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Selected problems of the termohaline structure and dynamics of the water masses in Norwegian and Greenland Seas

ABSTRACT: Based on the results of CTD measurements (in situ) made during r/v „Oceania" cruises in the Norwegian and Greenland Seas in 1986—1988 selected aspects of termohaline structure and water dynamics of chosen regions of the seas were described. Examples of space-time variations of temperature and salinity fields were presented and water masses geostrophic transport on the limits of the Norwegian Sea (upon the Atlantic Ocean and the Barents Sea) was estimated.

Key words: Arctic, Norwegian—Greenland Seas, termohaline structure, water dynamics.

Introduction

Waters exchange between the North Atlantic and the Arctic Sea play important role in formation of short-time fluctuations of the North Hemisphere climate. It takes place across the Norwegian and Greenland Seas, being a kind of climate buffer. In the Norwegian Sea sea-ice interaction dynamics processes are very clear (Marčuk 1983). The warm North Atlantic waters which flow into the Sea across the Faeroe—Shetland Channel undergo transformation and gradual cooling on their way northwards as the Norwegian Current.

In the north part of the Norwegian Sea some volume of these waters flows into the Barents Sea, and the another displaces northwards as West Spitsbergen Current. Aagaard and Greisman (1975) estimated, that this current gives almost 90% of global heat into the Arctic Sea Basin. Hence these waters largely contribute to mitigation of the climate of the area. Therefore the estimation of the heat fluxes fluctuations amplitude in the Norwegian—Greenland Seas is very important. It concerns especially short-time variations and perturbations of that transport of the borders of the Seas.

Based on the problems mentioned above the Norwegian—Greenland Seas Research Programme for 1986—1989 was worked out in the Institute of Oceanology, Polish Academy of Sciences.

Recognition and estimation of the space-time changes of the parameters which decide about ocean role in sea-air interaction processes and have real influence on formation of the North Hemisphere short-time climate variations — that was the aim of the programme.

Location of investigation areas is shown in Fig. 1. Reconnaissance was made in the Norwegian Sea EAZO (energetic active zone of the ocean) in 1986

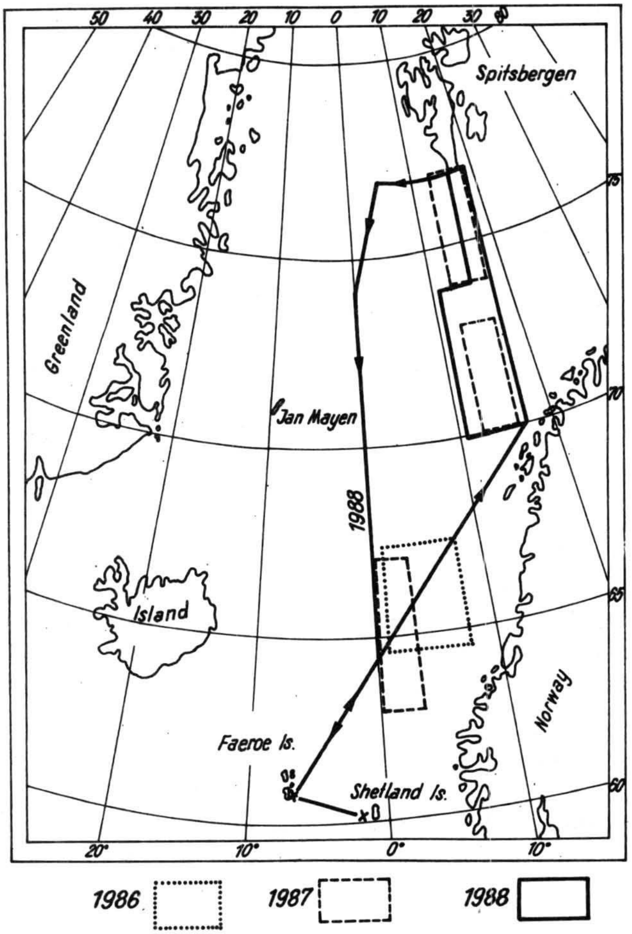


Fig. 1. Locations of the hydrographic stations examined during the cruises of r/v „Oceania" in the Norwegian and Greenland Seas in summer period of the 1986—88

to recognize the technical possibility of the ship. Investigation results and methodical experiences became the base for setting up the investigation programme 1987—1989. The programme included Poland into international Greenland Sea Project (1987)*.

Methods and technics of measurements

The investigation programme of the expeditions included:
— hydrological measurements (CTD, batometric soundings),
— measurements of basic meteorological parameters,
— biological measurements, i.e. quantitative and qualitative analysis of phyto- and zooplankton, and water samples chemical analysis,
— measurements of sea water acoustic and optical parameters (radiation, exctintion coefficient, fluorescence).

