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THERMAL BAR EVOLUTION OFF OAKVILLE, 2003: DATA REPORT

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Preamble

A multi-disciplinary team has been formed by the Ontario Water Works Research Consortium (OWWRC) to address the renewed issue of abundant *Cladophora* fouling beaches each summer in Lake Ontario. One aspect that is being studied is the development of the algae early in the spring. It is postulated that there may be a significant opportunity for vigorous growth during the spring thermal bar evolution when nutrient-rich waters are trapped nearshore. The thermal bar is a shore parallel front which separates descending waters at or near the freshwater temperature of maximum density (4° C) during spring and fall seasons. The thermal bar is important because of its influence on mixing, cross-shore exchanges and variability of biotic factors in the coastal zone. An intensive field study was undertaken in 2003 to document the thermal bar evolution at the west end of Lake Ontario. On a profile running from the 10 m contour to the 80 m contour off Oakville, ON, seven stations were established to monitor temperature and currents during the thermal bar evolution. Weekly profiles and water samples were also taken. By 24 April the thermal bar was well established at about the 20 m contour and persisted there until 14 May. By 26 May the 4° C isotherm had moved offshore. The currents were strongly shore parallel nearshore, less so offshore. This report summarizes the mean conditions during the deployment and serves as an interim report to the OWWRC while ongoing analyses and manuscript preparation are underway.

Évolution de la ligne de stratification thermique au large d'Oakville, 2003 : Rapport statistique

par

MG Skafel, RR Yerubandi, MN Charlton

Préambule

L'Ontario Water Works Research Consortium (OWWRC) a mis sur pied une équipe multidisciplinaire chargée de se pencher sur le problème récurrent de la pollution estivale des plages du lac Ontario causée par la surabondance des algues *Cladophora*. La prolifération algaire tôt au printemps est l'un des aspects à l'étude de ce problème. Les chercheurs ont pris comme hypothèse de travail qu'il existe une importante fenêtre d'intense croissance pendant la période de l'inversion thermique printanière, c.-à-d. à l'époque où l'eau riche en nutriments est captive de la zone littorale. La ligne de stratification thermique est un front thermique parallèle au rivage qui délimite la zone d'eau descendante à la densité maximale, ou tout près, de l'eau douce (à 4 °C) au printemps et à l'automne. La ligne de stratification thermique joue un rôle important à cause de son action sur le mélange des eaux, sur les échanges en direction de la zone pélagique ainsi que sur la variabilité des facteurs biotiques dans la zone côtière. Une étude intensive sur le terrain a été entreprise en 2003 pour établir le profil évolutif de la ligne de stratification thermique à l'extrémité ouest du lac Ontario. Le long d'un gradient s'étendant du niveau bathymétrique de 10 m jusqu'à celui de 80 m, au large d'Oakville en Ontario, les chercheurs ont implanté sept stations de surveillance de la température et des courants pendant la période de l'inversion thermique. De plus, des profils hebdomadaires ont été tracés et des échantillons d'eau ont été prélevés. Le 24 avril, la ligne de stratification thermique était bien établie à hauteur du niveau bathymétrique de 20 m environ. Elle y a persisté jusqu'au 14 mai. Le 26 mai, l'isotherme de 4 °C s'était déplacée vers le large. Les courants étaient fortement parallèles au rivage à proximité de la côte, moins au large. Le présent rapport présente un résumé des conditions moyennes pendant la période à l'étude. Il a valeur de rapport provisoire remis à l'OWWRC, d'ici à la fin des analyses et à la rédaction complète du manuscrit.

Thermal Bar Evolution off Oakville, 2003: Data Report

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1. Introduction

In the 1960's and 1970's attached algae, mainly *Cladophora*, caused serious problems in the nearshore of Lake Ontario. It grew in large amounts that died off each summer, detached and decayed, fouling local beaches. Research at the time showed that Lake Ontario was receiving excessive phosphorus, a nutrient that normally limits *Cladophora* growth in the shallow, well-illuminated nearshore zone. Through legislation and other measures phosphorus loadings to the lake were reduced and excessive growth of *Cladophora* was brought under control in the 1980's. In the intervening years the lake has undergone a number of changes. The introduction of zebra mussels and other exotic species has dramatically altered the ecology. The population, especially on the Canadian side of the lake, has grown substantially, now being some 6 million people in the watershed with the concomitant loading from wastewater treatment plants and storm sewer outfalls. Since 2000 fouling of beaches has again been reported as a problem. The cause of the increase in *Cladophora* growth and washing up on beaches is not well understood so optimal control measures cannot be prescribed.

A multi-disciplinary team has been formed to address this renewed issue of abundant *Cladophora.* One aspect of the issue that is being studied is the development of the algae early in the spring. It is postulated that there may be a significant opportunity for vigorous growth during the spring thermal bar evolution. The thermal bar is a shore parallel front which separates descending waters at or near the freshwater temperature of maximum density (4° C) during spring and fall seasons (Rodgers, 1965). The thermal bar is important because of its influence on mixing, cross-shore exchanges and variability of biotic factors in the coastal zone. During the thermal bar development cross-shore turbulent exchanges reduce drastically, hence, this zone will act as a barrier for the nutrients entering from coastal point and non-point sources. An intensive field study was undertaken in 2003 to document the thermal bar evolution at the west end of Lake Ontario.

This report provides an overview of the development of the mean temperature, conductivity and flow fields as they evolved during the period from early April to early June.

2. Field Campaign

On a profile running from the 10 m contour to the 80 m contour off Oakville, ON, seven stations were established to monitor the thermal bar evolution. The instrumentation was deployed in early April and retrieved in early June. In all, four ADCP's, five single point acoustic current meters (one Sontek Hydra, four Nobska Mavs), three transmissometers, and 36 temperature sensors in six fixed temperature profilers (FTP) were deployed. In addition, weekly profiles were taken at these stations and two shallower stations with a sonde (YSI or Hydrolab) to measure temperature, conductivity and other parameters. The details of the instrument deployment are summarized in Table 1 and Figure 1. Stations 21A and 22A were separate moorings for logistical purposes, but were adjacent to each other and will be referred to as 22A throughout the remainder of the report. The current meter at Station 20A flooded early in the deployment and no reliable data were recovered. Both current meters at Station 23A and the one at the bottom at Station 25A returned faulty direction information. The transmissometer at Station 27A malfunctioned.

Meteorological data were obtained from the NWRI sites at either end of the Burlington Ship Canal.

Table 1. Locations of instruments during the study.

Station	Instruments	Water Depth [m]	Instrument Depths [m]	Location	Comments
798		4.3		43° 27.167'N 79° 39.033'W	Profiling station
799		6.6		43° 27.117'N 79° 38.667'	Profiling station
20A	Sontek Hydra (currents, temperature)	11	10.4	43° 26.981'N 79° 38.544'W	Hydra failed
21A	ADCP (currents, temperature)	21	20.5	43° 26.734'N 79° 38.043'W	
22A	FTP (temperature)	22	1, 5, 10, 15, 20	43° 26.716N 79° 37.994W	
23A	FTP Mavs (currents, temperature) Transmissometers	31.2	1, 5, 15.2, 20.2 10.2, 30.2 10.7, 29.7	43° 26.512'N 79° 37.719W	Both Mavs failed
24A	FTP ADCP	41	1, 5, 10, 20, 30, 40 16	43° 26.174'N 79° 37.10'W	
25A	FTP Mavs	51.9	1, 5, 15.9, 20.9, 30.9, 50.9 10.9, 50.9	43° 25.894'N 79° 36.562'W	Mavs at 51.9 m failed
26A	FTP ADCP	62	1, 5, 10, 21, 31, 61 16	43° 25.435N 79° 35.742'W	
27A	FTP ADCP Transmissometer	82	1, 5, 10, 21, 31, 81 16 18	43° 24.20'N 79° 33.654'W	Transmissometer failed

3. Sonde Data

Profiles were taken approximately weekly at all of the stations. The 10 April and 8 May profiles were done with the Hydrolab and the remainder with the YSI sonde. Temperature and conductivity data were routinely sampled from all profiles, in addition chlorophyll and dissolved oxygen data are available. The data have been used to prepare cross sections of these variables along the transect from the shore to the offshore station to illustrate the spatial dependence of the parameters. Figure 2 shows the evolution of the temperature field from 10 April (Day 100) to 10 June (Day 161), together with selected cross shore velocities at the same time as the profiles. The temperature field was all below 4°C on Day 100, but by Day 114 a thermal bar was established, with the temperatures shoreward of the bar just reaching 5°C within about half a kilometre from shore. On Day 120 the thermal bar was stationed entirely over about the 30 m contour, the contours on the shoreward side reaching 7°C very near the shore. It remained at about the same location on Day 128, although the upper part of the 4°C isotherm was nearer the shore. On Day 134 the thermal bar intersected the bottom at about 20 m, while the upper portion was further offshore, over the 40 m contour. By Day 146 the thermal bar intersected the bottom at about 75 m, the upper portion was lakeward of all Stations; the inshore region was becoming stratified. On Day 154 the 4°C isotherm intersected the bottom at about 50 m, and was horizontal out to the outermost Station; stratification intensified over the study area.

Figure 3 shows the corresponding evolution of the conductivity field. The conductivity cross sections show that even on Day 100 there was some elevation of the conductivity shoreward of the 30 m depth contour. On Day 114 the conductivity was more elevated nearshore and the 320 µS/cm isopleth was similar in form to, and just lakeward of, the 4°C isotherm. The nearshore conductivity was reduced on Day 120 and the 310 µS/cm isopleth was near the thermal bar at about the 30 m contour. The nearshore concentrations increased on Day 128, and the 310 and 320 µS/cm isopleths bracketed the thermal bar. By Day 134 the nearshore conductivity decreased and the 300 µS/cm isopleth was close to the thermal bar, now near the 20 m contour; the 300 µS/cm isopleth was vertical while the isotherm sloped lakeward. On Day 146 there was stratification in the conductance nearshore (over 340 µS/cm within about two km of shore) and the 300 µS/cm isopleth was near the 50 m depth contour. On Day 154 the nearshore conductance was reduced and the 300 µS/cm isopleth had retreated to about the 30 m contour and sloping lakeward toward the surface. On Day 161 the conductivity was relatively uniform, but slightly elevated in the surface waters within 8 km of the shore.

