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REMOTE ACOUSTIC SENSING OF LARGE-SCALE OCEAN WATER INHOMOGENEITIES

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1. INTRODUCTION

Inhomogeneities of the ocean water medium can be detected and investigated using various acoustic sensing methods. First of all acoustic sensing can be carried out by means of a set of stationary sources and receivers of acoustic signals located at different distances from one another and at different depths in the area of the inhomogeneities studied. In this case acoustic tomography methods can be used which consist in insonifying the water medium along different sound propagation trajectories [1]. One of the versions of such a system consists in using stationary receivers and movable sources travelling in space either in horizontal or in vertical direction.

One can also implement acoustic sensing of inhomogeneities in the ocean by positioning sources and receivers in one point. In this case methods of underwater echo sounding can be used and information is obtained from the reception of the backscattered pulse signals radiated from a powerful sound source.

2. SOUND PROPAGATION THROUGH AN OCEANIC EDDY

Consider the results of experimental investigations of tone acoustic signal propagation along different acoustic traces crossing a mesoscale eddy in the region of the Kuroshio current in the northwest Pacific. Fig. 1 shows the temperature structure of an eddy at the ocean surface, the location of acoustic traces A and B at a horizontal travel of signal sources as well as radiation points S1-S4 at vertical sounding and receiving points RA and RB. This eddy is typical for the Kuroshio current and it can be observed for a long time in different years. It is located inside a frontal zone separating cold subarctic and warm subtropical waters [2]. Fig. 1 depicts the isotherms in degrees Celsium on the ocean surface for a warm anticyclonic eddy formed in June 1988. The centre of this eddy lied nearby the point 39°N, 149°E.

The experimental procedure consisted in using two ocean-going ships for all the traces. Signal reception was effected by means of drifting multi-channel radio buoys with hydrophones arranged along the vertical axis at different depths. By the radio chan-

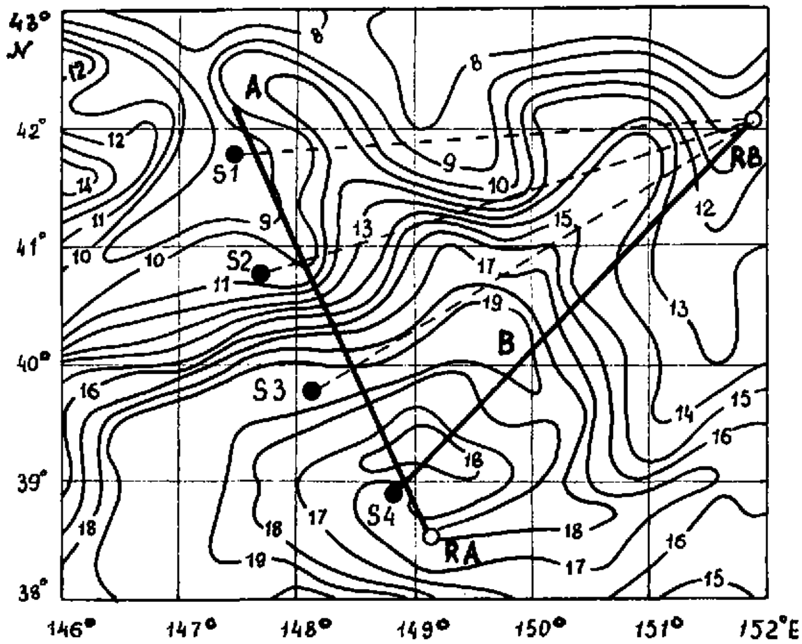

Fig. 1. Acoustical traces and vertical sounding of a warm anticyclonic eddy in the region of Kuroshio current

nel the received signals were transmitted to the receiving vessel located at a certain distance from the radiosonic buoy in order not to produce acoustic noises. Signal emission along the traces was accomplished by sound sources towed at a certain depth by a moving vessel. Normally, the depth of the sources in tow was about 100 m, the towing speed being about 8 knots. On the traces indicated, tone harmonic signals were radiated at different frequencies of the order of several hundred hertz. The acoustic measurements along each trace were accompanied by the measurements of hydrological parameters, such as temperature and salinity, at different depths which allowed the definition of sound speed as a function of depth.

