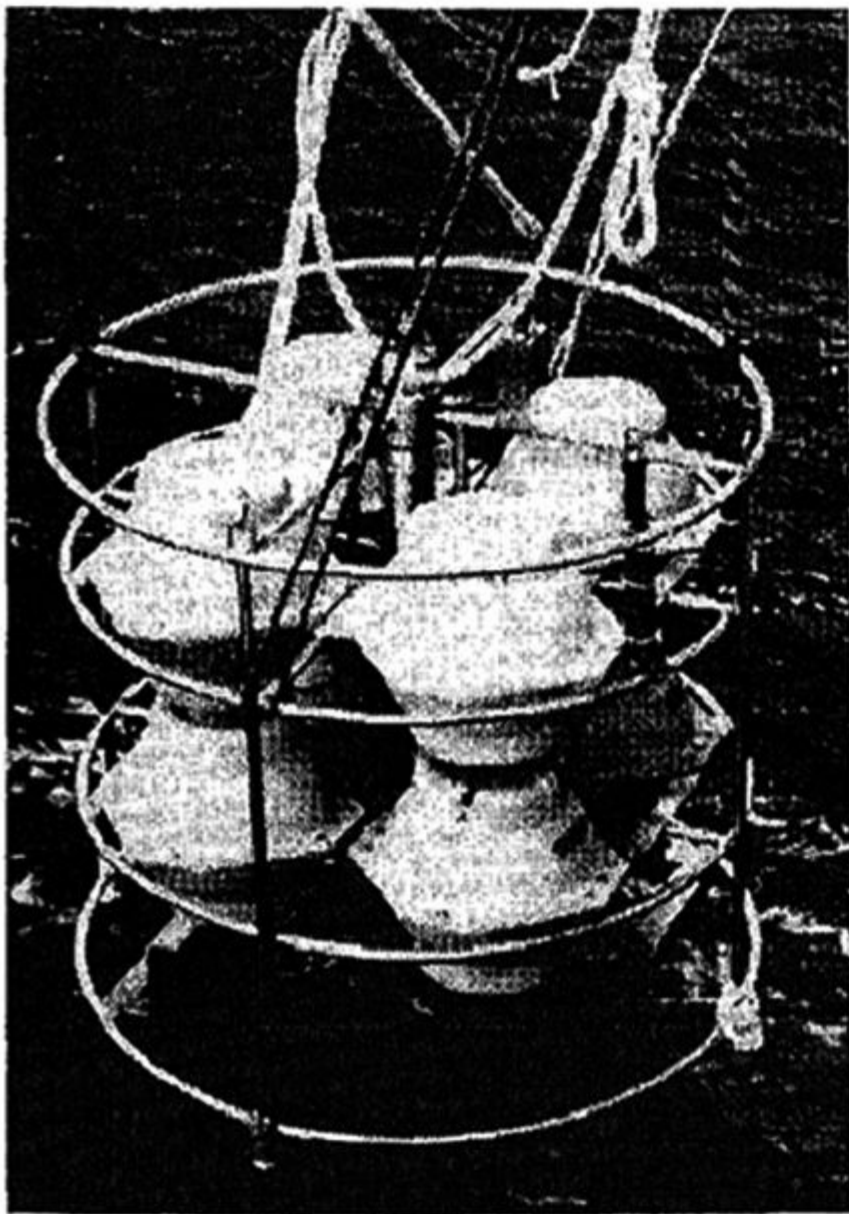


Figure 3: A photograph showing a unit of Sea-FAR.

