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Shelf Edge Current and its Effects on Fish Stocks

HYDROGRAPHY AND MACKEREL DISTRIBUTION ON THE SHELF EDGE WEST OF THE NORWEGIAN DEEPS

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SUMMARY

A combined acoustic, fishing and hydrographic survey was carried out in the Viking Bank area of the North Sea in December 1995. The aim of the survey was to locate and map the distribution of the western mackerel in the area prior to the start of their spawning migration and to determine the hydrographic background. The mackerel were located in high concentrations in greater than 200 m of water on the western edge of the Norwegian Trench. The area was defined with cooler waters to the east, south and west, suggesting that the distribution was controlled by water temperature. Data from CTD sections, sea surface temperatures and current meter moorings are presented and the implications for the control of distribution and migration of the western mackerel are discussed.

INTRODUCTION

Recent work on the migration of scombrid fish has suggested that water temperature is one of the major environmental parameters controlling direction and speed of migration (Walsh and Martin, 1986; Castonguay *et al.*, 1992; Walsh *et al.*, 1995; Reid *et al.*, in press). The winter migration of the western mackerel (*Scomber scombrus*) from feeding grounds in the North and Norwegian Seas to spawning areas south and west of Ireland occurs in the months of December to March. The migration path follows the shelf edge for most of its route, with the fish being found generally between the 100 and 250 m contours (Walsh *et al.*, 1995). Walsh *et al.* showed that the migration around the north of Scotland appears to follow a track which coincides with a tongue of warmer water transported northwards up the shelf edge by the shelf edge current (SEC). Observations made during an acoustic survey in January 1995 (Reid *et al.*, in press) indicated that when the migrating mackerel encountered an intrusion of unusually warm water onto the shelf the fish stopped their active migration and adopted different schooling behaviour. This led us to hypothesise that the spawning migration of this species may be influenced by "enviroregulation". This is a process by which the fish select their immediate environments by behavioural means (Neill, 1984). If the fish find themselves in some "non-preferred" temperature, they may swim faster or deeper in an attempt to gain more preferred temperatures. For example, Olla *et al.*, (1975) showed that mackerel swam faster at water temperatures below 7°C. Migration may be triggered when water temperature drops below a threshold, and the subsequent migration route constrained by the narrow tongue of warm water derived from the northward flowing current.

Analyses of commercial catch data have shown that prior to the start of migration, the bulk of the western mackerel appear to assemble along the 200 m contour in the north eastern North Sea (east of Viking Bank, approximately 60°N 3°30'E, see Fig. 1). The fish are known to arrive in this area in late autumn (from October) and remain in the general area until the start of active migration (Skagen pers. comm.). This area lies within the Norwegian controlled sector of the North Sea and is not open to mackerel fishing for UK fishing vessels. As a result, from December on, the UK fishing vessels tend to wait in UK waters until the fish start their migration (Masson, Simpson pers. comm.). Given accurate information from these vessels, it is then possible to determine the timing of the start of migration fairly accurately. In recent years migration has usually commenced in early to mid December.

If enviroregulation is constraining the distribution and migration of the mackerel, then it would be expected that immediately prior to the start of migration, the fish would tend to concentrate in the warmest areas of the North Sea, leaving those areas which cool earlier or faster. As these areas of aggregation also cooled migration would commence. The shelf edge area adjacent to Viking Bank is likely to be one area where the water will stay warmer, longer due to Atlantic inflow along the shelf margin. The present study was designed to use a combined acoustic, hydrographic and fishing survey to:

- confirm anecdotal information on the pre-spawning aggregation of mackerel
- to determine the hydrographic structure in the area of mackerel aggregation and whether this matched the predictions based on enviroregulation
- if possible, observe the mackerel at the start of their migration and determine the cues for that start

MATERIALS AND METHODS

A combined acoustic, fishing and hydrographic survey was conducted from the Scottish Office research vessel *Scotia* from 1-15 December 1995. Seven overlapping acoustic surveys were completed. The first of these was conducted as a pilot survey (Fig. 1), covering the area between 59°15'N and 61°30'N and along the 200 m contour (from 64 km west of the contour to 32 km east). This area was chosen on the basis of information from commercial. The subsequent six surveys concentrated on a smaller area which contained all the observed mackerel echotraces. This covered an area from 59°15' to 60°40'N (Fig. 1), and within 16 km of the 200 m contour to the west and 8 km to the east. All the surveys followed a zig-zag track design. The first survey used a baseline transect spacing of 16 km. The subsequent surveys used a baseline transect spacing of 3 km.

Acoustic data were collected using SIMRAD EK500 38 kHz and 120 kHz split beam echosounders. The transceivers were mounted in a catamaran towed body which was towed from a boom alongside the vessel at a depth of approximately 4 m. The echosounder range was maintained at 250 or 500 m throughout the survey with a pulse interval of 1.5 or 3 msec respectively. Output was recorded continuously as hard-copy and in digital form. The hard copy of the echogram was printed out in colour using a Hewlett-Packard PaintJet interfaced to the echosounder. Digital data was transferred by ethernet to a SUN SPARC IPC computer and recorded transmission by transmission in 0.5 m depth samples on DAT tapes. Echo integration (MacLennan and Simmonds, 1991) was carried out over 15 min intervals (25 nmi at 10 knots) by the echosounder and recorded on the printout. The system was calibrated using a standard target prior to the survey (Foote *et al.*, 1987).

Fishing was carried out on fish concentrations identified from the echogram, using a strengthened pelagic trawl. All fish (or a subsample for large catches) were scored for species, length, weight, sex and stomach contents. Otoliths were taken from subsamples of the mackerel and herring for subsequent age determination in the laboratory.

Sea surface temperature and salinity were continuously recorded throughout the survey using an OceanData model TSG 103 thermosalinograph connected to the vessels non-toxic sea water supply. Data were recorded with for subsequent analysis on a PC microcomputer. Simultaneous navigation data were recorded from a GPS navigation system connected to a PC running a plotter (MicroPlot - SIS Systems, Aberdeen). A series of CTD and XBT stations were carried out during the survey, and a CTD section across the 200 m contour was completed. Observations were obtained using a SeaBird 25 sealogger CTD with rosette water sampler. Salinity calibrations were performed using *in situ* water samples analysed on a Guildline Portasal salinometer.

Four current meters (Anderaa RCM-7) were deployed across the shelf break. Positions etc are presented in Table 1. The temperature and current measurements obtained from the three moorings were low passed filtered in order to remove the tidal component. The principal direction derived from the bottom current meter was used as the local along isobath direction, and velocities were resolved into along and across isobath directions.

RESULTS

The initial task of the survey was to determine the main location of mackerel aggregation. The map plotted in Figure 1 shows the general area of the survey. The pilot survey area was carried out to localise the main concentrations of mackerel. The bulk of the mackerel seen on this pilot survey were concentrated in a rectangular area defined by 59°30' to 60°30'N and 3°00' to 3°30'E. Twelve successful trawling operations were carried out (Fig. 2). Five of these were dominated by mackerel, five by herring, and two contained other species, mainly Norway pout, blue whiting and other gadoids. On the basis of these trawls, echotraces seen during the survey were assigned as mackerel, herring or others. In some cases it was not possible to give a definite assignment. Figure 3 is a close-up view of the main survey area showing the locations of those echotraces which could be positively assigned to herring or mackerel. It was apparent that the bulk of the mackerel were found in areas of water depth greater than 200 m, and the herring, generally, in shallower waters.

The hydrography of the area was examined in a number of ways. Figure 4 shows a contour plot of the sea surface temperature (SST) recorded during the pilot survey. The area was characterised by warmer water in the north and west, which extended in an arc towards the main area of mackerel concentration, in the lower right hand corner. The area where the fish were concentrated had cooler surface waters to the east, south and west. Figure 5 shows the evolution of SST in the main survey area as contour plots for three time periods: 4-6 December (Fig. 5a), 7-9 December (Fig. 5b) and 9-12 December (Fig. 5c). These plots confirm the presence of a tongue of warm water surrounded by cooler surface waters.

Additionally, the survey area appears to have become slightly warmer during the survey period.

