Bulletin of the Maritime Institute

Gdańsk, 2001, 28, 2

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SOME CHARACTERISTICS OF FINE STRUCTURE AND MICROSTRUCTURE OF BALTIC SEA WATERS

Abstract

It is generally agreed that fine structure and microstructure are usually beyond the resolution of numerical models. Nevertheless, corresponding processes have a considerable influence on water dynamics and exchanges in the Baltic Sea. Measurements of fine structure were carried out with the scanning CTD probe. Microstructure measurements were performed by towing a system with fast-response velocity, conductivity, and temperature sensors. Bottom turbulence was investigated with the Acoustic Doppler Velocimeter. Domains of high mixing and stirring activity were revealed by means of high-resolution profiling on temperature and salinity transects. These domains were found near inhomogeneities of bottom relief such as the Słupsk Sill, the bottom elevation on eastern boundary of the Słupsk Furrow and in areas of ray concentration of quasi-inertial internal waves. Data on transects with manifestations of convection provide an evidence of the non-uniform distribution of turbulence in the upper layer. A bottom turbulence patch with duration of about 2 hours was registered over the slope of the Gotland Deep. The rate of turbulent energy dissipation is about $10^{-5} cm^2/s^3$*. In the area of Hamrarne and Słupsk Sill, horizontal scales of turbulent patches are between 0(10m) and 0(100 m). All obtained data testify the high level of turbulent intermittency, so probability of detecting turbulent patches is high.*

1. Introduction

Fine structure and microstructure are typically beyond the resolution of numerical models. Nevertheless, the corresponding processes exert considerable influence on the water dynamics and exchanges in the Baltic Sea. Turbulence is one of such processes with insufficiently known parameters. Fine structure features associated with internal waves may be a basis for dynamical instability and subsequent diapycnal exchanges. Diapycnal exchange may be enhanced also in areas of intrusions. The above brief outline is provided to argue for the necessarily of investigations of fine structure and microstructure in the Baltic Sea.

2. Measurement technique

Analyses of fine structure based on the measurements conducted by using the CTD probe Idronaut. Measurements were carried out with the towed scanning probe. Towing velocity was usually about 4-6 knots. The horizontal resolution of scanning depends upon thickness of the considered layer and varies from hundred to several hundred meters. The vertical resolution is in the range of tens of cm. The microstructure was investigated by using the towed system "Grif". Microstructure probe included fast response sensors of velocity, velocity shear, conductivity, temperature, and also accelerometers and depth sensors. Towing velocity was usually in the range of 3-4 knots. The electronics was adjusted to record fluctuations up to 100 Hz.

The near bottom turbulence was measured with Acoustic Doppler Velocity meter (ADV) HYDRA, produced by Sontek. This device can perform current measurements in a wide frequency band, from low frequencies ("mean" currents) up to fluctuations with frequencies of 5 –12.5 Hz (depending upon acquisition frequency).

3. Peculiarities of fine structure

Convection. High-resolution measurements performed in the scanning mode reveals a structure of convection in the upper layer. The structure is formed during cold periods, when the sea surface gives up heat into the atmosphere. Fig. 1 presents data obtained during 26-27 January 1997 along the section from the Gotland Deep to the Gdańsk Basin. Domains of cold waters with temperature below 5°C are formed as a result of convective cooling. Horizontal scales of these domains vary from hundreds of meters to tens of km (the largest recorded domain is about 34 km). An interesting observation is that the most extensive domains are situated near the surface and that they are associated with lower salinity waters. On the other hand, narrow convective cells are visible in the areas of homogeneous upper layer. Cold water sinks inside these cells down to the halocline boundary. It might be concluded that there are two types of cold-water inhomogeneities in the upper layer of the Baltic Sea. Narrow domains with horizontal scales of hundreds of meters are apparently associated with deep convection and extend throughout the whole upper layer. Mesoscale domains of order 10 km are confined to first tens meters of the upper layer. Their extension is restricted by the small salinity gradient. Apparently more fresh water areas are generated by mixing of the river runoff and seawaters.

