REFLECTION OF LOW-FREQUENCY LONG-RANGE SOUND IN THE OCEAN

IGOR DIDENKULOV

Institute of Applied Physics
46 Ulyanov Str., Nizhny Novgorod, 603950, Russia
din@hydro.appl.sci-nnov.ru

Experimental results on energetic characteristics of low frequency (about 200 Hz) underwater channel sound reflection by ocean mountains and islands are presented. It is investigated also sound penetration into shallow water. Transformation of vertical structure of sound field over continental slope is considered. Continental slope and shelf-wedge reflection coefficients of low frequency sound propagating in the underwater waveguide were measured. Results of the work show that low-frequency sound reflections from large-scale bottom irregularities can be important in ocean acoustics.

INTRODUCTION

The development of high-power low-frequency sound sources and high gain receiving acoustic systems has been enhancing the range of observation of underwater inhomogeneities in the ocean from local to regional and up to the global scale. Acoustical tomography makes possible to get information about mean ocean temperature and mesoscale movements of water masses [1]. In this way some specific problems arise. One of them is what is the role of underwater mountains in formation of low-frequency sound field in the ocean and how it can be taken into account in tomography inversion. Another practical application of low-frequency long-range sound appears as a way to monitor large-scale ocean bottom map. It is known now that ocean bottom changes due to volcano and other tectonic processes and new underwater mountains arise from time to time. Therefore, the problem of large-scale acoustic mapping looks as attractive application of low-frequency ocean sounding.

It is known that underwater mountains can essentially decrease sound passing over them. This phenomenon has been studied theoretically and experimentally [2-5]. Some observations have been also made when sound was reflected by underwater mountains but did not study enough.

In this paper experimental results on energetic characteristics of low frequency sound reflection by ocean mountains and islands are presented and discussed. Experiments were made in the northwest Pacifics and central Atlantics to study reflection of low-frequency sound propagating in underwater sound channel reflection by continental slopes and to investigate sound penetration from deep water to the shelf zone.

1. EXPERIMENTS IN THE DEEP OCEANS

Measurements were made in the north-west part of the Pacific ocean over the continental slope of the Bering island and also in the central Atlantics in the region of the underwater mountain Large Meteor. They rise up from the 6000 and 5000 meters deep ocean bottom. In the experiments continental slopes were sounded with the high-power sound radiation systems of the 240 Hz frequency from the distances of about 600 and 200 km correspondingly. In the first case it was a vertical array of 16 sound sources spaced at half of wavelength apart each other. A center of this array was placed at the depth of the underwater sound channel axis (100 m). In the case of Atlantics measurement it was a volume-spread array of 4 sound sources, which was put at the 50 m depth. Acoustic signals in both cases were received on board of scientific research vessels by several vertically placed cable hydrophone arrays of the lengths up to the 150 m and also by a special acoustic probe consisting of hydrophone and depth measuring unit which could get a profile of acoustic field by diving to the 2000 m depth. The horizontal profile of sound field over the underwater mountain was also obtained by the horizontal cable hydrophone array towed by the receiving ship at the depth of 60 m. Measurements were made to get both characteristics of sound field propagating from the deep water to the shelf zone and back-reflected from continental slopes. Sound field measurements were made at different points in front of the slopes and along them up to the shallow water. The minimum depths were 33 m in the region of the Bering island and 300 m over the top of the underwater mountain Large Meteor.

For measurements of sound reflection coefficients the tone-burst signals were used and the receiving ships placed at the distances of 20-90 km from the slopes could receive both the forward and reflected signals. The positions of sounding and receiving ships during experiments were chosen by the mind that continental slopes must be sounded approximately normally to the contour lines. Schemes of experiments in the Atlantic and Pacific oceans are shown in figures 1 and 2, correspondingly.

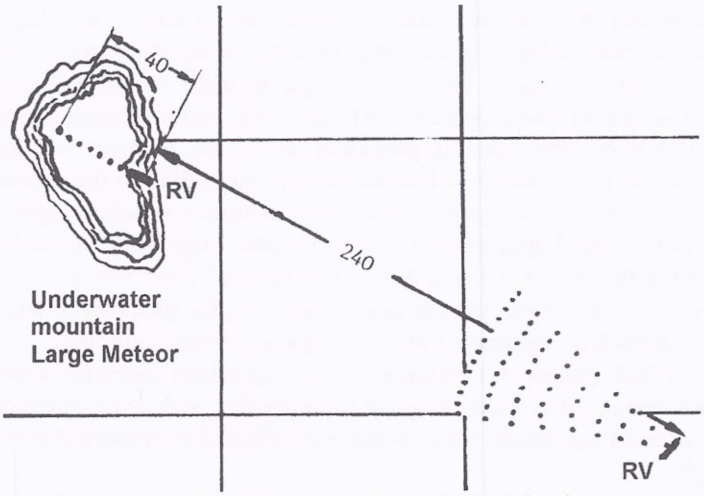

Figure 1. A scheme of the experiment in the Atlantic ocean.