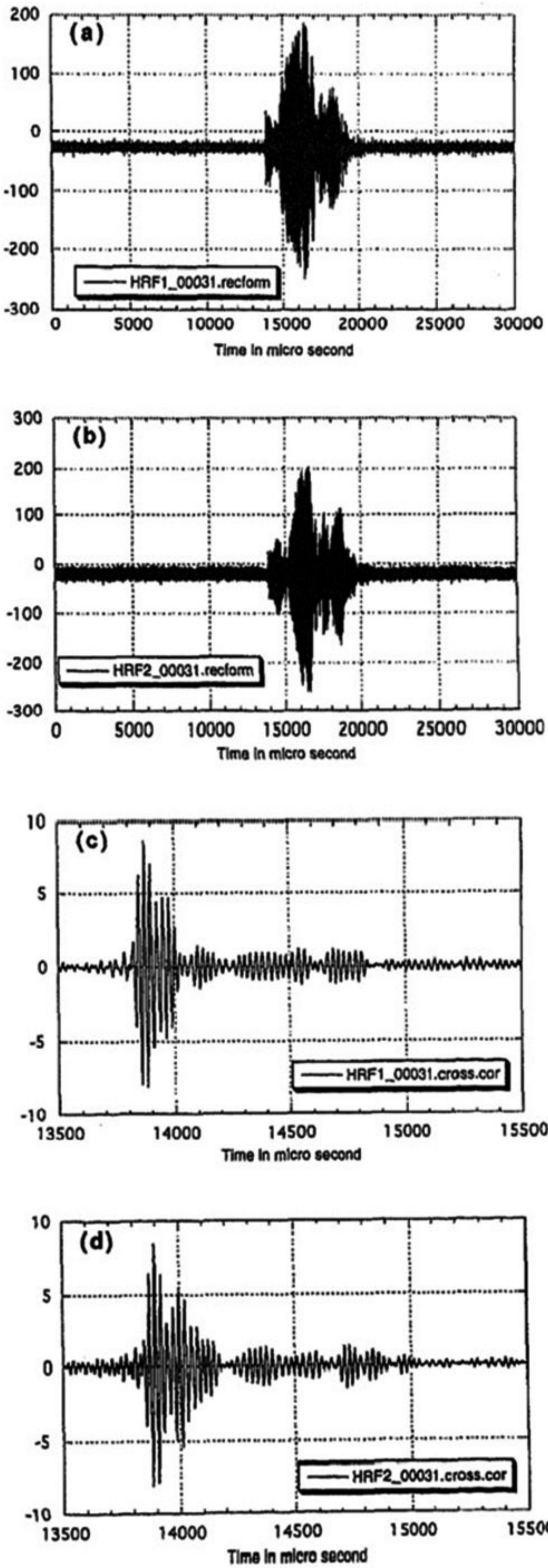


Figure 4: Examples of the recorded signal for a measurement epoch. Received signal at Unit I (a) and at Unit II(b). The cross-correlation with the transmitted signal: panel (c) is for received signal in panel (a) and (d) for (b).

the sound velocity variation from temperature changes. The changes of water temperature have the peak amplitude at 12 hours period. This period is obviously owing to the tide.

We empirically know the relation between temperature and sound velocity (Urick, 1983). By using this relation, and by assuming that salinity is constant temporally and spatially, and by assuming that temperature is constant spatially, we can estimate the baseline length along the ray path and its temporal changes, based on the observed temperature data. Fig. 7 shows the results. The standard scattering of repeated measurements is about 3.3 centimeters, which corresponds the 40 parts per million (ppm) repeatability for 760 meters baseline length. About the long term trends, we cannot find large changes in Fig. 7, which means the stability of travel time observation.

