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The Antarctic Coastal Current in the southeastern Weddell Sea*

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Summary. Between January and March 1989 during EPOS leg 3, a hydrographic survey was carried out in the southeastern Weddell Sea on transects across the continental shelf and slope off Kapp Norvegia and Halley Bay. This data set represents oceanographic conditions during Antarctic summer. Winter observations were obtained during the Winter Weddell Gyre Study in September and October 1989. During summer the water in the surface layer is relatively warm and of low salinity. In the area of Halley Bay exceptionally warm conditions were encountered with sea surface temperatures of nearly +1°C. Over the upper continental slope a frontal zone separates Eastern Shelf Water from Antarctic Surface Water in the near surface layer and from Warm Deep Water in the deeper layers. The horizontal pressure gradient associated with the front produces the high velocity core of the Antarctic Coastal Current. In winter Antarctic Surface Water is replaced by colder Winter Water of higher salinity. Measurements from current meters moored off Kapp Norvegia and Vestkapp are used to describe the mean features of the current field and its fluctuations. At Kapp Norvegia annual mean current speeds range from 10 to 20 cm/s. The geostrophic current shear indicates that the speed of the current core decreases towards Halley Bay. The currents show significant seasonal variations with strong interannual differences. These compare well with the variations of the wind field observed at the Georg von Neumayer Station. Superimposed are higher frequency fluctuations with an energetic range between 5 and 15 days which is found in the wind measurements as well. A considerable part of the current velocity variance is due to the tides. The oceanographic conditions are strongly influenced by the local bottom topography. A topographic rise at the shelf edge off Kapp Norvegia reduces horizontal advection and allows a patch of cold Winter Water to be preserved into the summer. In contrast, a patch of Warm Deep Water was found on the shelf of Halley Bay. This illustrates rather heterogeneous conditions in the near bottom layers due to differences in the exchange rate with the open ocean as well as with the near surface layers.

Introduction

The Antarctic Coastal Current determines the oceanographic regime around the Antarctic Continent where the oceanic water masses interact with the ice shelves. It is of particular interest in the Weddell Sea, because it represents the boundary current of the cyclonic subpolar Weddell Gyre. This current system supplies Weddell Sea Bottom Water to the Southern Ocean, a major constituent of the Antarctic Bottom Water which dominates the abyssal water masses of the world ocean. Due to the comparably weak currents in the interior of the Weddell Gyre, the boundary current contributes significantly to the volume transport of the gyre.

The Antarctic Coastal Current was first described by Deacon (1937). Sverdrup (1954) discovered downsloping isotherms towards the coast that indicate an onshore Ekman transport driven by easterly winds which prevail around the Antarctic Continent. Gill (1973) pointed out the importance of the coastal current for the circulation and the bottom water formation in the Weddell Sea. Detailed descriptions of the water masses based on measurements by means of modern instrumentation have been given by Carmack (1974), Carmack and Foster (1977) and Foldvik et al. (1985).

Since 1985 the Antarctic Coastal Current in the Weddell Sea has been the objective of a number of investigations carried out on *Polarstern* cruises in austral summer and winter. These cruises provided additional hydrographic and moored current meter data that had allowed a detailed description of the current field and the water masses. The winter cruises and the measurements with moored instruments have made it possible to determine seasonal and shorter period variability.

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At present, no model is available with sufficient resolution to simulate satisfactorily the wind-forced and thermohaline processes that determine the dynamics of the coastal current. Thermohaline processes in that area are due to sea ice formation and shelf ice melting. Consequently, many of the details of the current system are still of a rather speculative nature. Therefore we restrict the present paper to a description and do not attempt a complete understanding of all the details.

The data

Between 13 January and 10 March 1989 during the European *Polarstern* Study (EPOS) leg 3, *RV Polarstern* operated in the southeastern Weddell Sea (Fig. 1, Arntz et al. 1990). A CTD (conductivity for salinity, temperature, depth) survey was carried out in the area off Kapp Norvegia and Halley Bay. During the Winter Weddell Gyre Study (WWGS) from 6 September to 30 October 1989, a CTD section was realized from the northern tip of the Antarctic Peninsula to Kapp Norvegia (Augstein et al. 1991). On this transect 8 CTD-profiles were measured on the eastern continental slope and shelf (Fig. 1). The EPOS section off Kapp Norvegia was located 50 km southwest of the WWGS section.

All measurements were done with a NB Mark III CTD-sonde and extended to the bottom. The interstation distance varied between 2 and 60 km with narrow spacing over the steep parts of the continental slope. The CTD was

