

## Effectiveness of underwater devices in the Baltic Sea

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The effectiveness and range of ultrasound devices used in underwater investigation and exploration is greatly dependable on spatial distribution of acoustical parameters. Therefore, this problem is usually taken into careful consideration. The aim of the paper is to characterise the possible changes in the range of underwater devices used in conditions typical for the Southern Baltic. The main factor having an impact on the range of underwater devices, which could modify it significantly, is the variation in spatial distribution of the acoustical parameters, such as the sound speed, the nonlinear parameter B/A and the attenuation coefficient. All of the parameters change with changes in temperature and salinity, but the first and the second one depend strongly on temperature whereas the third one – attenuation coefficient – on salinity. The general trend in the changes of spatial distribution of the acoustical parameters during the year is known. The acoustical conditions in the upper layer are influenced by the flow of solar energy onto the sea surface and the acoustical parameters of the layer change seasonally. Whereas the acoustical conditions in the deep - water layer depends on inflows of highly saline water from the North Sea through the Danish Straits. However the casualistic factor modulating the acoustical conditions in the Baltic Sea plays the significant role in forming the actual situation and thus affecting the range of acoustical devices. Such anomalies are the subject of interest for exploitation of underwater devices, because they could change significantly a range of the devices. Variations in underwater acoustical range in the Southern Baltic caused by modifications in acoustical conditions are presented basing on a large number of in situ measurements. The analysis with applying data collected since 1950, allow to notice several untypical and unexpected acoustical conditions such as absence of underwater channel in summer 1990.

### 1 Introduction

Determination of direct sound propagation is the fundamental task in assessing the effectiveness and evaluating the range of acoustic devices used in underwater investigation. Among the factors that influence the propagation of elastic wave in the sea, the spatial distribution of the sound speed is the most important. Therefore, this problem is usually taken into careful consideration.

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

The Baltic Sea is located within the west-wind zone where dominate cyclones usually coming from the West or Southwest, and 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, 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 [4]. Due to these factors,

there is a continuous two-layer salinity stratification, which affects the basic physics and biology of the sea.

This fact is reflected also in the acoustical conditions of the Baltic which differ significantly from the ones typical for other shallow waters. Generally, phenomena forming the acoustical climate of the sea could be divided into two groups: phenomena causing long-term changes over whole area of the Southern Baltic and phenomena of the local importance. The acoustical conditions in the upper layer are influenced by the flow of solar energy onto the sea surface. Acoustical parameters of the layer change seasonally 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 evokes the dense bottom current that plays significant role in forming the hydrologic-meteorological situation affecting the acoustical conditions.

Characteristic for the Southern Baltic is appearance of short-term local phenomena changing considerably sound speed distribution in certain areas [2,4]. They cause difficulties in prognosing the acoustical conditions influencing the range of hydroacoustic devices. Inflow of river water, upwelling and vortices are the examples of such phenomena involving short-term local acoustical anomalies.

## 2 Acoustic climate of the Southern Baltic

The averaged distributions allow to assess the general trends and to find specific features for particular seasons. The acoustical conditions in the upper layer, where salinity is almost invariable, depend on the seasonal changes in temperature of water. In the winter temperature in the upper layer is nearly stable down to the depth of about 50 - 60 meters. Therefore the spatial distribution of the sound speed is nearly uniform at that season [1]. In other seasons temperature of water at the surface is higher than in the deeper layers. It involves the vertical gradient of the sound speed and the appearance of the minimum sound speed in its vertical distribution approximately at the border between the upper and the deep water layer. The value of the gradient is the highest in summer. During the year the gradient changes seasonally in accordance with the heat exchange between atmosphere and seawater. The thermal conditions in the winter exert an influence on the minimal value in the vertical sound speed distribution during successive seasons, while the maximal value of the speed at the surface depends on current conditions in each particular season [1]. The averaged sound speed distributions could be treated as an attempt to characterize the acoustic climate. They provide data for long-term prognosis of sound wave propagation in selected areas as well as in Southern Baltic Sea as a whole.

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## 3 Inflows and their acoustical aspect

The next step in the search for the specific features of the Baltic treated as a complex environment of sound propagation was to find out how the particular synoptic sound speed distribution differs from the averaged one and how does it influence the acoustical conditions.