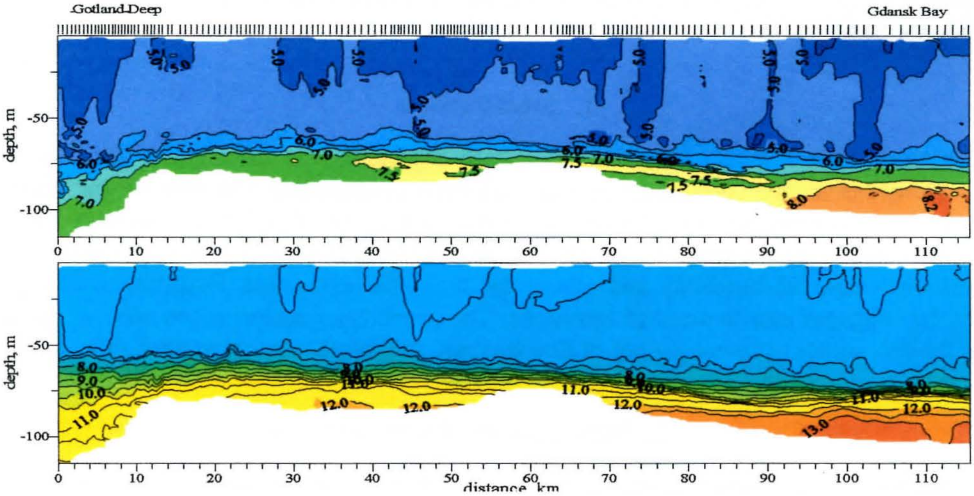

Fig.1. Temperature and salinity distributions on transect from the Gotland Basin to the Gulf of Gdańsk, performed on 26-27 January 1997

Intrusions. Intrusions of cold water in the intermediate layer above the halocline, most frequently occur among inhomogeneities of the Baltic Sea. Observations of such cold intrusions are presented in Fig. 2. The section extends from the Arkona Basin through the Bornholm Deep and the Słupsk Furrow up to the Gulf of Gdańsk. Measurements were performed during the period 9-12 September 1999. Cold waters with temperatures about 3.5-4°C form various structures. To the east of the Słupsk Furrow the structure of these waters is continuous. In the Słupsk Furrow, the cold-water layer breaks into fragments. The spatial scale of these fragments is about 15-20 km along the considered transect. Fragmentation of cold-water masses along their flow into the Słupsk Furrow is a typical phenomenon and it needs an adequate mathematical description.

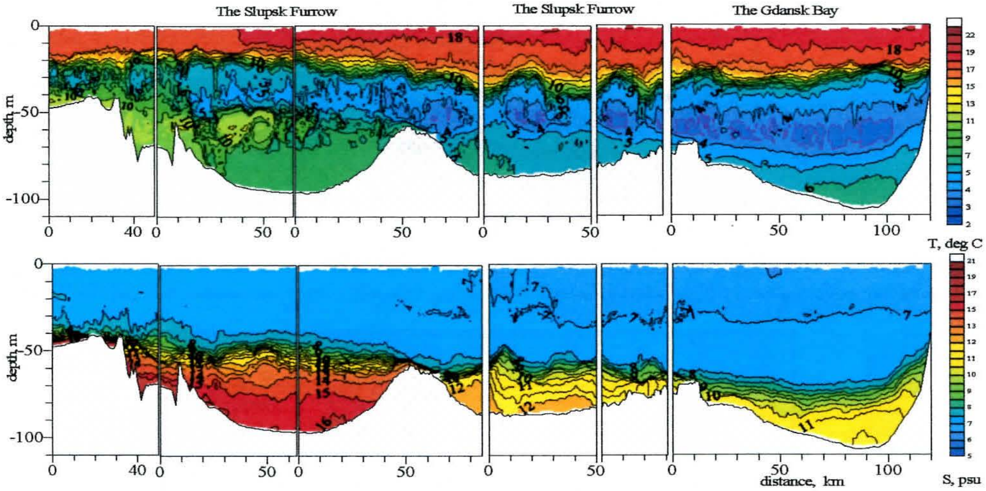

Fig.2. Temperature and salinity distributions on transect from Arkona through the Bornholm Basin, Słupsk Furrow, to the Gulf of Gdańsk

Warm intrusions were registered more than once in the halocline of the Gotland Deep and Gulf of Gdańsk. As a rule, they connect with fresh water inflows of small and moderate intensity. During the first phase, these waters spread from Arkona Basin through Hamrarne Strait into the Bornholm Basin. High-contrast warm intrusions with temperature of about 13°C were registered to the north and east of Bornholm in October 2001 (Fig. 3).

The dissipation of such warm intrusions is a subject of special interest. It might be connected to the occurrence of double diffusion processes in the Baltic Sea, in particular to the "diffusive" regimes [2]. The density ratio (the stability ratio) [2] is analysed on the profiles crossing warm cores. Unfortunately, metrological characteristics of the probe Idronaut are not quite sufficient to obtain reliable evaluation of the density ratio. A special procedure was employed for editing CTD data on vertical profiles to exclude density inversions and to smoothen temperature and salinity data in order to obtain their more realistic profiles.

