THE INFLOW OF HIGHLY SALINE WATER AS A FACTOR MODIFYING THE ACOUSTICAL CONDITIONS IN THE BALTIC SEA

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Abstract

The aim of the paper is to characterise the acoustic conditions in the Baltic Sea, especially directing the attention on their specific features in the deep water layer and showing the impact of inflow of highly saline water on them. This winter we observed one of the largest inflows for the last fifty years. Modifications in acoustical conditions caused by it are presented basing on a large number of in situ measurements

Introduction

The effectiveness and range of ultrasound devices used in underwater investigation is greatly dependable on spatial distribution of acoustical parameters. Therefore, this problem is usually taken into careful consideration.

The sound speed, the nonlinear parameter B/A and the attenuation coefficient are the main factors, which determine conditions of linear and non-linear elastic wave propagation in seawater. All of them change with changes in temperature and salinity, but the first and the second depend strongly on temperature whereas the third one – attenuation coefficient – on salinity

The acoustical conditions in the Baltic differ significantly from the one typical for other shallow waters. Generally in the Baltic Sea, two main layers can be distinguished: the upper layer and the deep-water layer. The acoustical conditions in the upper one are influenced by the flow of solar energy onto the sea surface. Acoustical parameters of the layer change seasonally similarly as in typical shallow water.

Whereas the acoustical conditions in the deep - water layer differ since they depend on inflows of highly saline water from the North Sea through the Danish Straits. The inflow involves the dense bottom currents. The general trend in their changes during the year is known, but the casualistic factor modulating them plays significant role in forming the hydrologic-meteorological situation and thus affecting the acoustical conditions.

Environmental conditions in the Baltic Sea

Underwater acoustical conditions generally reflected the hydrological conditions, but in the sea of such a small depth as the Baltic Sea, the climate influenced the hydrographical state of nearly the whole volume of the sea. That is why, environmental conditions must be so carefully investigated while acoustical conditions are considered.

The Baltic Sea is located within the west-wind zone where cyclones usually coming from the West or Southwest dominate, the environmental conditions and their variability are strongly linked to the meteorological-, hydrological-, and hydrographic processes and their interaction. All these processes influence the temperature and ice conditions, inflow of fresh water from rivers, exchange of water between various Baltic Sea sub-basins and with the Skagerrak-Kattegat system and the transport and mixing of water inside the Baltic Sea. The sea is nearly non-tidal and it is characterised by a significant fresh water surplus due to voluminous river runoffs. The renewal time of the water is estimated to be in general about 30 years, but it is spatially very variable. Due to these factors, there is a continuous two-layer salinity stratification, which affects the basic physics and biology of the sea.

The hydrological conditions are presently characterised by continuation of the stagnation period in the deep water and by ephemeral inflows of highly saline water from the Kattegat into the Baltic Basins.

The strongest inflows between 1880 and 1994 were observed in 1933 and in 1951. The last effective major inflows into the Baltic Main Basins occurred in 1976/77 and 1993/94. The last effective inflows occurred in January 2003. This event is estimated to be about 120-180 km^3 in volume, and calculations indicate that it might have been strong one. However, these so called "major" inflows are in general very small compared to the total volume of the Baltic Sea (in range of 0.1-0.5 % of the total volume), but their effects may be very significant for the changes in physical parameters in the deep-water layer.

The measurement results of temperature and salinity content at the sea bottom in February 2003, confirmed that there had been a relatively high inflow in January 2003 into the Bornholm Deep. The salinity of 19.2 PSU is the fourth highest figure recorded in the eastern part of the deep over the past 57 years.

Moreover, observations in March 2003 indicate that inflow waters are continuing to spread to the eastern parts of the southern Baltic.

