Development of Microstructure Measurements for Conditions in the Baltic Sea

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***Abstract*- The principal physical research tasks addressing environmental problems of the Baltic Sea are the study of ventilation of the deep water and of vertical mixing. To achieve progress, direct measurements of fine- and microstructure of water are necessary. Instrumentation to do this has been developed successfully; nevertheless the water structure in the Baltic Sea is so tricky that existing techniques need special adaptation and improvement. This paper presents several types of profilers: cycling profilers both towed and moored, and freely sinking or floating probes. Some of them perform direct microstructure measurements while others are necessary to obtain a properly resolved background measurement of thermohaline and current structure. We consider freely-moving CTDs as an alternative for direct dissipation measuring meters if the probe's motion is stable enough and its spatial resolution is high enough. Having in mind the Baltic conditions, special attention is paid to fine measurements close to the sea surface and within the bottom boundary layer. We try to adjust such instruments for use from small inexpensive boats, so that fine- and microstructure measurements will be more accessible.**

I. Introduction

The Baltic ecosystem suffers from insufficient ventilation of waters below a permanent halocline, and this is apparently the main problem to be studied. The ventilation of deep water is driven by gale-forced salt water inflows whose effectiveness can be measured by the amount, density, and oxygenation of the inflowing waters, which are subject to climactic changes. The frequency of major inflows has decreased in recent decades, supposedly because these were hampered by a greater freshwater input and by changes of mean zonal wind speeds [1]. A recommendation was made to study climate variability in the Baltic Sea and to detect climate changes by making long-term observations with high temporal and vertical resolutions at strategic locations (e.g. mooring data in all sub-basins) [1]. An observation system to do this should include measurement of physical parameters like temperature, salinity, current velocity, dissipation, and marine ecosystem parameters.

This paper presents some instruments developed at the Shirshov Institute of Oceanology and its Atlantic Branch that are useful in the observational systems for providing and compiling the necessary data volume and quality.

II. General approach

The best strategy for permanent observations supporting research in the Baltic Sea is considered to be a sequence of short (1 week) repeated surveys aimed to perform:

1) high spatial resolution 2D transects crossing basins with adjacent marginal zones by means of an undulating towed (U-tow) CTD combined with a towed ADCP; obtaining data to provide a background measurement of water structure and immediate current velocity field over the full depth interval with gaps of about 5m near the surface and near the bottom that are necessary for the instrument's safety and due to technical limitations;

2) detailed long-term observations in selected locations by means of moored profilers, which carry multi-parameter probes and current meters providing gross- and finestructure measurements of the water and estimates of the dynamical stability of the water column;

3) in close proximity to the moored profilers, performing high vertical resolution fine- and microstructure measurements by means of free falling profilers.

Program elements (1) and (3) should be repeated to describe the temporal variability of water structure and motion.

It is important to perform such program in all weather conditions. One more important requirement is to use the simplest boats for operations, including mooring installation and recovery. Ability to work with small boats makes field measurements more accessible and productive.

III. DESCRIPTION OF INSTRUMENTS

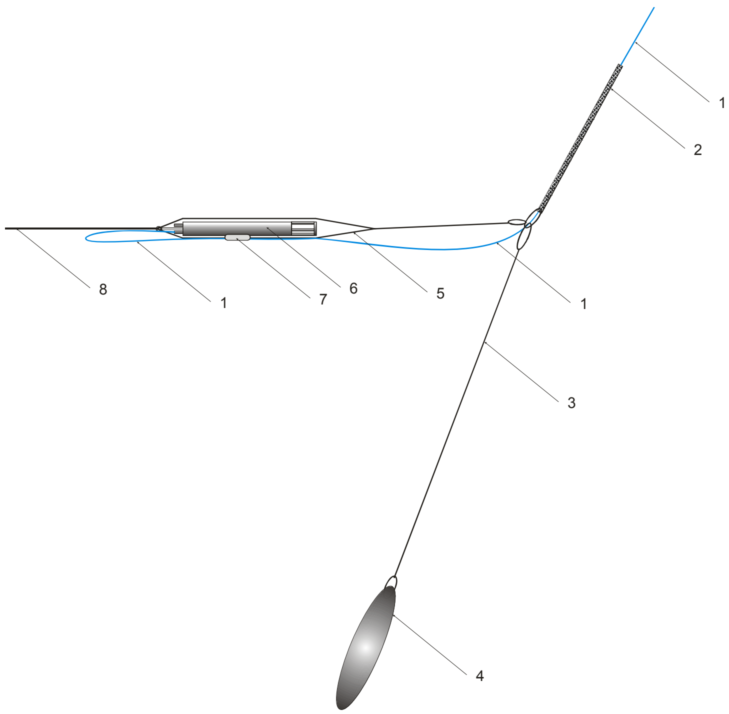


Fig. 1 Composition of a towed undulating multi-parameter profiler. 1 – towing cable, 2 - braided wire cable grip, 3 – rope, 4 – load, 5 – bridle, 6 – probe in plastic housing, 7 – connector, 8 – drag.