Fig. 4 presents temperature, salinity profiles and density ratio evaluations, which correspond to the core data from Fig. 3. A step structure of salinity profile can be seen at depth intervals, where temperature increases with depth. The steps alone suggest a possibility of the "diffusive" regime. At increasing temperature intervals, typical values of R_ρ are about 0.1 - 0.4. The "diffusive" regime appears possible at the upper boundaries of some warm intrusions.

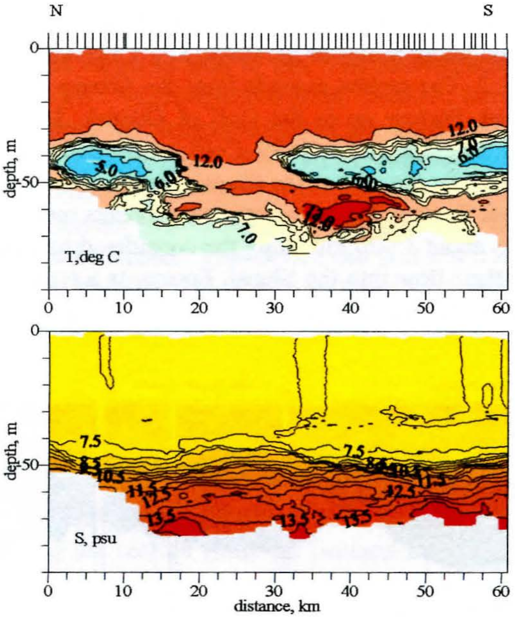

Fig.3. Temperature and salinity distributions on transect across north-west part of the Bornholm Basin in direction North-South (15 October 2001). Warm intrusion is clearly seen at depths of 60-70 m

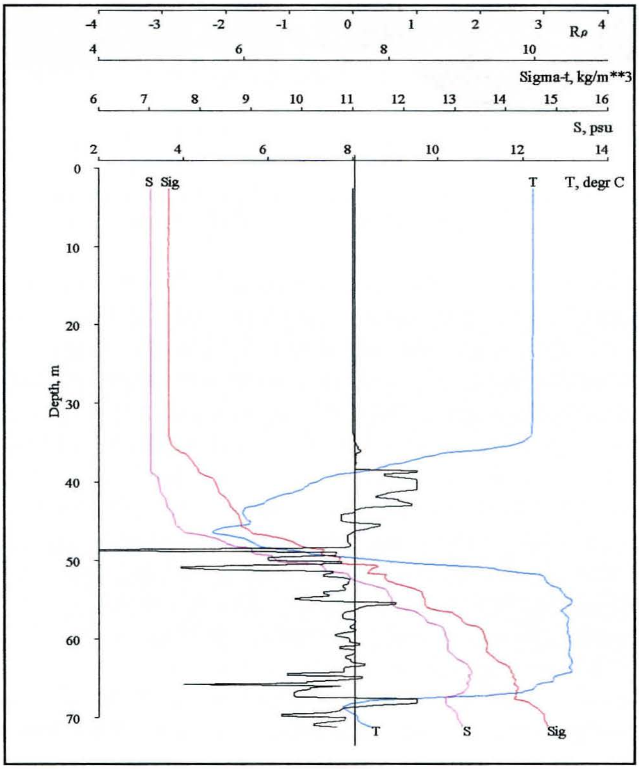

Fig.4. Temperature, salinity, density, density ratio profiles on the cast in area of warm intrusion in the north-western part of the Bornholm Basin

Internal waves. Data along transects in the area of the Słupsk Sill are of a special interest. Fig. 5 presents vertical distributions of temperature and salinity on three transects performed near the Słupsk Sill on 24 September, 14 October and 20 October 2001. Phases of waves observed in the transects on the western slope are different for each period of observation. On the contrary, measurements, carried out during shorter intervals, in 28-29 June 1998, show similarity of phase patterns (Fig. 6). At the short duration measurements, salty water overflows were registered. This fact means that the dynamics of this area is determined by the superposition of both long and short period internal waves. Note that great number of temperature inhomogeneities with scales of about 100 m was usually observed near the Słupsk Sill. Generally, salinity inhomogeneities were observed in the upper layer just above the sill crest and to the east from the crest along a distance of about 10 km (Fig. 6). These results suggest that the sill vicinity is frequently the area of dynamical instabilities, which are accompanied by stirring processes.

