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Tidal Effect of Reciprocal Sound Propagations at the Experiment in Hashirimizu Port

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Acoustical monitoring method could monitor wide area such as ocean because it can spatially measure the object with a few sensors. It is important to monitor ocean structure for understanding global climate changes and for controlling aquatic resources. In this report, we investigated sound propagation characteristics using acoustic data measured at Hashirimizu port of Yokosuka, Japan in August 2006 and 2007. Water depth change caused by tide affected received signal amplitude. It was also confirmed from simulated sound pressure by a finite difference time domain (FDTD) method through the change of assumed water depth. Relation of the travel time, vertical water temperature, and depth between the transducer and the sea surface is also indicated from the result of the experiment in 2007.

1 Introduction

Acoustic method has an advantage over other methods on ocean monitoring because it can monitor wide area with few sensors. For example in temperature monitoring, usual thermometer can monitor only a point of the sensor location, but it is possible to monitor average temperature of the sound propagating area using acoustic method. Furthermore, acoustic tomography method, which was introduced by Munk [1], enables spatial and temporal temperature or current distribution. Although satellite can monitor wide area in one time, it can monitor only the sea surface, satellites pass quite few times a day, and water vapor or clouds interfere with clear monitoring. In contrast, acoustic method can monitor spatially, and be possible to observe fixed-point for long period. However, refraction and reflection from the sea surface and seabed complicate the received signals especially at the shallow water. Therefore, many ocean experiment [2, 3] and simulation [4] were executed to clarify these effect and sound propagation. It is also have a possibility to reveal other ocean phenomena from propagating signals such as internal waves and vortex.

We had analyzed reciprocal sound data which was traveling more than 100 km retrieved in the equatorial central Pacific Ocean while a whole year in 2000. From these data, we had investigated relationship of the travel time fluctuations and ocean phenomena, and estimated current speed from the reciprocal travel time differences [5-8]. In this study, small scale reciprocal sound propagation experiment at Hashirimizu port was executed in the August 2006 and 2007. In this paper, we describe a brief of the experiment and represent the effect of tidal changes to the propagation sound in its amplitude level and travel time.

2 Experimental information

Hashirimizu port is a part of Tokyo bay which connects the Pacific Ocean. A pair of a sound propagation system was placed on either bank of Hashirimizu port as shown in Fig. 1 at the depth of about 1.2 m from the seabed. Transducers placed at the middle depth from the bank and propagation systems such as amplifiers, a global positioning system (GPS) receiver and recorders were on the bank near the transducers. Upper system on Fig. 1 is named as “sea side” and lower system is named as “land side” in this paper. The distance between the systems was about 120 m. Figure 2 shows the seabed configuration between the systems measured every 7 m from a boat. Left side shows sea side and right side shows land side. Horizontal axis shows the distance from the sea side and vertical origin means the sea surface of the measured date of 31st July in 2006. In Hashirimizu port, average sea depth is around 5 m and has smooth seabed with mad. Salinity and temperature at the depth of sea surface, middle and sea bottom were also measured at the same time. Figure 3 shows salinity and temperature of each depth between the systems. Though salinity at the bottom along the propagation area indicated higher than that of the other depth because the salinometer touched the seabed, salinity at the propagation area showed almost constant value. On the other hand, temperature at the propagation area had vertical gradient according to the solar heat, but almost constant in horizontal direction.

Figure 4 shows the block diagram of the sound propagation system. As the GPS receivers receives the time information and can generate 1 pulse per second (PPS) signal with the accuracy of ± 200 ns, this 1 PPS signal was used to synchronize both systems. Therefore, it is able to detect the accurate travel time between the systems. Sending Signal is generated at a function generator and amplified at an amp then transmitted from the transducer. Signal propagates through the ocean and received by the transducer at the opposite bank side. The received signal is recorded for 300 ms with the sampling rate 1 MHz after amplified and removed noise. Two systems on the either bank alternately changed signal sending and receiving every 30 s; reciprocal propagated sound record was obtained every 1 min.