A. U-tow CTD profiler

Undulating towed profilers, as we have concluded after several decades of their use, are the best tool for basin- and sub-basin scale measurements of water structure. Our last achievement in the improvement of U-tow systems is their simplification. We can use any standard probe produced by Idronaut, SeaBird, FSI, YSI, and other companies. We protect sensors and connectors by placing the probe into a thin-wall plastic housing. For proper orientation in the stream, the towing point is placed on the nose; arrangement of a tail part plays a minor role (Fig.1). Wide inlets and outlets in the frontal part of the housing provide proper flushing of the sensors. To prevent collisions with jelly-fish, seaweed, plastic bags etc., a protecting grid in front of the sensors is used (not shown).

We use a winch-operated system with a light load attached to the end of the armored cable a little bit below the probe as shown in Fig.1. Operating with heavy bodies is very inconvenient and dangerous for the probe due to high tension leading to strong vibrations, which can destroy the junction of the probe to the cable. The best winch-operated system should unwind the cable at the same speed or faster than the vessel moves.

B. Under-way ADCP profiler

In addition to measurements of spatial distribution of scalar fields we have developed similar measurements for the current velocity field with the remotely measuring acoustical Doppler current profiler, RDI's ADCP. It is known that spatial resolution of the ADCP depends on the frequency of its acoustical signal. The higher the frequency, the better is the resolution, but the shorter the range. For the shallow Baltic Sea, transmitting frequencies of 300 kHz or 600 kHz are commonly used; their ranges being 100 m and 50 m respectively. Thus, in all areas with depths up to 100 m and shallower, currents could be measured from the surface. If a basin is much deeper, then deepening of the ADCP is necessary. For this purpose we have built a carrier towed on a long armored cable in proper stable orientation at depths up to 200m (Fig.2). A special modem was designed for transmitting signals via a long single-core cable. The long heavy cable can be used only on large vessels. But the Southern Baltic almost everywhere is no more than 110m in depth, so we may work mostly with surface towed ADCPs, which are deployable even on small boats.

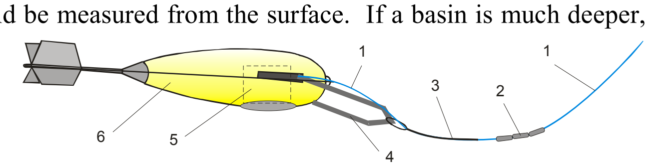


Fig. 2 Composition of a towed ADCP. 1 – towing cable, 2 – lead loads, 3 – braided wire cable grip, 4 – bridle, 5 – ADCP, 6 – carrier.

C. Moored vertical finestructure profiler

A moored profiler *Aqualog* is similar to the well known *McLane* moored profiler (www.mclanelabs.com). *Aqualog* moves down and up along a wire that stretches from subsurface flotation to an anchor on the sea floor. The profiler is a multi-sensor observational platform able to carry diverse oceanographic instruments. There are several models of *Aqualog* differing by line sizes and embedded measuring devices. Fig. 3 presents a platform which carries *Idronaut 316* multi-parameter probe, and this very platform was used in the Baltic Sea. Its properties are listed below:

- profiling speed: 0.1-0.3 m/s,
- profiling depth range: 5-600 m,
- total profiling distance: 800 km,
- maximum horizontal current velocity: 1 m/s,
- duration of observations: up to one year, depending on the frequency of runs per day; continuous profiling is possible.

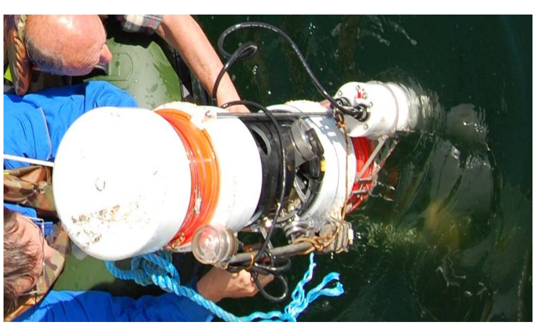


Fig. 3 Aqualog with attached Idronaut 316 CTD

Very slow and steady motion is the most attractive property of a moored system for performing repeated finestructure measurements.