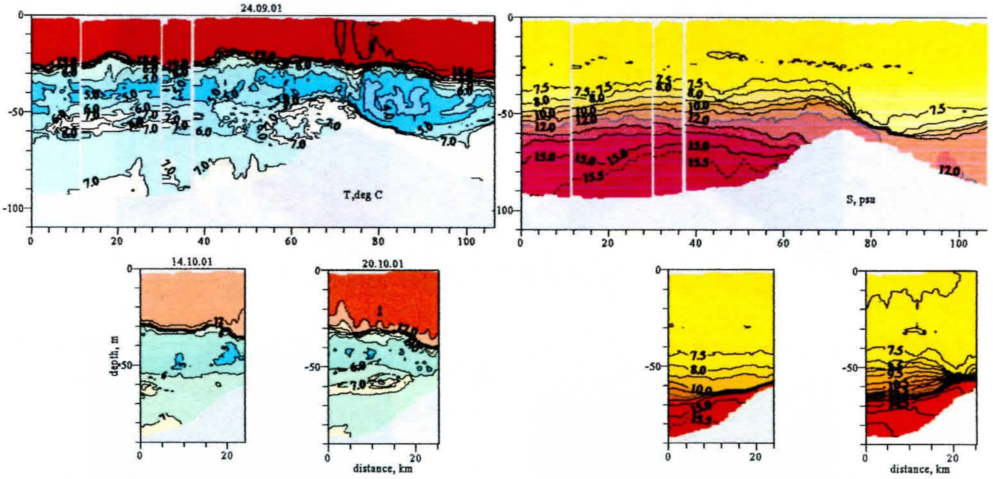

Fig.5. Thermohaline fields near the Słupsk Sill, measured on: 24.09.01, 14.10.01 and 20.10.01

4. Positive feedback between convection and internal waves

Specific deformations of salinity and density vertical distributions in the region of the Słupsk Sill and the Słupsk Furrow were observed. The deformation may be treated as rays of internal waves [2] (Fig. 7). The inclination of these rays enables to evaluate the wave frequency, which is close to the local inertial frequency and exceeds it by 2-4%. It also turns out, that different rays propagated from different points of the Bornholm Basin area concentrate in the area of the Słupsk Furrow and most often form two groups of rays. In cold seasons, when the upper layer is homogenous, rays are further focused in the eastern periphery of the Słupsk Furrow, in the region of higher bottom elevation. Owing to the closeness of ray trajectories for the incident and reflected waves, the probability of shear instability increases.

At that a vertical exchange as well as convection will be stimulated. The convection will homogenize and deepen the upper layer. Owing to it, ray trajectories will be more vertical and rays will be closer to each other. Thus a positive feedback may exist between convection and internal waves. The author believes that during some cold seasons, for example during winter 1999 – 2000, the extension of homogeneous layer down to the bottom of the eastern boundary of the Słupsk Furrow was caused by such a feedback.

