The Influence of Intratermocline Eddies on Sound Propagation in the Deep Part of the Sea of Japan

A B Kiryanov, B A Salnikov and E N Salnikov

1School of Engineering, Far Eastern Federal University, ul. Sukhanova, 8, Vladivostok, 690091, Russia

E-mail: Kiryanov.av@dvfu.ru

Abstract. The results of stochastic modeling of the influence of positive and negative intratermocline eddies (lenses) on the spatiotemporal structure of acoustic fields in the deep part of the Sea of Japan are presented. The lens shape was modeled by an ellipse. The lens center and the emitter were located on the axis of the underwater sound channel. The vertical distribution of the acoustic field inside the lens was studied at various ranges in front of the center, in the center and behind the center of the lens, as well as at ranges of 40 and 100 km. A negative lens focuses the ray paths on the axis of underwater sound channel at all ranges. A positive lens has a defocusing effect, yet with an increase in range it decreases significantly. The impulse response of the propagation channel was studied on the underwater acoustic channel axis at the ranges of 40 and 100 km. The maxima of impulse response during the passage of the sound emitter through the negative lens shift in time towards increasing, and when passing through the positive lens – towards decreasing with respect to the impulse response of the propagation channel in the absence of lenses.

1. Introduction

Intratermocline eddies (lenses) are regularly observed in the World ocean. They are ellipsoidal formations filled with warm or cold waters with horizontal axes from several tens to hundreds of kilometers and vertical axes from several dozens to hundreds of meters. Intratermocline lenses originate near the frontal zones of separation of water masses and move in space for dozens and hundreds of kilometers. In the area of the frontal zones, significant spatial gradients of the main hydrological characteristics of the environment, such as temperature, salinity, conditional density and speed of sound, are observed – comparing to their average values in the surrounding water environment. Horizontal temperature gradients in the frontal zone can vary from 0.1 to 30 °C / km; horizontal salinity gradients can vary from 0.1 to 30 °/° km. Studies have shown that in addition to large-scale, long-lived quasistationary vortices in the ocean, there are different scale vortex formations with lifetimes from several days to several months [1-3].

Currently, many countries are conducting research in order to develop technical solutions and design recommendations for effective network-centric underwater surveillance systems. The key task when developing such systems is to provide an underwater observation network consisting of underwater observatories, platforms, buoy stations and uninhabited vehicles for various purposes, interconnected with each other and the center for analysis and decision-making along the sonar channel at distances of dozens and hundreds of kilometers. The interaction of hydroacoustic and
hydrophysical fields in the marine environment can lead to theoretically unpredictable features and effects in the formation of the spatiotemporal structure of acoustic fields. This problem is relevant to the problems of applied hydroacoustics as well, since it requires special numerical experiments aimed at identifying the features of formation of acoustic fields that may affect the functioning of hydroacoustic complexes and systems at underwater sights [4].

In this paper, we present the results of stochastic modeling of the influence of intratermocline positive and negative lenses on the acoustic illumination fields of the aquatic environment. The field inside the lens and at ranges of 40 km and 100 km was investigated.

In order to take into account the effect of small-scale inhomogeneities of hydrology and intratermoclinic lenses, the sound velocity field is represented in computational models as

\[ C(x,z) = C_0(x,z) + \Delta C^+(x,z) + \Delta C^-(x,z), \]

where \( C_0(x,z) \) – the deterministic component of the sound velocity field, which in general, smoothly depends on both coordinates, and \( \Delta C^+(x,z) \) – the random component of the sound velocity field, this said \( \langle \Delta C^+(x,z) \rangle = 0 \), \( \Delta C^+(x,z) \) is the local change in vertical distribution of sound velocity, which was caused by a lens at the path of the sound emitter \( x, z \) – are the coordinates in range and depth, respectively.

2. The initial data of the numerical experiment

A numerical experiment was conducted for the hydrological conditions of the deep part of the Sea of Japan. The hydrological data for simulating the vertical distribution of sound velocity was taken from an interdepartmental information system for the resources of marine information systems and integrated information support for marine activities [5]. The emitter is located at the depth of 200 m, which corresponds to the axis of the underwater sound channel for a given area. The opening angle of the source is \( \pm 5^\circ \), the discreteness of the output of the ray paths is \( 0.02^\circ \). The random component of the sound velocity field was simulated using the Monte Carlo method [6,7], the number of experiments – 1000. The value of the random component of the sound velocity field \( \Delta C^\pm(x,z) \) was set to be 0.15 m/s.