In the present paper an analysis of the data obtained from hydrological measurements is presented. Electronic CTD sounder with Plessey sensors (accuracy 0.02°C, time constant 1.5 s) was used. Soundings were carried out down to the depth of 300 m (250 m in 1987). Additionally the Nansen bottles with reversing thermometers were used in 1986 for measurements of deeper layer parameters.

In 1988 Guildline sounder was used. Its accuracy was 0.00512°C. The soundings were carried out down to 1000 m.

Results and discussion

Hydrological section Faeroe Is. — Shetland Is.

Two basic research questions concerning hydrology of the area can be distinguished:
— estimation of Atlantic waters transport flowing into Norwegian Sea and transport of cool waters outflowing from the Sea;
— general recognition of the water circulation in the North Atlantic and Norwegian Sea limits — between Iceland and Faeroe Is. as well as Faeroe Is. — Shetland Is. Channel.

It is generally accepted that main inflow of the Atlantic waters into the Norwegian Sea enters across the Channel mentioned above. However, recent investigations showed, that the dynamics of the area is much more complicated

*An international plan for the Arctic Ocean. Ocean Sciences Board, second edition, Bremerhaven; April 1987 (unpubl. data).

(Suchovej 1977). In Fig. 2 diagram T — S for the Faeroe—Shetland hydrographic section made during r/v „Oceania" cruise in July 1988 is shown. Dooley and Meincke (1981) distinguish three basic water masses of that area:

	T (°C)	S (%)
— North Atlantic Water (NAW)	>9	>35.3
— Modified North Atlantic Water (MNAW)	>8	>35.1
— Norwegian Sea Deep Water (NSDW)	< −0.5	<34.92

It is well shown in the diagram that the waters with parameters intermediate between MNAW and NSDW can also occur.

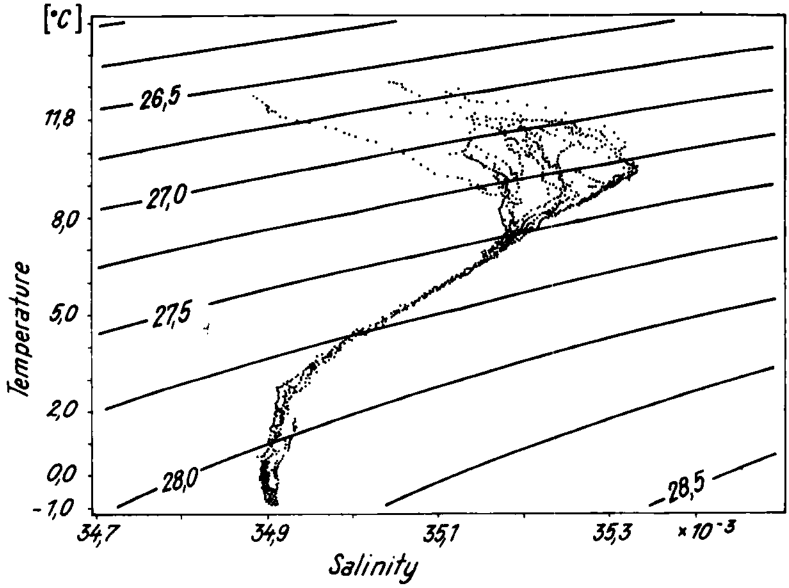


Fig. 2. T — S diagram for water masses in the hydrographic section in the Faeroe—Shetland Channel.

Based on the values of the water volume the transport across the Faeroe—Shetland section was estimated by means of dynamic method and shown in Fig. 3 (Zubov and Mamaev 1956). Positive values were assumed for flows into the Norwegian Sea. We can emphasize significant transport values for waters with Atlantic parameters and flowing back from the Norwegian Sea to Atlantic. It was probably caused by eddies carrying large heat and water masses. Waters, which flow above the Iceland Ridge from Atlantic play here some role. They flow around the Faeroe Is. and flow back to the Atlantic Ocean without sensible modification of their parameters (Suchovej 1977). Such scheme of flows is confirmed in Fig. 4.

