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Sound propagation in boundary region between warm core ring and cold water mass of the east sea area off Tsugaru Straits
津軽海峡の東方海域の暖水渦と冷水塊の間の境界領域における音波伝搬

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1. Introduction

The warm core ring of Kuroshio Extension and the cold water of Oyashio are bounded in the sea area off the coast of Sanriku. Moreover, the warm current of Tsushima that passed over the Tsugaru Straits goes south along the coast of Sanriku. And the warm eddy is formed in the east sea area off Tsugaru Straits at the same time. Consequently, a complex marine environment is formed by coexistence of the cold water mass and the warm core ring. A strong current rip occurs in those boundary regions. The current rip has a strong water temperature gradient vertically and horizontally. Therefore, it is influenced to sound propagation. Then, the Sound propagation is considered through the current rip of the boundary region between the warm eddy of Tsugaru and the cold water mass of Oyashio. The characteristics of sound propagation is analyzed at that sea area..

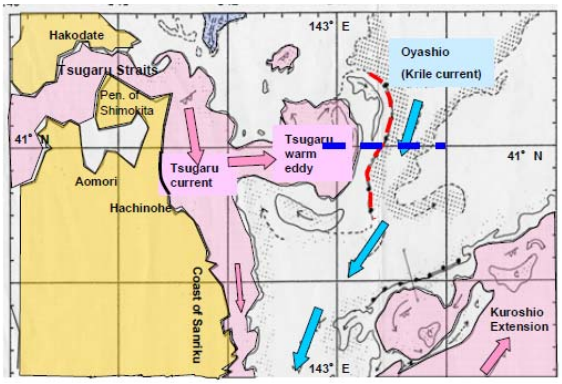

Fig. 1 Distribution of Warm water mass and Cold water mass off the cost of Sanriku.

2. Ocean environment of east sea area off Tsugaru Straits

The distribution of the warm core ring and the cold water mass off the coast of Sanriku in November is shown in **Fig. 1**. The vertical axis is a longitude, and the horizontal axis is a latitude. Tsushima warm current that passed over Tsugaru Straits goes south along the coast of Sanriku, and.the warm eddy is formed at the same time. On the other hand, Oyashio is a cold water and comes along Kurile Islands. A lower right in this figure is a warm water, and is the origin of Kuroshio. Therefore, a strong current rip occurs in this sea area where the warm core ring are bounded on the cold water mass of Oyashio.

Fig. 2 shows the structure of vertical temperature along the line of 41° N (broken straight line). The warm eddy and the cold water of Oyashio are met at this sea area. In this figure, the left side is Tsugaru Straits side, and the figures are a water temperature. The temperature of the warm eddy is 15℃ or more. Under this warm eddy, the water mass is Oyashio, a cold water. The depth of the warm eddy becomes shallow from 143° E toward the east. Toward the east side (right side in this figure) the water mass becomes Oyashio. The surface temperature is 7.5℃. Depth of minimum sound speed is 600m under the warm eddy, and 165m under Oyashio

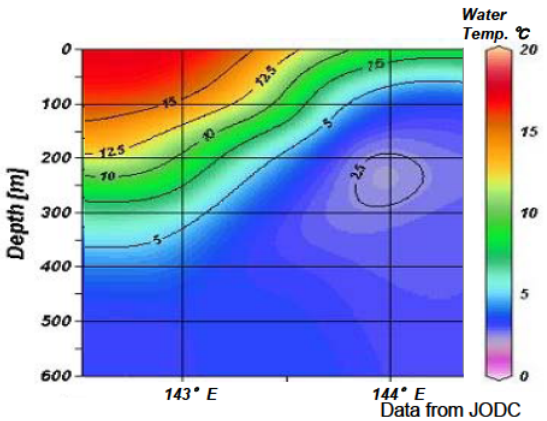

Fig. 2 Structutre of vertical temperature along 41°N line off Tsugaru Straits.

3. Sound propagation through current rip

The frequency used for the analysis is 100 Hz. To consider the characteristics of sound propagation on the current rip, the bottom depth is flat in 4000 m. Source depth is 100 m. FOR3D[1] is used for calculation.

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Two kinds of sound propagations are considered through the current rip in Fig. 2. One direction of sound propagation is from Tsugaru Straits side toward the east, another is a opposite direction, from the east to Tsugaru Straits side.

