Temporal variations of acoustic propagation in the strong tidal zone, Yellow Sea in the Northwest Pacific

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***Abstract*— The Yellow Sea of the northwest Pacific is semi-closed shallow water (< 100 m), and one of the strong tidal zone in world ocean. Acoustic propagation in the shallow waters can be affected by the changes of the oceanographic condition such as sound speed, wind, tide, and current. This paper here presents acoustic propagation characteristics from acoustic modeling with measured environmental data. For obtaining environmental data, a large buoy system to be installed 6 CTD was continuously deployed during over two months at a stationary station. From the studies, changes of the thermocline depth and temperature due to periodic tidal current have a strong influence on the fluctuation of the sound speed profile. And, the temporal fluctuations of the sound speed profile have an absolutely effects on the ray path of the mid frequency.**

Keywords— tide, thermocline, temporal fluctuations, acoustic propagation, acoustic modeling

I. INTRODUCTION

In general, the propagation of underwater sound mainly depends on the structures of water temperature. The effects relationship between spatio-temporal variations in the ocean condition and those in the received acoustic signal need to be understood. In particular, as tidal changes in shallow water, the impact will affect the acoustic propagation. Unlike the air propagations, the shallow-water acoustic propagation of give rise to multipath effects caused by the interaction with the interface reflection and refraction due to changes in the sound speed of the water column between the source and receiver. Propagation of sound in shallow water in terms of military scientific, engineering is the main subject of underwater acoustics. Also, in recent years, due to changes of the thermocline effects on the underwater communication and geoacoustic inversion has been studied for the role of uncertainty [1, 2, 3, 4]. Thus, the sound propagation in a given sea area becomes significant when considering characteristics.

In this study, the following were carried out for the purpose.

(1) the speed of sound at the peak time-varying dynamic characteristics analysis of the data

(2) the propagation characteristics of acoustic signal under dynamic characteristics of temporal variation

For this purpose, the characteristics of the sound propagation were modeled using the observed data in the Yellow Sea of the northwest Pacific Ocean. This paper here presents acoustic propagation characteristics from the acoustic modeling with measured environmental data. In 2011 a long and continuously observation was conducted to investigate ocean variability caused by strong tide. The average depth of this area is approximately 72 m. The study area is one of the strong tidal zone in the ocean. For obtaining environmental data, a large buoy system to be installed 6 CTD was continuously deployed during over two months (from August 14 to October 26, 2011) at a stationary station. A completely data was stored with 10 minutes interval.

II. OCEAN DATA AND ACOUSTIC MODELING

A. Ocean Data

To obtain accurately acoustic propagation modeling, the sound speed profile is one of important factors. The averaged sound speed profile calculated from CTDs is shown in Fig. 1.

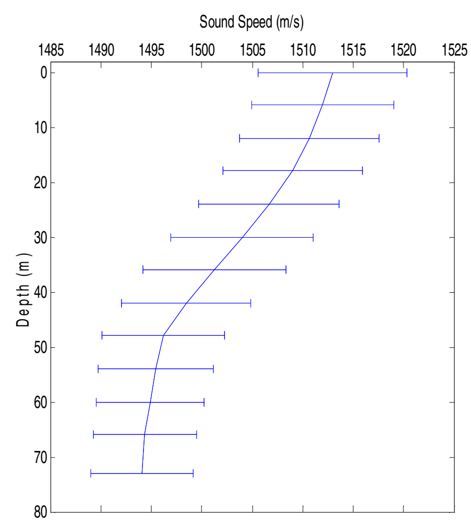

Fig. 1. Averaged sound speed profie with 1 standard deviation (error bars) at the stationary station mesured from August 14 to October 26, 2011.

The blue vertical line the average of the all sound speed profiles from August 14 to October 26, 2011. The blue horizontal line (error bars) is the one standard deviation of the average profile.