4. Temperature Time Series

The data from all the temperature sensors on the fixed moorings were used to prepare the time series of the isotherms, shown in Figure 4. The temperature sensors gave more detail in the time domain and less in the vertical domain compared to the sonde profiles. The hourly data were filtered using an 8 hour low pass filter. The 4°C isotherm appeared on Day 116 and again over the whole water column on Day 119 at Station 22A. It first appeared at Station 23A on Day 120 and remained there until to Day 134 (14 May). It then moved rapidly lakeward, passing Station 24A on Day 135 and Station 25A on Day 138, Station 26A on Day 139, and finally Station 27A on Day 144.

5. Wind and Current Data

The conditions at the lake side of the Burlington Pier are ideal for observing onshore winds, that is, wind out of the east and is the location of one of NWRI's meteorological stations. However it is a poor site for observing the prevailing westerly winds because of the three bridges, the large CCIW building complex, and numerous trees upwind during west winds. To overcome the problem, NWRI has installed a second meteorological station on the south end of the breakwater on the west side of the CCIW complex, open to the full fetch of Hamilton Harbour. The data used in this study are a combination of the data sets from the two sites. When winds were from the lake side of the barrier beach the 'pier' station was used and when the winds were from the harbour side of the beach, the 'breakwater' site was used. Thus the reported wind was always an onshore wind except for those few occasions the wind was blowing along the beach. The first panel in Figure 5. shows the onshore and alongshore components of wind stress, computed from the wind following Wu (1980), low-pass filtered at 24 hours. The alongshore direction is oriented along the axis of the lake, positive easterly, and positive cross shore is towards the northern shore. The low pass filtered alongshore and cross-shore velocities at the bin three metres below the surface at the ADCP stations are shown in the remaining panels of Figure 5. There were four significant wind events (all alongshore) during the deployment and several modest ones. Throughout, the alongshore flow was significantly greater than the cross shore flow, and the flow at the two inshore stations was much greater than at the offshore station. The three strong easterly wind events resulted in strong westerly directed alongshore flows at the inner stations, and the strong west wind on Day 132 resulted in strong east flow. The modest west wind on Day 107 produced a fairly strong east current at the inner stations.

The principal axes for currents at four depths at the ADCP sites are shown in Table 2. The regional shore parallel direction is about 55°T. The flows were stronger near the surface, but similar at all depths. The major axes directions were near the regional direction. The overall flow at Station 24A was the most alongshore dominated, followed by the flow at the inner most station, 22A. The alongshore dominance diminished progressively offshore from 24A.

Progressive vector diagrams (PVD) have been prepared for each ADCP, displaying the pseudo displacement of the water at four depths through the water column at each site. Figure 6 shows these diagrams for the whole measurement period. The open circles on the diagrams were inserted at seven day increments. These plots clearly show the shore parallel nature of the flow and indicate the large distances that water masses could move in the nearshore over the duration of the deployment (from about 100 km at Station 22a to over 200 km at 24A and 27A). In all cases the net displacement was to the southwest.

Table 2. Principal axes of the currents at the ADCP stations

Station (water depth [m])	Bin Depth [m]	Major Axis [m/s]	Minor Axis [m/s]	Major/minor Ratio	Direction [°T]
22A (21)	3	0.113	0.038	3.0	44
	8	0.109	0.035	3.1	44
	13	0.102	0.034	3.0	45
	18	0.094	0.037	2.5	45
24A (41)	3	0.102	0.025	4.1	40
	6	0.094	0.02	4.8	43
	10	0.088	0.017	5.3	45
	14	0.085	0.014	5.9	46
26A (61)	3	0.084	0.048	1.7	33
	6	0.062	0.027	2.3	42
	10	0.055	0.02	2.8	47
	14	0.053	0.017	3.2	49
27A (82)	3	0.048	0.032	1.5	61
	6	0.038	0.023	1.7	53
	10	0.037	0.021	1.7	51
	15	0.033	0.019	1.8	52

Figure 7 shows the PDVs for the period 1 May to 14 May (Day 120 to 134) when the thermal bar was relatively stationary between 2 and 3 km offshore. In striking contrast to the whole deployment period, during this period the net displacement at the two inshore stations was very modest: an excursion of some 50 km to the southwest was followed by a similar excursion to the northeast for a net displacement of about 10 km. At the two offshore stations the excursion to the southwest was followed by a much more modest return at Station 26A and virtual no return at 27A.

6. Transmissivity

The transmissivity data at Station 23A are plotted against time in Figure 8, along with the temperature at the same location and depths. All are low-pass filtered at 24 hours. Decreased voltage output of the transmissometer indicates a reduction in transmissivity. The transmissivity at both depths remained steady at about the same value until about Day 122 when the shallower instrument experienced reduced transmission for about two days, then recovering, then reducing continuously up to Day 155. The lower instrument held steady until Day 142 then reduced until Day 155 as well. The temperature at both depths was below 4°C prior to Day 120, near 4°C during the period from Day 120 to 135, and increased thereafter. From Day 120 to 134 is the period during which the thermal bar lingered in the vicinity of this station, as indicated in Figures 2 and 4.

7. Discussion

The deployment captured the evolution of the vernal thermal bar off Oakville in 2003. It was first detected on 24 April (Day 114) in the profiles and on 18 April (Day 118) at Station 22A. It finally extended offshore of the study site on 25 May (Day 145). The average offshore velocity was 0.25 km/day. From about 1 May to 14 May it lingered in the vicinity of the 30 m contour. This was a period of relative calm meteorological conditions. The difference in water conductivity data shoreward and offshore of the thermal bar indicates that the characteristics of water masses on either side of the bar were different. The higher conductivity inshore of the bar is consistent with high conductivity encountered in runoff and wastewater discharges, the values of around 300 μS/cm measured offshore were typical of open lake values measured in other years. The reduction in light transmission at Station 23A during the period starting about Day 122 is consistent with a front of more turbid nearshore water moving lakeward through that region, and is also consistent with the temperature and conductivity data.

Throughout the deployment the currents, driven dominantly by the wind, were strongly shore parallel, especially at the inner stations. Net displacements during the deployment were as much as 200 km/45 days or over 4 km/day towards the southwest. Clearly alongshore advection was a dominant process. In contrast, during the period the bar was relatively stationary, the net alongshore displacement at the inner stations was as little as 1 km/day while at the outer stations the net displacement was closer to 4 km/day, due to the fact that the flow did not reverse midway through the period as it did at the inner stations.

References

Rodgers, G K, 1965 The thermal bar in the Laurentian Great Lakes. Proc 8th Conference Great Lakes Res. Int Assoc Great Lakes Res, Pub 13, 358-363.

Wu, J 1980 Wind-stress coefficients over sea surface near neutral conditions – a revisit. J Phys Oceanogr, 10, 727-740.

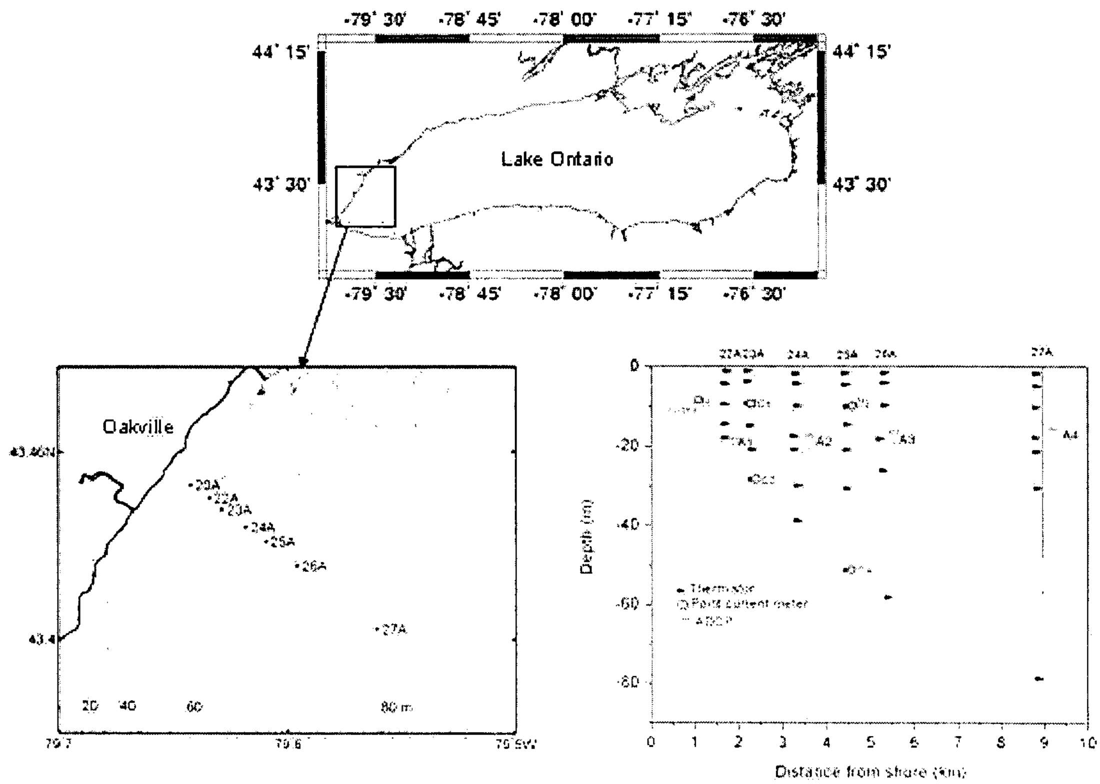


Figure 1. Study location and deployment configuration.

