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Satellite-Tracked Drifting Buoy Measurements off Labrador and Newfoundland, 1981-1983

D.B. Fissel and J.R. Birch

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Physical and Chemical Sciences Branch
Scotia-Fundy Region
Department of Fisheries and Oceans

Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia
Canada B2Y 4A2

December 1990

Canadian Contractor Report of Hydrography and Ocean Sciences No. 38

Fisheries and Oceans Pêches et Océans

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SATELLITE-TRACKED DRIFTING BUOY MEASUREMENTS OFF LABRADOR AND NEWFOUNDLAND, 1981-1983*

by

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* Prepared under contract to the Department of Fisheries and Oceans for the sea-ice program at the Bedford Institute of Oceanography, funded by the Federal Panel of Energy Research and Development.

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Cat. No. FS 97-17/38E ISSN 0711-6748

Correct citation for this publication:

Fissel, D. B. and J. R. Birch. 1990. Satellite-tracked drifting buoy measurements off Labrador and Newfoundland, 1981-1983. Can. Contract. Rep. Hydrogr. Ocean Sci. 38: ix + 106 pp.

ACKNOWLEDGEMENTS

The data collection and preliminary analyses for each individual year of operations were funded by Petro-Canada. We wish to thank Dr. J.R. Buckley and Mr. W. Thompson, both formerly of Petro-Canada, for initiating the study and contributing to the data analysis and interpretation. We also thank Dr. Simon Prinsenberg of the Bedford Institute of Oceanography, who made publication of this report possible through funds provided by the Panel of Energy Research and Development (PERD). Arctic Sciences personnel who contributed to the report included: Steve Oberski and Rene Chave for computer programming; Nancy Andrew for preparation of diagrams and figures; and Sheila Norton and Ferne Welsman for word processing and proofreading the text.

ABSTRACT

Fissel, D. B. and J. R. Birch. 1990. Satellite-tracked drifting buoy measurements off Labrador and Newfoundland, 1981-1983. Can. Contract. Rep. Hydrogr. Ocean Sci. 38: ix + 106 pp.

A total of 14 satellite-tracked drifting buoys were deployed off Labrador in the autumn of 1981 and the summers of 1982 and 1983. From the buoy positions, the near-surface circulation features were examined. The buoys also measured air pressure and sea temperature, transmitting all data via the ARGOS satellite system.

The combined results of the drifter studies of 1981 to 1983 were used to produce summary plots of average surface currents, and velocity characteristics tabulated by bathymetric regime. The two branches of the southeasterly flowing Labrador Current located over the marginal trough and continental slope/rise regions dominated the surface circulation patterns. The magnitude of the near-surface currents were typically 0.2 to 0.3 m/s in these regimes, except in the inner core of the offshore branch of the Labrador Current where average speeds of 0.3 to 0.5 m/s were realized. The two branches of the Labrador Current were separated by the directionally variable, but at times highly energetic currents occurring over the banks and saddles of the continental shelf.

The outer branch of the Labrador Current was characterized by strong (typically 0.4 m/s) flows concentrated in a narrow (<20 to 40 km) core located over the steeply sloping shelf edge. The southeastward flows extend to locations offshore of the strong current core over the continental slope and continental rise. These currents are reduced in magnitude (0.2 m/s) and gradually decrease with increasing depths.

RÉSUMÉ

Fissel, D. B. and J. R. Birch. 1990. Satellite-tracked drifting buoy measurements off Labrador and Newfoundland, 1981-1983. Can. Contract. Rep. Hydrogr. Ocean Sci. 38: ix + 106 pp.

Au total, 14 bouées dérivantes poursuivies par satellite ont été déployées au large du Labrador à l'automne de 1981 et pendant les étés de 1982 et de 1983. Les caractéristiques de la circulation près de la surface ont été examinées d'après les positions des bouées. Ces bouées permettaient également de mesurer la température et la pression de l'air, et toutes les données étaient transmises par le système satellitaire ARGOS.

L'ensemble des résultats des études avec bouées dérivantes menées de 1981 à 1983 a servi à produire des tracés sommaires des courants moyens en surface et des tableaux des caractéristiques des vitesses d'après le régime bathymétrique. Deux branches du courant du Labrador portant au sud-est sur les régions de la fosse de la marge continentale et de la pente océanique/talus continental dominent les configurations de la circulation en surface. Ces régimes sont caractérisés par des courants près de la surface dont l'ordre de grandeur varie de 0,2 à 0,3 m/s sauf dans la partie centrale de la branche du large du courant du Labrador, où des vitesses moyennes de 0,3 à 0,5 m/s ont été relevées. Les deux branches du courant du Labrador étaient séparées par des courants de direction variable, mais possédant à certains moments des énergies élevées, sur les bancs et ensellements du plateau continental.

La branche extérieure du courant du Labrador était caractérisée par des écoulements puissants (typiquement de 0,4 m/s) concentrés dans une étroite partie centrale suituée sur la bordure à forte pente du plateau continental. Les écoulements en direction du sud-est se prolongent jusqu'au large de la partie centrale au courant fort sur le talus continental et la pente océanique. La vitesse de ces courants est réduite (0,2 m/s) et elle diminue progressivement à mesure qu'augmente la profondeur.

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1. INTRODUCTION

Fourteen satellite-tracked drifting buoys were deployed off Labrador during the autumn of 1981, and the summers of 1982 and 1983. The buoys, tracked through the ARGOS satellite system, were equipped with atmospheric pressure and sea-surface temperature sensors. The data were used in a near real-time mode i support of drilling operations by Petro-Canada Inc. The areas of data collection are indicated in Figure 1 by the buoy tracks for each year of data collection.

The purpose of this report is to document and display the collected data and to present a preliminary analysis of the positional and velocity data.

The analysis and evaluation is complete up to December 31, 1983. After this time, the buoys were no longer operating in the area of interest.

2. DATA COLLECTION

2.1 THE BUOY

The drifting buoys, manufactured by Hermes Electronics Limited of Dartmouth, Nova Scotia, are illustrated schematically in Figure 2. Ten of the drifting buoys were standard models equipped with conventional "window-shade" drogues, while two buoys were air deployable units (see Table 1). Two other buoys were initially moored in placed, and subsequently broke loose from their moorings as a result of major storms passing by. For the standard units, the window-shade drogue accounts for over 94% of the total cross-sectional area of the buoy-drogue combination, the movements of these drifters are expected to be representative of near-surface currents over the depth range of the drogue, 4.3 to 11 m.

The air deployed drifting buoys (4077 and 4078) as illustrated in Figure 2B, come equipped with a holey sock drogue, having dimensions of 0.53 m (diameter) by 7.6 m (length). The length of the tether from the buoy to the front of the drogue is 20.4 m. At times when the drogue is hanging vertically and is entirely perpendicular to water current drag, the submersed area accounts for 87% of the total cross-sectional area. This type of drifter will also respond primarily to water current forcing but the direct wind effects could be larger.

Buoys 4079 and 4080 were originally moored on Nain and Saglek banks respectively. They broke free of their moorings and were subsequently tracked down the coast. One of these buoys was subsequently recovered in February 1983 in the vicinity of the Hibernia drilling area by Mobil Oil Ltd. personnel (J. Dempsey, Dobrocky Seatech (Nfld.) Ltd., personal communication). When recovered, approximately 70 m of 0.019 m diameter polypropylene line was still attached along with about 0.6 m of chain. Such a configuration would have 77% of the total cross-sectional area beneath the water line, assuming the polypropylene line is hanging vertically, and would respond primarily to near-surface currents.

2.2 THE ARGOS SYSTEM

The ARGOS system determines the platform position by measuring the Doppler shift of the carrier frequency of messages transmitted by the platforms. The transmitted messages are emitted approximately once each minute on a continuous

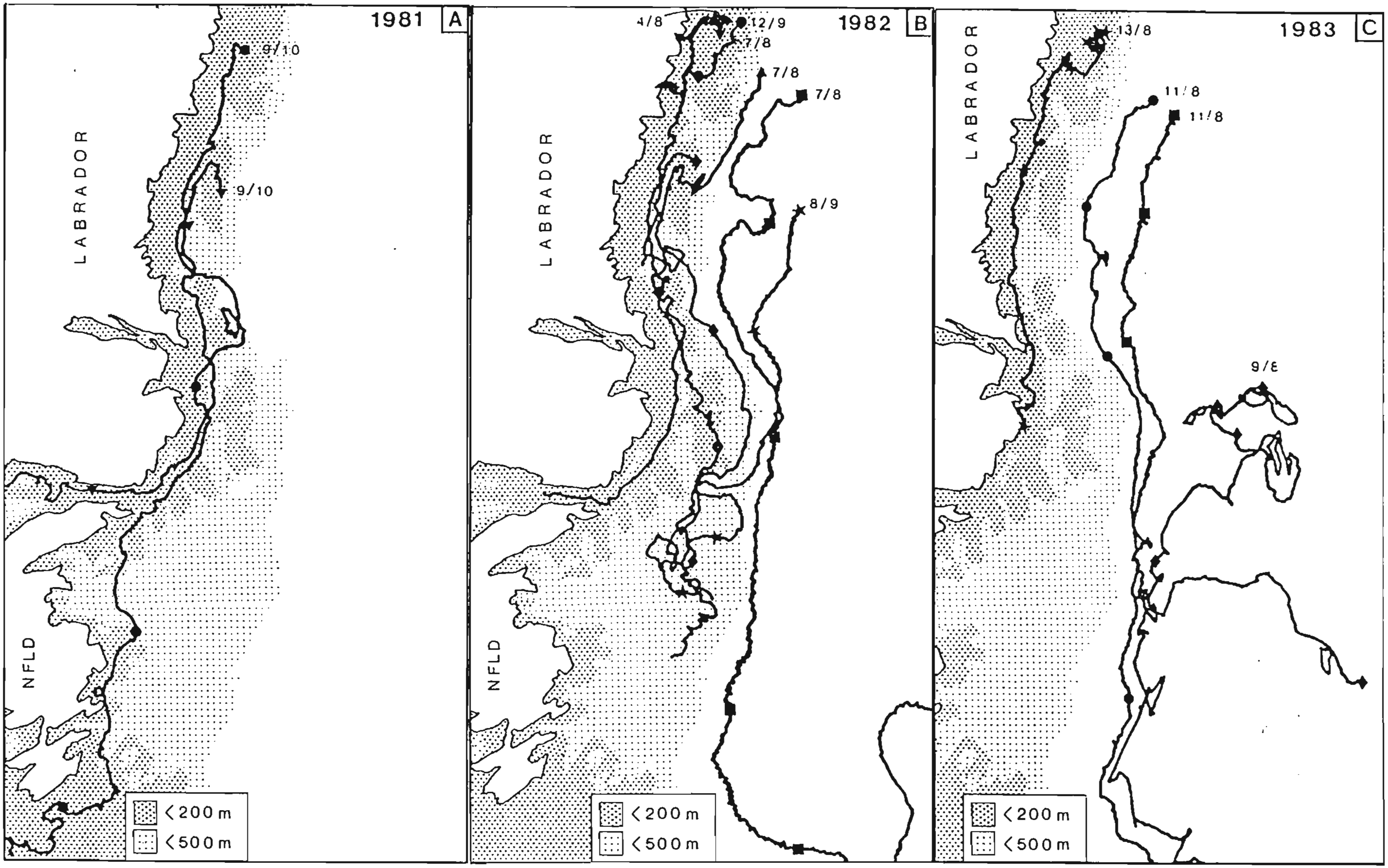

Figure 1: A composite plot of the trajectories of all drifting buoys in (a) 1981, (b) 1982 and (c) 1983. Also shown are the locations of anemometers operated from small offshore islands during 1982.

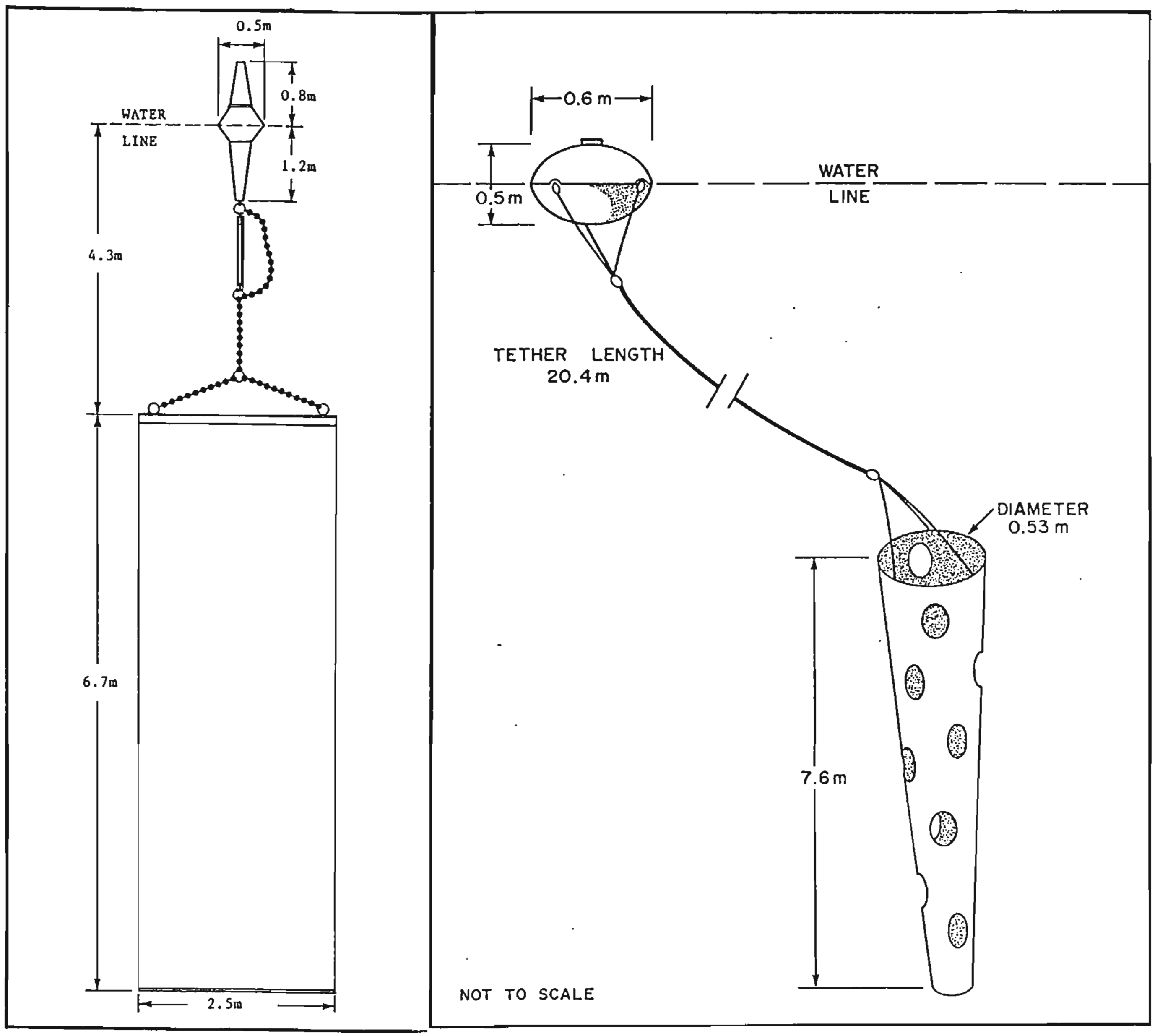

Figure 2: A schematic diagram of the satellite-tracked drifting buoys and attached drogues for (a) the standard drifter hull and (b) the air deployable buoys.

Table 1

Summary of deployment dates and area, fate (to December 31, of each year) and buoy-drogue configuration for each drifting buoy data set.

Drifter I.D.	Buoy-Drogue Configuration	Deployment Date	Deployment Area	Fate (to Dec. 31)
		1981		
4070	standard drifting buoy; "window shade" drogue	Oct. 9	centre of Saglek Bank	operating
4071	standard drifting buoy; "window shade" drogue	Oct. 9	centre of Nain Bank	aground Mar. 17 off west coast of Nfld; recovered
		1982		
4072	standard drifting buoy; "window shade" drogue	Aug. 7	offshore of Saglek Bank in 2400 m water depth	operating
4073	standard drifting buoy; "window shade" drogue	Aug. 4	on western side of Saglek Bank	grounded Aug. 29 south of Hebron
4074	standard drifting buoy; "window shade" drogue	Aug. 7	over continental slope of Saglek Bank	picked up Oct. 12 in Strait of Belle Isle
4075	standard drifting buoy; "window shade" drogue	Aug. 7	over centre of Saglek Bank	grounded Aug. 22 north of Hebron
4077	air deployable buoy; holey sock drogue	Sept.10	offshore in 3600 m water depth (near former site of Ocean Station Bravo)	operating
4078	air deployable buoy; holey sock drogue	Sept.8	offshore of Nain Bank in 3000 m water depth	operating
4079	standard drifting buoy; initially anchored, no drogue	Aug. 5 Sept.30	over Nain Bank began drifting	operating; recovered near Hibernia in Feb. 1983
4080	standard drifting buoy; initially anchored; no drogue	Aug. 6 Sept.12	over Saglek Bank began drifting	operating
		1983		
4071	standard drifting buoy; "window shade" drogue	Aug. 11	centre of Saglek Bank	operating
4091	standard drifting buoy; "window shade" drogue	Aug. 11	over continental slope east of Saglek Bank	operating
4094	standard drifting buoy; "window shade" drogue	Aug. 11	over continental rise east of Saglek Bank	grounded on Nov. 29 off S. Labrador
4093	standard drifting buoy; "window shade" drogue	Aug. 9	over abyssal depths off Hamilton Bank	operating

basis and include the outputs from the pressure and temperature sensors. When the raw data values reach the ARGOS centre in Toulouse, France, positions are computed and calibration equations applied to the pressure and temperature outputs to provide engineering values.

The data are then stored on the ARGOS computer. The most recently received data values can be accessed via telex or telephone lines. Most of the time, the position values are available within 4 hours of the measurement times. In addition, all ARGOS data were obtained on a computer tape once each month. Since the atmospheric pressure and sea-surface temperature are useful for forecast applications, the data were also transmitted back to North America on the Global Transatlantic System for use by weather services and Petro-Canada's consultant providing weather and sea-state forecast services.

For this report, all data were obtained from the monthly computer tapes generated by System ARGOS.

2.3 DRIFTER TRAJECTORIES

The tracks of all drifters to December 1983 are presented in Figure 1. Detailed track plots for each drifter are plotted on a series of 1:2,000,000 maps in Appendix 1. Plots and statistical summaries of drifter velocities derived from the time series positional data are shown in Appendix 2.

2.4 ATMOSPHERIC PRESSURE AND SEA-SURFACE TEMPERATURE DATA

The buoys were fitted with atmospheric pressure and sea-temperature sensors. The pressure sensors consist of a Paroscientific digiquartz transducer having a range of 920 to 1048 mbars and an accuracy of $\pm$1 mbar, according to the manufacturer's specifications. The sea-temperature sensor is a thermistor with a range of -5 to 35°C and a specified accuracy of $\pm$0.2°C. Intercomparisons of pressure and temperature data, obtained from different buoys during land-based testing, indicate the measurements are consistent to within the specified accuracies, although independent measurements were not available in the limited time allocated for testing.

The median value derived from each group of pressure and temperature measurements (1981-1982), as obtained from individual satellite overpasses, are plotted in Appendix 3. Occasional anomalous values were detected and corrected by automatic data scanning using first difference techniques. For differences of sequential readings exceeding 10 mbar in pressure and 2°C in temperature, the suspect values were replaced by linear interpolation. In most data sets, the number of corrected values amounted to approximately one percent of the total number of data samples.

2.5 LAND-BASED WIND MEASUREMENTS

In 1982, wind data were obtained from satellite transmitting automatic weather stations mounted on well-exposed offshore islands, operated by Petro-Canada in the summer and autumn of 1982. The sites of wind measurements, shown in Figure 1, are:

SITE	LATITUDE	LONGITUDE	PERIOD OF OBSERVATIONS
Quaker Hat Island	54°44'N	57°20'W	August 1 to December 31, 1982
Stirrup Island	57°37'N	61°19'W	August 23 to December 31, 1982

The anemometers provide hourly wind data from the standard measurement height of 10 m above ground level.

3. NEAR-SURFACE CIRCULATION FEATURES

3.1 POSITIONAL DATA

The number of positional fixes obtained for each drifter generally ranged from an average of 13 daily positions off northern Labrador to an average of 10 daily positions off Newfoundland.

The ARGOS data were first edited for unacceptable satellite fixes and redundant positions. The latitude and longitude values were then plotted versus time and anomalous values were identified and removed manually. The total number of erroneous positional values was small, numbering four or less for all drifters, with the exception of drifter 4091, used in 1983. For the latter data set, a total of 10 erroneous positions were detected from August 11 to November 14. (After November 14, the positional data rate for this drifter was reduced to an average of only two positions per day and it was no longer possible to determine which, if any, of the positions were erroneous.)

3.2 MAPS OF COMPUTED NEAR-SURFACE VELOCITIES

From the positional data of each drifter, velocities were computed (Appendix 2). To avoid large uncertainties in the velocity calculations, a minimum elapsed time of six hours was required between successive positions. Taking the 90% confidence level of positional accuracy in each component as 0.6 km (as derived from stationary land-based testing), the corresponding accuracy from velocity components would be 3.5 km/d or 0.04 m/s when calculated over six hours elapsed time.

Time series drifter velocities were then computed at uniform six-hourly intervals using linear interpolation. From these data, basic statistics were computed for each drifter track (Appendix 2).

Maps of vector-averaged near-surface currents in the western Labrador Sea, have been prepared, as derived from the 14 drifter tracks (Figures 3-6). Velocities have been vector-averaged over grids of approximately 50 and 25 km dimension, for maps of scale 1:6,750,000 (Figure 3) and 1:2,000,000 (Figures 4 to 6), respectively. One grid has been plotted on each map. For the 1:6,750,000 scale map only vector averages based on three or more velocities have been plotted. On the maps, the number of data points contributing to each average have been shown beside each vector.

3.3 DESCRIPTION OF DRIFTER MOTIONS

The Labrador Current consists of two spatially separated southeasterly flowing branches, one over the inner marginal trough and the other further offshore over the continental slope. Separating the two current streams is an

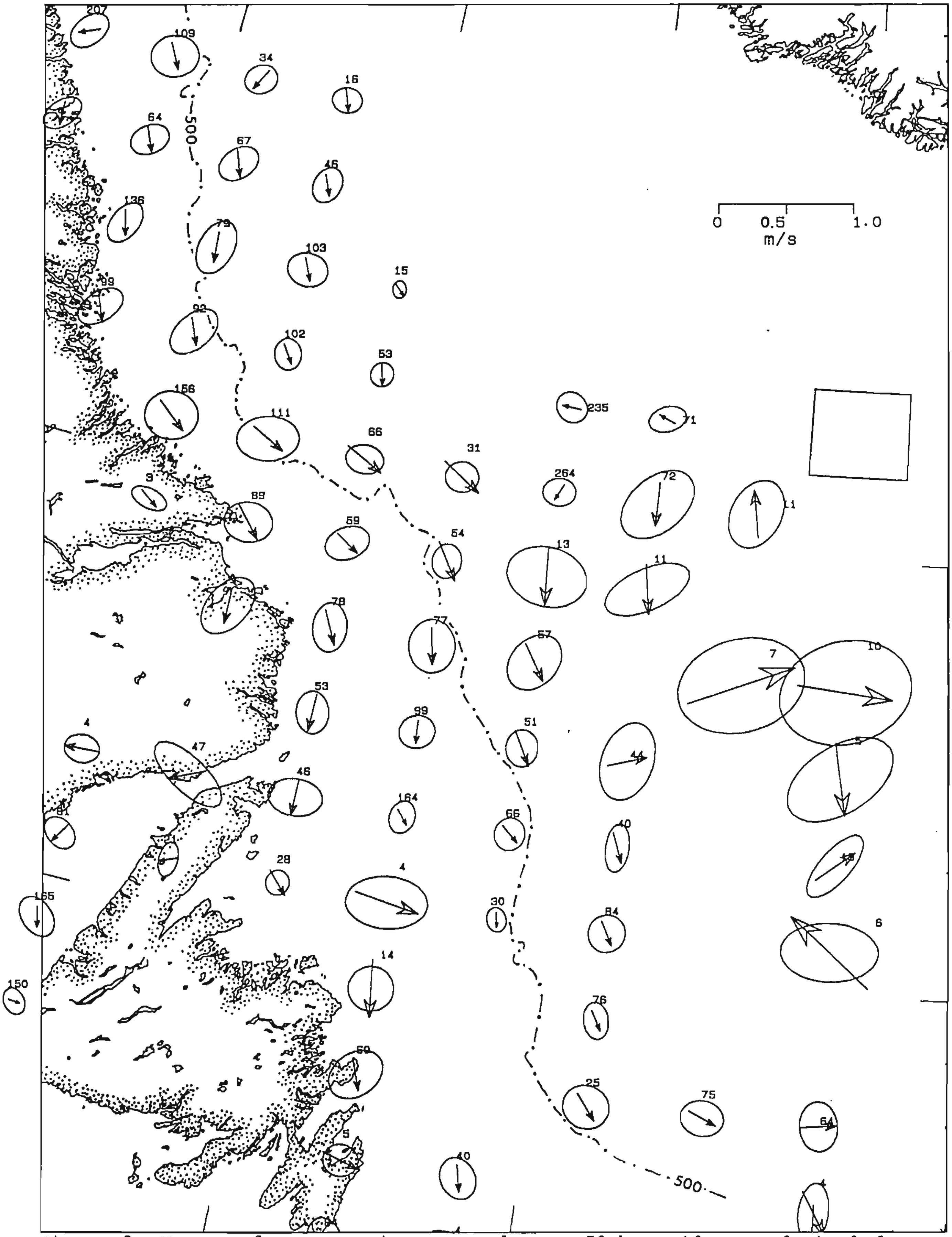

Figure 3: Near-surface currents averaged over 50 km grids, as derived from fourteen drifter trajectories obtained in the summer and fall of 1981 to 1983. The near-surface velocities are represented by the mean velocity vector. The number of six-hourly observations is noted above each vector. The maximum and minimum axes of the ellipses correspond to the components of the standard deviation resolved along the principal axes of variations.

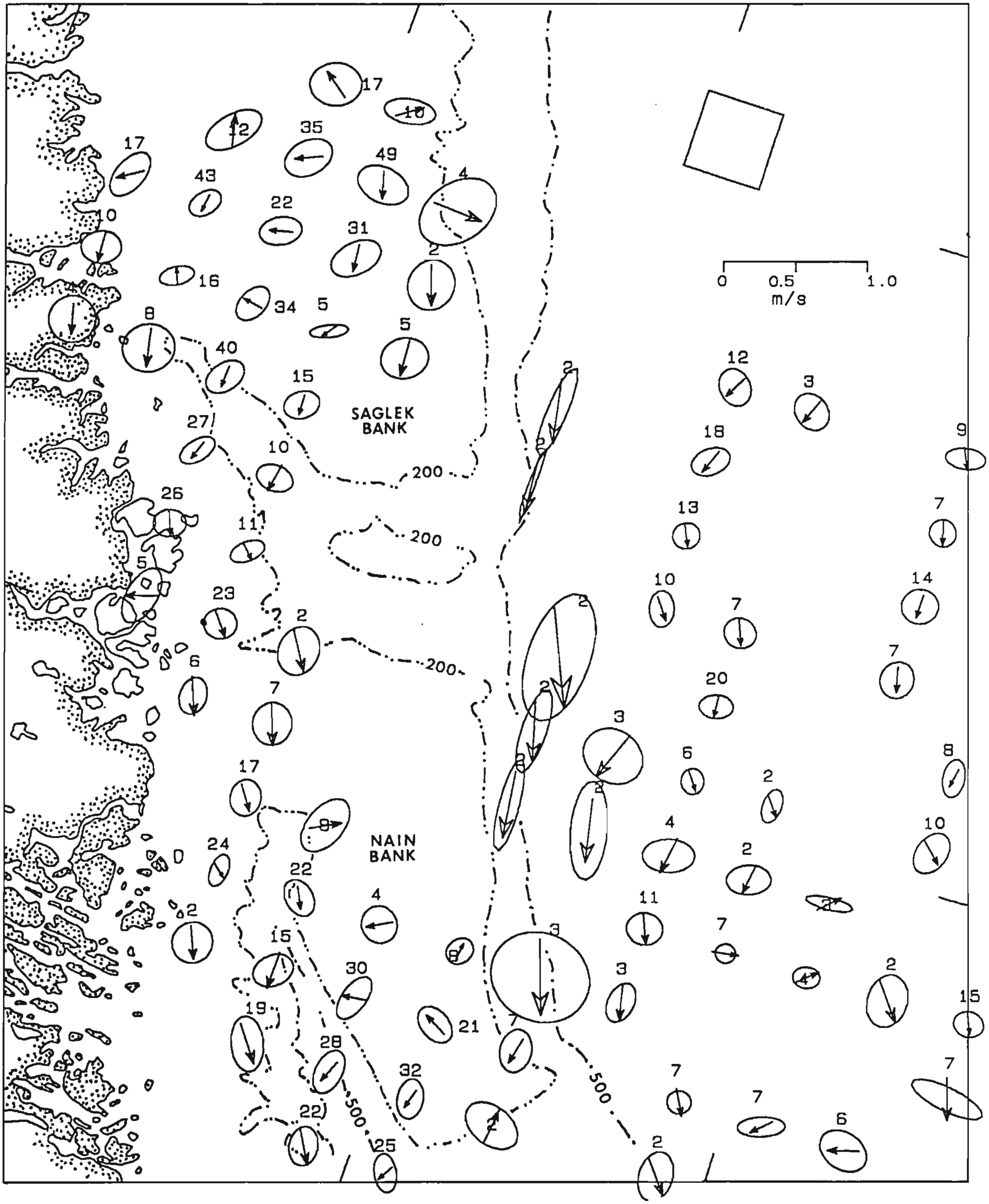

Figure 4: Near-surface currents off Northern Labrador averaged over 25 km grids. The map scale is 1:2,000,000. See the caption of figure 3 for more details.

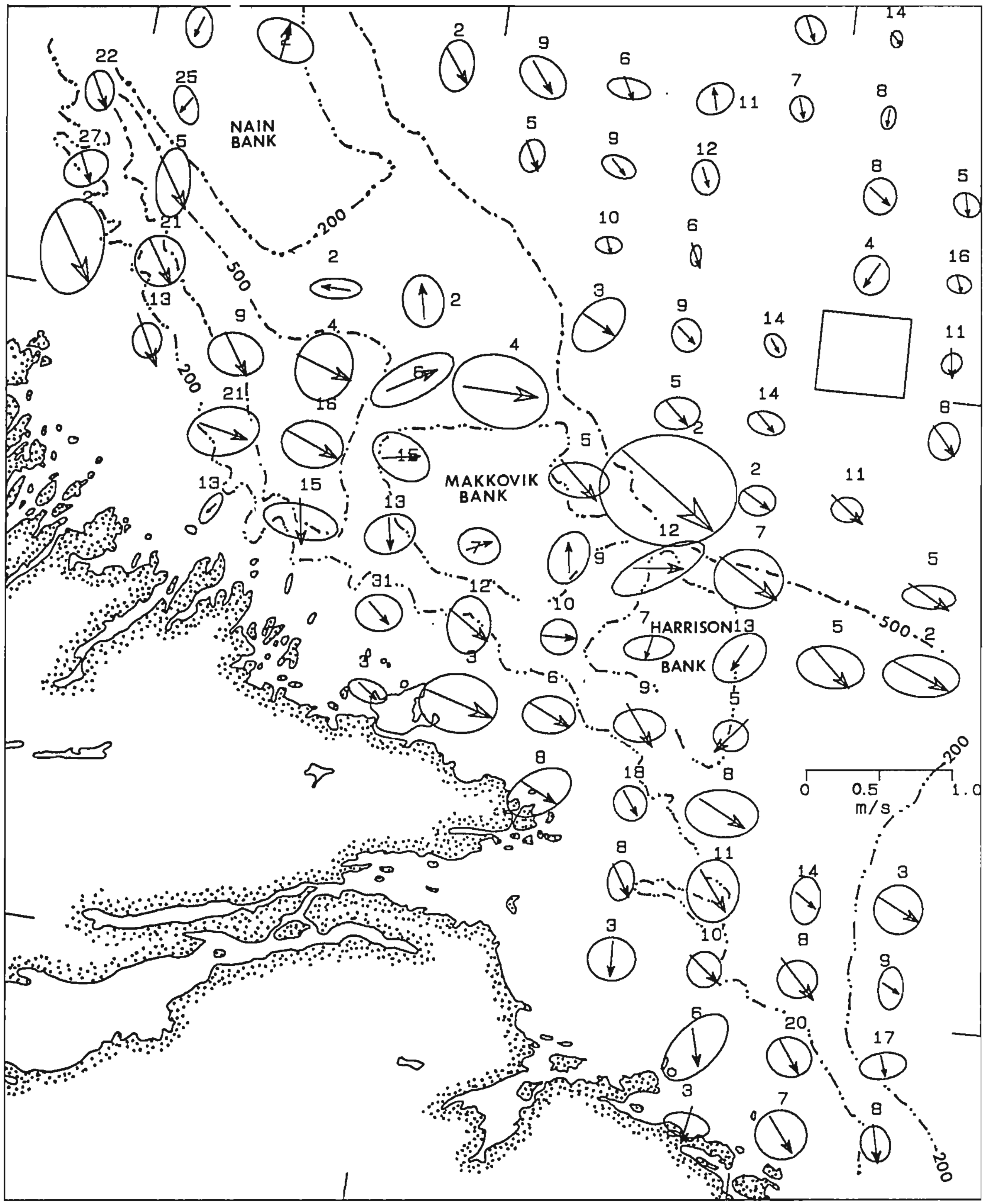

Figure 5: Near-surface currents off Central Labrador averaged over 25 km grids. The map scale is 1:2,000,000. See the caption of figure 3 for more details.

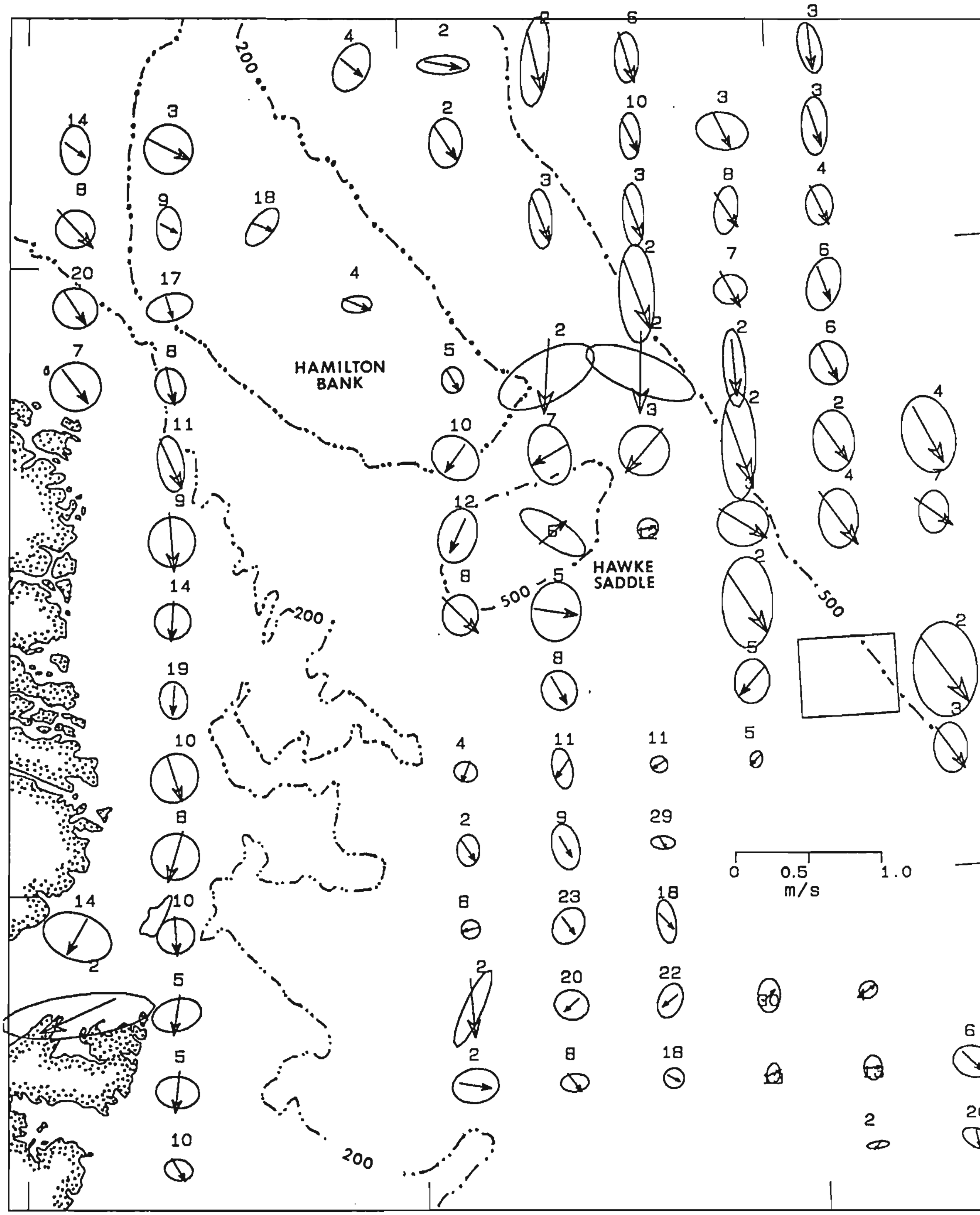

Figure 6: Near-surface currents off Southern Labrador averaged over 25 km grids. Scale is 1:2,000,000. See the caption of figure 3 for more details.

area of directionally unsteady flows centred over the various banks between the trough and slope (Buckley et al., 1981; Fissel and Lemon, 1990).

Exchanges between the two branches of the Labrador Current often occur through the saddles which separate the individual banks located over the middle portion of the shelf. Evidence of cross-shelf near-surface flows was obtained from the track of drifter 4070 in 1981, which exited the inner marginal trough in mid-November along the southern side of Hopedale Saddle and then returned on the inner trough current in late November by way of the northern side of Cartwright Saddle (Figure 7). Further evidence of cross-shelf exchanges through saddles is found in the 1982 drifter results. Drifter 4079 was observed to leave the marginal trough through Hopedale Saddle (October 17-15) and then to re-enter the marginal trough region through Hawke Saddle (November 10-16). Two other drifters also turned shoreward from the outer branch of the Labrador Current through Hawke Saddle (Figure 7). Drifter 4078 followed the bathymetry into and then out of Hawke Saddle rejoining the offshore branch of the Labrador Current. Drifter 4079 also used Hawke Saddle to travel from the offshore side of Hamilton Bank into the southern end of the marginal trough.

There are also occasions in which drifter tracks passed over banks in moving from one current branch to another (Figure 8). In the first of these, drifter 4074 travelled from the offshore branch to the inshore branch of the Labrador Current by way of Nain Bank (August 13-September 2). [This same pattern has been observed in the track of an iceberg in the spring of 1981 (Birch et al., 1982) and in a few observations of icebergs from a drill site on central Nain Bank (Marex, 1976).] Later, from November 17-30, drifter 4080 passed along the central axis of Hamilton Bank from Cartwright Saddle to the offshore branch of the Labrador Current. However, for both of these events, the net velocities were small, the motion having occurred over an extended period of time in comparison to drifters which moved through the saddles from one bathymetric regime to another. Therefore, these over-bank motions probably are not as important as exchanges through the saddles (described above) to the overall exchange between the two branches of the Labrador Current.

In 1982, the net motion experienced by drifters in the marginal trough and the outer portion of the offshore branch of the Labrador Current appeared to be approximately equal (Figure 9). This was based on the motions of two drifters released simultaneously in the vicinity of Saglek Bank. A drifter was released in each current branch and traversed roughly the same length of the Labrador coastline over a one month period. The magnitudes of the vector averaged velocity (or net velocity) within this period were 22.7 cm/s (trough) and 21.8 cm/s (slope). Note, however, that the offshore drifter was located in the outer portion of the offshore branch of the Labrador Current. Had this drifter been located in the intense but narrow portion of the Current located just beyond the shelf break, the drift speed would have been considerably larger, as discussed below.

Given the tendency for near-surface exchanges to occur through saddles as noted above, and the concentration of the two cores of the Labrador Current over steeply sloping bottom, topographic steering of near-surface currents appears to be important. Peterson and Symonds (1988) noted similar cross-shelf exchange patterns in satellite-tracked ice floe velocities in Hopedale and Hawke Saddles.

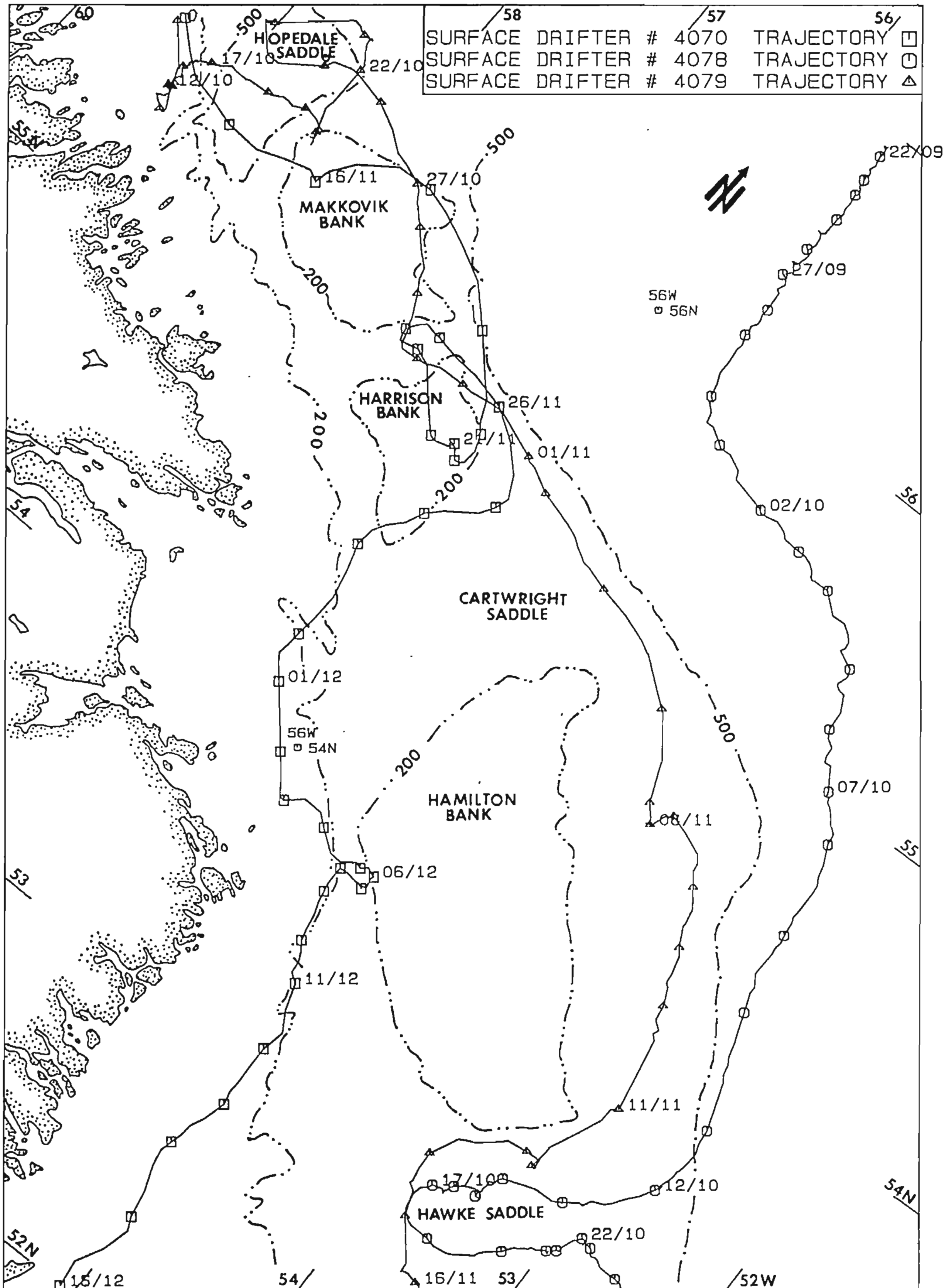

Figure 7: Portions of drifter trajectories indicative of near-surface exchanges between the inner and outer branches of the Labrador Current. (a) Drifter 4070 in 1981; (b) Drifter 4078 and 4079 in 1982.

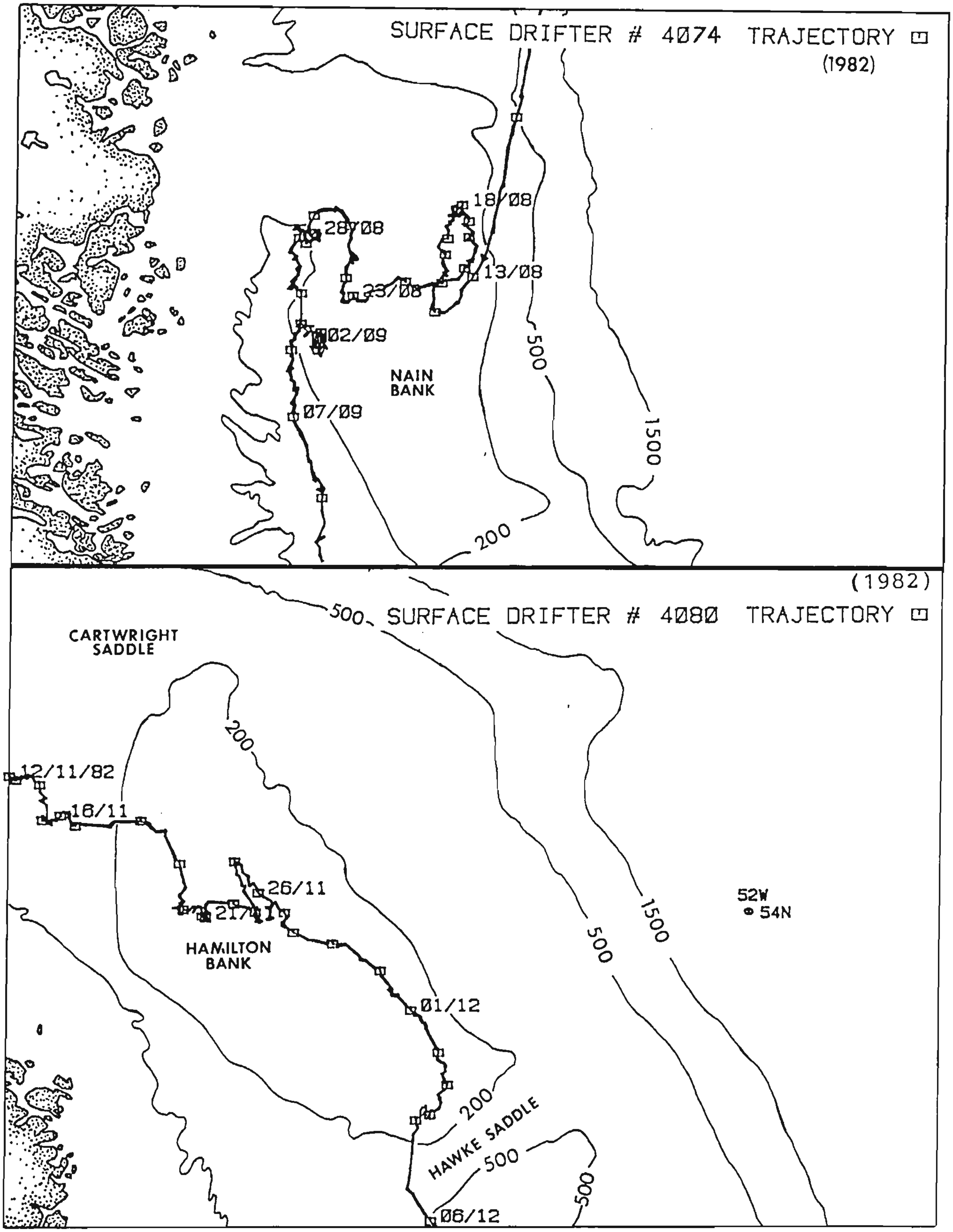

Figure 8: Portions of drifter trajectories which passed over banks in transferring from one branch of the Labrador Current to the other. (a) Drifter 4074 passing over Nain Bank, 1982; (b) Drifter 4080 over Hamilton Bank in 1982.

