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Moored Current and Hydrographic Measurements on the Southeast Shoal of the Grand Bank in 1986 and 1987

by

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ABSTRACT

Preliminary results are presented from the mooring component of a 1986 - 87 field study of current and hydrographic variability on the Southeast Shoal of the Grand Bank. A large fraction of the current variance is in the tidal/inertial bands, with the low-frequency currents being weak (a few cm/s) but variable with season, year, depth and location. Substantial temperature and salinity variability occurs on a range of time-scales.

INTRODUCTION

The Southeast Shoal of the Grand Bank is an area of considerable fisheries importance. The Shoal is the only offshore spawning site for capelin on the Newfoundland Shelf (Carscadden 1978); is near the northern limit of yellowtail flounder spawning (Pitt 1970; Fitzpatrick and Miller 1979); supports commercial fisheries for cod, yellowtail flounder, American plaice and redfish (Marine Research Associates Ltd. 1980); and has been quoted as the site of the highest benthic biomass on the Bank (Anderson and Gardner 1985). It is also the shallowest area of the Grand Bank and is traversed by the outer boundary of Canada's exclusive economic zone.

The historical physical oceanographic data from the Southeast Shoal are mainly temperature observations collected over many years. The climatological temperature distributions show that, during summer, the warmest bottom water on the entire Grand Bank occurs over the Shoal. This temperature feature is shown in Figures 1 and 2 which are based on monthly-mean temperatures for 1/2 x 1/2 degree areas provided by the Marine Environmental Data Service (MEDS) of the Department of Fisheries and Oceans (DFO) of Canada. The feature can be seen to evolve during the spring through fall seasons as part of a two-layer stratification. Two other oceanographic features cited to occur over the southern Grand Bank are a weak anticyclonic gyre (Kudlo et al. 1980) and occasional Slope Water intrusions (Templeman and Hodder 1965).

In 1986, DFO initiated a physical oceanographic field study on the Southeast Shoal. The purpose of this document is to outline the measurements made in, and present preliminary results from, the mooring component of the study which included the first moored current, temperature and salinity measurements on the Shoal. More detailed results on the moored measurements will be presented in a data report (Ross et al., in preparation 1988) and subsequent publications addressing the study objectives.

THE SOUTHEAST SHOAL EXCHANGE STUDY

The primary objectives of the study were to describe the seasonal evolution of the bottom-temperature feature in detail in some years, identify its origin, and infer the horizontal and vertical exchange rates over the Shoal from a heat budget for the feature's evolution. The study was also designed to provide information on any gyre centred over the Shoal and a description of the physical environment for concurrent fisheries studies such as the larval capelin study conducted by the Biological Sciences Branch (BSB) of DFO (Frank and Carscadden 1988) and McGill University.

In 1986 a pilot mooring program was conducted consisting of a current-meter and thermistor-chain mooring and surface-temperature buoy near the centre of the Shoal, and Ryan thermograph moorings to the west and east (see Fig. 3 for locations and Table 1 for details on the data returned). The mooring program was expanded in 1987 to include current-meter moorings to the west and east, Ryan thermograph moorings to the north and south, as well as the current-meter and thermistor-chain mooring and surface-temperature buoy near the Shoal's centre. Each current-meter mooring contained meters at two depths, one within 20 m of the surface intended to be representative of the relatively-warm upper layer and the other in the cool lower layer (at 10 m above the seafloor except at the 1987 western site). With the exception of three Ryan thermographs in 1987, all instruments were retrieved and provided some good data although there was substantial data degradation in both years due to biological fouling and instrument malfunctions. Hydrographic surveys of the Southeast Shoal were conducted during the mooring deployment and recovery cruise each year, and additional hydrographic observations were taken by the BSB of DFO during fisheries surveys and/or obtained from the IGOSS network through MEDS. The preliminary results presented here will be limited however to those from the current meters and surface-temperature buoy.

THE DATA

The current meters were Aanderaa RCMs equipped to measure current speed and direction, temperature and conductivity at 30-min intervals. Salinity was computed for each sampling interval from conductivity, temperature and pressure (value assigned where not available). Time series of the north and east components of velocity were computed from the speed and direction time series. Editing involving range specification, median filtering, spike removal and manual inspection was carried out on all the time series to remove obvious erroneous values. Portions of some of the time series were deleted due to serious data degradation. Offsets obtained from CTD and bottle observations at the mooring sites were applied to the salinity records where appropriate. Tidal analysis on 5-day blocks of the current data was used to identify portions of the rate time series with significant biological fouling of the instrument rotor; the rate records for (774,45m) and (830,44m) were truncated on this basis.

The resulting semi-hourly time series were taken as the raw data sets. To examine subtidal variability, the raw time series were low-pass filtered with a 129-point Cartwright filter (half-power point at period of 31 hr) and decimated to 6-hr samples, thereby removing tidal and inertial variability.

The surface temperature buoy telemetered sea surface temperature and atmospheric pressure readings to the Argos satellite data network at irregular intervals, typically 8 - 12 times a day. The resulting data were averaged over 6-hr intervals to obtain 6-hourly time series.

PRELIMINARY RESULTS

Currents

The raw current data are displayed in Figures 4 - 11 in the form of progressive vector diagrams for each instrument. These diagrams show the water parcel displacements implied by the currents measured at each site. The record means and the standard deviations of the raw and low-pass filtered time series are presented in Table 2.

Visual inspection of the progressive vector diagrams reveals "tidal/inertial" ellipses of a few kilometers superimposed on a longer-term drift which varies with location, vertical position, year and time within each record (the latter indicated by the meandering of the implied trajectory and/or the variable separation between day markers). These ellipses are consistent with the order (10 cm/s) tidal/inertial standard deviations (raw SD minus LF SD) implied by Table 2. The standard deviations show that variability on time scales up to a day accounts for a large fraction of the total current variance, but Figures 4 - 11 indicate that larger-scale drift is associated with the weaker low-frequency (subtidal) currents.

In 1986 the record-mean current at both vertical levels at the central site was toward the northwest: at about 2 cm/s during the 183-day record at the lower level and 3 cm/s during the 107-day record at the upper level. This is in rough agreement with the numerical model prediction of Greenberg and Petrie (1988) for a barotropic Labrador Current flowing into the Grand Banks region. However, Figures 4 and 5 indicate that the low-frequency current varied considerably during the measurement periods, showing a general increase from spring to fall, and Table 2 confirms that the standard deviations of the low-passed current exceeded the means.

The currents at the central site were somewhat different in 1987 (Figs. 6,7). At the lower level the record-mean was again northwestward but now less than 1 cm/s, while the upper-level record-mean was westward at 3 cm/s. The low-frequency standard deviations again exceeded the means and an increase in the low-frequency current in the latter portion of the records was again apparent.

The currents to the west of the Shoal (Figs. 8,9) show some similarity to those over the Shoal, but also significant differences. The lower-level record-mean and low-frequency standard deviations were similar to those observed at the central site in 1987, although the mean was westward during the period of overlap. In contrast, the upper-level mean was southwestward at only 1 cm/s due to several reversals in the low-frequency current.

The progressive vector diagrams for the eastern site (Figs. 10,11) also show weak record-mean currents, 4 cm/s to the southwest at the upper level and 2 cm/s to the south at the lower level. Although the standard deviations of the raw time series are substantially larger at this site than at the others, the low-frequency standard deviations are similar. However, there appear to be two alternating current regimes at the eastern site. There are periods of very weak (< 1 cm/s) mean flow (e.g. days 125-145; 225-245), interrupted by intervals of southward flow of about 5 cm/s. The concurrent salinity time series (discussed below) suggest that the latter intervals are associated with a westward displacement of the Labrador Current to the mooring site.

Temperature

The raw temperature data from the current meters are also displayed in Figures 4 - 11, and the 6-hourly data from the surface buoy in Figure 12. Record- and monthly-means of temperature are shown in Table 3, together with long-term monthly-means for the Shoal for comparison.