Seventh order M-sequence repeated for four times was used for sending signals. As the experiment was executed in August 2006 and August 2007, we use different transducers in each year. The signal was sent with the career frequency of 12 kHz in 2006 and 80 kHz in 2007.

Through the experiment period, thermometers were set at the bottom, near the transducer and surface of the both bank side to monitor temperature every 2 min. Water depth and salinity near the transducers were recorded in 2007.

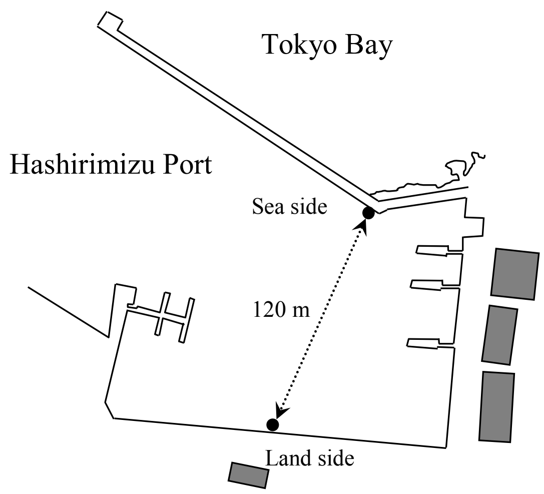

Fig.1 Arrangement of sound propagation system for reciprocal sound propagation.

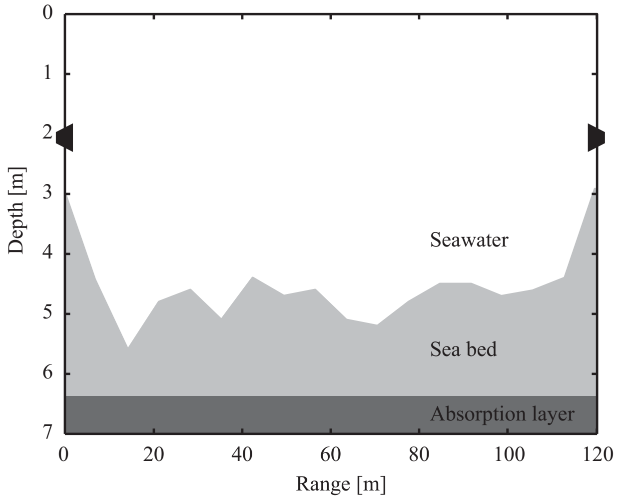

Fig.2 Shape of the seabed and analysis area for the calculation by FDTD method for §3.2.

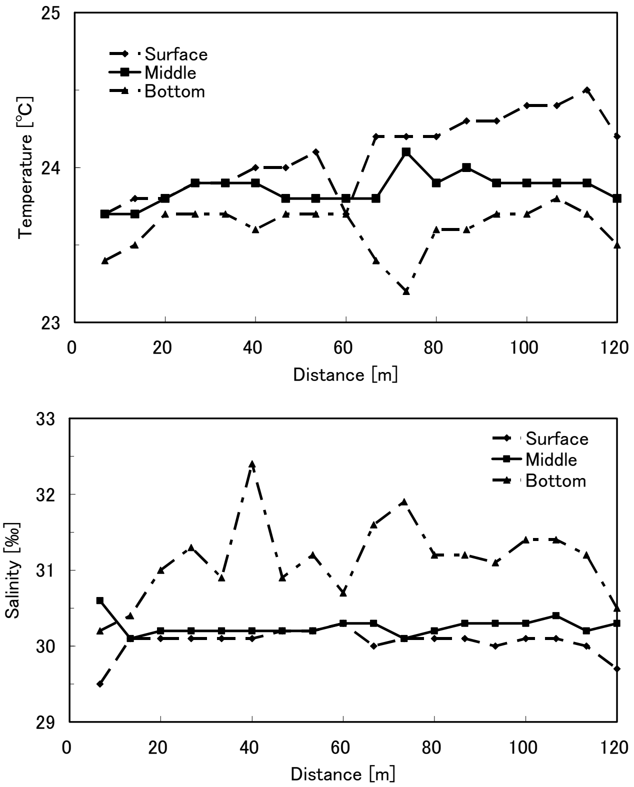

Fig.3 Distribution of temperature and salinity at the propagation area.