The CTD section was carried out to determine the vertical structure in the study area. A total of 12 dips were carried out. The results of these dips are presented in Figures 6a and 6b, along with the locations of the mackerel and herring aggregations. The shelf edge area where the mackerel were concentrated was characterised by the warmest water across the section. To the east, the surface waters were cooler and less saline, owing to the presence of the Norwegian Coastal Current. The deeper areas to the east, in the Norwegian trench were made up of cold, saline water - Norwegian trench bottom water. To the west of the shelf break, there was little or no stratification, but the water was again cooler than at the shelf break. All the evidence from both horizontal and vertical profiles of temperature suggest that the mackerel were concentrated in the area of the Norwegian Trench with the highest temperatures. This interpretation is confirmed by the TS plot for the section in Figure 7.

Prior to the survey, four current meter moorings were deployed across the shelf break in the north of the study area, the positions and other information are given in Table 1. The low-pass filtered current components and low-pass filtered temperatures are shown in Figure 8a-c. At the two most easterly moorings, it was evident that the decay of temperature stratification during the recording period occurred as a series of events, most probably wind-driven (Figs 8a and b). After complete vertical mixing had occurred, some events reintroduced stratification, by rapid cooling of the bottom waters. These cooling events were not clearly associated with reversals in the along isobath components, but may have been more dependent on an increased on-shelf flow of cold bottom water from the deeper Norwegian Trench. At mooring 543 stratification was much more persistent (Fig. 8c), with cooler waters remaining at the bottom until the end of the observational period. In order to clearly understand the results and to identify the controlling mechanisms responsible for the maintenance or erosion of thermal stratification on the Viking Bank, and the creation of cooling events, further comparative work is required relating the current meter results to one another, and to wind observations. This work is in progress.

Figure 9 shows stick plots for the three moorings which survived to be collected in December. Mooring 542 was furthest to the east, at 3°13'E, just east of the 200 m contour. The plots show that the flow was generally from the NNW and stronger at the deeper current meter. There was some evidence of reversal in the flow at meters 541 and 542 around the 18 November and again around 28 November. The westernmost mooring, which was over 30 miles from the 200 m contour, showed weaker transport and a much more variable pattern, and was probably dominated by wind effects.

DISCUSSION

The hypothesis being investigated in this study was that the distribution of mackerel is, at least in part, controlled by enviroregulation (Neill, 1984). If this hypothesis was true, the mackerel would be expected to move from the areas of low water temperature and to concentrate in the areas of highest water temperature. Anecdotal information from fishermen have suggested that the mackerel concentrate in such an area of the North Sea every year prior to migration. The present study has confirmed this and also shows that the mackerel are, as hypothesised, concentrated in the warmest areas. This needs to be qualified. Enviroregulation assumes that below a certain water temperature the mackerel will start to move faster, when they arrive in warmer water their movement will slow down and they will tend to concentrate there as long as the water temperature is suitable. Therefore we assume that the temperature in this area during the survey period was high enough that the fish were not stimulated to swim further.

Examination of the temperature records from the current meters shows that the deep water temperature in the area of mackerel concentration is relatively stable from September to December, and actually rises slightly over the period. This is presumably due to the mixing of the warmer surface waters as the stratification breaks down. Further onto the shelf area of the North Sea the deep water temperature is consistently lower (<8°C) throughout the deployment period. The deeper water in the Norwegian Trench is characterised as generally being cold water (<8°C). So the mackerel are essentially constrained between two colder water bodies. The current meters show that the flow into the area along the 200 m contour is consistently from the north, and this should transport the warmer Atlantic water of the Slope Current into the area. This is confirmed by the surface temperature plot in Figure 4. Further south the water temperatures are also colder (see Fig. 5) and it may be assumed to constrain migration in that direction.

There was no evidence from this study that the mackerel had commenced their migration. The fish aggregations were seen repeatedly at the same location, and were usually in contact with the seabed. Fishing vessels in the Scottish sector reported no sightings of mackerel schools, entering their waters. We would hypothesise that the migration would be likely to start when the area the fish were occupying during the survey had cooled below a critical level. From the current meter temperature records, this would be likely to occur either through slow cooling with the onset of winter, or more rapid cooling due to reversal of the normal current direction allowing the cooler southern waters to enter the area occupied by the fish. Both these scenarios may initiate migration, and the two possibilities may explain the variability in inset of migration.

ACKNOWLEDGEMENTS

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TABLE 1

Current meter details

Record No	Position	Depth (m)	Sounding (m)	Valid data starts	Valid data ends
5411 5412	60°26.83'N 02°51.86'E	27 95	106	1100 hrs 22 September 1995	0900 hrs 11 December 1995
5421 5422	60°28.55'N 03°13.02'E	30 195	206	1500 hrs 22 September 1995	0900 hrs 7 December 1995
5431 5432	60°30.17'N 02°8.95'E	31 109	120	1500 hrs 24 September 1995	1500 hrs 24 September 1995

