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Climatic structure of fields of near-bottom temperature, salinity and water density in the Northwest Atlantic

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Abstract

On the basis of long-term international oceanographic data, the climatic structure of near-bottom potential temperature, salinity and potential density in the area of the Northwest Atlantic between the Davis Strait and southern borders of the Newfoundland area is estimated. It was revealed that temperature, salinity and water density increase rapidly in dependence on the depth in areas of shelves and upper parts of continental slopes. On the lower part of the slopes' bottom and in the oceanic depressions, the combination of temperature fall and slow increase of salinity and water density was observed. The border between these areas is located close to maximum of bottom temperatures at depths of about 400-500 m.

In the upper structural area of the near-bottom layer the shelf thermal, haline and density frontal zones are located. They have common nature and are formed in the result of interaction between the Arctic and transformed Atlantic waters. Haline and density near-bottom frontal zones located in the shallow areas along the coasts of West Greenland and Labrador are specific for conditions of increased salinity variations in combination with relative stability of potential water temperature close to minimal values of these characteristics.

In the lower structural area of the near-bottom layer under the low variability of the near-bottom salinity and density, not extended slope thermal frontal zones are occurred, which are connected with the heightened thermal contrasts between warm intermediate and cold deep waters and attached to limited bottom areas close to the southern part of Greenland and off the Flemish Cap bank at the depth of 1 000-2 500 m.

Introduction

Development of investigations and fishery for deep-water fish species in the Northwest Atlantic demands knowledge on near-bottom biotopes over the wide oceanic area and, in particular, on climatic structure of fields of temperature, salinity and water density near the bottom. The existing concepts of these structures are quite limited, since the necessary data either are absent in the atlases of oceans (Anon., 1977, WOA05) or belong to some areas of the East Canada shelf (http://www.mar.dfompo.gc.ca/science/ocean/tsdata.html).

The given paper is an attempt to fill up the knowledge on the structure of fields of oceanographic characteristics in the near-bottom layer in the NAFO Convention Area located between the Davis Strait and southern borders of the NAFO area (NAFO Subarea 3).

Materials and Methods

Data sets necessary for building and analyzes of climatic fields of temperature, salinity and water density in the near-bottom layer was formed of historic data of water temperature and salinity measurements at the oceanographic stations contained in the World Ocean database 2001 (WOD01) and related to the part of the NAFO Convention

Area located in the position 40°-66°15´N, 42°-64°40´W. Because of the presence in the input data of a large number of stations, in which the lower horizon of measurements was sufficiently distant from the bottom, the necessity arose to select data in order to exclude these stations. Taking into account methodological limitations of bathometric measurements dominating in the historic database, the following conditions were accepted as selection criteria:

1. BD ≤ 200 m: BD - LOD ≤ 5 m;
2. BD > 200 m: (BD – LOD)/BD ≤ 0.02,

where BD – depth of the bottom, LOD – the last observation depth.

In accordance with the mentioned criteria, stations with the absent near-bottom measurements of water temperature and salinity, as well as backup stations and stations in fjords and off the coast at depths not less than 40 m, were excluded from the initial file. The last operation, as well as calculations and visualization of fields of potential temperature, salinity and potential water density in the near-bottom layer were carried out with the use of the ODV program [Schlitzer, R., 2005]. The use of the potential temperature and potential density was caused by the necessity of exclusion of the effect of water compressibility at the analysis of fields of the near-bottom characteristics in the interval of depths from several tens of meters to several kilometers. The resultant file united data of 25.1 thou. stations collected in the period of 1910-2000 (Fig. 1).

To estimate the spatial heterogeneity of near-bottom oceanographic characteristics the calculation and analysis of their horizontal gradients were done. With this aim the files of near-bottom water characteristics were preliminary interpolated with the use of SURFER program into junctions of a regular grid with a step of 33.3 km, and then the obtained data were used for calculation of the absolute values of horizontal gradients of the analyzed characteristics.

Determination of near-bottom frontal zones was carried out by analysis of fields of horizontal gradients of near-bottom oceanographic characteristics in accordance with criteria of K. N. Fedorov [Fedorov, 1983], who determines the frontal zones as areas with horizontal gradients of properties exceeding much those at the average even distribution of properties between their sustain minimum and maximum. As threshold values for thermal frontal zones in the investigated area, the values were accepted of horizontal gradients of the near-bottom potential temperature $0.045°C \cdot km^{-1}$, those for frontal zones in the fields of near-bottom salinity – $0.017\ km^{-1}$ and potential density – $0.012 \cdot 10^{-3}\ kg \cdot m^{-4}$. Location of frontal zones is identified by location of maxima of horizontal gradients equal or exceeding the mentioned threshold values; and lines, connecting the points of the computational grid corresponding to these conditions, are conditionally determined as axes of frontal zones.

Results and Discussion

A field of near-bottom potential temperature

Climatic annual distribution of near-bottom potential temperature and location of axes of near-bottom thermal frontal zones are in Figure 2. A common character of a potential temperature field reflects the combination of two opposite tendencies of its variation in dependence on depth:

- The increase of temperature from minimum (<1°C) in shallow coastal parts of the shelf areas, where the Arctic origin waters are distributed, to maximum (>3.3°C) located on the continental slopes at depths from 150-300 to 1 500-1 800 m and belonging to various modifications of waters of the Atlantic (sub-tropic) origin;

- The subsequent monotonous decline from the mentioned maximum to the relative minimum (1.5-2.3°C) located in the oceanic depressions and caused by distribution in the near-bottom layers of these areas of cold waters with high salinity and density formed by the Denmark Strait Overflow Water (DSOW).

A band of maximum of near-bottom potential temperature (θ_{max}) bordered the continental slopes divides not only the areas with opposite signs of temperature variation with the depth, but two groups of thermal near-bottom frontal zones in these areas as well. One of them is localized in the area of near-bottom temperature growth with the depth predominantly on shelves or along their edges and, therefore, can be conditionally determined as a system of shelf near-bottom thermal zones. The other group of near-bottom frontal zones, in which the lowering of near-bottom temperature with the increase of the bottom depth is sharper than the surrounding background, is revealed only in limited areas of continental slopes to the southwest of Greenland and in the area of Flemish Cap and conditionally determined as slope thermal near-bottom frontal zones.