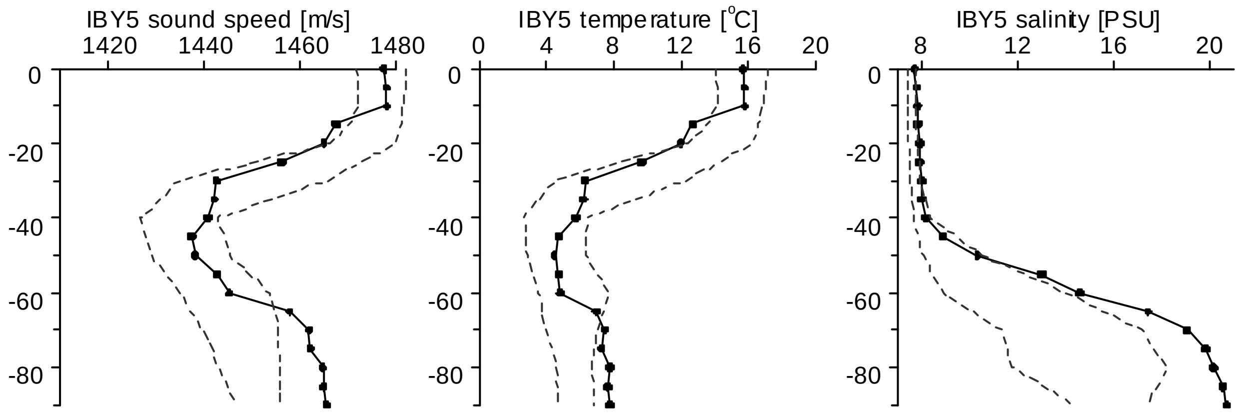

Figure 1: Vertical distribution of speed of sound, temperature and salinity in June 1952 on the background of curves imaging adequate standard deviations determined for period 1902-2002 One of the strongest major inflows in 1951 changed physical parameters in the Bornholm Deep for a long time. Salinity of 20.77-20.70 PSU and temperature of about 7.7-7.8°C remained in the deep water layer in this region at least from January till November 1952.

However, the new inflow in January 2003 must be regarded as a "cold" one – water temperature in the near-bottom layer in the Bornholm Deep was 3.4ºC lower than the long-term mean. The same mass of water after several transformations, when it reached the Gdansk Deep was still the "cold" one. In June, 30th the temperature at the bottom equalled 4.44ºC and was 1.25ºC lower than the value averaged over about 50 years. Salinity of 13.23 was higher about 1 PSU in comparison with the expected value.

Acoustic aspect of inflows

At certain anemobaric circumstances occur events known as inflows of highly saline water from the North Sea to the Baltic Sea through the Danish Straits. Because of rather small depth at the Darss Sill of about 20 meters, water, which flows over to the Baltic, is the surface water in the North Sea. Higher density of it in comparison with density of Baltic water causes the new water mass creation. The North Sea water, which propagates over the sill, falls down in the Baltic and moves into the deeper basins in form of the dense bottom current. However the current undergoes consecutive transformations on its way to the Eastern part of the Baltic, it maintains the characteristic features. It allows to distinguish the new water mass from primary "old" water, which was in the given basin before the inflow.

In the most cases, inflows carry water of higher salinity and higher temperature in comparison to the primary water. Those are called "warm" inflows. Rarely inflow consists of water with temperature lower than the temperature of the old deep water layer in the Baltic. In such a case event is called as "cold" inflow. The temperature of the surface water in the North Sea while the inflow occurs is the reason for the difference. Because typical time for inflows creation is autumn, temperature of the surface water is high and it is kept in the dense bottom current. When water from the North Sea falls over to the Baltic in winter, when temperature of the surface water is low, the "cold" inflow is observed.

Temperature of the inflow water is very important because acoustical parameters of seawater such as speed of sound and nonlinear parameter B/A increase with temperature and salinity increasing. In "warm" inflows influence of both of those parameters enlarge the effect of growing up values of acoustical parameters. Whereas in "cold" inflow water decreasing of temperature compensate the impact of increasing of higher salinity on values of acoustical parameters.

As it was mentioned inflow is a typical phenomenon but time of its appearance is rather not predictable. After few years of stagnation in 2002 and 2003 a large volume of water from the North Sea flowed twice into the Baltic. Characteristics shown in Fig. 2 allow to assess the impact of inflows basing on data collected in the Gdansk Deep region.

The situation in June 2002 could be used as the one to refer in the analysis. In the considered deep water layer the characteristics were typical for the region. Temperature of 6.66°C and salinity of 11.45 PSU results in speed of sound of 1449.6 m/s. Stronger winds in early autumn caused the inflow of water with high temperature. However its volume was rather poor, its impact was visible in the Gdansk Deep at the end of October. Close to the bottom the temperature increased of 1.98 °C and equalled 8.64 °C, whereas salinity grew up by 0.32 and equalled 11.77 PSU. It resulted in speed of sound of about 1458 m/s, higher by 14 m/s than the long-time mean.

