Flow across south and east boundaries of the Norwegian Sea*

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Water masses
Water and heat exchange
Norwegian Sea
Barents Sea

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Abstract

On the basis of the CTD vertical soundings carried out during the cruise of r/v 'Oceania' in summer 1988 in the Norwegian Sea the thermohaline structure of sea water is discussed. Estimates of the volume exchange of heat and water between the Norwegian Sea and the Atlantic Ocean and the Barents Sea are presented. Some ideas about the geostrophic circulation in the regions of observation are included in the paper.

1. Introduction

In summer 1988 during the cruise of r/v 'Oceania' the CTD vertical soundings were carried out at various hydrographic stations in the Norwegian Sea:

- in the region of the Faeroe and Shetland Islands (July 08–09),
- in the contact zone of the water masses of the Norwegian and Barents Seas (July 14–30), where the CTD survey area (polygon) is located.

The location of the hydrographic stations is presented in Figure 1. The chosen regions of the CTD observations play a very important role in the hydrological regime of the Norwegian Sea and the Arctic Seas. Through these areas the main part of the warm Atlantic waters is transported Northwards to the Barents and the Arctic Seas, where they create some climatological anomalies.

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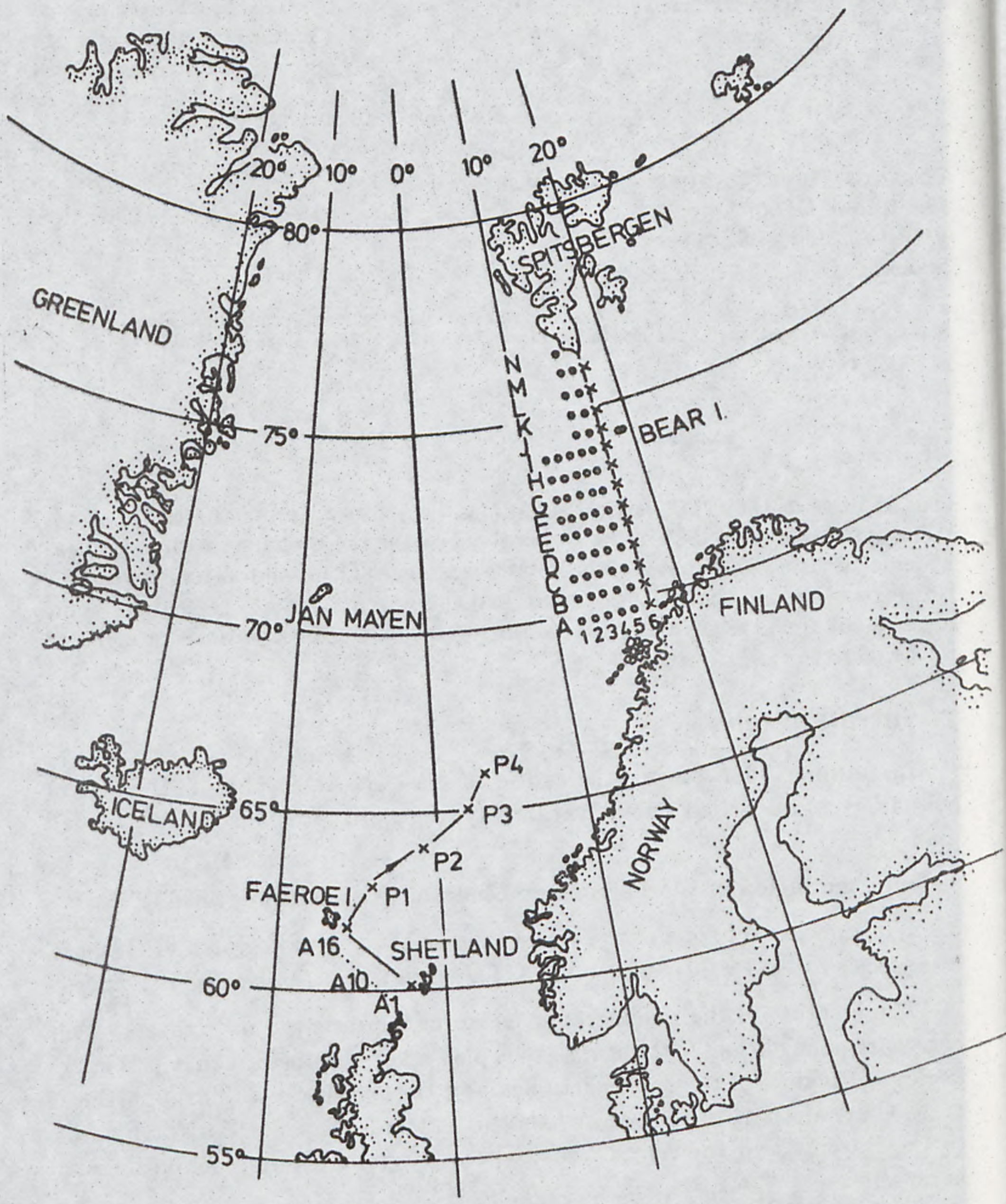