Aqualog is the best carrier for studying changes of water finestructure under the influence of strong winds. It can be moored before a gale and recovered after the gale.

D. Free falling finestructure profiler

A commonly used technique of vertical profiling is based upon a winch operated probe. A well known disadvantage of this technique is nonuniformity of the lowering speed due to rolling of the ship, which creates problem for investigations of the finestructure. For the Baltic Sea, losing the finestructure information is very painful, so it is very reasonable to refuse to use winches, especially when the bottom boundary layer (BBL) is the subject of special interest.

A free falling vertical finestructure profiler must comply with the next requirements:

1) motion of a probe must not be affected by ship rolling and by fast drift of the vessel, however, we don't stipulate the ability to measure the turbulence, because the corresponding requirement includes suppressing of vibrations. This problem is discussed in our separate presentation [2]. For probes measuring the finestructure of scalar fields, small vibrations and angular oscillations, which fully destroy the work of turbulent velocity probes, are not essential;

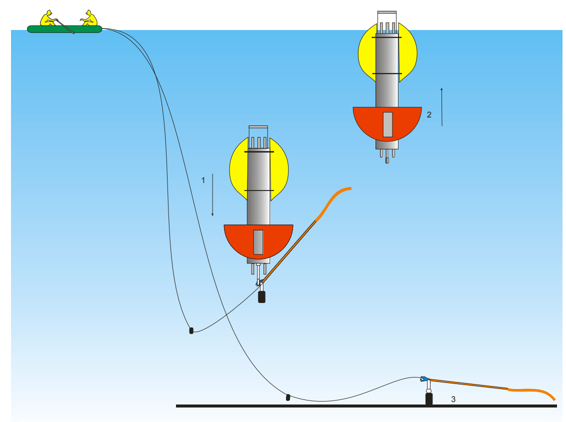


Fig.5 Sketch of a floating CTD profiler. 1 –sinking with ballast, 2 – floating up after releasing.

2) a probe must be easily recovered on board and ready for immediate repeating of the cast.

3) a probe must reach the bottom maintaining constant speed, maximum distance to the bottom when the probe brakes (stops) should be no more than 0.5 m,

4) sensors must be protected against damage when the probe meets the bottom.

To meet these requirements, we propose to use standard probes with high precision and fast sampling rates, light weight, and small dimensions, for instance, produced by Idronaut, SeaBird, FSI, YSI and other manufacturers. All our experiments were made with the Idronaut 316 multi-parameter probe. To meet requirements (1) and (2), a tethered quasi free-falling probe is recommended, a cord or a thin flexible cable should be freely supplied following the falling probe. However item (3) requires some additional measures. When the drift is fast enough, the cord after a while becomes taut, because the probe moves and the vessel drifts faster than the cord sinks. Increase of the tension decelerates the probe and deflects it from vertical. To prevent such behavior, the next strategy is presented: to divide the cord into two portions, the first one has a length corresponding to the maximum depth of profiling, while the length of the other portion should exceed the maximum distance of the vessel drift until the probe reaches its maximum depth; these portions should be wound on reels, one of them (drift compensating) should be placed on the vessel, the second one should be placed either on a light surface buoy or on the probe. To moderate the falling velocity, we use a parachute composed of 4 thin flat plastic plates, which keeps proper configuration by means of 4-limiting threads. The main details of the free falling system with the probe mounted reel are shown in Fig.4. The probe motion is practically free in both cases, although mounting the reel on the probe is preferable for automatic braking of rotation for preventing extra payout of the cord when the probe reaches the bottom (not shown).

E. Free floating finestructure profiler

A free falling vertical profiler is an expendable tool when a bottom is reached, however it is useless in a surface boundary layer study. For these purposes, a free floating profiler is recommended. Quality data are obtained only if the probe floats up to an undisturbed sea surface, which presumes that the work should be done at some distance and in a proper direction from a large vessel by means of a small boat. Recommended construction is very simple: the measuring instrument (Idronaut 316 probe or similar) is equipped with a float and some sort of drag (an inverted parachute, or flat disc, or hair brushes etc.). To lower the probe to the proper depth from which the profiling should begin, about 1 kg of ballast is used, which is then released. The probe could be either expandable or tethered. Details are shown in Fig.5. The load is