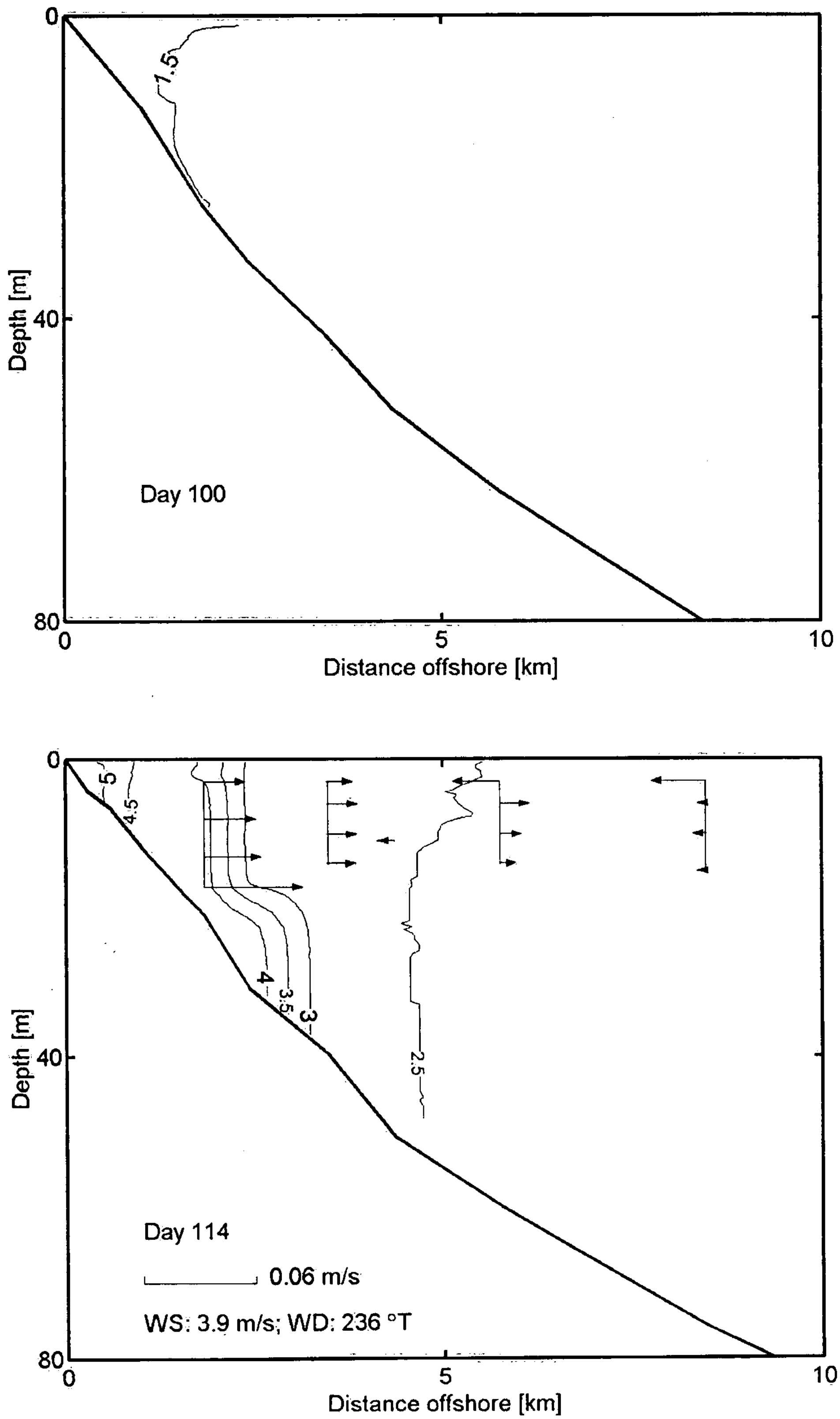


Figure 2. Isotherms [°C] and cross shore velocities.

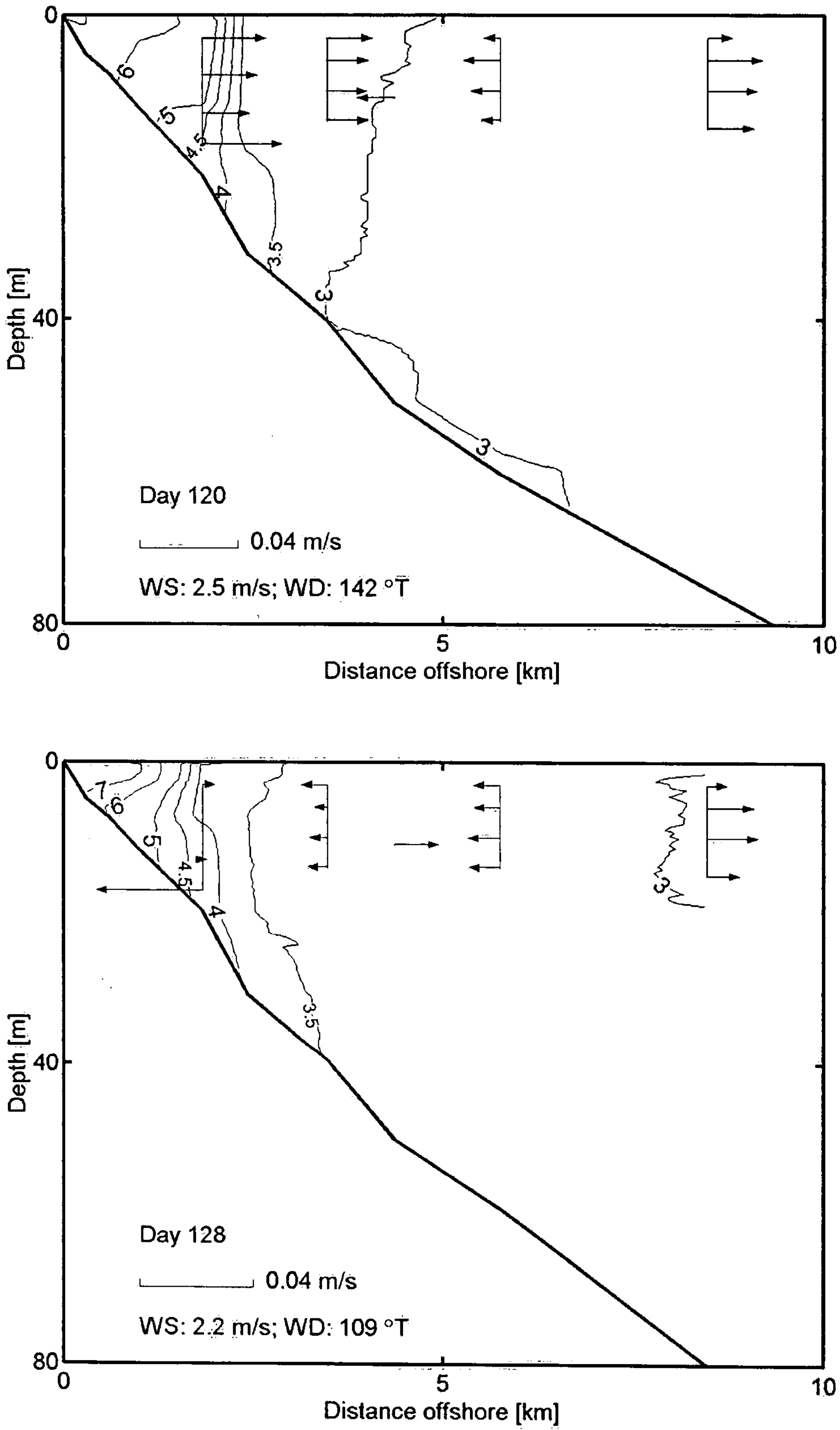
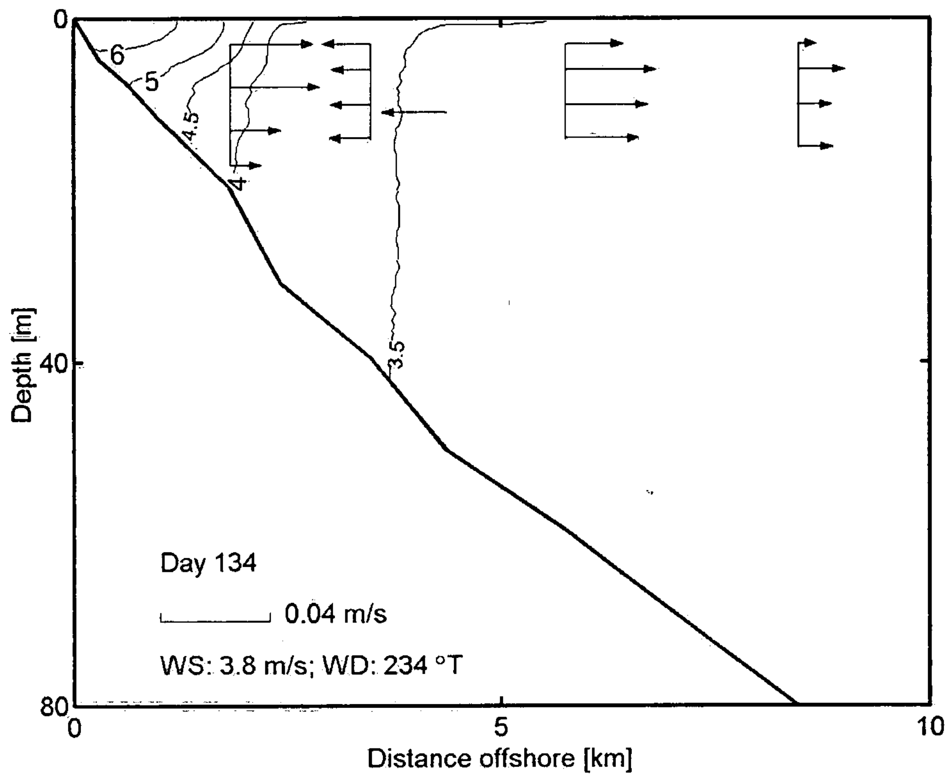


Figure 2 (cont'd). Isotherms [°C] and cross shore velocities.