The difference in modifications of Atlantic waters forming the band of maximum temperatures in the near-bottom layer close to the shelves edge is expressed in differences of a value of this maximum in various parts of the discussed area. The largest temperature values (5-6°C) in this band are localized on the southwestern slopes of the Great Bank and connected with so called slope waters distributed along the northern periphery of the Gulf Stream. Somewhat lower value of maximum of near-bottom temperatures is in the area of the southern Greenland (4-5°C), which belongs to both the transformed Irminger waters and Northwest Atlantic Mode Water (NWAMW) with temperature of 2-5°C and salinity of 34.5-34.85; the latter ones are formed on the northern periphery of the North Atlantic Current under the influence of the Labrador Current waters [Buch, 2000]. The least values of temperature (about 3.5°C) are in a sector of a band of maximum temperatures located above the continental slope along the East Canada between the Davis Strait and a “tail” of the Great Bank; this area is predominantly formed by the NWAMW mentioned above.

Analysis of thermal structure of near-bottom waters zoned with the account of differences of temperatures maxima is presented in Fig. 3. These data show the presence of opposite by sign tendencies of temperature variation under the increase of the bottom depth, as well as the location of its maxima and minima in the shallow shelf areas (the absolute minimum), over the continental slopes (maximum) and in the oceanic depressions (the relative minimum).

In the range of temperature increase with the depth, i.e. in areas of interaction of cold Arctic and warm transformed Atlantic waters, there are zones of temperature heightened horizontal gradients, corresponding to shelf thermal near-bottom frontal zones, together with areas of relative gradual variation of temperature with the depth. In these zones the potential temperature varies within range from -1°C to 5°C in the depth range from 80-100 to 400-450 m. Mean depth of the shelf thermal near-bottom frontal zones reveals a ratability to the depth of maximum of near-bottom temperature and reaches the largest value (290 m) in the area of distribution of the Baffin Land Current and the Labrador Current.

As it comes from Figures 2 and 3, the slope thermal near-bottom frontal zones belong to the area of decrease of the near-bottom potential temperature with the depth and are formed at depths from 900 to 2 900 m in the interval of potential temperature 4.5-2.1°C. Differing from the shelf areas, the depth of areas of the slope thermal near-bottom frontal zones increases with the decrease of the near-bottom temperature, and their extension is relatively small and limited by the local areas.

A field of near-bottom salinity

A climatic annual field of the near-bottom salinity shown in Figure 4 is characterized by its increase over the whole range of depth from minimal salinity 32.0-33.0 in the shelf areas to maximum of 34.95-34.98 in the oceanic depressions. The largest swings of salinity are located on the shelves and in the upper part of continental slopes; and in the deepwater the variability of salinity is very small. Therefore, large horizontal gradients of the near-bottom salinity identifying near-bottom haline frontal zones are concentrated in the discussed area exclusively in the first hundreds meters of the bottom depth. These frontal zones are the product of interactions of the Arctic waters with low salinity and transformed Atlantic waters with higher salinity (higher than 34.5).

In the limited shallow areas of the shelf of the southwestern part of Greenland and off the coast of Labrador both the pairs of haline frontal zones located in the neighborhood and the branches of these zones are occurred. One of the paired or branching haline frontal zone is located closer to the shore and corresponds to the sharp variation of salinity in the range of its relatively low values, whereas areas of this frontal zone located farther in the sea belong to intervals of higher salinity.

The haline structure of near-bottom waters is shown in detail in a series of diagrams of correspondence of near-bottom salinity and modules of its horizontal gradients to the bottom depth (Fig. 5), which are differentiated in accordance with regional differences of maxima of near-bottom temperatures. The presented data demonstrate the obvious presence of two areas of increase of salinity with the depth: an area of rapid growth of near-bottom salinity in the range from minimal values (<33.0) in the coastal parts of the shelf to 34.5-34.7 in the upper part of continental slopes at the bottom depth of about 450m, and the area of its slow variation located deeper. The upper part of near-bottom salinity variation includes the haline near-bottom frontal zones. Similar to shelf thermal near-bottom frontal zones, their haline counterparts expresses a tendency to increase a depth of location under the increase of salinity; and the largest average depth of areas of this zone belongs also to the area of distribution of cold currents system along the east Canada.

A specific feature of the spatial heterogeneity of the near-bottom salinity is small areas of haline near-bottom frontal zones, which are formed off the coast under temperature and salinity close to their minima. Formation of these zones takes place under the combination of the relative stability of temperature and salinity growth that is expressed (see below) in areas of quasi-horizontal areas of non-linear θS-correlations.

A field of near-bottom potential density

Climatic annual distribution of the water potential density in the near-bottom layer of the discussed area (Figure 6) is characterized by its increase with the depth over the whole depth range, and the most sufficient variations of this characteristic, similar to near-bottom potential temperature and salinity, takes place in areas of shelves and in the upper part of continental slopes. In these areas, where the increase of near-bottom temperature with the depth blend with the increase of the near-bottom salinity, the contributions of these characteristics into variation of near-bottom density are the opposite ones, and therefore, the observed accelerated growth of density reflects the domination of the effect of salinity variations. The contributions of both characteristics are positive and provide jointly for the resultant slow increase of water density in deep-water areas, which are located deeper than maximum of the near-bottom temperatures, and where variations of temperature and salinity with the depth have the opposite signs.

The near-bottom frontal zones in the field of the potential density, as well as the near-bottom haline frontal zones, are located only in the structural area of shelves and in the upper part of continental slopes. These frontal zones divide the coastal waters of the Arctic origin with low density from the deeper located transformed Atlantic waters with higher density (>1 027.5 – 1 027.6 kg*m^{-3}). In the limited shallow areas of the shelf in the southwestern part of Greenland and off the Labrador coast, where the local haline near-bottom frontal zones are present and belong to intervals of temperature and salinity close to their minima, the density near-bottom frontal zones corresponding to them are located as well.

The structures of the near-bottom potential density and its horizontal gradients (Figure 7) are in general similar to those of the near-bottom salinity (Figure 5) that demonstrates the prevailing role of variations of near-bottom salinity in changes of near-bottom water density.

Some properties of near-bottom frontal zones

A composition of thermal, haline and density near-bottom frontal zones, which were determined at the analysis of climatic yearly fields of the corresponding characteristics, is shown in Figure 8. The given scheme demonstrates almost complete geographical coincidence of all haline and density frontal zones, as well as predomination of the correspondence of haline and density frontal zones, located farther to the sea than their coastal branches, with the shelf thermal frontal zones.

The correspondence of geographical location of frontal zones means that there is a correspondence of thermal/haline and density properties in waters forming these zones. Fig. 9 presents θS-ratios between near-bottom frontal zones and θS-regressions, individual for shelf thermal, haline and density frontal zones and statistically significant at $p< 0.05$. As it comes from the above data, these individual regressions almost coincide in the θS-space in each of the discussed areas.