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 a rather small depth at the Darss Sill of about 20 meters, the 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 creation of the new water mass. 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. In most cases, inflows carry

water of higher salinity and higher temperature in comparison to the primary water. Those are called "warm" inflows. Rarely an inflow consists of water with temperature lower than the temperature of the old deep water layer in the Baltic. In such a case the event is called a "cold" inflow. The temperature of the surface water in the North Sea while the inflow occurs is responsible for the occurring difference.

An inflow is a typical phenomenon but the time of its appearance is rather not predictable. After few years of stagnation a large volume of water from the North Sea flowed twice into the Baltic in 2002 and 2003 [3]. The inflow of highly saline cold water recorded at the Darss Sill in January 2003 followed the one of water with high temperature observed in autumn 2002. Characteristics shown in Fig. 1 allow to assess the impact of inflows basing on data collected in the Gdansk Deep region in 2003.

The area between dashed lines showing the confidence interval of the averaged distribution of presented parameters could be used as the one to refer to in the analysis.

The acoustical condition in the deep-water layer differed from the typical one for that layer. As a consequence of the "warm" inflow, in March appeared the local maximum in the vertical sound speed distribution, rather unexpected at such depth. 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 °C. In the vertical distribution of speed of sound, the characteristic acoustic channel was well shaped. Its depth of about 50 meters was lower than typical. Impact of previous "warm" inflow was quite unnoticeable.

## 4 Local phenomena modifying acoustical conditions

Short-term local phenomena are observed in the Southern Baltic area which change considerably sound speed distribution in surrounding [2]. The examples of such phenomena involving short-term local anomaly can be observed in the upwelling near Rozewie, in the Gulf of Gdańsk as a consequence of the runoff of the Vistula water and in the vortices appearing at certain circumstances over all area of the Southern Baltic.

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

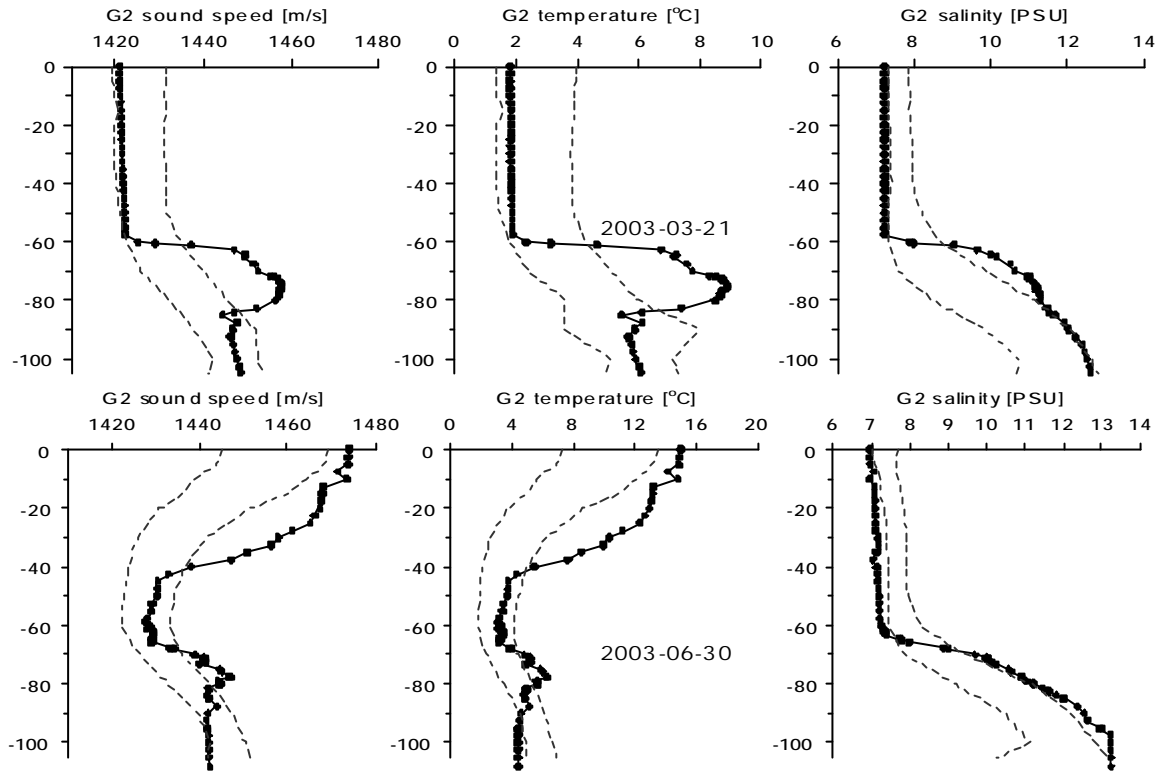


Figure 1. Vertical distribution of sound speed, temperature and salinity at the Gdansk Deep related to the confidence interval determined on the basis of data averaged for a period of over 50 years

