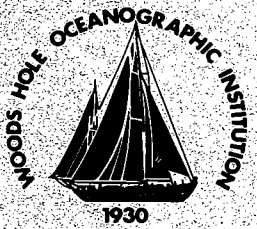
WHOI-90-01
COPY 1

Woods Hole Oceanographic Institution



SOFAR Float Mediterranean Outflow Experiment
Summary and Data from 1986 – 1988

by

Marguerite E. Zemanovic
Philip L. Richardson
James F. Price

January 1990

Technical Report

Funding was provided by the National Science Foundation through Grant Nos. OCE 82-14066, OCE 85-17375, OCE 86-00055, OCE 88-22826.

WHOI-90-01

SOFAR Float Mediterranean Outflow Experiment Summary and Data from 1986 - 1988

by

Marguerite E. Zemanovic, Philip L. Richardson, and James F. Price

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

January 1990

Technical Report

Funding was provided by the National Science Foundation through Grant Nos. OCE 82-14066, OCE 85-17375, OCE 86-00055, OCE 88-22826.

Approved for Distribution:

Robert C. Beardsley

Robert C. Beardsley, Chairman
Department of Physical Oceanography

Abstract

In October, 1984, the Woods Hole Oceanographic Institution SOFAR float group began a three and a half year field program to measure the velocity field of the Mediterranean water in the eastern North Atlantic. The principal scientific goal was to learn how the Mediterranean salt tongue is produced by the general circulation and the eddy diffusion of the Canary Basin. Thirty-two floats were launched at depths near 1100 m: 14 in a cluster centered on 32°N, 24°W, with nearest neighbors at 20 km spacing, 10 at much wider spacing to explore regional variations of first order flow statistics, and 8 in three different Meddies (Mediterranean water eddies) in collaboration with investigators from Scripps Institution of Oceanography and the University of Rhode Island.

The floats were launched in 1984 and 1985, and tracked with U.S. and French ALSs (moored listening stations) from October 1984 to June 1988. This report includes a summary of the whole three and a half year experiment, the final year and a half of data processed from the third ALS setting (October 1986–June 1988), and the first deep sea test of Bobber EB014 in the eastern subtropical North Atlantic (May 1986–May 1988). Approximately 60 years of float trajectories were produced during the three and a half years of the experiment.

Table of Contents

List of Tables

List of Figures

1 Introduction

The large-scale salinity distribution at thermocline depths in the North Atlantic is dominated by a tongue of salty water projecting westward from Gibraltar toward Bermuda (Worthington, 1976). The salinity anomaly originates in the Mediterranean Sea from an excess of evaporation over precipitation and flows out through the Strait of Gibraltar. The bulk of the salt tongue extends westward across the Mid-Atlantic Ridge. However, some of it may be traced into the Norwegian–Greenland Sea (Reid, 1979), where wintertime cooling and the relatively high salinity produce a dense water mass which is a major component of the North Atlantic Deep Water and can be traced into the South Atlantic, Pacific, and Indian Oceans (Reid and Lynn, 1971). The Mediterranean outflow is thus a prominent feature of the world ocean and particularly of the North Atlantic.

In 1984 we began a field experiment to observe the long-term displacement of Mediterranean water by tracking neutrally buoyant SOund Fixing And Ranging (SOFAR) floats. The aim of this experiment was to measure the velocity field of the Mediterranean water in the eastern North Atlantic. The general goals were to provide an improved description of the general circulation in the Atlantic eastern basin and a case study of eddy diffusion in a weakly energetic region. A specific goal was to learn how the Mediterranean salt tongue is produced by the general circulation and eddy diffusion of the Canary Basin. Thirty-two floats were launched at depths near near 1100 m (Figure 1, Table I); 14 floats were in a cluster with nearest neighbors at 20 km spacing, 10 floats were set at much wider spacing to explore regional variations of first order flow statistics, and 8 floats were launched in three different Meddies in collaboration with T. Rossby and L. Armi. In addition, current meters were moored for two years near the center of the float cluster at 500, 1000, 1100, and 3000 m. The floats were launched in 1984 and 1985,

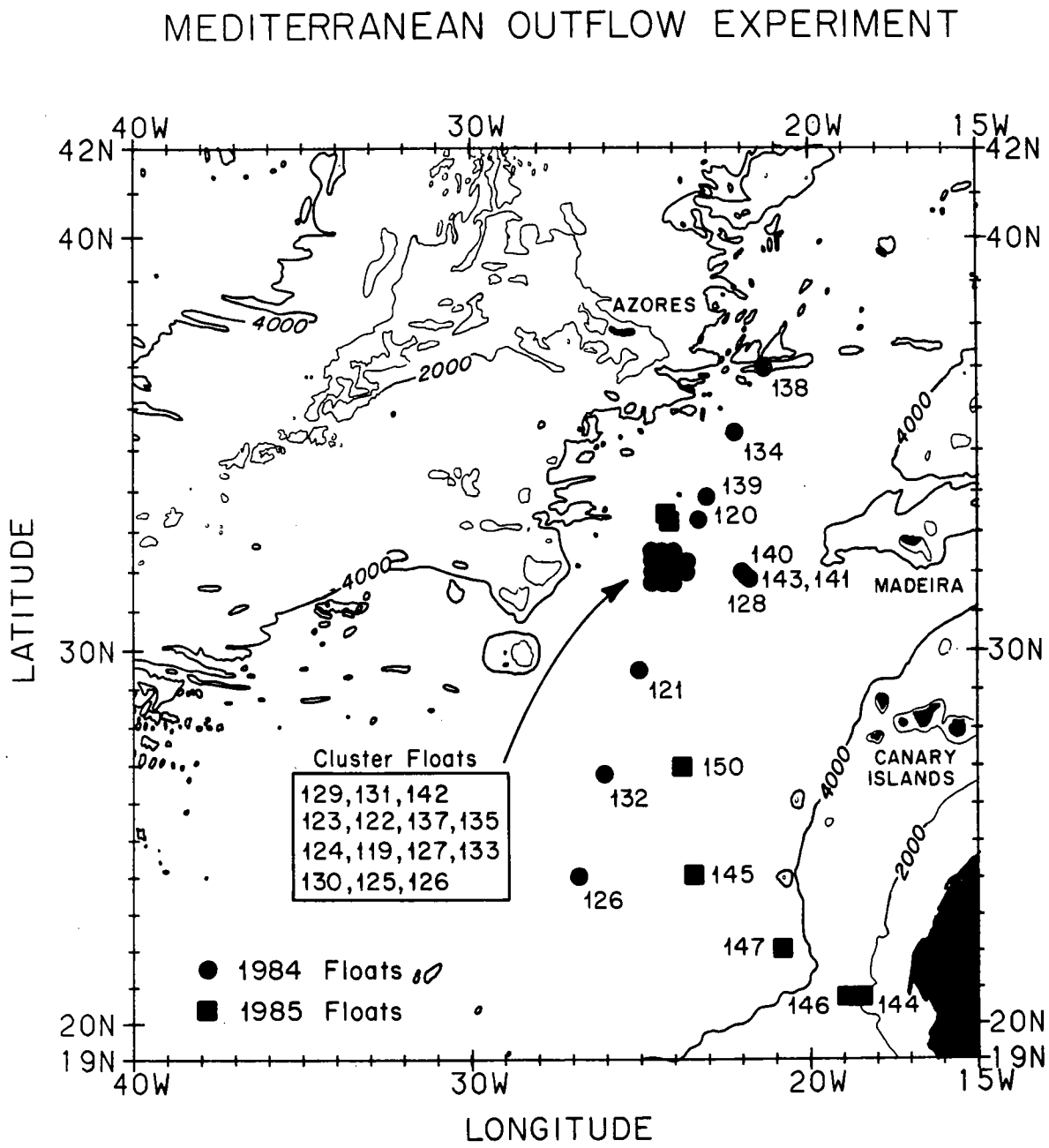


Figure 1: Float launch positions.

TABLE I

1984 - 1988 FLOAT FILE STATISTICS

FLOAT	START DATE yymmdd	START POSITION LAT. deg N	START POSITION LONG. deg W	STOP DATE yymmdd	STOP POSITION LAT. deg N	STOP POSITION LONG. deg W	NO. DAYS TRACKED	INIT. TEMP. deg C	AVE. TEMP. deg C	INIT. PRES. dbars	AVE. PRES. dbars
119	841022	31.981	24.281	850902	31.021	28.099	316	7.51	7.85	1207	1134
120	841025	33.073	23.148	851109	31.997	29.064	381	8.40	8.22	----	----
121	841020	29.517	24.978	880602	33.630	21.594	1322	7.35	8.27	1239	1122
122	841022	32.192	24.301	850221	32.135	26.836	123	7.62	7.48	----	----
123	841022	32.208	24.583	860119	35.802	30.354	455	7.72	8.25	1251	1129
124A	841021	31.971	24.536	860428	31.877	26.504	555	8.39	7.74	----	----
124B	860720	30.611	29.240	860821	31.108	30.245	33	----	----	----	----
125	841021	31.738	24.257	850513	31.374	26.963	205	8.22	8.47	----	----
126	841018	23.913	26.829	880613	24.323	23.519	1335	----	----	1284	1116
127A	841023	31.922	24.006	860628	33.823	28.644	614	8.51	8.03	1158	1101
127B	860812	34.015	28.334	860907	34.107	28.323	27	7.48	7.43	1102	1097
127C	870503	35.710	31.857	870821	34.891	31.075	111	7.24	7.18	1100	1099
128	841016	32.029	22.130	880613	22.459	20.191	1337	11.62	10.26	1195	1109
129A	841022	32.431	24.560	860923	29.160	30.276	702	8.39	8.20	1171	1096
129B	861006	28.935	30.026	871201	29.336	29.943	422	7.99	7.89	1074	1094
130	841021	31.761	24.526	870709	31.879	24.345	992	7.57	8.31	1263	1128
131	841022	32.417	24.267	880601	31.956	28.800	1319	7.99	8.04	1200	1099
132	841019	26.689	26.045	880613	28.806	19.077	1334	6.75	7.23	1242	1113
133	841021	31.889	23.687	871202	32.408	36.002	1137	8.62	8.10	1114	1099
134	841024	35.281	22.198	850323	35.750	20.507	151	7.99	7.43	----	----
135A	841021	32.173	23.718	860320	30.370	26.098	516	7.90	7.63	1234	1220
135B	860617	30.100	24.973	861217	30.262	27.451	549	----	----	----	----
136	841021	31.727	23.970	880613	32.748	23.484	1332	8.27	8.33	1168	1099
137	841022	32.199	24.004	880310	30.116	38.792	1236	8.30	8.23	1226	1109
138	841024	36.819	21.306	860604	38.987	17.240	589	9.96	9.75	1225	1145
139	841023	33.847	22.911	860726	33.822	20.816	642	7.99	8.84	1244	1124
140	841018	32.014	21.945	850211	30.095	22.134	117	9.64	10.86	----	----
141	841018	31.934	22.152	851203	28.908	24.006	412	11.72	10.03	1168	1018
142	841022	32.405	24.002	850410	31.591	26.368	171	8.03	8.28	----	----
143	841018	31.904	22.197	851122	26.686	23.084	401	----	8.64	1182	1146
144	850921	20.647	18.509	860108	19.311	17.745	110	----	----	----	----
145	850919	24.280	23.391	870321	20.130	25.386	549	7.39	8.11	1297	1143
146	850921	20.681	18.838	851029	20.023	18.556	39	----	----	----	----
147	850921	22.249	20.942	860218	21.576	22.009	151	----	----	----	----
148	851114	33.991	24.254	880503	32.222	18.445	930	11.96	8.82	1206	1134
149	851114	33.915	24.172	880604	33.327	30.544	933	12.65	9.57	1062	1016
150	851101	26.982	23.523	860522	25.338	24.481	203	8.89	8.15	----	----
							TOTAL 59.6 yrs.				

and tracked with U.S. and French moored listening stations (ALSs) from October 1984 to June 1988 (Figure 2, Table II).

2 Data Processing and Float Tracking: 1986–1988

In June 1988, we retrieved the final ALS setting of our eastern North Atlantic experiment containing data from October 1986 to June 1988. The ALS cassette tapes containing times of arrivals and telemetry for each float were processed at the Woods Hole Oceanographic Institution in three phases. The first phase converted the raw data into a time series of possible times of arrival and amplitudes of their correlations for each ten minute interval that the ALSs were in the water. The second phase, float tracking, had three steps: (1) identification and extraction of the float signals for each ALS; (2) tracking the floats and estimating the SOFAR float clock drift; and (3) creation of a FLOATER (McKee, 1986) file for each float containing unsmoothed positions and telemetry (temperature and pressure). A constant sound speed of 1.506 km/s was used to track the SOFAR floats. The third phase consisted of editing, interpolating, filtering, and smoothing the data to produce final float trajectories and velocity, temperature and pressure time series.

Trajectory and time series plots were inspected for outliers, and the preliminary FLOATER format files were edited where necessary to eliminate obviously bad positions, temperature, and pressure values. Listings of direction and speed derived from consecutive positions were used to detect unusually high speeds indicative of erroneous positions. First differences between consecutive temperatures and pressures were calculated and inspected for unrealistic values. Radical changes in temperature that were not accompanied by a similar change in

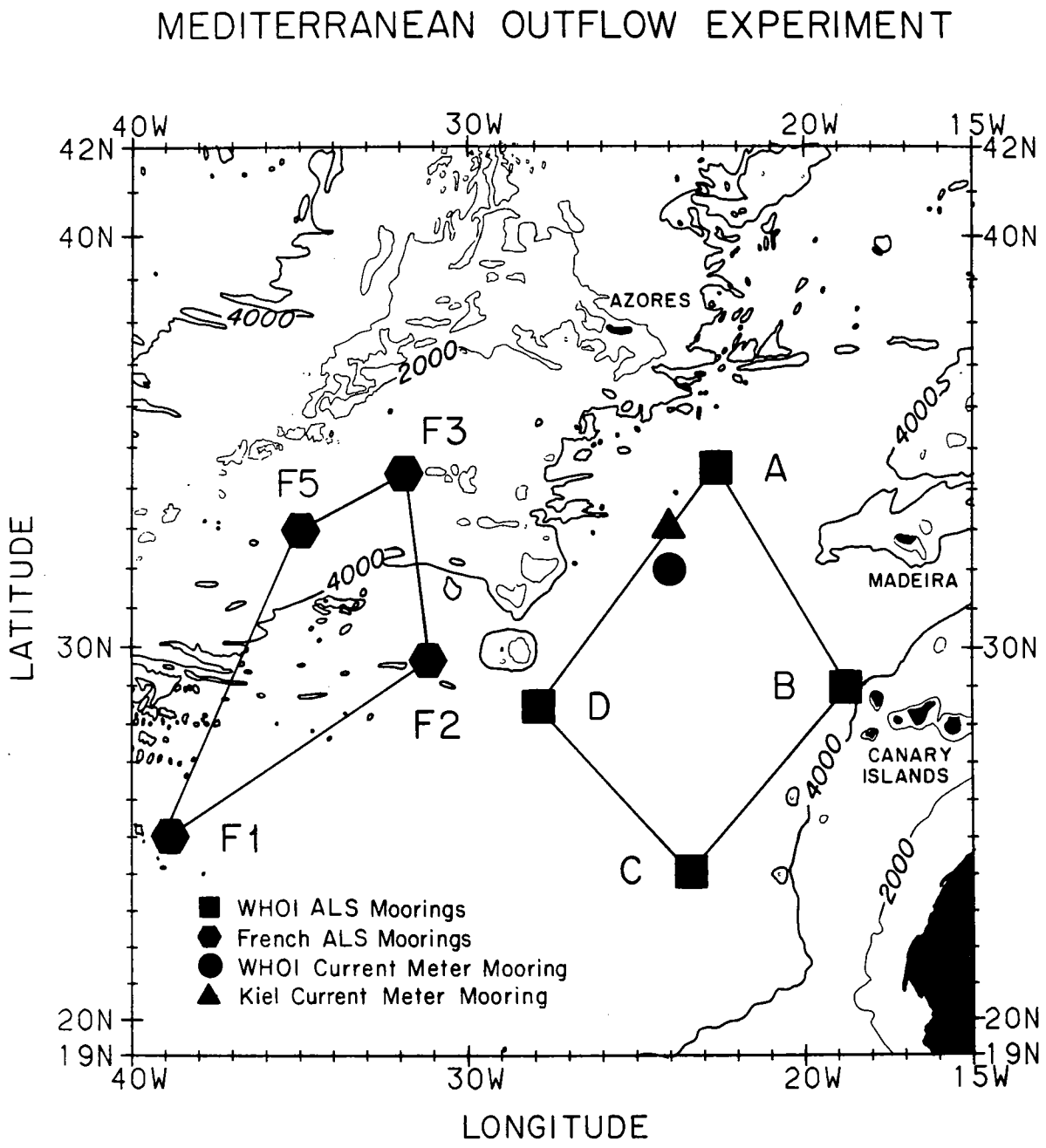


Figure 2: Location of autonomous listening station (ALS) moorings, current meter moorings, and bathymetry in the experimental area.

TABLE II

ALS MOORINGS

ALS SITE	ALS #	LAUNCH DATE yymmdd	RECOVERY DATE yymmdd	LATITUDE deg N	LONGITUDE deg W	ALS DEPTH (m)
			1984 - 1985			
A	140A	841021	850913	34.490	22.642	1800
B	137A	841013	850920	29.000	18.787	1200
C	138A	841014	850917	24.038	23.406	1000
D	139A	841017	850915	28.434	27.889	1400
F1	F11A	840615	850811	25.020	38.825	1500
F2	F07A	840617	850809	29.660	31.149	1500
F3	F10A	840612	850815	34.390	31.839	1500
			1985 - 1986			
A	141A	850913	861005	34.545	22.601	1800
B	144A	850920	861015	29.013	18.738	1200
C	143A	850917	861010	24.107	23.345	1000
D	142A	850915	861008	28.515	27.868	1400
F1	F06A	850811	861001	25.018	38.808	1500
F2	F09A	850809	861003	29.663	31.147	1500
F3	F18A	850815	861004	34.370	31.832	1500
			1986 - 1988			
A	150A	861003	880617	34.472	22.675	1800
B	153A	861015	**	29.130	18.757	1200
C	152A	861010	880614	24.157	23.322	1000
D	151A	861008	880615	28.503	27.843	1400
F1	T11A	861001	880307	25.068	38.805	1500
F5	T10A	860928	880307	33.042	34.940	1500

Note:
A-D were WHOI moorings and F1-F5 were moorings maintained by Centre Oceanologique de Bretagne, France.

** ALS 153A disappeared for unknown reasons.

pressure (or vice versa) were presumed to indicate an erroneous value. Temperature and pressure that drifted outside the range of the sensors were listed as being off scale.

Trajectories having gaps greater than ten days were broken into subfiles and labeled A, B, C, etc. Gaps of less than ten days duration in position, temperature, and pressure were linearly interpolated, producing daily values of temperature and pressure from the bi-daily values recorded.

These interpolated series were then filtered using a nine point two-day half-width Gaussian filter. Finally, a cubic spline was fitted to the smoothed positions and east and north components of velocity were calculated to coincide with the positions at 24-hour intervals. Float data from 1984–1986 were merged with those from 1986–1988.

A float file name is up to six characters long and is made up of three parts:

1. A two letter code to indicate the experiment, in this case, EB (for "Eastern Basin").

2. A one to three digit identifier assigned to the float before its launch.

3. A single letter suffix (A, B, C, ... Z) that was added to the file name if the float record was broken into sections due to gaps in the data. An example is float name EB135B — Experiment Code EB, Float 135, Section B.

Float tracking was more difficult and time consuming for this third ALS setting because: (1) only three of the four U.S. ALSs from the third setting were recovered (the fourth ALS disappeared for unknown reasons), (2) the floats had dispersed over a wider area (six floats went west of our array into the region of French ALSs, see Figure 3), and (3) we encountered some problems in using the French ALSs for tracking.

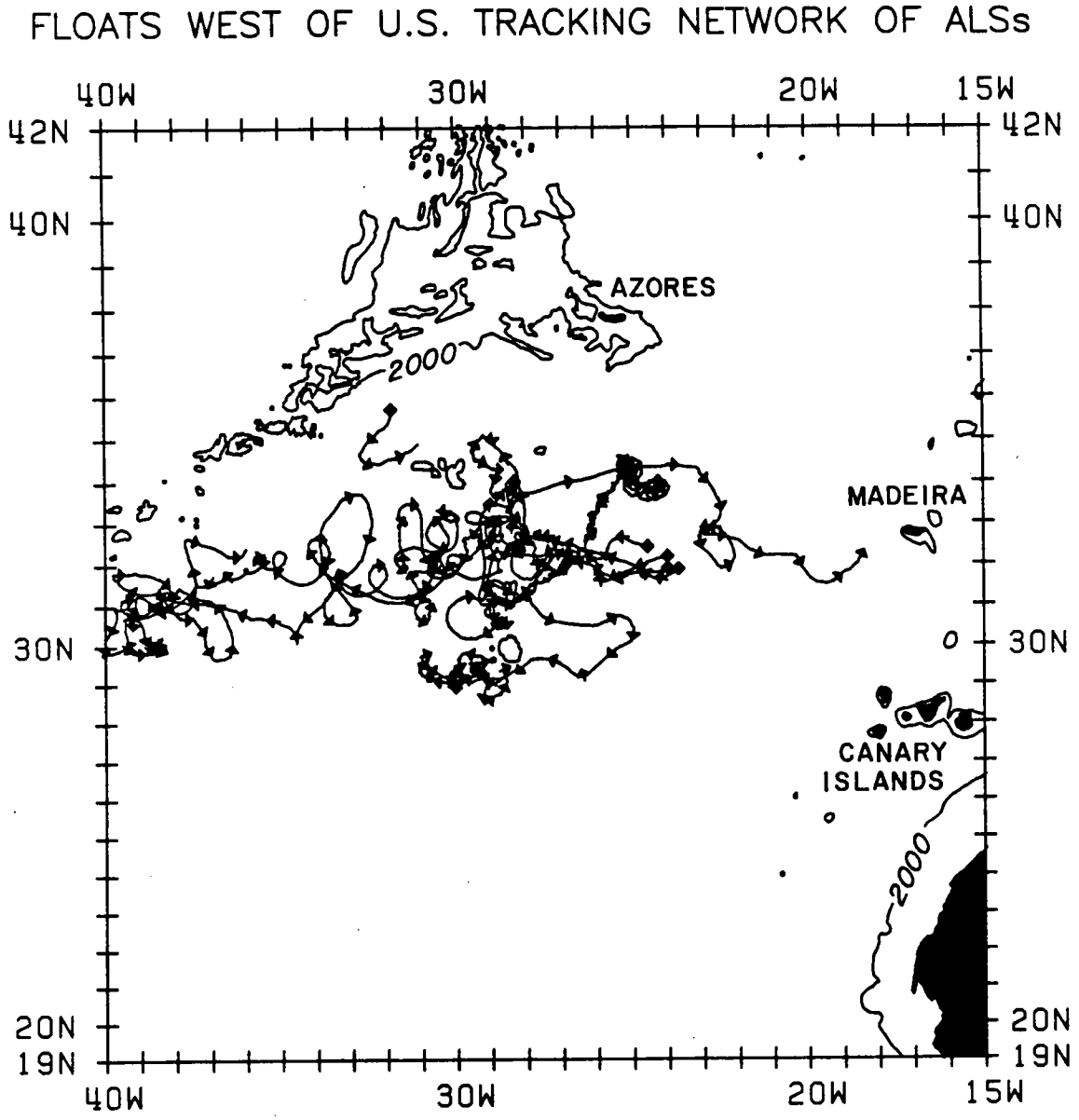


Figure 3: A composite of six float trajectories that drifted west of the U.S. array of moored listening stations. Listening stations deployed by the float group at Centre Oceanologique de Bretagne were used to track the floats that drifted west of about 29°W. Arrowheads are located at 30-day intervals along the trajectories.

The accuracy of the tracking may be judged by comparing the known launch position with the first position calculated by tracking. The differences between these two positions as well as the time difference between launch and the first position have been given by Price *et al.* (1986). The position difference is 5.6 km with an average time delay of nine hours, which is more than adequate accuracy for most purposes. A measure of the precision of the tracks can be obtained from (a) the variability in the ranges between a float and the ALSs for each position and (b) the point-to-point variations in the estimates of the float clock drift. Both of these suggest that the precision of the float positions is approximately 2 km.

The floats used in this experiment were very similar in design to the floats deployed in the Gulf Stream Recirculation Experiment (GUSREX) where they functioned fairly reliably. However, a defective component in the telemetry circuit discovered after launch caused some failures in temperature and pressure measurements and a shorter than average life of some floats. At the end of the experiment 11 of the 32 floats launched were still working (Figure 4). Figure 5 shows a fairly high failure rate during the first year and a half, after which the failure rate improved.

Data from the first two years has been processed and described in Armi *et al.*, 1988; Armi *et al.*, 1989; Käse *et al.*, 1986; Price *et al.*, 1986; Richardson *et al.*, 1989; Schmitz *et al.*, 1988; Tarbell *et al.*, 1987; and Zemanovic *et al.*, 1988.

3 Summary Plots

The major part of this report consists of: (1) figures summarizing results from the whole experiment including a complete set of individual trajectories of each float (Figures 6 to 10d), (2) figures summarizing the last year and a half of the experiment (Figures 11 to 13, Table III), (3) a description of Bobber float EB014 (Figures 14 and 15, Table IV) and (4) an Appendix, individual trajectories

and velocity, temperature and pressure time series plots from the last year and a half of the experiment (October 1986 to June 1988).

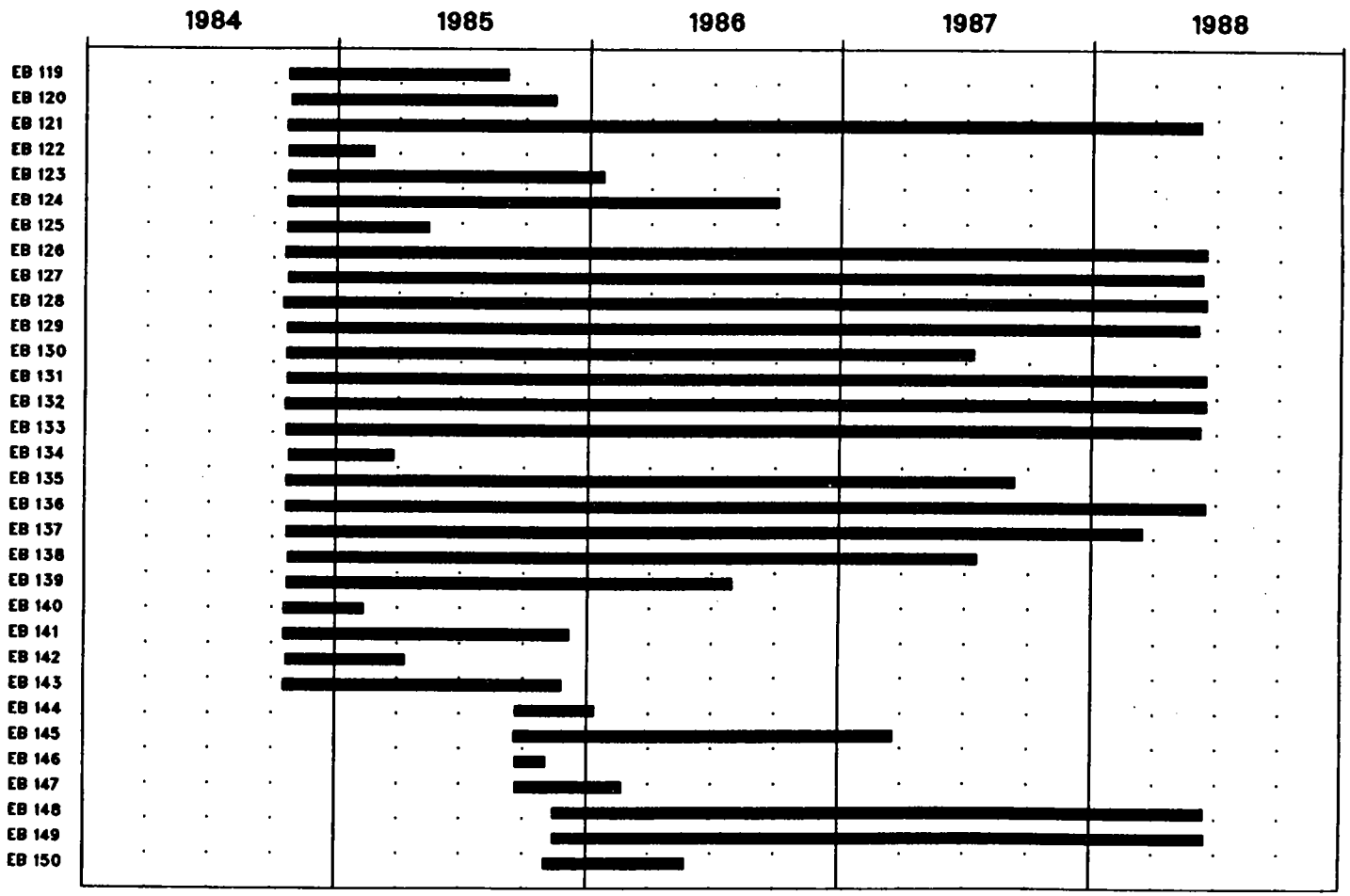


Figure 4: Bar graph showing the float lifetimes of all 32 eastern North Atlantic SOFAR floats (1984–1988).

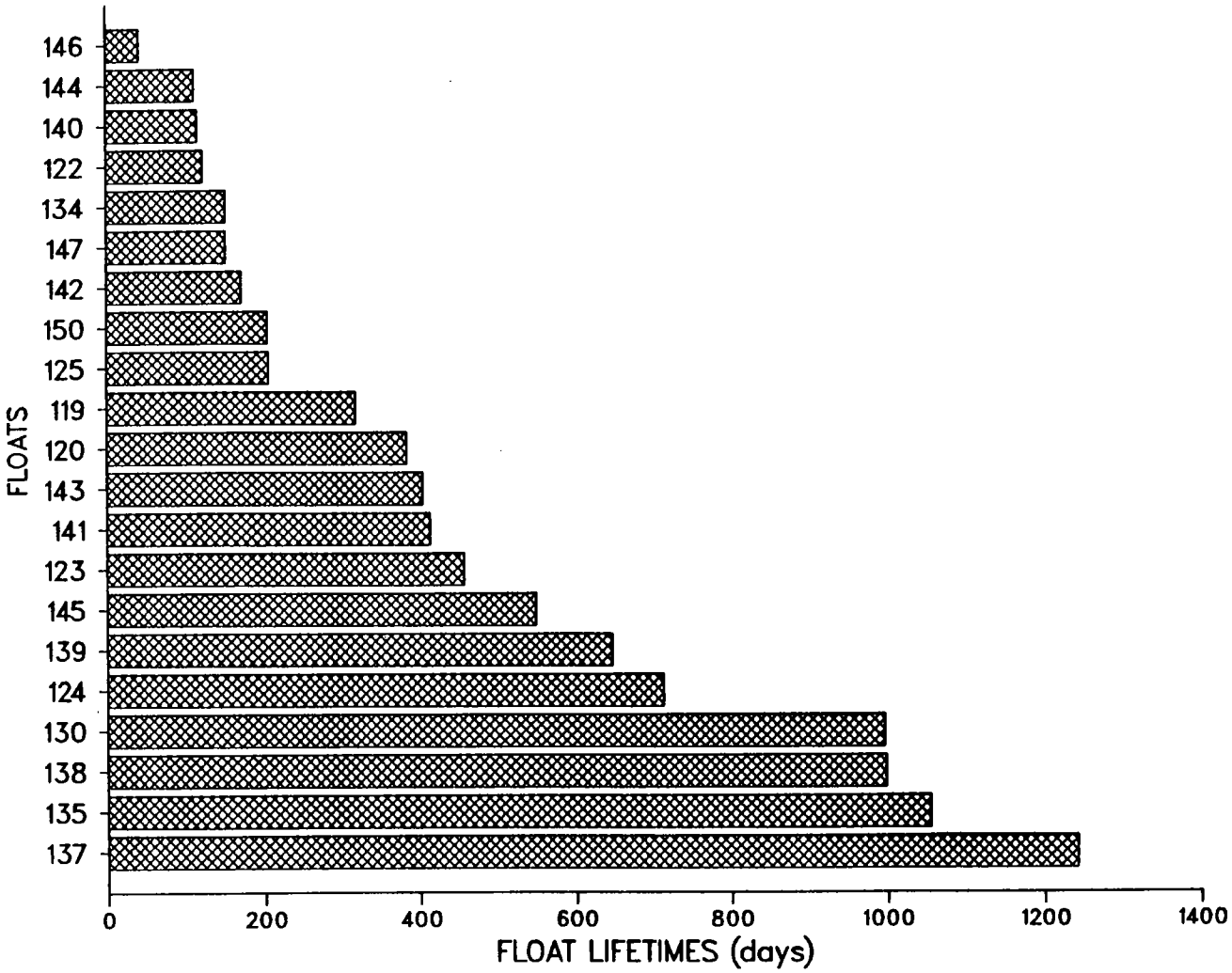


Figure 5: Bar graph showing lifetimes of floats that failed. Eleven floats were functioning normally when the ALS array was retrieved for the final time (see Figure 4).

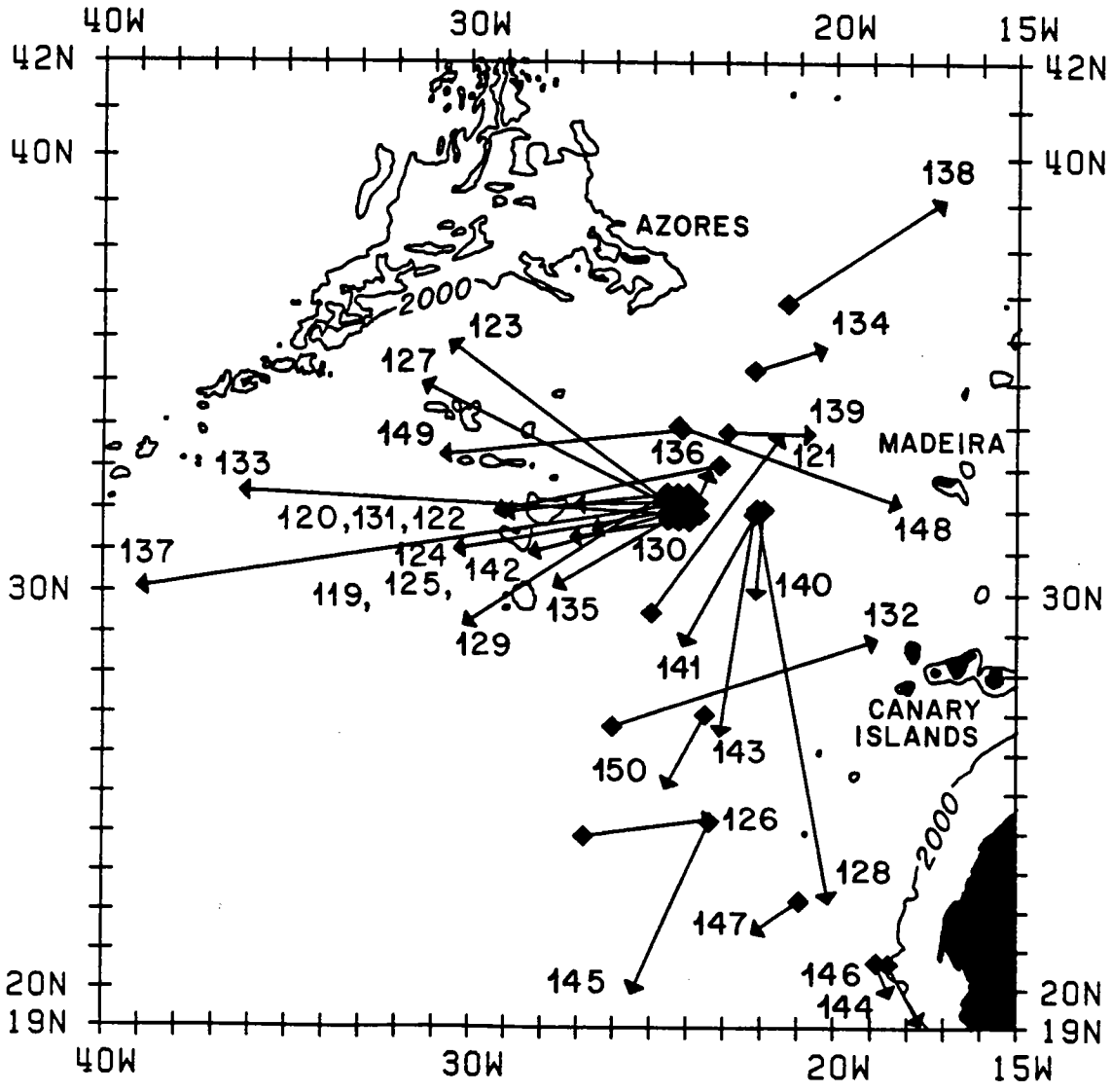


Figure 6: Displacement vectors from the first to last position of each float (1984–1988). Arrowheads mark final locations.

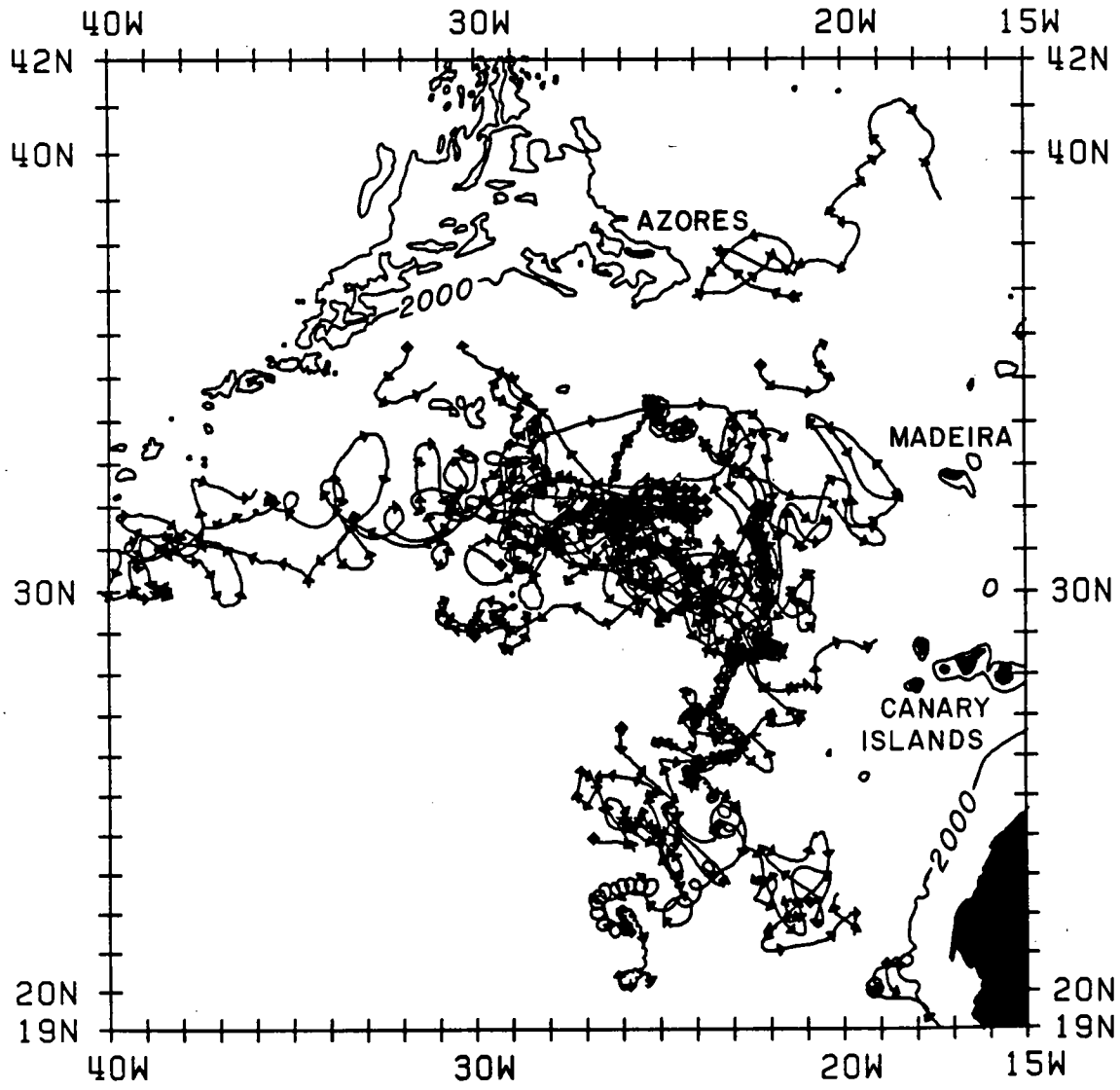


Figure 7: A composite of 32 float trajectories between 1984–1988. Arrowheads are located at 30-day intervals along the trajectories.

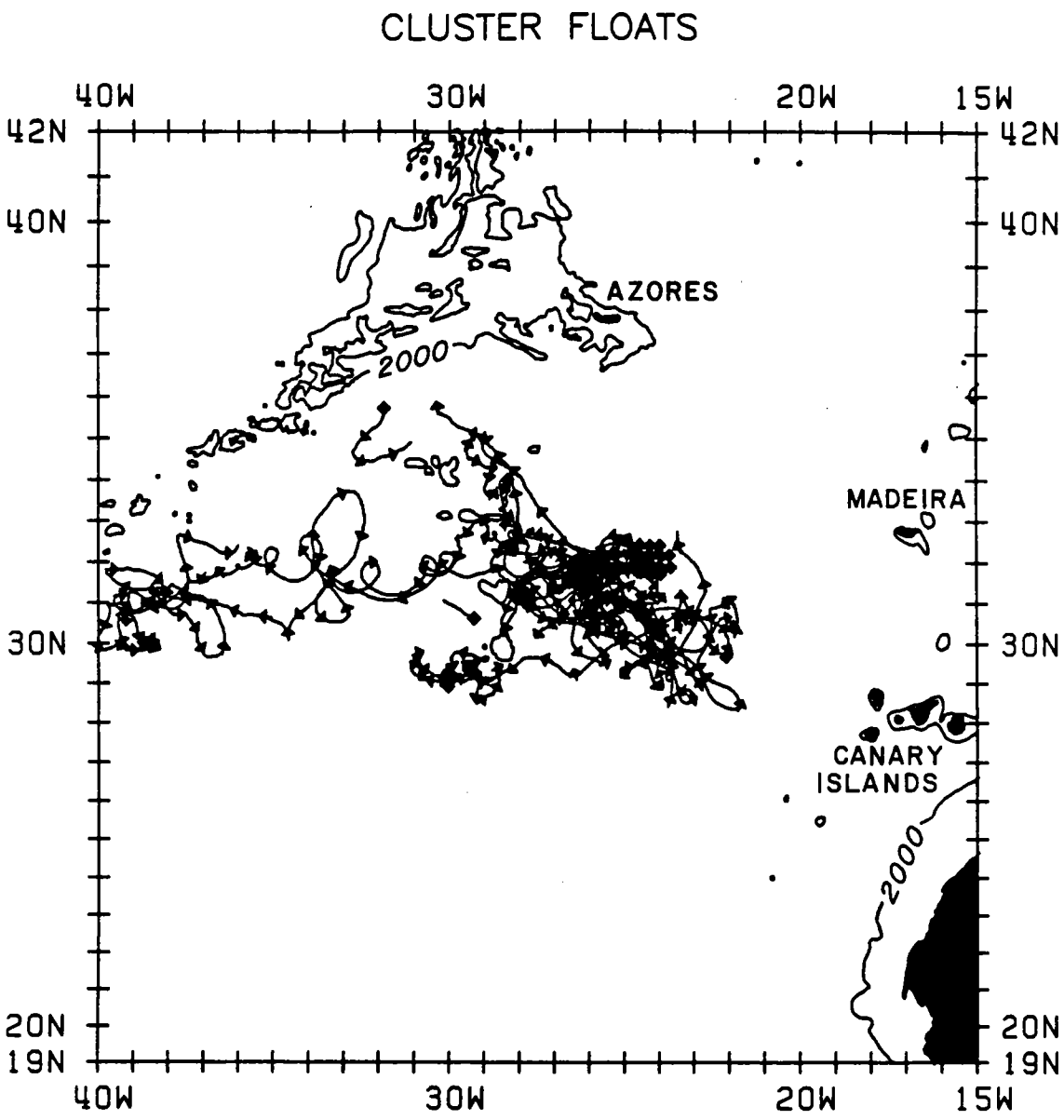


Figure 8a: A composite of 14 floats that were launched in a cluster centered on 32°N, 24°W, with nearest neighbors at 20 km spacing (1984–1988). Arrowheads are located at 30-day intervals along the trajectories.

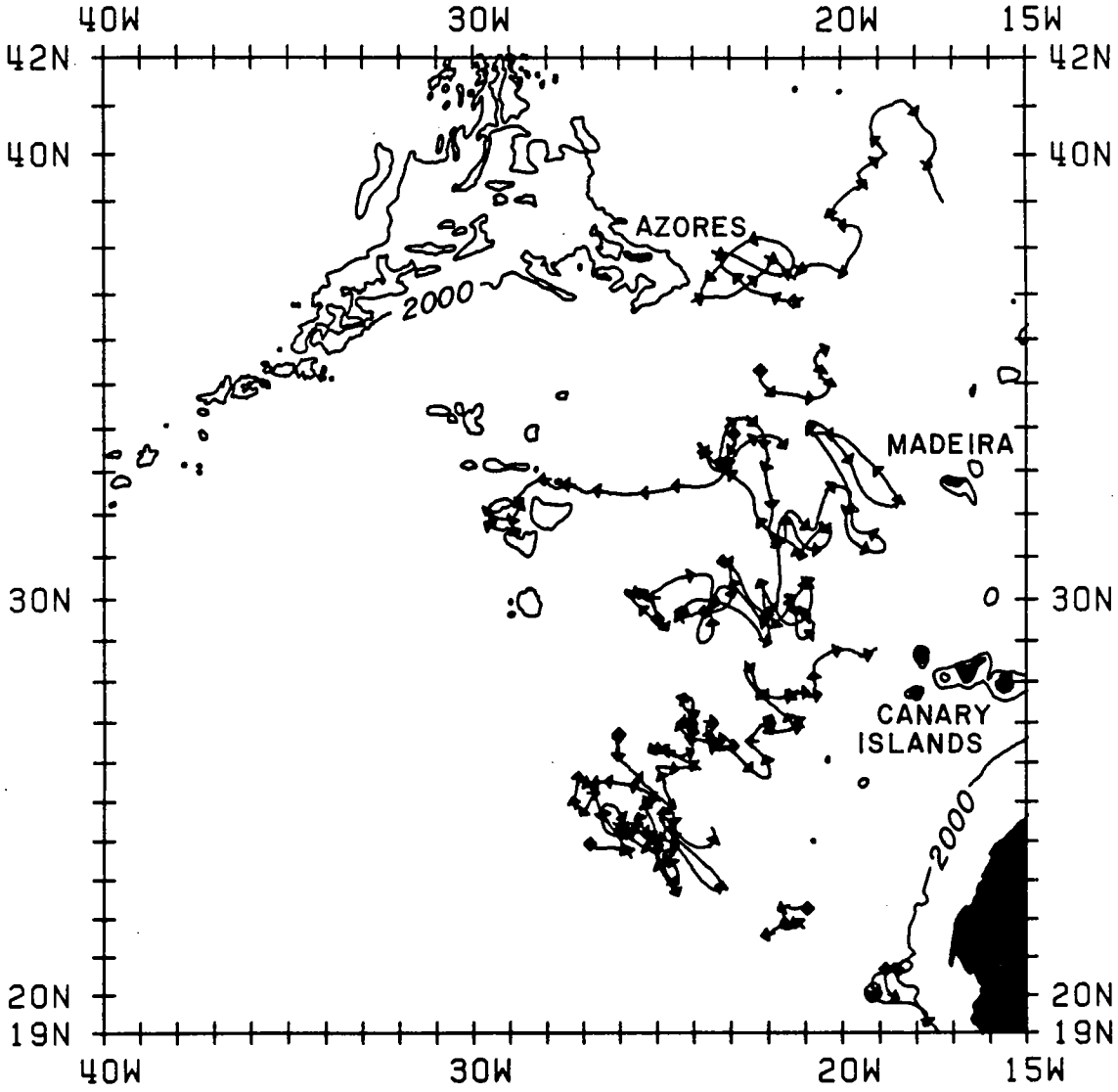


Figure 8b: A composite of 10 floats that were launched with wide spacing to explore regional variations of first-order flow statistics (1984–1988). Arrowheads are located at 30-day intervals along the trajectories.

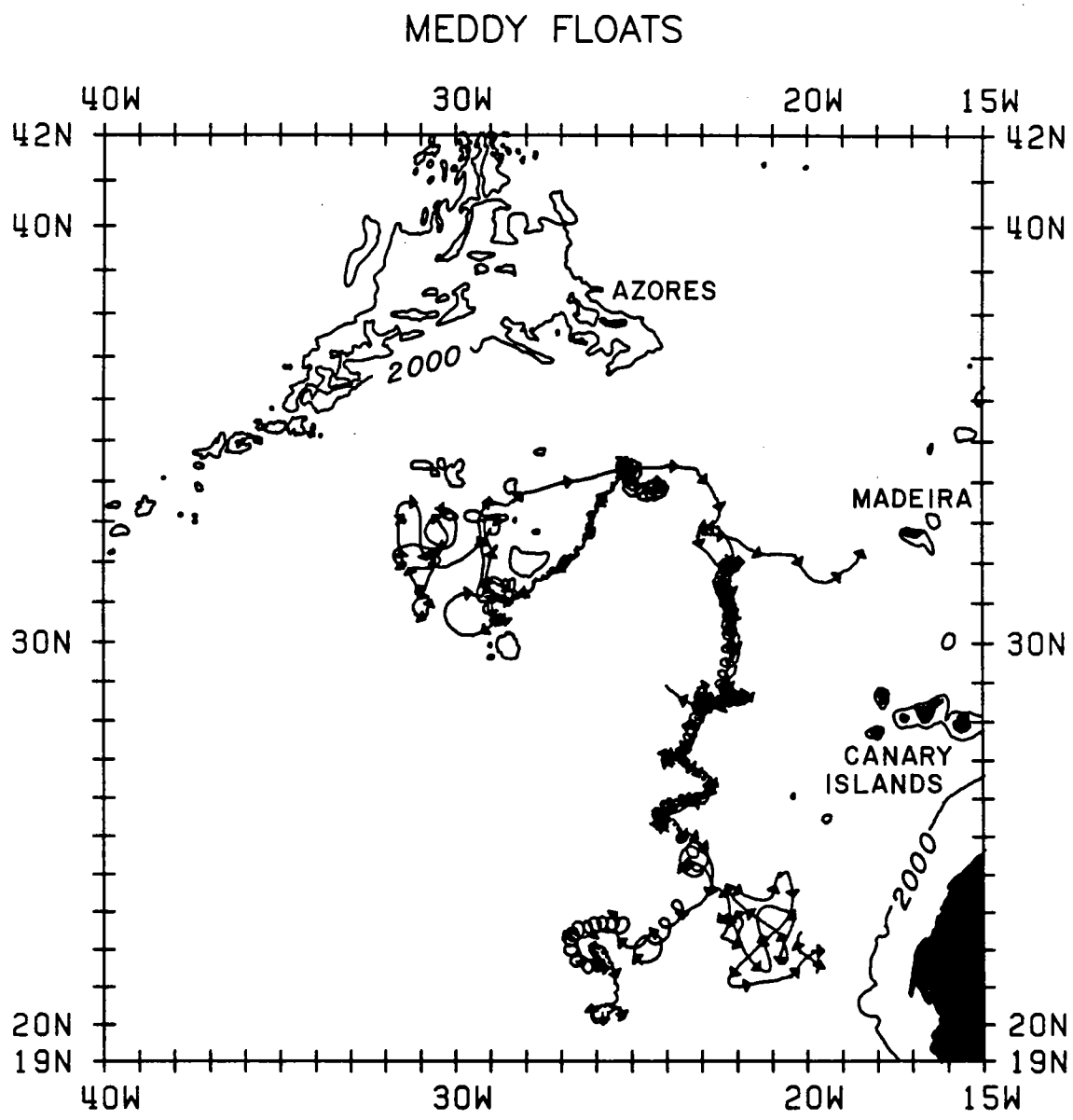


Figure 8c: A composite of eight floats that were launched in three different Meddies (Mediterranean water eddies) 1984–1988. Arrowheads are located at 30-day intervals along the trajectories.

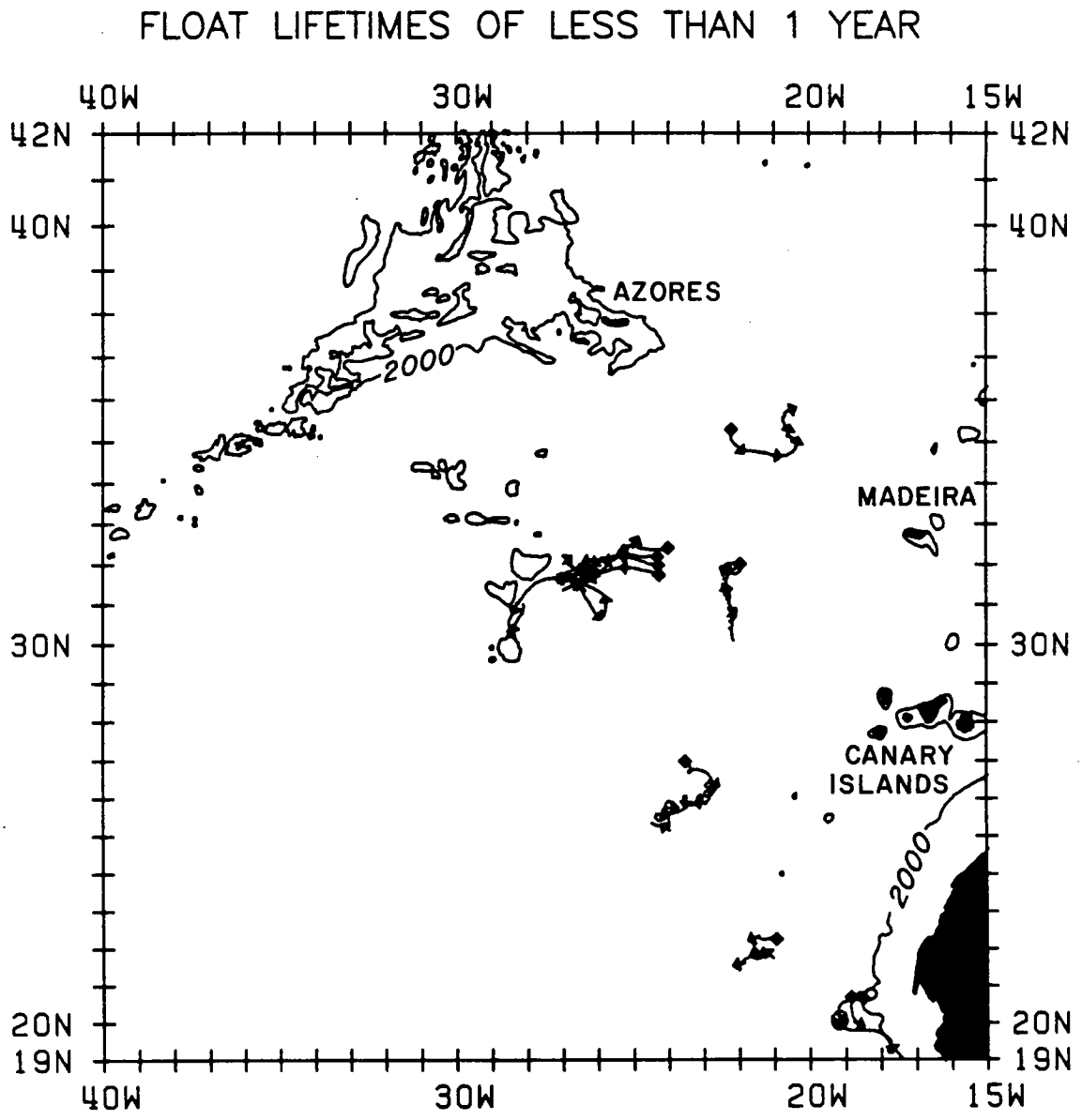


Figure 9a: A composite of 10 float trajectories with tracked lifetimes of less than one year. Arrowheads are located at 30-day intervals along the trajectories.

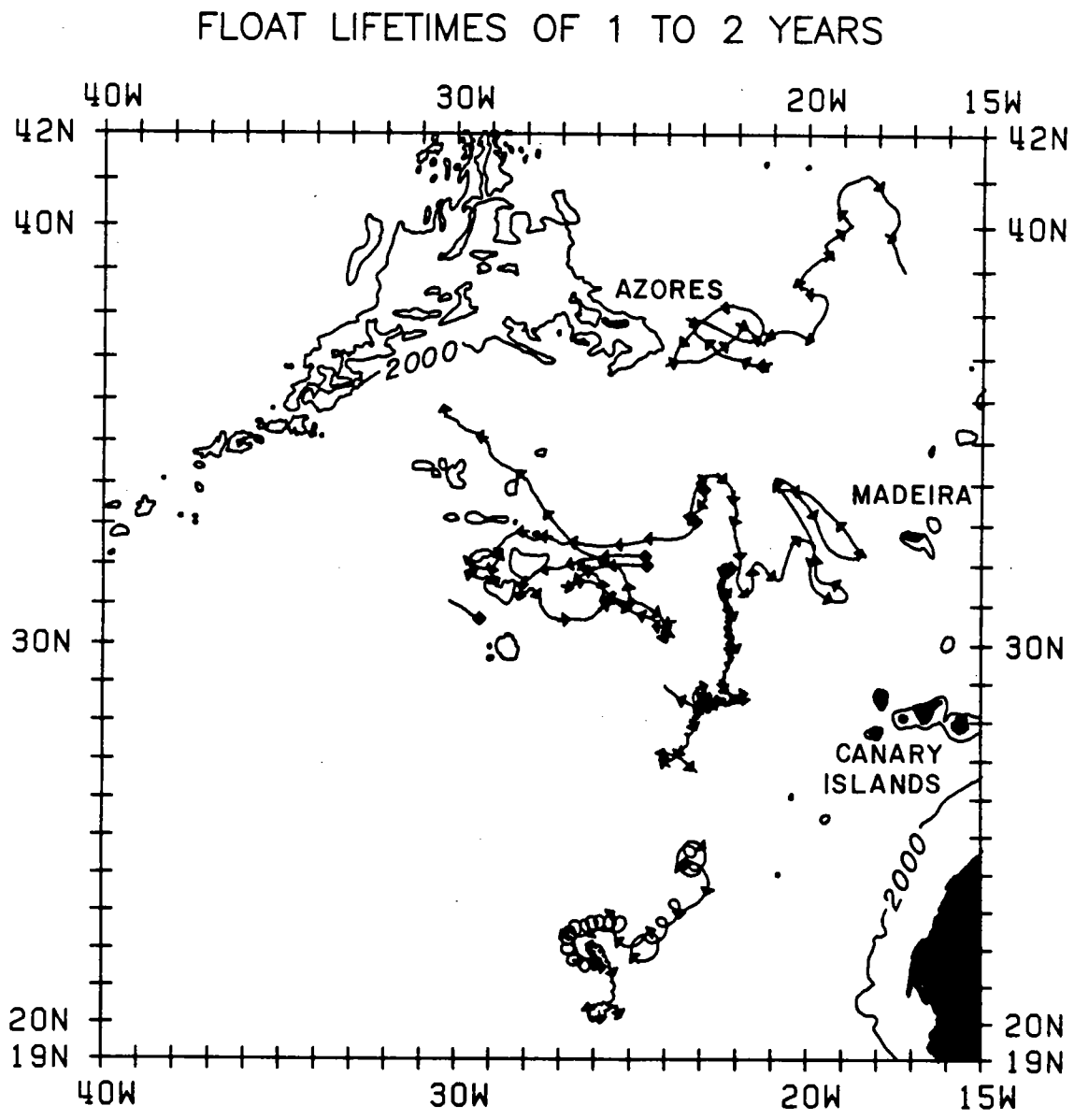


Figure 9b: A composite of eight float trajectories with tracked lifetimes of one to two years. Arrowheads are located at 30-day intervals along the trajectories.

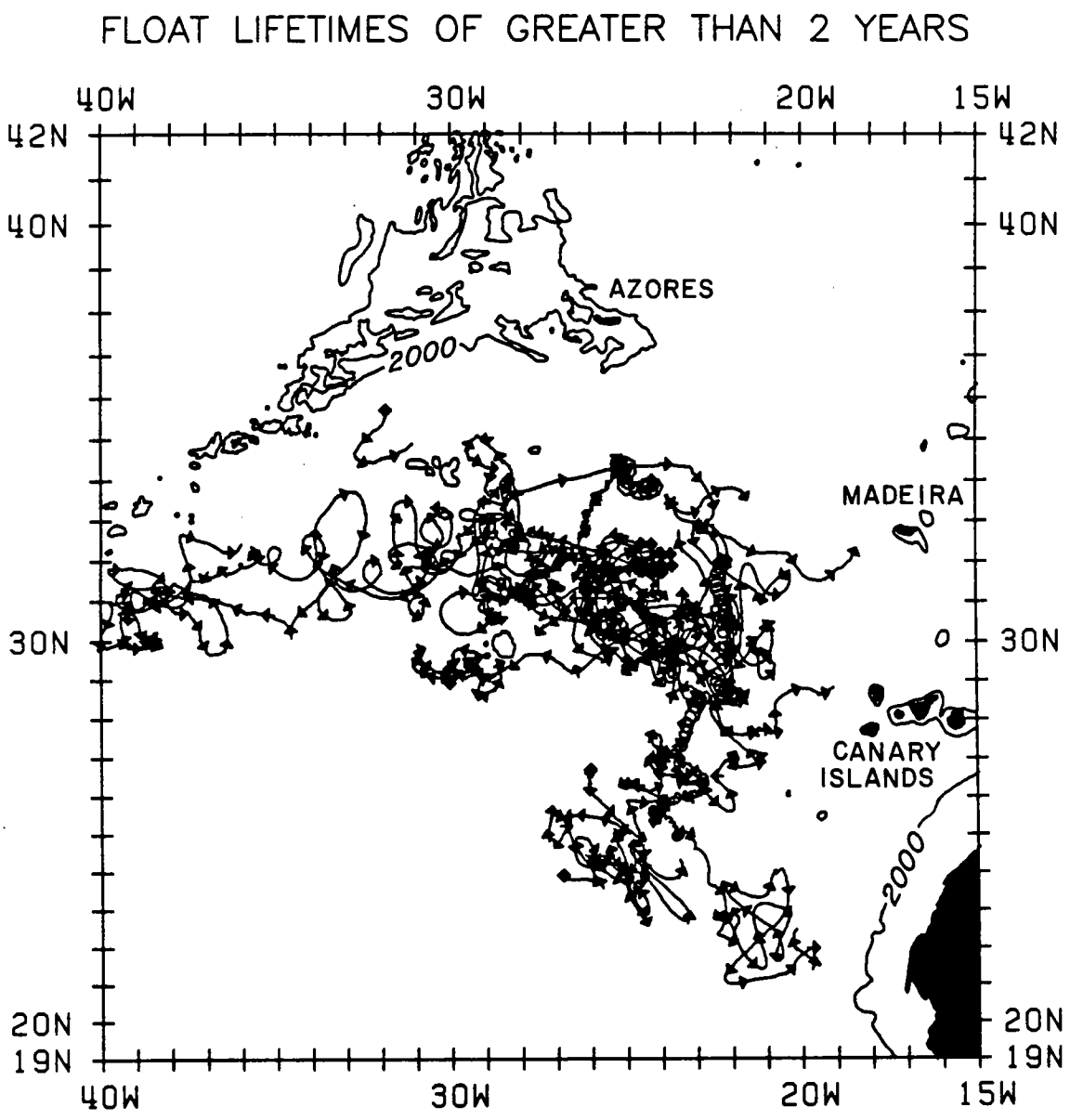


Figure 9c: A composite of 14 float trajectories with tracked lifetimes of greater than two years. Arrowheads are located at 30-day intervals along the trajectories.

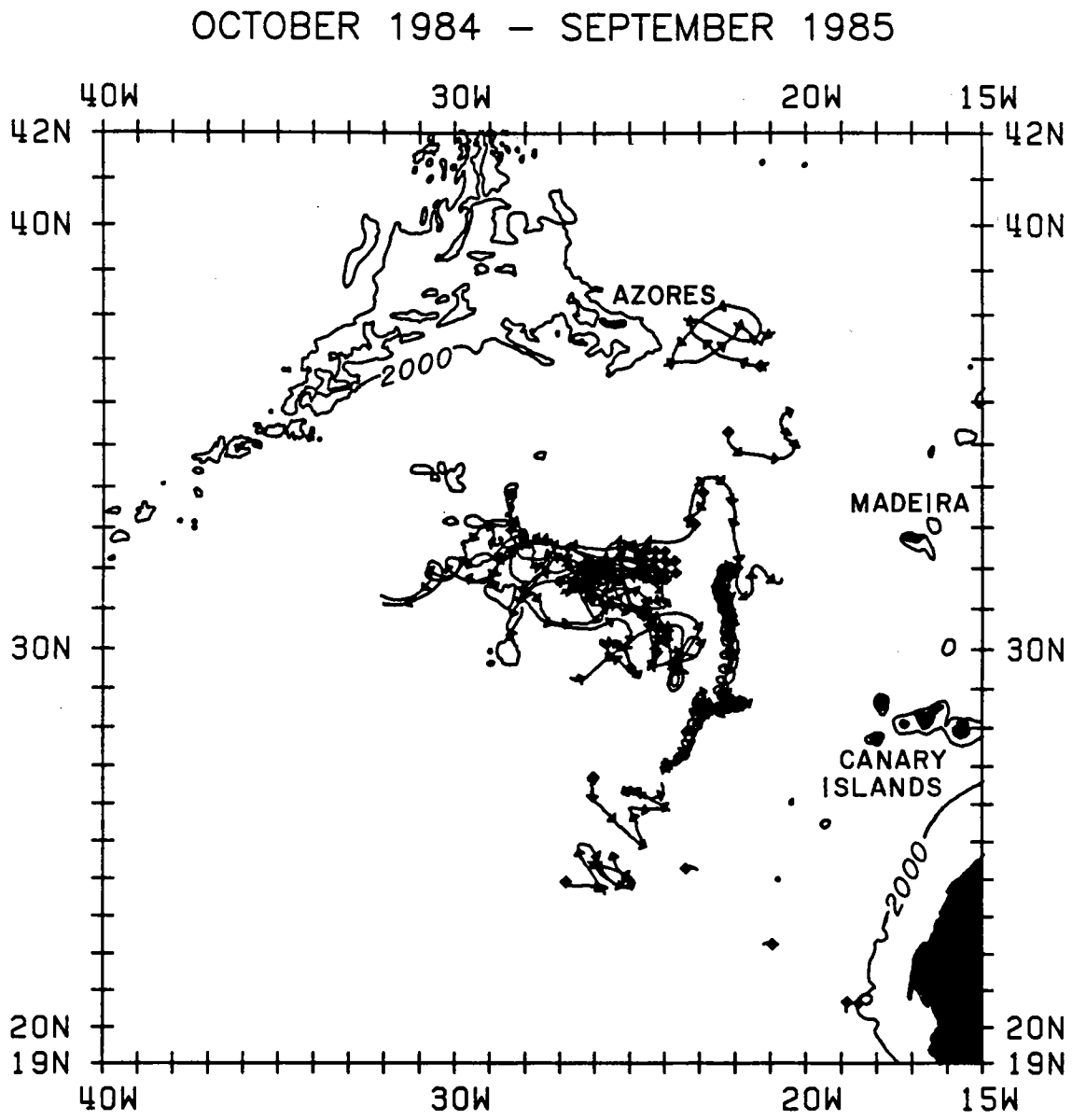


Figure 10a: A composite of float trajectories between October 1984–September 1985. Arrowheads are located at 30-day intervals along the trajectories.

