Hydrographic and current measurements in the Fram Strait, August 1981

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The hydrographic (CTD) observations and pendulum current measurements obtained with M/S 'Lance' in August 1981 in the area west and north of Spitsbergen, are presented. The warm and saline northward flow, known as the West Spitsbergen Current, is found to follow the shelf break. In the Fram Strait the hydrographic structure is complicated because of eddies and other transient movements. The current measurements suggest a two-layer structure where the velocity vector rotates in opposite directions in the two layers with a period near the semidiurnal tidal period.

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Introduction

The passage between Svalbard and Greenland, the Fram Strait, is the main connection between the Arctic Sea and the world oceans. It is very significant as regards the heat and mass exchange in the Arctic Ocean, and the large quantity of heat carried north by the ocean current influences the climate of the arctic region as a whole.

The main positive heat flux through the passage is provided by Atlantic Water which is transported northward in the West Spitsbergen Current. Almost equally significant in the heat balance is the export of cold polar surface water and ice by the East Greenland Current (Mosby 1962; Vowinkel & Orvig 1970; Aagaard & Greisman 1975). A careful study of the heat and water balance requires that the measurements be performed across the whole passage, since a substantial part of the northflowing Atlantic Water never enters the Polar Basin proper, but recirculates in the passage (Aagaard & Greisman 1975; SCOR Working Group 58, 1979).

In August 1981 the Norwegian Polar Research Institute (NP) arranged a multidisciplinary expedition with M/S 'Lance' in the Svalbard waters. The expedition was in two parts. The first cruise was concentrated in the area north and west of Svalbard, while the second was in the northern Barents Sea. This brief preliminary report deals with the physical oceanography programme in the Fram Strait as part of a joint project between NP and the University of Bergen.

Severe ice conditions in the Fram Strait prevented us from extending the stations into the East Greenland Current. Furthermore, due to damage in the CTD cable, the stations after St. 31 extend only to 1650 m. This unfortunately reduced the possibility of studying the exchange of bottom water between the Greenland Sea and the Polar Basin, which is a subject of considerable interest (Aagaard 1981).

Direct current measurements were obtained in the deeper parts of the passage, but some important stations on the continental slope west of Svalbard could not be taken because of poor weather conditions.

The positions of the stations are shown in Fig. 1.

Methods

Vertical profiles (Fig. 2) of temperature and salinity were obtained using a Neil Brown CTD sonde lowered at a speed of approximately 1 m/s. With a sample rate of 30 times per second, this gives a sample approximately every third centimeter. The CTD salinities were standardized against water samples taken with a Rosette sampler attached to the sonde. The bottles were triggered from the laboratory on board and the CTD values were noted simultaneously from the deck unit.
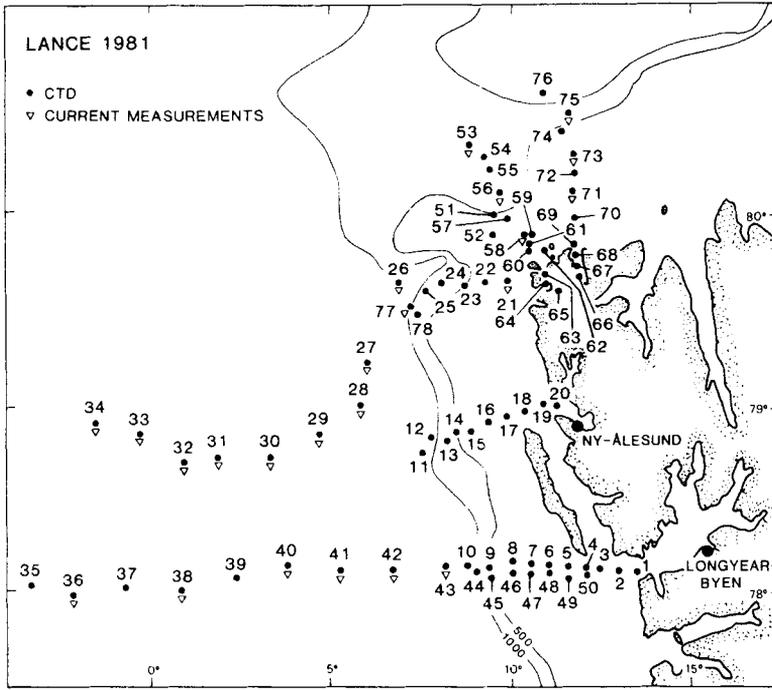
Fig. 1. Map showing the station positions. CTD stations are marked with circles and current measurements with triangles. Because of the presence of ice some sections do not follow a straight line.
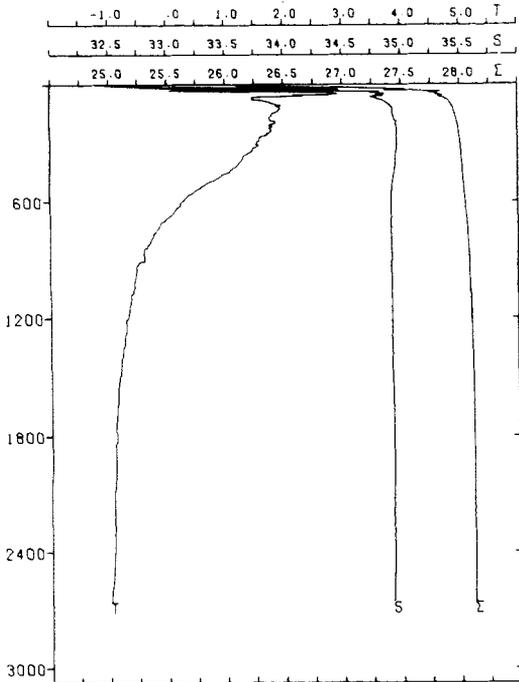
Fig. 2. CTD station 29, the deepest obtained on this cruise. Temperature (T), salinity (s) and density (Σ_θ) versus depth are shown. Except for a thin surface layer the water column is almost homogeneous.