Meteorologic information such as air temperature was monitored at about 1 km far from the experimental place.

3 Results

3.1 Received amplitude and tidal effect

Figure 5 shows the examples of the recorded signal in 2006. Propagating signals could be confirmed around 70 – 160 ms. As comparing with Fig.5(a) and (b), the amplitude of received signals varied from time to time. In addition, as usual noise parts have amplitude of less than 10 mV, there were also recorded large and spicular noises except for the propagating signals although the received sound removed

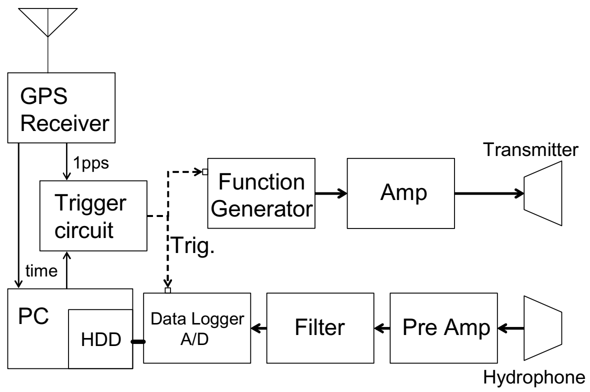

Fig.4 Block diagram of the sound propagation system.

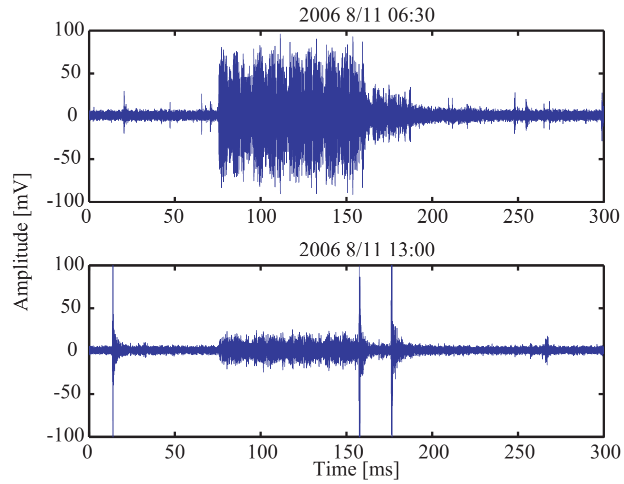

Fig.5 Samples of signals received at land side. (a) 6:30, (b) 13:00 on 2006/8/11.

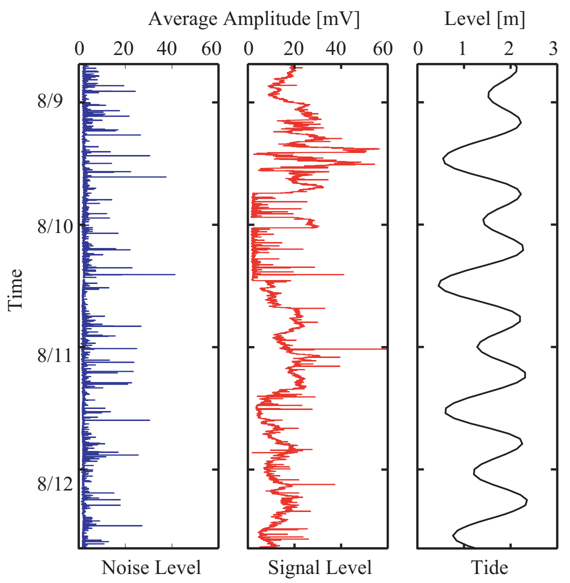

Fig.6 10 ms average amplitude value of noise and propagating signal received at bank side and water level at Yokosuka Port near Hashirimizu Port.