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. The value of the intensity loss (dB) is calculated using the following formula:

$$TL = 10 \log \left( \frac{p_{nm}^2}{p_0^2} \right) \quad (1)$$

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 as well as of local phenomena on acoustical conditions could be illustrated by examples given in Fig. 2. Diagrams show the transmission losses of the acoustical energy radiated by

the source of the same parameters determined for acoustical condition in June 2002, June 2003 and June 2004 in the Gdansk Deep region. The source is placed at the depth of 55 meters, corresponding approximately to the depth of the minimum in vertical sound speed distribution.

Vertical sound speed distribution in June 2002 represents the typical one for that region in late spring, whereas the situation in 2003 reflects the impact of two consecutive inflows mentioned in Chapter 3. The 3<sup>rd</sup> situation is created by vortex observed in the Gdansk Deep region in June 2004 that had caused the decreasing of the maximum in vertical sound speed distribution by about 25 meters. 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. The impact of the vortex in 2004 results in significant decreasing of the depth of acoustical channel - of about 25 meters in comparison to conditions observed in 2002 and 2003. In this situation acoustical energy spreads over all deep-water layer.

## 5 Conclusions

Spreading of acoustic energy and simultaneously the range of underwater devices is strongly influenced by changes in hydrological conditions not only in the upper layer but also in the deep-water layer. The inflows of highly saline water could create instantaneous sound speed spatial distribution completely different from the typical one for the region in the considered season

The local phenomena could change considerably acoustical condition for a short period (several days). The differences between synoptic and average distributions demonstrate the strength of the impact that physical factors have on them and confirm the necessity of investigating acoustical conditions when hydroacoustic equipment is used in underwater research.

## References

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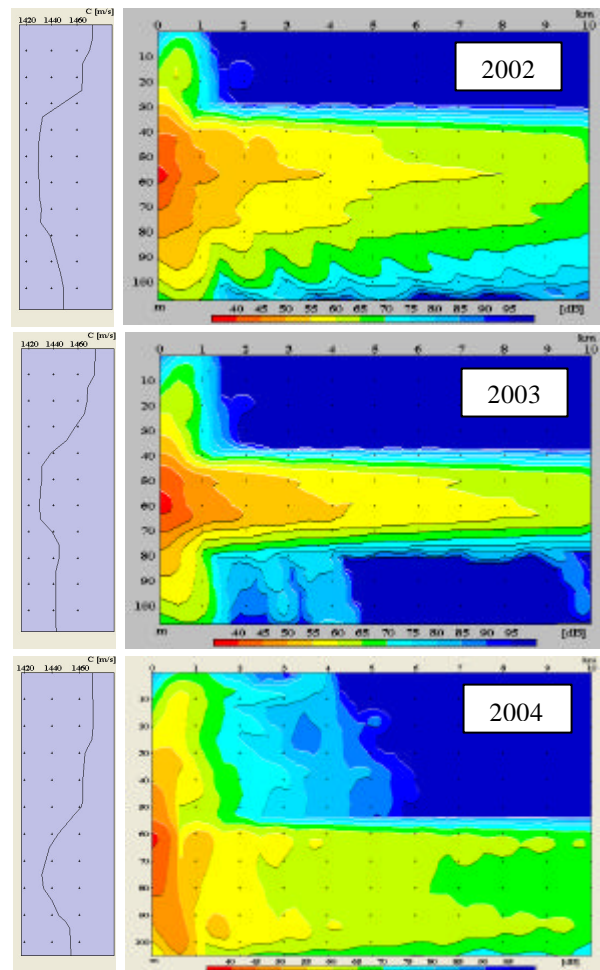


Figure 2. Vertical sound speed distribution and transmission loss plot in June 2002,2003 and 2004; depth of the sound source  $z=55$  m