10. WATER MASS EXCHANGES BETWEEN THE ARCTIC OCEAN AND THE NORDIC SEAS

G. Budéus, E. Fahrbach, V. Lüer, I. Meyer-Holste, S. Müller, B. Plüger, R. Plugge, S. Ronski, E. Schütt

Objectives

Exchanges between the North Atlantic and the Arctic Ocean result in the most dramatic water mass conversions in the World Ocean: warm and saline Atlantic waters, flowing through the Nordic Seas into the Arctic Ocean, are modified by cooling and freezing into shallow fresh waters (and ice) and saline deep waters. The outflow from the Nordic Seas to the south provides the initial driving of the global thermohaline circulation cell. The outflow to the north has a major impact on the large scale circulation of the Arctic Ocean. Measurement of these fluxes is a major prerequisite for the quantification of the rate of overturning within the large circulation cells of the Arctic and the Atlantic Oceans, and is also a basic requirement for understanding the role of these ocean areas play in climate variability on interannual to decadal time scales.

Fram Strait represents the only deep connection between the Arctic Ocean and the Nordic Seas. Just as the freshwater transport from the Arctic Ocean is thought to be of major influence on water mass formation in the Nordic Seas, the transport of warm and saline Atlantic water significantly affects the water mass characteristics in the Arctic Ocean. The inflow from the Arctic Ocean into the Nordic Seas determines to a large extent the formation of water masses which are advected through Denmark Strait to the south and participate in the formation of the North Atlantic Deep Water. The obtained data will be used, in combination with a regional model, to investigate the nature and origin of the transport fluctuations as well as the modification of signals during their propagation through the strait.

The specific objectives are:

- to measure the current, temperature and salinity fields on sections across Fram Strait
- to determine the characteristic time scales of the fluctuations, in particular, the contribution of the seasonal cycle
- to calculate seasonal and annual mean transports of mass, heat and salt
- to understand the origin of the fluctuations
- to detect the influences of low frequency fluctuations of the transports through Fram Strait on remote variations further south
- to detect interannual variability of the described processes.

Polar oceans are generally weakly stratified and hence oceanic currents are primarily determined by the barotropic flow component. Thus, geostrophic calculations based on hydrographic sections are not sufficient to determine the current field to the required accuracy. In these ice-covered areas, the barotropic component can only be determined from direct current measurements, since satellite altimetry is not yet able to supply appropriate measurements of sea level fluctuations under ice. Due to relatively large contributions of boundary and frontal areas and the small Rossby radius of deformation, relatively high horizontal resolution is required for the measurements.

However, measurements with bottom pressure recorders might allow to obtain transport estimates, if they are properly calibrated against a current meter array.

The net transport through Fram Strait is the difference between the northward flowing West Spitsbergen Current in the east and the southward flowing East Greenland Current in the west. A significant recirculation from of water from Atlantic origin occurs in several current branches south, in and north of Fram Strait. To estimate the intensity of the recirculation on the zonal transect across the strait a meridional transect is needed at the Greenwich Meridian.

Work at Sea

To measure the current field between East Greenland and West Spitsbergen, actually 14 mooring arrays are deployed across Fram Strait at 79°N, in water depths between 200 m and 2600 m water depth. For a sufficient vertical resolution, 3 to 4 instruments per mooring are required. Temperatures and salinities are measured together with the currents, to allow derivation of the heat and salt transports. Three of the moorings on the eastern side of the mooring array were recovered and redeployed with bottom pressure recorders (see tables).

Salinity sensors on moored instruments still suffer from uncertainties and are too expensive to be deployed in a large number. Therefore CTD stations (Fig. 2) are conducted across Fram Strait from the Spitsbergen shelf to the East Greenland shelf to ensure calibration of the moored instruments and to supply much higher spatial resolution. The transect did not reach the Greenland coast, but ended at 79°N 11°47'W due to the ice conditions which would have required more time to reach the fast ice edge than available.