At Station 25 we had to replace the CTD sonde after it hit the bottom and was damaged. Both CTDs seem to have worked well, and when obvious erroneous calibration points were removed we got r.m.s. errors of 0.006‰ and 0.005‰ in salinity.

Current measurements were obtained from pendulum current meters (Haamer 1974). These instruments consist of a plow-shaped wing into which a small plexiglass box is attached. Inside the box a compass needle is suspended on a string and the box is filled with a solution of gelatine, water, sugar and glycol.

Current measurements were performed by lowering a heavy weight (150–200 kg) on a 6 mm nylon rope, which passes through a meter wheel. The current meters were attached to the rope at predetermined distances from the weight. About 10 to 15 instruments were used at each station. Subsurface floats were tied to the rope above the upper current meter and a surface marker was attached. The rig was left unattended for about one hour to allow the gelatine solution to stiffen. The direction of the current was then determined by the compass needle orientation and the speed by the deviation of the string from the vertical.

The method has several drawbacks, especially when measurements are made in such cold and deep waters as in the Fram Strait. Because of currents the rope may deviate from the vertical, making the observation depths greater than intended. Because of the time needed to put out the system, there is also the risk that the gelatine solution will gel either during the actual lowering or while the system is approaching an equilibrium with the current field. To minimize these sources of error, the lowering was made at the highest possible speed; a system could be launched to 3000 m in 25–30 minutes. To increase the time available for lowering the current meters, the gelatine solution was kept as 'soft' as possible.

Since it is not possible to determine with certainty which observations have been affected by the factors described above, we will proceed as if all measurements giving sensible results are correct, while keeping in mind that uncertainty increases with increasing depth.

In spite of these drawbacks, pendulum measurements do provide a simple and easy method of obtaining an instantaneous picture of the current field at a station. The measurements presented here are the deepest so far made with pendulum current meters.

The CTD observations

The CTD stations (Fig. 1) define six sections which are presented here ordered from south to north.

The southernmost section along 78°N is presented in Fig. 3. Using the classification proposed by Swift & Aagaard (1981), we recognize several typical water masses. Below 800 m the Norwegian Sea Deep Water (NSDW) (t < −.4°C, 34.90‰ < S < 34.94‰) is the dominating water mass (see Fig. 3a and 3b). There is a salinity minimum at around 1000 m where the salinity is slightly below 34.90‰. This cold water mass (t ~ −1°C) is usually denoted as Greenland Sea Deep Water (GSDW) and is very dense (Fig. 3c). At the surface we find Polar Water (S < 34.4‰) which in summer may reach temperatures of up to +5°C.

The Atlantic Water (AW), defined by t > 3°C and S > 34.9‰, is found near the continental slope, sometimes penetrating up onto the shelf. This is demonstrated in Fig. 4. The geostrophic velocity field, which is computed assuming no motion at the maximum observation depth, shows

that the Atlantic Water flows northward (Fig. 3d). This flow is known as the West Spitsbergen Current (WSC).

On the sections taken farther north, we recognize the AW which follows the continental slope (see Figs. 5, 6 and 7, and 8). The geostrophic calculations also yield a fairly consistent WSC. In the northernmost section (Fig. 8), the AW seems to be colder and less saline than further south. This could indicate that the AW is modified by mixing as it flows northwards, but it is also possible that the current splits up and the main branch is north of St. 76.

The water masses in all sections are defined in the description of the section at 78°N. We would like to point out that at the surface on the outer parts of the two northernmost sections there is Polar Water with temperatures below 0°C. Polar Water is also found at the bottom of Raudfjorden (Fig. 8), and is probably produced there during winter.

On the two long sections the geostrophic velocities computed show a rather 'wiggly' nature (see Figs. 3d and 6d). This may be due to eddies in geostrophic balance with a radius of about 30 km. However, internal waves may distort the density field to such a degree that the apparent eddy structure is caused by the non-synoptic nature of the sections. This point is discussed further in the next section, where we present the current measurements.

Current measurements

Within the accuracy of the observed directions (±30°), the observations revealed thick vertical layers with approximately unidirectional flow. The direction and speed of the current in each of these layers were taken to be those found by vertical averaging over the layers. The resulting simplified current field is shown in plan view in Fig. 9. The surface currents, which are probably dominated by local winds, have not been included. It must be emphasized that this is a non-synoptic picture, and spans a period of 14 days.

