Linear and nonlinear wave propagation in the Southern Baltic

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INTRODUCTION

Recently a group of devices for underwater observation and communication designed on the base of linear theory is completed by the devices designed on the base of nonlinear theory of elastic wave propagation. It involves a visible increase in interest in their range in changeable sea conditions.

It is known that sound propagation in shallow water depends on many factors. Changes in the sound speed distribution in shallow water are the main factor influencing propagation of the wave of infinitesimal small amplitude. Propagation of finite amplitude wave in the sea depends moreover on spatial distribution of nonlinear parameter B/A as well as attenuation coefficient.

The aim of the paper is to characterise the conditions of linear and nonlinear elastic wave propagation in the Southern Baltic. The paper contains the results of experimental and theoretical research based on a large number of *in situ* measurements.

ACOUSTICAL CONDITIONS IN THE BALTIC SEA

The Baltic is a nontypical kind of the sea. It is a shallow sea of the lowest salinity in the world. Moreover, the conditions of acoustic wave propagation are much more complex than in other shallow waters. In typical shallow water appear seasonal changes in acoustical conditions in the upper layer of the depth of about 60-70 m caused by the changes in annual meteorological conditions. In deep water layer most often acoustical conditions are stable throughout the whole year. However acoustical conditions in the deep-water layer in the Southern Baltic change during the year. They depend on inflows of highly saline water from the Northern Sea through the Danish Straits, which evoke dense bottom current increasing the salinity at the bottom. The difference in vertical sound speed distribution in the Southern Baltic and the other shallow water could be noticed when we compare the data presented in Fig. 1.

Variation in the vertical sound speed distribution causes diffraction of an acoustic beam and therefore it is a main factor influencing the range of hydroacoustic devices. The averaged distributions of the sound speed determined for particular months allow to assess the general trends and find specific features for particular seasons. But prognosing of the conditions of sound wave propagation in the Baltic Sea remains a complex task because of many factors influencing them. The general mechanisms forming seasonal changes in acoustical climate of the sea are known well, but randomness of factors modulating them cause numerous anomalies of different scope. In long term prognosis the most important role plays the anomaly which is the consequence of long term meteorological conditions. In short term prognosis the local hydrological phenomena are the factor, which must be considered in predictions. Only monitoring of hydrological conditions in chosen area, for which short term anomalies are typical, allow to take them into account in hydroacoustical prognosis.

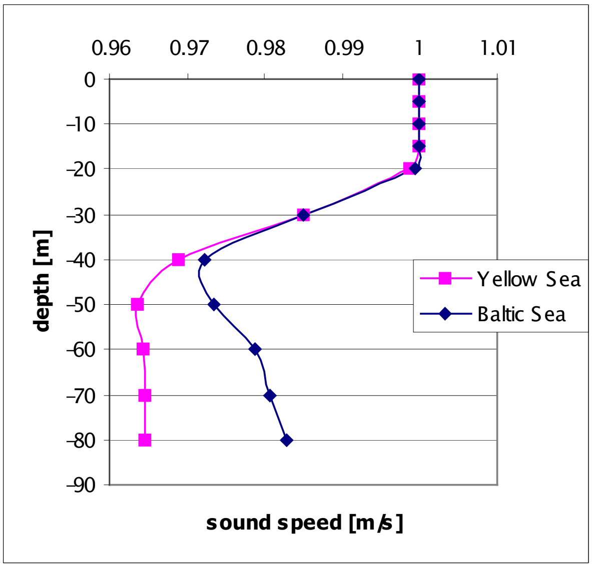

FIGURE 1. Normalised profiles of sound speed typical for summer in the Baltic Sea and in the Yellow Sea

FINITE AMPLITUDE WAVE PROPAGATION

Mechanism of nonlinear wave propagation is more complex than the linear one. The phenomenon is influenced not only by sound speed distribution but also by nonlinear and absorptive properties of medium.

Nonlinear properties of the sea are characterised by the nonlinearity parameter B/A, that is a function of temperature, salinity and static pressure. Because the main factor influencing it, similarly as the sound speed, is temperature, the shape of line illustrating vertical distribution of the nonlinear parameter B/A is close to the shape of the line showing the distribution of the sound speed. An example of vertical distribution of sound speed and nonlinear parameter B/A obtained experimentally is presented in Fig. 2.

Absorption is the other phenomenon having an impact on finite wave propagation. It is characterised by absorption coefficient, which depends strongly on frequency of propagating wave. Changes in absorption coefficient as a function of depth determined for two frequencies of wave: 20 kHz and 100 kHz, propagating in the same hydrological conditons are shown in Fig. 3.