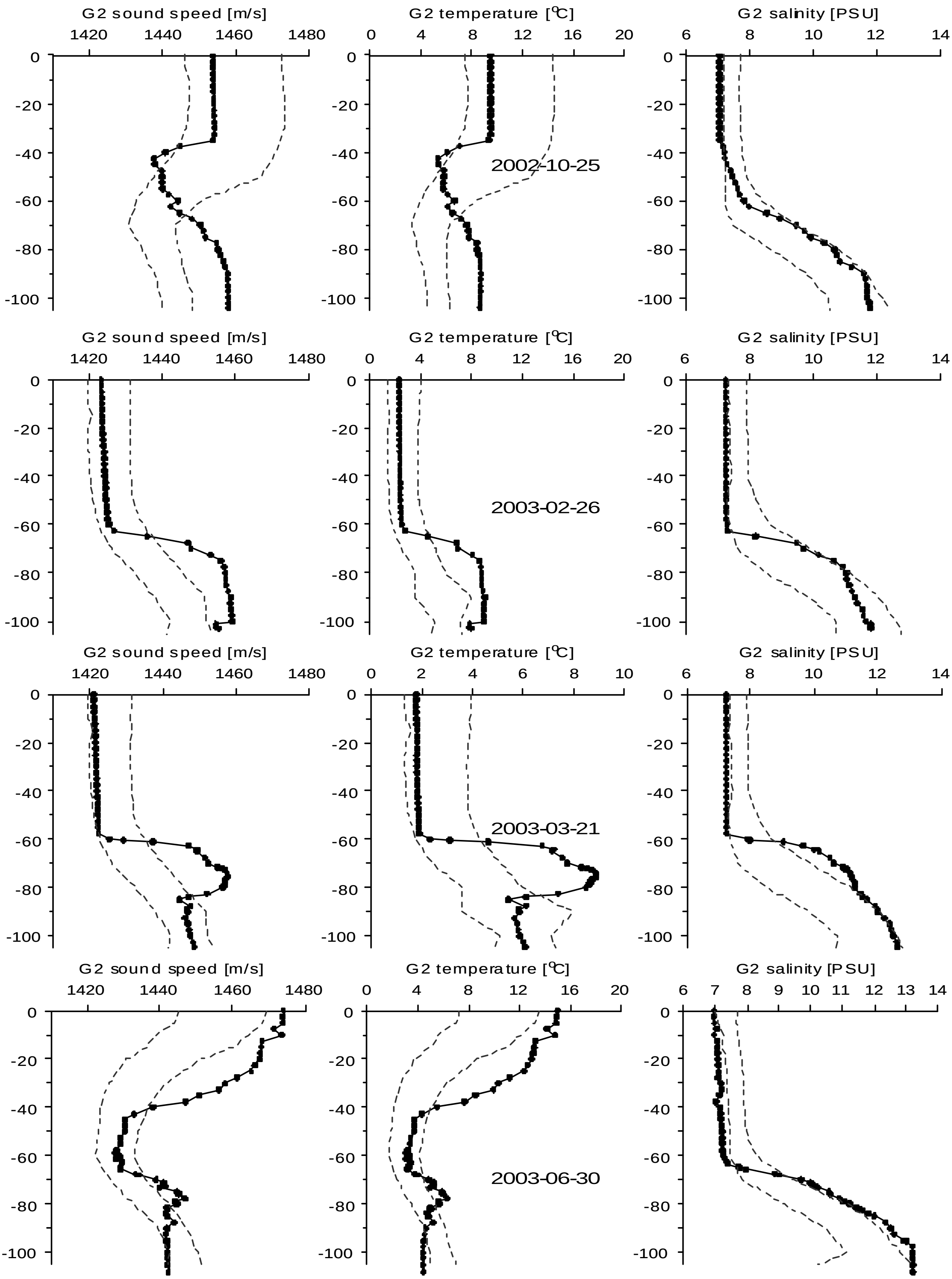

Figure 2: Vertical distribution of sound speed, temperature and salinity at the Gdansk Deep region

The inflow of highly saline cold water recorded at the Darss Sill between January 16th and 25th, 2003 was noticed in the Gdansk Deep in February.