their noise by band-pass filter. These spicular noises random are speculated as some kind of biogenetic sound. RMS for 10 ms of propagating signals and noise part were for each time. The left figure in Fig. 6 shows RMS for 10 ms of noise parts, middle figure shows that of propagating signal parts. While the end of 9th to morning of 10th August, as propagating signals could not be recorded because sending system had a trouble, RMS level are almost same calculated each recorded signals as shown in Fig. 6 to examine the amplitude changes of the propagating signals as the noise part. In both figures, RMS level sometimes shows unexpectedly high value because of including the spicular noises. Except these high values, although noise part keeps its RMS level less than 10 mV while the experimental period, propagating signal changes its RMS level with time. Tidal level at Yokosuka port which also faced Tokyo bay and few kilometers far from Hashirimizu port is figured on the right side of Fig. 6. Comparing RMS level of propagating signals with the tidal level, RMS level changes is similar to the tidal changes especially in the latter part of the experimental period. As the propagating area is very short and shallow space, direct signal and reflected signals propagate almost same time. Thus, recorded signal include all of the signals interfering each other. Because surface reflected signals changes their phase according to the surface level which mainly varies according to the tidal effect, recorded signals changes their amplitude from the interfere of the reflected signals.

3.2 Pressure changes by FDTD method

Recently, the FDTD method has often been adopted for analysis of underwater sound propagation [4, 8]. The FDTD method is adopted to simulate sound propagation in the experimental area with the average temperature and salinity. Water depth was varied to analyze the tidal effect to the sound propagation. The seabed configuration in Fig. 2 is used for calculated area for the FDTD method. We suppose

Table 1 Parameters for analysis of the FDTD method

	Density ρ[kg/m^3]	Sound speed c [m/s]	Attenuation constant γ [dB/λ]
Water	1000	*	0.0
Seabed	1500	1700	0.5
Absorption layer	1500	1700	5.0

* calculated from the McKenzie's equation [10]

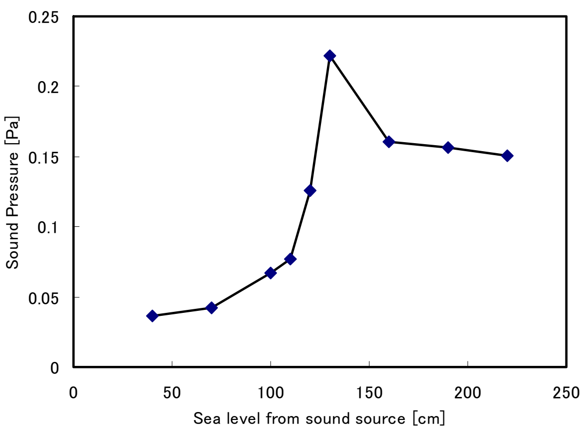

Fig.7 Relation of sea level and average sound pressure at receiver simulated by FDTD method.

two-dimensional space for the analysis with x-axis for range and y-axis for depth. An absorption layer is added below the seabed layer. Parameters of the water, seabed and absorption layer are given in Table 1. Average temperature and salinity is 24 °C and 30.5 ‰, respectively. The increments are $\Delta x = \Delta y$ = 12.5 mm of space andΔt = 1/1200 ms of time. Propagating sound pressure was estimated by the FDTD method with changing the distance from the transducers to the sea surface at 30 cm intervals from 40 cm to 220 cm. RMS levels of the sound pressure at the received point were calculated same as the experimental results. RMS pressure level versus depth between the transducer and sea surface is shown in Fig. 7. The higher the depth from the surface, the larger the RMS pressure level proves the relation between propagating signal amplitude and tidal level. These experimental and simulated results agree to the results of experiments conduced by Urick *et. al* at Florida coast [11].