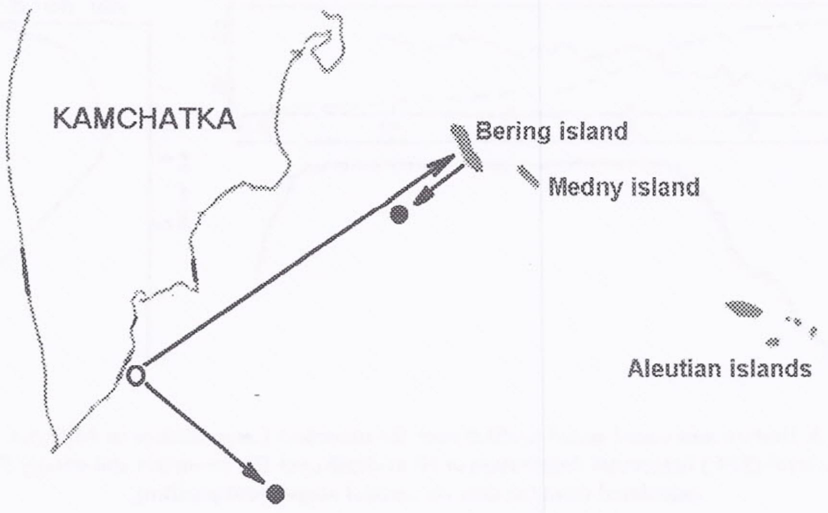

Figure 2. A scheme of experiments in the Pacific ocean.

2. RESULTS OF EXPERIMENTS IN THE DEEP OCEANS.

The results of measurements are shown below. Figure 3 represents the sound pressure level (SPL) and energy flux (EF) distributions over the mountain Large Meteor. SPL has been got by horizontally towed cable hydrophone array at the depth of 60 m, while EF has been calculated from the data on vertical sound field profiles obtained with the probe. The bottom profile over the mountain and sound speed profile near it are also shown in the figure. One can see that the energy flux is decreased more than 30 dB over the mountain while the signal pressure level at 60 m depth - only about 20 dB, that means the sound field intensity has nonuniform distribution in the water layer. The strongest changes of the energy flux take place within the range of about 5 km in front of the wedge of the mountain flat top where the bottom rises up from 1700 to 440 m depth and also within the 10 km range above the top. It means that some of modes, evidently of high numbers, die out when propagate in a shallow water conditions due to strong interaction with a bottom. The rest modes have less attenuation due to sound absorption by bottom. Vertical profiles of sound pressure level of acoustic signals, which propagate over the mountain in figure 4 for two points. It is clearly seen that there are a few propagating modes in the shallow water over the mountain. The forward and reflected signals got by putting the probe hydrophone at the depth of 100 m at 25 km distance in front of the mountain are shown in figure 5. The difference between levels of forward and reflected signals is a reflection coefficient that averaged value was found to be -25 dB.

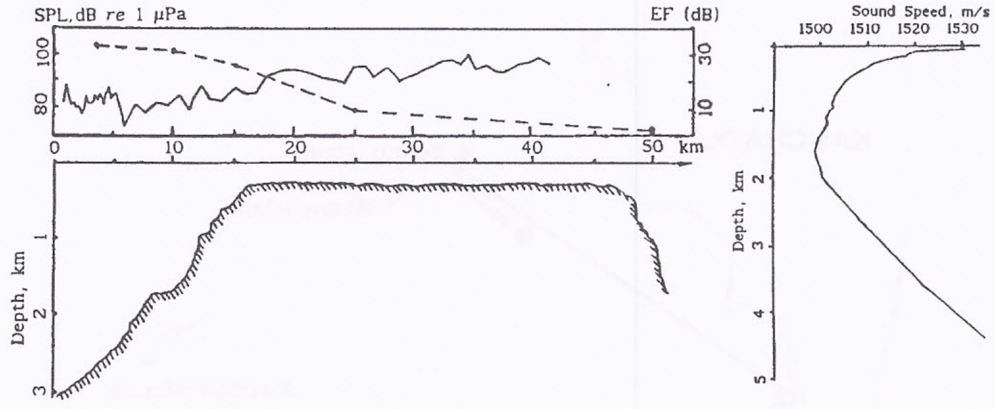

Figure 3. Bottom and sound speed profiles over the mountain Large Meteor in Atlantics. Sound pressure level (SPL) horizontal distribution at 60 m depth over the mountain and energy flux (EF) calculated from the data on vertical sound field profiling.