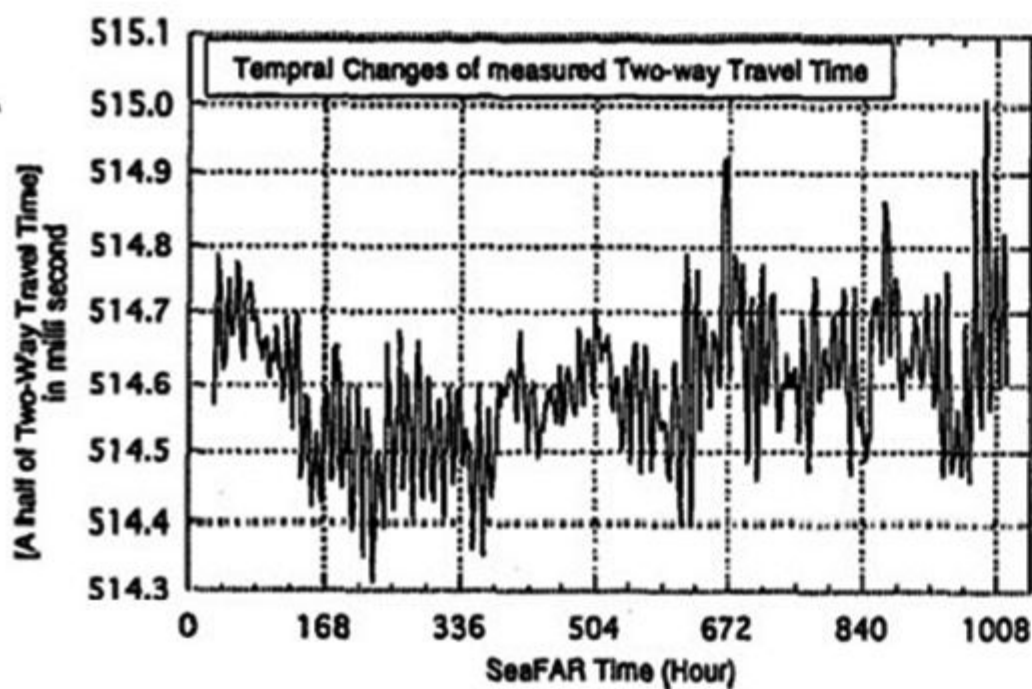


Figure 5: Preliminary results of 990 times repeated measurement of Two-way Travel time.

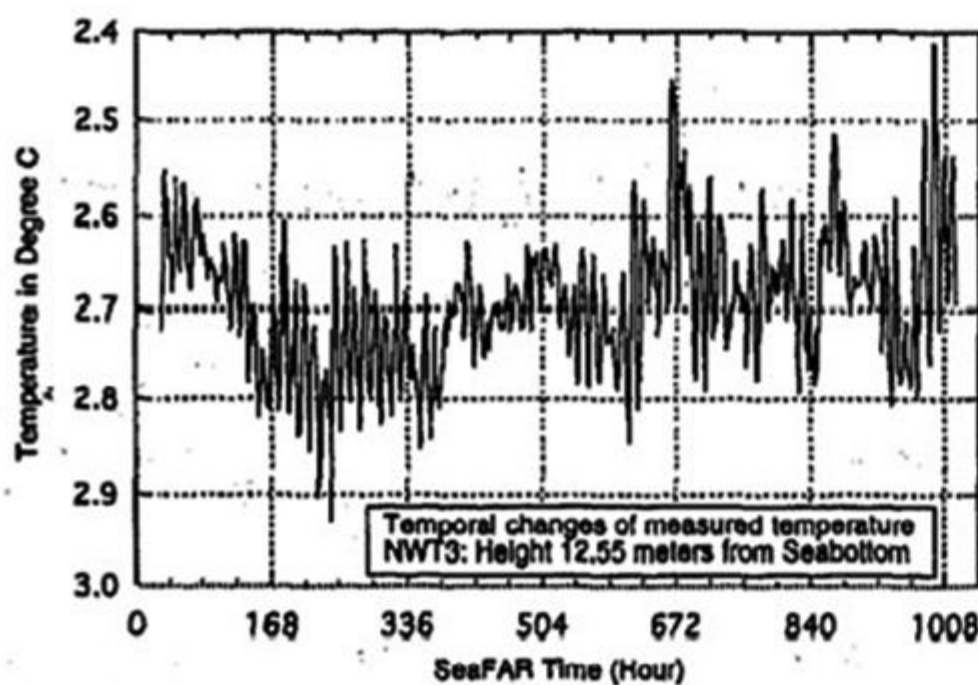


Figure 6: Observed sea water temperature changes at the point near to the middle of baseline. Thermometer is 12.5 meters high from the sea bottom.