Fig. 2 shows the variation of sound speed along trace A traversing an anticyclonic eddy in the second ten-day period of June 1988. The extent of trace A from the receiving site at 38°30'N, 149°10'E in subtropical waters to the final site at 42°10'N, 147°25'E in subarctic waters was about 400 km. In this case a warm anticyclonic eddy with the centre at 39°N, 149°E was observed. The effect of this eddy was manifested first of all in the increase of horizontal gradients of hydrological parameters and their associated sound speed. This resulted in substantial influence of the eddy on the formation of acoustic fields along trace A which is seen from Fig. 2. This figure depicts the change of signal levels at a frequency of 232 Hz with signal

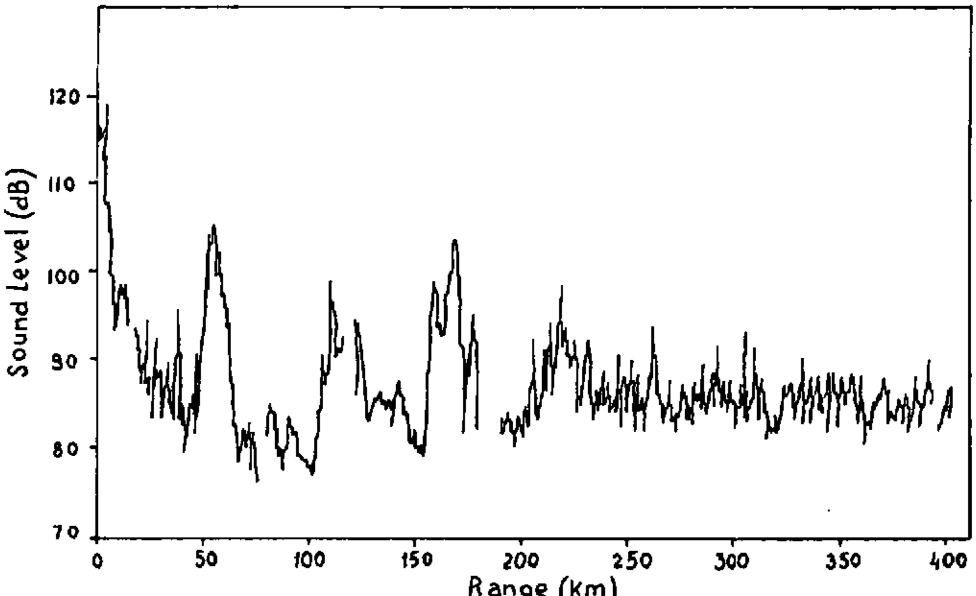

Fig. 2. Sound signal level along trace A crossing a warm eddy in the region of Kuroshio current. Frequency 232 Hz

reception at a 100-m depth. It is seen that within the coverage of similar warm eddies with sound reception in subtropical waters, sound field formation with convergence zones is possible which can be accompanied by the increase of maximum signal levels as the distance from the source increases. Such an effect of warm mesoscale eddies on sound propagation in the ocean was reported for the first time in our paper [3].

3. THE VERTICAL SOUND FIELD STRUCTURE

Consider the influence of an eddy on the variability of the interference sound field structure at the vertical sound source movement. The points of the vertical sounding are shown in Fig. 1. The measurement procedure consisted in a uniform submergence of a sound source to the depths of 100 m to 800 m. In this case tone signals with frequencies of 348 Hz and 696 Hz were radiated. Signal reception was carried out at the RB point at different depths from 100 m to 1000 m. Fig. 3 presents the results of measurements of acoustic signal levels with a frequency of 348 Hz in the process of lowering the source at the points S1 and S4 at the reception depths of 100 m and 1000 m. It can be seen that on lowering the sound source to the depths over 500 m at site S4 signal levels are increased by at least 15 dB and at site S1 a similar increase in signal levels is not

