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Abstract

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GEOPHYSICS

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ON THE CALCULATION OF THE VERTICAL PROFILE OF THE SPEED OF SOUND PROPAGATION IN THE MARINE ENVIRONMENT

At present, to calculate mean oceanographic characteristics as functions of depth, a method is used that consists in least-squares averaging of the characteristics on international standard depth levels (see, for example, ([1,2])). Practice has shown that, in a number of cases, this method does not give the desired results for calculating the vertical profile of sound speed.

Thus, for example, the solid curve in Fig. 1 represents the mean dependence, obtained in this way, of the speed of sound on depth for a 10-degree square located in the northwestern part of the Atlantic Ocean, for the warm half of the year (the standard levels in the figure are indicated by dots). The initial data for calculating the vertical profile of sound speed were observations of the temperature and salinity of seawater on international standard depth levels, collected for the period from 1900 to 1958 in the Catalogue of Deep-Sea Observations of the State Oceanographic Institute (in particular, data from the International Geophysical Year were used).

In Fig. 1, dashed curves delimit the scatter intervals* for the speed of sound on each level (the maximum interval reaches 90 m/sec). If it is assumed that the deviations from the mean curve obey the normal law, then the indicated intervals should contain about 90% of all observations. As we see, the deviations from the mean curve are extremely large. The acoustic field constructed from the resulting mean curve (even in a ray approximation) gives an unreliable picture.

In this note a new method is proposed for determining the mean dependence of sound speed on depth, based on the use of so-called "characteristic points." For this purpose the entire thickness of the ocean in the given region is divided into a certain number of layers, taking into account the physicochemical characteristics of the medium and, in particular, the θ-, S-curves (see, for example, ([3])). Next, each individual curve characterizing the dependence of sound speed on

Fig. 1

Figure 1: Fig. 1

depth z (the $c(z)$-curve) is approximated by the corresponding polygonal line with gradient dc/dz, constant within each of the layers. In this case the approximation error must not exceed some prescribed value Δc. The break points of the approximating polygonal line are the characteristic points in the (c, z) plane. Further, for each of the characteristic points the mean depth and sound speed. Connecting these mean coordinates by straight lines, we obtain a broken line characterizing the mean distribution of sound speed with depth. The described method takes into account the circumstance that, over time, the curve $c(z)$ changes, forming a family of curves similar to the given one. Therefore this method corresponds more closely to the nature of the phenomena occurring in the ocean and gives more reliable results, especially in those cases where there are sharp changes in the gradient dc/dz. In addition, the number of parameters characterizing the curve $c(z)$ is considerably reduced, which is also important for the analysis of acoustic processes.

Fig. 1

It should be noted that if, in the ocean region under consideration, there are areas with substantially different types of curves $c(z)$, i.e., areas with water masses of different nature, then these curves must be processed by the method of characteristic points separately for each area.

Let us illustrate the application of the proposed method for the same 10-degree square.

By analyzing the physical-geographical conditions and the θ-, S-curves in the region under consideration, two types of vertical profiles $c(z)$ were found. The first type, denoted below by the index A, is characterized by the vertical structure of the water masses of the warm North Atlantic Current and by the deep position of the axis of the underwater sound channel at about 1000 m. The vertical structure of the water masses of this type can be divided into 5 layers. The second type, denoted by the index B, is formed by the cold Labrador Current with a vertical structure of the water masses that can be divided into 4 layers.

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* The scatter of observed two-dimensional random quantities relative to their mean values will be characterized by a visual geometric characteristic—the scatter ellipse. For a one-dimensional random quantity the scatter ellipse degenerates into a scatter interval. Note that instead of the unknown true moments of the random variable we shall substitute sample moments into the equation of the ellipse; this, however, will not cause significant discrepancies if the number of observations is sufficiently large (not less than 10) (see, for example, (^{4})).

Fig. 2

Figure 2: Fig. 2

The axis of the underwater sound channel in type B is located at a depth of about 100 m.

When approximating the individual curves $c(z)$ by broken lines, the value of the maximum possible error was chosen as $\Delta c = 5$ m/sec. Approximation of the curves with greater accuracy made no sense, since the accuracy of the initial data (in particular, because of errors in determining depth) did not exceed this value.

The mean profiles $c(z)$ and the scattering ellipses for the characteristic points, denoted by triangles, calculated by the proposed method for the two types presented, are shown in Figs. 2 A and 2 B. If it is assumed that a characteristic point has a two-dimensional normal distribution, then the scattering ellipse should contain about 85% of all observations. As can be seen from Fig. 2, the possible deviations from the mean curve $c(z)$ are small. Since a characteristic point is a two-dimensional random variable, its scatter cannot be directly compared with the scatter of sound speed at any one of the standard horizons. However, if only one coordinate of the characteristic point—the sound speed—is taken and its interval of scatter is compared with the interval of scatter of sound speed at the corresponding standard horizon (taking into account the presence of the two types of curves A and B), it turns out that the former is almost always smaller than the latter. If the comparison is made at the characteristic point where the scatter interval is maximal, then in our example, for type A, the proposed method reduces the scatter interval

from 32 to 24 m/sec, and for type B from 54 to 19 m/sec. In this, deviations at the surface were not taken into account; naturally, they cannot be smaller than the corresponding seasonal and episodic fluctuations of temperature and salinity.

It should be noted that for depths at which the influence of seasonal variability is not felt, a significant correlation is observed between

Fig. 2

the depth of a characteristic point and the velocity at it (the correlation coefficient reaches 0.9). Preliminary analysis shows that there is also a significant correlation between the coordinates of different characteristic points (for example, an upward deviation from the mean depth at one characteristic point is often accompanied by a deviation in depth in the same direction at neighboring characteristic points). However, this question requires further investigation.

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Note: Figure translations are in progress. See original paper for figures.