Effects of seafloor topography on underwater acoustic channel

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Abstract. Sound wave is the main means of underwater communication at present. Focusing on effects of seafloor topography on underwater acoustic channel, some acoustic propagation models were compared and the BELLHOP method was chosen based on the experiment data of typical seafloor topography. Then the date of OFES model and SOM method were used to get the marine parameters of temperature, salinity, depth and sounding velocity along SS section near Diaoyu Island. At last, the acoustic propagations along the SS section in flat bottom and real seafloor topography were simulated using BELLHOP method. The comparison of acoustic propagation loss was presented. The results show that the BELLHOP method can be used to get authentic results of acoustic propagation under different seafloor topographies, and seafloor topography has a significant effect on acoustic propagation characteristics, which are also influenced by the depth of sound source and sound receiver.

1. Introduction
Seafloor topography is one of the boundaries, which has a very important impact on underwater acoustic propagation [1], which has been a hot topic in the field of acoustics research, and attracted great attention from researchers at home and abroad.

In California ocean experiment, Northrop found the "slope enhancement effect", that is, the loss of acoustic signal propagation will be reduced under the condition of continental shelf slope [2]. Tappert found that sound waves can travel down the slope of the continental shelf until near the axis of acoustics channel, i.e. the "mud flow effect" [3]. Subsequently, a series of underwater acoustic experiments were carried out in the United States, including AET, AST, ATOC, NPAL98, SLICE89, OWSP and so on. The effects of seamounts, slopes and other factors on acoustic propagation were studied [4]. In China, Zhao Xiaoqun studied the effect of seafloor topography on short-distance propagation of underwater acoustic channel in shallow sea area [5]. Pu Lianglong simulated the influence of typical seafloor topography, and found that sudden change of water depth would lead to rapid expansion of acoustics channel and increase propagation loss [6]. Based on the experimental results, Qin Jixing analyzed the "mud flow effect" of acoustic propagation in shallow sea area [7]. Those above studies mainly focus on the continental shelf slopes in shallow sea area, and there are few studies on acoustics propagation in deep sea and undulating terrain.

This paper focused on effects of seafloor topography on underwater acoustic channel using the data of OFES (OGCM for the Earth Simulator) model and SOM (Self Organizing Map) method, the parameters of ocean temperature, salinity, depth and sound velocity were obtained along the SS section near Diaoyu Island. Then the BELLHOP method was verified and used to simulate the acoustic propagation along SS section with flat bottom and underwater rugged terrain. While the path
loss of underwater acoustic propagation were given, the effects of underwater rugged terrain were analyzed.

2. Selection of acoustic propagation methods

2.1. Acoustic propagation methods
Acoustics propagation in the ocean follows the wave equation, which can be solved under given boundary conditions and marine environment parameters. The common solving methods include normal wave theory and ray theory. Normal wave theory is perfect, which is suitable for low frequency situations, but the boundary conditions are difficult to deal with and the results are not intuitive. Ray theory is generally applicable in high frequency situations. It is easy to set boundary conditions, and can obtain ray propagation and acoustic path loss. As a general rule, the lowest working frequency of ray theory is \( f = \frac{10c}{H} \), \( H \) for depth and \( c \) for sound velocity. In this paper, the average sound velocity of marine environment is about 1500 m/s, the average depth is more than 500 m, then the lowest working frequency of ray model is 30 Hz, while the working frequency of sound source in this paper is 280 Hz. Therefore, it is appropriate to choose the ray theory. However, there are some shortcomings in the conventional ray theory. In 1987, Porter proposed the BELLHOP ray tracing method (BELLHOP method)\[8\]. Adding the Gauss intensity profile, we can successfully solve the problem of the conventional ray theory in sound film region and caustic region. BELLHOP method can also give key parameters such as acoustic propagation loss and sound ray, which are consistent with theoretical model and experimental data. It has gradually become one of the most widely used methods in underwater acoustic simulation.

2.2. BELLHOP method validation
Considering that the working frequency of sound source is 280Hz in this paper, and the influence of seafloor topography is mainly studied, the applicability and reliability of BELLHOP method should be investigated. It is validated based on the results of ocean acoustic experiment.
In this experiment of ocean acoustic propagation, the sound source (frequency 280 Hz) was in depth 50 m, while the receiver was in depth 50 m too. The propagation loss at different distances within 30 km was measured from near to far. Vertical sound velocity distribution and seafloor topography in the test area are shown in Fig. 1. Then BELLHOP method was used to simulate the acoustic propagation and the results were compared with the experimental data, as shown in Figure 2. With the increase of propagation distance, the propagation loss increased gradually, and had a large fluctuation. When we compared the experimental data with the simulation results, they basically coincided with each other, which shows that BELLHOP method has good applicability under underwater rugged terrain and could be used to predict the path loss of underwater acoustic propagation.

