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The study of acoustic climate of the Southern Baltic

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This paper presents the statistical characteristics of seawater properties, which are necessary for predicting the propagation of acoustic waves in selected areas of the Baltic Sea. The statistics were elaborated based on long-term measurements of vertical distributions of sound speed, temperature, and salinity, and the nonlinearity parameter B/A. Nonlinear properties of the environment are considered, in connection to the use of devices based on parametric acoustic wave generation. Special attention was paid to the environmental aspects of the propagation of underwater noise generated by ship operations. Statistical characteristics of the vertical distribution of sound are shown as mean values, and the differences associated with statistical, seasonal, as well as, long-term, changes.

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1. INTRODUCTION

The Baltic is a sea characterized by small depths, and specific hydrological conditions, which differ significantly from conditions characteristic of shelf regions[1]. Small depth water areas usually consist of two layers: a surface layer in which atmospheric action is clearly noticeable (heat exchange, wind mixing) and a deep water layer in which this action does not occur[2]. A characteristic of the surface layer is seasonal warming and cooling of water from the surface to the depth whose magnitude depends mostly on the geographic latitude[3]. Commonly, changes in the salinity of seas with depths are very little. In the areas of ice melting, the salinity is slightly lower, and in the areas of high evaporation levels it is slightly higher, near the surface rather than in the deep water. These differences, however, do not exceed 2-3 PSU. It is the temperature distribution that is responsible for the vertical distribution of speed, which causes the surface layer speed to change seasonally; whereas, in the deep water layer, in which the temperature and salinity are fixed, it rises slightly with the depth, as a result of a rise in hydrostatic pressure[4,5]. For small depths, up to 200-300 meters it can be assumed as approximately constant.

The deep water layer in the Baltic has definitely got different characteristics from those in other shallow seas[6,7,8,9]. Due to the specific connection with the world's oceans only through the Danish Straits, through which water exchange between the North Sea and the Baltic Sea takes place, in the Baltic there occurs a phenomenon of the so-called "high salinity water overflow". They, due to a higher density than in Baltic water, form a near-bottom density current moving eastwards through successive deep water areas of the Baltic[10]. The water forming this current has definitely got a higher salinity and, also, often a higher temperature, than the water which it replaces. As a result, temperature and salinity distributions, characteristic only of the Baltic, form. In these distributions, in the deep water layers, the temperature and salinity rise with the depths[11,12]. This difference is significant, and can reach up to 10PSU, e.g. in the area of the Bornholm Deep (on the layer border to 8PSU and close to the bottom 18PSU). These specific distributions of hydrological parameters are reflected in the speed of an acoustic wave. In the surface layer, whose salinity is approximately constant, and equal to 7-8 PSU for the Southern Baltic basin, the sound speed changes with the seasons of the year, in the deep water layer it always rises in towards the bottom: and its magnitudes depend on the course of the phenomenon of inflow of more saline water from the North Sea.

The sound speed distribution is a factor which significantly affects the effectiveness and accuracy of readings displayed by devices using acoustic waves for underwater observation[13,14,15]. The phenomenon of refraction of an acoustic beam can cause errors in fixing the position or movement trajectory of an object under underwater observation; carried out either by sounding devices, or underwater navigation systems. Knowledge of long-term characteristics of a hydro-acoustic field, in a selected area, and of its local or short-term changes, is indispensable for appropriate interpretation of obtained measurement results[16].

This paper presents the characteristics of the hydrological conditions affecting the conditions of propagation of elastic waves: the distribution of acoustic wave speed, and the distribution of nonlinearity parameter B/A in the Baltic, worked out using the results of measurements carried out by the Sea Fisheries Institute, and the Hydrographic Bureau of the Polish Navy. The hydro-acoustic parameters were calculated based on the following dependencies: acoustic wave speed was determined from the so-called UNESCO equation, developed by Chen and Millero[17], and the magnitudes of the non-linear parameter B/A from the dependence given by R.T. Beyer[18].