Fig. 1. Location of hydrographic stations examined during the cruise of r/v 'Oceania' in the Norwegian and Greenland Seas in summer 1988

In our paper we present some estimates of water and heat exchange between the Atlantic Ocean and the Norwegian Sea and the Norwegian and Barents Sea. Some remarks about the thermohaline structure of the sea water and geostrophic circulation in the regions are presented.

2. Materials and results

2.1. Faeroe–Shetland Islands Channel

Our measurements allow a preliminary estimation of the hydrological conditions and thermohaline structure of water masses in the vicinity of the Faeroe–Shetland Channel. Figure 2 presents the T–S diagram showing the water mass characteristics at the stations in the Channel. Some typical water masses previously observed in the region (Dooley and Meincke, 1981) can be identified in the diagram:

- North Atlantic Water (NAW): $T > 9°\mathrm{C}$, $S > 35.3 \cdot 10^{-3}$,
- Modified North Atlantic Water (MNAW): $T > 8°\mathrm{C}$, $S > 35.1 \cdot 10^{-3}$,
- Norwegian Sea Deep Water (NSDW): $T < -0.5°\mathrm{C}$, $S < 34.92 \cdot 10^{-3}$.

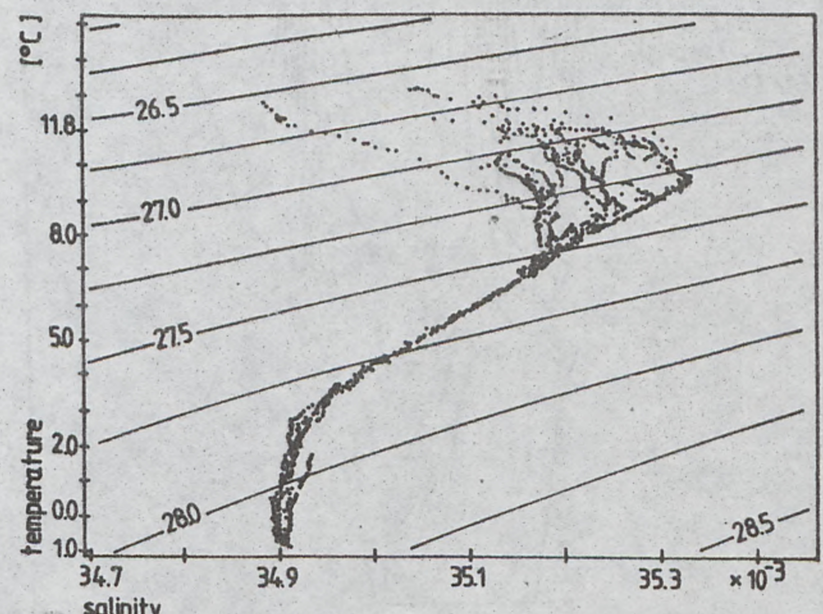

Fig. 2. T–S diagram for water masses in the hydrographic section in the Faeroe–Shetland Channel

Table 1. Water volume and heat transport through the hydrographic section Faeroe–Shetland Channel