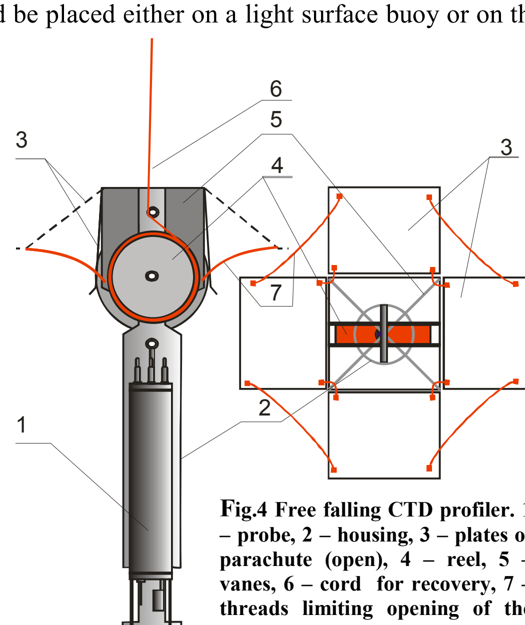


Fig.4 Free falling CTD profiler. 1 – probe, 2 – housing, 3 – plates of parachute (open), 4 – reel, 5 – vanes, 6 – cord for recovery, 7 – threads limiting opening of the parachute

suspended under the probe by means of a beam, having a hook from one side and a vane on another; the load is placed close to the hook, so the small vane may keep the load hooked when the probe sinks. When the motion stops either due to reaching the bottom or by stretching of the cord attached to the load, the beam rotates and drops, and the released probe floats up. Depending on the depth of profiling and time limitation, the profiler could be free or tethered (not shown) with the purpose of the tether only to reduce the time necessary for recovery.

IV. Results of measurements

In this section we intend to demonstrate how to improve the efficiency of surveying using only three customary instruments – two CTDs and an ADCP – and some variety of carriers of our own design. We followed this sequence of measurements: 1) an *Aqualog* mooring was installed in the middle of Gdańsk Deep from a ship of opportunity, 2) two weeks after this installation we performed a survey using a U-tow CTD combined with our towed ADCP crossing all the Southern Baltic basins first to the west (axial transect), then to the east (transversal transects), 3) during this survey *Aqualog* was relocated to the middle of the eastern slope of the Słupsk Sill, 4) we performed an environmental subprogram consisting of sediment and water sampling combined with a physical subprogram focused on a special study of the surface and bottom layers by means of free moving CTDs.

Fig.6 presents thermohaline and current velocity structure in the Southern Baltic. S T, S, and σ_t distributions correspond to absence of even moderate salt water inflow. Clear manifestation of this rare situation is the absence of thermohaline intrusions below the halocline in the Bornholm Basin. The dynamics of salt water below the halocline here is extremely low. Nevertheless, a Słupsk Sill overflow should exist; it is fed by a small elevation of the halocline/pycnocline above the sill. The sill also works like an obstacle for large scale horizontal motion. This creates a distortion of the velocity field near the sill, which is visible in the ADCP data. So, it is reasonable to look for some evidence of turbulence in the vicinity of the Słupsk Sill. Similar distortions are visible in other sites of the Southern Baltic: in the Bornholm Strait, in the middle of the Słupsk Channel, and even in the middle parts of the Bornholm and Gdańsk deeps, where the bottom relief is smoothed.