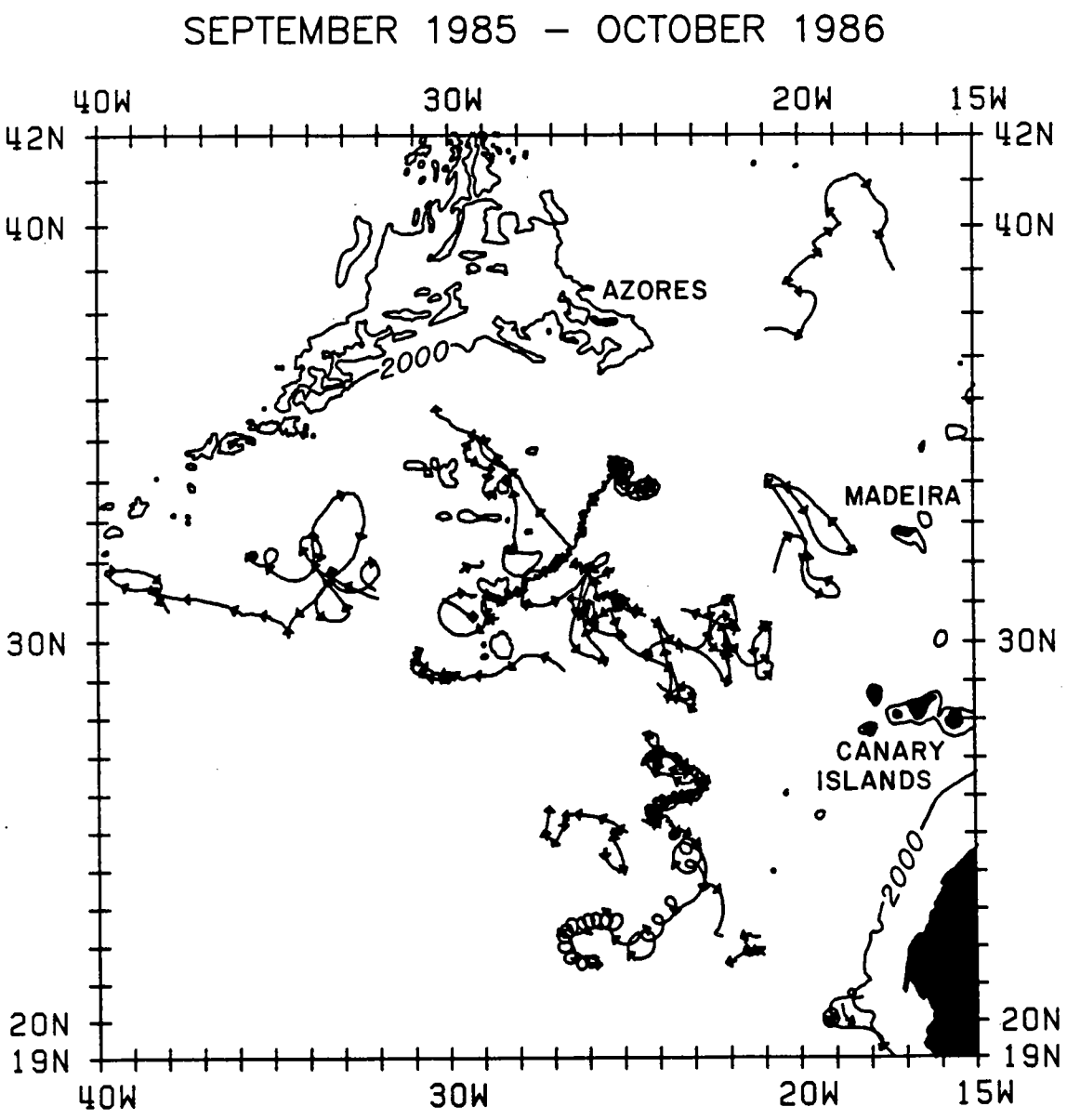


Figure 10b: A composite of float trajectories between September 1985–October 1986. Arrowheads are located at 30-day intervals along the trajectories.

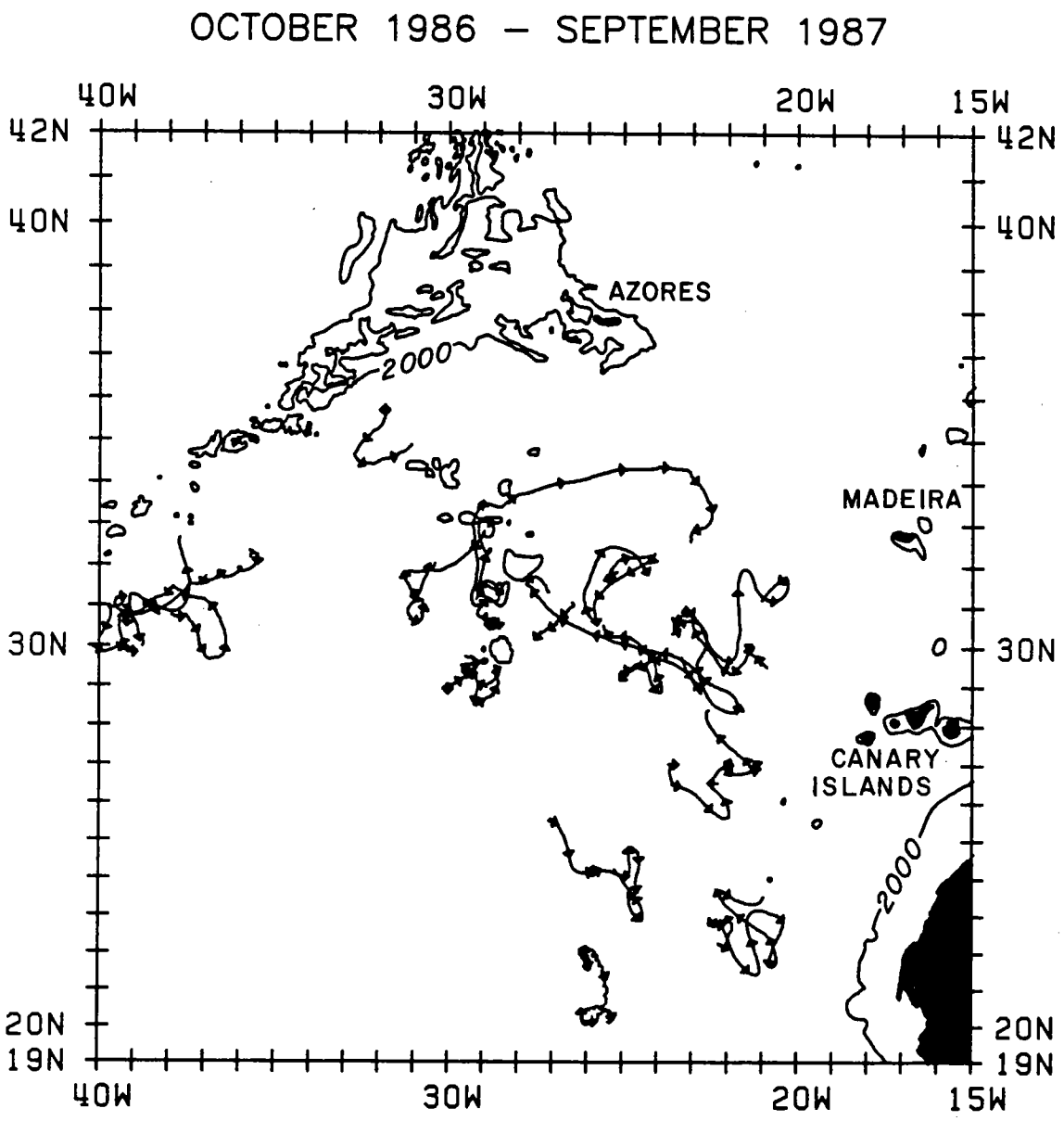


Figure 10c: A composite of float trajectories between October 1986–September 1987. Arrowheads are located at 30-day intervals along the trajectories.

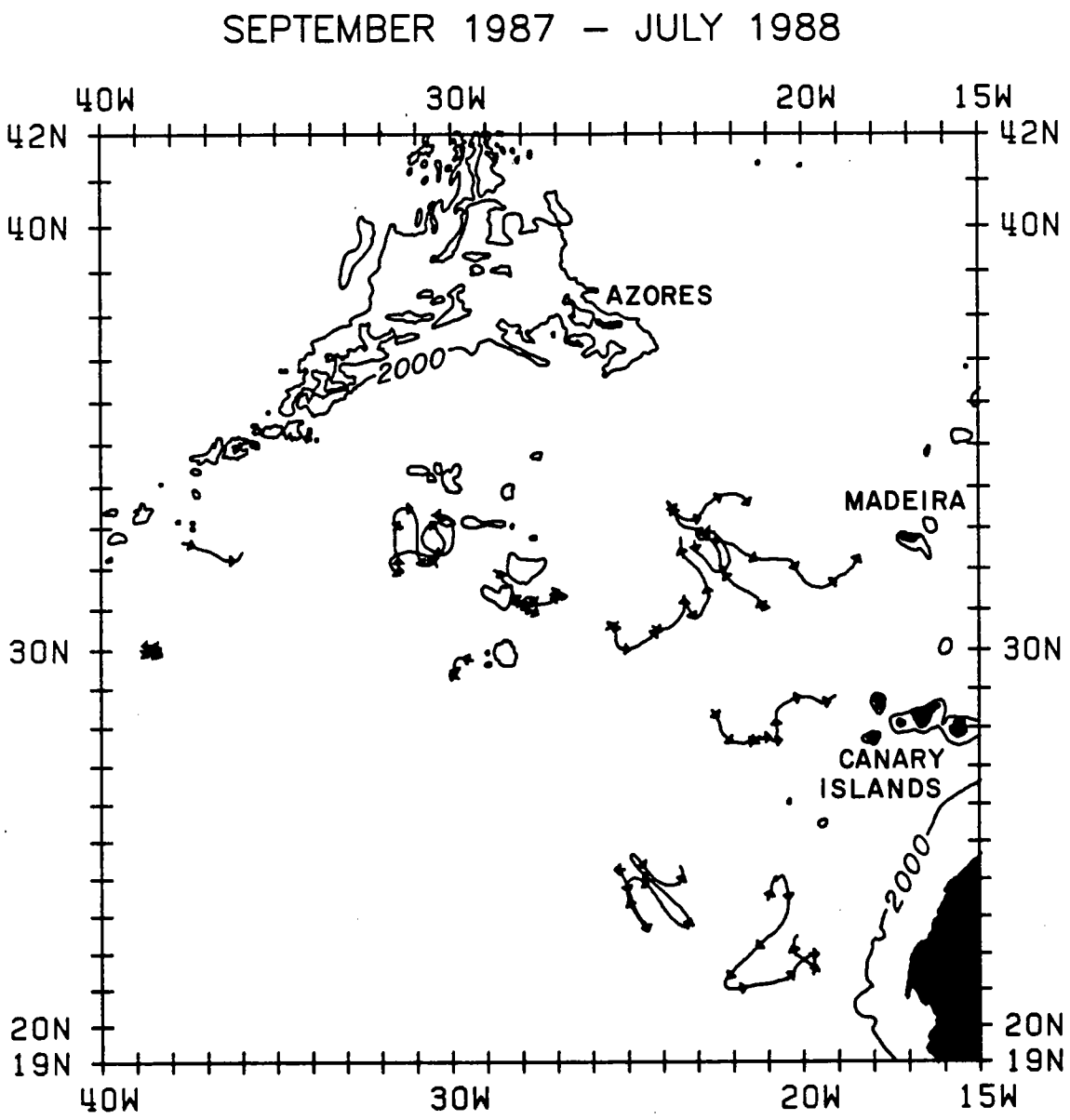


Figure 10d: A composite of float trajectories between September 1987–July 1988. Arrowheads are located at 30-day intervals along the trajectories.

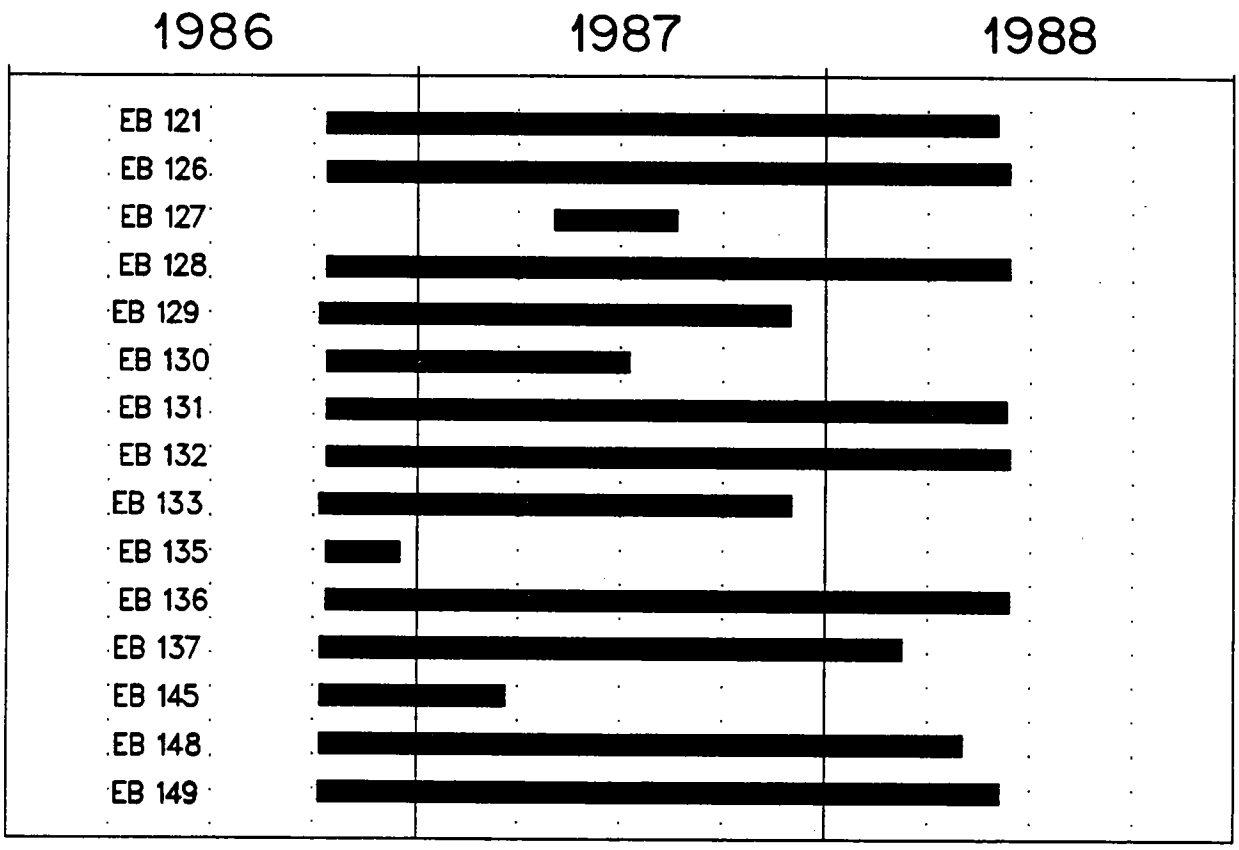


Figure 11: Bar graph showing the time that each float was tracked from the final ALS setting (1986–1988).

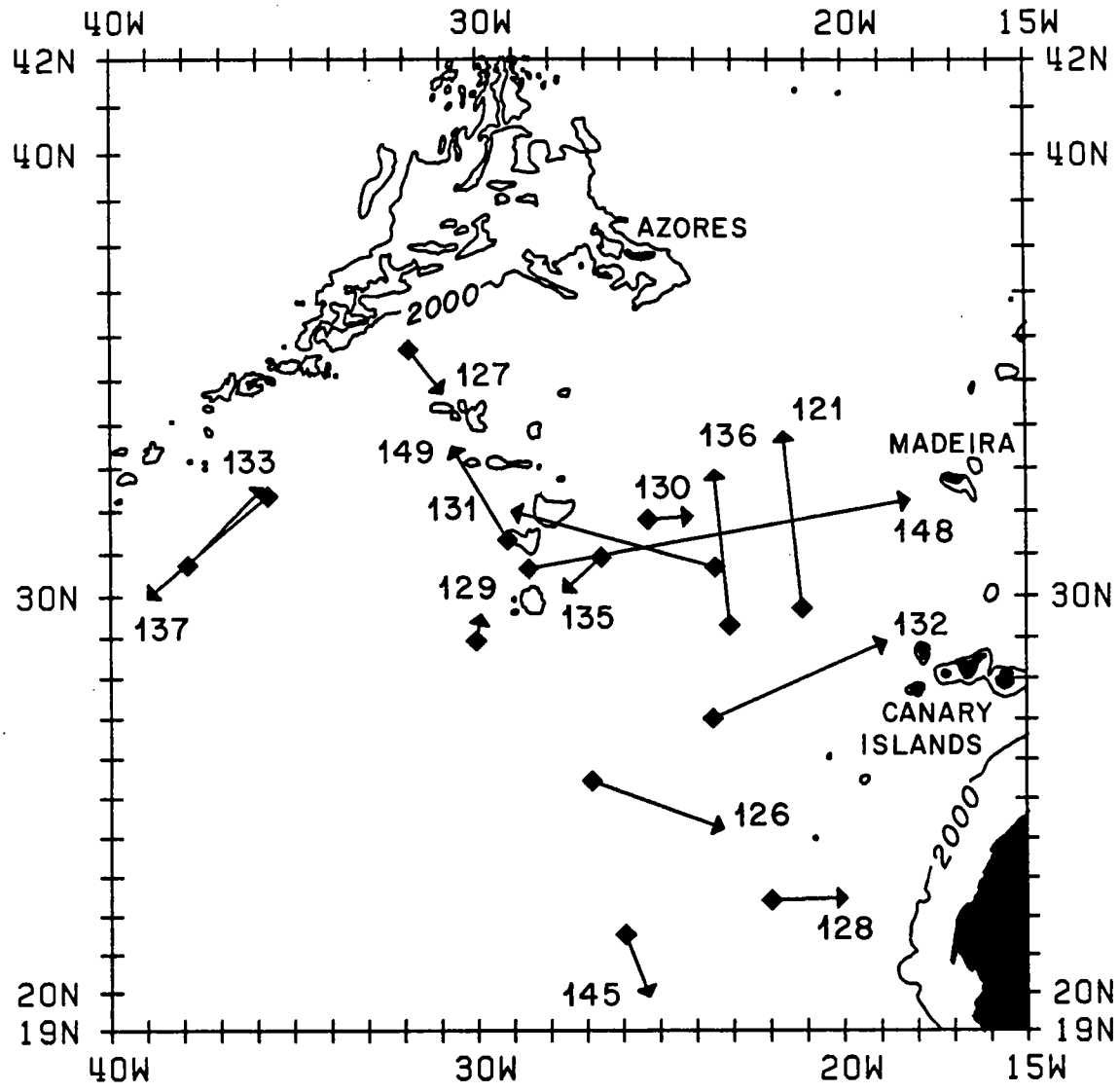


Figure 12: Displacement vectors from the first to last position of each float (1986–1988). Arrowheads mark final locations.

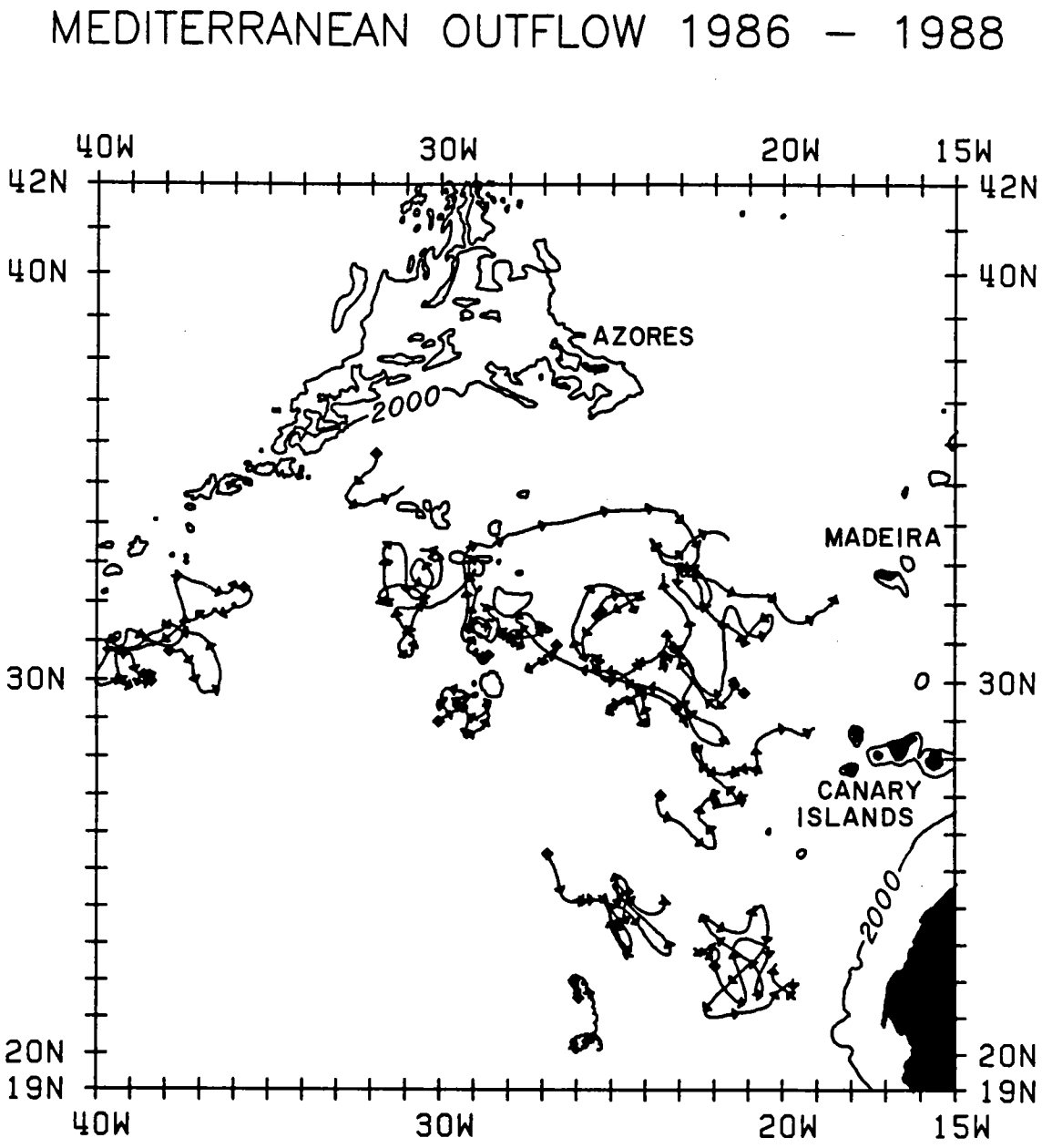


Figure 13: A composite of 15 float trajectories between 1986–1988. Arrowheads are located at 30-day intervals along the trajectories.

TABLE III

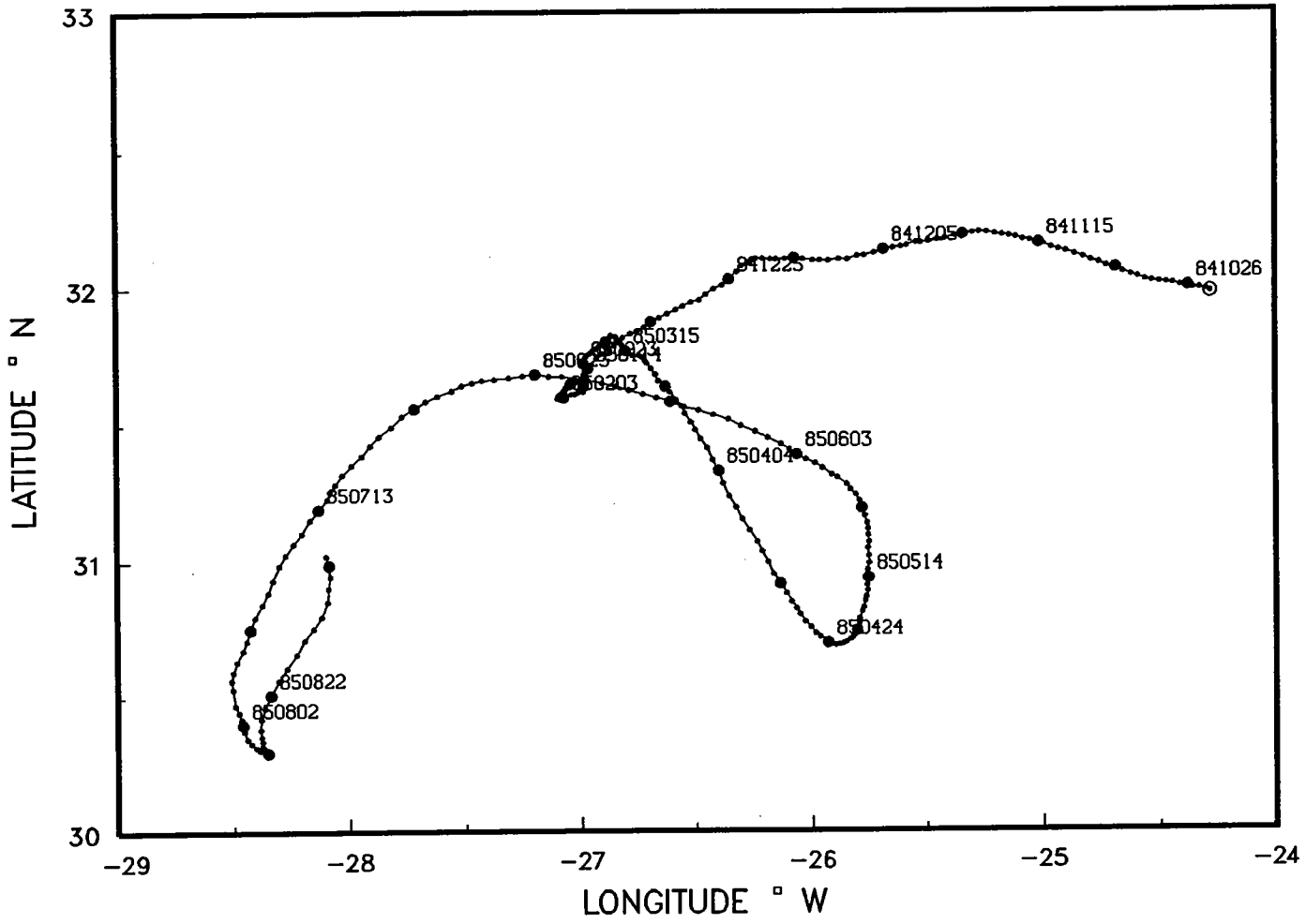
FLOAT FILE STATISTICS FOR 1986 - 1988 TRACKING

FLOAT	NOMINAL DEPTH (m)	START DATE yymmdd	START POSITION LAT. deg N	START POSITION LONG. deg W	STOP DATE yymmdd	STOP POSITION LAT. deg N	STOP POSITION LONG. deg W	NO. DAYS TRACKED	COMMENTS yymmdd
121	1100	861012	29.710	21.124	880602	33.630	21.594	600	
126	1100	861013	25.447	26.854	880613	24.323	23.519	610	
127C	1100	870503	35.710	31.857	870821	34.891	31.075	111	
128	1100	861012	22.415	21.978	880613	22.459	20.191	611	
129B	1100	861006	28.935	30.026	871201	29.336	29.943	422	
130	1100	861012	31.810	25.296	870709	31.875	24.345	271	died 870709
131	1100	861012	30.698	23.479	880601	31.956	28.800	608	
132	1100	861012	27.020	23.550	880613	28.806	19.077	611	
133	1100	861006	30.745	37.890	871202	32.408	36.002	423	
135B	1100	861012	30.929	26.593	861217	30.262	27.451	67	died 861217
136	1100	861012	29.301	23.092	880613	32.748	23.484	611	
137	1100	861007	32.349	35.713	880310	30.116	38.792	521	died 880310
145	1100	861007	21.538	25.947	870321	20.130	25.386	166	died 870321
148	1100	861007	30.660	28.584	880503	32.222	18.445	575	
149	1000	861006	31.341	29.151	880604	33.327	30.544	608	

4 Summary Trajectories of Individual Floats: 1984–1988

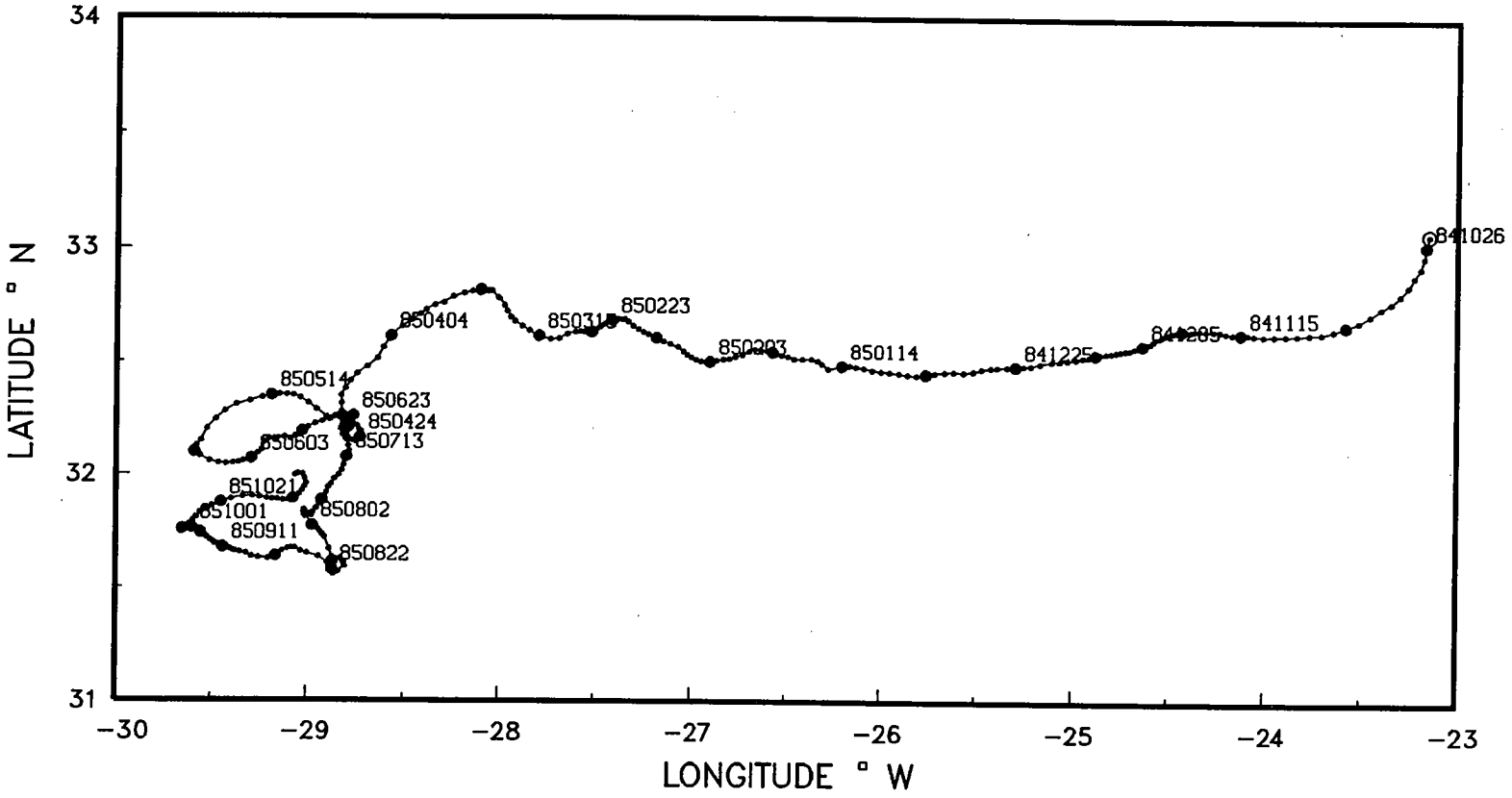
Thirty-two individual summary trajectories are presented for our three and a half year eastern North Atlantic SOFAR float experiment (October 1984–June 1988). Each float trajectory is plotted on a mercator projection, and negative numbers indicate longitudes west of the Greenwich Meridian. Along the trajectories, open circles denote the first float position, small dots mark the daily positions, large dots the tenth day, and every twentieth day is annotated with the date.