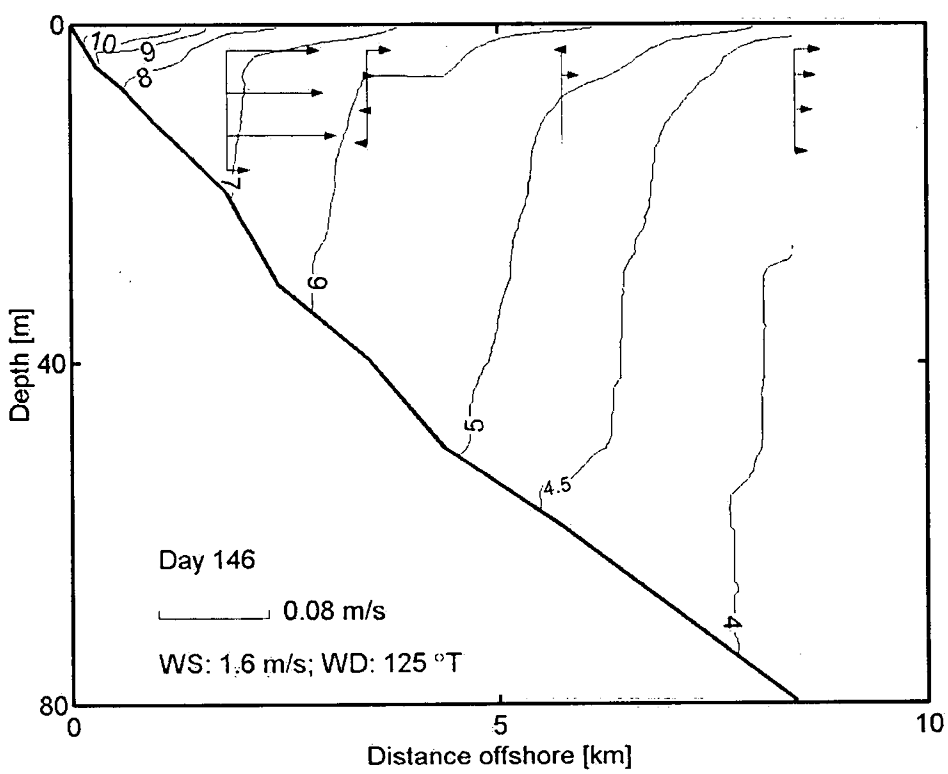


Figure 2 (cont'd). Isotherms [°C] and cross shore velocities.

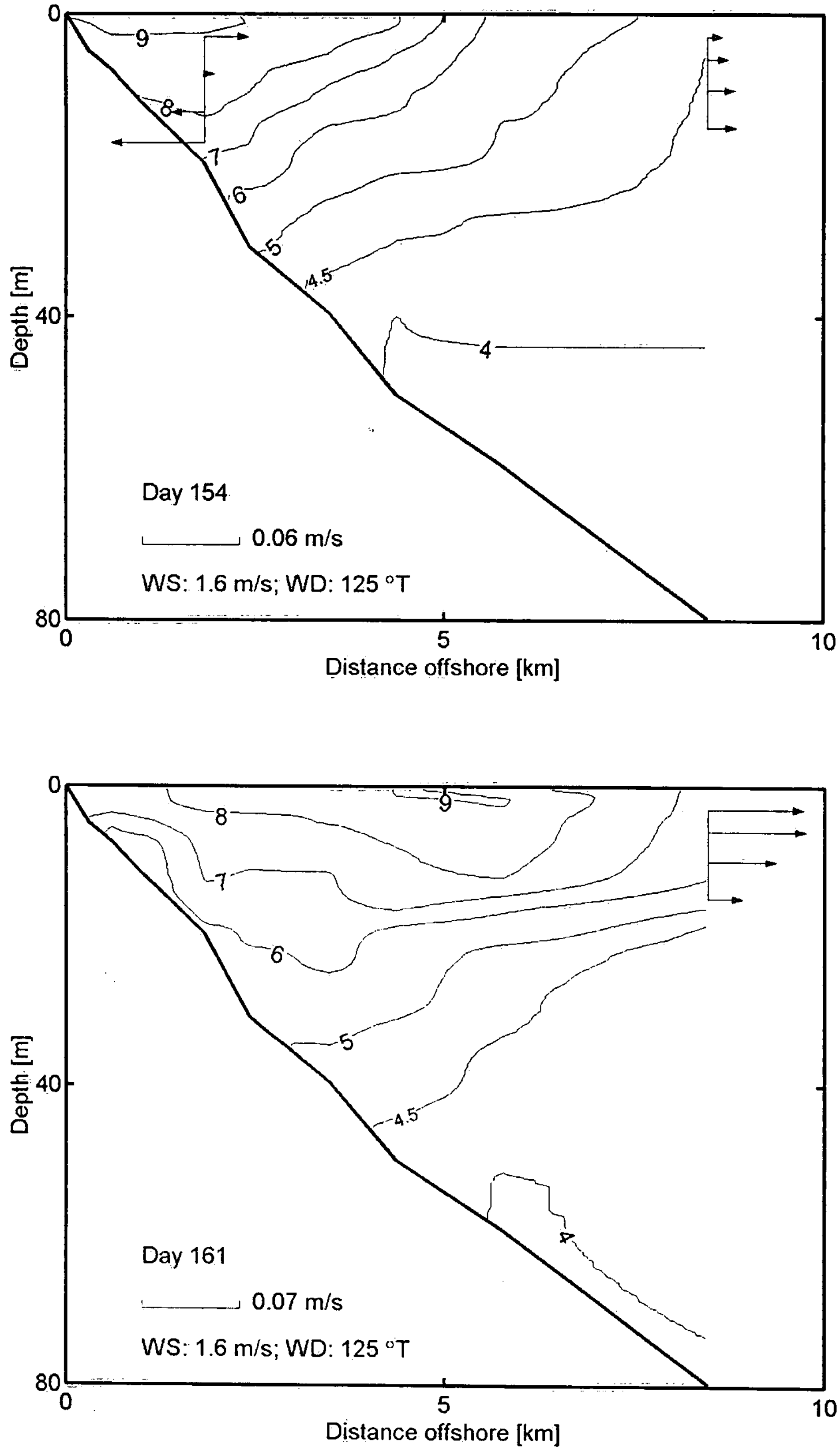


Figure 2 (cont'd). Isotherms [°C] and cross shore velocities.

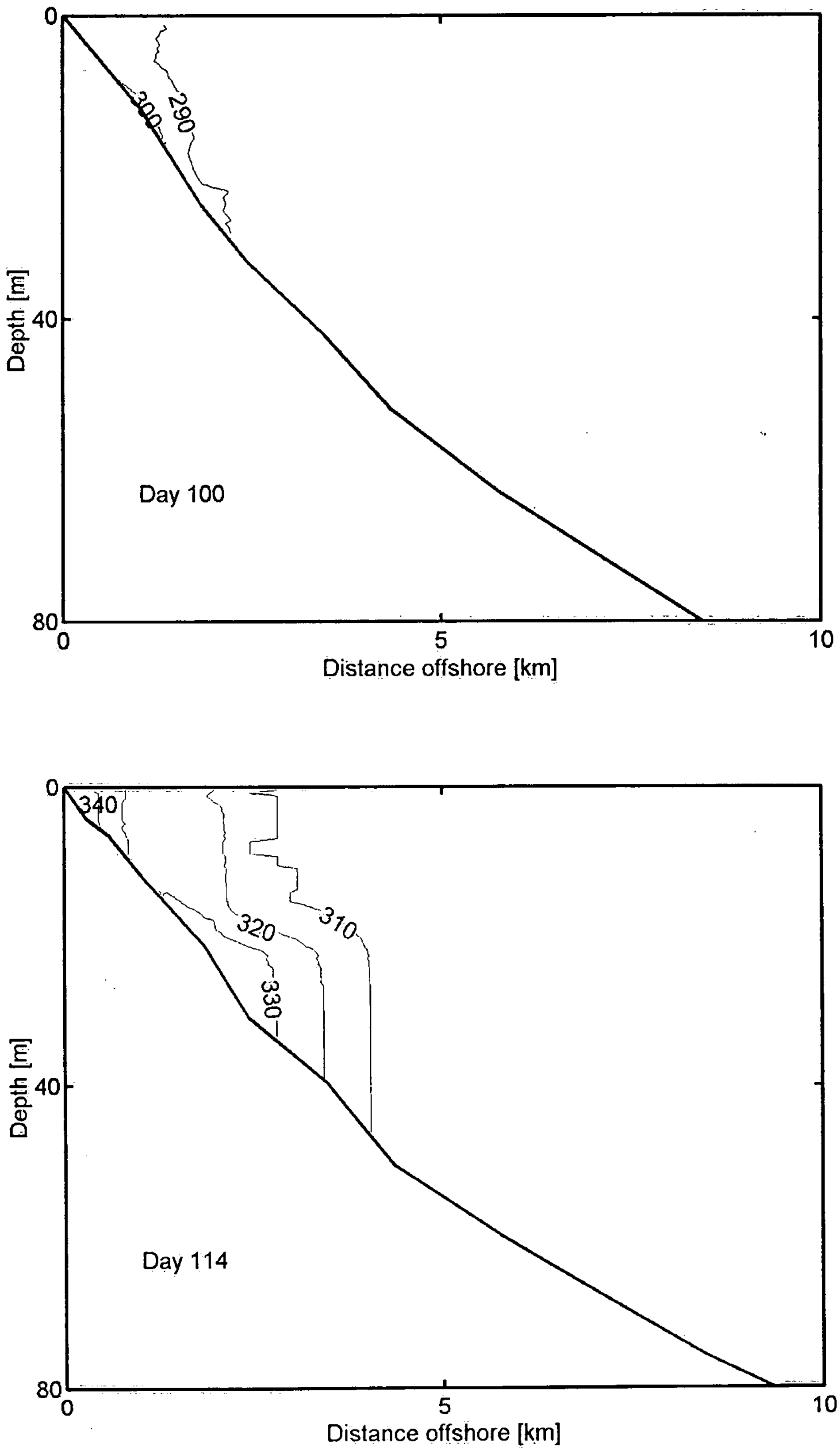


Figure 3. Specific conductance [μS/cm].

