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Estimation of Propagated Pulse Waveform in Lűtzow-Holm Bay of Antarctic Ocean Calculated by Parabolic Equation Method

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ABSTRACT

Recently, the climate research of Ocean using Autonomous Underwater Vehicle (AUV) is being planned in Antarctic Ocean. In this study, in order to know the characteristics of sound propagation in Lűtzow-Holm bay of Antarctic Ocean for acoustical communication of AUV, we calculate pulse waveform using parabolic equation method with inverse Fast Fourier Transform algorithm. Sound velocity profile of Lűtzow-Holm bay was obtained from 31-th Japanese Antarctic Research Expedition (JARE-31) which carried out from 1991 to 1992. We have investigated about the influence of amplitude of pulse wave by bathymetry in transverse line 'OW' and 'L' of the bay in Antarctic Ocean. We assumed that the one transmitter was placed three different depths at 50, 100, and 150 m and propagation range was constant at 39 km and 36 km in OW and L traverse lines. We calculate propagation pulse in Antarctic Ocean with three bottom models to know the influence of amplitude of pulse wave by bathymetry, clearly. By confirming the fluctuation of amplitude of pulse to influence by depth of source and receivers, we estimate about the amplitude of pulse by parabolic equation method to change the depth of source and receivers. As a result, the variation of amplitude of pulse wave is about -3 dB when source depth is 100 m in OW traverse line. In addition, the variation of amplitude of pulse wave is about -3 dB when source depth is 100 m in OW. In L transverse line, the variation of amplitude of pulse wave is about -4 dB when source depth is 100 m. the amplitude of pulse varies from 5dB to -10dB when source depth change from 50 m to 300 m .

INTRODUCTION

Ocean Acoustic Tomography (OAT) using sound propagation times in ocean is useful observation system to know the actual temperature, salinity concentration of water and oceanic current[1-4]. Recent years, the acoustic thermometry of the ocean is being planned in many countries, because it is important to know the observation data of environments in many ocean for any researches of fisheries society, geology and aerologic. OAT needs an adequate numerical method of sound propagation to obtain the prior information of the ocean. Therefore, we have been developed numerical analysis method of sound propagation in Ocean[5].

On the other hand, it is important to research the phenomenon of Ocean climate in the Antarctic Ocean, because polar region was large influenced to the energy circulation of the global climate. Therefore, measurement of oceanic environment carried out in the Antarctic Ocean by many countries. For example, the Japanese Antarctic Research Expedition (JARE-31) conducted a two-year program of atmosphere /sea-ice/ocean study in Antarctic Ocean from 1991 to 1992[6]. However, the observation of boundless ocean with ice layer on sea surface was very difficult.

Recently, the climate research of Ocean using Autonomous Underwater Vogel (AUV) is being planned in the Antarctic Ocean. The underwater communication is famous method for remote control by AUV in sea-water, and the research of the improvement of the transmission rate in underwater communication was developed[7-9].

The purpose of this study describe about the characteristics of sound propagation loss in Antarctic Ocean for development of underwater communication. In order to know the characteristics of sound propagation loss in Antarctic Ocean, we estimated the amplitude of pulse wave propagated in underwater of Lűtzow-Holm bay in two transverse lines. We have investigated about the influence of amplitude of pulse wave by bathymetry in transverse line OW of the bay in Antarctic Ocean model that was covered ice surface for 39 km in range. And, We have investigated about the influence of amplitude of pulse wave by bathymetry in transverse line L of the bay in Antarctic Ocean at 3 km in range. By comparing with the amplitude of the pulse wave with or without reflected pulse from bottom, we ware assumed three kinds of bottom media in this sea area.

In this study, we calculated pulse waveform used by parabolic equation method. Parabolic Equation (PE) method [10-12] is very useful method to calculate the sound propagation in the field. However, this method can be calculate only continuous sound field, therefore, common PE method do not calculate pulse wave in time domain. Then, we used inverse Fast Fourier Transform algorithm for the calculation of pulse waveform in time domain. This method is very famous method to convert to frequency domain to time domain.