EASTERN BASIN 119



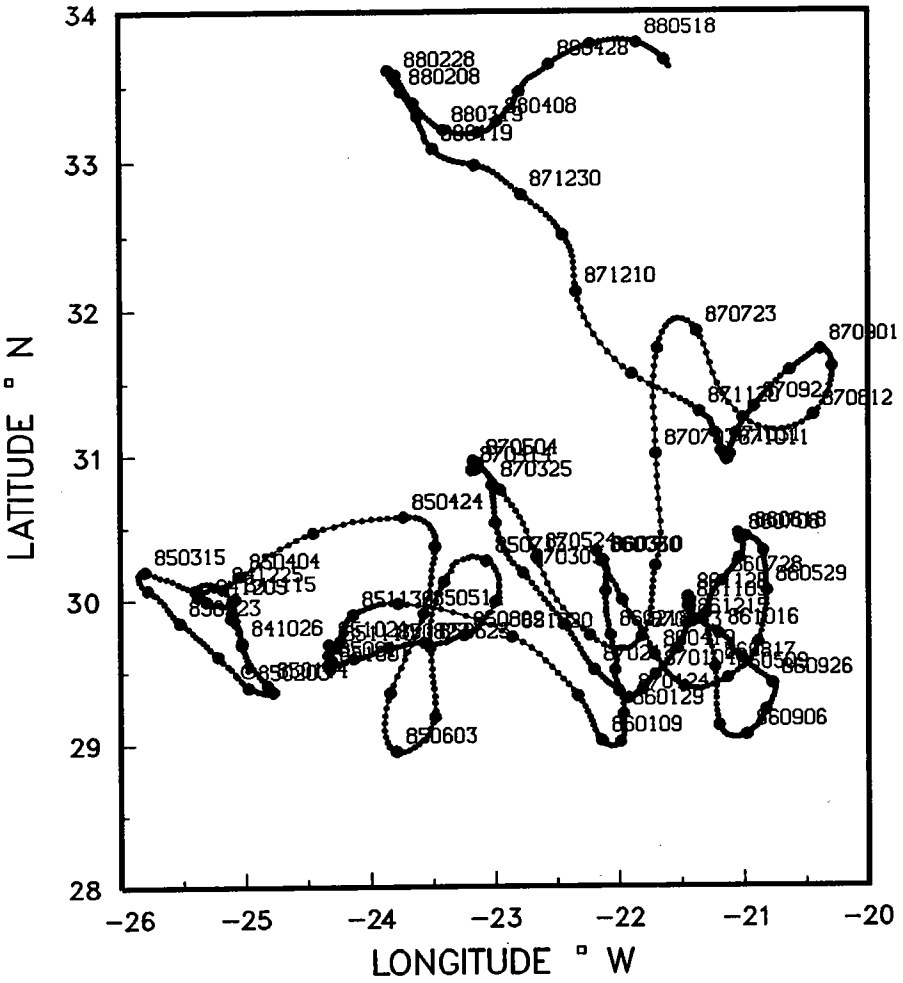
PLOT 1 OF 1
.DAT

EASTERN BASIN 120



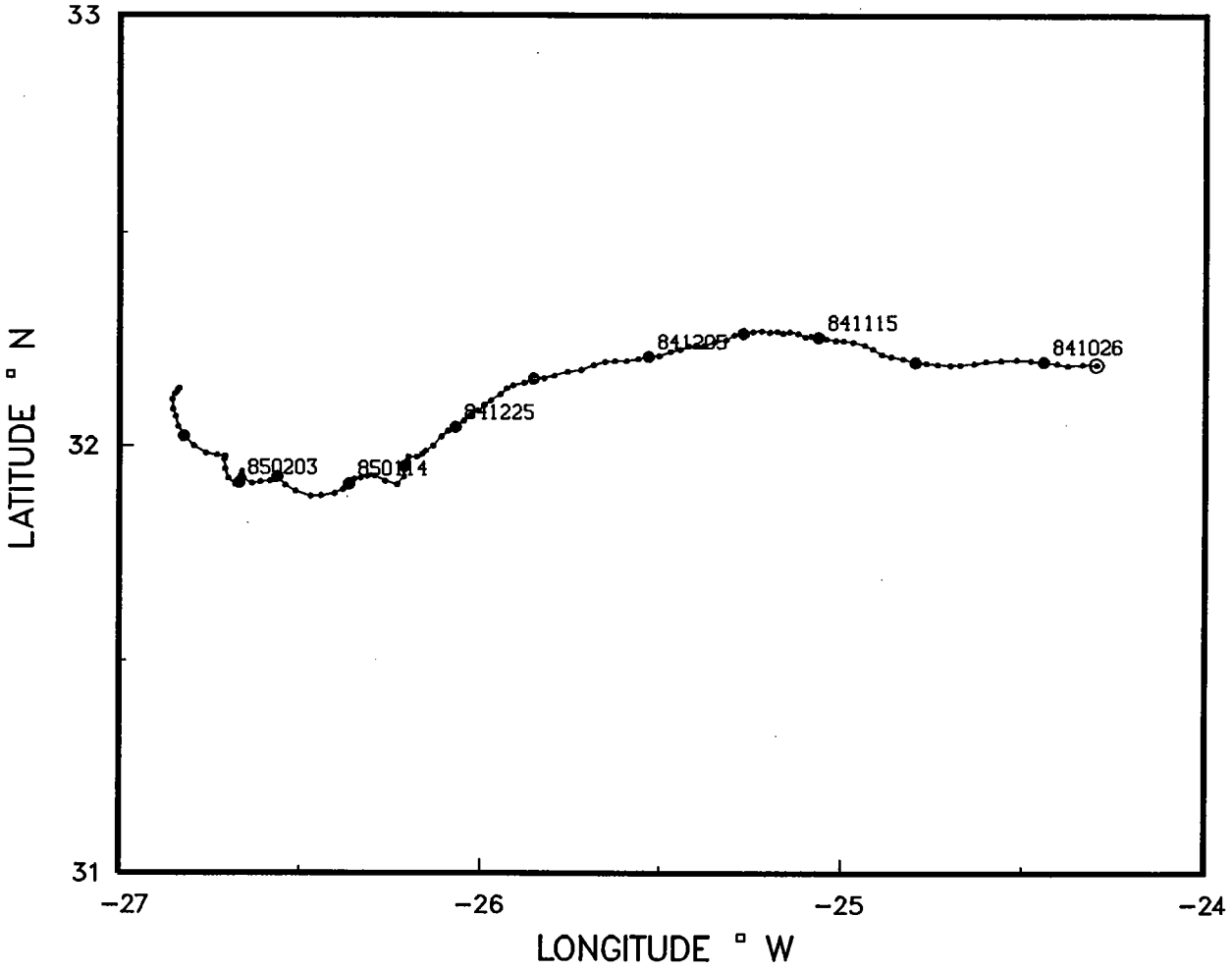
PLOT 1 OF 1
.DAT

EASTERN BASIN 121



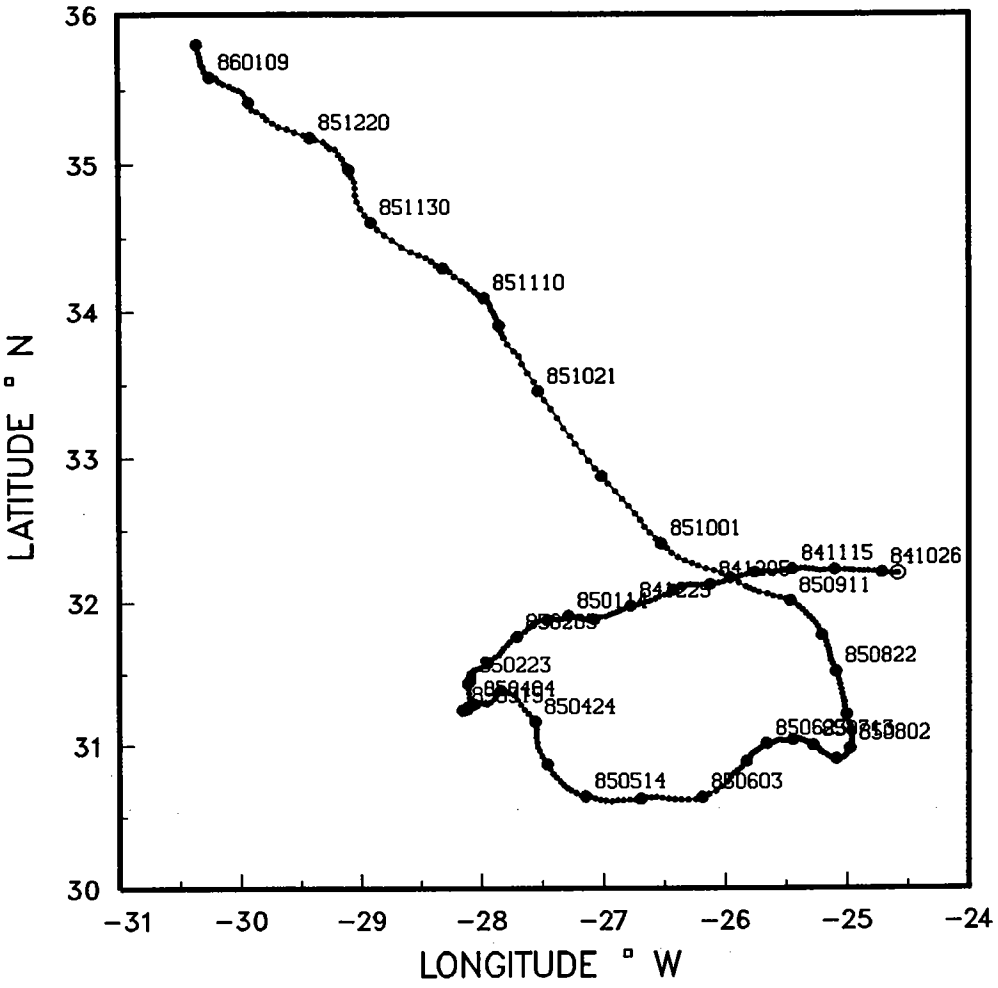
PLOT 1 OF 1
.DAT

EASTERN BASIN 122



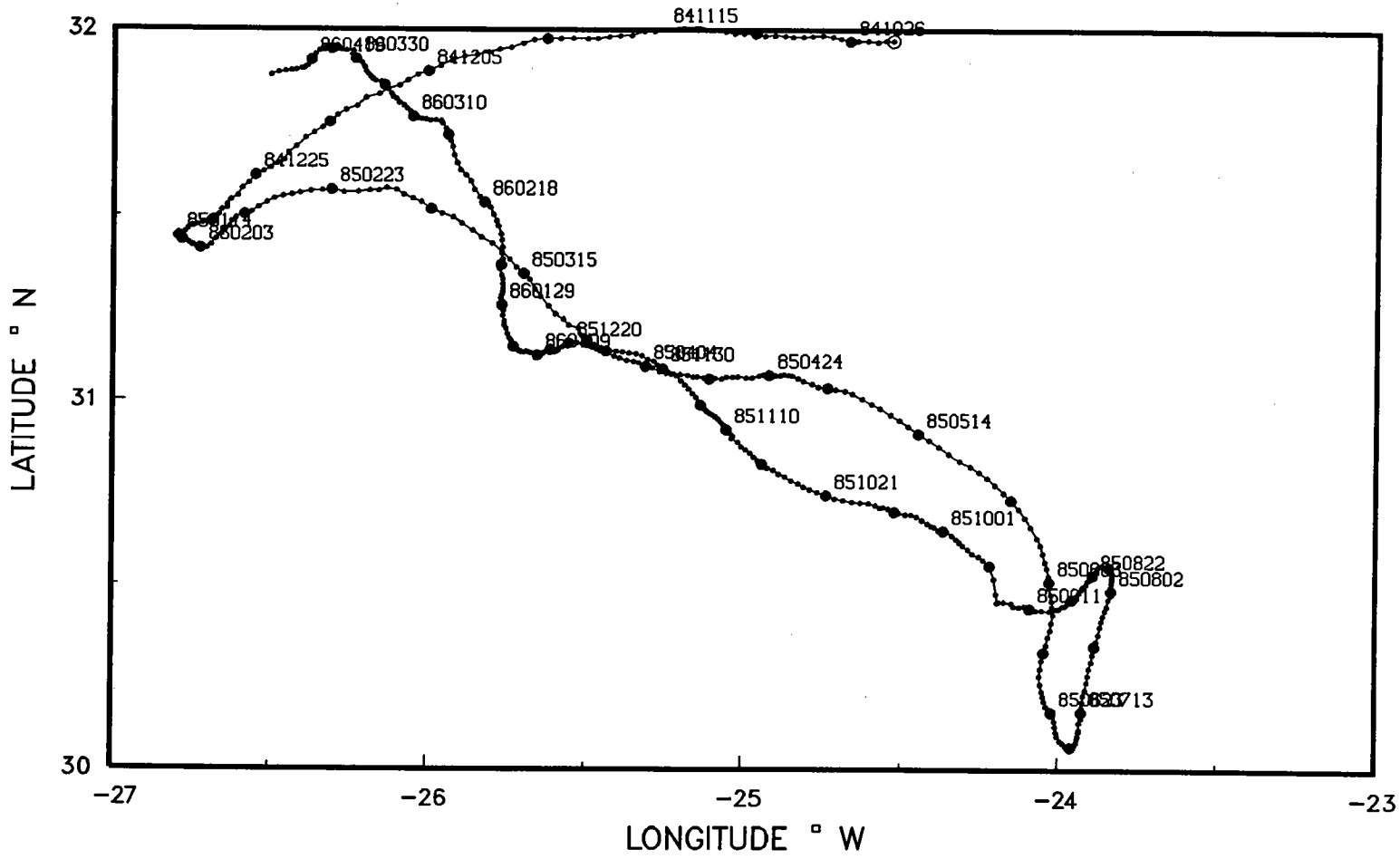
PLOT 1 OF 1
.DAT

EASTERN BASIN 123



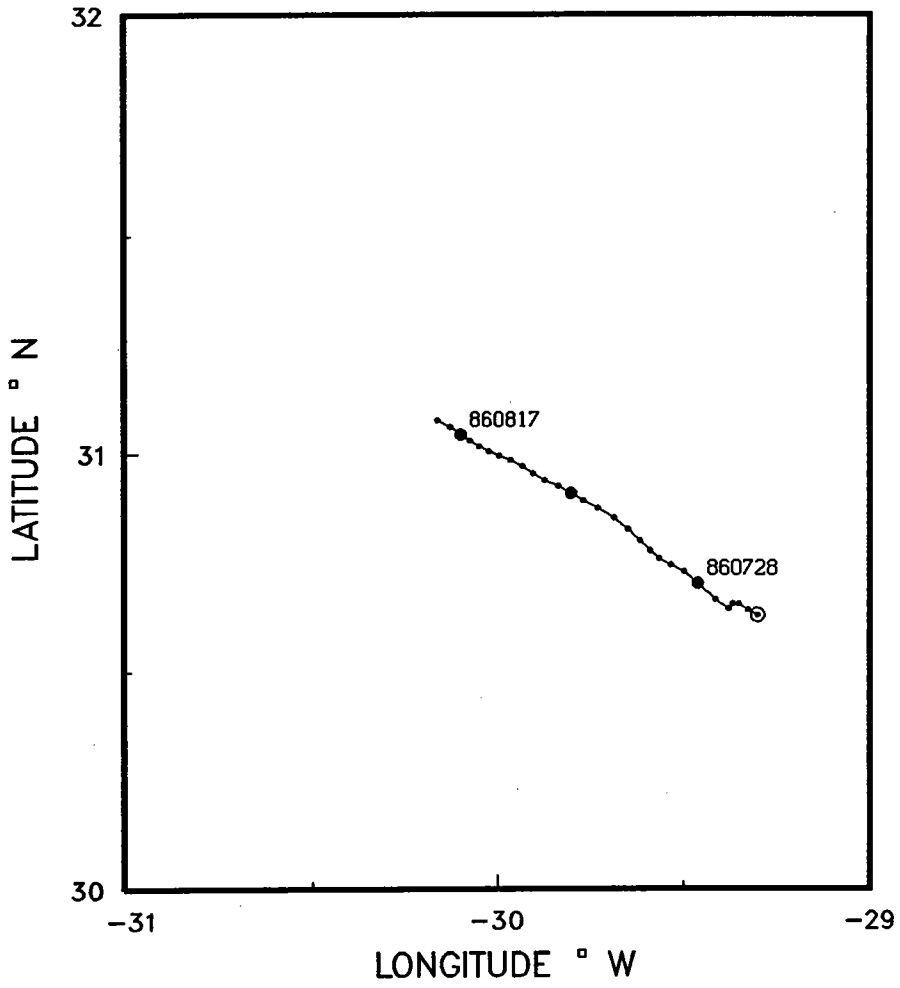
PLOT 1 OF 1
.DAT

EASTERN BASIN 124A



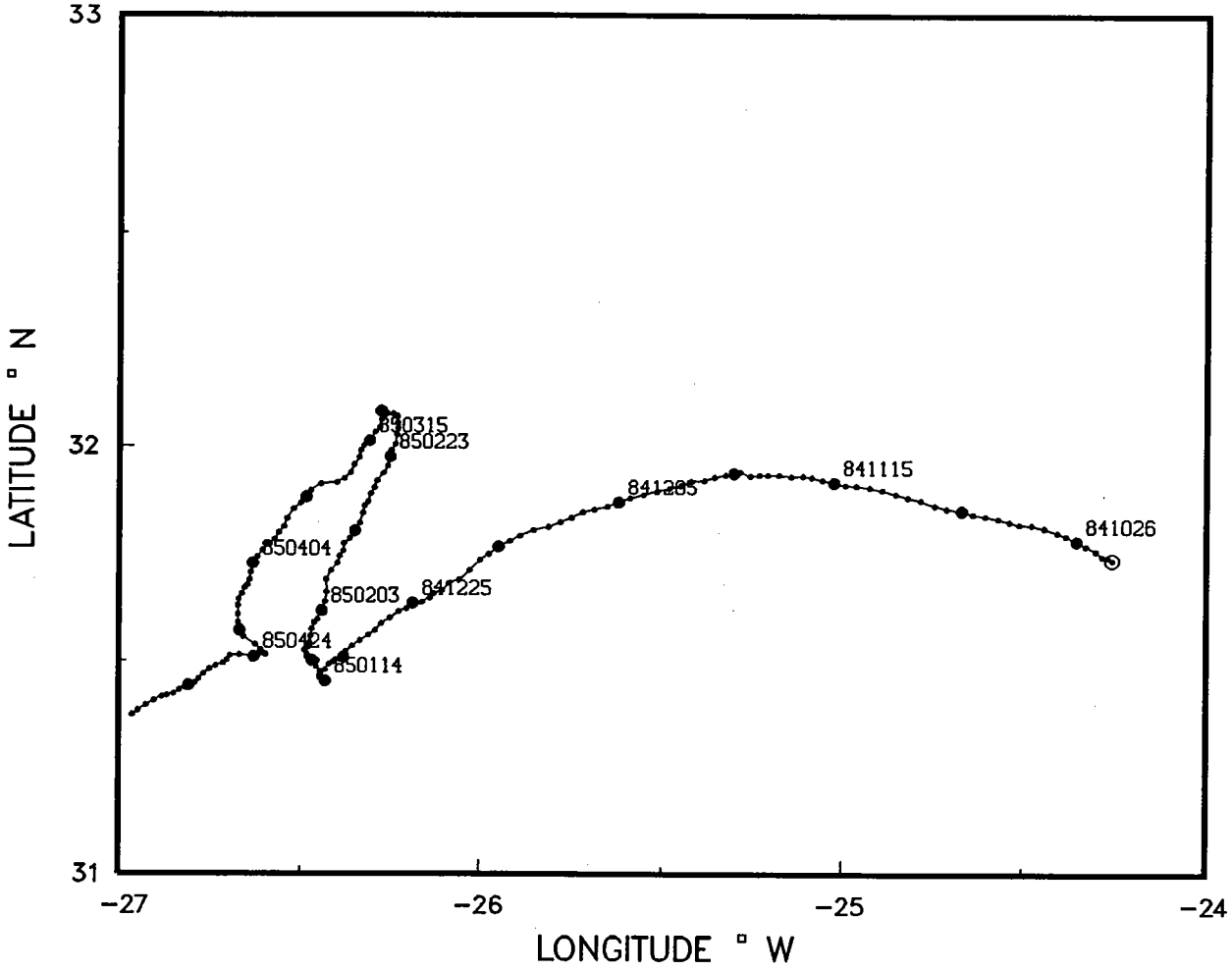
PLOT 1 OF 1
.DAT

EASTERN BASIN 124B



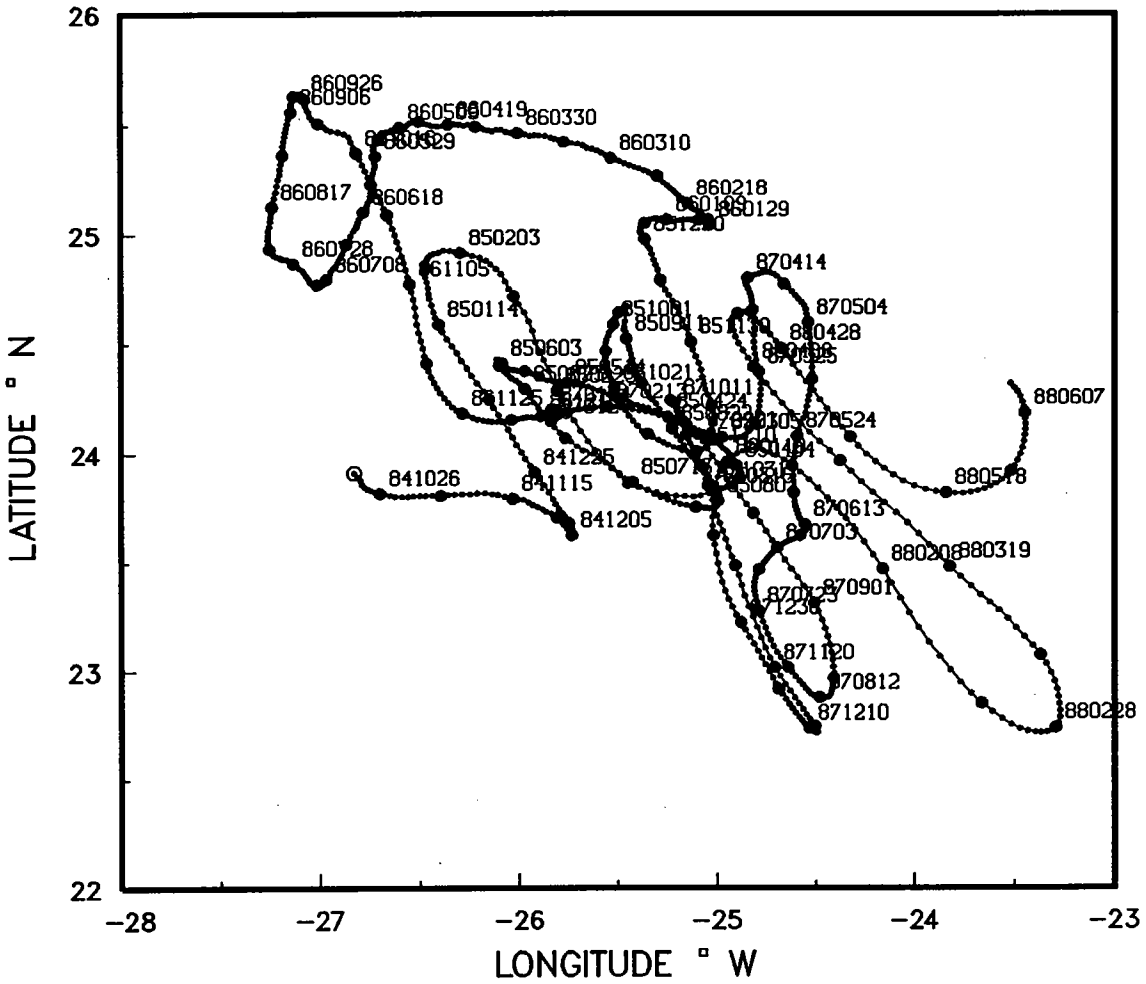
PLOT 1 OF 1
.DAT

EASTERN BASIN 125



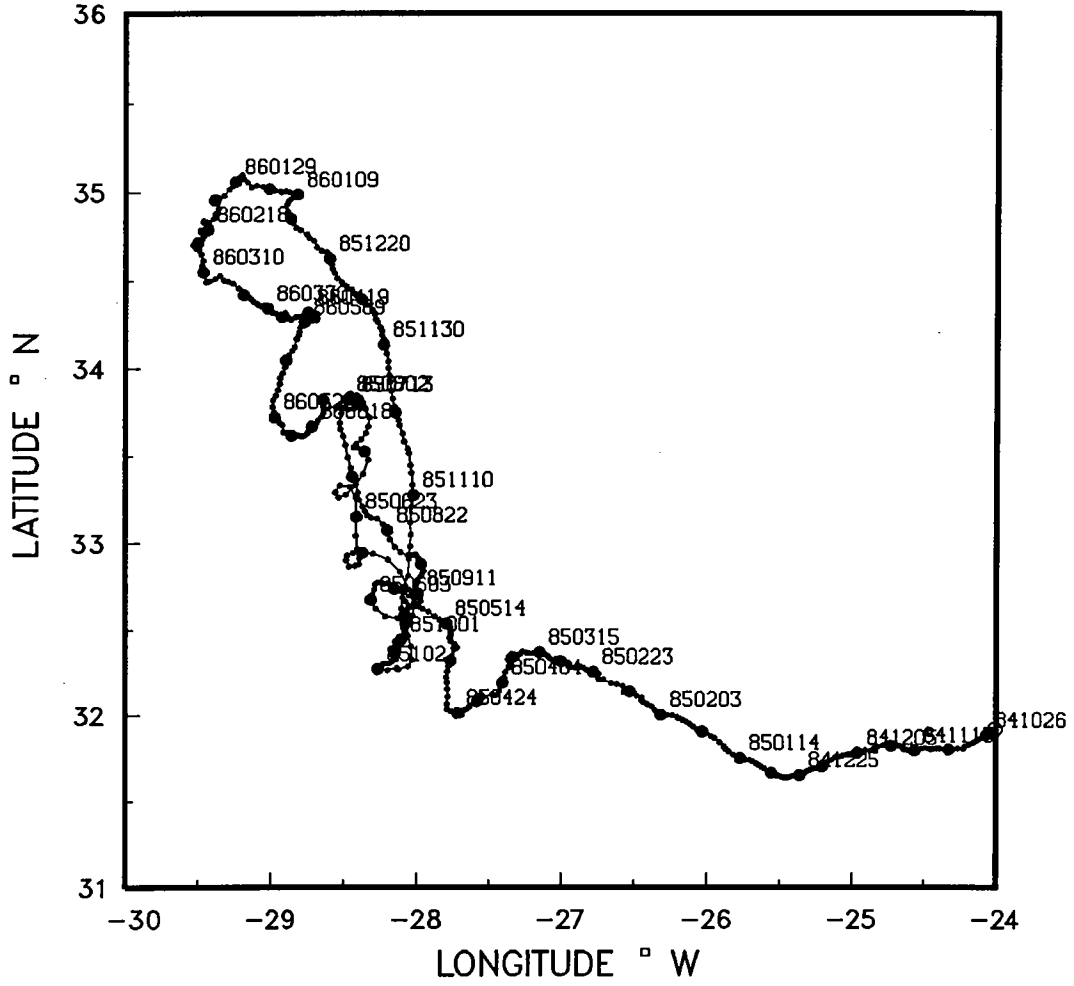
PLOT 1 OF 1
.DAT

EASTERN BASIN 126



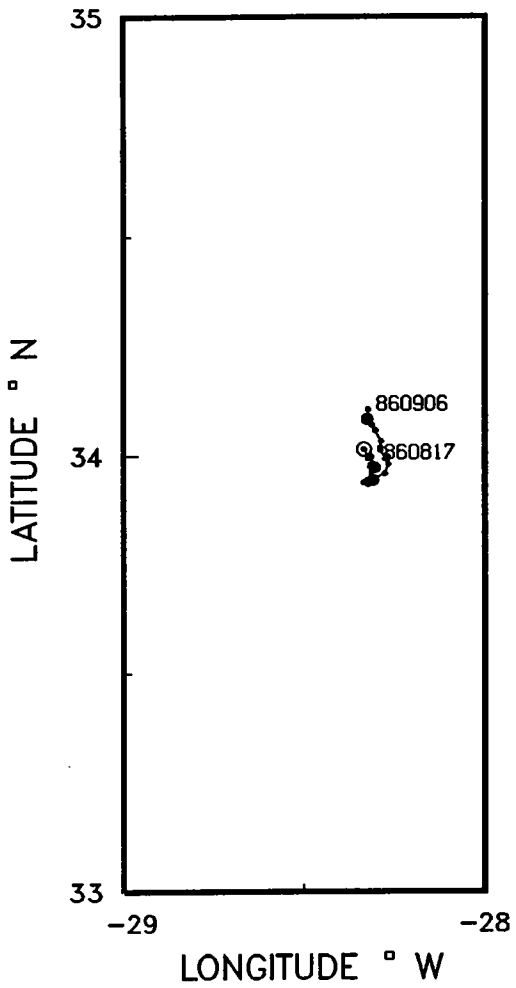
PLOT 1 OF 1
.DAT

EASTERN BASIN 127A



PLOT 1 OF 1
.DAT

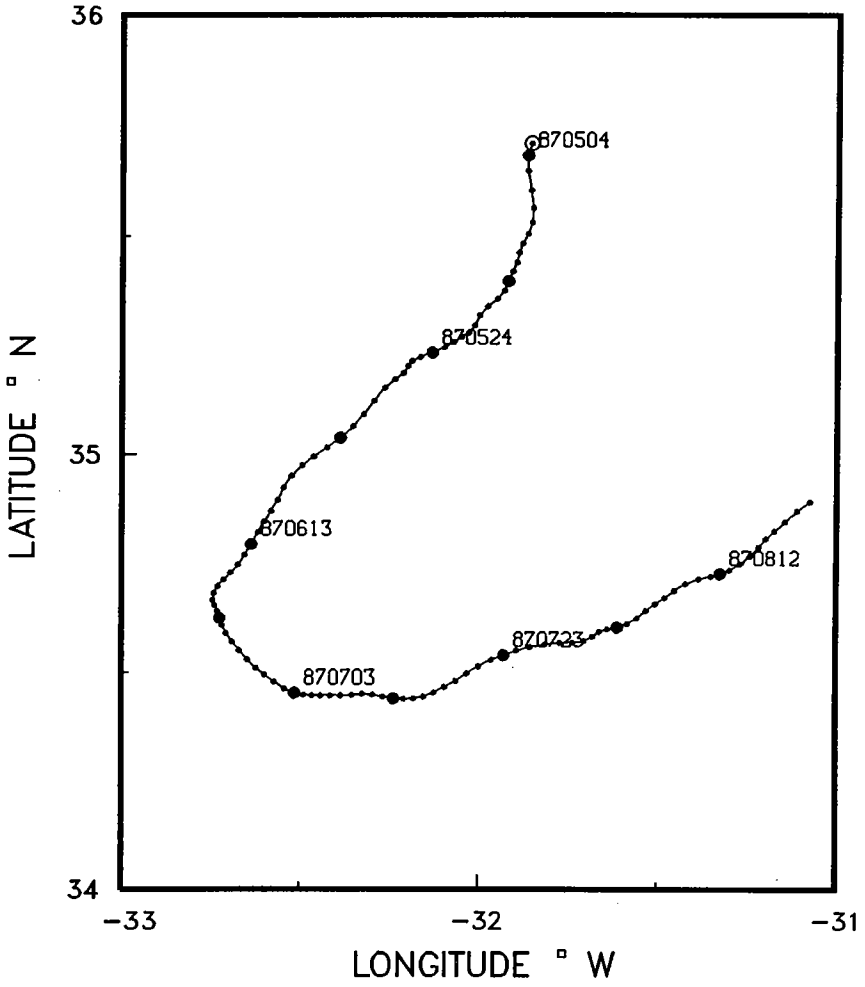
EASTERN BASIN 127B



40

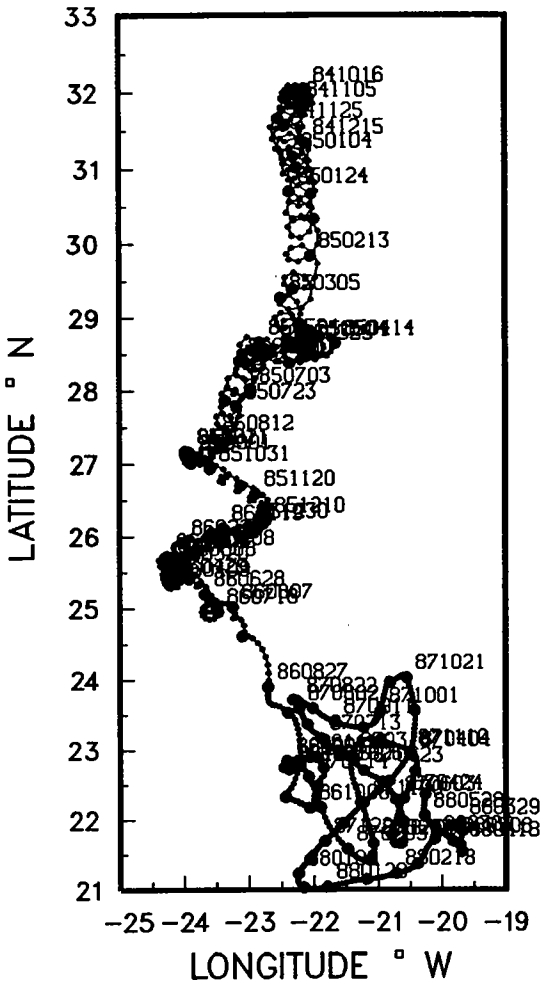
PLOT 1 OF 1
.DAT

EASTERN BASIN 127C



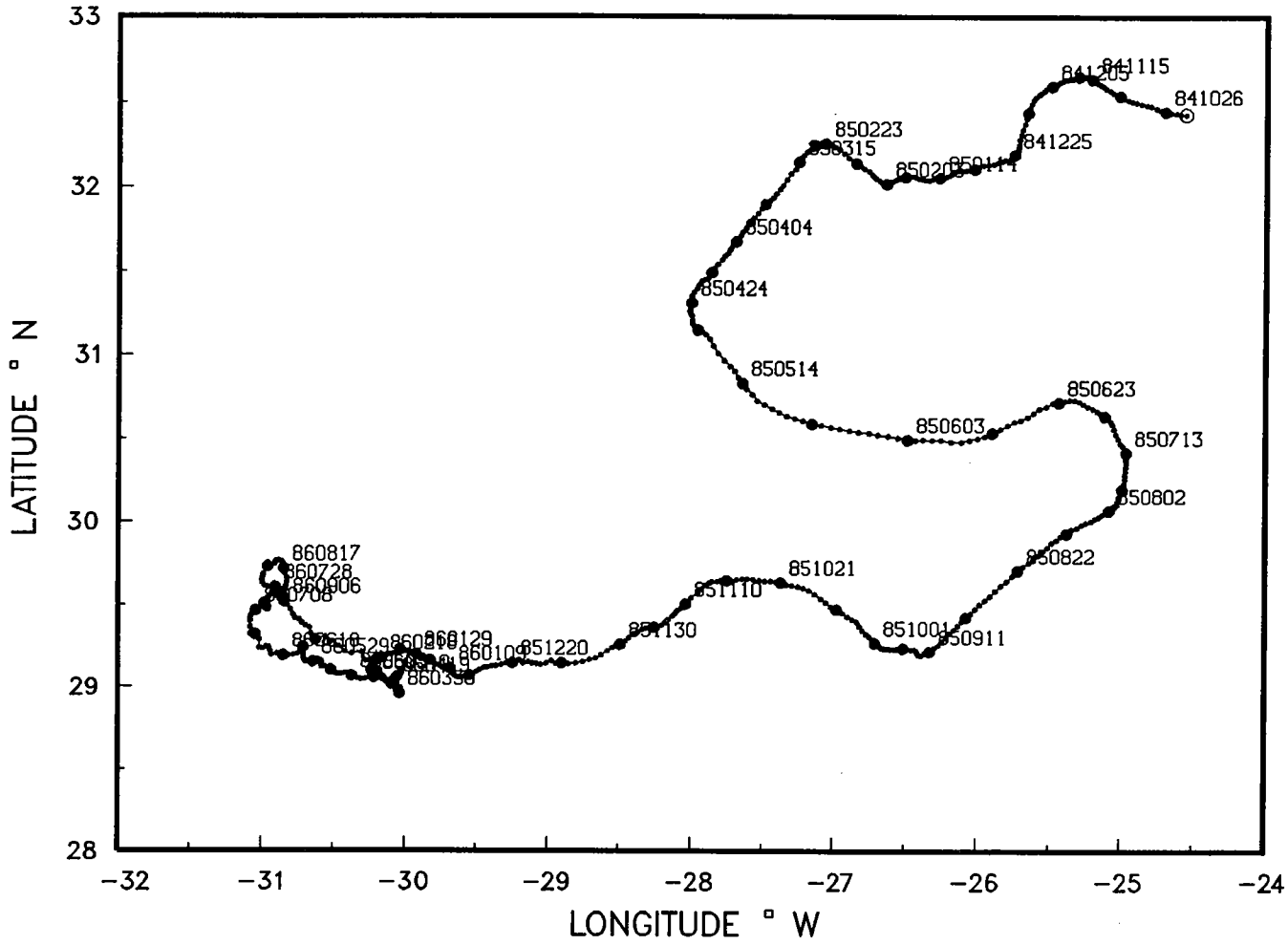
PLOT 1 OF 1
.DAT

EASTERN BASIN 128



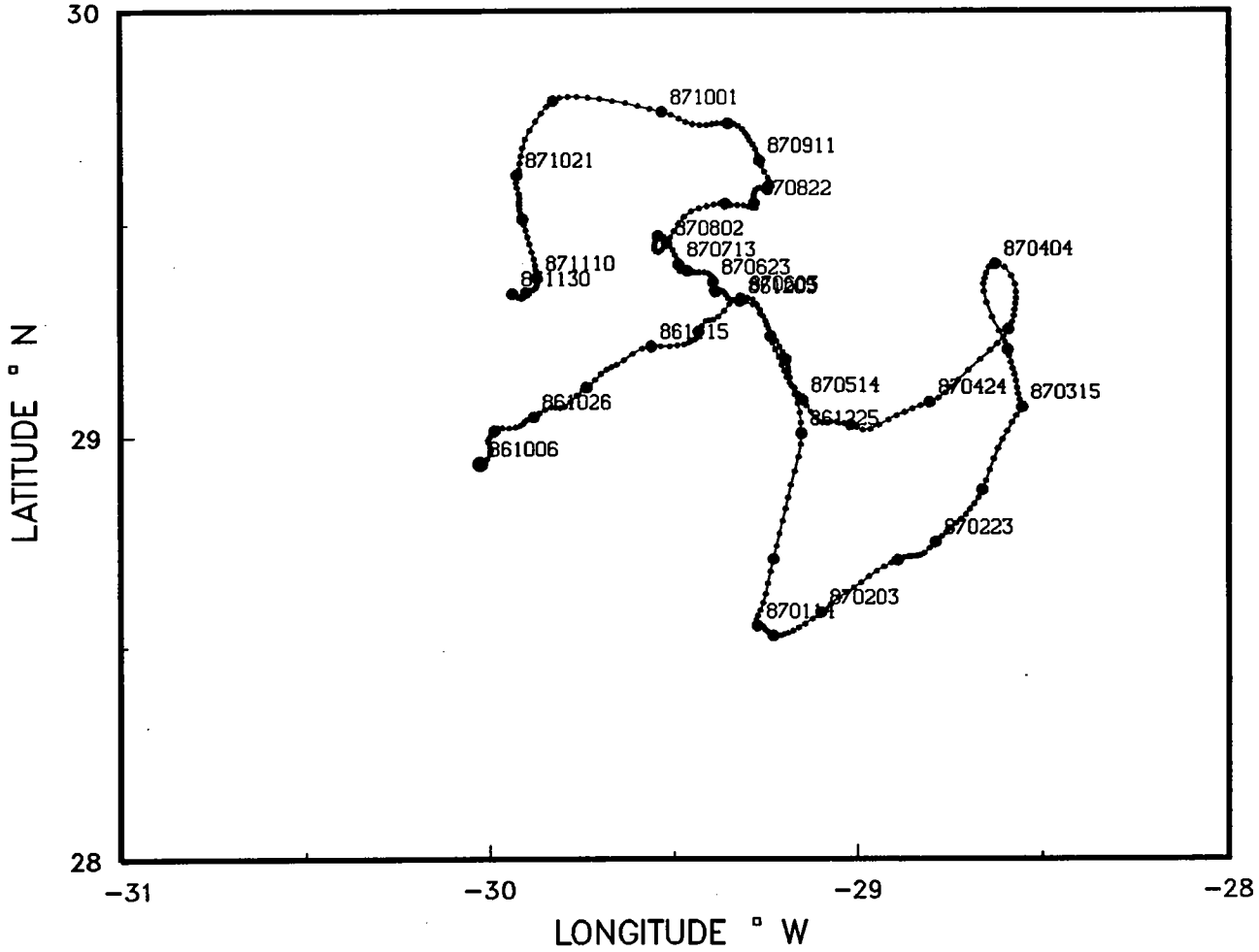
PLOT 1 OF 1
.DAT

EASTERN BASIN 129A



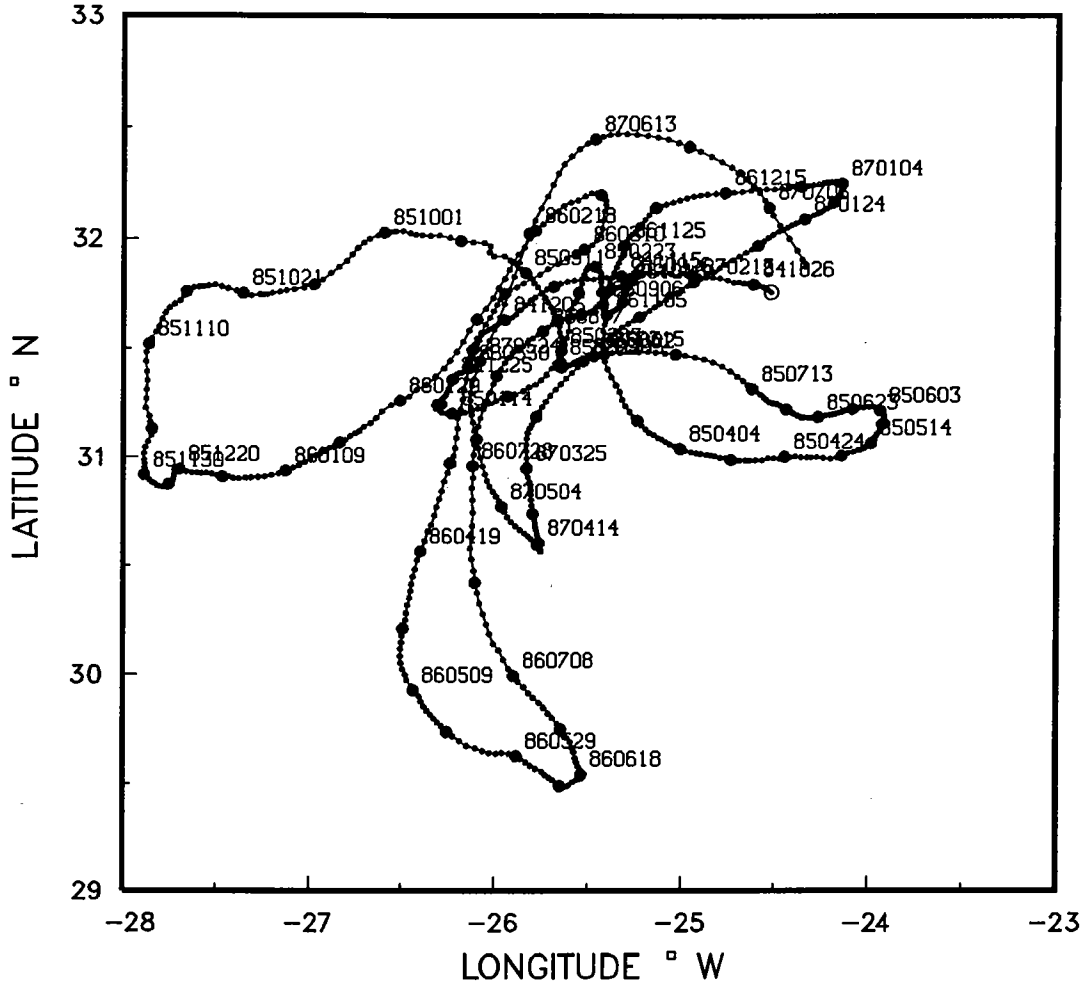
PLOT 1 OF 1
.DAT

EASTERN BASIN 129B



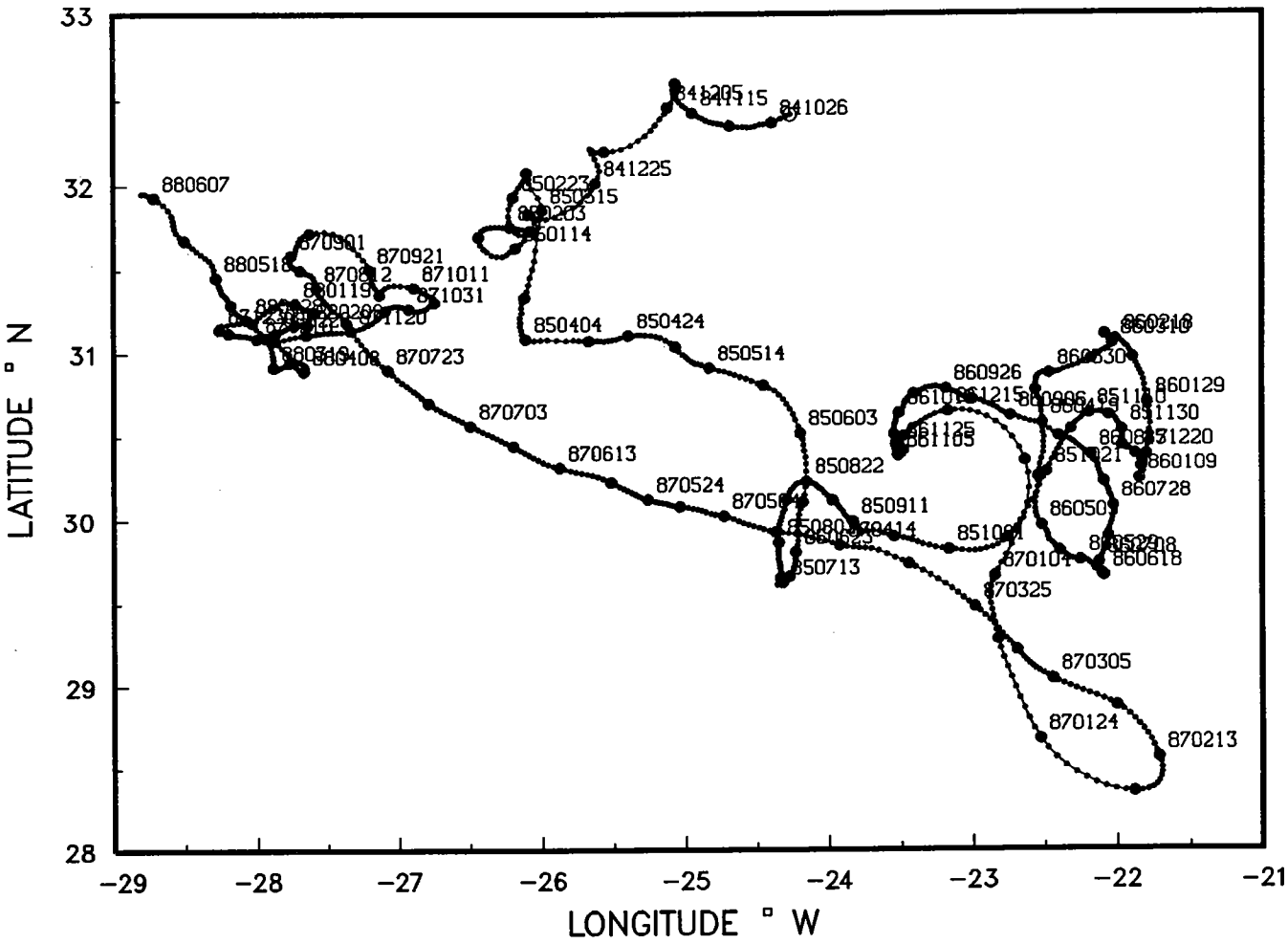
PLOT 1 OF 1
.DAT

EASTERN BASIN 130



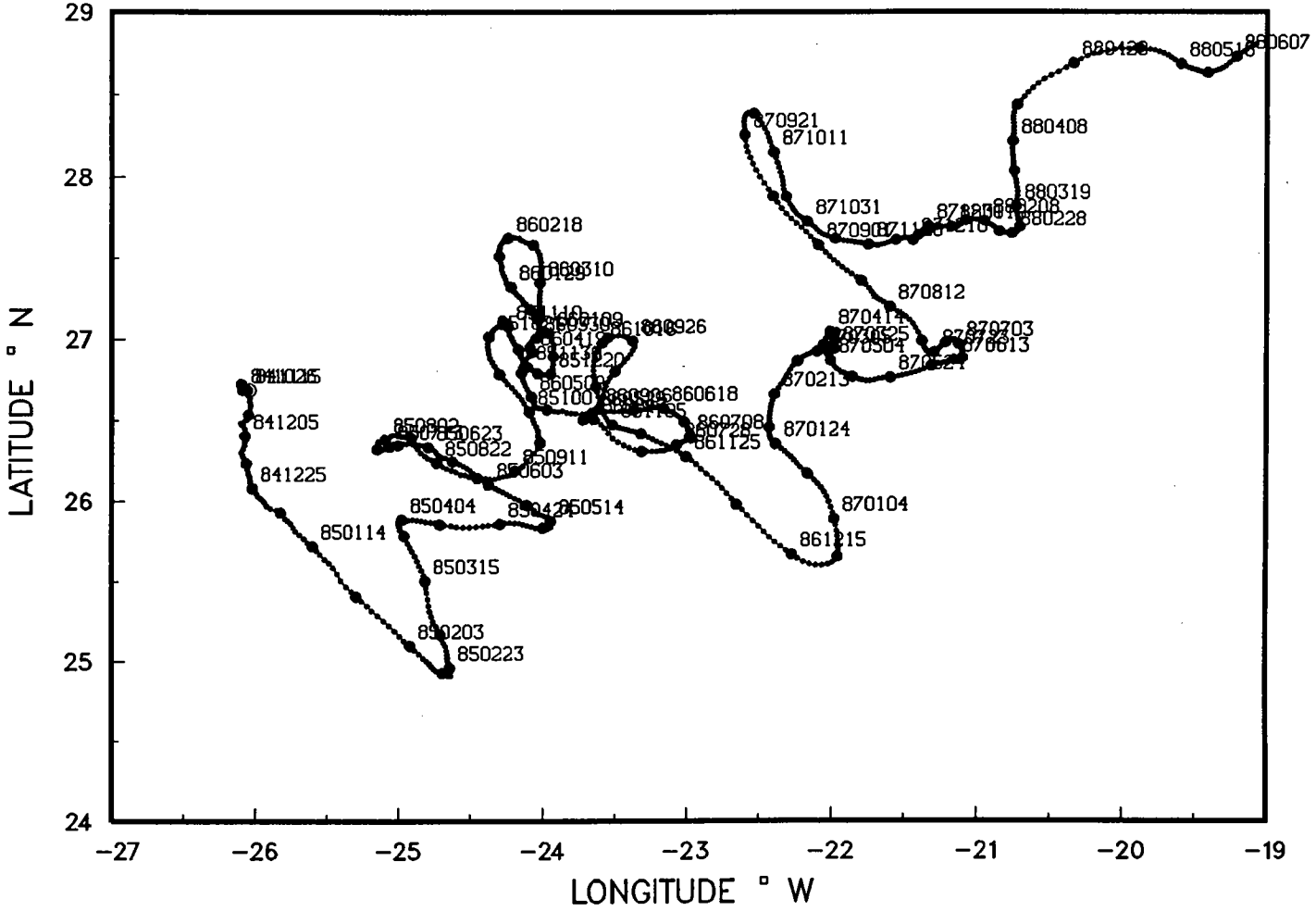
PLOT 1 OF 1
.DAT

EASTERN BASIN 131



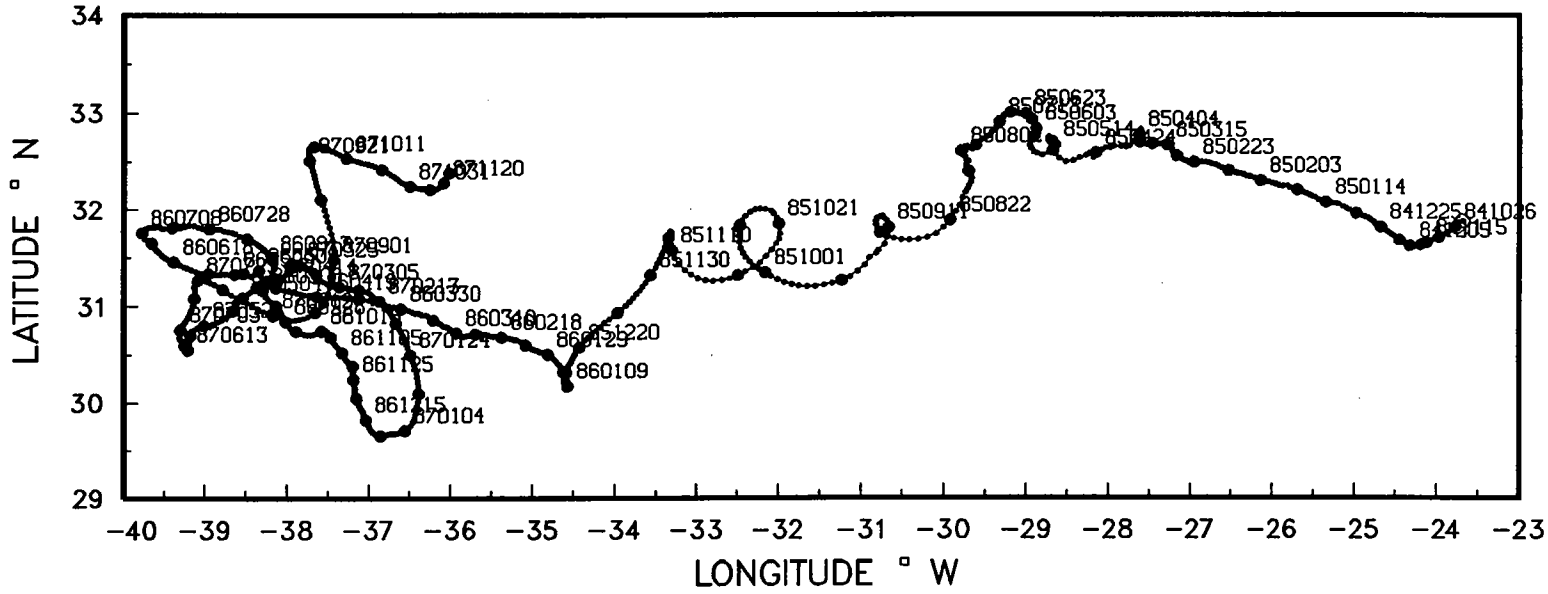
PLOT 1 OF 1
.DAT

EASTERN BASIN 132



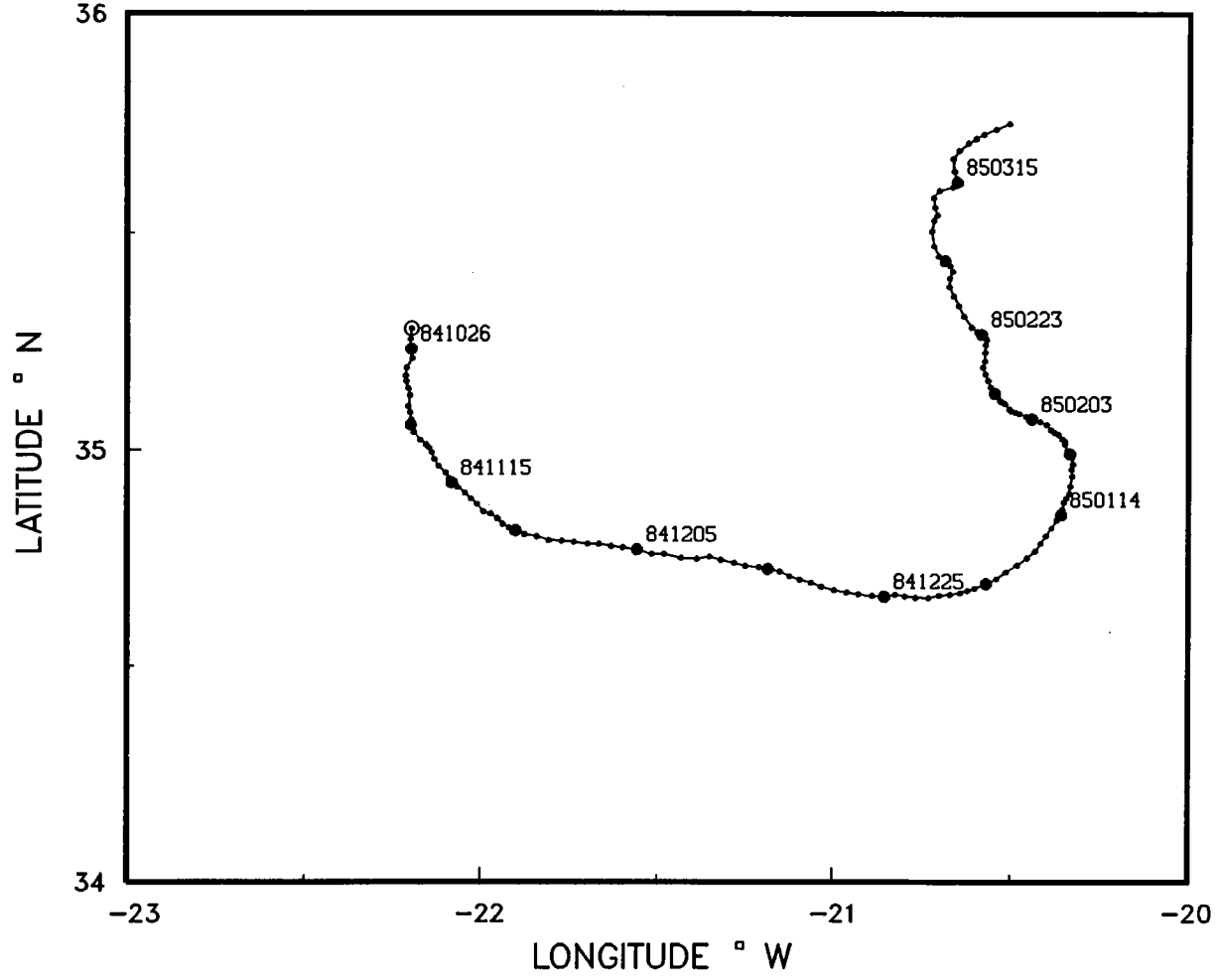
PLOT 1 OF 1
.DAT

EASTERN BASIN 133



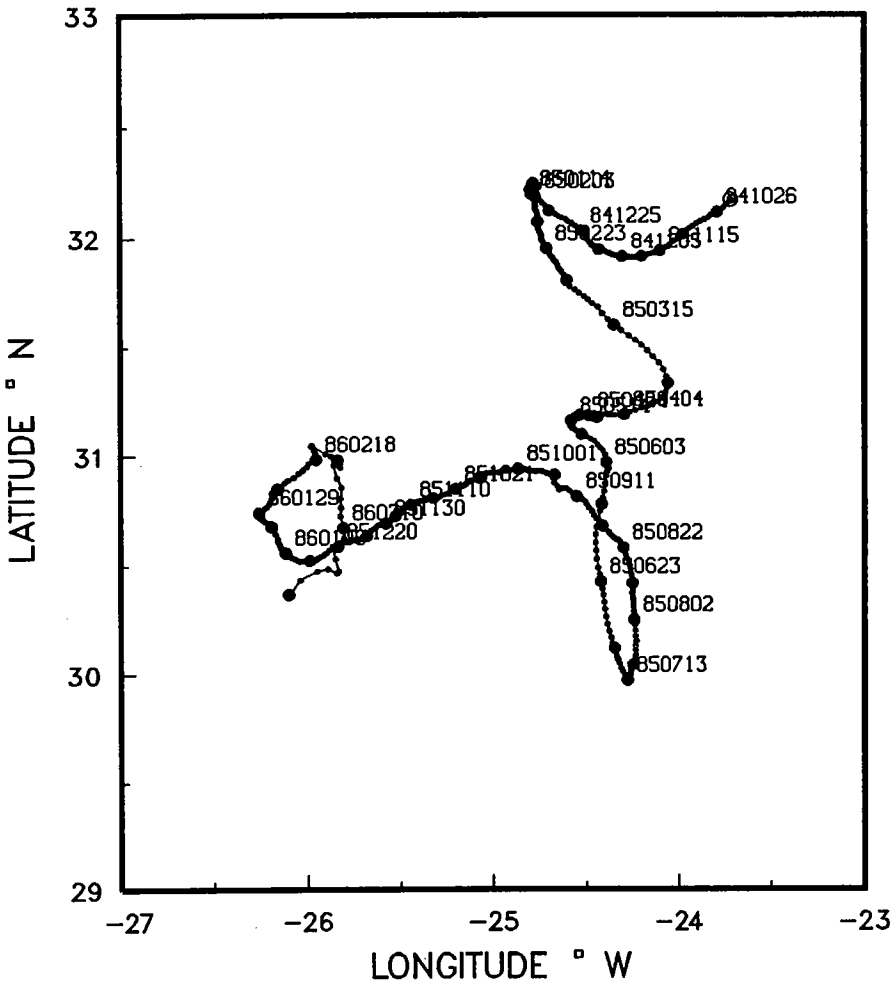
PLOT 1 OF 1
.DAT

EASTERN BASIN 134



PLOT 1 OF 1
.DAT

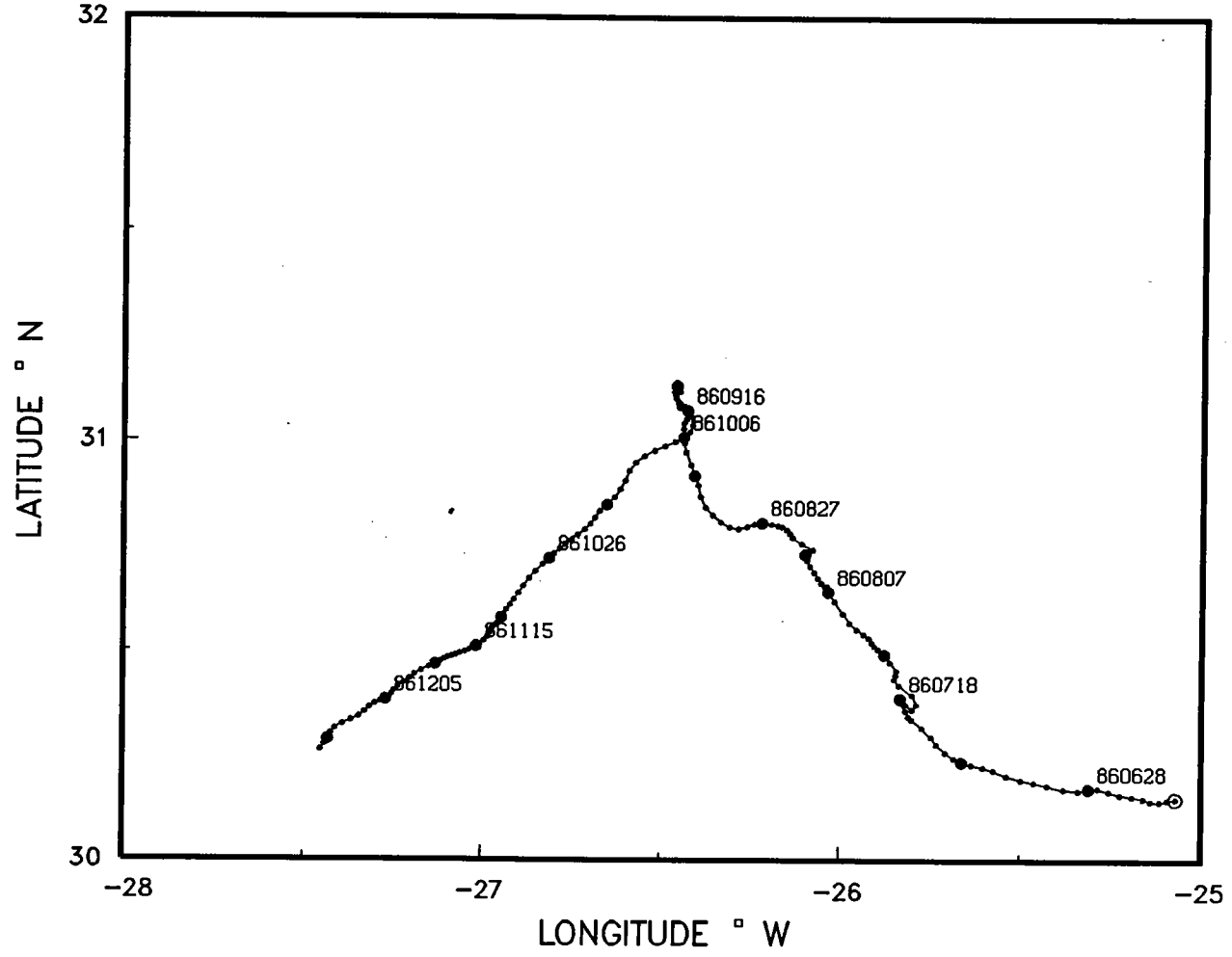
EASTERN BASIN 135A



50

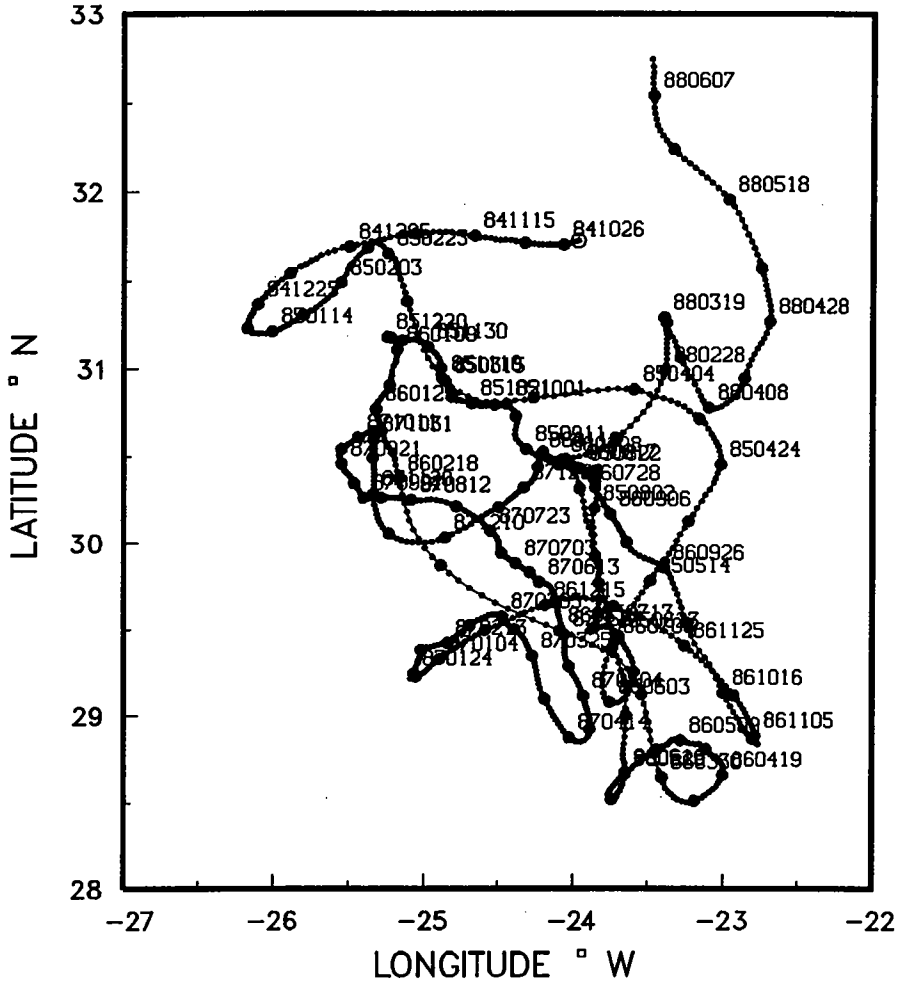
PLOT 1 OF 1
.DAT

EASTERN BASIN 135B



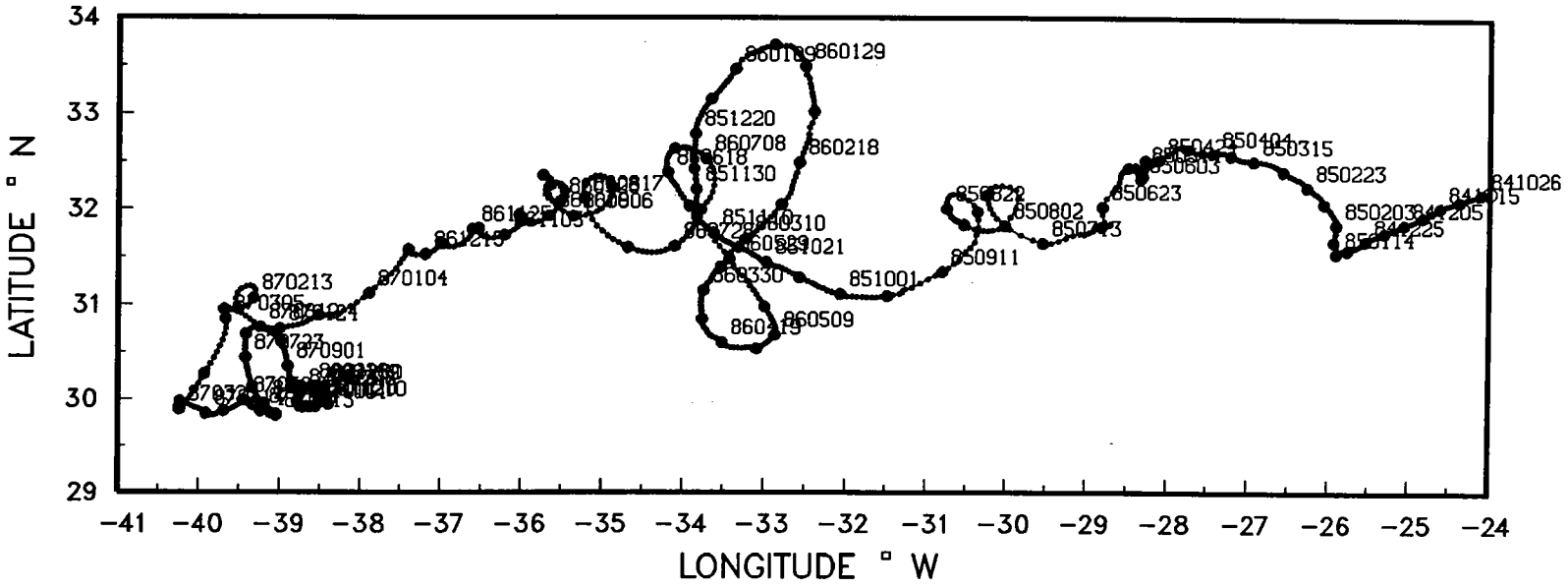
PLOT 1 OF 1
.DAT

EASTERN BASIN 136



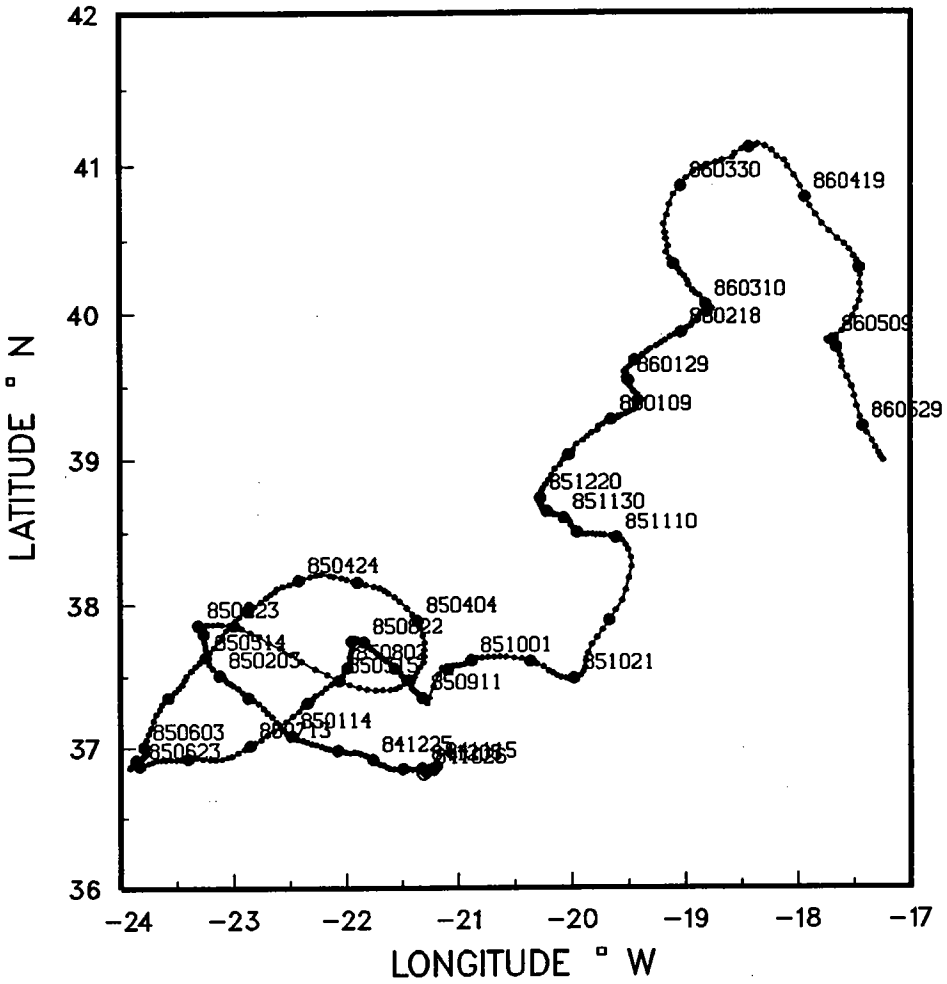
PLOT 1 OF 1
.DAT

EASTERN BASIN 137



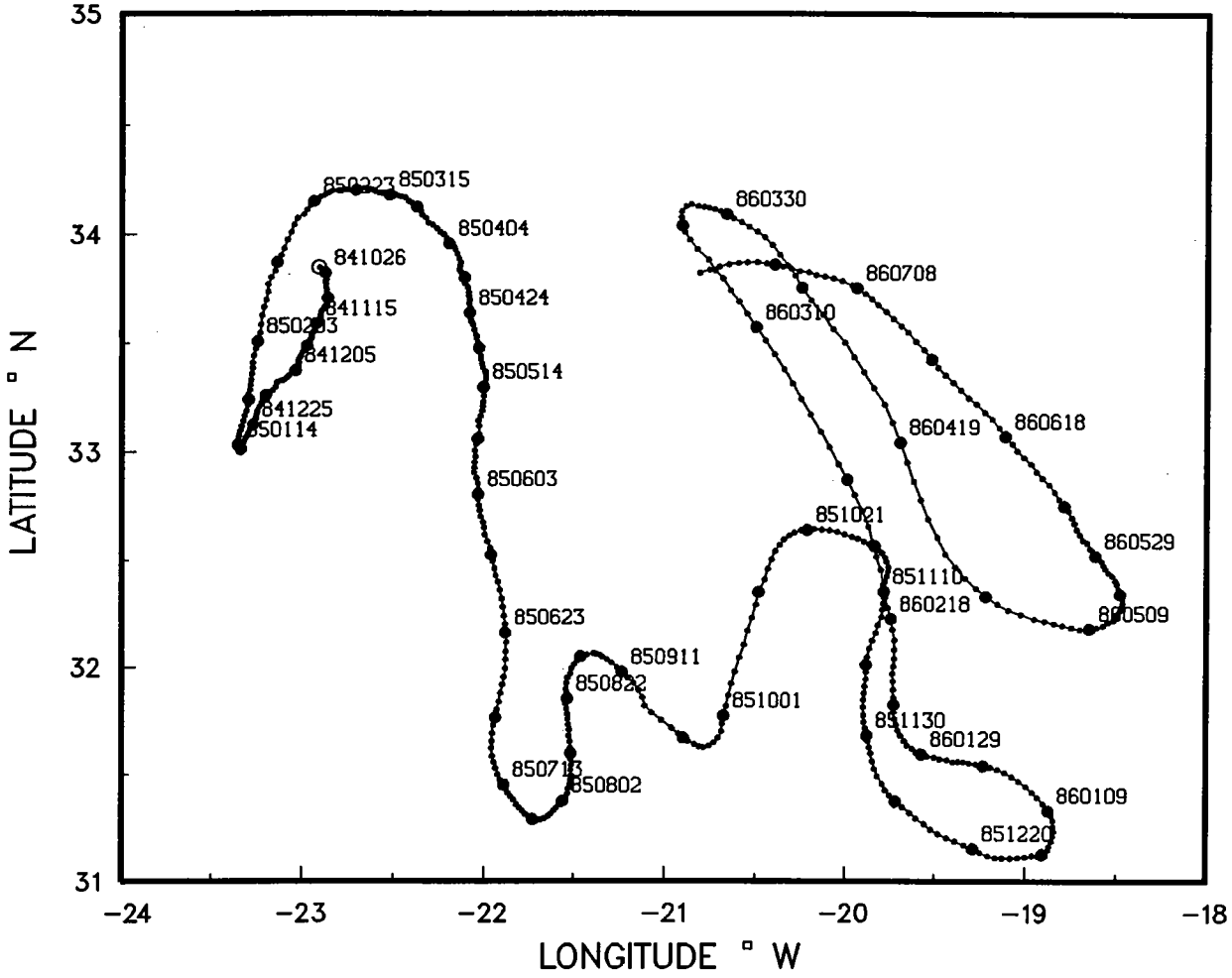
PLOT 1 OF 1
.DAT

EASTERN BASIN 138



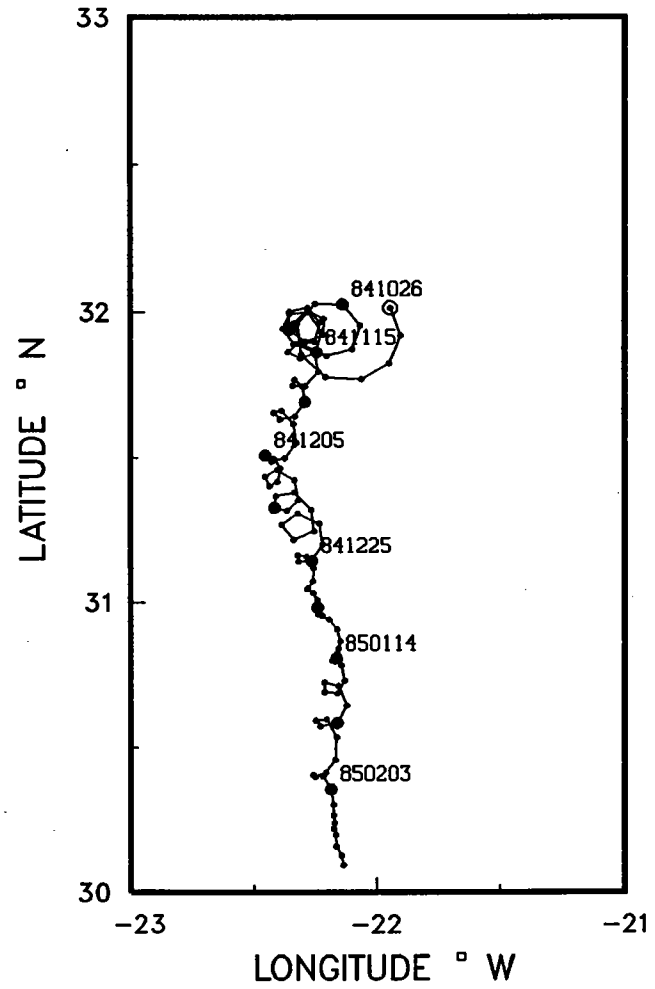
PLOT 1 OF 1
.DAT

EASTERN BASIN 139



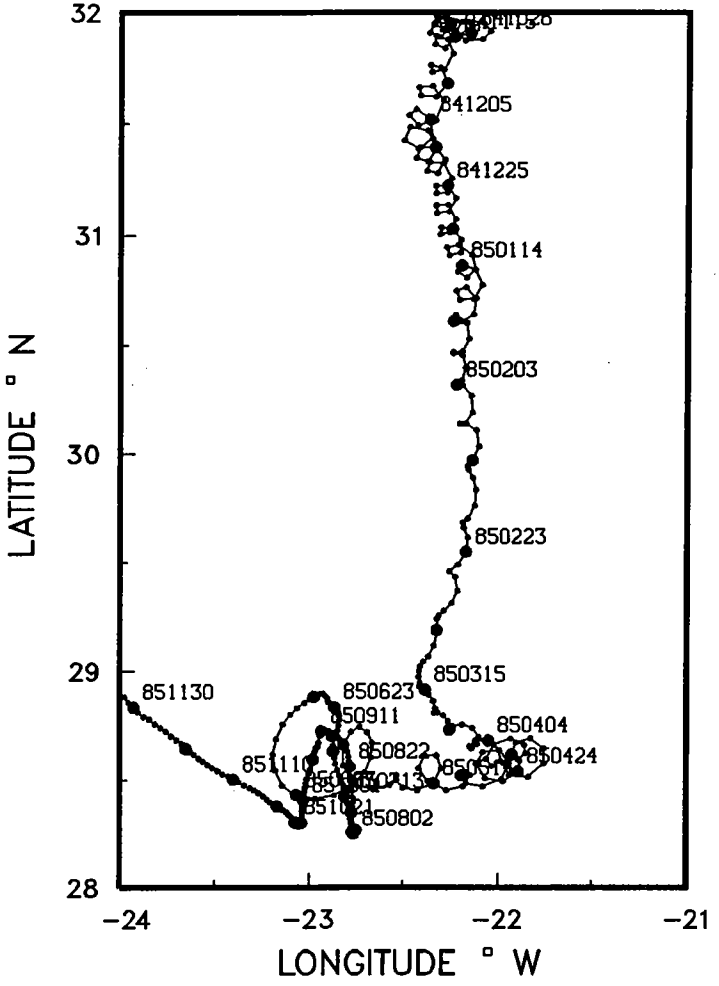
PLOT 1 OF 1
.DAT

EASTERN BASIN 140



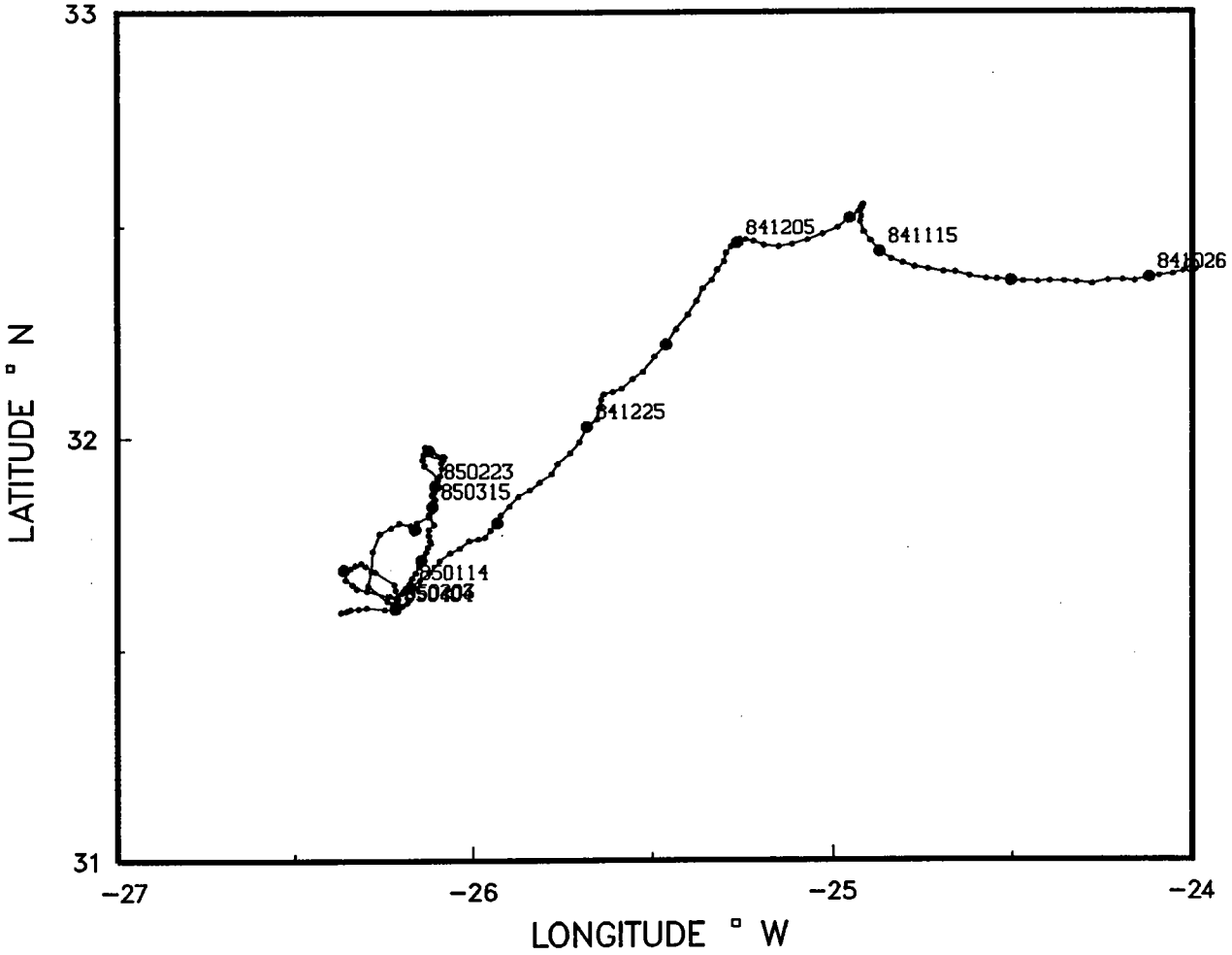
PLOT 1 OF 1
.DAT

EASTERN BASIN 141



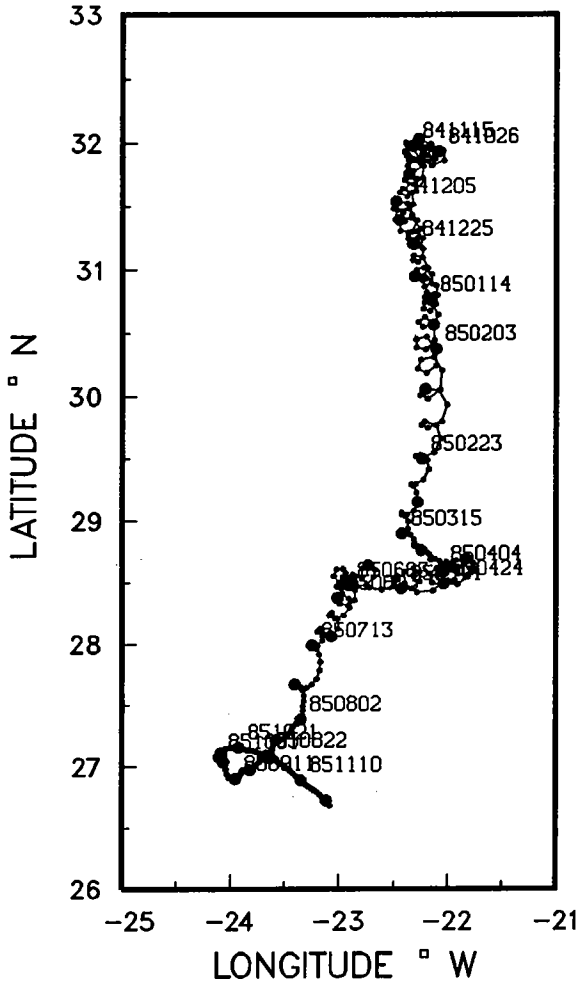
PLOT 1 OF 1
.DAT

EASTERN BASIN 142



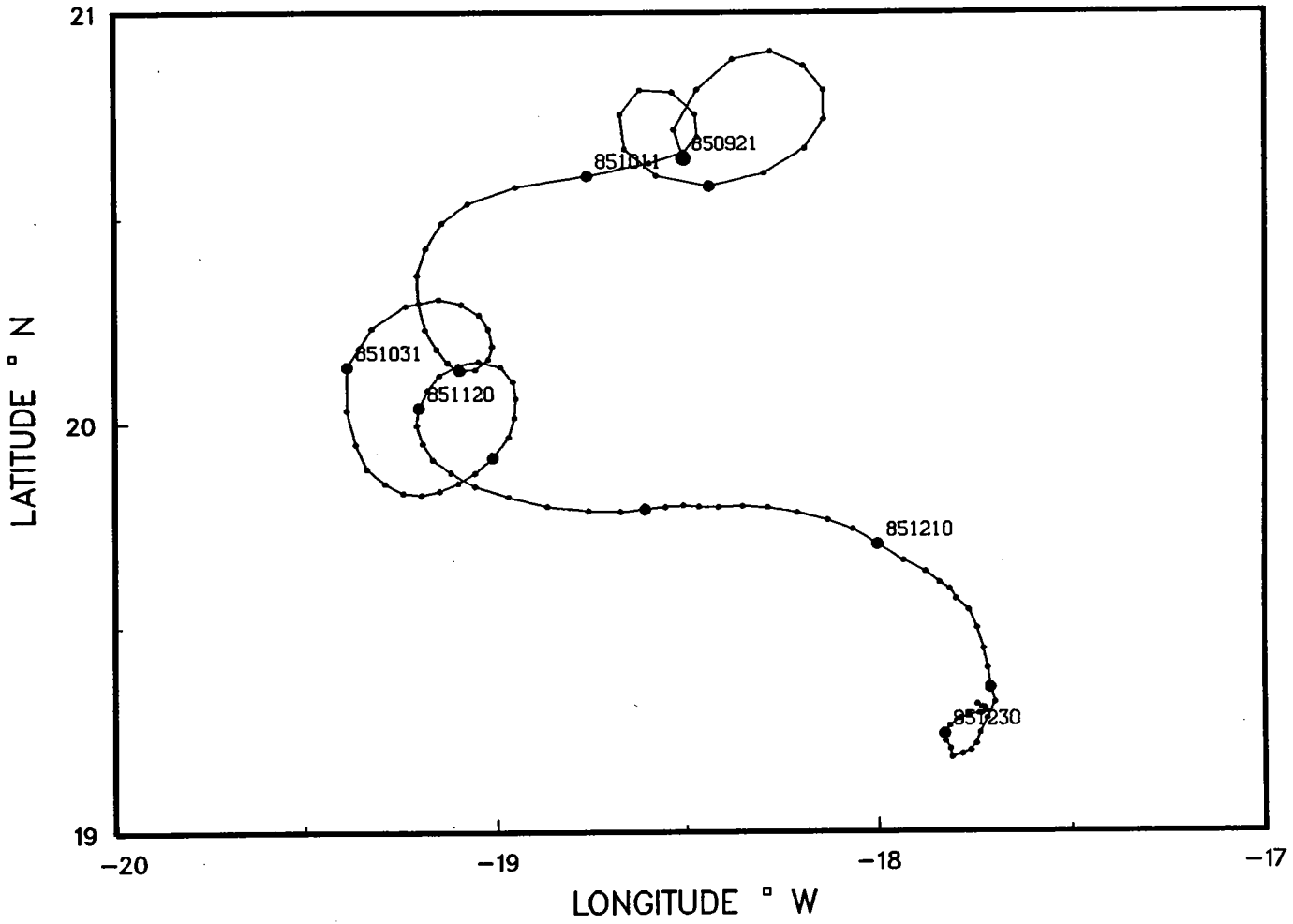
PLOT 1 OF 1
.DAT

EASTERN BASIN 143



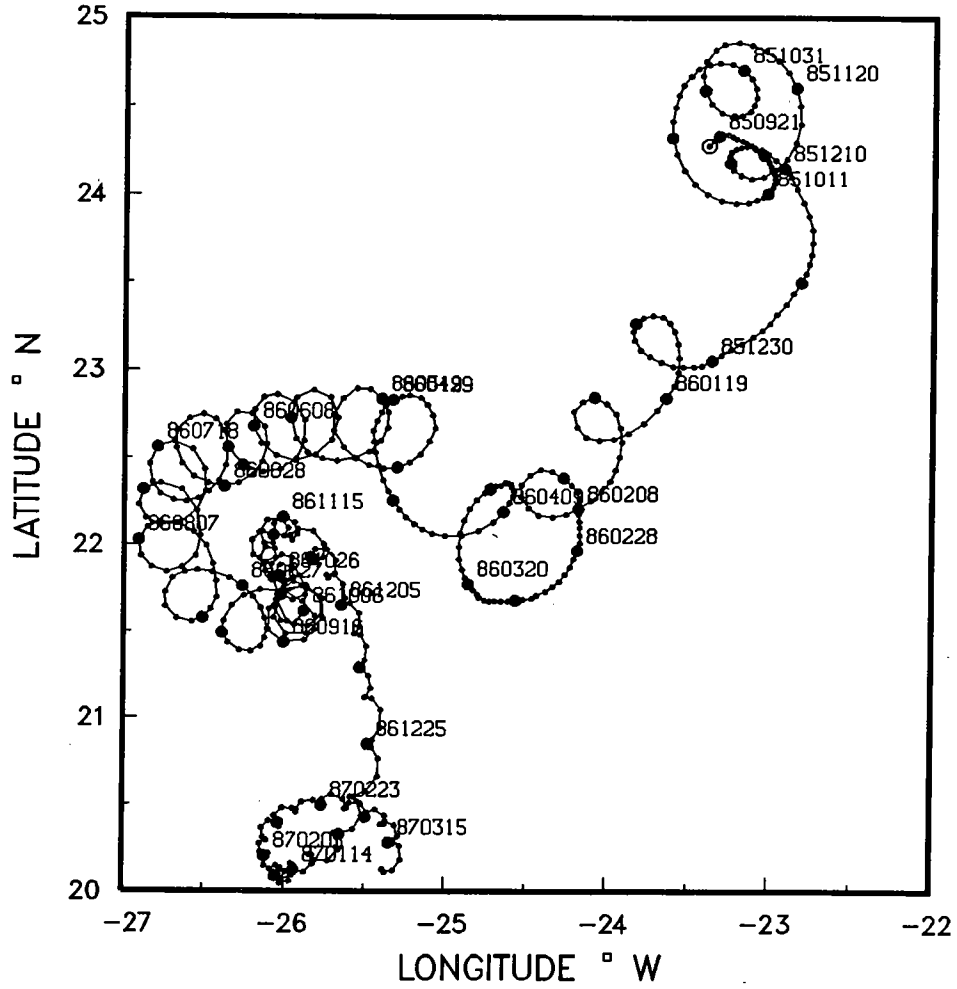
PLOT 1 OF 1
.DAT

EASTERN BASIN 144



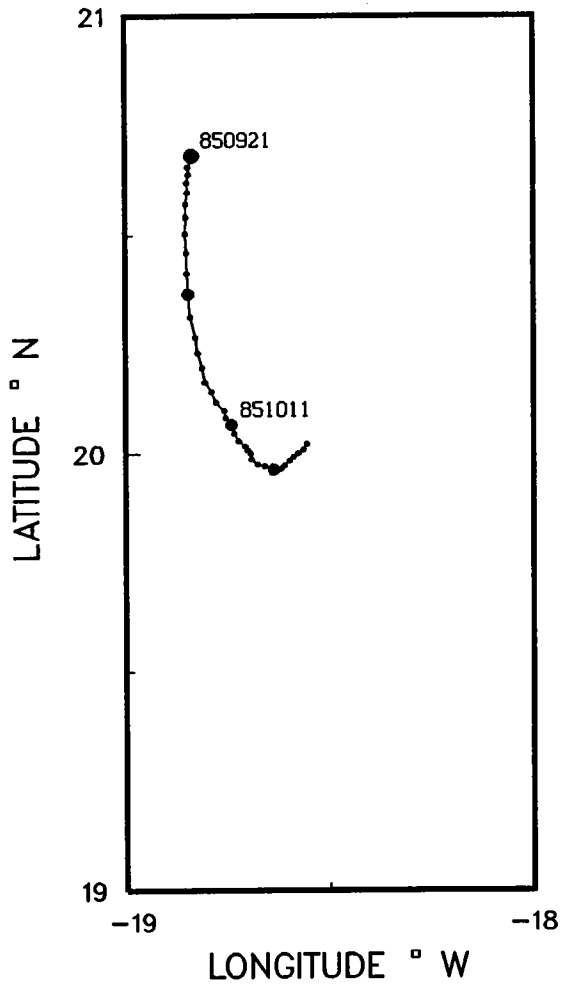
PLOT 1 OF 1
.DAT

EASTERN BASIN 145



PLOT 1 OF 1
.DAT

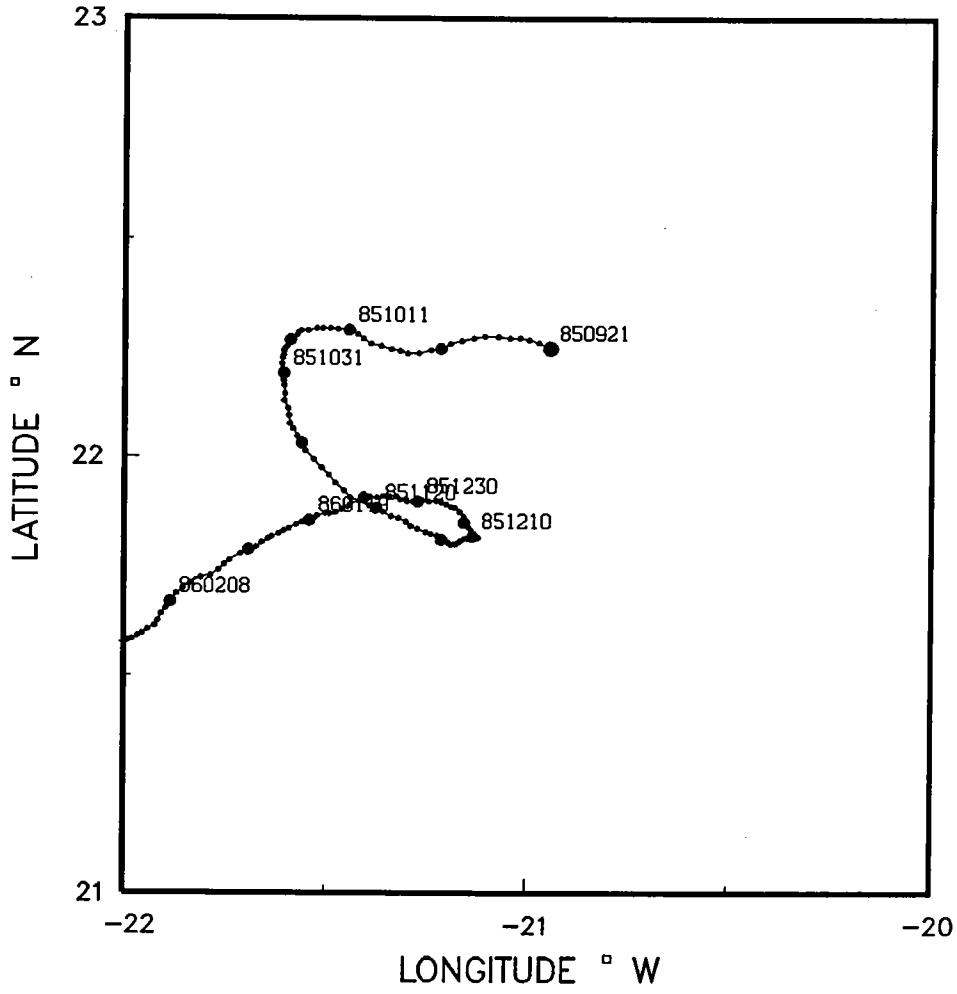
EASTERN BASIN 146



62

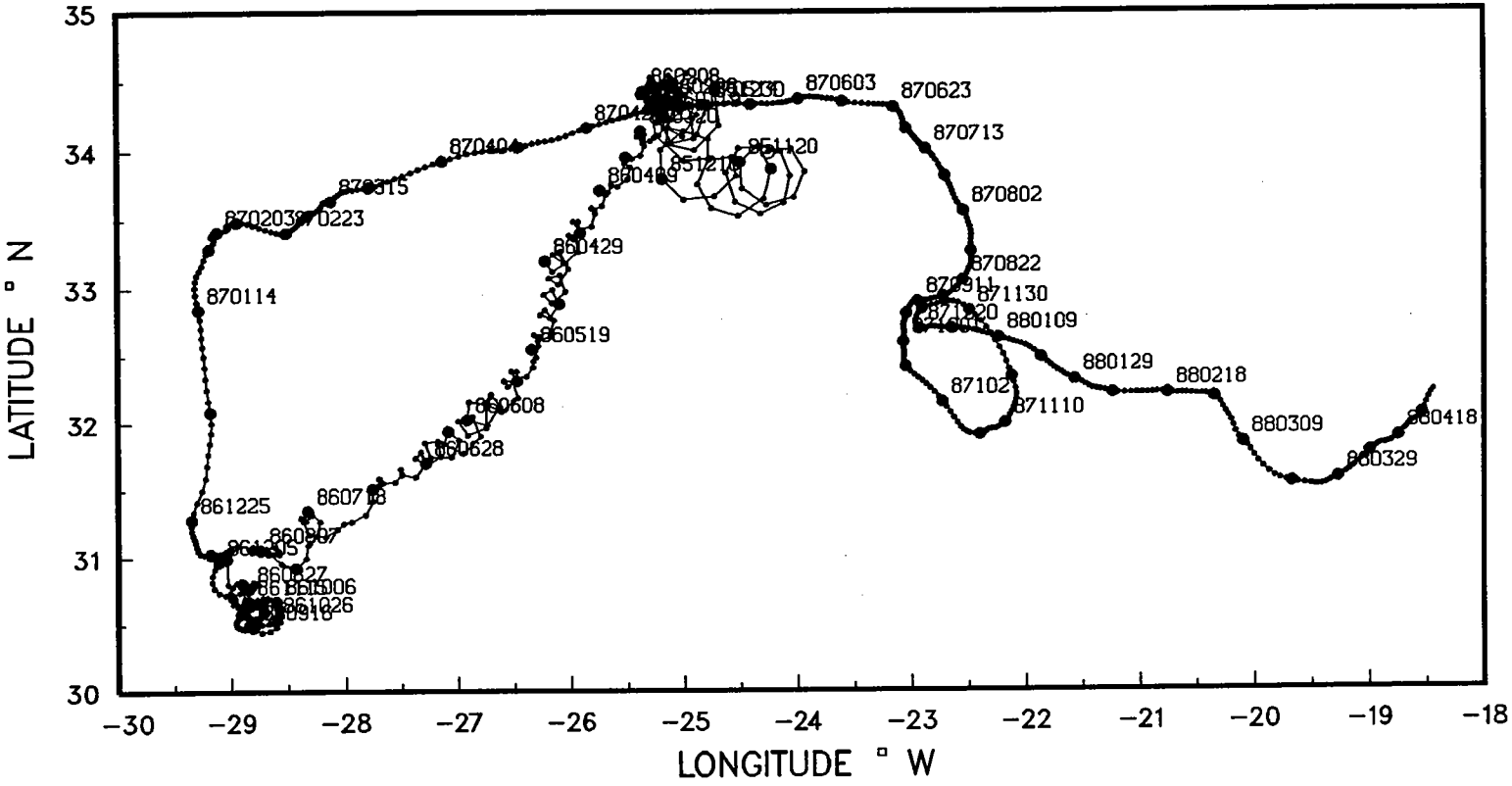
PLOT 1 OF 1
.DAT

EASTERN BASIN 147



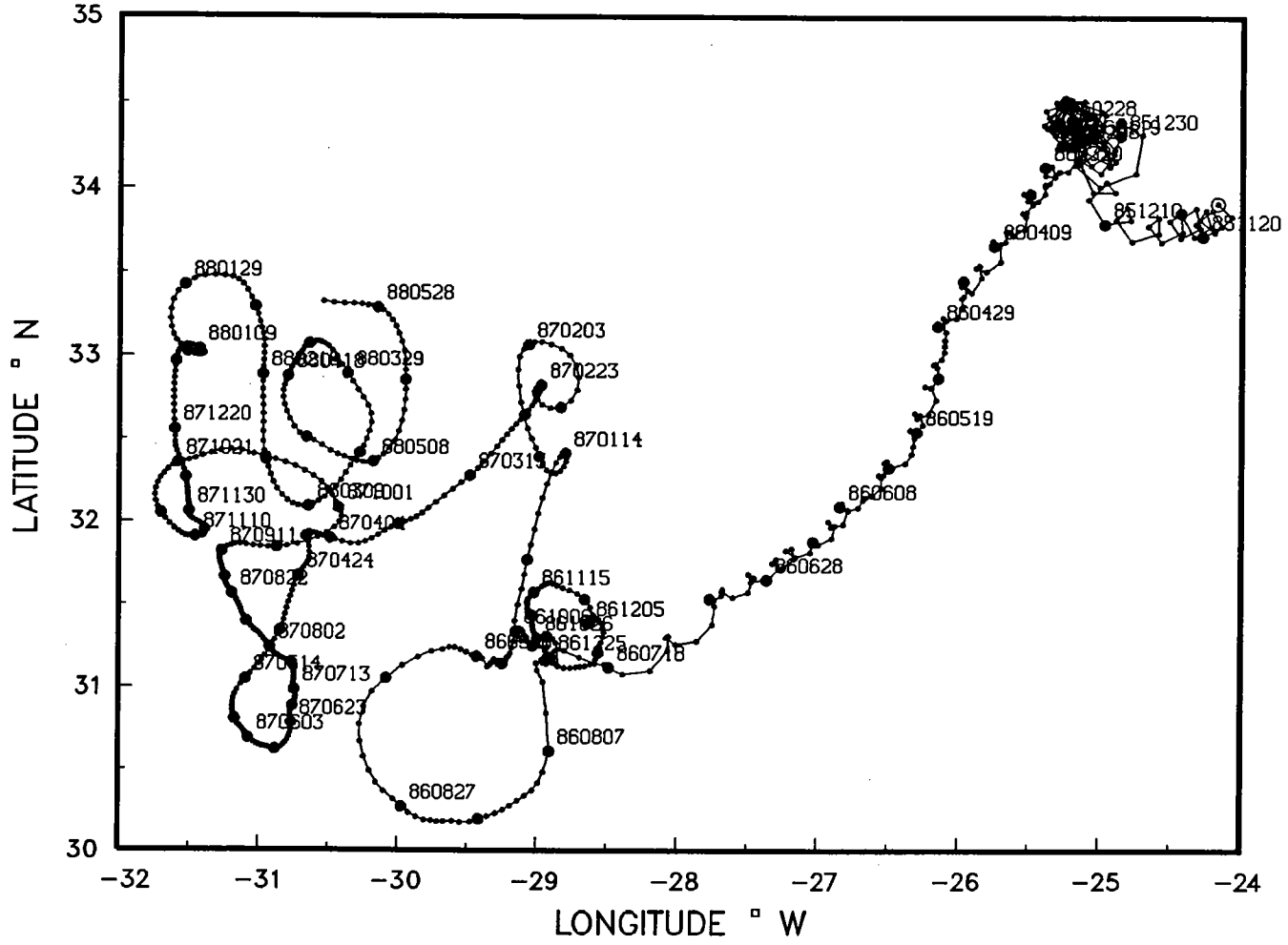
PLOT 1 OF 1
.DAT

EASTERN BASIN 148



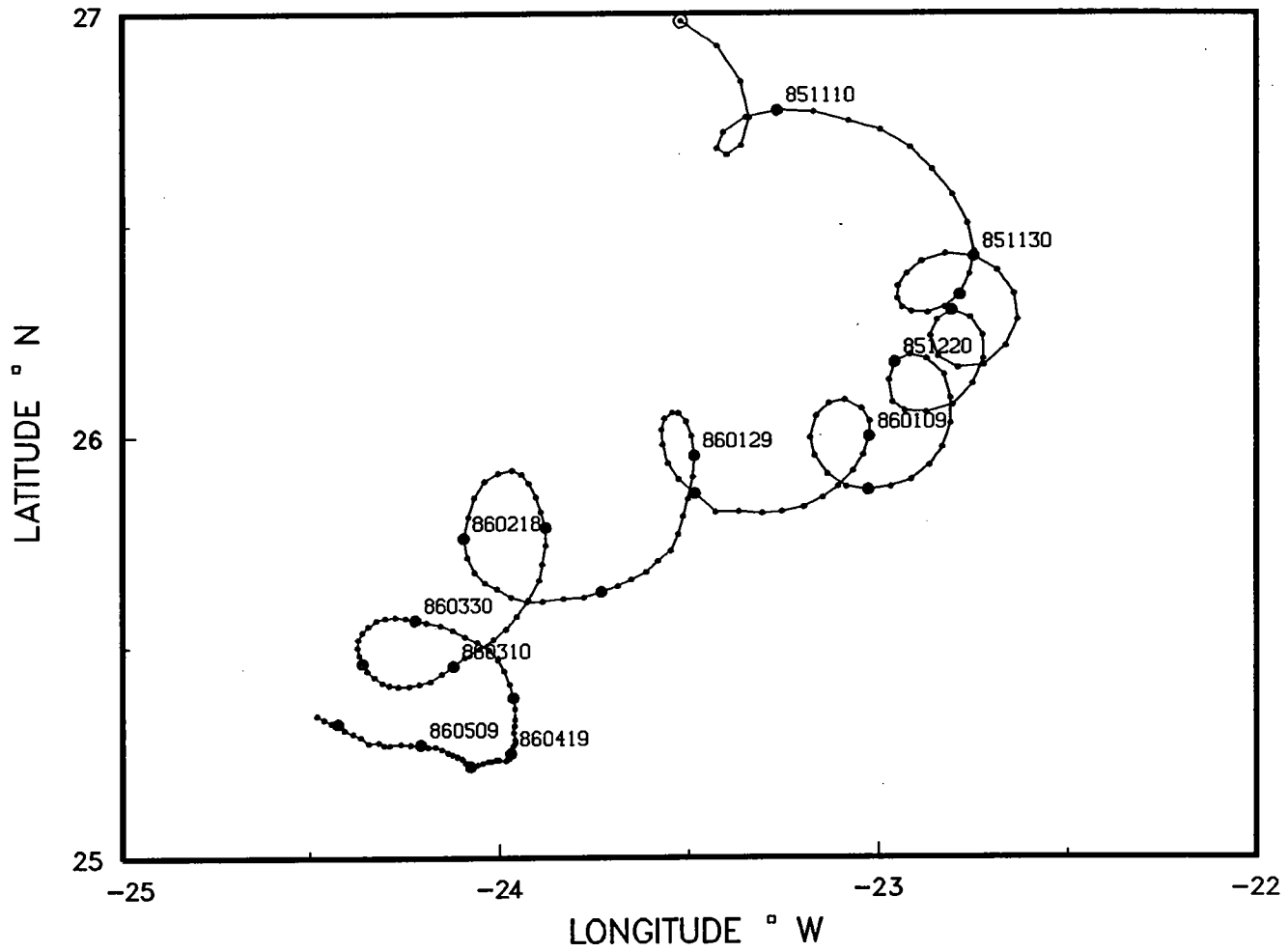
PLOT 1 OF 1
.DAT

EASTERN BASIN 149



PLOT 1 OF 1
.DAT

EASTERN BASIN 150



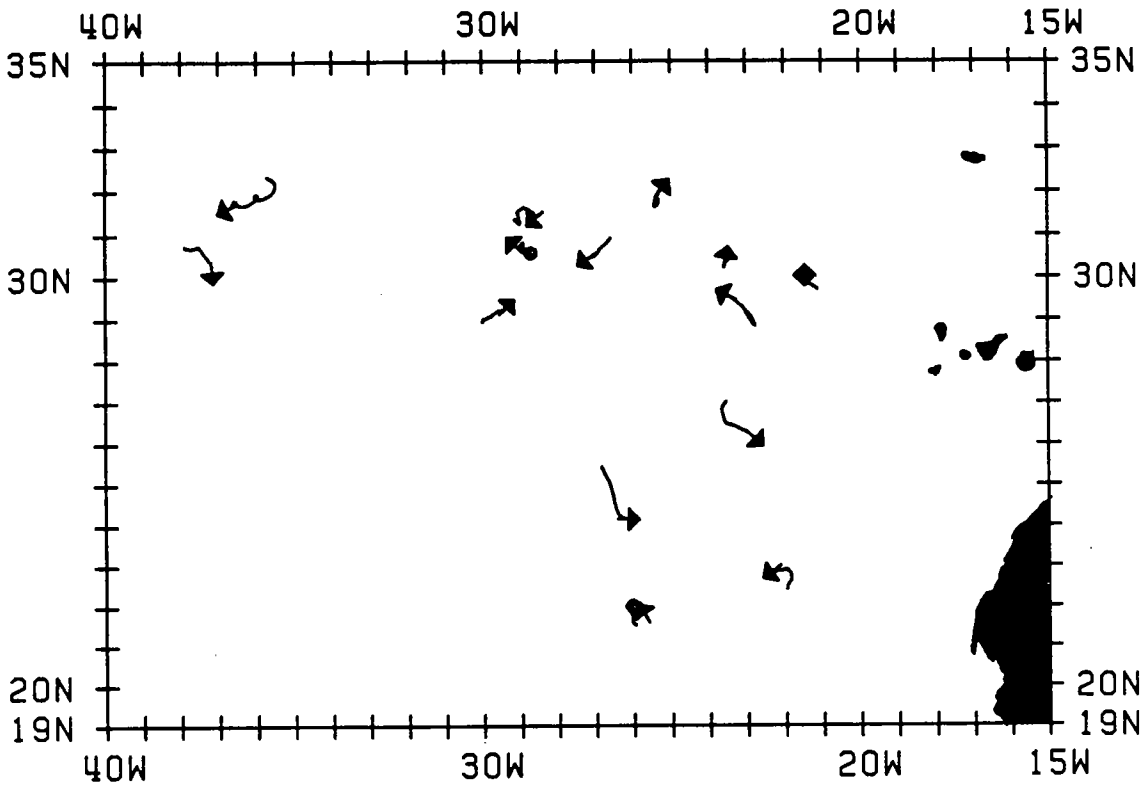
99

PLOT 1 OF 1
.DAT

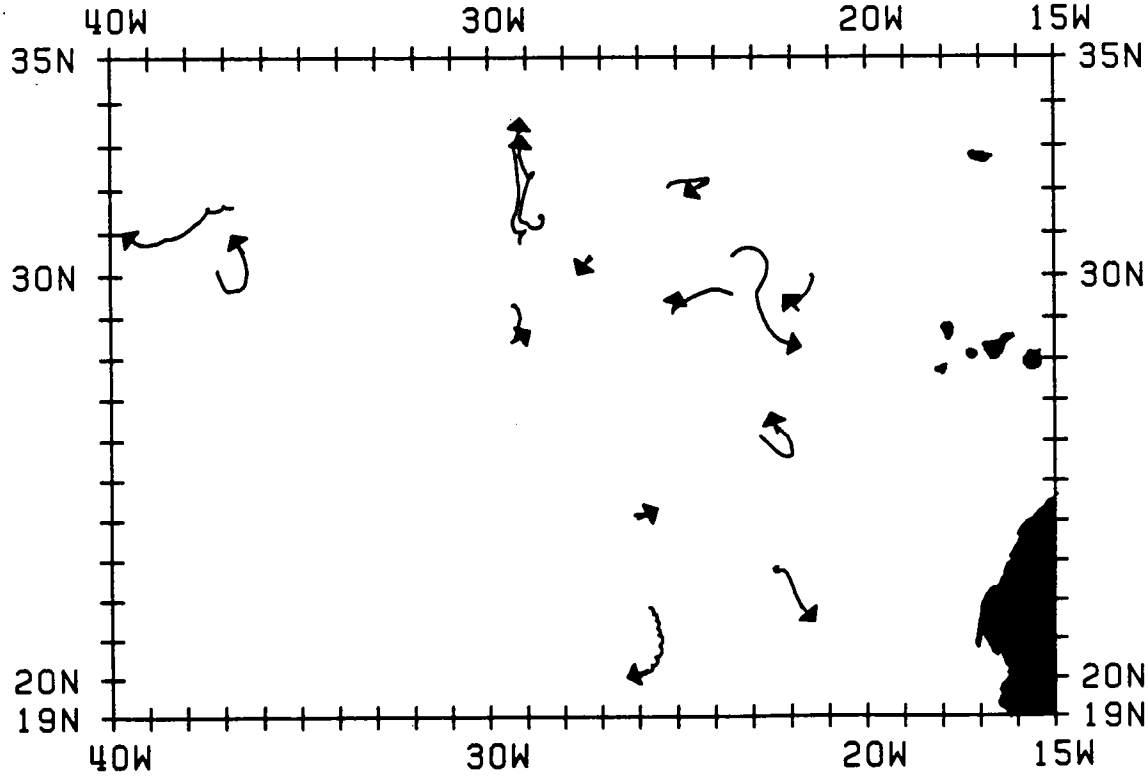
5 Two-Month Composites of Trajectories: 1986–1988

Ten plots are presented showing a summary of all float trajectories for each two-month period from October 1986 to June 1988.

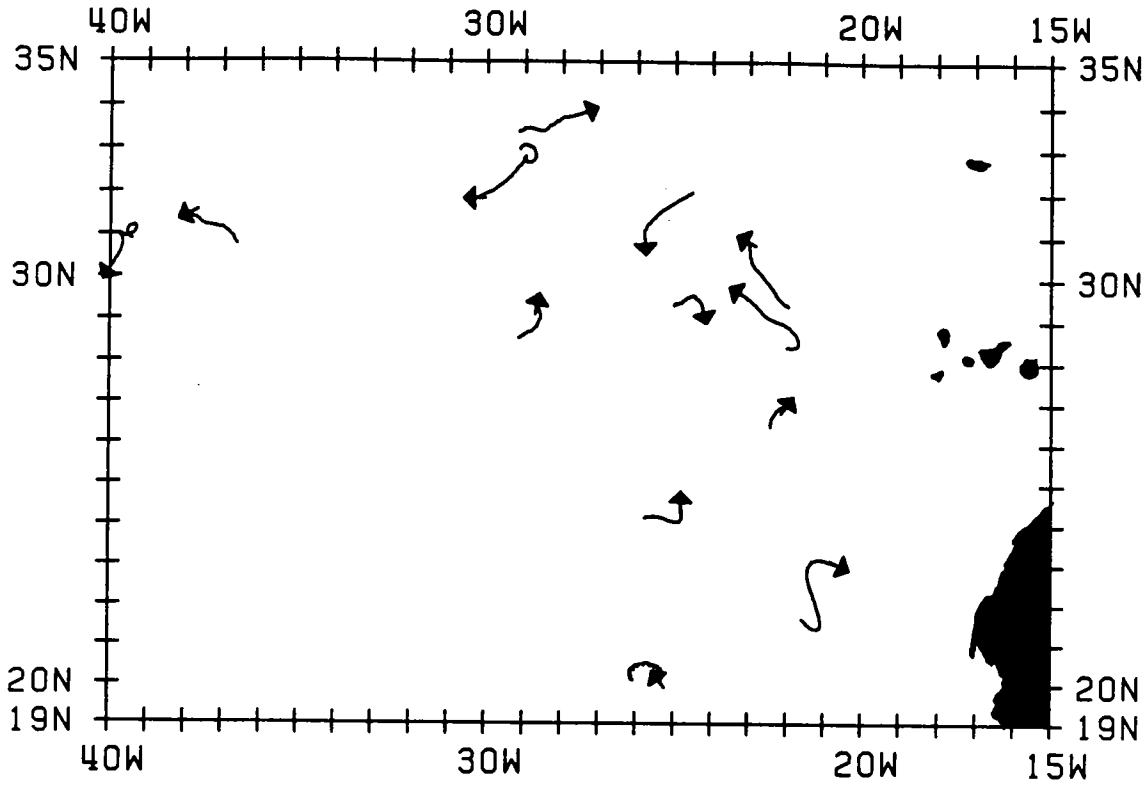
OCTOBER – DECEMBER 1986



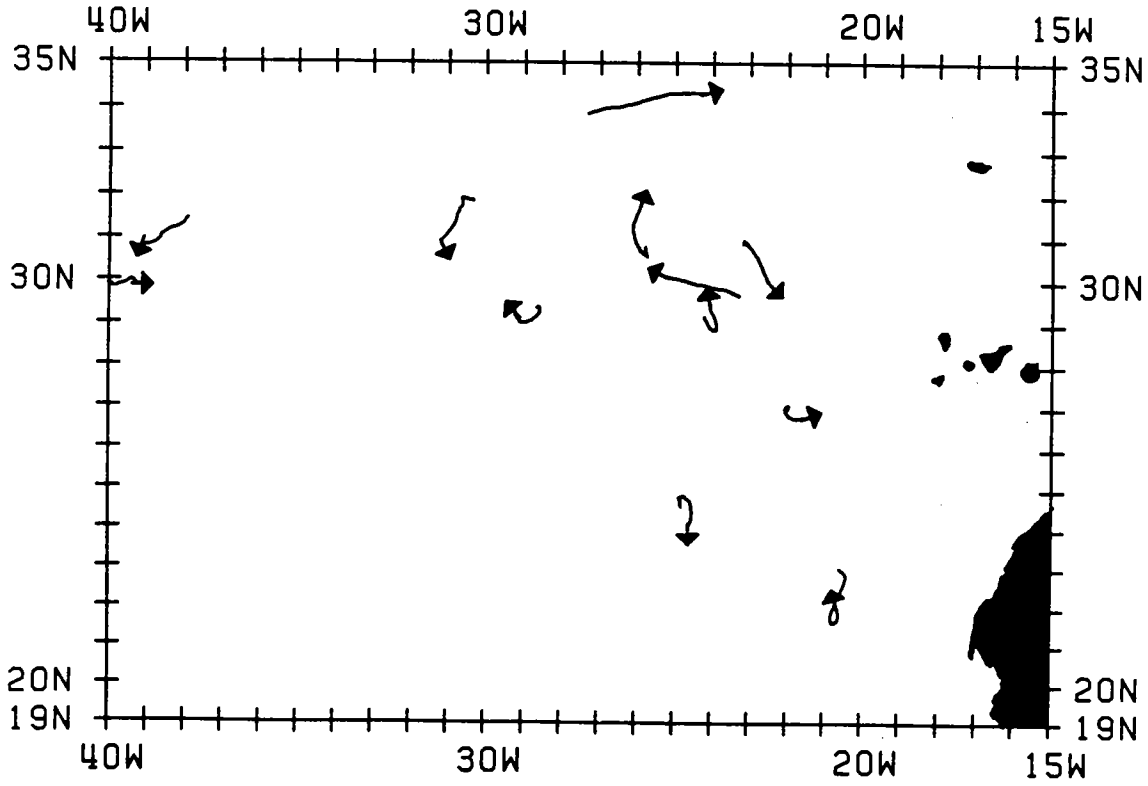
DECEMBER 1986 – FEBRUARY 1987



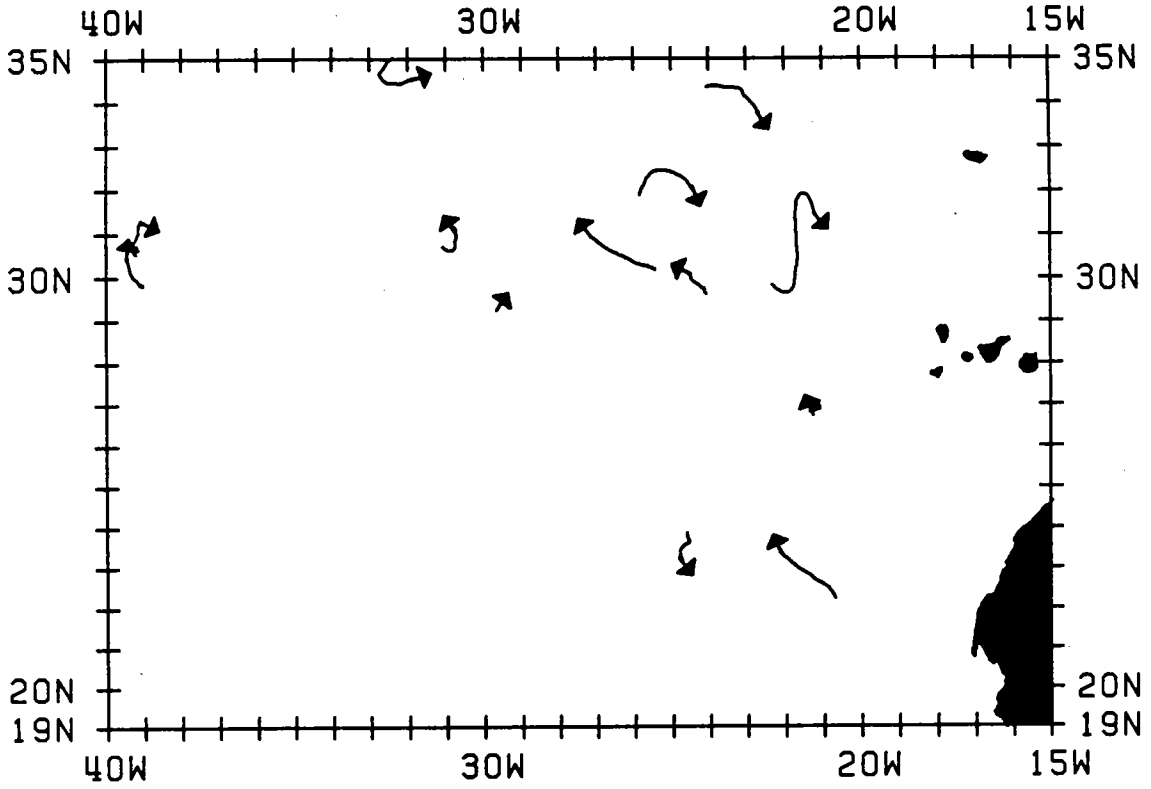
FEBRUARY – APRIL 1987



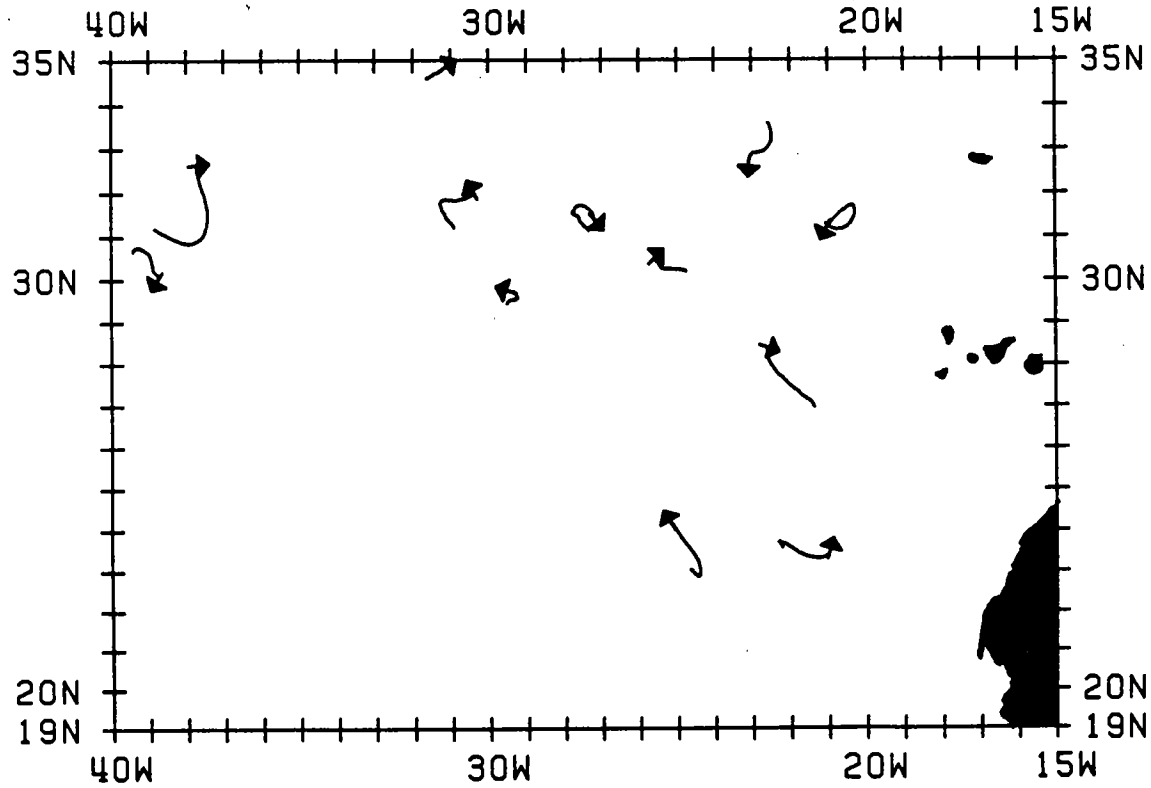
APRIL – JUNE 1987



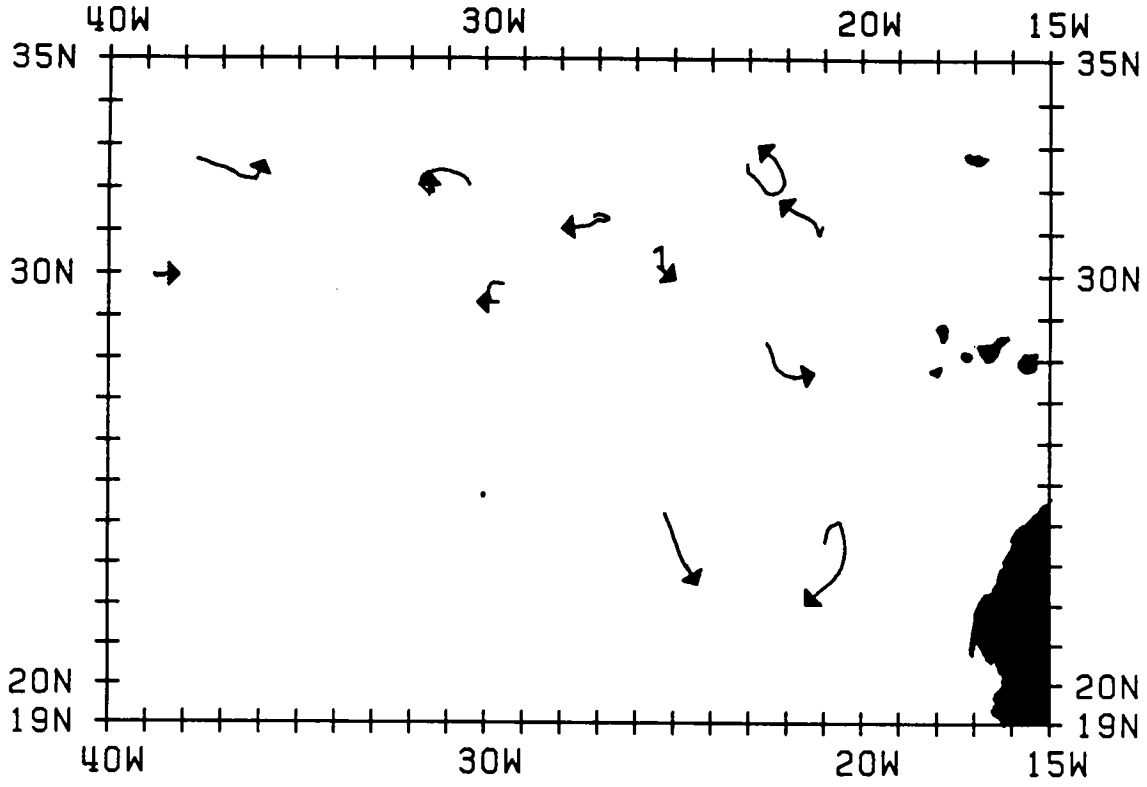
JUNE – AUGUST 1987



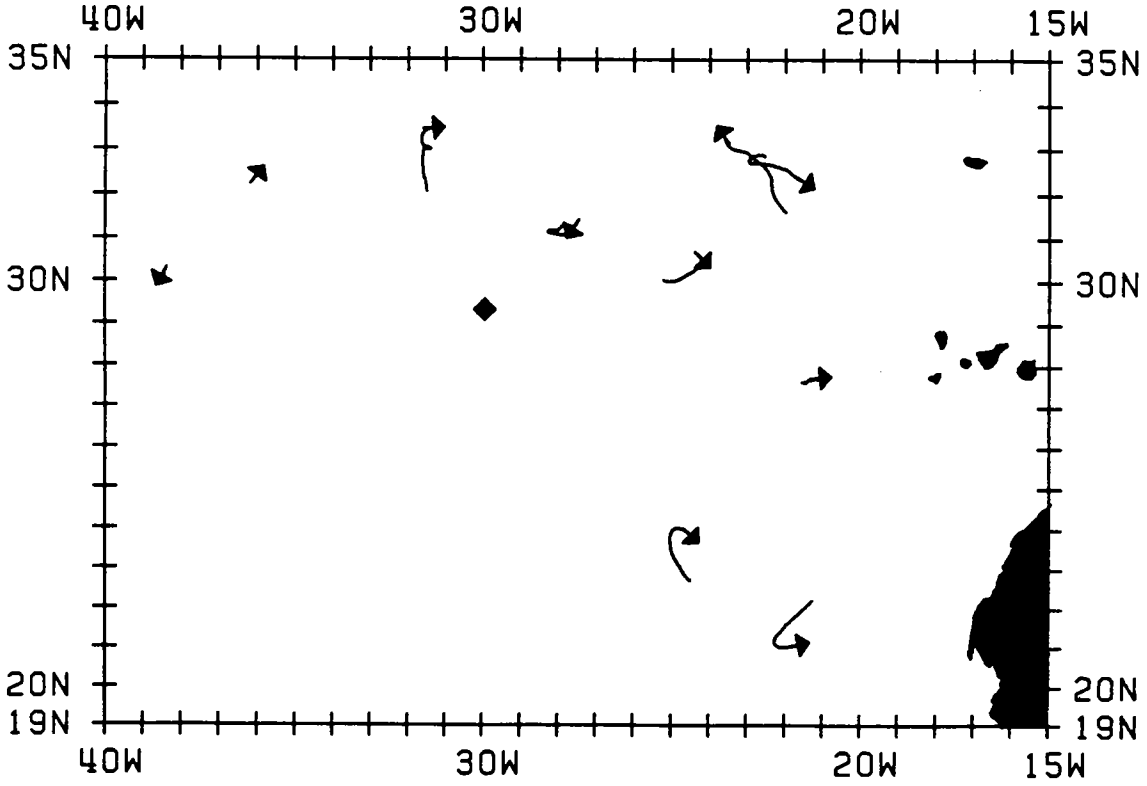
AUGUST – OCTOBER 1987



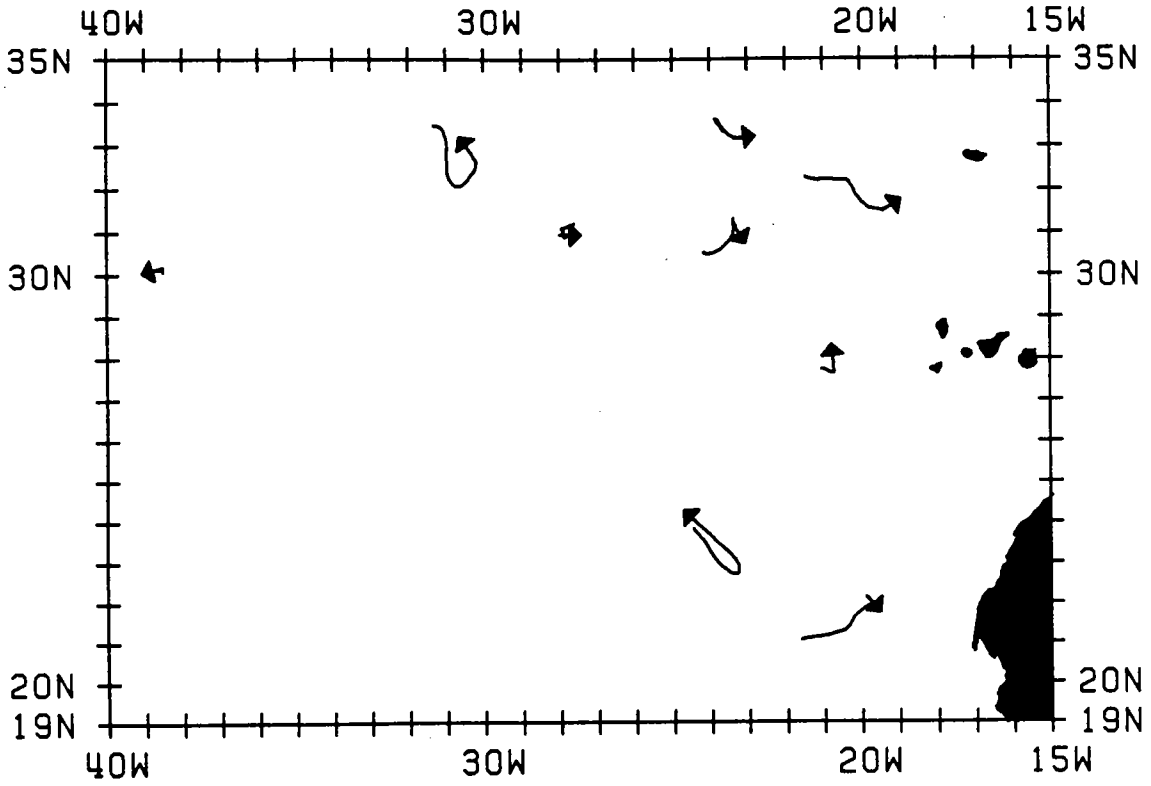
OCTOBER – DECEMBER 1987



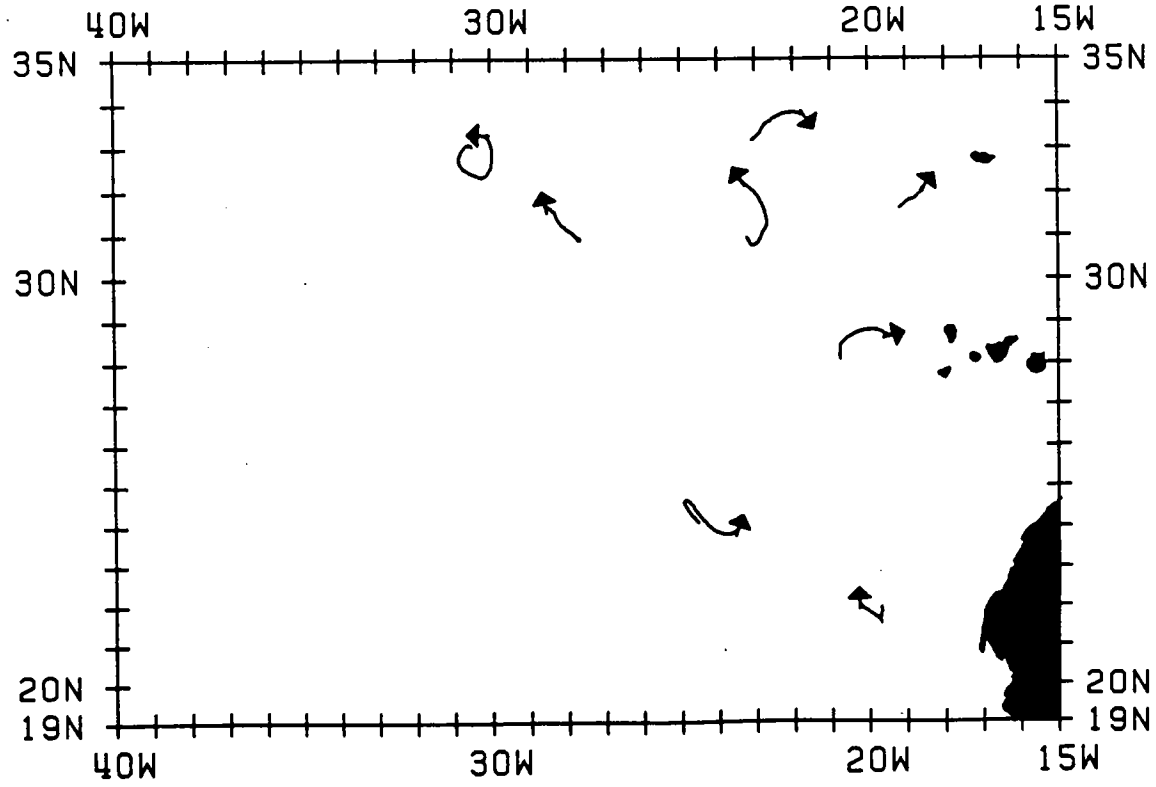
DECEMBER 1987 – FEBRUARY 1988



FEBRUARY – APRIL 1988



APRIL – JUNE 1988



6 Bobber Float EB014

Bobbers are SOund Fixing And Ranging (SOFAR) floats equipped with a new Controllable Buoyancy System (CBS). The CBS can cause the float to rise or sink by pumping oil in or out of an external bladder, thereby varying the float's displacement and buoyancy. The Bobber senses the ambient temperature and pressure and uses this data to regulate its motion according to a prescribed control algorithm.

The CBS mechanism was given its first deep sea test during a cruise to the eastern subtropical North Atlantic in May 1986, but the test gave mixed results. Although the Bobber did cycle vertically, it cycled sluggishly and overshot its prescribed turning points by as much as 50 db. However, Bobber EB014 was left in the water and continued to cycle until June 1988 when the eastern North Atlantic tracking network of Autonomous Listening Stations (ALSs) was recovered for the final time (see Table IV). This test demonstrated the long life time of the CBS, and also demonstrated that shallow floats could be heard at long ranges (1500 km).

The trajectory and telemetry for Bobber EB014 are shown in Figures 14 and 15. The column thickness for EB014 was roughly 250 db because the turning points were roughly 100 db and 350 db. This very large column thickness was partly due to the desire to see large excursions on this first test, and partly to lag in the platinum resistance thermometer of EB014.

TABLE IV

BOBBER FILE STATISTICS FOR 1986 - 1988 TRACKING

BOBBER	START DATE yymmdd	START POSITION LAT. deg N	START POSITION LONG. deg W	STOP DATE yymmdd	STOP POSITION LAT. deg N	STOP POSITION LONG. deg W	NO. DAYS TRACKED
014A	860514	31.078	29.935	871129	33.571	37.171	565
014B	880401	31.185	32.972	880504	31.530	35.856	34

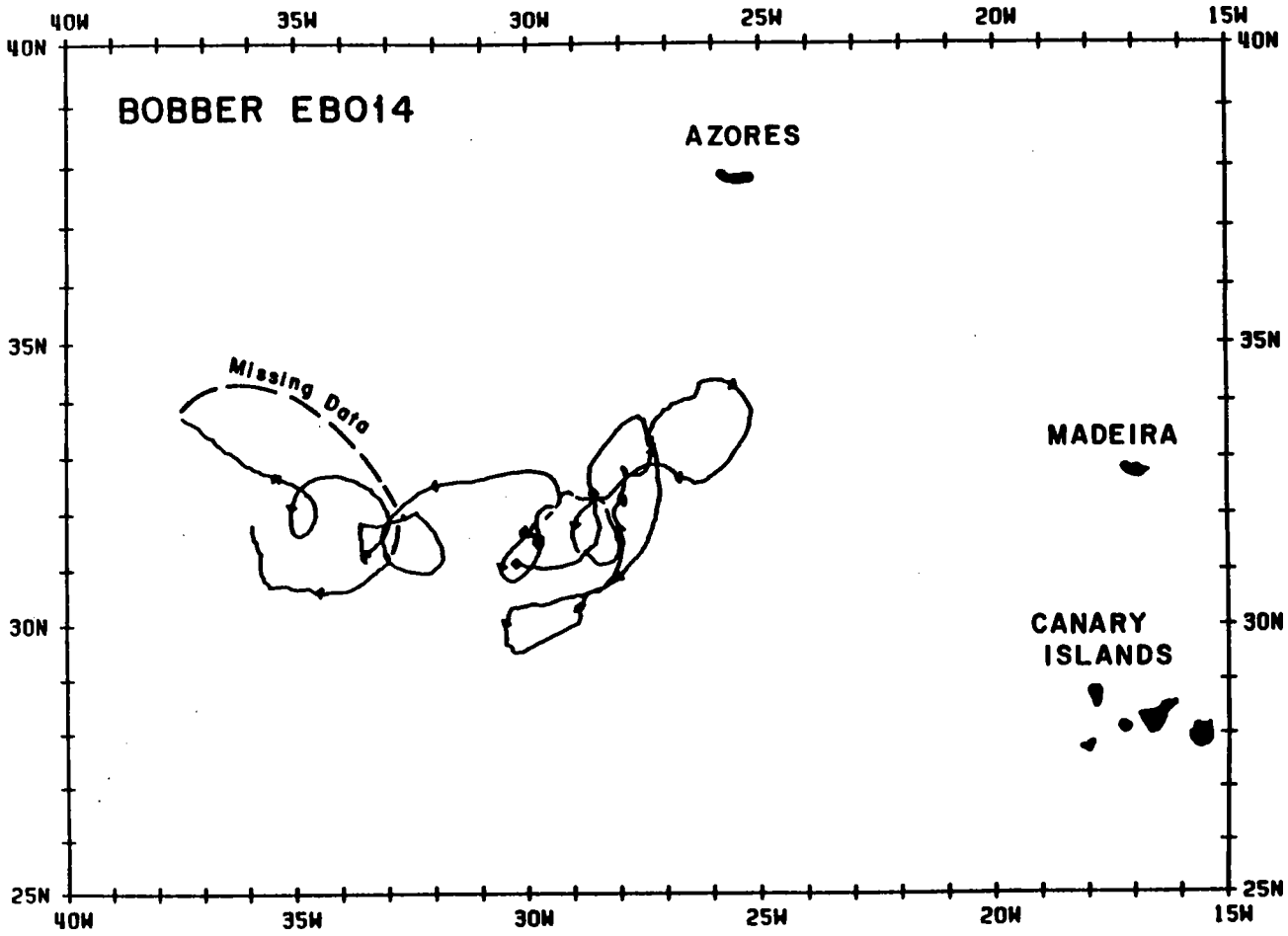


Figure 14: The first long term Bobber trajectory from the spring 1986 tests in the eastern subtropical North Atlantic (trajectory begins May 12, 1986 and ends May 2, 1988). The mean depth of the Bobber was 200 db. Arrowheads are shown at 30-day intervals along the track. The gap in winter 1987 was due to shadowing of the tracking stations (ALSs) by a shallow seamount. The record ends when the tracking stations were recovered for the final time in summer 1988.