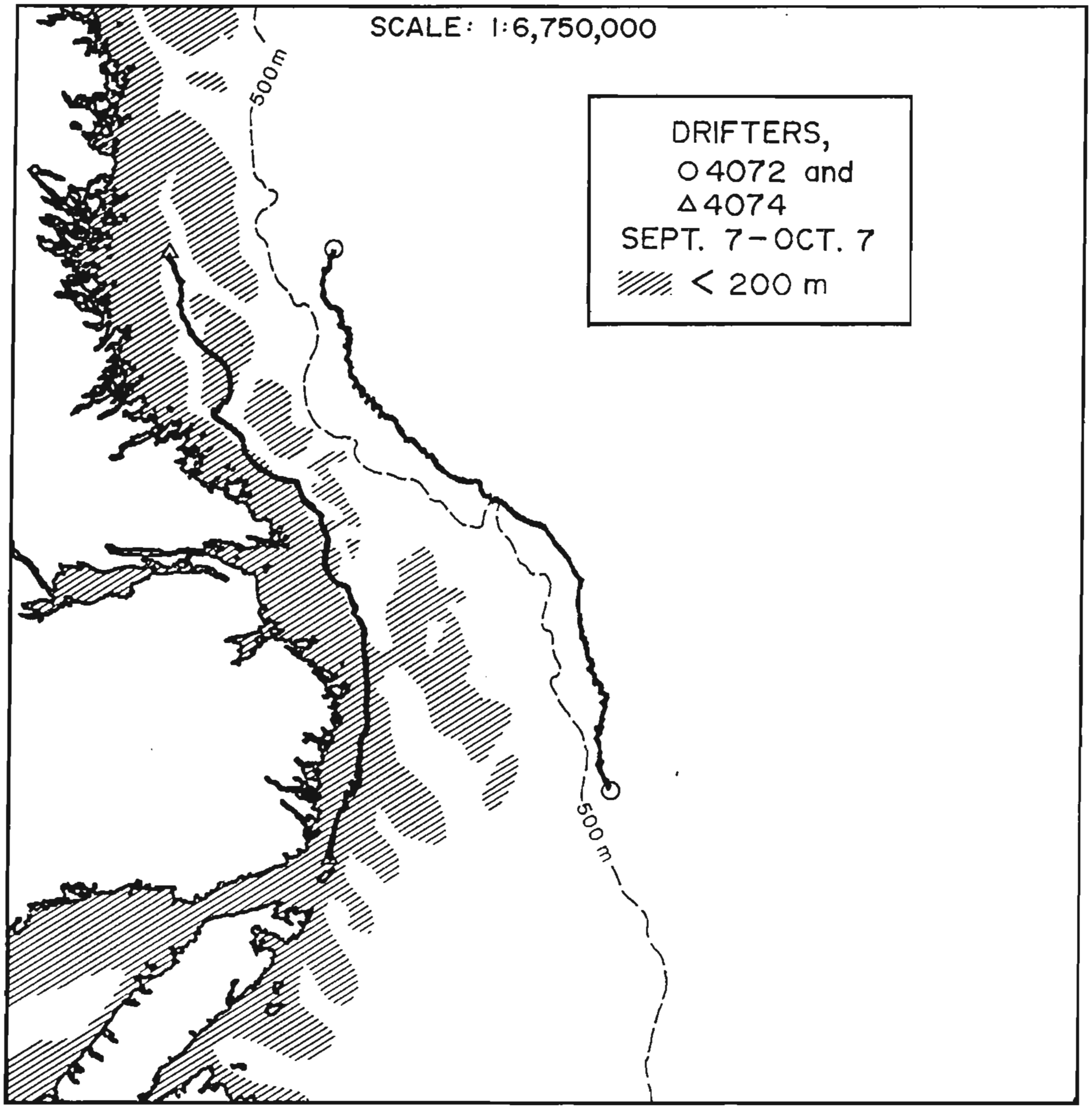

Figure 9: The simultaneous trajectories of drifters 4072 and 4074 for the period September 7- October 7, 1982.

The upstream origin of the inner branch of the Current as a well defined entity is unclear. The motions of drifters 4073 and 4080 in 1982, and 4094 in 1983, indicate that the surface flow becomes stronger and steadier off the southwestern edge of Saglek Bank. This corresponds to the northern edge of the channel separating Saglek from Nain Bank. Although bathymetrically separated from the marginal trough, the data indicate that the inner core of the Current may first become identifiable in this region.

Of the 1981-1983 drifter data, only one trajectory overlay the shelf break region as far north as Saglek Bank (Figure 4). This drifter (4074 in 1982) followed the 500 m bathymetric contour south, then curved shoreward onto Nain Bank. For the northern portion of the Labrador Shelf, the data are insufficient to describe the characteristics of the offshore branch of the Labrador Current. The possible existence of intrusive circulation patterns south of Saglek and Nain banks, as well as the underlying cause of the motion of 4074 onto Nain Bank, must await further measurements.

Labrador Current Velocity Statistics by Bathymetric Regime

Each of the drifter trajectories obtained north of the Strait of Belle Isle (52°N) was divided into individual segments according to the type of bathymetric regime (trough, bank, saddle, continental slope, continental rise and abyssal waters). The choice as to bathymetric regime was made arbitrarily and some segments, where the drifter was oscillating between two regimes, were not used. Velocity statistics were then computed according to type of bathymetric regime. (The steadiness factor, B, is defined as the ratio of the magnitude of the mean velocity magnitude to mean speed. Ramster et al. (1978) suggest that values of B significantly less than 70% are indicative of unsteady flows for which the vector mean is not representative of their true nature).

Table 2 provides statistics of summer near-surface currents during the summer and autumn seasons off Labrador, based on three years of drifter data (1981-1983). The results contained in Table 2 can be summarized as follows:

(1) The inner core of the Labrador Current follows the marginal trough. Speeds here are typically 0.2 to 0.4 m/s with a mean speed of 0.26 m/s over the records of three summers, 1981-1983. The current is relatively steady as indicated by the 80% steadiness (B) factor. The maximum speed travelled by a drifter over a 6-hour interval was 0.85 m/s, although generally peak speeds were in the 0.5-0.6 m/s range.

(2) The offshore branch of the Labrador Current consists of: a strong current core following the continental slope/shelf break, with reduced southeasterly flows over the deeper waters of the continental rise (1,500-3,000 m). In the shelf break/inner slope portion, the mean speed was large at 0.39 m/s and the flows had a high degree of directional steadiness (B=93%). Average current speeds were about 50% greater than over the marginal trough. The amount of data over the continental slope is limited by comparison to other regions, with only 33 days in total compared to 173 over the marginal trough. The lateral shear in the deeper waters of the offshore branch are discussed below.

Table 2: Velocity statistics for segments of six-hourly interpolated drifter velocity data according to bathymetric regime. Note that summary statistics are computed as time-weighted means for velocity magnitude and mean speed and as overall maximum for maximum speed. The steadiness factor B is defined as the ratio of net velocity to mean speed times 100%. (Note: Segments of drifter tracks not used: 4073, Aug.22-23 Grounded at times on coastline at 59°N; 4074, Aug.29-Sept.6 Inner edge on Nain Bank or trough?; 4079, Oct.1-3 Nain Bank or trough?; 4079, Oct.10-20 Trough or inner portion of Hopedale Saddle; 4080, Nov.12-17 Trough or inner portion of Cartwright Saddle.)

Drifter	Period	# of Days	Net Vel Mag. (Vec Avg)	Speed Mean	Speed Max	B %
			(m/s)			
a) Marginal Trough (*inner trough <200 m)						
4070*	Oct.25-Nov.10,1981	16	0.183	0.214	0.789	86
4070	Nov.10-15,1981	5	0.306	0.330	0.605	93
4070	Nov.29-Dec.12,1981	13	0.183	0.243	0.598	75
4071	Oct.30-Nov.15,1981	16	0.327	0.379	0.815	86
4073	Aug.24-27,1982	3	0.362	0.374	0.563	97
4074	Sep.7-21,1982	14	0.222	0.255	0.457	87
4074	Sep.22-Oct.7,1982	15	0.243	0.269	0.765	90
4079	Oct.5-9,1982	4	0.395	0.403	0.620	98
4080	Oct.3-19,1982	16	0.133	0.174	0.429	76
4080*	Oct.20-Nov.11,1982	22	0.184	0.262	0.852	70
4094*	Oct.12-Nov.3,1983	22	0.116	0.174	0.415	67
4094	Nov.3-11,1983	8	0.315	0.351	0.713	90
4094*	Nov.11-30,1983	19	0.158	0.262	0.620	60
	Mean	173	0.206	0.25	0.850	80
b) Banks						
4070	Oct.9-25,1981	16	0.041	0.133	0.424	31
4078	Sep.30-Oct.6,1982	6	0.264	0.295	0.444	89
4071	Oct.9-27,1981	18	0.033	0.152	0.372	22
4073	Aug.9-20,1982	11	0.028	0.194	0.437	15
4074	Aug.13-28,1982	15	0.048	0.170	0.707	28
4075	Aug.7-22,1982	15	0.056	0.195	0.610	29
4078	Oct.26-Nov.11,1982	16	0.075	0.119	0.422	63
4080	Sep.13-Oct.3,1982	20	0.082	0.174	0.390	47
4080	Nov.18-Dec.5,1982	17	0.104	0.174	0.428	60
4094	Aug.12-Oct.12,1983	61	0.021	0.204	0.534	10
	Mean	195	0.048	0.177	0.707	27

Drifter	Period	# of Days	Net Vel Mag. (Vec Avg)	Speed Mean	Speed Max	B %
			(m/s)			
c) Saddle						
4070	Nov.27-29,1981	2	0.314	0.326	0.396	96
4078	Oct.12-23,1982	11	0.045	0.213	0.437	21
4079	Oct.21-25,1982	4	0.084	0.312	0.482	27
4079	Nov.12-15,1982	3	0.251	0.330	0.530	76
	Mean	20	0.111	0.262	0.530	42
d) Continental Slope (Depth: 300-1,500 m)						
4072	Oct.5-11,1982	6	0.402	0.412	0.594	98
4074	Aug.7-12,1982	5	0.508	0.520	0.723	98
4078	Oct.6-12,1982	6	0.387	0.400	0.635	96
4079	Oct.26-Nov.11,1982	16	0.294	0.334	0.557	88
	Mean	33	0.363	0.388	0.723	93
e) Continental Rise (Depth: 1,500-3,000 m)						
4072	Aug.7-22,1982	15	0.103	0.179	0.349	57
4072	Aug.23-Sep.6,1982	14	0.112	0.256	0.578	44
4072	Sep.7-Oct.4,1982	27	0.205	0.247	0.542	83
4078	Sep.9-29,1982	20	0.123	0.136	0.334	90
4070	Nov.19-25,1981	6	0.070	0.197	0.538	35
4071	Aug.12-Oct.12,1983	61	0.156	0.222	0.626	70
4091	Aug.12-Oct.17,1983	66	0.137	0.210	0.736	65
	Mean	209	0.150	0.215	0.736	70
f) Abyssal Waters (Depth: >3,000 m)						
4077	Sep.12-Dec.31,1982	109	0.007	0.124	0.404	6
4093	Aug.10-Nov.29,1983	111	0.031	0.223	1.100	14
	Mean	220	0.019	0.174	1.100	11

(3) Current velocities over the banks are variable in direction, resulting in low net vector-averaged velocities. Speeds are typically about 0.2 m/s, but can reach 0.6-0.7 cm/s, over six-hour averaging periods.

(4) Relatively little data are available for the saddle regions. Mean speeds were comparable to those in the marginal trough, about 0.26 m/s. The steadiness factors are less due to the intrusive character of the current in these areas.

(5) Offshore of the Labrador Current, in the abyssal zone, net velocities are low due to the directional variability. Mean speeds averaged 0.17 m/s. However, high velocities were exhibited by both drifter 4072 during December 1982, and 4093 during November-December 1983 in a region roughly 300-400 km north of Flemish Cap. The high velocities observed in this offshore region may reflect the influence of the North Atlantic Current.

A comparison (Figure 10) was made of the drifter results and the subsurface current measurements (from depths of 52 to 102 m) based on the 1980 current meter data (Fissel and Lemon, 1990). The current meter velocity statistics were derived from 10-minute samples while the drifter velocity statistics are based on 6-hourly interpolated values. As a result, the mean speeds and, in particular, the maximum speeds will tend to be underestimated in the drifter velocities as compared to the current meter velocities. The near-surface currents are generally larger than those at greater depths (Figure 10). Over the trough and slope regimes, the near-surface currents are larger by approximately a factor of two. The increases are somewhat less for currents over the banks, particularly for net velocities. Given the very limited amount of saddle data for both drifters (20 days) and current meters (one location only), the comparisons are of questionable significance. Steadiness factors agree to within 30% or better within the same bathymetric regimes, reflecting the same high degree of directional variability over banks and saddles, and much reduced variability over the trough and slope.

Lateral Shear in the Offshore Branch of the Labrador Current

The drifter data were used to examine lateral shear in the offshore branch of the Labrador Current at near-surface levels. Previous studies (e.g. Smith, Soule and Mosby, 1937) using indirect geostrophic methods have shown that the core of the offshore branch of the Labrador Current is centred over the outermost portion of the continental shelf and the continental slope, associated with depths ranging from 300 m to perhaps 1,500 m.

Four drifters in 1982 (4072, 4074, 4078 and 4079) and two in 1983 (4071, 4091) travelled persistently to the southeast in the offshore branch of the Labrador Current. Based on data of portions of these six drifters, when located offshore of the banks and north of 52°N, the net velocity over two-day intervals were plotted as a function of water depth (Figure 11). The results show that the core of the current (near-surface speeds of 0.25 to 0.54 m/s) occurs over depths ranging from 300 m to as deep as 1,700 m. From 1,700 to 3,000 m over the less steeply sloping continental rise, average net velocities are reduced from 0.25 to 0.12 m/s, although there is substantial scatter in the data. These results agree well with the earlier results based on geostrophic methods, and indicate the current core location to be in the 300 to 1,700 m depth range.

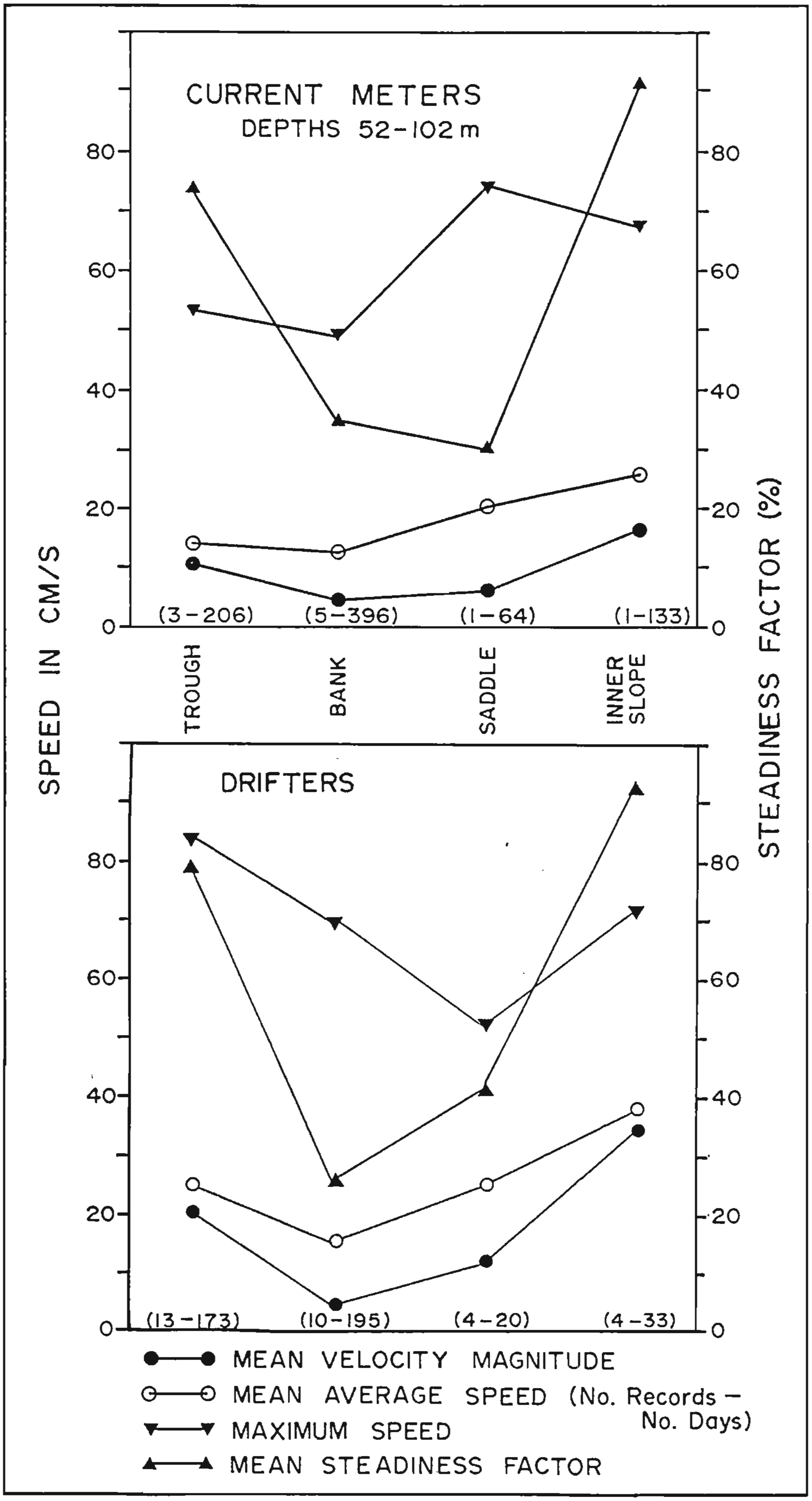

Figure 10: Summary statistics by bathymetric regime as computed from the 1981 to 1983 drifter results (this study) and the 1980 subsurface current meter results (Fissel and Lemon, 1990).

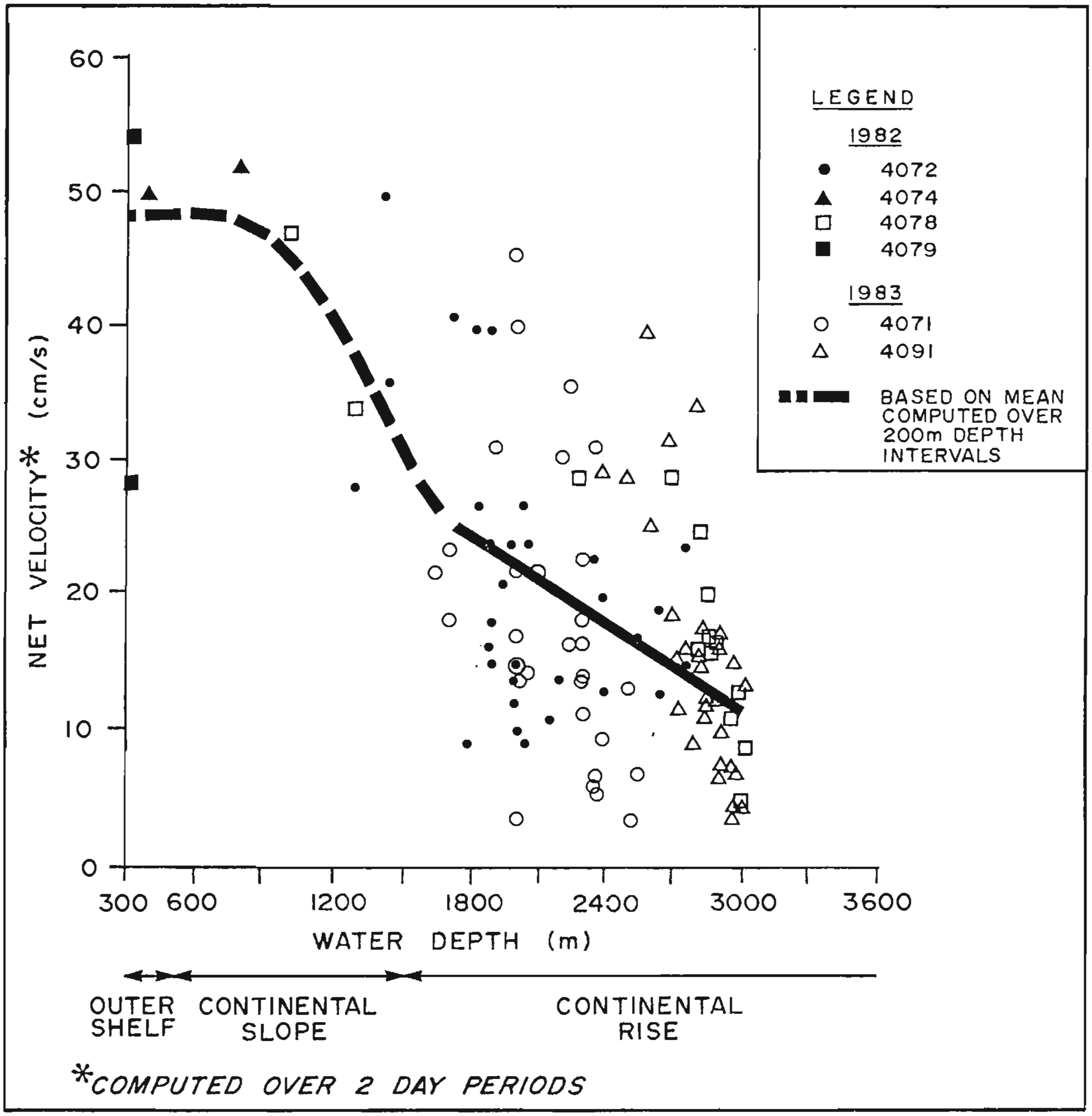

Figure 11: The net-velocity magnitude, computed over two-day record segments, of drifters travelling over the continental slope and rise and the outer edge of the continental shelf; 1982 and 1983.

Most of the data points in the 1,800 to 2,800 m depth range, having higher speeds of 0.3 to 0.45 m/s, were measured over the more steeply sloping region off Cartwright Saddle and northern Hamilton Bank. In this region, the width of the continental slope and rise decreases markedly. The separation between the 300 and 3,000 m bathymetric contours decreases from 170 km, off Nain Bank, to 90 km off Cartwright Saddle. Drifters 4072, 4079 (in 1982), 4071 and 4091 (in 1983) all accelerated as they moved south through this area. For example, 4071 increased speed from about 0.1-0.2 m/s to 0.45 m/s (2 day averages) and 4091 from 0.15-0.2 to 0.35-0.4 m/s. In this region off Cartwright Saddle, current speeds appear to increase over the entire shelf break/continental slope - continental rise cross section. A representative mean speed curve for this portion of the outer shelf/slope region would be about 0.1 m/s above the curve plotted in Figure 11.

The results presented above point to a correlation between surface current speeds and bottom slope in the outer branch of the Labrador Current. This correlation appears to hold, both laterally across the width of the Current and along-stream, where acceleration in the currents along a particular isobath coincides with increased bottom slope, as was the case off Cartwright Saddle. Further investigation is required to quantify the apparent relationship and to determine the time and spatial scales of the response of the current to changes in bottom slope.

4. SUMMARY

Preliminary results from 14 drogued drifters released during the autumn of 1981 and the summers of 1982 and 1983 are presented in this report.

The combined 1981-1983 data in the form of average near-surface current maps, results in the most complete maps of directly measured near-surface circulation available for this area (Figures 3-6). The two branches of the Labrador Current are clearly evident, separated by weaker and directionally variable flow over the banks. Mean near-surface current speeds (over six hours) in the inner and outer branches of the Labrador Current are typically 0.26 and 0.39 m/s respectively, suggesting the offshore branch of the current is faster. Currents in the saddle regions are moderately strong, averaging 0.26 m/s, and intrusive in character. Currents are generally weaker offshore of the Labrador Current; however in late fall of both 1982 and 1983, the drifters moved at speeds on the order of 0.75 m/s in the region about 550 km northeast of Newfoundland.

The outer branch of the Labrador Current can be divided into: (1) an intense (0.4 m/s) but narrow (<20-40 km) core current trapped over the steeply sloping shelf edge and inner continental slope area and (2) an outer portion of weaker current speeds (0.2 m/s) found further offshore over the reduced slopes of the continental rise. The apparent correlation between near-surface current speed and bottom slope for the offshore branch of the Labrador Current may also exist along the length of the Current as illustrated by the current speeds and bottom slope exhibiting concurrent increases off Cartwright Saddle.

5. REFERENCES

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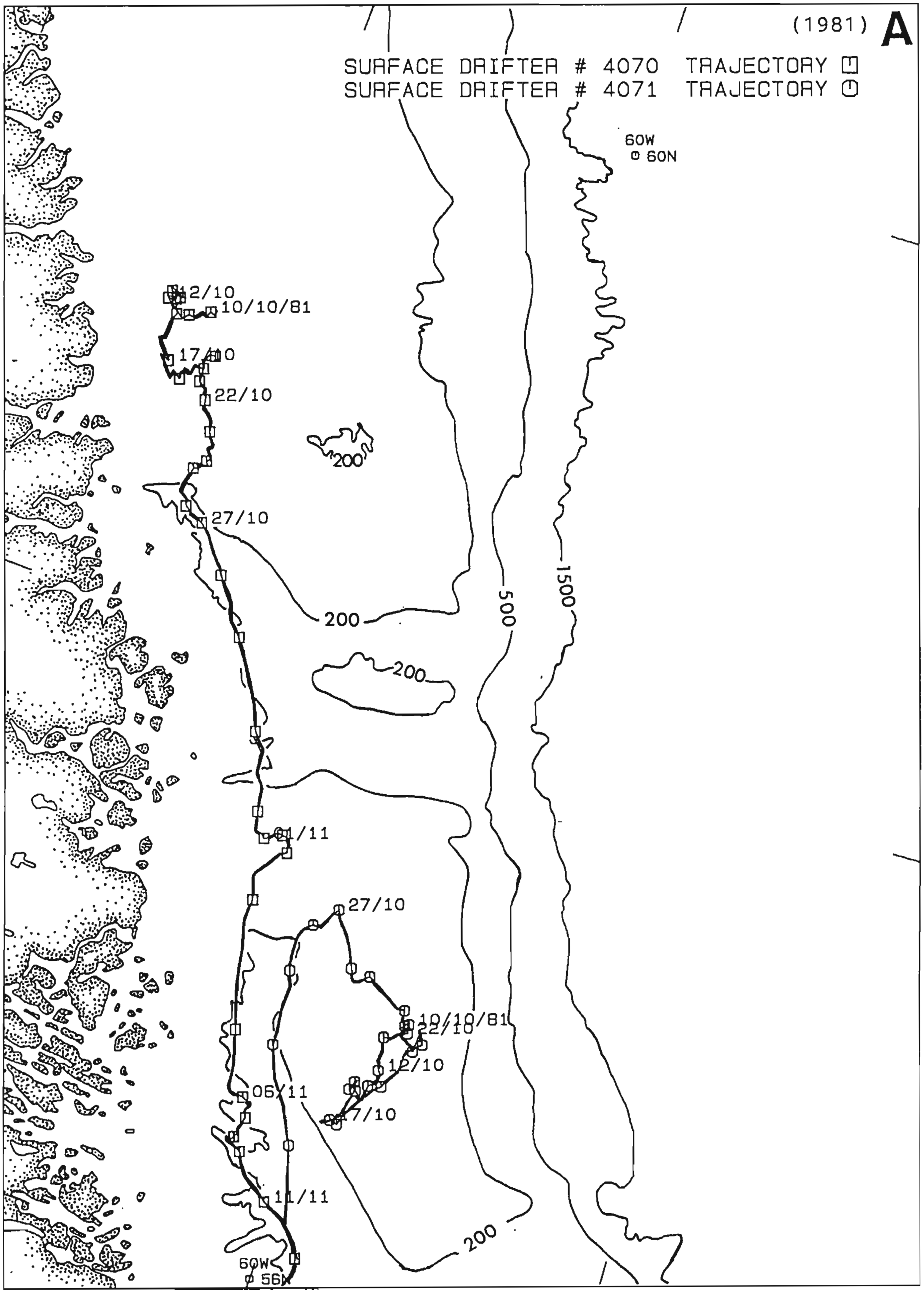
APPENDIX 1

DETAILED TRACK PLOTS

The first map indicates the areal coverage of the various base maps. The base map used for each track plot is identified by the letter in the upper right hand corner. All maps are 1:2,000,000 scale, Lambert Conformal projection. Bathymetric contours have been included in order to outline the bank regions and the continental slope.


GREENLAND
LABRADOR
NEWFOUNDLAND
A
B
C
D
E
F
G
H
I
60 N
56 N
52 N
48 N
56 W
52 W
48 W
44 W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A
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SURFACE DRIFTER # 4071 TRAJECTORY
60W
60N
12/10
10/10/81
17/10
22/10
200
27/10
200
500
1500
200
01/11
27/10
10/10/81
22/10
12/10
06/11
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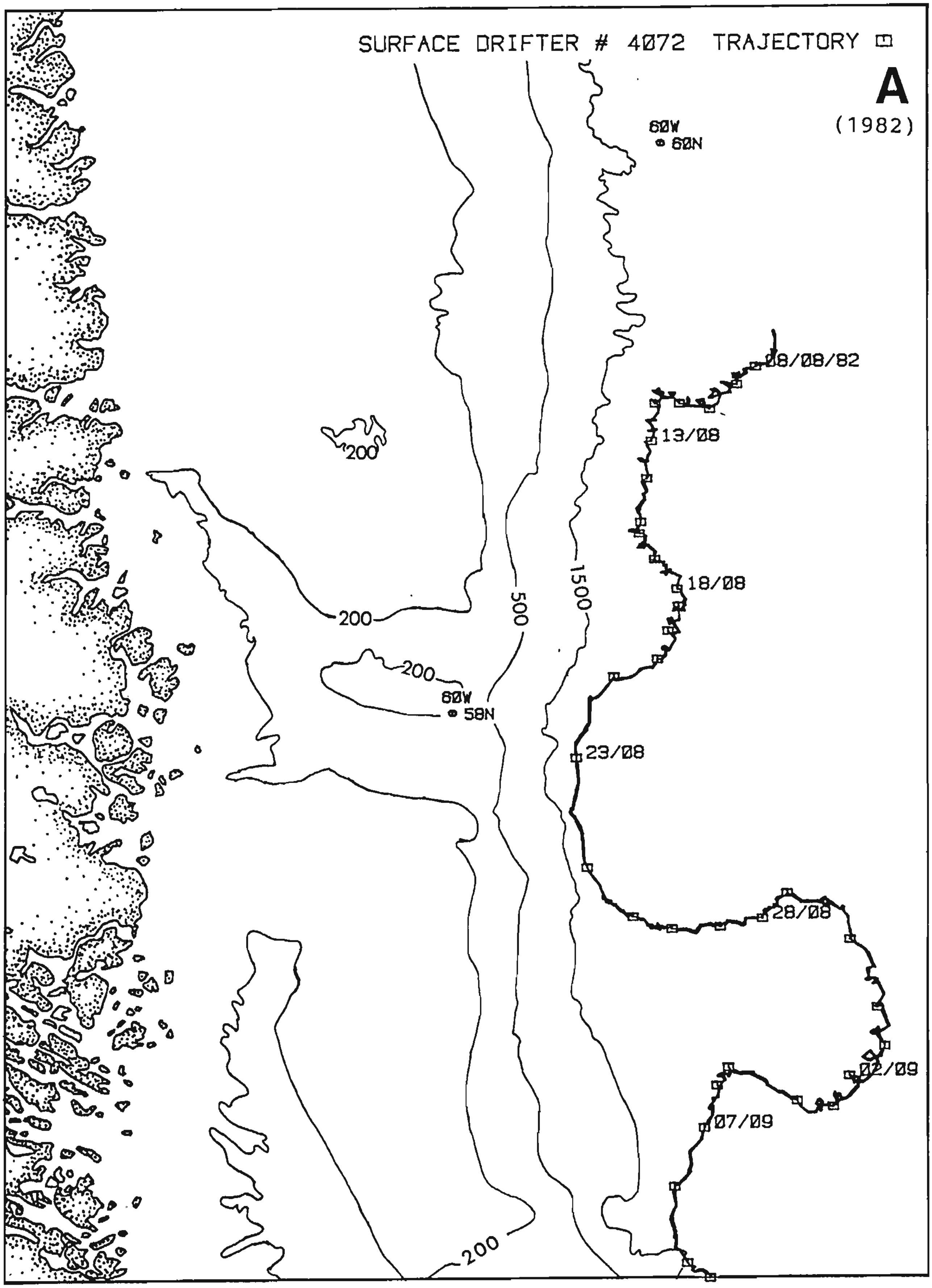
11/11
200
60W
56N



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60N
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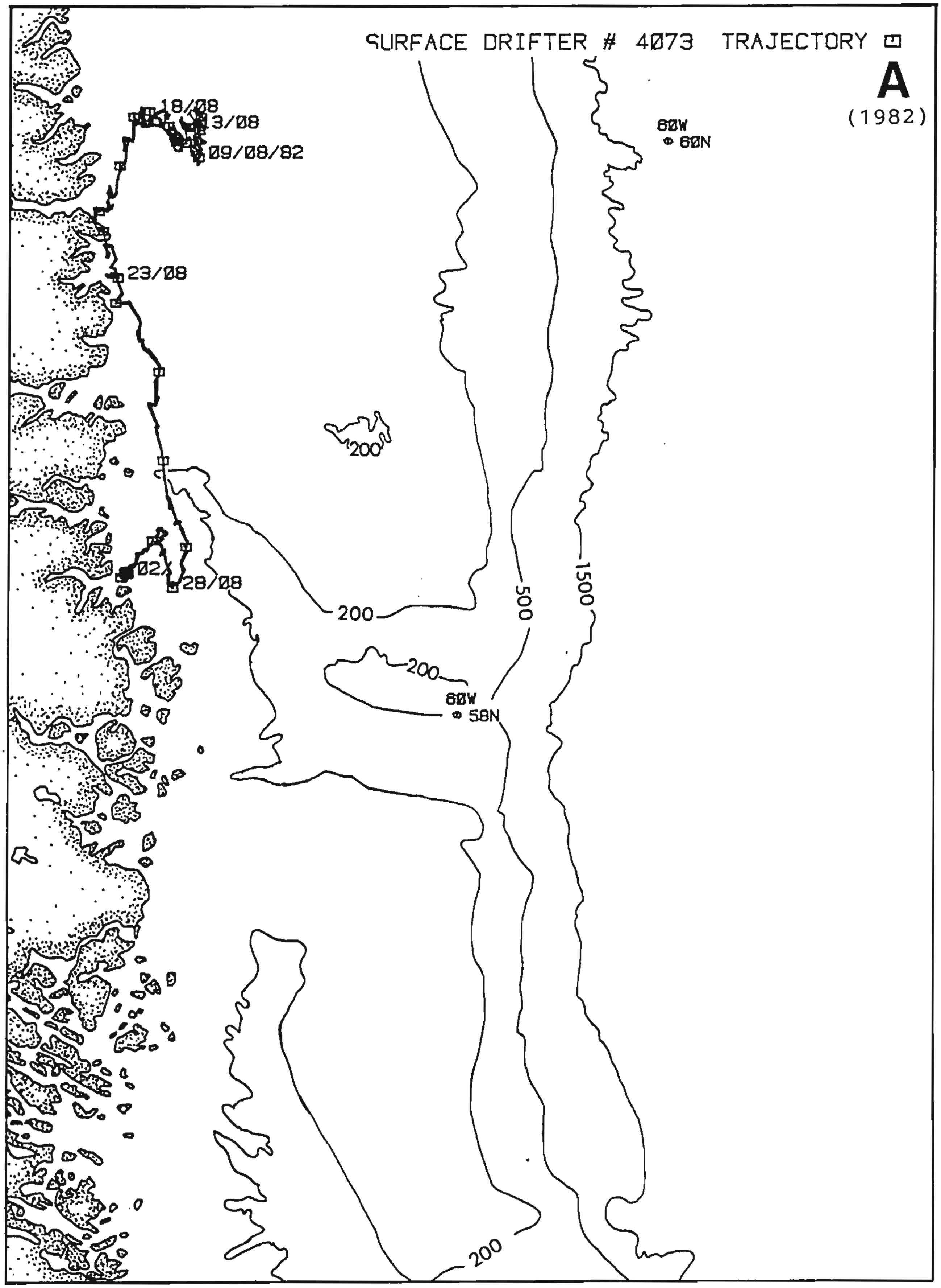
23/08
28/08
02/09
07/09
200
200
200
200
500
1500
60W
58N