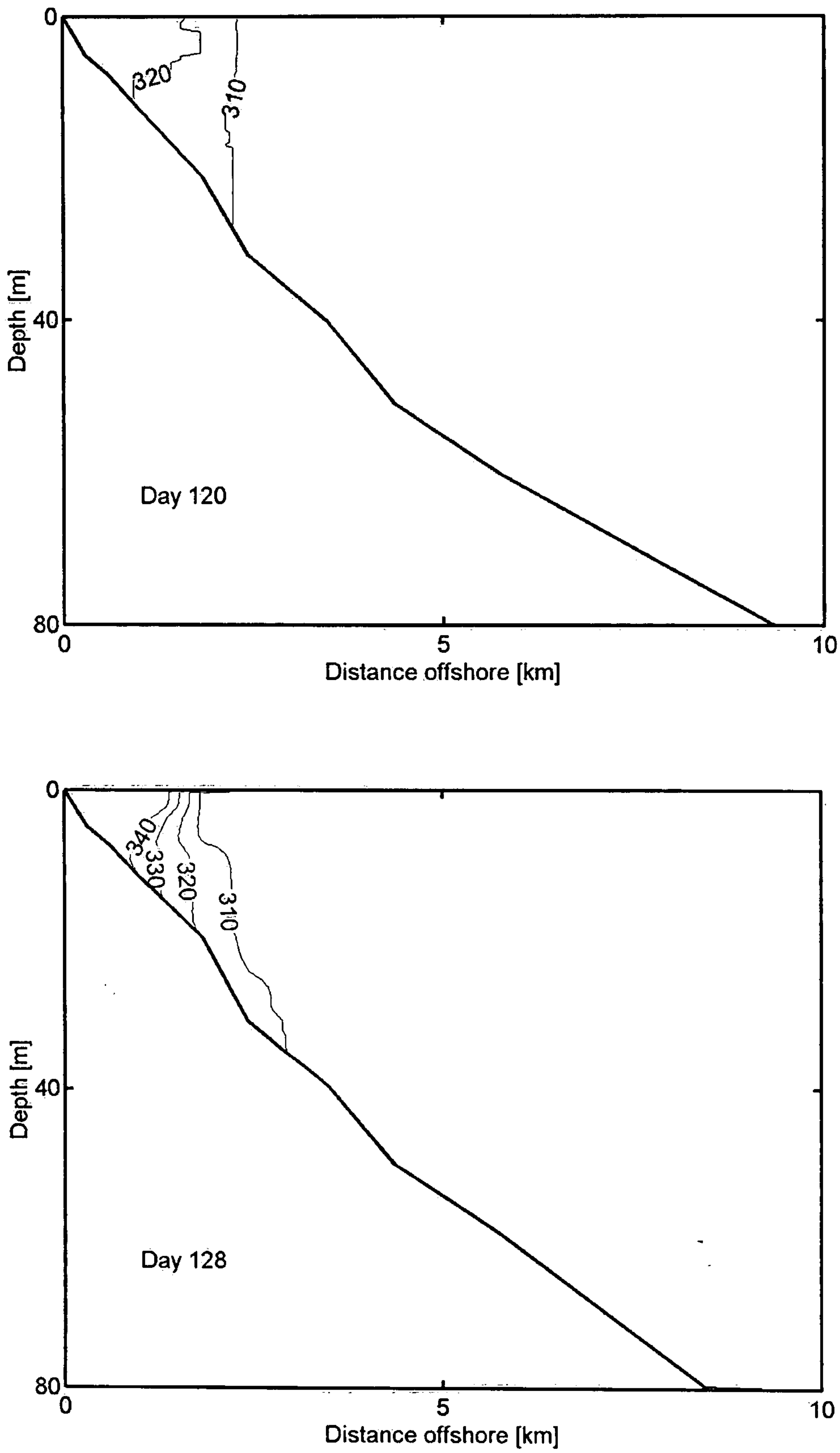


Figure 3 (cont'd). Specific conductance [μS/cm].

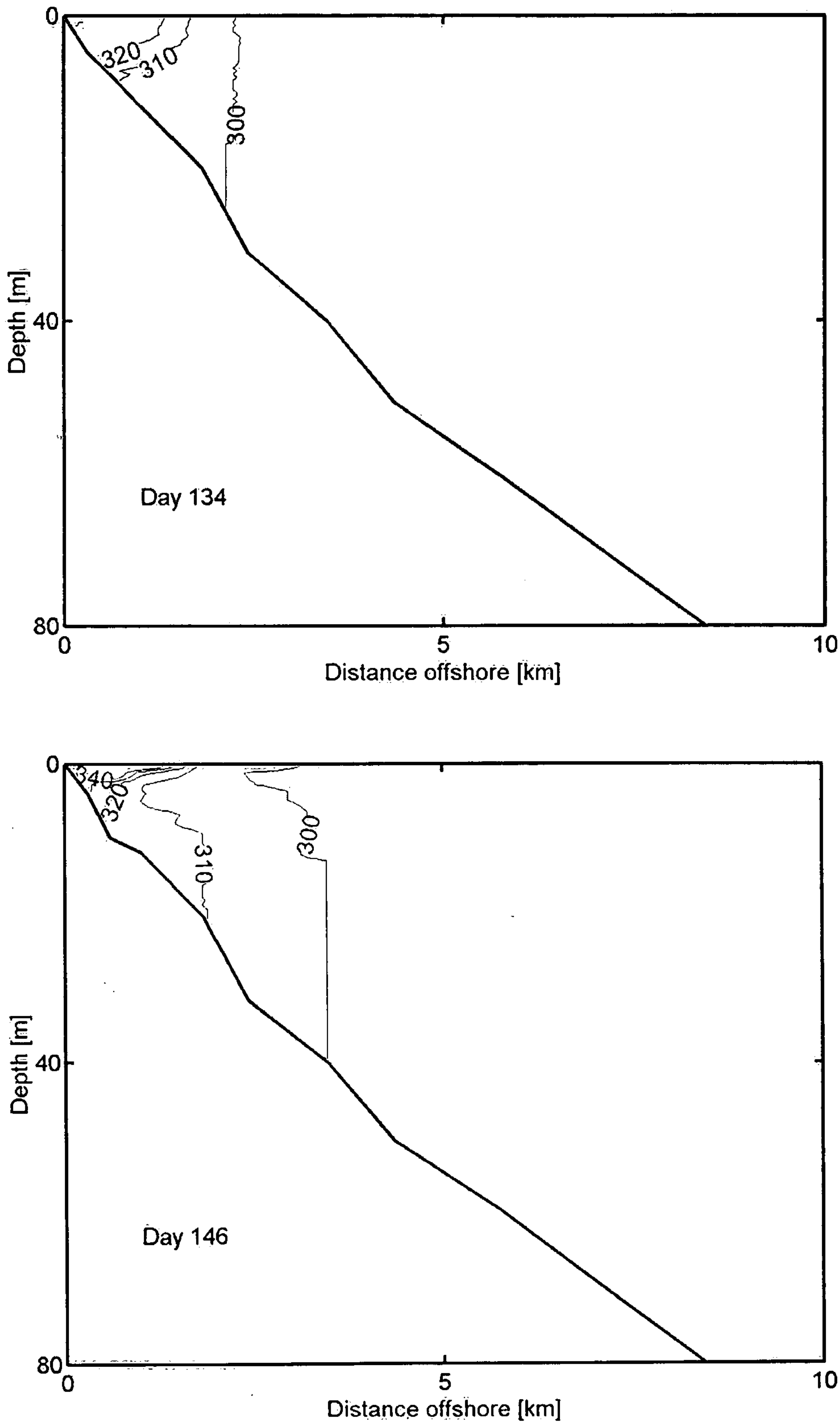


Figure 3 (cont'd). Specific conductance [μS/cm].

