Interannual variability in the hydrophysical fields of the Norwegian-Barents Seas confluence zone*

OCEANOLOGIA, No. 38 (1)
pp. 81–98, 1996.
PL ISSN 0078–3234

Arctic Seas
Hydrography
Variability

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Manuscript received September 14, 1995, in final form October 31, 1995.

Abstract

Every summer since 1987 (except 1990), the Institute of Oceanology has conducted oceanographic research in the area between Norway and Spitsbergen, and between 12 and 17°E from the board of r/v 'Oceania'.

The data collected show quite substantial, interannual variations in physical properties and transport. In the north-east corner of the area investigated (close to Storfjord) surface-water temperatures differed by > 6°C (2.6°C in summer 1993 and 8.8°C in summer 1992) and salinity by > 1.5 PSU.

The depth of the thermocline and temperature gradients fluctuated, as did the depth of the maximum salinity layer. Water transport across the 15°E meridian in the upper 1000 m layer calculated by geostrophic methods varied from 2.6 to 8.9 Sv eastwards and from 1.1 Sv to 5.1 Sv westwards.

The largest variations were observed in the surface waters and in the north-eastern and south-eastern parts of the confluence zone, *i.e.* in the areas most strongly influenced by Barents Sea waters. In the areas occupied by Norwegian-Atlantic waters and in deeper layers, conditions were much more stable.

1. Introduction

The Norwegian-Barents Sea opening plays a significant role in water, heat and salt exchange between GIN Seas and the Polar region. Along the Norway – Bear Island – Spitsbergen transect the cross-section is 163 km^2 in area (Hopkins, 1991) and is predominantely shallow, except for the Bjornoya Trough (> 500 m) south of Bear Island. According to the generally accepted

* This study was presented at the Nordic Seas Symposium, Hamburg, March 7–9, 1995.

picture of water circulation, Norwegian-Atlantic waters and Norwegian Coastal waters are transported into the Barents Sea, and Barents Sea waters towards the Norwegian Sea. Moving along the Norwegian slope, the Norwegian Atlantic Current (NAtC) splits into a northbound branch (the West Spitsbergen Current – WSC) and an eastward branch (the North Cape Current – NCC). These two currents carry Norwegian Atlantic Water (NwAtW) or simply Atlantic Water (AW) which, according to Helland-Hansen and Nansen (1909), has S > 35 PSU and T > 2°C. Close to the Norwegian coast the NCC carries fresher Norwegian Shelf Water (NwShW) with T = 2–13°C and S = 31–35 PSU. The mean volume of NwAtW transported by WSC calculated by the geostrophic equation varies from 1.1 Sv (Hill and Lee, 1957) to 3.2 Sv (Kislyakov, 1960), depending on the location of the transect and the depth of the reference level. Using current-meter data collected at 79°N during 1971–1972, Aagaard *et al.* (1973) and Greisman (1976) calculated respective WSC transports of 8.0 and 7.0 Sv (a minimum of 3 Sv in February and a maximum of 11 Sv in September). Hanzlick (1983) quotes a value of 5.6 Sv (max. 11.9 Sv in December, min. 1.4 Sv in March) at 79°N using current-meter data from 1976–1977 and hydrography. The volume of NwAtW transported by the North Cape Current is given by Timofeyev (1963) as 1.64 Sv and by Kudlo (1961) as 3.6 Sv. Using the geostrophic equation and TS data collected during the summers of 1988–1991, Jankowski and Schlichtholz (1993) calculated the transport in the confluence zone as varying from 1.4 to 6.7 Sv.

The above workers do not distinguish between NwAtW and NwShW in their calculations. Some NwAtW (*ca* 0.27 Sv according to Timofeyev, 1963) moves into the Barents Sea through the northern part of the South Cape – Bear Island section, as well as with the South Spitsbergen Current. Barents Sea Water is carried into the Norwegian Sea principally by the Bjornoya Trough Current along the northern slope of the Bjornoya Trough and by the East Spitsbergen Current south of the South Cape. Two water types are predominantly transported with these currents: Barents Sea Atlantic Water (BrAtW: T:2–5°C, S > 34.8 PSU) and Barents Sea Polar Water (BrPW: T ≈ 1–3°C, S < 34.4 PSU) (Hopkins, 1991). As a result of local cooling of BrAtW of T < 1°C and S = 35 PSU (Dietrich, 1969; Dickson and Doddington, 1970), Barents Sea Bottom Water (BrBW) is also found in the confluence zone, mostly in the deepest part of the Bjornoya Trough.

Waters tend to recirculate, especially around Bear Island and through the South Cape – Bear Island passage. Timofeyev (1993) estimated the transport of Barents Sea waters into the GIN Seas at 0.94 Sv. Kudlo gives a value of 3.1 Sv for transport returning via the Bjornoya Trough Current.

Jankowski and Schlichtholz (1993) calculated the geostrophic transport from the Barents Sea as varying from 0.8 to 5.2 Sv across the 15°E meridian.

2. Data and methods

Every summer since 1987 (except 1990) oceanographic measurements have been made by r/v 'Oceania' in the area between Norway and Spitsbergen, and between 13°E and 17°E (Fig. 1).

CTD stations were located at every 30′ latitude and 1° longitude. Guideline 8709 and Sea-Bird 9/11 instruments were used. Most of the records were limited to 1000 m depth by the cable length, except the 1993–1994 casts, which extended down to nearly 2000 m. Readings were recorded on a 486 PC and averaged every 1 and 5 dbars. In most cases the 1000 dbar no-motion level was chosen for the geostrophic calculations.

3. Interannual variability

3.1. Temperature

A quite substantial temperature variability was recorded in the upper water layers (Fig. 2). In the north-eastern corner of the area investigated, *e.g.* between Bear Island and the southern tip of Spitsbergen the differences in surface-layer temperature were considerable – as much as 5–6°C – and even higher (max. 6.2°C at station L4). The next highest variability was observed in the south-eastern corner of the study area – up to 2–3°C. The most stable temperatures were recorded in the western and central parts of the area: differences were below or around 1°C. The highest summer surface-layer temperatures were recorded in 1992, the lowest such temperatures in 1994 in the southern part and in 1993 in the northern part of the study area.

At 100 m depth, temperatures varied much less than at the surface, the lowest amplitude recorded being 0.2°C at station B3 and the highest – 3.4°C at J6. In the area to the south of Bear Island the temperature was much more stable (amplitude 0.2–0.7°C) than in the northern part of the study area (around and above 2°C). The southernmost transect A was an exception, the temperature variability being relatively high there.