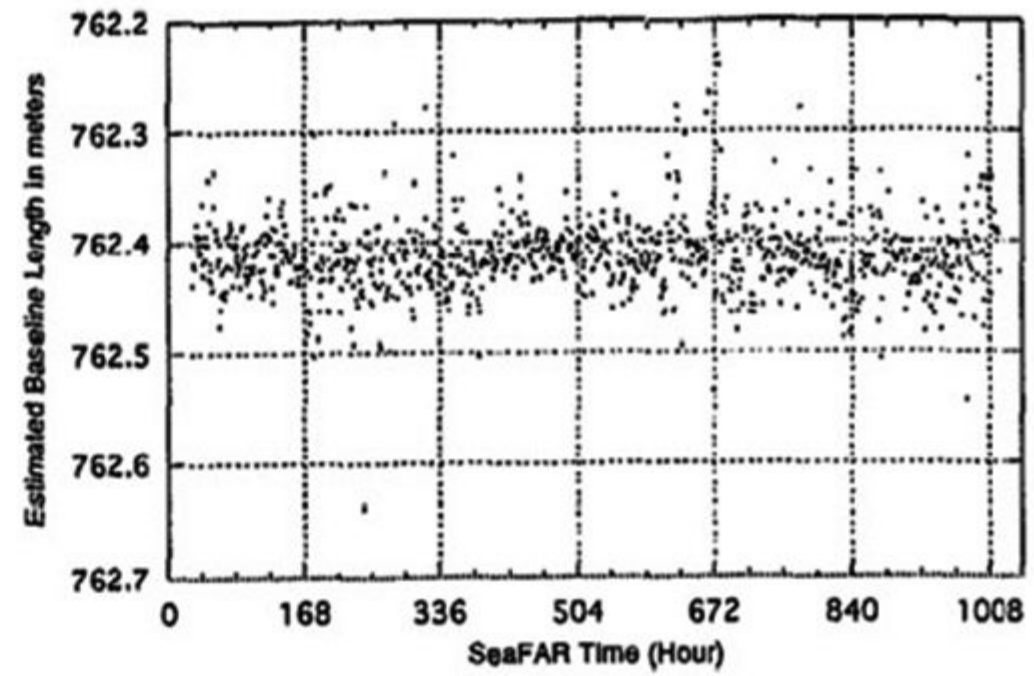


Figure 7: Estimated baseline length based on the results in Fig. 6 and Fig 7. The empirical relation between temperature and sound velocity is by Mackenzie (Mackenzie 1981; Urick, 1983).

4. Conclusions

We obtained the 40 ppm repeatability for single measurement as a preliminary results for the baseline length of 760 meters. However, this preliminary result is based on the temperature data at only a point. For the estimation of baseline length, we should consider the spatial variation of temperature. Fortunately, we have measured temperature variations at 7 points to estimate the spatial distribution of sound velocity. We hope the repeatability will be increased by using these temperature data.

Moreover, we think that errors contain some information about the sea bottom environment. The detailed analysis of errors will reveal the seabottom nature. And we can obtain more accurate information about the baseline length changes.

We hope that the development of SeaFAR is one step for the observation of the seafloor plate motions.

Acknowledgment

The authors greatly appreciate the crew of Survey Vessel Shoyo at the Hydrographic department. They are very patient for our many complicated request for the sea trial experiments.

This developments a work in the "Ridge Flux Project" funded by the Science and Technology Agency.

References

Fujimoto H., 1995, Precise Seafloor Acoustic Ranging, - Observation of Horizontal Sea-

- floor Crustal Movements- Jour. Japan Soc. Mar. Surv. Tech., 7(2), p1-10 (in Japanese).
- Fujimoto, H., T. Kanazawa, and H. Murakami (1995), Experiment on Precise Seafloor Acoustic Ranging - A preliminary Results of Observation-, Jour. Seism. Soc. Japan, 48(2), p289-292 (in Japanese).
- Mackenzie K.V. 1981, Nine-term Equation for Sound Speed in the Oceans, J. Acoust. Soc. Am., 70:807.
- Nagaya, Y., T. Yabuki, F. Ono, and A. Asada, 1996, Development of the seafloor acoustic ranging system, Rep. Hydro. Res., 32, p89-99 (in Japanese)
- Spiess, F.N., 1980, Acoustic techniques for Marine geodesy, Mar. Geod., 4(1), 13-27.
- Spiess, F.N., 1985; Analysis of a Possible Sea Floor Strain Measurement System, Mar. Geod., 9(4), 385-398.
- Spiess, F.N. & J.A. Hildebrand, 1995, Employing Geodesy to Study Temporal Variability at a Mid-Ocean Ridge, Eos Trans., AGU, 75(45), 451.
- Urick, R.J., 1983, Principles of underwater sound 3rd ed., McGraw, Hill, New York, pp423.
- Yabuki, T., Y. Nagaya, A. Asada, F. Ono, and K. Tajiri, 1994, Development of a seabottom horizontal distancemeter for observation of seafloor movements. Proceedings INSMAP '94, 493-498.