The temperature time series show the seasonal evolution of a strong thermal stratification as discussed above and shown in the MEDS data in Table 3. This stratification is associated with the enhanced seasonal warming of the near-surface waters. However, strong variability on other time-scales is apparent, particularly at the upper levels.

The 10-20 m observations (Figs. 4,6,8,10) show intervals of intense high-frequency (periods shorter than the 30-min sampling interval) variability, presumably associated with internal-wave-induced vertical displacements of the thermocline at the sensor location. The occurrence of the strongest such variability at the 20-m level in July-August 1986 (Fig. 4) is consistent with the thermocline's location at that depth in the thermistor-chain records (not shown) for that period.

At the surface (Fig. 12) there are occasional temporary increases in temperature by typically a few C° , but by as much as 8 C°. The occurrence of these increases during the daytime suggests that they are signatures of the so-called "diurnal thermocline" associated with the daily solar insolation cycle. In any case, such variability poses problems for the representativeness of sea surface temperature observations such as infrared imagery.

There is also significant temperature variability on the time-scale of days to weeks, particularly at the sea surface (Fig. 12), but also in the near-bottom region (Figs. 5,7,9,11) although reduced in magnitude. In particular, the surface temperature at the central site decreased by over 10 C° during the passage of Tropical Storm Charley in August 1986, which also coincided with the emergence of a large cohort of capelin larvae (Frank and Carscadden 1988). The result of this variability is that the seasonal progression of temperature in particular years does not show the smooth variation of the long-term seasonal cycle. Visual comparison of the temperature time series with the current and wind (not shown) time series suggests that much of this variability is wind-induced, although the relative contributions of air-sea heat exchange, vertical mixing, and horizontal displacements of temperature features are unclear.

Comparison of the 1986 and 1987 monthly-means with the long-term means (Table 3) suggests that, except for May and June of 1987, temperatures were below normal throughout the water column on Southeast Shoal in 1986 and 1987. However, the temperature differences between mooring sites suggests that such conclusions from moored measurements at a few locations should be considered with caution, due to the possibility of temperature variations at some mooring sites merely reflecting spatial shifts in temperature features such as that over the Shoal. Preliminary examination of the hydrographic survey data from 1986 indicates that such shifts contributed to the near-bottom temperature variability at the central site.

Salinity

The raw salinity time series are also displayed in Figures 4 - 11, and the 1986, 1987 and long-term monthly-means for the southeastern Grand Bank (Drinkwater and Trites 1986) are shown in Table 4.

The time series show that periods of increased high-frequency salinity variability generally coincide with those for temperature, as expected (it should be cautioned, however, that some high-frequency salinity variability may be an artifact of the non-coincident temperature and conductivity sampling).

There are also significant variations on time-scales of days to weeks, some with associated temperature fluctuations but other events without a corresponding temperature signal. The latter include the temporary occurrence at the central site's upper level around day 130 in 1987 (Fig. 6) of low-salinity water similar to that at the western site, and the occurrence at the western site's upper level around day 156 (Fig. 8) of higher-salinity water similar to that at the central site. These fluctuations are associated with a near-surface salinity front between the sites (Table 4) with little associated temperature gradient (Table 3). While the western-site salinity increase is associated with westward drift at that site consistent with a large-scale displacement of the front, the central-site freshening is associated with a local westward (instead of eastward) current although the low-frequency current was in the opposite direction at the western site. The opposing currents at the two sites during the latter event and the lack of a clear relation between the salinity and current variations suggest that these events may be more than a simple frontal displacement, perhaps reflecting the translation of a detached eddy.

The most interesting salinity variations however occurred on seasonal and interannual time-scales. In 1986 the salinities at the central site were below the long-term means (henceforth referred to as "normal") during the spring and (at depth) early fall (Table 4), but increased to above-normal values in July, particularly at depth. The latter increase was apparently associated with a westward drift over the Shoal, although the salinity subsequently decreased in spite of an increased westward (and northward) drift. In 1987 in contrast, the salinities at the central site were as much as a unit greater than in 1986 and substantially above normal until early fall. The occurrence of positive salinity anomalies at Station 27 in 1987 and the lagged correlation of these anomalies with positive salinity anomalies off West Greenland (Myers et al. 1988) suggest that the observed interannual variation on Southeast Shoal may be related to advection of an anomalous water mass from the north. An alternative would be the occurrence of a Slope Water intrusion from the southwest (e.g. Templeman and Hodder 1965) during the intervening winter, but the moored measurements do not clearly distinguish between these possibilities. During May and June, salinity at the central and eastern sites was higher than at the western site and not supportive of a southwestern slope origin. On the other hand, the time series and progressive vector diagrams provide a consistent picture of the arrival of low-salinity near-surface water at the central and eastern sites in late June (Figs. 6,10), apparently associated with the westward displacement of the Labrador Current discussed above. Reduced upper-level salinities persisted at the eastern site during the southward-flow regime, but there was no strong corresponding signal at the lower level in spite of the similar southward flow.

SUMMARY

The moored measurements taken as part of the Southeast Shoal Exchange Study reveal current and hydrographic variability over a range of time scales.

Currents with periods in the tidal and inertial bands account for a large fraction of the current variance on the southern Grand Bank. The low-frequency and record-mean currents are generally weak, particularly in the lower layer away from the eastern shelf-break. There is, however, a suggestion of significant seasonal and interannual variability in the low-frequency currents. Averaged over the entire records, there is little support for an anticyclonic gyre around the Southeast Shoal, although there are periods of low-frequency flow in an anticyclonic sense at individual sites. This is particularly true on the eastern part of the Shoal where the Labrador Current appears to be intermittently displaced onto the Bank.

The time scales of temperature and salinity variability range from minutes for internal-wave displacements in the seasonal thermocline/halocline, through one day for the diurnal thermocline at the sea surface, through days and weeks for wind-forced events and perhaps eddies, to seasonal and interannual variations. In particular, there are large seasonal and interannual changes in salinity which should have significant dynamical implications for circulation and vertical mixing.

These measurements will be analyzed and interpreted in conjunction with hydrographic survey data taken during the study. In addition, moored measurements are being made again in 1988 at the central and western sites as part of a continued larval capelin study with BSB and McGill University.

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TABLE 1. Summary of mooring positions, depths and data return periods for all moored measurements made as part of the Southeast Shoal Exchange Study in 1986 and 1987. The instruments were: Aanderaa current meters (CM), Aanderaa thermistor chains (TC), a Hermes/Argos surface-temperature buoy (STB), and Ryan thermographs (RT). The periods of good data return for some parameters are less than those indicated for the instrument.

Mooring No.	Position Lat(N),Long(W)	Water Depth(m)	Instrument (Depth,m)	Data Return Period (dd.mm)
1986:				
774	44°14.4',50°04.2'	55	CM(20)	18.04-03.08
			CM(45)	18.04-17.10
			TC(22-52)	18.04-17.10
			STB(0)	18.04-17.10
775	44°14.4',50°45.6'	65	RT(14)	18.04-12.05
			RT(40)	18.04-06.09
			RT(65)	18.04-16.10
776	44°14.4',49°30.0'	49	RT(13)	18.04-21.08
			RT(39)	18.04-20.08
			RT(49)	18.04-13.10
1987:				
830	44°16.0',50°05.3'	54	CM(11)	03.05-02.10
			CM(44)	03.05-18.10
			TC(12-42)	03.05-18.10
			STB(0)	03.05-18.10
			RT(54)	04.05-18.10
831	44°14.9',50°58.8'	70	CM(14)	03.05-19.10
			CM(47)	03.05-19.10
			RT(70)	05.05-04.10
832	44°13.3',49°19.5'	55	CM(12)	04.05-18.10
			CM(45)	04.05-18.10
			RT(55)	05.05-21.08
833	45°00.0',50°03.9'	59	RT(12)	Nil
			RT(59)	05.05-18.10
834	43°30.3',50°05.7'	55	RT(12)	Nil
			RT(55)	Nil

TABLE 2. Record means, standard deviations of the raw time series (Raw SD), and standard deviations of the low-passed time series (LF SD) for the east and north components of velocity. See Table 1 for locations and approximate durations.