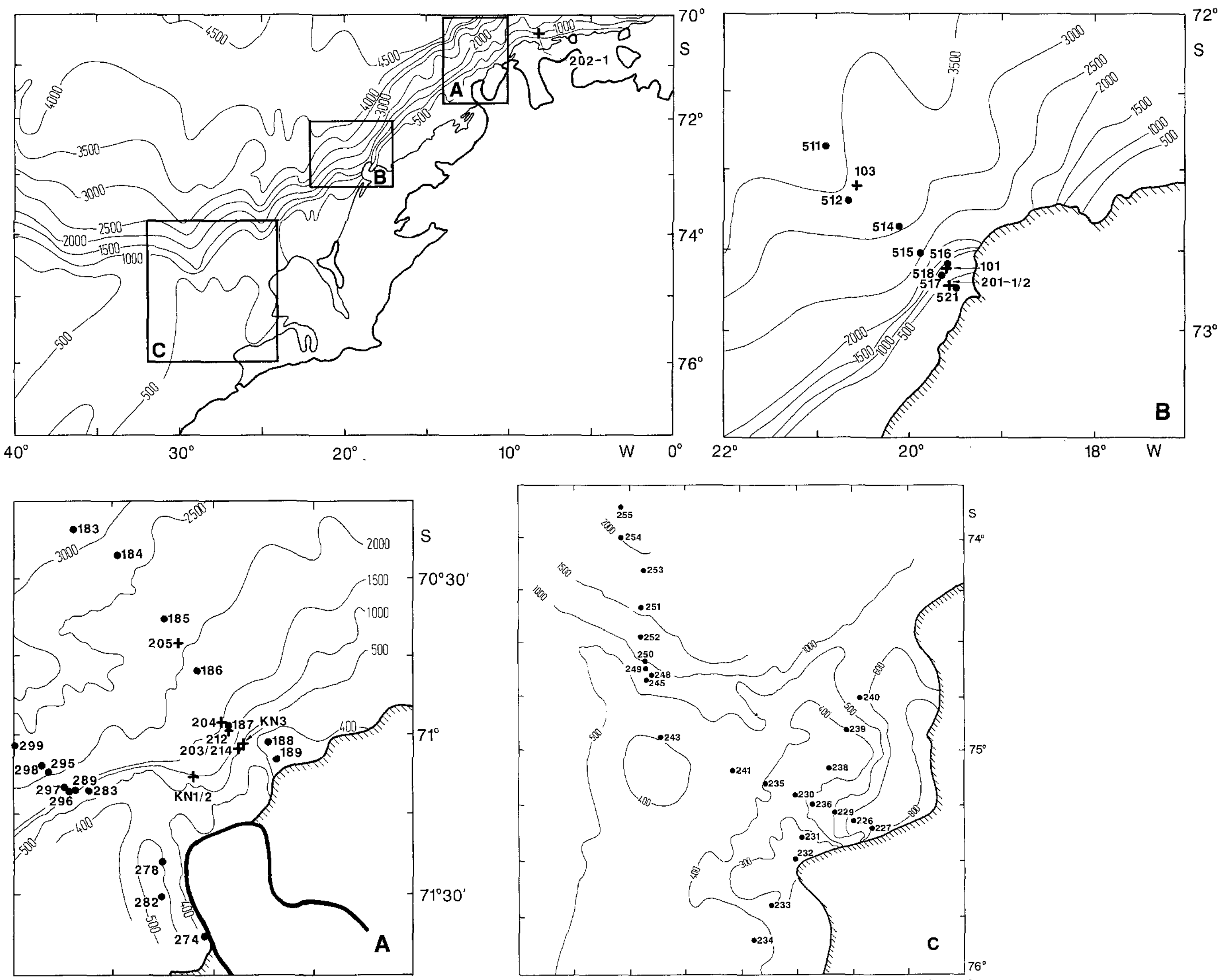

Fig. 1 A–C. Topographical map of the southeastern Weddell Sea with the locations of moorings (*crosses*) and CTD profiles (*dots*) off Kapp Norvegia (**A**), Vestkapp (**B**) and Halley Bay (**C**). The depth contours in the overview map are derived from the ETOPO5 data set, those in maps **A** and **C** from hydrosweep and seabeam soundings processed by H. Hinze and H. W. Schenke (personal communication), and those in map **B** from *Polarstern* soundings with the navigational sounder. The depths are given in meters

calibrated before and after the cruises by the Scripps Institution of Oceanography for temperature and pressure. During the cruises the performance of the instrument was checked with digital thermometers and pressure meters as well as with mercury protected and unprotected thermometers. At all stations 12 to 24 water samples were taken for salinity determination with a Guildline Autosal 8400A. The salinity profiles calculated from the conductivity measurements were adjusted to fit the salinity samples. The accuracy in salinity, temperature and pressure of the processed CTD data below the thermocline is better than 0.003, 3 mK and 3 db, respectively. All salinities in the paper are given in PSU.

Direct long-term current measurements were obtained with bottom moored instrumentation on the continental slope and shelf off Kapp Norvegia (Fig. 1). One set of moorings were laid during EPOS in February 1989 (Arntz et al. 1990) and recovered in February 1990. On four moorings in water depths of 430, 676, 1,522 and 2,123 m, nine current meters recorded for 6 to 12 months. A second deployment period lasted from October 1989 to November 1990. Time series of shorter duration were measured 1986 in the Vestkapp area (Fig. 1, Fahrbach and Rohardt 1988). From 17 October 1986 to 22 February 1987 eight current meters recorded at depths between 30 and 3,411 m in water of 3,415 m deep. The relatively short duration of the measurements assured that shallow current meters would not be affected by icebergs. Between those two periods of intense mooring work a programme with one mooring was carried out at Kapp Norvegia and Atka Bight. A full summary of the moored current meter measurements used in this paper is given in Table 1.

The temperature and salinity fields

The temperature and salinity fields in the southeastern Weddell Sea are determined by four water masses which are depicted in the potential temperature/salinity (Θ/s) diagrammes for the Kapp Norvegia area in summer (Fig. 2, top) and in winter (Fig. 2, middle), and for the Halley Bay area in summer (Fig. 2, bottom). The near surface water masses are subject to significant seasonal changes (Figs. 2 and 3). In summer, a warm water mass with low salinity, the Antarctic Surface Water (ASW), is generated by solar heating and freshwater input due to melting of sea ice. It disappears in winter due to cooling and brine release when sea ice is formed. Then the surface mixed layer consists of Winter Water (WW) with freezing or near freezing temperatures and salinities from 34.4 to 34.52 (Carmack 1974). WW is still present in summer to be identified as a temperature minimum below the ASW layer.

The ASW can change its characteristics on shorter than seasonal time scales. The Halley Bay survey (Fig. 2, bottom) was done during a period of weak winds, whereas the Kapp Norvegia survey (Fig. 2, top) was preceeded by gale force winds. The obvious differences in the ASW temperatures and salinities reflect not only regional variations but also the time variability in consequence of the intermittant wind induced vertical mixing.

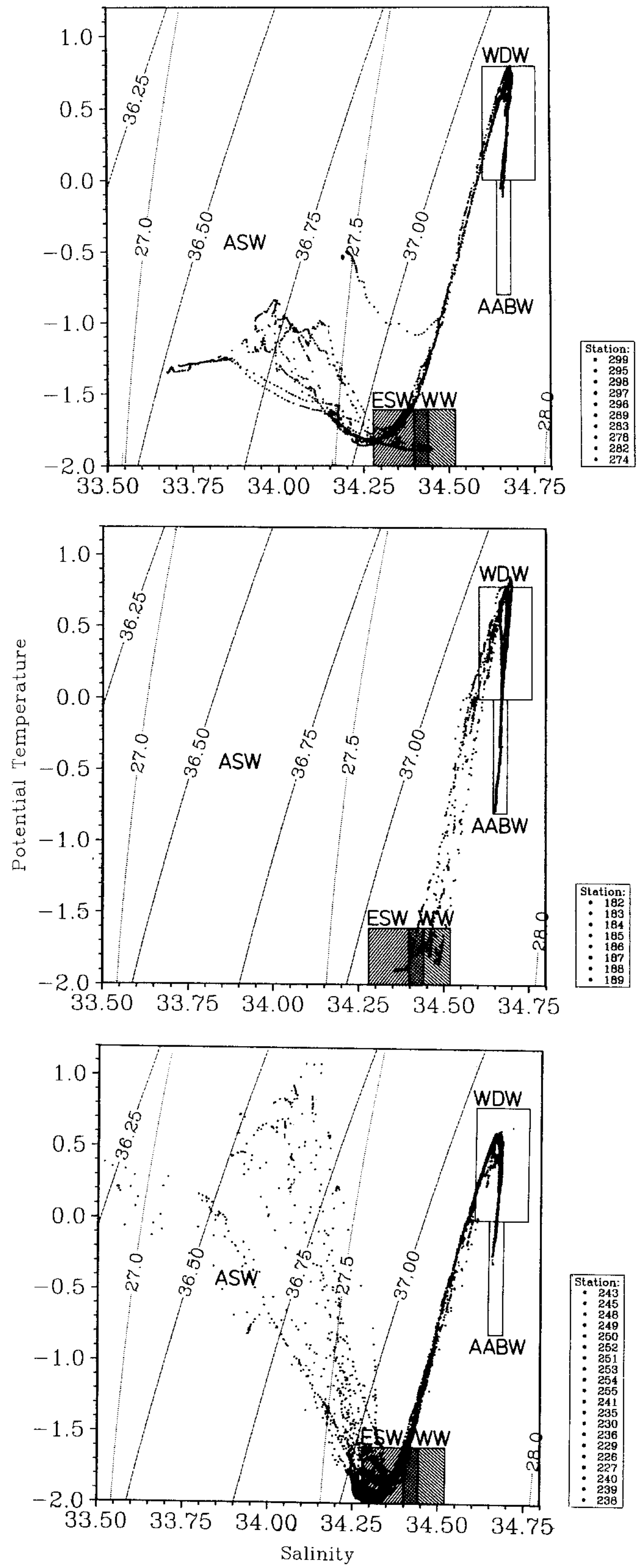

Fig. 2. Potential temperature/salinity diagrammes depicting the water masses of the southeastern Weddell Sea in the Kapp Norvegia area in summer (*top*) and in winter (*middle*), and near Halley Bay (*bottom*) in summer. *ASW* = Antarctic Surface Water, *WW* = Winter Water, *ESW* = Eastern Shelf Water, *WDW* = Warm Deep Water, *AABW* = Antarctic Bottom Water