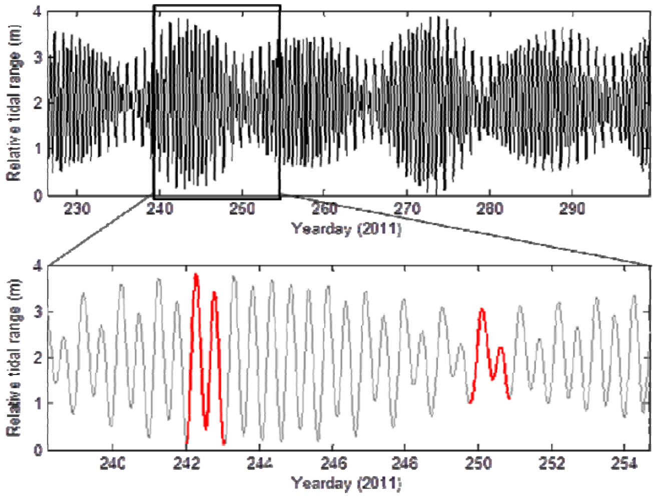

Fig. 2. Mooring data of tide in the stationary station. The mesured depth changes using tidal guage shows typical M2 cycle.

Sound speed structure in from the upper to lower depth is equivalent changes.

In the study area, there is a strong semi-diurnal cycle with two high tides and two low tides in a period during every 24 hours (Fig. 2). Generally, The barotropic effects of tide make the elevation of tidal ranges [6]. The effect is that the water depth is increasing and decreasing by 2~4 meters in the area. The baroclinic effects of tide represent the two fluctuations which are the depth change and gradient of the thermocline. The top panel in the Fig. 2 shows variations of relative tidal range observed during October and November due to the tidal effects.

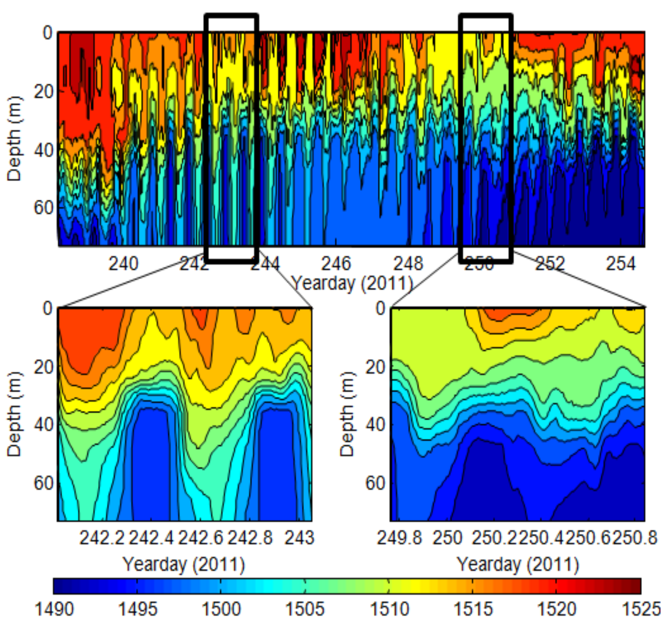

Fig. 3. The time series of the sound speed data from CTDs at the stationary station during the observation from August 26 to September 11, 2011.

In the study, we focused on the specific data including spring and neap tide that is enlarge part in the bottom panel in the figure 2. The selected date (17 days) corresponding to the data was August 26 to September 11. Especially, the red line on the left side of the bottom panel in the Fig. 2 shows the depth change during a day period of the spring tide and the left red line shows the change in the depth during a day period of the neap tide. The difference of water depth between spring tide and neap tide periods is reached to 2 meter. And the depth difference caused by diurnal inequality was greater in the neap tide. The impact of these differences affects the sound propagation.

During 17 days, time-series data of the sound speed obtained from the CTD is shown in the top panel of the Fig. 3. It shows that the thermocline oscillates between 20 and 50 meters affected by typical M2 cycle. There is a strong correlation between the semi-diurnal tide and the sound speed fluctuations at the station. Among the total time-series, during the spring tide period, sound speed between the upper and lower layer was a large difference, and thermocline depth vertically changed with a periodic cycle (left panel in the Fig. 3). Whereas, during neap tide period, sound speed difference between in the layers and thermocline depth were small and less changed, respectively (right panel in the Fig. 3). Especially, in the neap tide, structures of the sound speed had a non-periodic cycle due to the diurnal inequality.