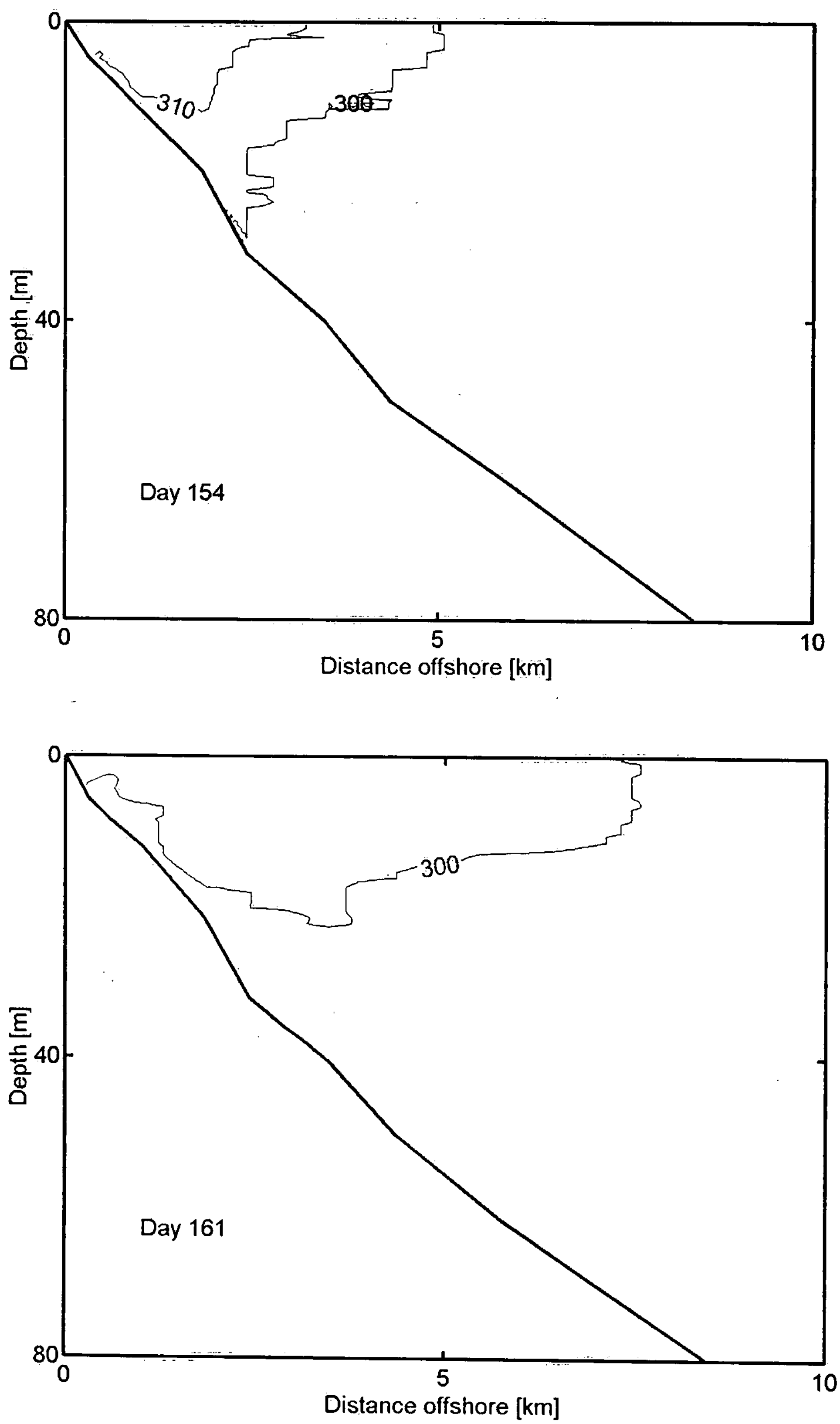


Figure 3 (cont'd). Specific conductance [μS/cm].

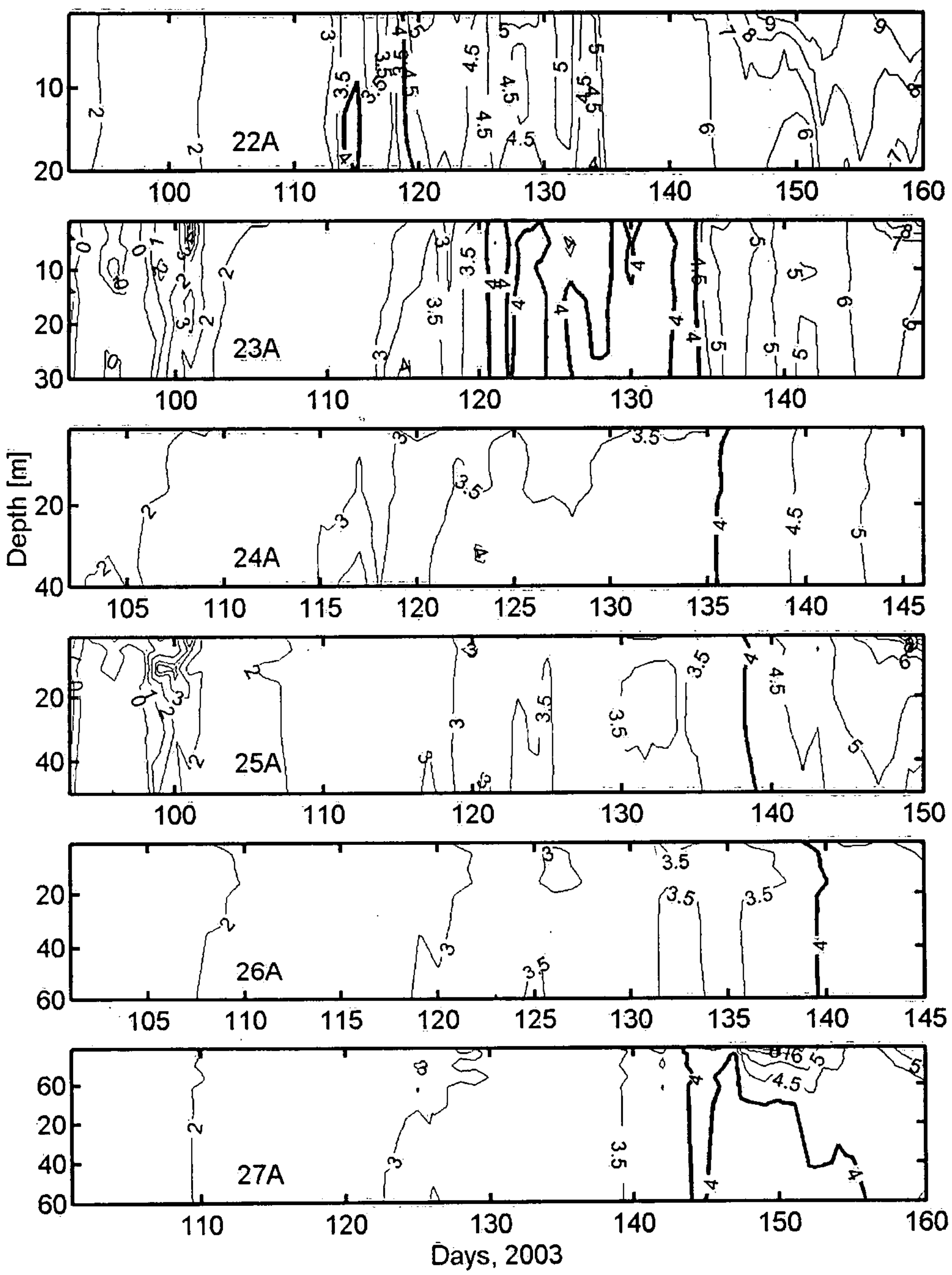


Figure 4. Time series of the isotherms at six Stations.

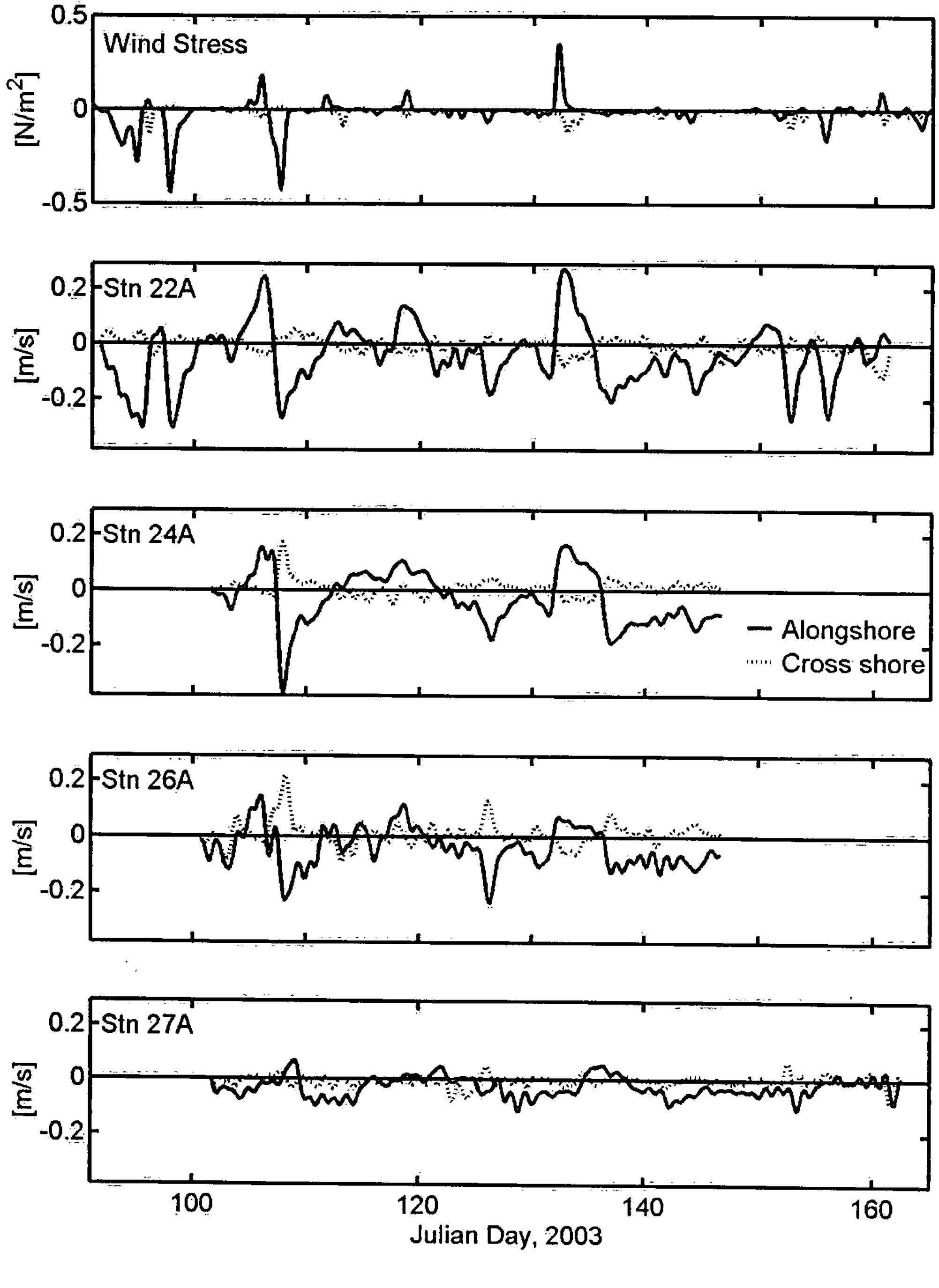


Figure 5. Time series of filtered alongshore and cross shore wind and currents.