To determine the different branches of the Atlantic Water entering the Arctic Ocean a transect was made from the northwestern corner of Spitsbergen to the northwest across the southern part of Sofia Deep. At the western slope of Sofia Deep the transect veered to the southwest and reached the Greenwich Meridian at 79°40'N. From there, it went approximately south, but was adapted to the ice conditions. The measurements ended on the way south to Tromsø at 75°15'N 00°00'. However the horizontal station distance had to be increased up to 30 nm in the deep basins.

Preliminary Results

The CTD section (Figs. 2 and 19) across Fram Strait from the Spitsbergen shelf to the East Greenland shelf did show the expected water mass distribution with warm saline water of Atlantic origin on the eastern side in the West Spitsbergen Current and colder and less saline in the southward return flow on the western side. Cold and low saline Polar Water was observed on the western side and over the east Greenland shelf. Since the transect did not reach the Greenland coast, the recirculation on the shelf could not be determined.

The different branches of the Atlantic Water entering the Arctic Ocean were detected an a transect from the northwestern corner of Spitsbergen to the northwest across the southern part of Sofia Deep (Figs. 2 and 20) and on the western slope of Sofia Deep (Figs. 2 and 21). On the Greenwich Meridian the recirculation front was encountered at 79°'N.

The long term development of the water mass properties is shown in Fig. 22. Mean temperatures and salinities are given for two depth levels (5 to 30 m and 50 to 500 m). Horizontally three areas are distinguished: the West Spitsbergen Current (WSC), between the shelf edge and 5° E, the Return Atlantic Current (RAC) between 3°W and 5°E and Polar Water in the East Greenland Current (EGC) between 3°W and the Greenland shelf. It has to be noted that the data from Fram Strait are scattered from spring to autumn and consequently affected by the annual cycle which is most pronounced in the upper layers. Therefore, the observation time indicated in the figure has to be taken into account.

11. ACKNOWLEDGEMENT

The achievements during the cruise were only possible because of an effective and heartful cooperation between the ship's crew and the scientific party. We are grateful to Master Dr. Boche and his crew for another example of the traditionally good cooperation on board. We want to thank as well to all those, even if we are not able to call them all by name, who contributed to the success of the cruise by their support on shore during planning, preparation and while we have been at sea.