Level of no motion	Water volume [$10^6\ m^3 \cdot s^{-1}$]			Heat volume [$10^{12}\ J \cdot s^{-1}$]		
	diff.	into A.O.	into N.S.	diff.	into A.O.	into N.S.
450 m	2.30	−2.14	4.44	21.3	−63.8	85.1
550 m	1.07	−3.12	4.20	21.3	−94.3	115.5
800 m	−0.64	−4.36	3.73	2.4	−122.7	125.2
1000 m	−0.91	−4.62	3.71	−0.6	−125.8	125.2
VAR(35)	3.74	−1.65	5.38	48.3	−49.4	97.8

Positive values were assumed for the volume transport directed towards the Norwegian Sea:
A.O. – Atlantic Ocean,
N.S. – Norwegian Sea,
VAR(35) – level of no motion, variable in the section according to the run of isohaline $35 \cdot 10^{-3}$.

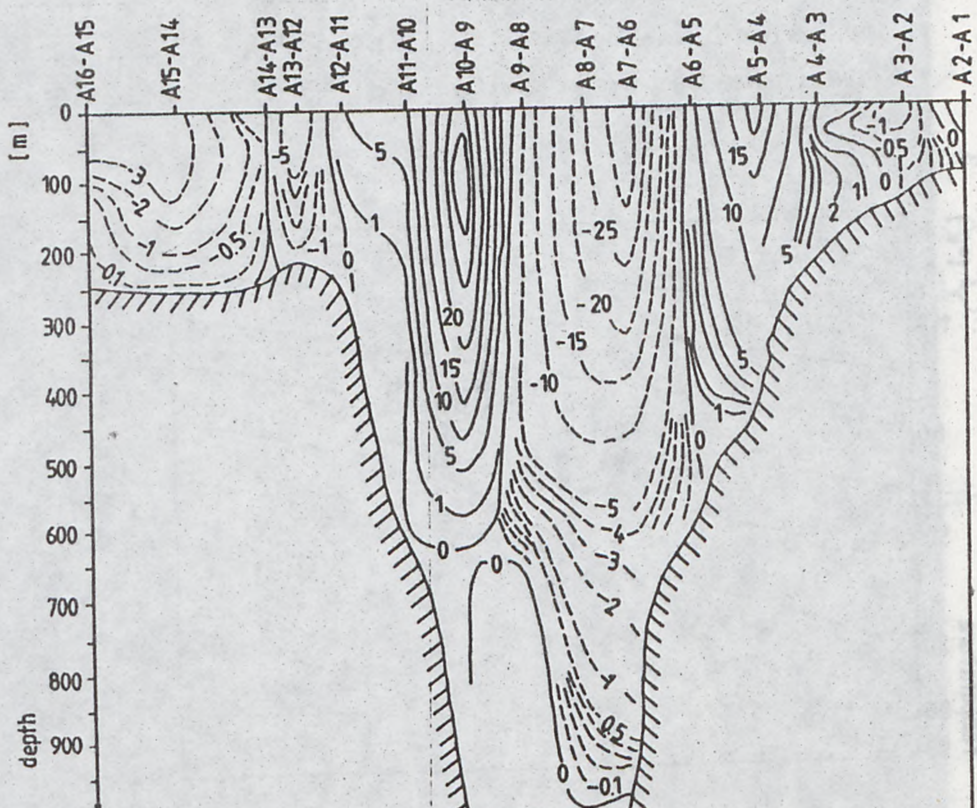

Fig. 3. Distributions of the current velocity component [$cm \cdot s^{-1}$] perpendicular to the plane of the section (positive values towards the Norwegian Sea) for the level of no motion chosen at a depth $z = 1000$ m