Figure 1. Survey areas and positions of moorings and CTD Line - December 1995

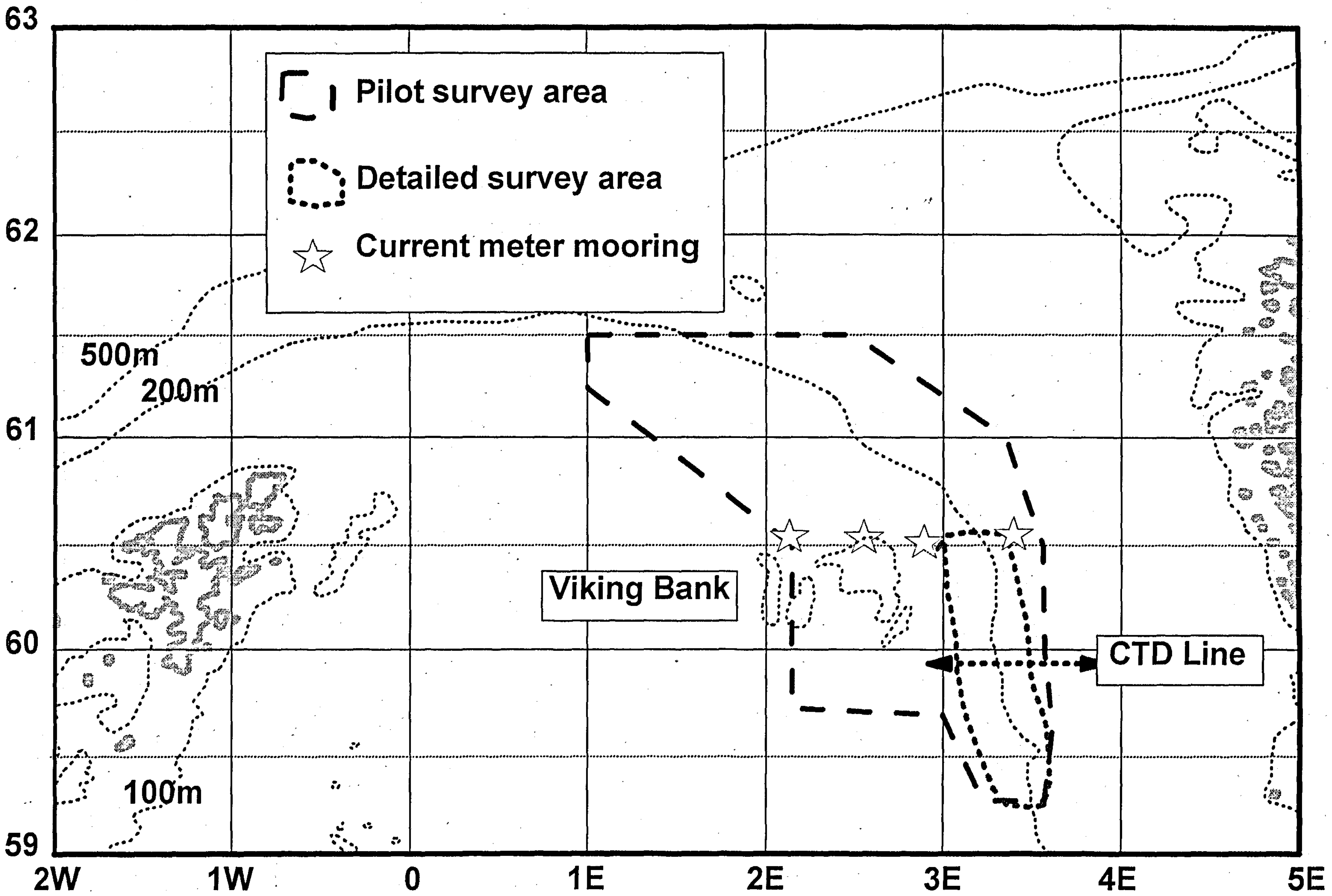


Figure 2 Haul positions and composition December 1995

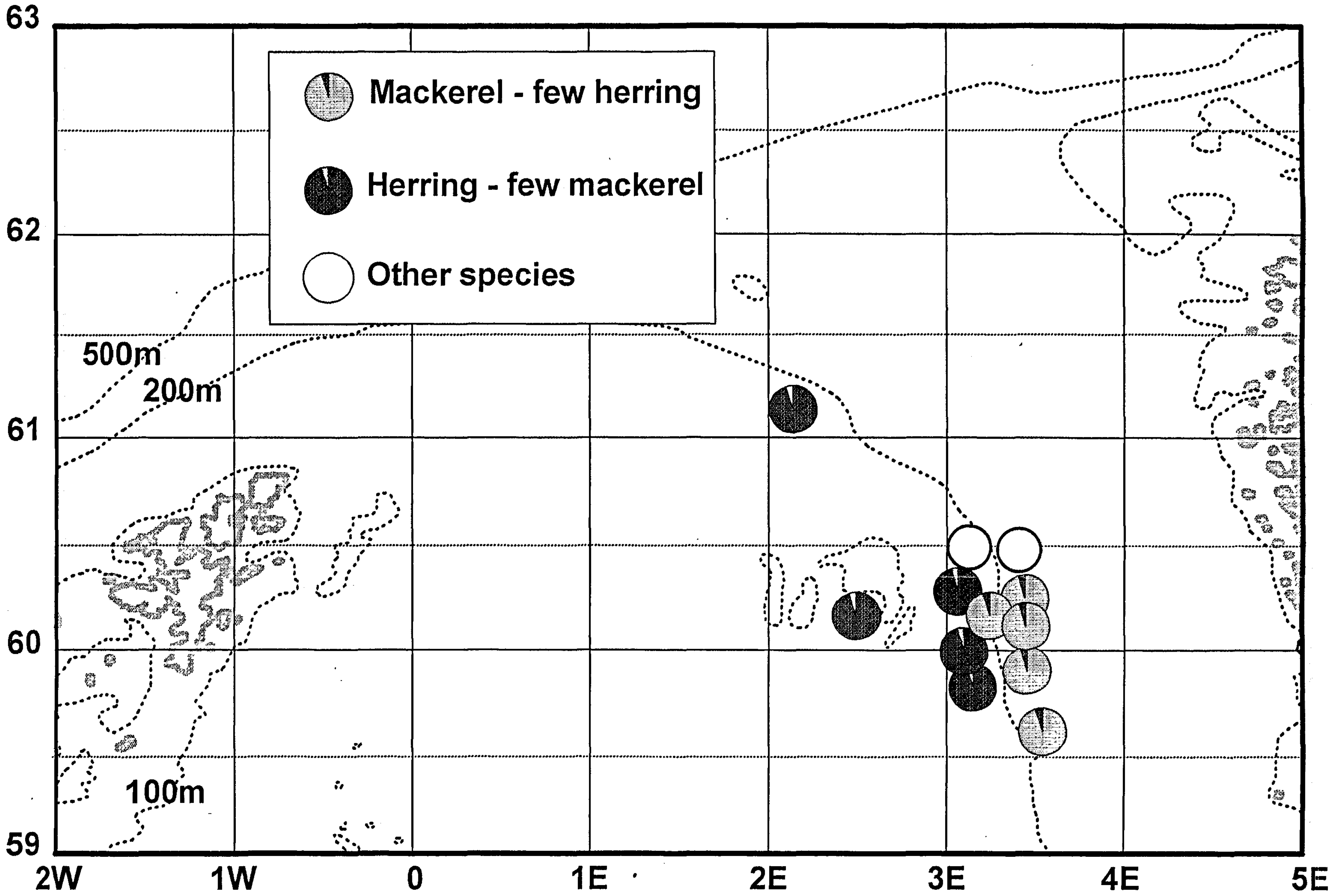