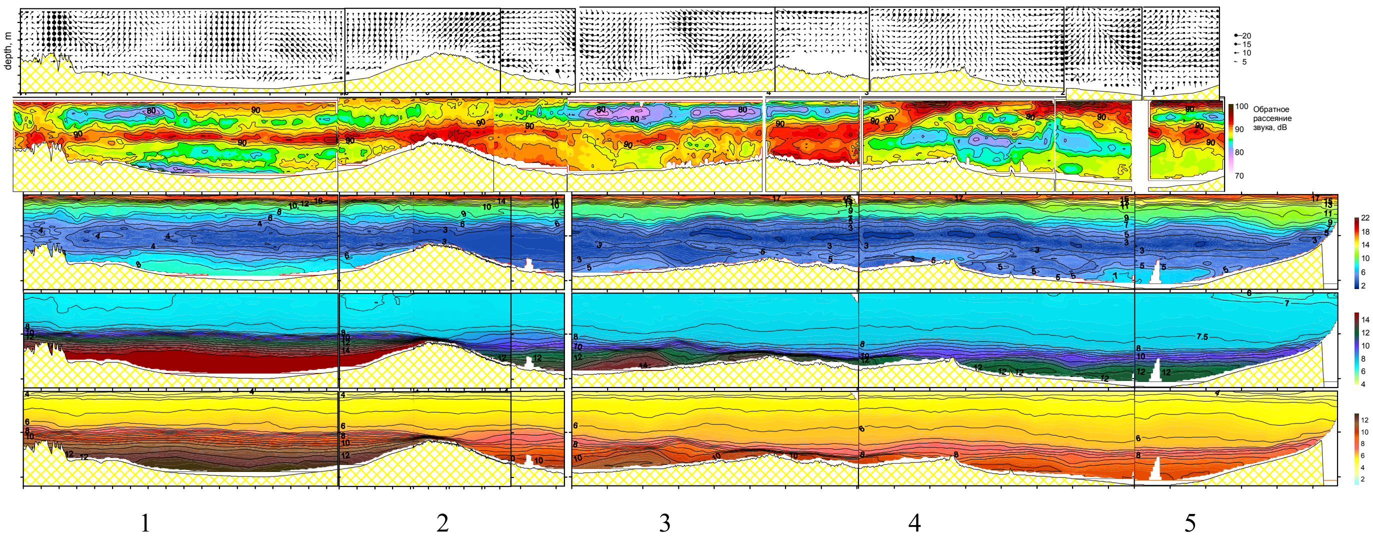
The ADCP provides useful data on intensity of the backscattered (BS) signal, which is proportional to concentration of some sort of suspended particles. We don't know exactly the nature of these particles, but consider they could be particles resuspended from the seabed and/or swimming plankton (or other scatterers). The first possibility follows from specific distribution of the BS power in the vicinity of sills and slopes, and the halocline level (Fig.6, Bornholm Gate, Słupsk Sill, eastern part of the Słupsk Channel); here plumes of turbidity are formed directed probably by the dominating flows; note that near the Bornholm Gate no plume is observed directed toward the east and sinking down. That is evidence of the absence of strong saltwater inflow. The second follows from the formation of two arc-like features (red color) at the eastern part of the transect; this could be explained by diurnal migration of the plankton.

A towed CTD is not good for studying small scale mixing because its motion is not uniform enough. To check our expectations, we have to examine records of *Aqualog* and free falling/floating CTDs, which move more steadily.

Fig.7 and 8 present T and σ_t contours and finestructure variations in time in the Gdańsk Deep during the 18-day long *Aqualog* CTD record. Its deployment position is shown in Fig.6. Casts began below a summer thermocline and stopped about 10 m above the bottom. The remarkable feature of this record is its domination by inertial internal waves, which cause ~14-hour undulations of isolines within the whole water column. Much longer undulation also exists, that is apparently an internal seiche. On a smaller scale, intrapycnocline intrusions regularly occur; many of them have temperature inversions while salinity/density profiles are monotonic. The conclusion is that these intrusions are inactive (slow). However a few salinity/density profiles demonstrate micro inversions, which could be formed by rare local overturns. We believe that such inversions are not artifacts usual when the probe moves fast and calculated salinity profiles in layers with sharp temperature gradients form well known spikes. *Aqualog* moves very slowly and steadily, so the spiking shouldn't occur.

In Fig.9 and 10 there are similar *Aqualog* CTD data for the Słupsk Sill area, above the eastern slope; the position is shown in Fig.6. The duration of these measurements was 6 days; the depth profiling rate of the deployment was the same as in the Gdańsk Deep. It is seen that the hydrographic structure above the sill is different from that in the middle of the Gdańsk Deep. Internal waves are irregular and weak. Density micro inversions (probable local overturns) occur much more frequently. Such features are reasonable for this area, where oppositely directed fluxes of salt and brackish waters should meet, sharpening the shear. It is a pity that *Aqualog* didn't penetrate into the BBL where much stronger and possibly permanent turbulence generation could exist. We can check this supposition by means of free falling CTDs. Only one cast of a free (non tethered!) floating CTD was made close to the mooring before its recovery. We avoided deep repeated casts because plastic foam floats forcing the probe to return to the surface were not reliable enough at that water pressure. This lone cast (Fig.11) demonstrates salinity and density micro inversions in the BBL, which we believe are not artifacts (spikes); this appears from comparison of temperature and salinity/density finestructure fluctuations in the BBL and intermediate layers: The temperature has sharp changes in both depth intervals while the salinity/density – only in the BBL. A number of shallow repeated casts were made here to detect finestructure near the surface, where *Aqualog* didn't work. Due to surface heating, the floating probe, operated at a distance from the drifting ship, showed corresponding increases of temperature in a layer of 4-5 m thickness (Fig.12). However, this effect is not surprising.