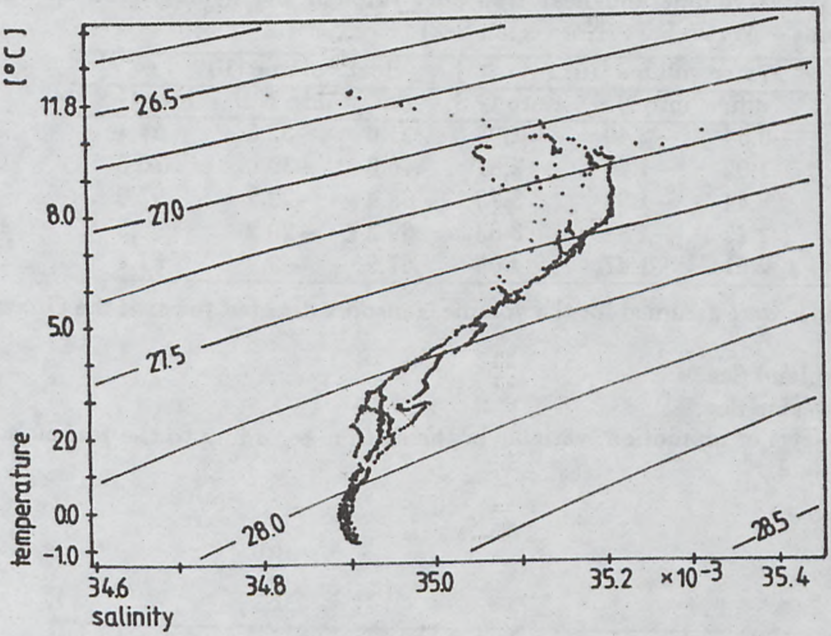

Fig. 4. *T–S* diagram for water masses in the hydrographic section Faeroe Islands – North–East (Norwegian Sea)

Assuming that the fluctuations in the course of isotherms and isohalines, (probably due to tidal waves) were less significant for the modifying of the structure and dynamics of water than the disturbances due to mesoscale eddies moving in the region, the currents' velocity component, perpendicular to the plane of the hydrographic section in the Channel, was estimated by the classical dynamic method (Zubov and Mamayev, 1956). Table 1 presents the calculated values of water volume and heat transport through the hydrographic section in the Channel. Figure 3 shows, as an example, the velocity component distribution in the section for the case of the level of no motion chosen at a depth $z = 1000$ m. Analysis of Table 1 and Figure 3 indicates the complexity of the structure of water dynamics in the Channel. A considerable water transport (with characteristics typical of the Atlantic waters) to the Atlantic Ocean from the Norwegian Sea is worth emphasizing. It is probably caused by eddies occuring in the Channel area and transporting horizontally great amounts of heat and water.

Waters flowing from the Atlantic Ocean through the Channel between Iceland and the Faeroe Islands, around the Faeroe Islands from the North, and back through the Faeroe–Shetland Channel to the Atlantic Ocean, play

Table 2. Water volume and heat transport through the hydrographic section Faeroe Islands – North–East (Norwegian Sea)

Level of no motion	Water volume [10^6 m$^3\cdot$s^{-1}]			Heat volume [10^{12} J$\cdot$s^{-1}]		
	diff.	into N.S.	into G.S.	diff.	into N.S.	into G.S.
450 m	−0.54	−2.49	1.95	21.6	−32.5	54.1
550 m	1.02	−1.79	2.81	46.3	−30.0	76.3
800 m	2.44	−1.34	3.78	68.4	−29.2	97.6
1000 m	2.49	−1.34	3.83	69.3	−29.2	98.5
VAR(35)	2.61	−1.47	4.08	57.9	−9.9	67.1

Positive values were assumed for the volume transport directed towards the Greenland Sea:
G.S. – Greenland Sea,
N.S. – Norwegian Sea,
VAR(35) – level of no motion, variable in the section according to the run of isohaline $35 \cdot 10^{-3}$.