2. OCEAN – ATMOSPHERE INTERACTION

Hydrological conditions of oceans and seas are shaped by phenomena connected with reciprocal action by the spheres of Earth. The climate and weather on Earth are shaped by three basic climate-forming processes: heat circulation, water circulation and air circulation: as well as geographical factors: the array of lands and oceans, heights above sea level, and distances from a sea (ocean).

The climate of the Southern Baltic is influenced by the Atlantic Ocean, and the East European continent. The direct action of processes occurring in the atmosphere, within a yearly cycle, on the changes in the thermoahaline structure of water is noticeable in the surface layer, whose depth in the Baltic extends up to 70 meters[19]. This phenomenon is illustrated by the example presented in Fig. 1. Here can be seen the vertical temperature distributions in the region of the Gdańsk Deep within 2010.

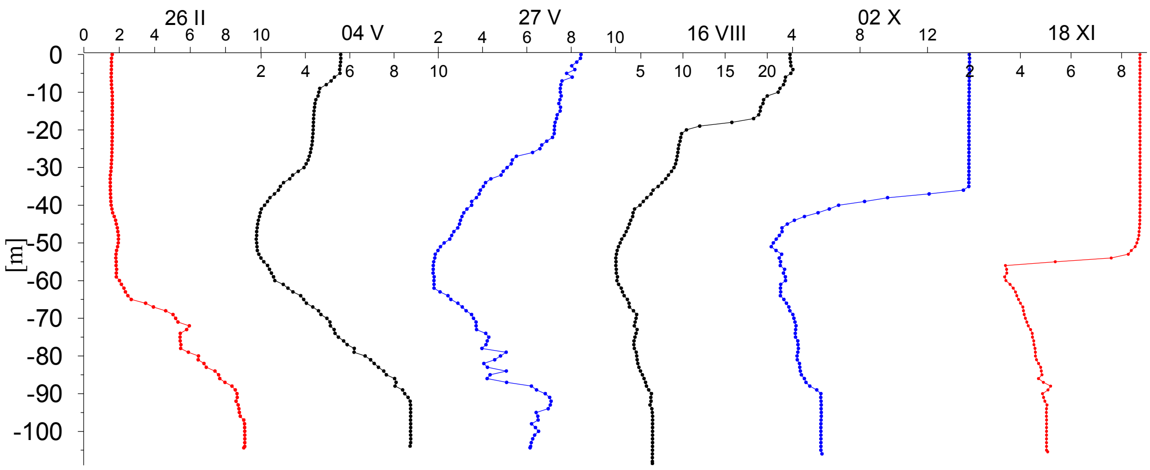

Figure 1: Changes in temperature [°C] in the Gdańsk Deep in the depth function over 2010.

The effect of solar energy is reflected in the water temperature at the surface, which was the lowest in February (1.60 °C), gradually rose, reaching 5.59 °C at the beginning of May, 8.44 °C at the end of May and finally 22.70 °C in August.

In the following months, the value of the temperature at the surface dropped, due to the smaller inflow of the solar energy, and increased effect of wind in the Autumn. As the result of the water mixing, a uniform layer was formed. It extended to 36 meters in October, and its temperature was 14.48 °C. In November, the depth of this layer rose to approximately 53 meters, and its temperature dropped to 8.72°C. The flow-through of heat in the surface layer also caused water to warm at higher depths. In the example under consideration, the water temperature in February was 1.60 °C across the whole surface layer. In the following months, water was warmed from the surface, and ranged from 1.78 °C at the depth of 50 meters, in May, (minimum temperature in the vertical distribution) to 3.38 °C in November, at the depth of 59 meters.

3. TRANSFORMATION OF THE ATLANTIC WATER

A high inflow of fresh water from the Baltic Sea (on average 480 km3 per year), leads to a strong outflow of surface water, of low density, to the North Sea, which constitutes approximately 60% of the whole inflow of fresh water to the North Sea. On the other hand, water containing more salt, and having a higher density, flows into the Baltic Sea in the deep water layer[20]. The flow through the Danish Straits, and the bars from the Great Belt and Oresund to the Baltic Sea can, in no way, be described as constant in the two flow-through layers.