The depth of the surface mixed layer is 50 to 100 m in the open ocean and increases to more than 500 m near the continental shelf edge. This deepening is partly due to downwelling as a result of onshore Ekman transport (Sverdrup 1954; Gill 1973) and partly due to deep convection in the coastal polynya. In the eastern Weddell Sea the polynya frequently extends over the continental slope because of the narrow shelves. The horizontal density gradients associated with the sloping isolines determine the baroclinic pressure field of the Antarctic Coastal Current.

The water masses on the eastern shelves are of much lower salinity than WW (Fig. 3, Deacon 1937). This water mass, with salinities between 34.28 and 34.44, is known as Eastern Shelf Water (ESW) in contrast to the Western Shelf Water (WSW) found on the Filchner/Rønne shelf (Carmack 1974). ESW is freshened due to the admixture of melt water from the ice shelves. In the summer the cold ESW is still visible as a temperature minimum below the warm surface water.

Below the WW a water mass with higher temperatures and salinities, the Warm Deep Water (WDW), is found offshore in intermediate depths from 250 to 1,000 m (Fig. 3). It originates in the Antarctic Circumpolar Current (Carmack and Foster 1977) and is injected from the north into the Weddell Gyre east of 20°E (Gouretzky and Danilov 1992). In the Kapp Norvegia area the warm and high saline core reaches potential temperatures of 0.8°C and salinities of 34.69; the salinity maximum is about 100 m deeper than the temperature maximum. The depth of the core increases towards the coast from 300 m in the open sea to 800 m at the continental slope. There, the temperature and salinity maxima are significantly deeper in winter than in summer (Fig. 3).

Below the WDW a colder and less saline water mass, the Antarctic Bottom Water (AABW), is found with temperatures below 0°C and salinities from 34.64 to 34.68 (Carmack 1974). It occupies most of the volume of the water column in the deep ocean. This water mass circulates in the Weddell Gyre and consists of a mixture of water masses newly formed and advected into the gyre.

The same water masses found at Kapp Norvegia can be identified in the Halley Bay area (Fig. 2, bottom). There the WW-layer extends over the continental slope to a depth of more than 600 m (Fig. 4, top). Whereas at Kapp Norvegia the isolines drop above the upper continental slope, this occurs off Halley Bay only over the foot area of the slope. Slightly offshore of the shelf edge a doming of the

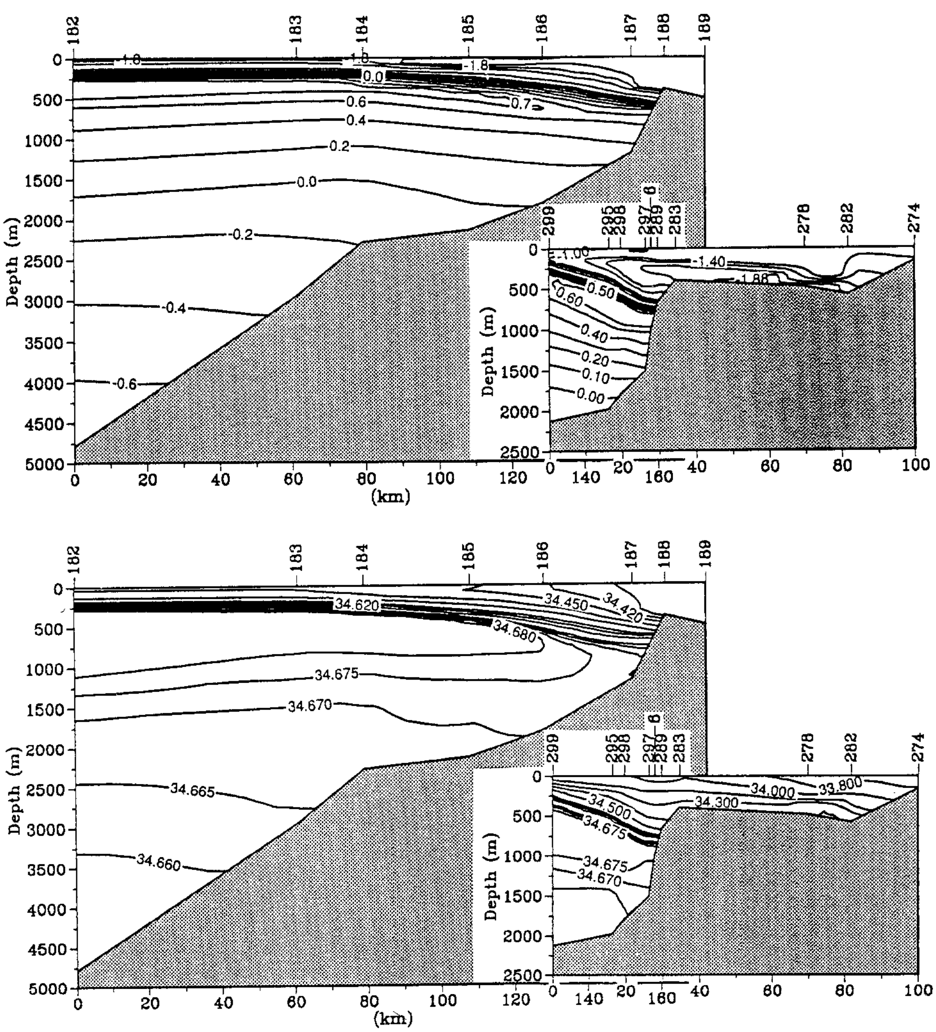

Fig. 3. Vertical sections of potential temperature (*top*) and salinity (*bottom*) off Kapp Norvegia in February 1989 (*right*) and October 1989 (*left*). For the locations of the stations see Fig. 1