The community of properties ranges and quasi-identity of θS-regressions, peculiar for each of areas, is the basis to assume that shelf thermal, haline and density near-bottom frontal zones are the components of the oceanic near-bottom frontal zone formed at the interaction of the Arctic and Atlantic waters.

Nonlinear θS-regressions of the near-bottom frontal zones waters (two upper schemes in Figure 9) demonstrate the combination of quasi-horizontal and incline areas, which reflects the peculiarity of processes of waters interaction. In quasi-horizontal areas of θS-regressions, where salinity variations blend with the relative stability of potential temperature, there are conditions for formation of only haline and density frontal zones. Incline areas of nonlinear and linear θS-regressions reflects the conditions of existence of both haline and density and shelf thermal near-bottom frontal zones.

Conclusion

Thermal/haline and density structure of near-bottom biotopes in the Northwest Atlantic is characterized by the presence of the upper and low structural parts. The upper structural part covers shelves and upper continental slopes and differs by the relatively rapid increase of temperature, salinity and density with the depth, and the lower one is distributed over the rest part of the bottom on the slopes and in the oceanic depressions and corresponds to the combination of the temperature fall branch with continuing and slow increase of salinity and water density. The border between these areas is located close to maximum of near-bottom temperatures at depths of about 400-500 m.

In the upper structural area of the near-bottom layer the shelf thermal, haline and density near-bottom frontal zones are located; they have the same nature and are formed by interaction between the Arctic and transformed Atlantic waters. Haline and density near-bottom frontal zones located in the shallow areas along the coasts of West Greenland and Labrador are specific for combination of heightened variations of salinity and relative stability of potential temperature close minimal values of these characteristics. Nearby shelf edges, where the potential temperature, salinity and potential density increase with the depth, there are both haline and density and shelf thermal near-bottom frontal zones.

In the lower structural area of the near-bottom layer, small variability with the depth of the near-bottom salinity and density blend with heightened temperature contrasts between warm intermediate and cold deep waters only in the limited areas close to the southern part of Greenland and off the Flemish Cap at depths 1 000-2 500 m, where not very distant areas of slope thermal near-bottom frontal zones are located.

Acknowledgement

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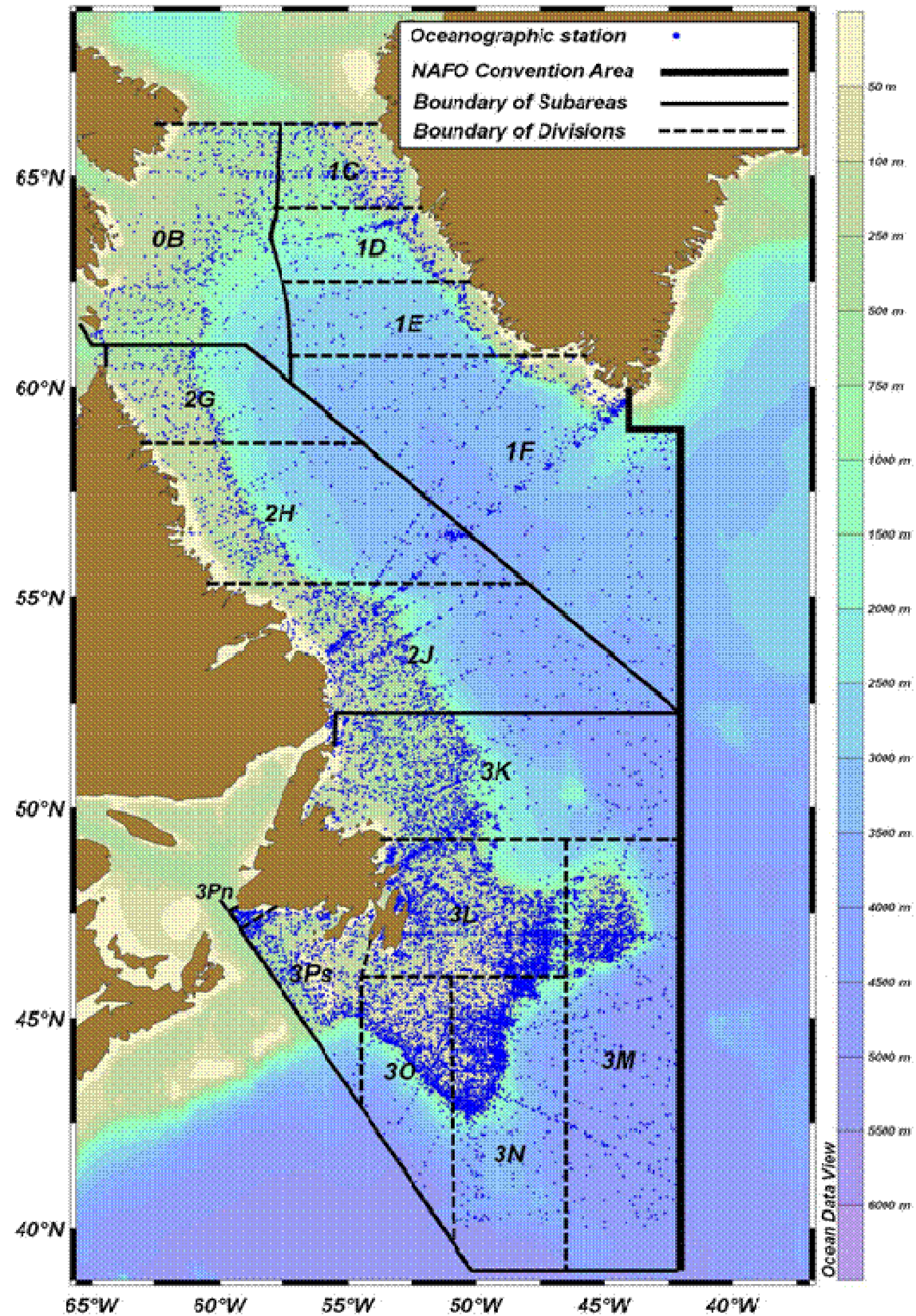

Fig.1. Location of oceanographic stations with near-bottom measurements of temperature and salinity in the Northwest Atlantic. A set is selected from data of WOD01 for the period 1910-2000.