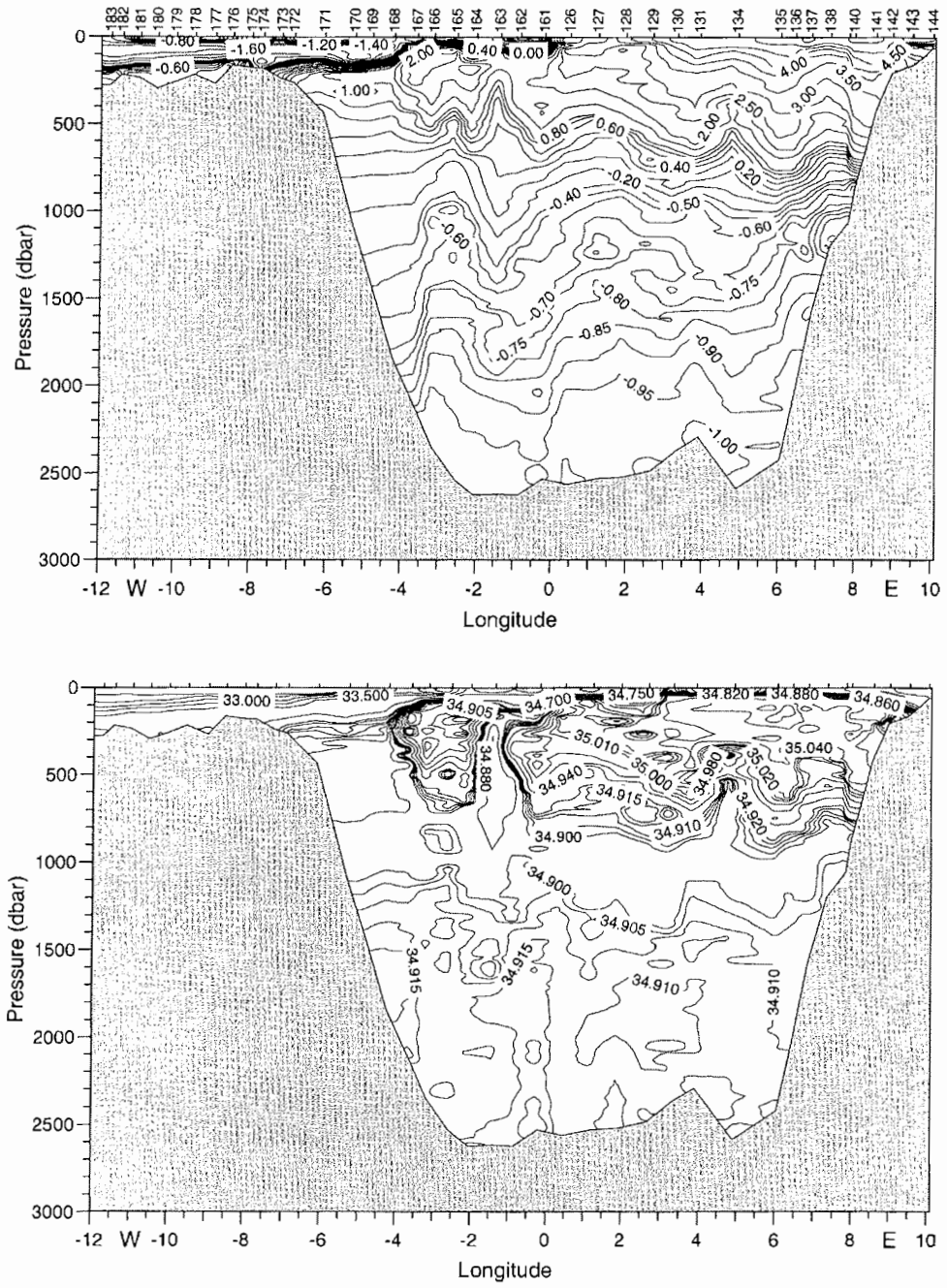

Fig. 19: Transect of potential temperature and salinity across Fram Strait along 79°00'N in the west and 78°50'N in the east. For locations of stations see Fig. 2.
Abb. 19: Vertikalschnitt der potentiellen Temperatur und des Salzgehalts durch die Framstraße auf 79°00'N im Westen und auf 78°50'N im Osten. Zur Lage des Schnitts, siehe Abb. 2.