3-1 Sound propagation from Tsugaru Straits sides

The result is shown in **Fig. 3**. Vertical axis is depth in m, and horizontal axis is distance in km from sound source. Bottom is 4000m in depth. Sound wave radiated at a steep angle is reflected at bottom. A part of sound wave forms surface duct (SD) propagation. Layer depth (LD) of the warm eddy is 150m in the sound source location, and 50m in 12km. LD on forming SD in 100Hz is about 140m [2]. LD becomes shallow to the east. It will be cut off depth at the east side of the warm eddy. Therefore, sound wave is not trapped by SD, and Convergence Zone (CZ) propagation is formed. CZ distance is 55km, and turning depth is 3750m.

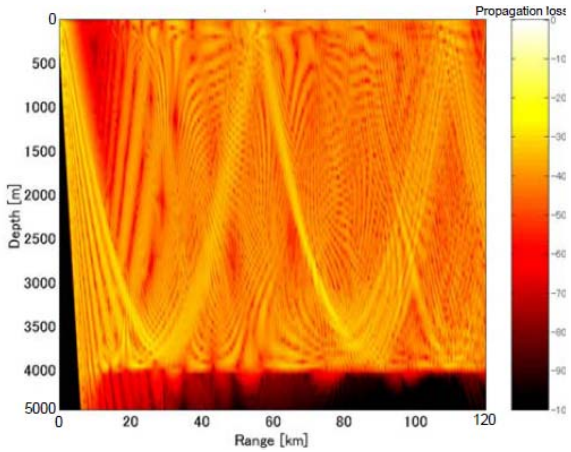

Fig. 3 Sound propagation from Tsugaru Straits side.
source depth;100 m bottom depth:4000 m.

3-2 Sound propagation toward Tsugaru Straits sides

Fig. 4 shows the result of propagating the sound wave toward Tsugaru Straits contrary to the foregoing paragraph. The left side of this figure is a Tsugaru Straits side, and the representation of distance is opposite to Fig. 3. LD of Oyashio sea area is 30m or less, and the sound wave of 100Hz is not trapped by SD. Therefore, all sound waves are refracted to the direction of bottom. A part of refracted wave is shifted to SC propagation. The depth of SC axis becomes deep from the depth of 200m. Under the warm eddy, it's 400m or more in depth. SC axis of Oyashio sea area in November reaches near sea surface. It doesn't enter the warm eddy though the sound wave is propagated along SC axis. On the other hand, CZ propagation occurs. CZ range is 50km. And, turning depth is 2000m in shallowest depth. This is because surface temperature is lower than that of the warm eddy.

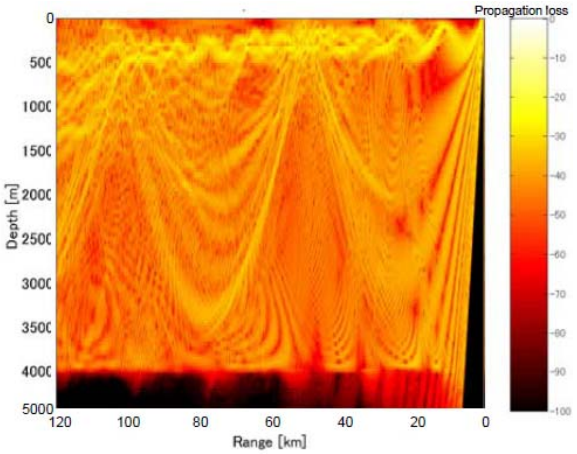

Fig. 4 Sound propagation toward Tsugaru Straits side.
source depth;100 m bottom depth:4000 m

4. Summary

Sound propagation in the boundary region between the warm eddy and the cold water mass, off Tsugaru Straits, was analyzed. The sound propagation was examined in two directions along the line of 41° N. One is the direction from the warm eddy to the east side. And, other one is a direction from the cold water mass of Oyashio to the warm eddy. In the sound propagation of both directions, there is a great difference in the propagation pattern. In the region of the warm eddy, cutoff in 100Hz occurs because LD of the warm eddy becomes shallow though the SD propagation occurs. The sound wave radiated at a steep angle is reflected on the bottom. Moreover, a part of sound wave is shifted to the CZ propagation. But, SD propagation doesn't occur when the propagation path is reversed. However, the CZ propagation and the SC propagation occur. In the cold water mass of Oyashio, SC axis is about 130m in depth. Therefore, the sound wave in the depth of sound source in 100m is trapped by SC. The sound wave trapped by SC is propagated along SC axis. Under the warm eddy, the depth of SC axis is 400m. Moreover, surface temperature of Oyashio is low compared with the warm eddy. As a result, the distance of CZ is being shorter than that of the warm eddy, and turning depth becomes shallow, too.

References

1. D. Lee *et al.*, "*Numerical Ocean Acoustic Propagation in Three Dimension*", World Scientific, (1995)..
2. R. J. Urick, "Sound Propagation in the sea", PENINSULA PUBLISHING (1982).