Figure 3. Positions herring and
mackerel aggregations4 - 13 December 1996

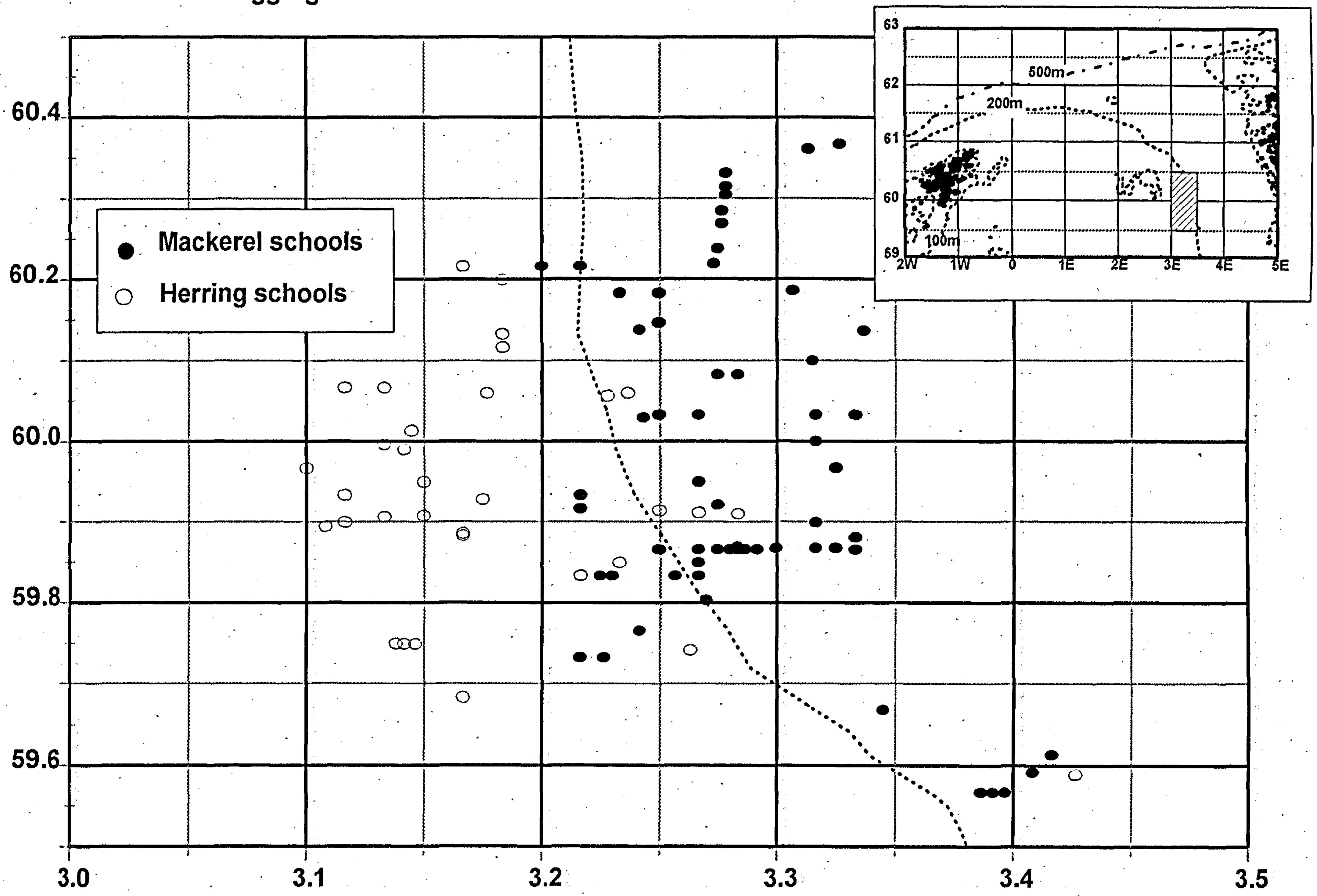


Figure 4. Surface temperature contours - Viking Bank Area December 1995