Site,Depth	East Velocity(cm/s)			North Velocity(cm/s)		
	Mean	Raw SD	LF SD	Mean	Raw SD	LF SD
1986:						
774, 20m	-2.2	13.1	3.0	2.2	11.3	4.8
774, 45m	-1.7	11.6	2.4	1.7	9.0	3.1
1987:						
830, 11m	-2.6	15.1	5.2	0.3	13.2	4.4
830, 44m	-0.4	11.1	2.3	0.6	7.9	2.1
831, 14m	-0.7	12.7	6.5	-0.7	11.1	4.8
831, 47m	-0.5	7.2	2.4	0.4	6.5	2.1
832, 12m	-2.0	17.3	4.9	-2.9	15.3	5.0
832, 45m	-0.5	11.4	1.9	-2.0	9.7	4.1

TABLE 3. Record- and monthly-means of temperature (degrees C) from the current meters and surface temperature buoy. The MEDS long-term monthly-means for Southeast Shoal are also shown.

Site, Depth	Record	Apr	May	Jun	Jul	Aug	Sept	Oct
1986:								
774, 0m	9.8	4.7	4.2	7.8	12.7	13.7	12.3	9.4
774, 20m	5.4	1.7	3.0	5.6	8.7			
774, 45m	2.7	1.4	2.5	2.8	2.8	3.1	2.6	3.5
1987:								
830, 0m	10.9		5.9	6.9	12.5	14.2	13.5	13.3
830, 11m	10.1		5.7	6.5	11.1	13.7	13.4	
830, 44m	3.2		3.3	4.4	2.8	2.5	2.7	3.5
831, 14m	10.7		5.8	7.5	10.5	13.7	14.6	13.9
831, 47m	2.6		1.8	2.7	2.6	2.7	3.8	3.2
832, 12m	6.9		3.4	4.0	8.4	11.5	10.9	10.0
832, 45m	0.4		0.7	0.6	-0.2	-0.2	-0.3	-0.5
MEDS:								
0 m		2.2	4.2	9.3	11.9	17.7	15.4	13.5
10 m		2.1	4.2	8.9	11.2	17.2	15.2	13.4
20 m		2.1	3.6	6.6	8.2	12.9	13.0	13.0
50 m		1.8	2.6	3.5	4.5	3.6	3.9	4.8

TABLE 4. Record-means and monthly-means of salinity from the current meters. For comparison, Drinkwater and Trites' (1986) long-term monthly-means for the subarea "Southeastern Grand Bank" are also shown.

Site, Depth	Record	Apr	May	Jun	Jul	Aug	Sept	Oct
1986:								
774,20m	32.57	32.56	32.58	32.53	32.65			
774,45m	32.75	32.66	32.58	32.77	33.06	32.78	32.69	32.60
1987:								
830,11m	32.75		33.07	33.16	32.79	32.45	32.27	
830,44m	33.30		33.37	33.34	33.27	33.42	33.30	32.93
831,14m	32.68		32.58	32.90	32.93	32.62	32.50	32.47
831,47m	32.97		32.84	33.08	33.28			
832,12m	32.67		33.17	32.87	32.42	32.39	32.19	32.17
832,45m	33.18		33.28	33.26	33.17	33.21	33.04	32.95
Drinkwater and Trites (1986):								
10 m		32.97	32.82	32.61	32.27	32.33	32.18	32.32
20 m		33.01	32.85	32.70	32.45	32.55	32.43	32.44
50 m		33.11	33.05	33.00	32.81	32.97	33.06	32.94

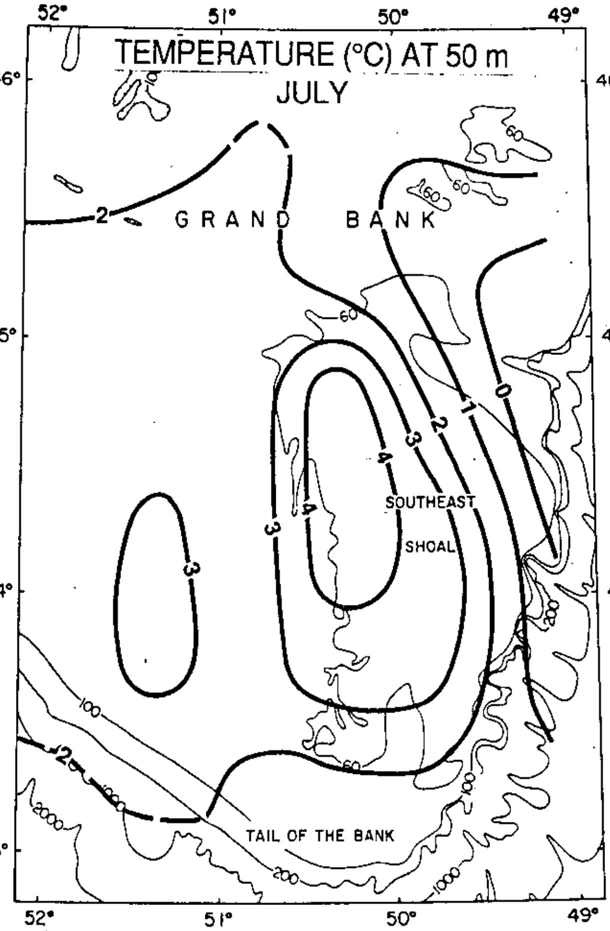


Figure 1. Climatological temperature distribution at the 50-m level on the southern Grand Bank in July. Contours are based on the MEDS long-term monthly-means for 1/2 x 1/2 degree areas.

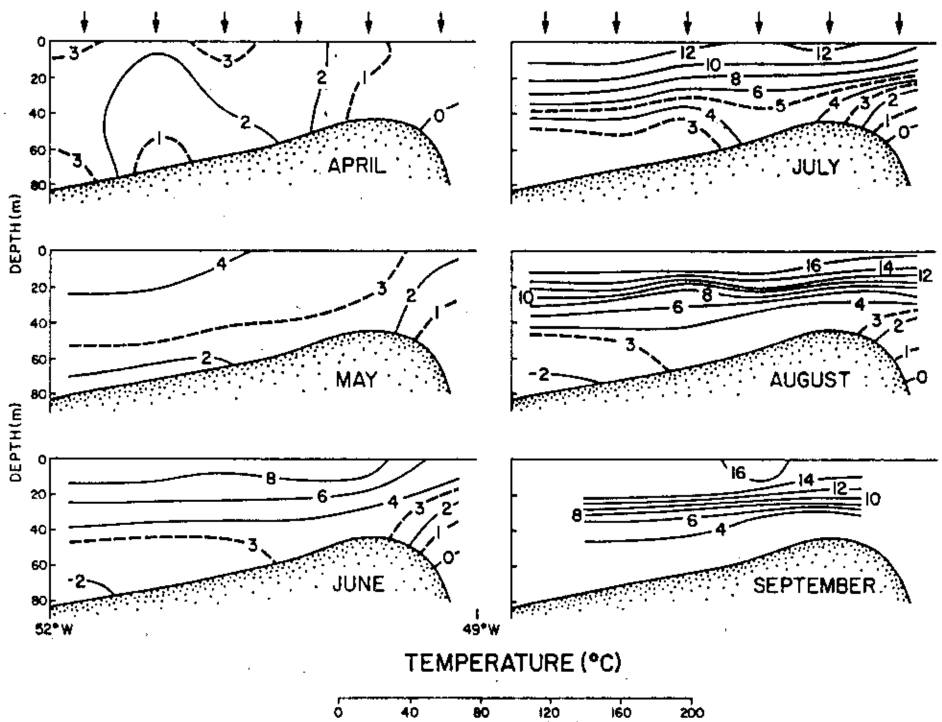


Figure 2. Seasonal evolution of the climatological temperature distribution on a vertical west-east section across Southeast Shoal. Contours are based on the MEDS long-term monthly-means for 1/2 x 1/2 degree areas between 44°N and 44°30'N.