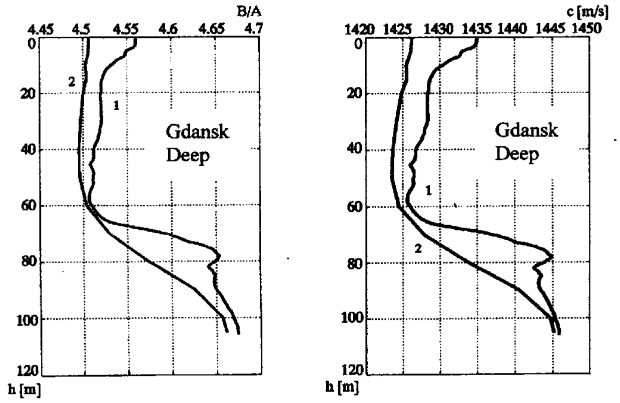

FIGURE 2. Profiles of sound speed and nonlinear parameter B/A in the Gdansk Deep region in April: 1 – measured in April 1994, 2 averaged in 1980 – 2000

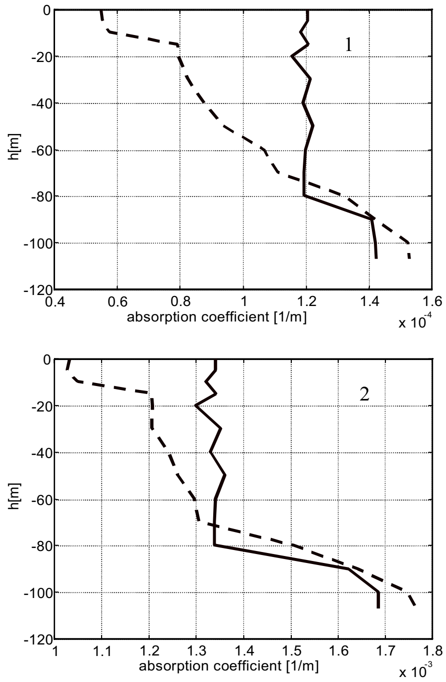

FIGURE 3. Changes in the absorption coefficient in the Gdansk Deep region in March (——) and in August **(- - -)**: 1 – f= 20 kHz, 2 - f = 100 kHz

The expression, which contains parameters of a source of wave and parameters of the medium influencing the phenomenon of nonlinear propagation could be given in the following form:

$$\varepsilon \operatorname{Re}_a = \left(\frac{B}{2A} + 1 \right) \frac{\rho_o c_o v_o}{b \omega} \tag{1}$$

where ε is the nonlinear coefficient, Re_a – Reynolds number, B/A – nonlinearity patrameter, ρ_o - density, c_o – sound speed, v_o - velocity, b – absorption parameter, ω - angular frequency. The comparision of vertical distribution of the sound speed, nonlinearity parameter B/A and $\varepsilon \operatorname{Re}_a$ determined for the same hydrological conditions in the Gdansk Deep is given in Fig. 4.

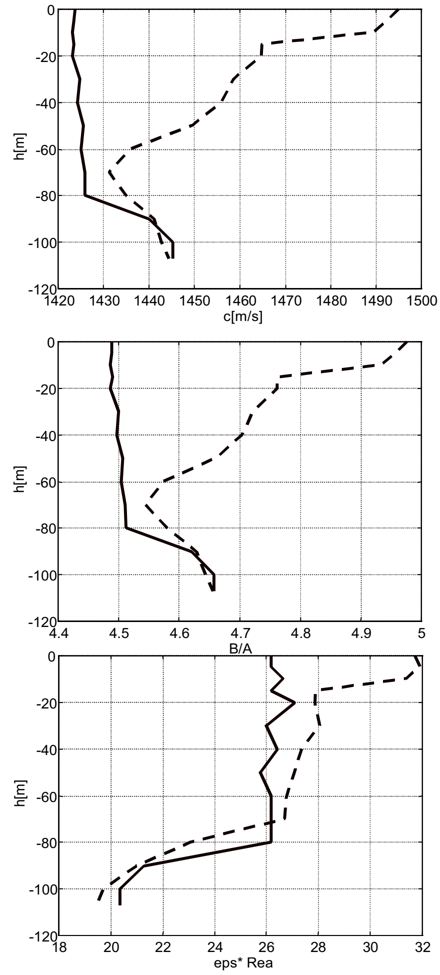

FIGURE 4. Vertical distribution of the sound speed, nonlinearity parameter B/A and ε Re_a in the Southern Baltic

CONCLUSIONS

Prognosing linear as well as nonlinear wave propagation in the Southern Baltic we have to take into account many factors influencing them.

Temperature of water is the factor having the strongest impact on the sound speed and the nonlinear parameter B/A. Therefore the spatial distribution of the parameter B/A in the Southern Baltic is similar to the temperature distribution and the sound speed distribution. The absorption coefficient depends more than the nonlinearity parameter on salinity of the sea water, and changes with the frequency. That is why, the spatial distribution of the value $\varepsilon \operatorname{Re}_a$ differs significantly from the spatial distribution of the sound speed and the parameter B/A.

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