![Figure 1. Marine Environment of Acoustic Experiment.](image1)

![Figure 2. Verification of BELLHOP Method](image2)
3. Influence of seafloor topography on acoustic channel

3.1. Marine environmental parameters of SS section
JAMSTEC (Japan Agency for Marine-Earth Science and Technology) provides the output data of OFES (OGCM for the Earth Simulator) mode. It is the result of QuickScat wind field forcing, and the time range is 2000-2006. The temporal resolution of the data is 3 days, and the spatial resolution is 0.1 degree. There are 54 layers in the vertical direction. The vertical resolution varies from 5 m in the surface layer to 330 m in the bottom layer, and the maximum depth is 6065 m. The output of the model is compared with the observed data, and the validation results show that the data is suitable for the study of large-scale ocean circulation and mesoscale eddies [9].

SOM method is based on unsupervised neural network, which is an effective method for feature extraction and classification. This method can be considered as a clustering method, similar to K-means clustering. Based on the minimum Euclidean distance, the modes are arranged on a two-dimensional mesh point, and each input unit corresponds to an optimal matching mode. The SOM method is more powerful than the traditional method (such as EOF method) in feature extraction [9]. Using the method of SOM, the coupled circulation modes in east and northeast of Taiwan are extracted from the sea surface dynamic height anomaly data of multi-source satellite altimeter from 1993 to 2008 by Jin Baogang et al. [9]. It is revealed that a dipole structure exists in the east and the northeast of Taiwan Island, the anticyclonic (cyclonic) eddy east of Taiwan can induce a cyclonic (anticyclonic) eddy in the northeast of Taiwan, the formation of the dipole can be explained by the vorticity conservation theory.

SS section is located near the northeast of Taiwan Province (24° N, 121° E) and in the southern section of the Kuroshio in the East China Sea. See Fig. 3. Here, the seasonal variations of the Kuroshio are complex (such as streamline axis, path and flow amplitude), and are more representative. Therefore, this paper chooses SS section as the research object, and uses SOM method to analyze OFES data. Two typical three-dimensional fields of two dipole modes are extracted. After average processing, the data are used as typical marine environmental parameters for underwater acoustic simulation. See Figure 4. The seafloor topography of SS section is provided by ETOPO1 data of NOAA [10], with spatial resolution of 1’.

![Figure 3. Seafloor topography of SS section.](image)

![Figure 4. Marine environment of SS section.](image)

3.2. Underwater acoustic channel influenced by seafloor topography
Along SS section near Diaoyu Island, it is assumed that the frequency of sound source is 280Hz, and the receiver is located at 200m and 900m respectively to test the effects of seafloor topography on different depths. According to the hypothesis of sedimentary layer, the sound velocity is 1550m/s and the density is 1.5g/cm³. With the boundary conditions of ideal flat bottom or seafloor topography, the
BELLHOP method was used to simulate underwater acoustic channel and propagation path loss. The attenuation of acoustic propagation along this section is obtained as follows:

![Figure 5](image1)

**Figure 5.** Path loss of acoustic propagation (up: flat seafloor; down: real seafloor topography).

![Figure 6](image2)

**Fig. 6** Path loss of acoustic propagation in different depth (left: 900m; right: 200 m).

It can be seen from Fig. 5 and Fig. 6 that under the assumption of flat bottom, while the sound source is located at the axis of the channel (depth 800 m), the structure of acoustic propagating along the acoustic channel axis is clear and regular, the upper part of the acoustic channel is not affected by the reflection of the seafloor, including the convergence area and the acoustic shadow area. the lower part of the channel axis is affected by both the propagation along the channel and the reflection of the
seafloor, and there is no obvious acoustic shadow area. But in the real seafloor terrain, the acoustic propagation along the acoustic channel axis is greatly affected by the reflection of seafloor terrain, the basic structure is destroyed, and there is no obvious acoustic channel propagation any more. Especially in the long distance, the elevation of the terrain basically blocked the acoustic channel axis; the upper part of the channel axis is also affected by the reflection of seafloor terrain, the acoustic shadow area disappears basically, and in the long distance, the propagation is affected by the elevation of the terrain, and the loss is slightly reduced. The lower part of acoustics channel axis is mainly controlled by the reflective effect of the undulating terrain, including the convergence area and the shadow area.

4. Conclusion
The BELLHOP method is used to simulate the acoustics propagation under ideal flat seafloor and real seafloor topography along SS section near Diaoyu Island. The path loss of acoustics propagation are given, and the effects of seafloor topography on acoustic channel are compared and analyzed. The results show that:
- The results of BELLHOP method are in good agreement with the experimental data. It has good applicability in the real seafloor terrain and can be used to predict the acoustic propagation characteristics.
- For the underwater acoustic channel, the complex terrain of the seafloor will have an obvious impact on the path loss along the acoustic channel.
- In different depths, the influence of seafloor topography is different for the acoustic propagation characteristics.

In the future, this method can be applied to underwater acoustic channel evaluation and application.

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