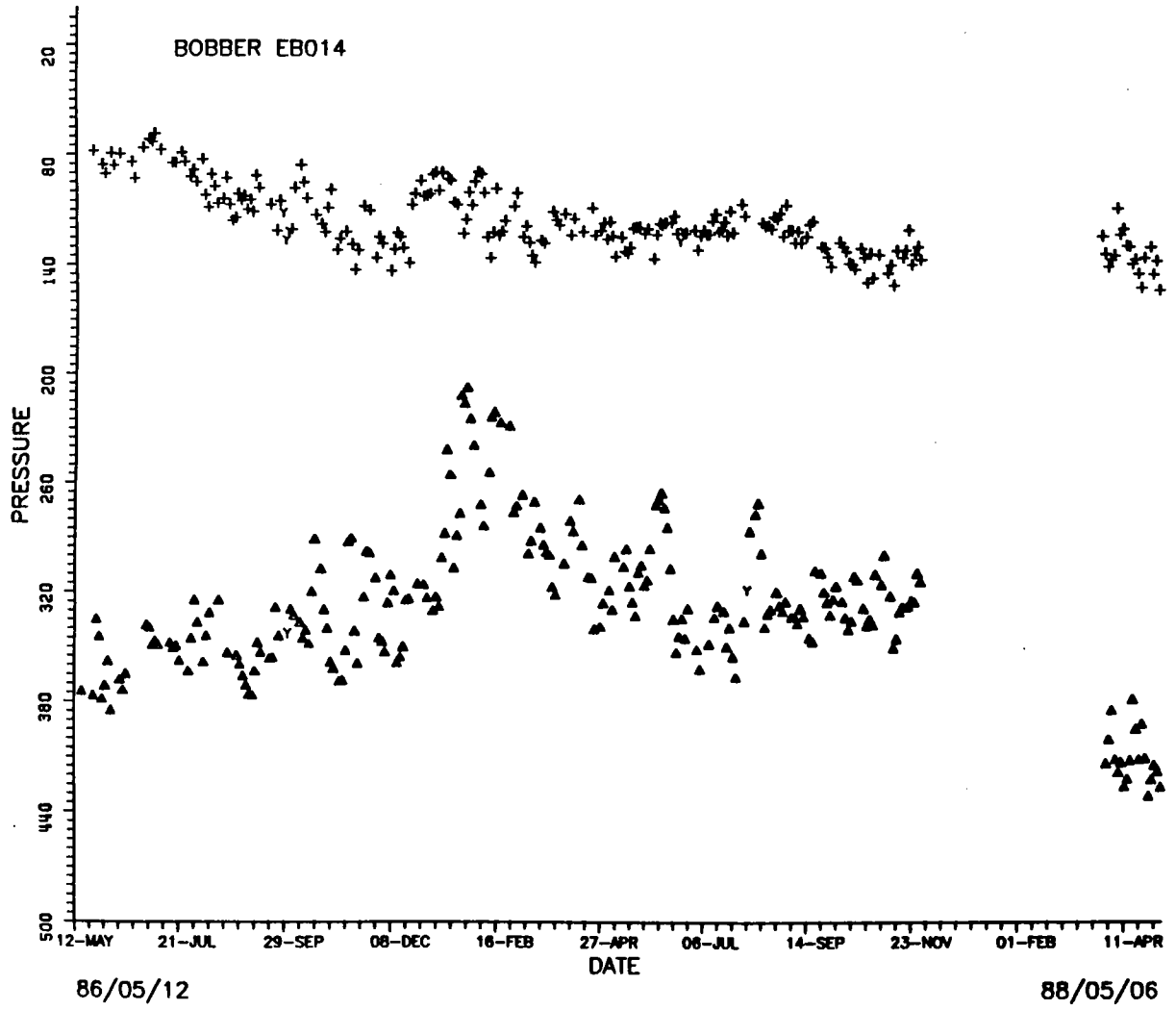


Figure 15: Pressure telemetry from EB014. The upper set of points are the upper turning level, and the lower set are the lower turning level. This Bobber was given a minimum pressure not to ascend above, 80 db, which it appears to have reached in spring 1986 and again in winter 1987. The upper turning level was thus almost surely affected by vertical mixing during at least these periods. The gap in winter 1987 is the same gap that occurs in Figure 14.

7 Acknowledgements

This research was made possible with funds provided by the National Science Foundation under Grants OCE82-14066, OCE86-00055 and OCE88-22826 entitled A Study of Advection and Diffusion in the Eastern North Atlantic, principal investigators J. F. Price and P. L. Richardson, and Grant OCE85-17375 entitled Field Tests of Controllable Buoyancy System (CBS) SOFAR Floats as a Pilot Study of Oceanic Subduction, principal investigator J. F. Price.

SOFAR floats, ALSs and Bobbers were purchased from Webb Research Corporation. They were ballasted, prepared for sea, launched and retrieved by the WHOI float operations group consisting of J. R. Valdes, R. D. Tavares and B. J. Guest. The floats were tracked by M. E. Zemanovic at the Woods Hole Oceanographic Institution using a system developed by W. B. Owens. C. M. Wooding modified some of the tracking programs, and M. A. Lucas typed the manuscript. We wish to thank Dr. Yves Desaubies and the officers and crew of the research vessel *Charcot* for their hospitality during the June 1988 ALS recovery cruise.

8 References

Armi, L. D., D. Hebert, N. Oakey, J. F. Price, P. L. Richardson, H. T. Rossby and B. Ruddick, 1988. The history and decay of a Mediterranean salt lens. *Nature*, **333**, 649–651.

Armi, L. D., D. Hebert, N. Oakey, J. F. Price, P. L. Richardson, H. T. Rossby and B. Ruddick, 1989. Two years in the life of a Mediterranean salt lens. *Journal of Physical Oceanography*, **19**, 354–370.

Käse, R. H., J. F. Price, P. L. Richardson, and W. Zenk, 1986. A quasi-synoptic survey of the thermocline circulation and water mass distribution within the Canary Basin. *Journal of Geophysical Research*, **91**(C8), 9739–9748.

McKee, T. K., 1986. A summary of historical SOFAR float data in the western North Atlantic, 1972–1981. *Woods Hole Oceanographic Institution Technical Report*, **WHOI-86-24**, 722 pages.

Price, J. F., T. K. McKee, J. R. Valdes, P. L. Richardson, and L. Armi, 1986. SOFAR float Mediterranean Outflow Experiment, 1984–1985. *Woods Hole Oceanographic Institution Technical Report*, **WHOI-86-31**, 199 pages.

Reid, J. L., 1979. On the contribution of the Mediterranean Sea Outflow to the Norwegian–Greenland Sea. *Deep-Sea Research*, **26A**, 1199–1223.

Reid, J. L., and R. J. Lynn, 1971. On the influence of the Norwegian–Greenland and Weddell Seas upon the bottom waters of the Indian and Pacific Oceans. *Deep-Sea Research*, **18**, 1063–1088.

Richardson, P. L., D. Walsh, L. Armi, M. Schröder, and J. F. Price, 1989. Tracking three Meddies with SOFAR floats. *Journal of Physical Oceanography*, **19**, 371–383.

Schmitz, W. J., Jr., J. F. Price and P. L. Richardson, 1988. Recent moored current meter and SOFAR float observations in the eastern Atlantic near 32N. *Journal of Marine Research*, **46**, 301–319.

Tarbell, S. A., P. L. Richardson, and J. F. Price, 1987. Moored current meter data from the Canary basin near 32N 24W (1984–1986), Volume XL. *Woods Hole Oceanographic Institution Technical Report*, **WHOI-87-19**, 34 pages.

Worthington, L. V., 1976. On the North Atlantic circulation. *The Johns Hopkins Oceanographic Studies*, **6**, 110 pages.

Zemanovic, M., P. L. Richardson, J. R. Valdes, J. F. Price, and L. Armi, 1988. SOFAR float Mediterranean Outflow Experiment — Data from the second year, 1985–1986. *Woods Hole Oceanographic Institution Technical Report*, **WHOI-88-43**, 230 pages.

9 Appendix — Plots of Individual Floats: 1986–1988

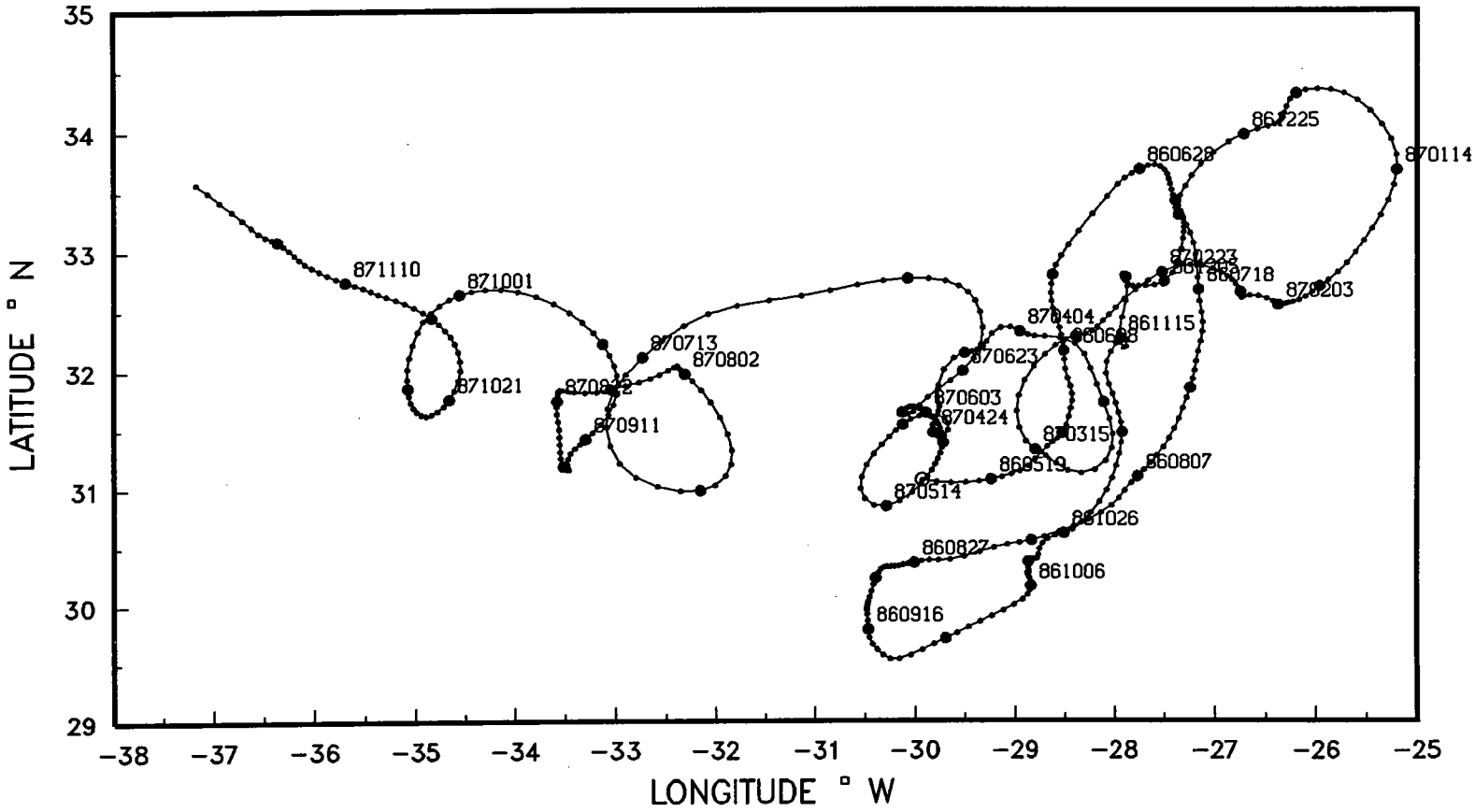
A trajectory plot and time series plots are presented for each float and Bobber EB014. The order of the time series plots is velocity stick diagram, u and v velocity component overplot, and temperature and pressure overplot, when available. A common scale is used for the time axis but the y axis varies for each float according to the minima and maxima of the variables plotted. Two hundred days of data are plotted on each page and data points are marked daily. Float files of lengths greater than 200 days are continued on subsequent pages. The time axis is annotated with the calendar months.

A trajectory for each float is plotted on a mercator projection. For the longitude axis, negative numbers indicate longitudes west of the Greenwich Meridian. Along the trajectories, open circles denote the first float position, small dots mark the daily positions, large dots the tenth day, and every twentieth day is annotated with the date.

Stick plots show velocity every day. The stick length indicates the speed in cm/sec, and the angle the stick makes with the horizontal axis represents the direction. North is toward the top of the page. The east and north components of of velocity can be seen separately in overplots plotted to the same scale as the stick plots.

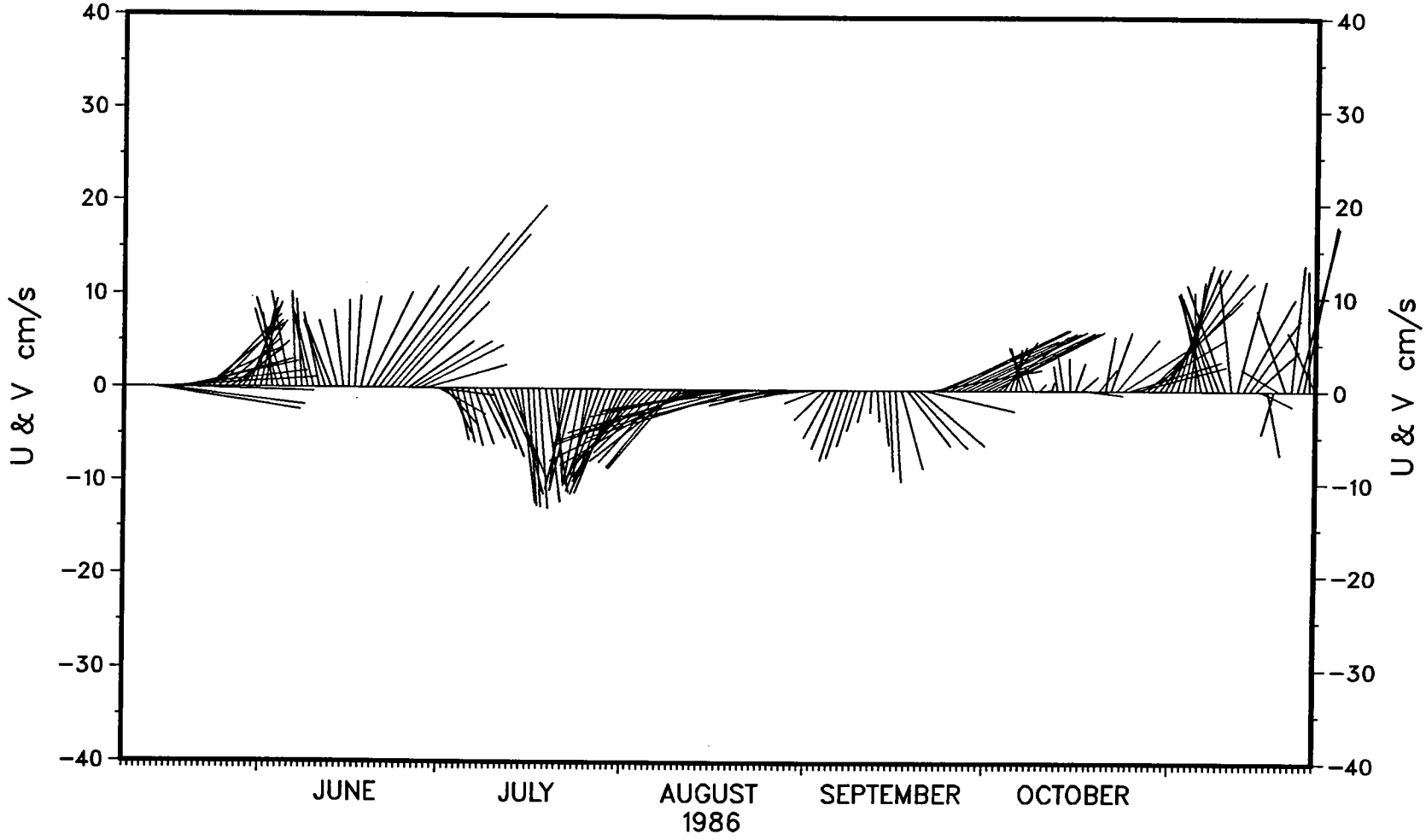
Temperature and pressure are overplotted, temperature on a centigrade scale marked on the left y axis, pressure in decibars marked on the right y axis with deeper values at the bottom of the scale. Temperature and pressure that drifted outside the range of the sensors were listed as being off scale.