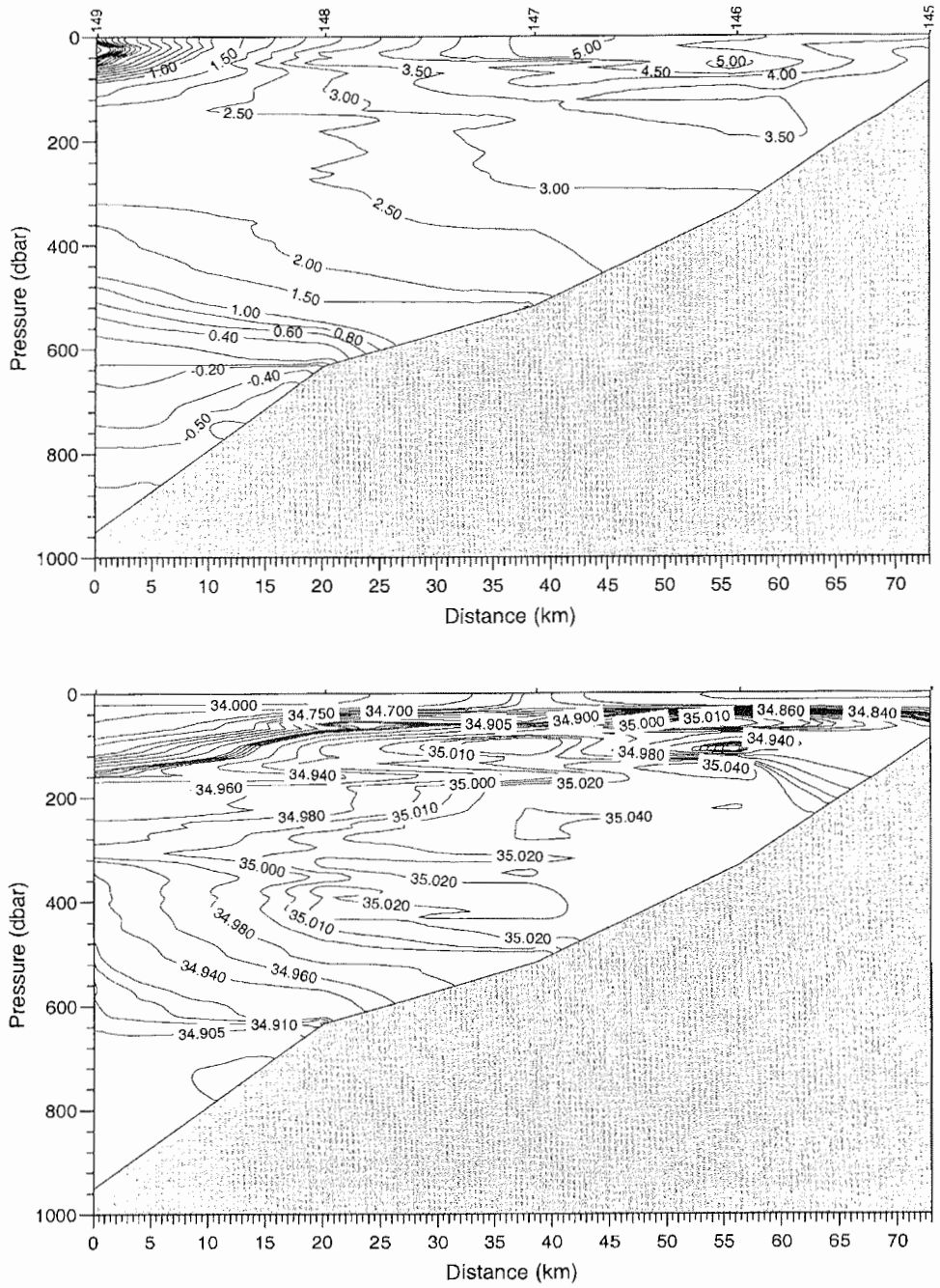

Fig. 20: Transect of potential temperature and salinity north of Fram Strait crossing the flow of Atlantic Water north of Spitsbergen. For locations of stations see Fig. 2.
Abb. 20: Vertikalschnitt der potentiellen Temperatur und des Salzgehalts nördlich der Framstraße, um den Strom von Atlantischem Wasser nördlich von Spitzbergen zu erfassen. Zur Lage des Schnitts, siehe Abb. 2.

