Investigation of the vertical distribution of the sound speed of the Gulf of Gdansk in the years 2000-2010

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The conditions of the acoustic wave propagation in the southern Baltic are much more complex than in other shallow waters. In the typical shallow water, seasonal changes in acoustical conditions in the upper layer, of the depth of about 60-70 m, are observed. They are caused by variation of the annual meteorological conditions. Most often, in the deep water layer, acoustical conditions are stable throughout the year. However, in the Southern Baltic they change during the year also in the deep water layer. They depend on the inflows of highly saline water from the Northern Sea through the Danish Straits, which evoke a dense bottom current increasing the salinity at the bottom. The vertical sound speed distribution in the Southern Baltic is strongly dependent on the hydrological conditions.

In the paper the characteristic elements of acoustic climate of the Southern Baltic will be considered, based on data concerning the Gulf of Gdansk. Averaged characteristics of temperature, salinity and sound speed for the years 2000-2010, as well as anomalies, have been determined.

Keywords: shallow water acoustics, underwater acoustic climate

1. Introduction

Currently, we observed a continuous increase in demand for devices for underwater observation. Sonar systems are used in many works related to the seabed and the ocean [7, 8, 9]. Since World War II, they became the subject of continuous monitoring of the conditions of sound propagation in the Atlantic Ocean. Interest in the Baltic Sea took place much later. In the Fifties of the last century in the Baltic Sea seasonal changes in sound propagation were discovered [3]. The natural conditions of the Baltic Sea are described in detail in literature [11, 12]. Reports characterizing the acoustic climate of the Baltic Sea in detail are rare. Terms of propagation of acoustic waves in the southern part of the Baltic Sea are much more complicated than in other shallow waters [3,4,5,6]. In typical shallow seas conditions of sound propagation in the upper layers depend on the season. The depth of the upper layer depends on the latitude. Salinity and temperature in the bottom layer are practically constant, and do not depend on seasonal change. However, in the Baltic Sea changes occur also in the deep layer. Acoustic conditions in the Southern Baltic sea are changing during the year. This is due to the influx, through the Danish Straits, of dense, salty water from the North Sea.

2. Method and material

The paper presents the results of 87 measurements over the decade, from one station at Gdańsk Deep. All the measurements were performed by National Marine Fisheries Research Institute. The first measurement was conducted on February 15, 2000, the last one on November 18, 2010. The measurement included the temperature and salinity at depths of 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 105 meters. To determine the speed of sound, the Del Grosso formula [1] describing the dependence of the speed of sound on temperature, salinity and depth, recommended by UNESCO was used.

An important feature of the Baltic waters is permanent stratification according to the salinity – Fig. 1. There are two main layers[10]: upper water and deep water. Upper waters have low salinity, are well mixed water, the temperature depending on season, from 0°C to 24°C. In deep water there is increased salinity, and nearly constant water temperature. Between upper and deep layer is an intermediate layer – halocline. It is characterized by rapidly changing salinity.

In the summer months, on the temperature graph it is possible to observe the intermediate layer: thermocline - this layer is characterized by rapidly changing temperature with depth. In the Gulf of Gdańsk, water temperature in the upper layer ranges from 2°C to 24°C. Salinity in the analyzed decade is contained in the range from 5.88 PSU in the surface layer to 7.8 PSU.

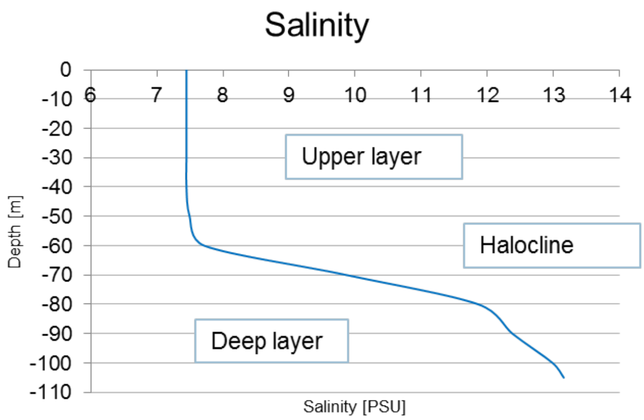

Fig. 1. Layers of Baltic water.