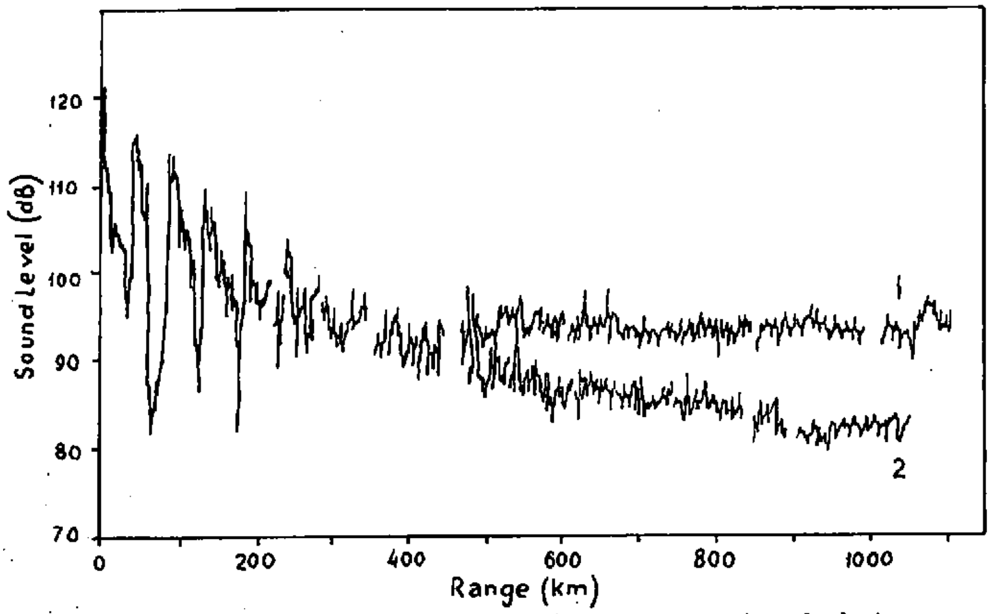

Fig. 3. Sound signal level along an extended trace crossing a frontal zone in the northwest Pacific
1 - frequency 232 Hz, 2 - frequency 696 Hz

observed. This regularity is accounted for by the fact that along the trace, from the radiation site S1 to the reception site RB, the water mass hydrological structure is approximately uniform, while along the trace, from the radiation site S4 to the reception site RB, a substantial horizontal variability of the hydrological water mass structure is observed. Close to the eddy core and at the site S4, the underwater sound channel axis lies at a depth of about 500 m. At the sites S1 and RB it lies at a depth of about 100 m. This explains the difference in the sound field interference structures received at the point RB at radiating from points S1 and S4.

4. SOUND PROPAGATION THROUGH A FRONTAL ZONE

Fig. 4 presents the results of research on sound propagation along a trace cutting an extended frontal zone in the northwest Pacific in the first ten days of August 1988. In this case the sources were towed from south to north: from a site at 33°54'N, 156°52'E in subtropical waters to subarctic waters. The final site at the trace was at 44°22'N, 156°56'E. The maximum range at signal propagation was about 1160 km. Fig. 4 shows the change of the levels of signals with frequencies of 232 Hz and 696 Hz received at a depth of 650 m. The influence of different sound