At this and greater depths the highest summer temperature was recorded in 1992, the lowest in 1993. High temperatures were also registered in the summers of 1992 and 1994, and low ones in 1988 (Fig. 2). The magnitude of temperature variations decrease with increasing depth and below 200 m was very slight.

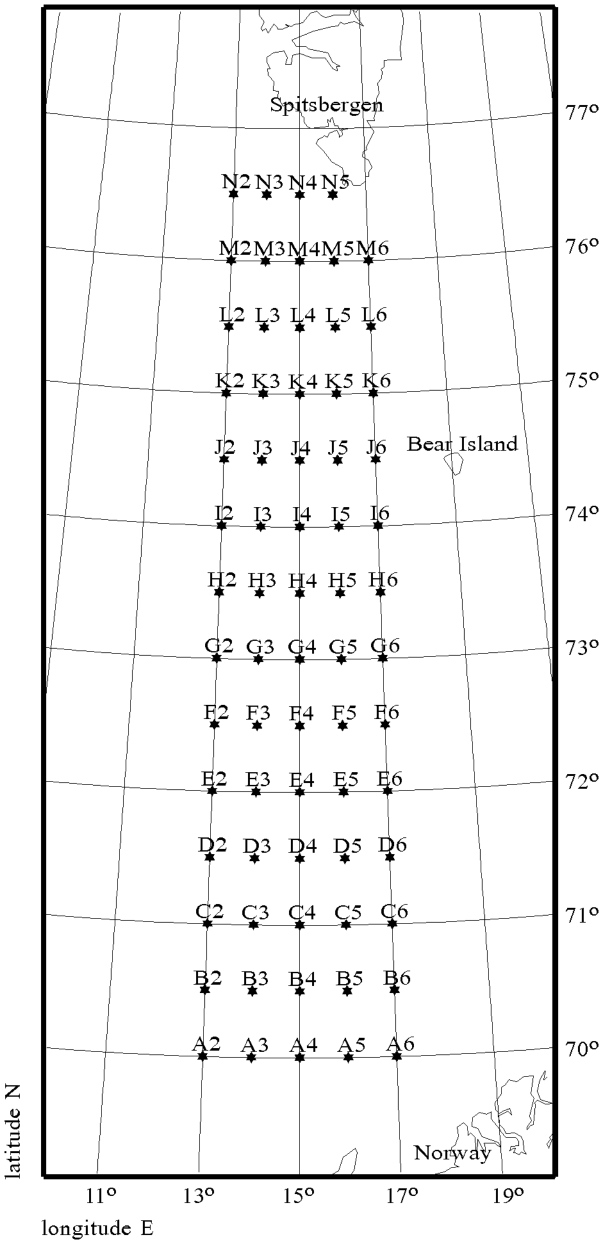


Fig. 1. The area investigated and stations grid

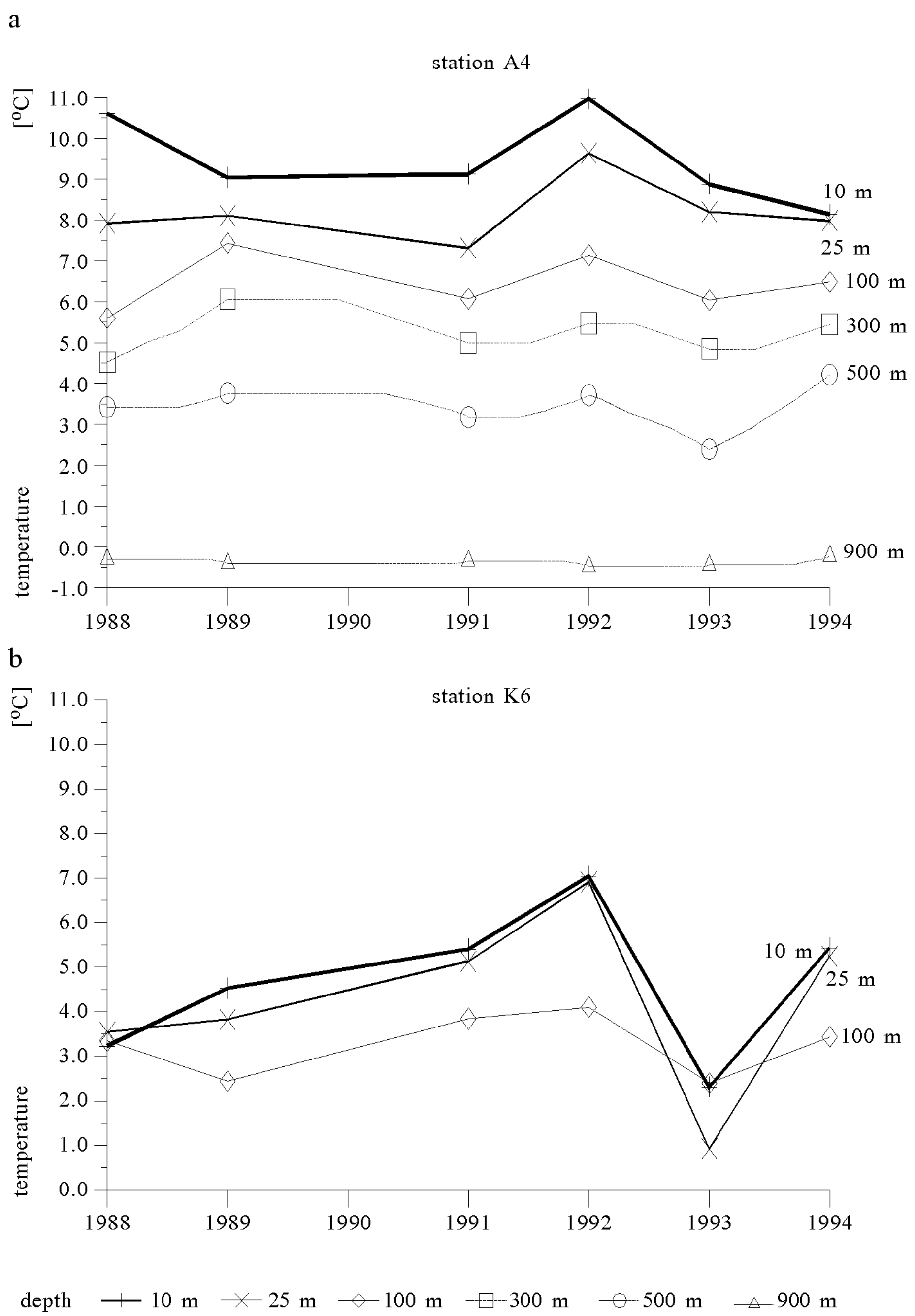


Fig. 2. Temperature variations at stations A4 (a) and K6 (b)

The thermocline was very weak (gradients < 0.1°C/m), and was not observed everywhere and each year. It was more often recorded in the west and south-west at depths ranging from 0–40 m to 40–80 m.