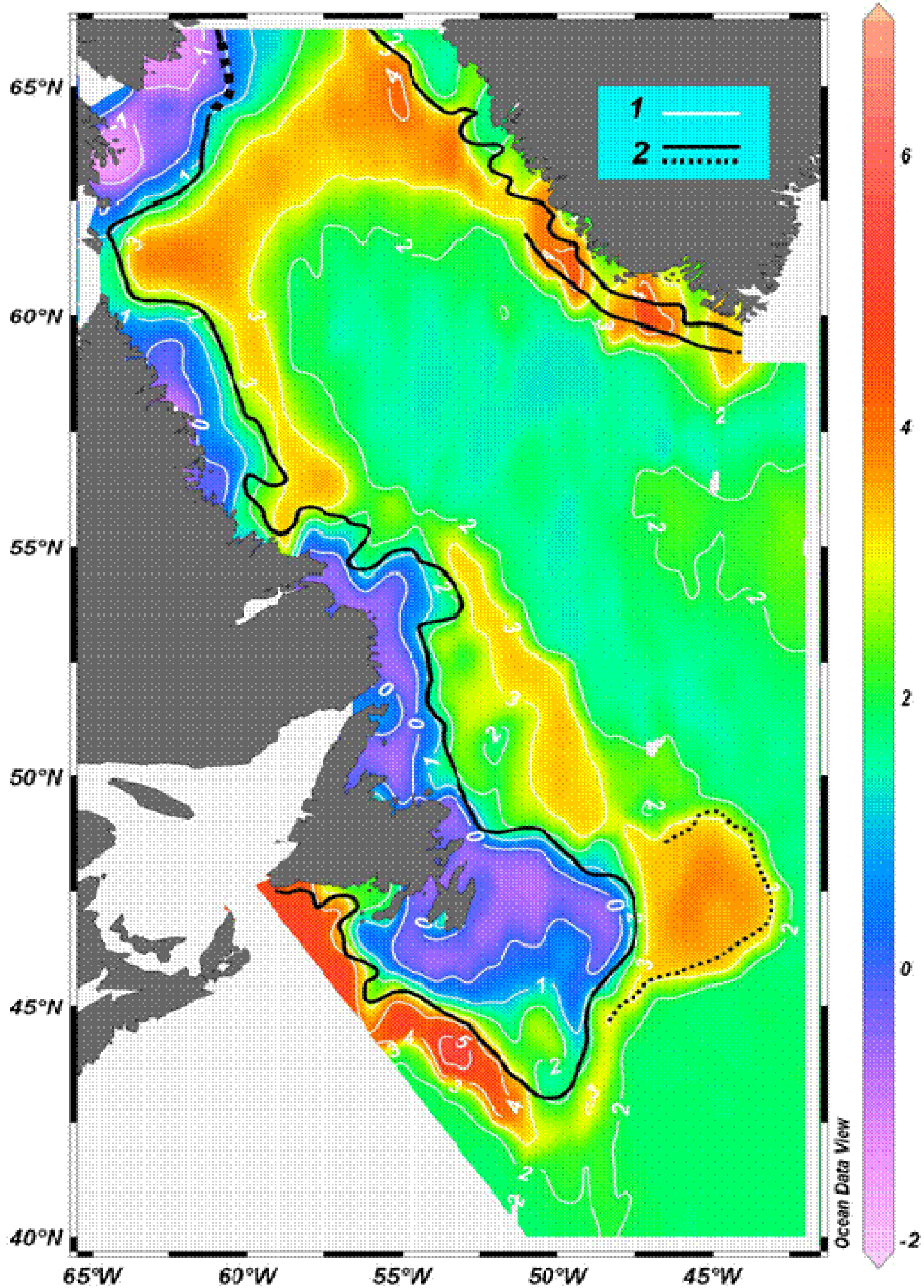

Fig.2. Distribution of potential temperature (°C) and axes of thermal frontal zones in the near-bottom layer.
1 - Isotherms, 2 – Axes of frontal zones; dotted line designates areas of frontal zones with maximum horizontal gradients of the near-bottom potential temperature, which are less than threshold value 0,045 °C•км$^{-1}$ by a value up to 50%.