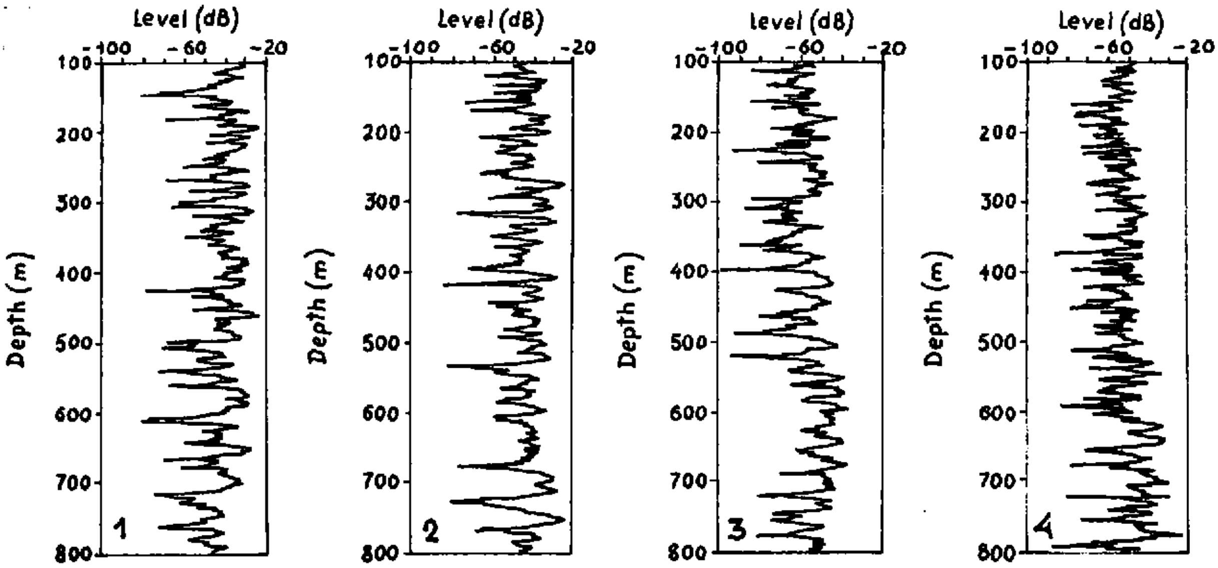

Fig. 4. Sound field interference structure of signals with frequency 348 Hz, reception in site RB. 1 - radiation from site S1, reception at 100-m depth; 2 - S1, 1000 m; 3 - S4, 100 m; 4 - S4, 1000 m

attenuation on the change of signal levels at different frequencies is apparent. The increase of signal levels at a lower frequency of 232 Hz with the increase of the distance from the source within the range of 1050 km to 1160 km should also be noted. This effect depends on the fact that when signals are received at the depth of the underwater sound channel in subtropical waters, the increase of sound level is possible as the towed source approaches the axis of the underwater sound channel in subarctic waters. Sound energy propagation occurs along the underwater sound channel changing in depth along the trace. It is necessary that the transition of the underwater sound channel axis from one depth to another proceed monotonously and the sound beam capture angle does not at least reduce. Sound propagation under such conditions can lead to the abovementioned rise of the sound level as the distance between the source and receiver increases. A similar effect had been reported for the first time by Barridge and Weinberg [4] who studied signal propagation from explosive sources in the North Pacific.

5. PULSE SIGNAL SCATTERING FROM INHOMOGENEITIES

Consider a possibility of acoustic sounding of sea water structure inhomogeneities using pulse underwater echo sounding when

powerful pulse acoustic signals are radiated and backscattered signals are received. In this case the radiating and receiving systems may not be widely spaced but may be located practically in the same place. The information about spacial variability of the water medium is obtained from the time and spectrum analysis of backscattered signals, which are usually called acoustic reverberation signals. The information about inhomogeneities is obtained from repeated pulse sounding of the water medium and accumulation and analysis of reverberation signals. It should be noted that the level of the signals backscattered at acoustic reverberation caused by large-scale inhomogeneities in the ocean water medium is less by about 120-130 dB than the powerful radiated initial signals.
Fig. 5 depicts different realizations of pulse soundings in the Pacific ocean along a trace traversing a frontal zone. Sound propagation along this trace was discussed in the previous section. To radiate powerful pulse signals, a specially designed deep-water acoustic waveguide-type source was used. It was mounted at a depth of 800 m close to the underwater sound channel axis in subtropical waters in the southernmost site. Tone pulse signals with a 222.15 Hz carrier frequency and duration of 40 s were emitted. The acoustic pressure level preset for the sound source was about $5\cdot10^4$ Pa.m. Signal reception was performed at a depth close to that of the source. Signal radiation and reception was carried out at the point of the receiving system position at the very beginning of the trace whose coordinates had been indicated above. Fig. 5 shows the time history of the reverberation signal spectrum which carries information about backscattering corresponding to different distances. It is well seen that in the backscattered signal spectrum, apart from the main spectral frequency component of 222.15 Hz, there are also spectral components with the envelope maxima differing from the frequency of the emitted signal. This shape of signal spectra can be the result of the Doppler frequency shift due to backscattering from eddy formations in the ocean. In Fig. 5 the structure of the signals backscattered from eddy formations at distances about 700 km is clearly seen. The comparison of these results with the hydrological parameters along the trace described in the previous section testifies to the agreement between the arrival time of the reflected signals and the location of sea water structure inhomogeneities in the front area in question.