ENVIRONMENTS OF LŰTZOW-HOLM BAY IN ANTARCTIC OCEAN

Bathymetric chart of Lűtzow-Holm bay

Observations of marine environments are being by the national polar region laboratory in the South Pole from 1989 to 1992. The Japanese Antarctic Research Expedition (JARE-31) conducted a two-year program of atmosphere /sea-ice/ocean study in Lűtzow-Holm bay and in its surrounding sea of the Antarctic Ocean. The purpose of this observation is to understand a geophysical role of ice-covered ocean in the processes of the Antarctic Ocean climate.

Figure 1 shows the bathymetric chart of Lűtzow-Holm bay. As shown in this figure, the sea depth has changed greatly on traverse line OW, the depth of OW5 and OW1 are 758 m and 158 m, respectively. There is a submarine valley under sea bottom between from L5 to L4, the depth of valley is about 965 m. In this sea area, the water temperature and the salinity are measured at each position from OW1 to 5, from L1 to 5, and from P1 to 4 in Fig. 1. The average thickness of ice covered sea surface in the measurement point is about 1.0 to 2.5 m.

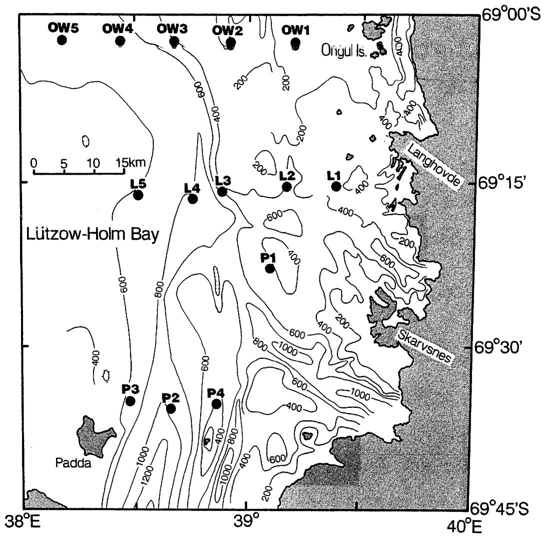


Figure 1. Map of Lutzow-Holm bay

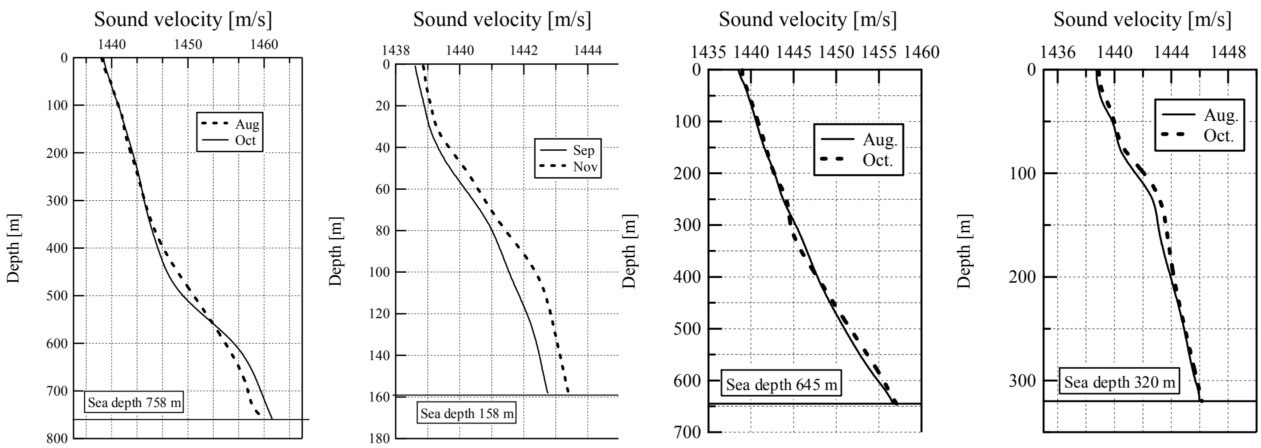
Sound velocity profile of Lűtzow-Holm bay at JARE-31