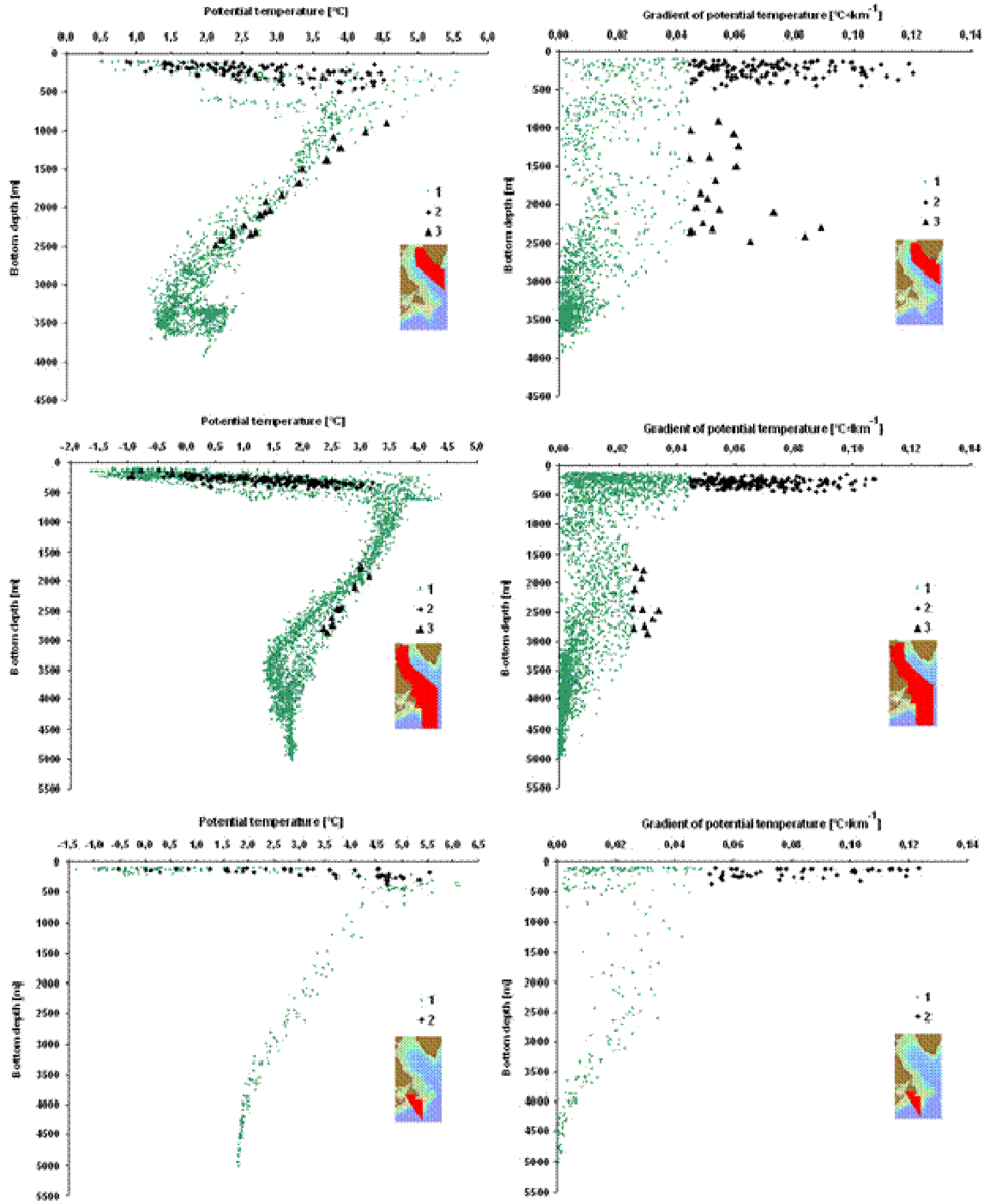

Fig.3. Dependences of water potential temperature (left) and absolute values of horizontal gradients of potential temperature (right) in the near-bottom layer on the bottom depths. 1 – Characteristics outside thermal frontal zones; 2 – Characteristics of shelf thermal frontal zones; 3 – Characteristics of slope thermal frontal zones. In penetrated figures red colour designates the areas, to which the corresponding data belong.

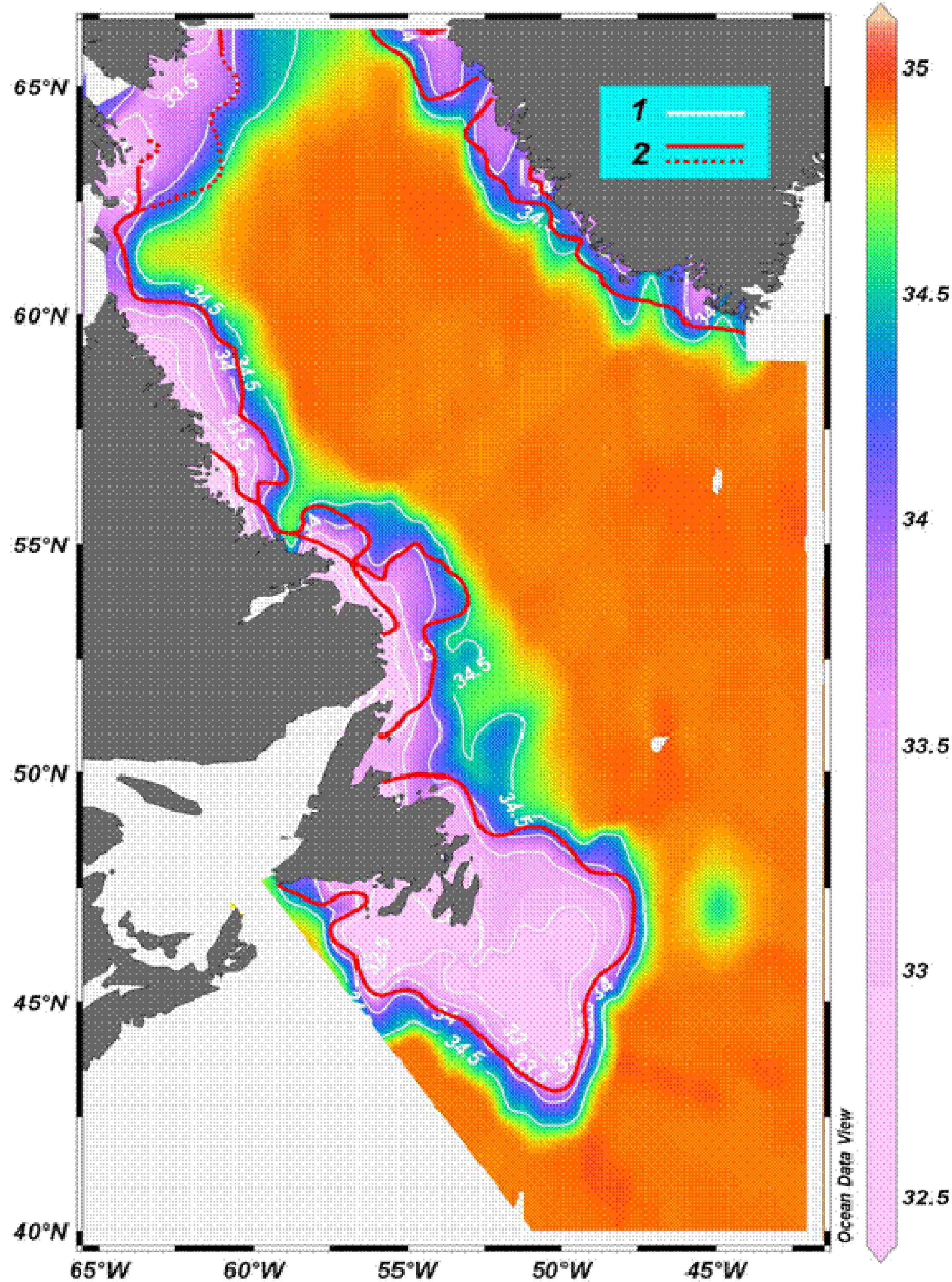

Fig.4. Distribution of water salinity and axes of haline frontal zones in the near-bottom layer.
1 – Isohalines, 2 – Axes of frontal zones; dotted line designates the areas of frontal zones with maximal horizontal gradients of near-bottom salinity, which are less than 0,017 $км^{-1}$ by a value up to 30%.