6. CONCLUSION

The results presented in this paper are indicative of the possibility of determining sea water structure inhomogeneities by in-

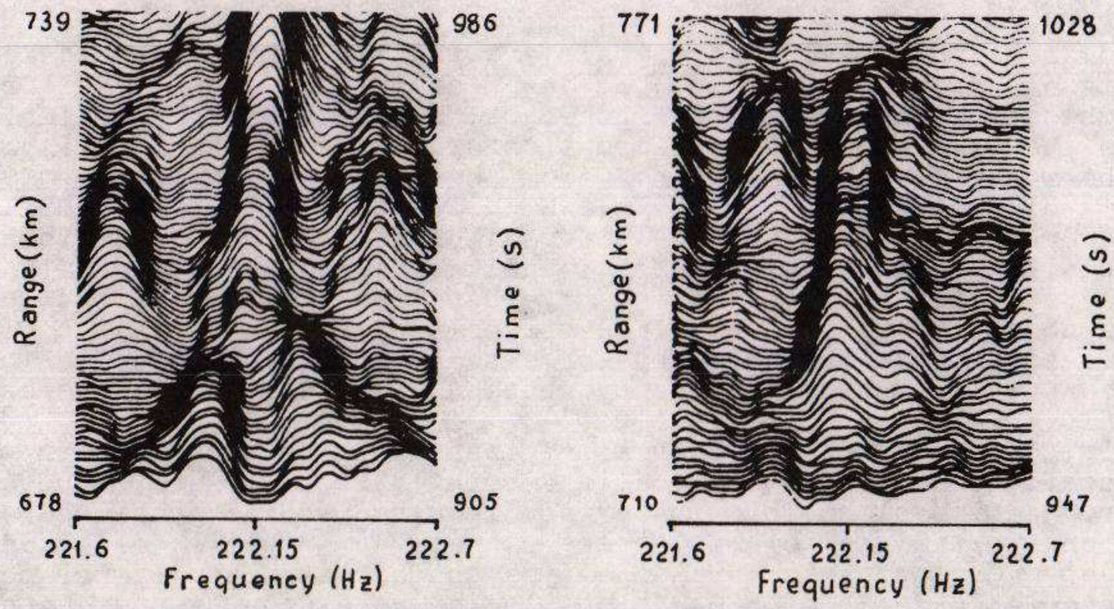

Fig. 5. Spectrum of the signals backscattered from inhomogeneities along an extended trace. Frequency 222.15 Hz, pulse length 40 s

sonification which is realized during the study of sound propagation along the traces with movable sources and receivers. In case of very extended traces with typical ranges of several thousand kilometers, such insonification is a time-consuming process as the speed of shifting the sources and receivers is always limited. A situation is possible to arise when the time of measurements exceeds characteristic time of stable existence of sea water inhomogeneities. In some situations, the methods of remote sounding of sea water inhomogeneities based on the possibility of obtaining information from backscattered pulse signals emitted by powerful sources can prove to be more preferable.

7. REFERENCES

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