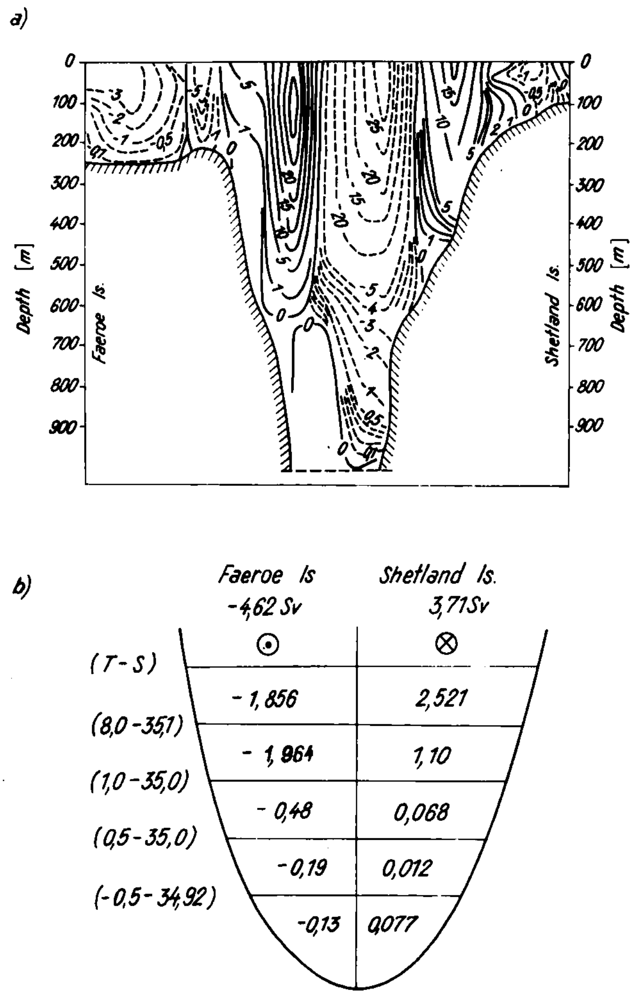


Fig. 3. Geostrophic flow in the hydrographic section in the Faeroe—Shetland Channel a) distributions of the current velocity component (cm s^{-1}) perpendicular to the plane of the section (positive values-towards the Norwegian Sea) for the case of level of no motion chosen at the depth of z = 1000 m, b) scheme of the integral volume water transport (Sv) for the typical water masses (1 Sv = 10^6 m^3 s^{-1}).

On the basis of the field data in the hydrographic section Faeroe Islands — NE (toward the Norwegian Sea) the current velocity component and volume water transport were estimated by the dynamical method (Zubov and Mamaev 1956). It can be clearly observed that water masses with characteristics of the Atlantic waters are transported in the direction to the Faeroe—Shetland Channel.

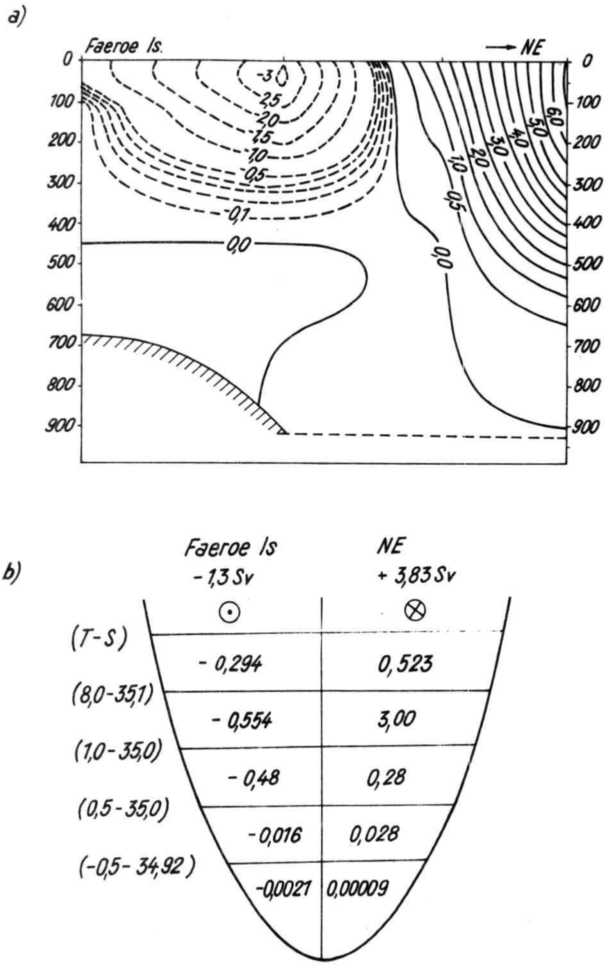


Fig. 4. Geostrophic flow in the hydrographic section of the Faeroe Islands — NE; a) distributions of the current velocity component (cm s^{-1}) perpendicular to the plane of the section (positive values-towards the Greenland Sea) for the case of level of no motion chosen at the depth of $z = 1000$ m, b) scheme of the integral volume water transport (Sv) for the typical water masses.