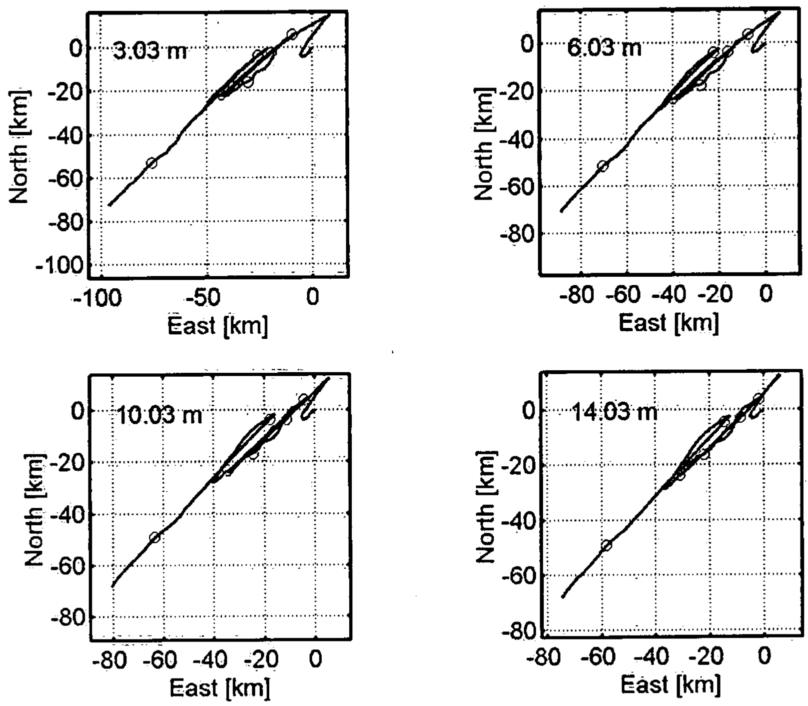


Figure 6. Progressive vector diagrams for the whole deployment at Station 22A (1 April to 10 June).

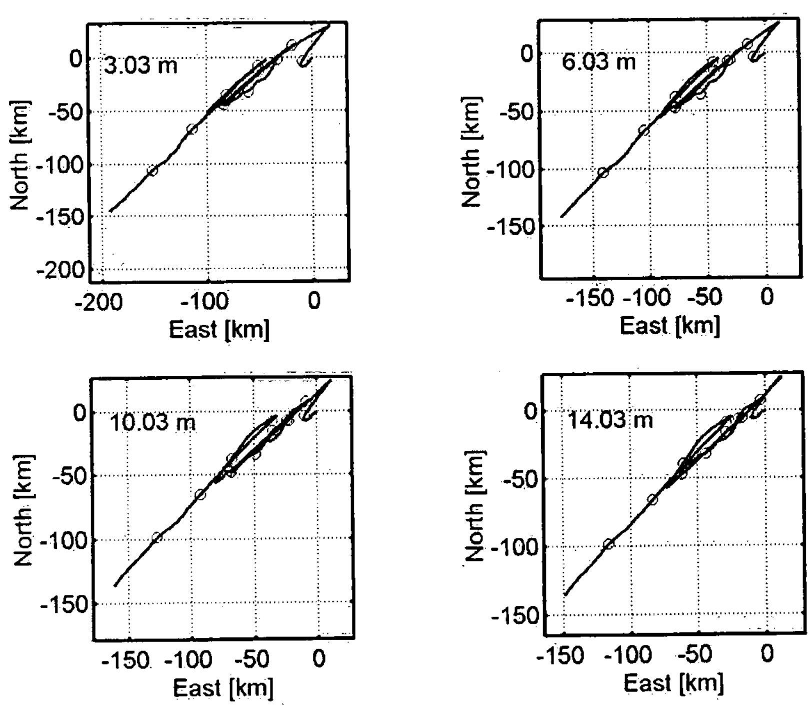


Figure 6 (cont'd). Progressive vector diagrams for the whole deployment at Station 24A (11 April to 26 May).

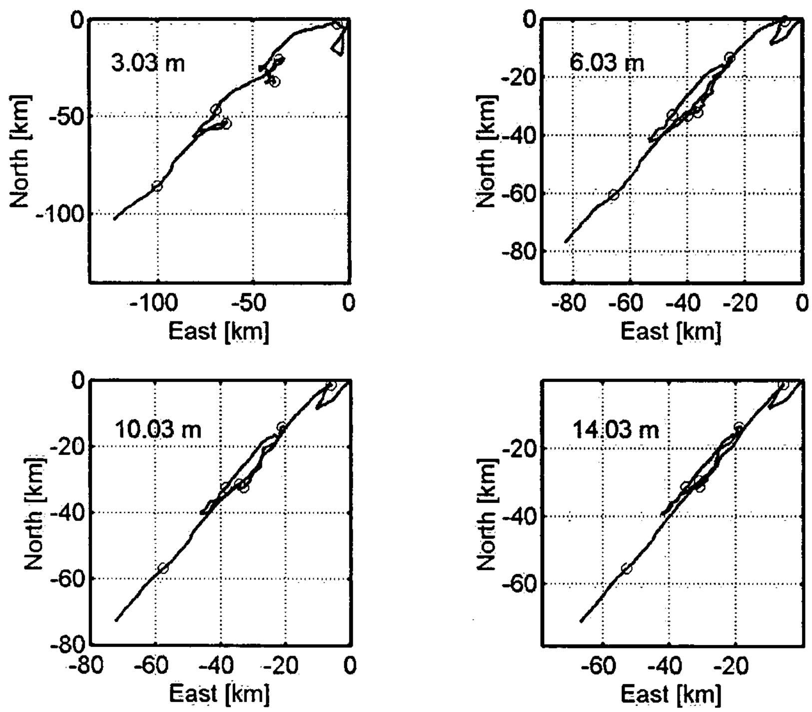


Figure 6 (cont'd). Progressive vector diagrams for the whole deployment at Station 26A (10 April to 26 May).

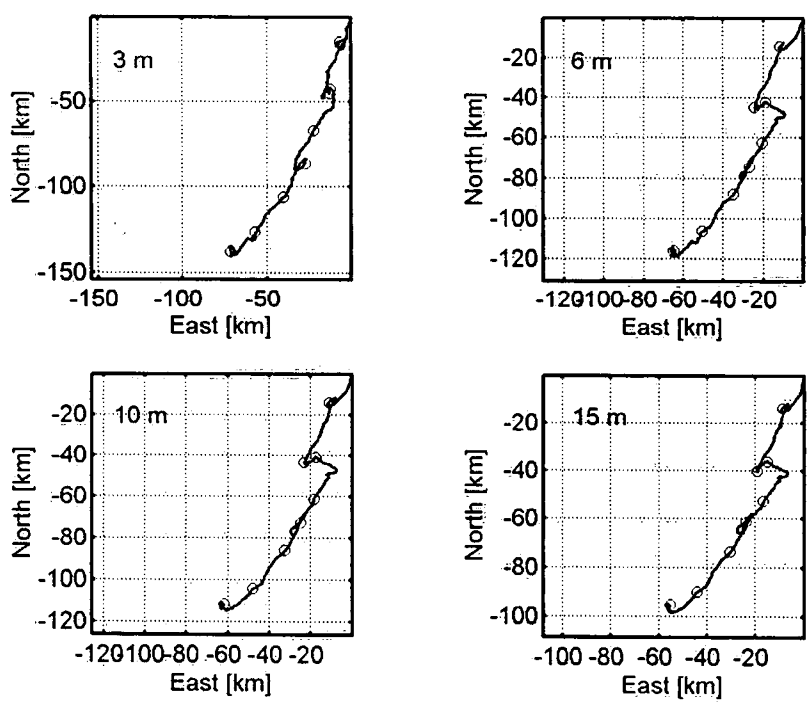


Figure 6 (cont'd). Progressive vector diagrams for the whole deployment at Station 27A (10 April to 10 June).