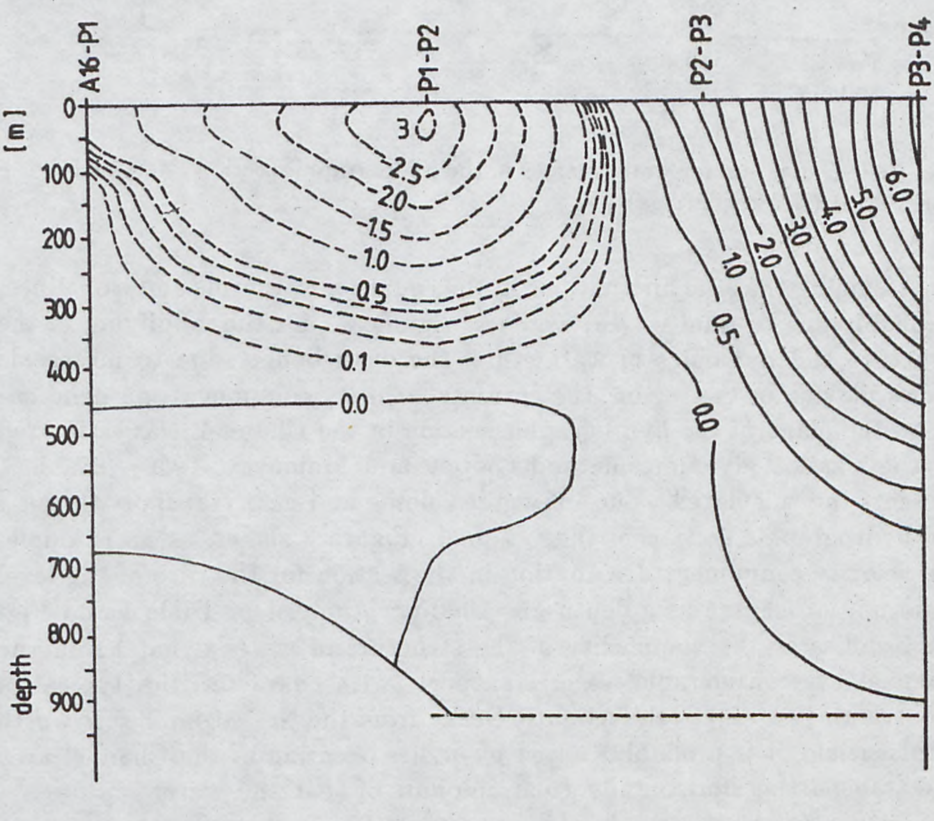

Fig. 5. Distributions of the current velocity component [cm$\cdot$s^{-1}] perpendicular to the plane of the section (positive values towards the Greenland Sea) for the level of no motion chosen at a depth $z = 1000$ m

a significant part here. This is illustrated by the measurements (July 09–12, 1988) in another hydrographic section –the Faeroe Islands – North–East. Figure 4 presents the T–S diagram characterizing the complex thermohaline structure of water in the section. As in the Faeroe–Shetland Channel, NAW, MNAW and NSDW water masses have been observed. Velocity components as well as water volume and heat transport through the section were estimated analogically (Tabl. 2 and Fig. 5). The analysis of Figure 5 and Table 2 indicates that the assumptions on the circulation of Atlantic waters in the vicinity of the Faeroe Islands – a significant part probably comes back to the Atlantic Ocean through the Faeroe–Shetland Channel without important modifications (Sukhovey, 1977) – have been corrected.

The discussed results give the approximate values of water volume and heat transport between the Atlantic Ocean and the Norwegian Sea.

2.2. CTD survey area between Spitsbergen and Scandinavian Peninsula

The measurements of temperature and salinity enable the estimation of the dynamics and structure of water masses in the region.

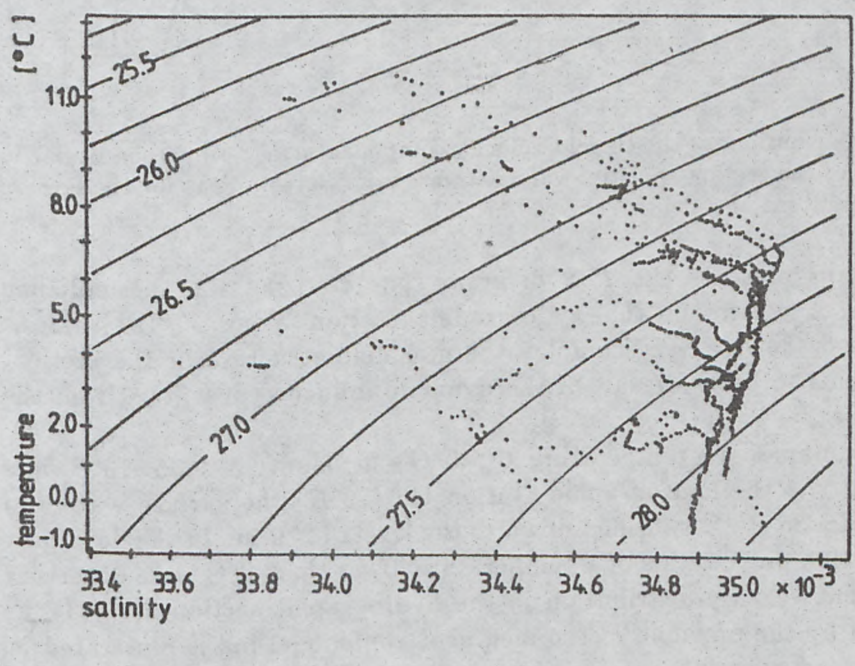

Fig. 6. T–S diagram for water masses in the hydrographic section Spitsbergen–Scandinavian Peninsula (along 17°)