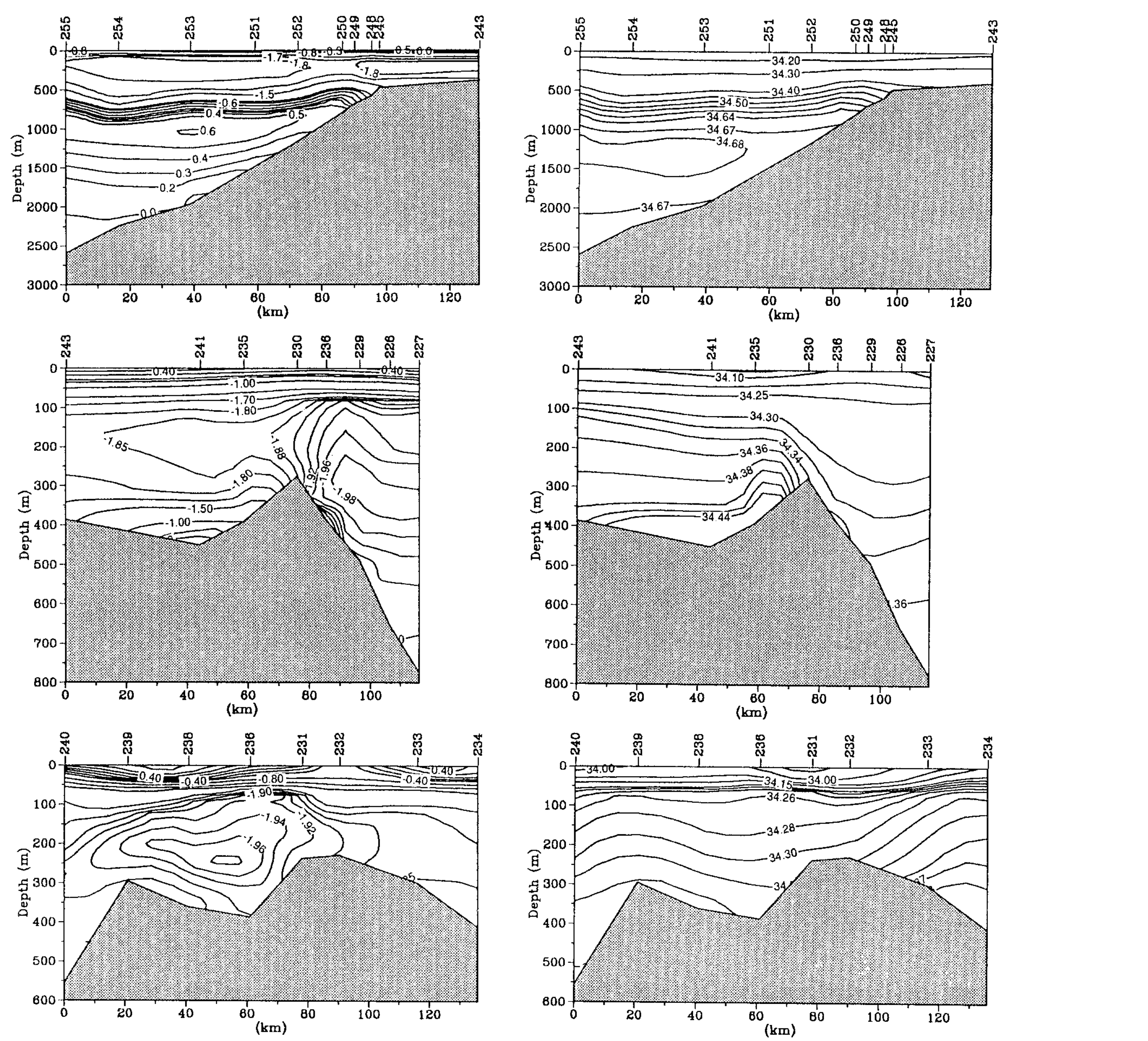

Fig. 4. Vertical sections of potential temperature (*left*) and salinity (*right*) carried out off Halley Bay in February 1989, perpendicular to the slope (*top*), across the shelf (*middle*) and along the shelf (*bottom*). For the locations of the stations see Fig. 1

thermocline between the WDW and WW indicates the effect of upwelling events. This is supported by the weakening of the WW temperature minimum. The core of the WDW with a temperature of 0.6°C is colder than off Kapp Norvegia. The much smaller inclination of the isolines in comparison to the Kapp Norvegia area suggests that the Antarctic Coastal Current weakens to the south and leaves the upper continental slope. The calculation of the geostrophic current shear confirms this feature.

Over the outer shelf (Fig. 4, middle), in water depths of 450 m below the ESW, water with WDW characteristics in the near bottom layer is found. This results from WDW intrusions on the shelf and gives evidence to the existence of exchanges across the shelf edge.

Further to the east, a trench of 900 m depth penetrates from the shelf edge towards the ice shelf (Fig. 1). In this trench temperatures below -1.94°C and salinities from 34.2 to 34.32 are found between 150 and 400 m. This water is less saline than ESW observed by Carmack (1974) and supercooled with respect to the surface pressure. We take the low temperatures as an indicator that this water emanates from the ice shelf, where it was cooled below the freezing point at surface pressure and freshened due to melt water influx. On the along shelf section, this water can be followed to the north (Fig. 4, bottom). The gradual warming is consistent with a northward flow.

The features of the sea surface temperature distribution (Fig. 5) are inverted from those of the subsurface temperatures. A tongue of water with temperatures up to 0.9°C extends from north to south. The warm water belt is interrupted by a patch of colder water with temperatures as low as -0.8°C. The cold water is located over the ridge

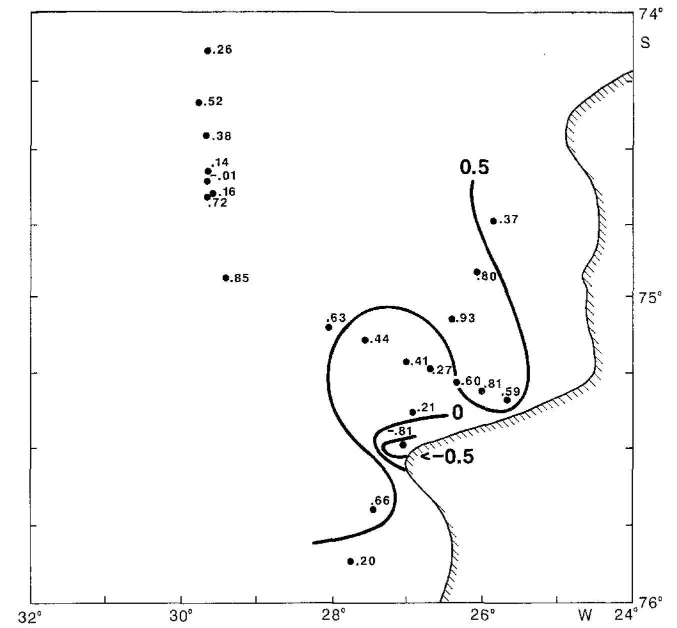

Fig. 5. Sea surface temperature in °C observed in the area of Halley Bay in February 1989 at CTD-stations measured in 6 to 8 m below the surface

formed between the southward trench and the shelf inclined to the west. Without a time series in that area we can only speculate about the origin of those warm and cold patches. From the ice concentrations derived from passive microwave images (Viehoff, personal communication) we know that the southeastern Weddell Sea was ice free since the beginning of December. A period of calm weather with clear skies and little wind was observed in January when *Polarstern* proceeded south from 71°S. As water and air temperatures differed only slightly and no heat was required to melt ice, the full heat gain from the solar radiation was available to heat the surface mixed layer. The cold patch off the cape visible in Fig. 5 could be either due to topographically steered upwelling or to the cross frontal circulation related to the subsurface front between the northward flowing ESW on the eastern side of the crest and the southward flowing WW at the western side.