A significant portion of infusions, which maintain the stratification of the Baltic, is connected with various occurrences characterized by the short time, and moderate salinity. On the other hand, the main infusions, which occur, on average, once in 10 years, decide not only about the renewal of the near-bottom layer, by the rich-in-oxygen inflowing water, but also strongly influence the general stratification of the Baltic Sea.

In connection with the high differentiation of thermohaline conditions in the Baltic, and conditions of water exchange with the ocean, a high stratification of water is recorded in this sea. Layering of water in the Southern Baltic basin is illustrated by the diagrams (Fig. 2, Fig.3) which show vertical temperature and salinity distributions for four months: February, May, August and November, averaged for the period from 1960 to 2010 in which features characteristic of winter, spring, summer and autumn seasons are noticeable. The division into two layers: upper and deep, is clear. The upper one is characterized by a constant salinity value in the depth function, independently of the season of the year, and seasonal changes in temperature resulting from heat exchange between water and atmosphere. For the deep layer, a gradual increase in temperature and salinity towards the bottom, in all seasons of the year, is characteristic.

Depending on the degree of its progress, the Baltic surface water spread between the surface and the halocline, has a thickness up to 60m, averaged temperature from 1.95° do 18°C, depending on the season of the year, and the averaged salinity of approximately 7.5 PSU. Winter water displays an averaged temperature of 2.7-3.68°C, and is limited by the halocline. Between the halocline and the bottom there occur waters of higher temperature 4-7 °C and higher salinity 8PSU (so called deep water layer). The highest salinity value in this layer depends on the sea region, e.g. in the vicinity of the Bornholm Deep it reaches 18 PSU and in the vicinity of the Gdańsk Deep -12PSU.

This saline water spread, at the highest depths, is slowly transformed into fresh water, and is removed in long time intervals (a few, to a dozen, years) by very strong infusions carrying water having a density higher than the density of stagnant water.

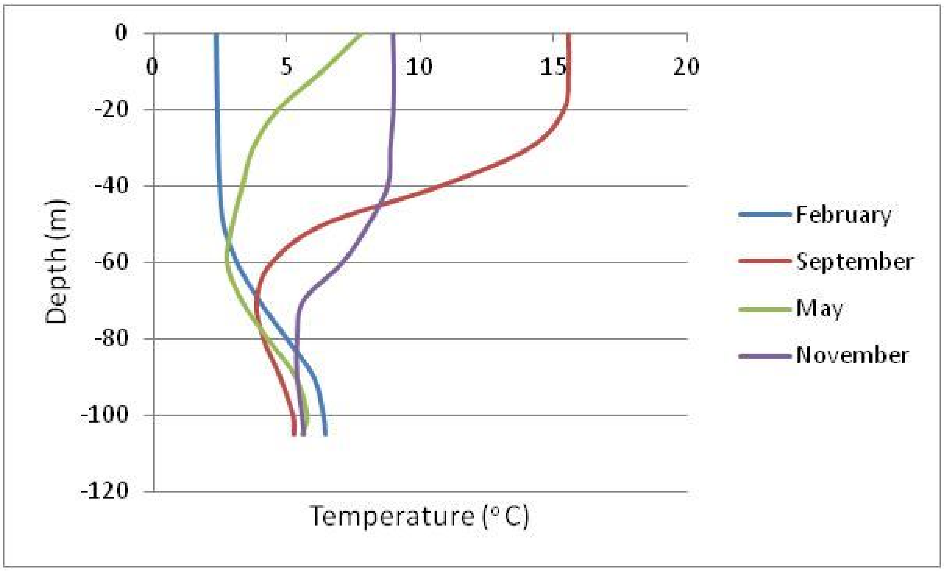

Figure 2. The changes in temperature in the depth function in the Gdansk Deep for selected months, averaged for the period 1960-2010.