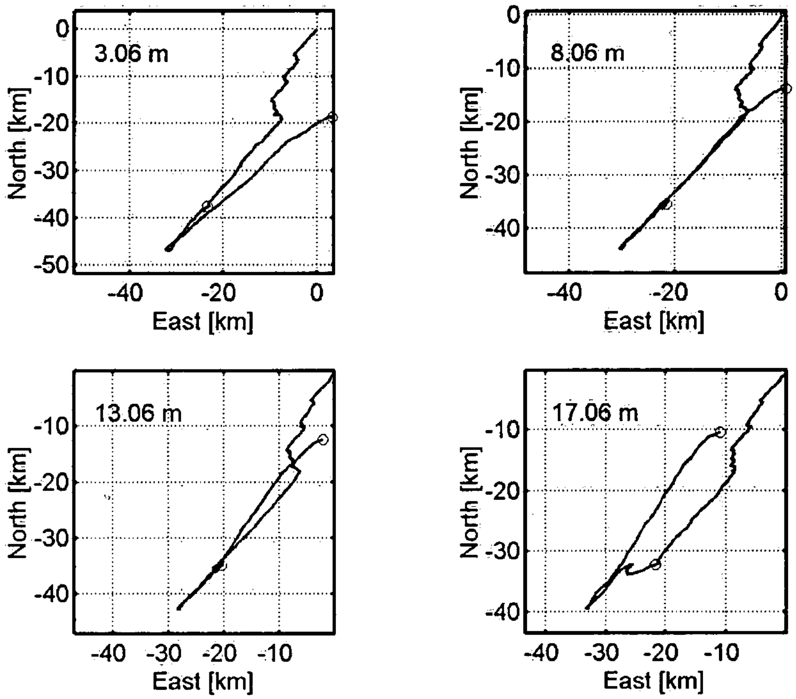


Figure 7. Progressive vector diagrams at Station 22A for the period from 1 May to 14 May (Day 121 to 134).

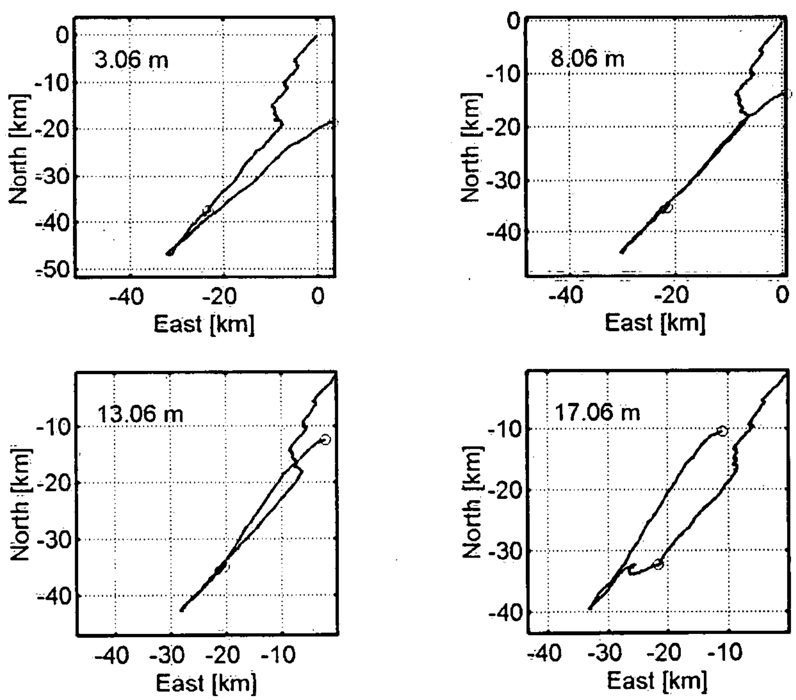


Figure 7 (cont'd). Progressive vector diagrams at Station 24A for the period from 1 May to 14 May.

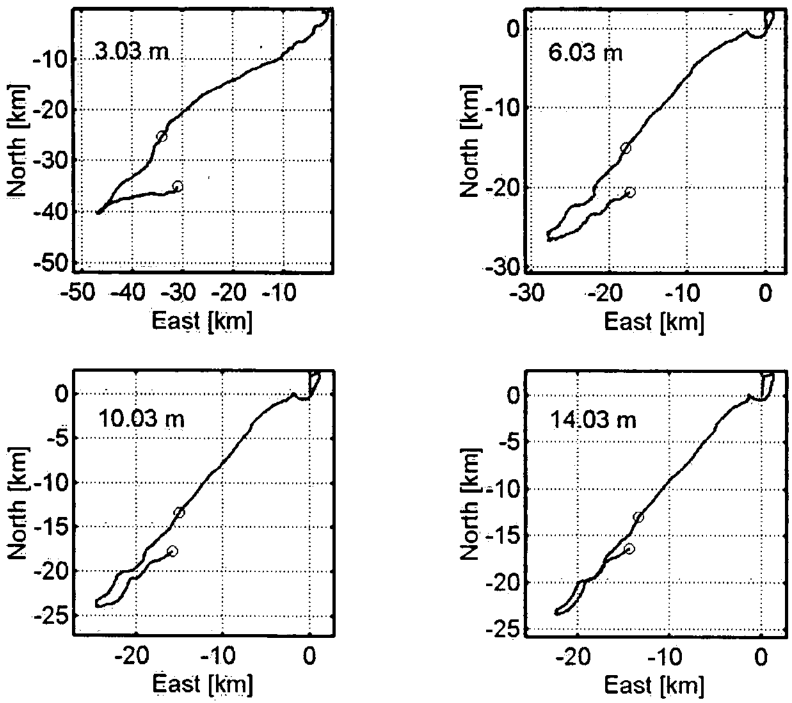


Figure 7 (cont'd). Progressive vector diagrams at Station 26A for the period from 1 May to 14 May.

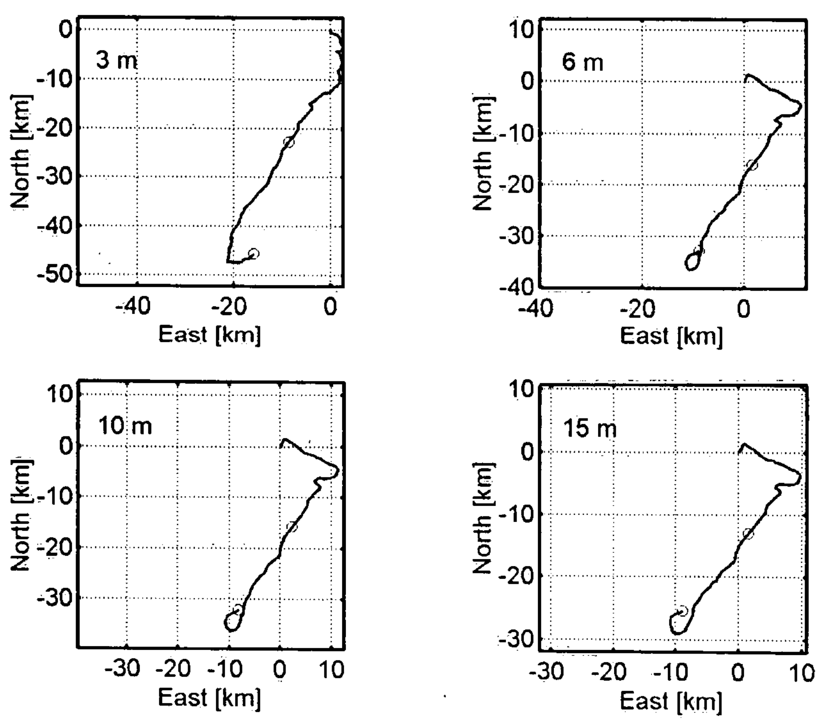


Figure 7 (cont'd). Progressive vector diagrams at Station 27A for the period from 1 May to 14 May.

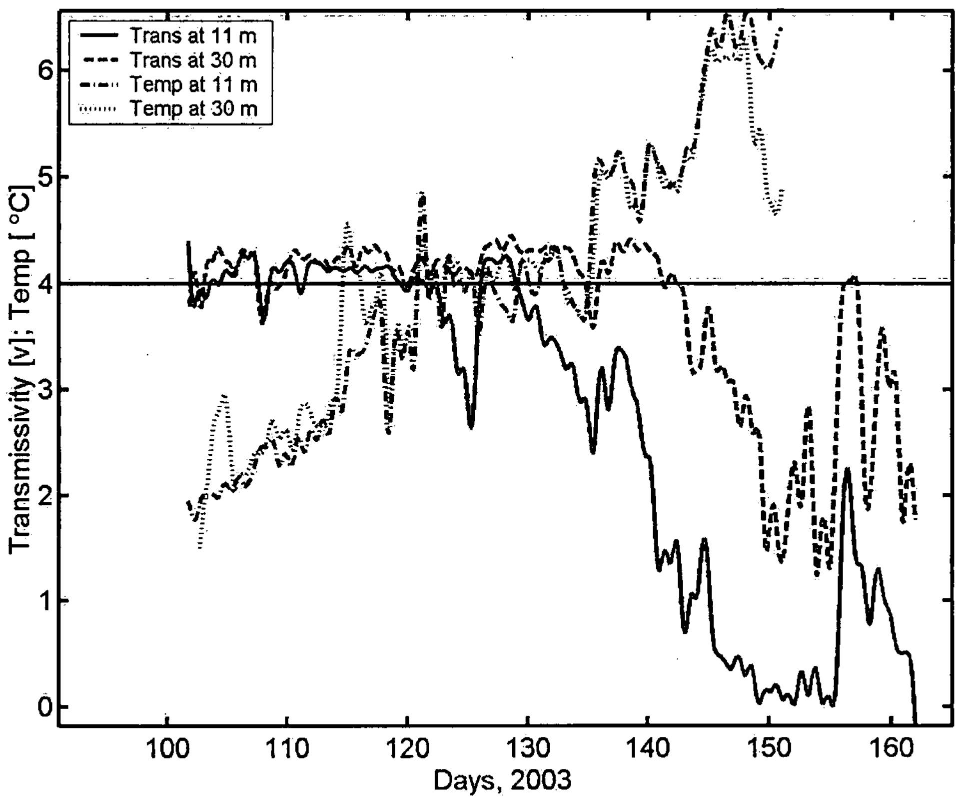


Figure 8. Traansmissivity and temperature time series (24 hour low-pass filtered) at Station 23A.

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