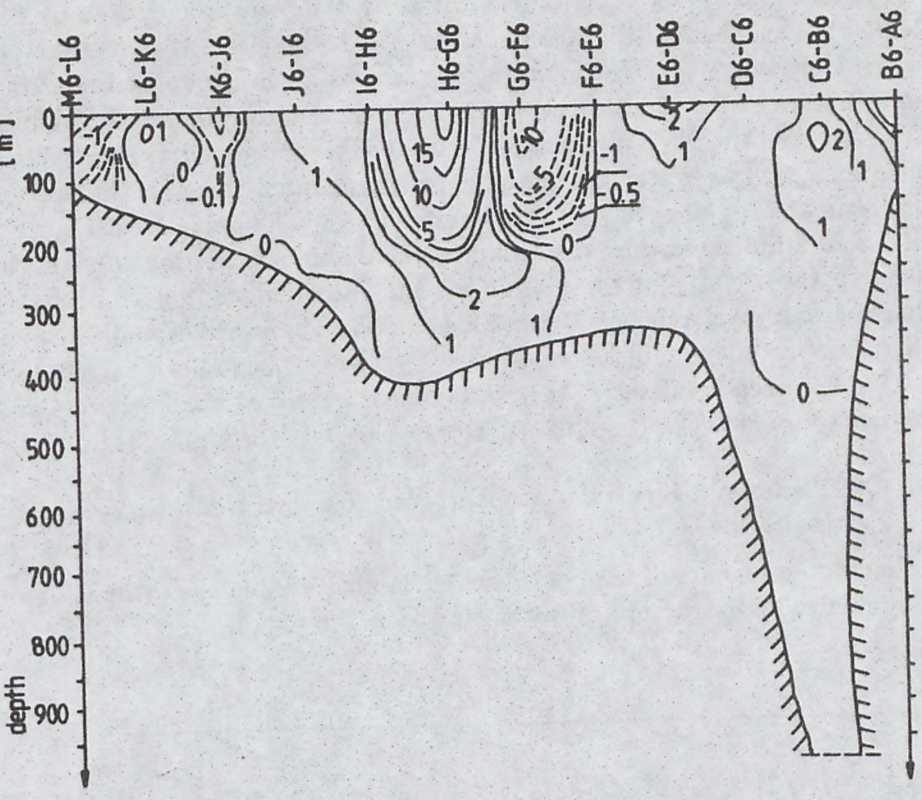

Fig. 7. Distributions of the current velocity component [cm · s^{-1}] perpendicular to the plane of the section (positive values towards the Barents Sea) for the level of no motion chosen at a depth $z = 1000$ m

Figure 6 presents the T–S diagram characterizing the thermohaline structure of waters in the hydrographic section along 17°E. Analysis of Figure 6 shows a very complex thermohaline structure in the section, which seems to be the result of the dynamic influence of waters from the Barents Sea.

Water masses of a temperature $T > 0$°C and salinity $S > 35 \cdot 10^{-3}$ were dominant. At the hydrographic Station G6 (73°N) the surface waters of salinity $S > 35 \cdot 10^{-3}$ subsided down to the level of 220 m. In the deep part of the section only waters of a temperature lower than 0°C were observed. The current velocity distribution in the hydrographic section along 17°E, estimated by the previously described geostrophic method is illustrated in Figure 7. A strong anticyclonic eddy can be seen, which is probably one of the causative factors of the complexity of water structure in this sea area (Fig. 6).