Norwegian Sea EAZO area (STD survey area of NOSEX-86)

In Fig. 5, as an instance, the spatial distribution of the sea water temperature and salinity prepared on the basis of the NOSEX-86 data and the climatological data from Levitus' Atlas (Levitus 1982) are presented. The differences in the run of isotherms and isohalines and also in the values of both parameters for the NOSEX-86 data and climate ones can be obviously noticed. Next figure (Fig. 6) presents the spatial field of dynamical heights at the sea surface and at the depth equal to 100 m estimated using both data sets. One

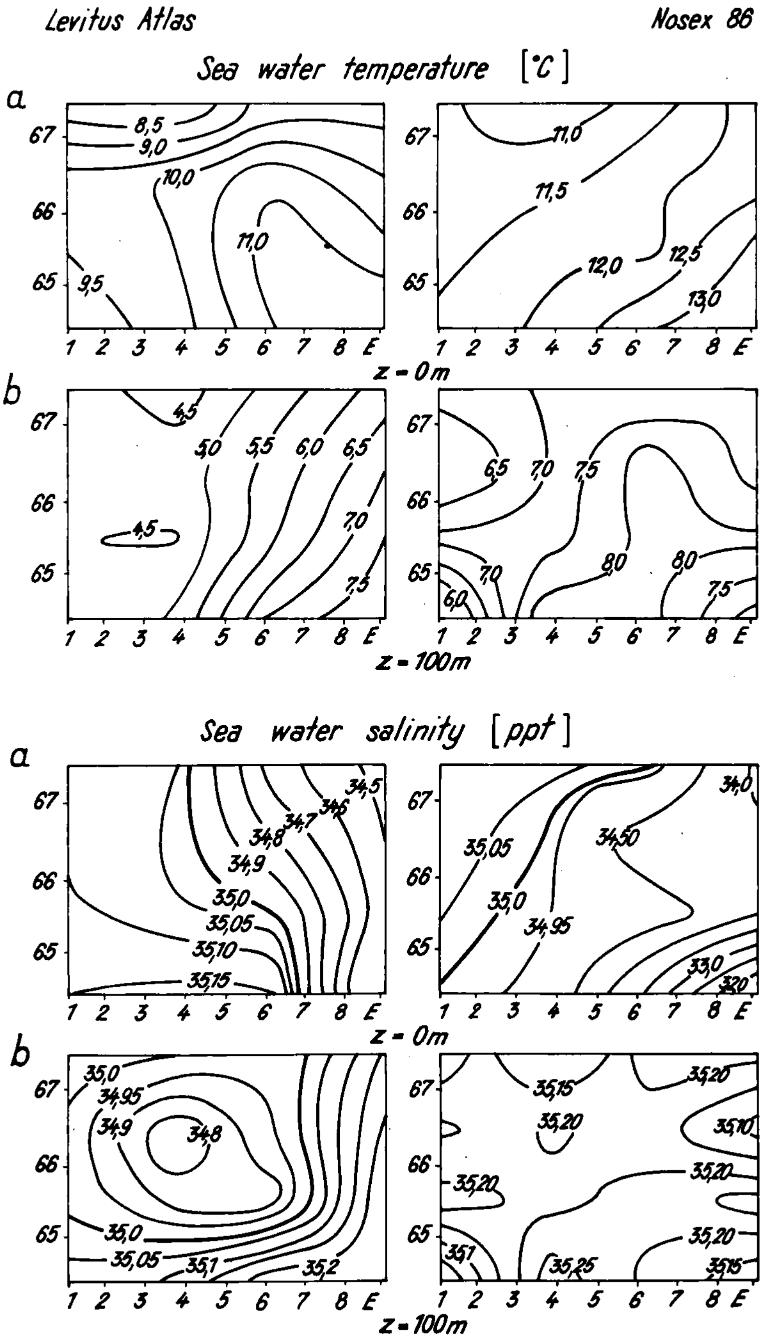


Fig. 5. Spatial distribution of temperature (°C) and salinity (ppt) prepared on the basis of the NOSEX-86 data and data from the Climatological Levitus' Atlas (Levitus 1982):
a) at the sea surface z = 0 m; b) at the depth z = 100 m.