The remarkably high sea surface temperature of nearly 1°C was compared with the historical record available in the Southern Ocean Data Bank of Gouretzky and Olbers (personal communication). In that data set 432 SST measurements are documented for the Weddell Sea south of 70°S during the period from 1930 to 1988. The subset from the area between 74 and 76°S contains 69 measurements. Three of them show temperatures warmer than 0°C, but all are colder than 0.6°C. We conclude that our observations represent anomalously high temperatures due to favourable ice and weather conditions which lasted until 11 February, when strong winds induced intense vertical mixing and rapid cooling to negative temperatures.

The mean current fields

Most of the available long-term current measurements were made with instruments deployed near Kapp Norvegia (Fig. 1). The deployment occurred at the end of the EPOS-period of CTD observations. This makes two restrictions on the interpretation: the records do not cover the period of our hydrographic observations and the measurements are only representative of a limited area. However, data from short period moorings deployed in 1986 off Vestkapp agree in the general features. We therefore assume that one can generalize the observed structures to a certain extent. More crucial for the interpretation are the fluctuations in the various time scales which will be discussed in the next paragraph. The area of Halley Bay is obviously different from the more northern

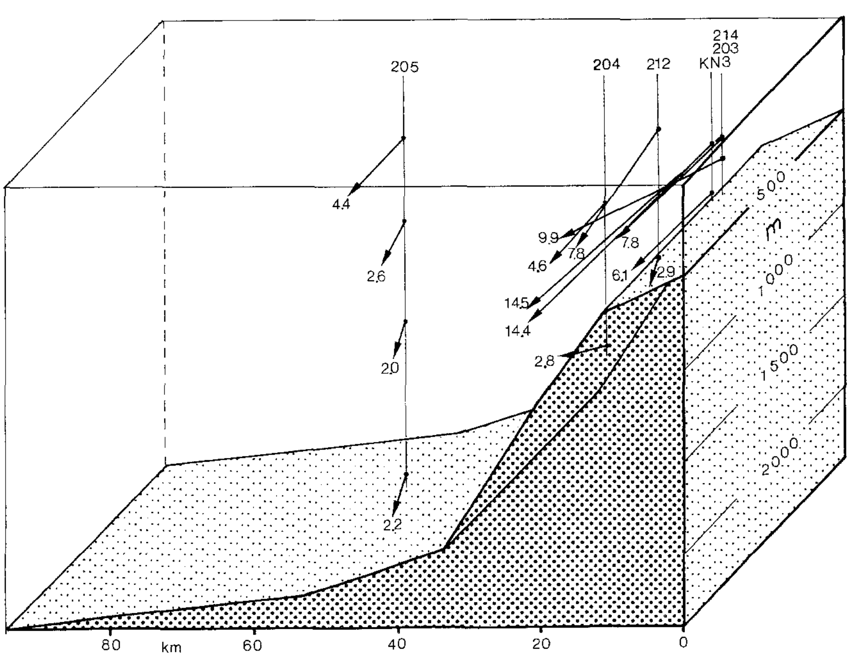

Fig. 6. Long-term mean currents on the shelf and slope off Kapp Norvegia observed with current meters moored from February 1989 to November 1990. The box is oriented parallel and perpendicular to the continental slope. The mooring identification is given on top of the mooring; for the locations see Fig. 1. The numbers at the *arrowhead* indicate current speed in cm/s. For the observation periods see Table 1

locations off Kapp Norvegia and Vestkapp due to the transition from the narrow shelf in the north to the wide Filchner/Rønne shelf. This topographical constraint forces the Antarctic Coastal Current to split into one branch following the continental slope and another one penetrating onto the shelf as evidenced in the hydrographic data (e.g. Carmack and Foster 1977).

The long-term means of measurements from the Kapp Norvegia moorings, calculated over the full time series, show mean current speeds between 2 and 15 cm/s directed essentially parallel to the bottom topography (Table 1). The strongest currents of 15.4 cm/s are found 255 m below the surface over the upper slope in 682-m deep water at the KN2-mooring (Table 1). The current core over the upper slope is confirmed by the other long-term moorings (Fig. 6). If we extend the current profile by using the geostrophic shear derived from a CTD section, the speed of the current core in the near surface layers amounts to 25 cm/s. Further offshore in 2,123-m deep water the current speeds decrease to 4.4 cm/s in the upper and 2.2 cm/s in the bottom boundary layer. At an intermediate depth of 1,550 m a minimum of 2.0 cm/s is found.

The moorings deployed in the Vestkapp area (Fig. 1) show a current with similar structures with a high velocity core speed of 13 cm/s over the upper slope and decreasing speeds offshore and towards the bottom (Fig. 7). In contrast to the Kapp Norvegia current meters where the shallowest instrument was at 255 m depth, the Vestkapp moorings reached into the near surface layers with the shallowest instrument at 30 m. The outermost mooring 103 in 3,415-m deep water is representative of an area with rather weak geostrophic current shear. The current speeds averaged over four months are 9.7 cm/s at 30 m below the surface, 8.6 cm/s at 40 m and 6.3 cm/s at 383 m. Between 30 and 40 m depths a rather strong vertical shear of 11 cm/s per 100 m indicates the transition from the directly wind driven layer to the geostrophic interior. Below, the vertical shear of 0.67 cm/s over 100 m between 40 and 383 m is comparable to the geostrophic shear of 0.56 cm/s per 100 m between 50 and 350 m obtained from CTD stations 511 and 512 (Fig. 1).

The current directions are strongly constrained by the bottom topography. The annual mean directions on the Kapp Norvegia line vary from 197° to 257° at different

Table 1. Averages of current speed and direction, maxima and RMS deviation of current speed for hourly values measured with moored instruments of Kapp Norvegia, Vestkapp and Atka Bight. For the locations see Fig. 1