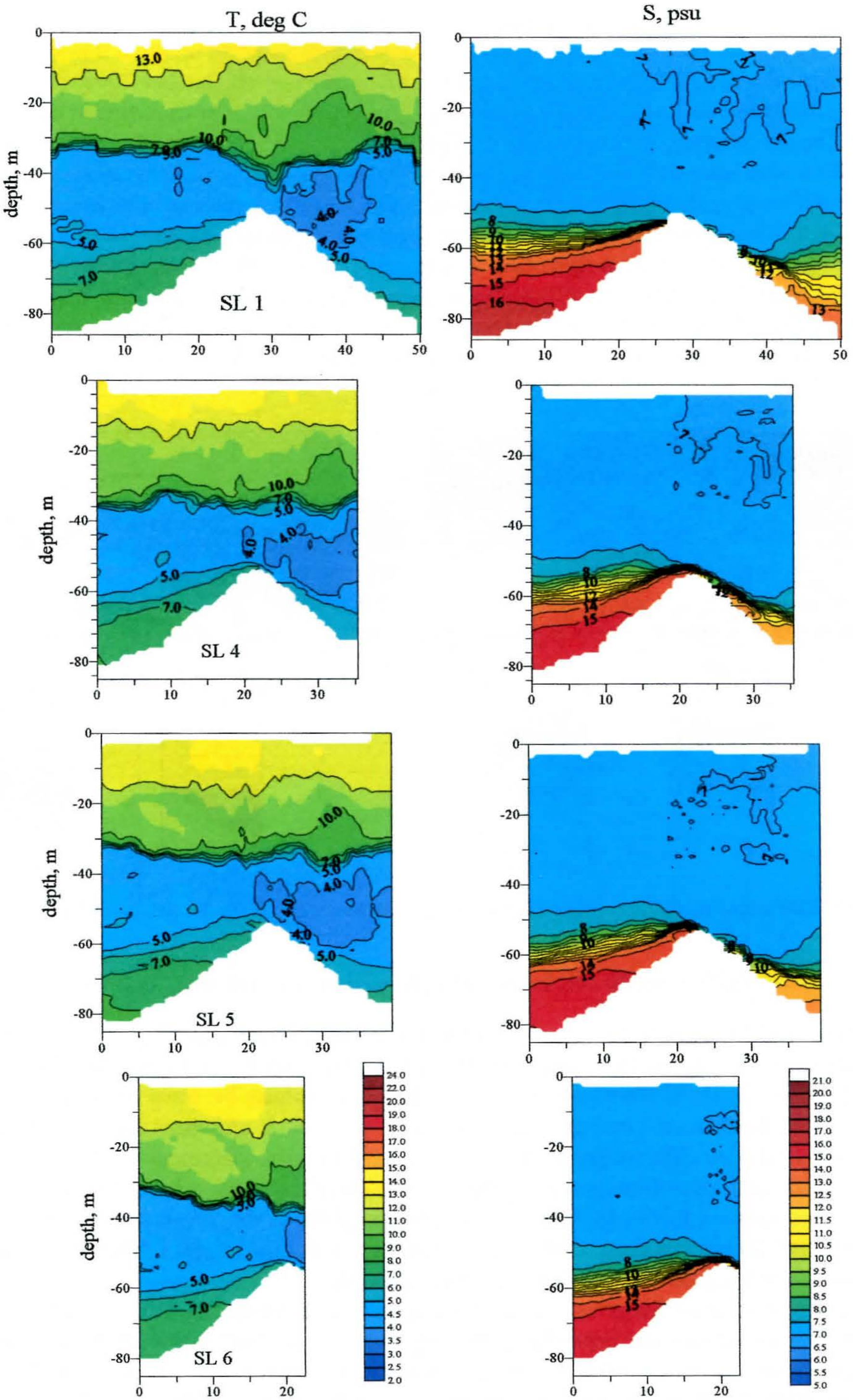

Fig.6. Temperature and salinity distributions on repeated transects in area of the Słupsk Sill, 9-12.09.1999

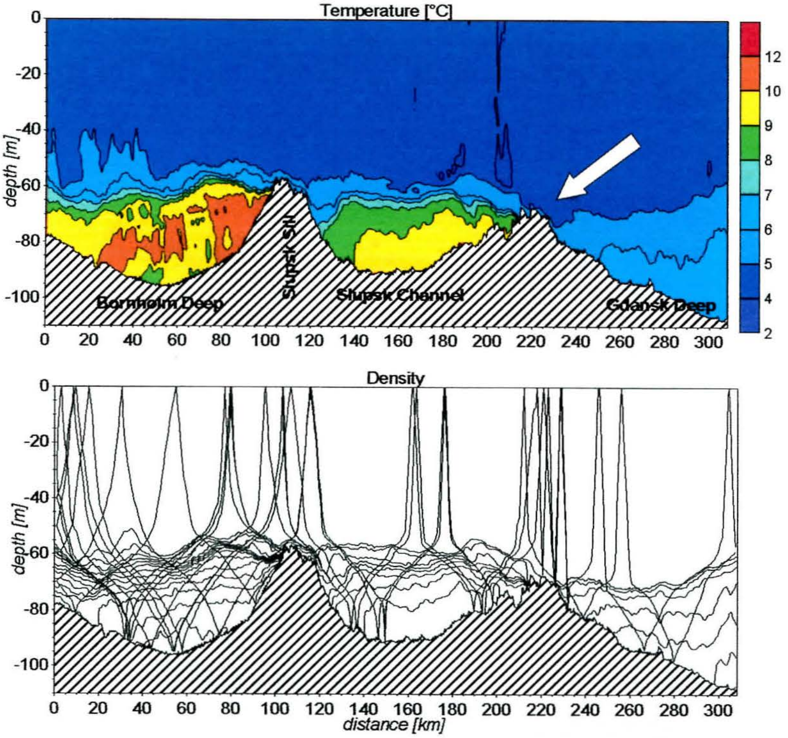

Fig. 7. Transects of temperature (upper figure) and density field (lower figure) for January 2000 (r/v "Oceania"). Rays of internal waves are superimposed. Arrow shows the place with deep convection until near bottom layer

5. Microstructure patches near the Słupsk Sill and in the Hamrarne Strait

Field measurements of conductivity microstructure and turbulent velocity fluctuations can clarify two important questions. First, one needs to know the character of turbulent intermittence – where and how frequently turbulence occurs. Second, it is significant to evaluate the intensity of turbulent fluctuations or dissipation rates.