In the summer of 1994 the thermocline did not exist at all. The depth of the 2°C isotherm, which serves as the limit of Norwegian Atlantic Waters, varies from *ca* 300 to *ca* 750 m, and was, in general, deeper in the summer of 1989 and shallower in 1988 and 1992. Variations in these values develop differently in different parts of the area, which is an indication of the dominant influence of local dynamics.

The 2°C isotherm was usually found to lie deeper than the 35 PSU isohaline by 20 to 100 m, except in summer 1989, when 35 PSU was recorded 20 m to 200 m deeper than 2°C.

3.2. Salinity

As was the case with temperature, the greatest variations in salinity were observed in the surface layer (Fig. 3) and in the north-eastern corner of the area. There, salinity differences reached values of > 1 PSU, with a maximum of 1.65 PSU at station L5 (35.05 PSU in 1991 and 33.40 PSU in 1993). Smaller, but still quite considerable fluctuations in surface-water salinity were also observed in the south-eastern part (0.50–0.75 PSU). Variability was low (0.1–0.2 PSU) in the west-central and south-western sections of the study area, *i.e.* in the area under the influence of Atlantic waters. At station L2 nearly the same salinity was recorded every summer. The highest salinity was observed in the summer of 1991, the next highest in 1994; the lowest values were recorded in 1989 and 1993.

The amplitude of salinity variations decreases rapidly with increasing depth: at 100 m it is as low as 0.05–0.15 PSU, the highest values (0.50 PSU) being found in the south-eastern corner and in the area close to Bear Island.

The depth of the maximum salinity layer, which is the core of the Norwegian-Atlantic Water, varied within the 50–400 m range. The depth of its upper boundary ranged from 0 to 200 m and the layer itself was from 150 m to 850 m thick. This depth varied at different rates in different parts of the study area and it was difficult to find any regularity, except perhaps during the summer of 1989 when, nearly everywhere, Atlantic waters penetrated much deeper than in any other year.

3.3. The transport of heat and matter

The geostrophic transport of water, salt and heat is shown in Tab. 1. Large fluctuations of all the parameters are in evidence. At the southern boundary of the experimental area (transect A) northward water transport

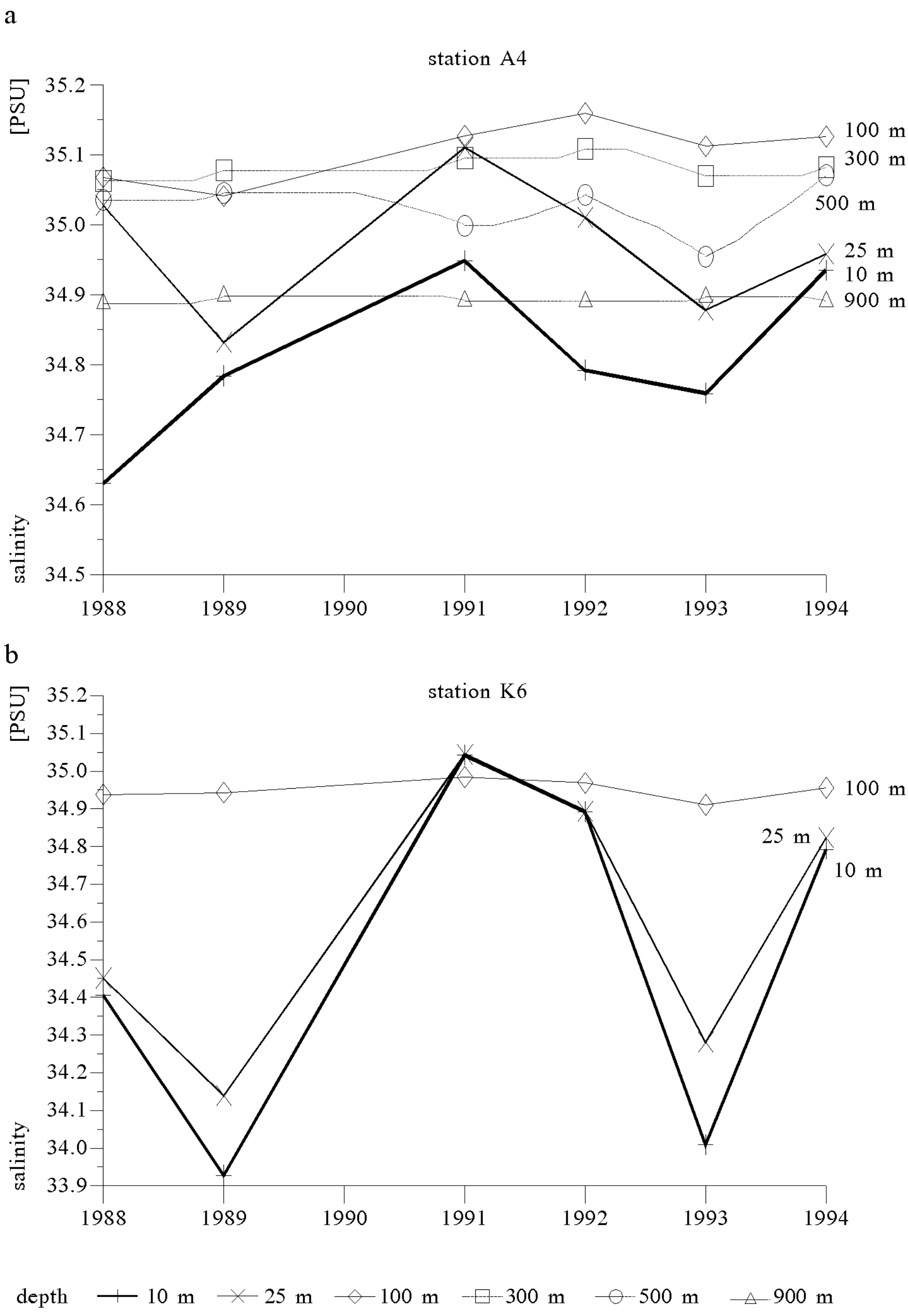
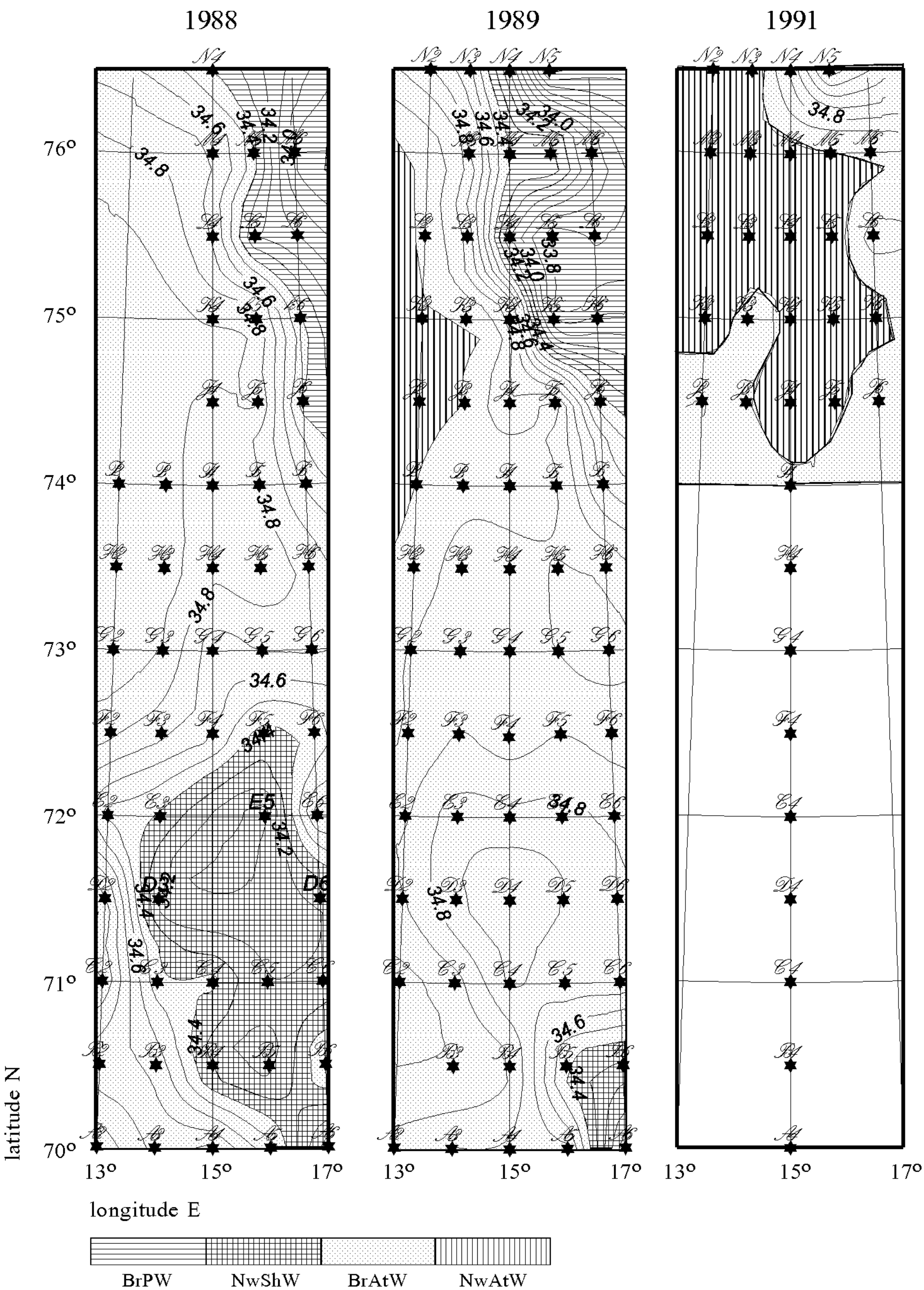