EASTERN BASIN 014A



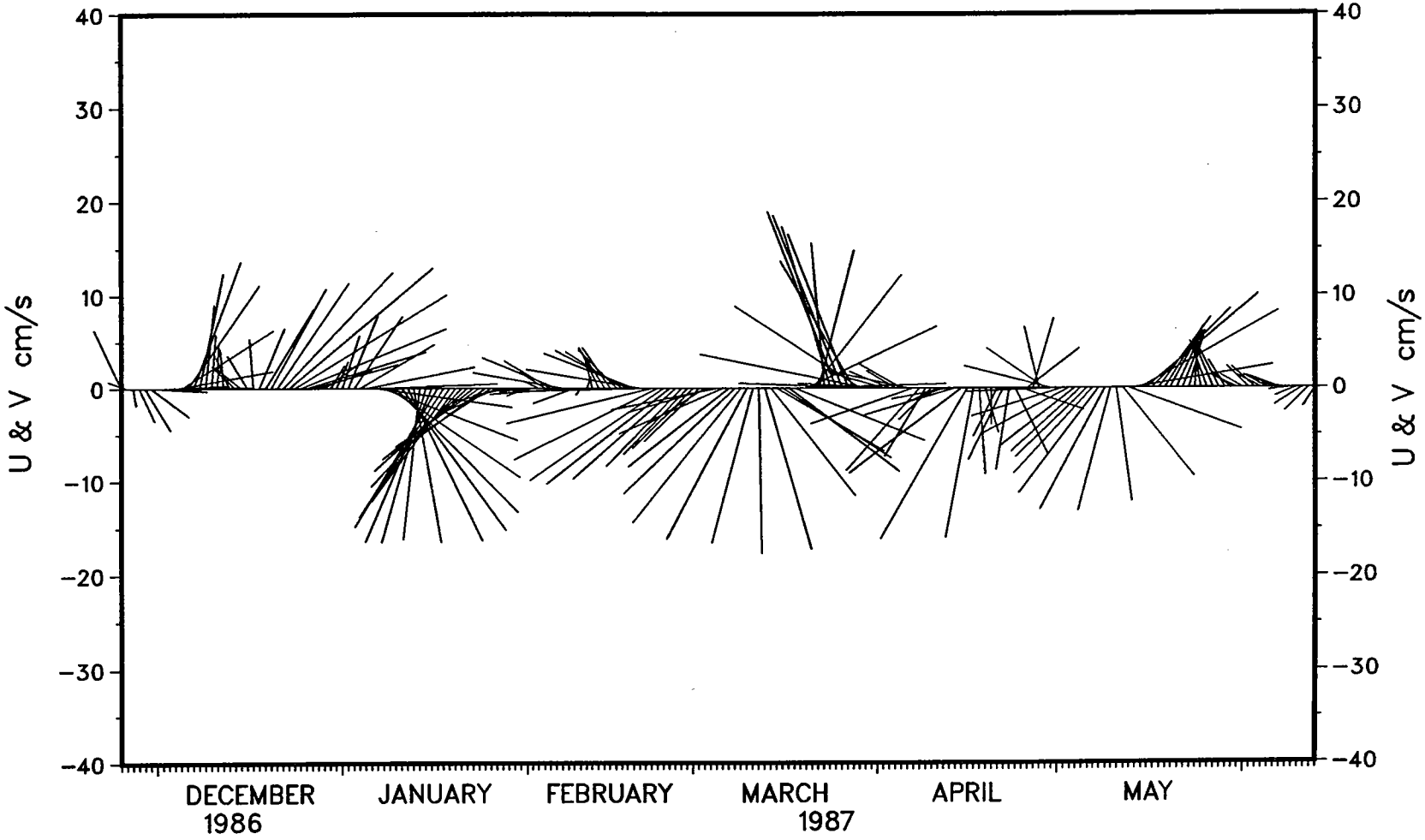
PLOT 1 OF 1
.SPL

EASTERN BASIN 014A



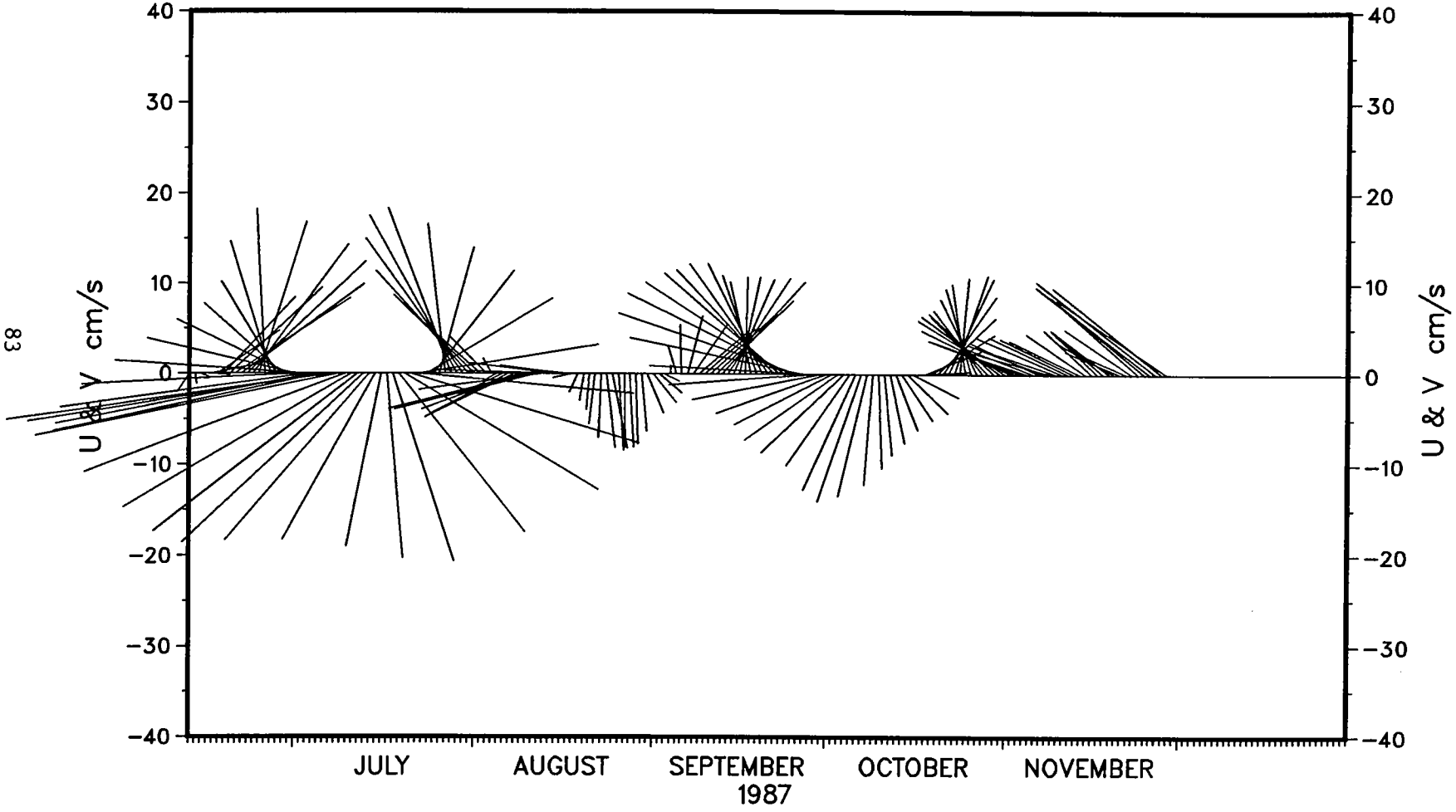
PLOT 1 OF 3
.SPL

EASTERN BASIN 014A



PLOT 2 OF 3
.SPL

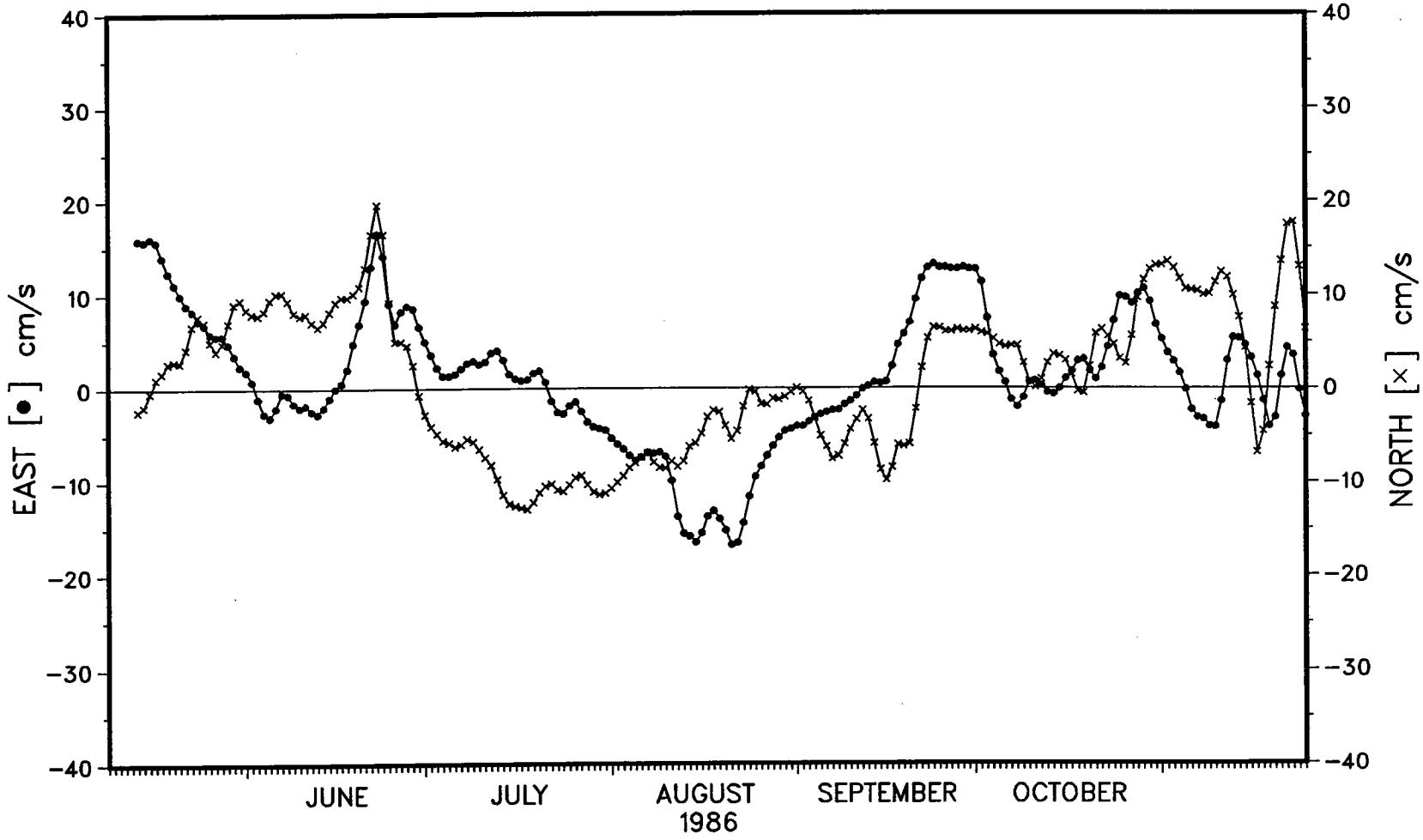
EASTERN BASIN 014A



83

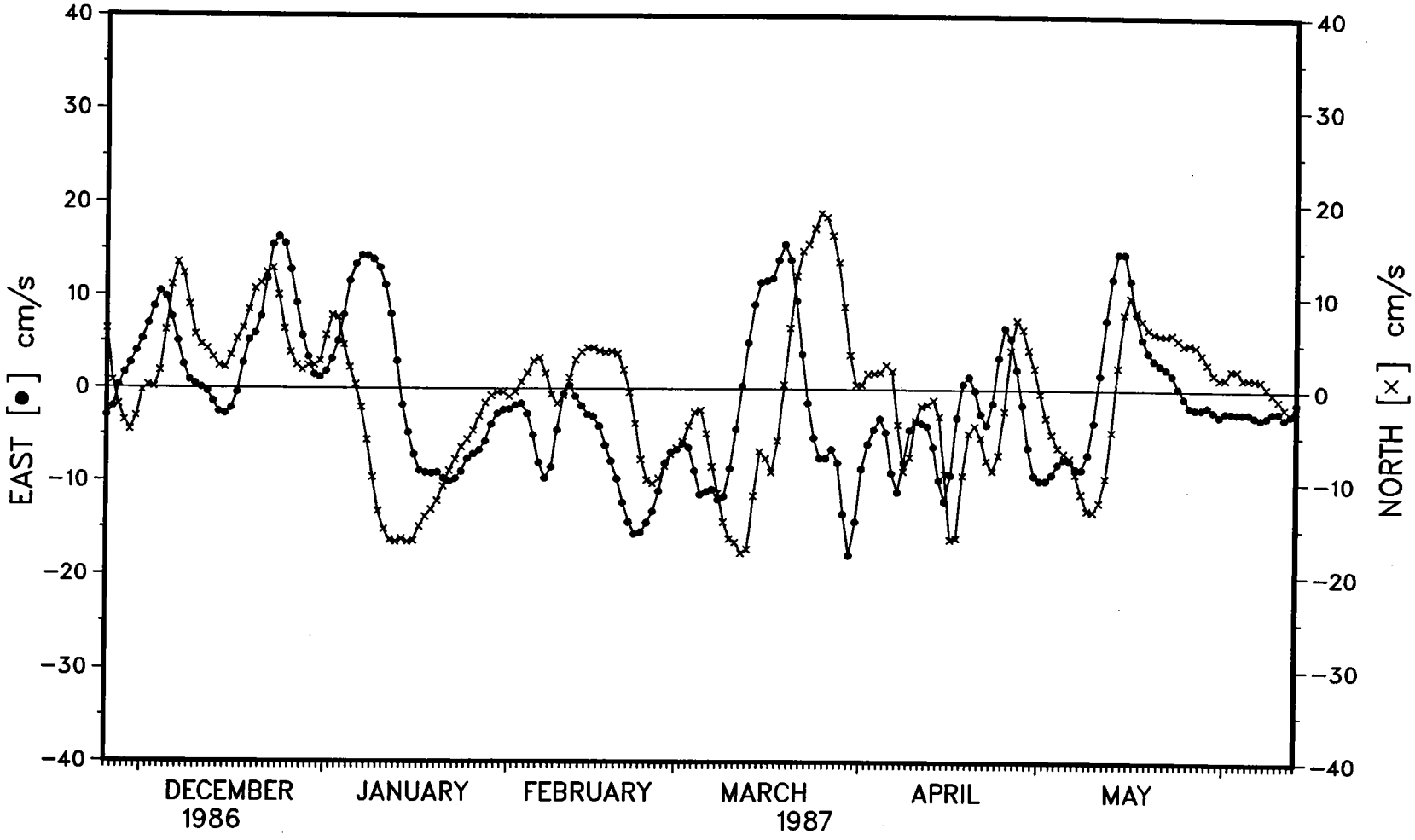
PLOT 3 OF 3
.SPL

EASTERN BASIN 014A



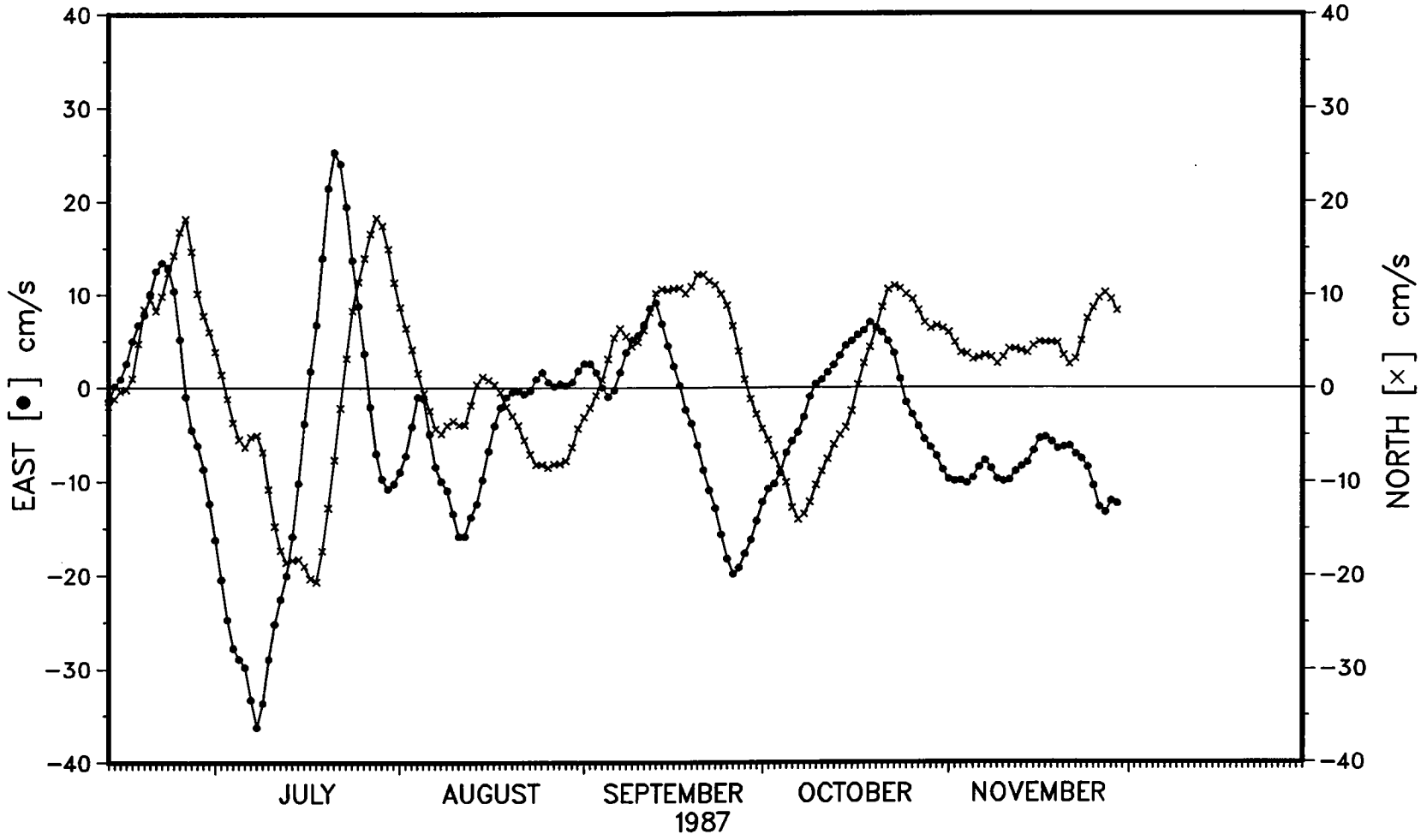
PLOT 1 OF 3
.SPL

EASTERN BASIN 014A



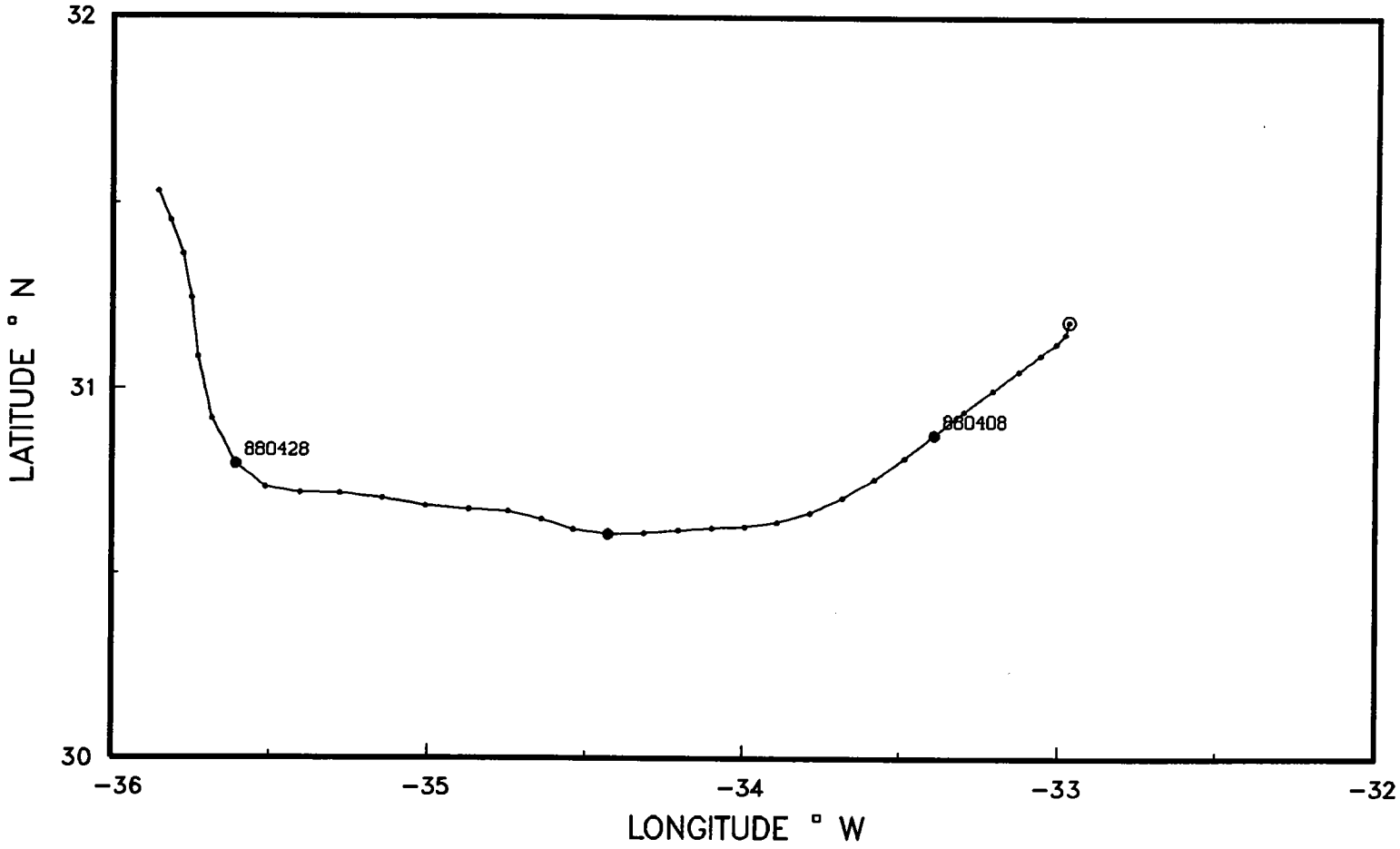
PLOT 2 OF 3
.SPL

EASTERN BASIN 014A



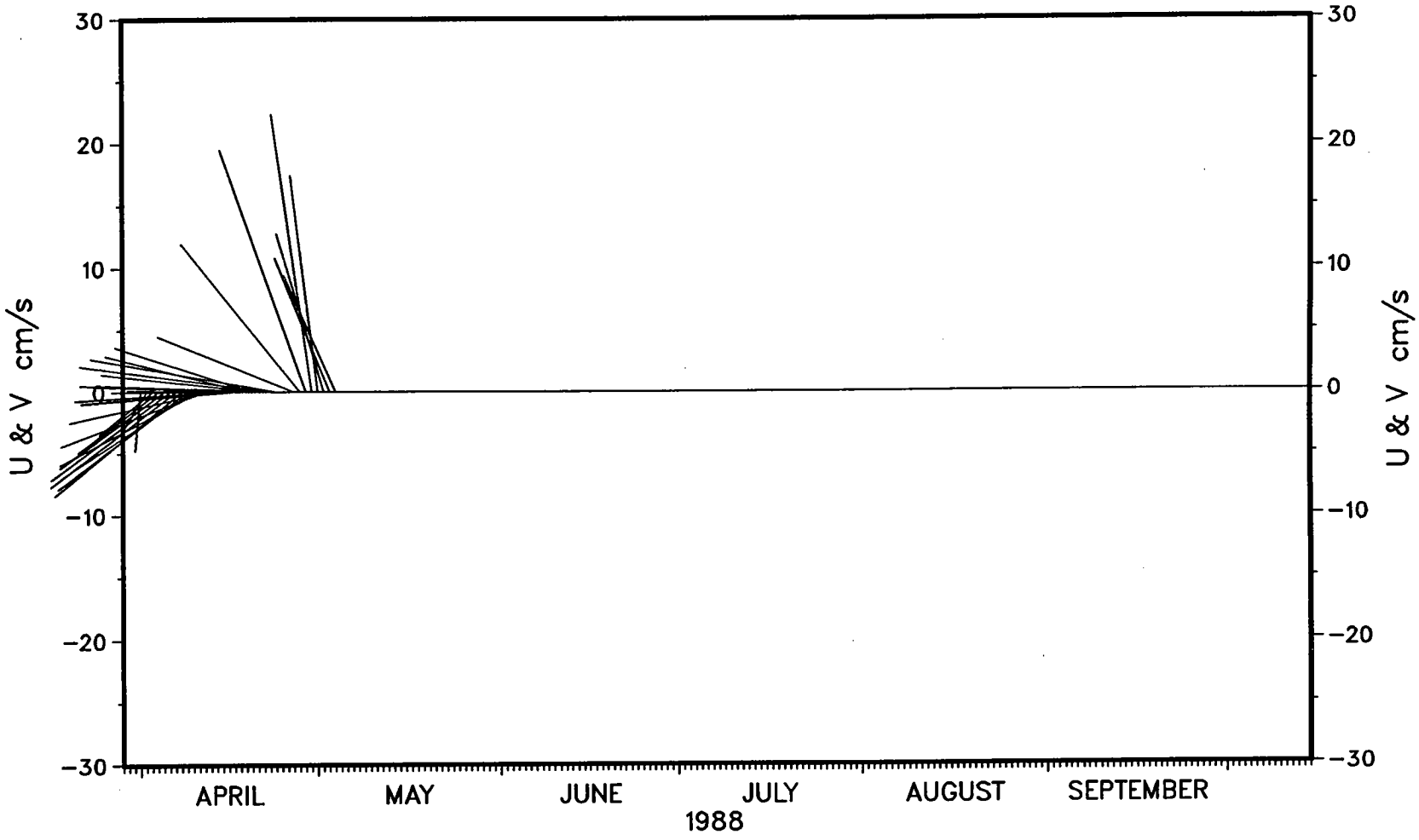
PLOT 3 OF 3
.SPL

EASTERN BASIN 014B



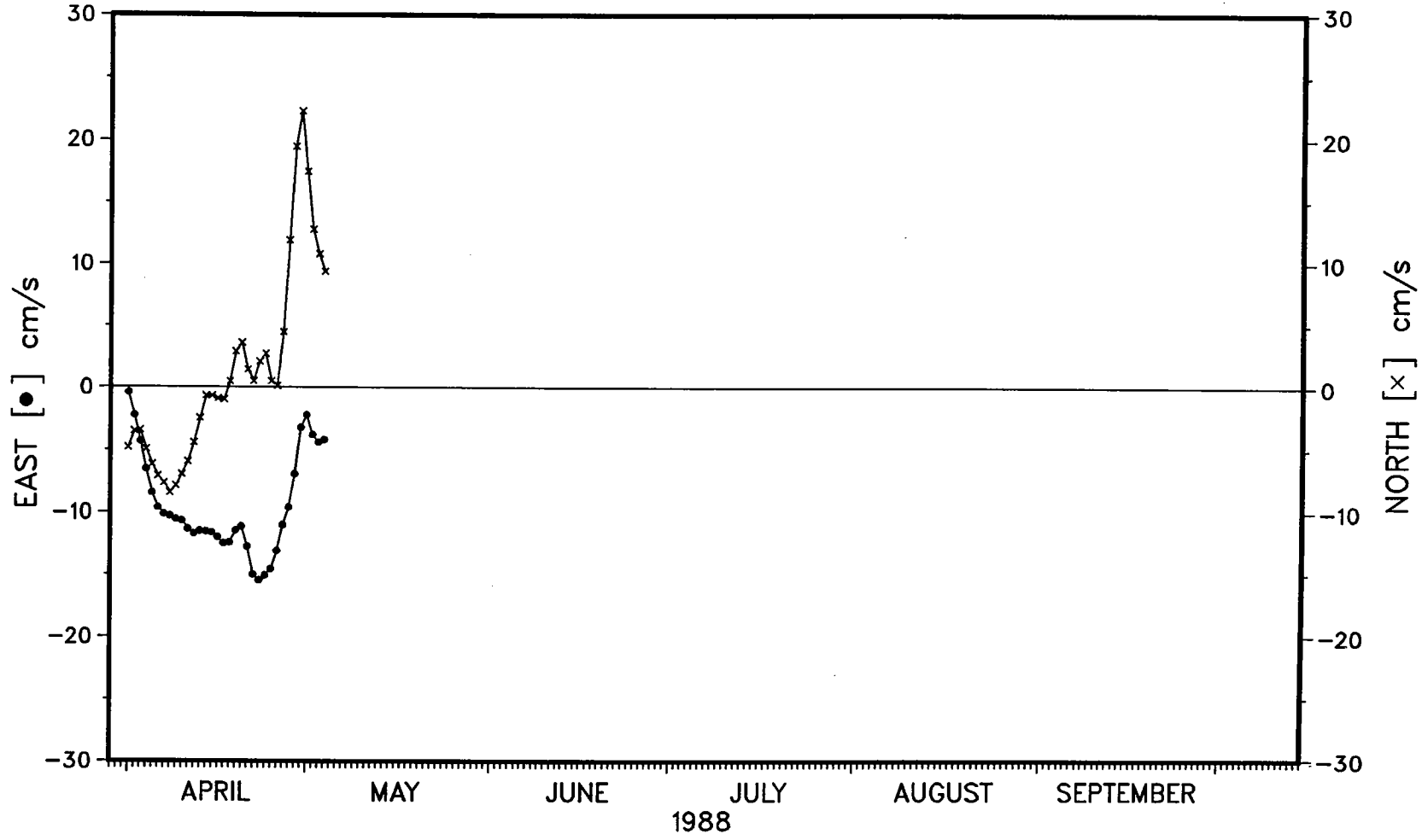
PLOT 1 OF 1
.SPL

EASTERN BASIN 014B



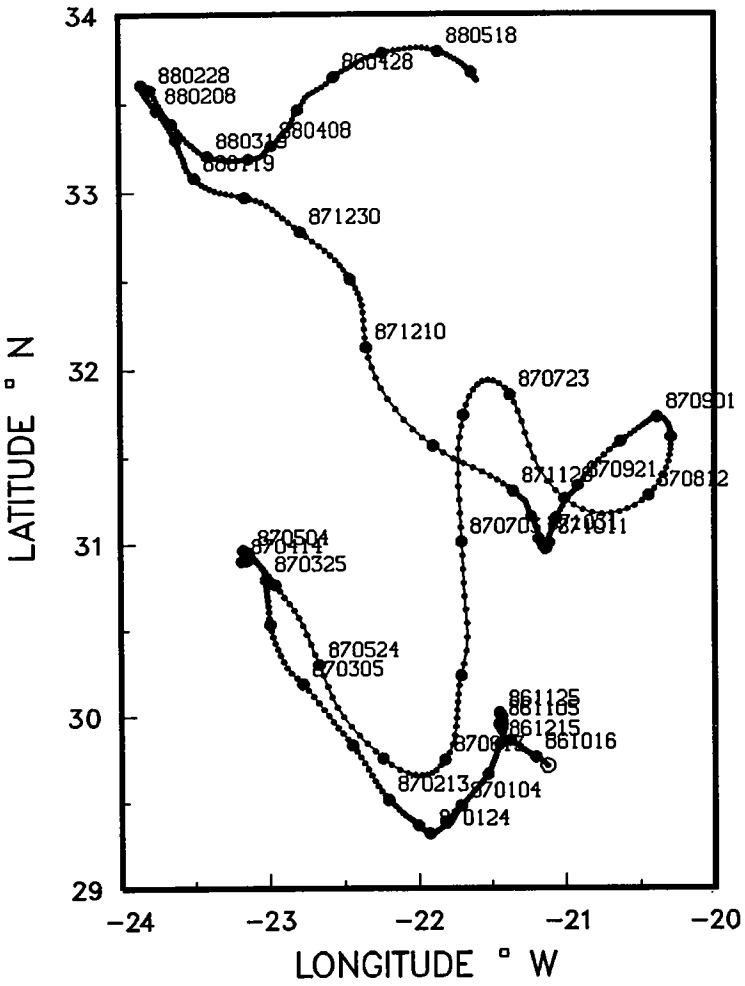
PLOT 1 OF 1
.SPL

EASTERN BASIN 014B



PLOT 1 OF 1
.SPL

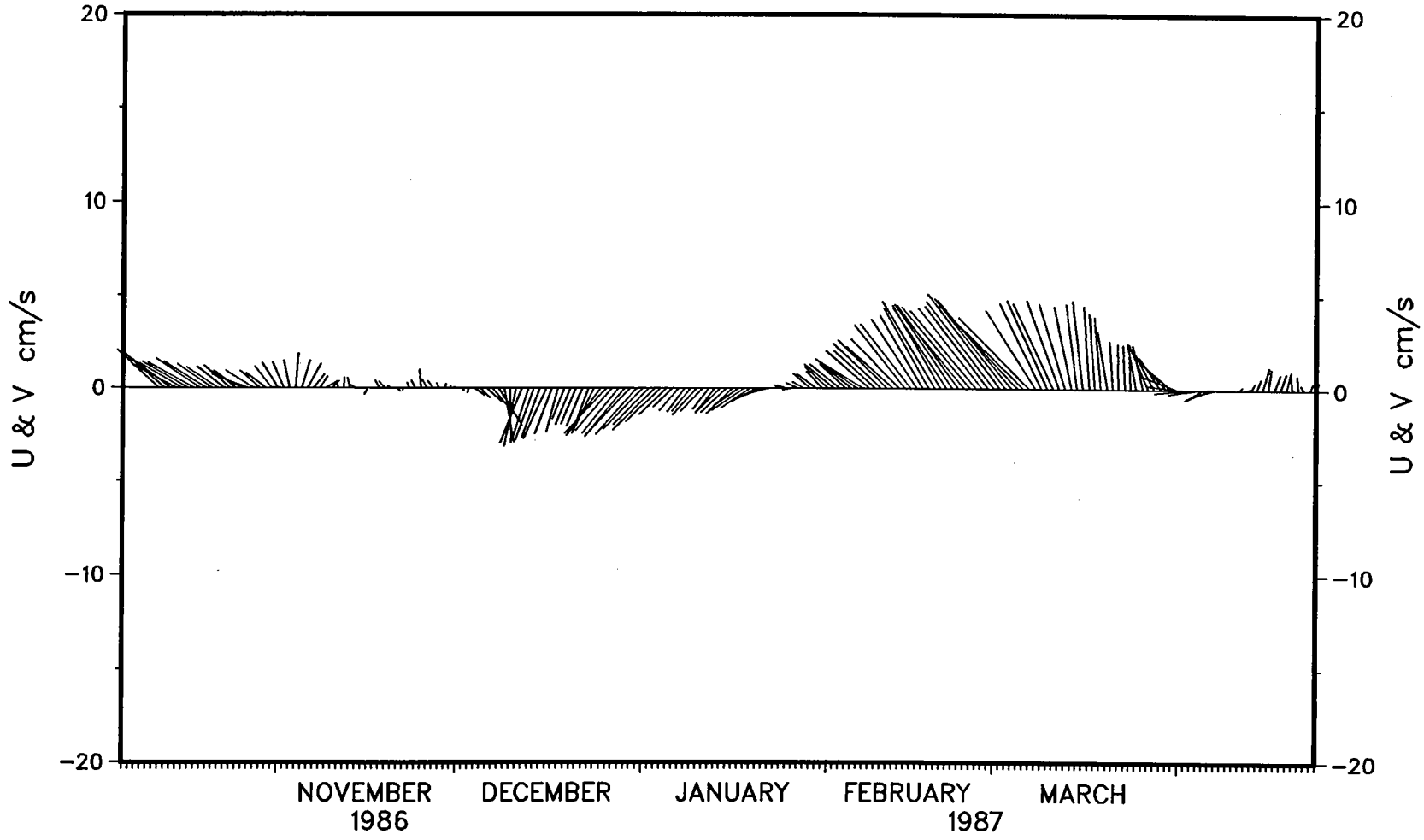
EASTERN BASIN 121



06

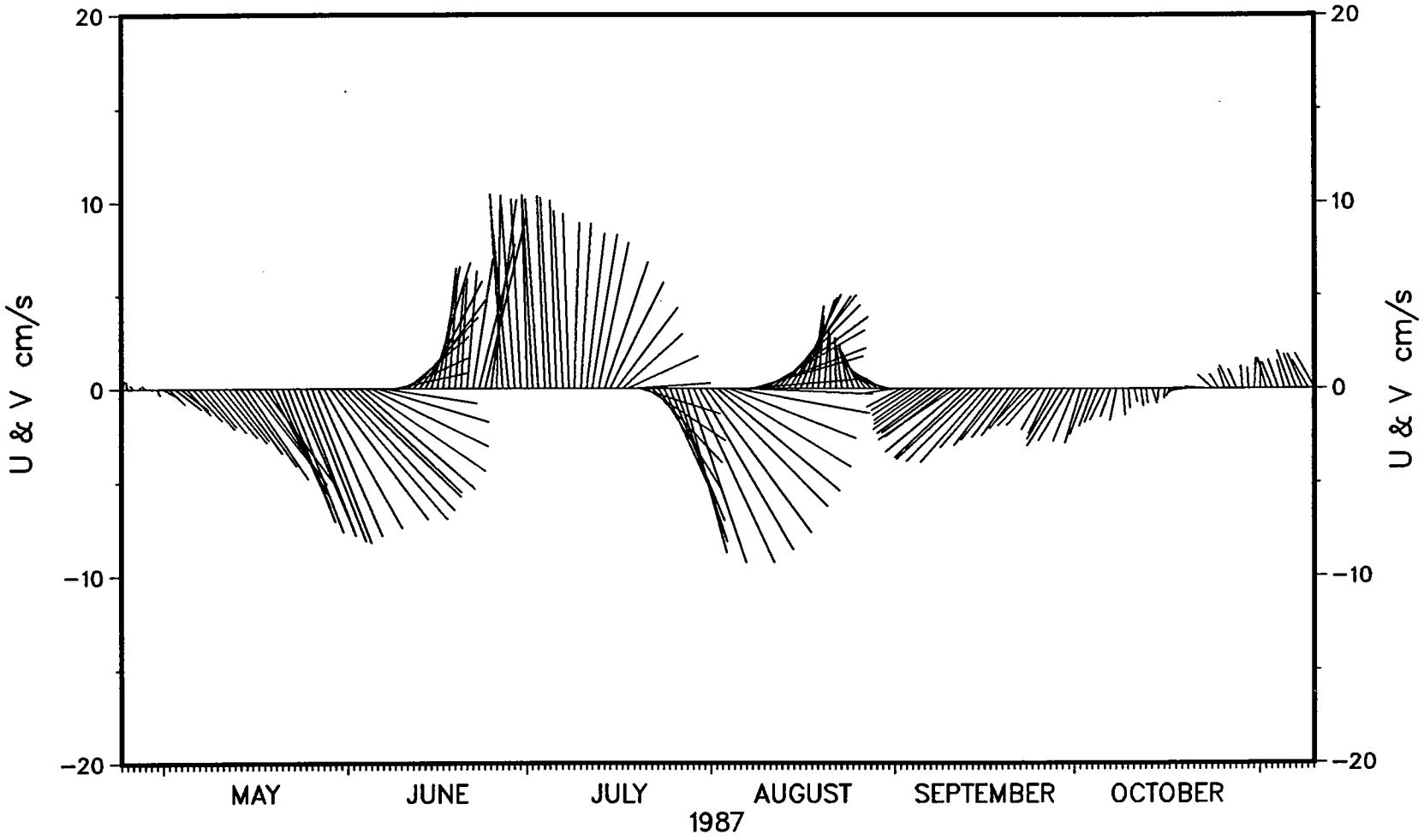
PLOT 1 OF 1
.SPL

EASTERN BASIN 121



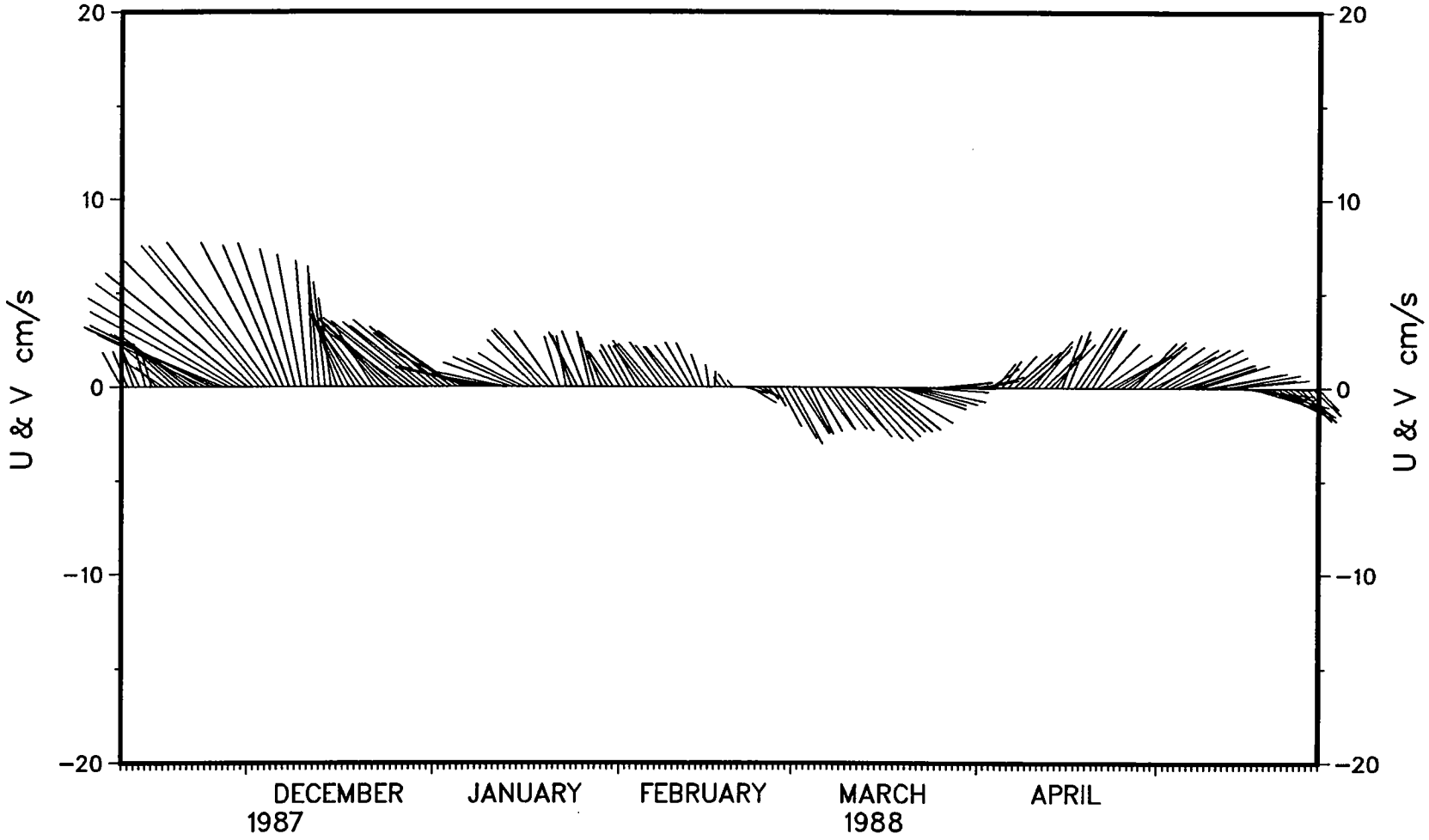
PLOT 1 OF 4
.SPL

EASTERN BASIN 121



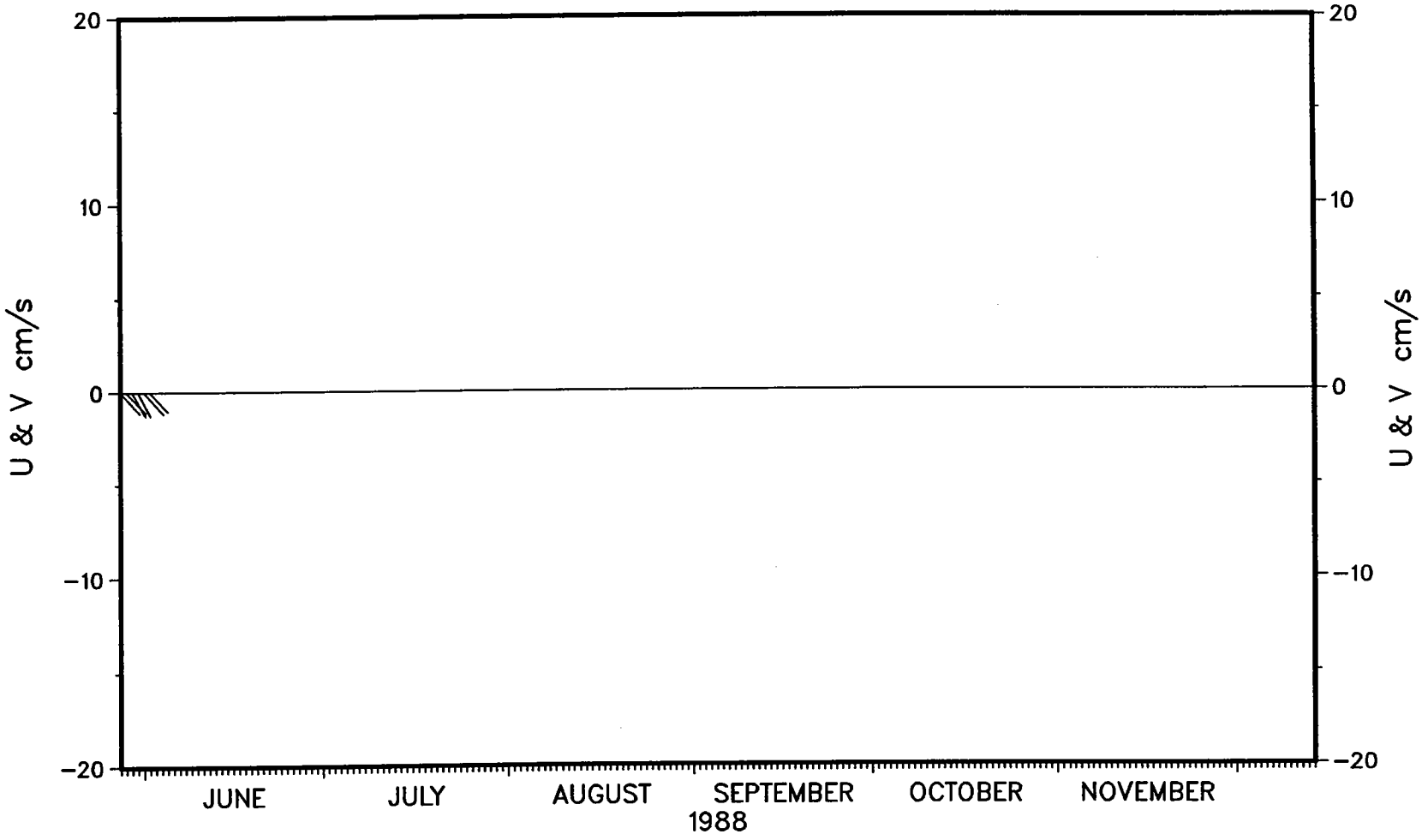
PLOT 2 OF 4
.SPL

EASTERN BASIN 121



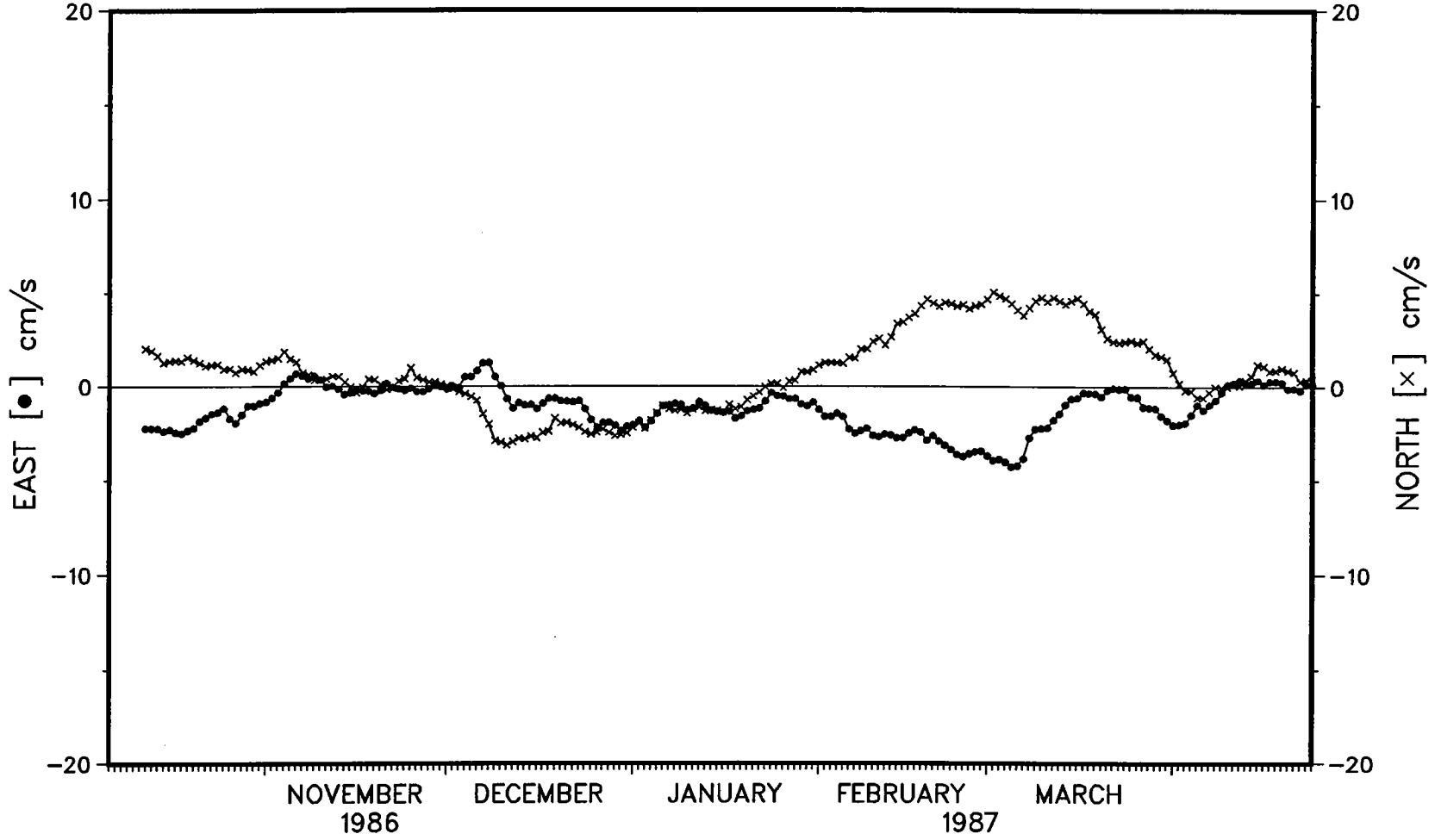
PLOT 3 OF 4
.SPL

EASTERN BASIN 121



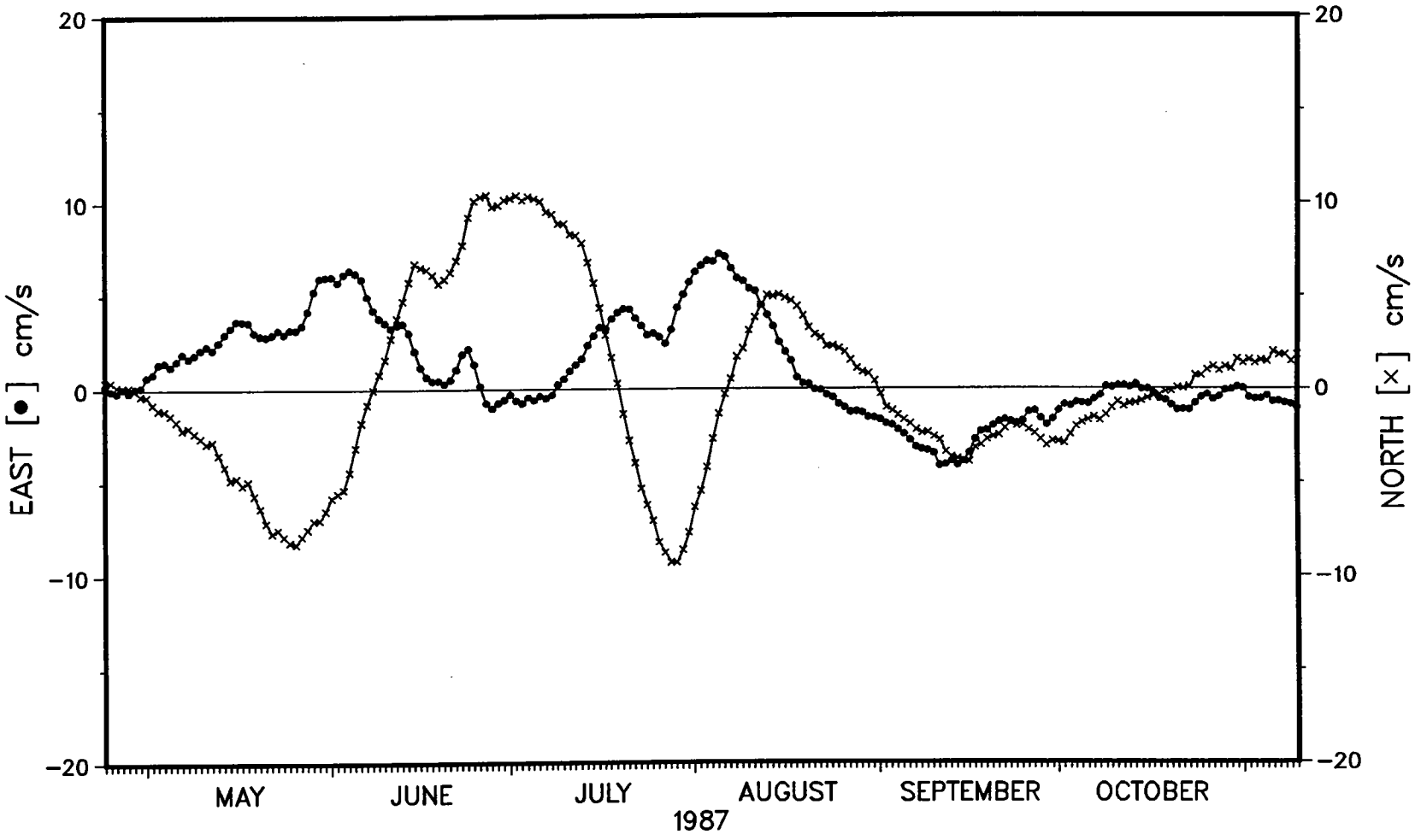
PLOT 4 OF 4
.SPL

EASTERN BASIN 121



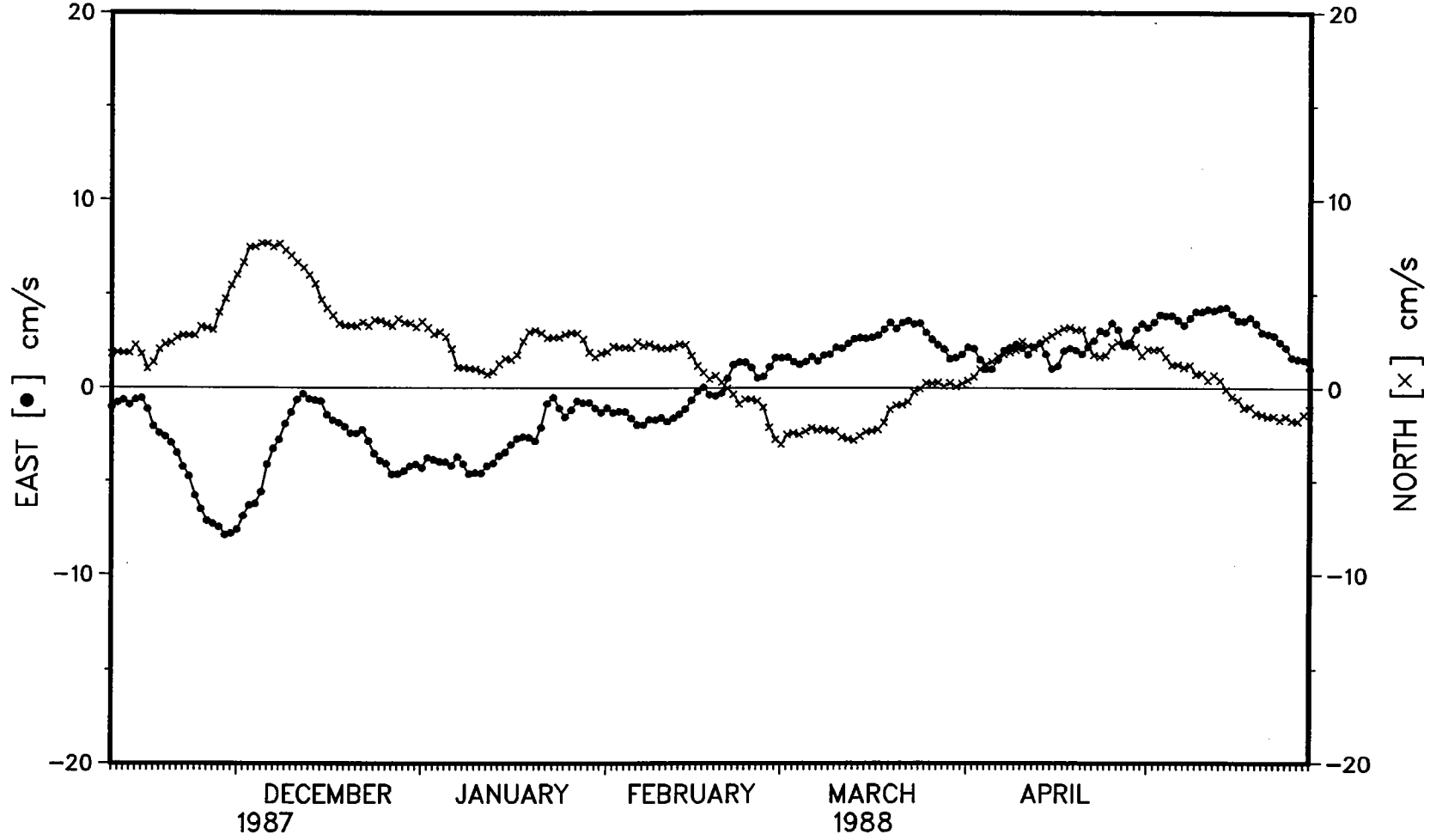
PLOT 1 OF 4
.SPL

EASTERN BASIN 121



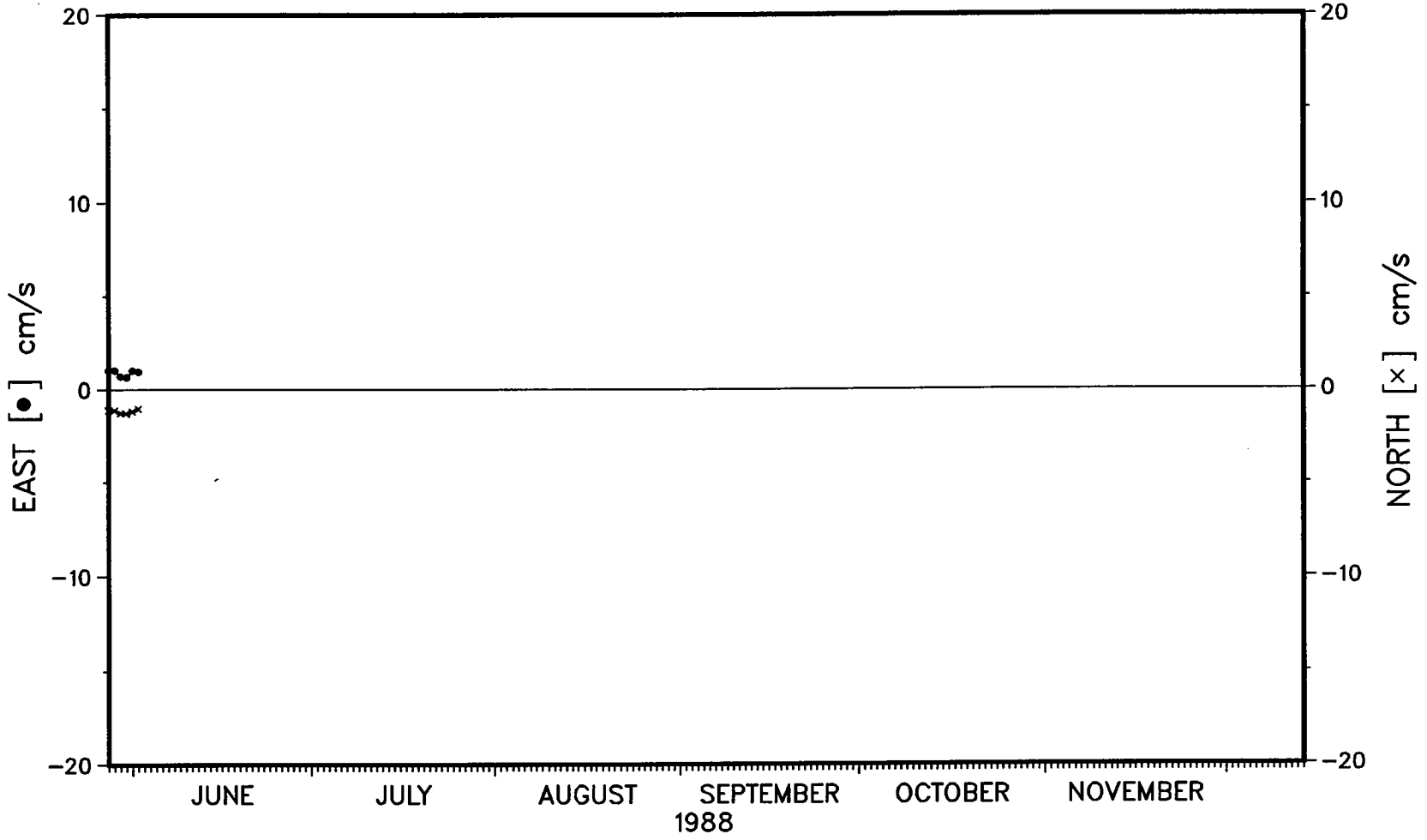
PLOT 2 OF 4
.SPL

EASTERN BASIN 121



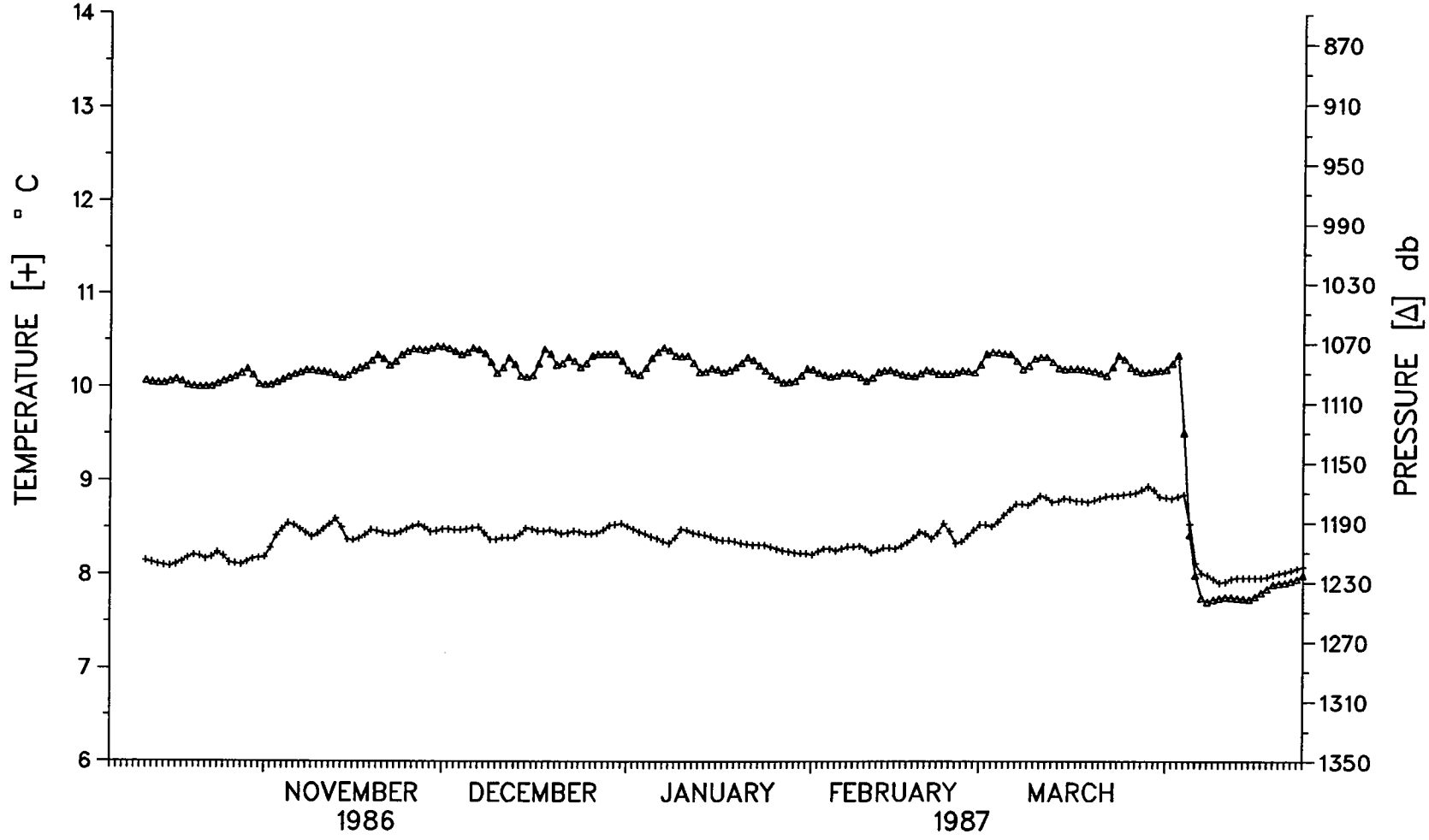
PLOT 3 OF 4
.SPL

EASTERN BASIN 121



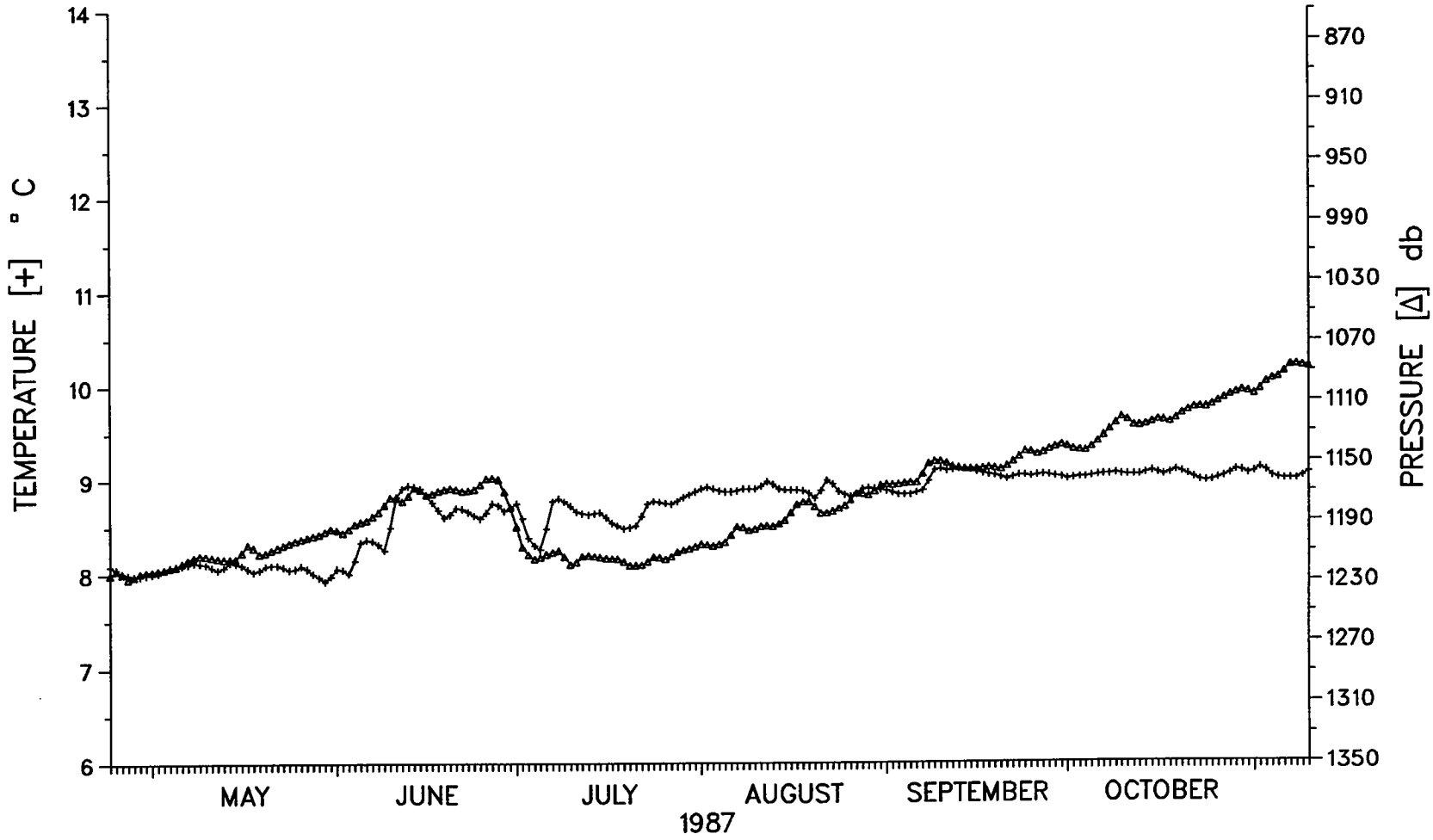
PLOT 4 OF 4
.SPL

EASTERN BASIN 121