The sound velocity profiles of Lűtzow-Holm bay on transverse line OW are shown in Fig. 2. These profiles were calculated by measurement data using Del-Grosso equation[13]. As shown in Fig. 2(a), the bottom depth of OW5 is about 785 m which measured water temperature and the salinity the ocean side. The water temperature of sea surface about -1.8 degrees, and it is changed rapidly near sea surface. When depth is higher than 100 m, water temperature was constant value which is about -0.5 degrees. All sound velocity profile has changed almost linearly. In generally, sound velocity profile to the direction of depth in Ocean is depended on the water pressure, water temperature, and salinity. Measurement point OW5 has constant value of temperature higher than 100 m of depth. Therefore, sound velocity only depends on water pressure in each observation point. The bottom depth of OW1, which is located near bay side, is about 185 m as shown in Fig. 2 (b). Figures 2 (c) and (d) show the sound velocity profile in measurement points of Lűtzow-Holm bay on transverse line L, respectively. The profile has been changed linearly as same as Fig. 2 (a) and (b). The difference of sound velocity by the season is very small.

SIMULATION MODEL IN LŰTZOW -HOLM BAY ON TRANSVERSE LINE OW

Bathymetric chart of transverse lines OW and L, and Simulation model for sound propagation

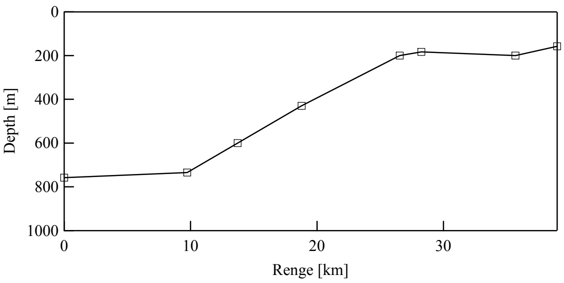
The characteristics of sound propagation analyzed between OW5 and OW1 on transverse line OW whose distance was about 39 km. Figure 3(a) shows bathymetric chart of transverse line OW. As shown in this figure, bathymetry of transverse line OW has gradual upslope model, which is common bottom model in shallow water. In this simulation, we neglected ice layer of sea surface because we hope to know the influence by bottom reflection in this study. The boundary condition of sea surface adapts pressure release boundary condition that is famous boundary condition at calculation of sound propagation in Ocean. Sound velocity profile was obtained by Fig. 2 (a) at each observation point. Any point of sound velocity to the horizontal direction was calculated by Fig. 2 (a). We assume density of water is 1.0 g/cm^3. The depth of the sound source was assumed to be 100



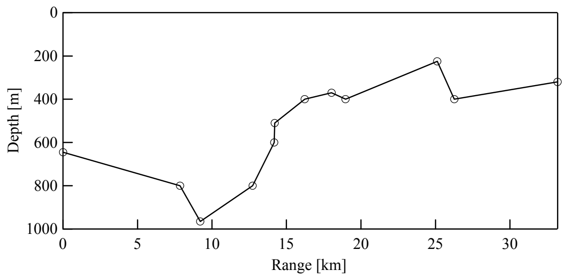
(a) OW5 (b) OW1 (c) L5 (d) L1

Figure 2. Sound velocity profiles of Lűtzow-Holm bay. Figures 2 (a), (b), (c) and (d) shows the sound velocity profile in measurement points OW5, OW1, L5 and L1, respectively. These profiles were calculated by measurement data using Del-Grosso equation using measurement data for JARE-31.

m from sea surface. Figure 3(b) shows bathymetric chart of transverse line L. This transverse line has a seamount at 24km in range.



(a) Bathymetric chart of transverse line OW.



(b) Bathymetric chart of transverse line L.

Figure 3. Bathymetric chart of two transverse lines.

Figure 4 shows simulation model for sound propagation in Antractic Ocean using parabolic equation method. We assumed that the one transmitter was placed three different depths at 50, 100, and 150 m and propagation range was constant at 39 km and 36 km in OW and L traverse lines. We calculate propagation pulse in Antarctic Ocean with three bottom models to know the influence of amplitude of pulse wave by bathymetry, clearly. By confirming the fluctuation of amplitude of pulse to influence by depth of source and receivers, we estimate about the amplitude of pulse by parabolic equation method to change the depth of source and receivers.