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18/08
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09/08/82
23/08
02
28/08
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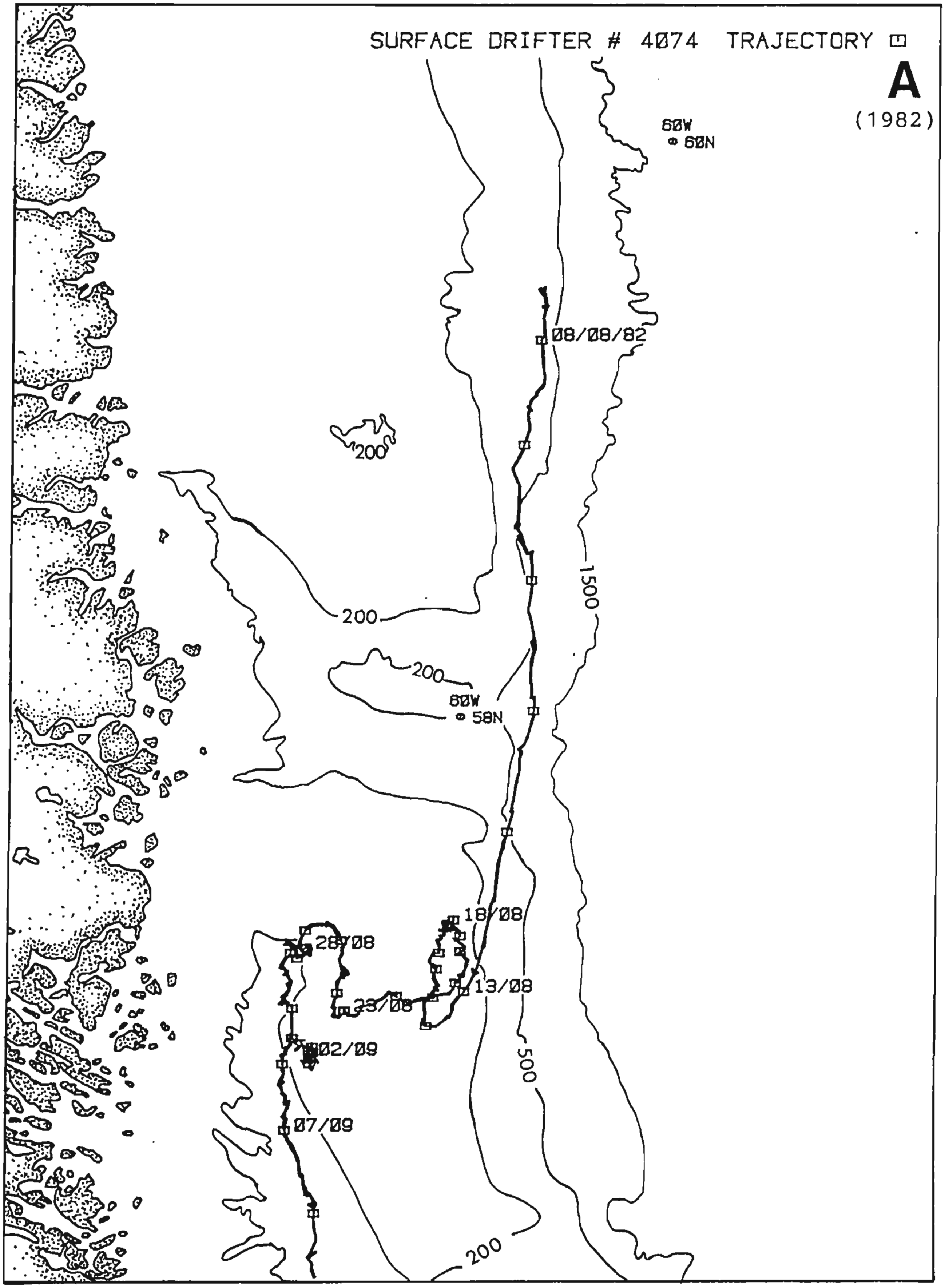
200
200
200
500
1500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200
200
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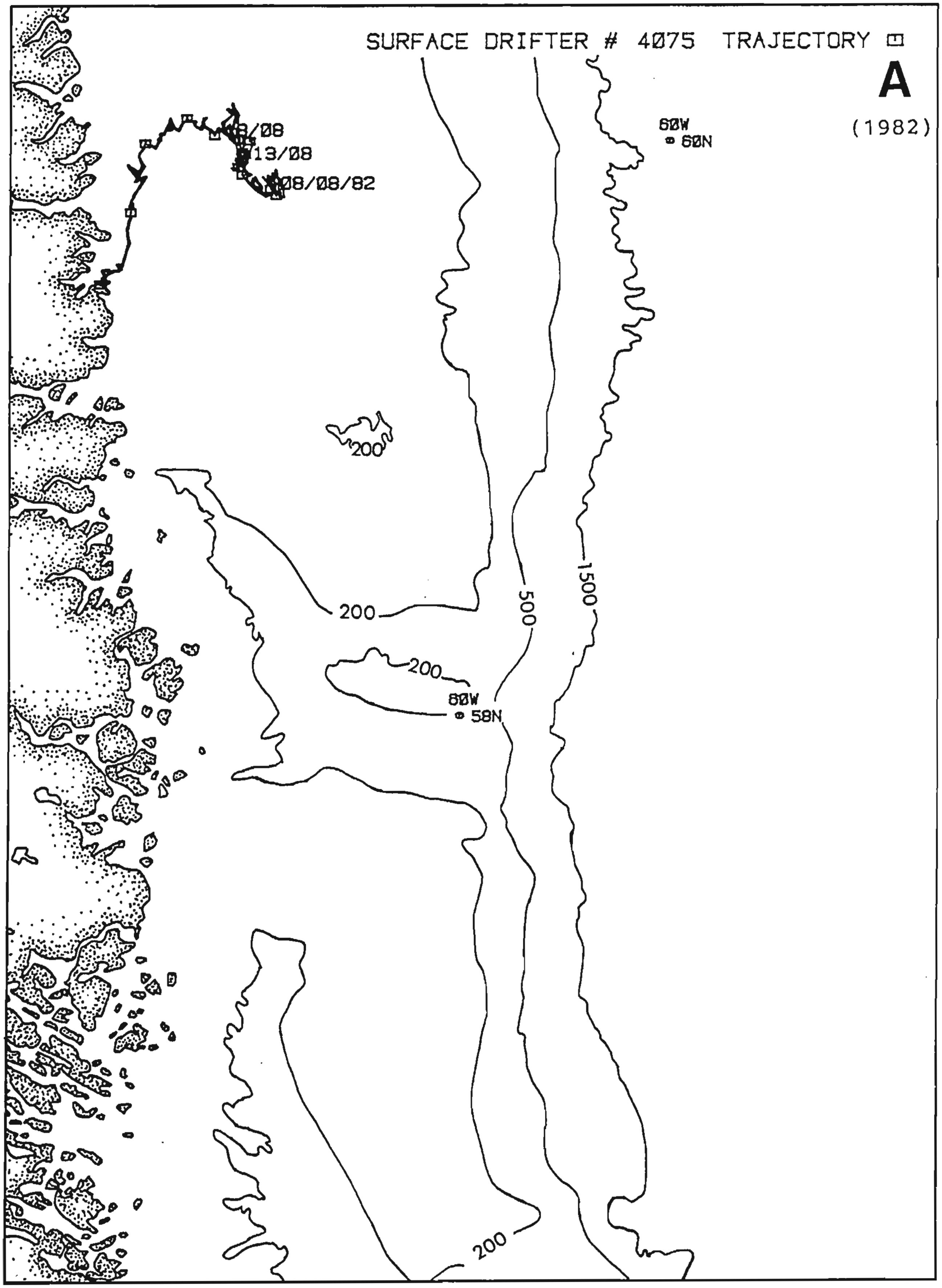
13/08
23/08
02/09
500
07/09
200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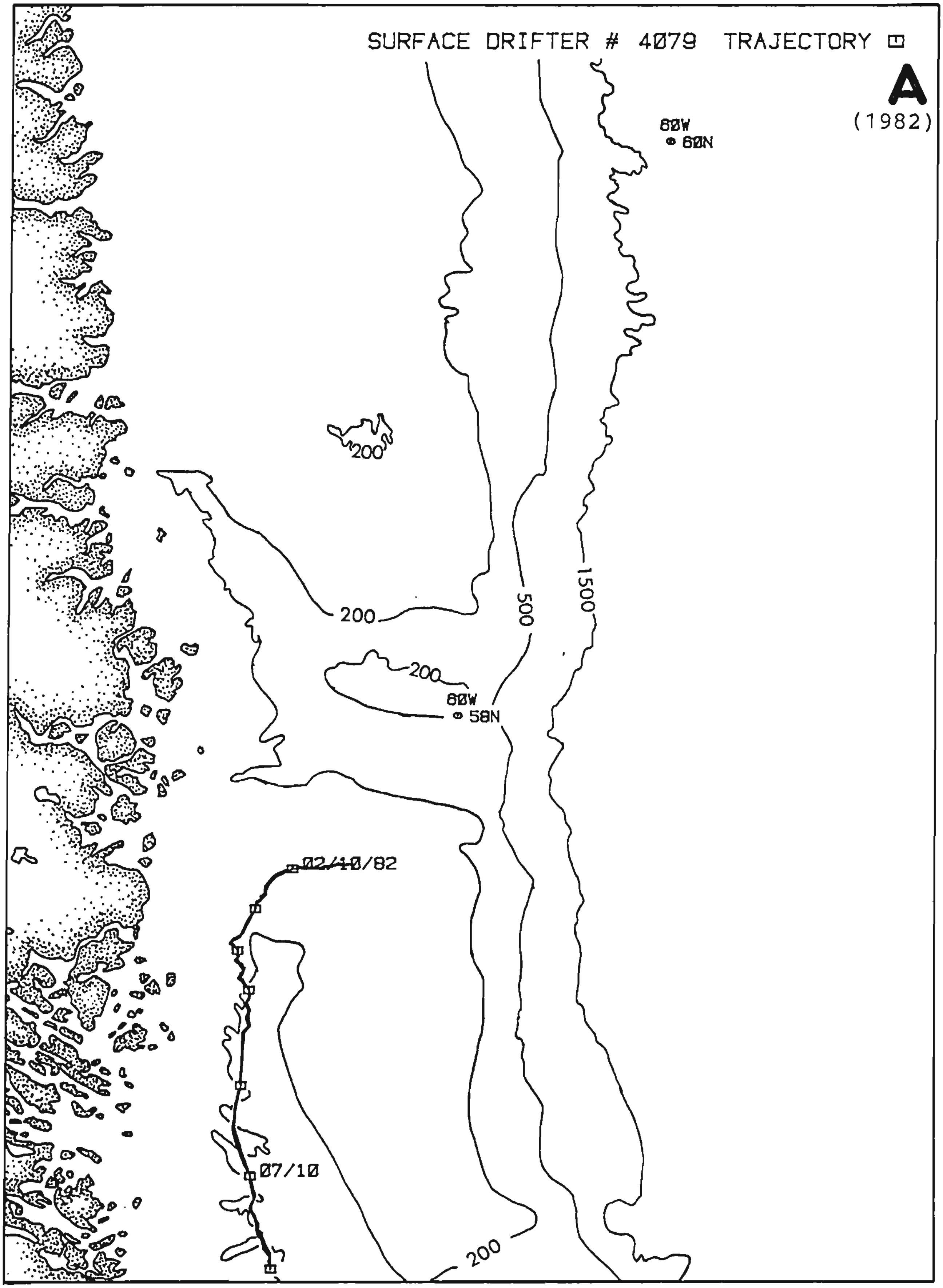
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200
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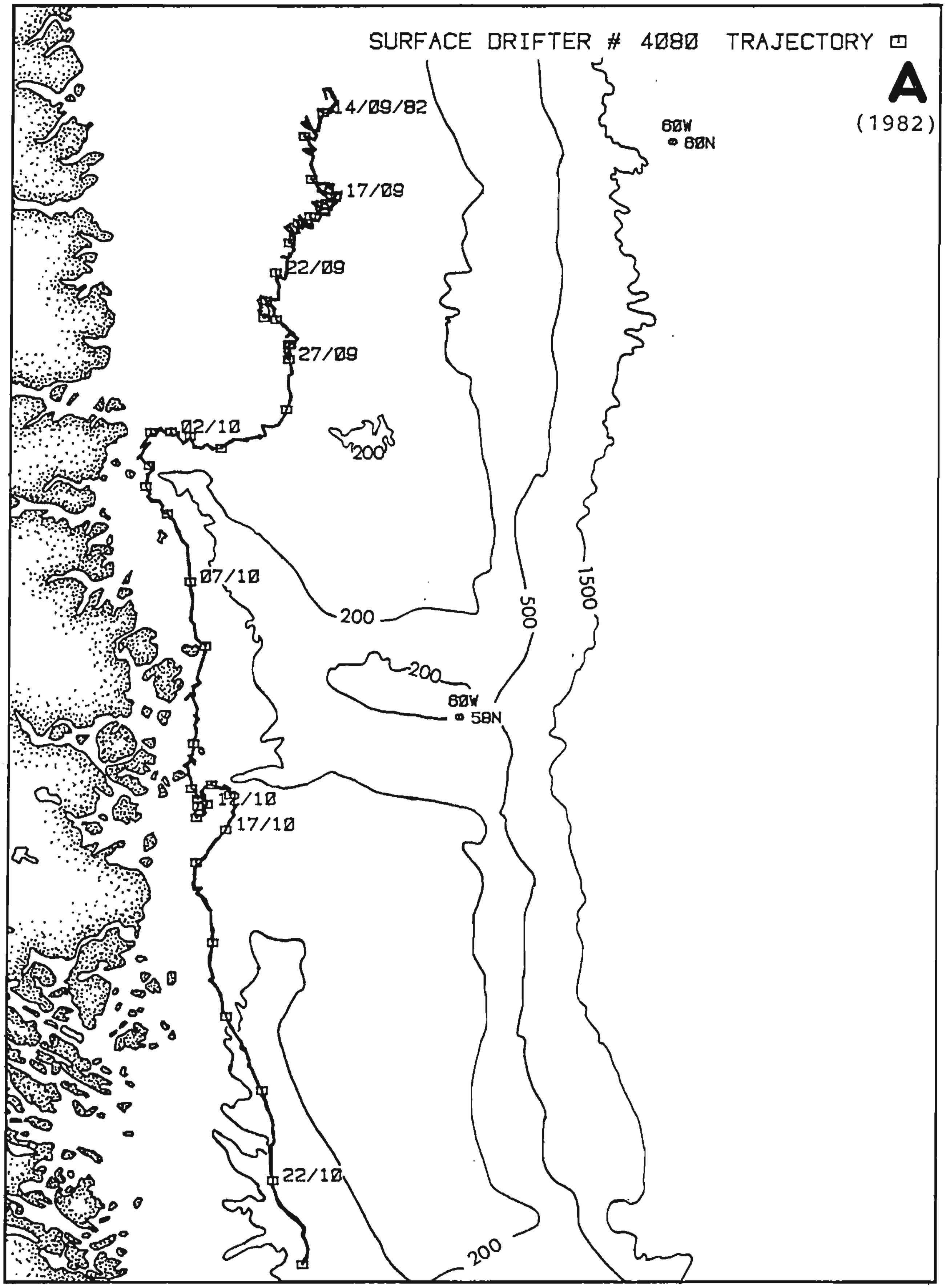
02/10/82
07/10
200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27/09
02/10
07/10
12/10
17/10
22/10
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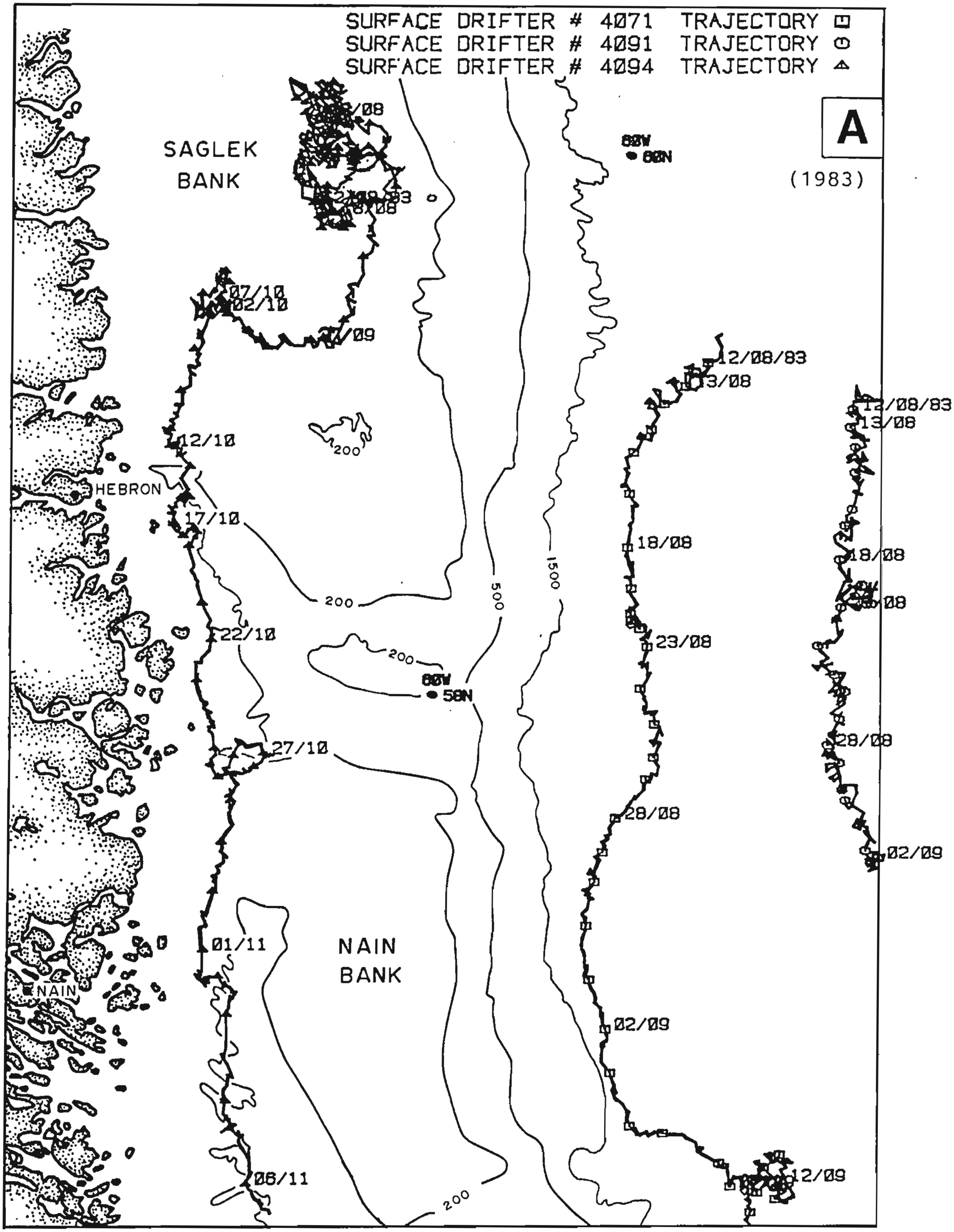
60N
60W
58N
200
200
200
200
500
1500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SURFACE DRIFTER # 4091 TRAJECTORY
SURFACE DRIFTER # 4094 TRAJECTORY
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NAIN BANK
HEBRON
NAIN
60W
60N
60W
58N
200
500
1500
07/10
02/10
27/09
12/10
17/10
22/10
27/10
01/11
06/11
12/08/83
13/08
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02/09
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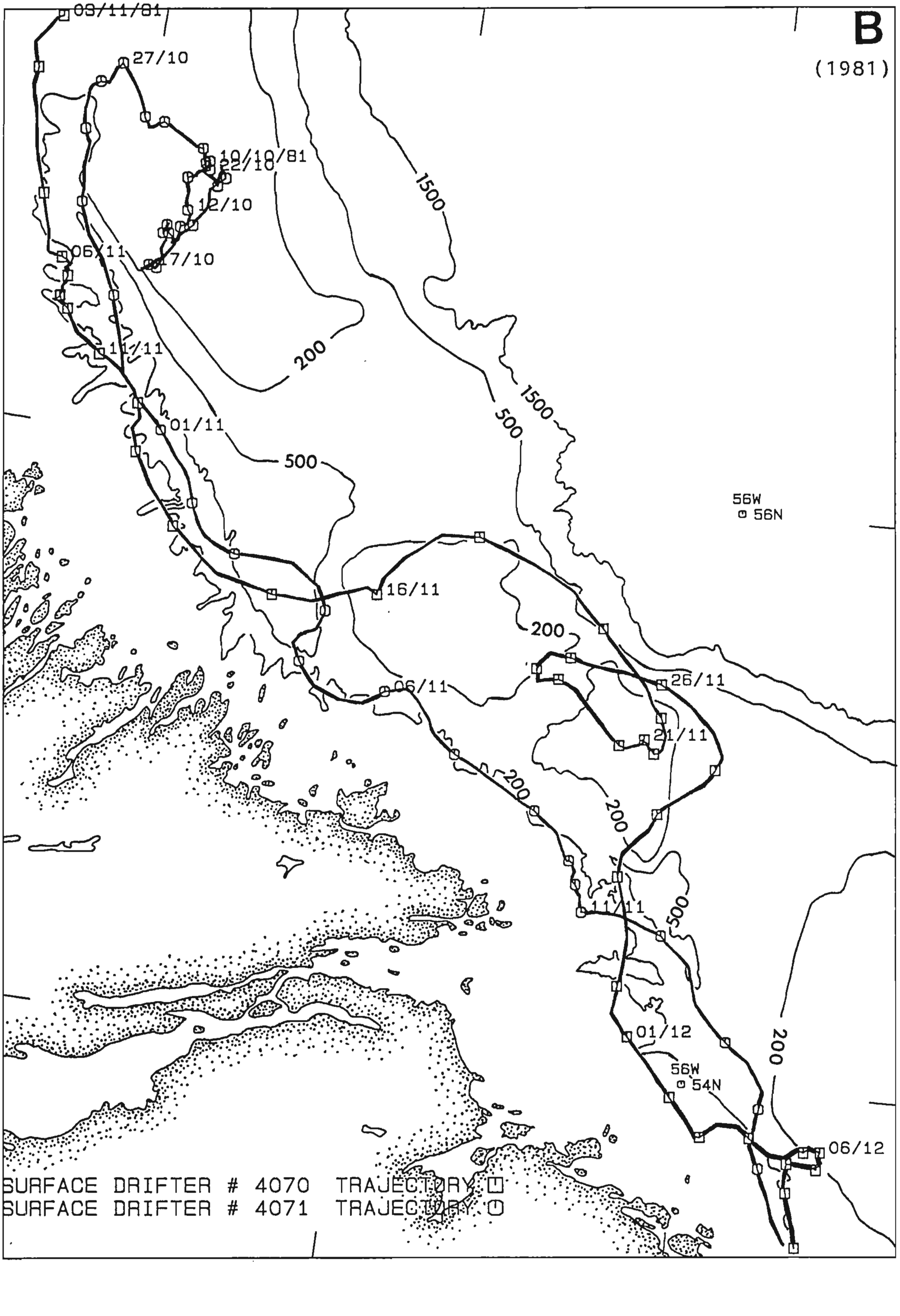
13/08
18/08
28/08
02/09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21/11
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06/12
1500
1500
500
500
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56W
54N
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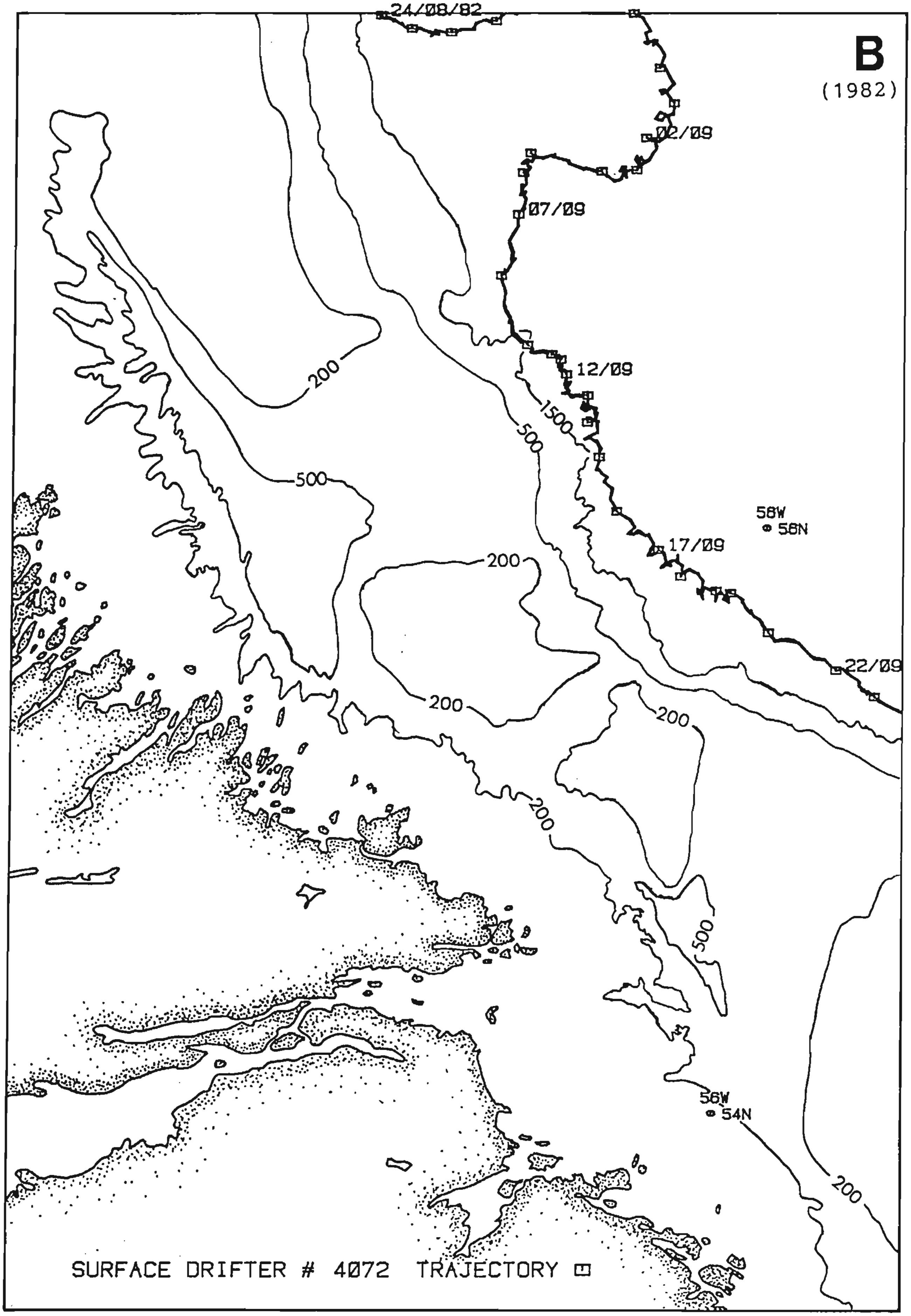
SURFACE DRIFTER # 4071 TRAJECTORY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22/09
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1500
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56W
54N
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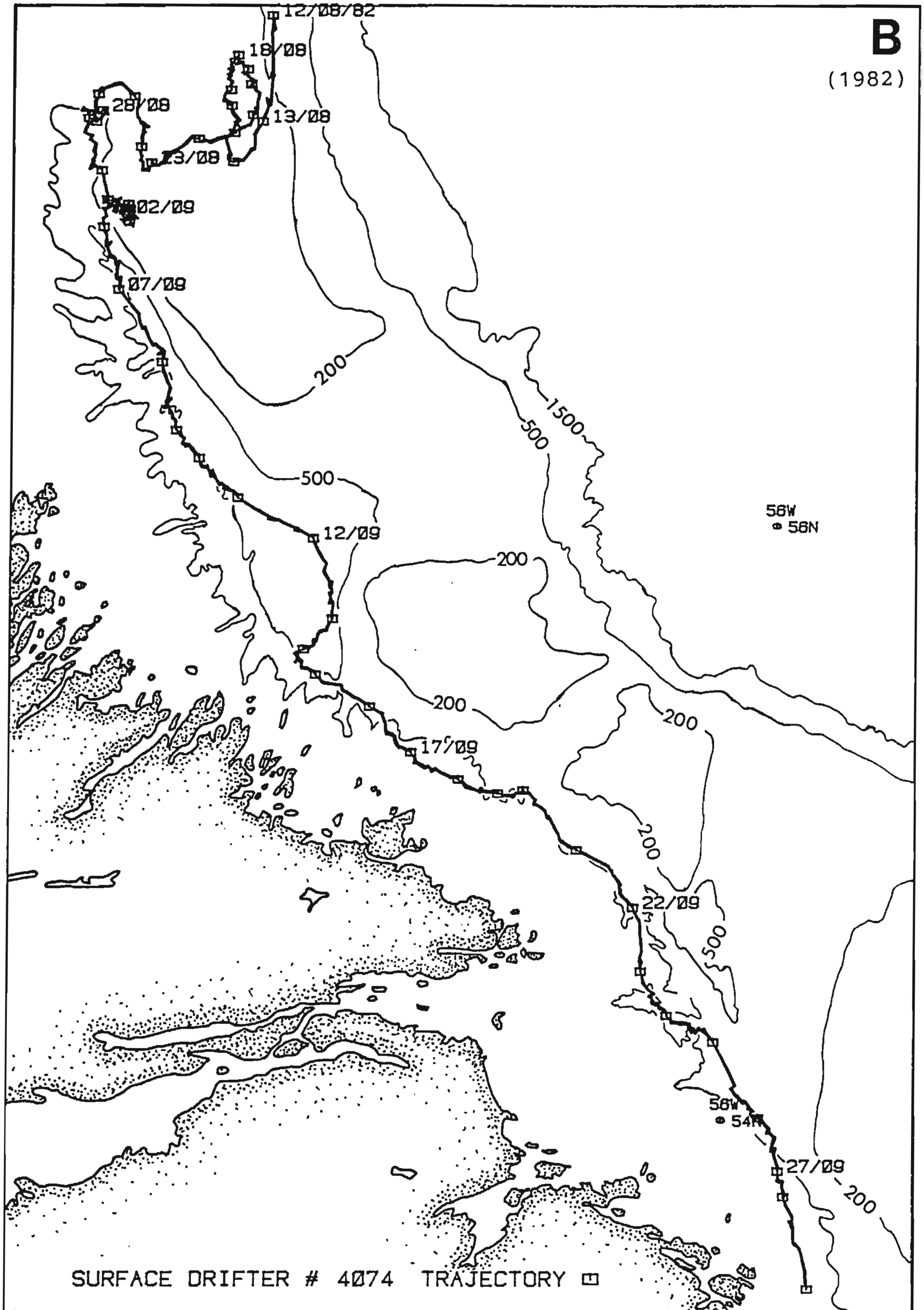
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13/08
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02/09
07/09
200
1500
500
500
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58N
12/09
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200
200
17/09
200
22/09
500
56W
54N
27/09
200
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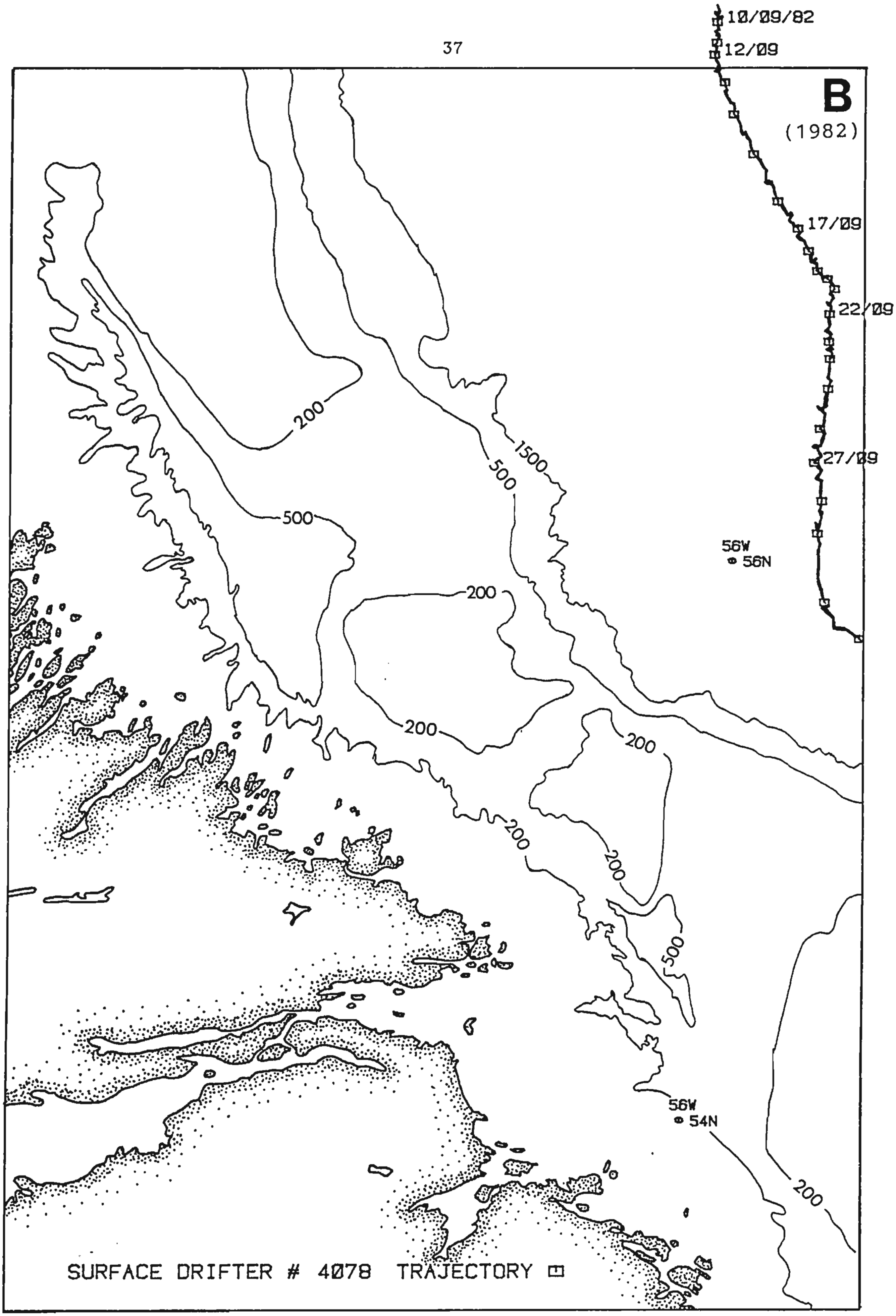
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12/09
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17/09
22/09
27/09
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56W
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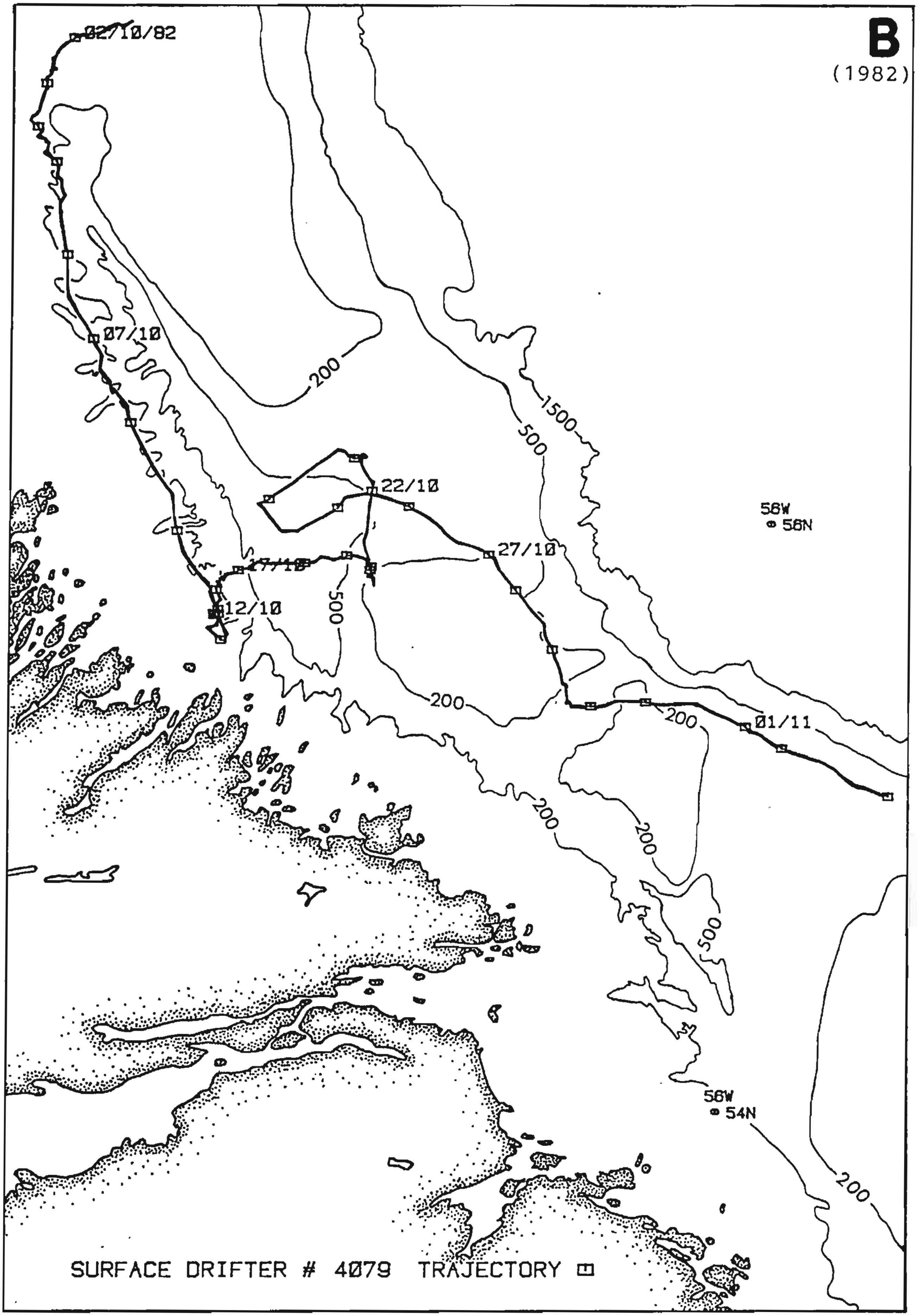
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27/10
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01/11
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500
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58N
58W
54N
200
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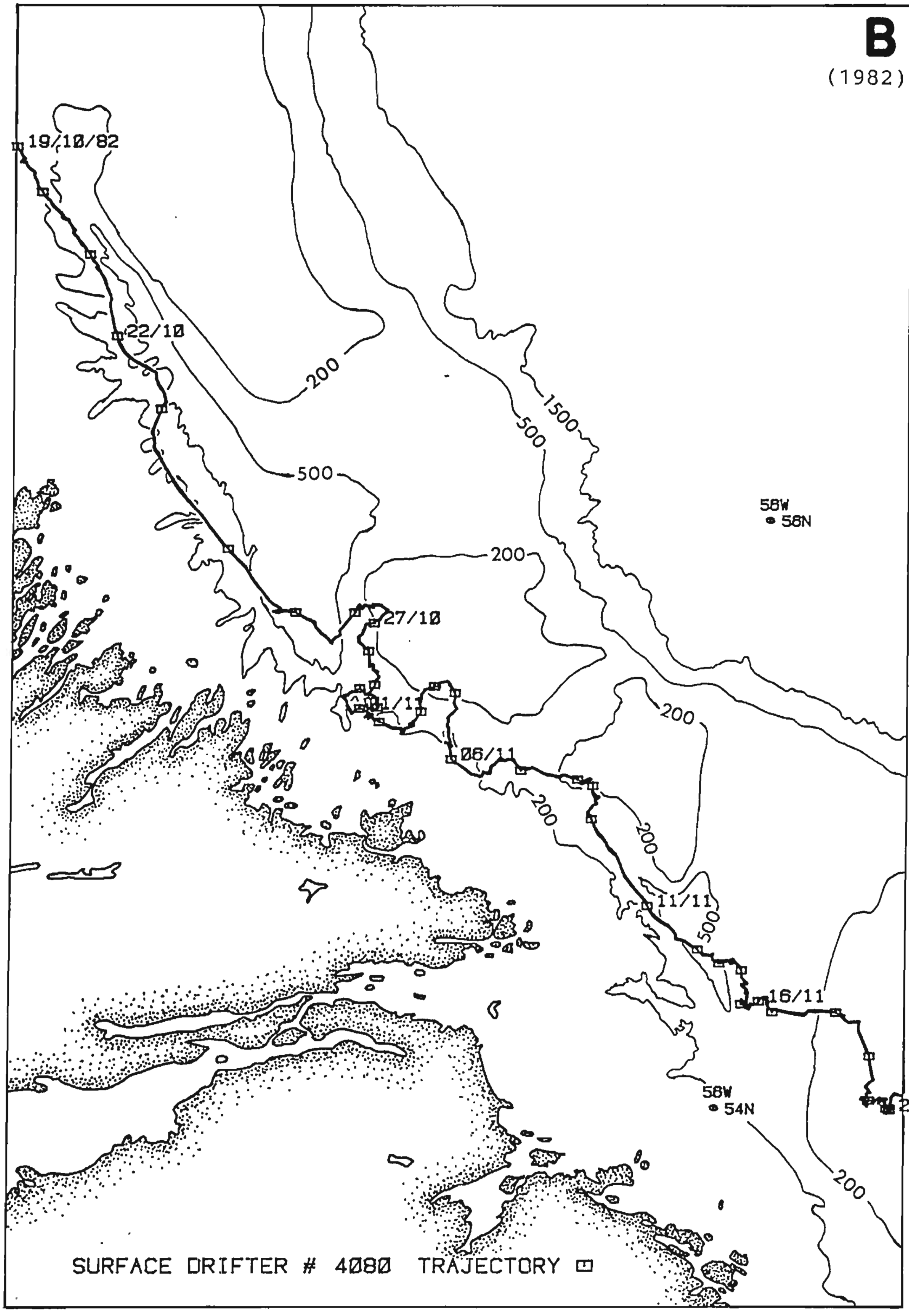
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27/10
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06/11
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16/11
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58W
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200
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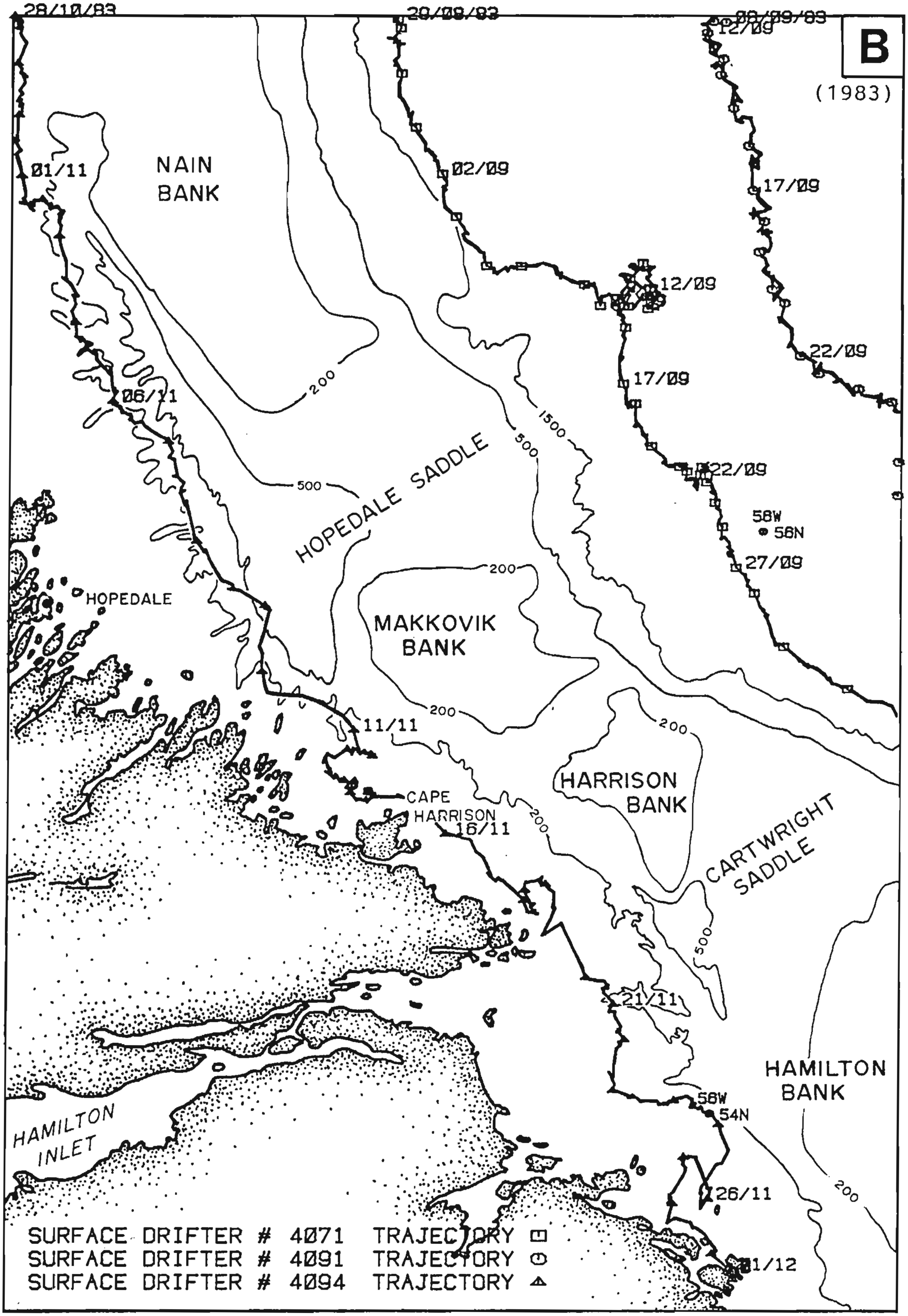
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01/11
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22/09
17/09
06/11
200
500
1500
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MAKKOVIK
BANK
200
11/11
HARRISON
BANK
CAPE
HARRISON
16/11
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SADDLE
21/11
HAMILTON
INLET
HAMILTON
BANK
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01/12
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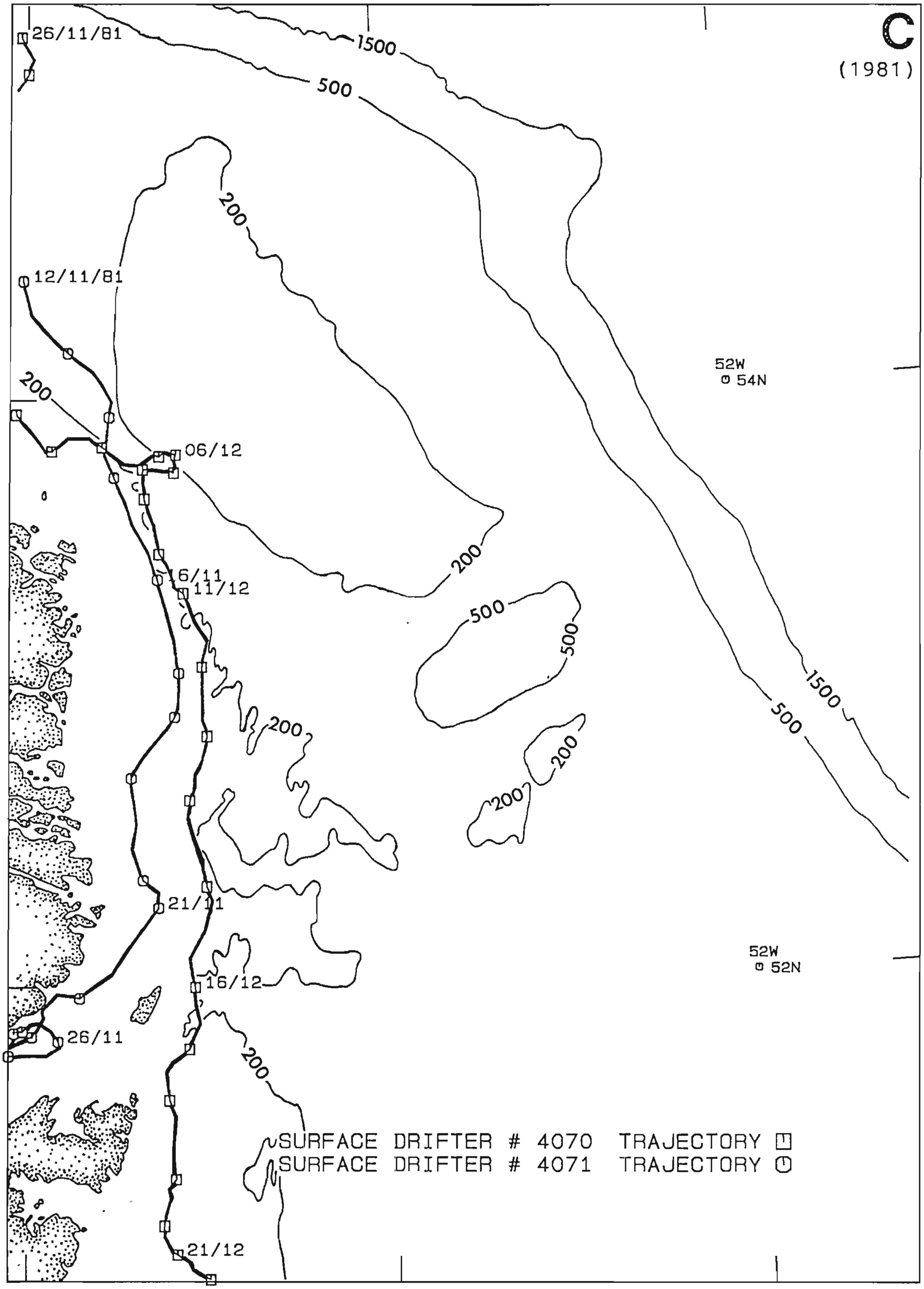
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500
1500
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200
200
200
21/11
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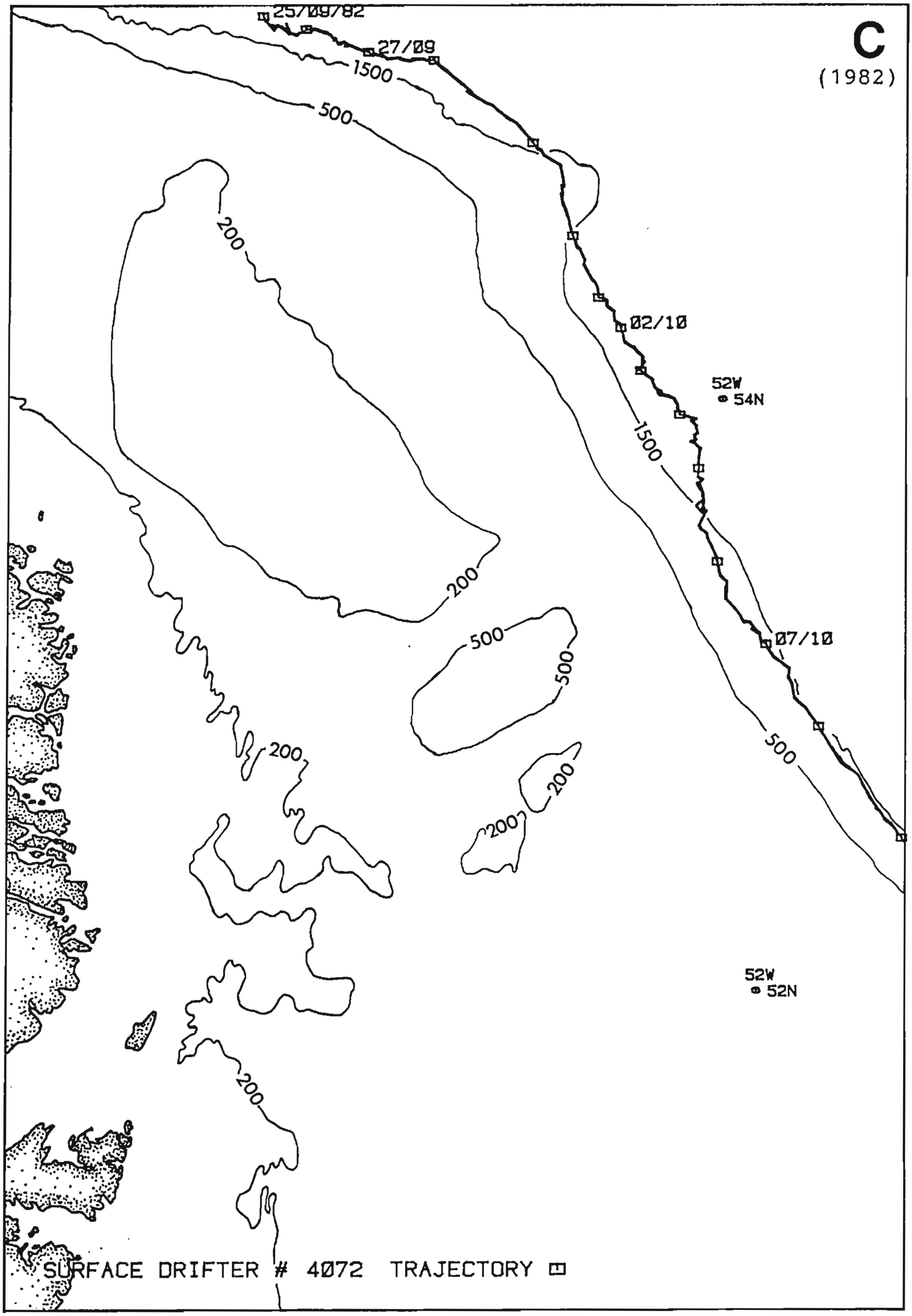
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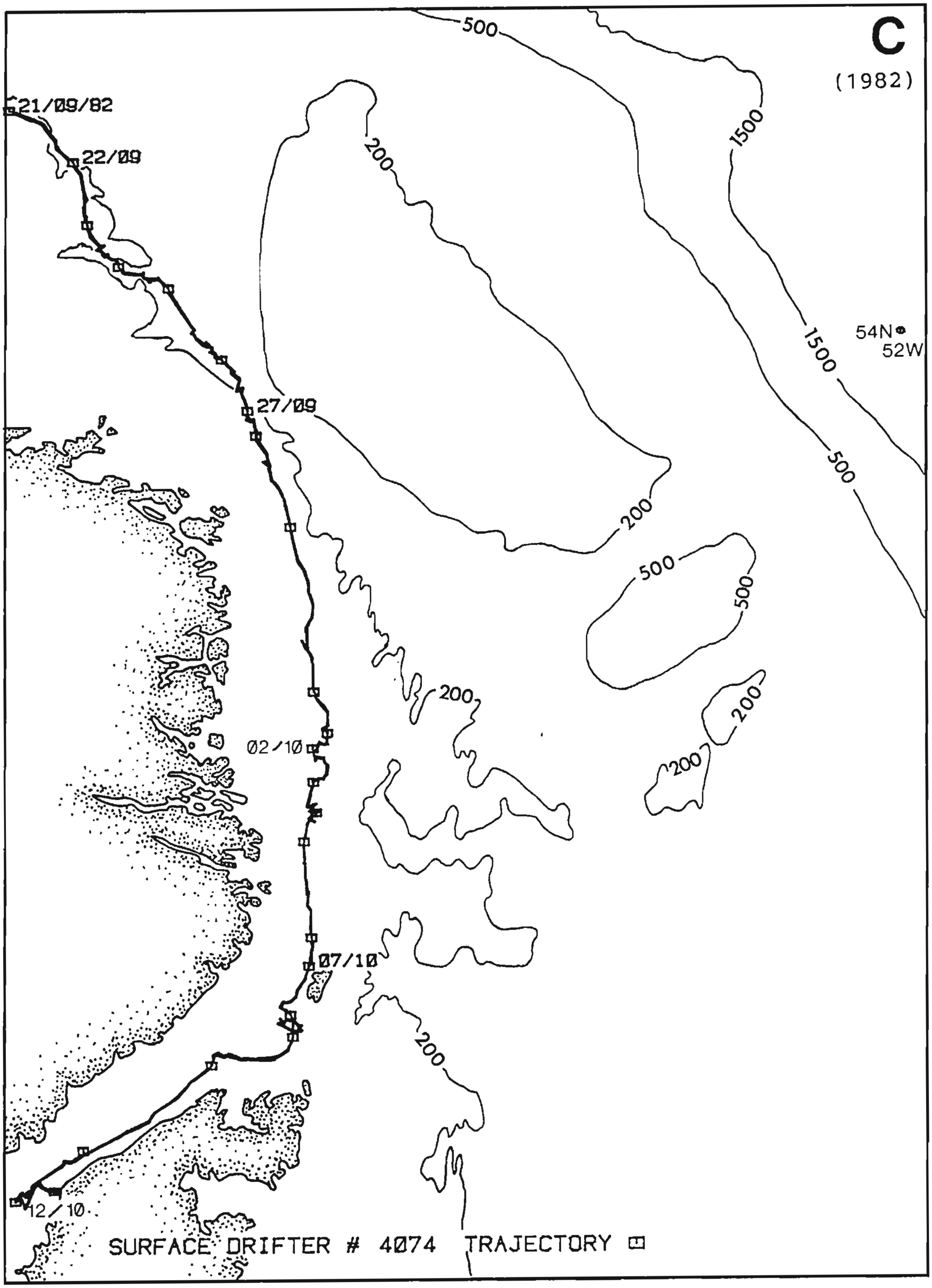
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54N
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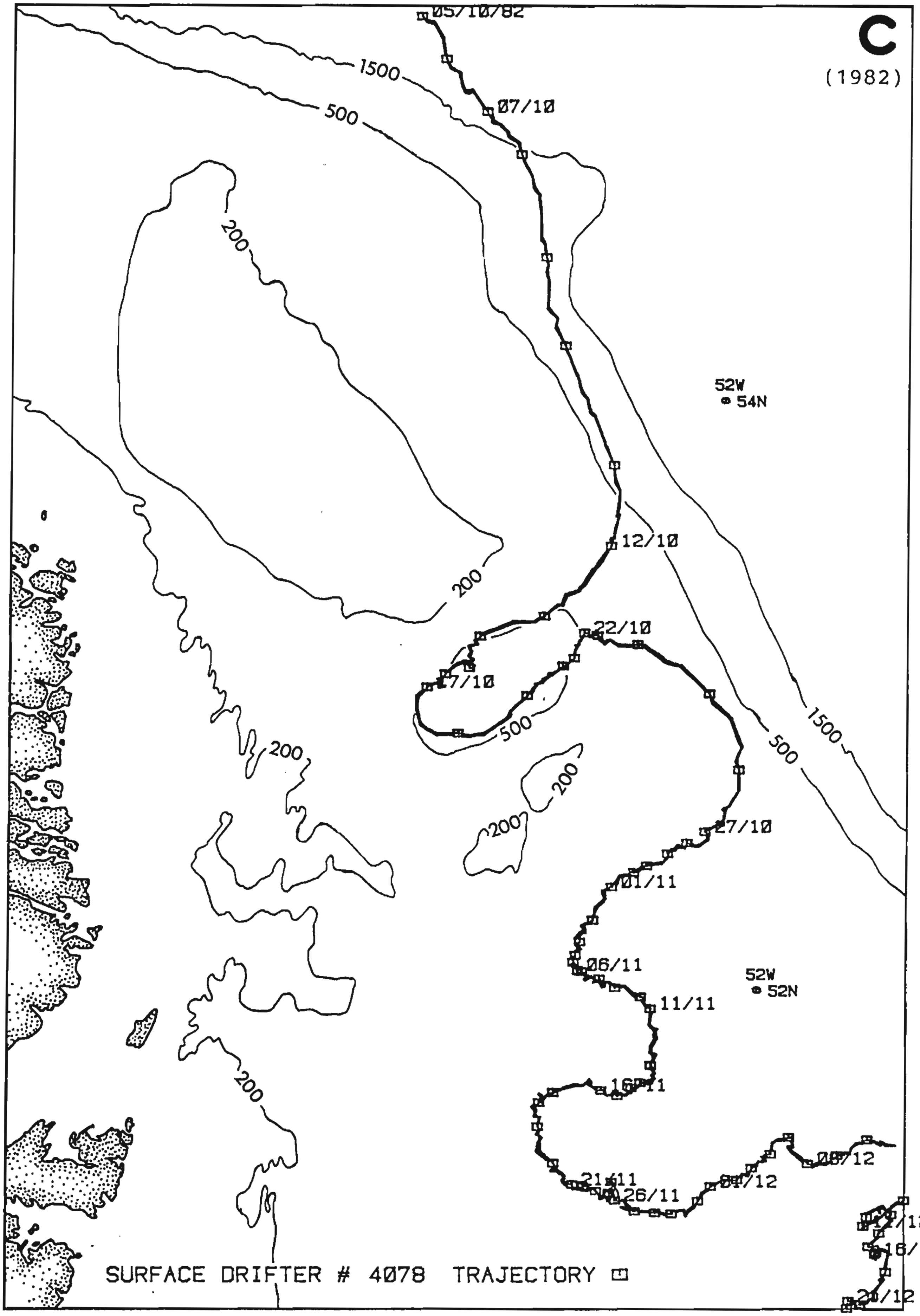
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05/10/82
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54N
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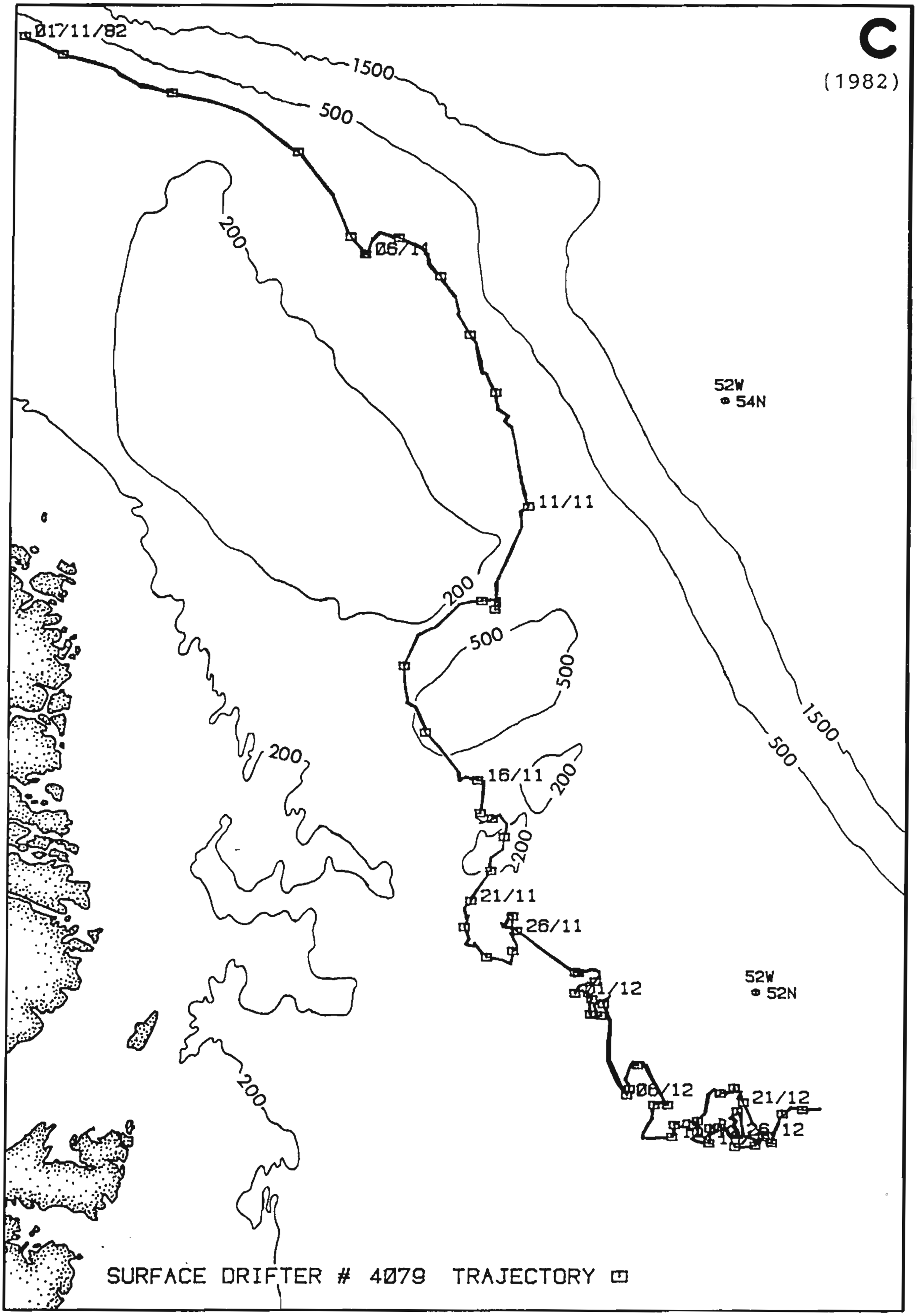
C
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01/11/82
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11/11
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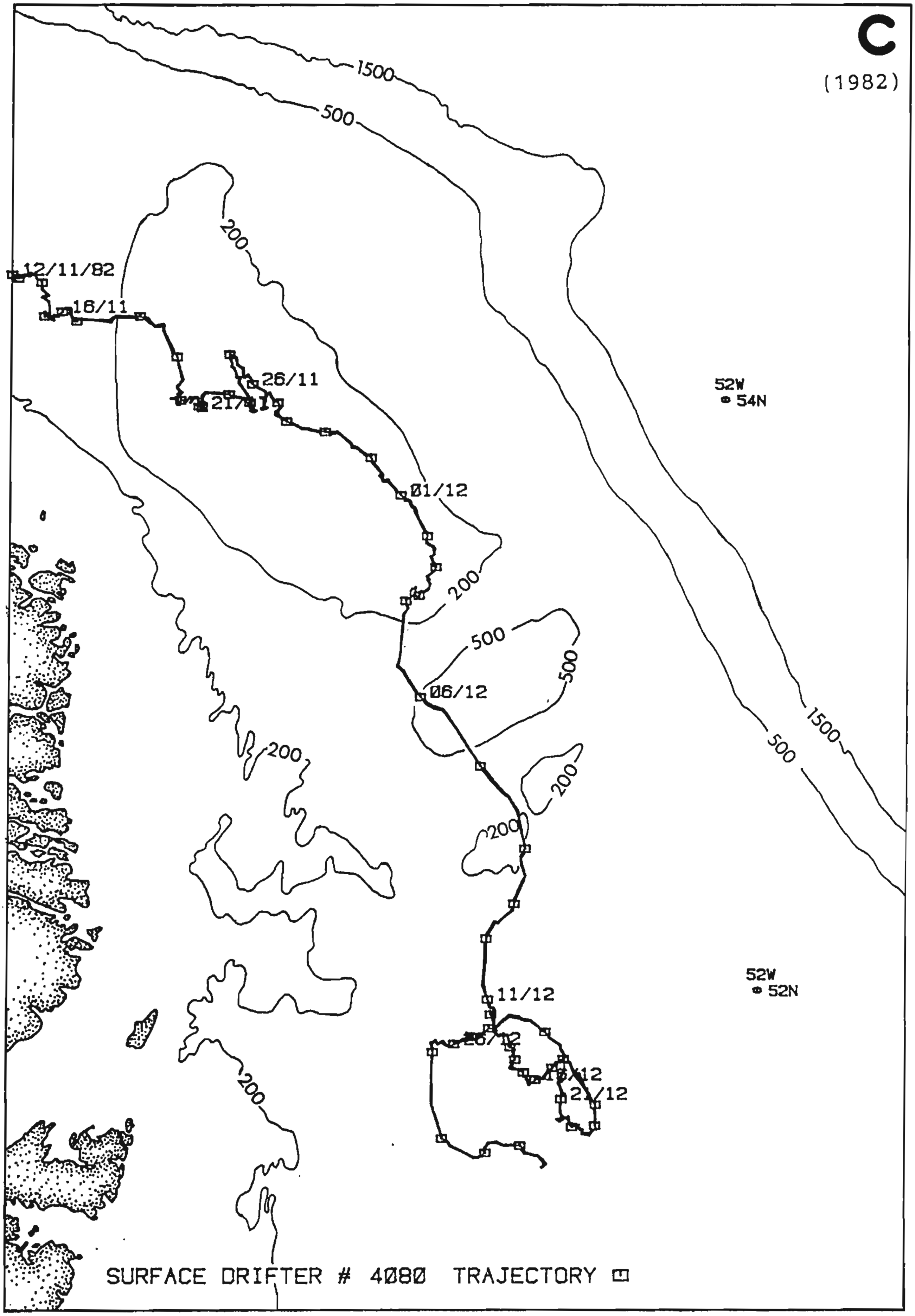
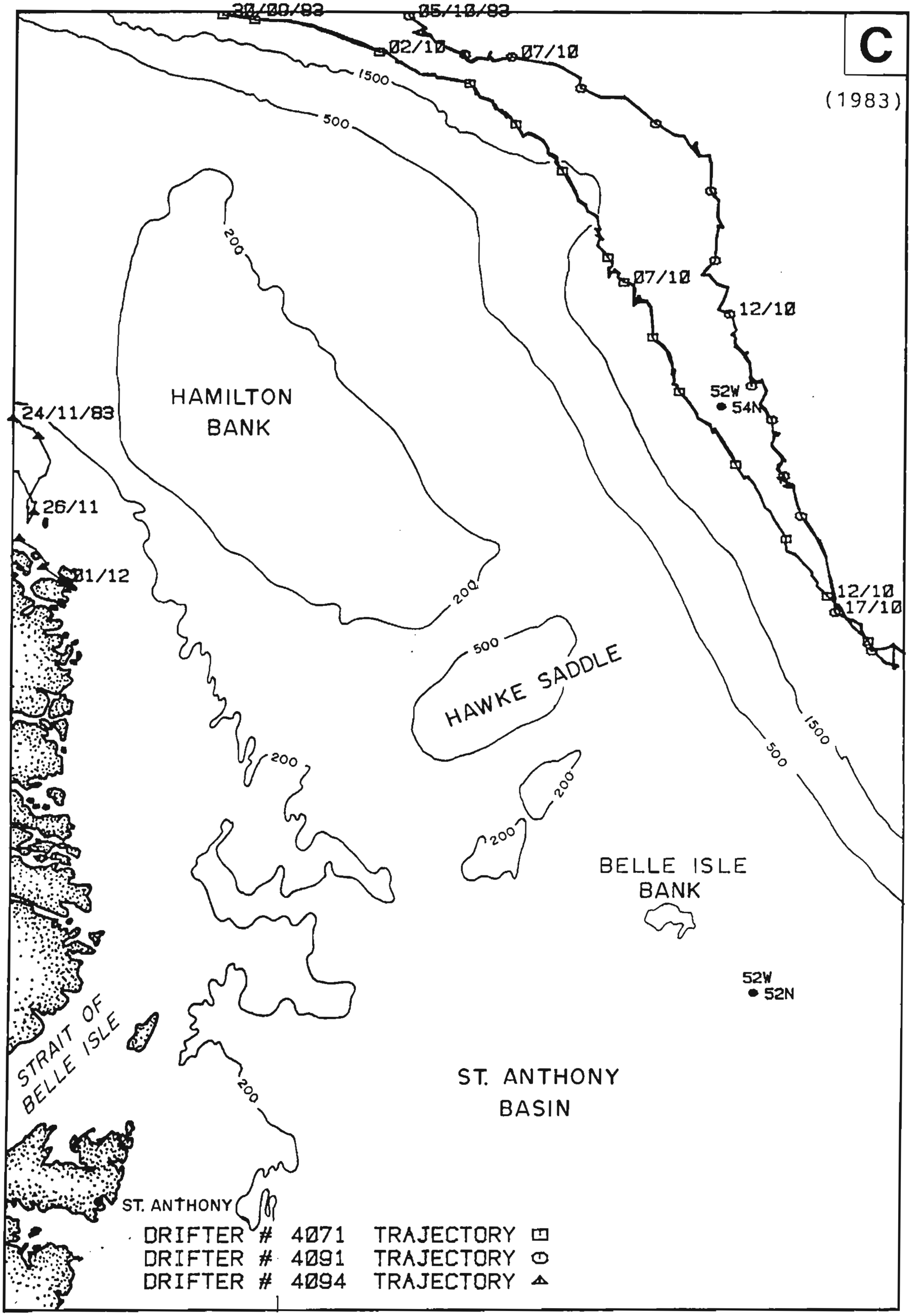
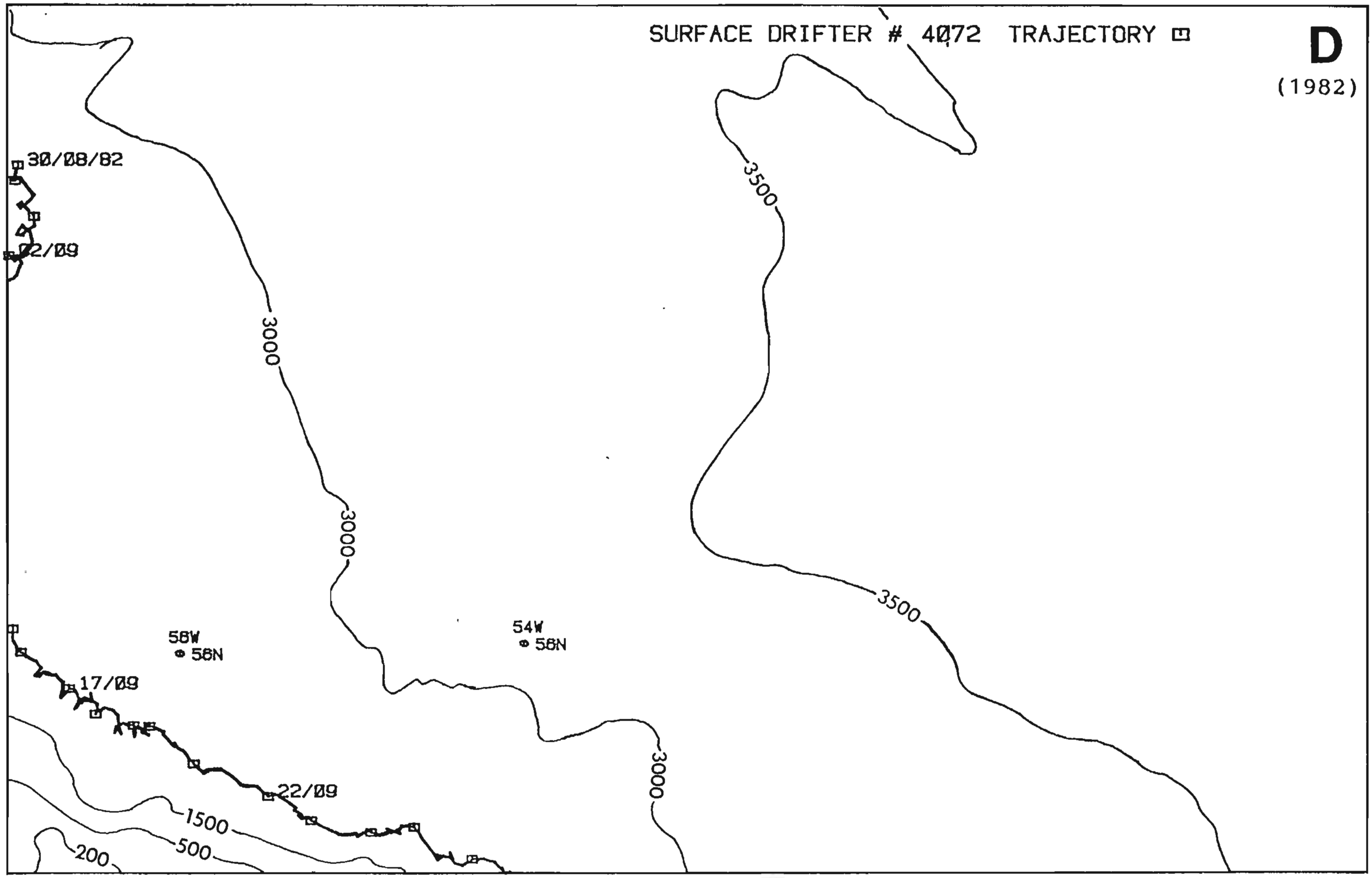
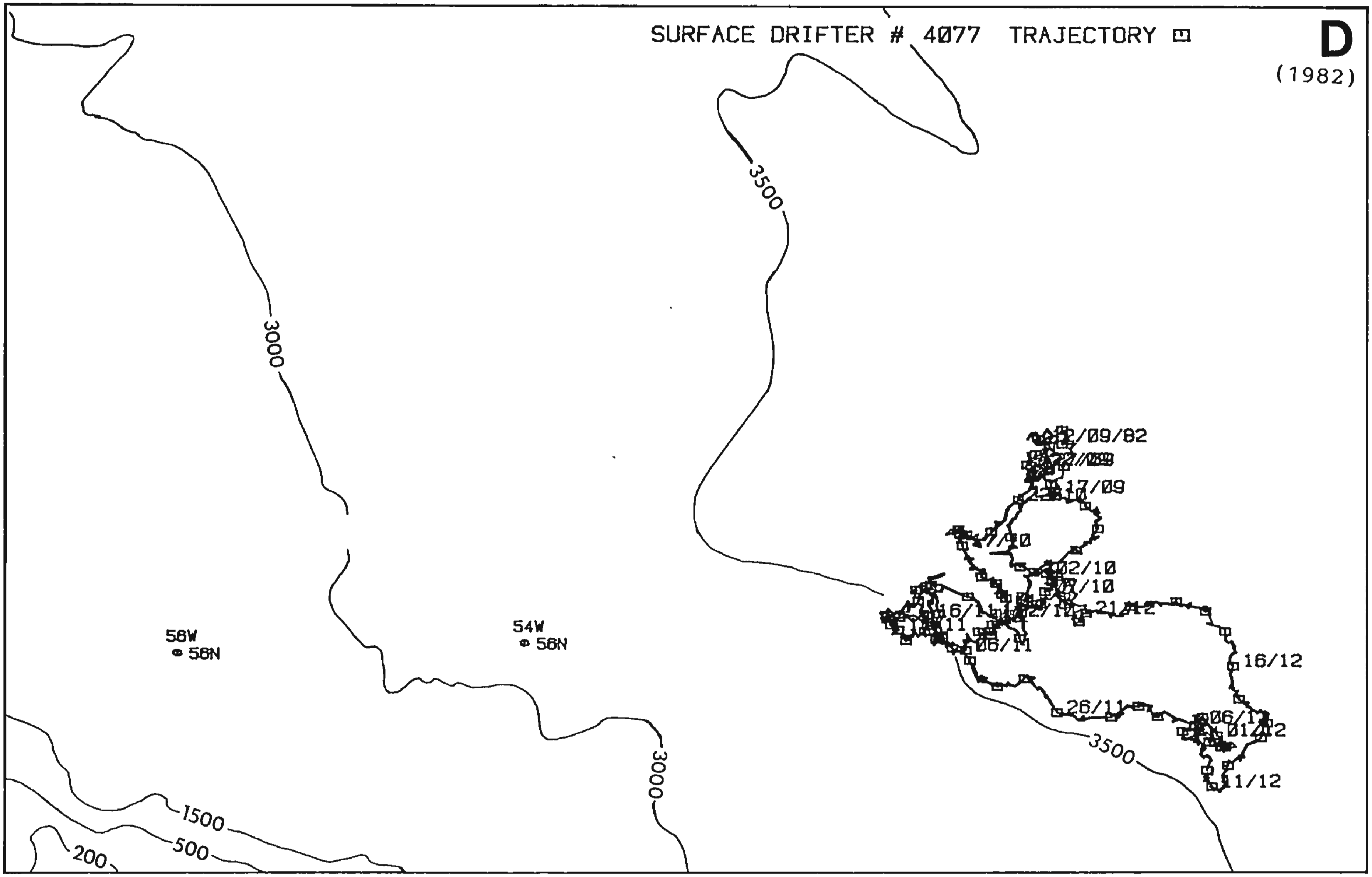
200
1500
500
21/11
26/11
52W
52N
1/12
08/12
21/12
26/12
200
SURFACE DRIFTER # 4079 TRAJECTORY