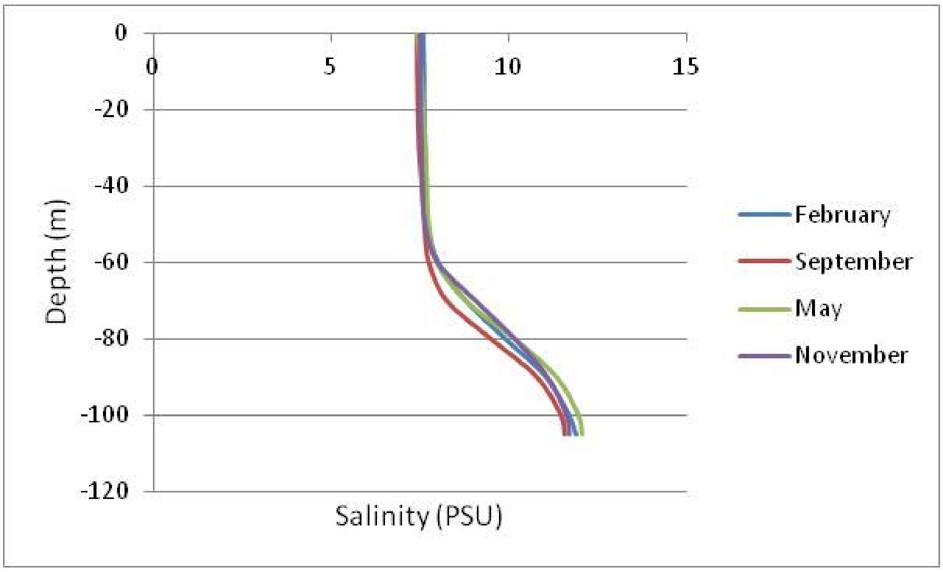

Figure 3. The changes in salinity in the depth function in the Gdansk Deep for selected months, averaged for the period 1960-2010.

4. THE PROPAGATION CONDITIONS OF ELASTIC WAVES

The propagation conditions of elastic waves depend on spatial distribution of sound speed, and in the case of waves having high intensity and waves of non-linear generation, an important role is also played by the spatial distribution of the nonlinearity parameter B/A[21,22].

In Figure 4, data from April 2009 is used as an example, to show the interdependence between the distributions of hydrological and hydro-acoustic parameters.

The averaged data, collected for many years, is used to work out the characteristics of the so-called "acoustic climate", and constitutes the point of reference for single measurements. Comparing data collected for many years with the data averaged over a shorter period of time, also produces some interesting information. Based on the hydrological data from 1960-2010, it can be claimed that over the decade 2000-2010, in winter the water temperature in the area of the Gdańsk Deep was significantly higher than the long-term average, both in the upper layer and the deep layer, and in February it exceeded the long-term value by approximately 0.6°C near the surface, and over 1.1°C near the bottom (Fig.5). This tendency is also visible in distributions averaged for the summer months. In August, water temperature near the surface averaged for the years 2000-2010 was higher by over 1°C near the surface, and by approximately 1.3°C near the bottom (Fig.6). This is proof for mild winters at the end of the 50 year-long period considered. Additionally, it indicates a high flow of warm Atlantic water into the deep layer.