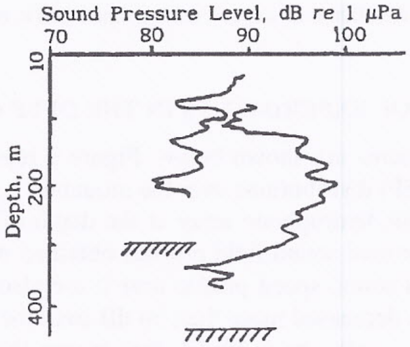

Figure 4. Sound pressure level profiles at the points of 440 and 300 m bottom depth over the mountain Large Meteor.

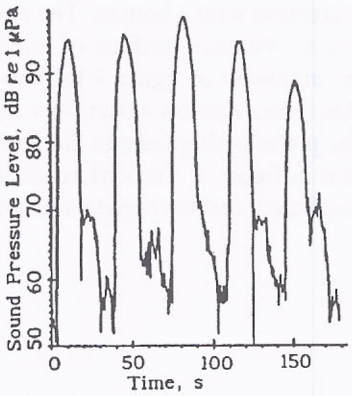

Figure 5. A sequence of forward and mountain-reflected sound signals.

Results `for the Pacific ocean measurements are depicted in the next four figures. Figure 6 shows a typical sound speed profile during experiment. Illustrations represented in figure 7 are vertical SPL profiles for forward and reflected by Bering island sound signals when a receiving ship with a hydrophone array was at 50 km distance from the edge of shelf zone. Tone-burst signals of 32 s duration were used. Sound pressure levels, presented at this figure has been obtained by averaging of 10 pulses. It is clearly seen that the vertical SPL structure is very similar for forward and reflected signals. It was also observed that levels of reverberation-like signal components in the reflected signals were small compare to levels of the coherently reflected one that is similar to the experiment in Atlantics (figure 5).

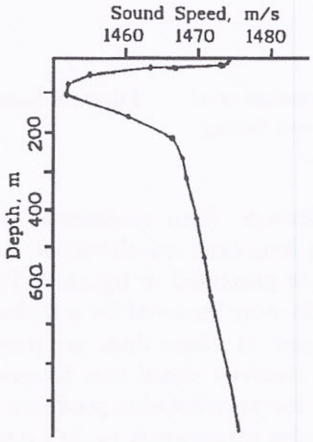

Figure 6. Sound speed profile for north-west Pacific ocean experiment.

It may be concluded from all of this that there is no essential energy transformation between modes in a reflection i.e. the reflection coefficient does not depend on the mode number. The same was observed also at another point at the distance of 90 km from the edge of shelf zone. Measurements made at different points with bottom depths 6100, 4600, 1000, 150, 50, 33 m has shown that the averaged over the array hydrophones pressure level is approximately the same when the bottom depth is 1000 m or more and decreases for less values of depth. An evaluation of energy flux in the waveguide cross section made by using experiment data gives the following: energy flux decreased about 15 dB with the bottom rising up from 1000 to 150 m and approximately keep the same value (within experiment accuracy) with the bottom rising up from 150 to 33 m. It can be explained in term of that source array system sounded only upper about 500 m layer. The vertical structure of sound field is about the same in the deep water and has strong variation in the shelf zone. Figure 8 shows single-mode profile of sound field observed at the point with a bottom depth of 33 m.

Thus it was found that an averaged value of sound reflection coefficient from the Bering island is about -(20-25) dB that is very closed to the case of underwater mountain Large Meteor. It shows that a reflected by continental slopes sound can be observed in the ocean at least at level of -(20-25) dB compare to the level of forward field.

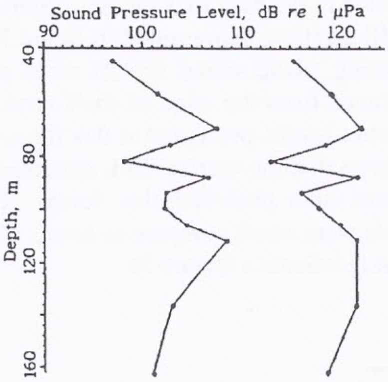

Figure 7. Pulse-averaged sound pressure level vertical distribution for forward and Bering island-reflected signals.