Measurements performed with the microstructure probe "Grif" allow to solve the first objective. The second one, due to difficulties with suppressing the interference during towing, may be solved only after a comparison with the low noise data from another probe such as a free falling probe. At present, such a probe is under in situ tests. After completing of the probe testing the opportunity for a reliable evaluation of the dissipation rate will arise.

Fig. 8 presents data of intense conductivity microstructure patches obtained with towing "Grif". These data were obtained on 7 January 2000, over the western slope of the Słupsk Sill. Along with the microstructure measurements, the scanning CTD probe was towed, so simultaneous measurements of fine and microstructure were conducted. Microstructure data were superimposed over the vertical distributions of temperature and density gradient. It shows that more intense microstructure patches are located mainly in the layer of maximum density gradients. Where this layer splits up, locations of patches split up correspondingly to positions of maximum density gradients. It is also important to emphasize that inhomogeneities of the density gradient field are revealed in Fig. 8, and they are located there along internal wave rays.

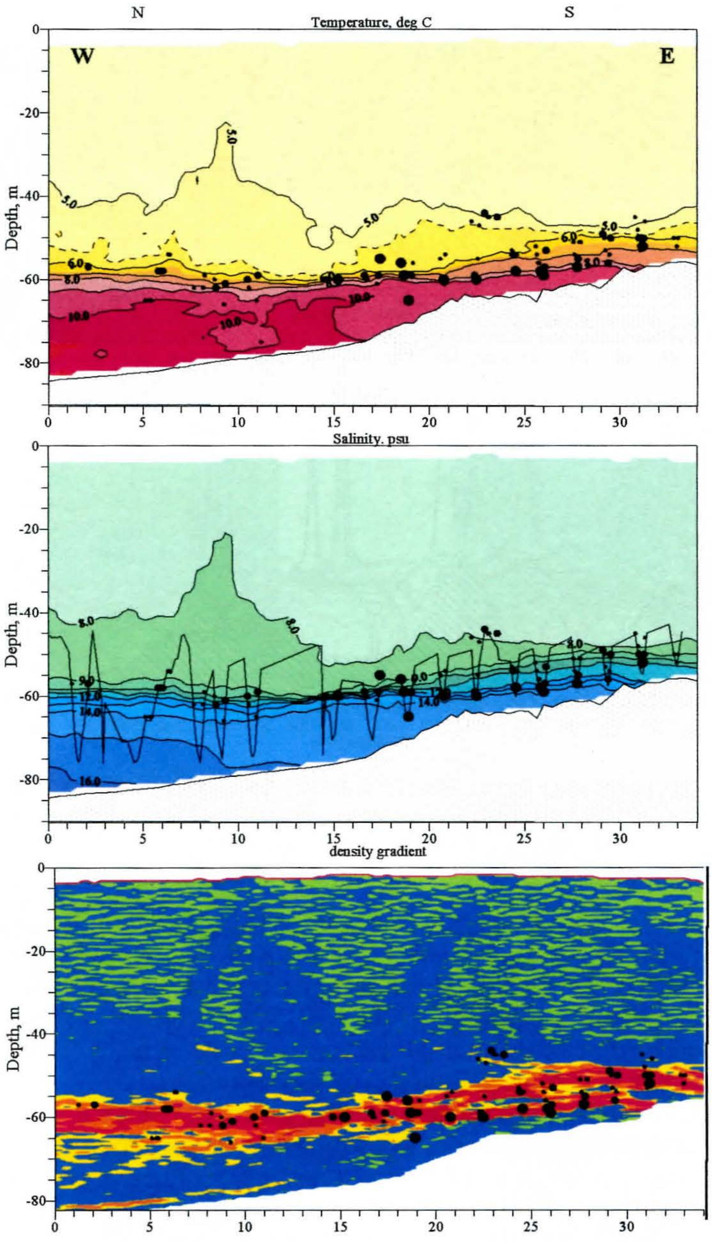

Fig.8. Data of temperature, salinity and density gradient at the transect along the western slope of the Słupsk Sill with trajectory of microstructure probe "Grif" (measurements on 07.01.00). Symbols ● placed in the points with intense conductivity microstructure

In September 2001, towing of the probe "Grif" was carried out from the Arkona to Bornholm Basin. The length of the track was about 44 km. Fig. 9 presents examples of turbulent velocity fluctuations, velocity shear and conductivity. Near the bottom, in the depth interval 54-55 m, the patches of intense fluctuations are visible. The duration interval of these patches is about 30 s, which corresponds to a length scale of about 60 m.