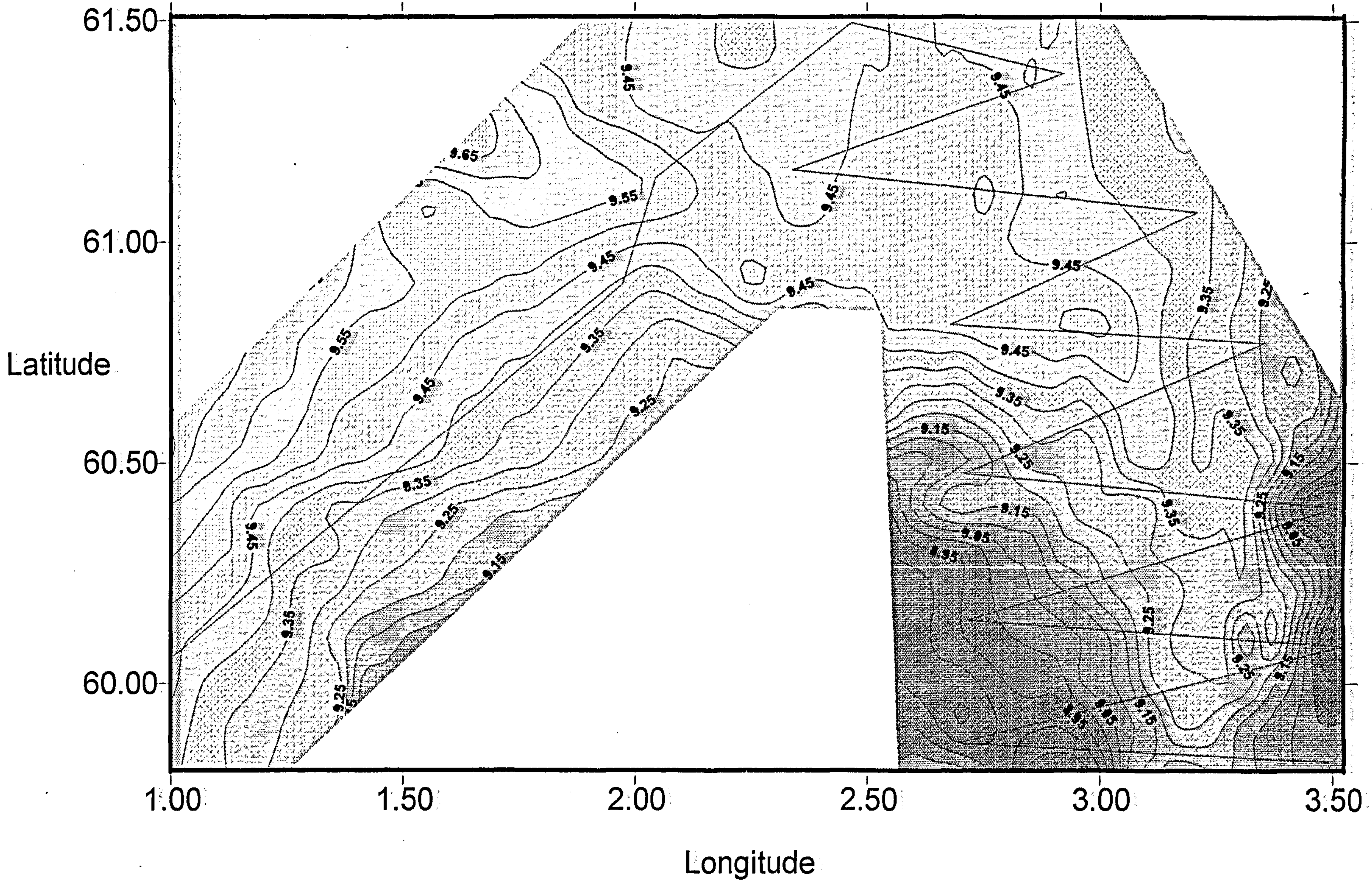


Figure 5a. Sea surface temperatures 4 - 6 December 1996

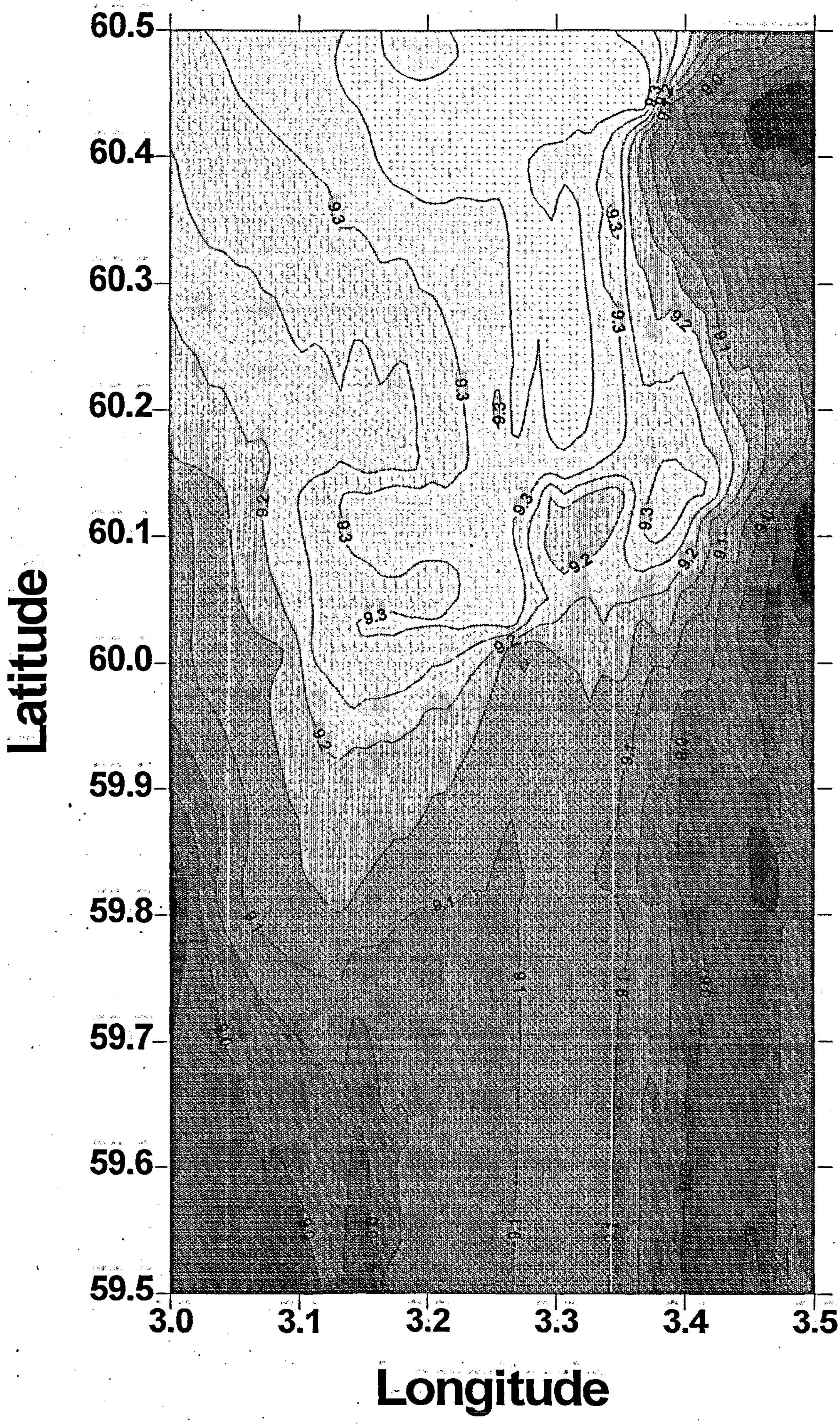


Figure 5b. Sea surface temperatures 7 - 9 December 1995