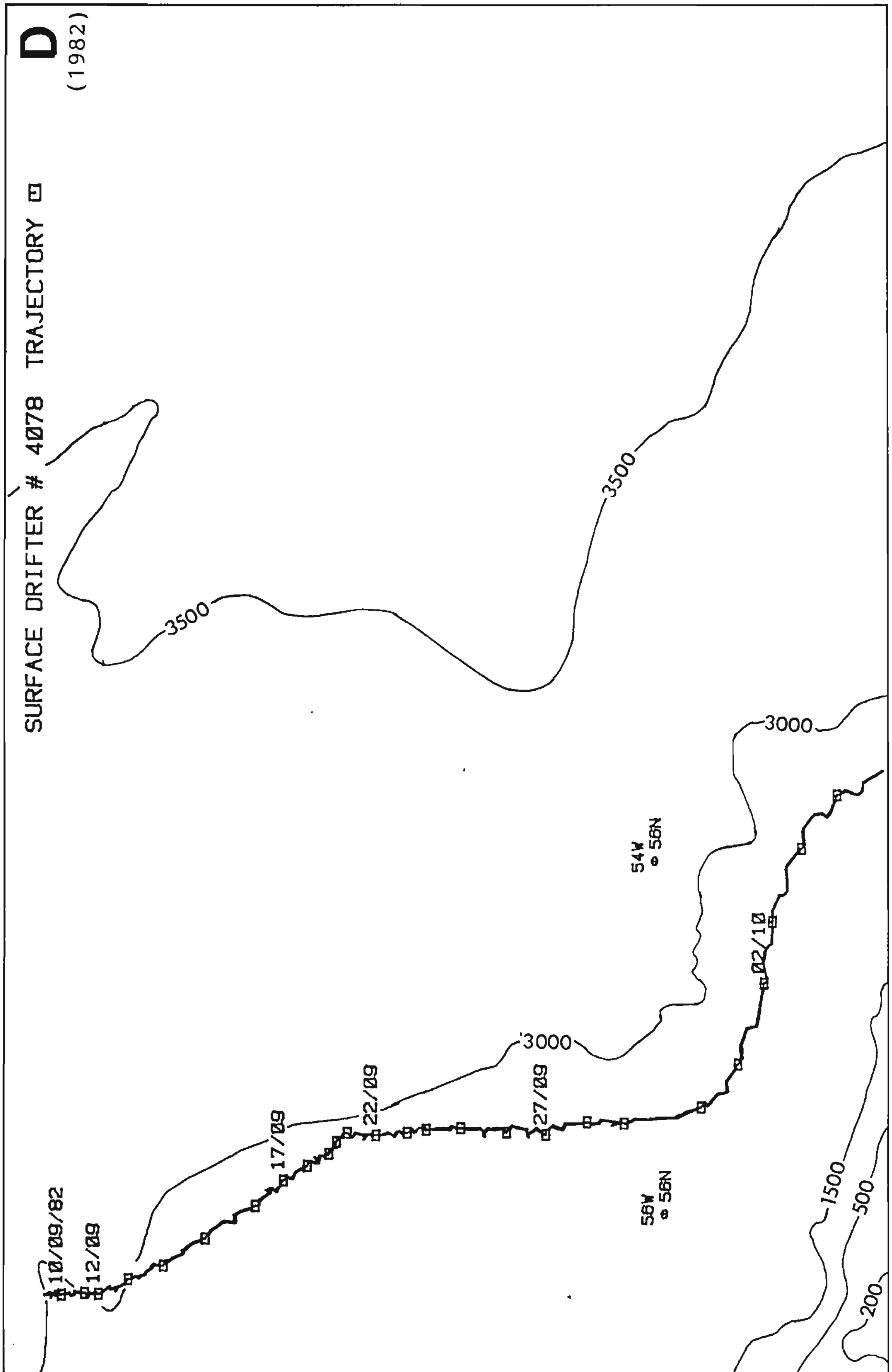

C
(1982)
1500
500
200
12/11/82
16/11
26/11
21/11
01/12
06/12
11/12
26/12
16/12
21/12
52W
54N
52W
52N
SURFACE DRIFTER # 4080 TRAJECTORY

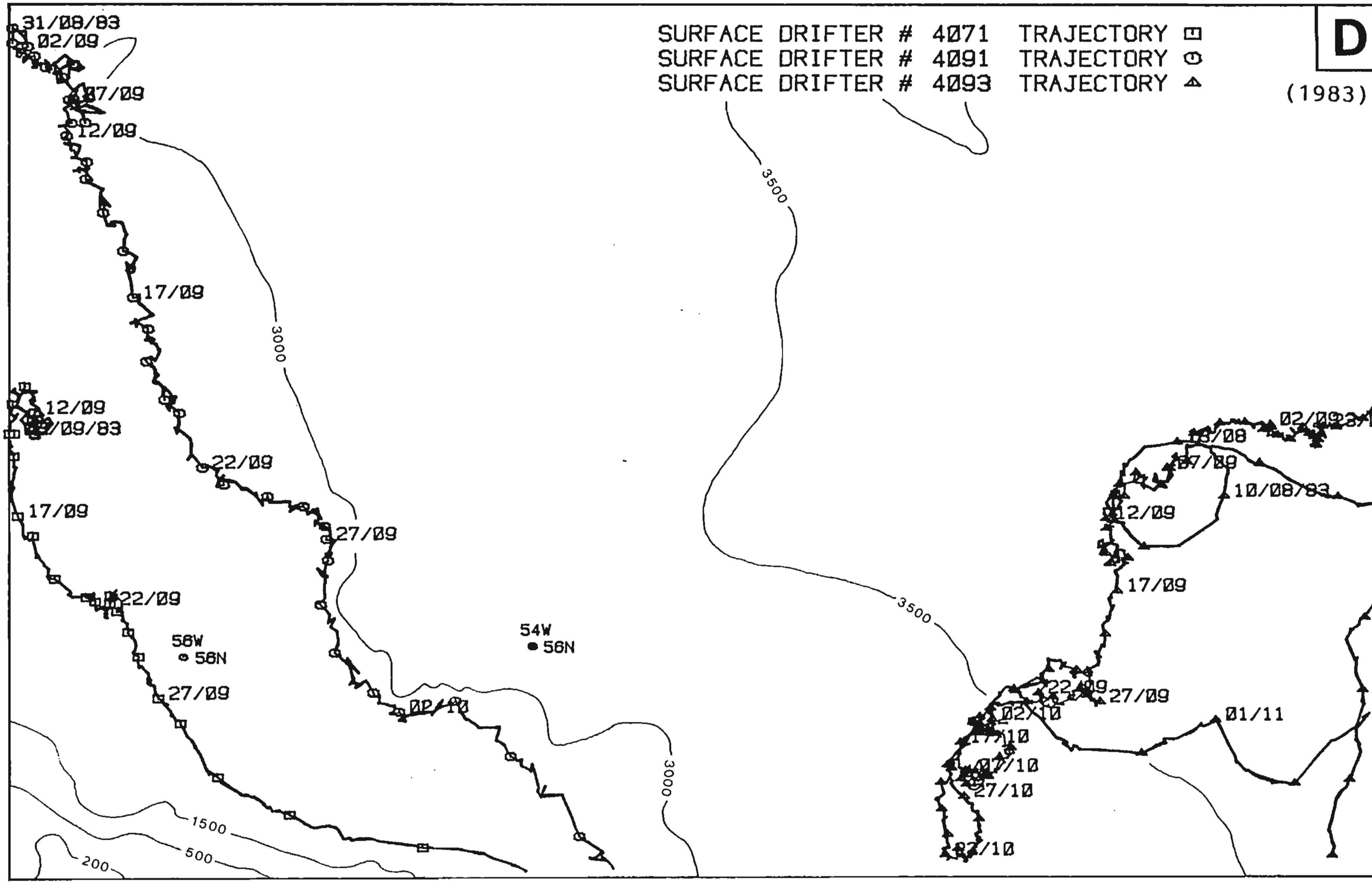

C
(1983)
30/09/83
05/10/83
02/10
07/10
1500
500
200
07/10
12/10
52W
54N
24/11/83
HAMILTON
BANK
26/11
01/12
12/10
17/10
500
HAWKE SADDLE
200
1500
500
200
200
200
BELLE ISLE
BANK
52W
52N
STRAIT OF
BELLE ISLE
200
ST. ANTHONY
BASIN
ST. ANTHONY
DRIFTER # 4071 TRAJECTORY
DRIFTER # 4091 TRAJECTORY
DRIFTER # 4094 TRAJECTORY

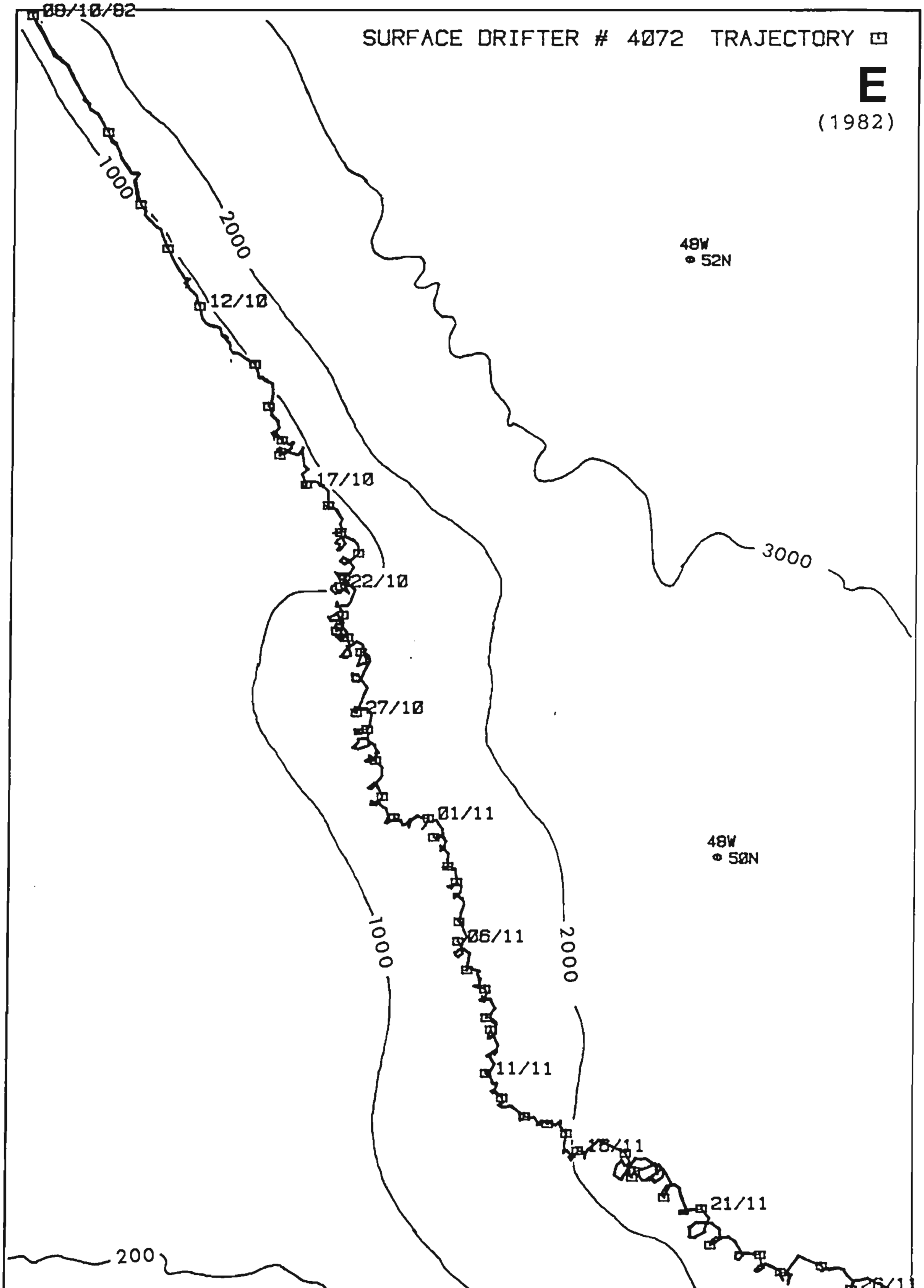

SURFACE DRIFTER # 4072 TRAJECTORY
D
(1982)
30/08/82
02/09
17/09
22/09
58W
58N
54W
58N
3000
3000
3000
3500
3500
1500
500
200

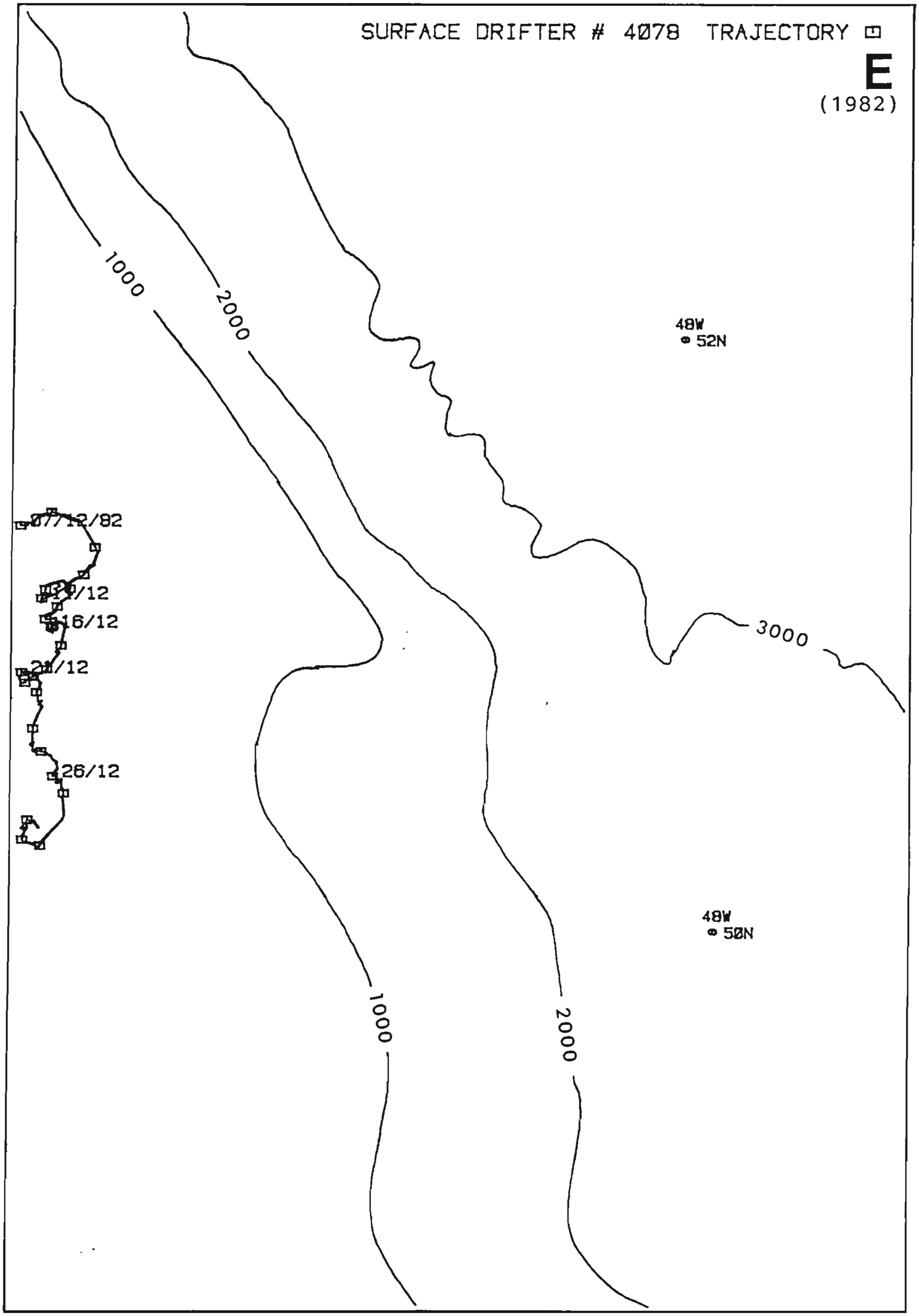


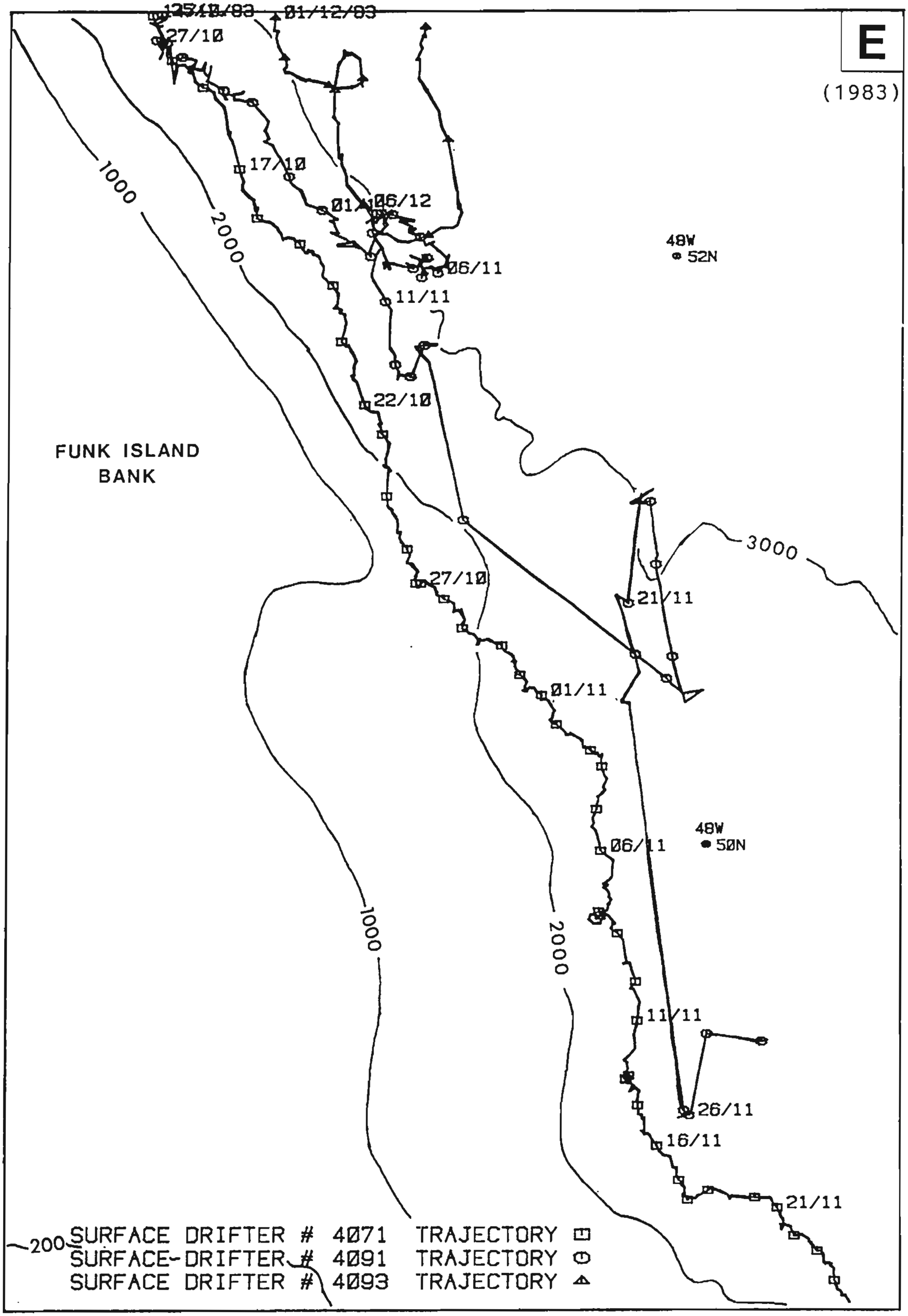
SURFACE DRIFTER # 4077 TRAJECTORY
D
(1982)
3500
3000
1500
500
200
58W
58N
54W
58N
17/09
16/12
26/11
06/11
11/12

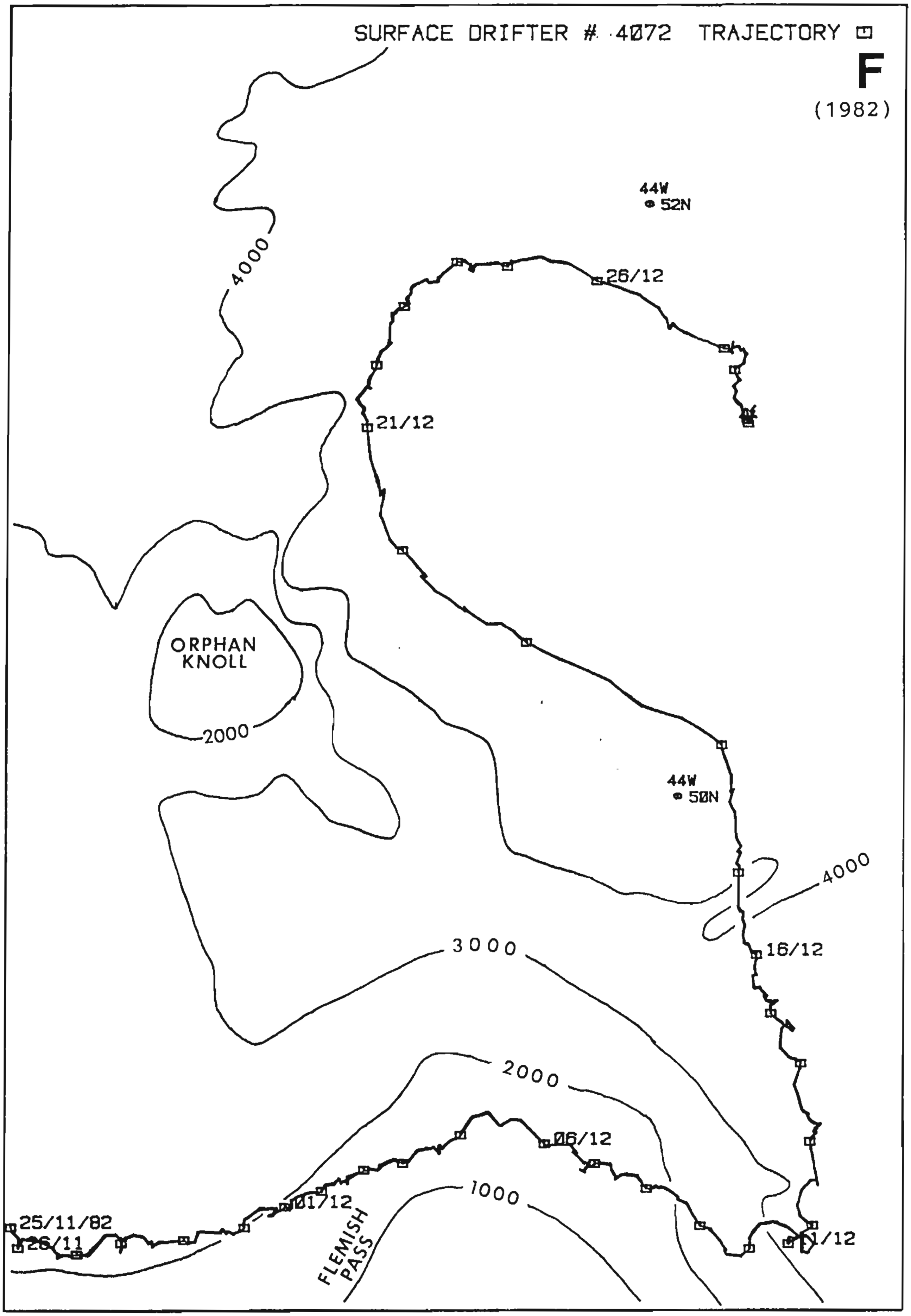

D
(1982)
SURFACE DRIFTER # 4Ø78 TRAJECTORY
3500
3500
3000
3000
54W
56N
56W
56N
1500
500
200
1Ø/Ø9/82
12/Ø9
17/Ø9
22/Ø9
27/Ø9
Ø2/1Ø