The current field on the deeper (>2000 m) stations (29–43) has a marked two-layer structure. The thickness of the two layers is 500–1000 m. The velocity in a thinner (50–100 m) bottom layer often coincides with that in the lower main layer, but on two stations (29, 35) it is in the opposite
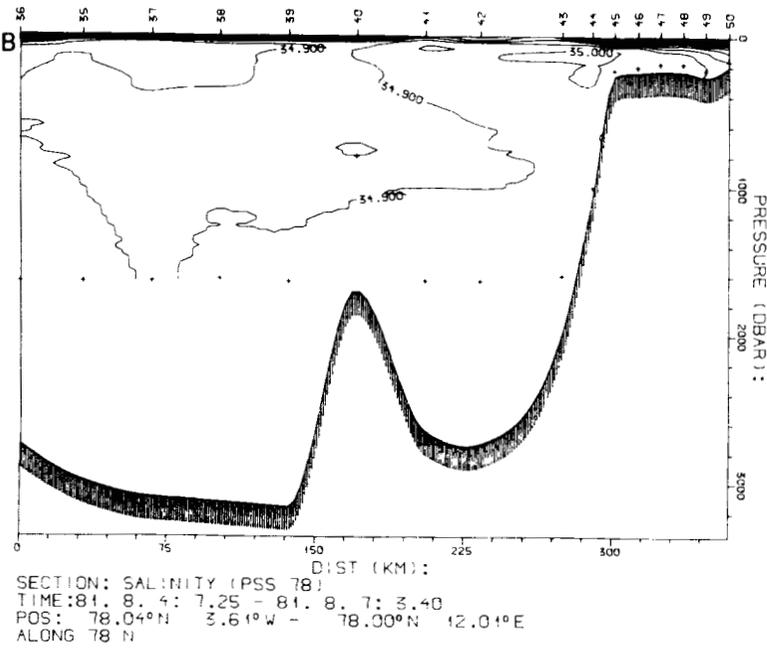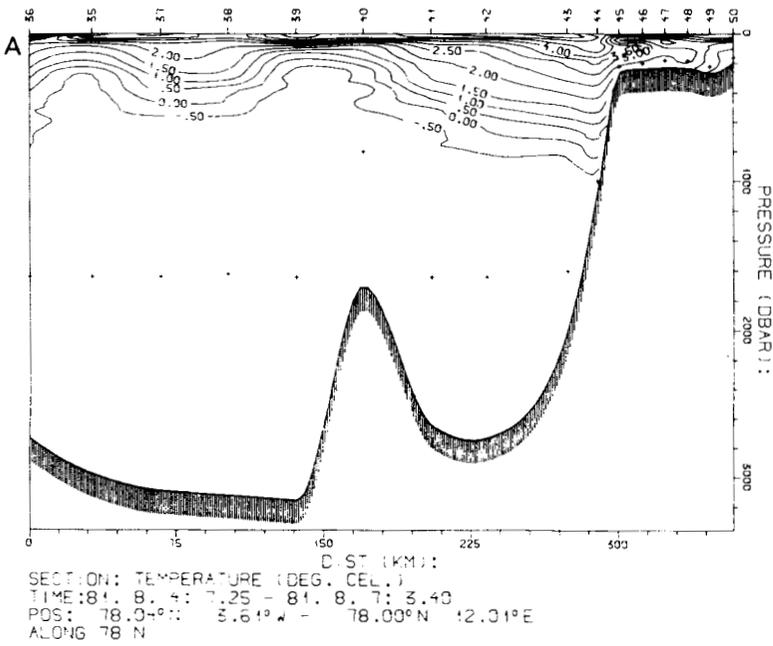
Fig. 3. Contours of (A) temperature, (B) salinity, (C) density, and (D) geostrophic velocity computed with zero at maximum observation depth based on the CTD section along 78°N defined by Stations 36–50. Maximum observation depths are marked with crosses.
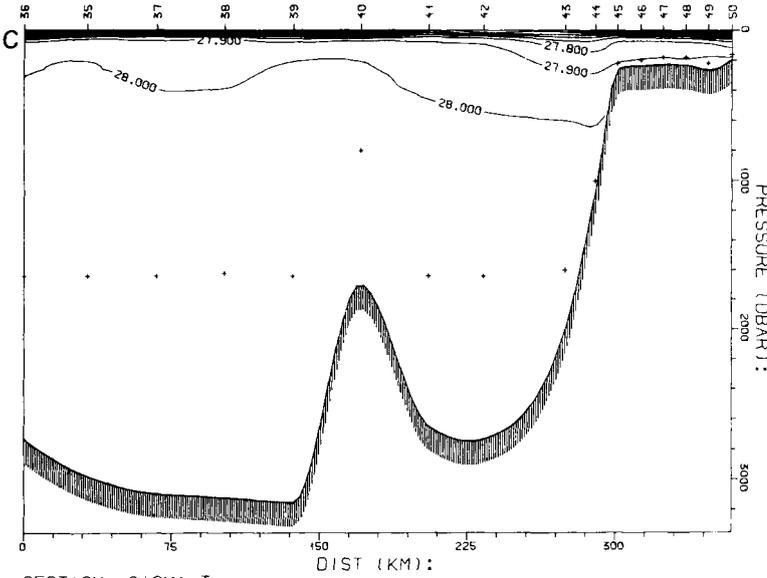
SECTION: SIGMA-T.
TIME:81. 8. 4: 7.25 - 81. 8. 7: 3.40
POS: 78.04°N   3.61°W -   78.00°N 12.01°E
ALONG 78 N
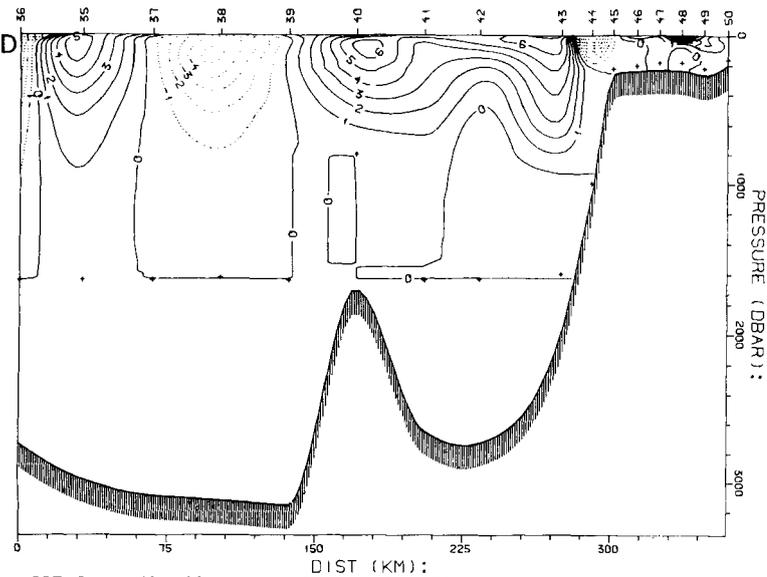
SECTION: GEOSTROPHIC VELOCITY (CM/SEC.)
TIME:81. 8. 4: 7.25 - 81. 8. 7: 3.40
POS: 78.04°N   3.61°W -   78.00°N 12.01°E
ALONG 78 N
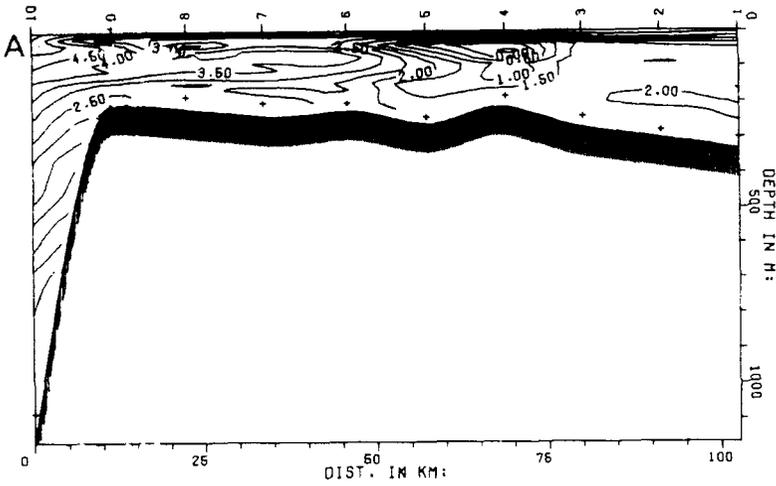
TEMPERATURE IN DEG. CEL.
SECTION   ALONG 78   78.13°N   8.99°E - 78.13°N   13.49°E
DATE: JULY 28 - 29, 1981
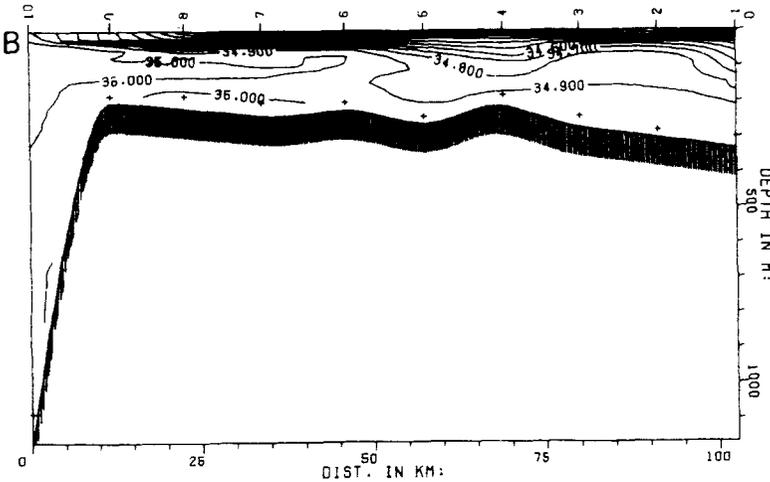
PRACTICAL SALINITY
SECTION   ALONG 78   78.13°N   8.99°E - 78.13°N   13.49°E
DATE: JULY 28 - 29, 1981