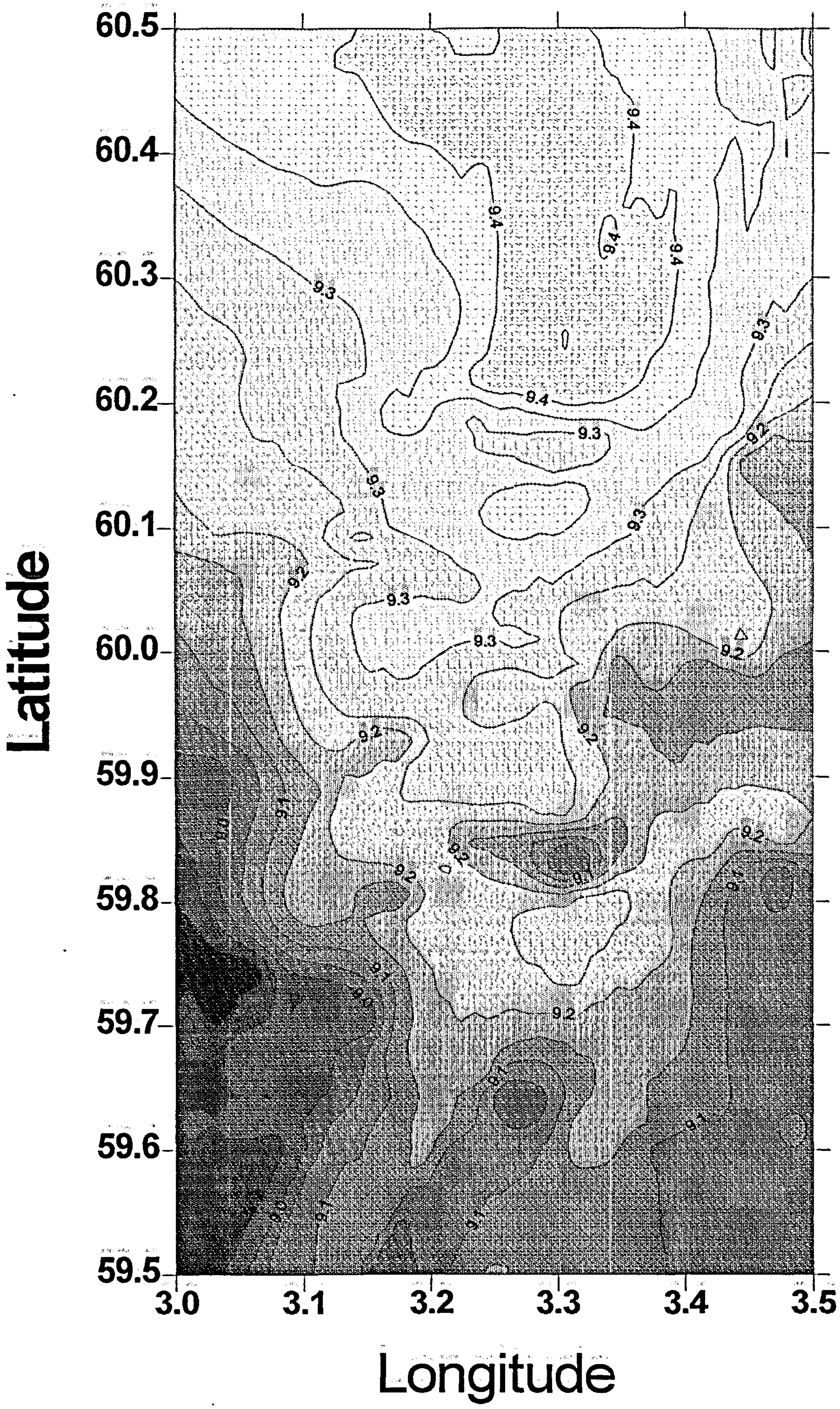


Figure 5c. Sea Surface Temperatures
9 - 12 December 1996

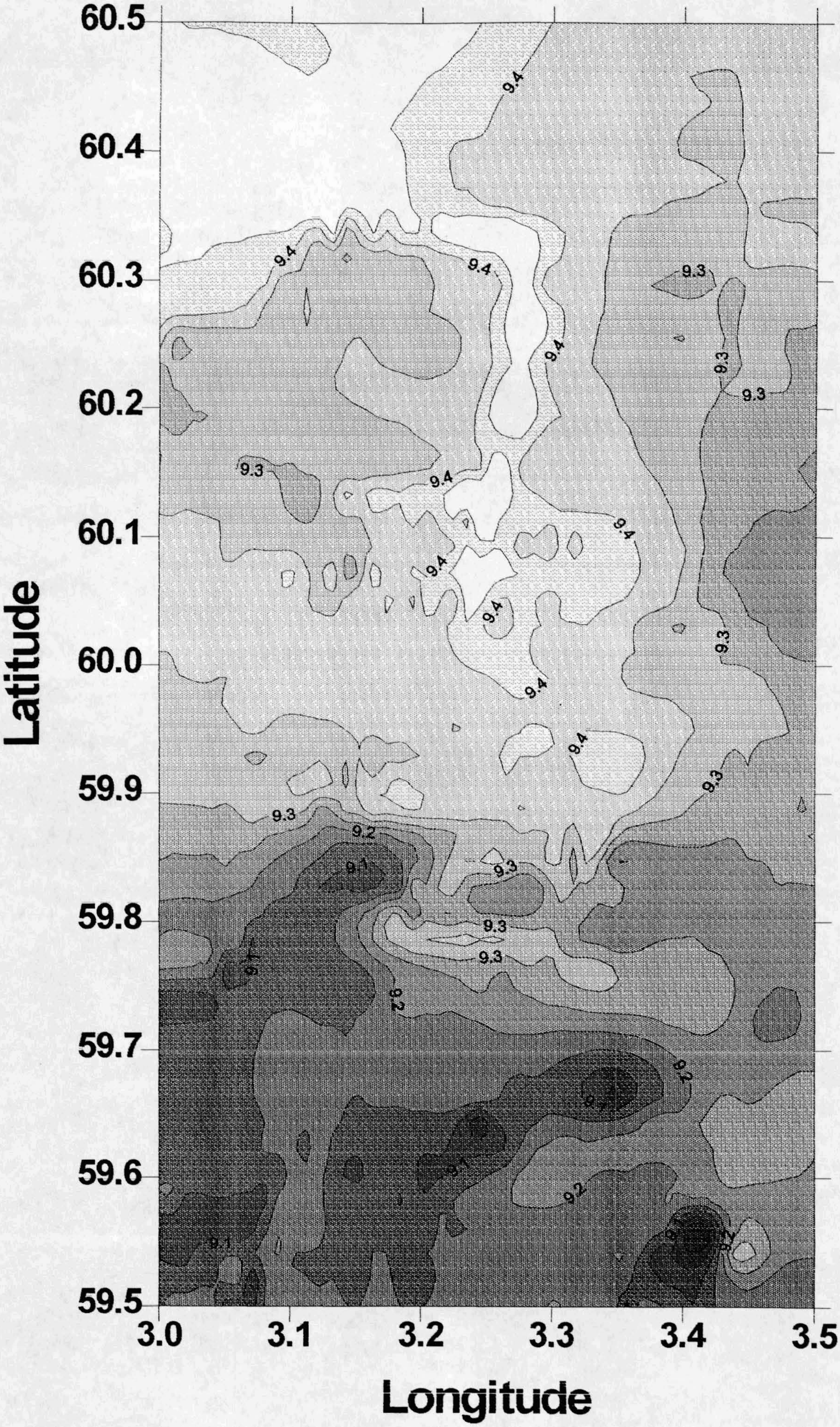
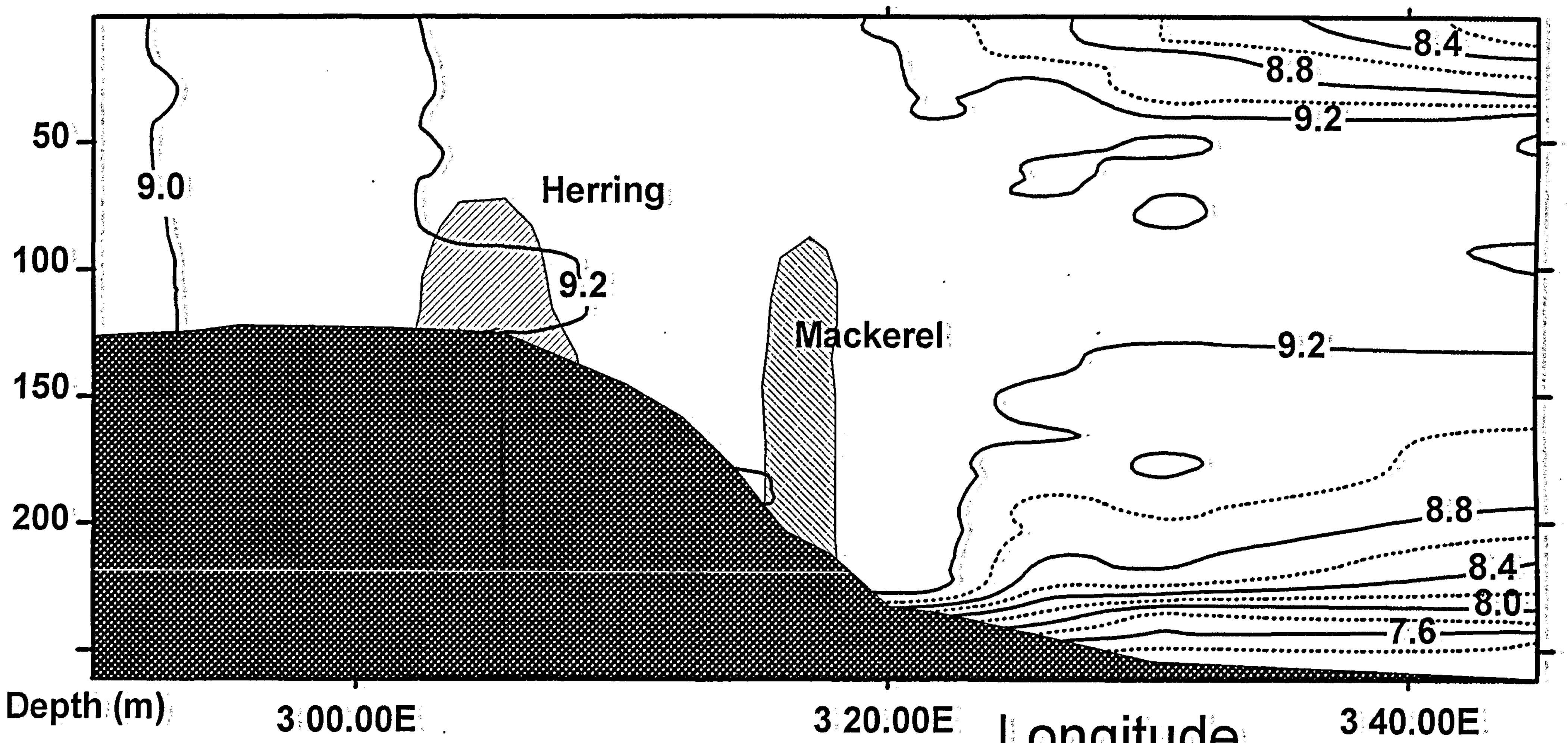
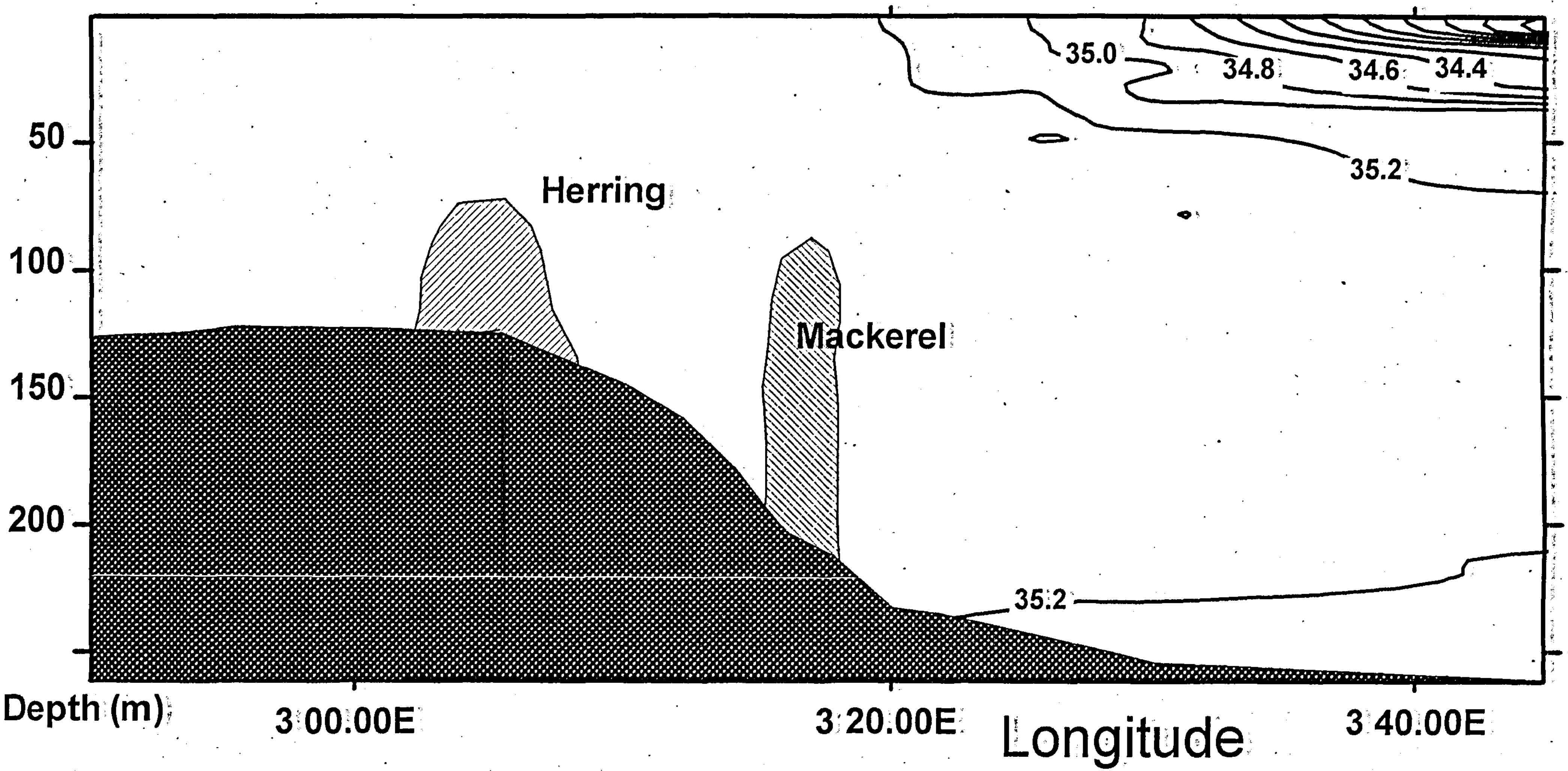