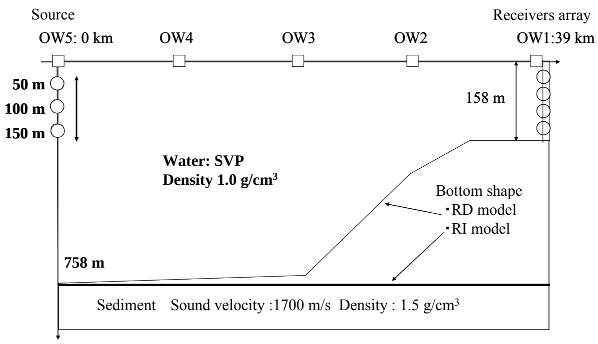


Figure 4. Simulation model for sound propagation in Antractic Ocean using parabolic equation method. In this case, we adapted a bathymetric chart of transverse line OW.

The sound source was radiated Gaussian pulse to the horizontal direction calculated by Eq. (1)

$$s(t) = \sin\left[2\pi f_0 \left(t - t_0\right)\right] \exp\left\{-\left[w\left(t - t_0\right)\right]^2\right\} \qquad (1)$$

Where, t is time, $s(t)$ indicates sound waveform in time domain. f_0 indicates the center frequency of sound source. When t equals t_0, this equation takes the maximum value in the all time. w relates band width of frequency spectrum.

Acoustic parameters of three kinds bottom model

In this simulation, in order to investigate about the characteristics of sound propagation in Lűtzow-Holm bay, we calculated sound pressure filed by PE method with three sea bottom models that were varied the depth of sea bottom and acoustical parameter as shown in Fig. 5. In the first case, we defined Range-Independent (RI) model that model has a flat sea bottom. The depth of this model was 758 m as same as depth at OW5 point. In the second case, the depth of sea bottom in this mode which was defined by Range-Dependent (RD) model was assumed by measurement bathymetry as shown in Fig. 3. In last case, the model, which was defined by Absorption layer (AB) model, has a flat sea bottom with absorption layer to neglect reflected pulse wave from sea bottom. In these cases of RD model and RI model, acoustical parameter of bottom assumed 1700 m/s in sound velocity and 1.5 g/cm^3 in density.

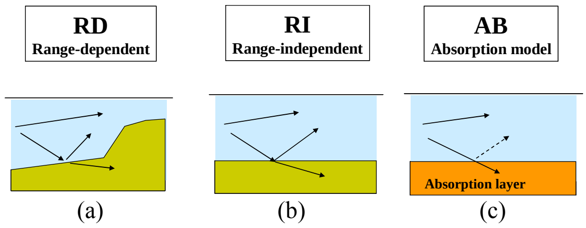


Figure 5. Three sea bottom models that were varied the depth of sea bottom and acoustical parameter. (a) is changed bottom depth to range direction using measurement data, (b) is constant depth at 758m, (c) has a absorption layer to neglect reflective wave from sea water-bottom interface.

CALCULATION RESULTS

Figure 6 shows estimated waveform calculated by parabolic equation method to propagate in the Antarctic Ocean using inverse Fourier transfer in the case of transverse line OW. In this case, we calculated sound propagation assumed three bottom models. Figure 6 (a) shows estimated pulse waveform in the case of RD model. It is assumed that bottom depth data was used by measurement data. Figure 6 (b) shows estimated pulse waveform in the case of RI model. This model was assumed the float bottom shape which bottom depth equal to the depth of source point. In Fig.6 (c), bottom layer equivalent to absorption layer. The bottom depth was constant value. As shown Fig. 6 (a), main pulse wave are received at t = 1.12 [s]. Received pulse wave after 1.13 [s], which has large radiation angle, was reflected sea bottom because propagation length was larger than main pulse. If received pulse has large radiation angle do not reflected sea bottom, arrival time of the pulse became a fast, because the pulse wave propagated to the fast area of sound velocity. As shown Fig. 6 (b), first arrival pulse at t = 1.11 [s] propagated to the deeper area in sea water. Three set pulse waves was arrived at t = 1.12 [s] and t = 1.19 [s]. These pulse waves were reflected from sea bottom and surface. The proof of these results was clearly shown as Fig. 6 (c). As a result, amplitude of sound pulse was different to three cases. However, the maximum difference value was about -3 dB between RD model and RI model. The value of changing amplitude is very small.

Figure 7 shows estimated waveform calculated by parabolic equation method to propagate in the Antarctic Ocean using inverse Fourier transfer in the case of transverse line L. As show Fig. 7, the value of changing amplitude is very small as same as Fig.6. The maximum difference value was about -5 dB between RD model and RI model.