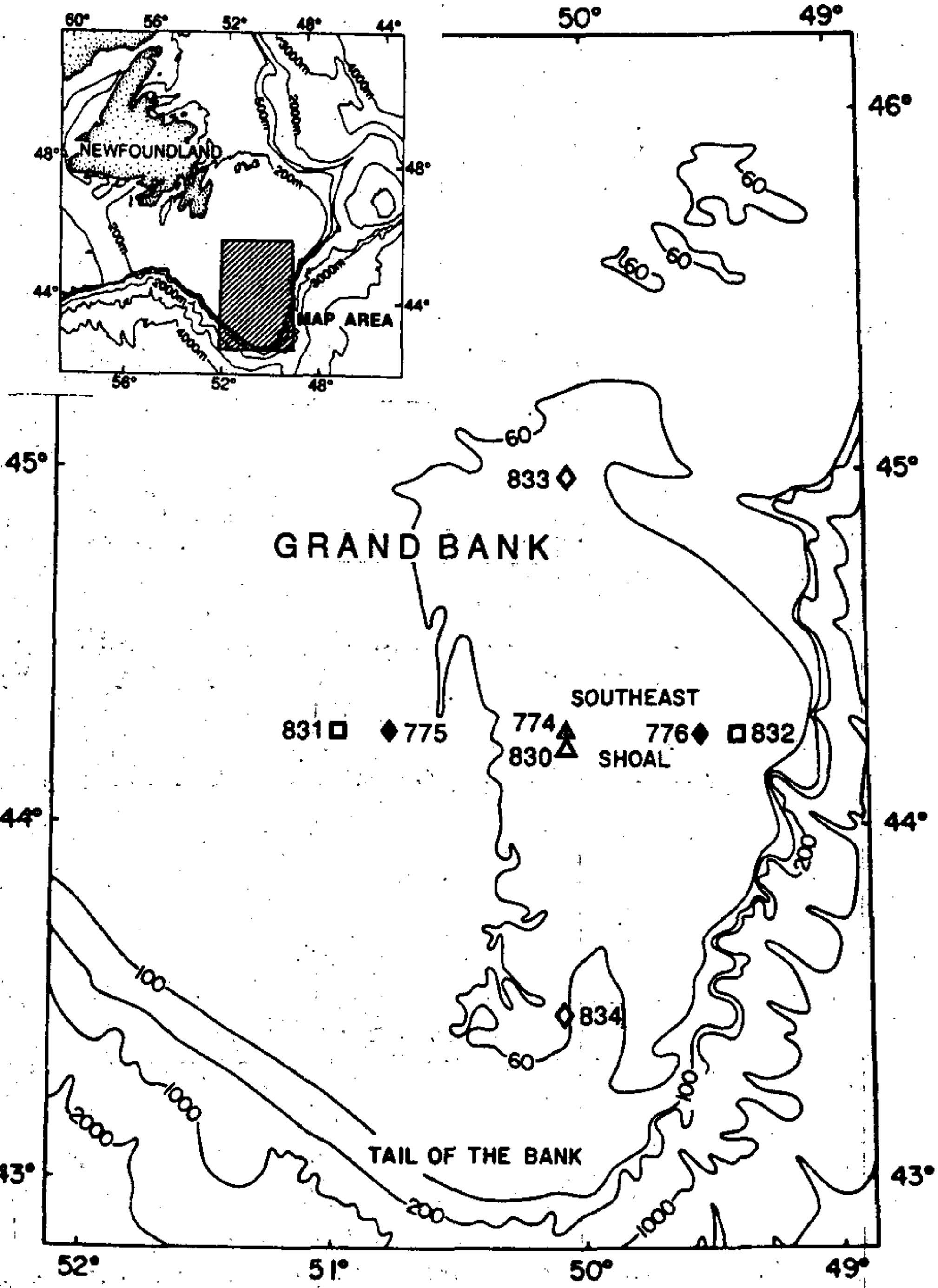


Figure 3. Map showing mooring sites on the Southeast Shoal of the Grand Bank. Closed symbols denote 1986 sites and open symbols 1987 sites.

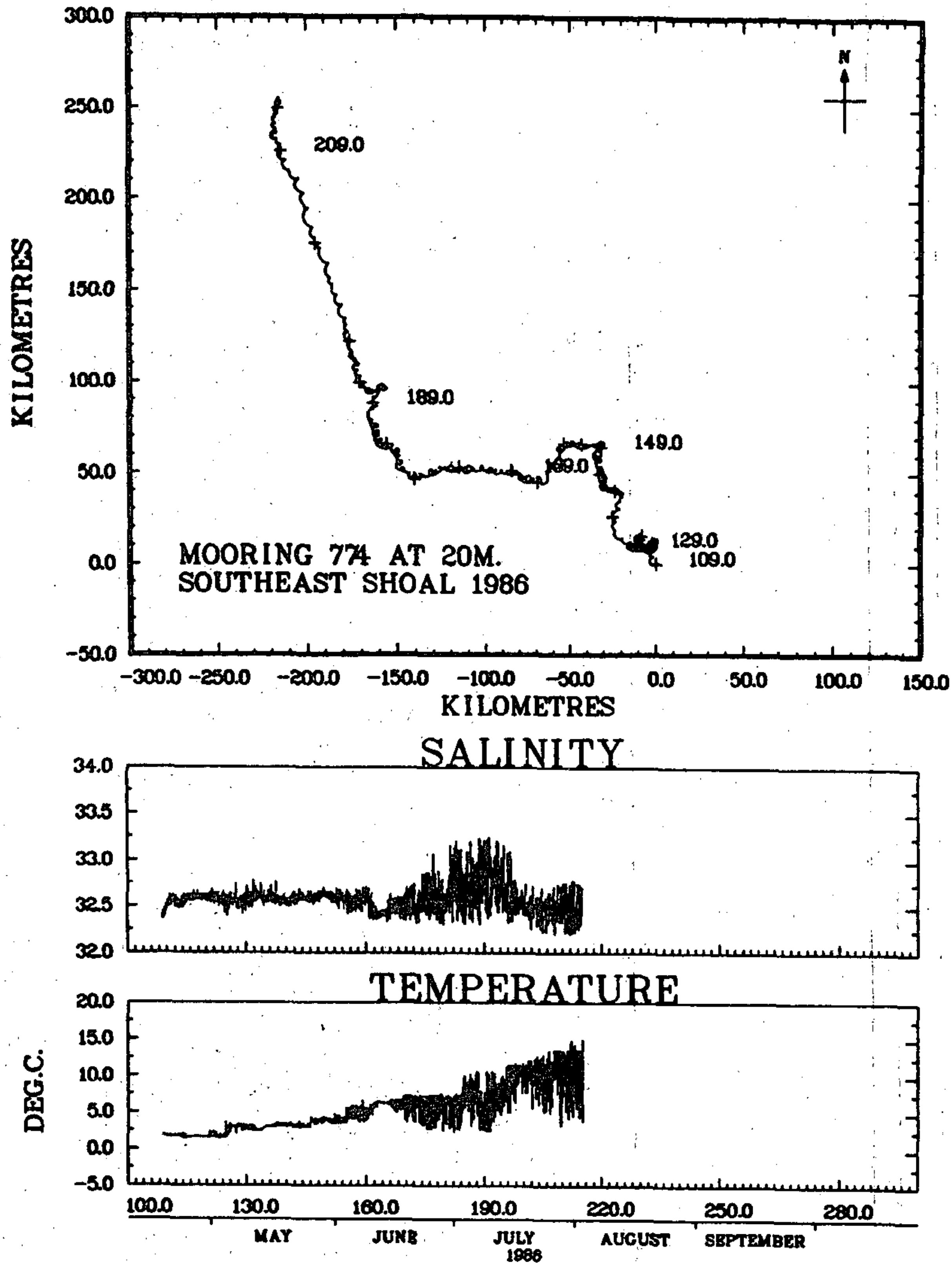


Figure 4. Progressive vector diagram and time series plots of salinity and temperature from raw data at the 20-m level at the central site (mooring 774) in 1986. Days are marked at 20-dy intervals on the progressive vector diagram.