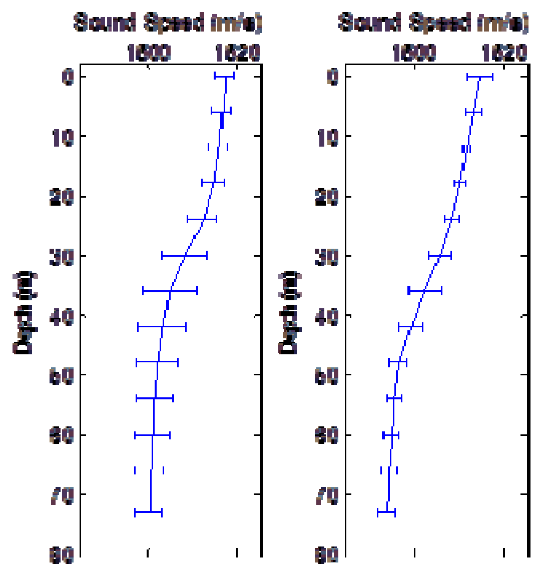

Fig. 4. Average sound speed profies with 1 standard deviation (error bars) during spring tide and neap tide.

Considering the whole measurement time (from summer to autumn), the deviation of the sound speed within the water column was totally large (see Fig. 1). Considering the variation for a short time, the its deviation for spring and neap tide was small, compared that of the whole measurement (Fig. 4).

For both spring and neap tide, the deviation of the sound speed was large around thermocline, and was relatively small upper and lower layer of the thermocline. In the meantime, thermocline deviation at spring tide is larger than that of neap tide.

B. Acoustic Modeling

The simulations are for a range-independent shallow-water environment using the sound speed profiles in strong tidal zone to study the variations of the received signal due to the water column fluctuations with short time period. Acoustic propagations were computed using a ray-based model for a source at 30 m depth, a receiver at 30 m depth, a source-receiver range at 5 km and a source frequency with 5 kHz.

Fig. 5 shows typical simulation in the averaged sound speed profile using the whole observation data. The path-length of rays that is reflected at the surface and the bottom shortens and lengthens due to the barotropic effects. Then, the rays to be affected by the barotropic motion have a high grazing angles. Therefore, the rays having higher angle are late arrivals on the modeled signal. In the baroclinic effects, the changes of the thermocline have an influence on the first arrival signal such as refracted path.

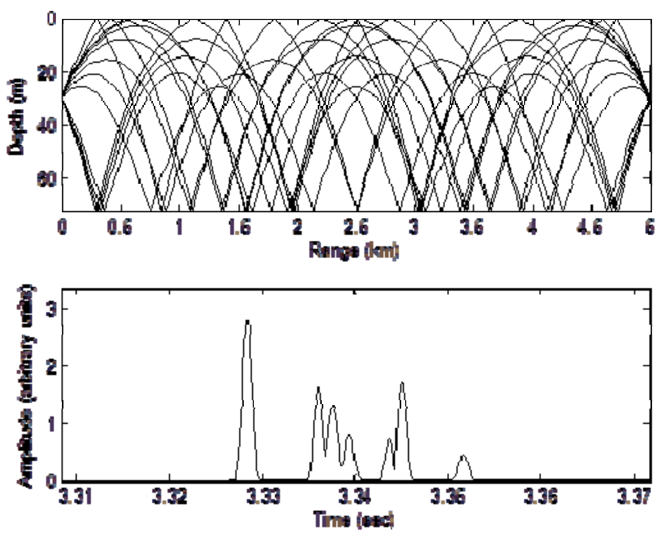

Fig. 5. Propagation characteristics using the Fig. 1 environment: The top panel shows eigenray tracing. The bottom pannel shows modeled signal for a typical pulse arrival. Eigenrays showing rays arriving from source, 30 m depth. The range and depth of the receiver are 5 km, and 30 m, respectively.

III. ACOUSTICAL EFFECTS OF OCEAN VARIATIONS

To examine tidal effects on acoustic propagation, we utilized the sound speed data at 10-minute intervals over a 24 hour period under the conditions of spring tide and neap tide, respectively. The Fig. 6 shown a simulation of the acoustic signals during spring tide and neap tide.

During the spring tide and neap tide, there is a phase difference of about 90 degrees between tidal cycle and arrival shape of acoustic signal (compared bottom panel in Fig. 2 with Fig. 6). Most of the ray paths does not change significantly. The sound speed fluctuations that caused by thermocline changes varying with time are reason to change arrival pattern of refracted and reflected path.