Current meter	Instr. depth (m)	Water depth (m)	Location		First value	Duration days	Average		Max	RMS
			lat. (S)	long. (W)			speed (cm/s)	direction to north	speed (cm/s)	
201-1	245	415	72°52′	19°33′	17.10.86	32	2.6	228	21.6	6.1
	345					32	2.6	223	23.6	6.8
101	45	815	72°49′	19°36′	17.10.86	31	10.7	233	33.1	6.4
	173					31	9.9	247	44.5	4.9
	615					31	12.6	221	31.9	5.7
	810					31	6.6	224	21.6	4.3
103	30	3415	72°33′	20°36′	17.10.86	127	9.7	267	37.9	8.2
	40					127	8.6	271	37.7	5.7
	71					127	7.1	288	37.1	6.9
	383					127	6.3	261	27.3	5.3
	494					127	5.1	259	21.2	4.2
	695					127	3.7	258	17.0	3.4
	1425					127	1.9	253	14.6	2.2
	3411					127	3.1	246	18.1	3.2
201-2	280	461	72°53′	19°38′	21.02.87	320	7.5	231	33.8	4.7
	380					320	6.8	220	29.2	4.3
202-1	280	468	70°26′	08°18′	26.02.87	324	5.7	271	32.2	4.3
	380					324	5.4	277	33.8	4.3
KN1	255	642	71°08′	12°11′	04.01.88	53	7.1	266	48.5	9.1
	640					53	5.3	298	32.2	6.6
KN2	255	682	71°08′	12°12′	01.03.88	331	15.4	262	54.3	10.7
203	425	430	71°03′	11°46′	22.02.89	246	14.5	230	68.8	10.7
KN3	293	676	71°02′	11°45′	22.02.89	365	14.4	227	54.0	10.8
	671					296	6.1	228	53.3	7.7
204	706	1522	70°56′	11°58′	22.02.89	309	4.6	223	22.6	3.6
	1517					262	2.8	257	30.0	4.3
205	335	2123	70°43′	12°22′	22.02.89	310	4.4	225	26.1	4.5
	805					310	2.6	209	30.8	3.3
	1550					310	2.0	197	42.8	3.3
	2090					201	2.2	199	23.8	3.7
212	309	1050	70°59′	11°49′	08.10.89	431	7.8	216	29.7	4.0
	999					431	2.9	199	16.7	2.6
214	362	467	71°03′	11°46′	26.01.90	317	7.8	228	42.3	5.7
	462					298	9.9	245	41.7	6.1

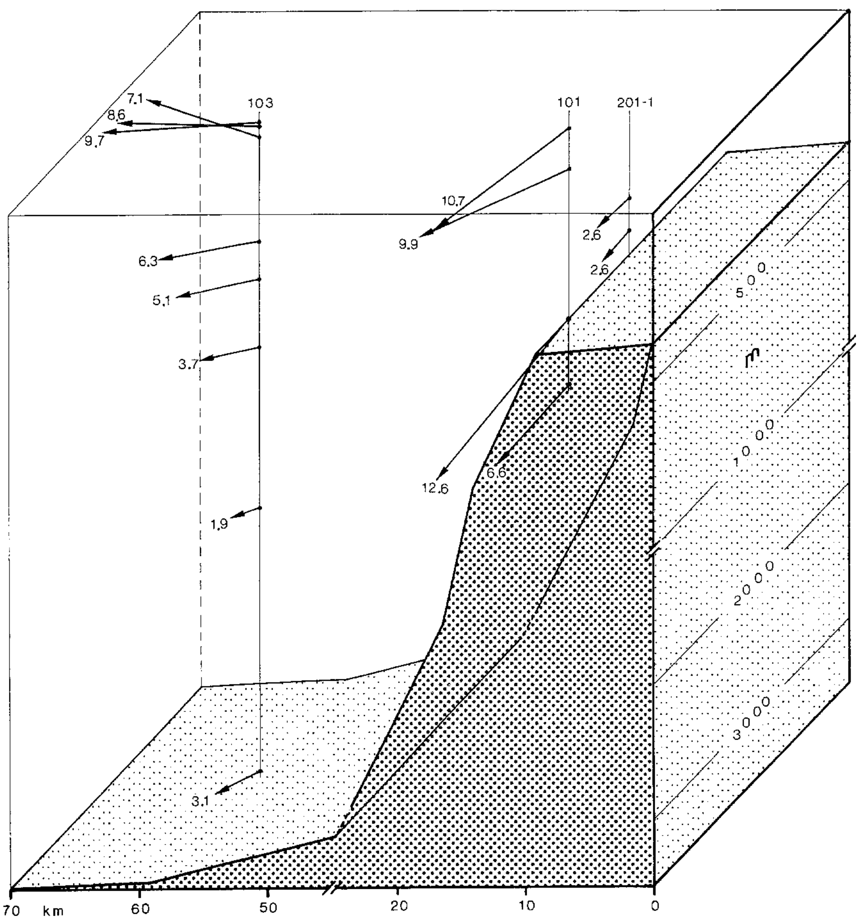

Fig. 7. Monthly mean currents on the shelf and slope off Vestkapp observed with current meters moored from October to September 1986. The box is oriented parallel and perpendicular to the continental slope. The mooring identification is given on top of the mooring, for the locations see Fig. 1. The numbers at the *arrow head* indicate current speed in cm/s. For the observation periods see Table 1

locations and depths. The direction derived from the six shallowest current meters (between 309 and 706 m depth) range from 216° to 230°. Due to the high variability of the topography, it is difficult to define the along-slope and cross-slope directions, which change with the length scale under consideration. We therefore selected a line at 225° perpendicular to the large scale topographic gradient as along-slope and a line at to 315° as offshore and refer all currents measured on the Kapp Norvegia line to these directions. The observed pattern of the cross slope circulation has to be used with greatest care, because due to the large along-slope currents, small errors in the determination of the along-slope direction can result in relatively large cross-slope currents. Taking into account this uncertainty, the near-bottom currents on the upper slope point offshore and represent part of a cross-shelf circulation cell with downwelling over the slope.

The current fluctuations

The time variability of the currents is spread over a broad spectral range. The standard deviations and the maxima of the current speeds are given in Table 1. Because of the differences in the locations of the current meters and the short observation period of only four years, we are not able to determine a trend in the annual averages. The time series data are summarized as three monthly running means in Fig. 8. In this presentation, it should be noted that the observations in 1987 were made on the shelf, in 1988 and 1989 on the upper continental slope in water depths of 682 m and 676 m respectively, and in 1990 in water 1,050 m deep. Furthermore the instrument depths varied between 293 and 255 m. As the current core is located over the upper slope (Figs. 6 and 7) the strong currents observed in 1988/1989 do not reflect time but spatial variability.

The longest period we can look at is the seasonal cycle. In the time series of the current speed two different modes of variation can be detected. In 1989 and 1990 maxima in the current speed occurred in April and minima were reached in August. In 1989 a secondary maximum was observed in November. In 1990 the time series ended in October. Therefore we do not yet know whether this is a regular feature. In 1987 and 1988 the fall maxima lasted until July and the minima were reached in November (Fig. 8). A similar mode of variation can be identified in the wind measurements from the Georg von Neumayer Station. In 1989 and 1990 two maxima occured in the wind speed in April and October, whereas in 1987 and 1988 maxima were reached in July and June. A semiannual period in the variations of meterological properties was first described by Van Loon (1967), and is obvious in the surface air pressure and wind speed measurements carried out from 1981 to 1987 at the Georg von Neumayer Station (Wamser and Gube-Lenhardt 1989).