Fig. 4. Same as Fig. 3 but based on the section along 78°N defined by Stations 1–10. Stations 10–14 are in the same position as 44–50. Note the different scales on the axis.

direction. These deep measurements, however, are rather unreliable (see discussion above). The directions of flow in the two main layers change considerably from station to station. The observed speeds are rather high – 10 cm/s – and vary only a little with depth.

If east-west sections drawn from Stations 26–34 and 35–43 (Figs. 10, 11) are compared with the computed geostrophic sections (Figs. 6d, 3d), the agreement is poor. Neither the magnitude of the current nor the vertical shear show any significant correspondence. The current measurements give a marked two-layer structure on the southern section (Fig. 11) with a southward moving upper layer above a northward flow in the lower layer. On the northern section (Fig. 10) the
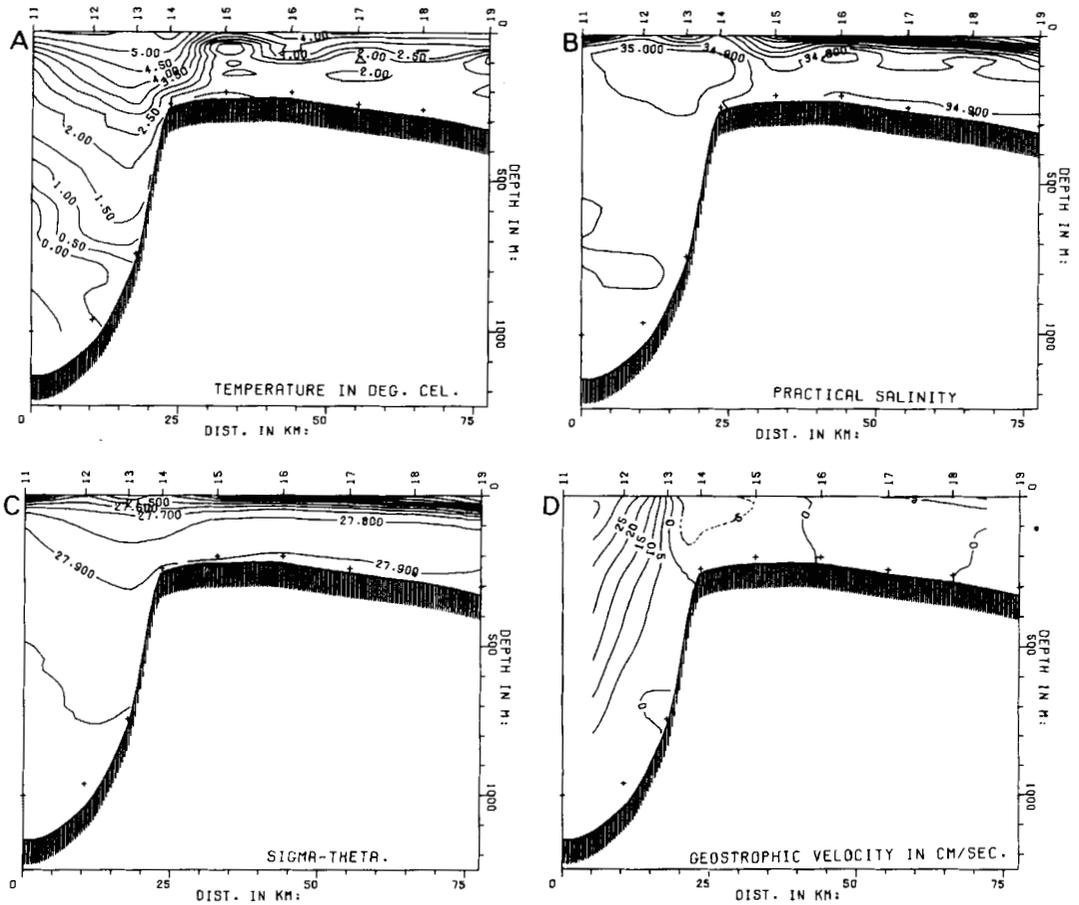
Fig. 5. As Fig. 3 for Stations 11–19.