It is worthy of note that sensors stay at an upper end of the floating body, so they didn't reach the bottom, and the blank interval was about 70 cm. A free falling CTD is better from this point of view. The falling probe was tested in the Gdańsk Deep and gave good results. The BBL here was well mixed (Fig.12). *Aqualog* also showed weak finestructure at 10-20 m altitude above the bottom (Fig.8). The most intensive finestructure was developed here at depths of intrusive motion (Fig.8). Apparently intrusions move isopycnally, the last follows from smoothness of salinity/density profiles, except spikes at the upper thermocline. That is an interesting property of the Gdańsk Basin, which is at first a buffer pool but not a transiting branch on the long way of salt inflow propagation, in contrast to the Słupsk Channel.



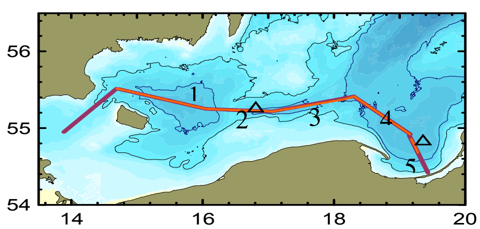


Fig.6 2D distribution of (top to bottom): current velocity (vectors), acoustical backscatter, temperature, salinity, and density. Arrows show main legs of transects: 1 – Bornholm Deep, 2 – Slupsk Sill, 3 – Slupsk Furrow, 4 – western flank of the Gdansk Deep, 5 – eastern flank of the Gdansk Deep. Triangles mark positions of *Aqualog* moorings.

V. CONCLUSIONS

To perform multipurpose research programs, it is impossible to limit the choice of instruments to only a single probe. Each instrument has its own limitations and disadvantages. For this reason we have to combine a variety of advanced instruments and to modify their practical use in compliance with unique Baltic conditions.

Towed undulating CTDs provide a very informative picture of the general state of large area of the sea. It is desirable to reach the bottom for each cast; however, that is dangerous for the probe and needs special experience from the personnel if the probe is not equipped with an acoustic altimeter.

Towed ADCP is also a very useful instrument for revealing the background current field; it can be easy combined with the U-tow CTD.

To study mixing processes, not only special microstructure profilers but much simpler tools could be used – free falling and/or floating CTDs, which are usually available to researchers. Moored autonomous vertical profilers have very limited distribution among researchers; however, our experience shows that this system also can be acceptable for numerous institutes in a simplified version. The described *Aqualog* is first of all a universal carrier, better to say – a smart carrier with a control and feeding functions for replaceable measuring probes. It can be made more easily then a fully equipped measuring system.

The proposed modifications of the research systems grounded upon well known components is not very complicated and leads by the shortest way to better understanding of physical processes having key importance for the Baltic Sea both in deep basins and shallow coastal areas.