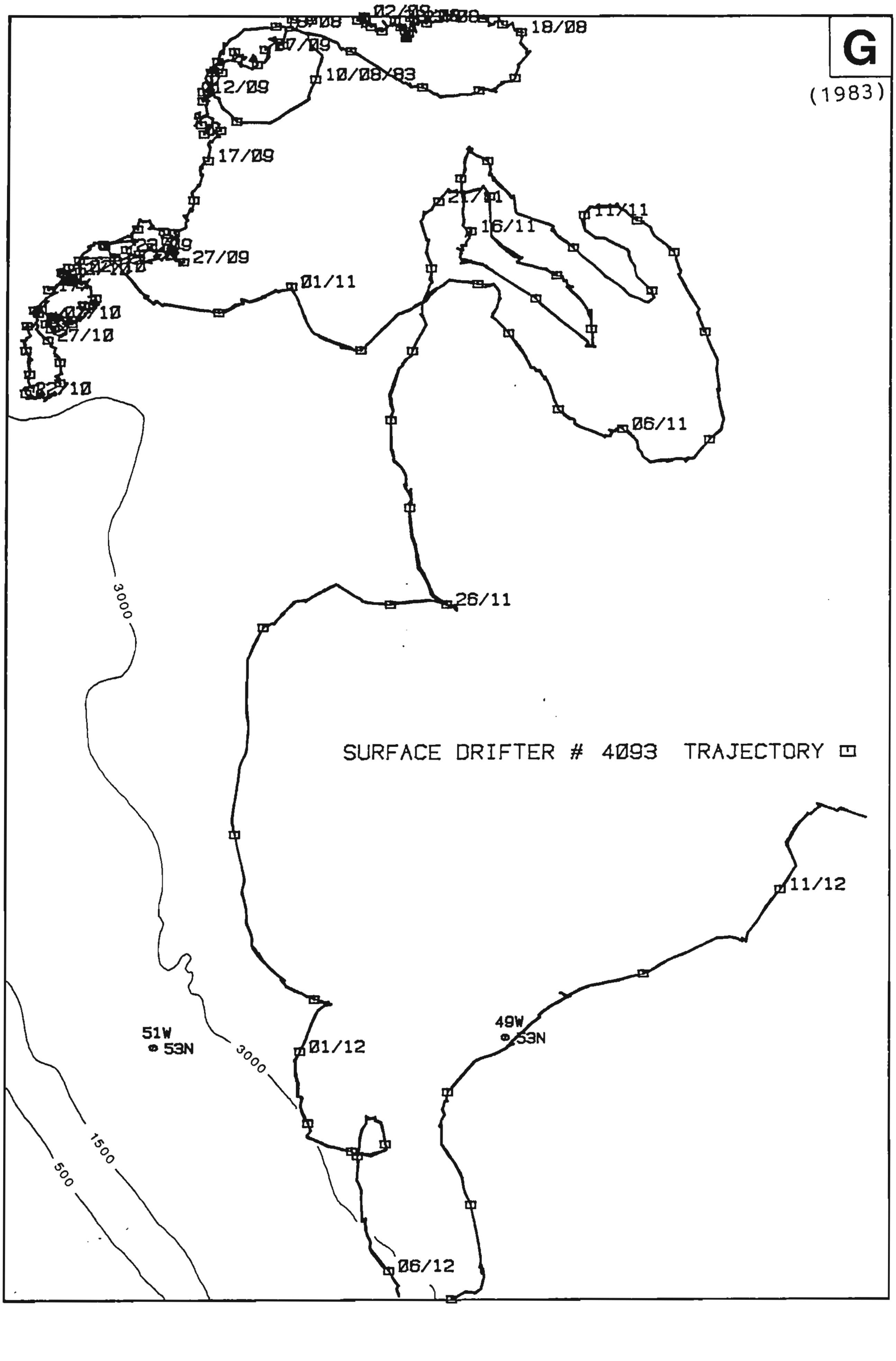

SURFACE DRIFTER # 4071 TRAJECTORY
SURFACE DRIFTER # 4091 TRAJECTORY
SURFACE DRIFTER # 4093 TRAJECTORY
D
(1983)
31/08/83
02/09
07/09
12/09
17/09
22/09
27/09
02/10
17/09
22/09
27/09
56W
56N
54W
56N
3500
3000
3500
3000
1500
500
200
02/09
23/08
10/08/83
12/09
17/09
22/09
27/09
02/10
17/10
27/10
01/11
21/11

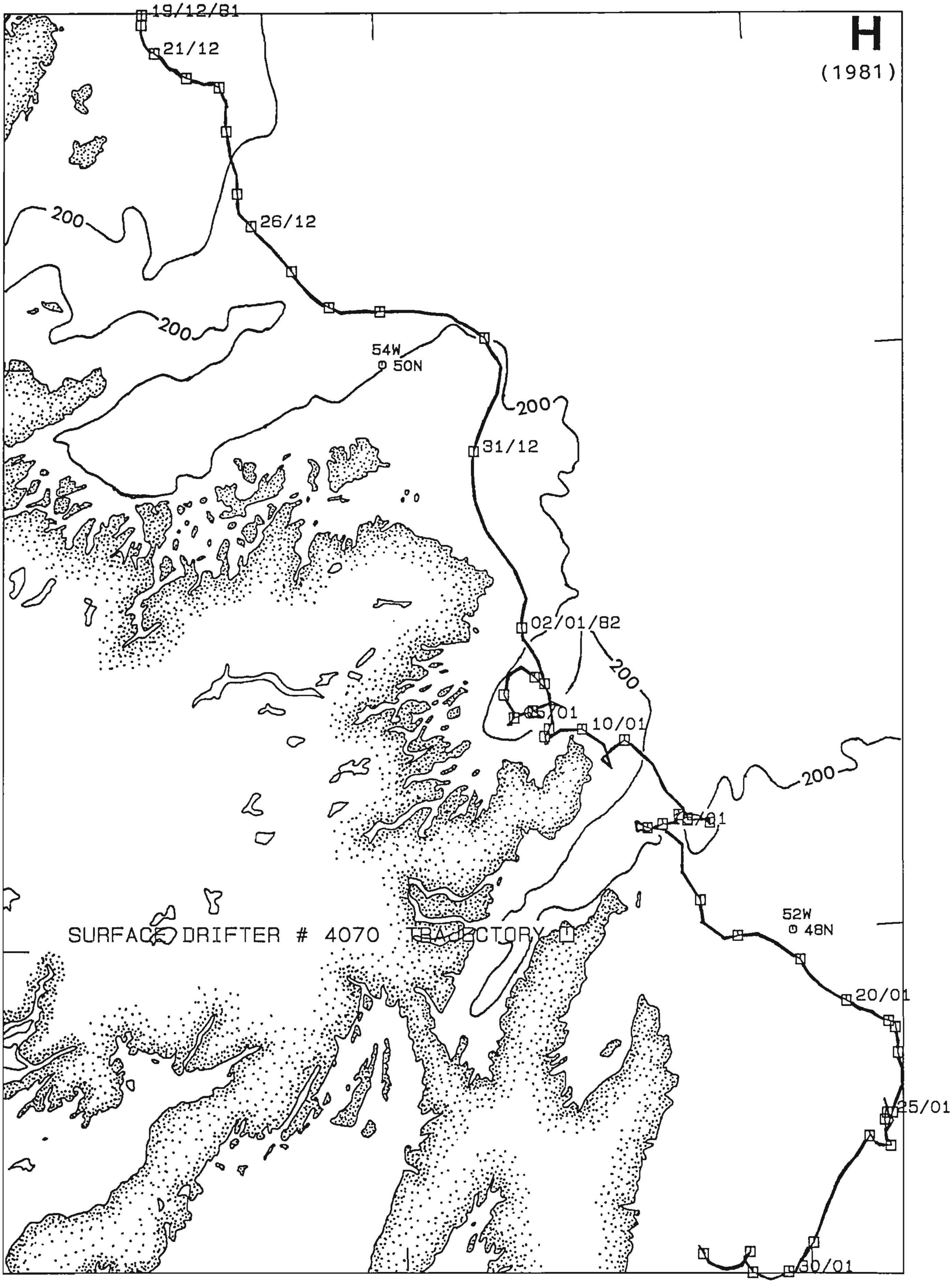

SURFACE DRIFTER # 4072 TRAJECTORY
E
(1982)
08/10/82
12/10
17/10
22/10
27/10
01/11
06/11
11/11
16/11
21/11
26/11
1000
2000
3000
200
48W
52N
48W
50N
GRAND BANKS

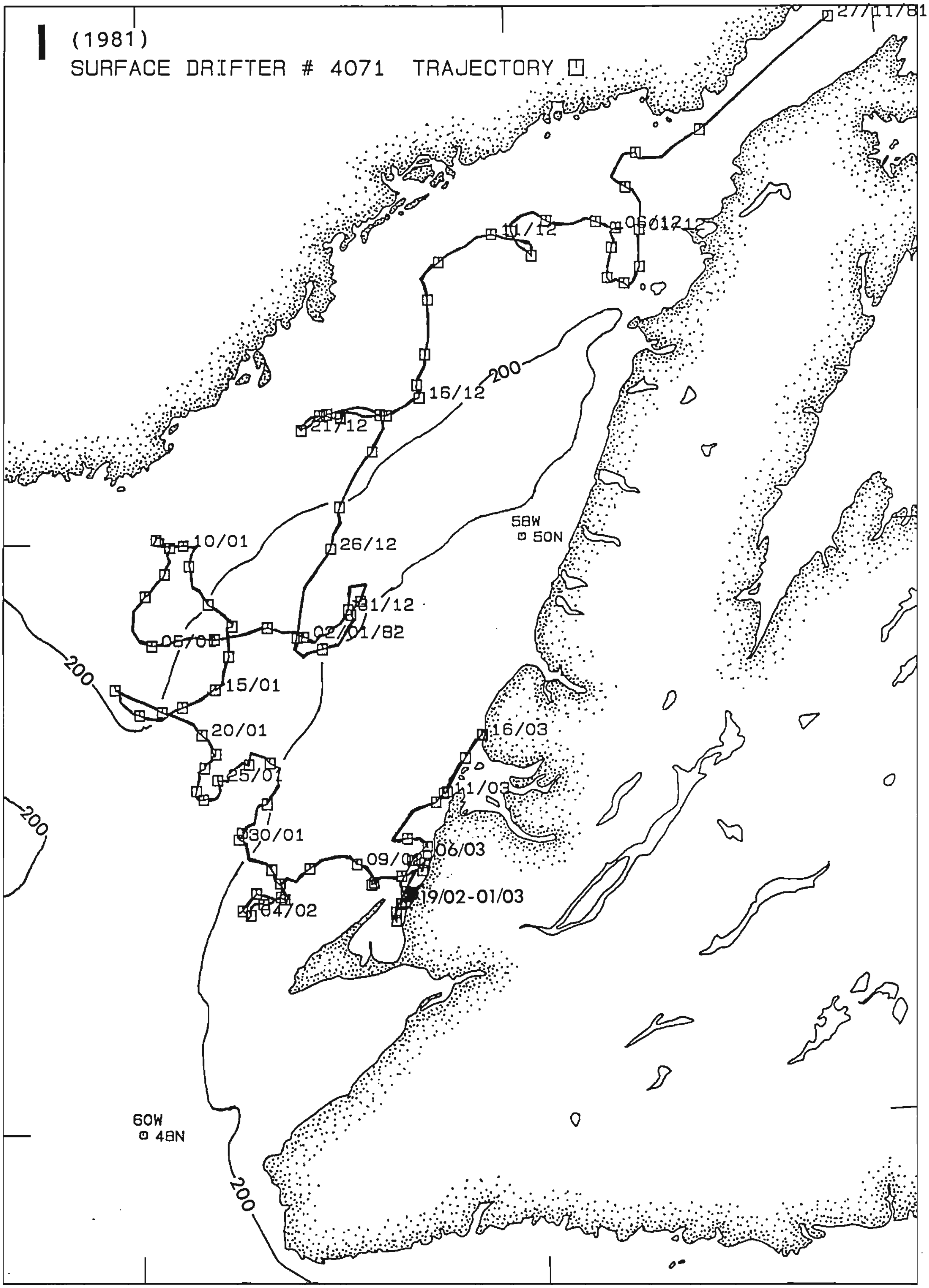

SURFACE DRIFTER # 4078 TRAJECTORY
E
(1982)
1000
2000
3000
48W
52N
48W
50N
07/12/82
16/12
26/12
1000
2000


E
(1983)
27/10
01/12/83
17/10
06/12
06/11
11/11
22/10
27/10
21/11
01/11
06/11
11/11
26/11
16/11
21/11
48W
52N
48W
50N
FUNK ISLAND
BANK
1000
2000
3000
1000
2000
200
SURFACE DRIFTER # 4071 TRAJECTORY
SURFACE DRIFTER # 4091 TRAJECTORY
SURFACE DRIFTER # 4093 TRAJECTORY


SURFACE DRIFTER # 4072 TRAJECTORY
F
(1982)
44W
52N
44W
50N
4000
26/12
21/12
ORPHAN
KNOLL
2000
4000
16/12
3000
2000
06/12
1000
25/11/82
26/11
01/12
FLEMISH
PASS
1/12


G
(1983)
18/08
10/08/83
12/09
17/09
27/09
01/11
27/10
16/11
11/11
06/11
26/11
SURFACE DRIFTER # 4093 TRAJECTORY
11/12
51W
53N
49W
53N
01/12
3000
3000
1500
500
06/12

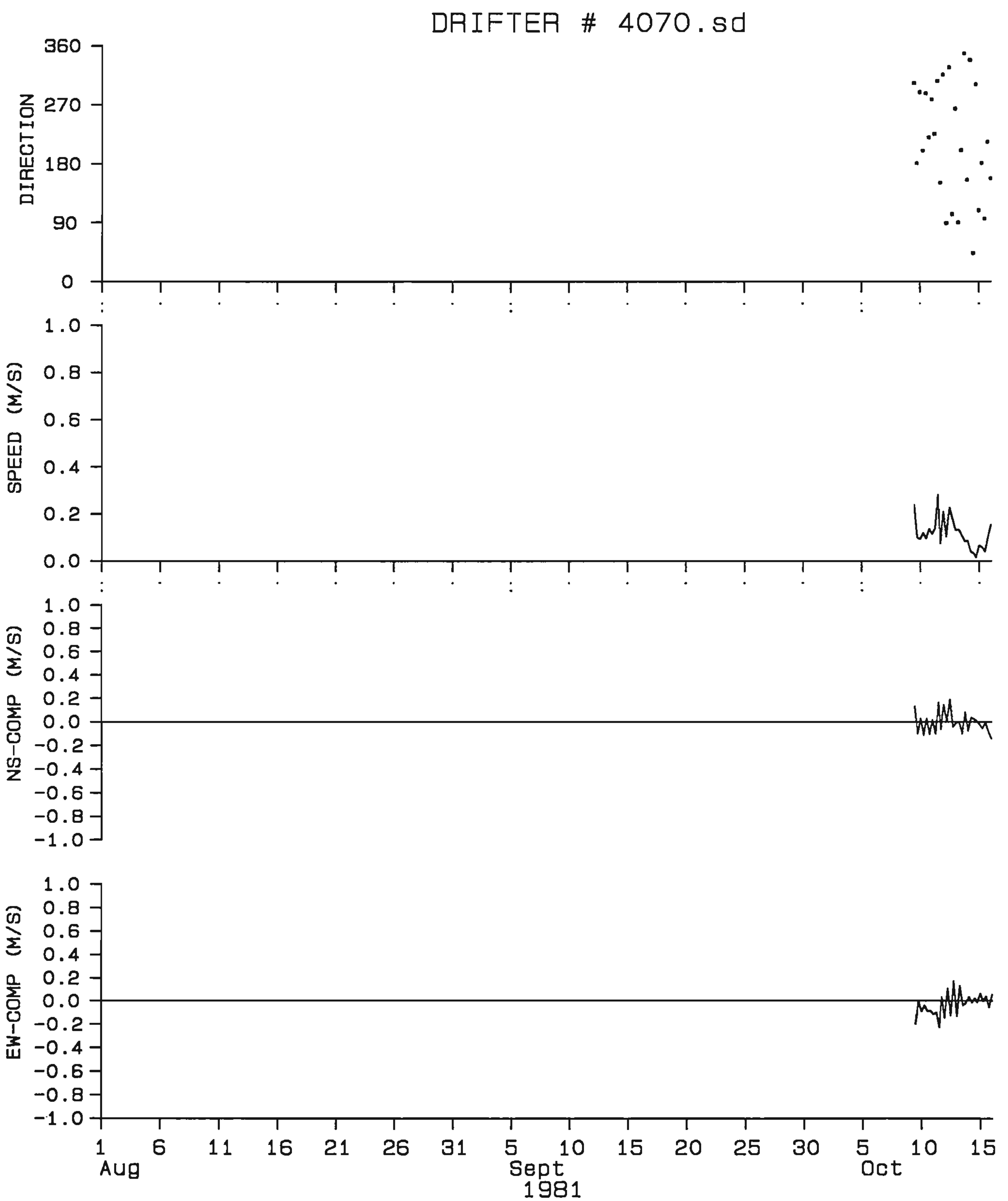

H
(1981)
19/12/81
21/12
26/12
200
200
54W
50N
200
31/12
02/01/82
200
10/01
200
52W
48N
20/01
25/01
30/01
SURFACE DRIFTER # 4070 TRAJECTORY

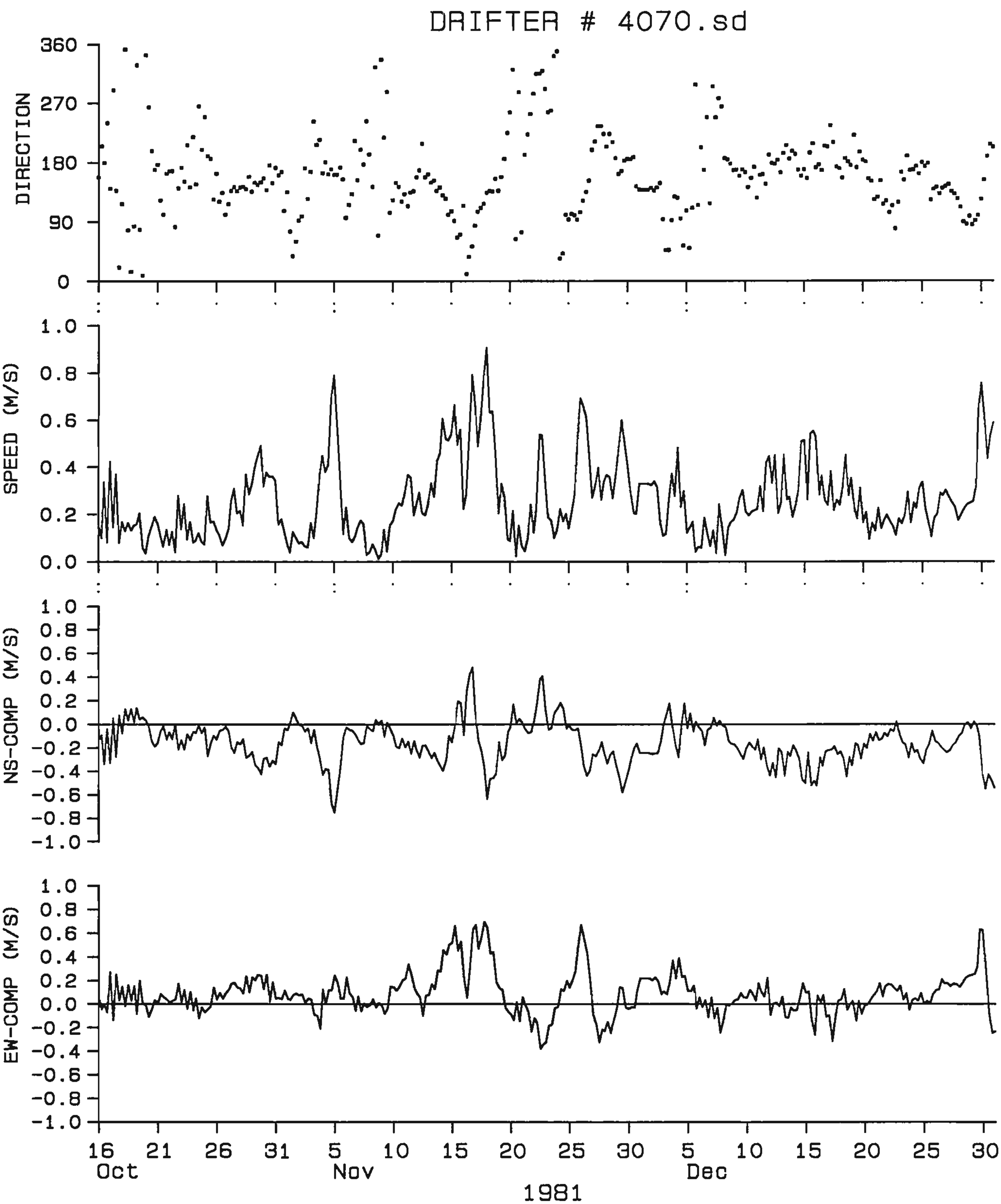

I (1981)
SURFACE DRIFTER # 4071 TRAJECTORY
27/11/81
06/12
11/12
16/12
200
21/12
26/12
10/01
31/12
05/01
02/01/82
200
15/01
20/01
25/01
200
16/03
11/03
30/01
06/03
09/02
19/02-01/03
04/02
58W
50N
60W
48N
200

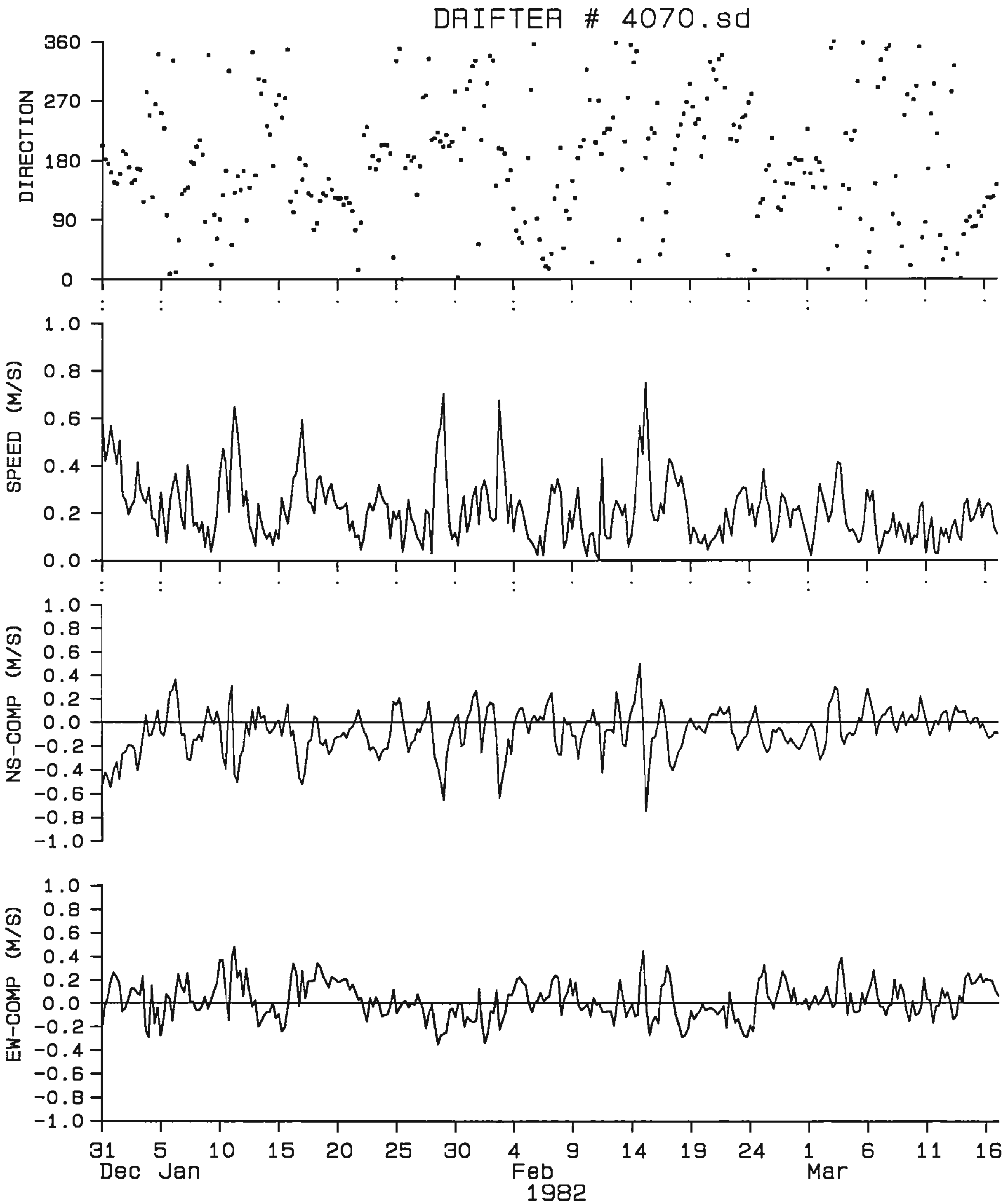
APPENDIX 2

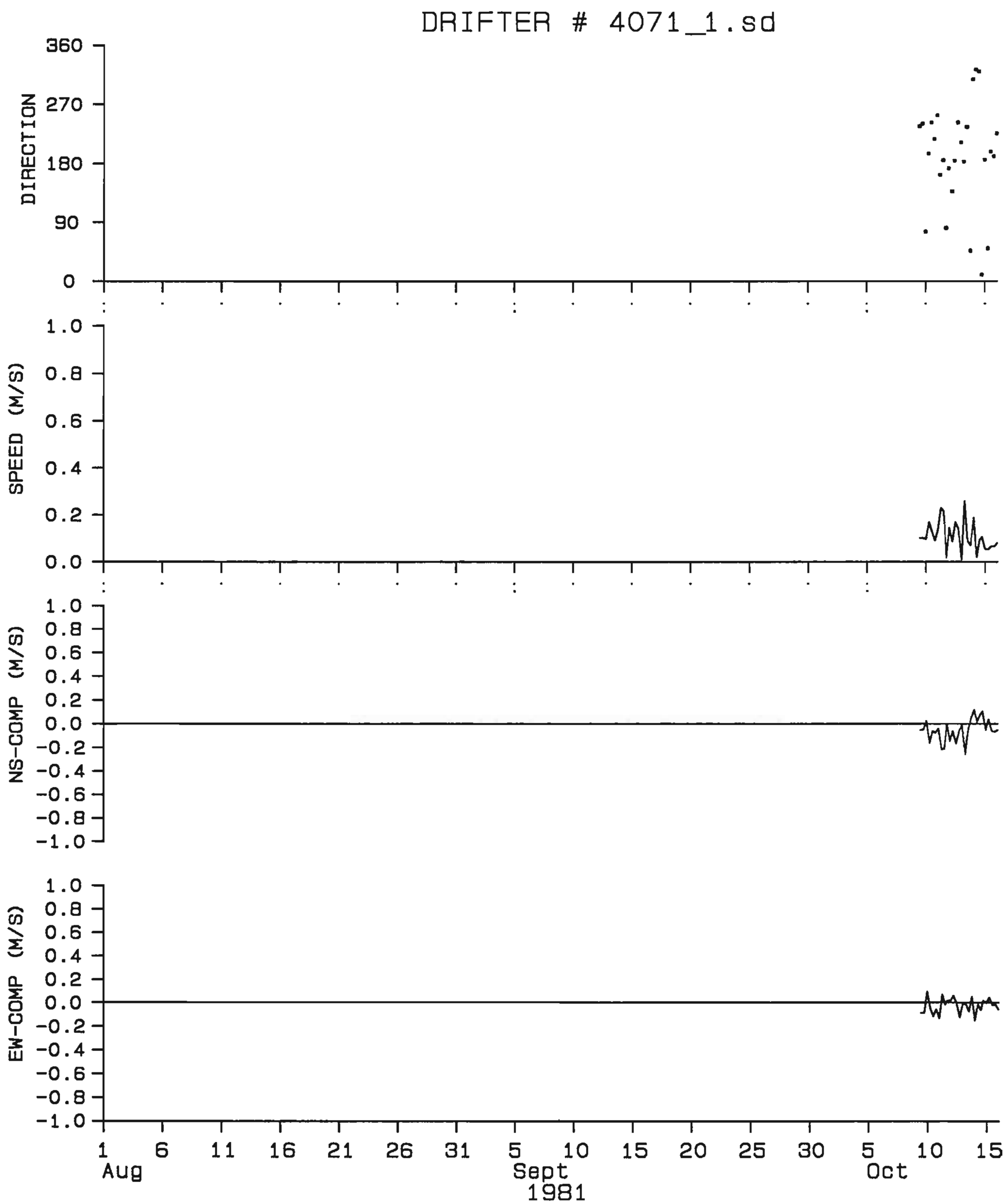
PLOTS AND STATISTICAL SUMMARIES

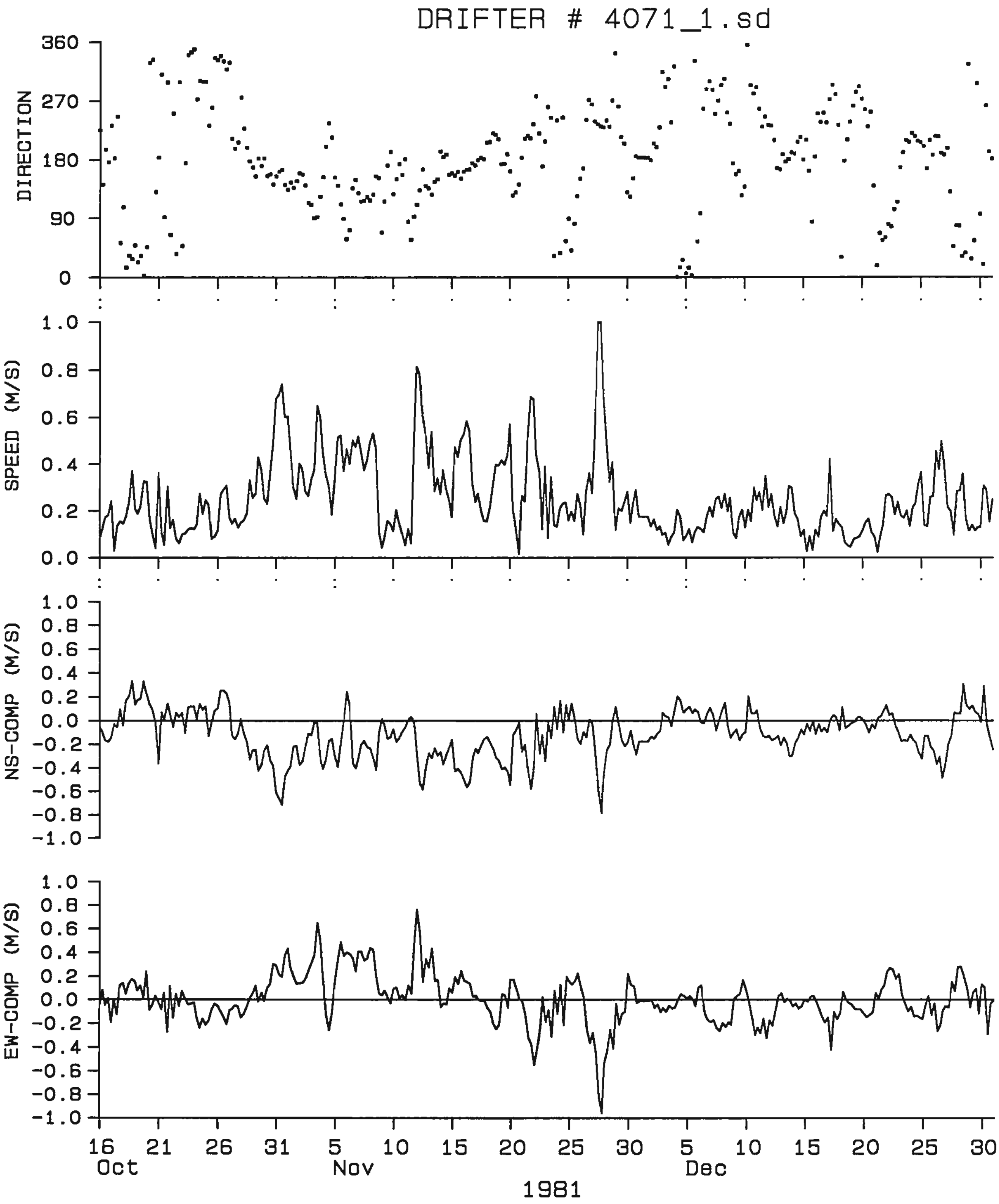
OF DRIFTER VELOCITIES


DRIFTER # 4070.sd
DIRECTION
360
270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
Aug
Sept
Oct
1981

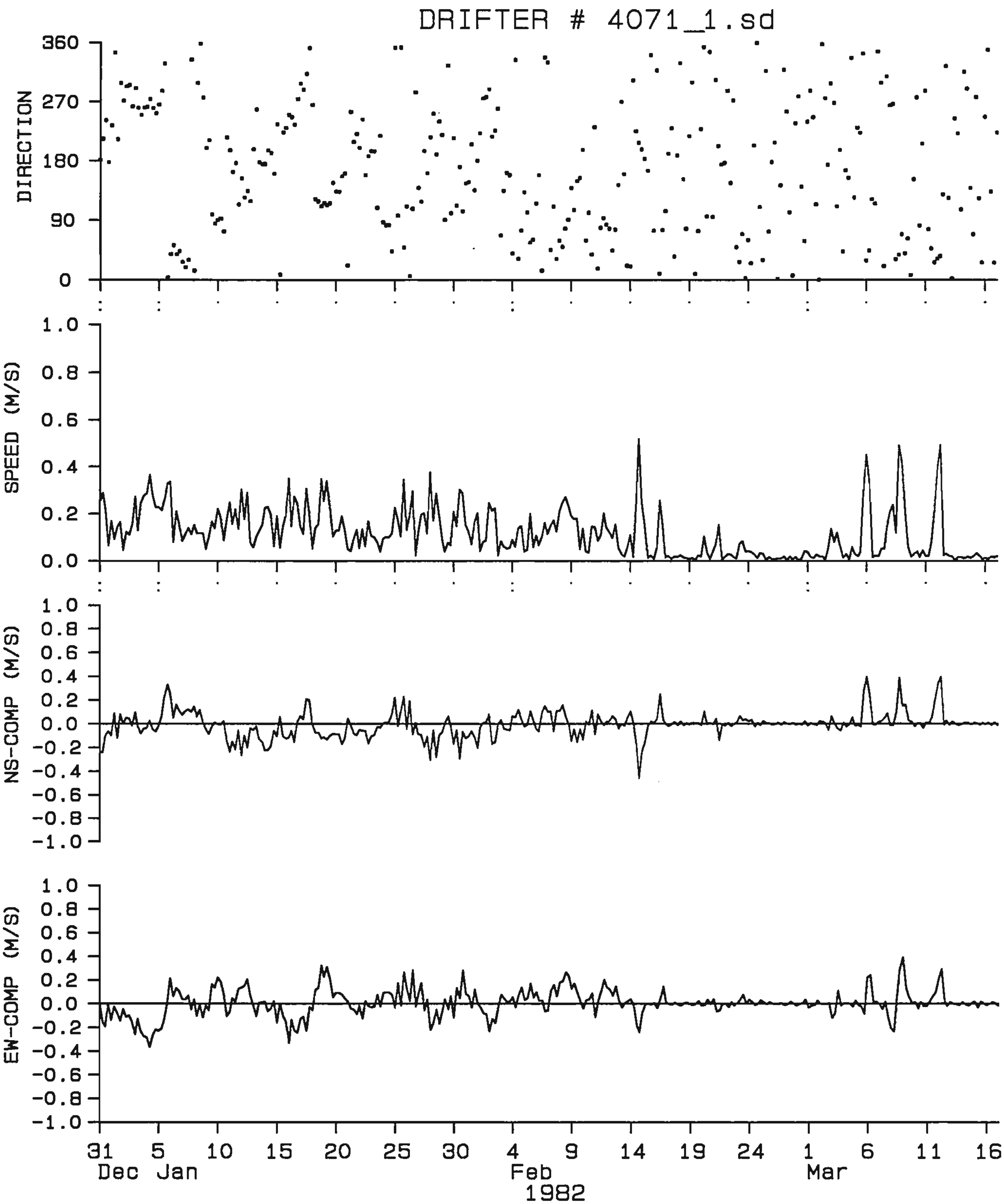

DRIFTER # 4070.sd
DIRECTION
360
270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
16 21 26 31 5 10 15 20 25 30 5 10 15 20 25 30
Oct
Nov
Dec
1981

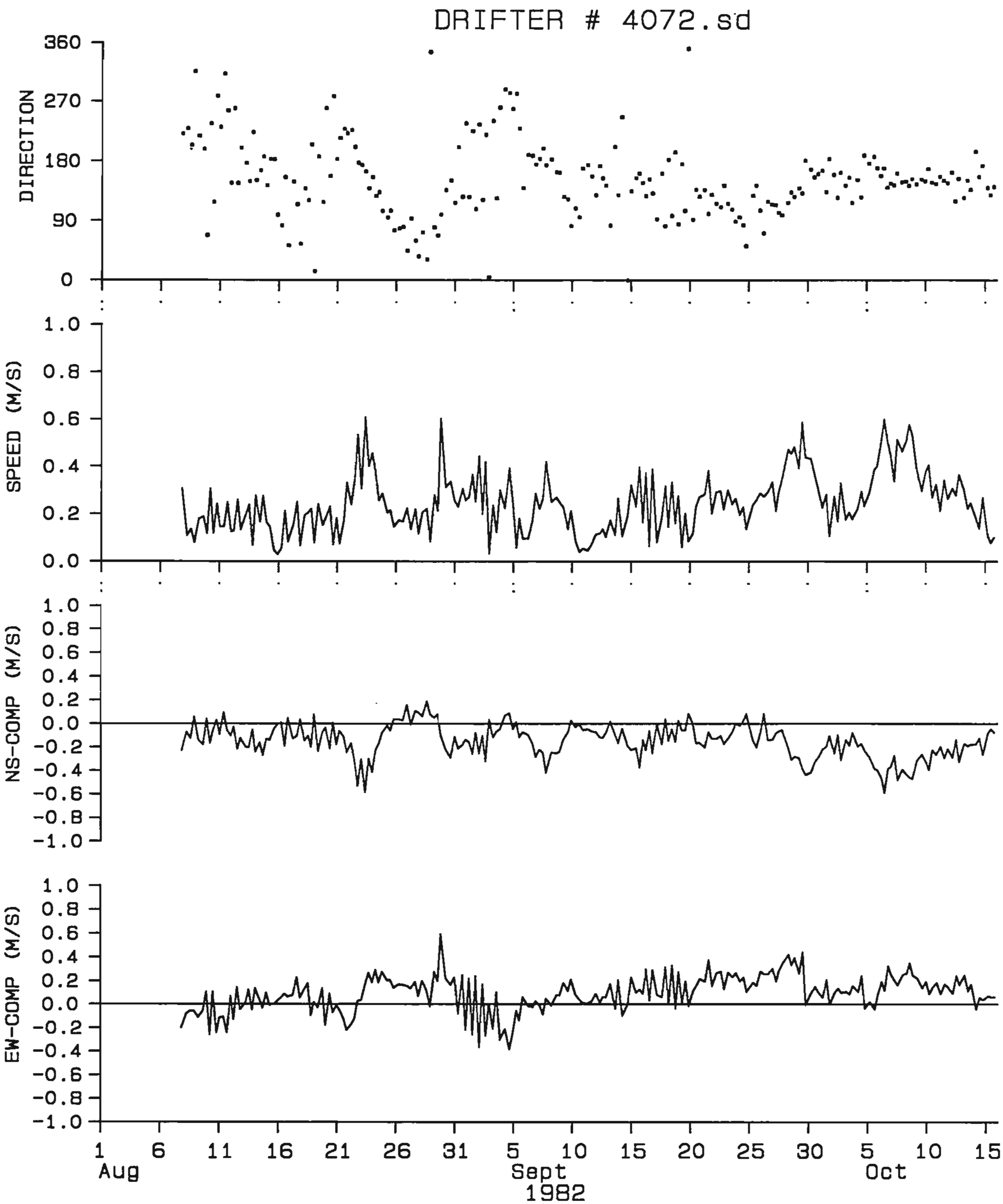

DRIFTER # 4070.sd
DIRECTION
360
270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
31 5 10 15 20 25 30 4 9 14 19 24 1 6 11 16
Dec Jan Feb Mar
1982


DRIFTER # 4071_1.sd
DIRECTION
360
270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
Aug
Sept
Oct
1981



DRIFTER # 4071_1.sd
DIRECTION
0
90
180
270
360
SPEED (M/S)
NS-COMP (M/S)
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
16 21 26 31 5 10 15 20 25 30 5 10 15 20 25 30
Oct
Nov
Dec
1981


DRIFTER # 4071_1.sd
DIRECTION
360
270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
31 5 10 15 20 25 30 4 9 14 19 24 1 6 11 16
Dec Jan
Feb
Mar
1982


DRIFTER # 4072.sd
DIRECTION
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270
180
90
0
SPEED (M/S)
1.0
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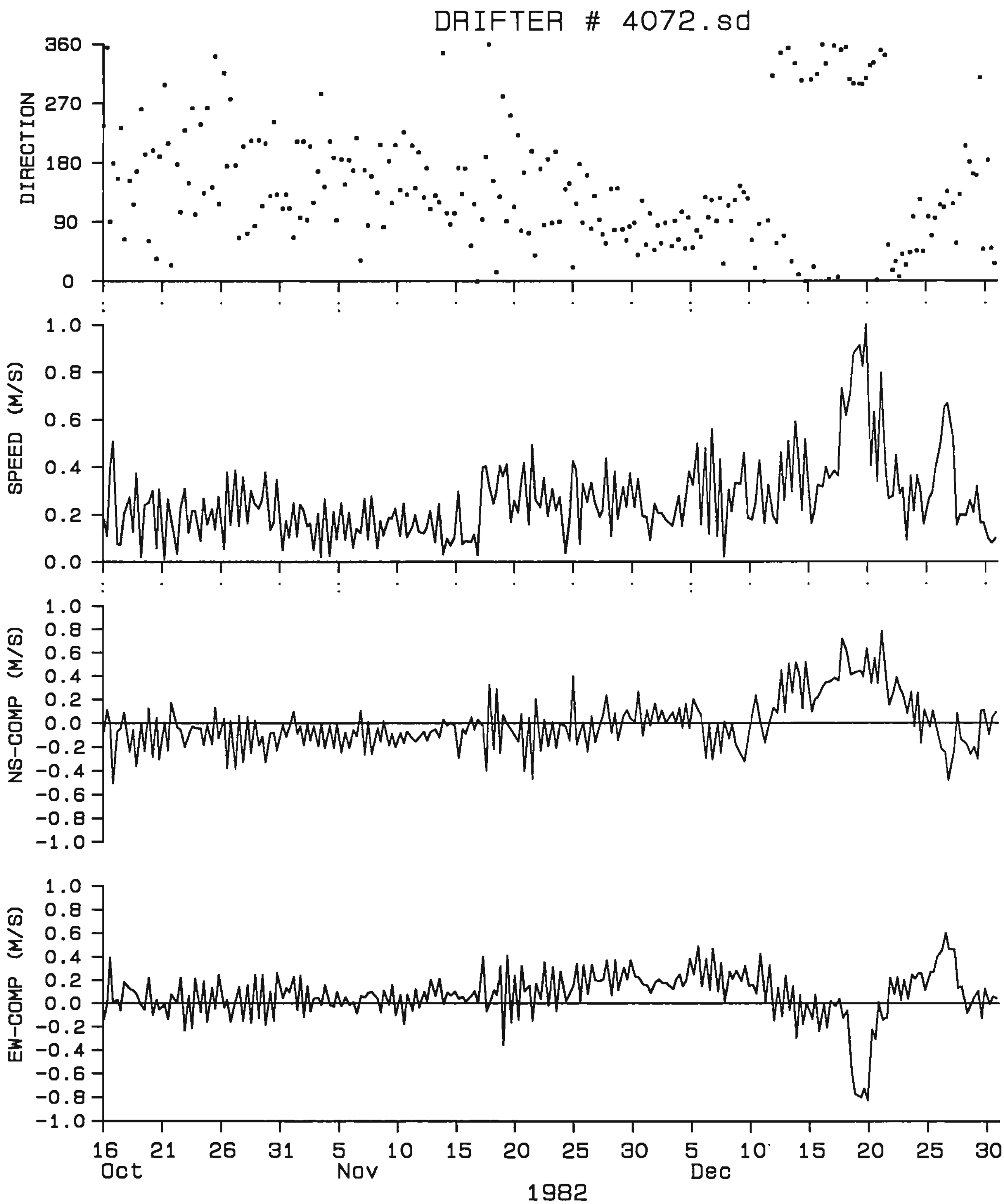
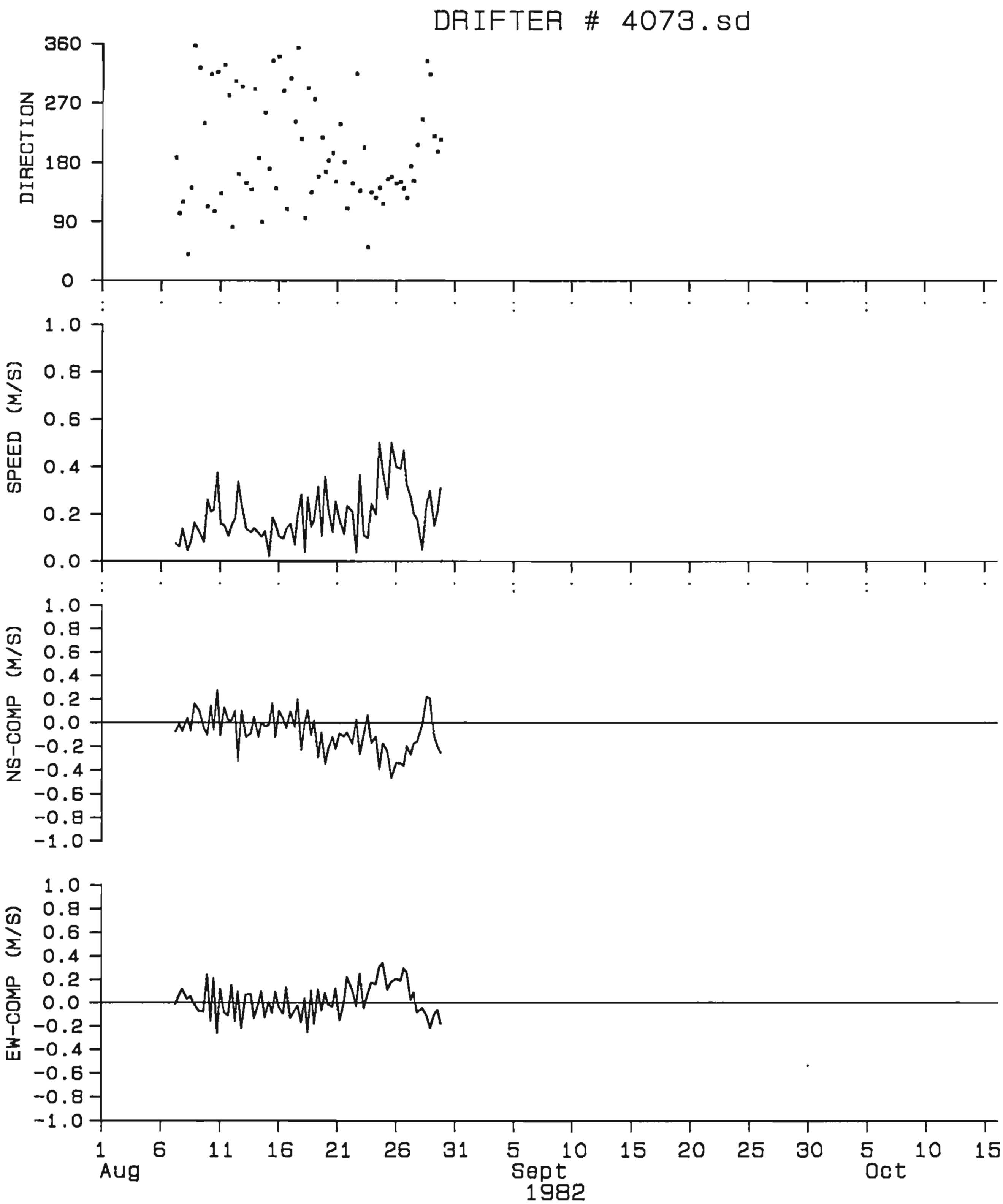
0.6
0.4
0.2
0.0
NS-COMP (M/S)
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
Aug
Sept
Oct
1982