direction of flow changes in both layers from station to station, suggesting the presence of eddies.

Just as internal waves may distort the density field and affect the geostrophic computations, transient motions such as tides may dominate the current field. With comparatively few stations distributed over such a long period (10 days), it is almost impossible to separate time and space variations and identify mean and transient motions.

In order to proceed we make the following hypotheses:

(a) Semidiurnal tidal motion (M2) is the dominant periodic motion in the area.
(b) The wavelength of the periodic motion is so large that all stations have the same phase.

This permits us to use all stations as one time series taken at a single station.

Tidal motions in broad basins may be described by long gravity waves which are affected by the rotation of the earth. We therefore compute the angular velocity necessary to give the observed change in current direction between the stations. Since we are looking for semidiurnal tidal motions, 360° has been added to the observed change of angle if the time difference between two stations is greater than 12 hours. The angle between the currents in the two layers changes from station to station, indicating a baroclinic velocity field. Assuming that the velocity vector turns clockwise in the upper layer and counter-clockwise in the lower layer, we find that the average angular velocity in the upper layer is −

TEMPERATURE IN DEG. CEL.
SECTION   ALONG 79.4   78.98°N   1.51°W - 79.67°N   10.00°E
DATE: JULY 31 - AUGUST 3. 1981

PRACTICAL SALINITY
SECTION   ALONG 79.4   78.98°N   1.51°W - 79.67°N   10.00°E
DATE: JULY 31 - AUGUST 3. 1981

GEOSTROPHIC VELOCITY IN CM/SEC.
SECTION   ALONG 79.4   78.98°N   1.51°W - 79.67°N   10.00°E
DATE: JULY 31 - AUGUST 3. 1981

SIGMA-THETA.
SECTION   ALONG 79.4   78.98°N   1.51°W - 79.67°N   10.00°E
DATE: JULY 31   AUGUST 3. 1981
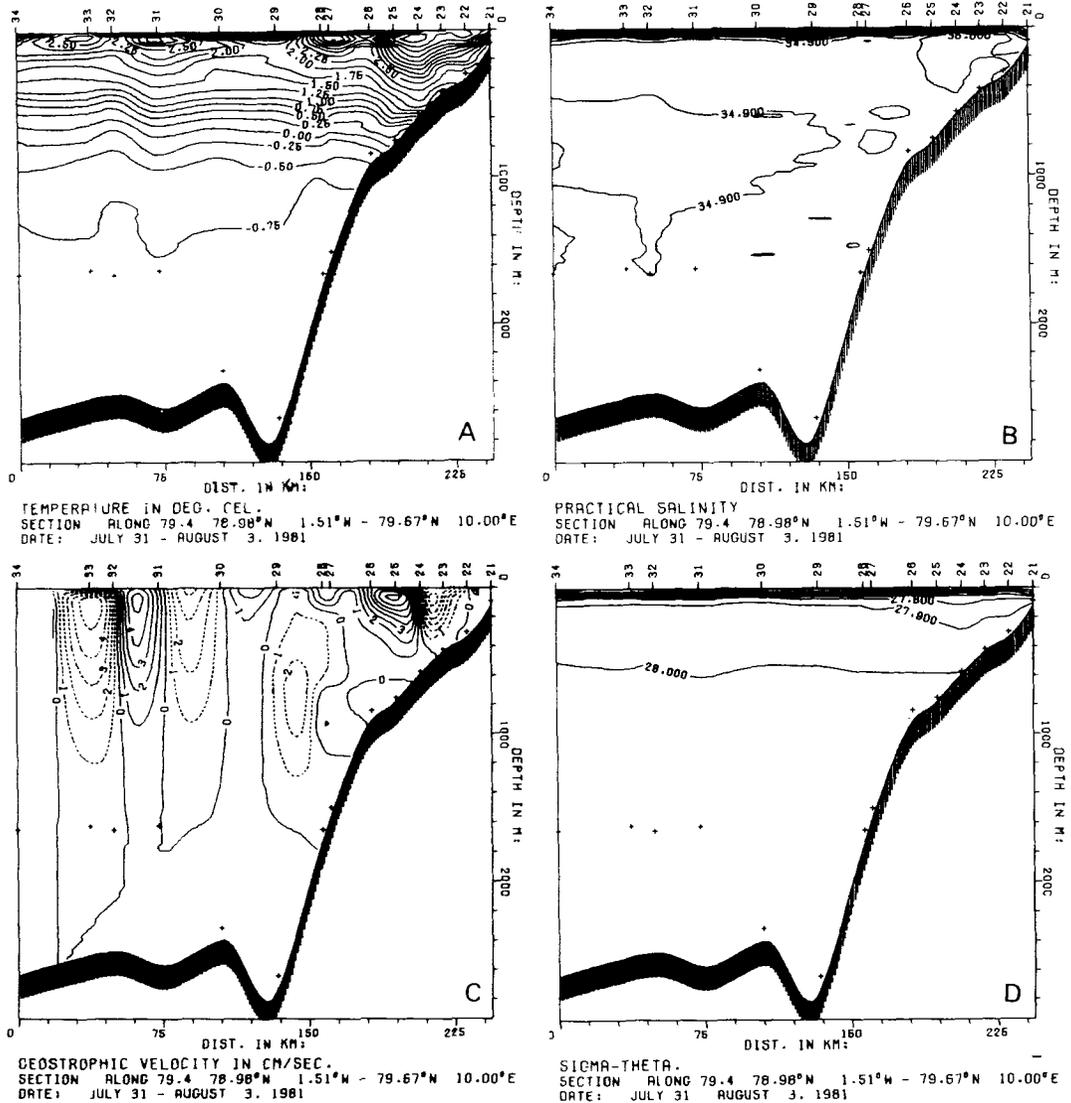
Fig. 6. As Fig. 3 for Stations 212–34.