3. Acoustic climate of the Gulf of Gdańsk

On the acoustic climate of the Baltic Sea irregular phenomena have impact. Sound speed in 2010 presents a typical annual distribution – Fig. 2. This graph shows a few phenomena that affect the speed of sound in the Baltic Sea. The speed of sound in the top layer is in the range of 1420 m/s in January, to an exceptionally high 1500 m/s in August. This is due to heat transfer at the boundary layers of water - atmosphere. A factor influencing the acoustic propagation conditions in the deep layer is the inflows of salt water from the North Sea. Another phenomenon changing the climate are strong winds, observed in November.

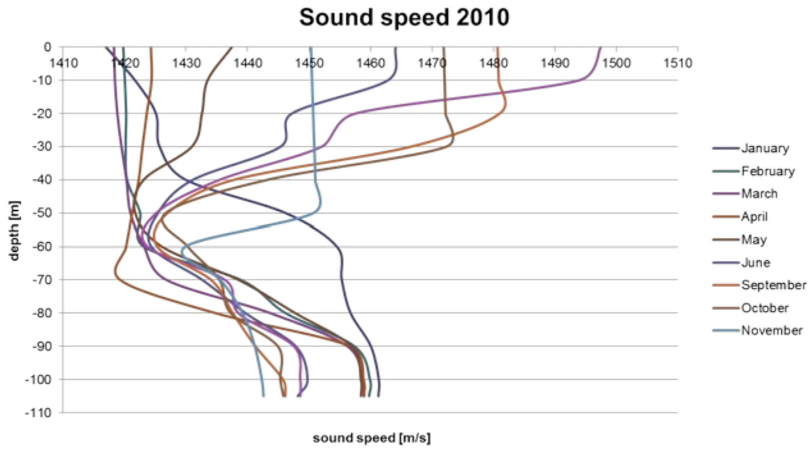

Fig. 2. Distribution of the speed of sound in 2010.

Surface water temperature depends on temperature, as shown in the graph. In the last decade maximum temperature was in July 2005 – 23.26°C and minimum value was in January 2010 – 1.03°C. Fig. 3 shows the seasonality of distribution. The lowest values occur at the beginning of the year, and the highest in July and August.

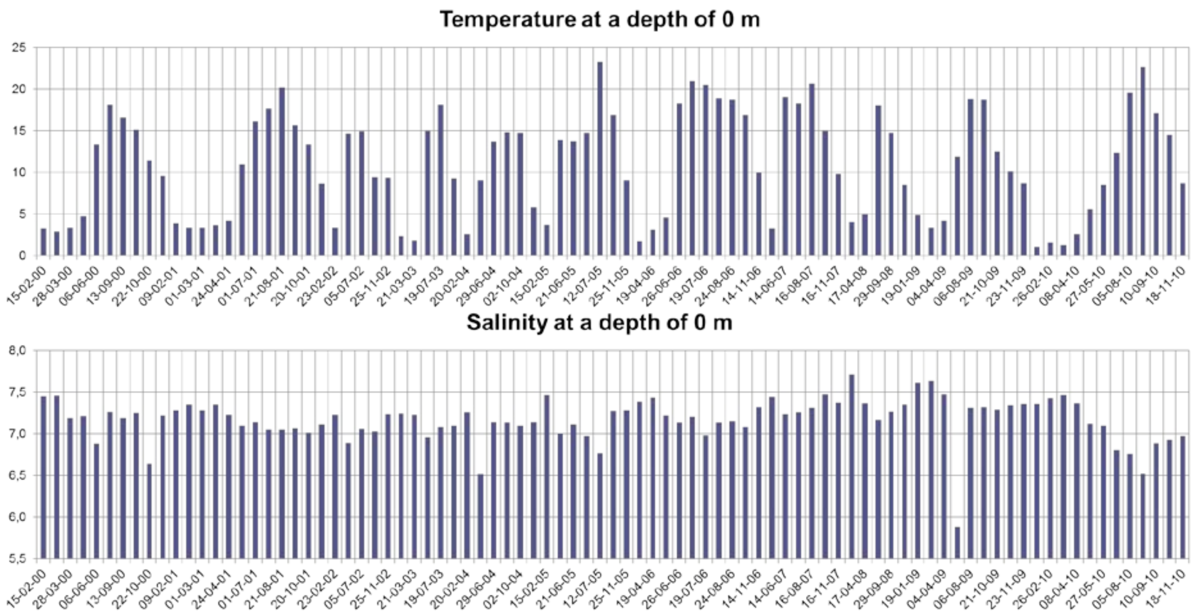

Fig. 3. Conditions for the surface layer.