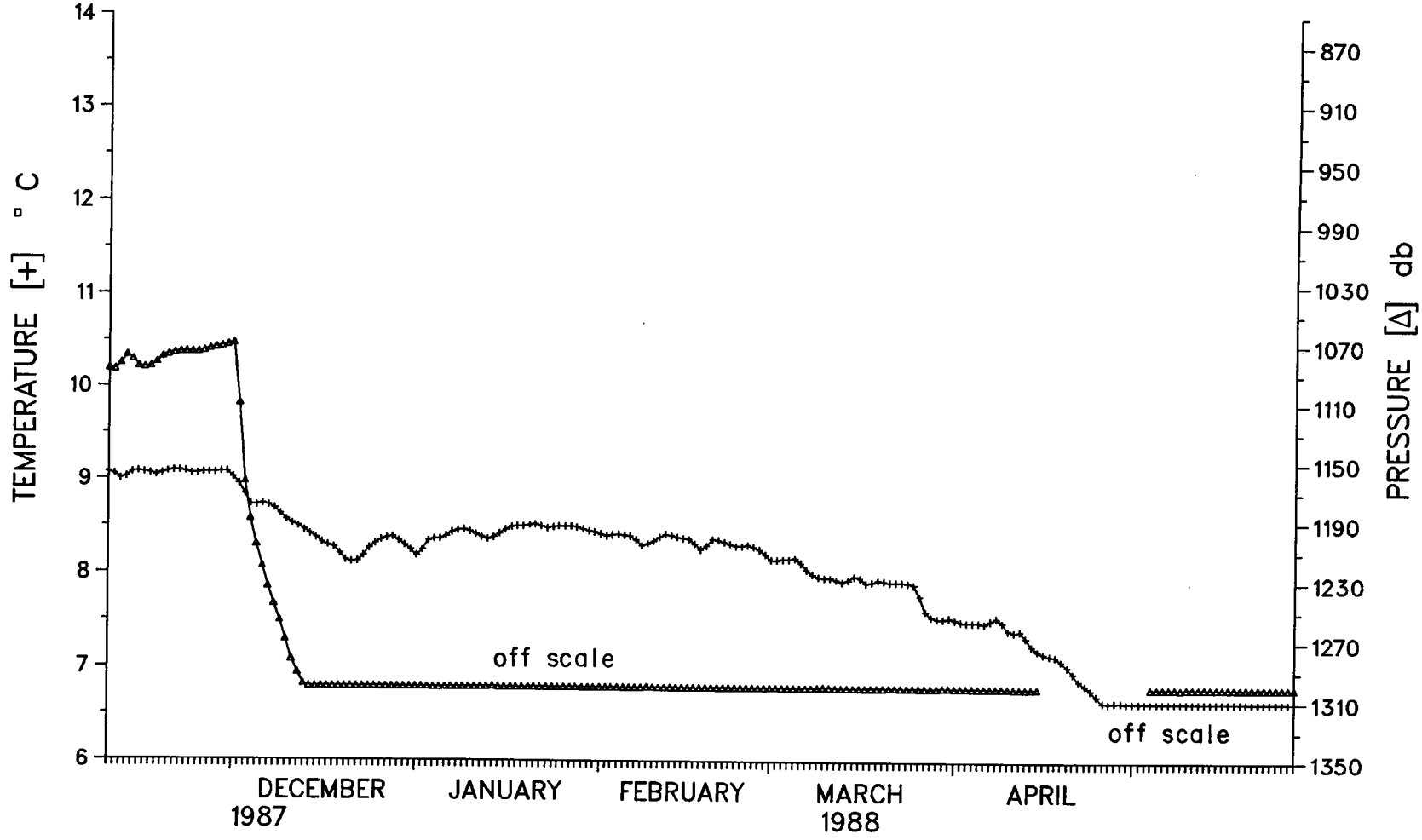
PLOT 1 OF 4
.SPL

EASTERN BASIN 121



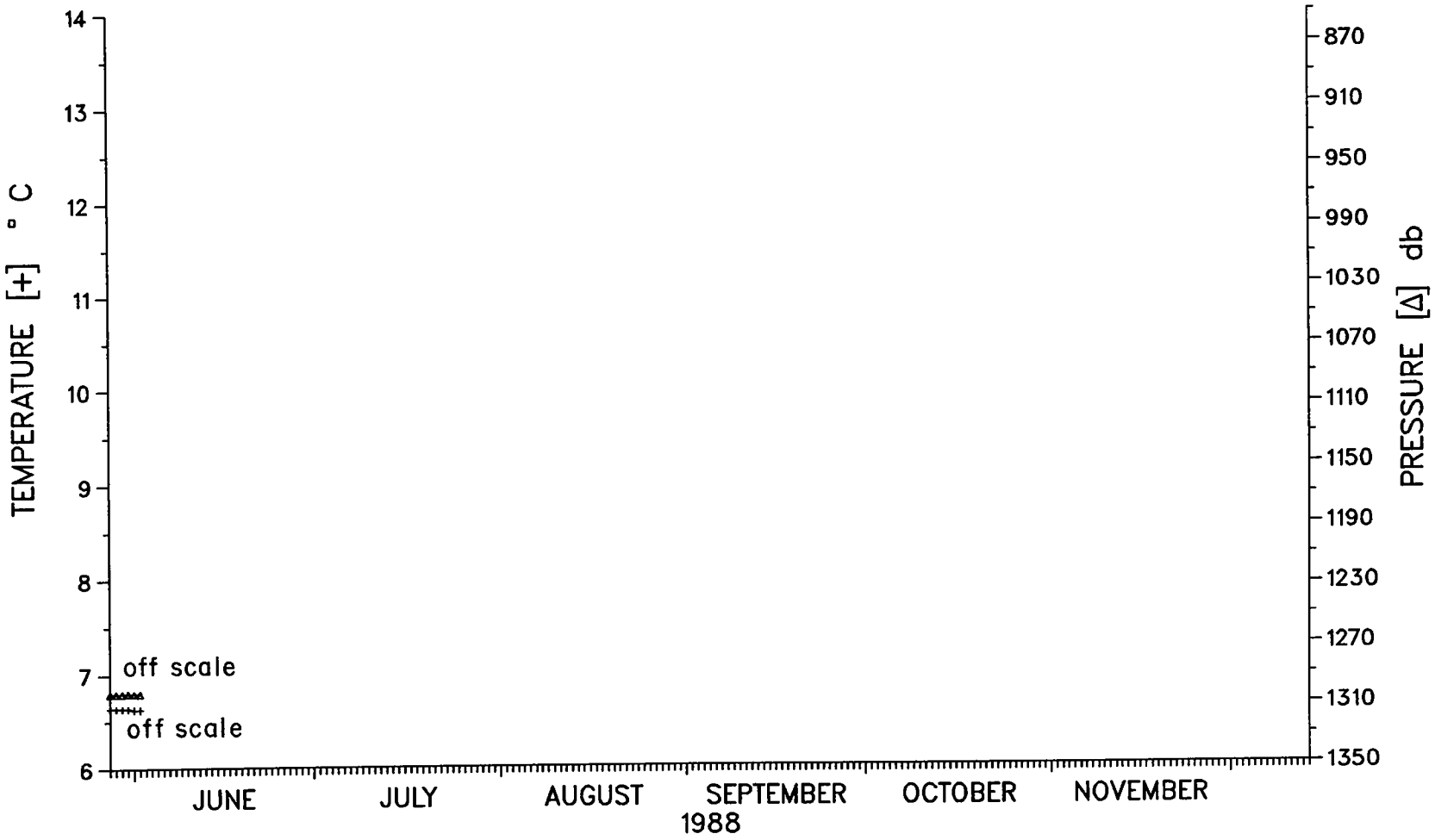
PLOT 2 OF 4
.SPL

EASTERN BASIN 121



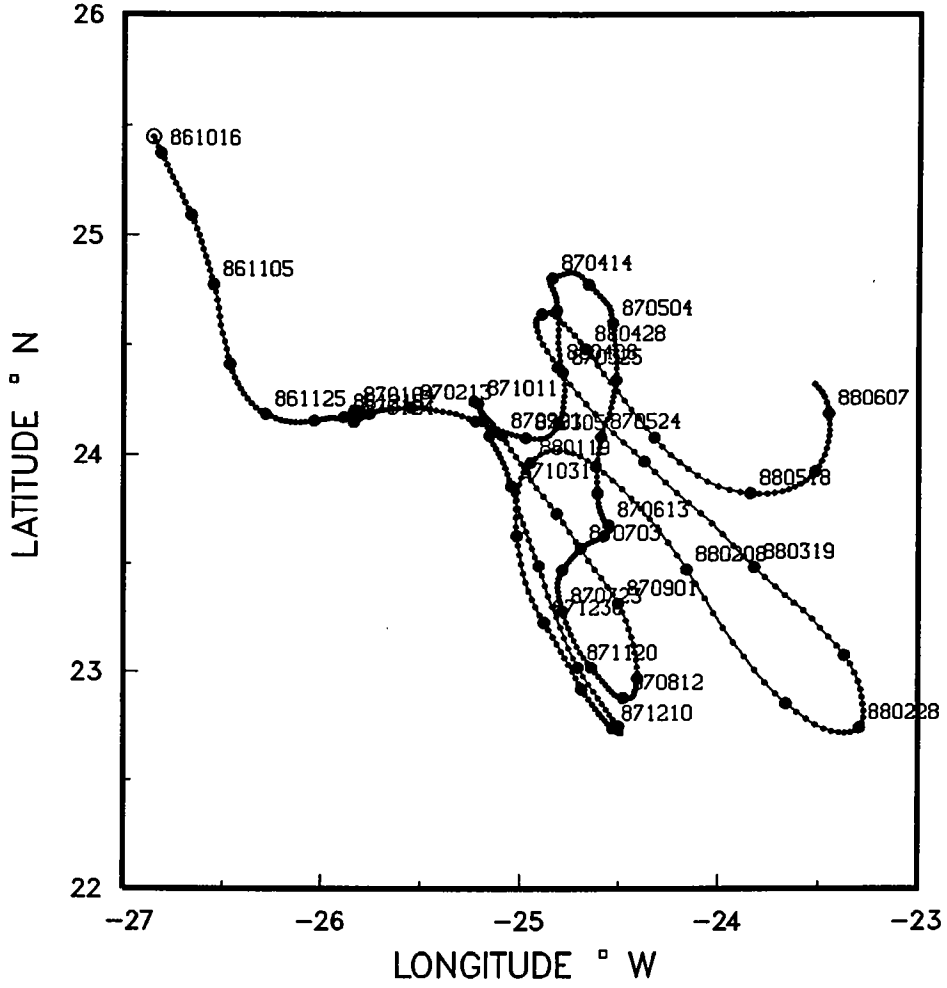
PLOT 3 OF 4
.SPL

EASTERN BASIN 121



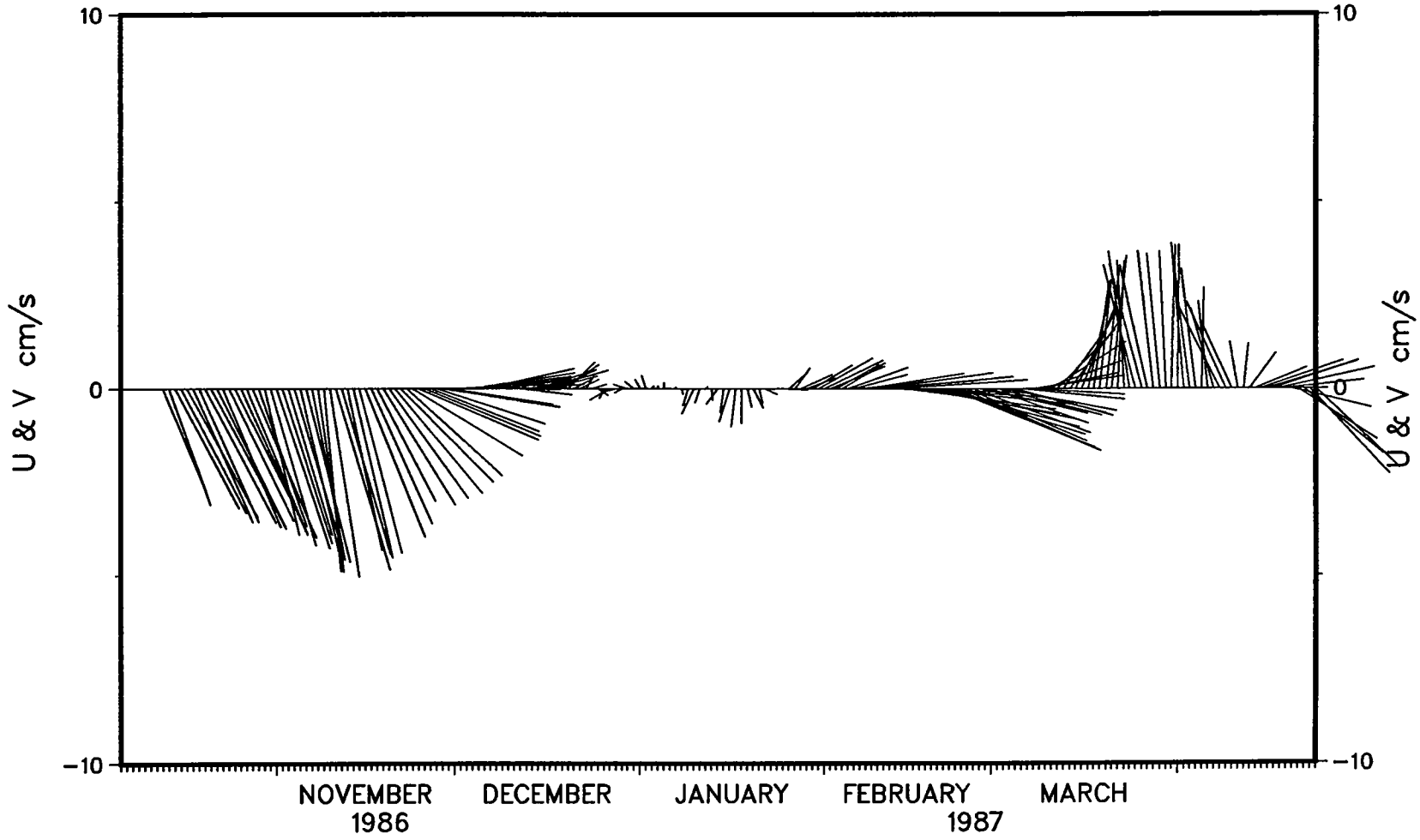
PLOT 4 OF 4
.SPL

EASTERN BASIN 126



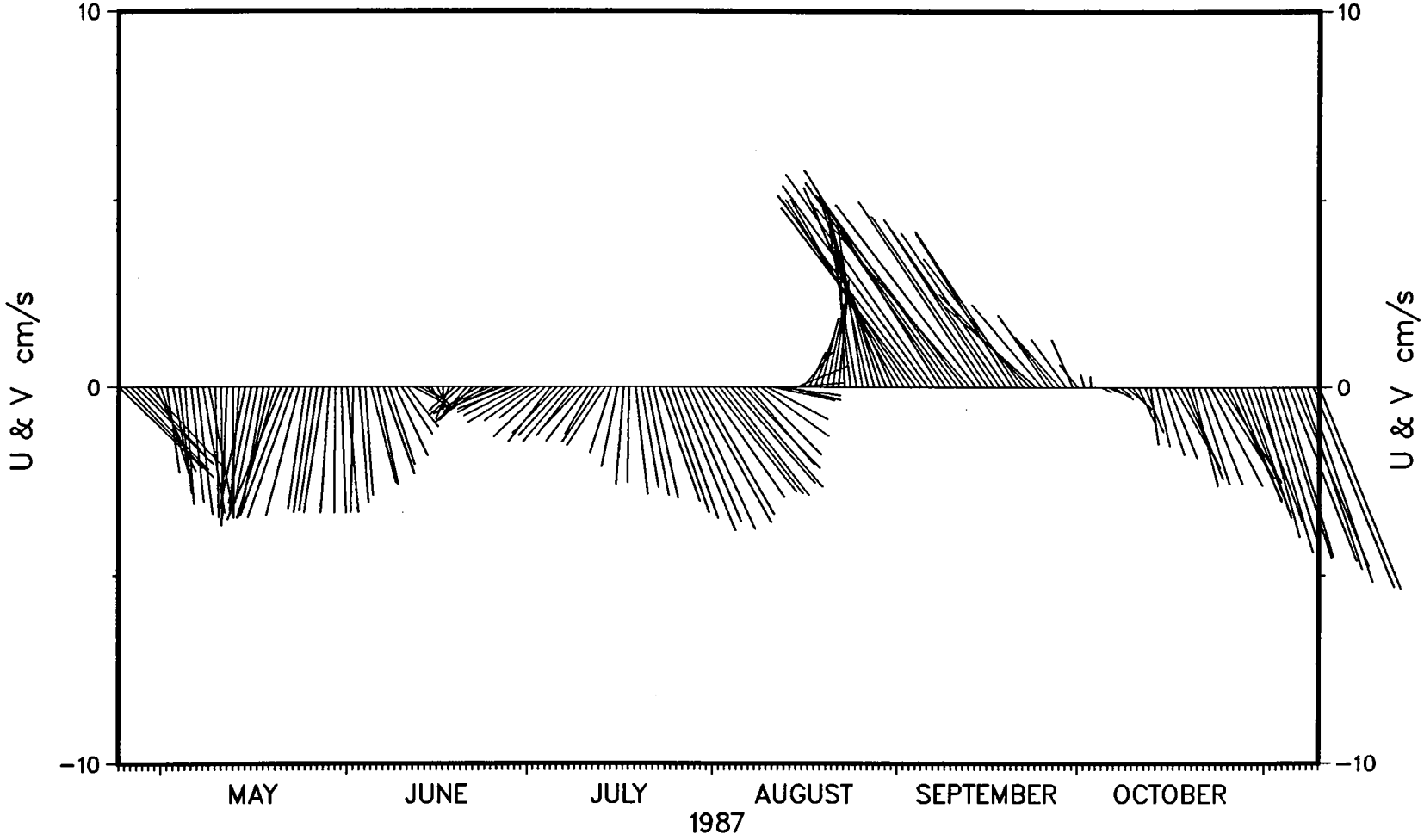
PLOT 1 OF 1
.SPL

EASTERN BASIN 126



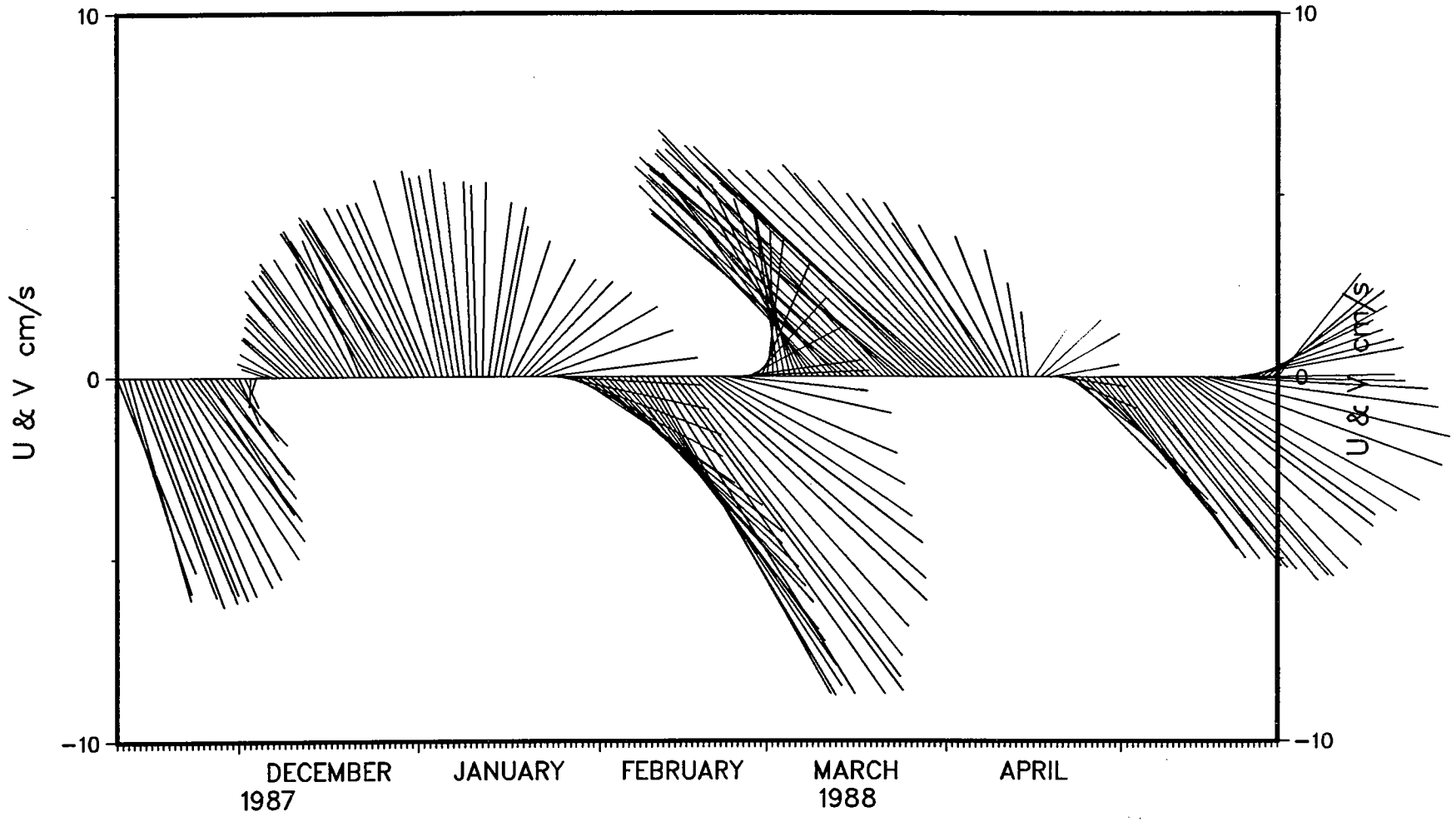
PLOT 1 OF 4
.SPL

EASTERN BASIN 126



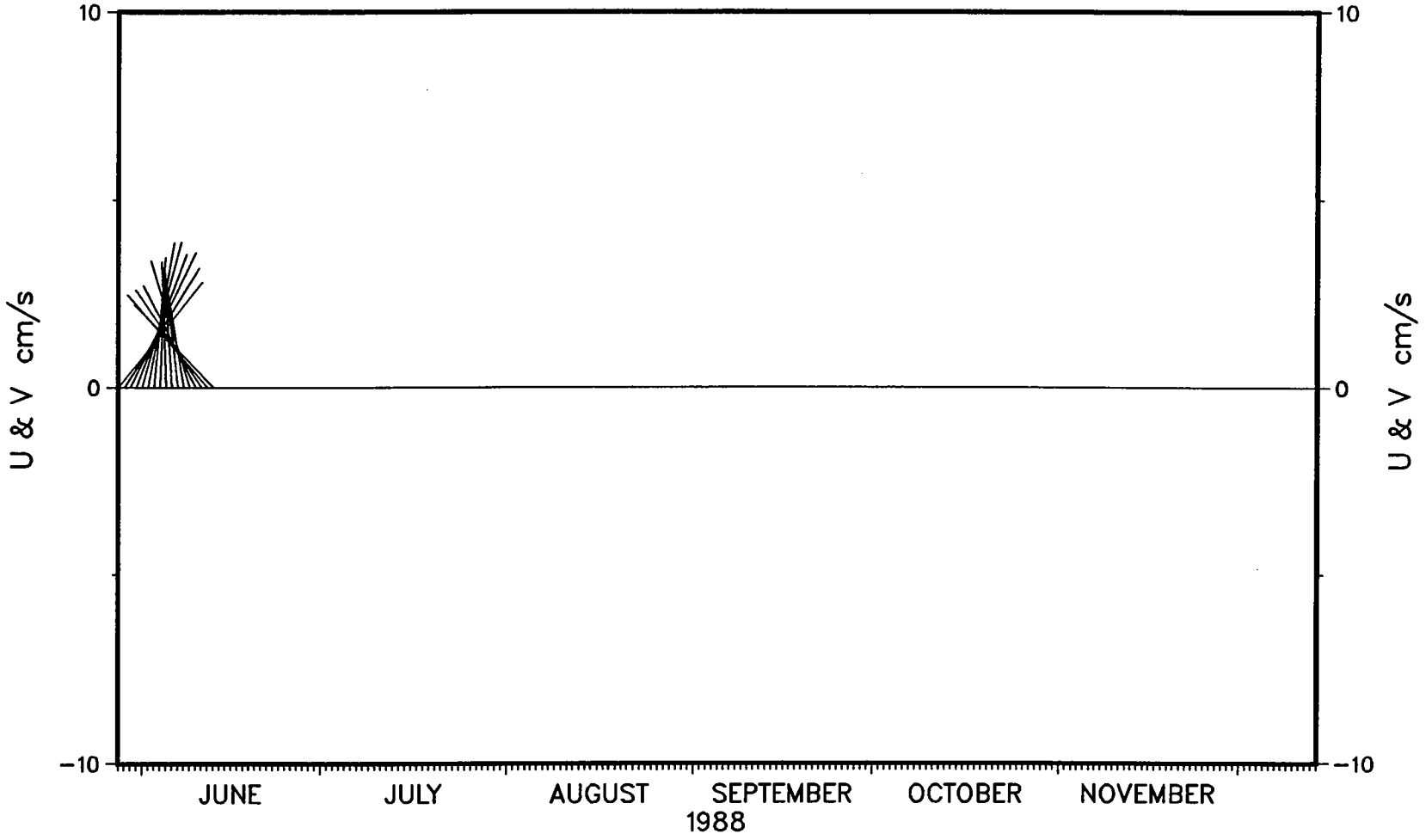
PLOT 2 OF 4
.SPL

EASTERN BASIN 126



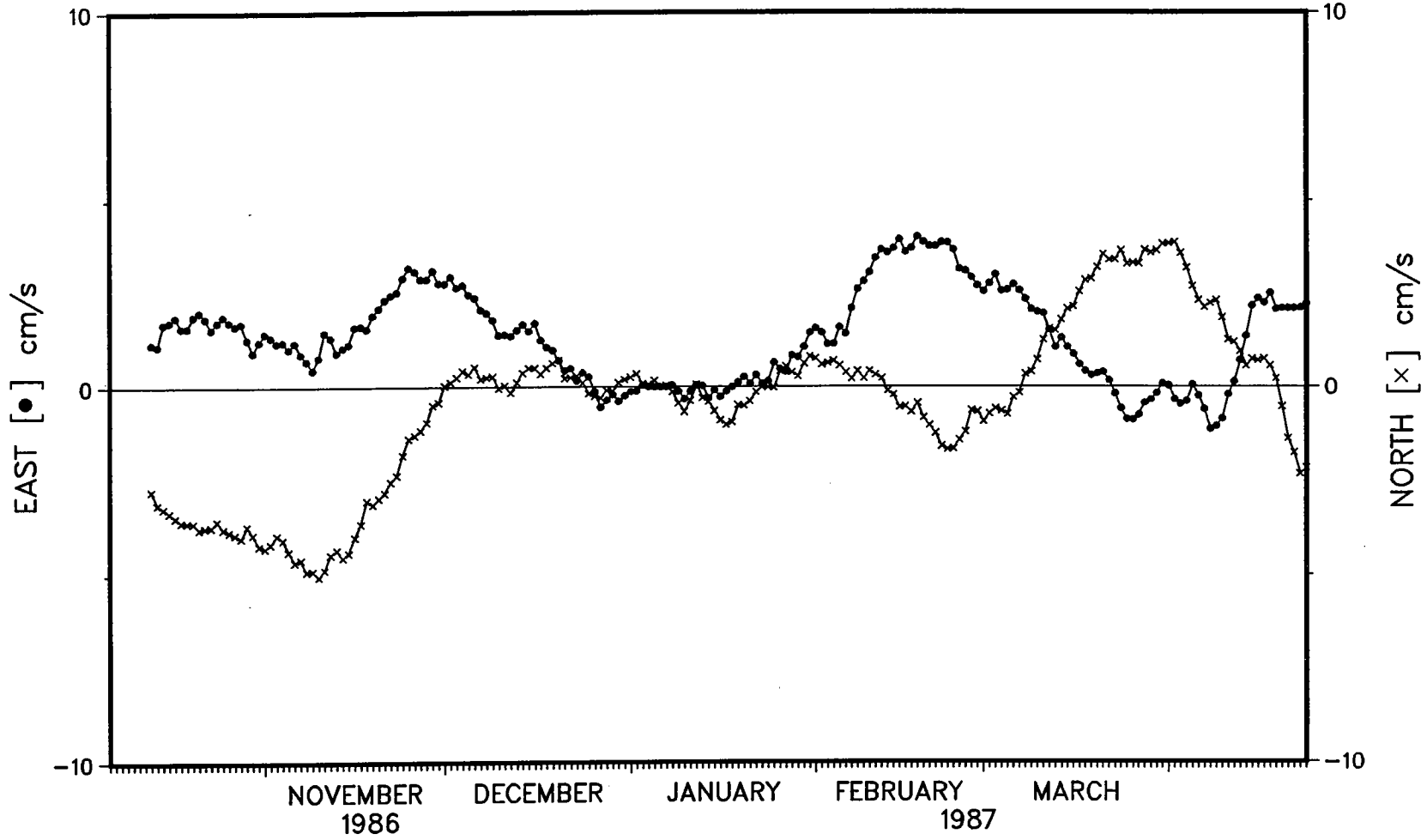
PLOT 3 OF 4
.SPL

EASTERN BASIN 126



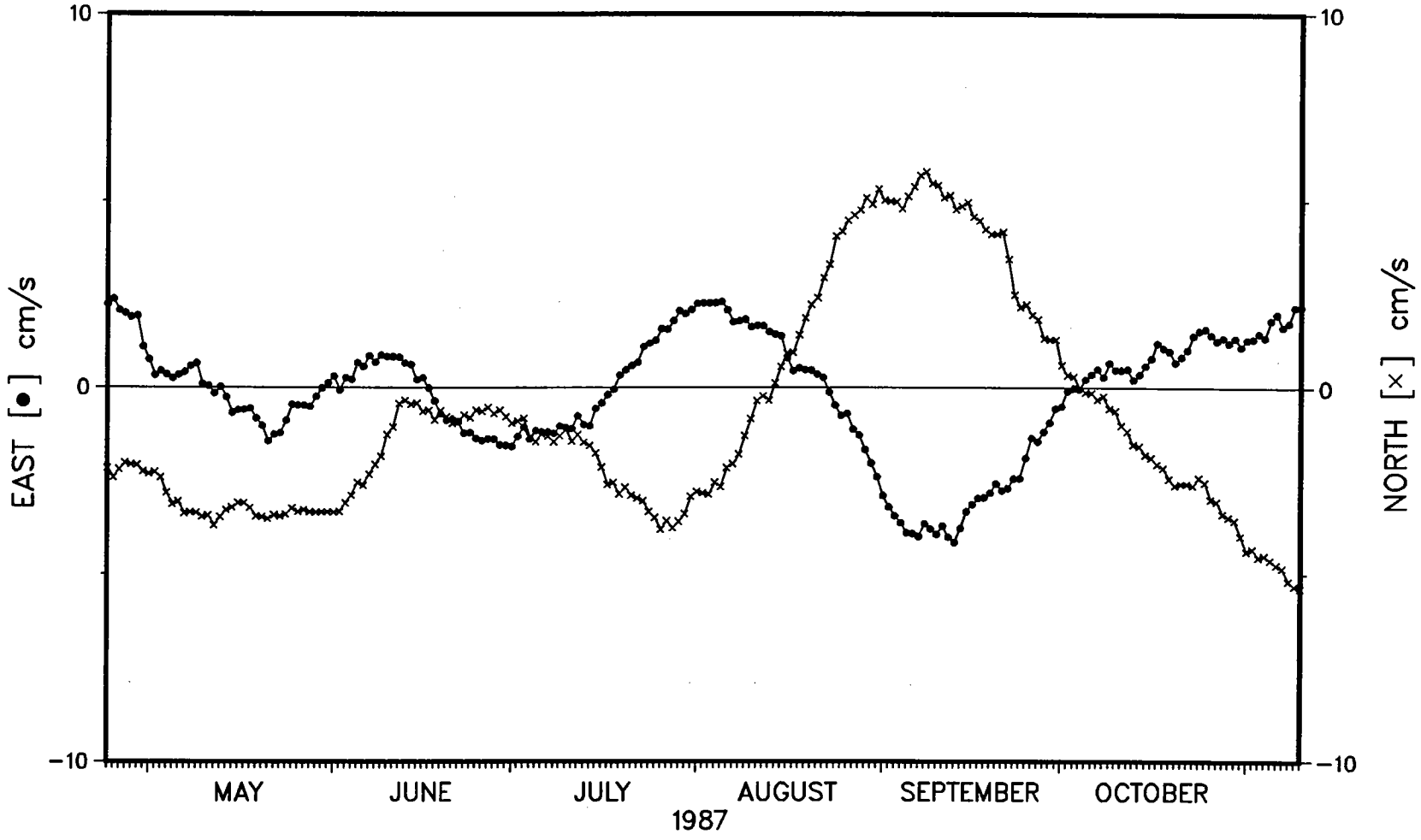
PLOT 4 OF 4
.SPL

EASTERN BASIN 126



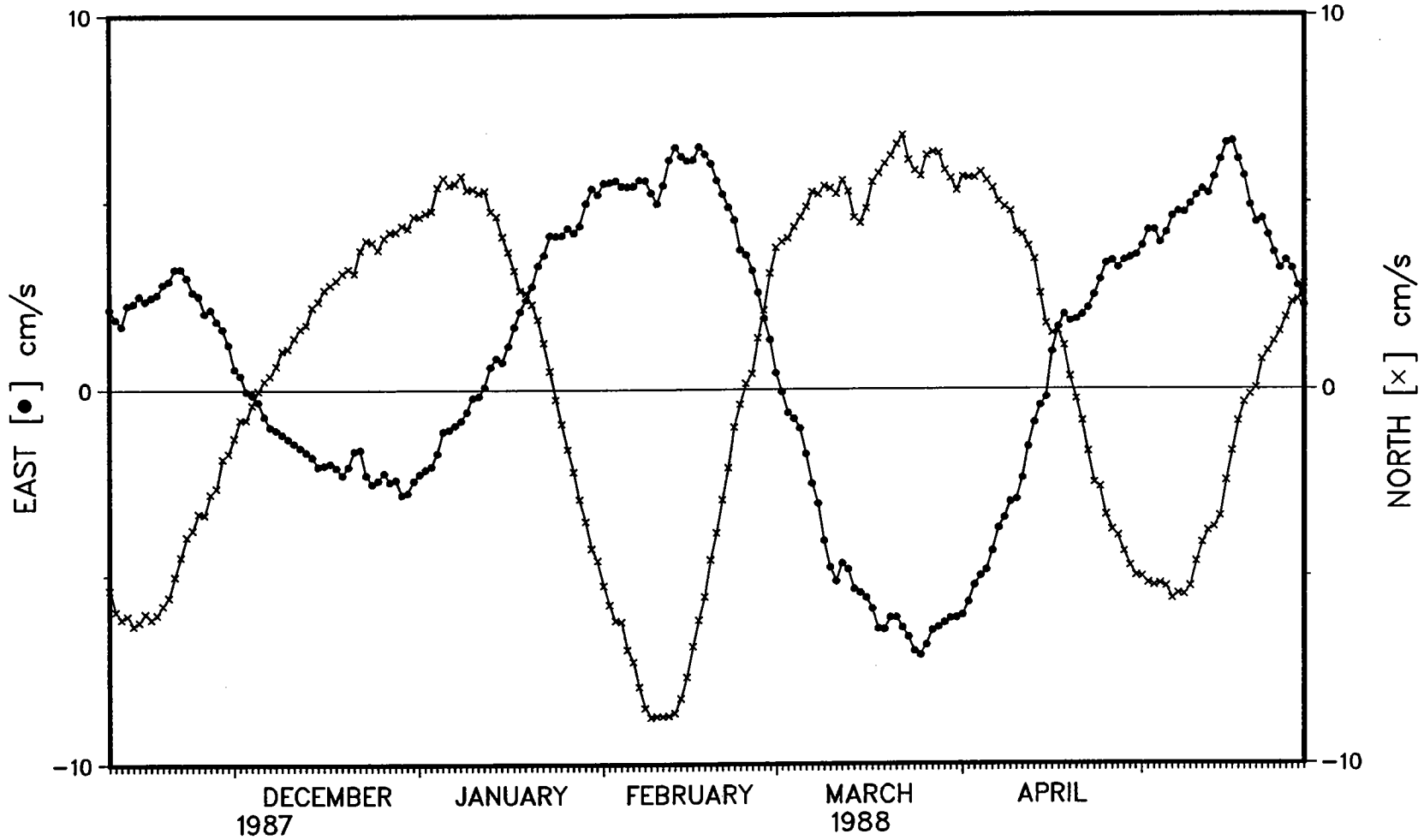
PLOT 1 OF 4
.SPL

EASTERN BASIN 126



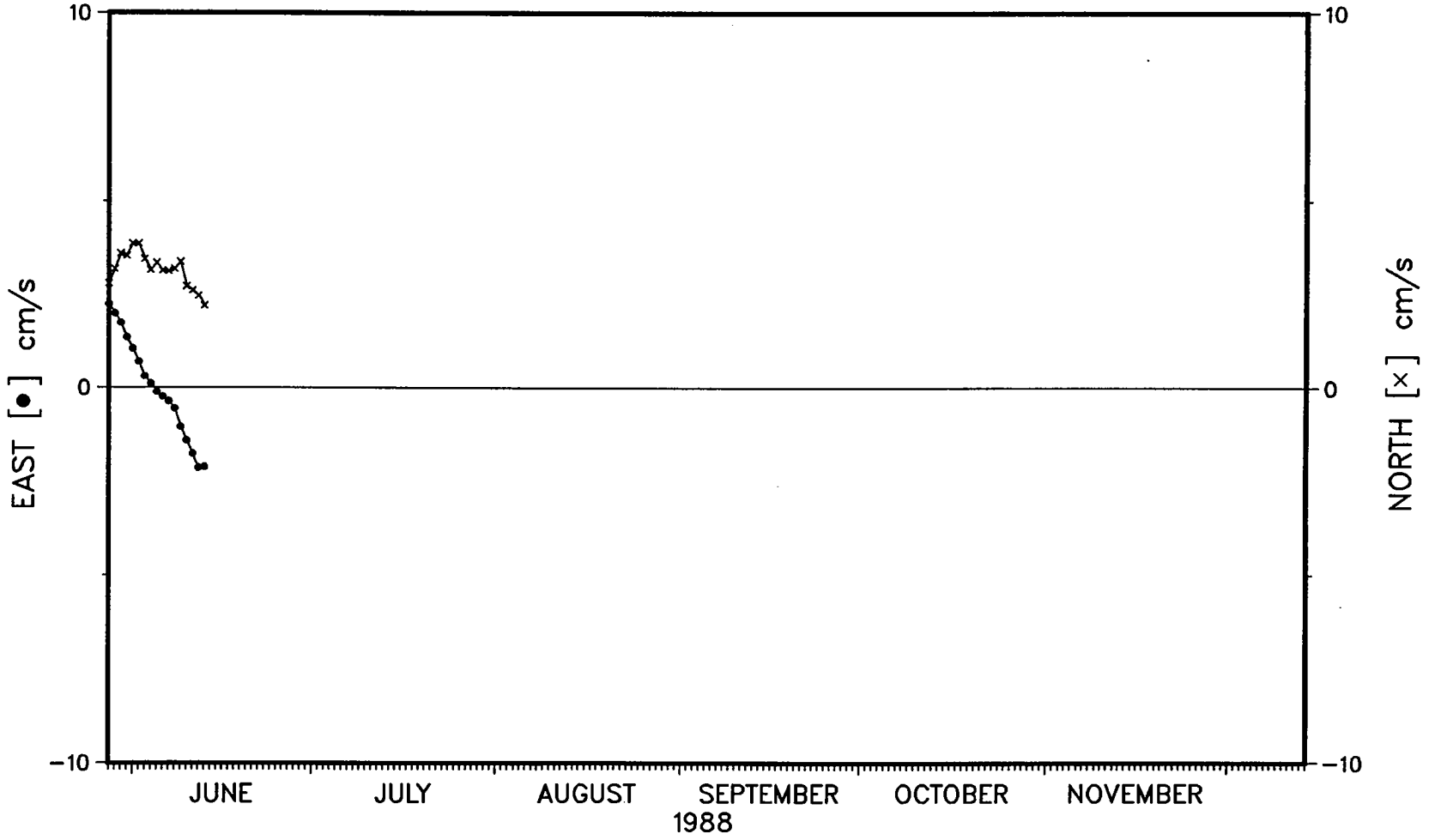
PLOT 2 OF 4
.SPL

EASTERN BASIN 126



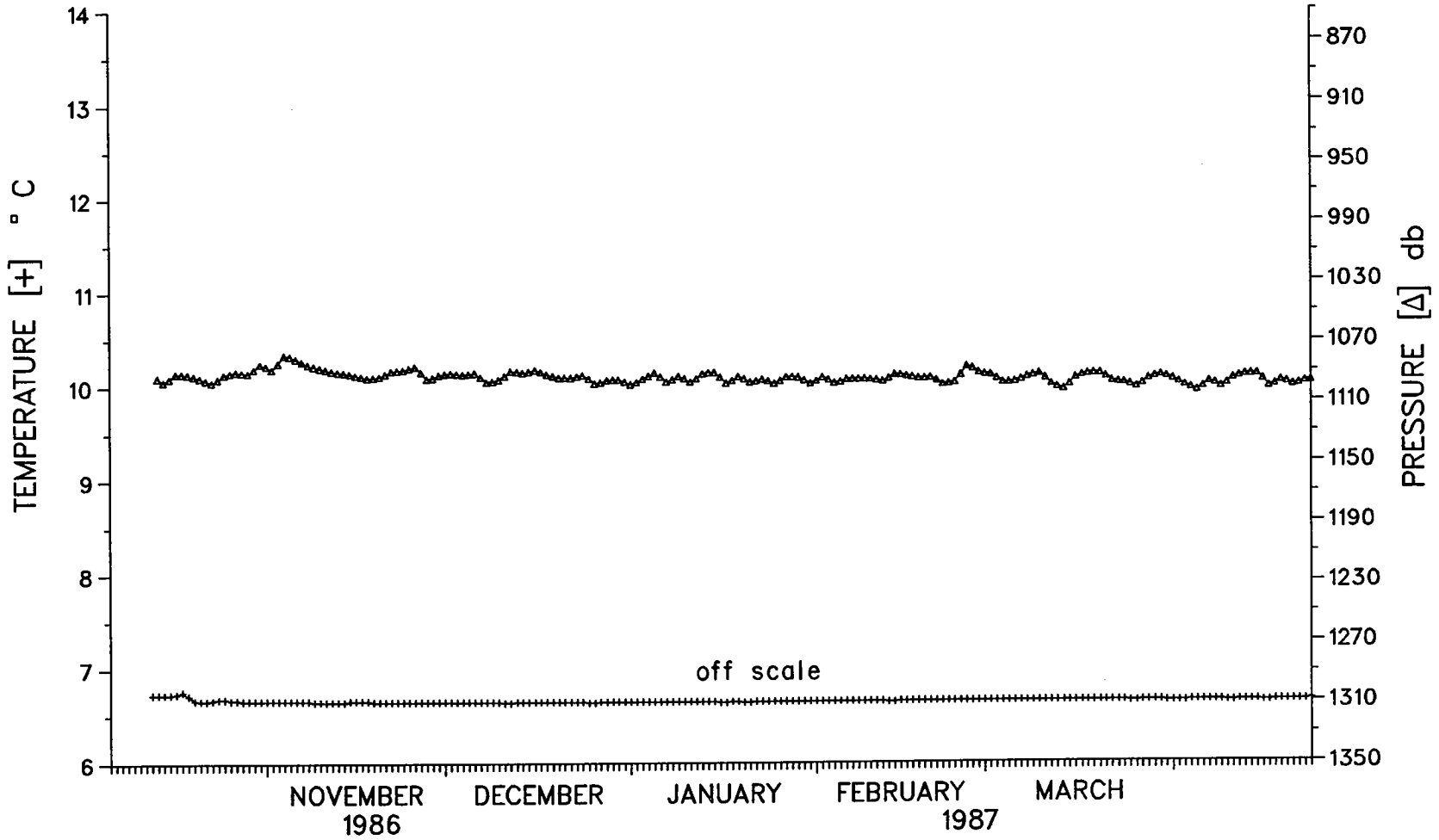
PLOT 3 OF 4
.SPL

EASTERN BASIN 126



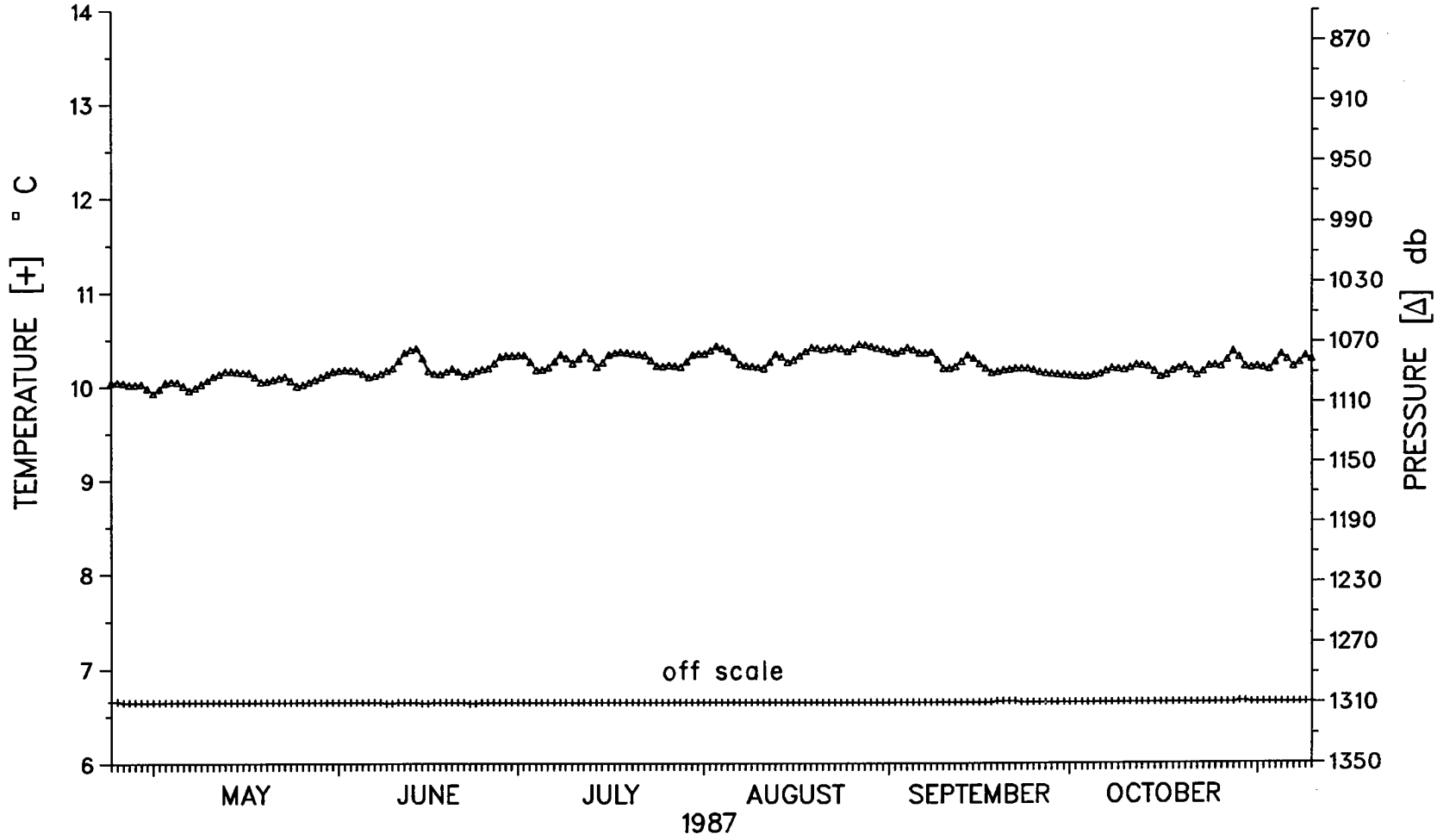
PLOT 4 OF 4
.SPL

EASTERN BASIN 126



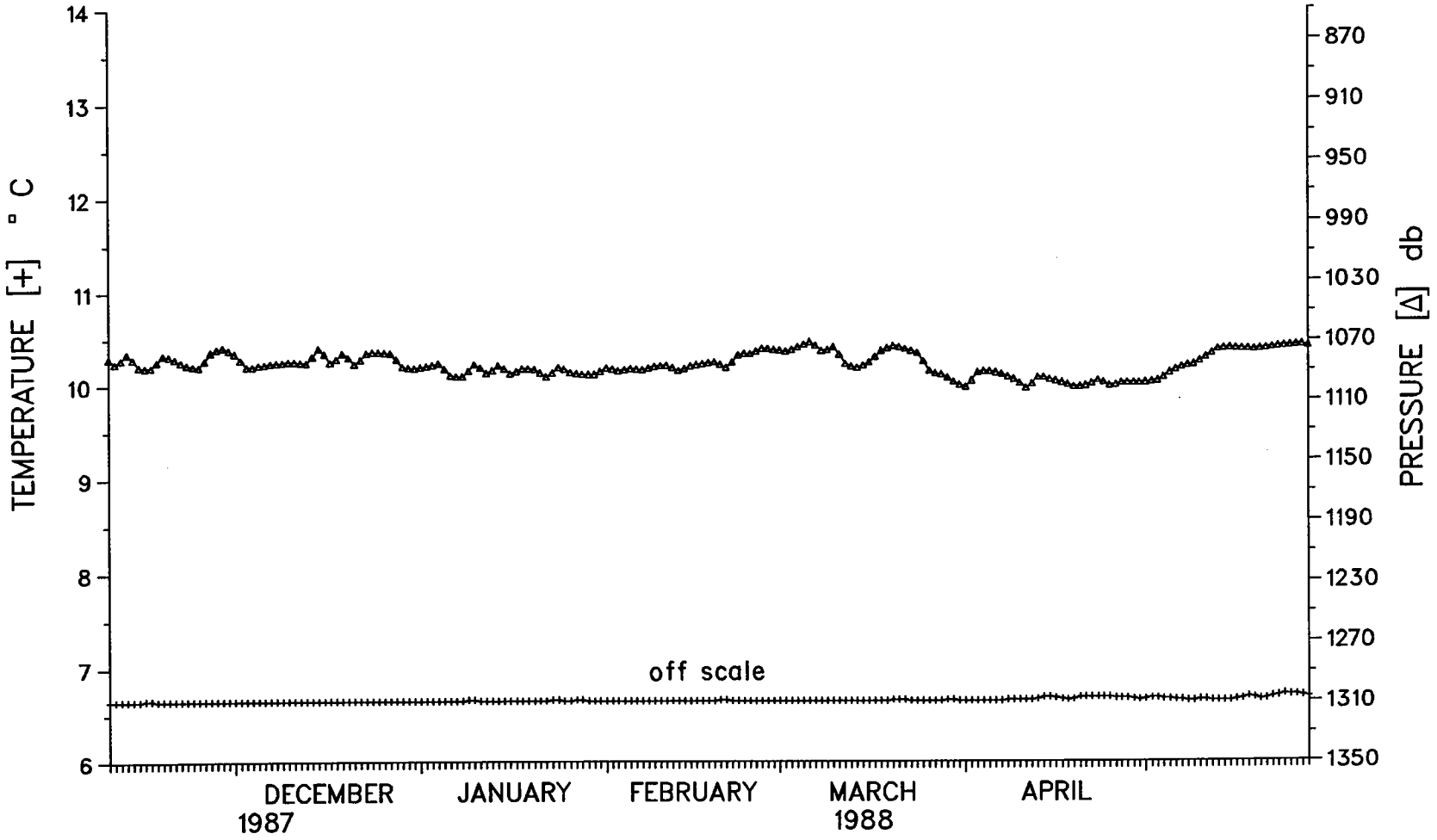
PLOT 1 OF 4
.SPL

EASTERN BASIN 126



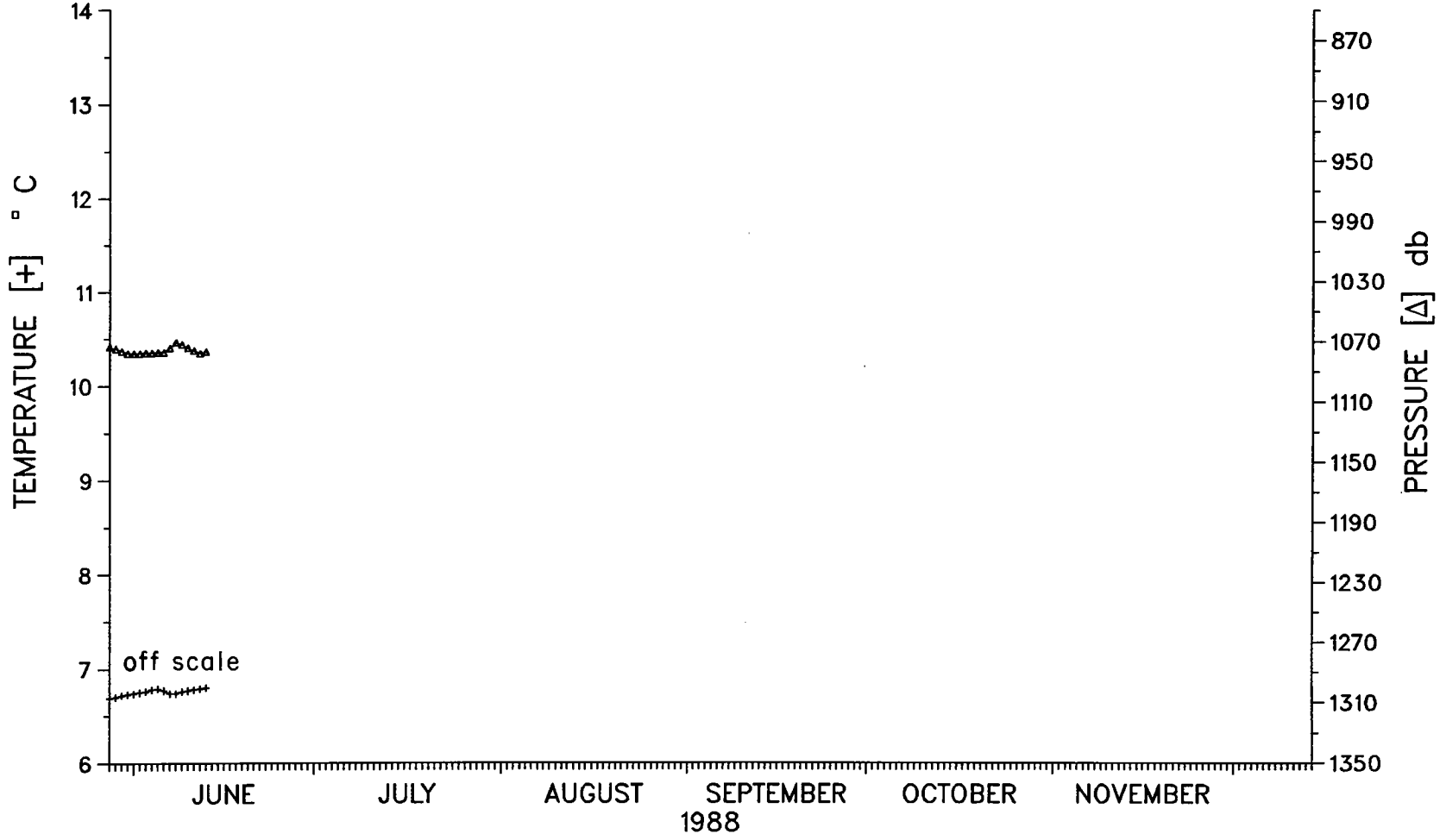
PLOT 2 OF 4
.SPL

EASTERN BASIN 126



PLOT 3 OF 4
.SPL

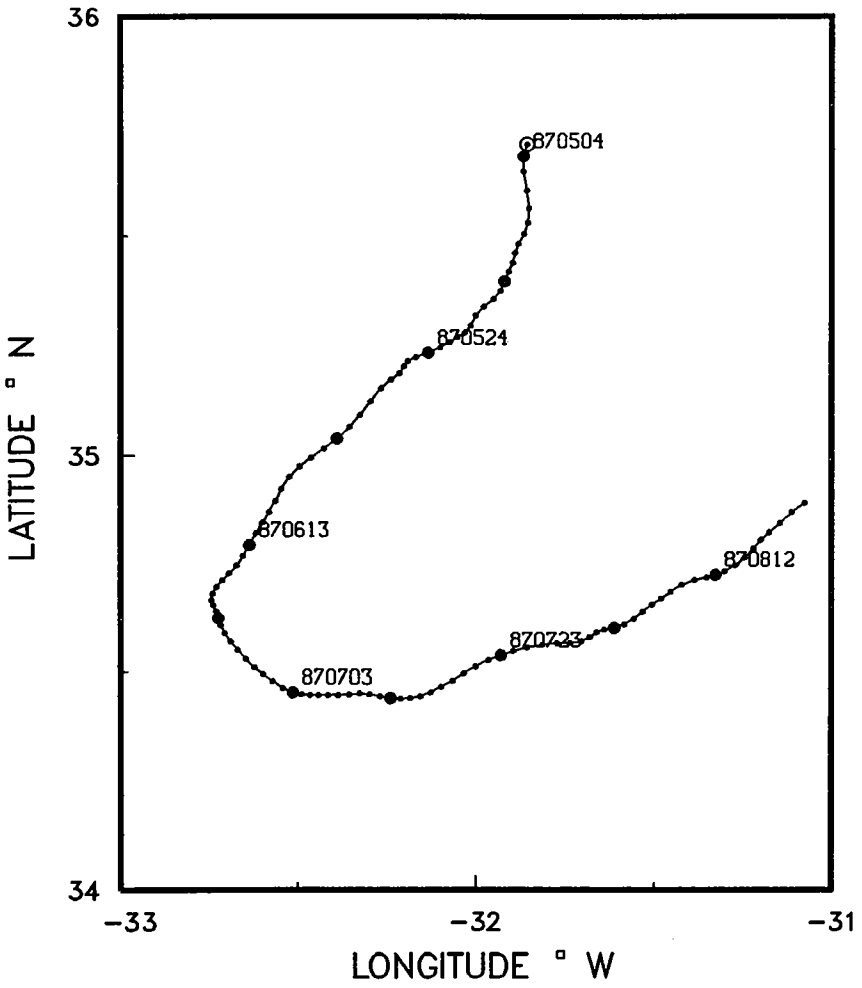
EASTERN BASIN 126



115

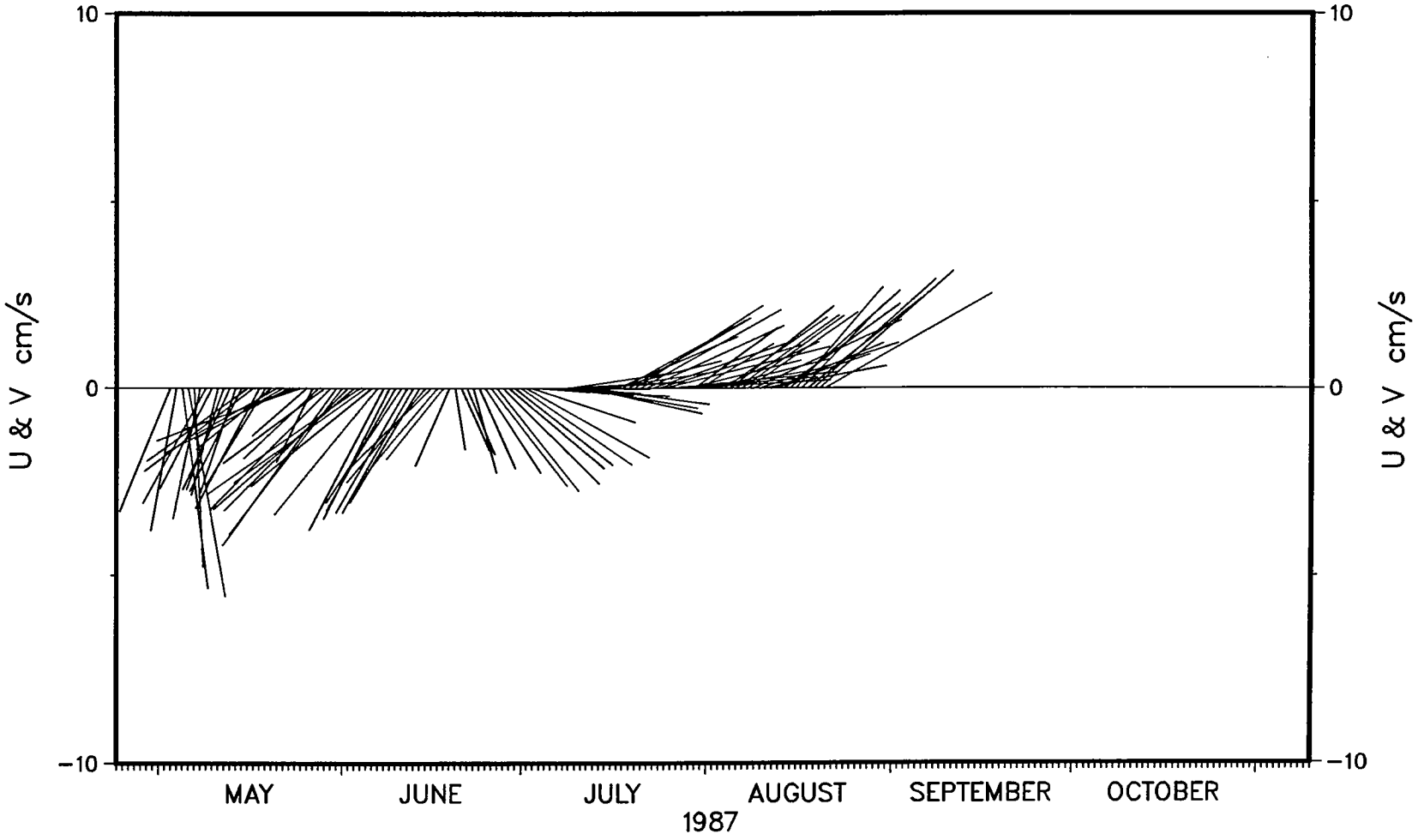
PLOT 4 OF 4
.SPL

EASTERN BASIN 127C



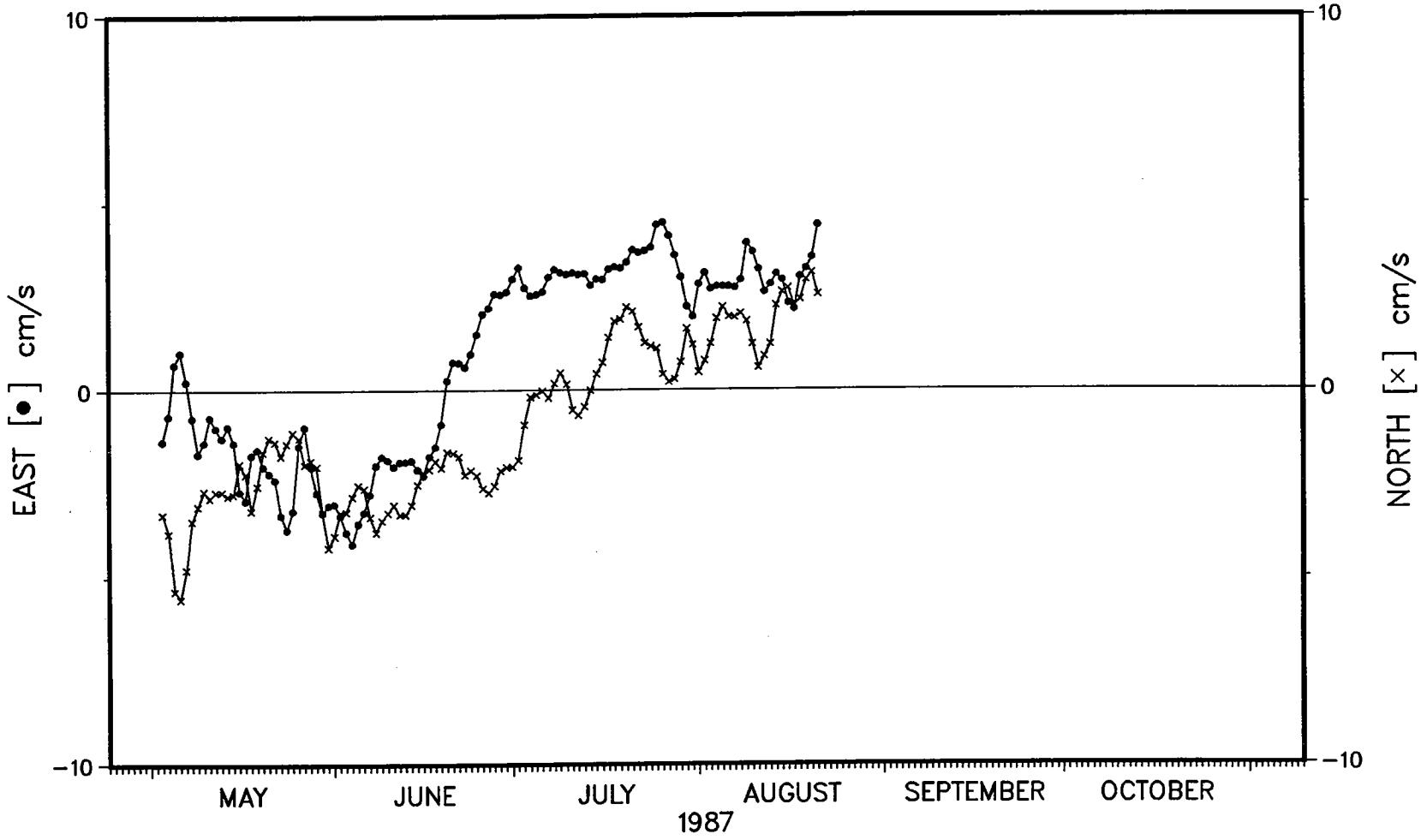
PLOT 1 OF 1
.SPL

EASTERN BASIN 127C



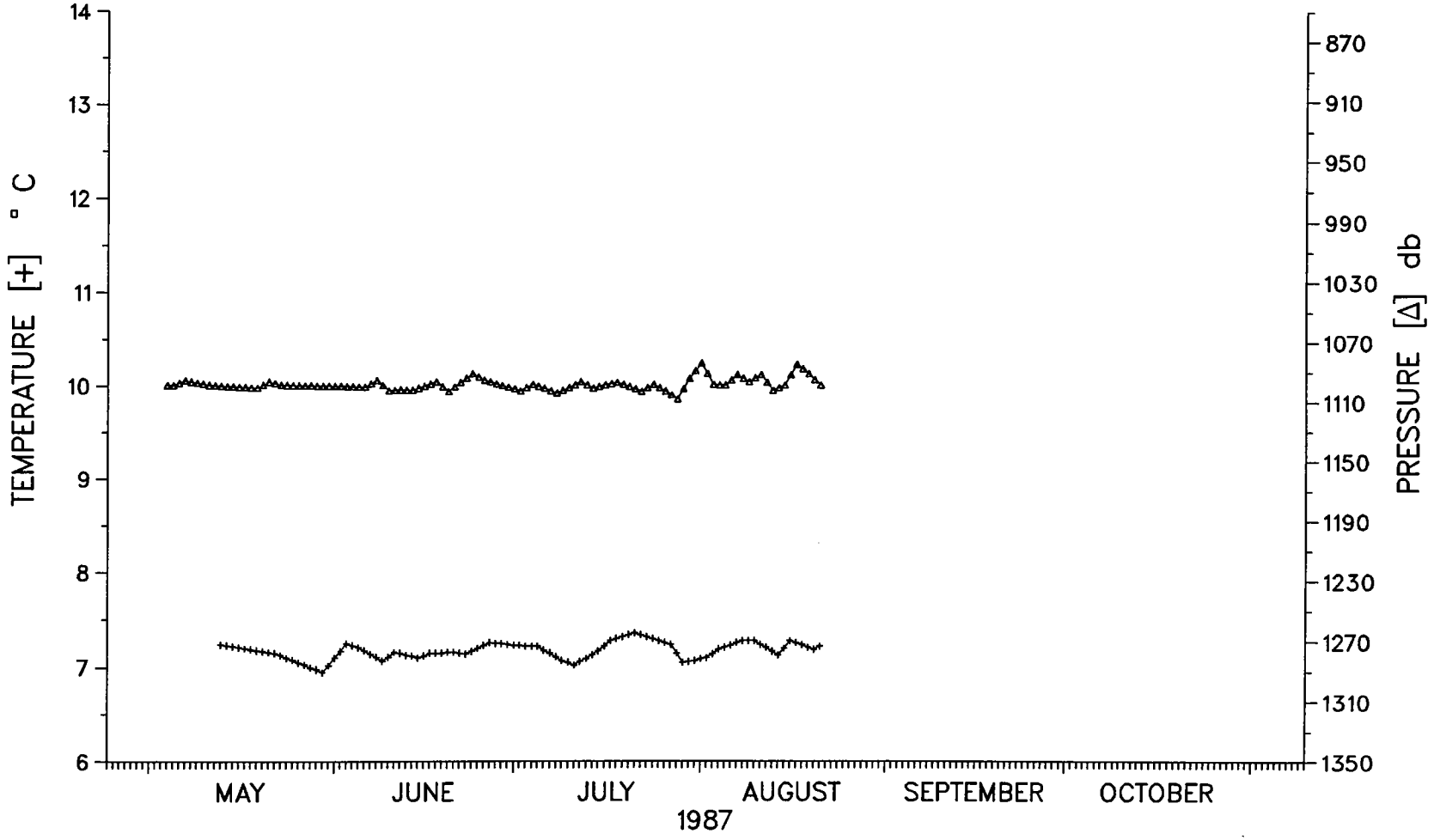
PLOT 1 OF 1
.SPL

EASTERN BASIN 127C



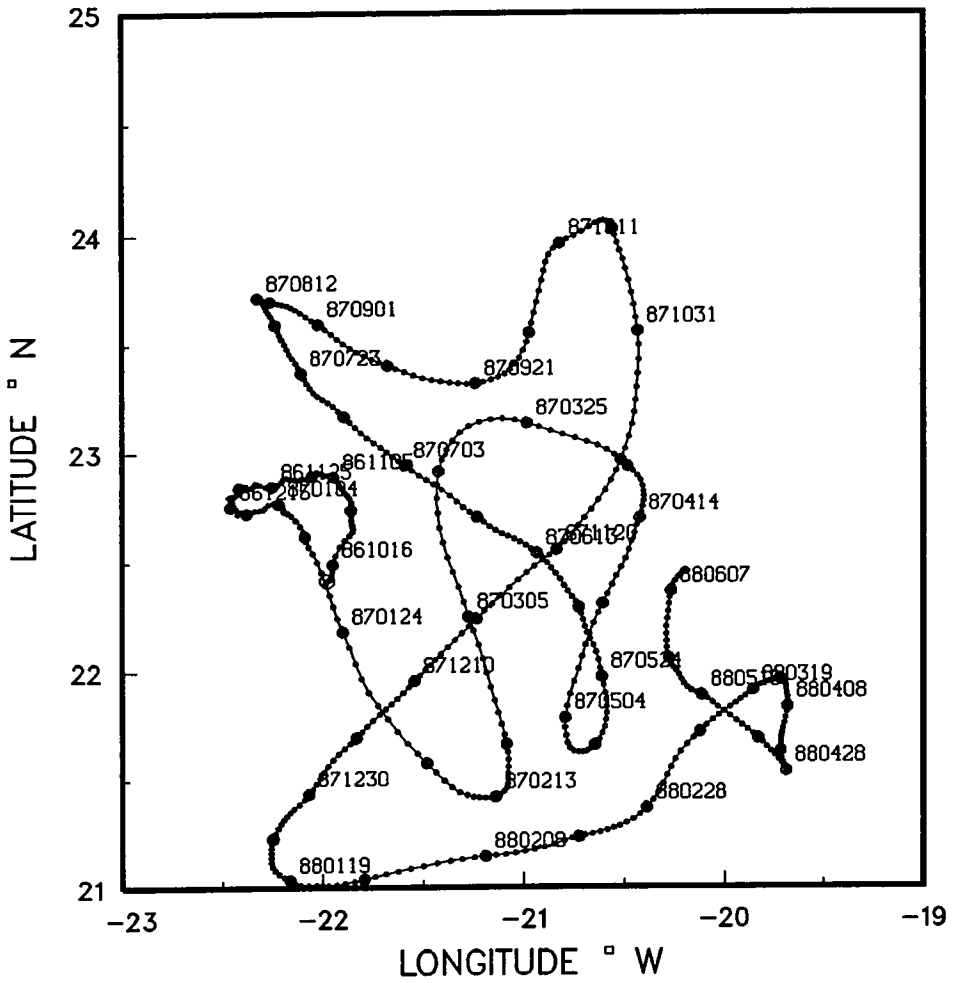
PLOT 1 OF 1
.SPL

EASTERN BASIN 127C