Table 2. Results of tidal analysis. Method of analysis: M. G. Foreman (1978); minor axis: <0: anticlockwise rotation; inclination measured anticlockwise from east; $F=(O_1+K_1)/(M_2+S_2)$; *N*: number of hourly values used for the analysis

Mooring	Depth (m)	Const.	Major axis	Minor axis	Incl.	Phase	F	*N*
AWI 202-1	280	O_1	1.15	−0.43	86	39		
Atka Bight		K_1	1.20	−0.17	77	51	0,48	7476
		M_2	3.06	+0.61	14	344		
		S_2	1.96	+0.33	12	9		
AWI 202-1	380	O_1	1.31	−0.35	74	28		
Atka Bight		K_1	1.35	−0.03	68	37	0.56	7476
		M_2	2.90	+0.45	6	322		
		S_2	1.91	+0.28	9	345		
KN2	255	O_1	2.14	+1.08	143	13		
Kapp		K_1	1.57	+0.79	140	57	0.72	7939
Norvegia		M_2	3.43	−0.11	80	226		
		S_2	2.34	−0.18	83	279		
AWI 203	425	O_1	5.17	+0.51	42	262		
Kapp		K_1	3.80	+0.69	41	278	1.96	5896
Norvegia		M_2	2.73	−0.28	23	23		
		S_2	1.77	+0.28	17	35		
KN3	293	O_1	4.95	+1.55	41	268		
Kapp		K_1	3.21	+1.44	45	288	1.42	8775
Norvegia		M_2	3.63	+0.35	15	61		
		S_2	2.43	+0.60	15	85		
KN3	671	O_1	2.16	+0.85	153	66		
Kapp		K_1	1.31	+0.77	147	106	0.86	7104
Norvegia		M_2	1.48	−0.11	130	210		
		S_2	1.36	−0.21	139	238		
AWI 202-2	280	O_1	0.54	+0.06	79	78		
Vestkapp		K_1	0.41	+0.06	88	85	0.22	7476
		M_2	2.68	+0.61	74	352		
		S_2	1.50	+0.16	77	11		
AWI 202-2	380	O_1	0.47	+0.06	66	80		
Vestkapp		K_1	0.42	+0.04	90	90	0.28	7476
		M_2	2.05	+0.26	73	351		
		S_2	1.16	−0.01	83	1		

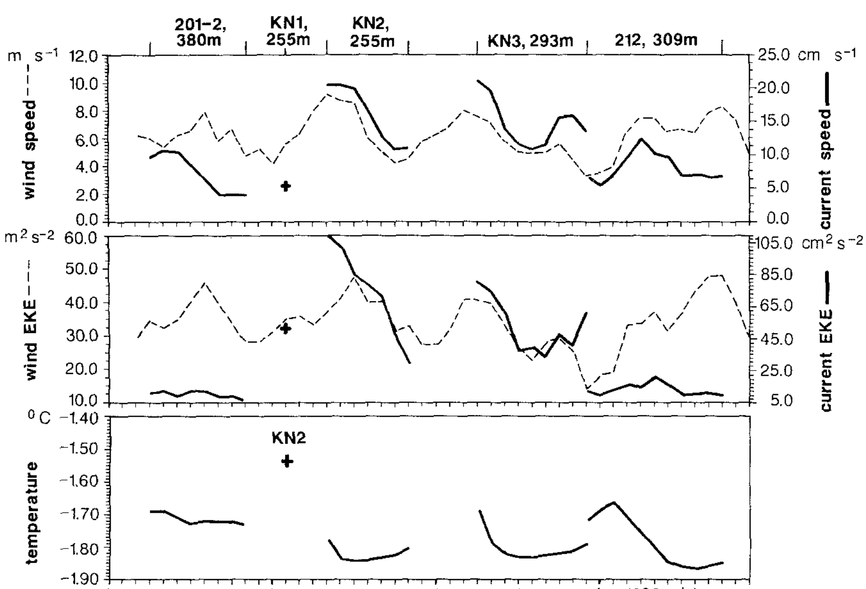

Fig. 8. Time series of three month running means of the coastal current speed and the wind speed measured at the Georg von Neumayer Station at the Atka Bay (*top*), eddy kinetic energy of current and wind (*middle*), and water temperatures (*bottom*). For the locations of the moorings see Fig. 1. Note that the different locations of the current meters prohibits connecting the time series from the individual mooring periods

The correlation between the seasonal cycle of wind and current speeds points to the wind as an important driving force of the coastal current. The correlation of strong easterly winds with strong westward currents is consistent with the mechanism described by Sverdrup (1954) who postulated onshore Ekman transport to build up a pressure gradient. The seasonal variations of the current decrease towards the bottom and offshore. In contrast to the currents the temperatures show an annual cycle. The related seasonal variations of the stratification implies a seasonal change of the baroclinic current field with an annual cycle. The contribution of wind and thermohaline forcing of the Weddell Gyre is presently investigated by use of a numerical model (Olbers 1991) which shows that both forces have to be taken into account.

The variability of the currents and winds with shorter periods than the seasonal cycle is presented as eddy kinetic energy ($EKE = (u'^2 + v'^2)/2$). It was calculated over a running three months mean of low-pass filtered data with u′ and v′ being the deviations from the means. The EKE time series show maxima during periods of high current and wind speeds (Fig. 8). The EKE of the currents decreases offshore and with depth. The correlation of maxima in wind and current EKE suggests that wind induced fluctuations contriubte to the observed variability with periods smaller than three months.

A significant contribution to the variance results from fluctuations in a time period band between 5 and 15 days. They are obvious in the time series (Fig. 9) and the power spectra (Fig. 10) of the currents on the upper slope. In the power spectra of KN3 a peak appears at 11.5 days period. The peak is stronger in the longslope component than in the one perpendicular to the slope. It decays with increasing depths and towards the deep ocean. In deep water an intensification can be observed towards the bottom.

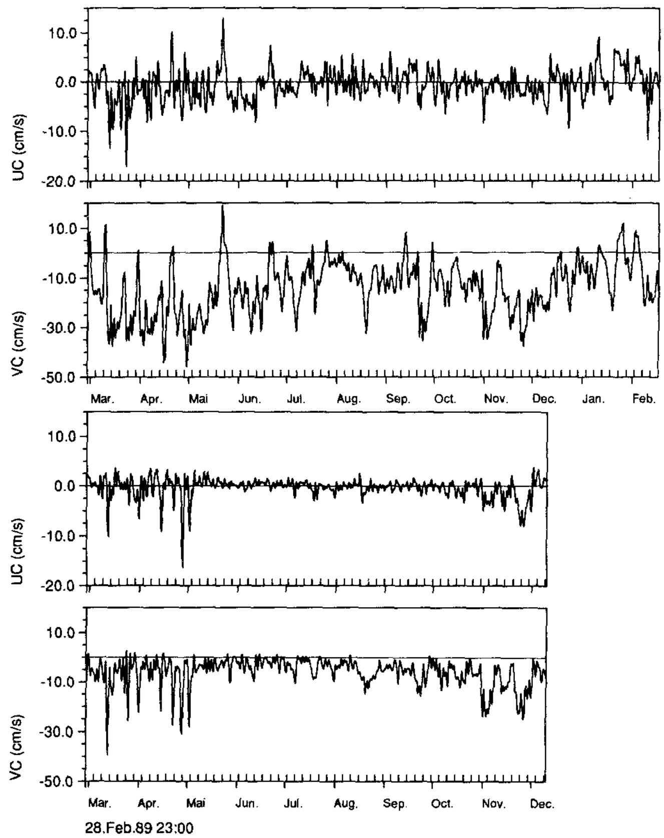

Fig. 9. Time series six hourly mean current speeds from instruments moored off Kapp Norvegia fom February 1989 to January 1990 in 293 m (*top*) and 671 m (*bottom*) depth in 676 m deep water. The time series were low-pass filtered with a 40 h half power point Lanszos square taper filter before averaging to eliminate most of the tidal variability. The orientation is UC positive on-slope to the southwest and VC positive along-slope to the northeast