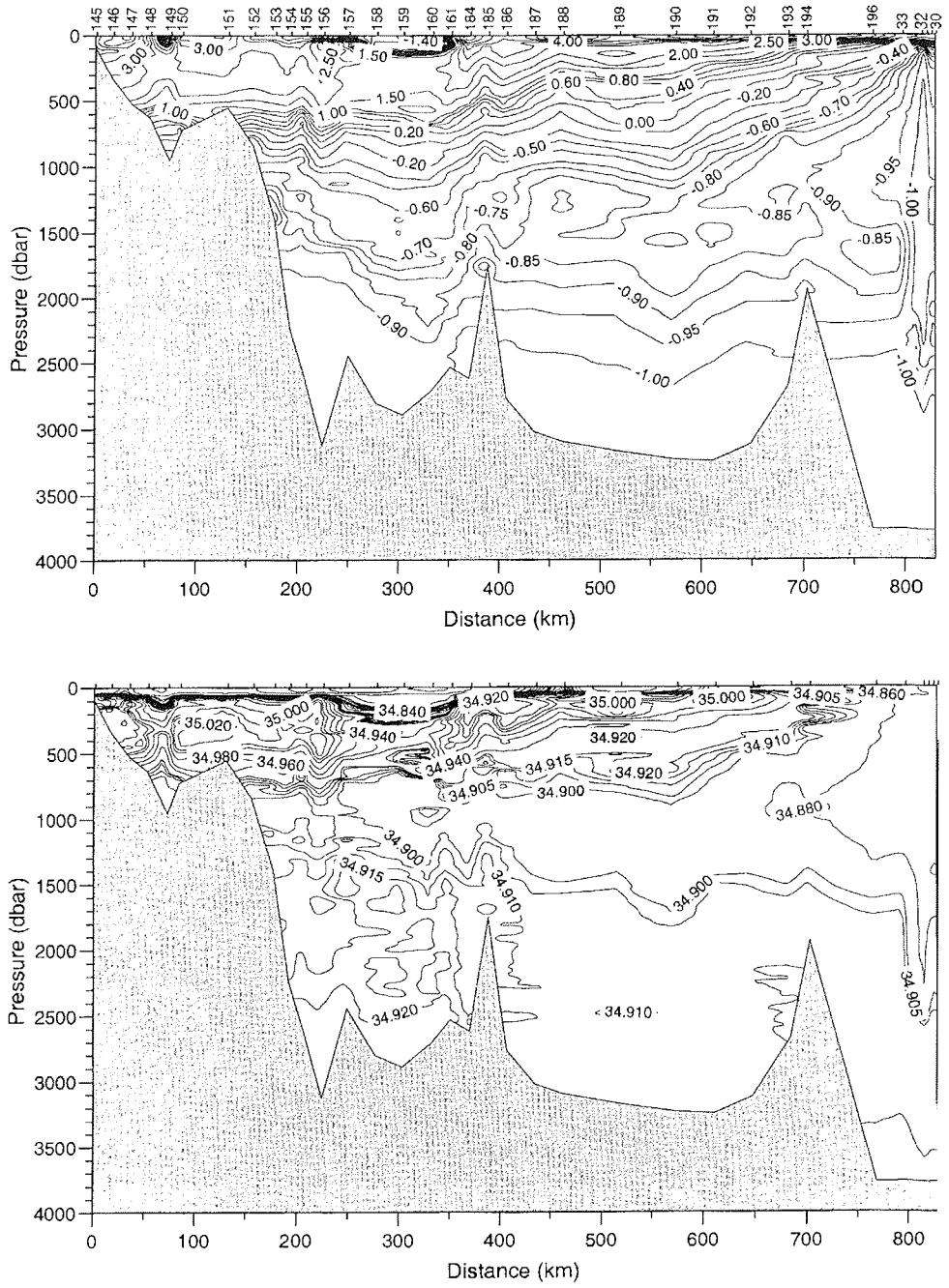

Fig. 21: Transect of potential temperature and salinity across Fram Strait from the southern end of Yermak Plateau to the Greenwich Meridian and along it up to 75°00'N. For locations of stations see Fig. 2.
Abb. 21: Vertikalschnitt der potentiellen Temperatur und des Salzgehalts durch die Framstraße vom südlichen Rand des Yermakplateaus zum Meridian von Greenwich und entlang ihm bis 75°00'N. Zur Lage des Schnitts, siehe Abb. 2.