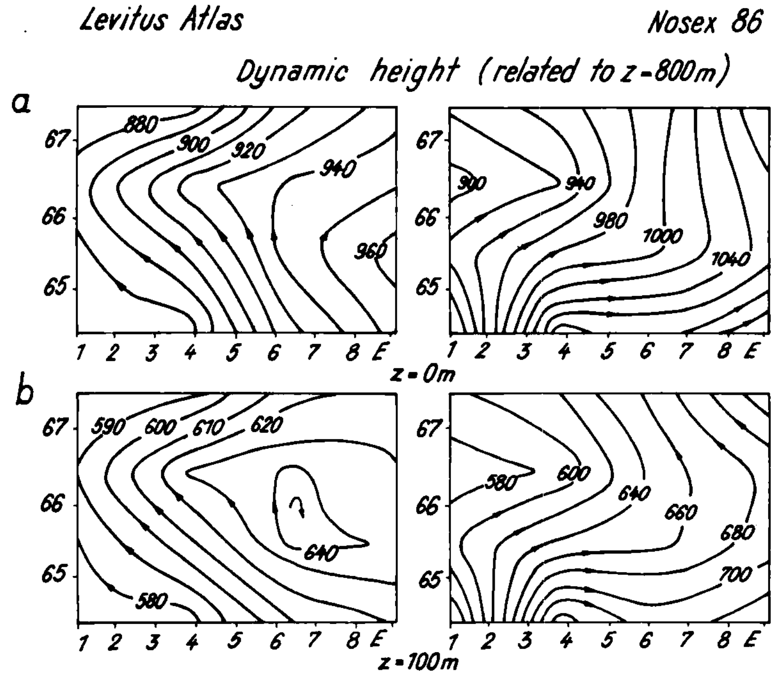


Fig. 6. Field of dynamical topography prepared on the basis of the NOSEX-86 data and data from the Climatological Levitus' Atlas (Levitus 1982) for the case of level of no motion chosen at the depth of z=800 m:
a) at the sea surface z=0 m; b) at the depth z=100 m.

can observe the clear discrepancies in the directions of meanders of the main flow going up to the North through the survey area for the case of the NOSEX-86 data set comparing with the mean climatological circulation of sea water. These differences in the spatial distribution of hydrophysical parameters show the strong variability of the hydrological regime in the region of observations. The Coastal Norwegian Current influences the variability (Saetre and Ljoen 1971), so far as its waters passed through the eastern part of the NOSEX-86 polygon area.

Region of confluence between the waters of the Norwegian and Barents Seas

The boundary between the Norwegian and Barents Seas extends along the line from the North Cape over the Bear Island to the South Spitsbergen. The limit area is the region of so called confluence zone (i.e. contact zone), where the warm Norwegian Sea water masses meet with the colder ones from the Barents

Sea. Two hydrological fronts can be found — one near the Bear Island and the second in the South Spitsbergen (Špajcher and Moreckij 1964). In the region the warm Atlantic waters divide on: the West Spitsbergen Current, transporting the Atlantic water masses to the Arctic Sea and the North Cape Current as well as the South Spitsbergen Current carrying these waters into the Barents Sea. In that region the survey areas in experiments in 1987 and 1988 were situated.