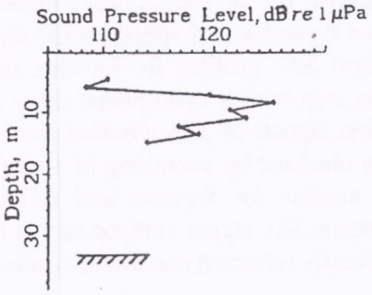

Figure 8. Sound pressure level profile in the shelf of Bering island.

Low-frequency sound reflections from continental slopes of islands and underwater mountains can generate a strong long-time reverberation. Examples of reverberation signals obtained in the Altantic ocean are presented in figure 9. They were obtained in monostatic configuration, *i.e.* acoustic signals were received by a hydrophone deployed from the sound radiation research vessel (see figure 1). Since there are many underwater mountains around the mountain Large Meteor the received signal was formed by reflections from them. The upper plot in figure 7 represents the reverberation produced by the emitted acoustic pulse of 100 s duration, while the lower plot corresponds to 20 s duration of the emitted pulse at the carrier frequency 240 Hz.

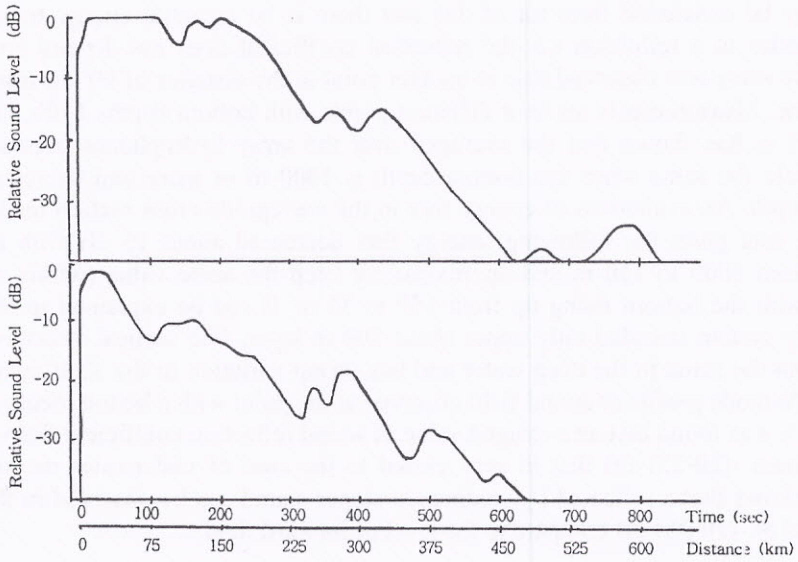

Figure 9. Reverberation signals obtained in the region of the Large Meteor underwater mountain in the Atlantic ocean at the frequency 240 Hz for pulse duration 100 s (upper) and 20 s (lower). Sound level values are normalized. Additional horizontal axis of distance is calculated for the sound velocity 1500 m/s.

3. EXPERIMENTS ON SOUND REFLECTION FROM THE SHELF WEDGE.

In previous chapter it was shown that sound reflection coefficients from continental slopes can reach acoustically essential values at low frequencies. It is also interesting to estimate the reflection coefficient from the shelf wedge. To this end special experiments were done in the shelf of Kamchatka. A scheme of monostatic experiment is shown in figure 10. A vertical array of 16 sound sources spaced at half of wavelength apart each other were deployed from the research vessel. A center of this array was placed at the depth of 100 m. A receiving hydrophone was supported near the bottom by the weight and floating sphere. Relatively short acoustic pulses of 2.5 s duration at the frequency 240 Hz were emitted by the array. A typical received signal is shown in figure 11.

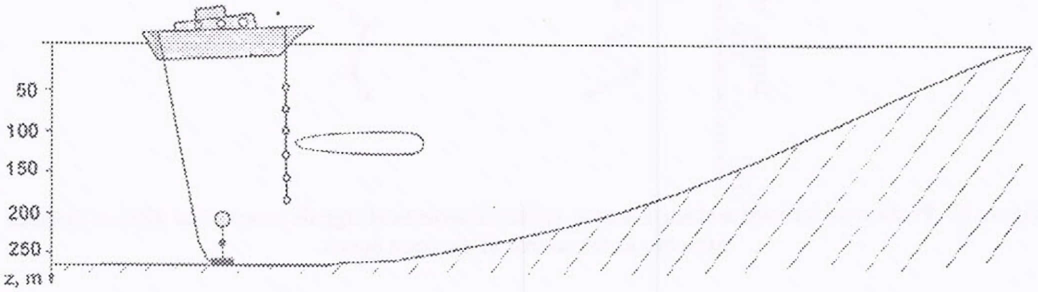

Figure 10. A scheme of experiment in the Pacific ocean in the shelf of Kamchatka.