Fig. 3. Salinity variations at stations A4 (a) and K6 (b)

in the summer of 1989 was 3.1 Sv, whereas the previous year it had been only 0.1 Sv. Salt and heat transport display similarly large interannual variations. Unexpectedly, southward transport prevails over that moving in a northerly direction at this transect. In the northern section (transect J) the opposite is observed: northward transport prevails over southward, which seems to be the natural state of affairs. Transport values were high to the north and east during the summer of 1989 and to the south and west during 1992 and 1994. Eastward transport is the dominating feature at transect 4 along 74°N.

Table 1. Transport of water, salt and heat in the confluence zone

Transport/Year		1988	1989	1991	1992	1993	1994
			transect A (70°N)				
volume (Sv)	N	0.12	3.14	–	–	0.27	0.25
	S	1.21	0.72	–	–	1.27	1.98
salt (kg s^{-1} × 10^6)	N	4.50	112.93	–	–	9.91	8.79
	S	43.60	25.79	–	–	45.68	71.33
heat (MW × 10^6)	N	2.74	82.35	–	–	6.33	7.09
	S	21.72	13.74	–	–	26.30	44.62
			transect J (74°30′N)				
volume (Sv)	N	3.78	1.04	–	2.02	1.59	2.75
	S	0.13	0.51	–	0.75	0.20	0.21
salt (kg s^{-1} × 10^6)	N	135.85	37.64	–	72.60	57.34	98.90
	S	4.68	18.51	–	26.99	7.11	7.63
heat (MW × 10^6)	N	49.39	20.57	–	39.51	30.02	52.71
	S	0.92	6.56	–	11.18	3.18	3.66
			transect 4 (15°E)				
volume (Sv)	E	3.69	8.92	4.32	5.21	2.65	4.62
	W	1.15	4.93	3.23	5.10	2.86	2.12
salt (kg s^{-1} × 10^6)	E	132.83	321.46	155.72	187.49	95.52	166.44
	W	41.39	177.30	116.43	183.51	102.88	76.21
heat (MW × 10^6)	E	66.48	206.47	87.31	119.60	56.37	98.38
	W	18.88	110.37	65.15	112.46	56.18	41.80


1988
1989
1991
76°
75°
74°
73°
72°
71°
70°
latitude N
13°
15°
17°
longitude E
BrPW
NwShW
BrAtW
NwAtW