Surface water salinity ranges from 5.88 PSU in April 2009 to 7.72 PSU in February 2008. The impact on salinity in the surface layer is due to the influx of fresh water from rivers. The average salinity of surface water in 2000-2010 amounted to 7.16 PSU.

The acoustic conditions at the bottom of the Gdańsk Deep look completely different – Fig. 4. Water temperature and salinity of the lower layer of the filling depends on the salt of the ocean. Simultaneous increase in salinity and temperature means a continuous infusion of salt water – for example January 2010: temperature 9.35°C salinity 12.56 PSU. Increased salinity and decreased temperature means a cold infusion – for example June 2003, salinity 13.23 PSU, temperature 4.44°C.

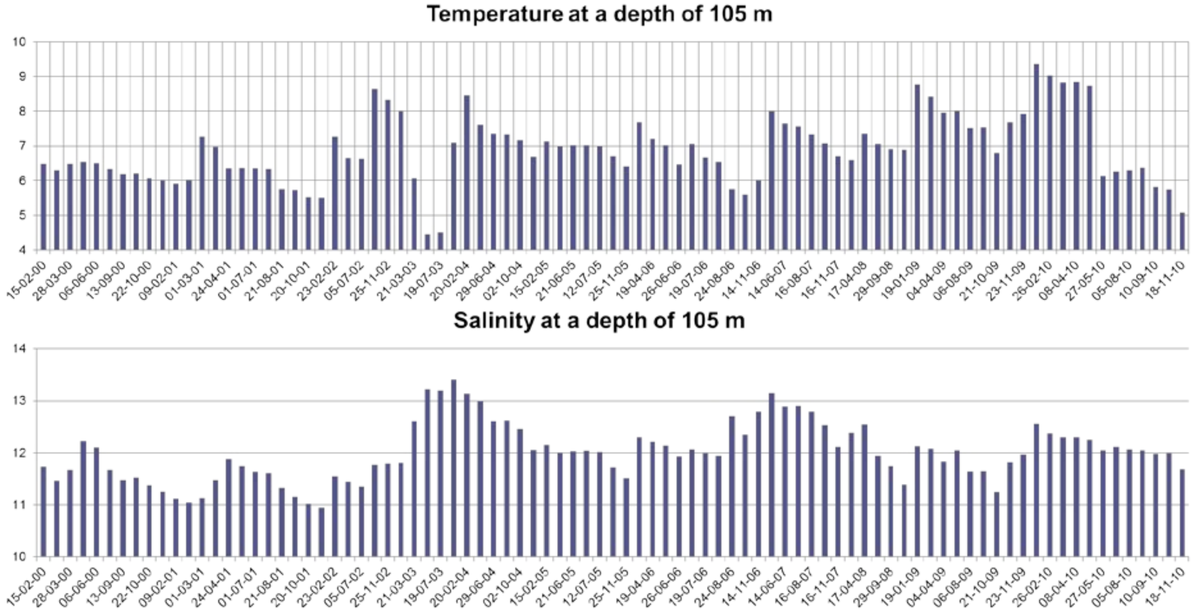

Fig. 4. Conditions for the deep layer.

Analyzing the acoustic conditions of the Baltic Sea must be distinguished, summer season, as opposed to the winter season. Schedules showing sound speed and temperature, significantly differ from each other. In winter months, represented by February – Fig. 5. Temperature on the upper layer is from 1.6 °C to 4.07 °C. To a depth of 60 meters, or in some cases, of 80 meters, temperature is constant. Thermocline is at different depths, from 50 meters in 2010, to 80 meters in 2000. Then, the temperature rises toward the bottom. The difference between the temperatures at the bottom was more than 4°C. A very similar distribution is the speed of sound, since it depends largely on the temperature. The upper layer of the speed of sound varies from 1420 m/s to 1430 m/s. The lower layer of the speed of sound varies from 1445 m/s to 1460 m/s.