Figure 6a. Temperature contours and fish positions along CTD line - December 1995



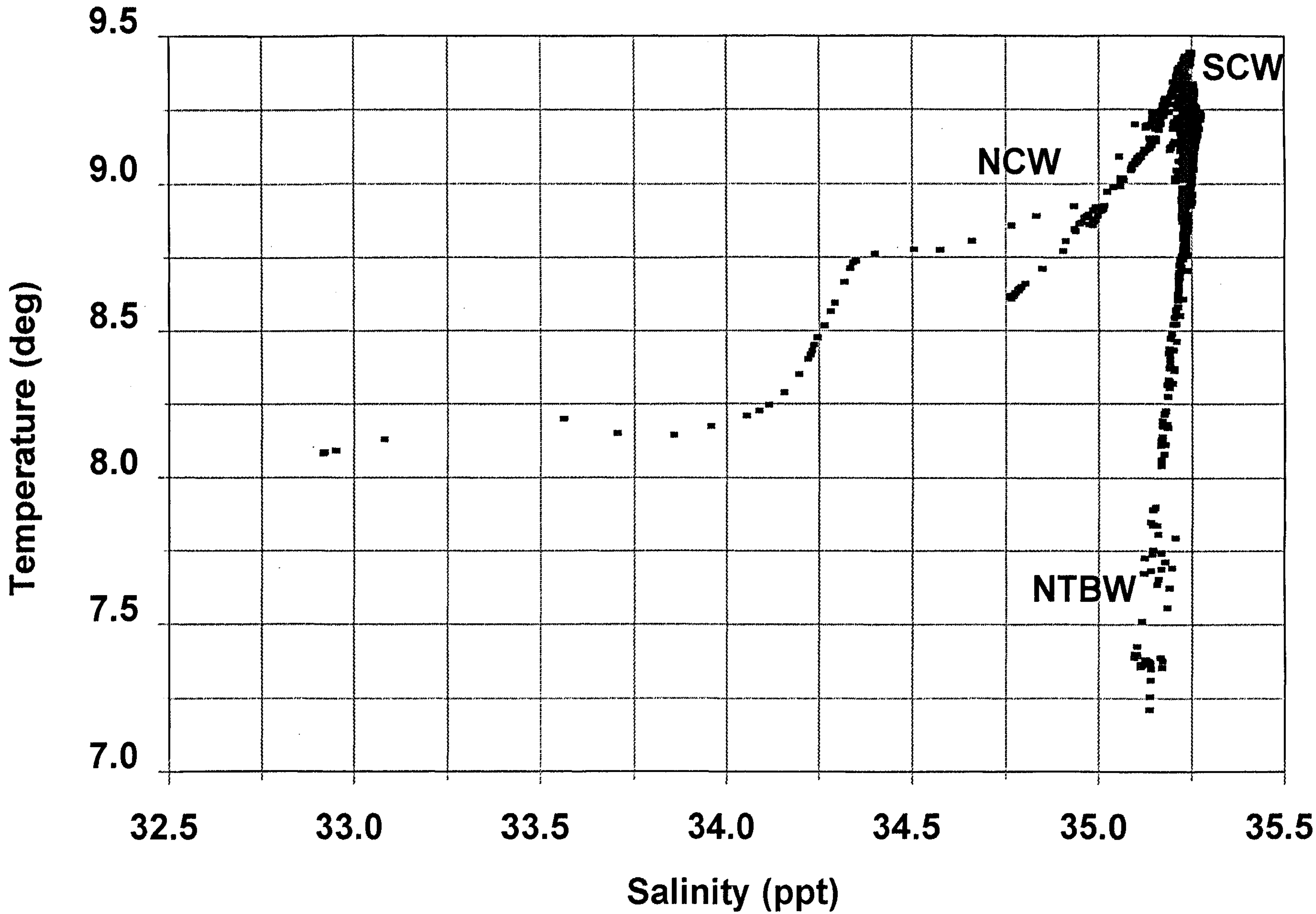
12-12-1995
Latitude 59
55.00N

Figure 6b. Salinity contours and fish positions along CTD line - December 1995



12-12-1995
Latitude 59
55.00N

Figure 7. Temperature & salinity plot at CTD Section



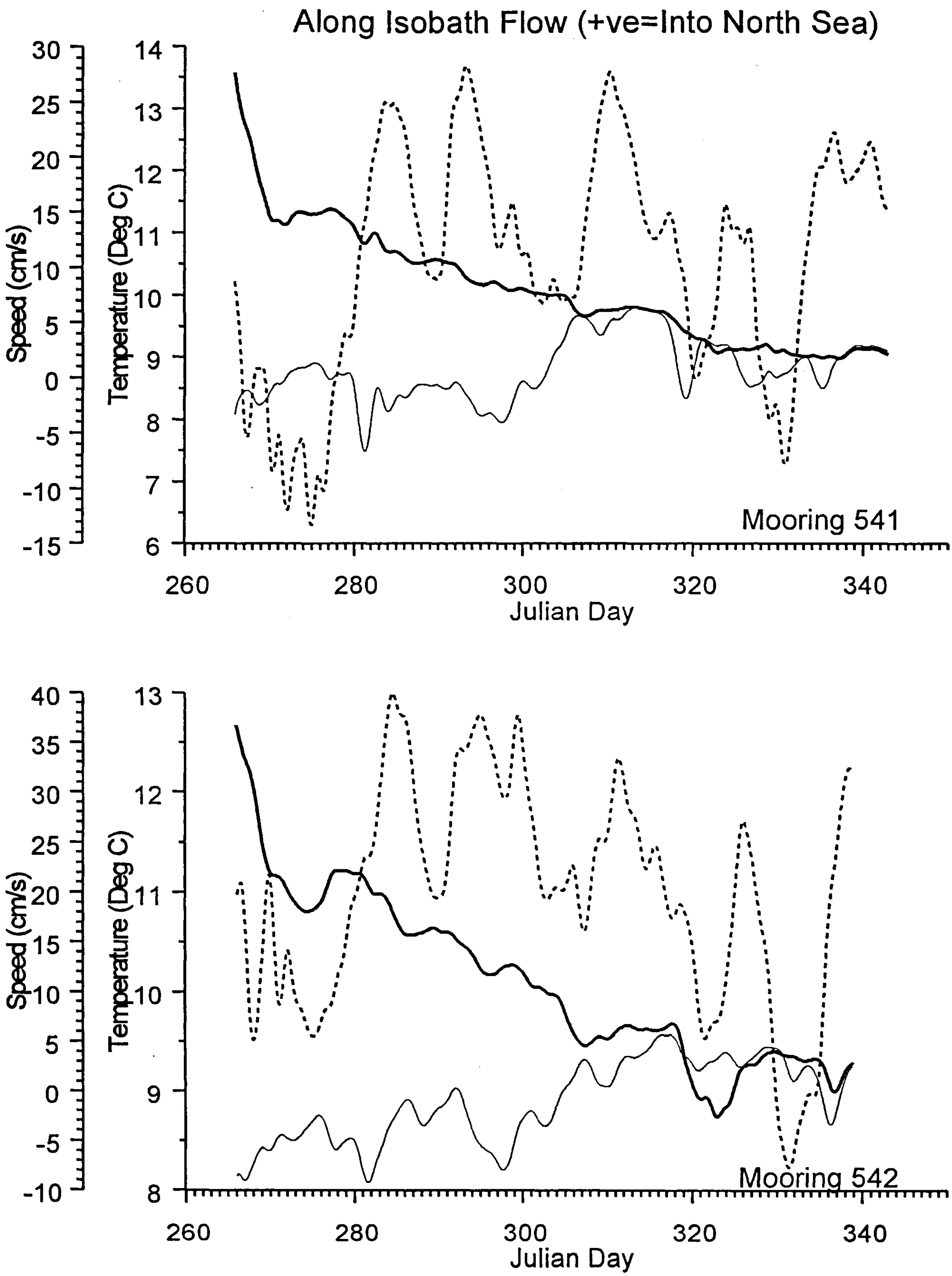


Figure 8a. Along isobath current component and temperatures at the two eastern moorings.

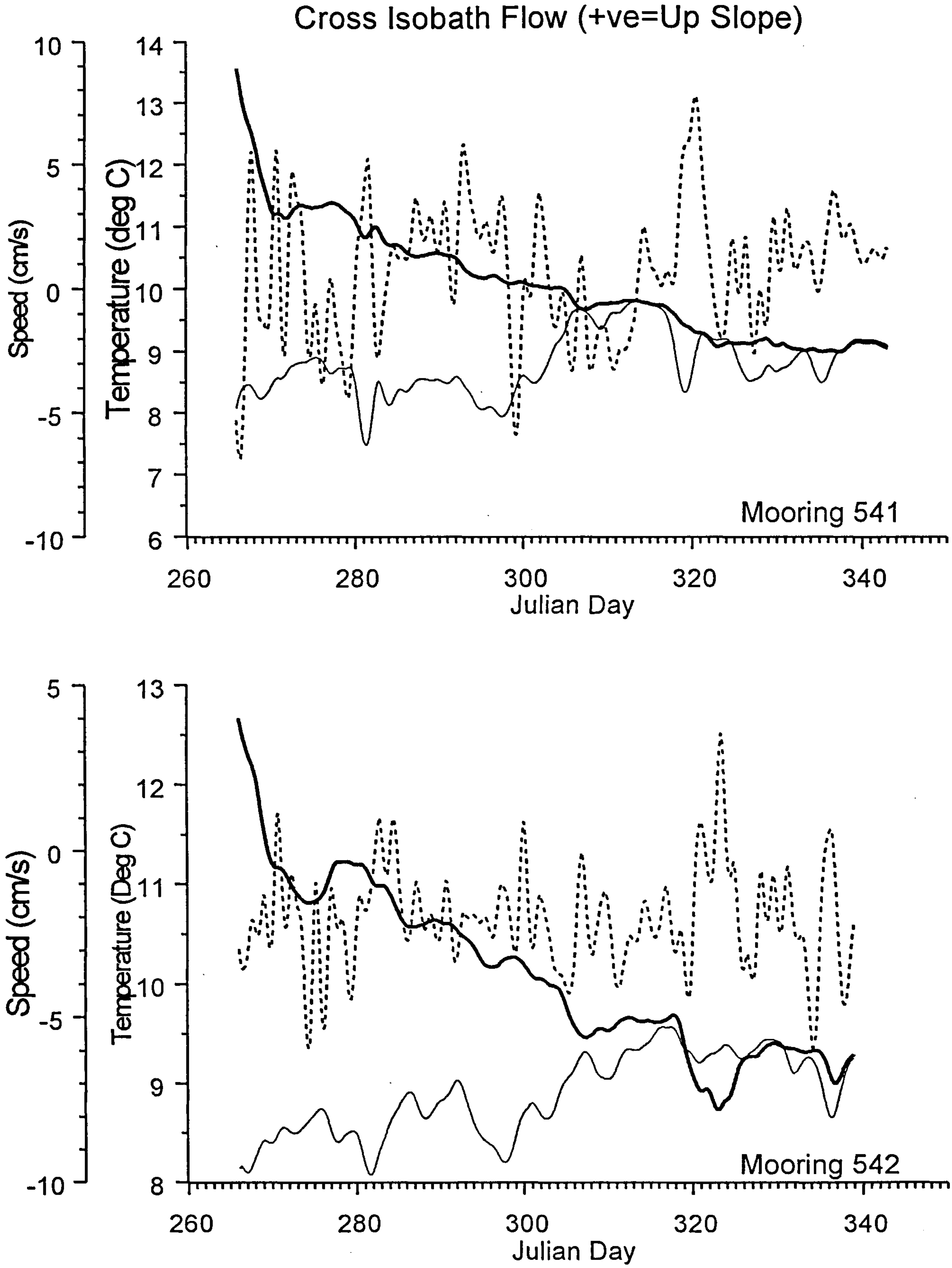


Figure 8b. Up slope current component and temperatures at the two eastern moorings