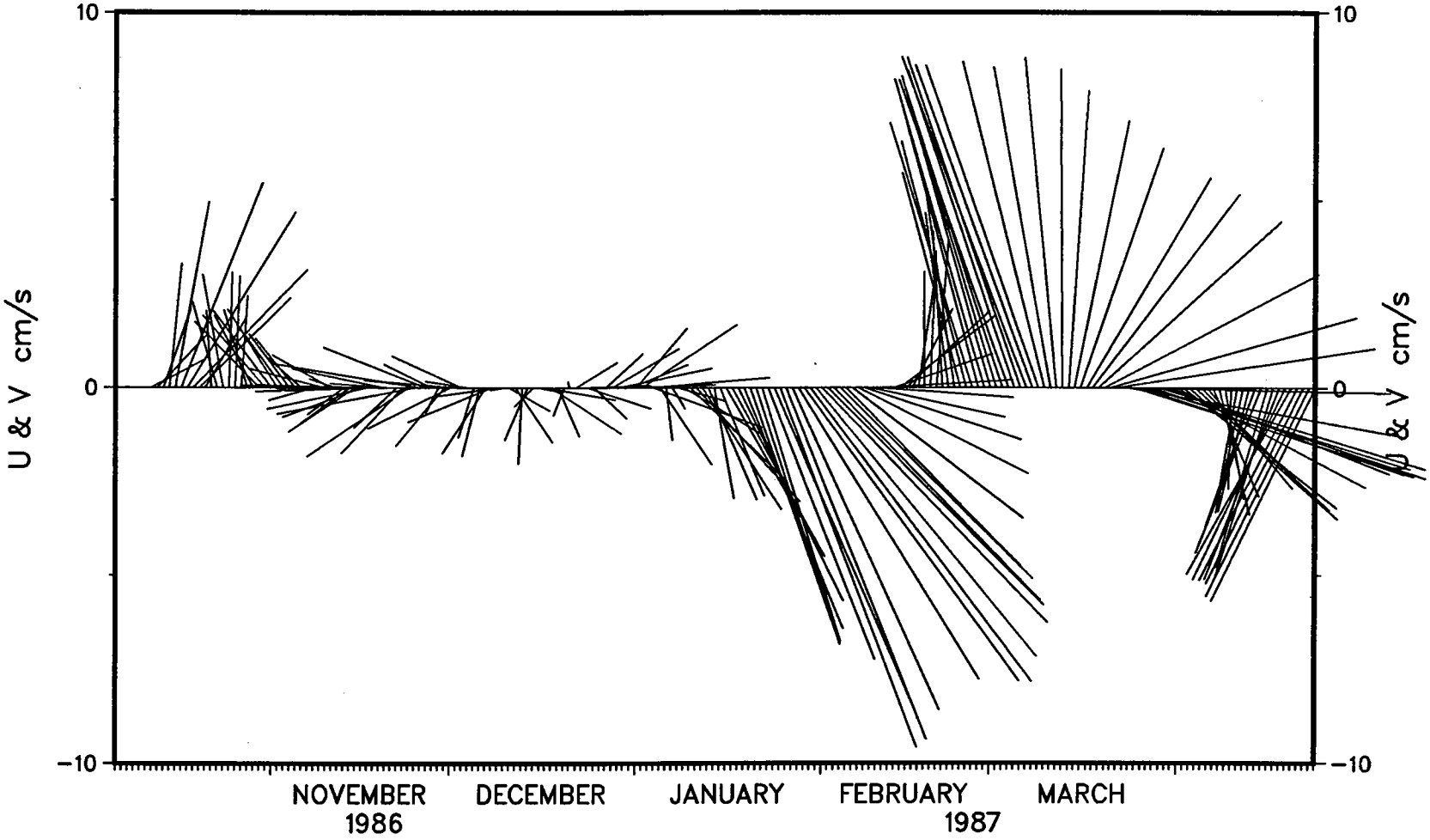
PLOT 1 OF 1
.SPL

EASTERN BASIN 128



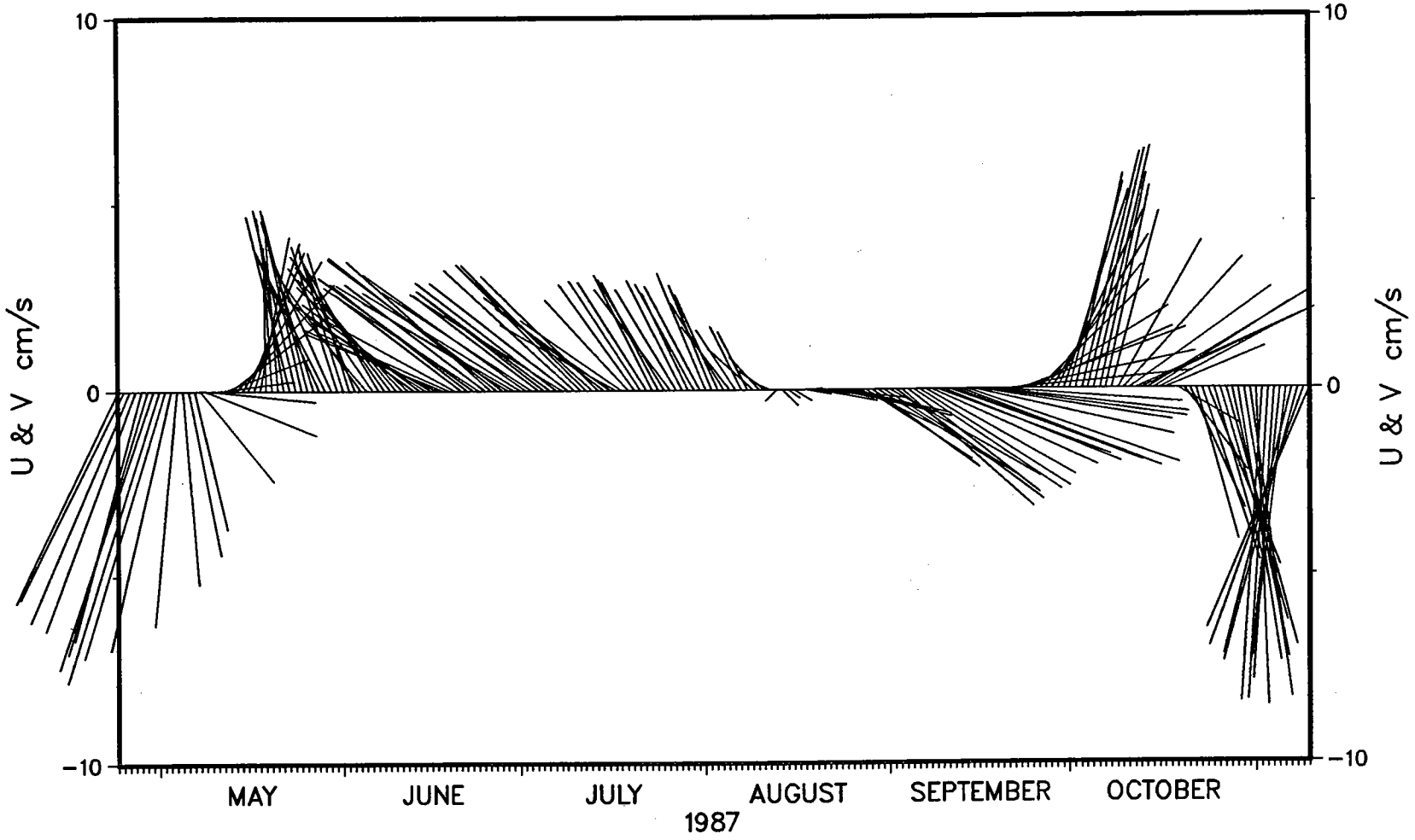
PLOT 1 OF 1
.SPL

EASTERN BASIN 128



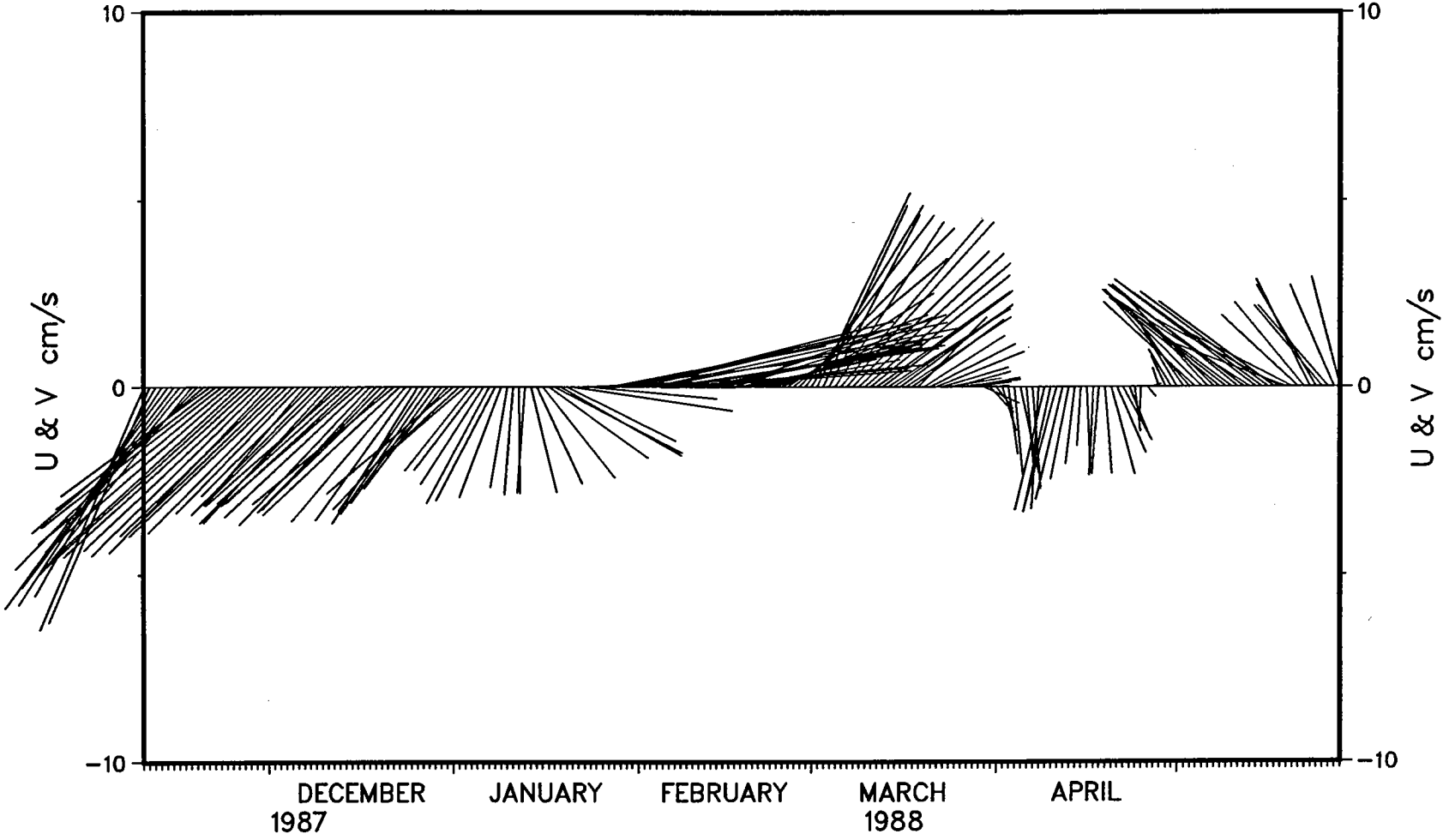
PLOT 1 OF 4
.SPL

EASTERN BASIN 128



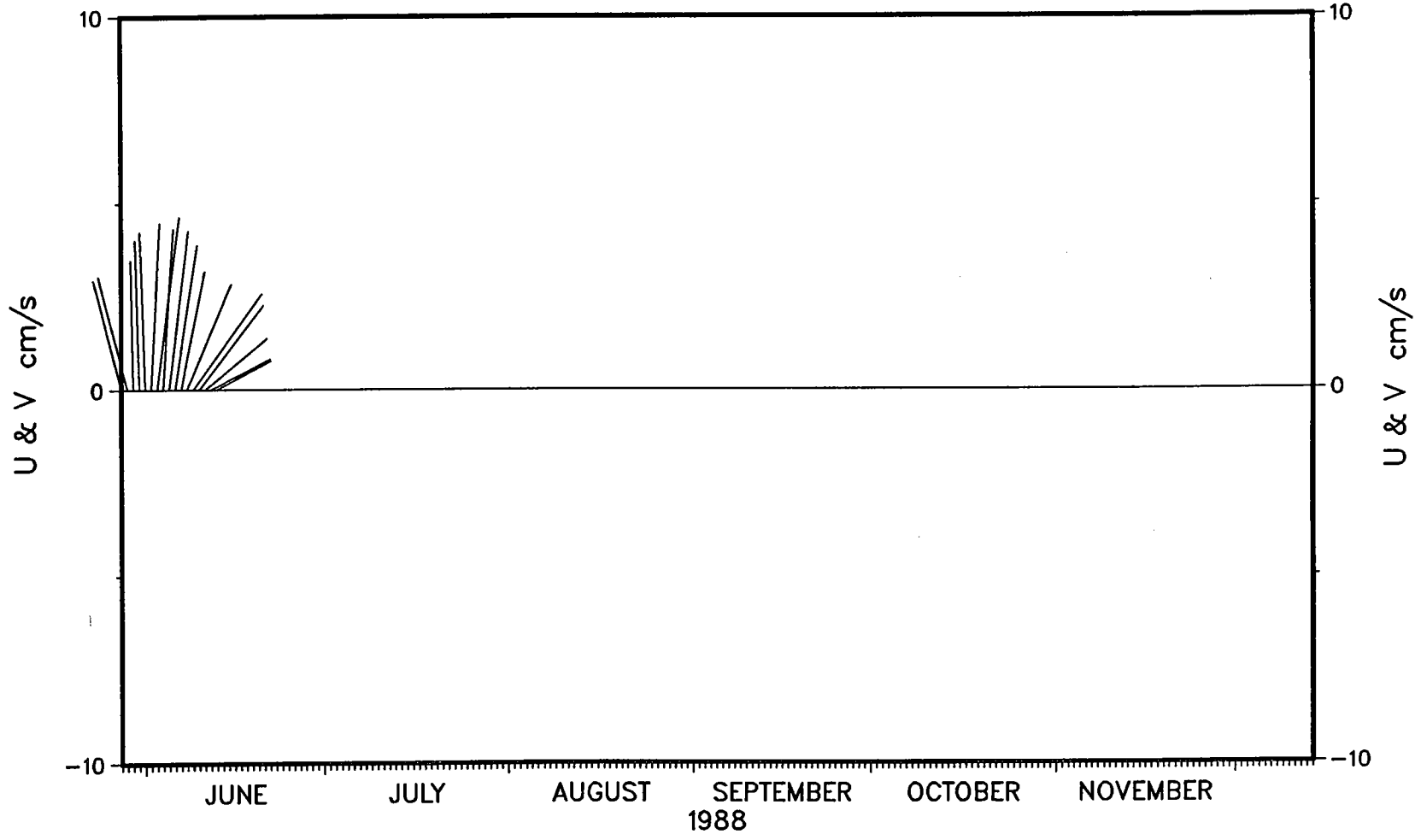
PLOT 2 OF 4
.SPL

EASTERN BASIN 128



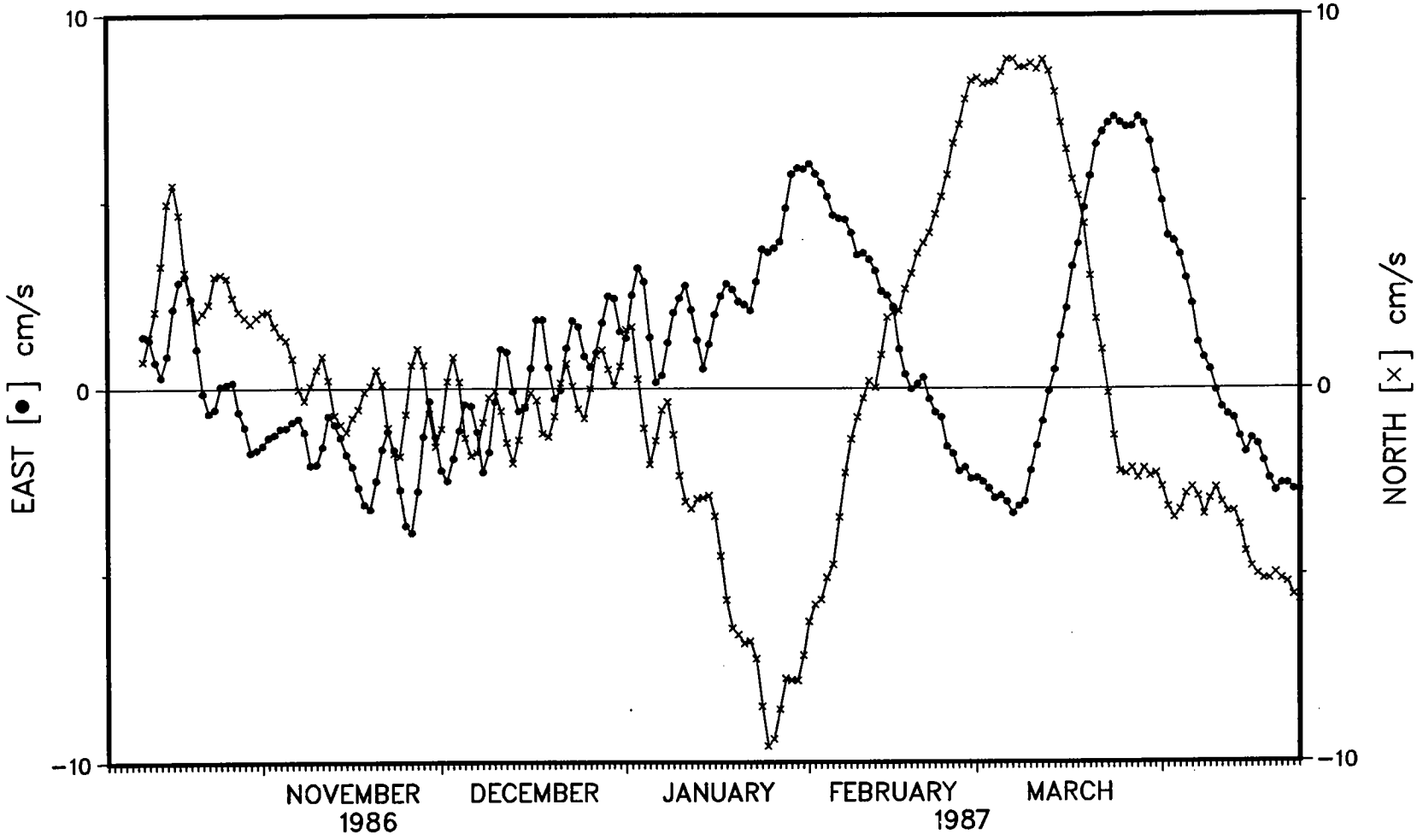
PLOT 3 OF 4
.SPL

EASTERN BASIN 128



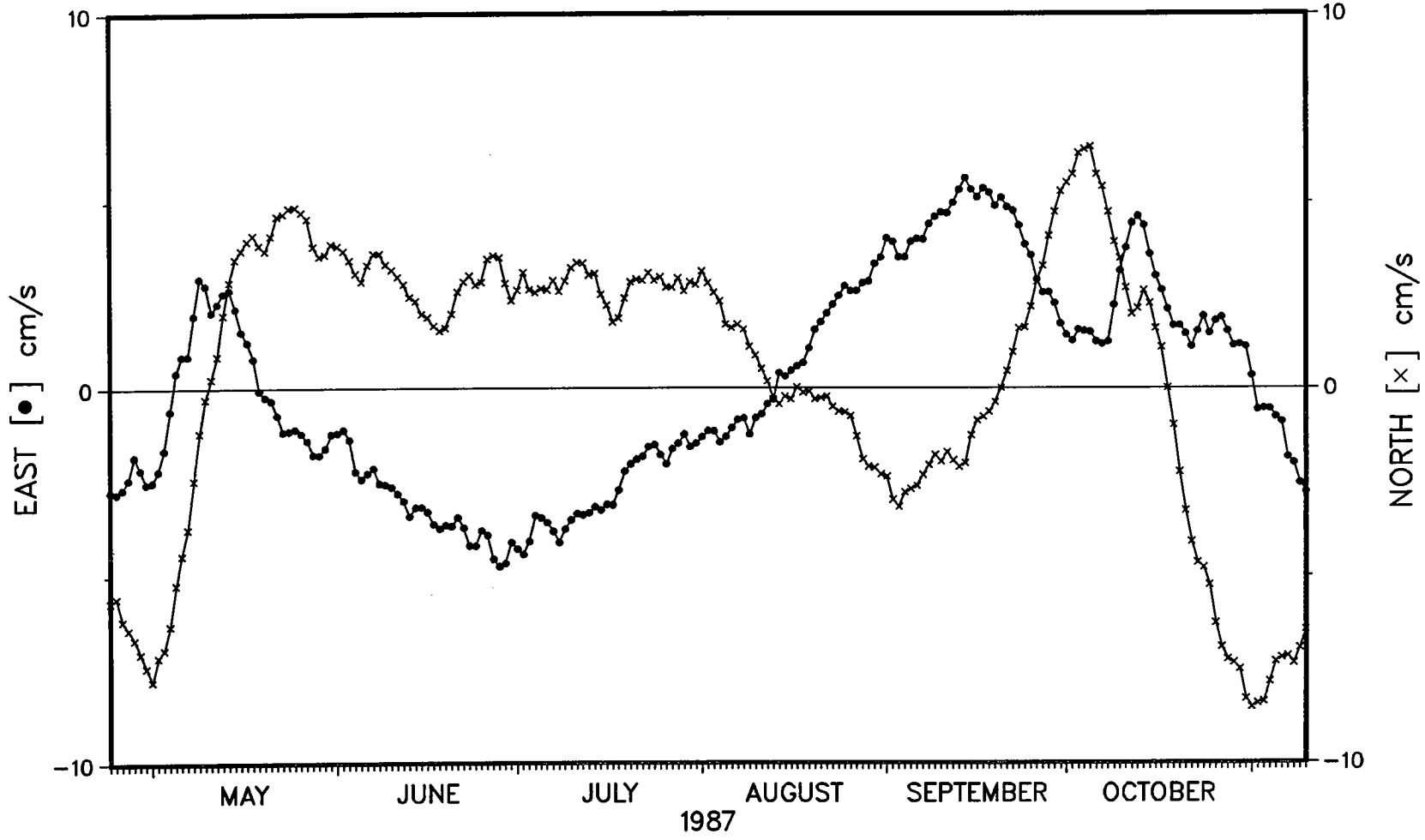
PLOT 4 OF 4
.SPL

EASTERN BASIN 128



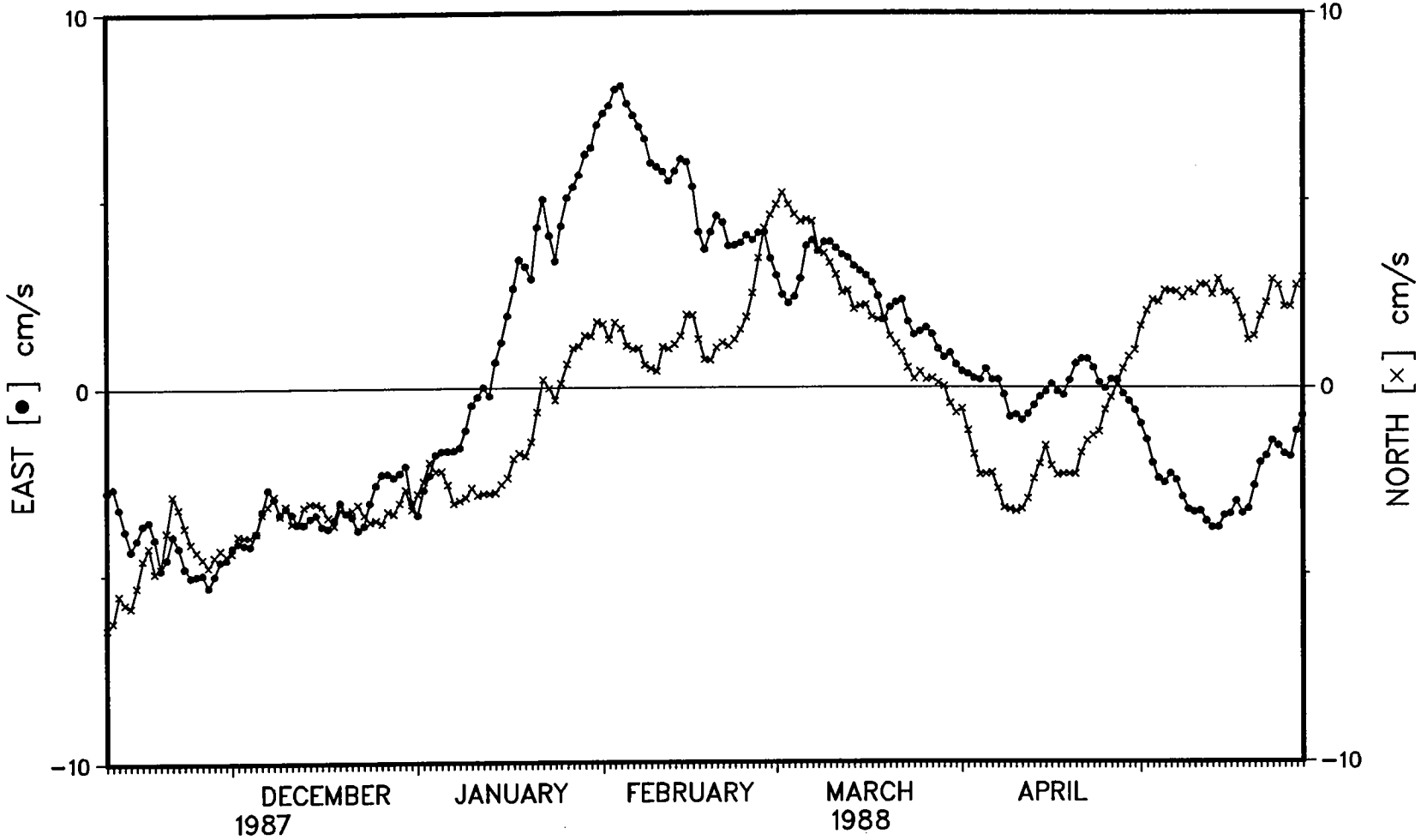
PLOT 1 OF 4
.SPL

EASTERN BASIN 128



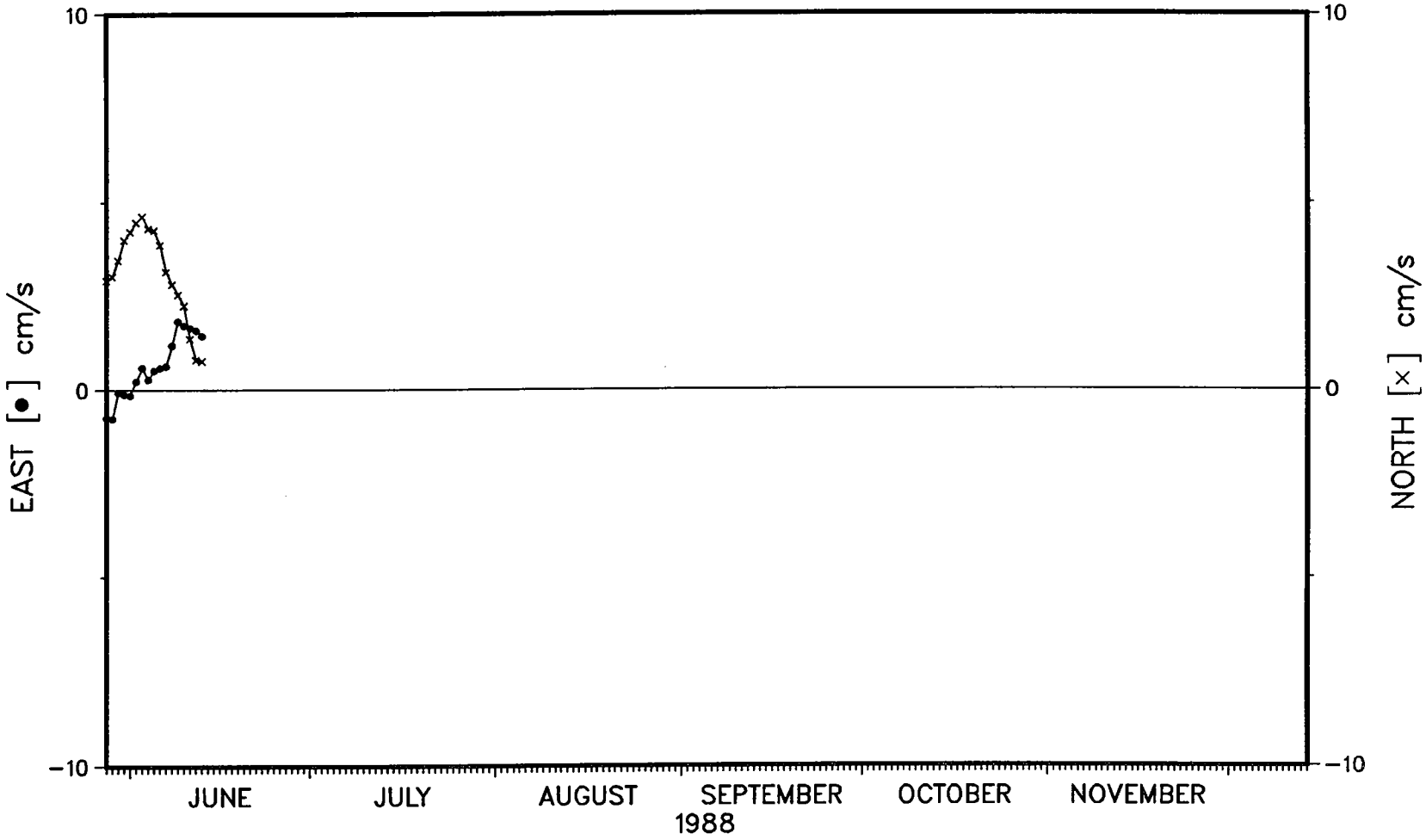
PLOT 2 OF 4
.SPL

EASTERN BASIN 128



PLOT 3 OF 4
.SPL

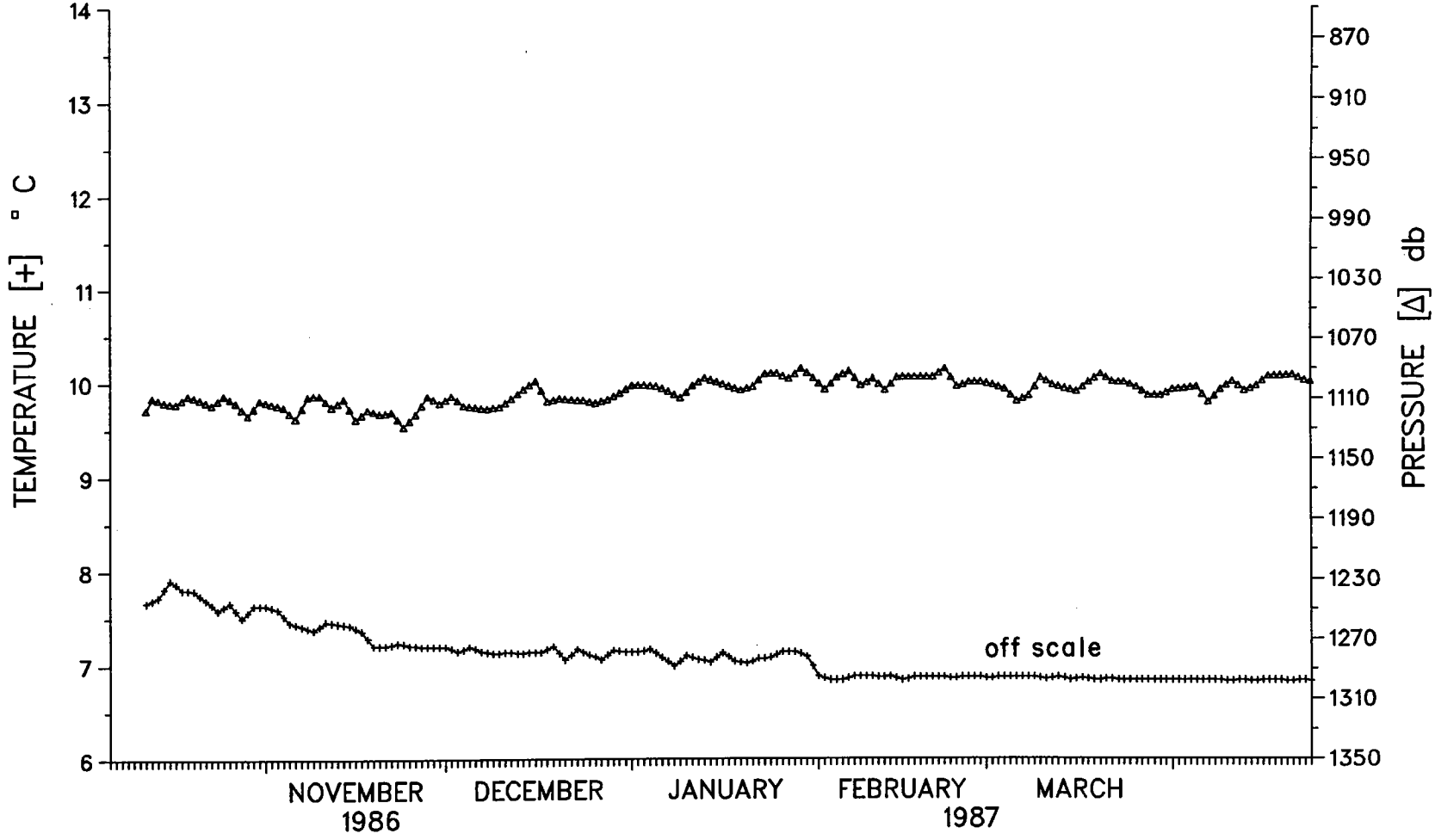
EASTERN BASIN 128



128

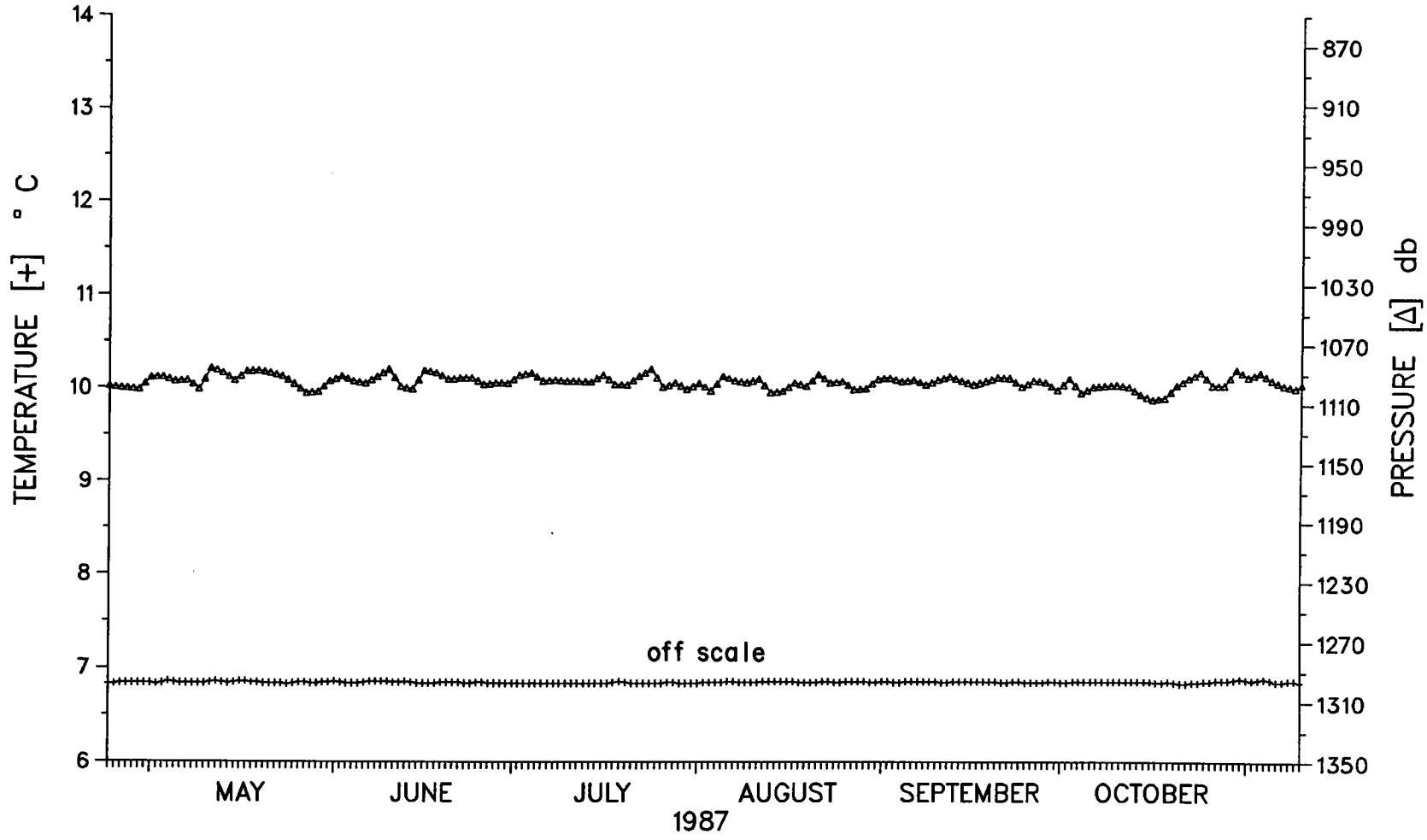
PLOT 4 OF 4
.SPL

EASTERN BASIN 128



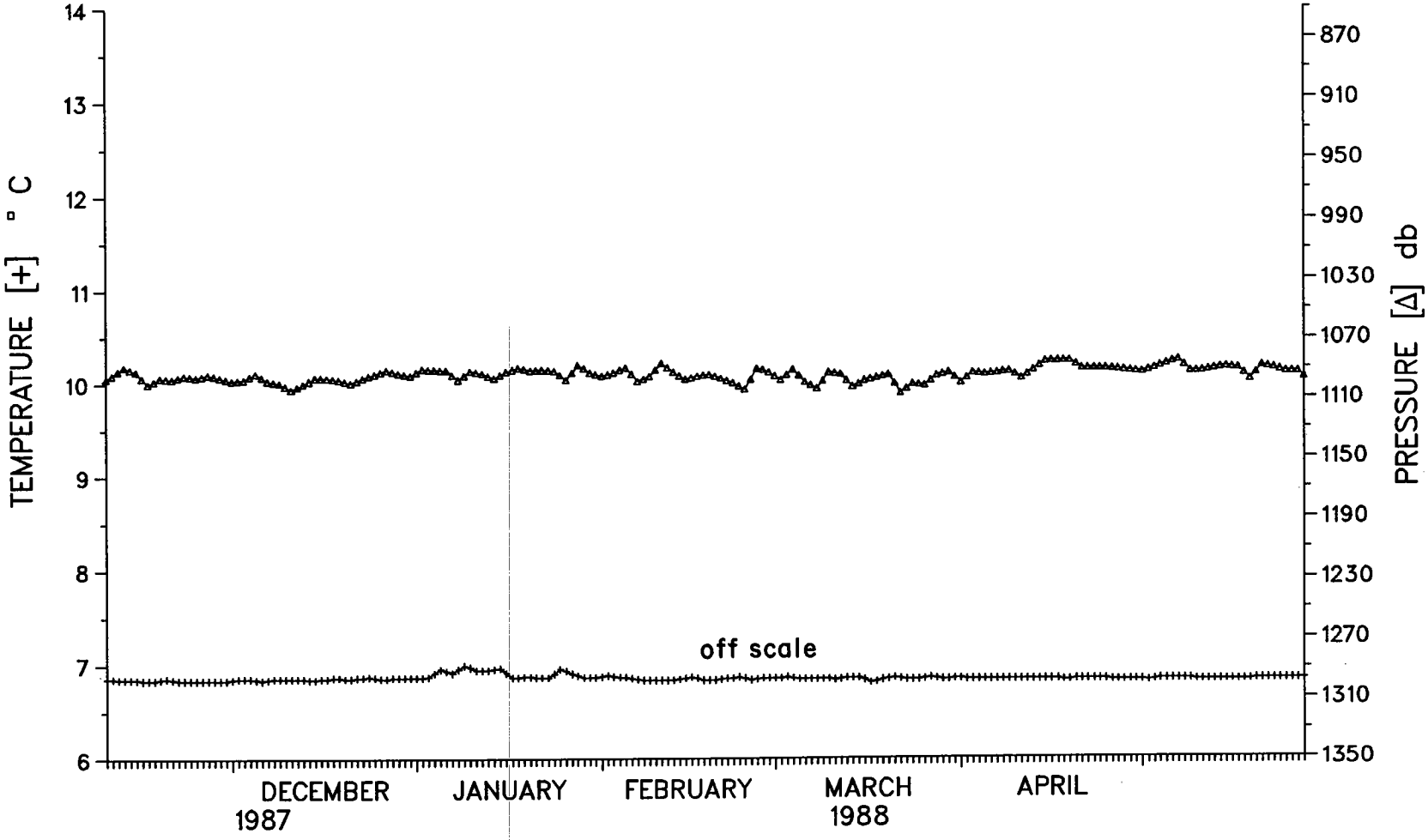
PLOT 1 OF 4
.SPL

EASTERN BASIN 128



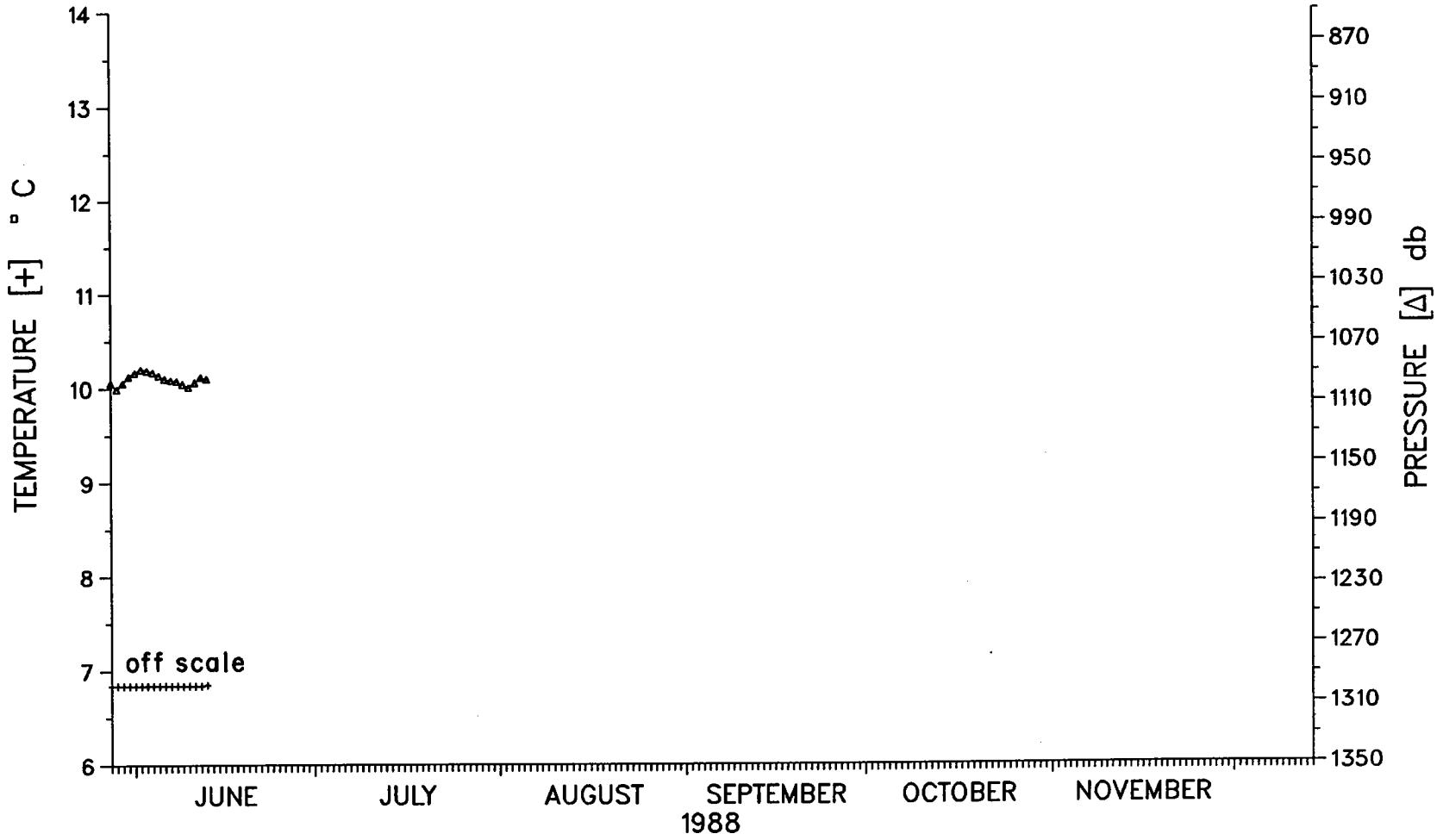
PLOT 2 OF 4
.SPL

EASTERN BASIN 128



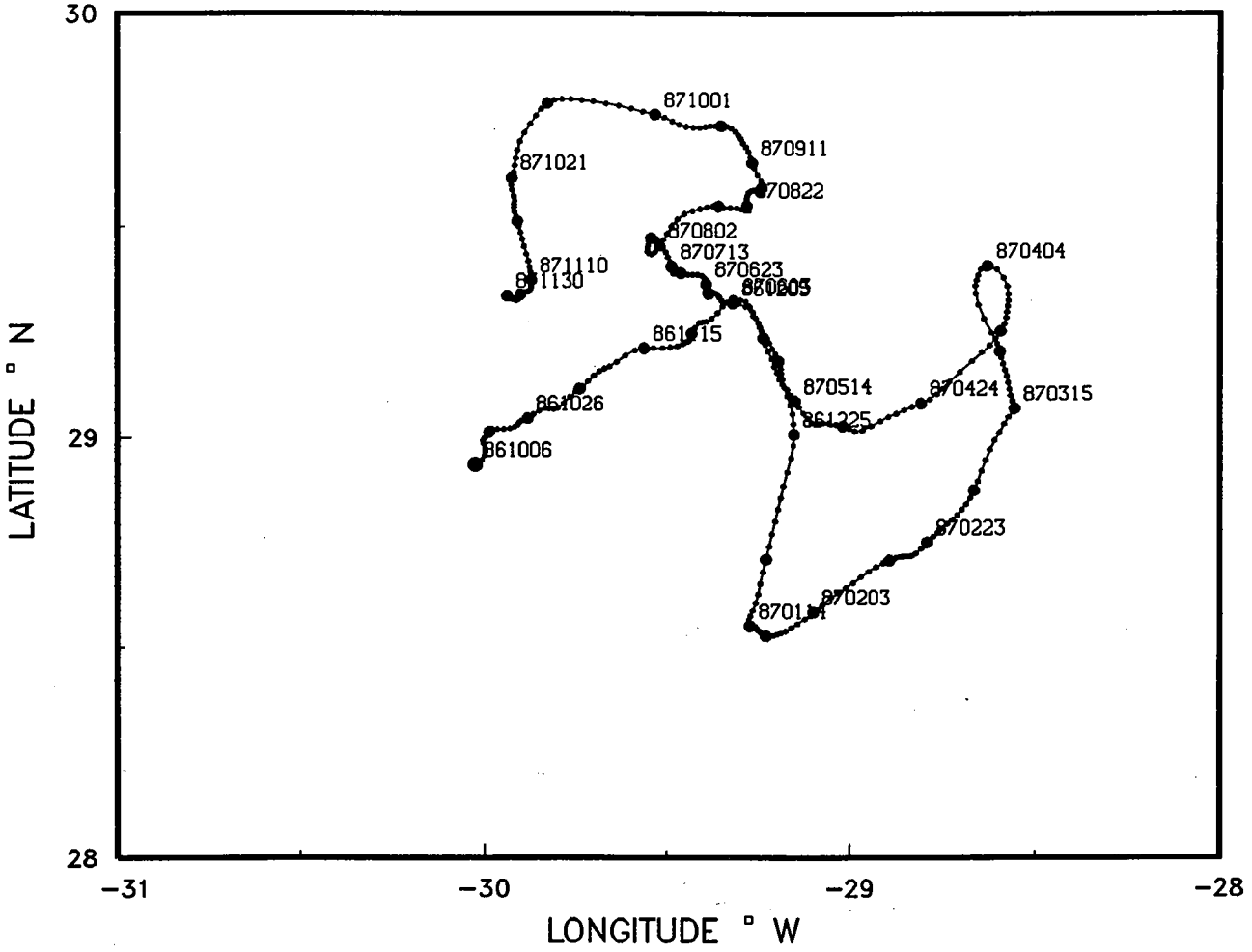
PLOT 3 OF 4
.SPL

EASTERN BASIN 128



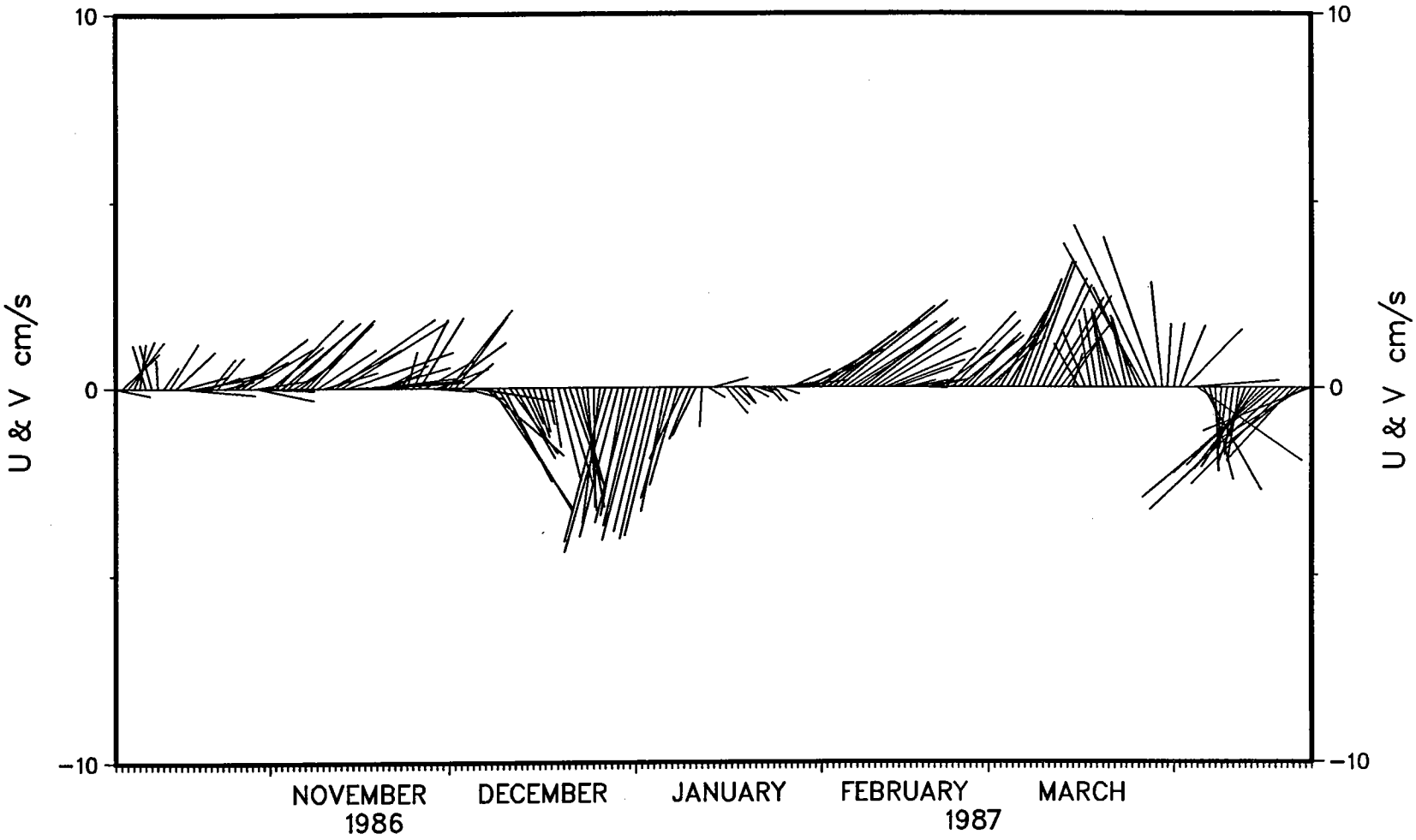
PLOT 4 OF 4
.SPL

EASTERN BASIN 129B



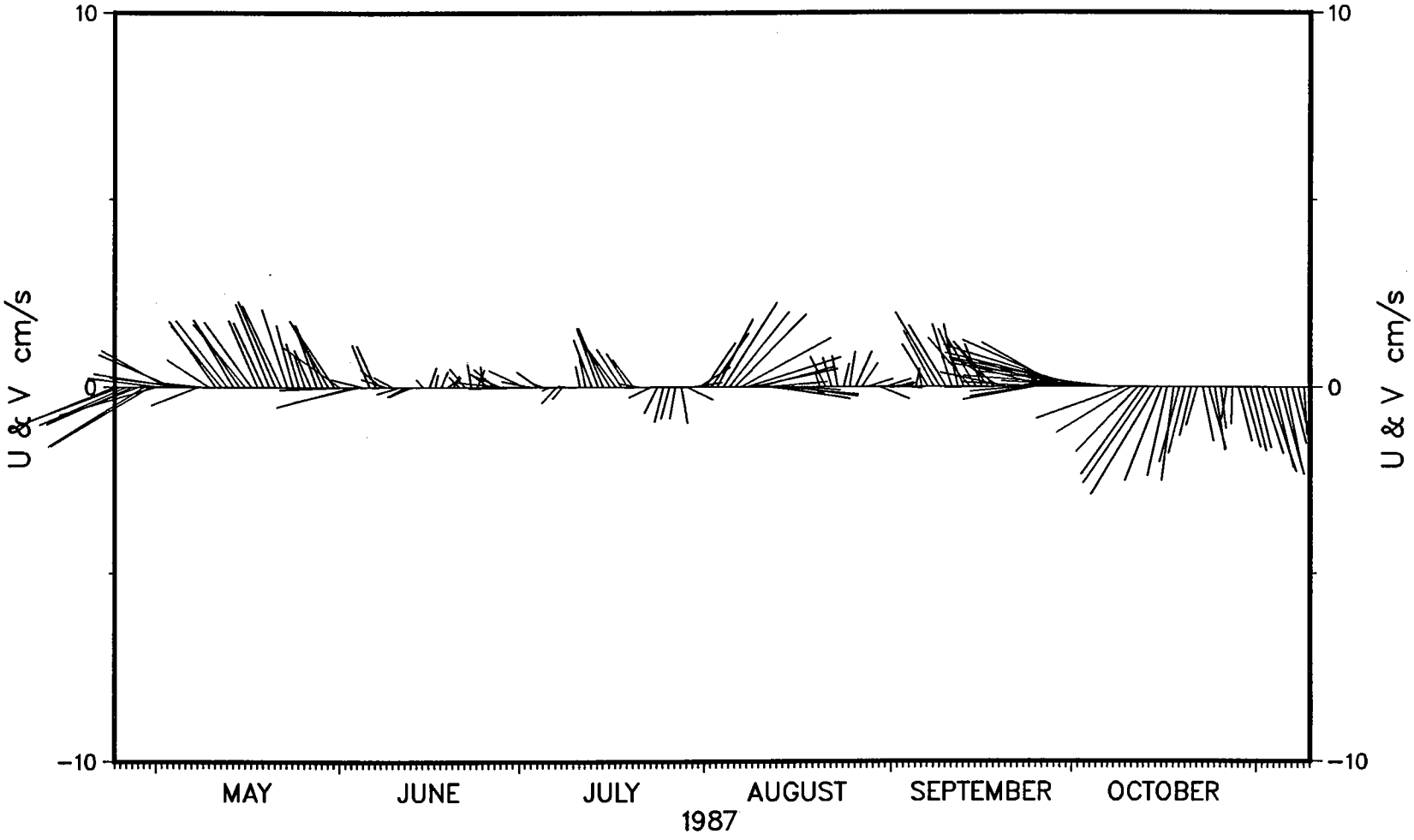
PLOT 1 OF 1
.SPL

EASTERN BASIN 129B



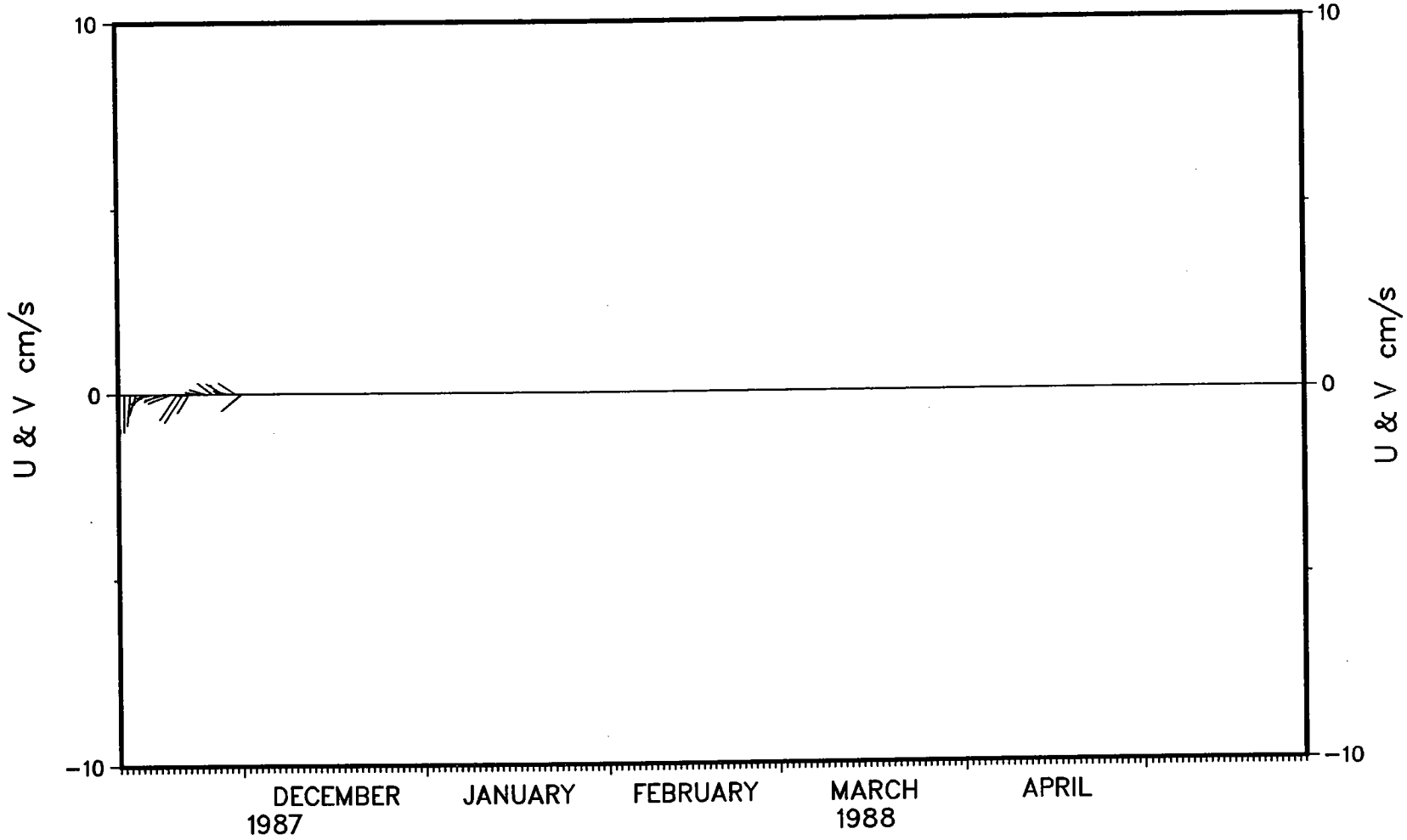
PLOT 1 OF 3
.SPL

EASTERN BASIN 129B



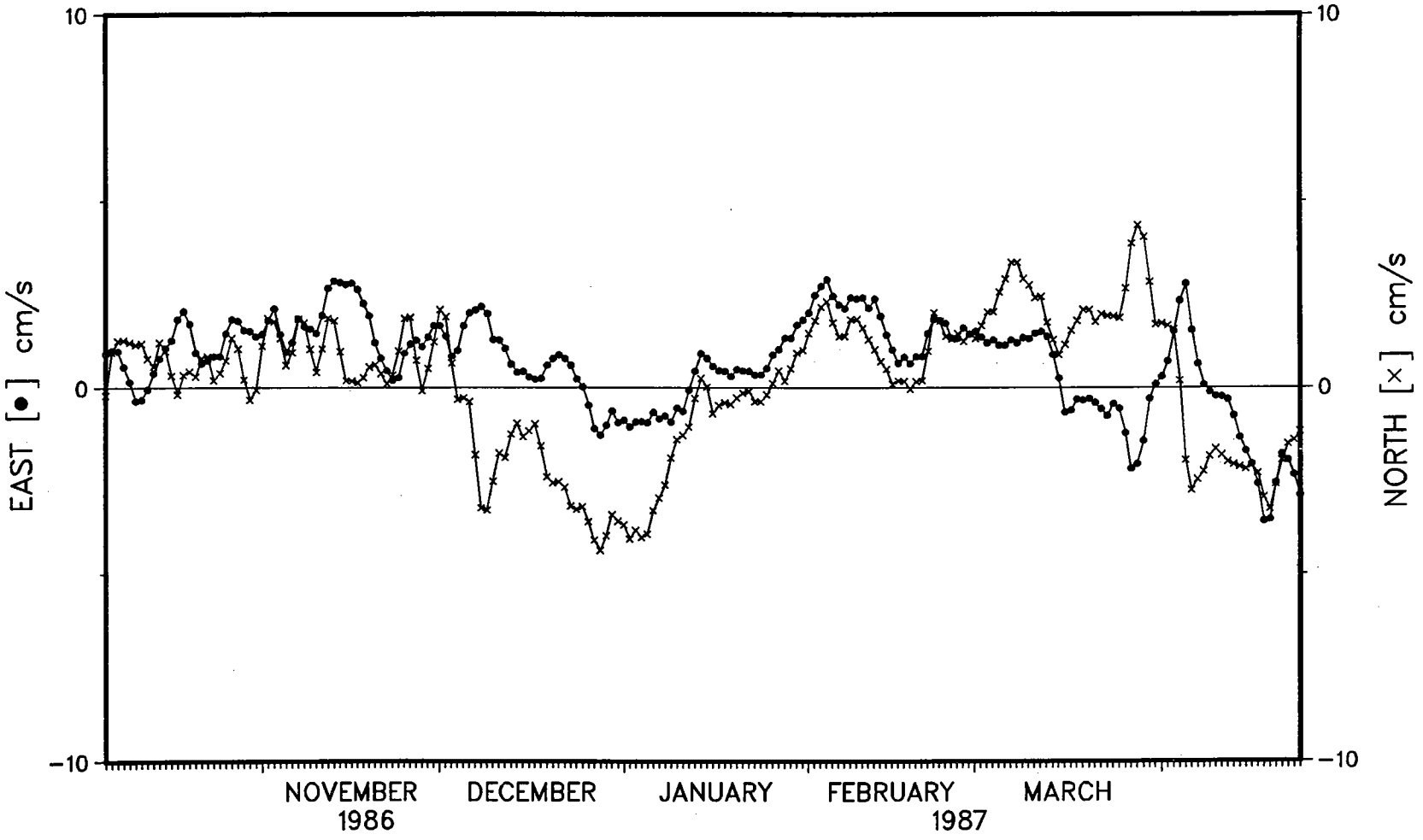
PLOT 2 OF 3
.SPL

EASTERN BASIN 129B



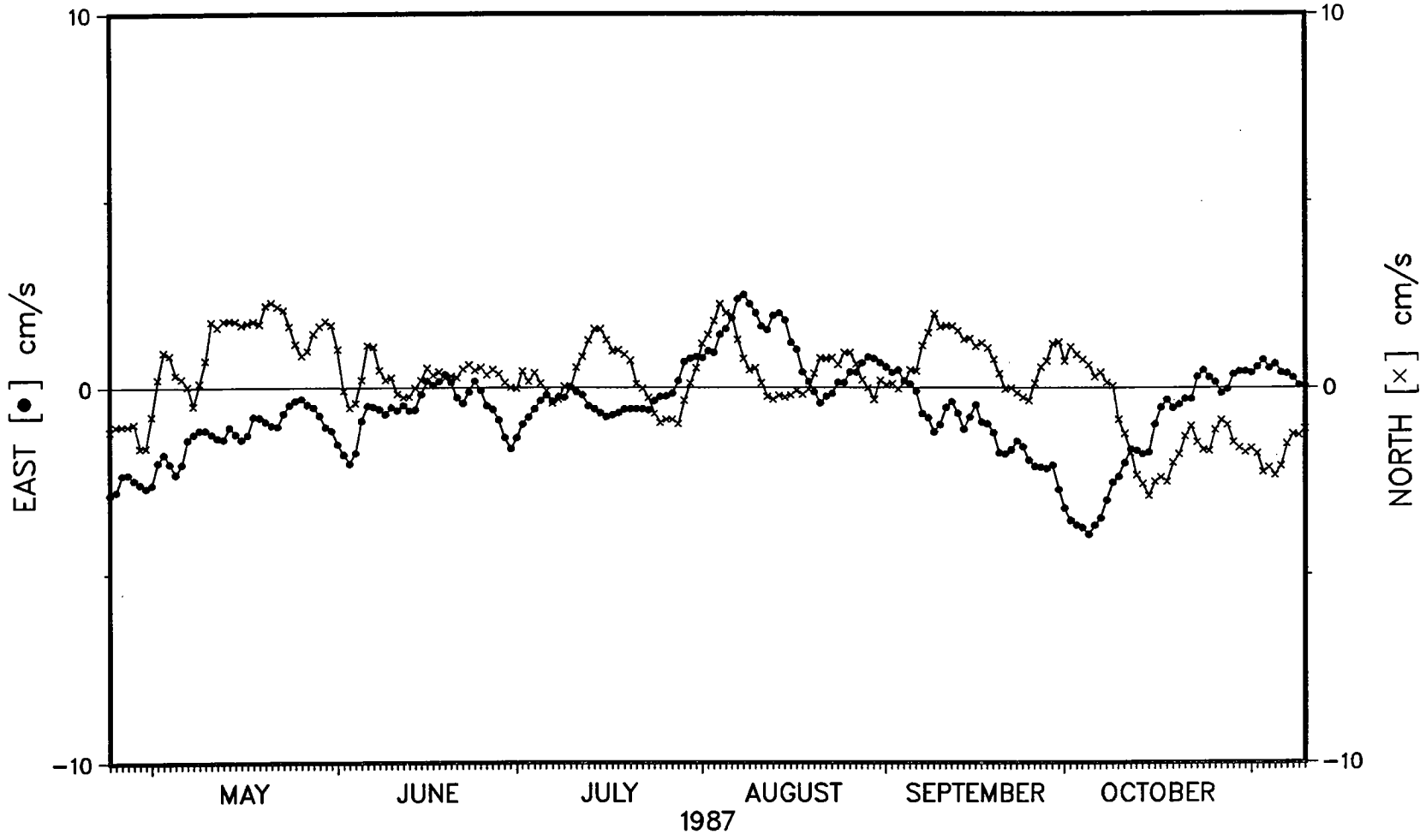
PLOT 3 OF 3
.SPL

EASTERN BASIN 129B



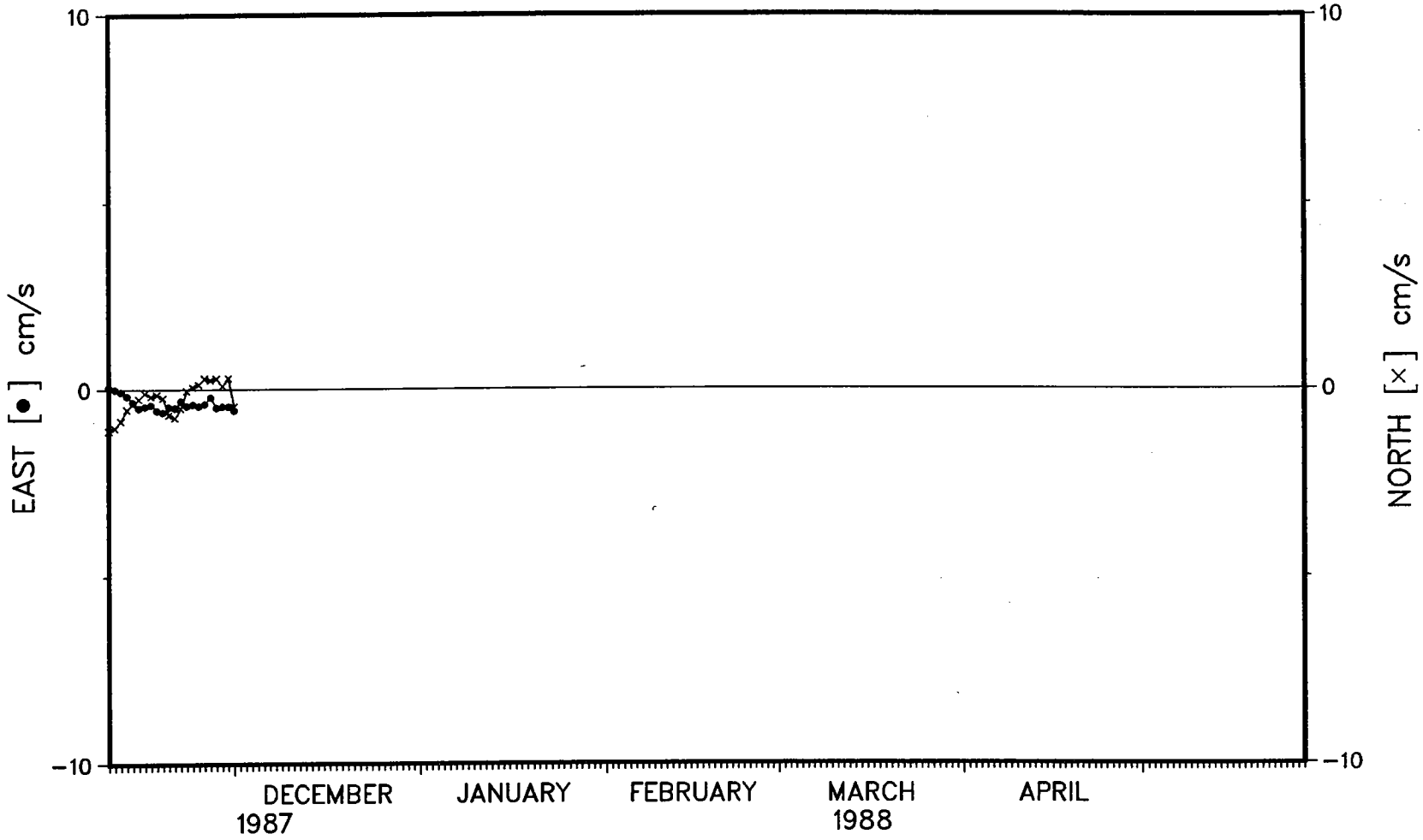
PLOT 1 OF 3
.SPL

EASTERN BASIN 129B



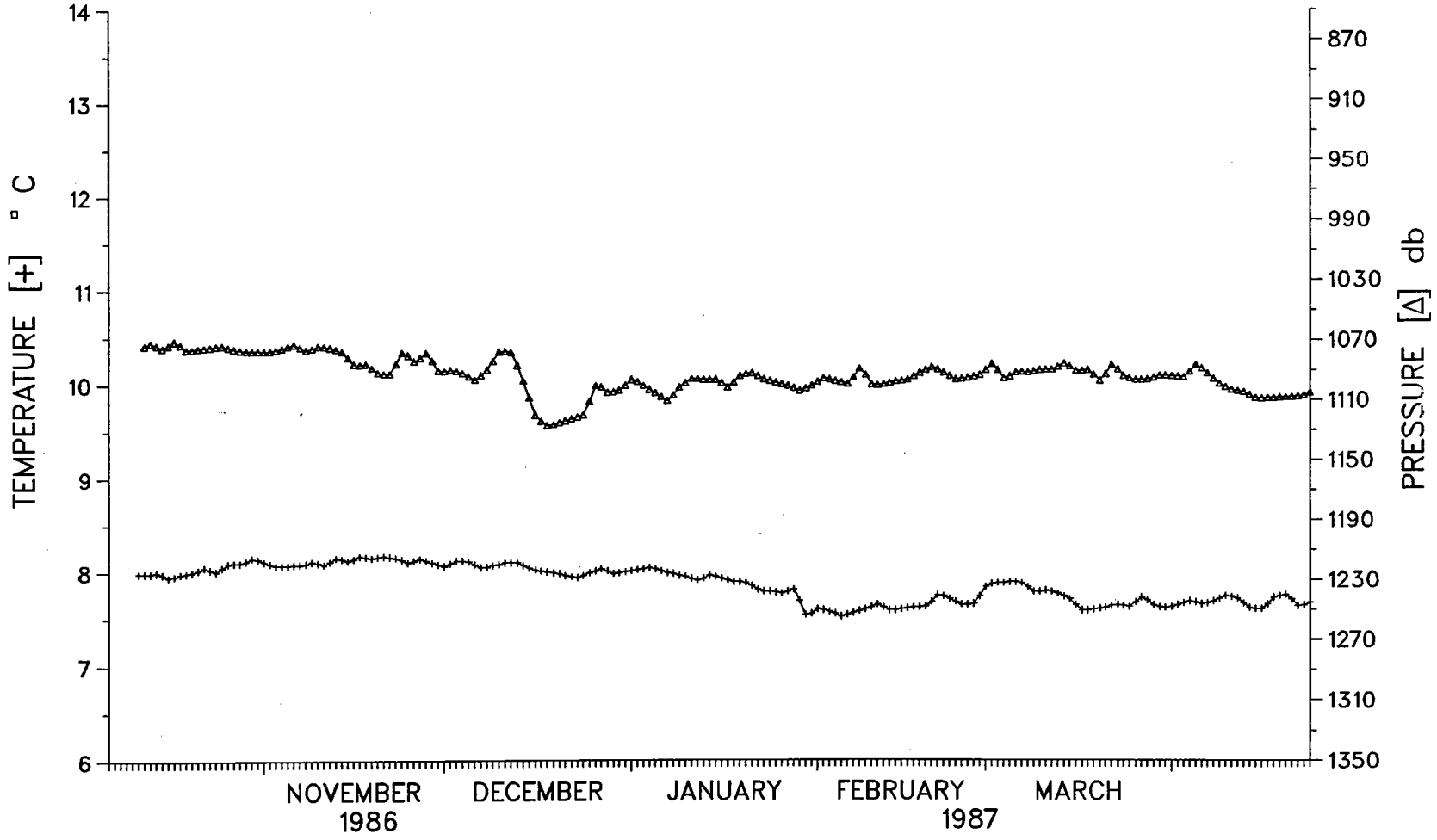