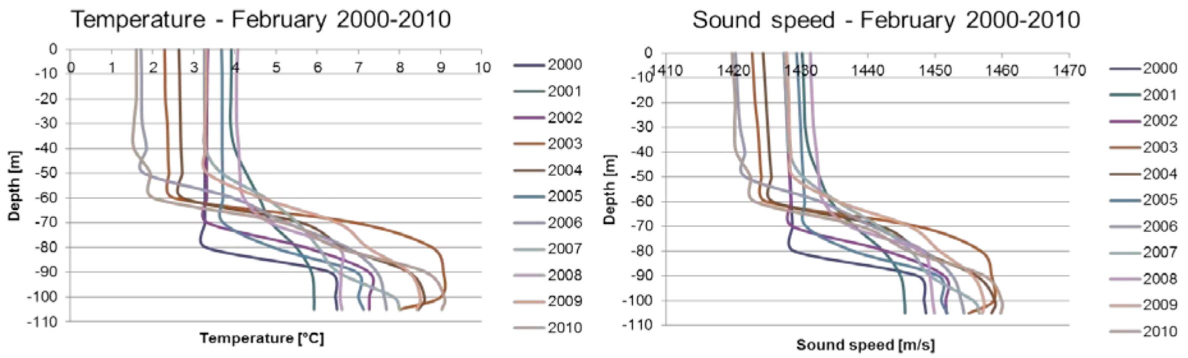

Fig. 5. Conditions (temperature and sound speed) in the winter season.

A typical summer month can be represented by August – Fig. 6. The highest temperature is observed on the surface of the water. The temperature decreases, and reaches to the lowest value in the intermediate layer then grows towards the bottom.

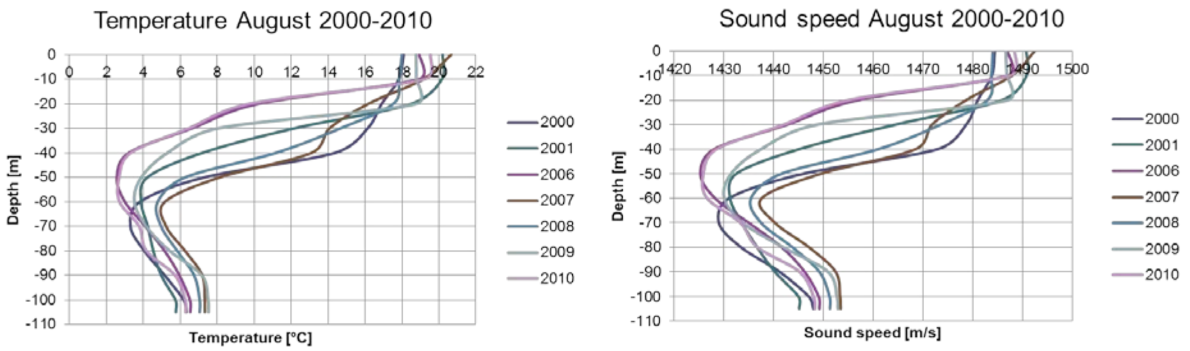

Fig. 6. Conditions (temperature and sound speed) in the summer season.

The chart of speed of sound is very similar to the shape of the temperature graph. In upper layer is a big difference in the speed of sound between winter and summer season, nearly 70 m/s. Bottom layer has similar values. Irregular, rather inflows of the ocean saltwater, can best be seen in the intermediate layer at a depth of 50 to 70 meters – Fig.7.