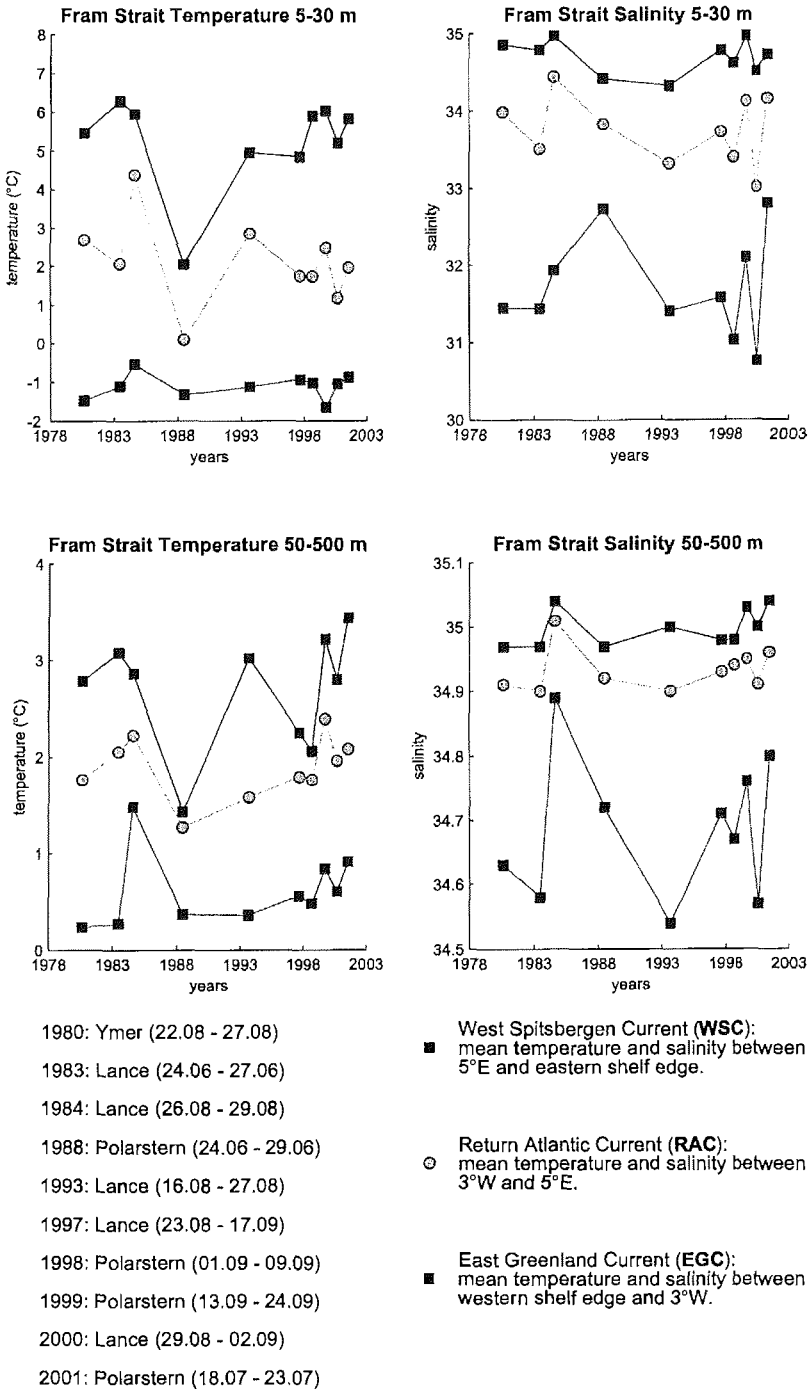

Fig. 22: Mean potential temperature and salinity of the Atlantic Water in Fram Strait on transect from 1984 to 2001.
Abb. 22: Mittlere potentiellen Temperatur und des Salzgehalts des Atlantikwassers in der Framstraße bestimmt mit hydrographischen Schnitten von 1984 bis 2001.

Moorings recovered in Fram Strait during ARKXVII/1.
Verankerungen, die während ARKXVII/1 in der Framstraße aufgenommen wurden.