In March, salinity at the bottom was of 12.60 PSU. Because it has been a cold inflow, temperature at the bottom decreased to 6.07 PSU. The layer of old deep water moved up to the depths from 60 to 80 m and have the maximum temperature. It created unusual sound speed vertical distribution with strong border between the uniform upper layer, local maximum with sound speed value higher than in the upper layer of about 40 m/s, and nearly uniform layer at depths from 85 m towards the bottom.

In June the impact of "cold" inflow was more impressive. The salinity grew up to 13.23 PSU, while the expected value was 11.71 PSU. The temperature in near-bottom layer decreased to 4.44 PSU, while the long-time mean equals to 5.96 ^{o}C. In the vertical distribution of speed of sound, the characteristic acoustic channel is well shaped. Its depth of about 50 meters is lower than typical. Impact of previous "warm" inflow is quite unnoticeable. In the deep water layer fine structure is observed with generally stable sound speed value at depths below 80 meters, instead the steeply increasing curve towards bottom.

Such anomalies are the subject of interest for exploitation underwater devices. A range of the devices depends strongly of speed of sound distribution. It could be assessed by means of the transmission loss plot analysis.

The transmission plot graphically illustrates the loss of intensity the sound suffers as it travels within the area spanned by the range and depth axis. Transmission losses are considered to be the sum of the loss due to spreading and the loss due to attenuation. Spreading loss is a geometrical effect representing the weakening of a sound signal as it spreads outwards from the source. The specific conditions of shallow water are taken into account. Attenuation loss includes the effects of absorption and scattering.

Changes in acoustic field are given as a relative level of intensity of sound compared to the intensity at the point placed in the acoustic axis distant 1 meter from the source. To determine the transmission loss at an arbitrary position in the plot the color coding is used. The value of the intensity loss (dB) is calculated using the following formula:

$$TL = 10 \log \left(\frac{p_{nm}^2}{p_0^2} \right)$$

where p_{nm}^2 is the square of the acoustic pressure at considered point, and p_0^2 is the square of the reference pressure.

The impact of inflows on acoustical conditions could be illustrated by examples shown in Fig. 3. Diagrams are given of transmission loss determined for the same source placed at the depth of 55 meters, corresponding to the depth of the minimum in vertical sound speed distribution. In June 2003, acoustic channel is well shaped at depths of 40-70 meters, whereas in June 2002 conditions for transmission acoustic energy for a long distance is worse because of spreading in nearly whole volume of water at depths below 30 meters.

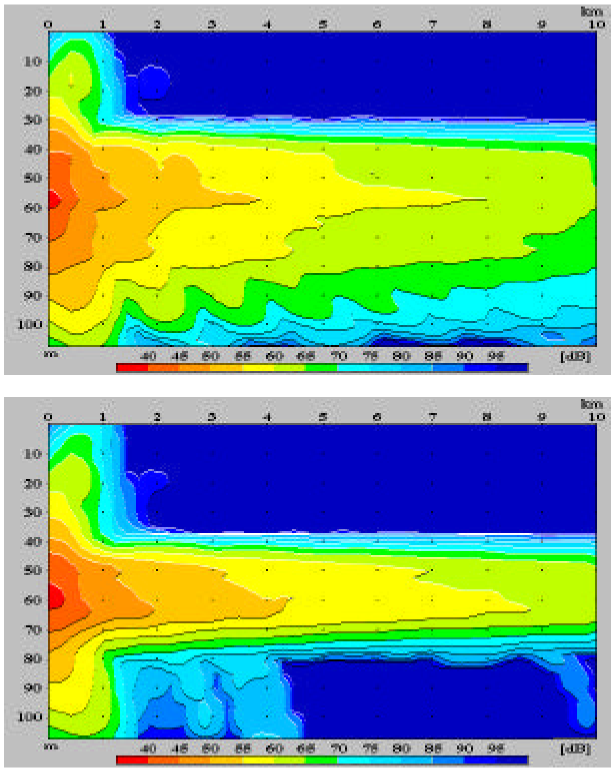

Figure 3: Transmission loss diagrams at the Gdansk Deep region obtained for June 2002 (upper) and June 2003 (lower); depth of source 55 meters

Conclusions

Acoustical conditions in the Baltic are strongly influenced by changes in hydrological and meteorological conditions. The inflows of highly saline water could create instantaneous sound speed spatial distribution completely different from typical for the region in considered season.

References

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[2] ICES Report: Environmental conditions in the Baltic, 2002/2003, 42-55, 2003.