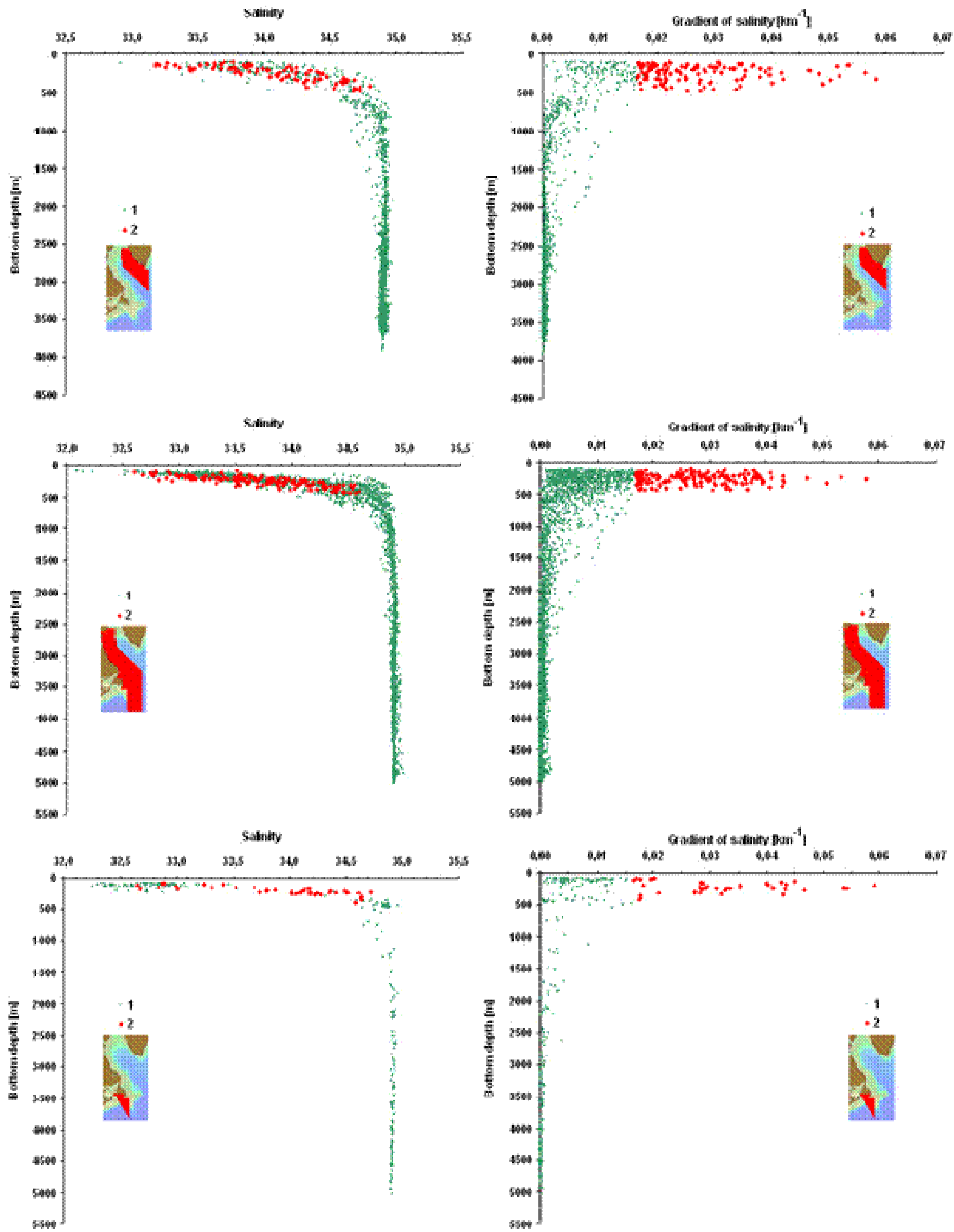

Fig. 5. Dependences of water salinity (left) and absolute values of horizontal gradients of salinity (right) in the near-bottom layer on the bottom depths. 1 – Characteristics outside haline frontal zones; 2 – Characteristics of haline frontal zones. In penetrated figures red colour designates the areas, to which the corresponding data belong.

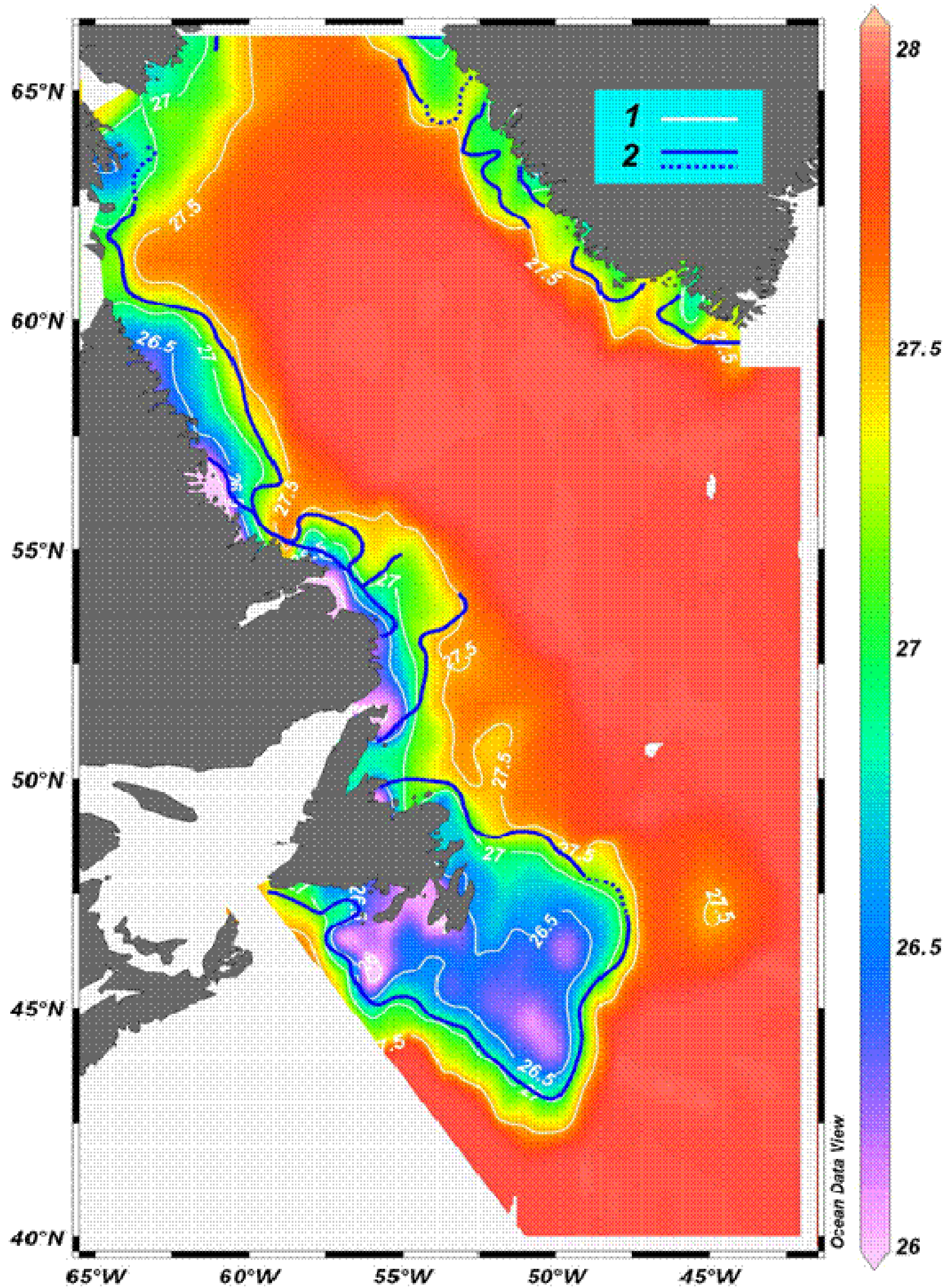

Fig. 6. Distribution of potential water density (kg*m^{-3}) and axes of density frontal zones in the near-bottom layer.
1 – Isopycnics; 2 – Axes of frontal zones; dotted line designates the areas of frontal zones with maximal horizontal gradients of near-bottom potential density, which are less than threshold value 0,012*10^{-3}kg*m^{-4} by a value up to 30%.