Recovered moorings							
Mooring-name	Latitude Longitude	Date&Time(UTC) of first record	Water-depth	Instrument Type	Instrument Ser. No.	Instrument Depth	Record-length(days)
F 2-4	78°50.37 N	18 Aug. 2000, 12:48	794 m	FSI ACM	1557	56 m	348
	08°18.35 E			SBE 37	212	57 m	348
				AVTC	9402	259 m	348
				AVT	9767	785 m	188
				SBE 16	1253	786 m	348
F 6-4	78°50.01 N	04 Aug. 2000, 15.21	2637 m	FSI ACM	1562	59 m	362
	05°02.53 E			SBE 37	217	60 m	362
				AVTPC	10872	262 m	362
				AVT	9187	1518 m	362
				AVT	9185	2634 m	362
				SBE 26	258	2637 m	362
F 8-3	78°50.00 N	06 Aug. 2000, 08:22	2470 m	FSI ACM	1564	60 m	360
	02°33.70 E			SBE 37	221	61 m	360
				AVTP	8417	143 m	360
				AVTP	11888	249 m	360
				AVTPC	11613	750 m	360
				AVTP	9786	1506 m	360
				AVT	9782	2462 m	360
FEVI 1	79°01.70 N	19 Aug. 2000, 22:05	2456 m	Sed. trap		256 m	320
	04°20.86 E			Sed. trap		2286 m	0
				AVT	10873	2441m	347

Abkürzungen/ Abbreviations:

FSI-ACM	Falmouth Scientific 3-dimension acoustic current meter with temperature and pressure sensor
AVTPC	Aanderaa current meter with temperature, pressure, and conductivity sensor
AVTC	Aanderaa current meter with temperature and conductivity sensor
AVTP	Aanderaa current meter with temperature and pressure sensor
AVT	Aanderaa current meter with temperature sensor
SBE 16	SeaBird Electronics self contained CTD, type: SeaCat
SBE 26	SeaBird Electronics high resolution water level recorder
SBE 37	SeaBird Electronics MicroCat CT recorder
Sed. Trap	Salzgitter Electronics SZE Sediment trap

Moorings deployed in Fram Strait during ARKXVII/1.
Verankerungen, die während ARKXVII/1 in der Framstraße ausgelegt wurden.

Deployed moorings						
Mooring-name	Latitude Longitude	Date&Time(UTC) of deployment	Water-depth	Instrument Type	Instrument Ser. No.	Instrument Depth
F 2-5	78°50.35 N	12 July 2001, 15:54	794 m	ACM/CTD	1471	57 m
	08°18.30 E			SBE 37	449	58 m
				AVTP	8418	262 m
				SBE 37	219	782 m
				AVT	10495	788 m
				SBE 26	226	794 m
F 6-5	78°49.95 N	15 July 2001, 17:15	2626 m	ACM/CTD	1449	52 m
	05°02.55 E			SBE 37	445	53 m
				AVTPC	8400	248 m
				AVTPC	12326	1504 m
				AVTPC	12330	2620 m
				SBE 26	259	2626 m
F 8-4	78°50.05 N	17 July 2001, 18:11	2470 m	AVTP	10005	59 m
	02°33.83 E			SBE 37	446	61 m
				AVTPC	8401	145 m
				AVTP	8402	251 m
				AVTPC	8396	752 m
				AVTPC	12328	1508 m
				AVT	10532	2464 m
				SBE 26	261	2470 m
FEVI 2	79°01.80 N	14 July 2001, 11:46	2482 m	Sed. trap		259 m
	04°20.30 E			Sed. trap		2310 m
				AVT	10496	2466 m

Abkürzungen/ Abbreviations:

ACM-CTD	Falmouth Scientific 3-dimension acoustic current meter with CTD sensor head (CTD=Conductivity, Temperature, Depth)
AVTPC	Aanderaa current meter with temperature, pressure, and conductivity sensor
AVTP	Aanderaa current meter with temperature and pressure sensor
AVT	Aanderaa current meter with temperature sensor
SBE 26	SeaBird Electronics high resolution water level recorder
SBE 37	SeaBird Electronics MicroCat CT recorder
Sed. Trap	Salzgitter Electronics SZE Sediment trap