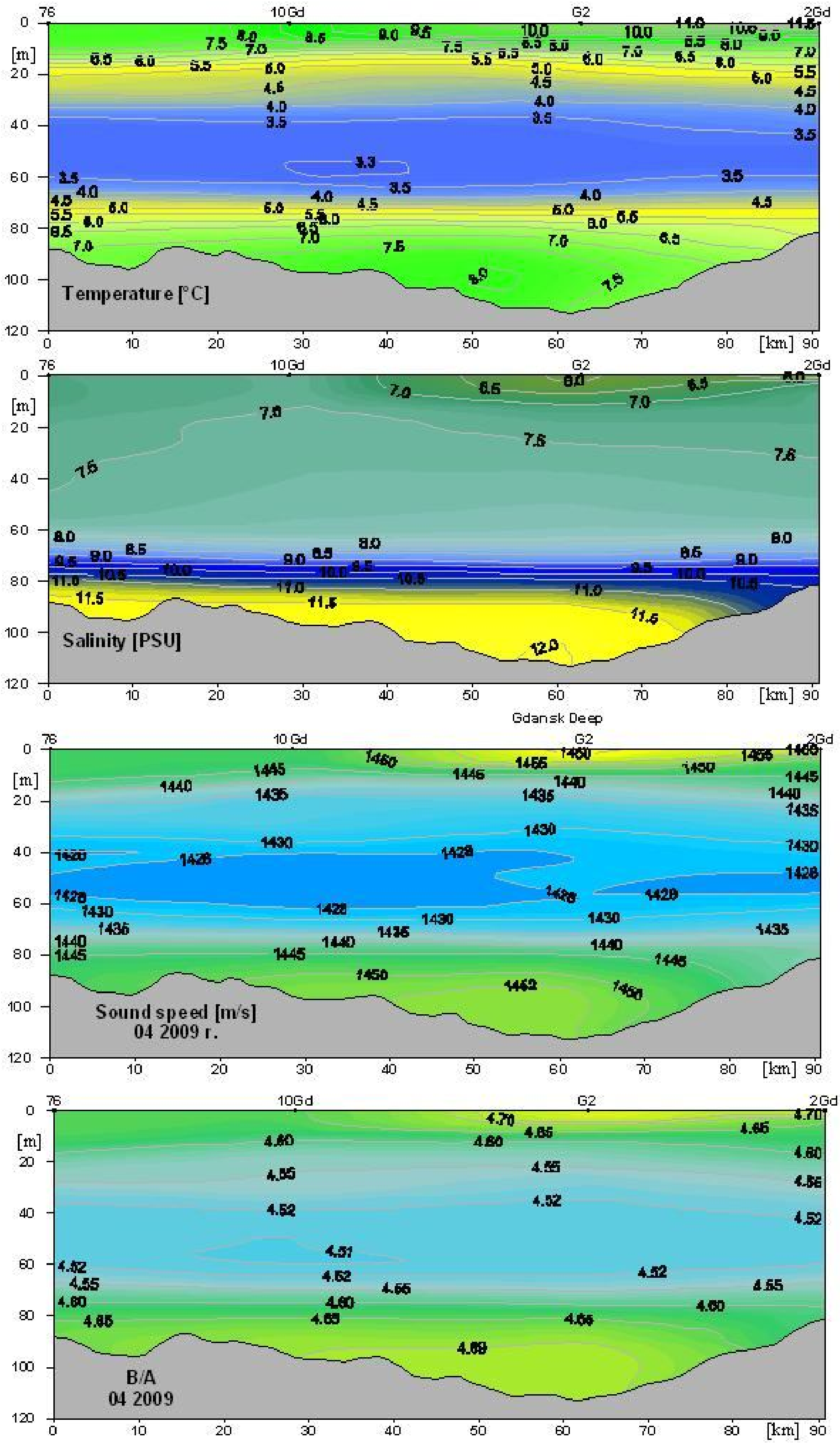

Figure 4. The vertical distribution of temperature, salinity, sound speed and parameter B/A on the profile in the area of the Gdansk Deep.

