

Modeling of the sound field fluctuations due to internal waves in the shelf zone of the ocean

Boris G. Katsnelson

I. INTRODUCTION

In given work we consider space-time variations (fluctuations) of the sound field from the source initiated by moving nonlinear internal waves in shelf zone of the ocean (shallow water). These fluctuations should be observed during rather long time (several hours and more).

II. OCEANOGRAPHIC SITUATION

Oceanographic features of nonlinear (soliton-like) internal waves can be listed on the base of observation:

- geometrical shape of envelope of IW (or surface of constant density, or temperature) can be described by different formulas, in the simplest case it can have KdV form. Wave length is about several hundreds meters (300- 500 in different areas), amplitude can reach 10-15 m, train contains up to 10-12 separate solitons;
- trains of IW are being generated in area of shelf break, they are living during a few hours (up to 10h), they move at approximately constant velocity $\sim 0.5-1$ m/s;
- direction of propagation is almost perpendicular to coastal line, more exactly from SW06 experiment we got angle diagram of directions of propagations of track during two weeks of observation. Width of diagram is $\sim 15^\circ$
- wave front of train is almost plane, radius of curvature can be estimated as $\sim 20-30$ km
- perturbation of water media is concentrated in comparatively thin layer of thermocline (for typical conditions of Atlantic coast of US thermocline layer is about 10-15 m within water layer of more than 80 m)

It means that trains of IS form some anisotropic in horizontal plane structure of shallow water environment and in turn provide some specific features of propagating sound signals depending on direction of waves propagation. More exactly, if we suppose that wave front of IW coincides with X-axis (direction of propagation is Y-axis), then properties of signals depend on polar angle α between acoustic track and X-axis.

III. SOUND SIGNALS PROPAGATION

As main mechanisms of fluctuations we consider:

- Adiabatic variability (abbreviation AV, when sound field follows local variations of waveguide parameters, for example oscillating depth of thermocline layer)
- Modes coupling (MC, when moving perturbation initiate creation of additional waveguide modes causing in turn fluctuations of the sound field at the receiver)
- Horizontal refraction (HR, or redistribution of the sound field in horizontal plane taking place in presence of remarkable horizontal gradients of waveguide parameters)

So we can construct circular diagram with the source at origin. For different sectors in horizontal plane we have different nature and in turn parameters of fluctuations. For small value of α we have predominating influence of HR, for $\alpha \sim \pi/2$ MC plays the main role in formation of the sound field, in area $\alpha \sim 10^\circ - 15^\circ$ AV determines variations of the sound field. Of course in dependence of waveguide parameters specific values of angle α can be different.

All mentioned above situations took place in different experiments on sound propagation in presence of internal waves [1-3] (Rubinstein et al in Gulf of Mexico, Zhou et al in Yellow Sea, Badiey et al in the SWARM'95 experiment etc). Consequently different properties of received signals were registered. Below we consider characteristics of received sound signals for different situations. As the main measured value we take temporal dependence of intensity of the sound field, or, more precisely, total intensity as a function of depth $I(z, T)$, spectral and modal intensities $I_\omega(T), I_n(T)$, as a function of frequency and mode number. As characteristics of sound field fluctuations we analyze scintillation index for all types of intensity:

$$SI_{I_\omega}^2 = \left\langle \frac{\delta I_{I_\omega}^2}{\langle I_{I_\omega} \rangle^2} \right\rangle, \quad \delta I_{I_\omega}^2 = \langle I_{I_\omega}^2 \rangle - \langle I_{I_\omega} \rangle^2 \quad (1)$$

(1)

Let's consider different sectors in horizontal plane, corresponding to different orientation of the sound propagation.

HR sector. If receiver (for example vertical line array) is located in this area then during some time of observation fluctuations of intensity is due to redistribution of the sound field in horizontal plane. This redistribution has the character of focusing/defocusing behavior in horizontal plane. Theoretical modeling of this situation is based on techniques "vertical modes and PE in horizontal plane". Results of modeling for intensity fluctuations give good agreement with experimental data, obtained in the SWARM'95 experiment We consider:

- vertical distribution of intensity as a function of time. Specific features of these variations is synchronicity of dependence – in other words for different depths maximums or minimums take place simultaneously;
- frequency dependence of scintillation index for separate modes repeats frequency dependence of refraction index in horizontal plane for the same modes and can be considered as some invariant of measurable values. That is one of the main qualitative results

MC sector. In this case sound intensity fluctuations are provided by different modal composition at the point of receiver taking place as a result of different modes coupling for different positions of moving perturbation (soliton or train of solitons).

We consider the following characteristics:

- spectrum of sound intensity in low frequency area (1-10 cph). These fluctuations are provided by motion of perturbation along range-periodical structure of the sound field in horizontal plane. It is shown that in mentioned spectrum there are maximums, corresponding to predomination of intensity fluctuations for separate pairs of waveguide modes. These pairs of modes correspond to modes, having turning point in area of thermocline;
- arrival times for different modes. It is shown that arrival times of additional (created) modes are concentrated in area of "optimal" frequencies, corresponding to mentioned modes, tangent to thermocline layer. In ray language rays, having turning point in area of thermocline, have "optimal" ray cycle, corresponding to scale of interference beating of adjacent modes at "optimal" frequency.
- correlation function (both temporal and range dependent). It is shown that in accordance with existence of "optimal" ray cycle and another parameters correlation length (correlation time) is almost the same for different sound frequency;
- frequency dependence of fluctuations of modal intensity. It is shown that the main contribution to intensity fluctuations is given by coupling modes at "optimal" frequencies.

For MC sector maximums in spectrum of fluctuations depend on velocity of soliton, moving along acoustic track. It means, that for one and the same soliton and for acoustic track placed at different angles to wavefront if IW we should observe some shift in spectrum of fluctuations. Existence of this frequency shift is demonstrated both in theory and experimental results of the SW06 experiment.

Theory of modes coupling provided by moving soliton is elaborated for low and high frequency sound waves.

REFERENCES

- [1] Rubinstein D., and Brill M. Acoustic variability due to internal waves and surface waves in shallow water. In Ocean Variability and Acoustic Propagation. J.Potter and A.Warn-Varnas (eds), Kluwer, 1991, 215-228,
- [2] Zhou, J.X., Zhang, X.S., and Rogers, P. Resonant interaction of sound waves with internal solitons in the coastal zone. *J. Acoust. Soc. Am.* 90(4), 2042-2054 (1991)
- [3] M. Badiey, J. Lynch, X. Tang, J. Apel and the SWARM group, "Azimuthal and temporal dependence of sound propagation due to shallow water internal waves." *IEEE J. Oceanic Eng.* 27(1), 117-129 (2002)