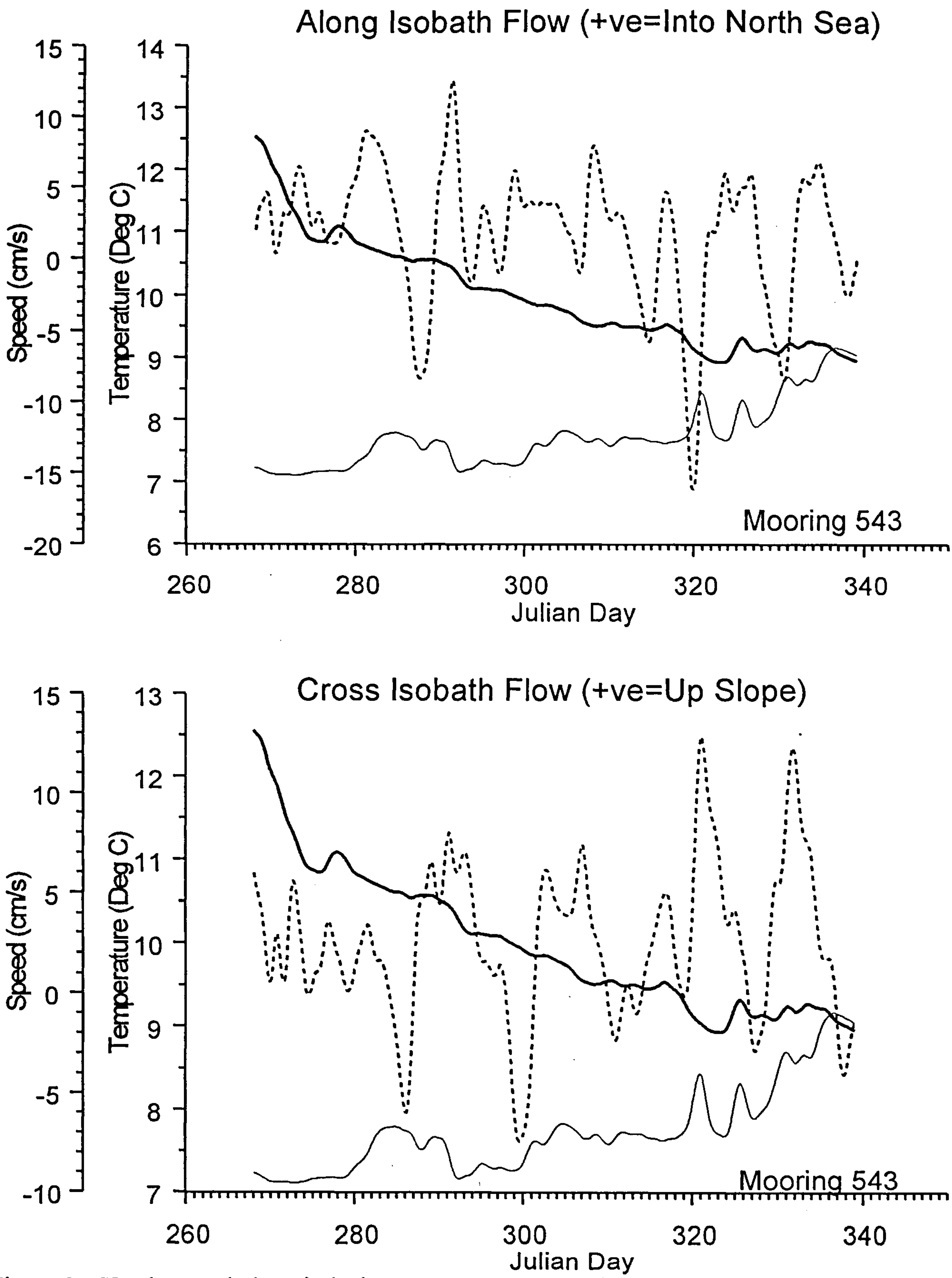


Figure 8c. Up slope and along isobath current component and temperatures at the western mooring

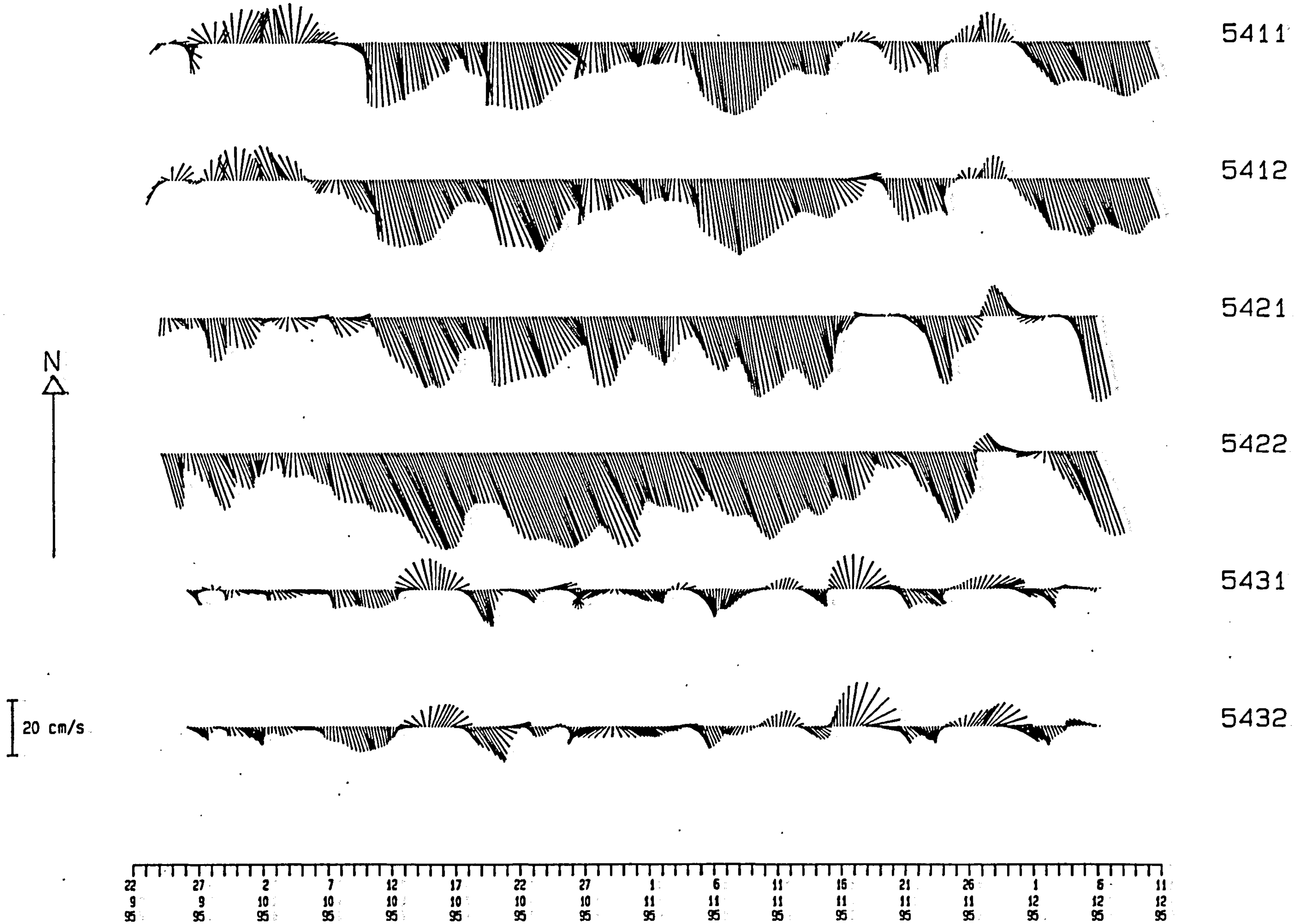


Figure 9. Current vector stick plots for the three pairs of current meters.