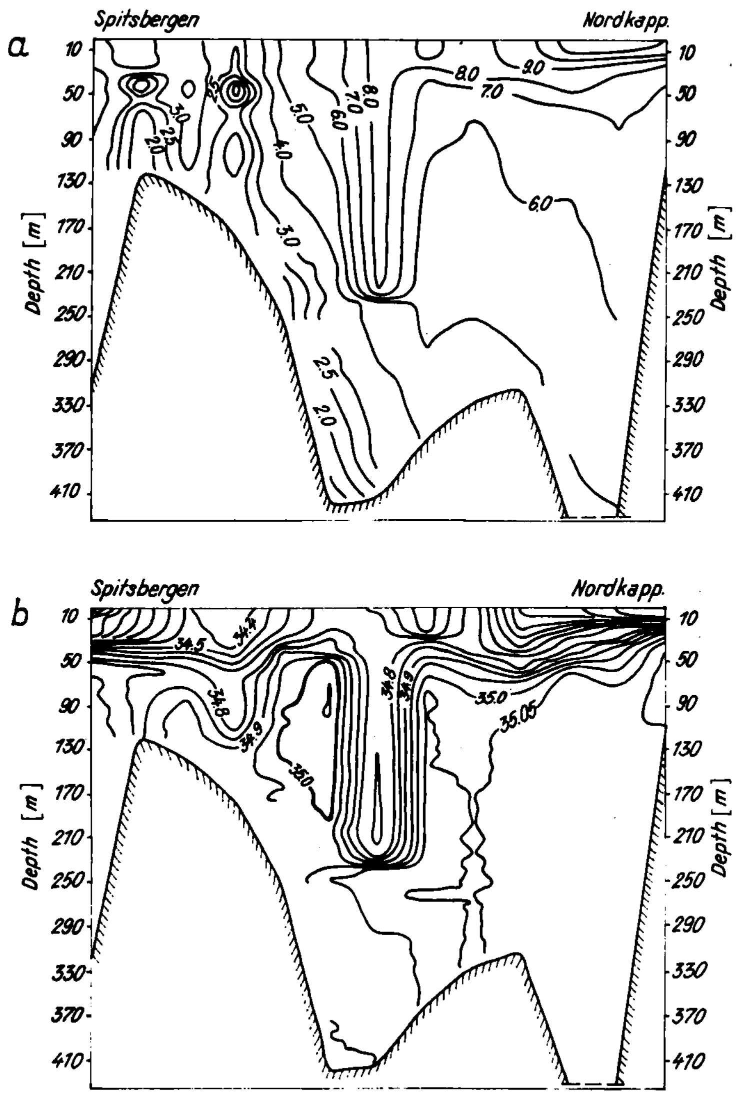


Fig. 7. Spatial distribution of temperature (°C) and salinity (ppt) in the hydrographic section Spitsbergen—North Cape (along 17°E):
a — temperature, b — salinity.

In Fig. 7 the vertical distribution of the sea water temperature and salinity in the hydrographic section Nordkapp— Spitsbergen along 17°E for summer 1988 is presented. The complexity of termohaline structure of the waters in the section caused the complicated vertical distribution of the velocity current component calculated by the dynamical method (Fig. 8a). The values of the geostrophic volume water transport estimated for the typical water masses are presented in Fig. 8b. It can be easy seen that main part of the volume transport is directed to the Barents Sea and what is worth to notice one can not find the water masses with the characteristics of the Norwegian Sea Deep Water (NSDW).

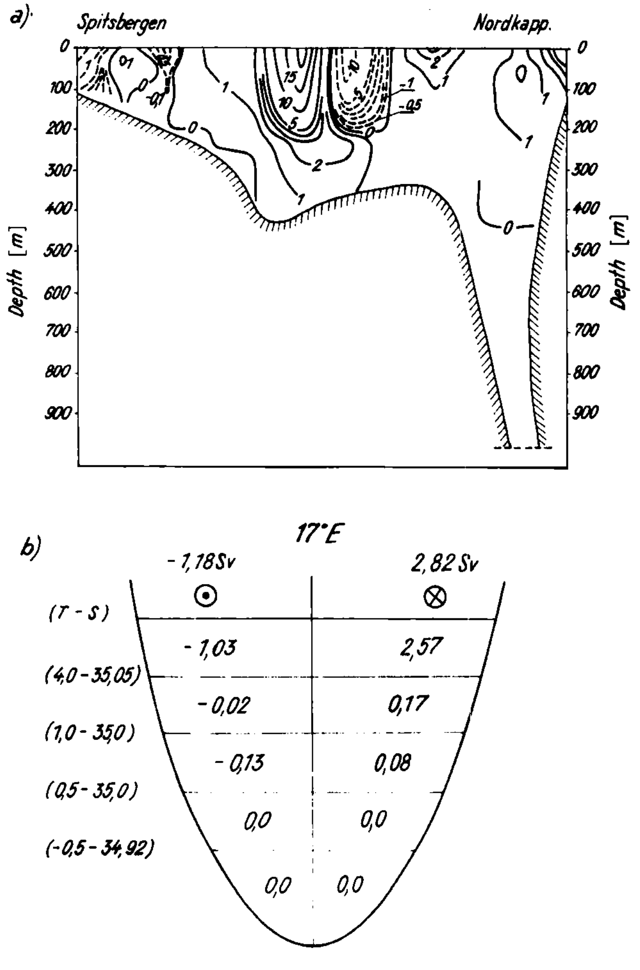


Fig. 8. Geostrophic flow in the hydrographic section Spitsbergen—North Cape (along 17°C); a) distribution of the current velocity component (cm s^{-1}) perpendicular to the plane of the section (positive values-towards the Barents Sea) for the case of level of no motion chosen at the depth of z = 1000 m,

b) scheme of the integral volume water transport (Sv) for the typical water masses.

The complexity of the picture of the vertical distribution of the temperature and salinity fields in the survey area — collapsing down of the warm surface waters (Fig. 7) is probably caused by the variability of the dynamics of the water circulation. To illustrate that in Fig. 9 the field of dynamical topography at chosen depths calculated on the basis of the AREX-88 data is presented. In the field of the geostrophic flow some of the anticyclonic eddies can be found which, as can be supposed, disturbed the temperature and salinity field changing the volume water and heat transport.