35°/h and in the lower layer 26°/h. The reverse situation, with the velocity in the upper layer turning anticlockwise and in the lower layer clockwise, gives the corresponding values, 25°/h (upper) and −23°/h (lower) (see Table 1). This should be compared with 29°/h, which is the average angular velocity for M_2. It must be admitted that the scatter is considerable. A possible interpretation of these observations is a tide generated baroclinic wave. The directions of the orbital motions in the two layers cannot be decided from the data. This is not surprising since

the mean time lag between the stations (~10 h) is close to the semidiurnal period.

The currents observed on the continental slope and shelf north and west of Svalbard are stronger and their direction corresponds better with those found from the geostrophic computations. On the western slope the current is generally to the north (Fig. 10) and coincides with the core of saline Atlantic Water entering the Polar Basin (see Fig. 6). The east-west component (Fig. 9), on the other hand, shows great variations from station to station. Whether these variations are generated
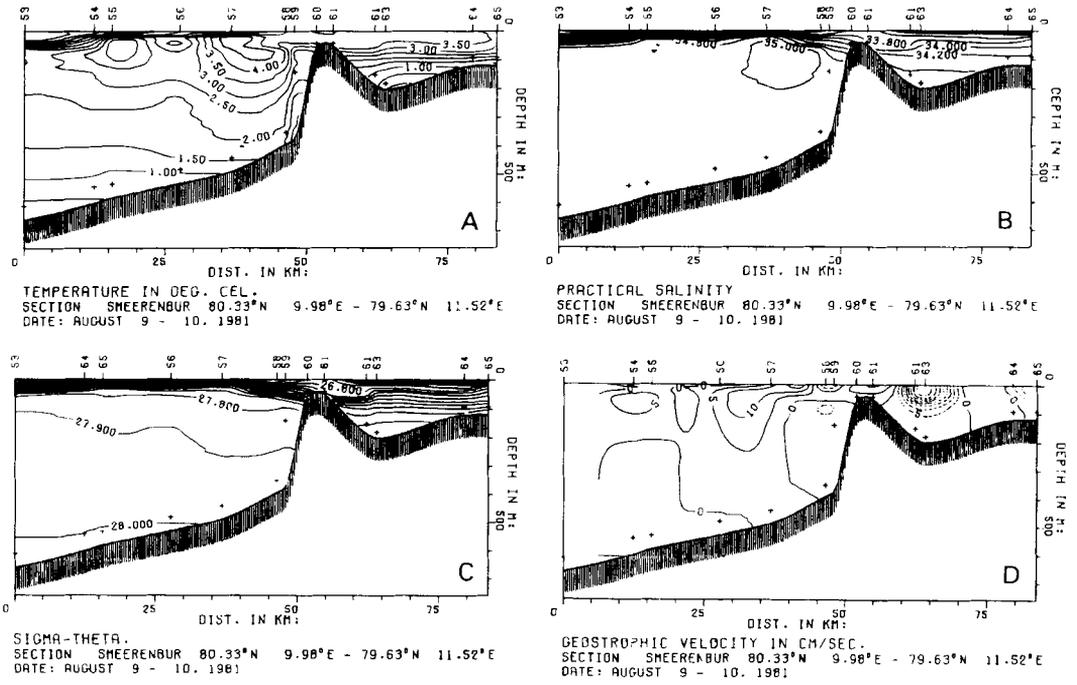
Fig. 7. As Fig. 3 for Stations 53–65.
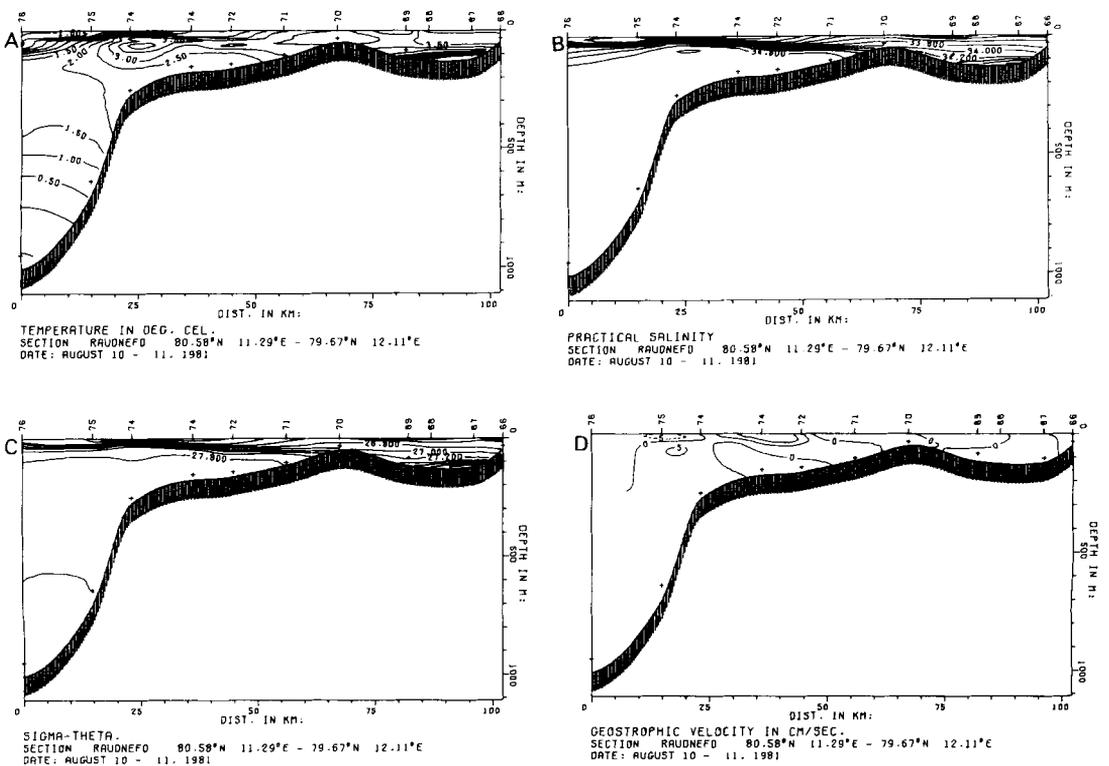
Fig. 8. As Fig. 3 for Stations 66–76.
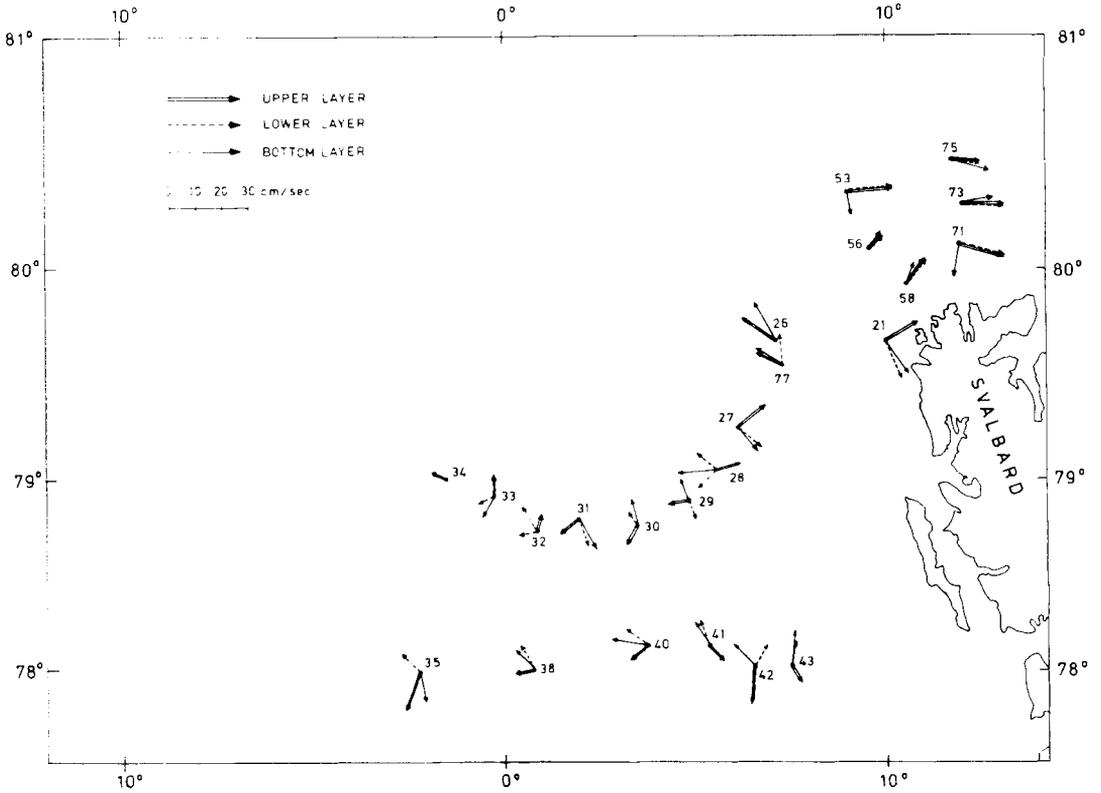
Fig. 9. Pendulum current measurements. vertical layer means. see text.
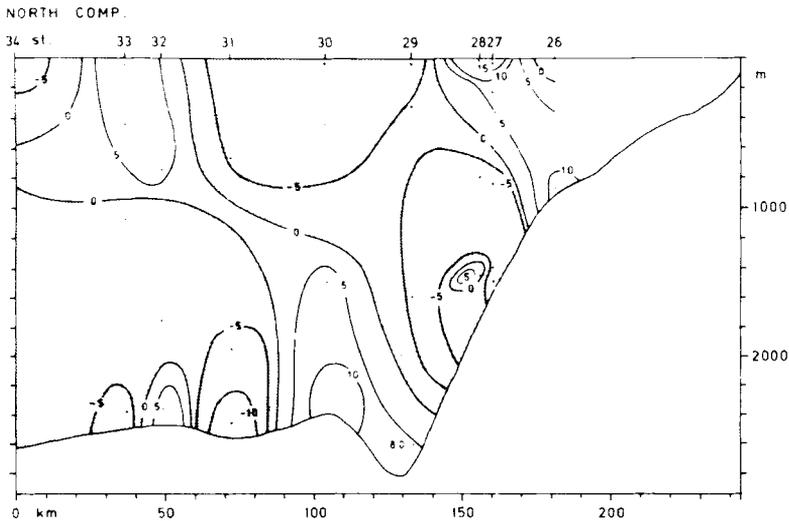
Fig. 10. Contours of north component of current based on measurements at Stations 26–34.
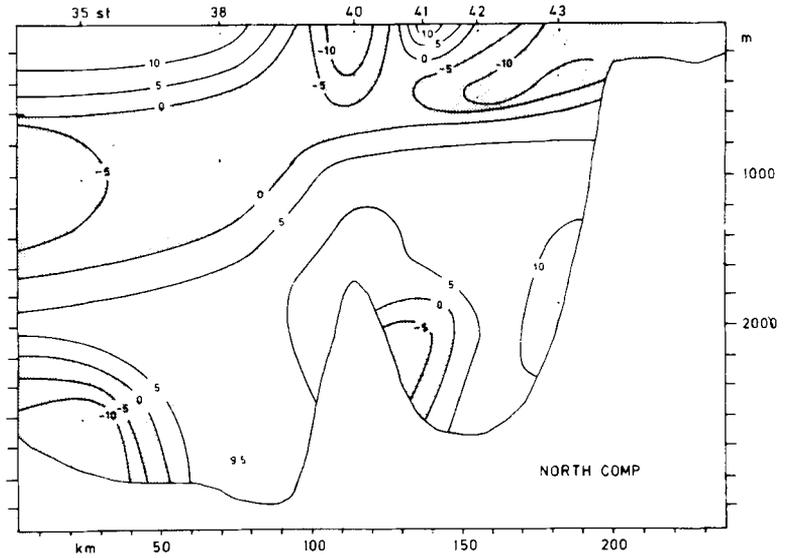
Fig. 11. As Fig. 10 for Stations 35–43.