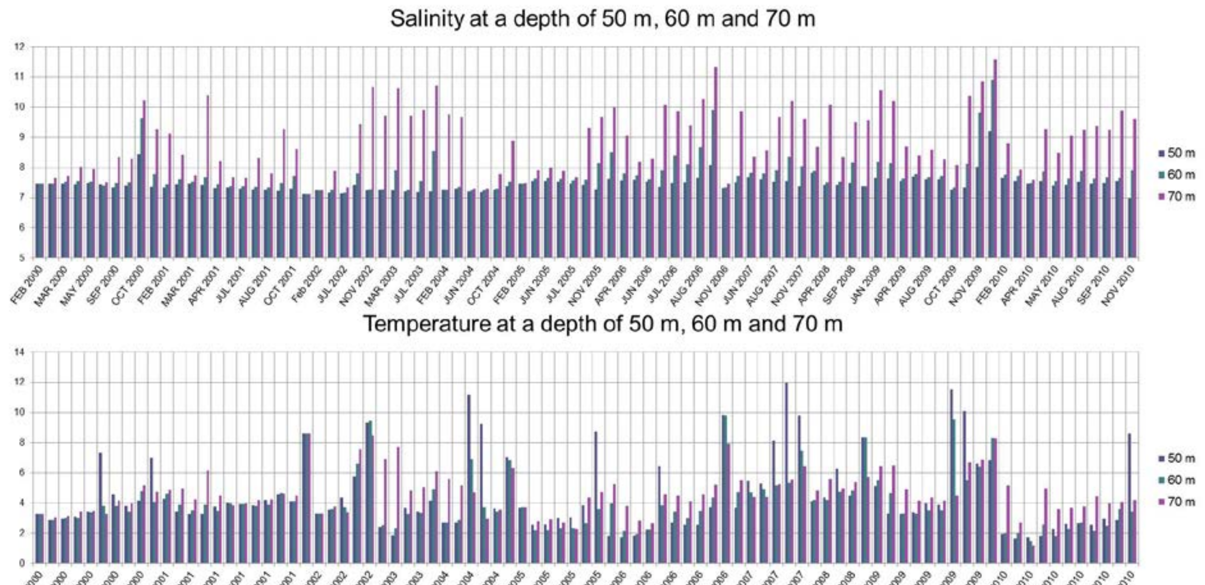

Fig. 7. Conditions for the intermediate layer.

In the previous decade, the lowest salinity was in February 2000. Halocline decreased by more than 20 compared to the average values in February 2000 to 2010- Fig. 8. The effects of low salinity of deep water are visible also on the temperature and the speed of sound. Types of salinity, temperature and speed of sound have a very similar shape. You can see a clear reduction of the intermediate layer. Salinity in February 2000 to a depth of 60 meters was the same as the average salinity in the analyzed decade. Then, the average salinity of the depth of 60 meters grew; in February 2000 increased salinity started at a depth of 80 meters. The difference between the average salinity and the actual measurement in February 2000 at a depth of 80 meters was 2.91 PSU. In the deep layer salinity was lower by 0.42 PSU. The temperature in February was almost constant to a depth of 80 meters. The average temperature in February is constant up to a depth of 40 meters, then increasing towards the bottom. At a depth of 80 meters was observed the biggest difference between the values, equal to 2.87 °C. The temperature difference in the surface layer was 0.26 °C in the deep layer of 1 °C.

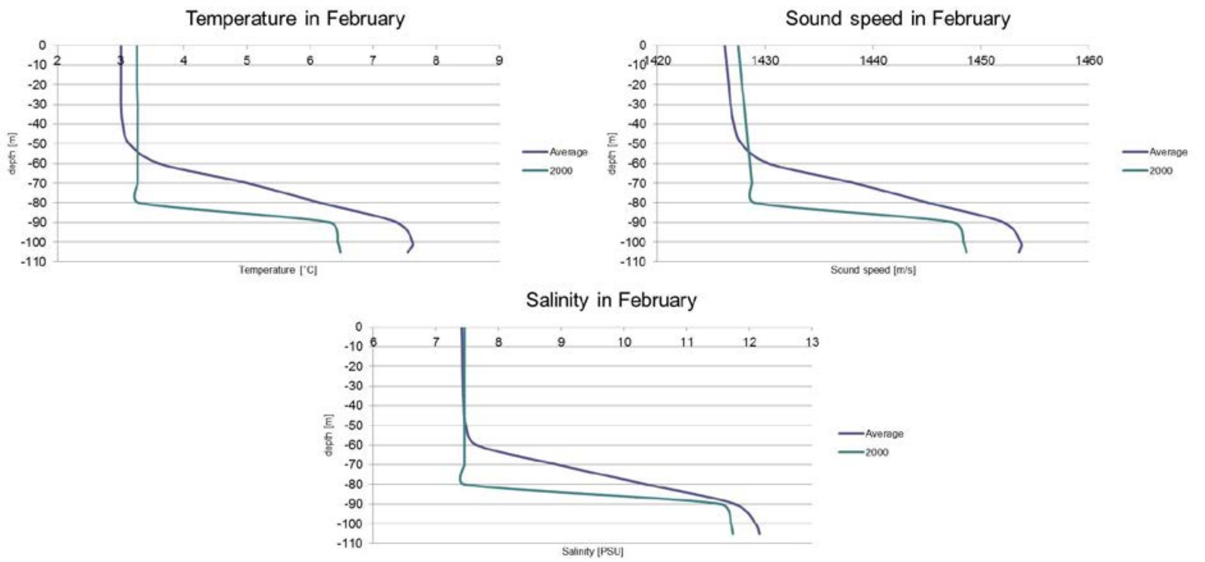

Fig. 8. Conditions (temperature, sound speed, salinity) in February 2000.