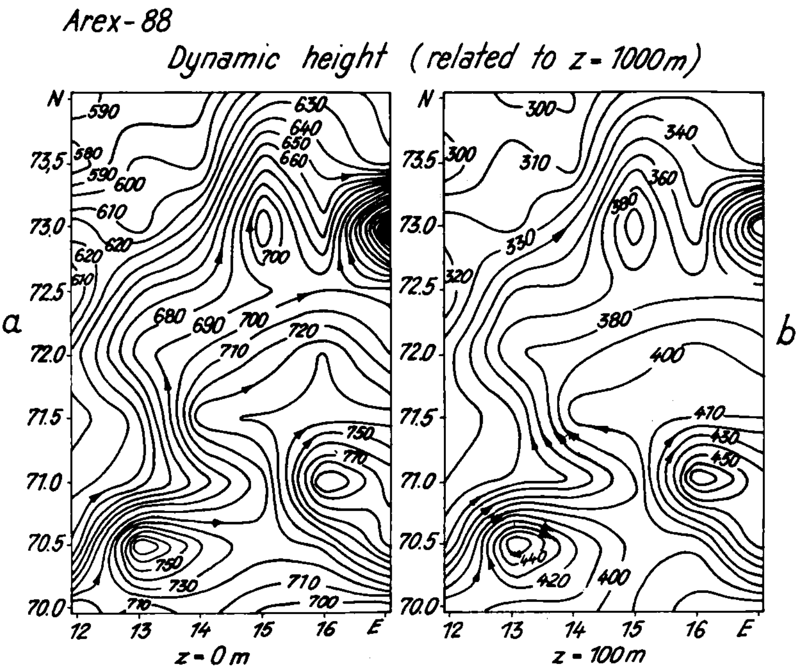
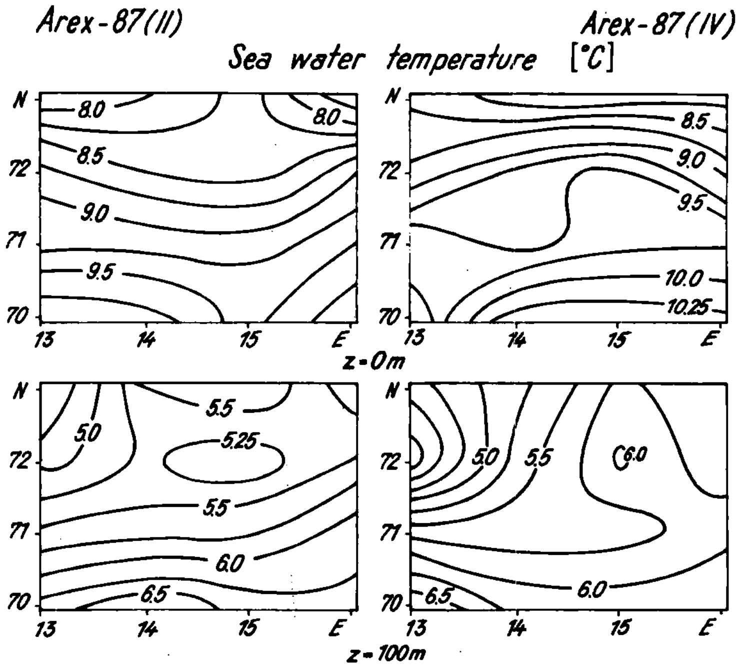


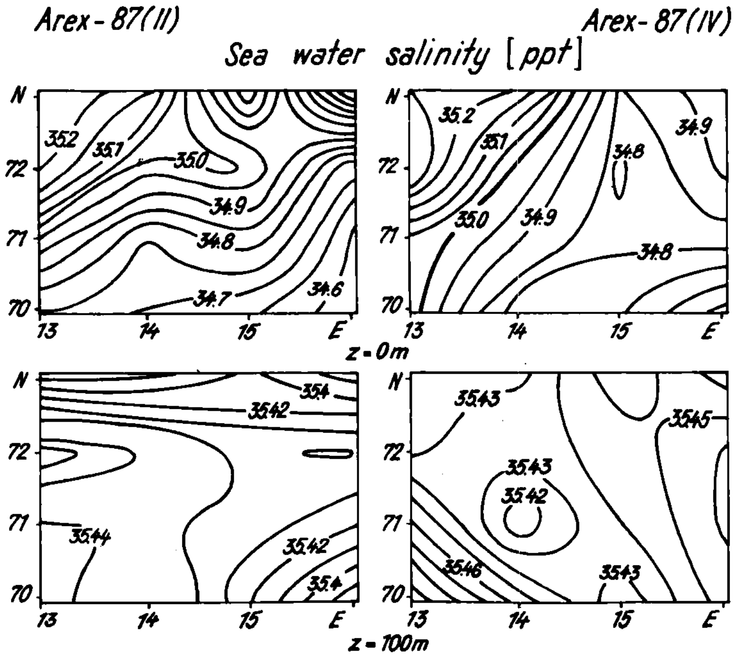
Fig. 9. Field of dynamical topography prepared on the basis of the AREX-88 data for the case of level of no motion chosen at the depth of z = 1000 m:
a) at the sea surface z = 0 m; b) at the depth z = 100 m.