However, simulated result shows that received pressure level decrease after the depth higher than 130 cm. This phenomenon can be confirmed at high tide in the morning on 11th Augusut that propagating signals becomes smaller according to the tidal elevation at the top part of high tide. But other part does not indicate such behavior.

3.3 Travel time and temperature changes

M-sequence modulated signal has an advantage in measuring accurate travel time in the noisy environment because it can be treat as a pulse after demodulated by the original M-sequence. As sending signal include 4 times of M-sequence signal, recorded signal shown in Fig. 8(a) was cut the length of one cycle M-sequence and added as shown in Fig. 8(b). Effects of spicular noises and other noises can be almost removed by these processes. The added signal were demodulated with M-sequence and transformed to get amplitude components as shown in Fig. 8(c). In the experiment of 2006, we could not get accurate travel time continuously because of the firmware trouble of the GPS

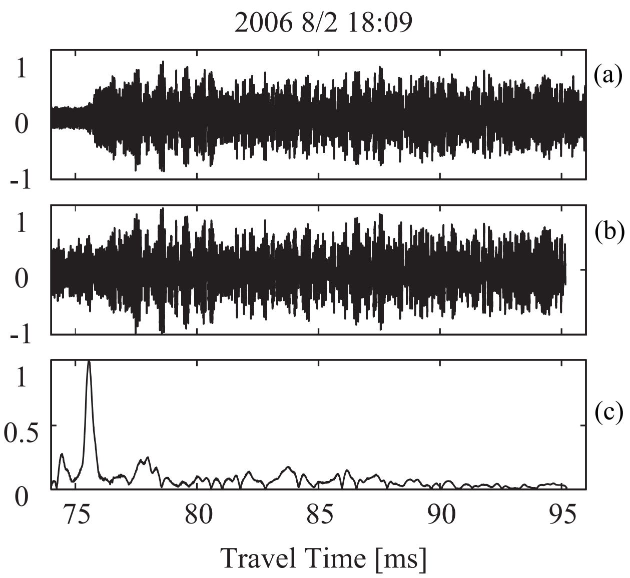

Fig.8 (a) Received signal at 18:09 on August 2, 2007, (b) superimposed signals of the received signal with the length of 1 M-sequence cycle, and (c) amplitude component of M-sequence demodulated signal.