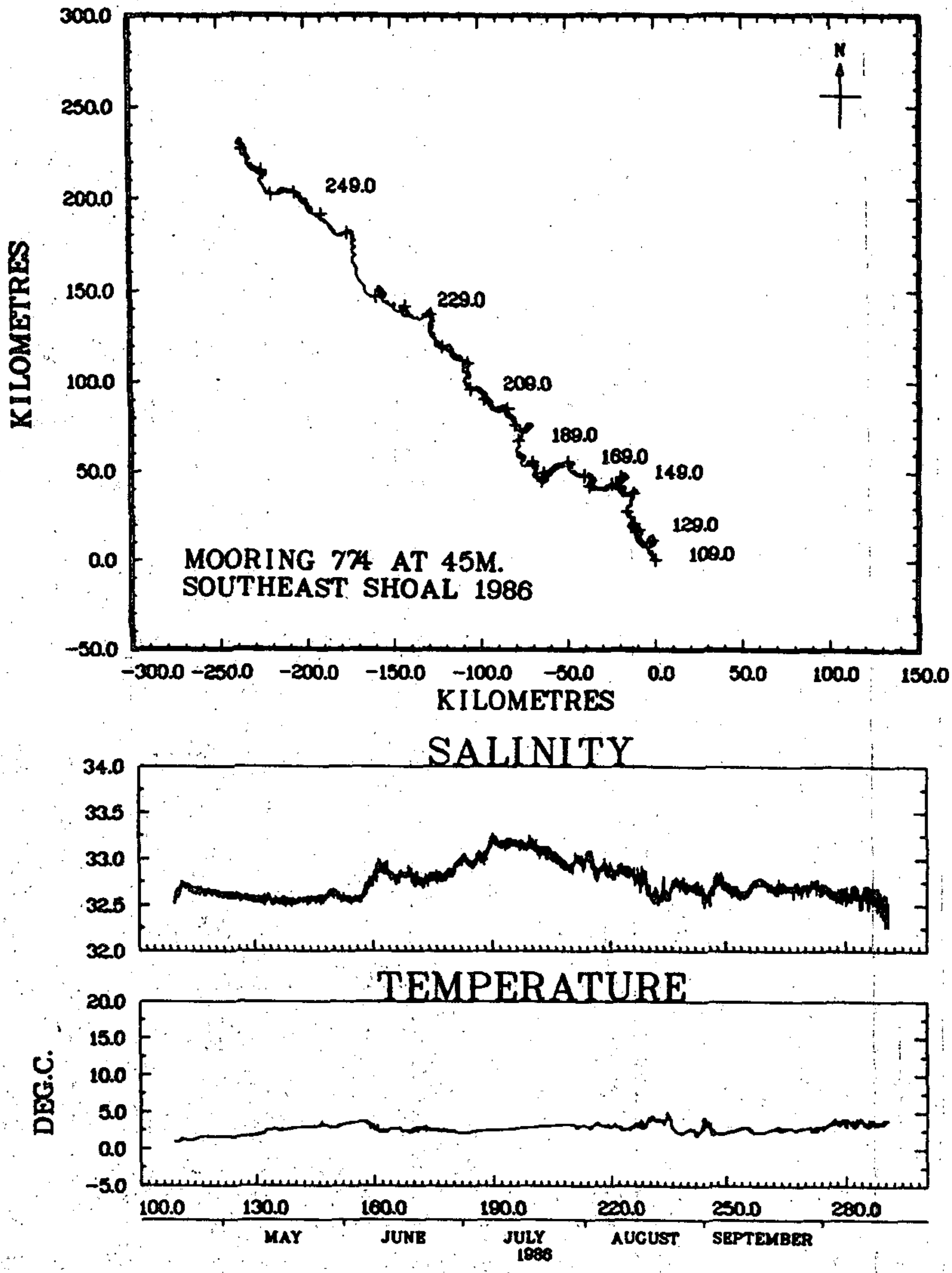


Figure 5. Progressive vector diagram and time series plots of salinity and temperature from raw data at the 45-m level at the central site (mooring 774) in 1986. Days are marked at 20-dy intervals on the progressive vector diagram.

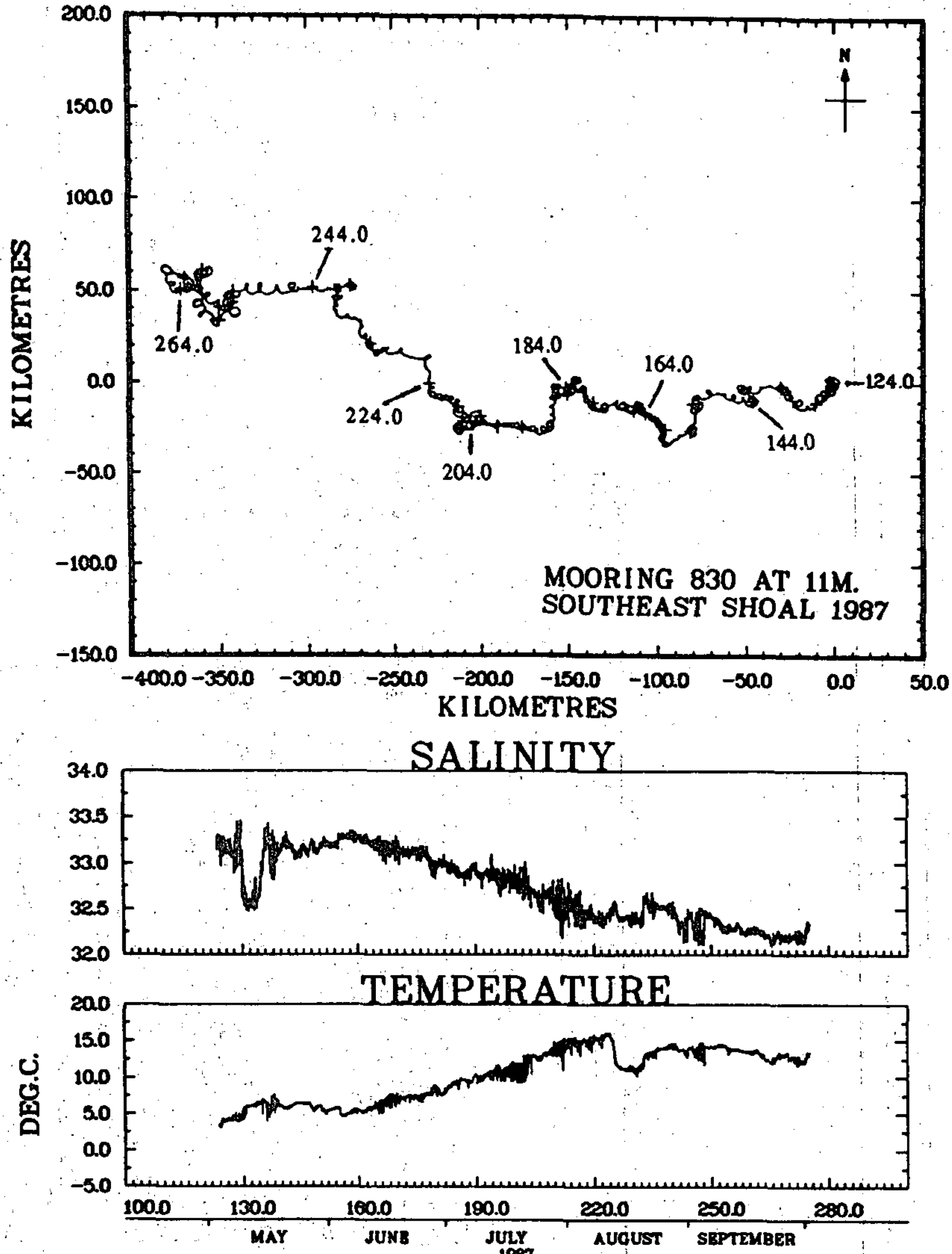


Figure 6. Progressive vector diagram and time series plots of salinity and temperature from raw data at the 11-m level at the central site (mooring 830) in 1987. Days are marked at 20-dy intervals on the progressive vector diagram.