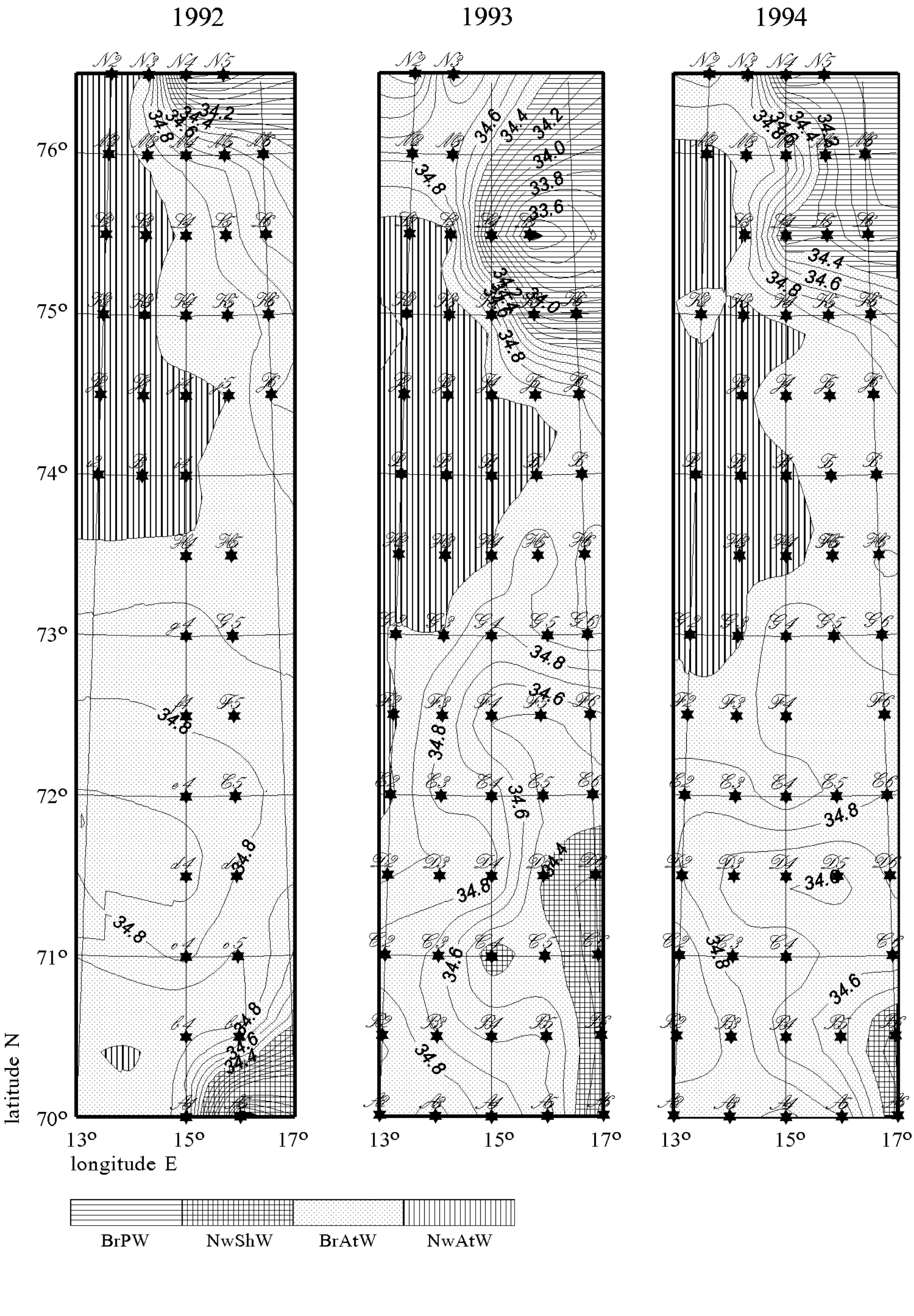
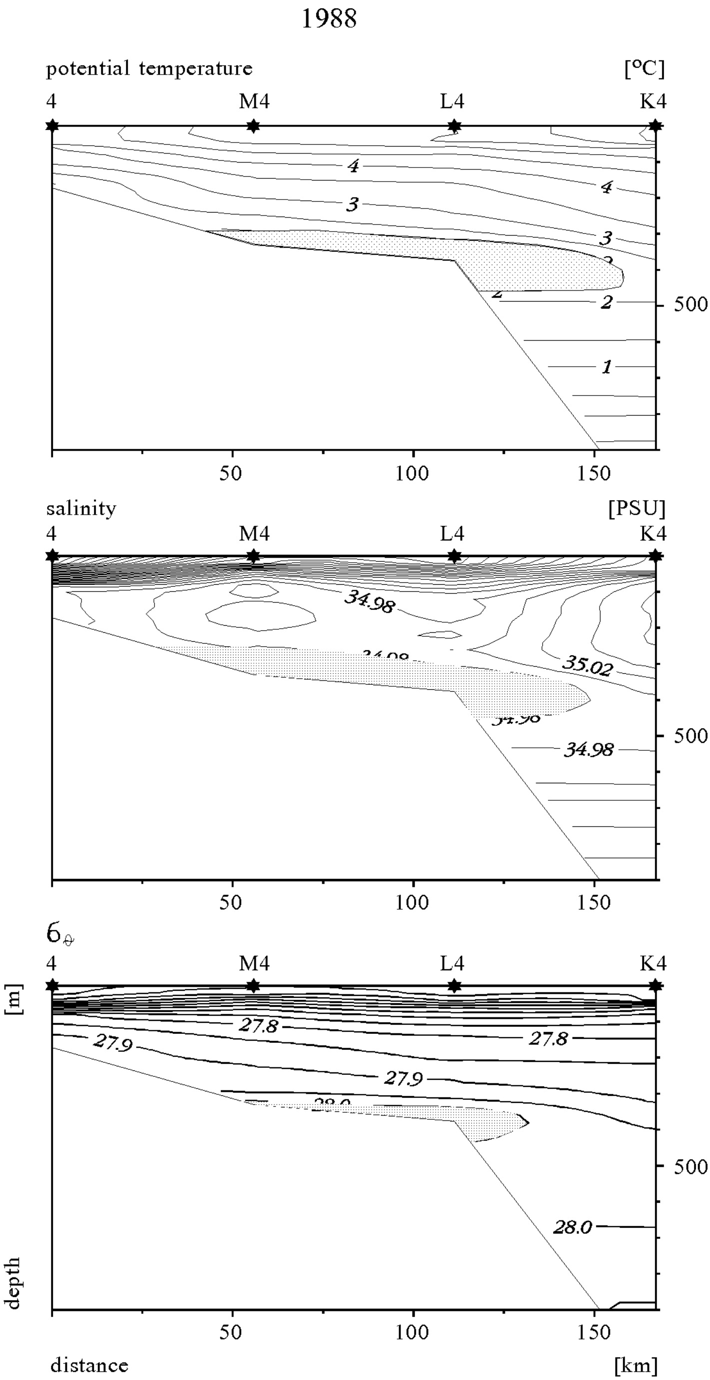
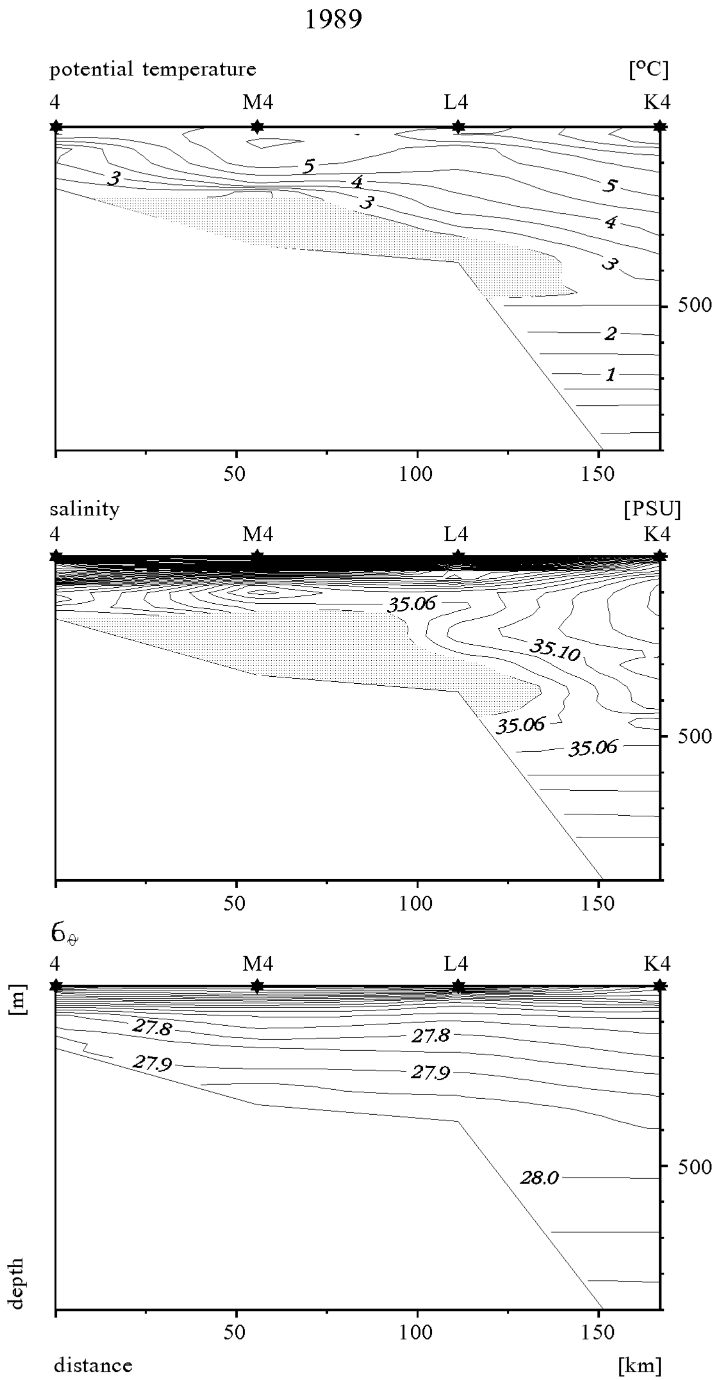