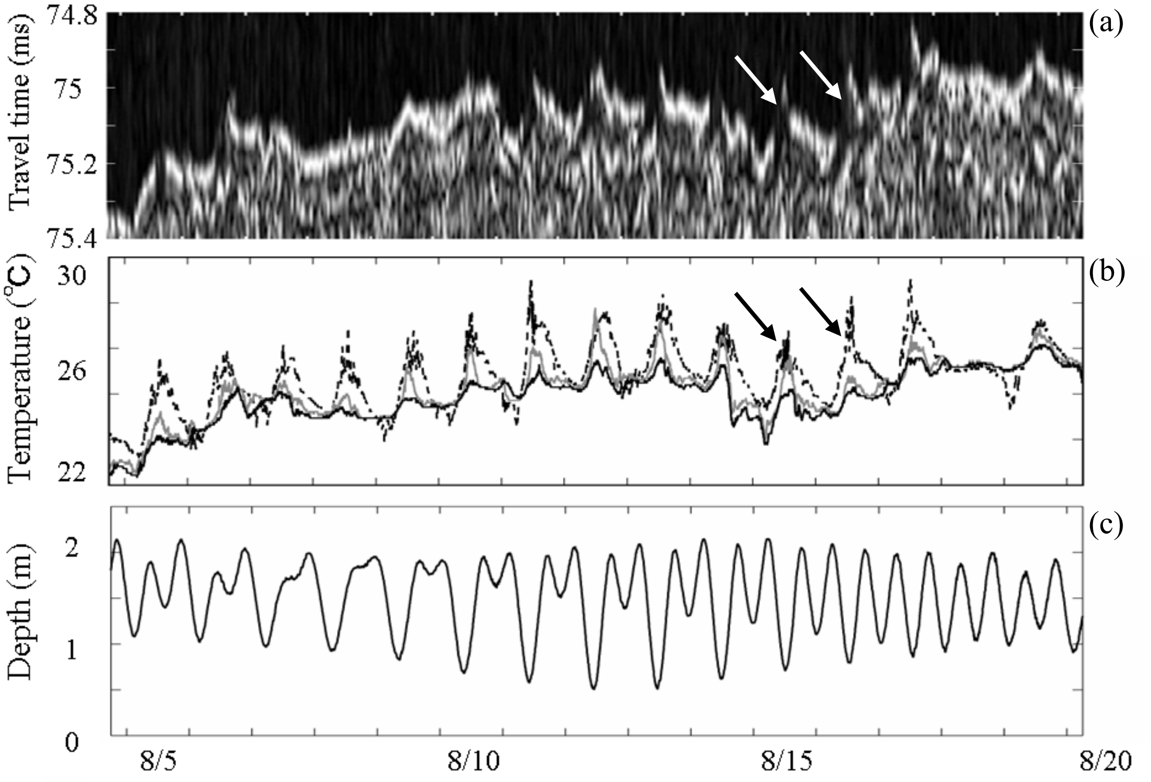

Fig.9 (a) Extracted amplitude of received signals correlated with M-sequence. (b) Water temperature at sea side. (Solid line) water temperature around seabed, (gray line) water temperature near the transducer, (dashed line) water temperature near the sea surface. (c) Distance between the surface and the transducer.

receiver which control sending and receiving timing of the propagation system. Therefore, travel time was calculated only the data in 2007. Figure 9 shows the travel time changing through the experimental period of 4th-20th August in 2007. At the same time, water temperature at the sea surface, depth around the transducer, and the seabed were measured every 2 min and plotted by dashed line, gray line and solid line, respectively on Fig. 9(b). Figure 9(c) shows the depth between the transducer and the sea surface monitored by conductivity temperature depth meter (CTD) near the transducer every 5 min. Gray scale indicates the amplitude of the signals in Fig. 9(a). White part means strong amplitude and black part means weak amplitude. The first strong amplitude appeared around 75 ms. The first white band located at the front of the black part around 75.2 ms are the point of the direct pass. Sound speed calculated by McKenzie's equation [10] with average temperature 24 °C and average salinity 30.5 ‰ at the depth of 2 m is 1527 m/s. Thus, distance between the systems is derived 114.5 m. As the accurate measurement between the systems by a laser distance meter shows 116.3 m, acoustic monitoring result has validity.

Tracking the first white band, travel time varies according to the changes of water temperature in Fig. 9(b). But in some part, the first arrival amplitude suddenly disappeared such as around noon of 15th and 16th August as indicated by white arrows in Fig. 9(a). In such period, it is confirmed that water vertical gradient of water temperature is steep shown as arrows in Fig. 9(b) and depth from the transducer to the sea surface is very low given as Fig. 9(c). It is assumed that the direct pass could not reach the received transducer because high vertical temperature gradient refracts the propagating sound. Furthermore, the very low depth because of the tidal effect seems to make refracted sound into the seabed. It is necessary to confirm by simulation in future.

4 Conclusions

Reciprocal sound propagation experiment at Hashirimizu port in Japan was conducted while the August in 2006 and 2007. Amplitude of the propagating signal was varied from hour to hour according to the surface level of the tidal effect. The simulation by the FDTD method indicated that received sound pressure level changed by shifting surface level; it is confirmed the experimental result. Moreover, the first arrival signal varied its travel time according to the temperature changes but some part could not receive the direct signals. In such cases, vertical temperature gradient was steep and depth from the sea surface to the transceiver was very low.

These results suggest new function for long period acoustic ocean monitoring. In future works, we will analyze reciprocal sound propagation and estimate current effects. In addition, we will reveal the effects of tide and other ocean phenomena to the sound propagation reconstructing experimental results by simulation.

Acknowledgments

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