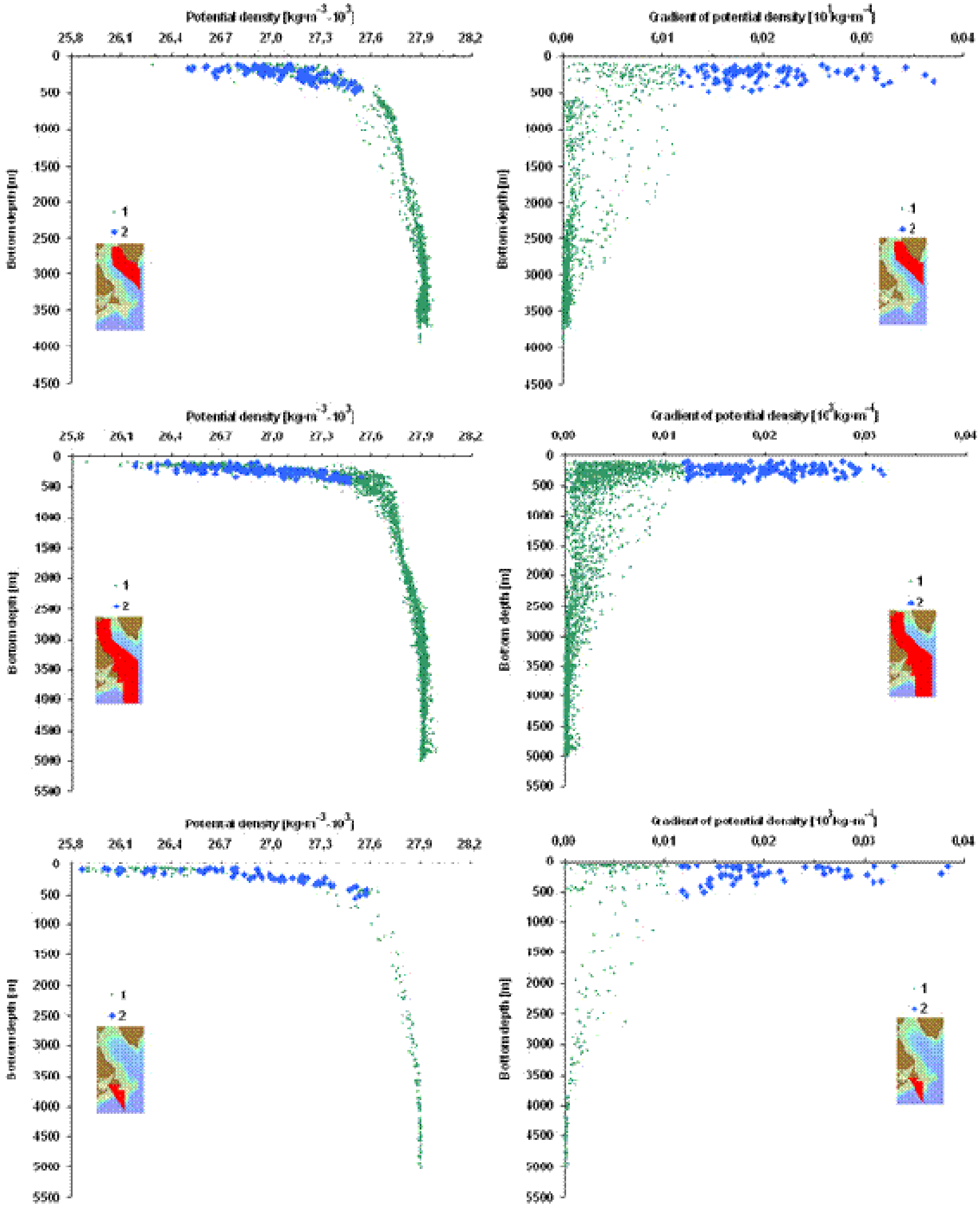

Fig. 7. Dependences of water potential density (left) and absolute values of horizontal gradients of potential temperature (right) in the near-bottom layer on the bottom depths. 1 – Characteristics outside density frontal zones; 2 – Characteristics of density frontal zones. In penetrated figures red colour designates the areas, to which the corresponding data belong.