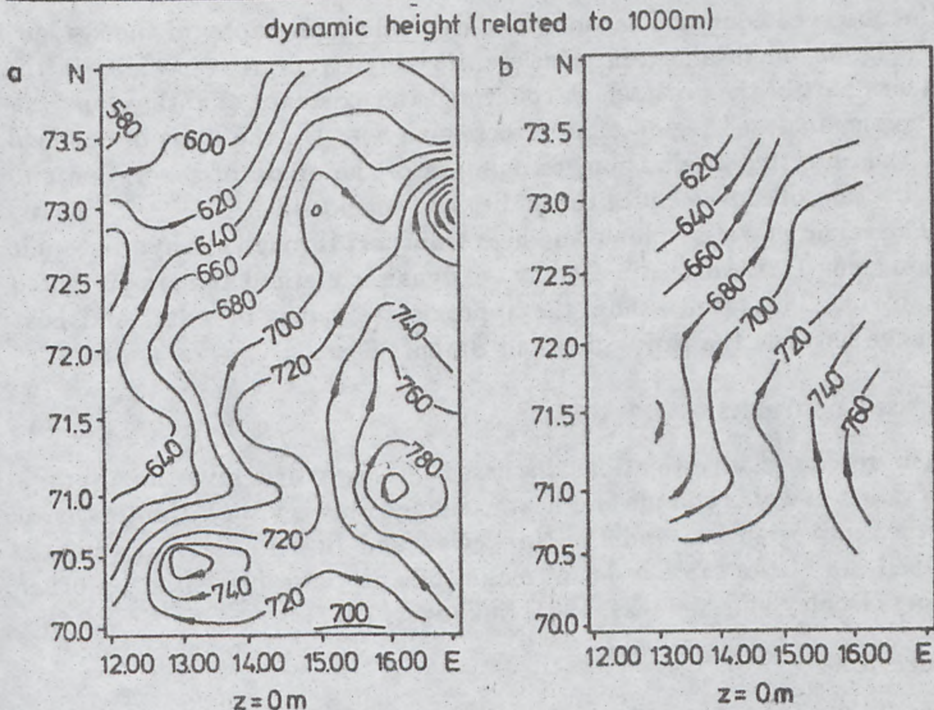

Fig. 8. Dynamic topography at the sea surface relative to the depth $z = 1000$ m: a – without smoothing, b – with smoothing using a Laplacian type operator

The dynamic topography of the sea surface in the CTD area is presented in Figure 8a to illustrate the special pattern of geostrophic circulation. In the field of the geostrophic flow some anticyclonic eddies can be found, probably modifying the temperature and salinity fields within the area. The net of hydrographic stations in the area was relatively sparse, therefore it may be difficult to accept the observed eddies, located around the separate net nodes, as significant. The field of dynamic topography of the sea surface was smoothed with a Laplacian type operator to estimate the importance

Table 3. Water volume and heat transport through the hydrographic section Spitsbergen–Scandinavian Peninsula (along 17°E)

Level of	Water volume [10^6 $m^3 \cdot s^{-1}$]			Heat volume [10^{12} $J \cdot s^{-1}$]		
no motion	diff.	into N.S.	into B.S.	diff.	into N.S.	into B.S.
400 m	1.64	−1.18	2.82	53.1	−29.8	82.9
1000 m	1.91	−1.11	3.02	59.7	−27.2	86.9

Positive values were assumed for the volume transport directed towards the Barents Sea:
N.S. – Norwegian Sea,
B.S. – Barents Sea.

of the observed eddies. The smoothed dynamic topography of the sea surface (Fig. 8b) maintained, in principle, its eddy-structure, especially in the southern part of the area, which confirmed the existence of anticyclonic eddies in the analyzed region of the Norwegian Sea. On the basis of our field data the objective localization, recognition of the origin of generation and the direction of movement of the eddies are not possible.

The values of water volume and heat transport through the hydrographic section along 17°E were estimated by the dynamic method and are presented in Table 3. The results show the approximate values of water and heat exchange between the Norwegian and Barents Seas.

3. Final remarks

The results of investigations discussed in this article give the approximate values of water volume and heat exchange between the Atlantic Ocean and the Norwegian Sea and the Norwegian and Barents Seas. Estimates obtained are of the same order of magnitude as those presented by other authors (Dooley and Meincke, 1981; Sukhovey, 1977).

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