DRIFTER # 4072.sd
DIRECTION
360
270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
16 21 26 31 5 10 15 20 25 30 5 10 15 20 25 30
Oct
Nov
Dec
1982


DRIFTER # 4073.sd
DIRECTION
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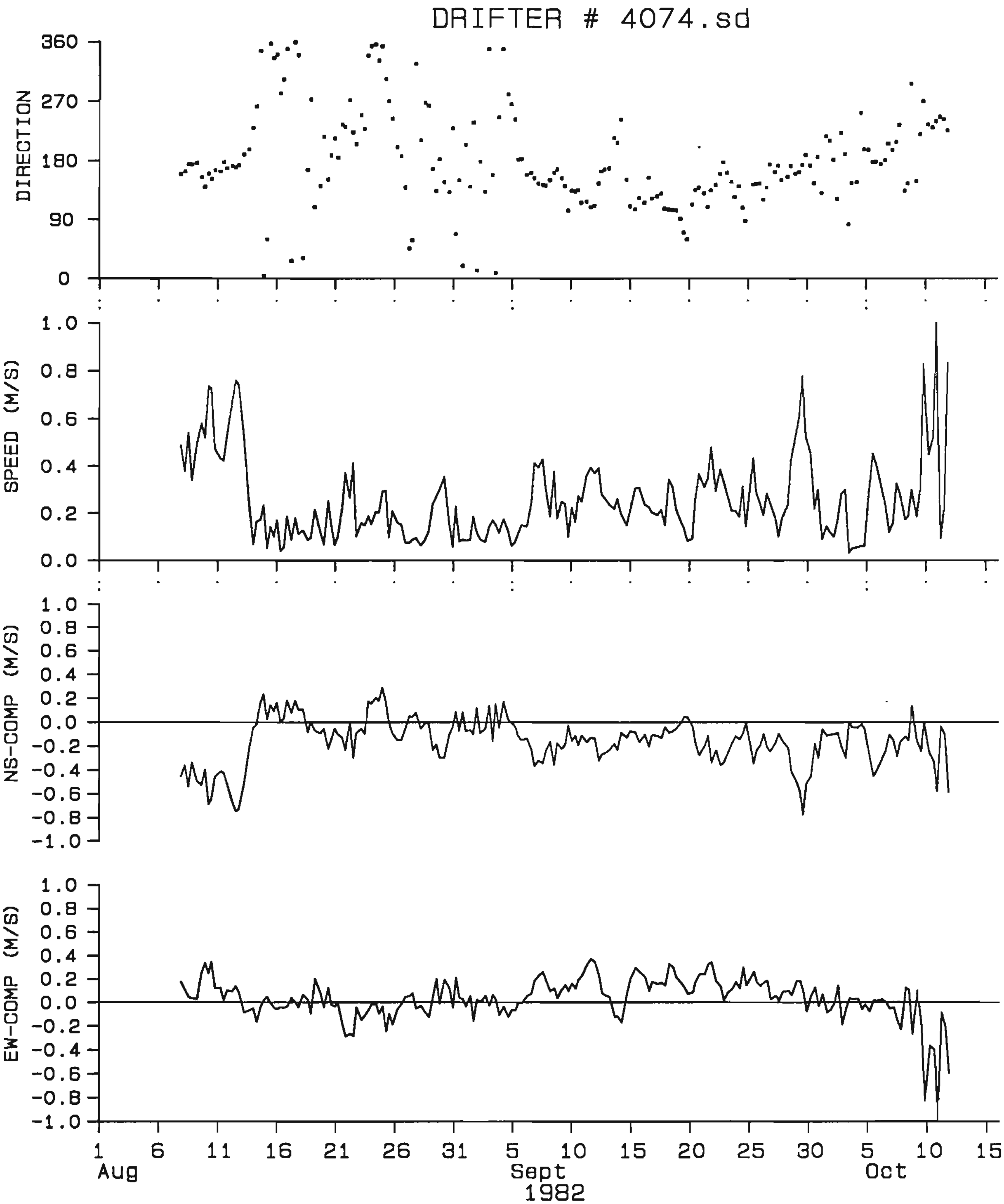
270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
Aug
Sept
1982
Oct


DRIFTER # 4074.sd
DIRECTION
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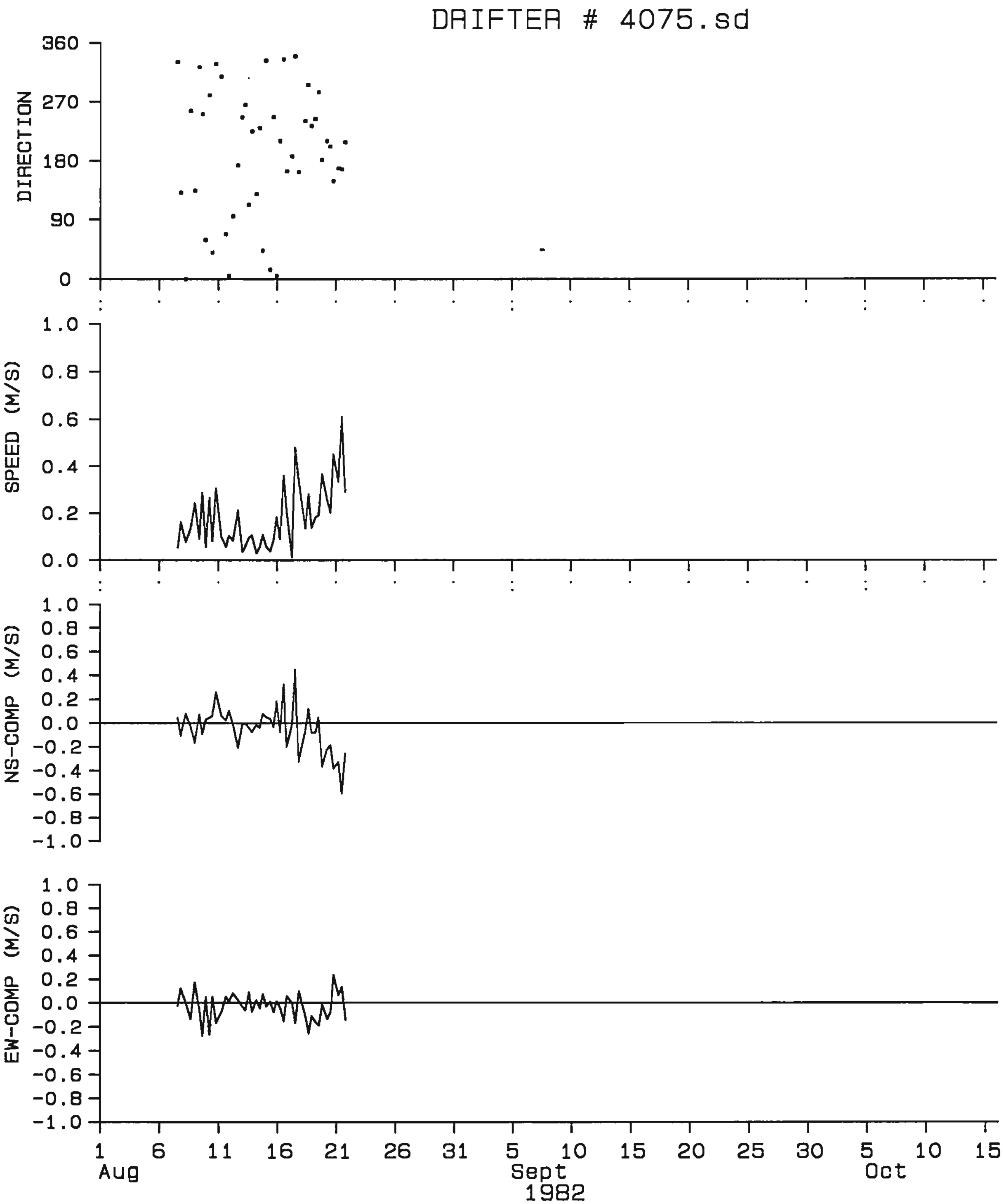
270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
EW-COMP (M/S)
-0.2
-0.4
-0.6
-0.8
-1.0
1
6
11
16
21
26
31
5
10
15
20
25
30
5
10
15
Aug
Sept
Oct
1982


DRIFTER # 4075.sd
DIRECTION
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270
180
90
0
SPEED (M/S)
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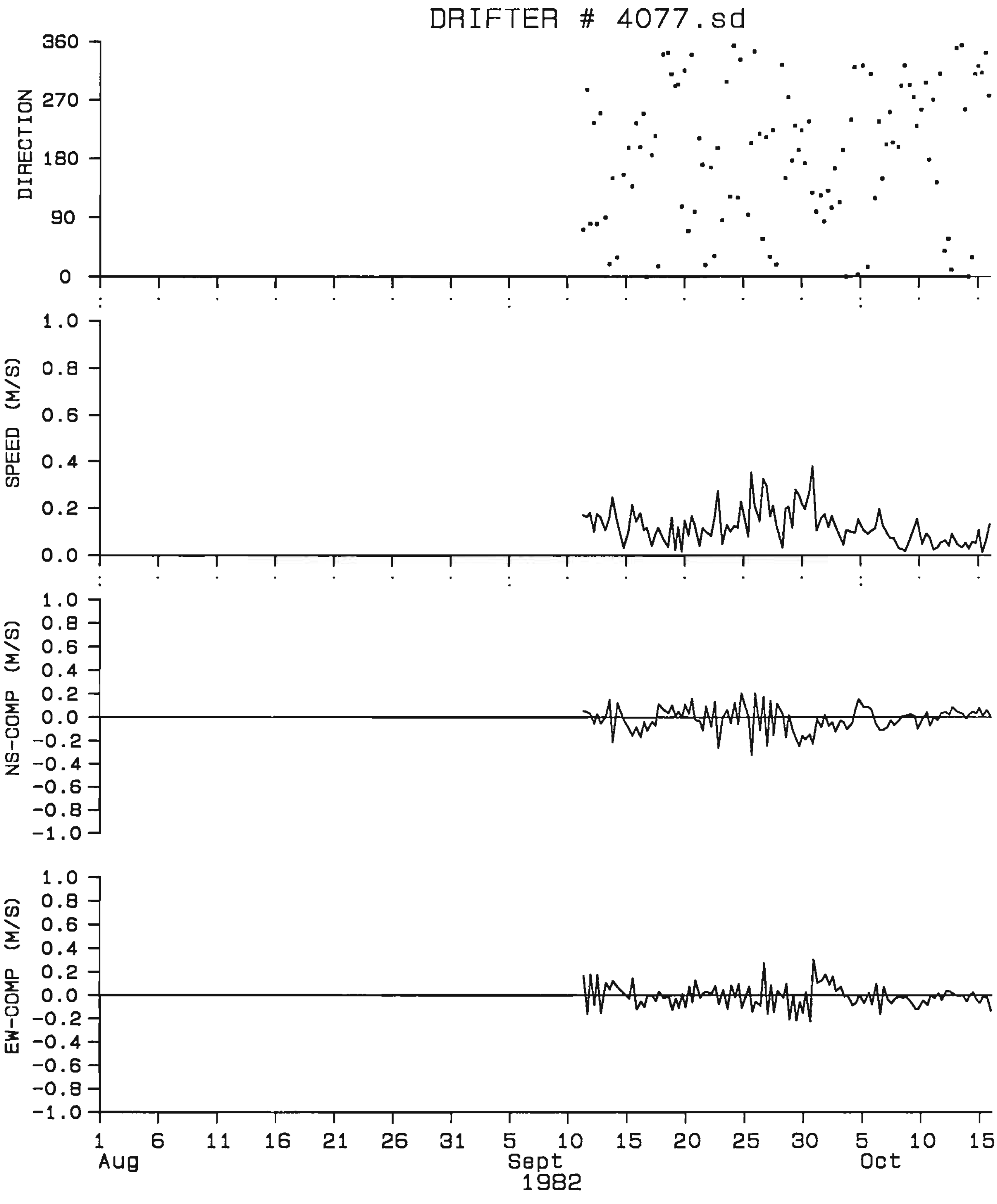
0.6
0.4
0.2
0.0
NS-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
Aug
Sept
1982
Oct


DRIFTER # 4077.sd
DIRECTION
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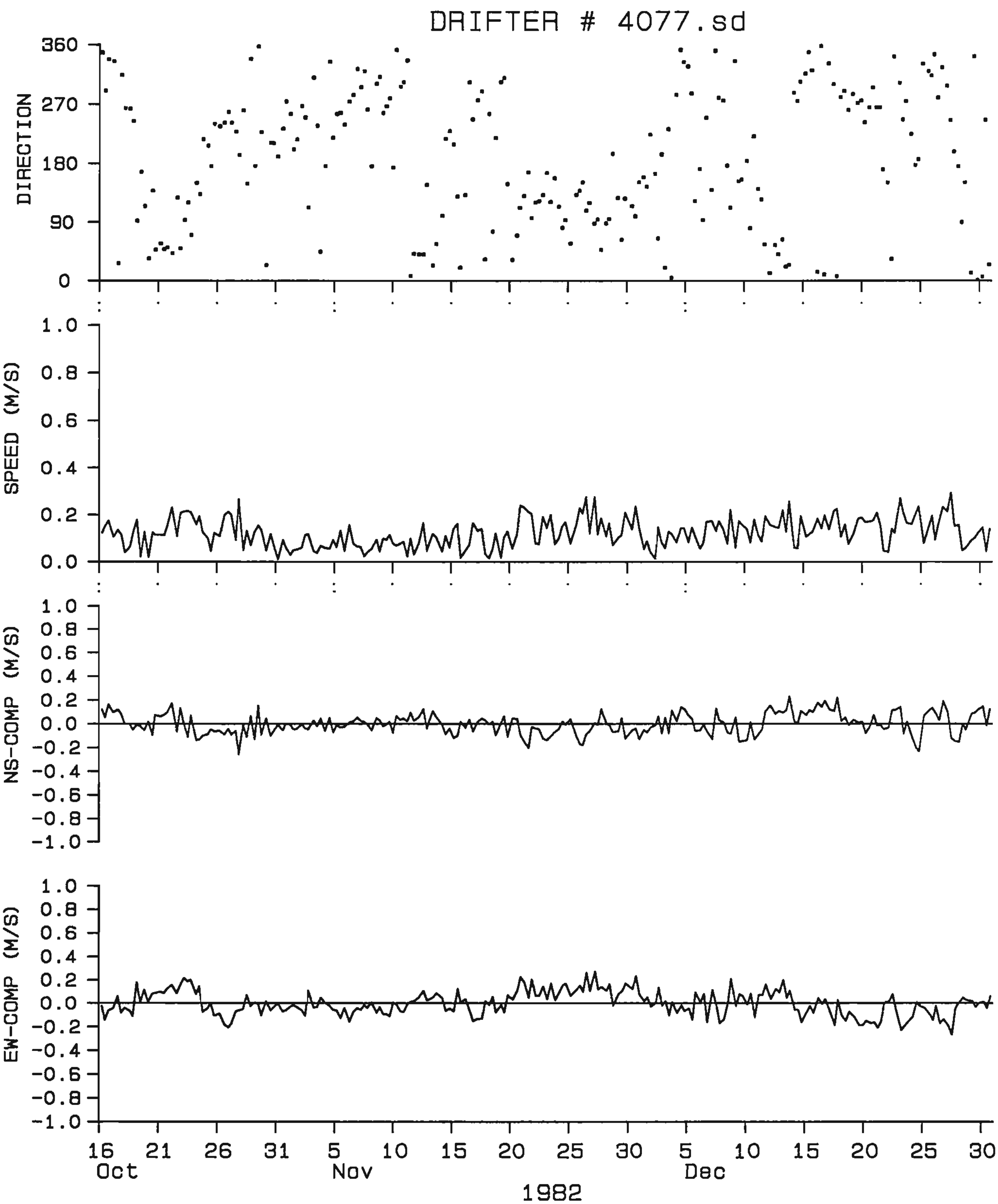
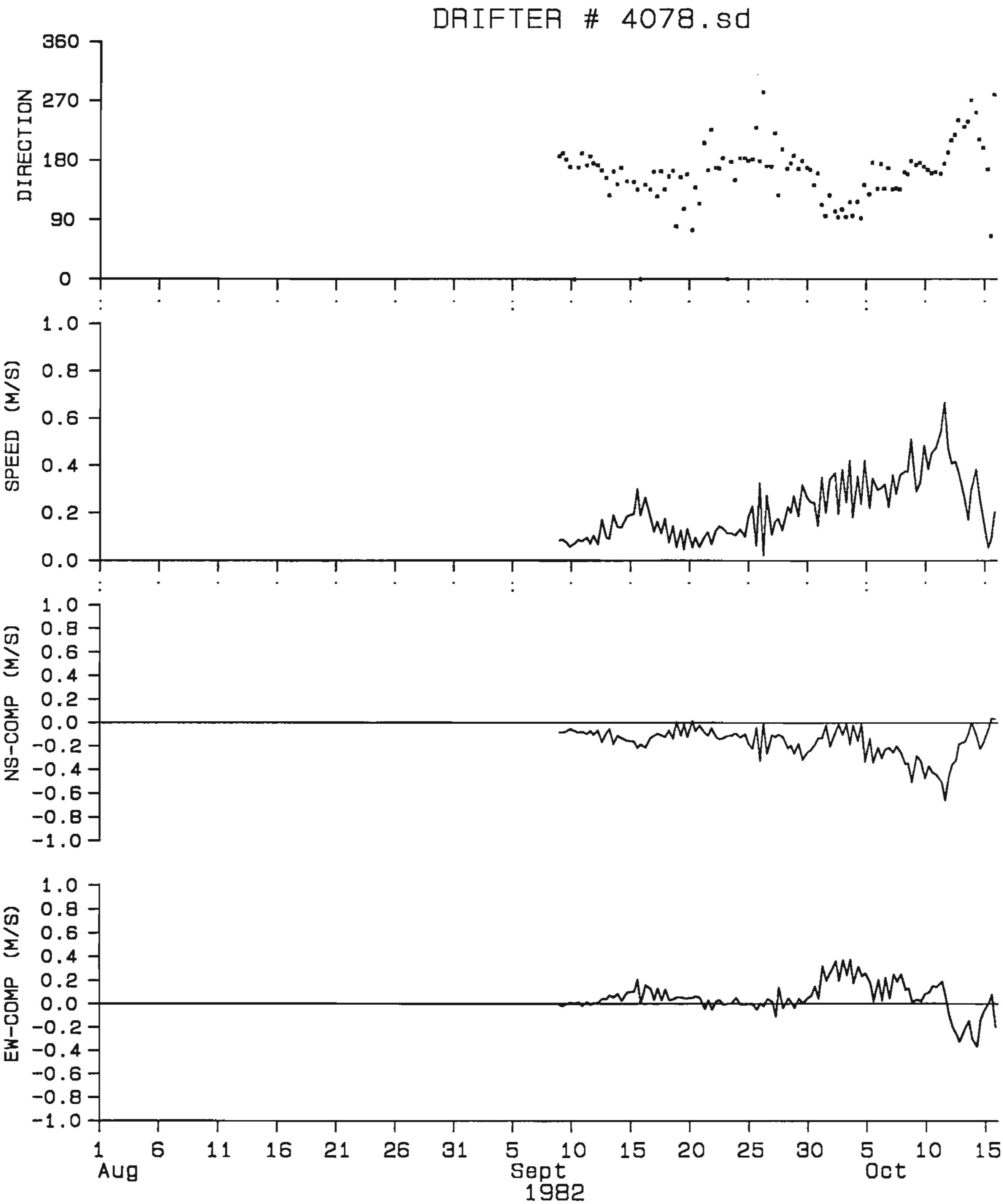
270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
Aug
Sept
1982
Oct


DRIFTER # 4077.sd
DIRECTION
360
270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
16 21 26 31 5 10 15 20 25 30 5 10 15 20 25 30
Oct
Nov
Dec
1982


DRIFTER # 4078.sd
DIRECTION
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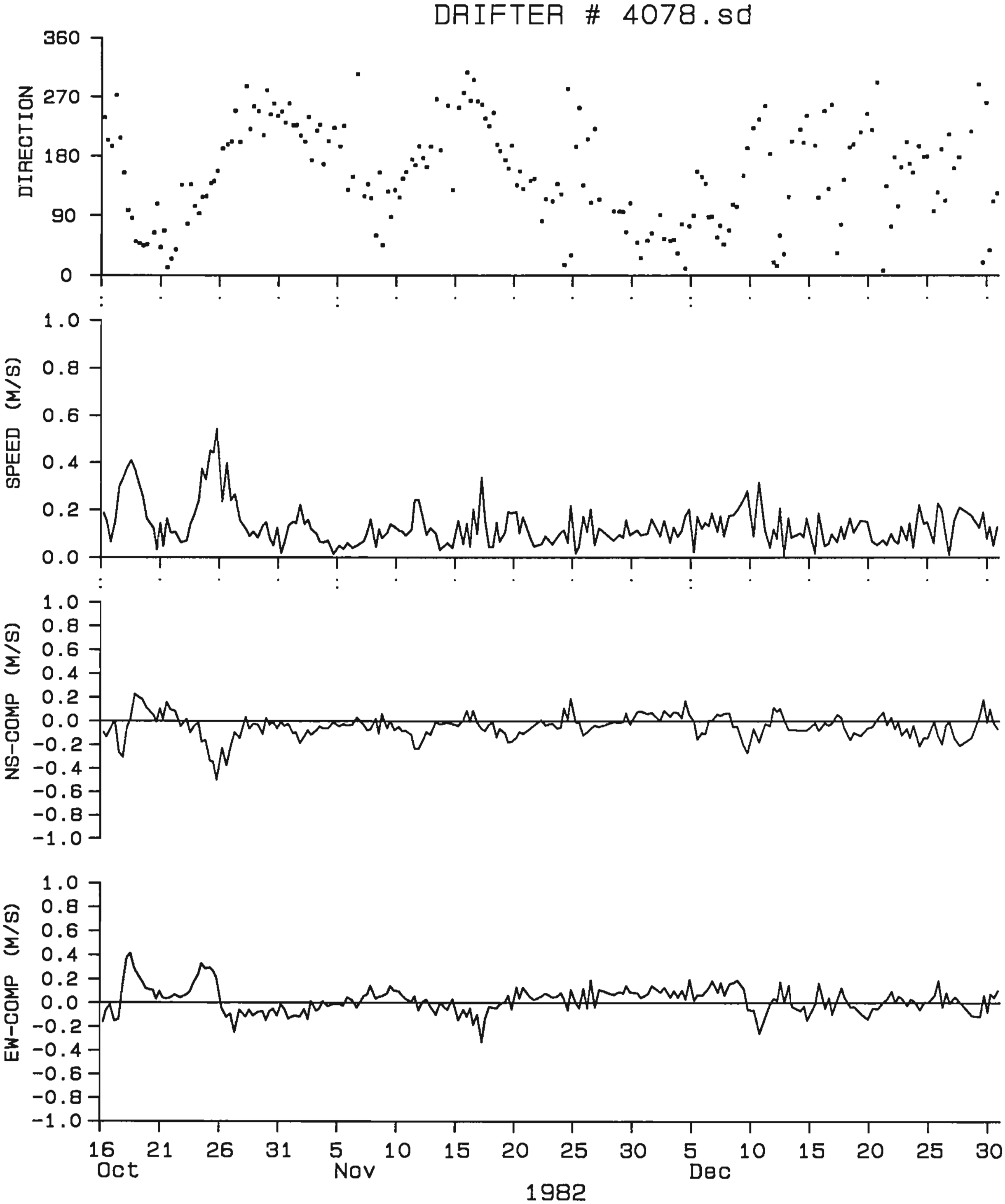
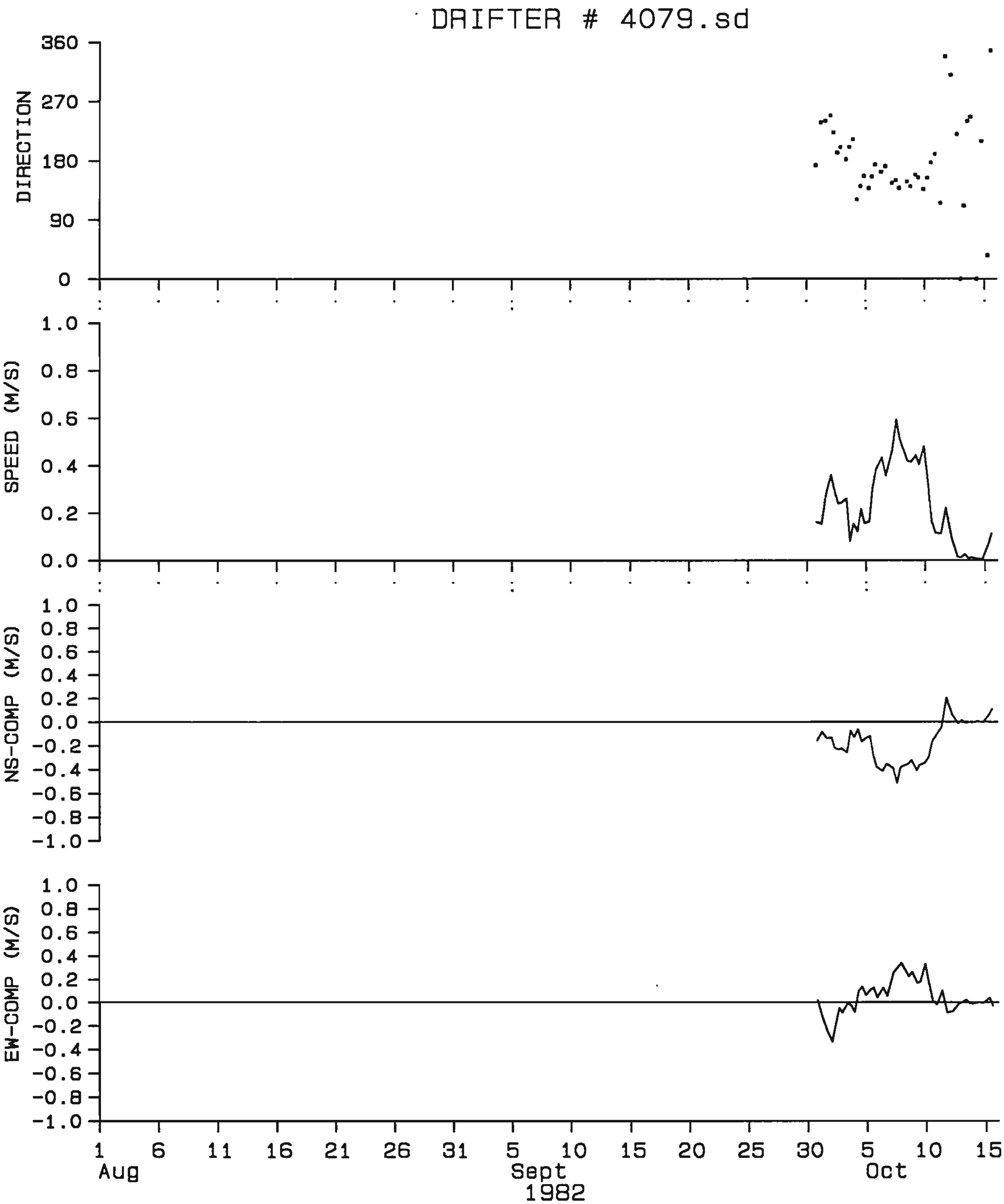
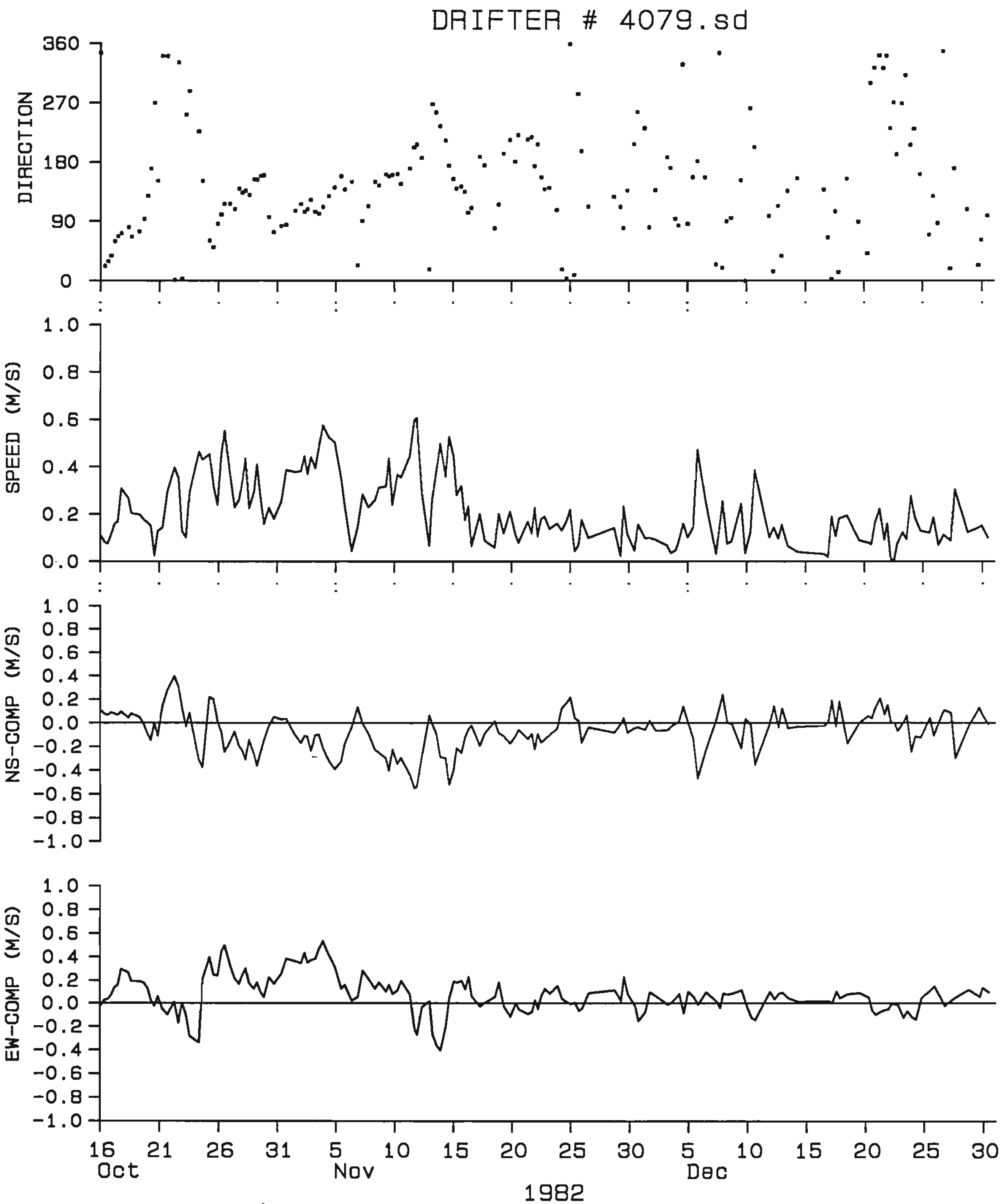
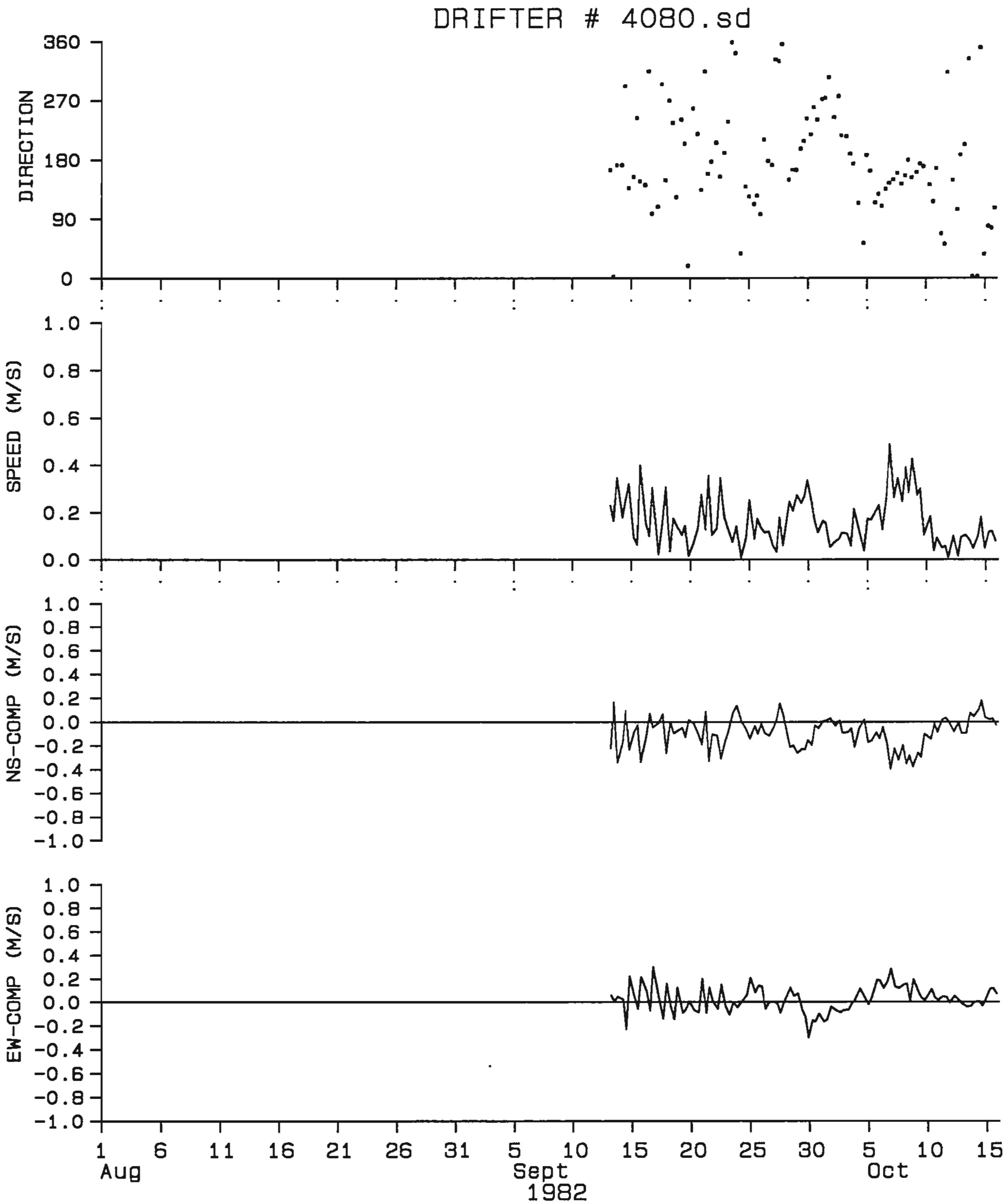
270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
Aug
Sept
1982
Oct


DRIFTER # 4078.sd
DIRECTION
360
270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
16 21 26 31 5 10 15 20 25 30 5 10 15 20 25 30
Oct
Nov
Dec
1982


DRIFTER # 4079.sd
DIRECTION
360
270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
Aug
Sept
Oct
1982


DRIFTER # 4079.sd
DIRECTION
360
270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
16 21 26 31 5 10 15 20 25 30 5 10 15 20 25 30
Oct
Nov
Dec
1982


DRIFTER # 4080.sd
DIRECTION
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270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
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-0.6
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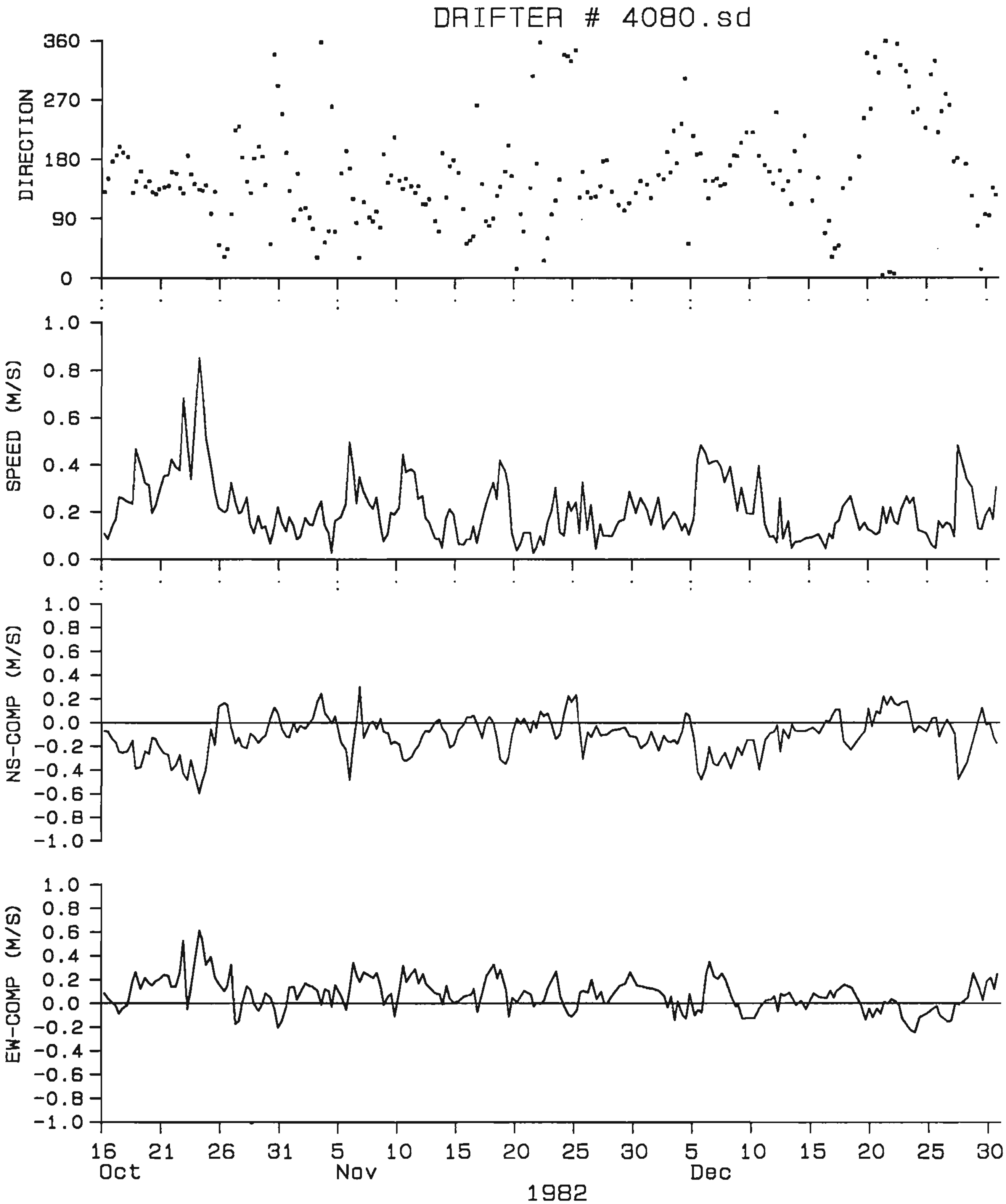
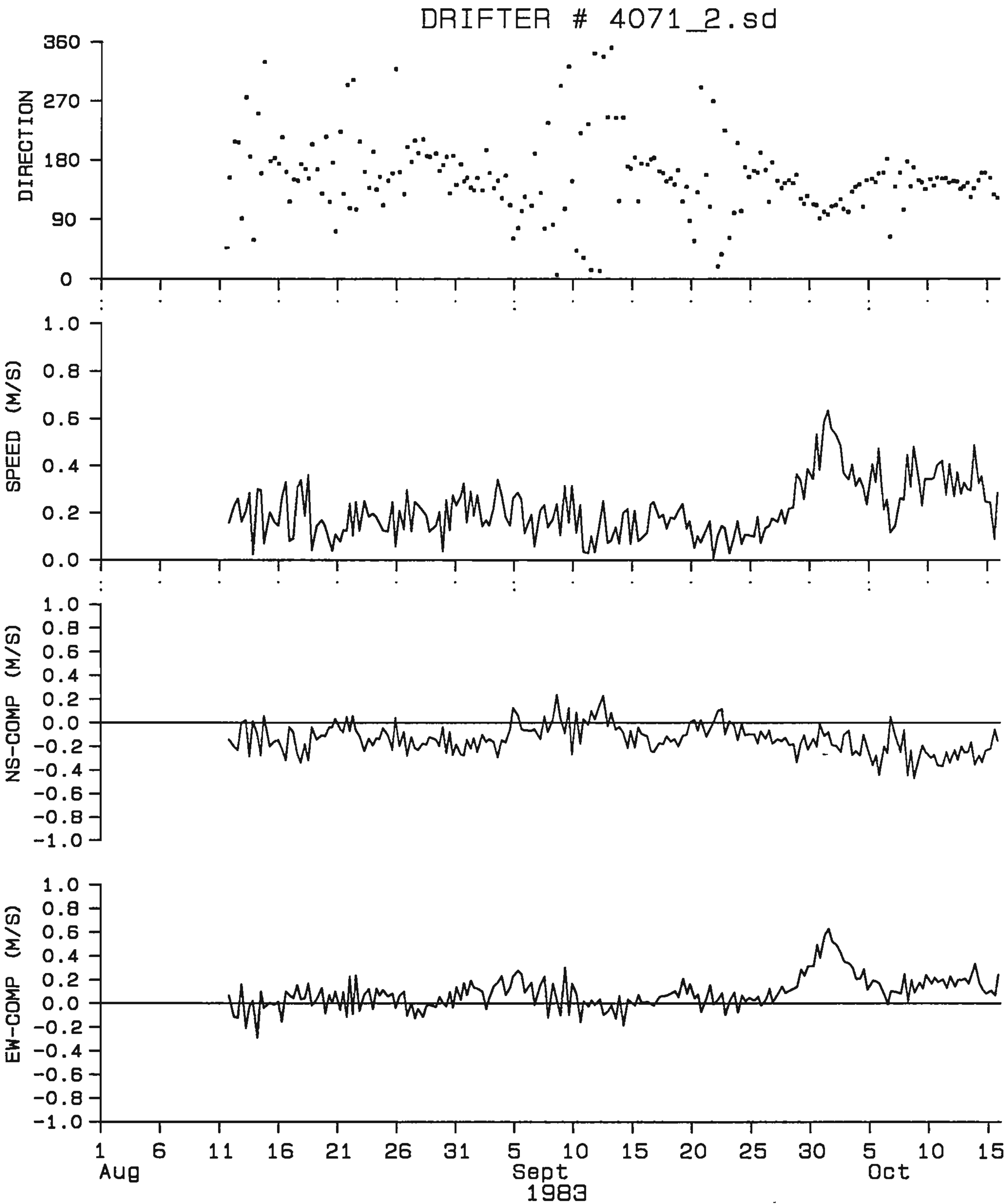
-1.0
1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
Aug
Sept
Oct
1982


DRIFTER # 4080.sd
DIRECTION
360
270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
EW-COMP (M/S)
-0.2
-0.4
-0.6
-0.8
-1.0
16 21 26 31 5 10 15 20 25 30 5 10 15 20 25 30
Oct
Nov
Dec
1982