In June 2004, at a depth of 10 to 70 meters, can be observed a big difference in temperature, sound speed and salinity between the mean values and actual instantaneous values – Fig. 9. The difference in temperature at a depth of 50 meters was almost 7 °C. At the same depth, the speed of sound differs by 30 m/s. Towards the bottom, the differences are reduced temperature in the deep layer, June was higher by 0.7 °C, the sound speed of 3 m / s, with a salinity of 0.3 PSU.

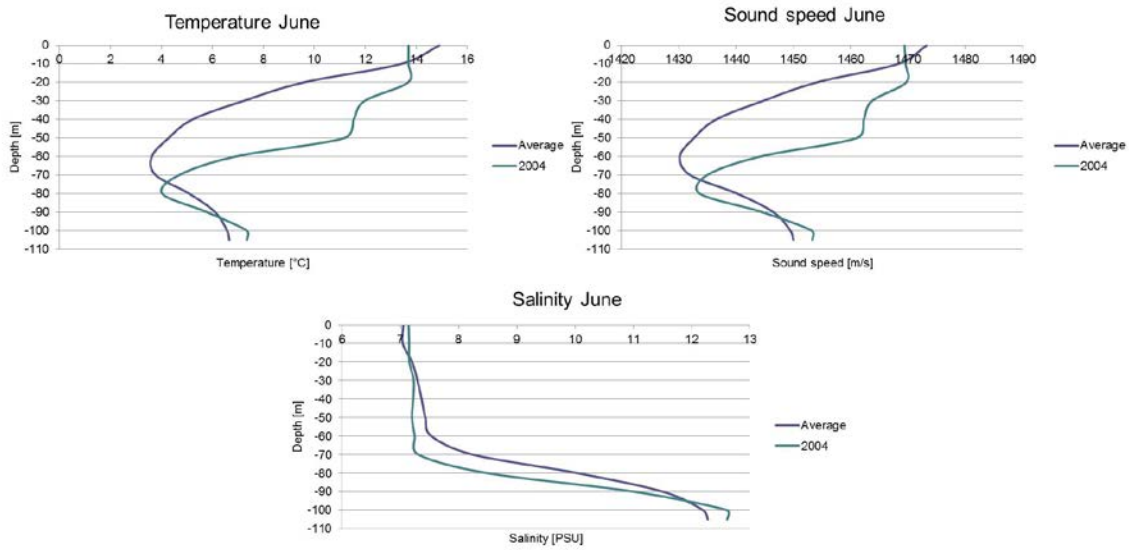

Fig. 9. Conditions (temperature, sound speed, salinity) in June 2004.

Strong cold winds causing mixing of water to a depth of about 50 meters. This phenomenon is most apparent on the distribution of temperature and speed of sound – Fig. 10. The surface layer cools down, and creates good conditions for propagation. Temperature, speed of sound and salinity are fixed to a depth of 50 meters in 2010 to 70 meters in 2008. Then, in the intermediate layer, the speed of sound and the temperature reach a minimum value, and then are increasing towards the bottom.