Fig. 4. Area occupied by different water masses (10 m depth)

a


1988
potential temperature
[°C]
4
M4
L4
K4
4
4
3
3
2
500
1
50
100
150
salinity
[PSU]
34.98
35.02
34.98
σθ
27.8
27.9
28.0
depth [m]
distance
[km]

b


1989
potential temperature
[°C]
4
M4
L4
K4
5
4
3
3
5
4
3
2
1
500
50
100
150
salinity
[PSU]
4
M4
L4
K4
35.06
35.10
35.06
35.06
500
50
100
150
σϑ
4
M4
L4
K4
27.8
27.8
27.9
27.9
28.0
500
depth [m]
50
100
150
distance
[km]

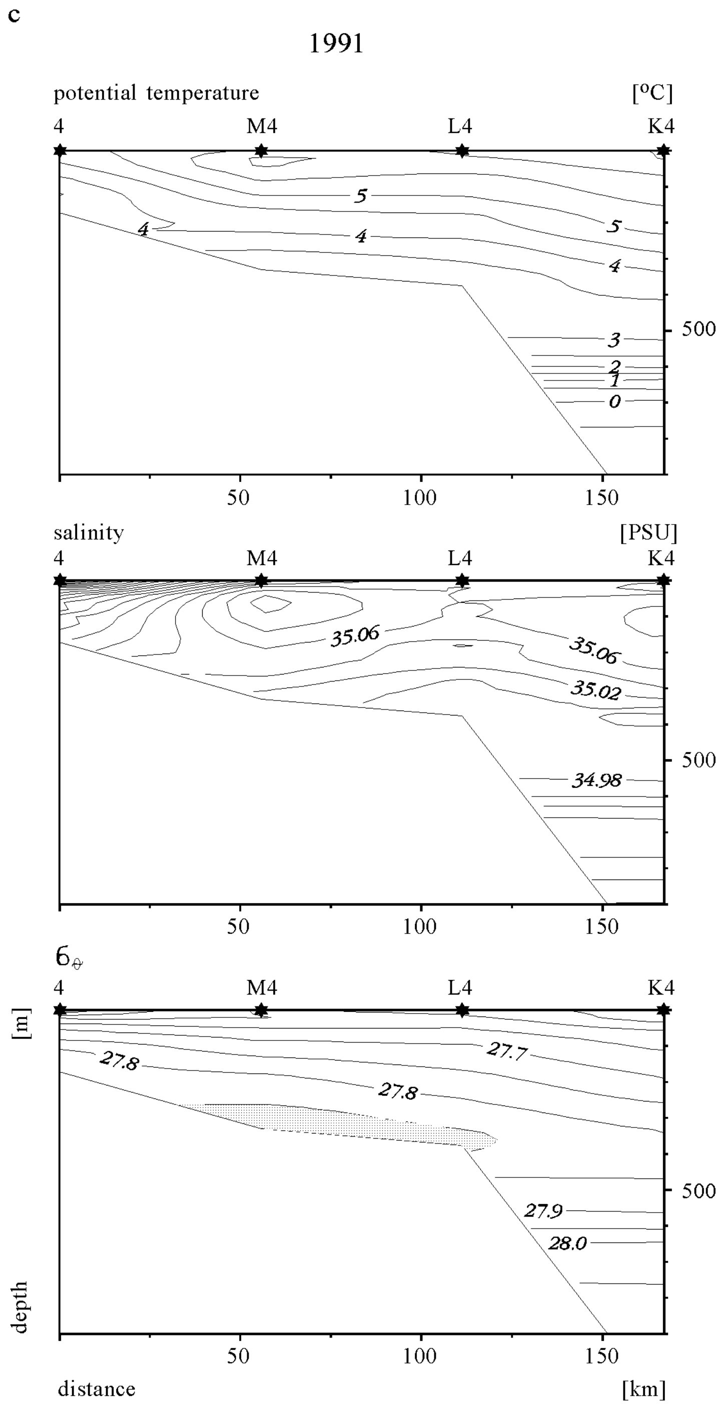
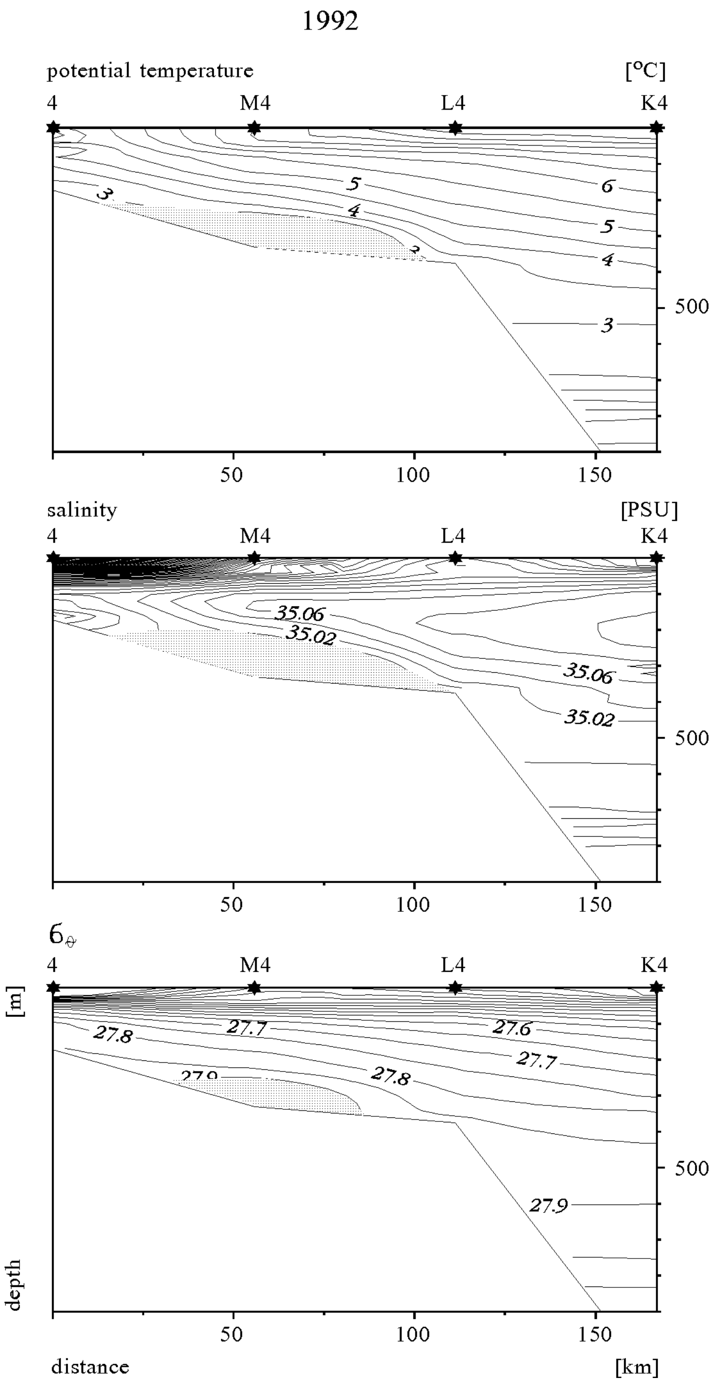
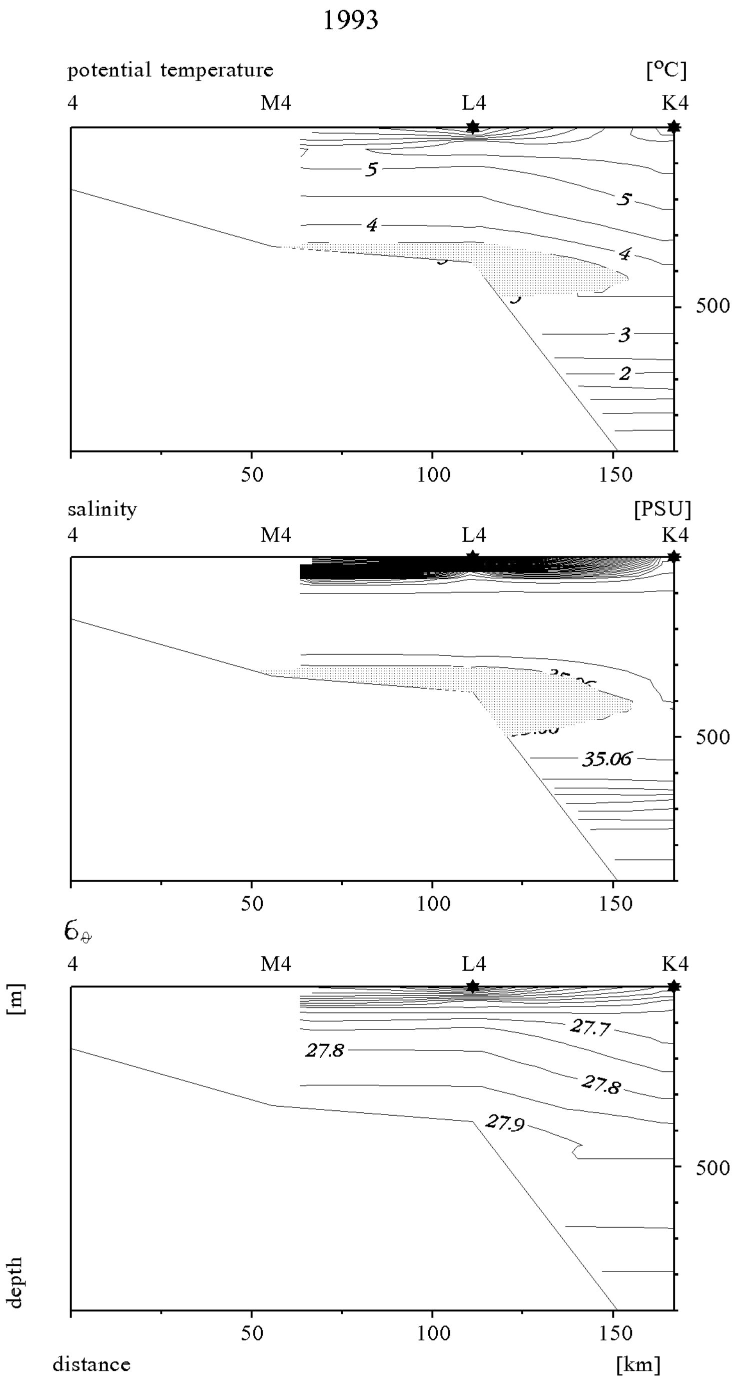