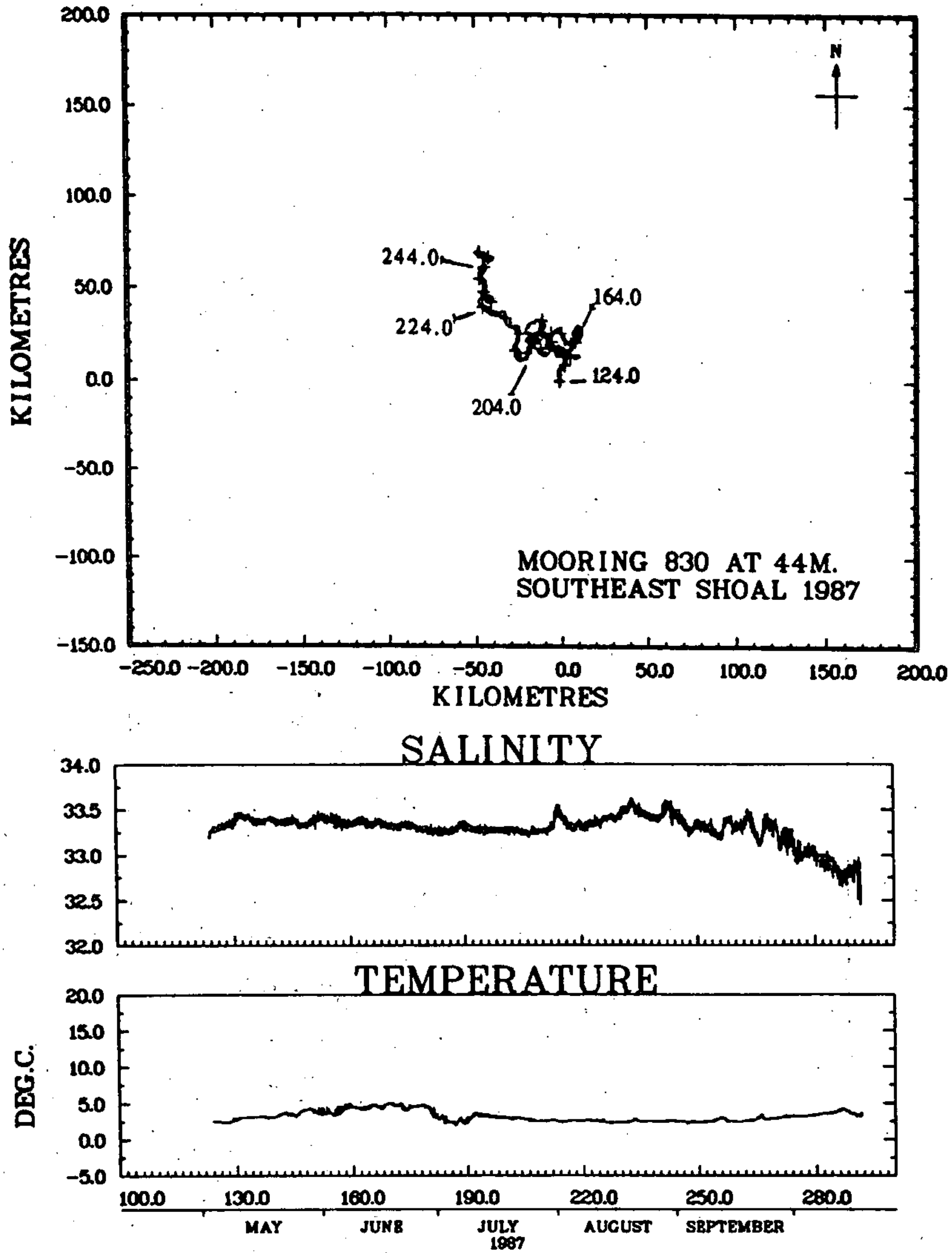


Figure 7. Progressive vector diagram and time series plots of salinity and temperature from raw data at the 44-m level at the central site (mooring 830) in 1987. Days are marked at 20-dy intervals on the progressive vector diagram.

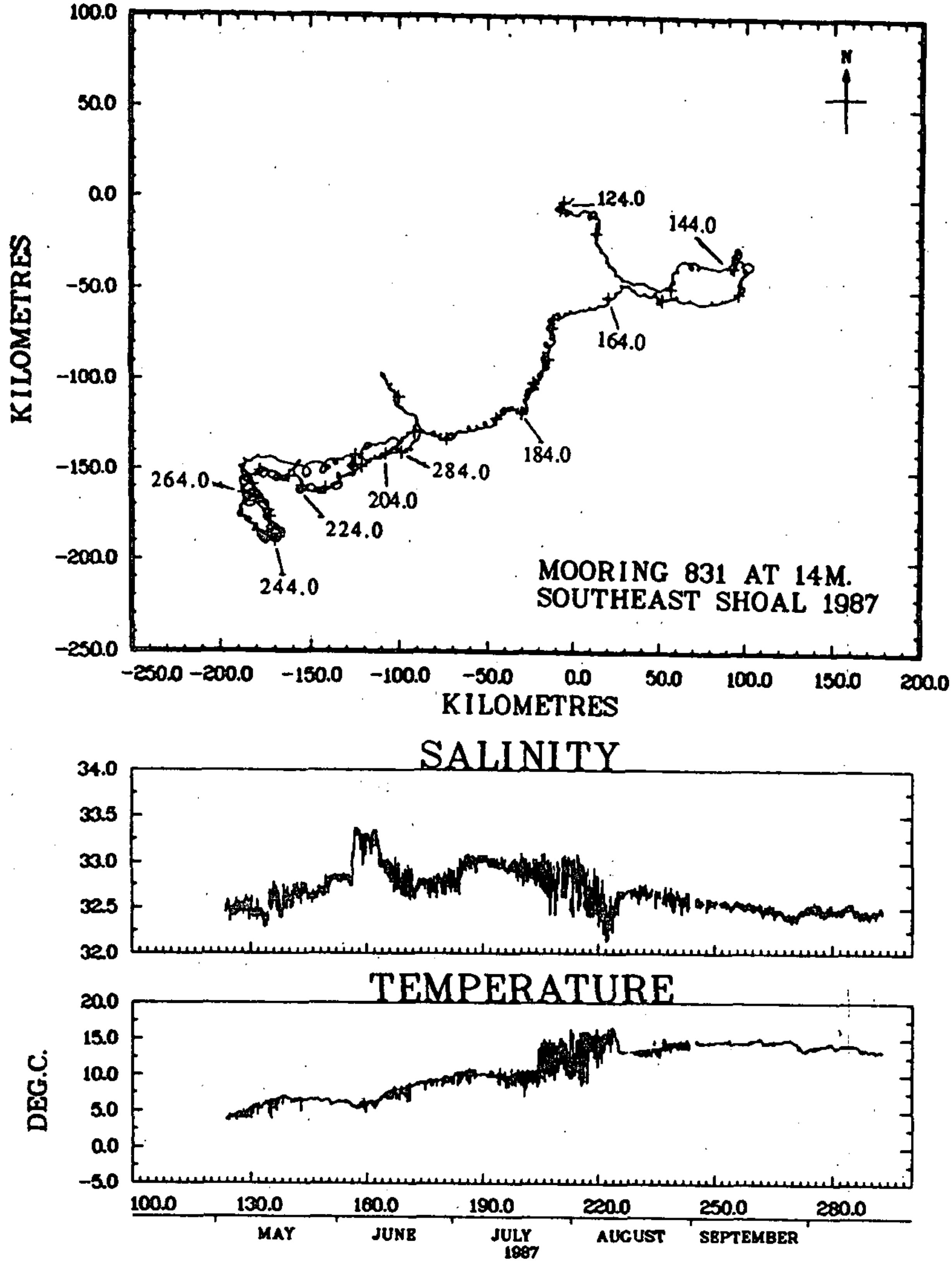


Figure 8. Progressive vector diagram and time series plots of salinity and temperature from raw data at the 14-m level at the western site (mooring 831) in 1987. Days are marked at 20-dy intervals on the progressive vector diagram.