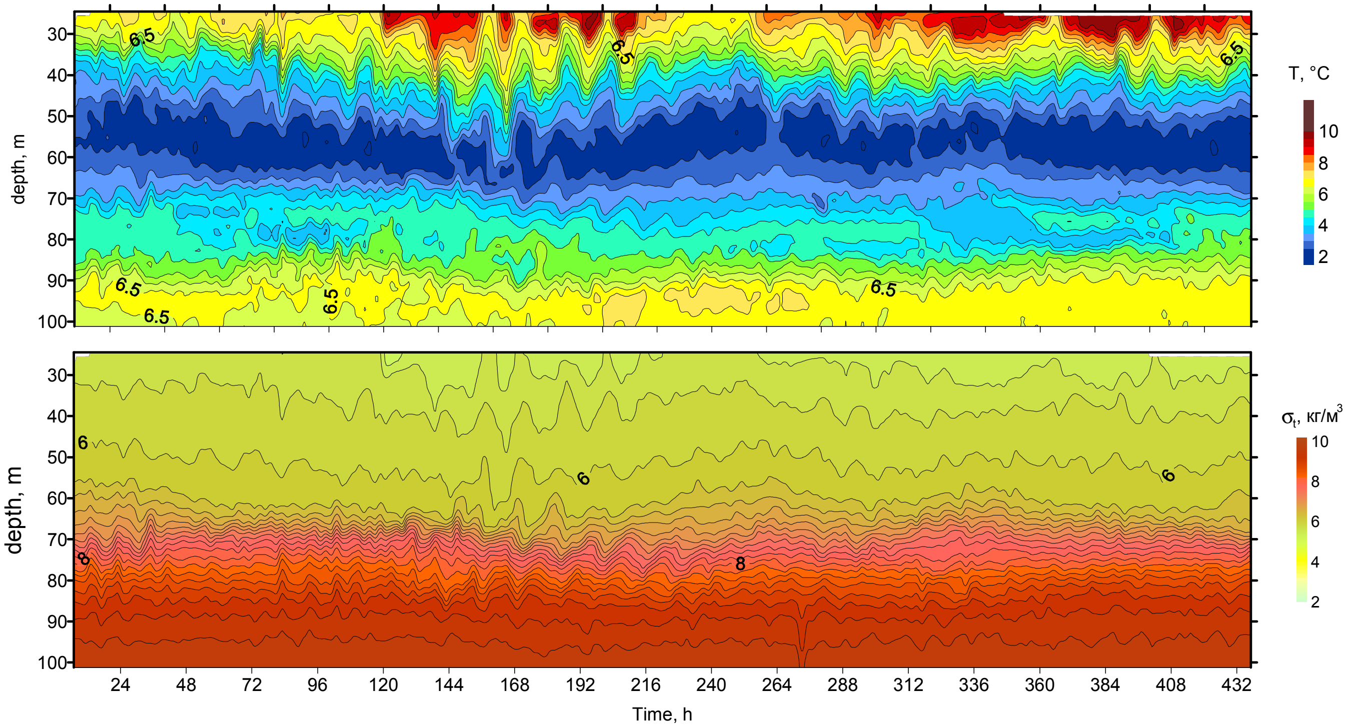


Fig.7 Temperature and density distributions vs. depth/time in the center of the Gdańsk Deep

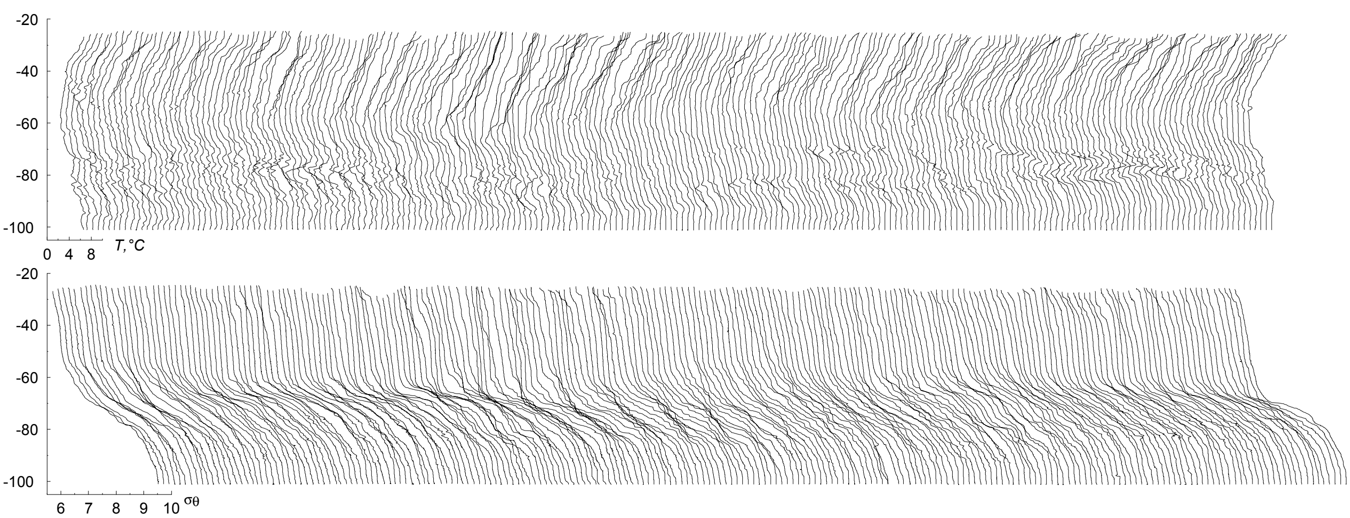


Fig.8 Time series of temperature and density finestructure profiles in the center of the Gdansk Deep, x-scale is similar to that in Fig.7

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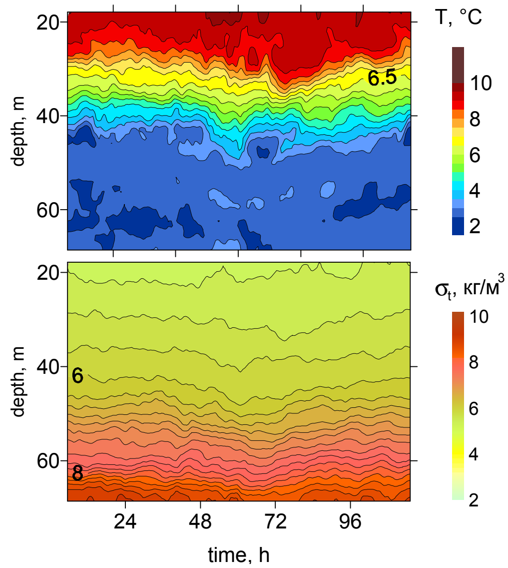

Fig. 9 Temperature and density distributions vs depth/time above eastern slope of the Slupsk Sill

REFERENCES

[1] M. Meier, R. Feistel, J. Piechura, L. Arneborg, H. Burchard, V. Fiekas, N. Golenko, N. Kuzmina, V. Mohrholz, C. Nohr, V. Paka, J. Sellschopp, A. Stips, and V. Zhurbas, *Ventilation of the Baltic Sea deep water: a brief review of present knowledge from observations and models*, Oceanologia, 48 (S), 2006, pp. 133–164.