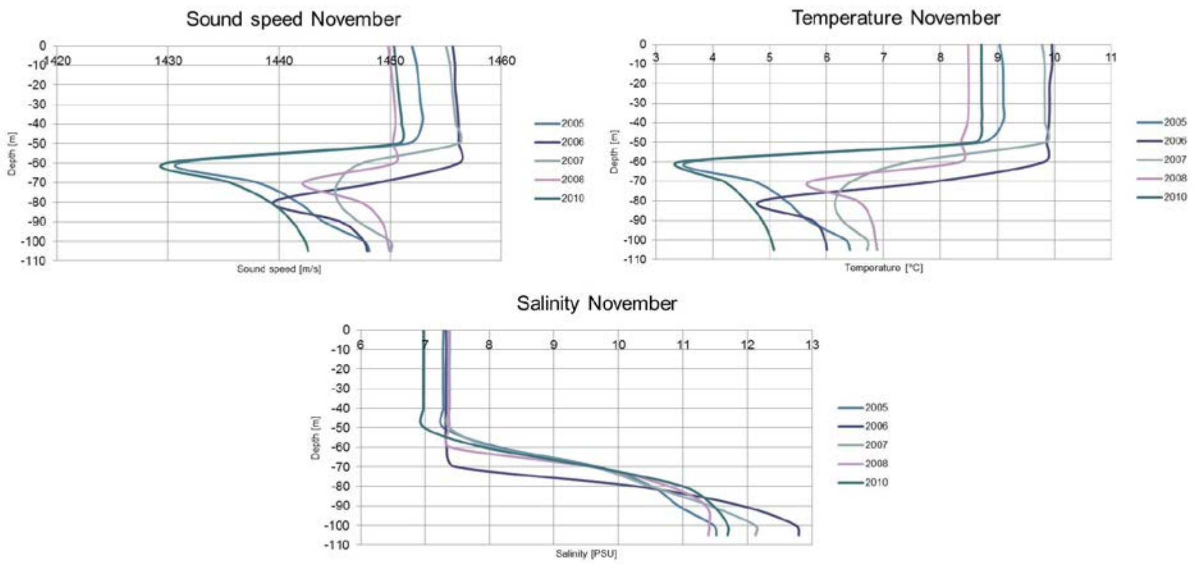

Fig. 10 Conditions (temperature, sound speed, salinity) in November

A recently observed phenomenon in the present decade is the impact of fresh water from the river Vistula. During calm weather, fresh river water, which is less dense than the salt water of the Baltic sea, goes deep into the Gulf of Gdansk. A consequence of this is that there are short-term changes to temperature and salinity of the surface layer - to a depth of about 20 meters – Fig. 11. On 4th of April 2009 surface water temperature was 4.2 °C. On June 29 temperature had increased by more than 8 °C. Salinity on 4 April was equal to 7.47 PSU and on April 29 was only 5.88 PSU. Freshwater from the Vistula river lowered salinity, and significantly raised the temperature of the water. In the deeper layers of the distributions, values are similar to each other.

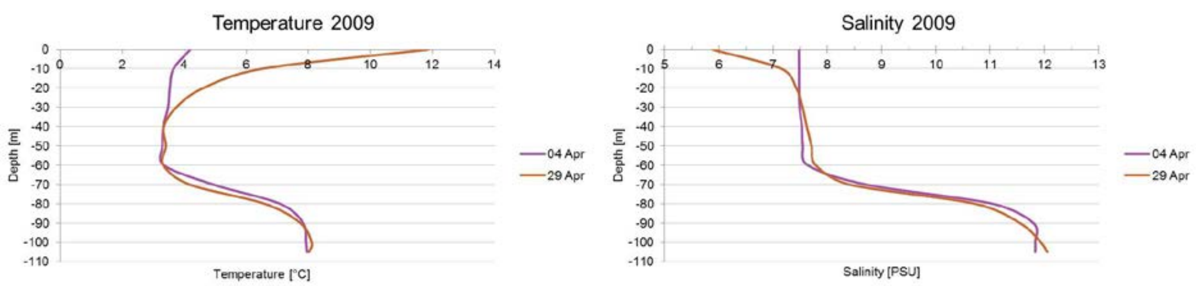

Fig. 11 Conditions (temperature, sound speed, salinity) in April 2009

4. Conclusion

The acoustic climate of the Gulf of Gdansk is constantly changing due to long- and short-lived phenomena. The acoustic conditions in the upper layer depend on the meteorological conditions. The water temperature depends mainly on the air temperature. Salinity and temperature values of the surface water are affected by the infusion of fresh water from the Vistula river that occurs during windless weather. Another phenomenon of the changing conditions of the upper layers are vortexes. Temperature, salinity, and speed of sound in the intermediate layer, and the bottom, are dependent on the infusions of salt water from the ocean. The volume and frequency of inflows are irregular. The direct impact of inflows in the area of Gdańsk Deep, on the speed of sound, is slight. It changes the salinity, but inflows occur once every few years. In order to know the actual conditions of the propagation of acoustic waves, there is a need for continuous monitoring of the marine environment, and analysis of the results. Temperature of water is the factor that has the strongest impact on the sound speed. Therefore, the distribution of the temperature in the Southern Baltic is similar to the sound speed distribution.

Acknowledgements

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