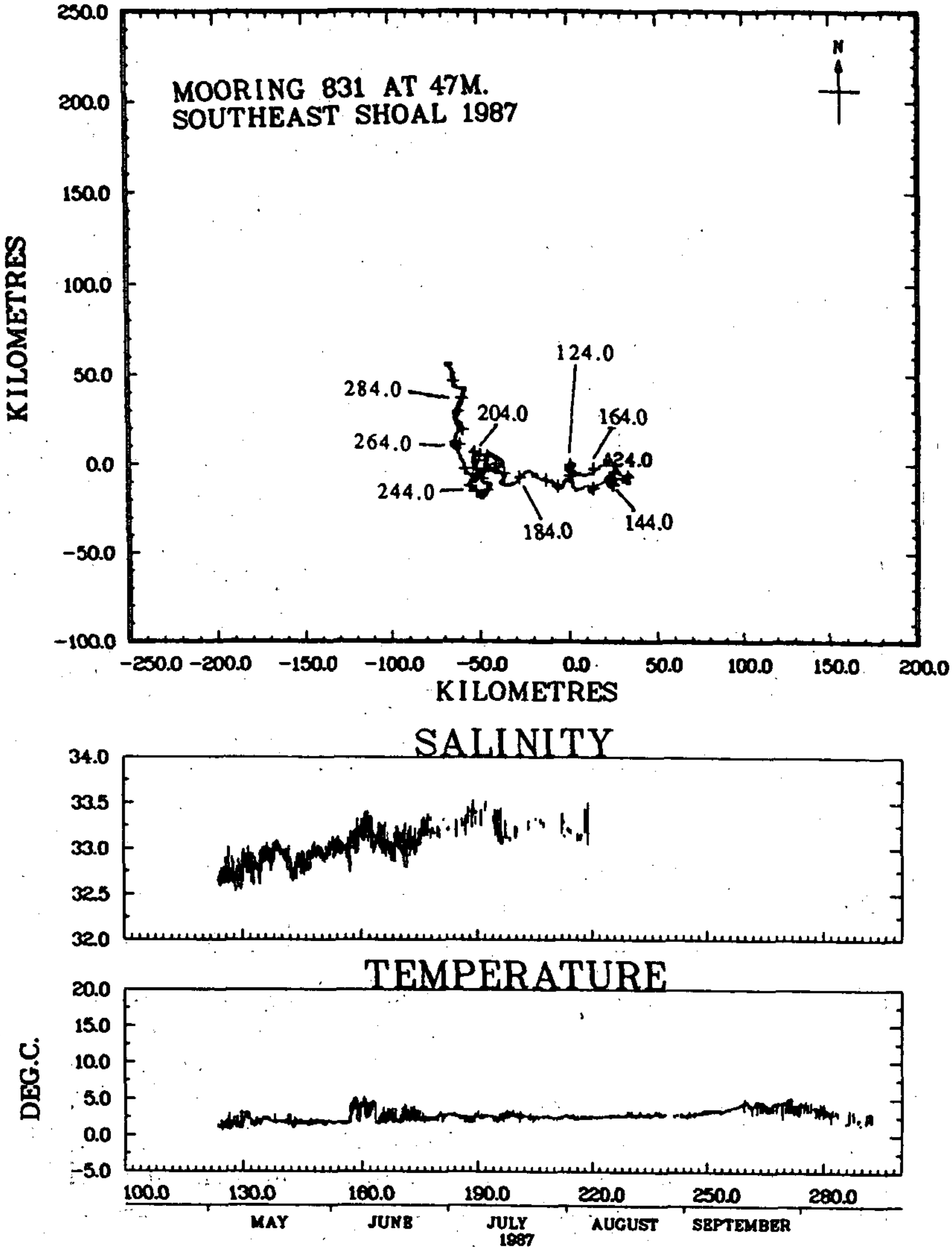


Figure 9. Progressive vector diagram and time series plots of salinity and temperature from raw data at the 47-m level at the western site (mooring 831) in 1987. Days are marked at 20-dy intervals on the progressive vector diagram.

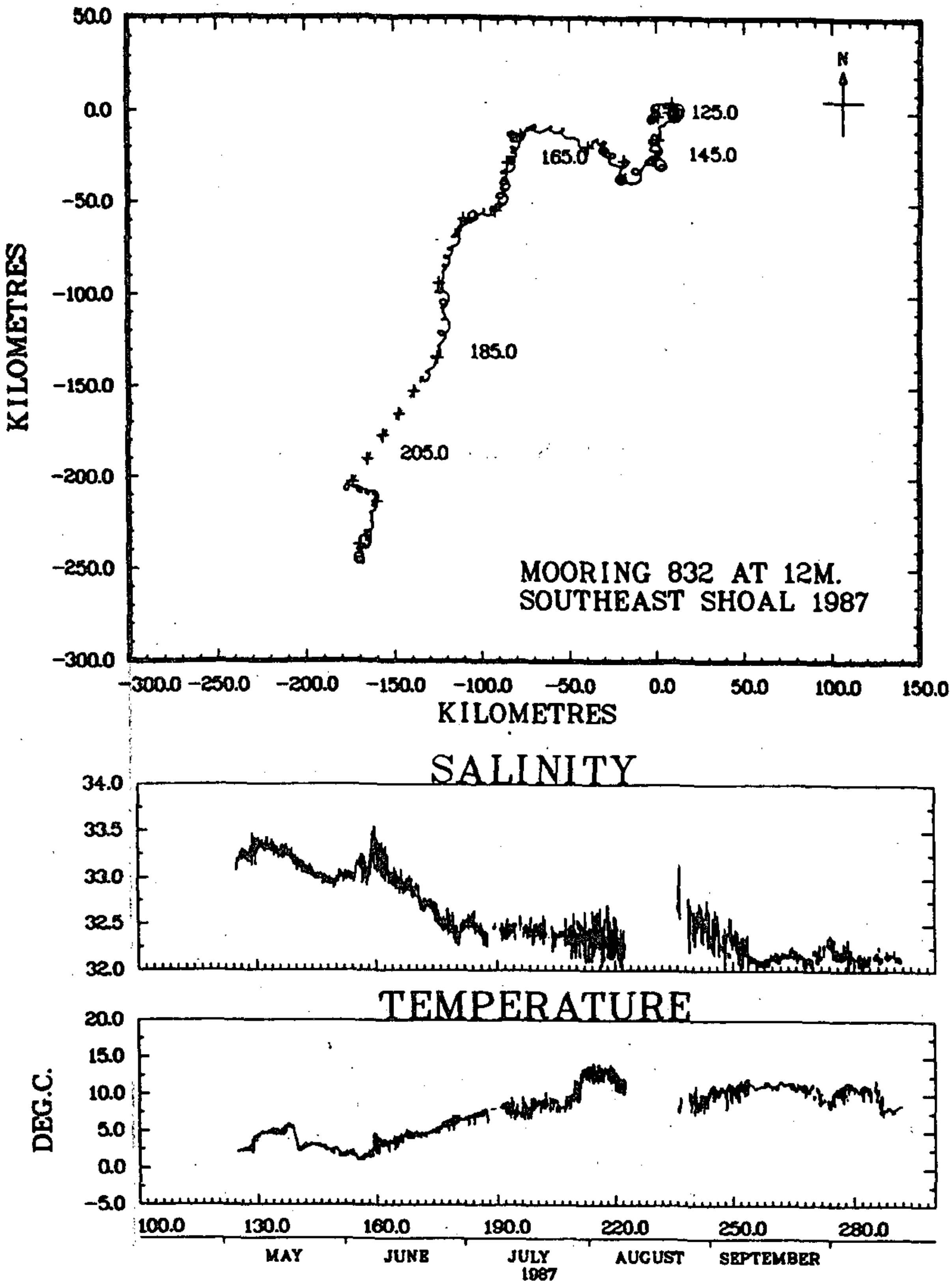


Figure 10. Progressive vector diagram and time series plots of salinity and temperature from raw data at the 12-m level at the eastern site (mooring 832) in 1987. Days are marked at 20-dy intervals on the progressive vector diagram. There is a gap in the current record during which the record-mean values are used.