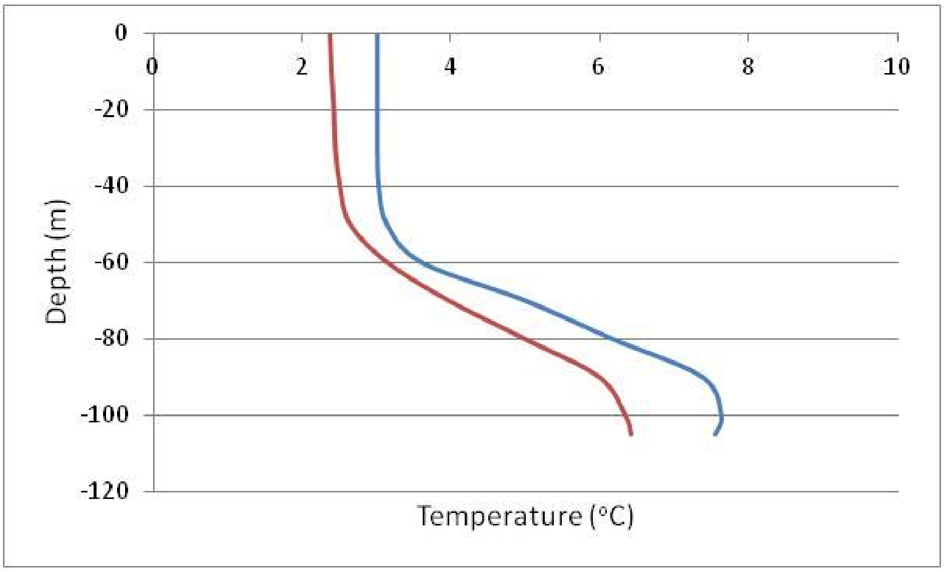

Figure 5. The vertical distribution of water temperature in February in the area of the Gdansk Deep averaged for the periods 1960-2010 and 2000-2010.

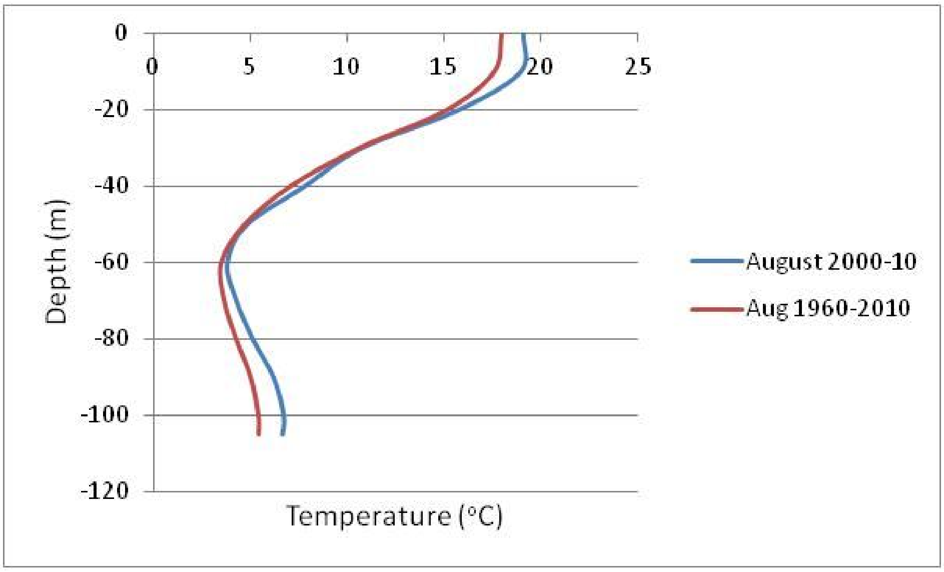

Figure 6. The vertical distribution of water temperature in August in the area of the Gdansk Deep for the periods 1960-2010 and 2000-2010.

Such changes in hydrological conditions affect the changes in propagation directions of acoustic waves, which is shown in the example of the speed sound distribution and non-linear parameter B/A distribution in February in the Gdansk Deep (Fig. 7 and Fig.8).