CONCLUSIONS

In this study, in order to know the characteristics of sound propagation in Antarctic Ocean, we will know the characteristics of sound propagation in this Ocean. We used numerical analysis method to obtain the characteristics of sound propagation. In calculation results used by ray theory, it is shown that propagation pass was large influenced by bathymetry, because transverse line OW has upslope sea bottom and this area was near the Antarctica. On the other hand, it is clearly shown that continuous sound pressure field calculated by PE method was small influenced by bathymetry. In order to obtain the accuracy heavier of sound propagation in Antarctic Ocean, we calculate pulse waveform calculated by PE method to propagate in the Ocean using inversion Fourier transfer in three bottom model.

As a result, amplitude of sound pulse was different to three cases. The maximum difference value was about -3dB between Range-Dependent model and Range-Independent model. It is clearly shown that the influence of the amplitude of sound pulse by bathymetry was small on transverse line OW and L in Antarctic Ocean.

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15 A.N. Author, “Title of a book chapter” in Title of Published Book ed. A.N. Editor, (Oxford University Press, New York, 198 1) pp. 4 5–55

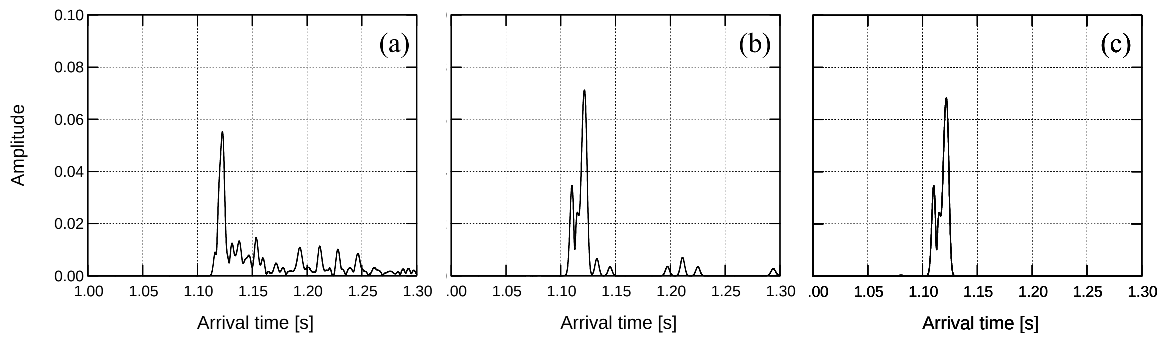

Figure 6. Estimated waveform calculated by parabolic equation method to propagate in the Antarctic Ocean using inverse Fourier transfer in the case of transverse line OW . (a) , (b) and (c) show calculation results of RD, RI and AB model.

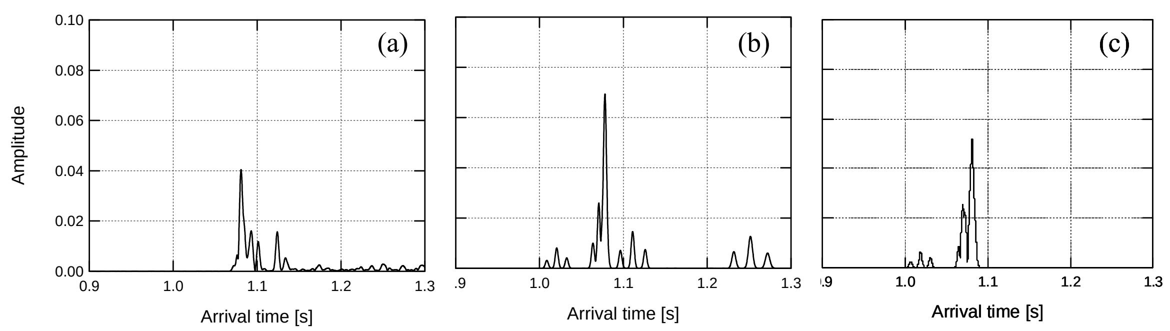

Figure 7. Estimated waveform calculated by parabolic equation method to propagate in the Antarctic Ocean using inverse Fourier transfer in the case of transverse line OW . (a) , (b) and (c) show calculation results of RD, RI and AB model.