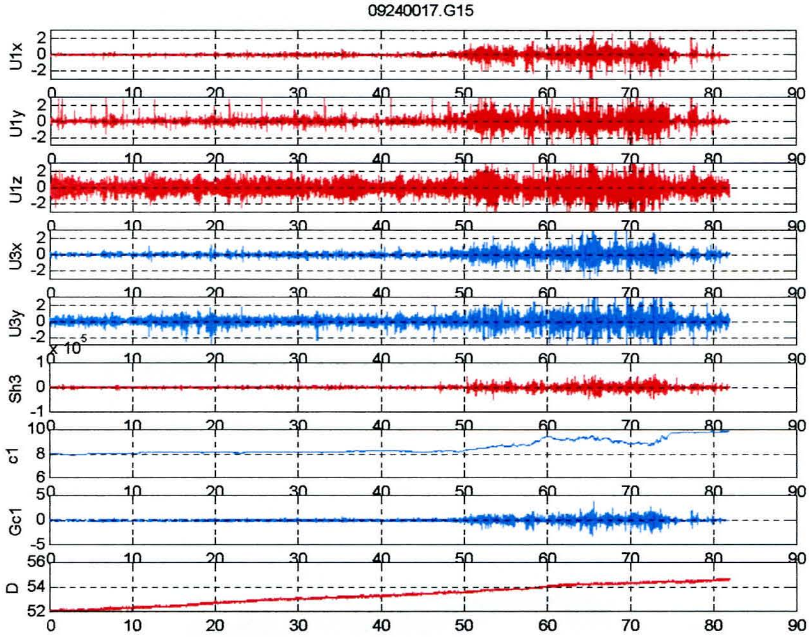

Fig. 9. An example of microstructure measurements of velocity fluctuations (U1x, U1y, U1z, U3x, U3y, cm/sec), velocity shear (Sh3, relative units), conductivity (c1, mSm/sm), conductivity fluctuations (Gc1, mSm/sm) and depth (D, m)

6. Near bottom turbulence, dissipation rate

Measurements of near-bottom turbulence were carried out with two devices: the Acoustic Doppler Velocity meter (ADV) HYDRA produced by Sontek, and a specially developed by the Atlantic Branch of Oceanology Institute in Kaliningrad device with electromagnetic (EM) sensor for velocity fluctuations measurements. These devices operated independently from each other on the special bottom-mounted platform. The sensors were placed at a distance of 1 m from the bottom. The system was installed in December 2000 over the slope of the southwestern part of the Gotland Deep.

Velocity data obtained by ADV are presented in Fig. 10a. A pronounced intensification of fluctuations occurs from time 4.4 hr. To compare signals from the two devices, data from ADV were filtered and low frequencies were cut off. Fig. 10b presents the filtered ADV data; Fig. 10c shows the raw EM sensor data. Data obtained by means of the EM sensor confirm the enhancing of velocity fluctuations.

Long period oscillations with scales of 1 to 10 minutes are superimposed on the higher frequency fluctuations. On the background, parts of the signal have noisy character. Spectra (Fig. 11) are exponential function from the frequency and at this sense they are in agreement with the theoretical conception.

The comparison of data obtained from the two devices installed on the same platform proves the reliability of the observed phenomenon, where a non-disturbed flow over bottom changes into a flow with intense velocity fluctuations and oscillations with time scales from

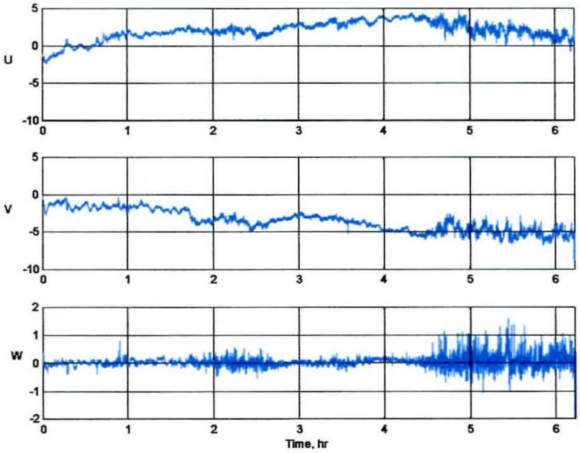

Fig.10 a. Horizontal (u, v) and vertical (w) velocity (ADV) data, obtained at the slope of the Gotland Deep on 10 December 2000