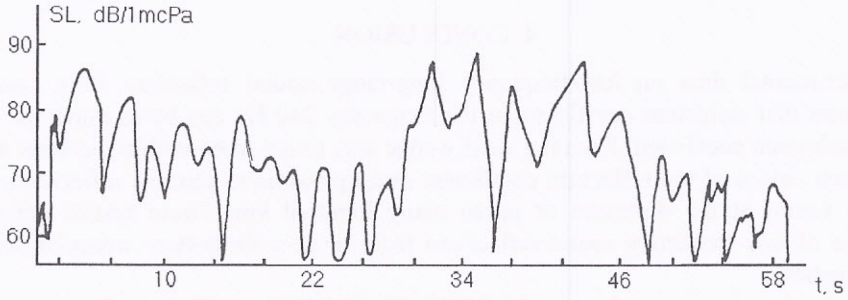

Figure 11. Sound pressure level (in dB re 1 μPa) versus time of reverberation acoustic signal received in the shelf for pulse duration of 2.5 s at the carrier frequency 240 Hz.

One can see from the figure 11 that the envelope of the reverberation signal decreases with time up to about 30 s. For these time delays the reverberation is due to multiple surface-bottom reflections and scattering from bottom irregularities. Around 30s of the time delay the received signal has high value. This time delay corresponds to the distance from the sound source array to the shore. However it is hard to estimate the reflection coefficient from this measurement because one need to know the propagation losses in such a complicated environmental conditions. To measure the reflection coefficient we used the receiving system deployed from the receiving vessel far from the shelf in the deep ocean. The receiving vessel was at the distance 500 km from the sound source vessel in such a place that the line connecting two vessels was perpendicular to the ocean shore (see figure 2). In such a configuration the receiving system recorded first the forward signal from the source and after that the signal reflected from the shelf wedge. This scheme allows one to eliminate the propagation losses between sound source and receiver by comparing the direct ad reflected signals if the distance between them is much larger than the distance from the sound source to the shore. The results of measurements of the vertical structures of the direct and reflected signals for pulse duration of 10 s at the carrier frequency 240 Hz are shown in figure 12. The vertical structure was measured by the short vertical receiving array.

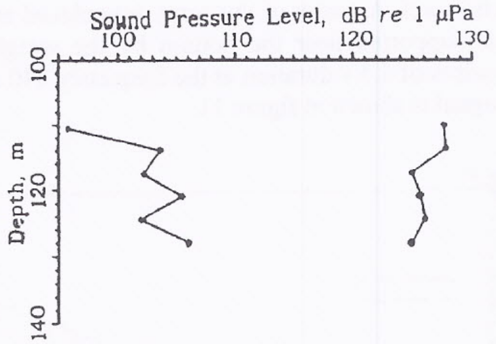

Figure 12. Profiles of forward and shelf wedge-reflected acoustical signals received at 500 km distance from the sound source in the open ocean.

It is easy to estimate from the figure 12 the reflection coefficient as about –(20-30) dB. In contradictory to the continental slope reflection one can see some difference in the forward and reflected field profiles for shelf wedge reflection.

4. CONCLUSION

Experimental data on low-frequency long-range sound reflection from continental slopes shows that reflection coefficient at the frequency 240 Hz can be as much as -(20-30) dB. The reflection coefficient from the shelf wedge was found to be within the same range of values. Such values of the reflection coefficient make possible to observe reflections of low-frequency sound at the distances of up to many hundred km. These results demonstrate importance of low-frequency sound reflections from large-scale bottom irregularities in the ocean acoustics.

This work was supported in part by RFBR (01-05-64426, 01-05-64162).

REFERENCES

1. W. Munk, R. Spindel, A. Baggeroer, T. Birdsall, The Heard Island feasibility test, J. Acoust. Soc. Am., Vol.96, 2330, 1994.
2. D. Nutile, A. Guthrie, Acoustic shadowing by seamounts, J. Acoust. Soc. Am., Vol.66, 1813, 1979.
3. G. Ebbeson, R. Turner, Sound propagation over Dickins seamount in the northeast Pacific ocean, J. Acoust. Soc. Am., Vol.73, 143, 1983.
4. N. Chapman, G. Ebbeson, Acoustic shadowing by an isolated seamount, J. Acoust. Soc. Am., Vol.73, 1979, 1983.
5. H. Medwin, R. Spaulding, The seamount as a difracting body, Bottom- Interacting Ocean Acoustics, Ed. W.A.Kuperman and F.B.Jensen, Plenum, New York, 1980, pp. 421-438.