Table 1. The change in direction of the currents in the two layers on Stations 29–43. For explanation, see text.

Station	Δ t h	θ upper degrees	Δθ upper degrees	θ upper o/h	θ lower degrees	Δθ lower degrees	θ lower o/h
Anticyclonic rotation in upper layer							
29		260			160		
30	10	210	−310	−31.0	325	+195	+19.5
31	10	230	−20	−2.0	160	+165	+16.5
32	8	15	−145	−18.1	260	+260	+32.5
33	6	0	−345	−57.5	245	−15	+2.5
34	4	295	295	−73.8			
35	20	200	−(265 + 360)	−31.3	315	+(290 + 360)	+27.0
38	30	260	−(60 + 2·360)	−26.0	315	+(0 + 2·360)	+24.0
40	9	230	−330	−36.7	305	+10	+1.1
41	5	135	−265	−53.0	340	+325	+65.0
42	5	185	−50	−10.0	50	+290	+58.0
43	6	150	−325	−54.2	10	+40	+6.7
				−35.8			25.3

Station	Δ t h	θ upper degrees	Δθ upper degrees	θ upper o/h	θ lower degrees	Δθ lower degrees	θ lower o/h
Cyclonic rotation in upper layer							
29		260			160		
30	10	210	50	5.1	325	−165	−16.5
31	10	230	340	34.0	160	−195	−19.5
32	8	15	215	26.9	260	−100	−12.5
33	6	0	15	2.5	245	−345	−57.5
34	4	295	65	16.2			
35	20	200	(95 + 360)	22.8	315	−(70 + 360)	−17.9
38	30	260	(300 + 720)	34.0	315	−(0·720)	−24.0
40	9	230	30	3.3	305	350	−38.9
41	5	135	95	19.0	340	35	−7.0
42	5	185	310	62.0	50	70	−14.0
43	6	150	35	5.8	10	320	−53.3
				21.1			−26.1
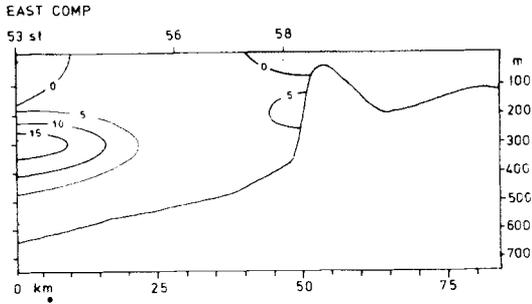
EAST COMP

Fig. 12. Contours of east component of current based on measurements at Stations 53–58.

locally by the bottom topography, or are due to transient motions, cannot be decided from so few data.

On the north-south sections north of Svalbard (Figs. 12, 13) we find a relatively strong (10–15 cm/s) and persistent flow towards the east. These observations show that the Atlantic Water present on the shelf moves east north of Svalbard as it enters the Polar Basin. This agrees with the classical observations made by Nansen (1915), Sverdrup (1933), and Mosby (1938).

Summary

Our measurements show a complicated structure in the waters and motions in the Fram Strait. It

EAST COMP
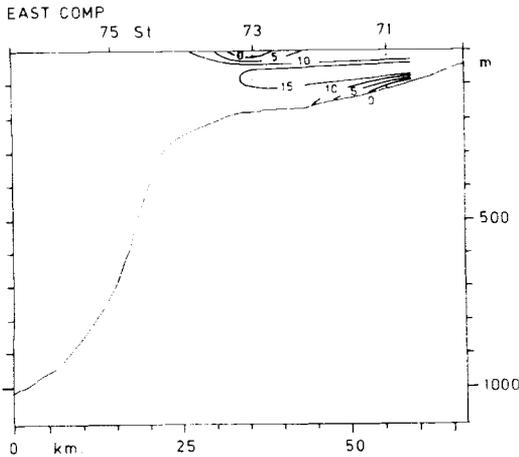
Fig. 13. As Fig. 12 for Stations 71–75.

is a region where 4–5 different water masses meet and mix and perhaps new water masses form. The simple inflow-outflow current pattern is complicated by baroclinic tides and probably by strong eddy motions. To reasonably resolve the structure in the passage would require a much greater effort than the present one.

The warm and saline West Spitsbergen Current is revealed both by CTD measurements and direct current measurements. It follows the shelf break, turning east north of Svalbard.

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