[2] V. Paka and V. Zhurbas, *Measurements of turbulence in the Denmark Strait overflow*, in this volume.

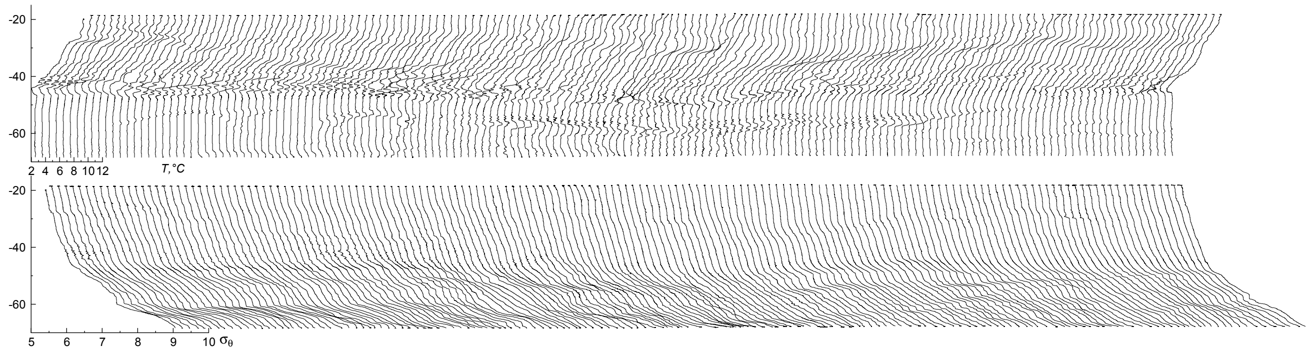

Fig. 10 Time series of temperature and density finestructure profiles above the eastern slope of the Slupsk Sill

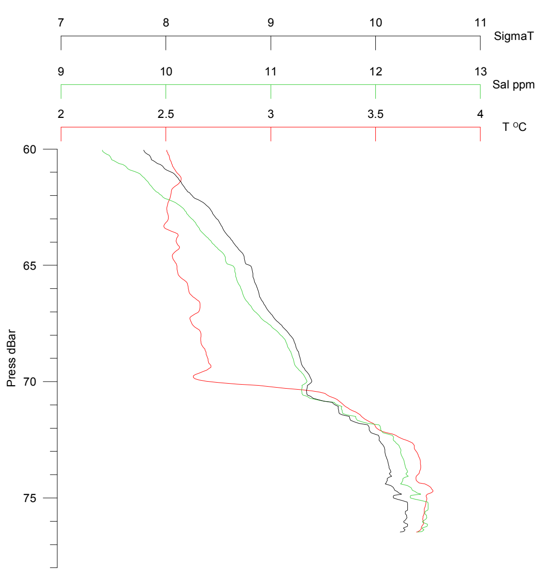

Fig. 11 Vertical finestructure measured by free floating CTD

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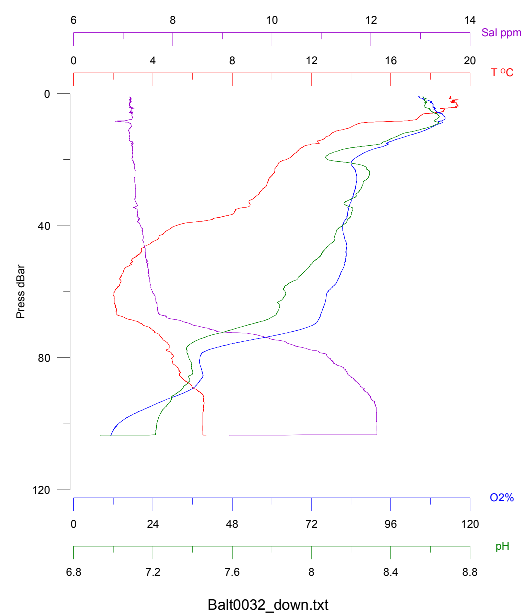

Fig. 12 Vertical finestructure measured by free falling CTD