DRIFTER # 4071_2.sd
DIRECTION
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270
180
90
0
SPEED (M/S)
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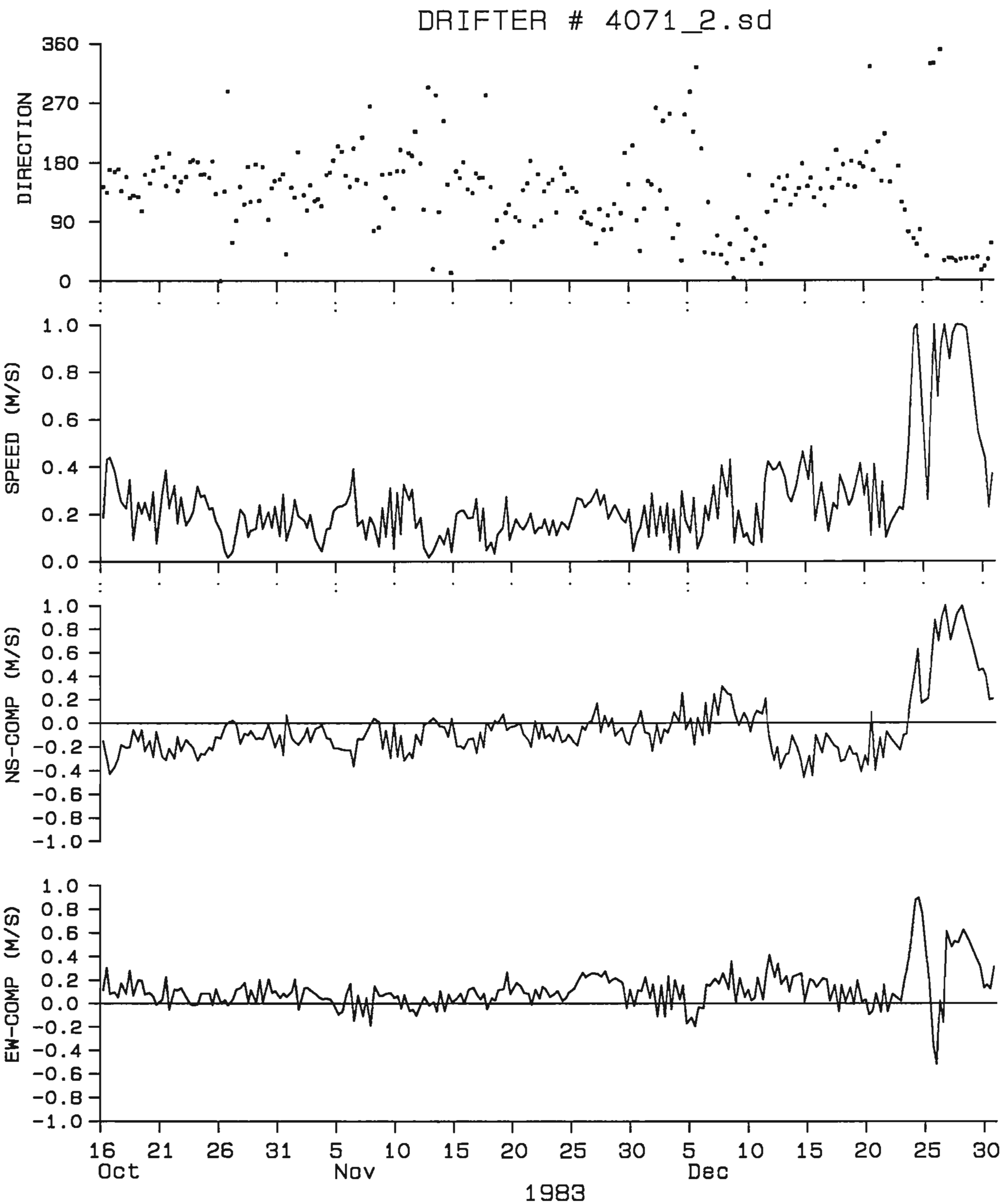
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
Aug
Sept
Oct
1983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DIRECTION
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270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
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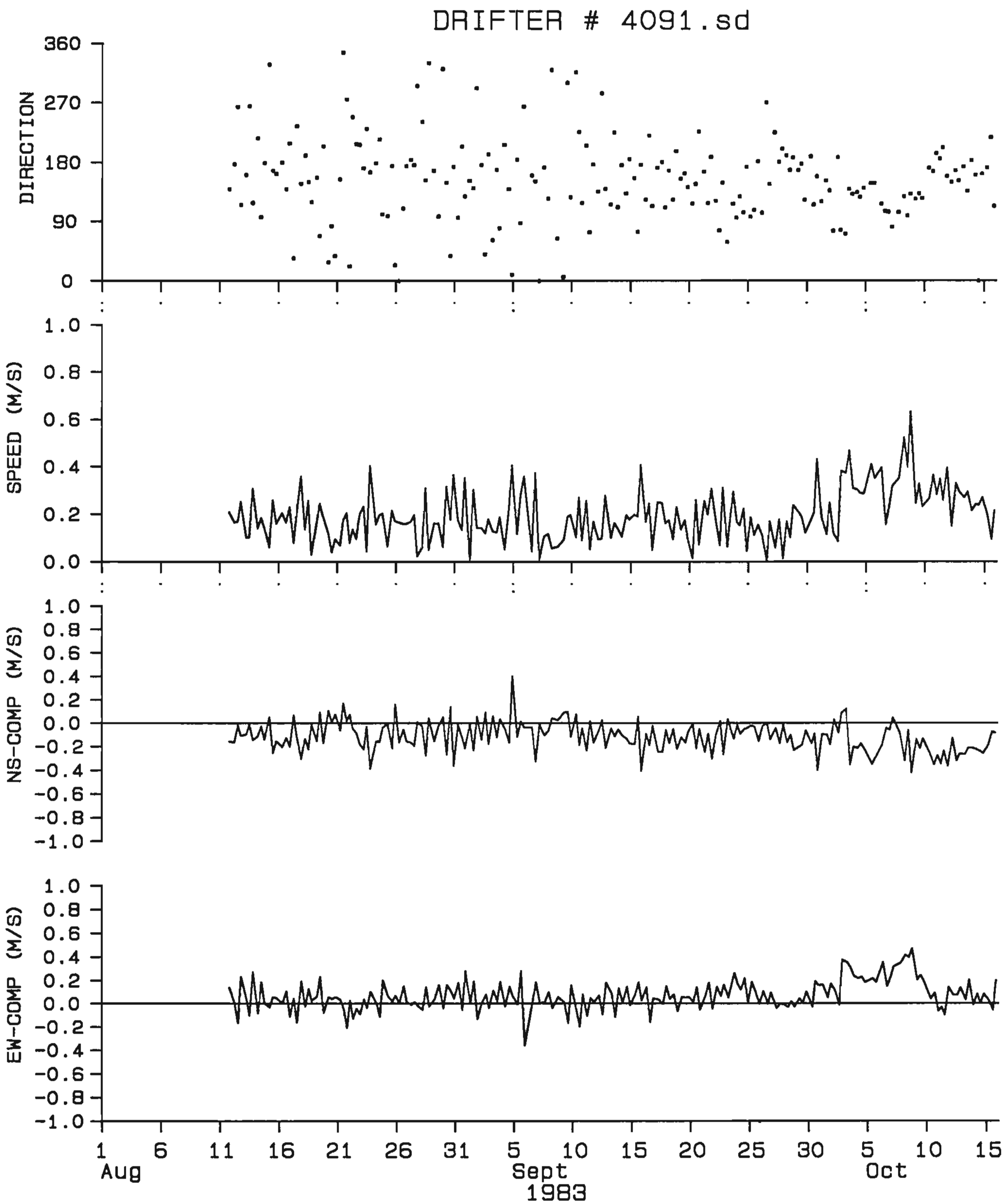
-0.6
-0.8
-1.0
16 21 26 31 5 10 15 20 25 30 5 10 15 20 25 30
Oct
Nov
Dec
1983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DIRECTION
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270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
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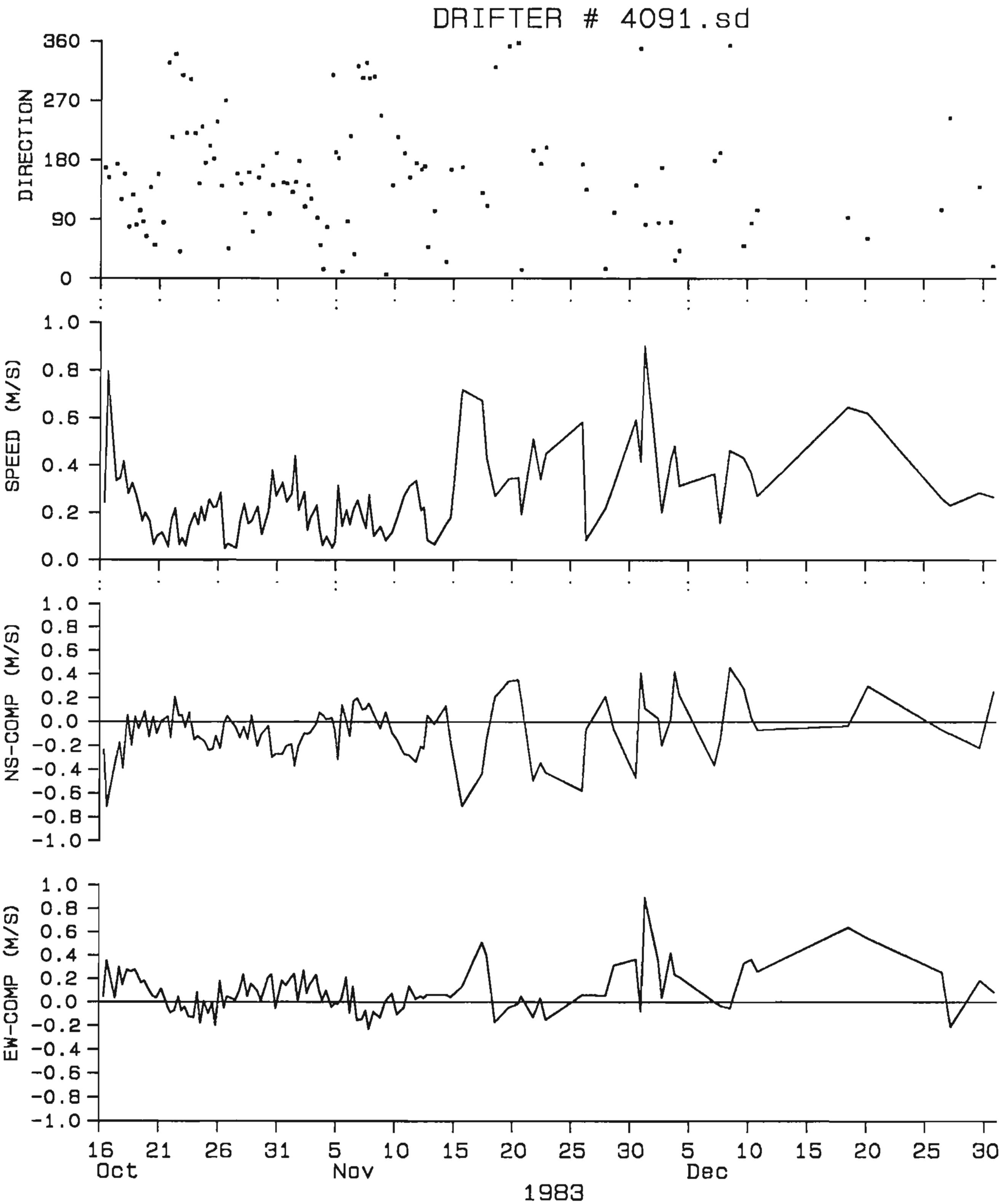
-0.4
-0.6
-0.8
-1.0
1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
Aug
Sept
1983
Oct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DIRECTION
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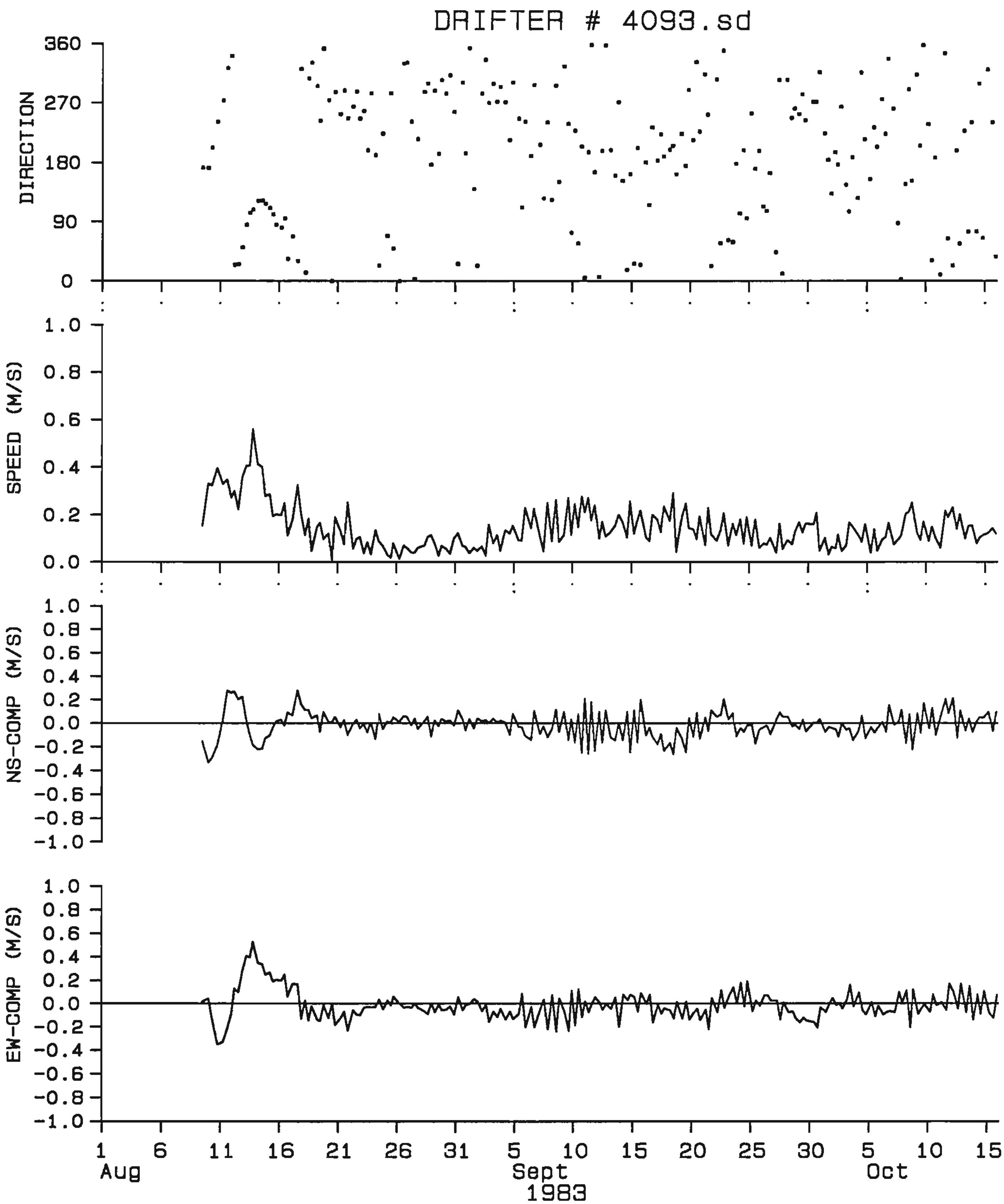
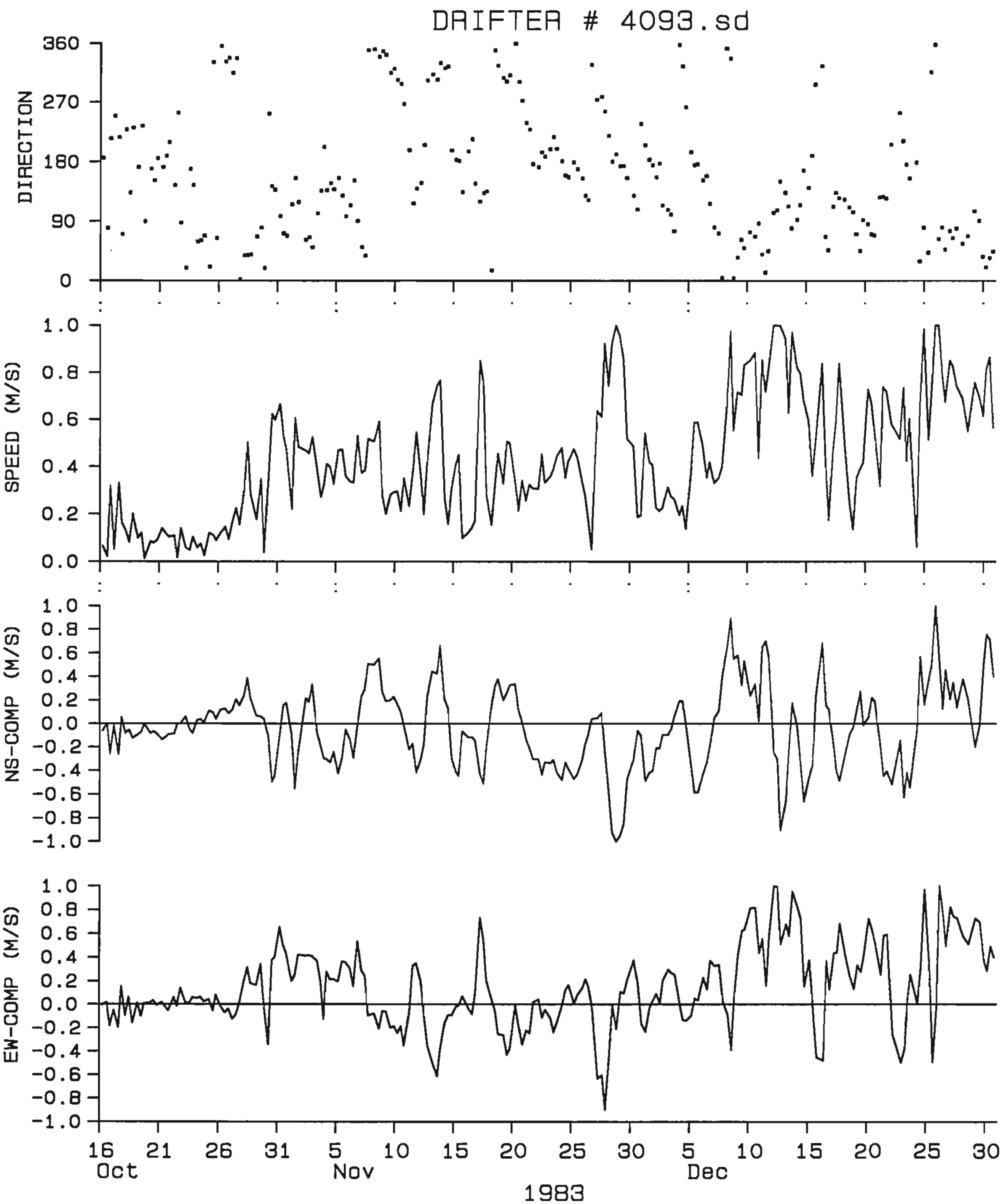
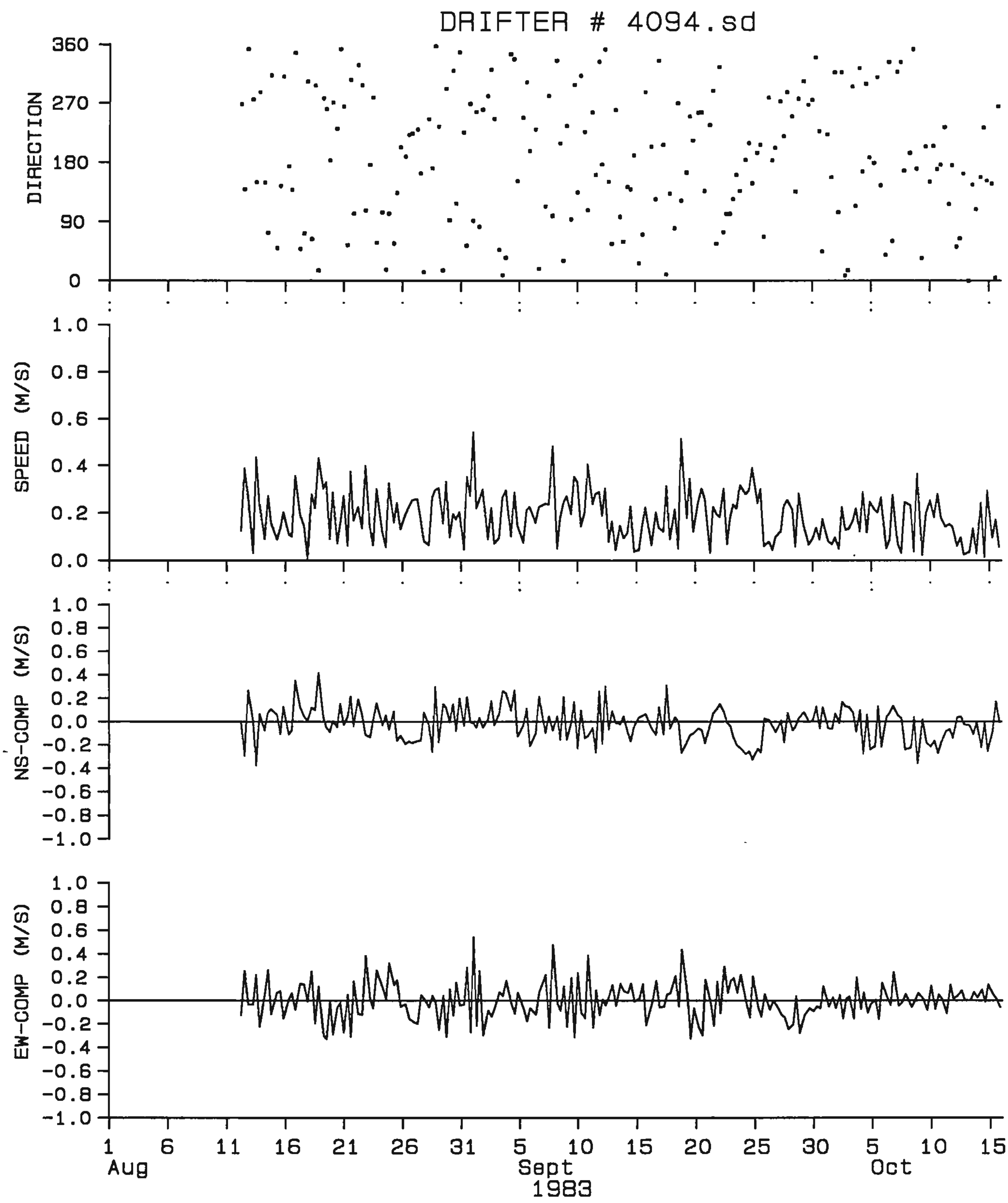
270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
16 21 26 31 5 10 15 20 25 30 5 10 15 20 25 30
Oct
Nov
Dec
1983


DRIFTER # 4093.sd
DIRECTION
360
270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
Aug
Sept
Oct
1983



DRIFTER # 4093.sd
DIRECTION
360
270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
EW-COMP (M/S)
-0.2
-0.4
-0.6
-0.8
-1.0
16 21 26 31 5 10 15 20 25 30 5 10 15 20 25 30
Oct
Nov
Dec
1983


DRIFTER # 4094.sd
DIRECTION
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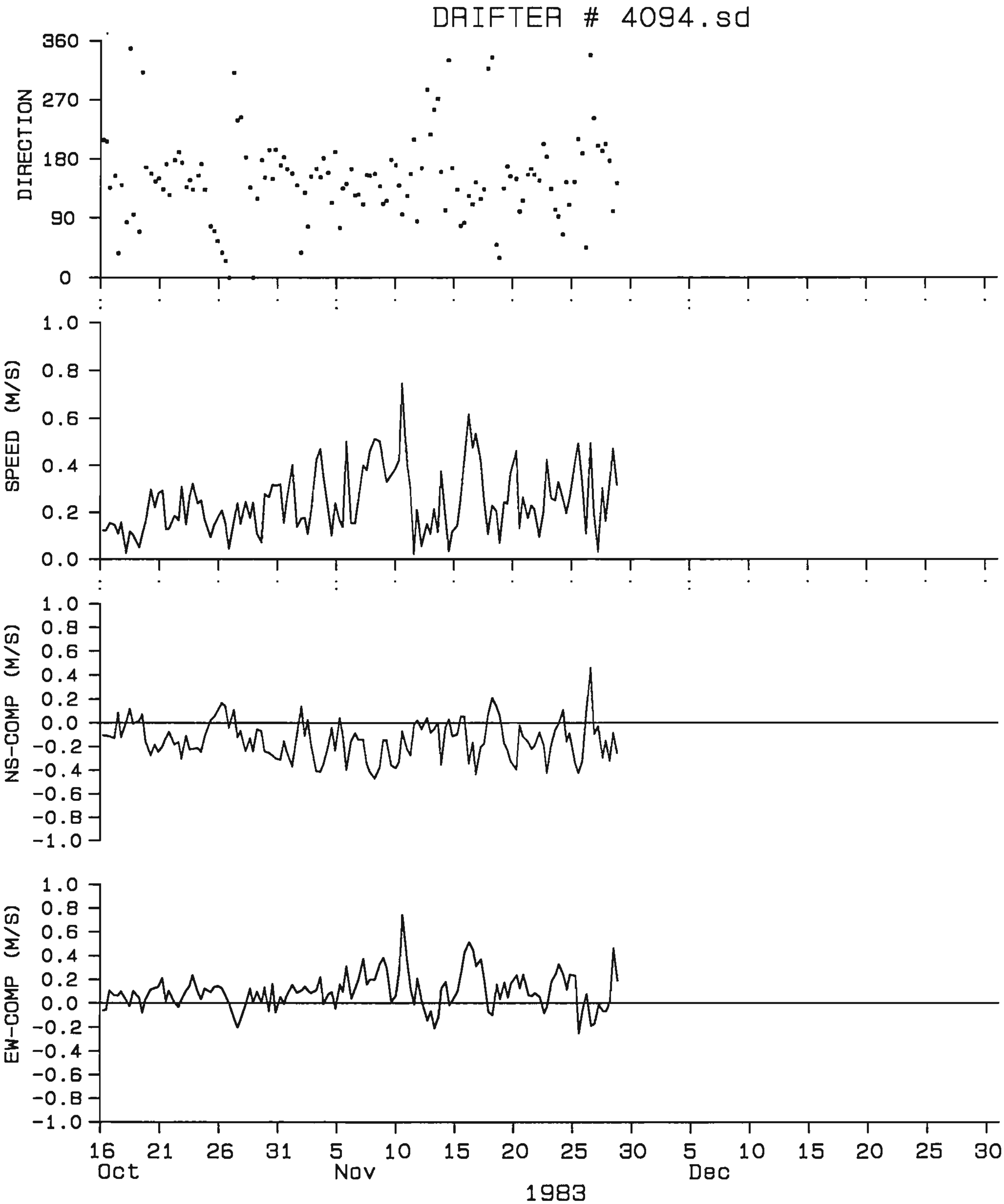
270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
Aug
Sept
Oct
1983


DRIFTER # 4094.sd
DIRECTION
360
270
180
90
0
SPEED (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
NS-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
EW-COMP (M/S)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
16 21 26 31 5 10 15 20 25 30 5 10 15 20 25 30
Oct
Nov
Dec
1983

4070 Drifter Velocity Statistics
start date is 1981 10 9 12 0 0.0
stop date is 1982 3 31 16 0 0.0

QUANTITY	UNITS	MEAN	STD.DEV.	MAXIMUM	MINIMUM
speed	m/s	0.215	0.146	0.905	0.002
direction				359.9	0.2
ew_comp	m/s	0.049	0.157	0.693	-0.377
ns_comp	m/s	-0.104	0.173	0.501	-0.750

4071_1 Drifter Velocity Statistics
start date is 1981 10 9 12 0 0.0
stop date is 1982 3 21 4 0 0.0

QUANTITY	UNITS	MEAN	STD.DEV.	MAXIMUM	MINIMUM
speed	m/s	0.175	0.155	1.238	0.001
direction				359.5	0.3
ew_comp	m/s	0.007	0.160	0.761	-0.959
ns_comp	m/s	-0.059	0.161	0.541	-0.783

4072 Drifter Velocity Statistics
start date is 1982 8 7 14 51 51.0
stop date is 1982 12 30 18 51 51.0

QUANTITY	UNITS	MEAN	STD.DEV.	MAXIMUM	MINIMUM
speed	m/s	0.232	0.141	1.001	0.006
direction				359.5	0.4
ew_comp	m/s	0.083	0.164	0.604	-0.807
ns_comp	m/s	-0.072	0.186	0.774	-0.580

4073 Drifter Velocity Statistics
start date is 1982 8 6 21 50 39.0
stop date is 1982 8 29 17 50 39.0

QUANTITY	UNITS	MEAN	STD.DEV.	MAXIMUM	MINIMUM
speed	m/s	0.167	0.110	0.487	0.007
direction				356.5	1.6
ew_comp	m/s	0.023	0.117	0.334	-0.228
ns_comp	m/s	-0.077	0.141	0.238	-0.450

4074 Drifter Velocity Statistics
start date is 1982 8 7 16 38 42.0
stop date is 1982 10 11 18 38 42.0

QUANTITY	UNITS	MEAN	STD.DEV.	MAXIMUM	MINIMUM
speed	m/s	0.245	0.164	1.083	0.016
direction				358.6	0.8
ew_comp	m/s	0.036	0.161	0.371	-0.930
ns_comp	m/s	-0.157	0.187	0.280	-0.750

4075 Drifter Velocity Statistics
start date is 1982 8 7 10 0 6.0
stop date is 1982 8 21 18 0 6.0

QUANTITY	UNITS	MEAN	STD.DEV.	MAXIMUM	MINIMUM
speed	m/s	0.153	0.116	0.599	0.009
direction				359.0	0.8
ew_comp	m/s	-0.027	0.091	0.221	-0.261
ns_comp	m/s	-0.049	0.160	0.378	-0.584

4077 Drifter Velocity Statistics
start date is 1982 9 11 4 43 13.0
stop date is 1982 12 30 18 43 13.0

QUANTITY	UNITS	MEAN	STD.DEV.	MAXIMUM	MINIMUM
speed	m/s	0.107	0.058	0.347	0.005
direction				359.8	0.6
ew_comp	m/s	-0.003	0.090	0.280	-0.252
ns_comp	m/s	-0.005	0.082	0.217	-0.318

4078 Drifter Velocity Statistics
start date is 1982 9 8 18 40 32.0
stop date is 1982 12 30 20 40 32.0

QUANTITY	UNITS	MEAN	STD.DEV.	MAXIMUM	MINIMUM
speed	m/s	0.155	0.106	0.652	0.003
direction				359.0	1.6
ew_comp	m/s	0.033	0.111	0.406	-0.359
ns_comp	m/s	-0.087	0.118	0.226	-0.647

4079 Drifter Velocity Statistics
start date is 1982 9 30 12 2 44.0
stop date is 1982 12 30 10 2 44.0

QUANTITY	UNITS	MEAN	STD.DEV.	MAXIMUM	MINIMUM
speed	m/s	0.198	0.138	0.604	0.001
direction				359.4	0.3
ew_comp	m/s	0.068	0.146	0.531	-0.398
ns_comp	m/s	-0.087	0.158	0.392	-0.551

4080 Drifter Velocity Statistics
start date is 1982 9 13 0 1 45.0
stop date is 1982 12 30 18 1 45.0

QUANTITY	UNITS	MEAN	STD.DEV.	MAXIMUM	MINIMUM
speed	m/s	0.187	0.119	0.847	0.002
direction				359.6	0.1
ew_comp	m/s	0.061	0.122	0.606	-0.289
ns_comp	m/s	-0.100	0.143	0.288	-0.592

4071_2 Drifter Velocity Statistics
start date is 1983 8 11 15 25 1.0
stop date is 1983 12 31 17 25 1.0

QUANTITY	UNITS	MEAN	STD.DEV.	MAXIMUM	MINIMUM
speed	m/s	0.227	0.173	1.202	0.003
direction				358.7	0.043
ew_comp	m/s	0.105	0.144	0.892	-0.495
ns_comp	m/s	-0.088	0.206	1.039	-0.469

4091 Drifter Velocity Statistics
start date is 1983 8 11 14 19 59.0
stop date is 1983 12 31 14 19 59.0

QUANTITY	UNITS	MEAN	STD.DEV.	MAXIMUM	MINIMUM
speed	m/s	0.245	0.160	0.892	0.005
direction				359.6	0.1
ew_comp	m/s	0.120	0.176	0.884	-0.335
ns_comp	m/s	-0.088	0.179	0.449	-0.705

4093 Drifter Velocity Statistics
start date is 1983 8 9 6 32 17.0
stop date is 1983 12 31 18 32 17.0

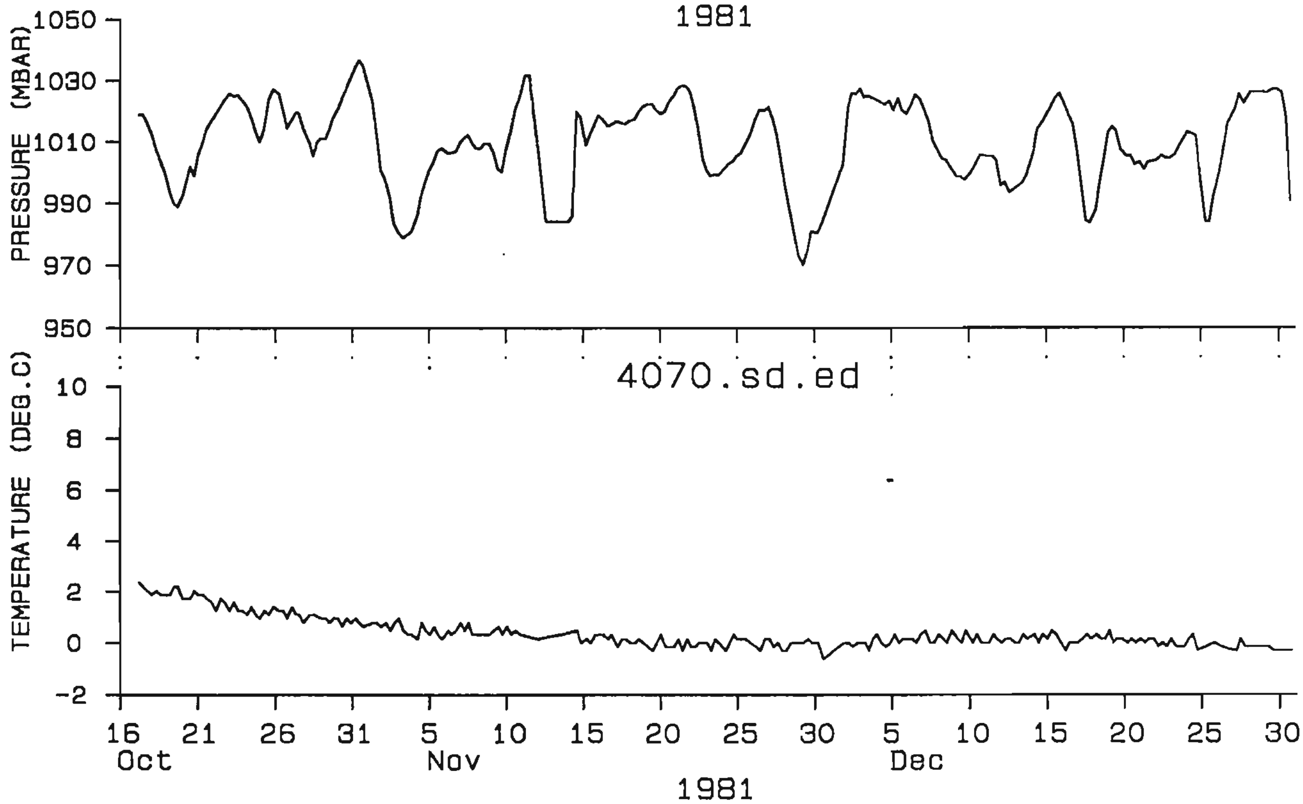
QUANTITY	UNITS	MEAN	STD.DEV.	MAXIMUM	MINIMUM
speed	m/s	0.284	0.245	1.243	0.005
direction				359.8	0.5
ew_comp	m/s	0.069	0.267	1.106	-0.854
ns_comp	m/s	-0.025	0.252	0.976	-1.025

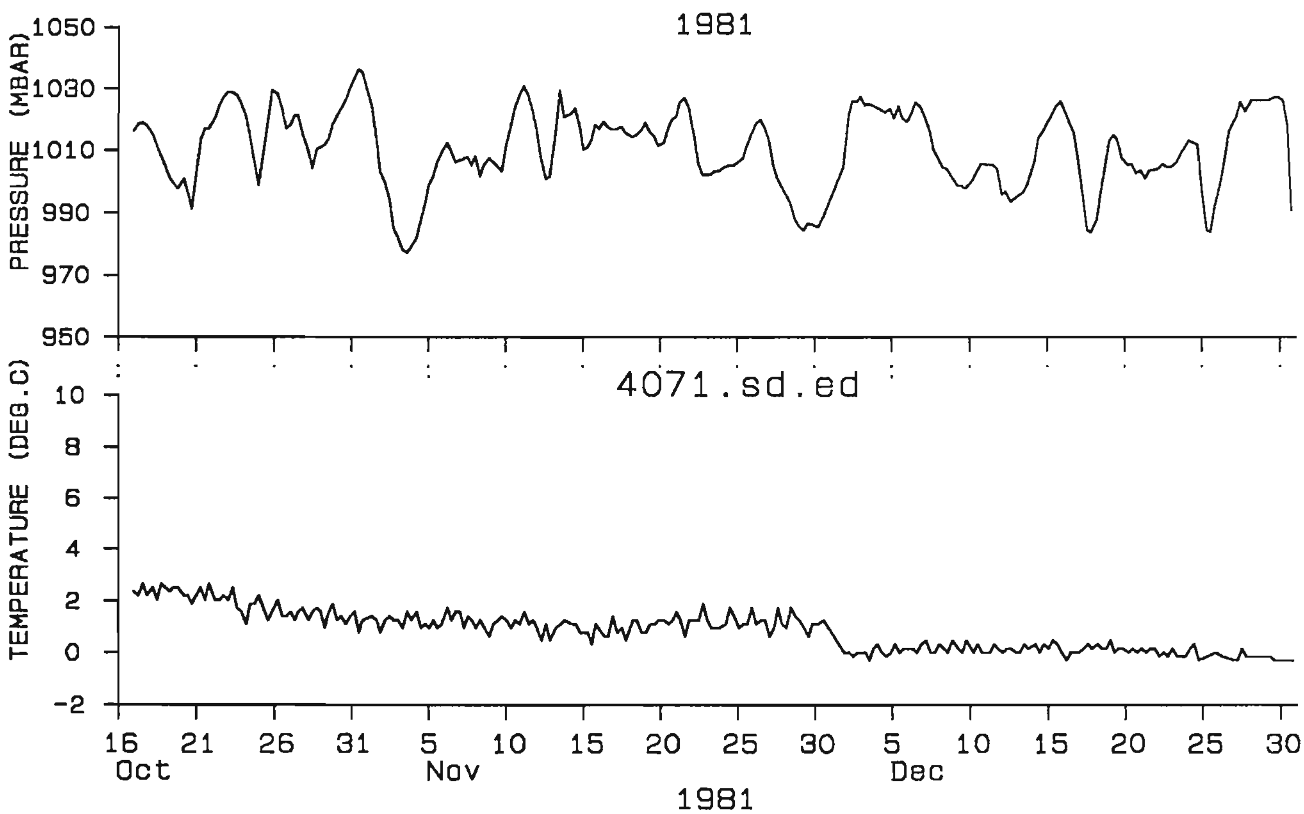
4094 Drifter Velocity Statistics
start date is 1983 8 11 23 41 25.0
stop date is 1983 11 28 19 41 25.0

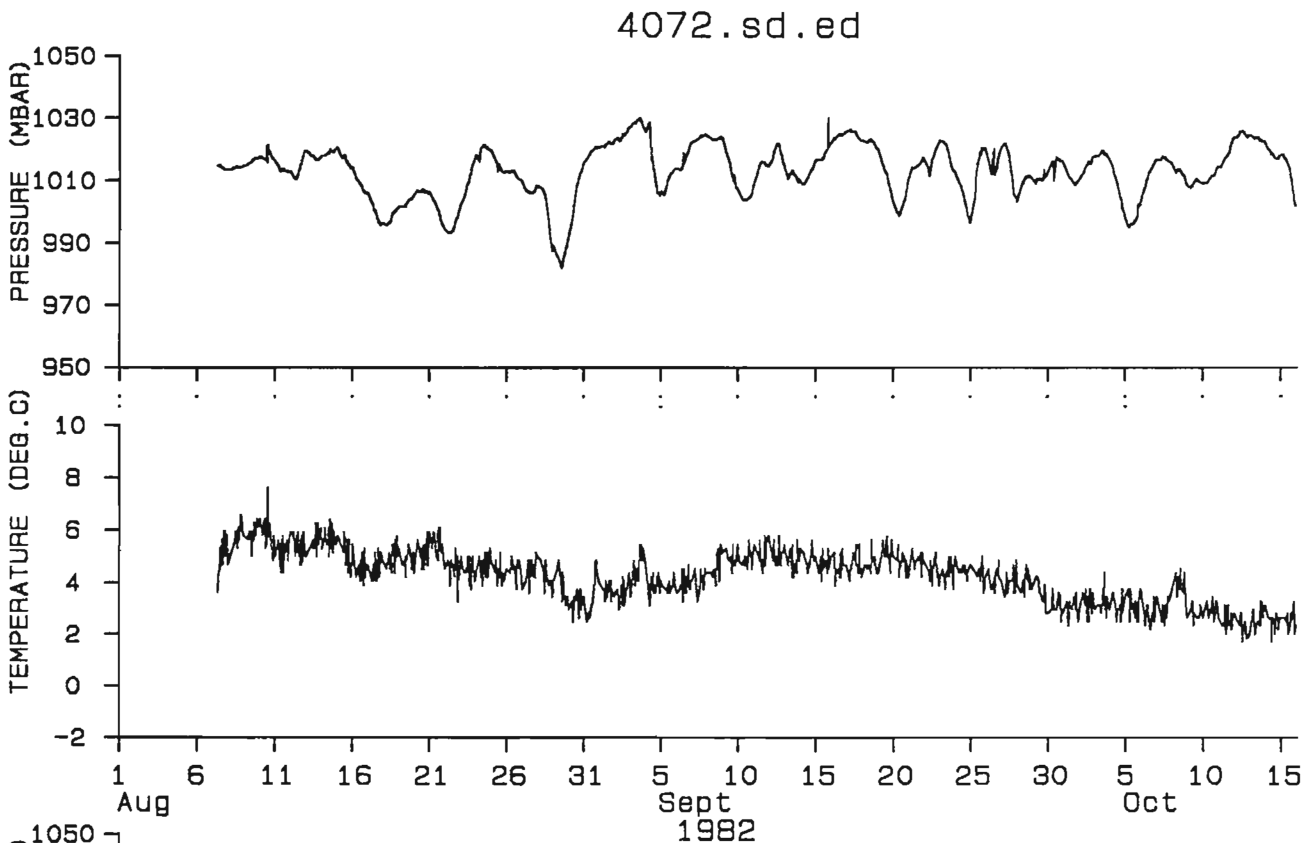
QUANTITY	UNITS	MEAN	STD.DEV.	MAXIMUM	MINIMUM
speed	m/s	0.185	0.113	0.698	0.006
direction				359.9	1.3
ew_comp	m/s	0.041	0.138	0.692	-0.322
ns_comp	m/s	-0.070	0.146	0.431	-0.470

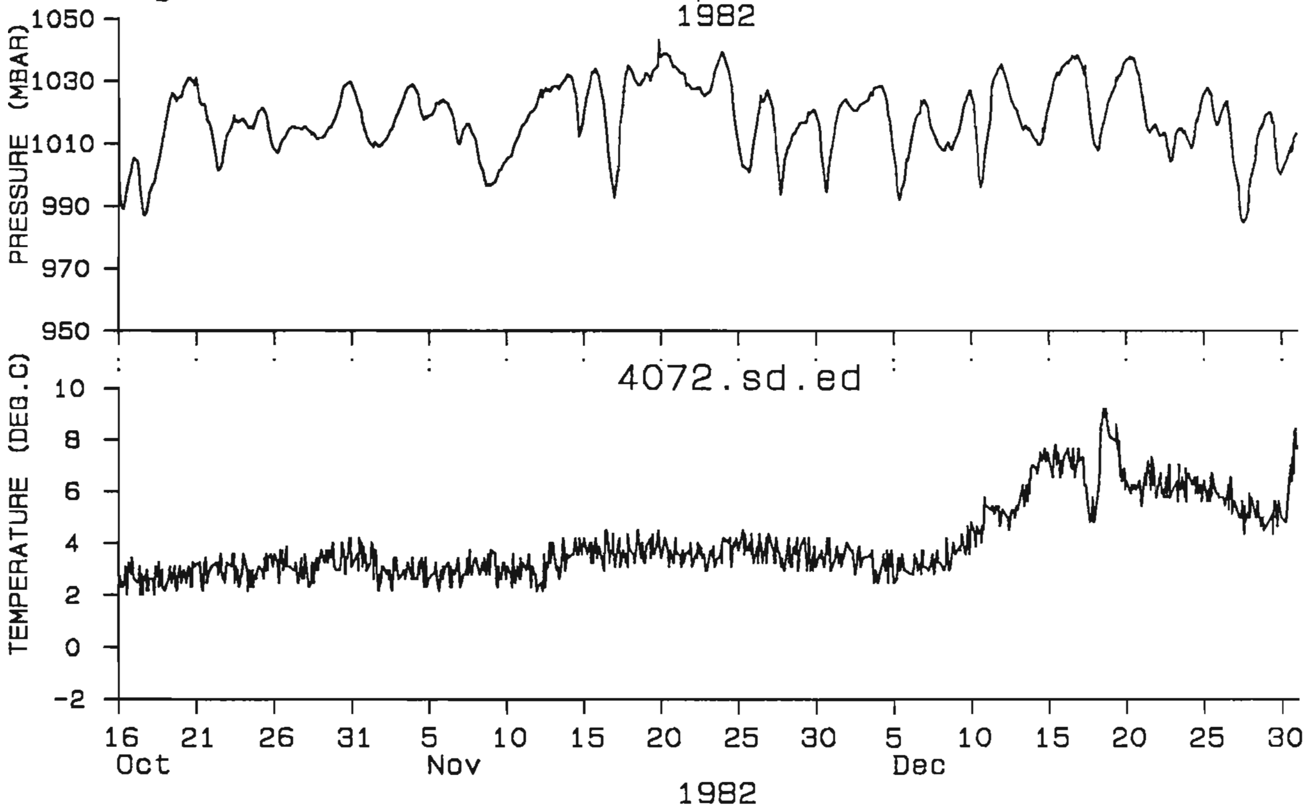
APPENDIX 3

PLOTS OF SEA TEMPERATURE AND AIR PRESSURE MEASURED FROM DRIFTING BUOYS


1981
PRESSURE (MBAR)
1050
1030
1010
990
970
950
4070.sd.ed
TEMPERATURE (DEG.C)
10
8
6
4
2
0
-2
16 21 26 31 5 10 15 20 25 30 5 10 15 20 25 30
Oct
Nov
Dec
1981


1981
PRESSURE (MBAR)
1050
1030
1010
990
970
950
4071.sd.ed
TEMPERATURE (DEG.C)
10
8
6
4
2
0
-2
16 21 26 31 5 10 15 20 25 30 5 10 15 20 25 30
Oct
Nov
Dec
1981


4072.sd.ed
PRESSURE (MBAR)
1050
1030
1010
990
970
950
TEMPERATURE (DEG.C)
10
8
6
4
2
0
-2
1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
Aug
Sept
Oct
1982