To show the role of the eddies in the modification of the sea water temperature and salinity spatial picture the results of the STD soundings, repeated with time delay of two weeks in the polygon area of AREX-87 (70—73°N, 13—16°E), are presented in Figs. 10a and 10b. Next figure (Fig. 10c) presents the geostrophic circulation for both hydrographic surveys. Analysis of Figs. 10a, 10b and 10c indicates that the anticyclonic eddy structure passed through the region of the observations and moving to the North North West (NNW) modified the field of sea water temperature and salinity in the survey area of AREX-87.

a)


Arex-87(II)
Arex-87(IV)
Sea water temperature [°C]
N
72
71
70
13
14
15
E
8.0
8.5
9.0
9.5
10.0
10.25
z=0m
5.0
5.25
5.5
6.0
6.5
z=100m

b)


Arex-87(II)
Arex-87(IV)
Sea water salinity [ppt]
N
72
71
70
13
14
15
E
35.2
35.1
35.0
34.9
34.8
34.7
34.6
z=0m
35.4
35.42
35.43
35.44
35.45
35.46
z=100m

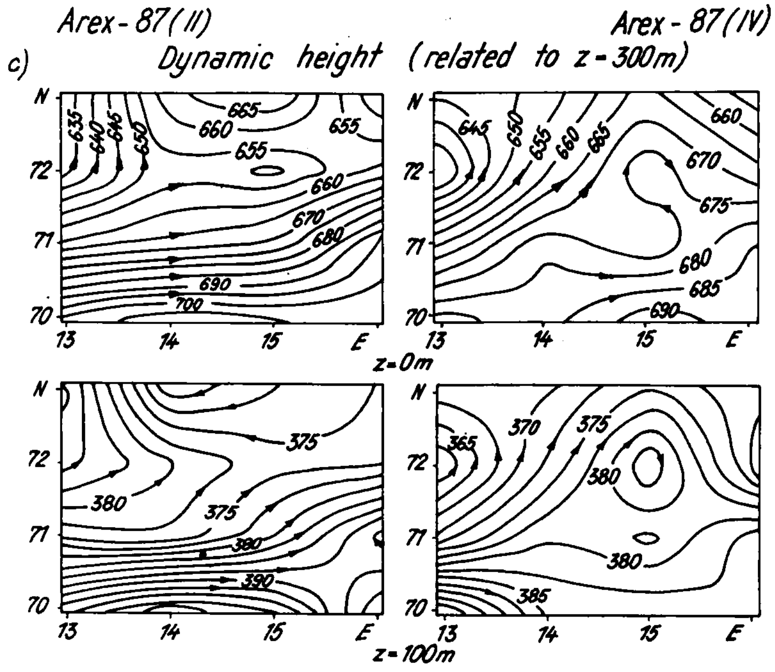


Fig. 10. Spatial distribution of temperature (°C), salinity (ppt) and dynamical heights at the depths z=0 m and z=100 m prepared on the basis of the AREX-87 data in polygons II and IV (surveys with two-weeks time delay): a — temperature; b — salinity; c — dynamical heights (for the case of level of no motion chosen at the depth of z=300 m).

Conclusions

The preliminary results of the investigations made during the cruises of r/v „Oceania" in 1986—88 and their analysis were presented. Some important features of the heat and water transport in the Norwegian and the Barents Seas can be underlined:

— perturbations of the heat and water transport in the Faeroe—Shetland Channel;

— the role of the eddies in the confluence zone of the Norwegian and the Barents Seas.

More complete discussion of the above mentioned problems can be done after the analysis of the results of the cruise of 1989 and results of the investigations of other countries participating in the Greenland Sea Project.

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Streszczenie

Na podstawie rezultatów pomiarów CTD (in situ), wykonanych w czasie rejsów r/v „Oceania" w Morzach Norweskim i Grenlandzkim w latach 1986—1988 omówiono wybrane aspekty struktury termohalinowej oraz dynamiki mas wodnych wybranych rejonów. Przedstawiono przykłady zmian pól temperaturowych i zasoleniowych w czasie i przestrzeni oraz oceniono geostroficzny transport mas wodnych na obrzeżach Morza Norweskiego.