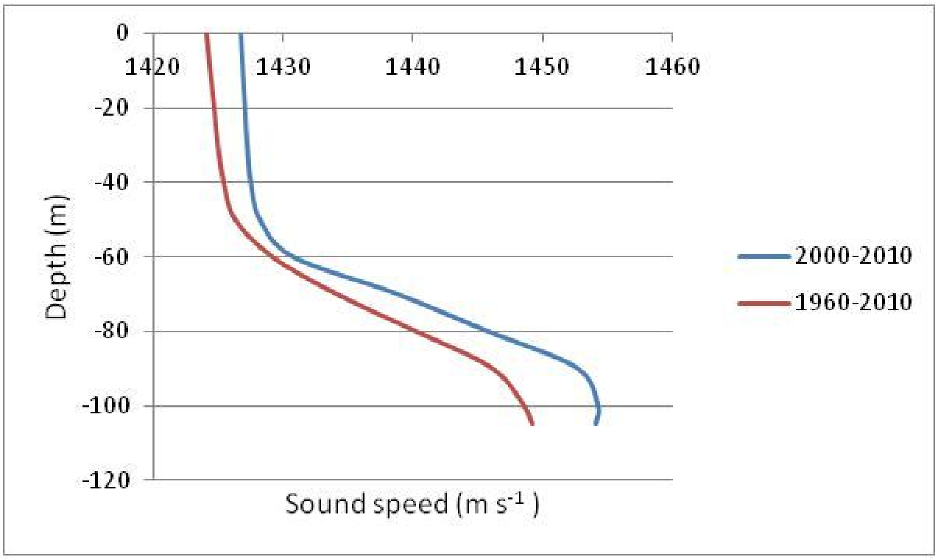

Figure7. The vertical distribution of sound speed in February in the Gdansk Deep averaged for the periods 1960-2010 and 2000-2010.

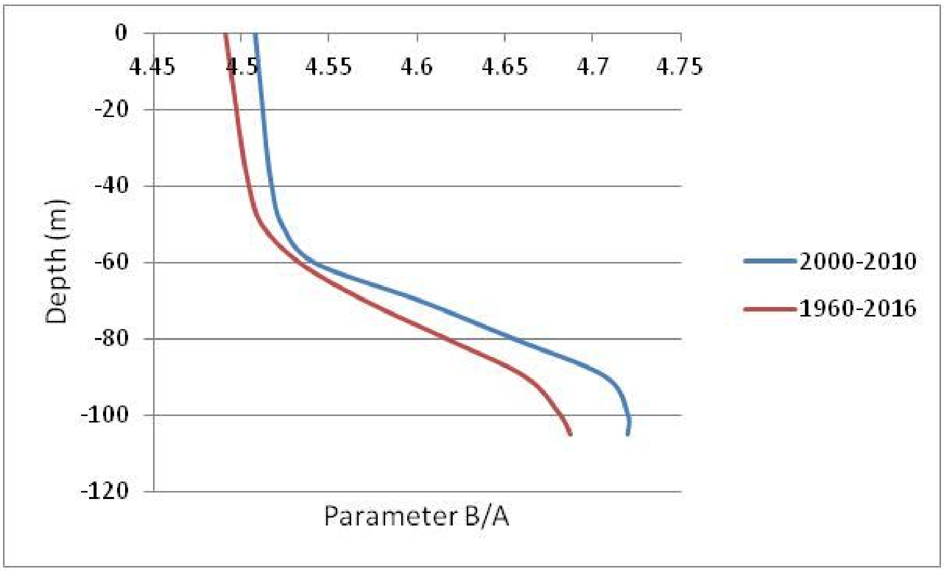

Figure 8. The vertical distribution of non-linear parameter B/A in February in the Gdansk Deep averaged for the periods 1960-2010 and 2000-2010.

5. CONCLUSIONS

The Baltic Sea is an almost-closed water basin, where seasonal changes in water properties, especially in temperature, are relatively high. This mainly holds true for the upper layer of the sea. The measurement data presented here, collected over a long period of time, allows for a statistical determination of average values for particular months. This data is a premise for forecasting both the acoustic climate of selected areas, as well as for ranges of acoustic devices in these selected periods.

In addition, this paper presents data concerned with distributions of non-linear properties in the form of the nonlinearity parameter B/A. This data can be, in practice, used when parametric sonar is employed.

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