PRESSURE (MBAR)
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1030
1010
990
970
950
4072.sd.ed
TEMPERATURE (DEG.C)
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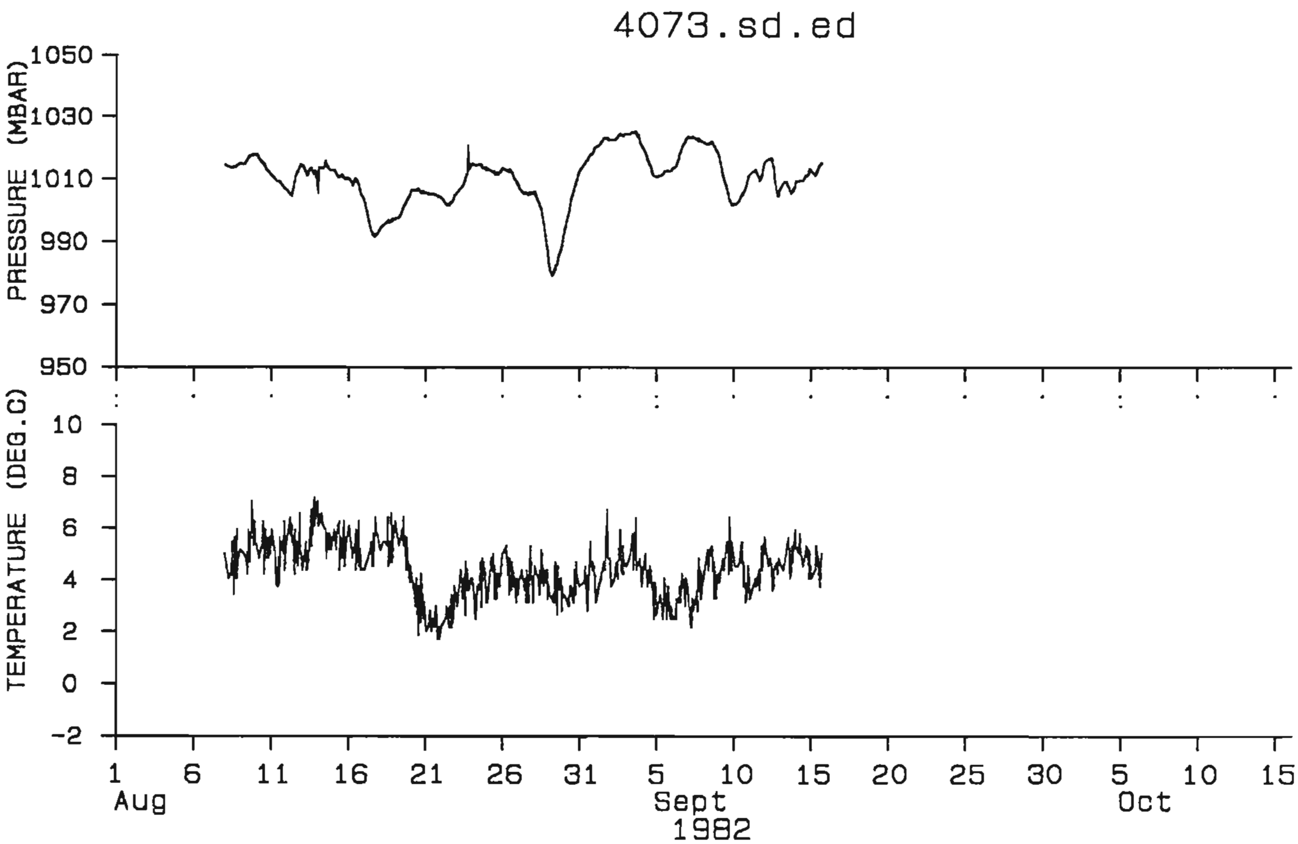
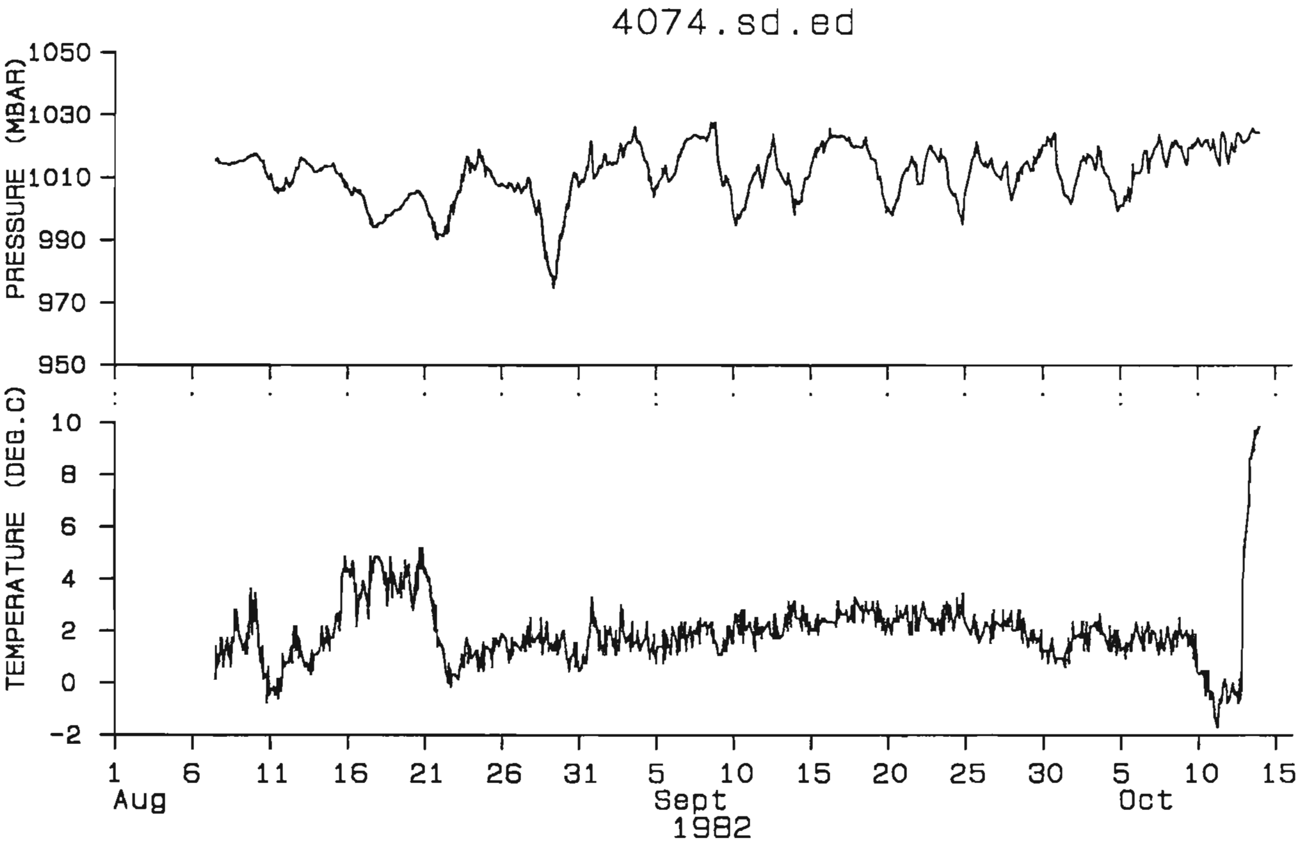
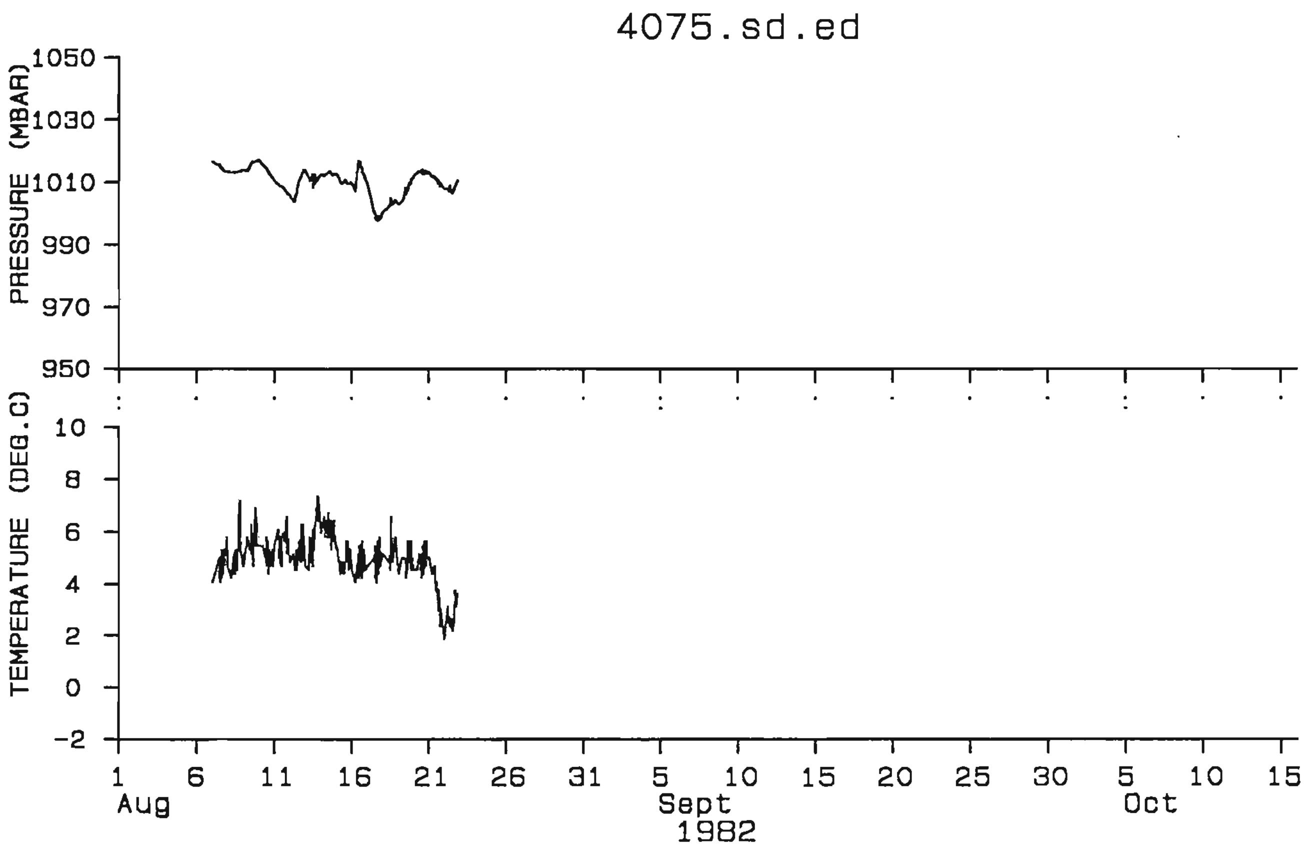
8
6
4
2
0
-2
16 21 26 31 5 10 15 20 25 30 5 10 15 20 25 30
Oct
Nov
Dec
1982


4073.sd.ed
PRESSURE (MBAR)
1050
1030
1010
990
970
950
TEMPERATURE (DEG.C)
10
8
6
4
2
0
-2
1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
Aug
Sept
Oct
1982


4074.sd.ed
PRESSURE (MBAR)
1050
1030
1010
990
970
950
TEMPERATURE (DEG.C)
10
8
6
4
2
0
-2
1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
Aug
Sept
Oct
1982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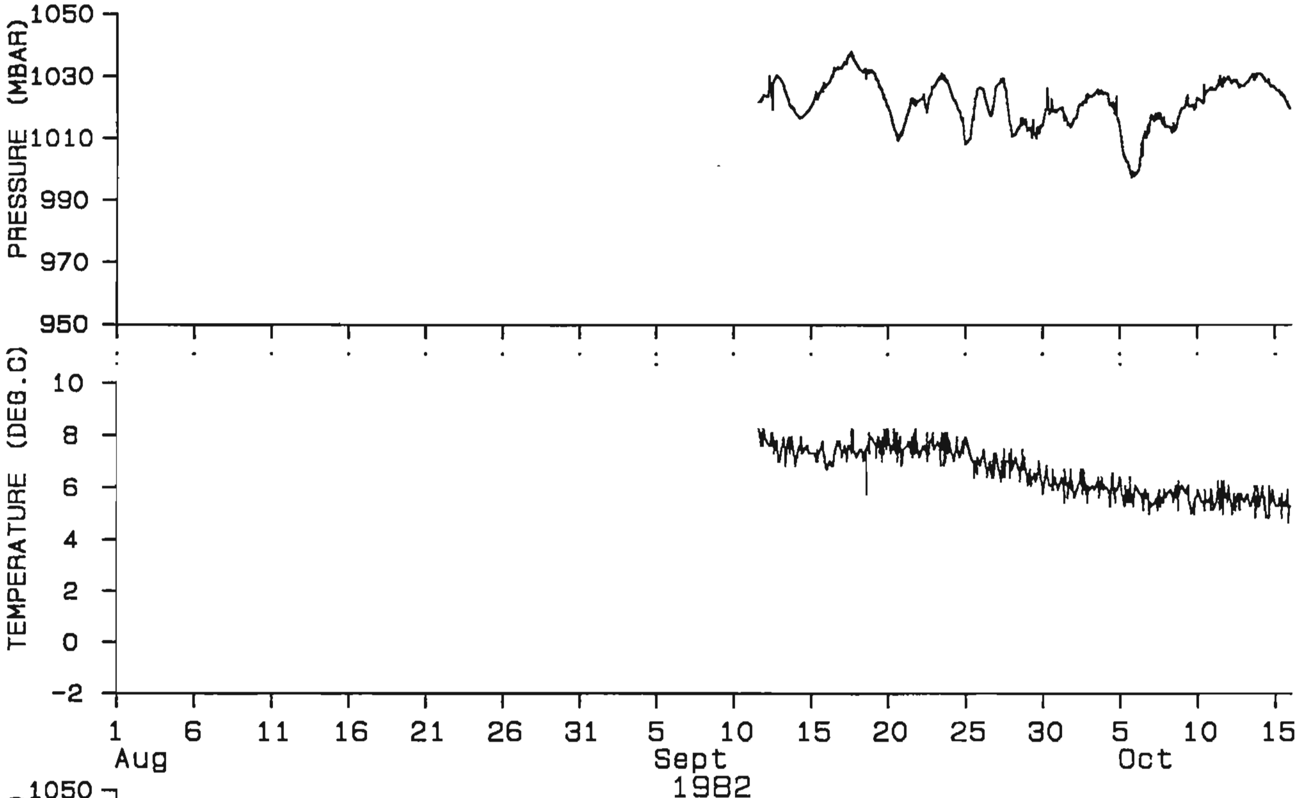
PRESSURE (MBAR)
1050
1030
1010
990
970
950
TEMPERATURE (DEG.C)
10
8
6
4
2
0
-2
1
6
11
16
21
26
31
5
10
15
20
25
30
5
10
15
Aug
Sept
Oct
1982

4077.sd.ed


PRESSURE (MBAR)
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1030
1010
990
970
950
TEMPERATURE (DEG.C)
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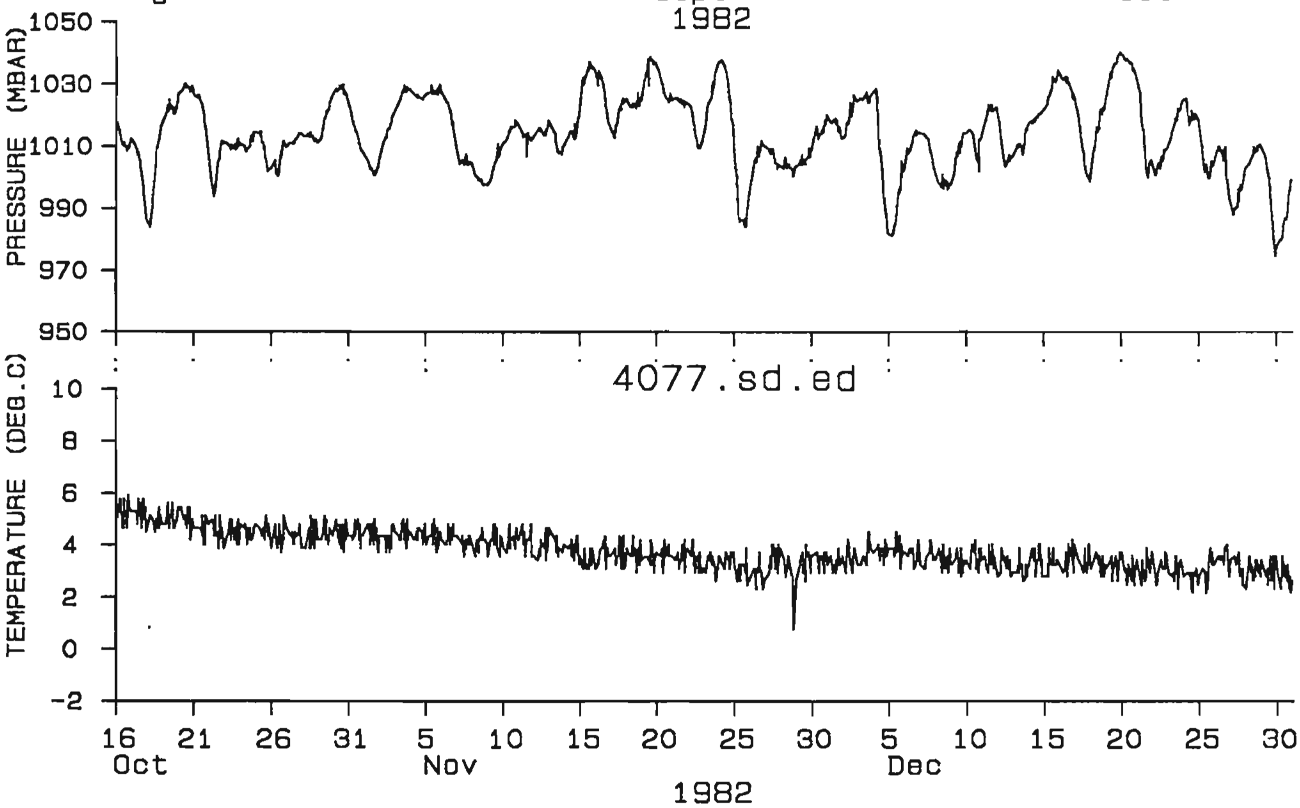
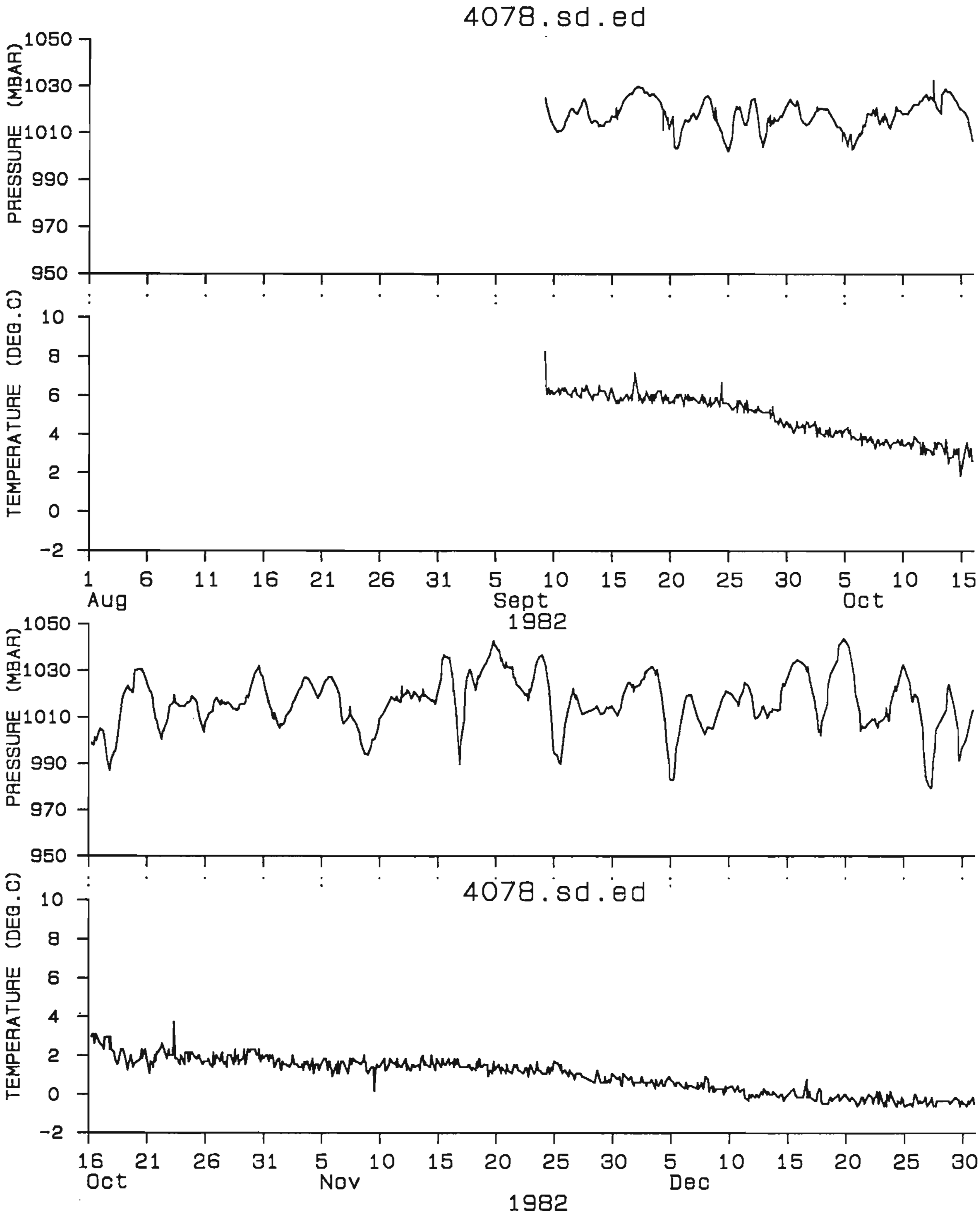
6
4
2
0
-2
1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
Aug
Sept
Oct
1982


PRESSURE (MBAR)
1050
1030
1010
990
970
950
4077.sd.ed
TEMPERATURE (DEG.C)
10
8
6
4
2
0
-2
16 21 26 31 5 10 15 20 25 30 5 10 15 20 25 30
Oct
Nov
Dec
1982


4078.sd.ed
PRESSURE (MBAR)
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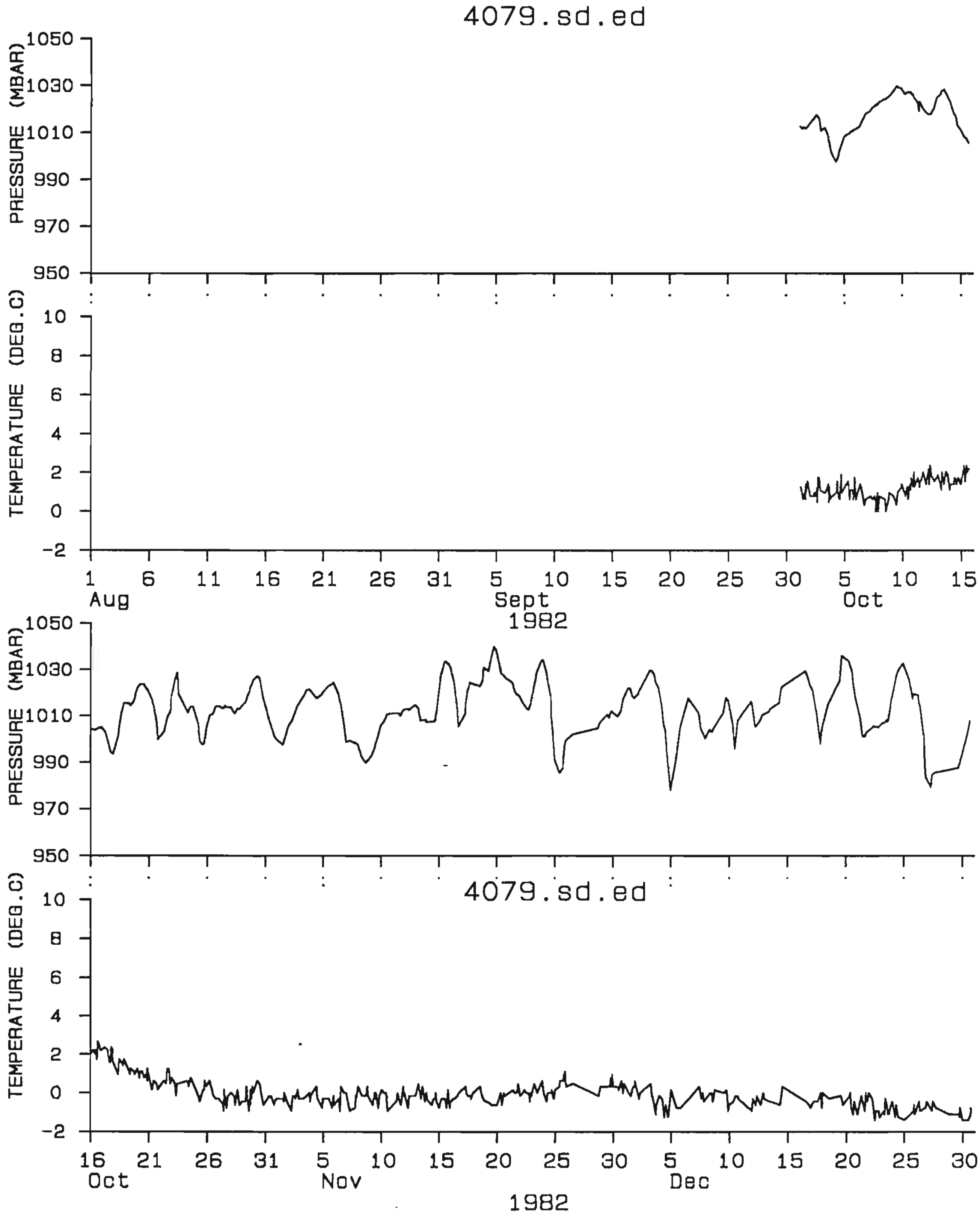
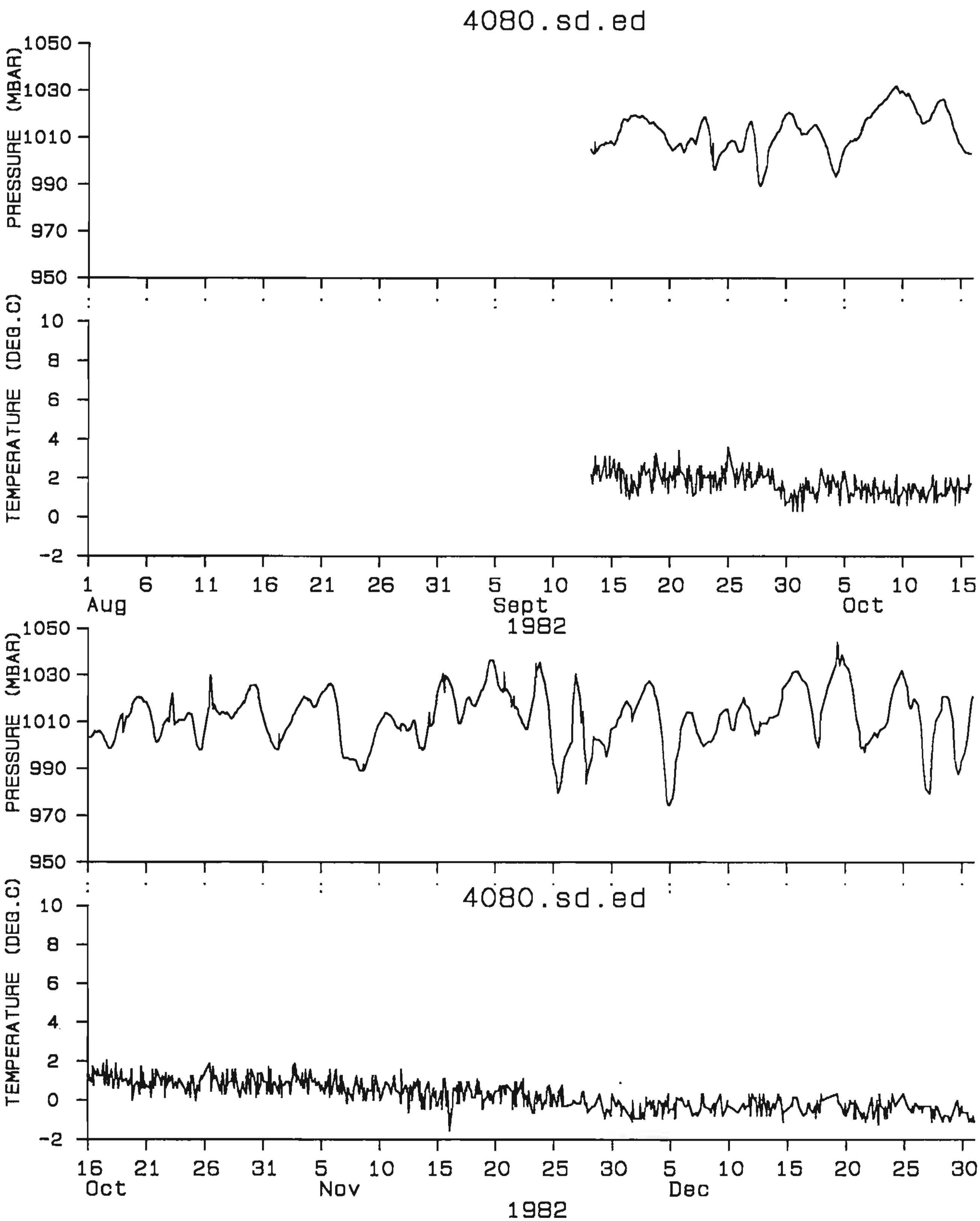
1030
1010
990
970
950
TEMPERATURE (DEG.C)
10
8
6
4
2
0
-2
1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
Aug
Sept
Oct
1982
PRESSURE (MBAR)
1050
1030
1010
990
970
950
4078.sd.ed
TEMPERATURE (DEG.C)
10
8
6
4
2
0
-2
16 21 26 31 5 10 15 20 25 30 5 10 15 20 25 30
Oct
Nov
Dec
1982


4079.sd.ed
PRESSURE (MBAR)
1050
1030
1010
990
970
950
TEMPERATURE (DEG.C)
10
8
6
4
2
0
-2
1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
Aug
Sept
Oct
1982
PRESSURE (MBAR)
1050
1030
1010
990
970
950
4079.sd.ed
TEMPERATURE (DEG.C)
10
8
6
4
2
0
-2
16 21 26 31 5 10 15 20 25 30 5 10 15 20 25 30
Oct
Nov
Dec
1982

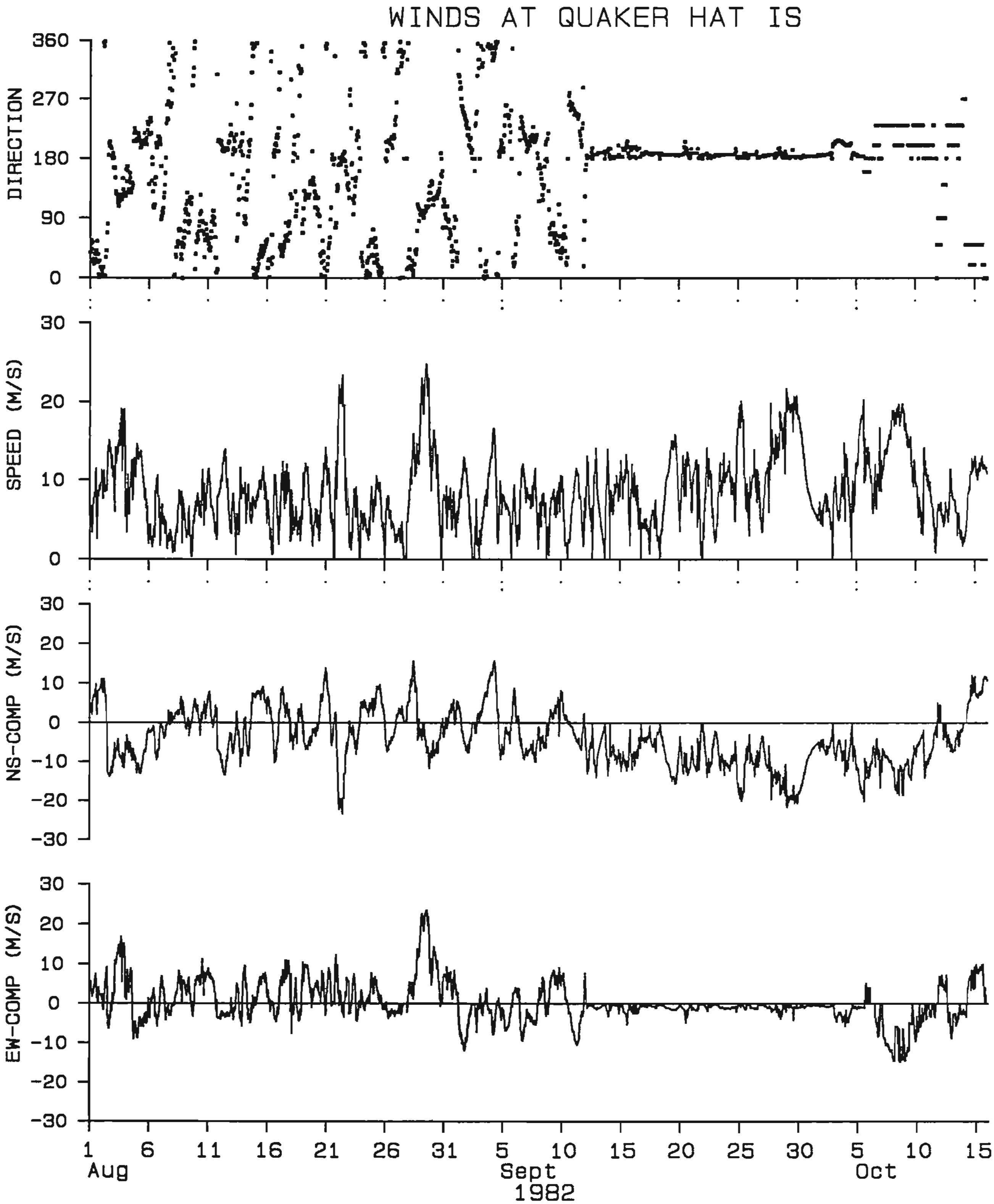

4080.sd.ed
PRESSURE (MBAR)
1050
1030
1010
990
970
950
TEMPERATURE (DEG.C)
10
8
6
4
2
0
-2
1 6 11 16 21 26 31 5 10 15 20 25 30 5 10 15
Aug
Sept
Oct
1982
PRESSURE (MBAR)
1050
1030
1010
990
970
950
4080.sd.ed
TEMPERATURE (DEG.C)
10
8
6
4
2
0
-2
16 21 26 31 5 10 15 20 25 30 5 10 15 20 25 30
Oct
Nov
Dec
1982

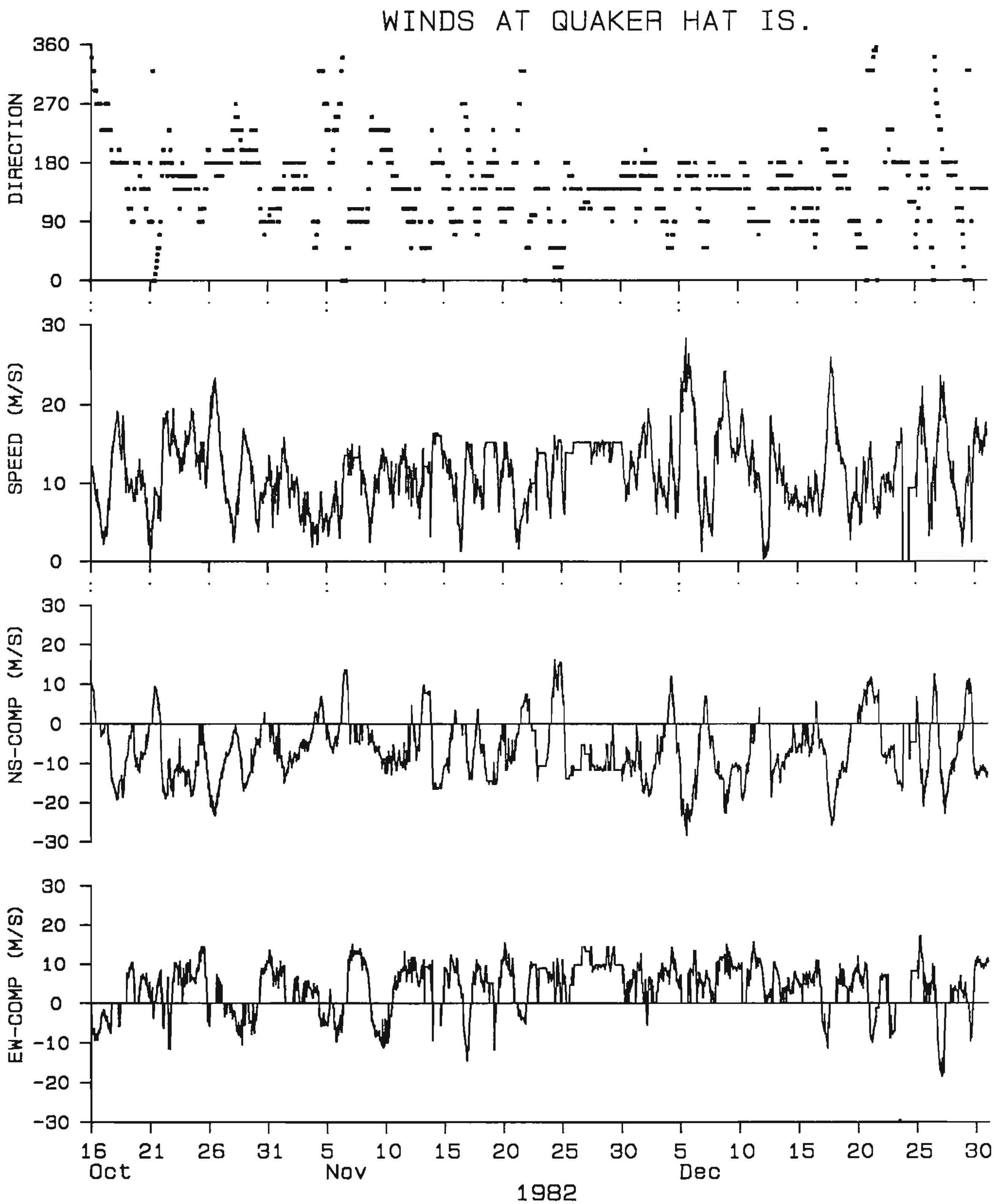
APPENDIX 4

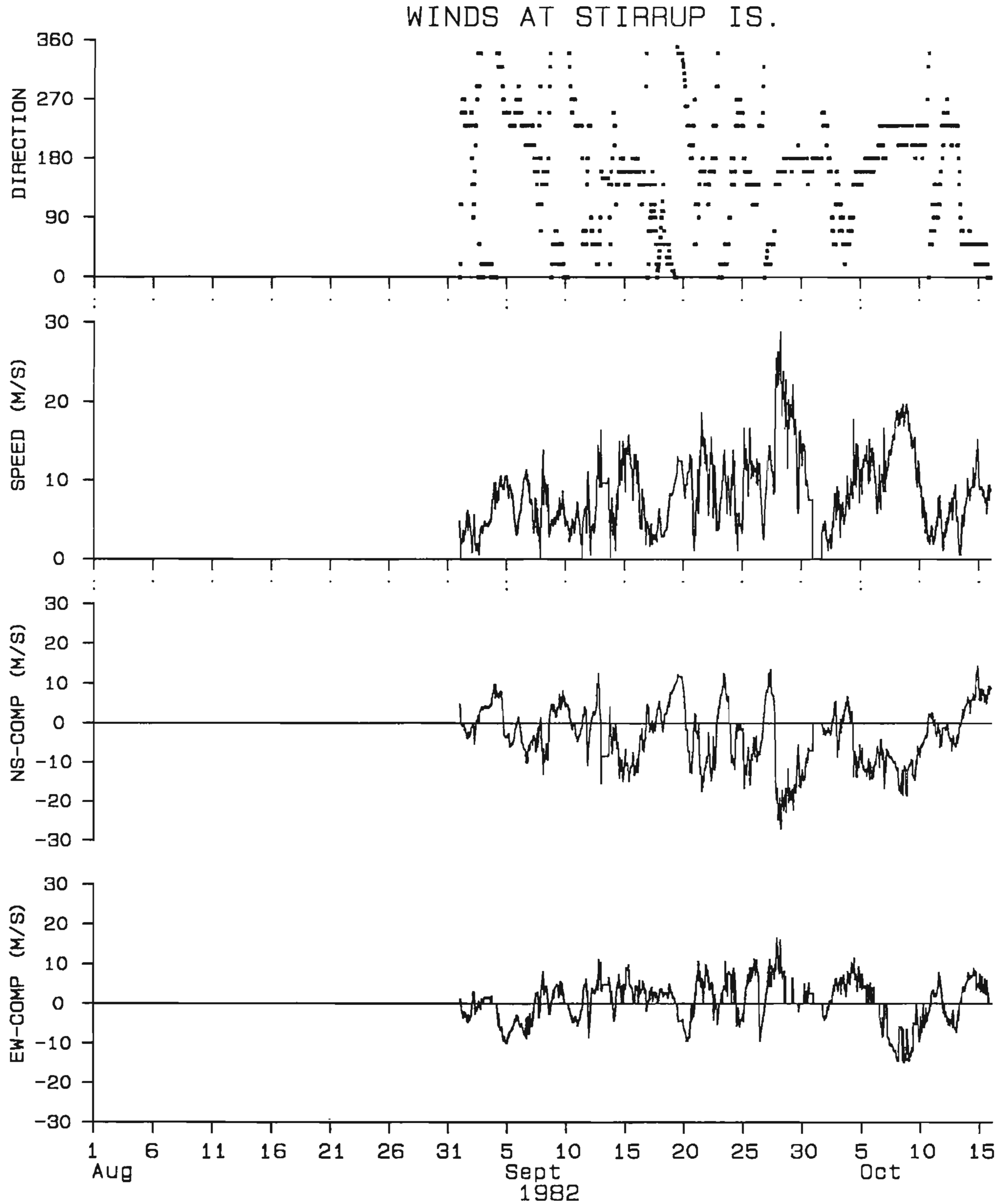
PLOTS OF WIND DATA

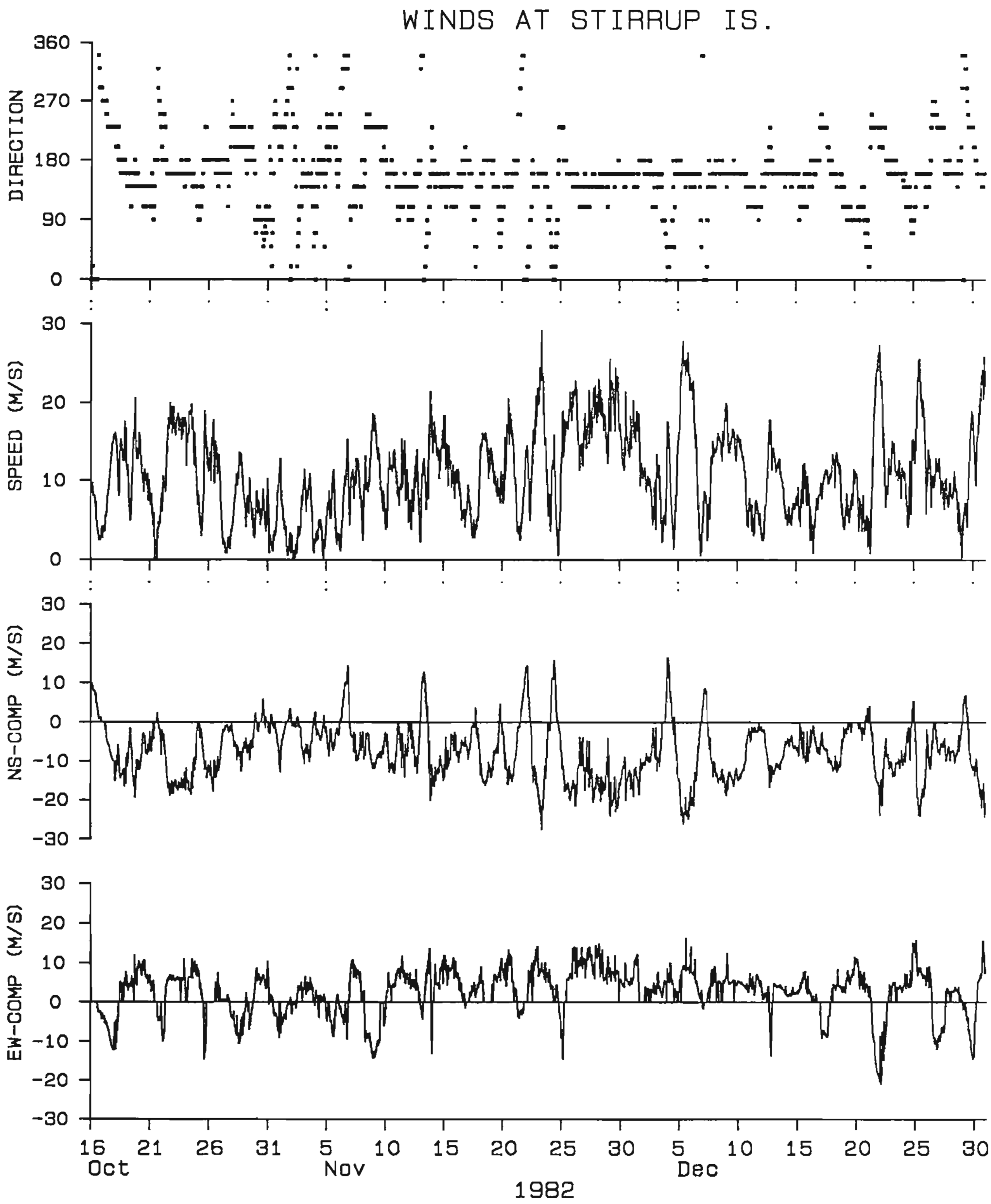
OBTAINED AT OFFSHORE ISLANDS

DURING 1982


WINDS AT QUAKER HAT IS
DIRECTION
360
270
180
90
0
SPEED (M/S)
30
20
10
0
NS-COMP (M/S)
30
20
10
0
-10
-20
-30
EW-COMP (M/S)
30
20
10
0
-10
-20
-30
1
6
11
16
21
26
31
5
10
15
20
25
30
5
10
15
Aug
Sept
Oct
1982


WINDS AT QUAKER HAT IS.
DIRECTION
360
270
180
90
0
SPEED (M/S)
30
20
10
0
NS-COMP (M/S)
30
20
10
0
-10
-20
-30
EW-COMP (M/S)
30
20
10
0
-10
-20
-30
16 21 26 31 5 10 15 20 25 30 5 10 15 20 25 30
Oct
Nov
Dec
1982


WINDS AT STIRRUP IS.
DIRECTION
360
270
180
90
0
SPEED (M/S)
30
20
10
0
NS-COMP (M/S)
30
20
10
0
-10
-20
-30
EW-COMP (M/S)
30
20
10
0
-10
-20
-30
1
Aug
6
11
16
21
26
31
5
Sept
10
15
20
25
30
5
Oct
10
15
1982


WINDS AT STIRRUP IS.
DIRECTION
SPEED (M/S)
NS-COMP (M/S)
EW-COMP (M/S)
16 21 26 31 5 10 15 20 25 30 5 10 15 20 25 30
Oct
Nov
Dec
1982