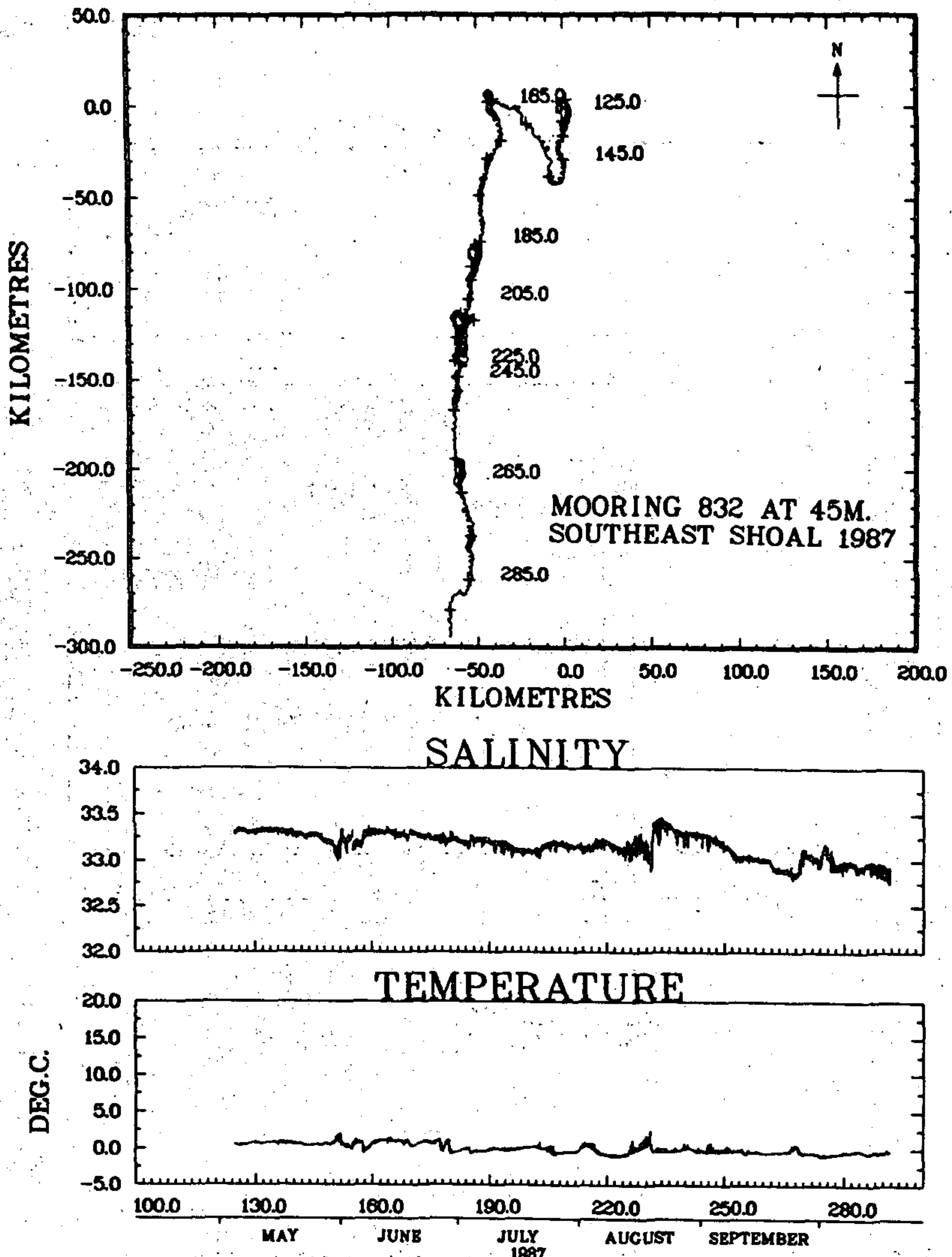
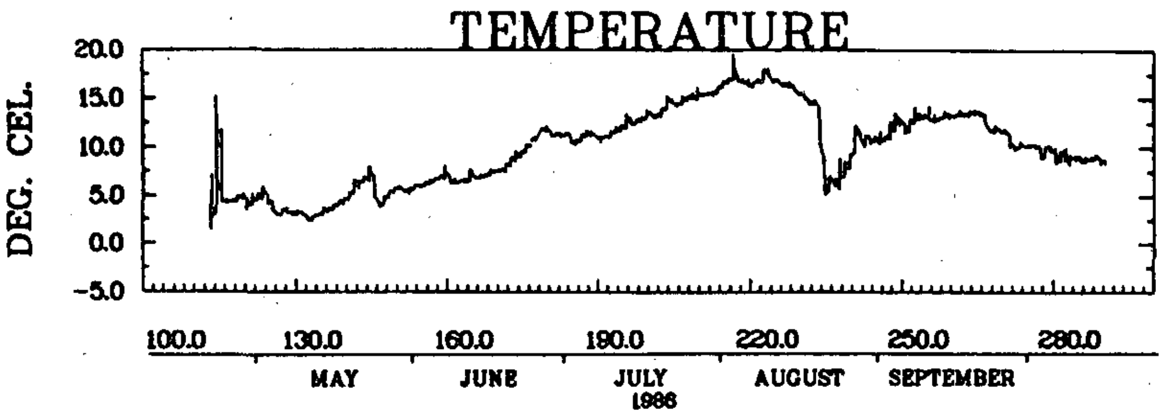


Figure 11. Progressive vector diagram and time series plots of salinity and temperature from raw data at the 45-m level at the eastern site (mooring 832) in 1987. Days are marked at 20-dy intervals on the progressive vector diagram.



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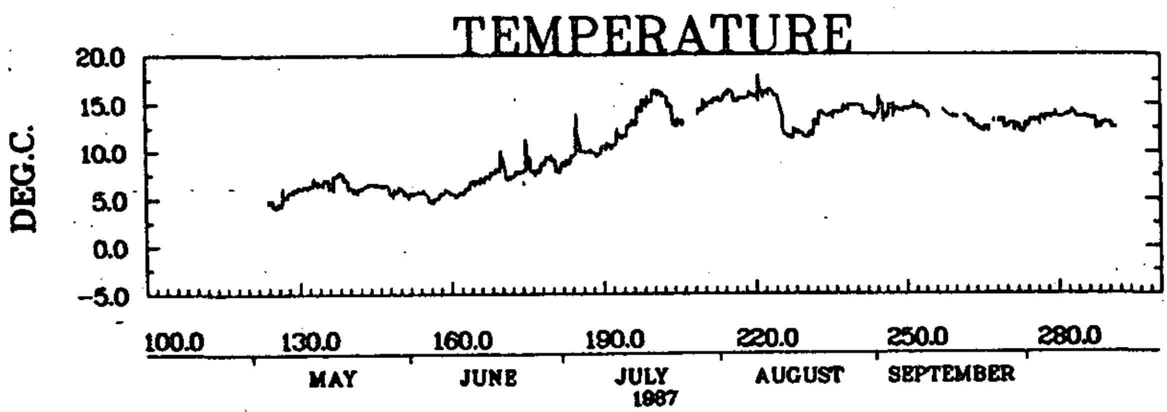

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Figure 12. Time series of 6-hourly surface temperature at the cental mooring site in 1986 and 1987.