The intratermocline lens was modeled by an ellipse with center located at a depth of 200 m and a distance of 29 km from the emitter. Lens sizes were the following: 20 km in range and 80 m in depth. The local change in the deterministic component of the vertical distribution of sound velocity caused by the presence of the lens was simulated by taking into account the determinate correction \( \Delta C = (x, z) = \pm 5 \) m/s in the center of the lens, the value of which came down to zero at the boundaries of the lens – according to a parabolic law.

3. Results and discussion

Figure 1 shows the vertical distribution of the acoustic field inside the positive and negative lens at the ranges of 24 km (in front of the coordinate of the center of the lens), 29 km (center of the lens) and 34 km (behind the center of the lens). From the presented results it follows that the negative lens focuses the ray paths inside the lens, and the positive lens defocuses. In this case, the positive lens suppresses the acoustic field at the axis of the underwater sound channel.

Figures 2 and 3 show, respectively, the vertical distribution of the acoustic and impulse characteristics of the propagation channel near the boundary of the lens at a distance of 40 km and away from the lens at a distance of 100 km and a depth of 200 m.
Figure 1. The vertical distribution of the acoustic field inside the lens at a distance of 24 km (a), 29 km (b), 34 km (c).
Figure 2. Vertical distribution of the acoustic field (a - without a lens, c - with a negative lens, e - with a positive lens) and impulse response (b - without a lens, d - with a negative lens, f - with a positive lens) at a distance of 40 km.
Figure 3. Vertical distribution of the acoustic field (a - without a lens, c - with a negative lens, e - with a positive lens) and impulse response (b - without a lens, d - with a negative lens, f - with a positive lens) at a distance of 100 km.

At both ranges, the negative lens focuses the acoustic field on the axis of an underwater acoustic channel. At a distance of 40 km, the positive lens dampens the field on the axis of an underwater acoustic channel, and at a distance of 100 km, the effect of suppressing the field by the positive lens is
not observed, while the maximum vertical distribution of the acoustic field has shifted 20 m below the axis of an underwater acoustic channel.

**Table 1.** The time shift of the maxima of the impulse responses as the sound emitter passes through the negative and positive lenses.

| Distance (km) | Negative lens, Δt (ms) | Positive lens, Δt (ms) |
|--------------|------------------------|------------------------|
| 40           | 55                     | -23                    |
| 100          | 63                     | -14                    |

The maxima of impulse characteristics during the passage of the sound emitter through the negative lens shift in time towards increasing, and when passing through the positive lens – towards decreasing with respect to the impulse response of the propagation channel in the absence of lenses (see Table 1). It should be noted that the presence of a positive lens reduces the amplitude of the maximum impulse response by 5-6 times at all studied ranges.

4. **Conclusion**

The results of numerical experiments to study the effects of intratermocline eddies on the spatiotemporal structure of acoustic fields can be used for operating the information transmission systems through the sonar channel and underwater navigation.

**References**

[1] Akulichev V A, Bugaev L K, Morgunov Yu N, Half Yu A and Solovyov A A 2009 The influence of a synoptic vortex on the propagation of acoustic signals in the Northwestern Pacific *Underwater research and robotics* *FEB RAS Scientific & Technical Journal* (Vladivostok: Dalnauka) pp 40-56

[2] Fedorov V K 1983 The physical nature and structure of ocean fronts (Leningrad: Gidrometeoizdat)

[3] Filyushkin B N, Sokolovsky M A, Kozhelupova N G and Vagina I M 2014 On Lagrangian methods for observing intratermocline vortices in the ocean *Oceanology* vol 54 6 pp 737–43

[4] Morgunov Yu N, Bezotvetnykh V V, Borodin A E, Burenin A V and Voitenko E A 2016 Research on the functional peculiarities of the regional system of underwater navigation support in various hydrological conditions *Fundamental and Applied Hydrophysics* vol 9 3 pp 80–86

[5] Interdepartmental information system for access to the resources of marine information systems and integrated information support for marine activities URL: http://portal.esimo.ru

[6] Kiryanov A V, Salnikova E N, Salnikov B A and Slesarev N Yu 2015 Modeling and study of main regularities of the formation of sound fields in randomly inhomogeneous underwater waveguides *Proc. of Meetings on Acoustics* 24 Issue 1 *5th Pacific Rim Underwater Acoustics Conf.: PRUAC 2015* 23 (Vladivostok)

[7] Salnikov B A and Salnikova E N 2008 Modeling and study of the zonal structure of acoustic fields in randomly inhomogeneous underwater waveguides *Underwater studies and robotics / FEB RAS Scientific & Technical Journal* (Vladivostok: Dalnauka) pp 47-57