In the flow tide, the first arrival paths were formed with two reasons; (1) the slope of the thermocline is weakens, and (2) depth of the thermocline is expanded toward the lower layer. On the other hand, at ebb tide, the slope of the thermocline is stronger and thermocline move to upper layer. Formation of the late arrival path is caused by the effects of the thermocline variation (top panel in Fig. 6). The shape of the arrival signals that is affected by diurnal inequality is relatively less deformation during spring tide.

Comparing the averaged sound speed under the spring tide, as the sound speed under the in neap tide is reduced, the overall time of arrival signals is slower (bottom panel in Fig. 6). In the first period of the neap tide, the thermocline is strong. Whereas, the thermocline gradually weakened in the second period of neap tide. The effect is due to the negative gradient of sound speed profile, and then the ray path is much more interaction with the bottom boundary. Because of its effects, the difference between the arrival time of the signal is reduced.

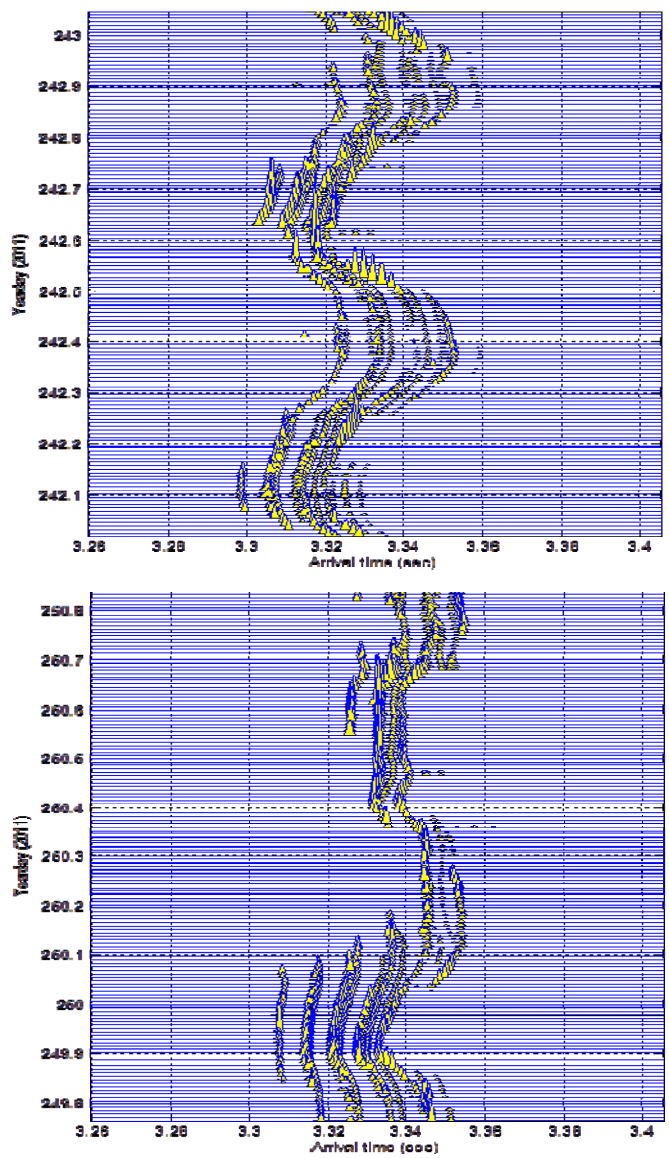

Fig. 6. Simulation of the acoustic signals during spring tide (top panel) and neap tide (bottom panel). The frequency is 5 kHz, source and receiver is 30 m depth.

IV. SUMMARY

As tidal changes in shallow water, the impact will affect the acoustic propagation. This paper here presents acoustic propagation characteristics from acoustic modeling with measured environmental data. In 2011 a long and continuously observation was conducted to investigate ocean variability caused by strong tide. The average depth of this area is approximately 72 m. For both spring and neap tide, the deviation of the sound speed was large around thermocline, and was relatively small upper and lower layer of the thermocline. In the meantime, thermocline deviation at spring tide is larger than that of neap tide. The sound speed fluctuations that caused by thermocline changes varying with time are reason to change arrival pattern of refracted and reflected path. The shape of the arrival signals that is affected by diurnal inequality is relatively less deformation during spring tide. Results show a direct relationship between sound speed variations caused by tide and the acoustic propagation in this shallow water region.

ACKNOWLEDGMENT

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