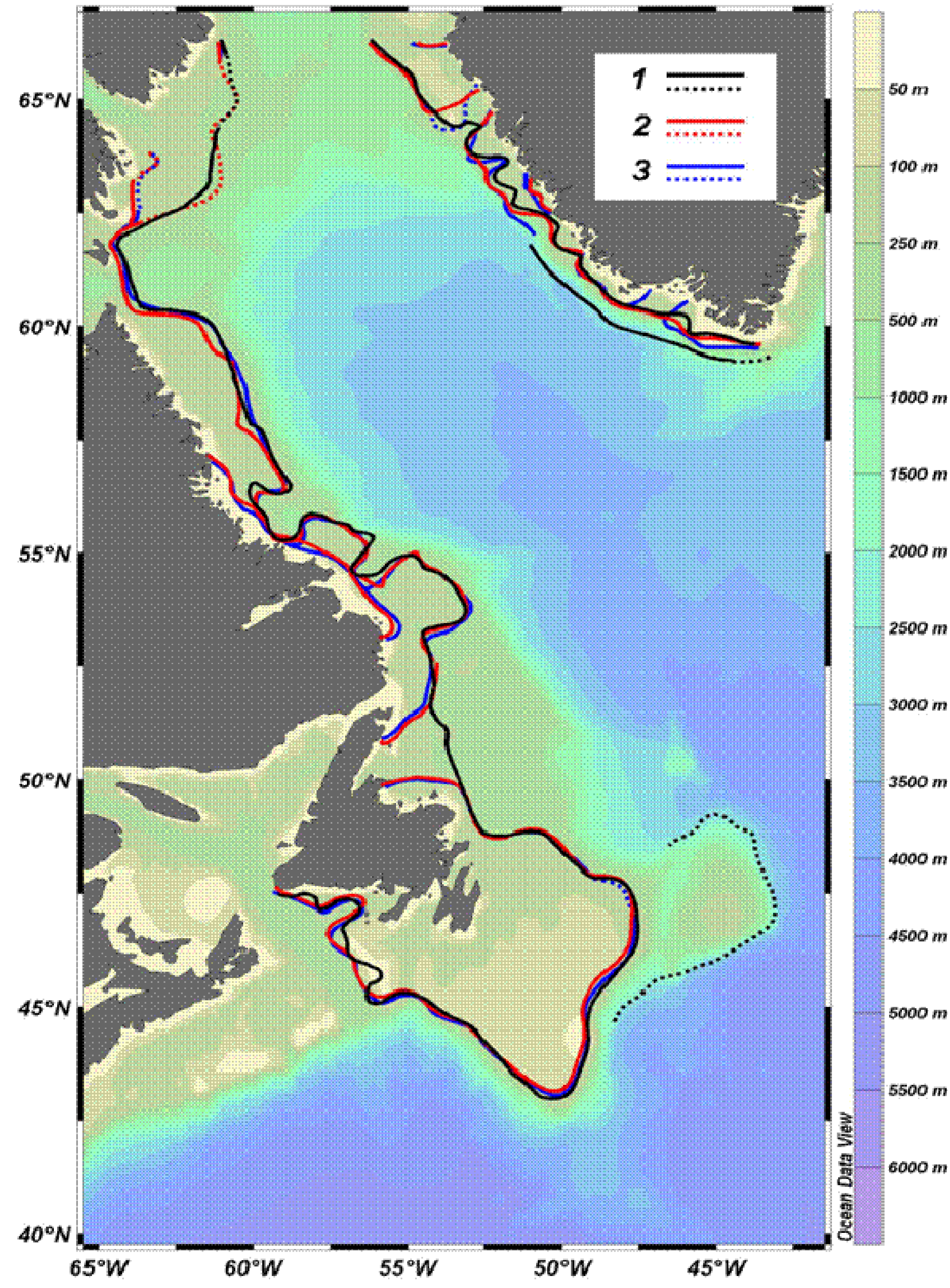

Fig. 8. Location of frontal zones axes in the fields of potential temperature (1), salinity (2) and density (3) of water in the near-bottom layer. Dotted line designates the areas of frontal zones with maximal horizontal gradients of near-bottom characteristics, which are less than threshold values by a value up to 30-50 %.

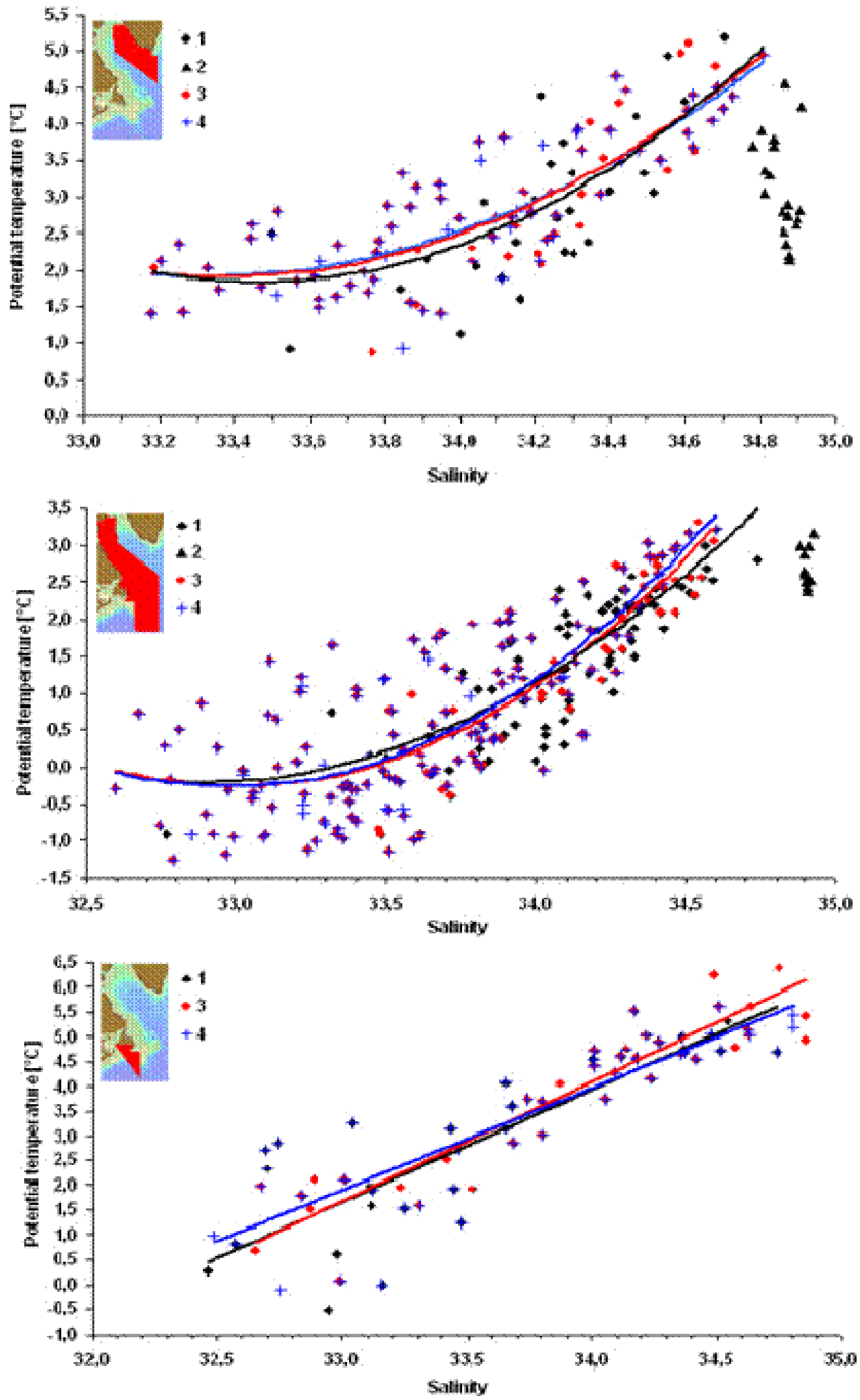

Fig. 9. θS-diagrams of waters of thermal shelf (1), thermal slope (2), haline (3) and density (4) frontal zones in the near-bottom layer.

θS-regressions are shown by black lines for the shelf thermal frontal zones, by red lines – for haline frontal zones and by blue lines – for density frontal zones. In penetrated figures red colour designates the areas, to which the corresponding data belong.