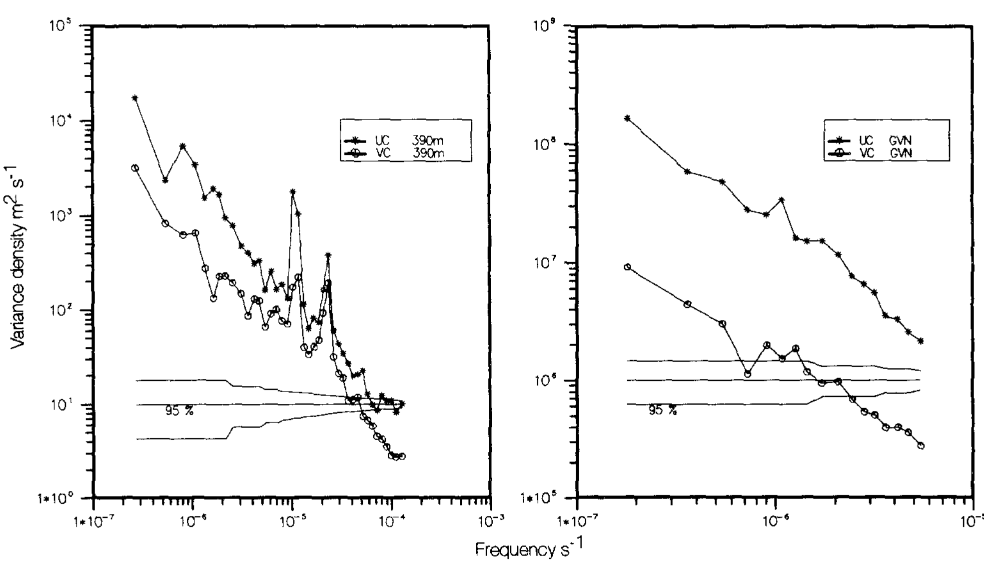

Fig. 10. Power spectra of the non-filtered current meter time series from instruments moored off Kapp Norvegia fom February 1989 to January 1990 (*right*, orientation of UC and VC as in Fig. 9) and from wind measurements at Georg von Neumayer Station (*left*, UC to the east, VC to the north)

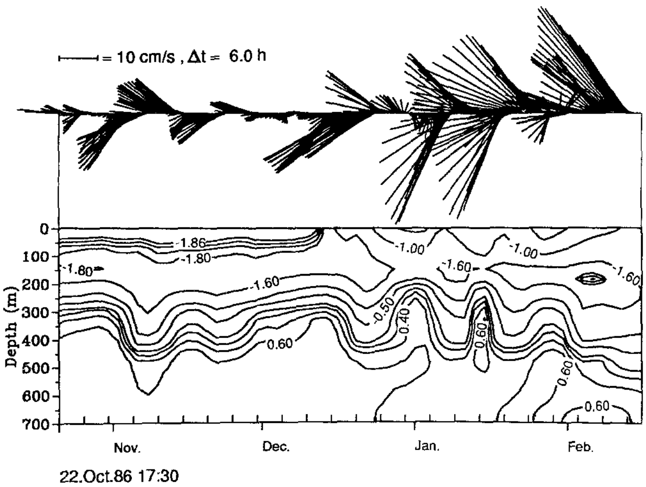

Fig. 11. Stick plot diagramme of the time series of six hourly mean current speeds and isopleth diagrammme of the temperature measurements from instruments deployed in mooring 103 off Vestkapp from October 1986 to March 1987 in 3,415 m deep water

Fluctuations in the same spectral range were first reported by Foster and Middleton (1979) from a time series measured 50 m above the bottom in the central Weddell Sea. Foster and Middleton (1979) discuss basin modes or eddies as possible mechanisms for that frequency range. However the winds at Georg von Neumayer Station show fluctuations of a similar frequency range (Fig. 10). We therefore assume that wind forcing plays an important role in the generation of the fluctuations. During the observation period of the Vestkapp mooring a fluctuation period of 15 days was observed with speeds of up to 35 cm/s (Fig. 11). The short time series of four months is consistent with the observations of Foster and Middleton (1979) who found an increase of the intensity of the fluctuations in austral summer. This is consistent with the observation in 1989 when the fluctuations were much stronger from March to May and again from November to December. However the maximum EKE was shifted from April to August in other years (Fig. 8).

The tidal regimes from Atka Bight to Vestkapp are remarkably different (Table 2). As indicated by the form factor F, the tidal currents in the Atka Bight area are of the mixed, predominantly diurnal type. Near Kapp Norvegia we find mixed, predominantly diurnal tidal currents whereas they are semidiurnal in the Vestkapp region. As a result of the complicated bottom topography, the small width of the shelf at the steep slope shape and sense of rotation of the tidal ellipses vary with position and water depth. The amplitudes of the principal components range between 0.5 cm/s at Vestkapp to 6 cm/s at Kapp Norvegia.

Discussion

Using measurement from hydrographic surveys and moored instruments we have given a description of the Antarctic Coastal Current in the southeastern Weddell Sea. From the time series it is obvious that all parameters are subject to intense fluctuations. This implies that greatest care must be taken, if one tries to deduce the physical background of biological processes from short term observations such as single hydrographic profiles. Relatively small scale variability, which is often related to the bottom topography can lead to wrong conclusions if the physical parameters are not measured in sufficient detail. The water temperatures in the Halley Bay area is one example. There, we found the warmest water of nearly 1° C in the surface layer just above the coldest water emanating from the ice shelf. Even in relatively shallow depths it is not possible to draw any conclusion from surface temperatures about the water column below.

A patch of cold Winter Water is preserved on the Kapp Norvegia shelf into the summer. In contrast, we found a patch of Warm Deep Water on the Halley Bay shelf separated by only 20 km from the water emanating from the ice shelf. This illustrates the rather heterogeneous conditions in the near bottom layers due to differences in the exchange rate with the open ocean as well as with the near surface layers. Patches of Winter Water were most likely ventilated during the last winter whereas Warm Deep Water patches result from horizontal advection of poorly ventilated water.

The exchange between the deep ocean and the shelf occurs in events with periods of 5 to 15 days. The events are more frequent during periods with strong currents. Inflow in the deep layers is not balanced by a shallow outflow, but occurs in the whole water column in varying intensity (Fig. 9). This implies a three dimensional mass balance of the shelf area. Reversals of the coastal current to a northerly direction are exceptions. The probability is higher in the deeper levels than at the shelf edge.

Whereas the mean current speeds are small, from 2 to 15 cm/s, the superposition of events and tides can result in high velocities. The maximum speed, still measured as an hourly average, was 68.8 cm/s. This represents a significant power to erode and transport suspended matter.

The observational programme in the Kapp Norvegia area is still continuing in the framework of the Weddell Gyre Study 1989 to 1993. We obtain time series from that programme which will allow determination of the variations at the different time scale with more statistical certainty. Modelling efforts (e.g. Olbers 1991) will help us to understand the physical processes which determine the fluctuations.

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