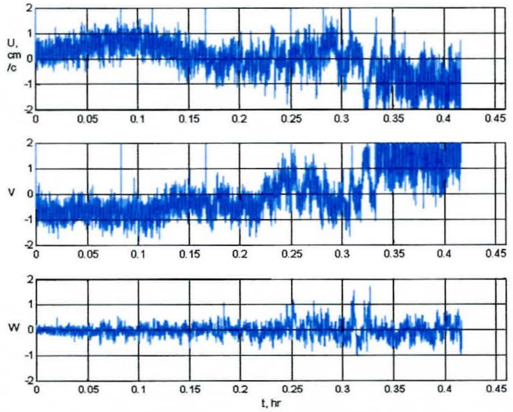

Fig.10 b. ADV velocity fluctuations during an interval of their high intensity

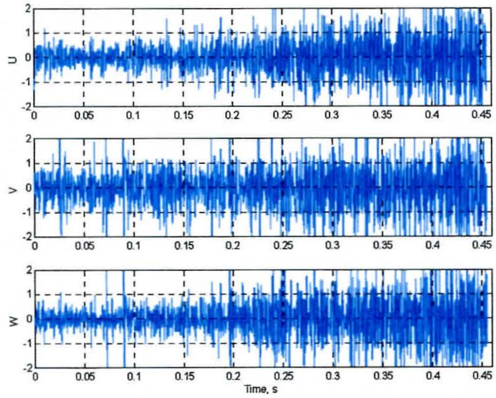

Fig.10 c. EM velocity fluctuations during an interval of their high intensity seconds to minutes. Long period oscillations of scale of minutes represent the horizontal velocity components. The higher frequency variability characterizes vertical velocity component. It is in agreement with the turbulence theory for stratified fluid: at some space-time scales fluctuations of horizontal velocity exceed vertical ones.

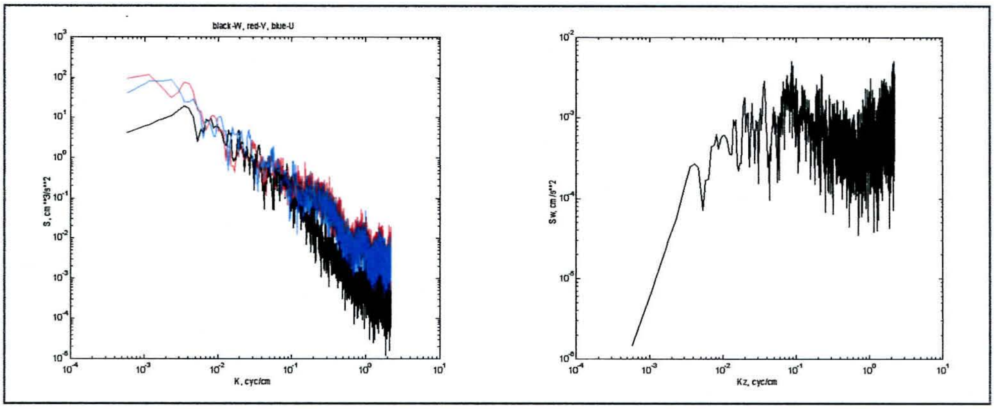

Fig. 11. Space spectra of velocity fluctuations and spectrum of energy dissipation for a disturbed interval. Evaluations based on ADV data

Since along with velocity fluctuations the mean velocity components (low frequency components) were measured, one may evaluate space spectra. If fluctuations are much less than mean velocities, such evaluation can be based on the Taylor hypothesis [3]. In reality measured fluctuations were about 1 cm/s, the mean velocity was about 6-7 cm/s. The dissipation rate of about $1.5*10^{-5}$ cm^2/sec^3 is obtained from space spectrum and spectrum of dissipation.

7. Conclusions

Analysis of the thermohaline field fine structure, velocity and conductivity microstructure testify to a high level of intermittence of small scale and mesoscale processes. Character of these structures is subject to a considerable seasonal variability. There are areas subjected to instabilities. It is not possible to reconstruct all such details in numerical models. Possibly a development of several numerical models for various seasons and regions is a way for taking into account details, which are inherent to some areas or definite seasons.

Acknowledgments. This study was supported by RFBR, Grant 01-05-64631.

References

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