Fig. 5. Areas occupied by cold, fresher waters (shaded) on the temperature, salinity and density transects (northern part of cross-section 4); 1988 (a), 1989 (b), 1991 (c)

a


1992
potential temperature
[°C]
4
M4
L4
K4
3
5
4
3
6
5
4
500
3
50
100
150
salinity
[PSU]
4
M4
L4
K4
35.06
35.02
35.06
35.02
500
50
100
150
σθ
4
M4
L4
K4
[m]
27.8
27.7
27.6
27.7
27.9
27.8
500
27.9
depth
50
100
150
distance
[km]

b


1993
potential temperature
[°C]
4
M4
L4
K4
5
5
4
4
500
3
2
50
100
150
salinity
[PSU]
4
M4
L4
K4
35.06
500
50
100
150
σ_θ
4
M4
L4
K4
27.7
27.8
27.8
27.9
500
depth [m]
50
100
150
distance
[km]

c

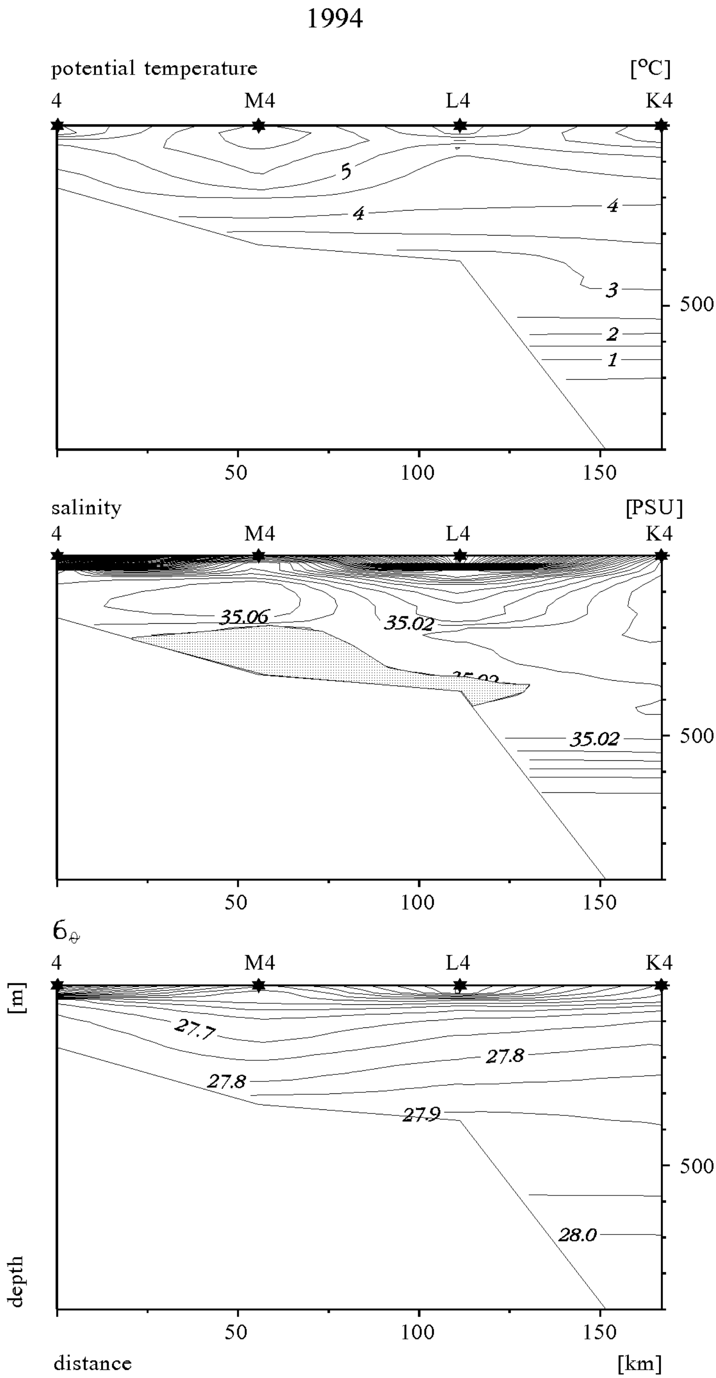


Fig. 6. Areas occupied by cold, fresher waters (shaded) on the temperature, salinity and density transects (northern part of cross-section 4); 1992 (a), 1993 (b), 1994 (c)

4. Discussion and conclusions

The data collected during six summer seasons (1988–1994) in the Norwegian-Barents Sea confluence zone show that the interannual variations in water properties and transport are very large. In some places the temperature differed by > 6°C, the salinity by > 1.5 PSU and transport by almost one order of magnitude. The largest fluctuations were observed in the north-eastern and south-eastern parts of the study area. The north-eastern part, adjacent to the Storfjord, periodically comes under the strong influence of very cold (*ca* 0°C and less) Polar Barents Water of very low salinity (< 34 PSU). Each inflow of such water lowers the temperature and salinity, which, however, rise again after some time as a result of mixing. The large fluctuations in the south-eastern corner are due to the variable inflow of Barents Atlantic Water, or Norwegian Shelf Water carried by the return current (Piechura, 1993). Especially large varations are broght about by the latter type of water. On the other hand, the most stable conditions are observed in the area dominated by Norwegian Atlantic Water (the west-central part) (Fig. 4).

It can be concluded that the fluctuations in the confluence zone are caused by changes in the general water circulation, and by the inflow and outflow of Atlantic and Polar waters in particular.

As an example, Figs. 5 and 6 show the interannual variations in temperature, salinity and density of bottom waters caused by the varying intensity of the inflow of cold, fresher waters from the north.

The water circulation in the confluence zone depends in turn on the general circulation in the Arctic seas and the North Atlantic Ocean.

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