PLOT 2 OF 3
.SPL

EASTERN BASIN 129B



PLOT 3 OF 3
.SPL

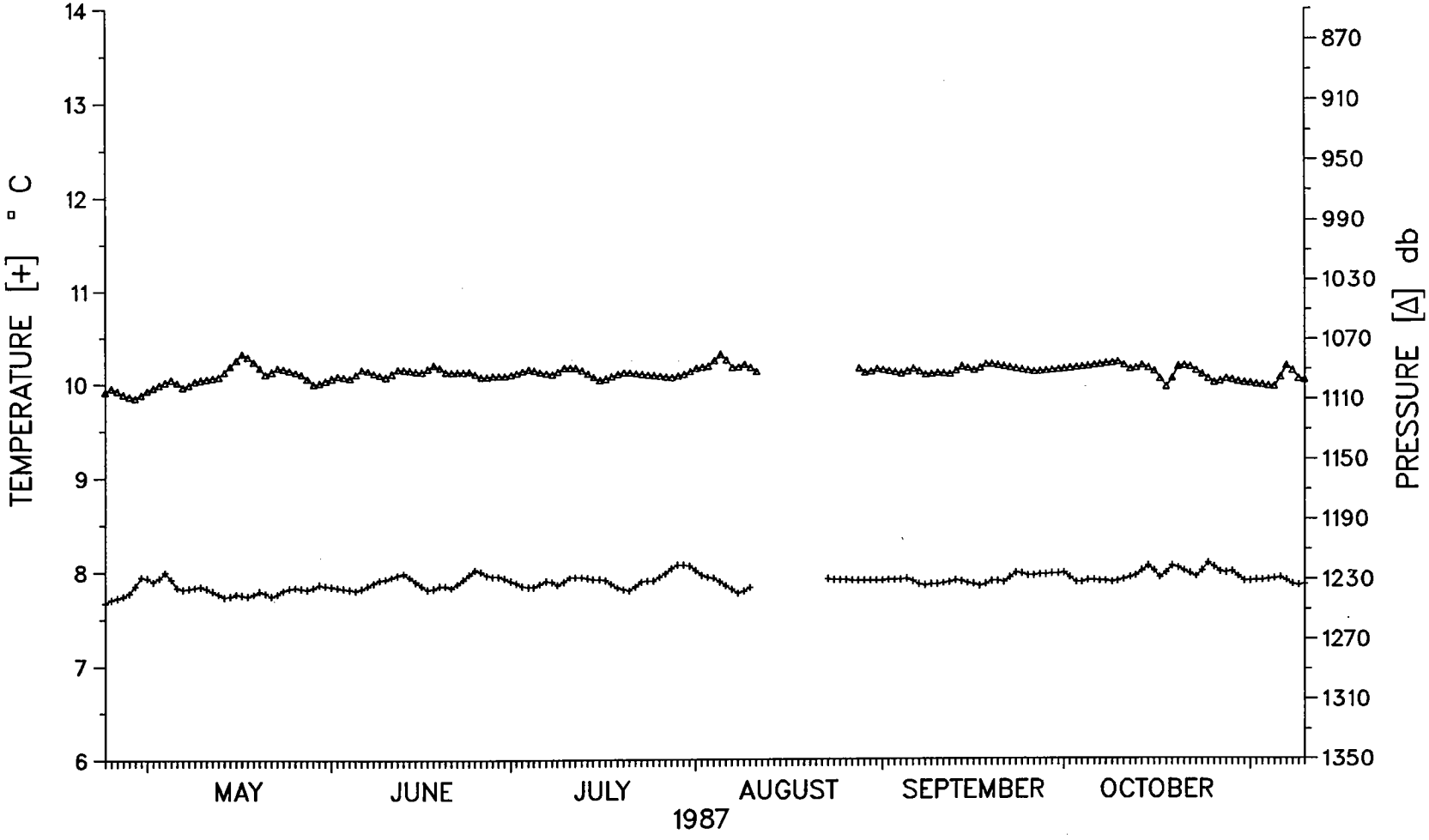
EASTERN BASIN 129B



140

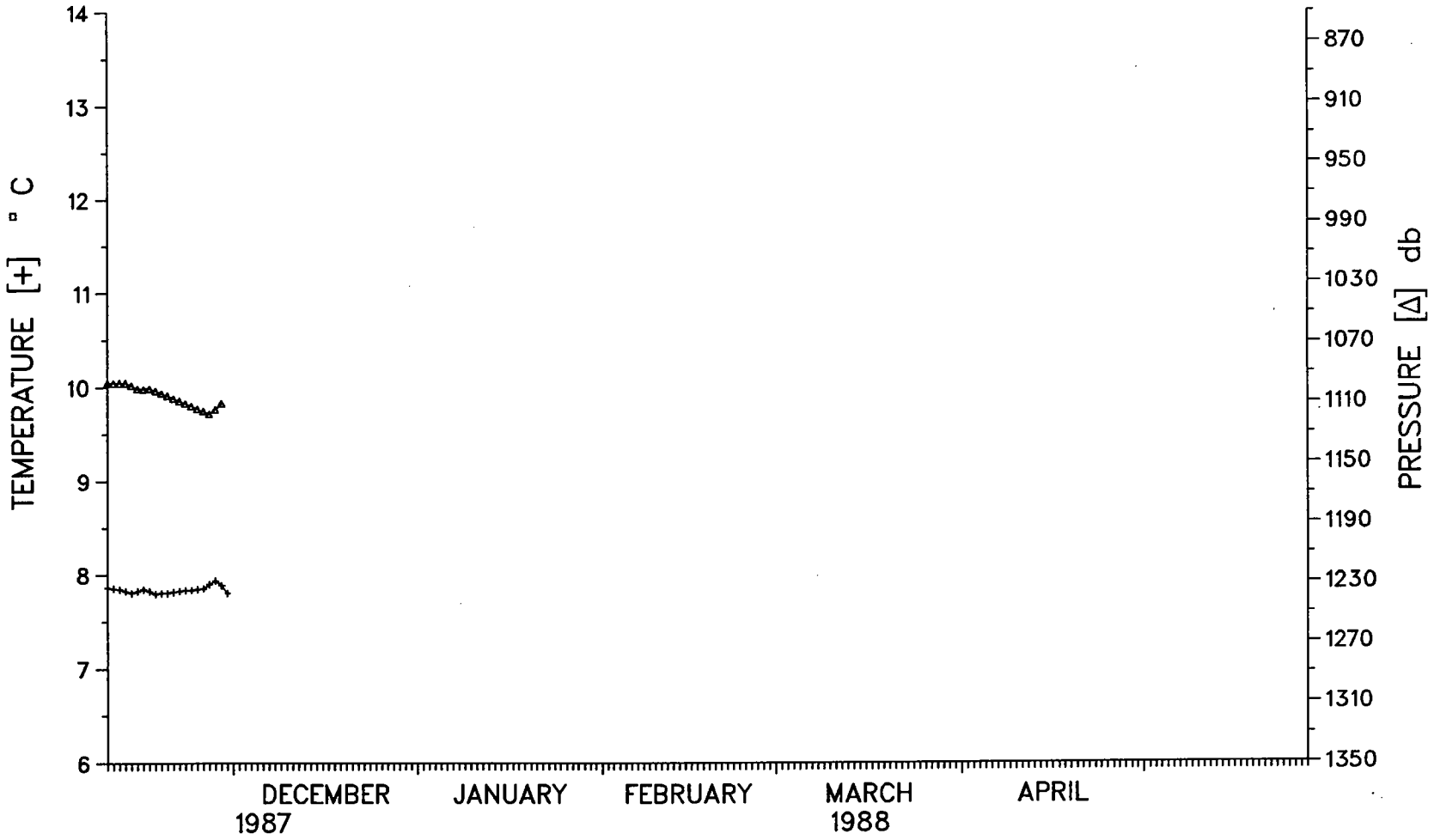
PLOT 1 OF 3
.SPL

EASTERN BASIN 129B



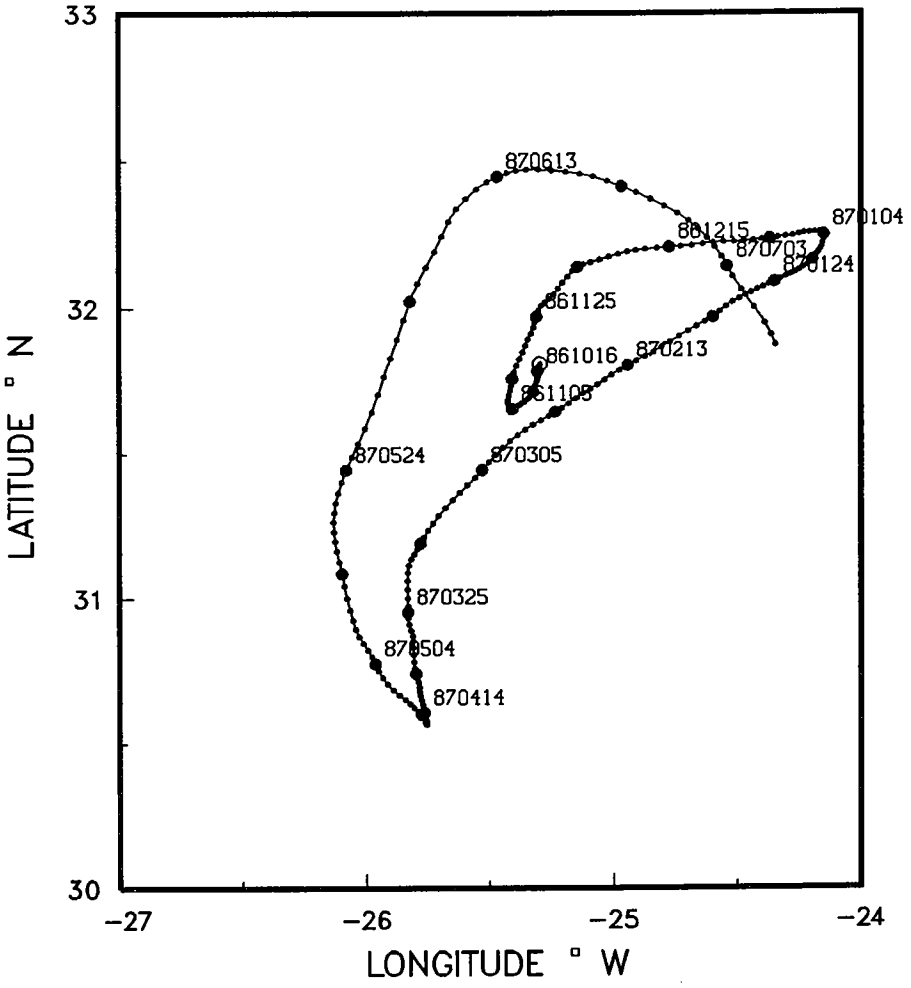
PLOT 2 OF 3
.SPL

EASTERN BASIN 129B



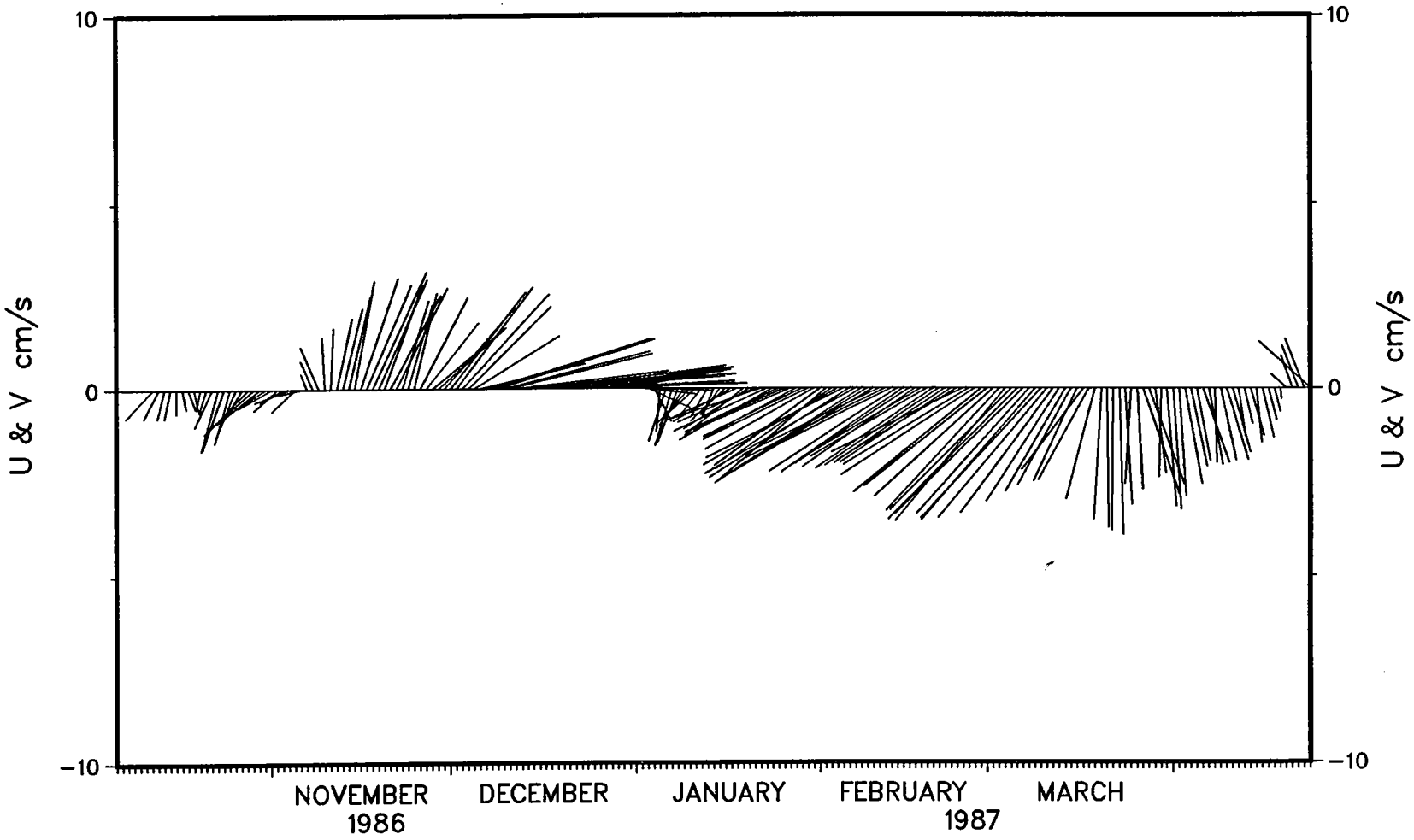
PLOT 3 OF 3
.SPL

EASTERN BASIN 130



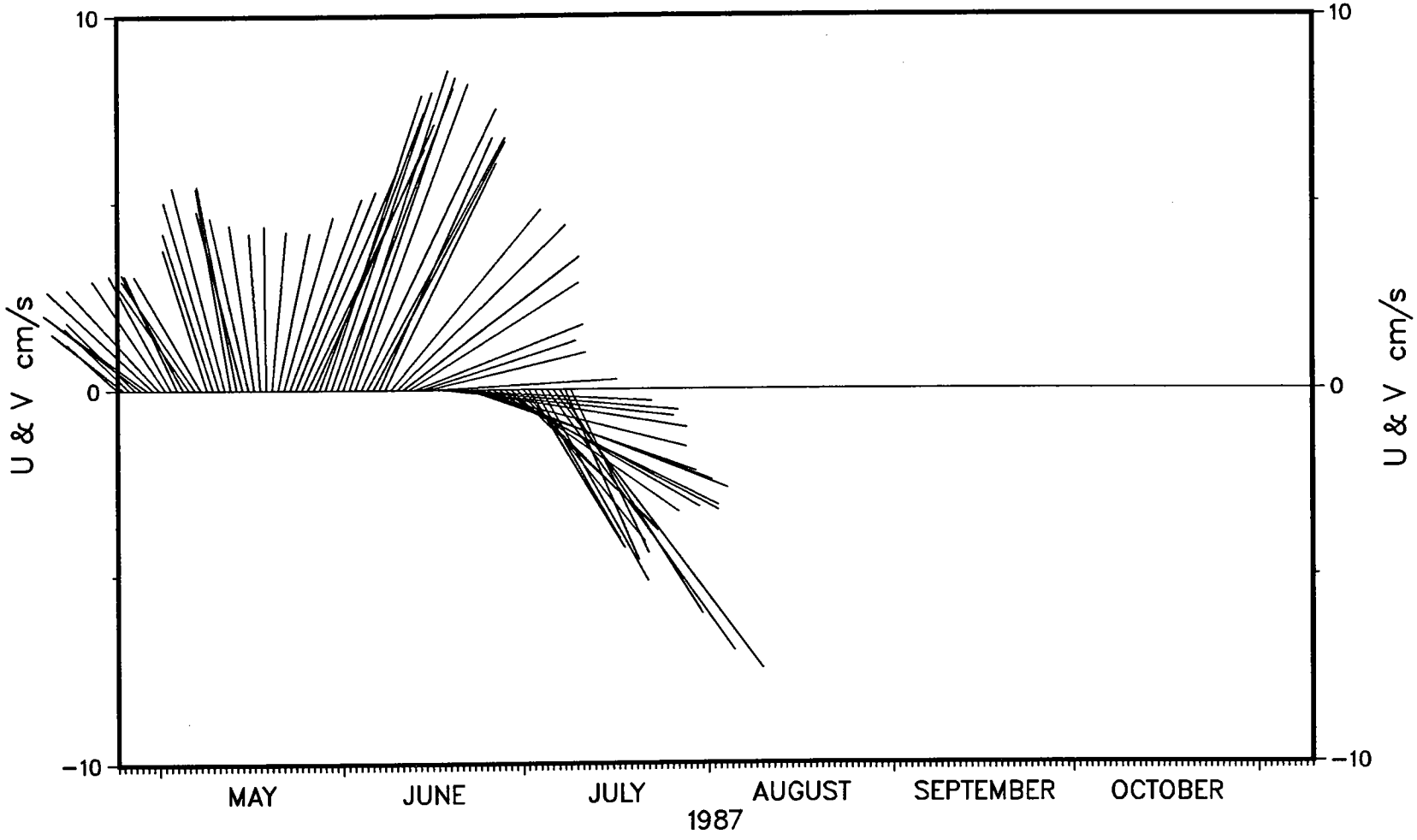
PLOT 1 OF 1
.SPL

EASTERN BASIN 130



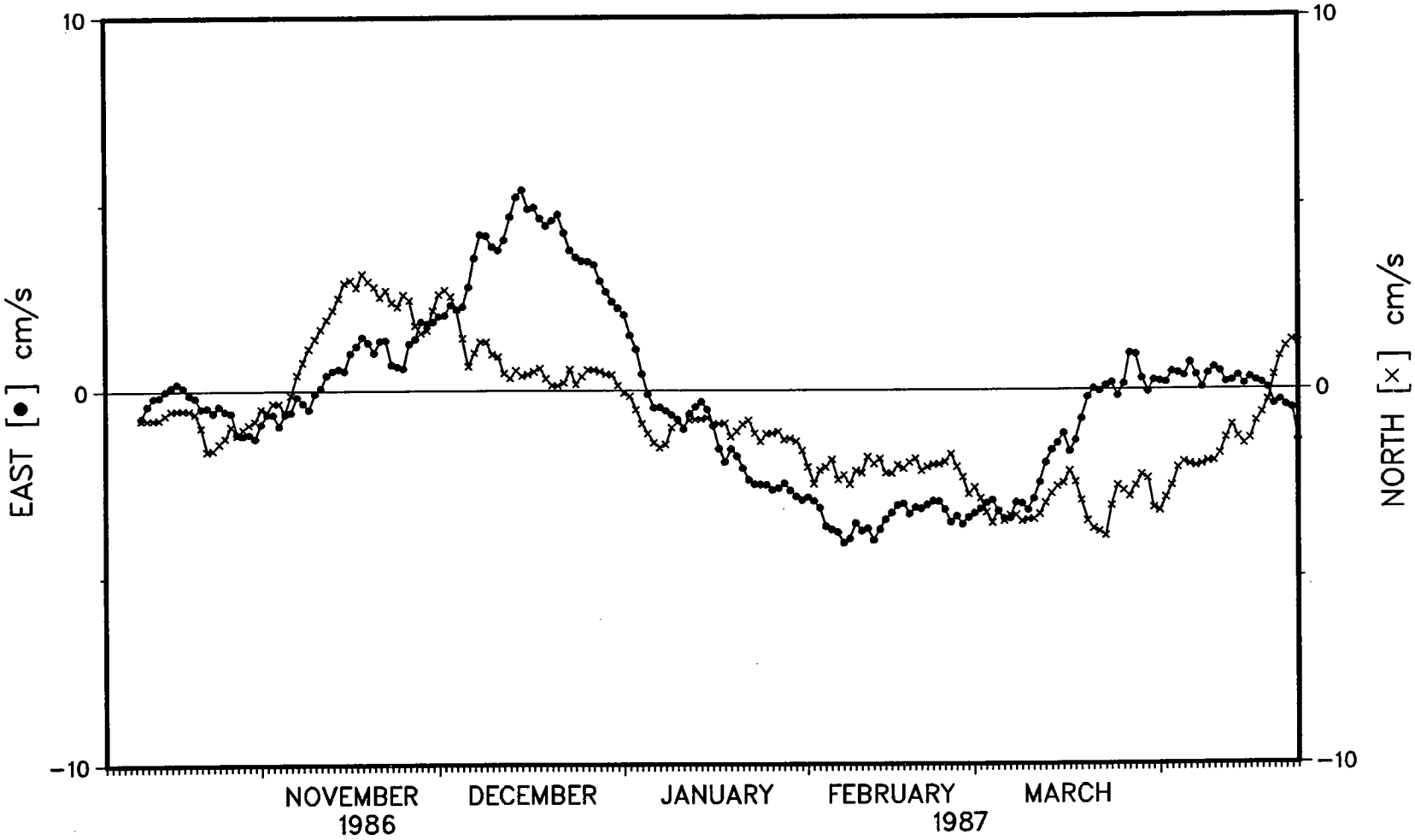
PLOT 1 OF 2
.SPL

EASTERN BASIN 130



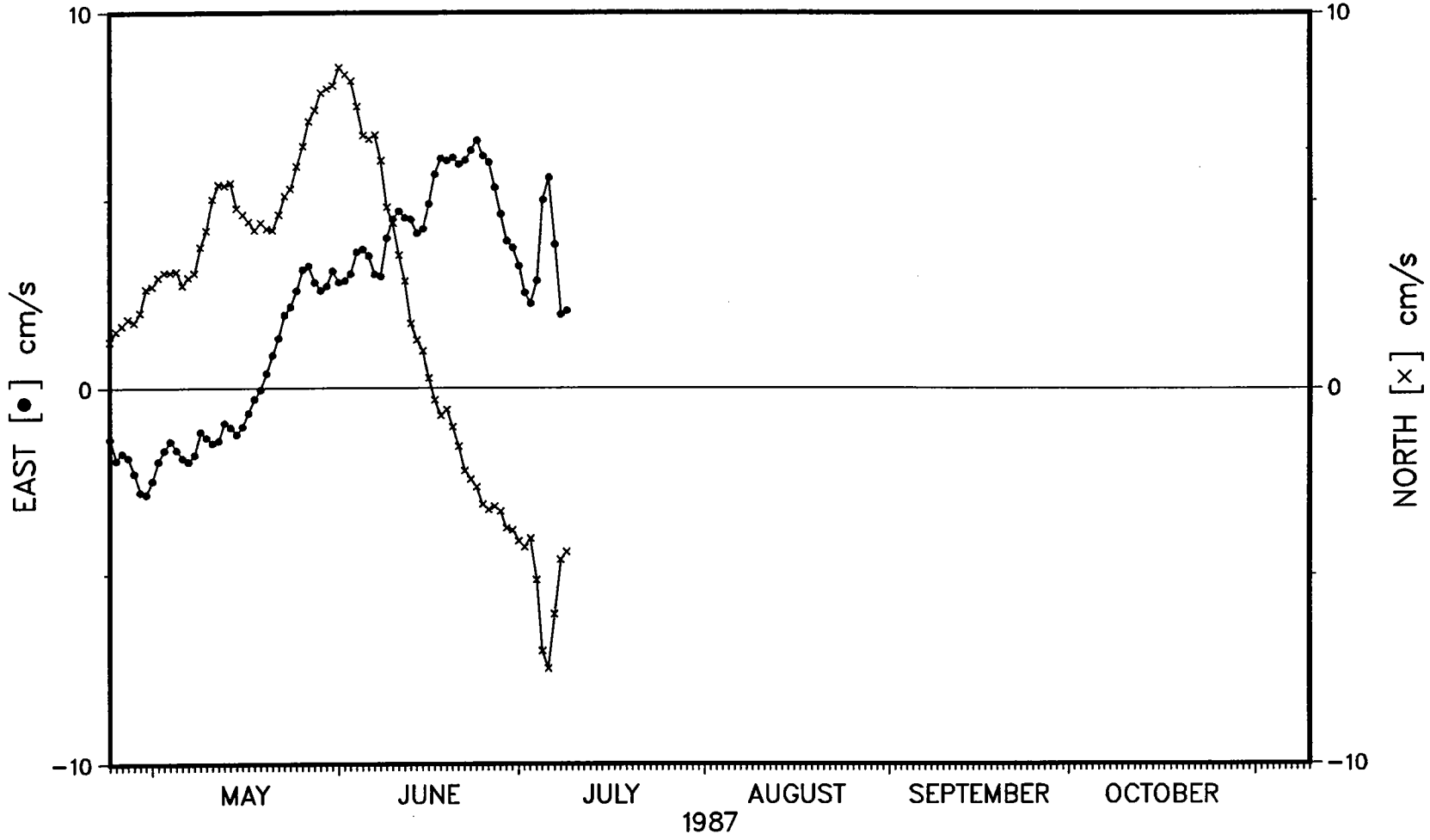
PLOT 2 OF 2
.SPL

EASTERN BASIN 130



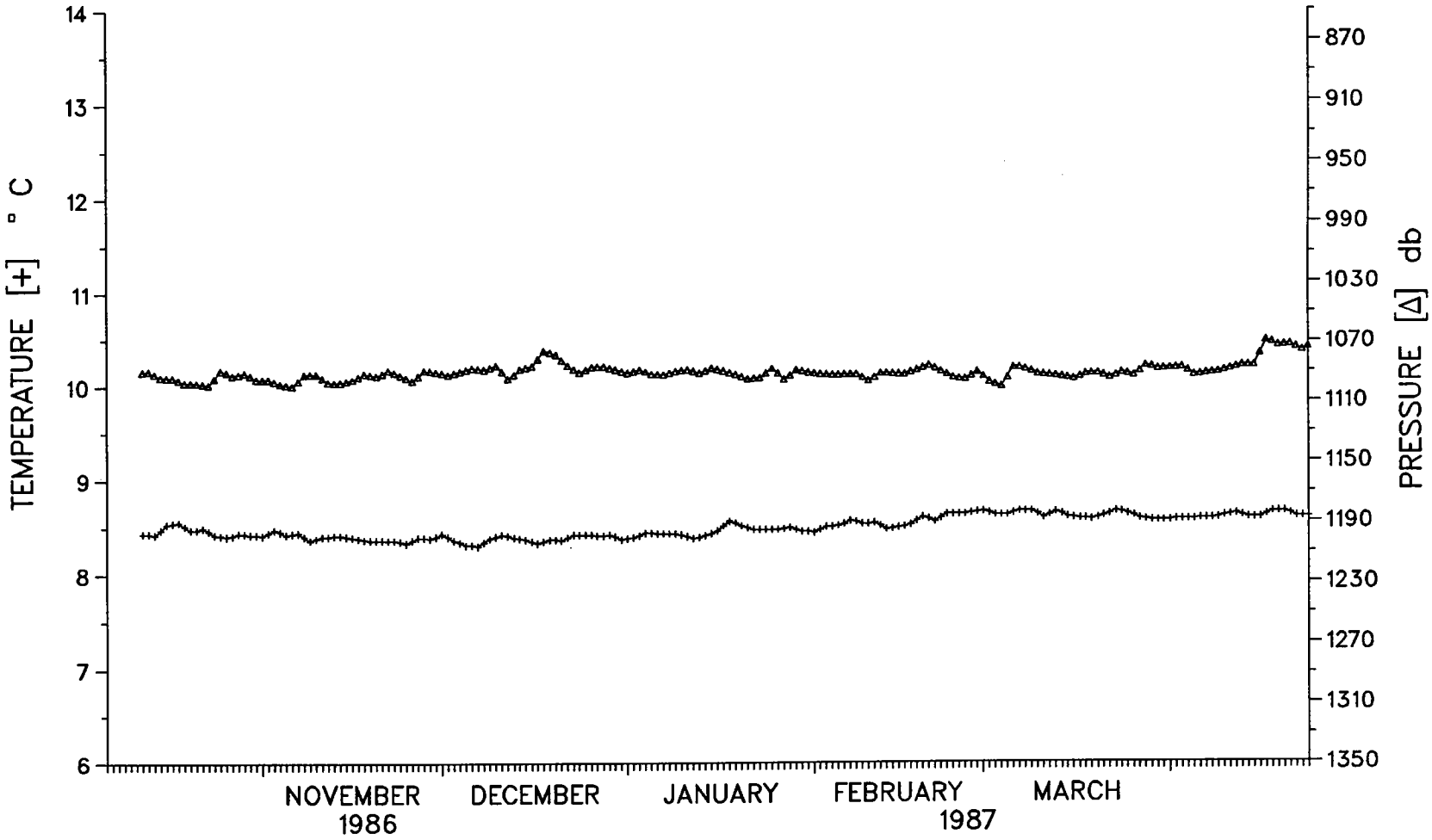
PLOT 1 OF 2
.SPL

EASTERN BASIN 130



PLOT 2 OF 2
.SPL

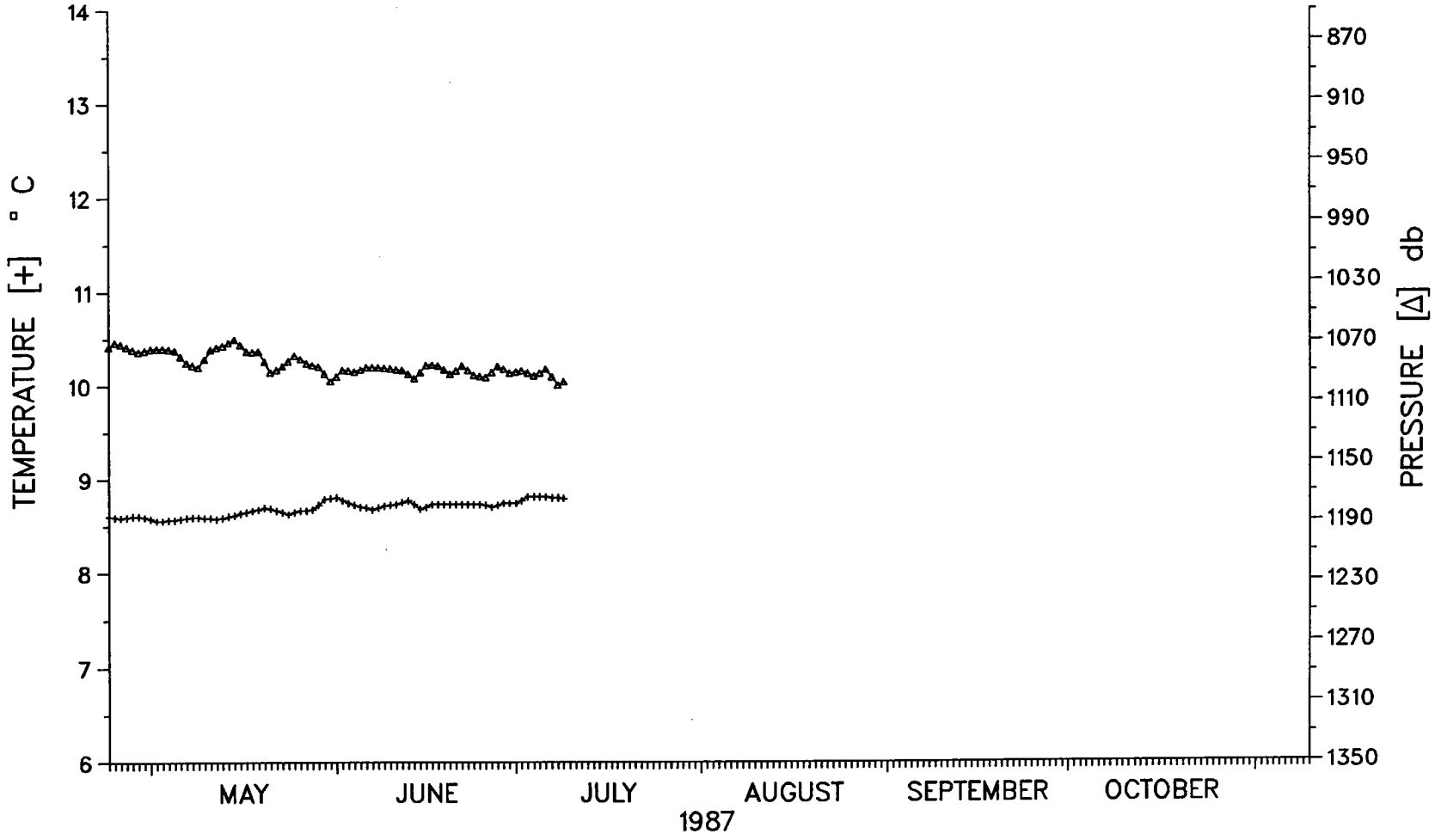
EASTERN BASIN 130



148

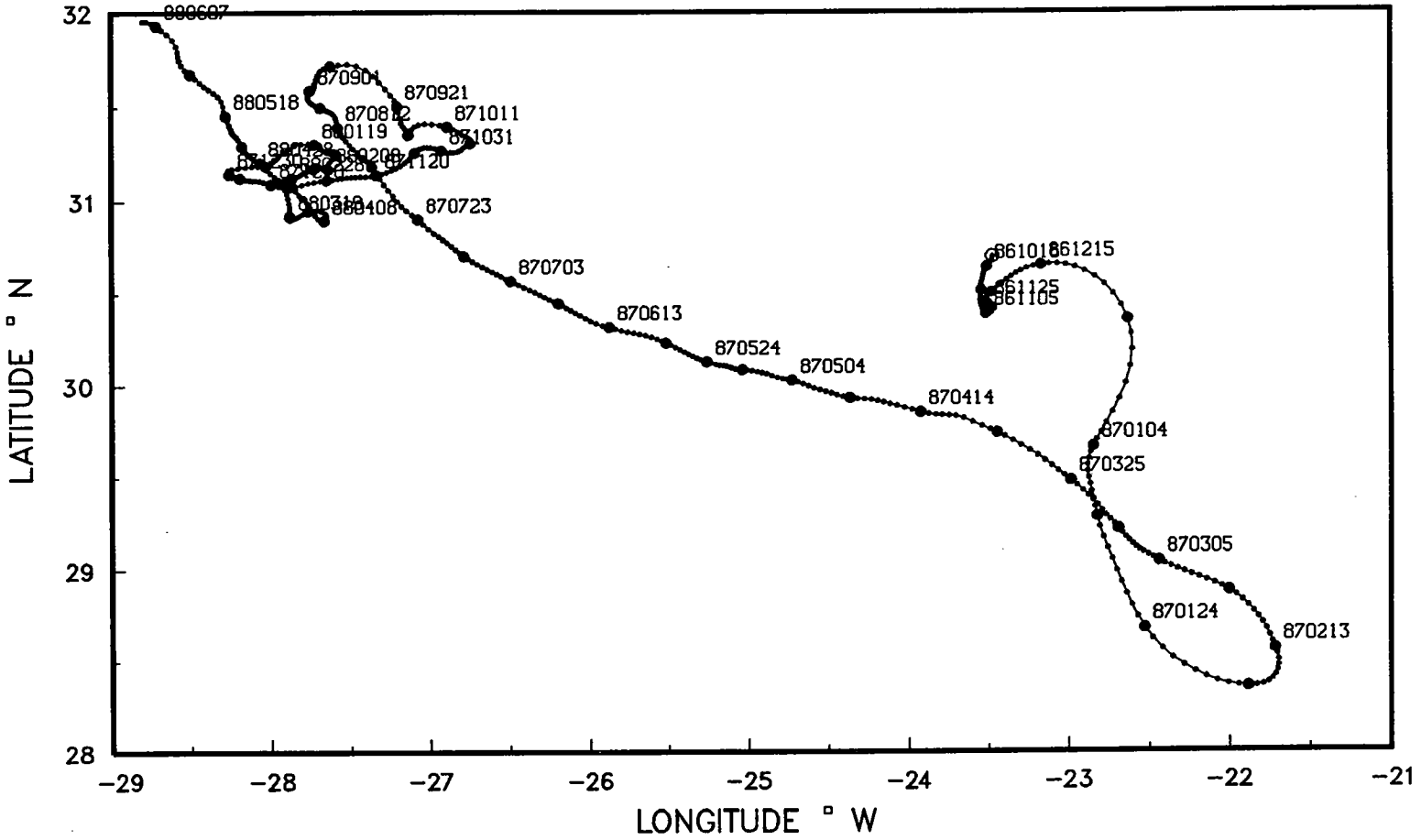
PLOT 1 OF 2
.SPL

EASTERN BASIN 130



PLOT 2 OF 2
.SPL

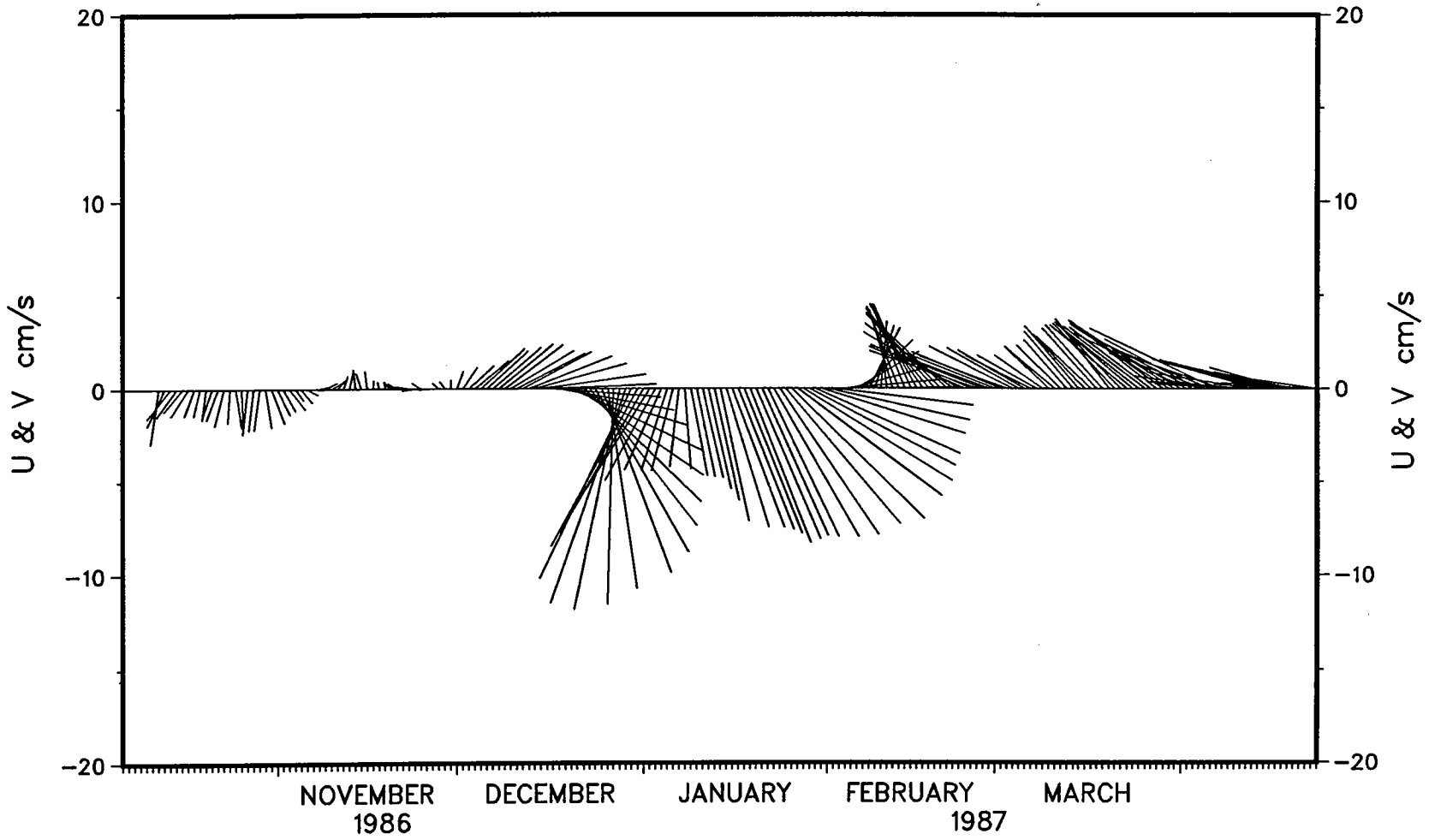
EASTERN BASIN 131



150

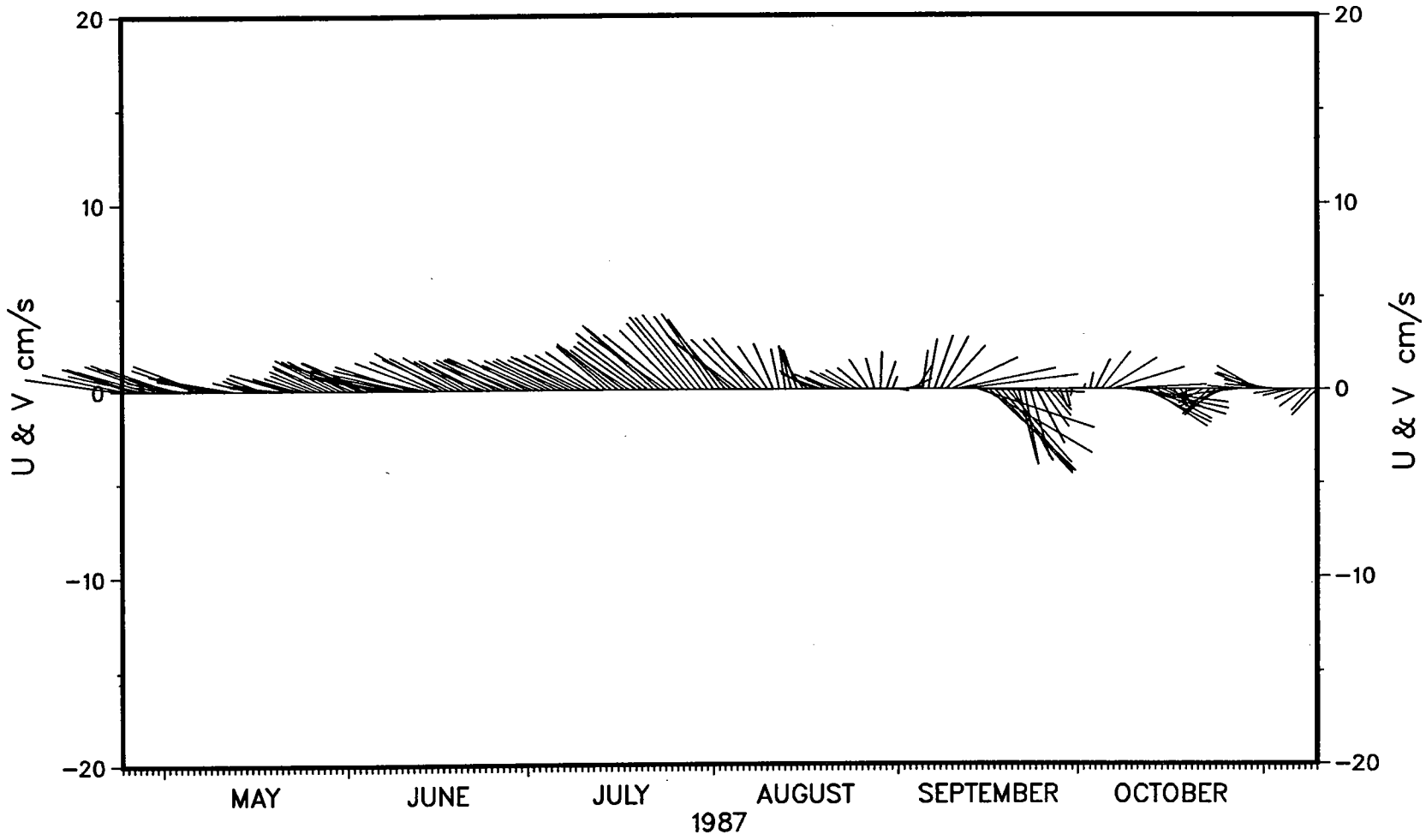
PLOT 1 OF 1
.SPL

EASTERN BASIN 131



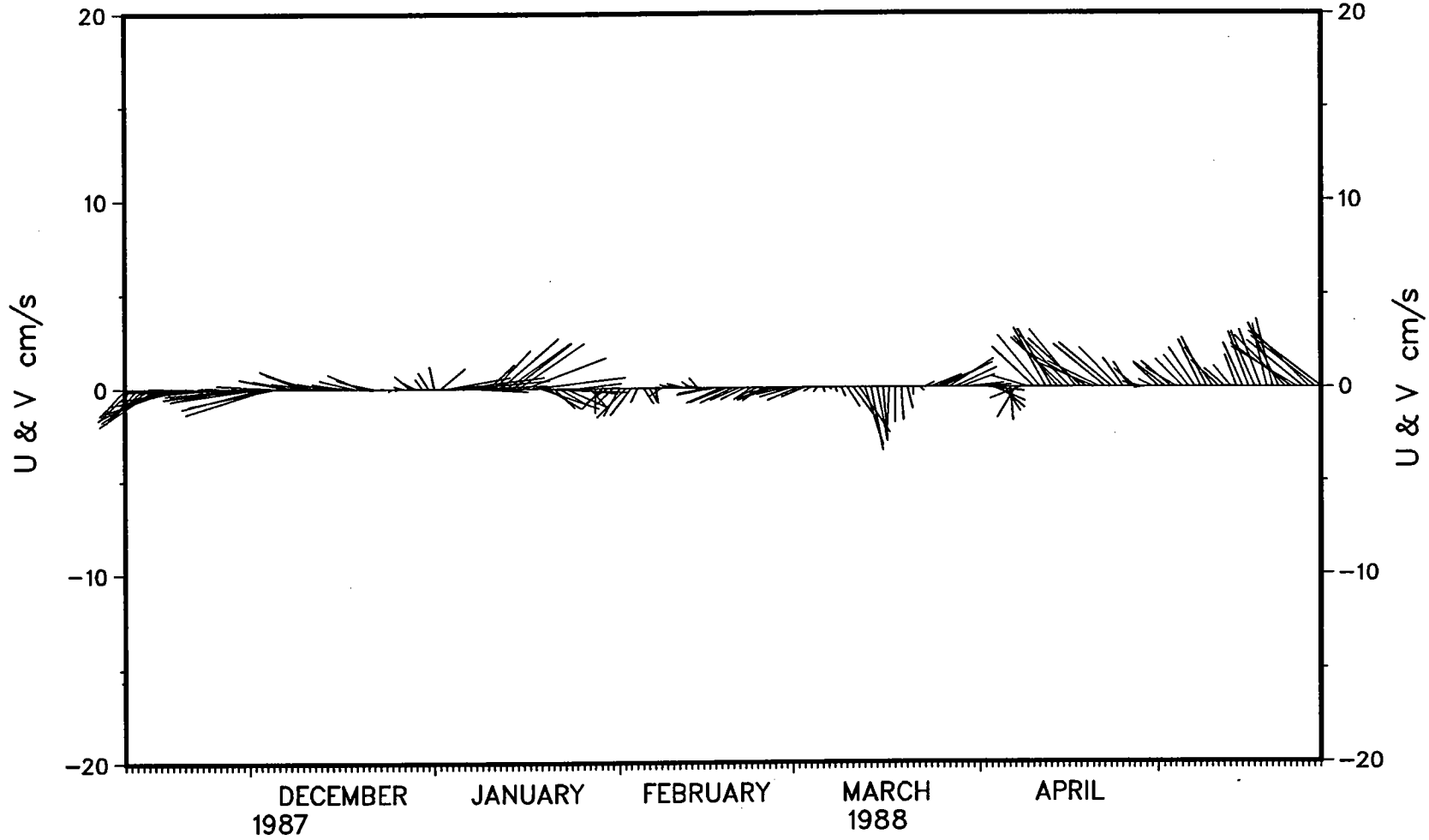
PLOT 1 OF 4
.SPL

EASTERN BASIN 131



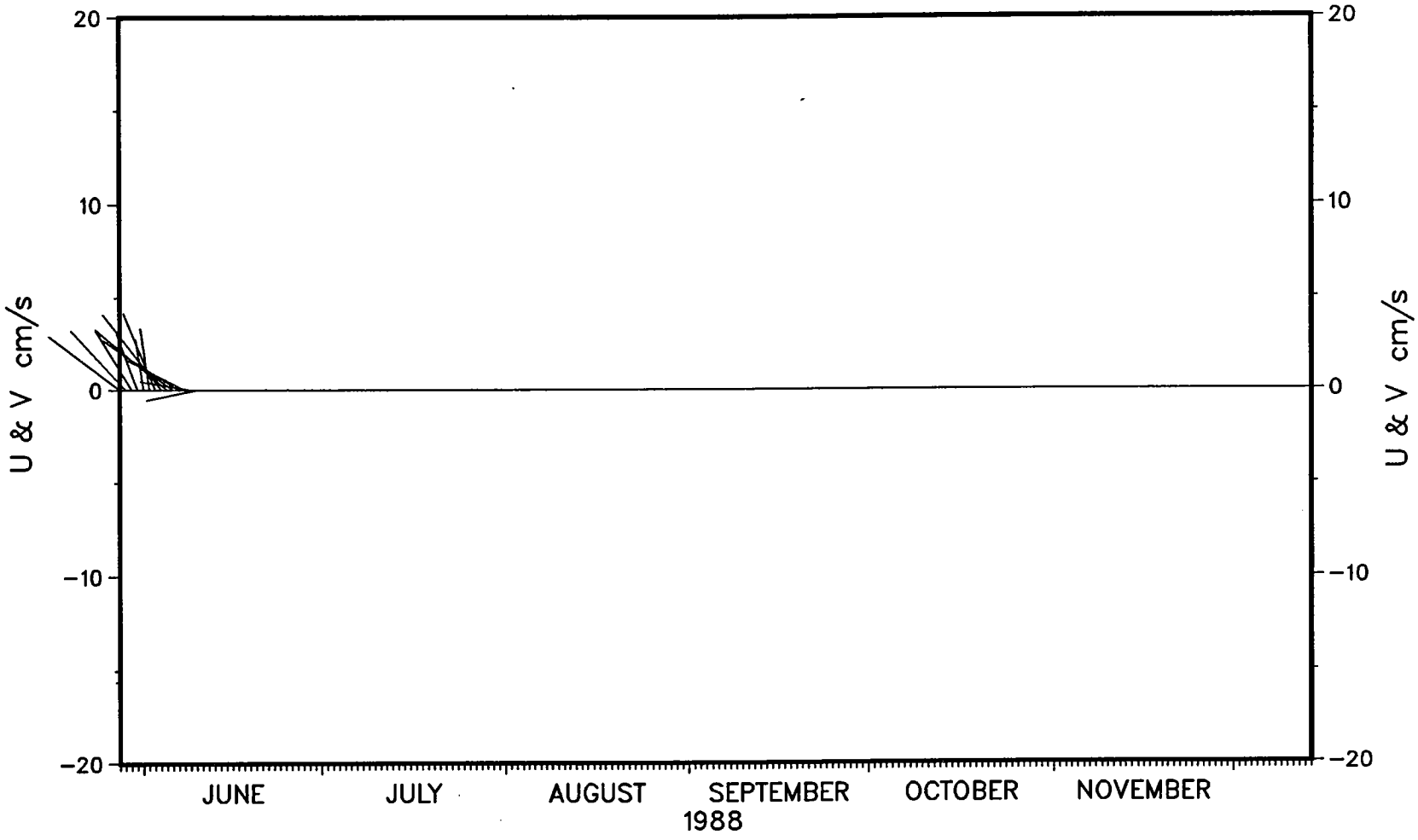
PLOT 2 OF 4
.SPL

EASTERN BASIN 131



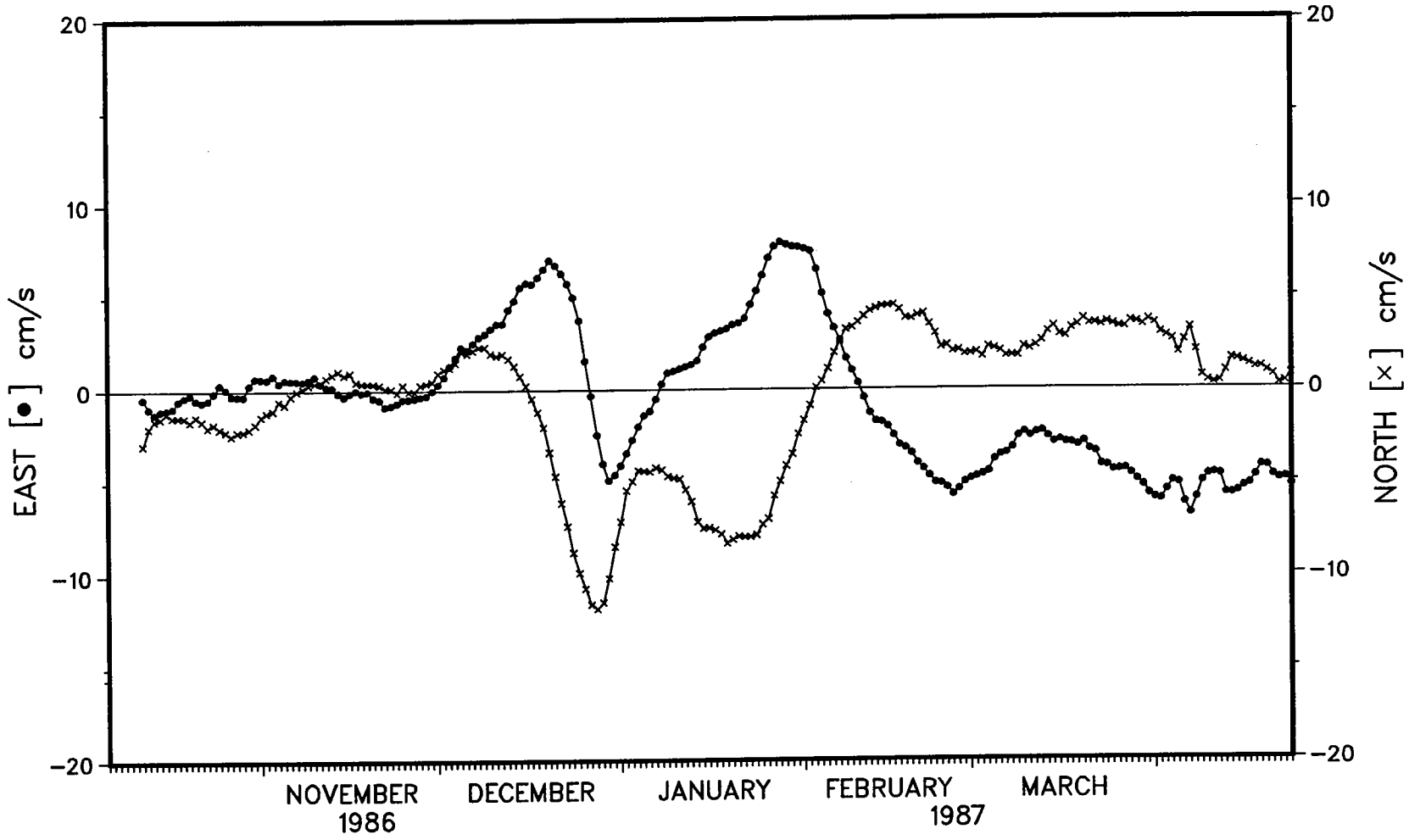
PLOT 3 OF 4
.SPL

EASTERN BASIN 131



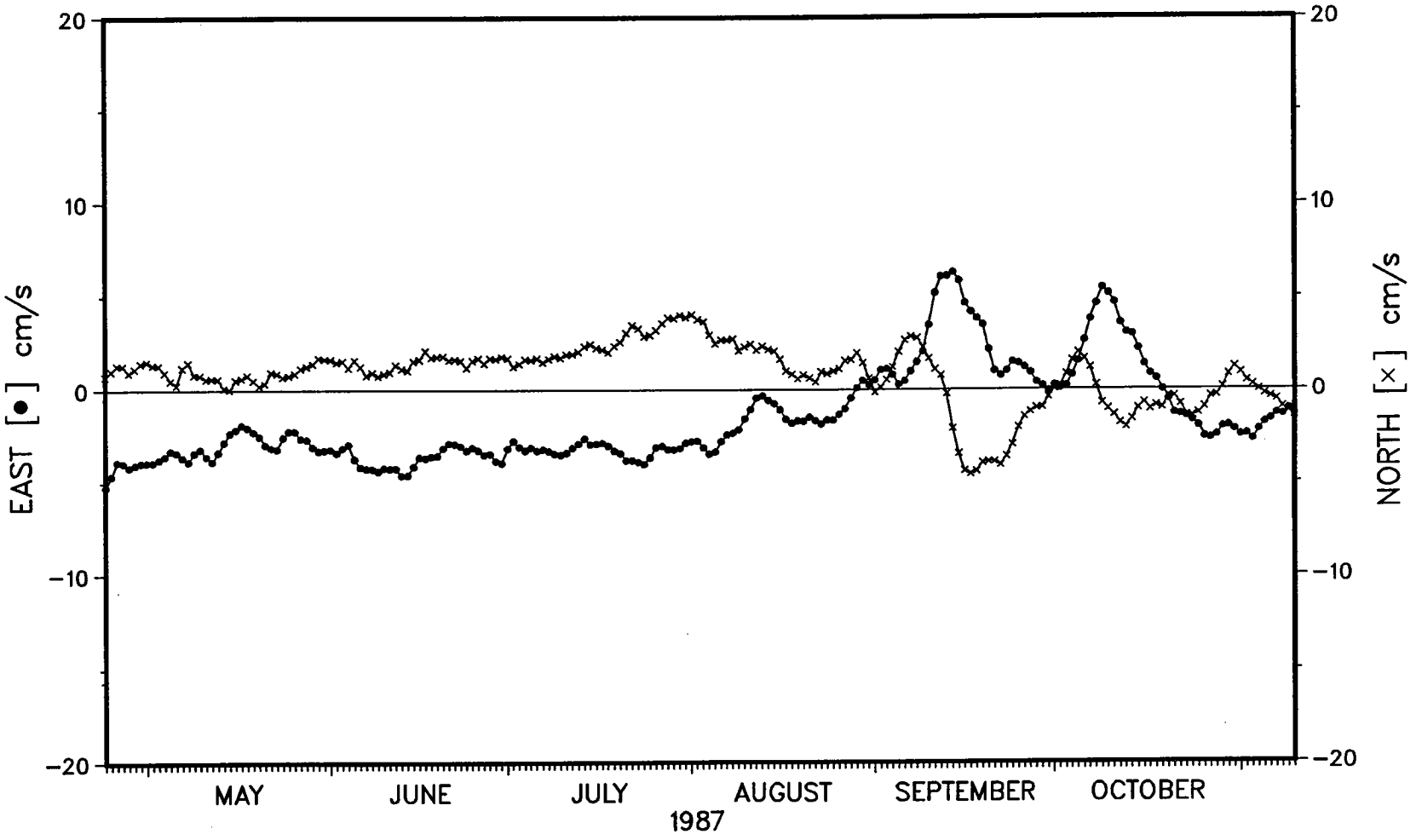
PLOT 4 OF 4
.SPL

EASTERN BASIN 131



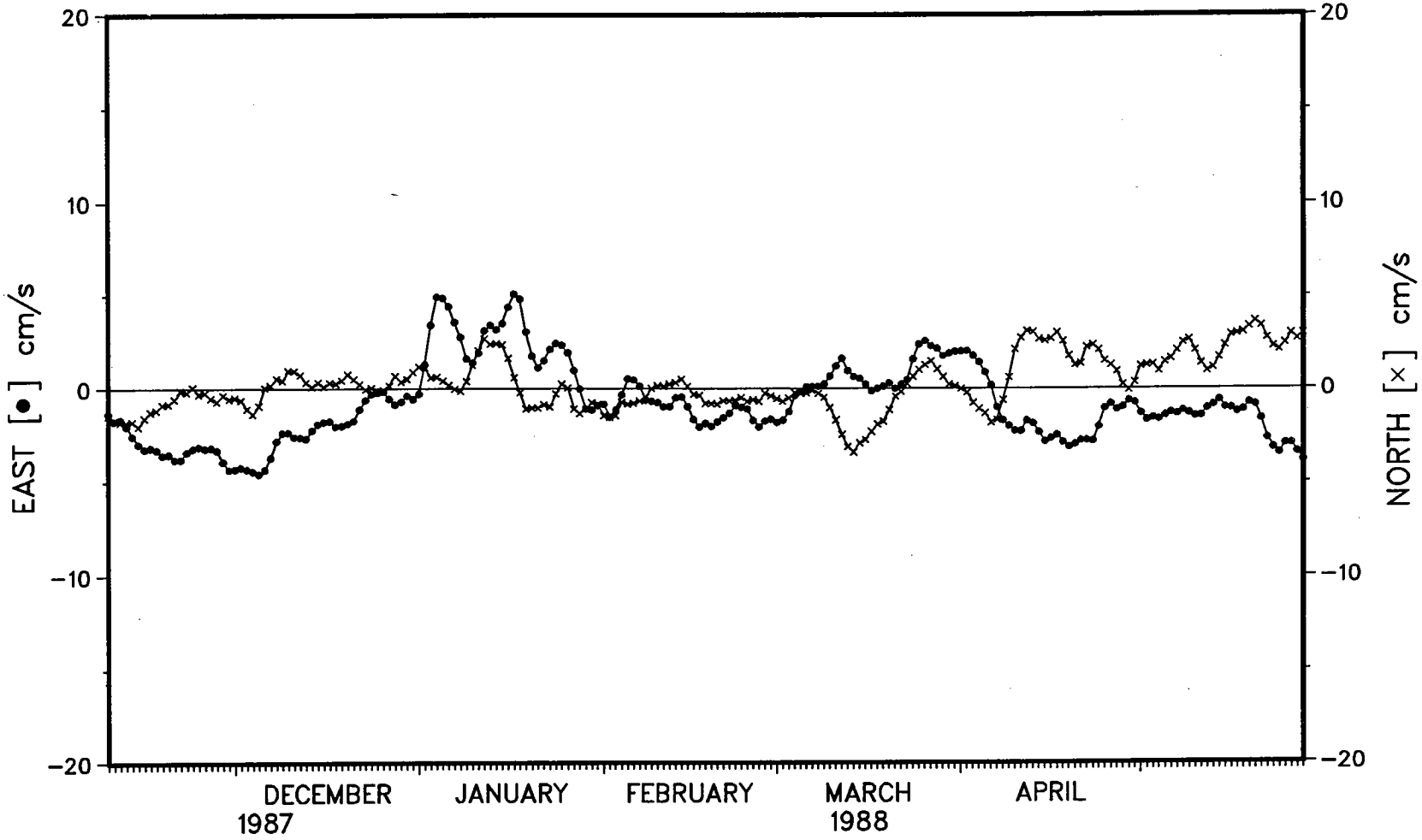
PLOT 1 OF 4
.SPL

EASTERN BASIN 131



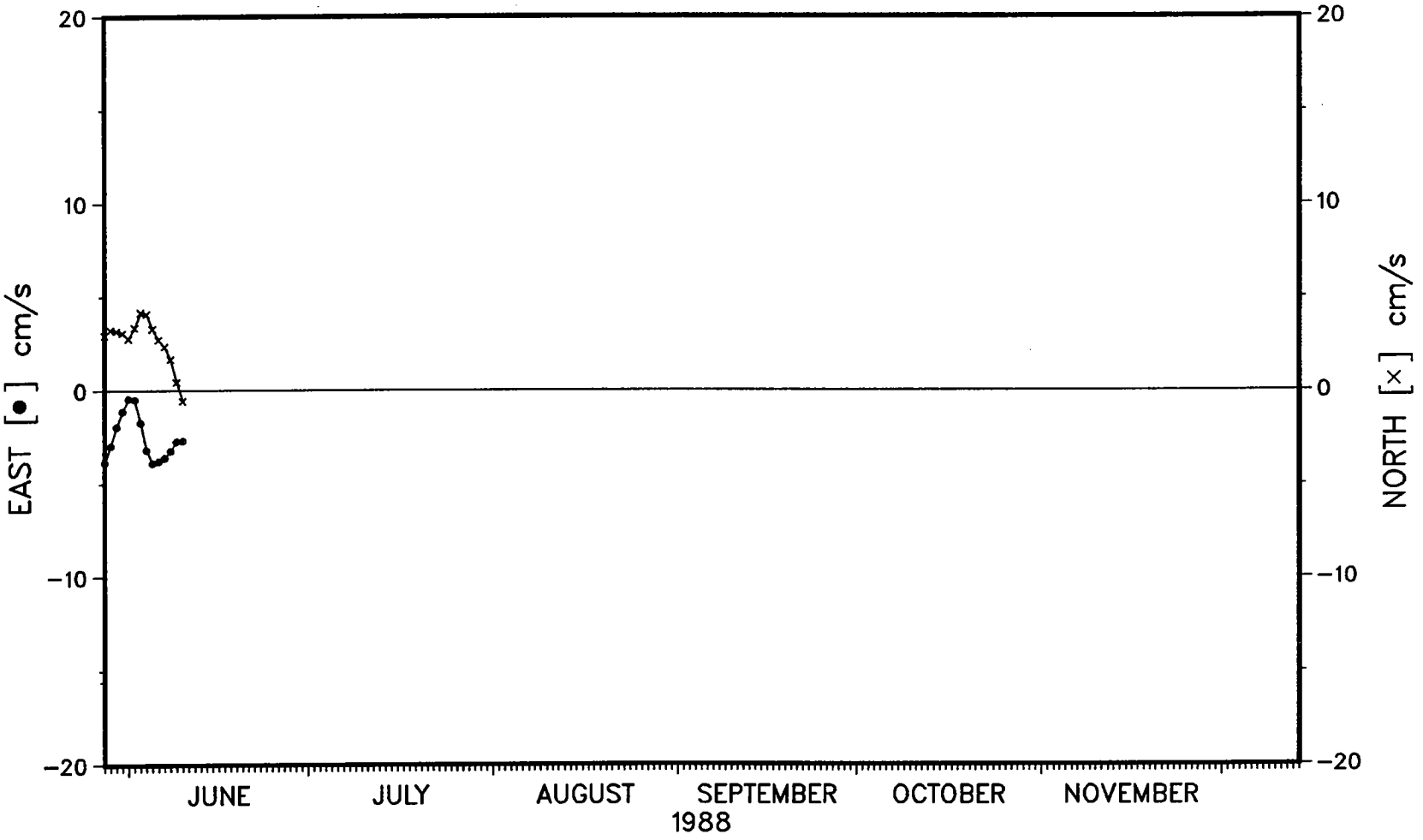
PLOT 2 OF 4
.SPL

EASTERN BASIN 131



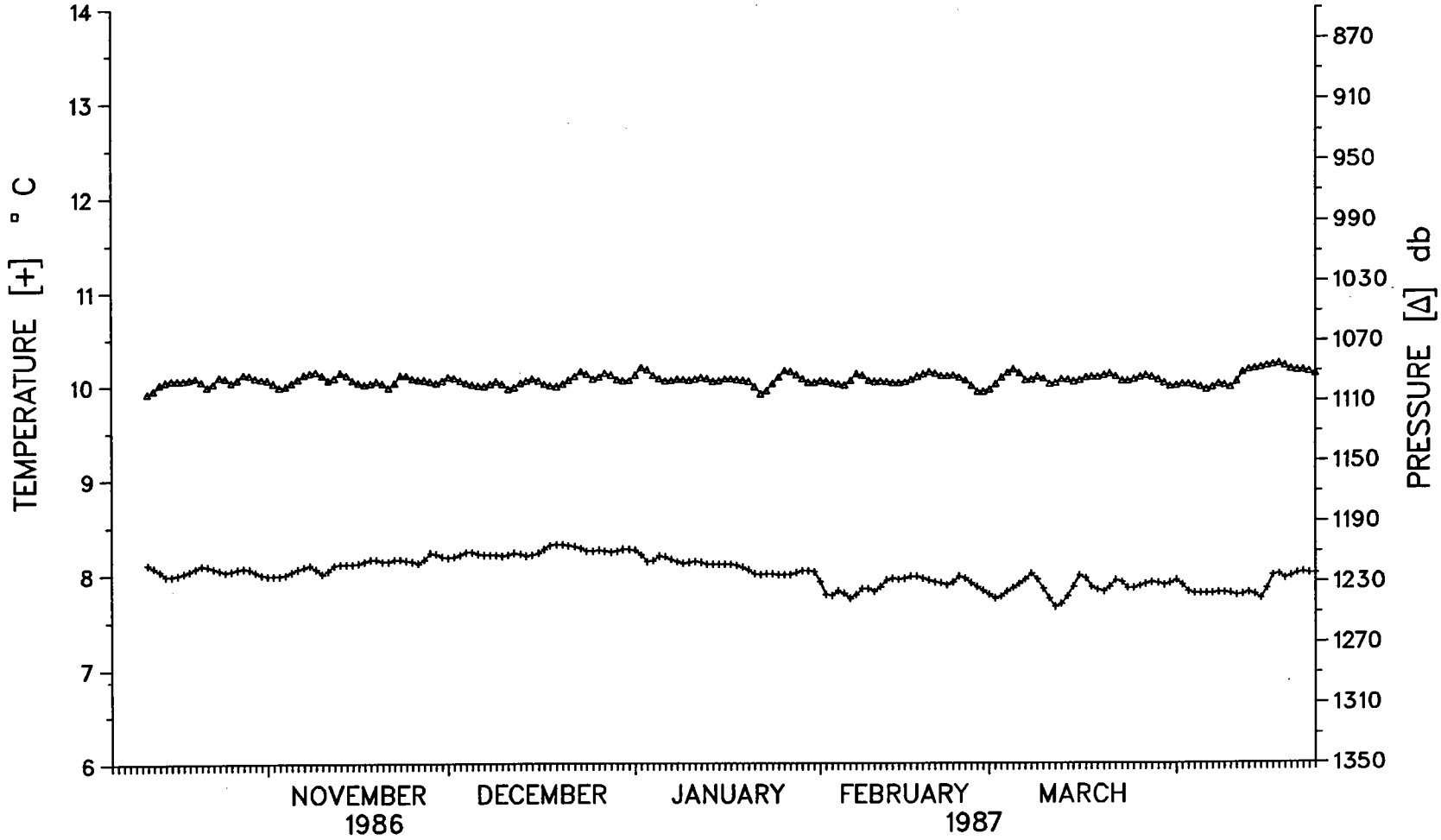
PLOT 3 OF 4
.SPL

EASTERN BASIN 131



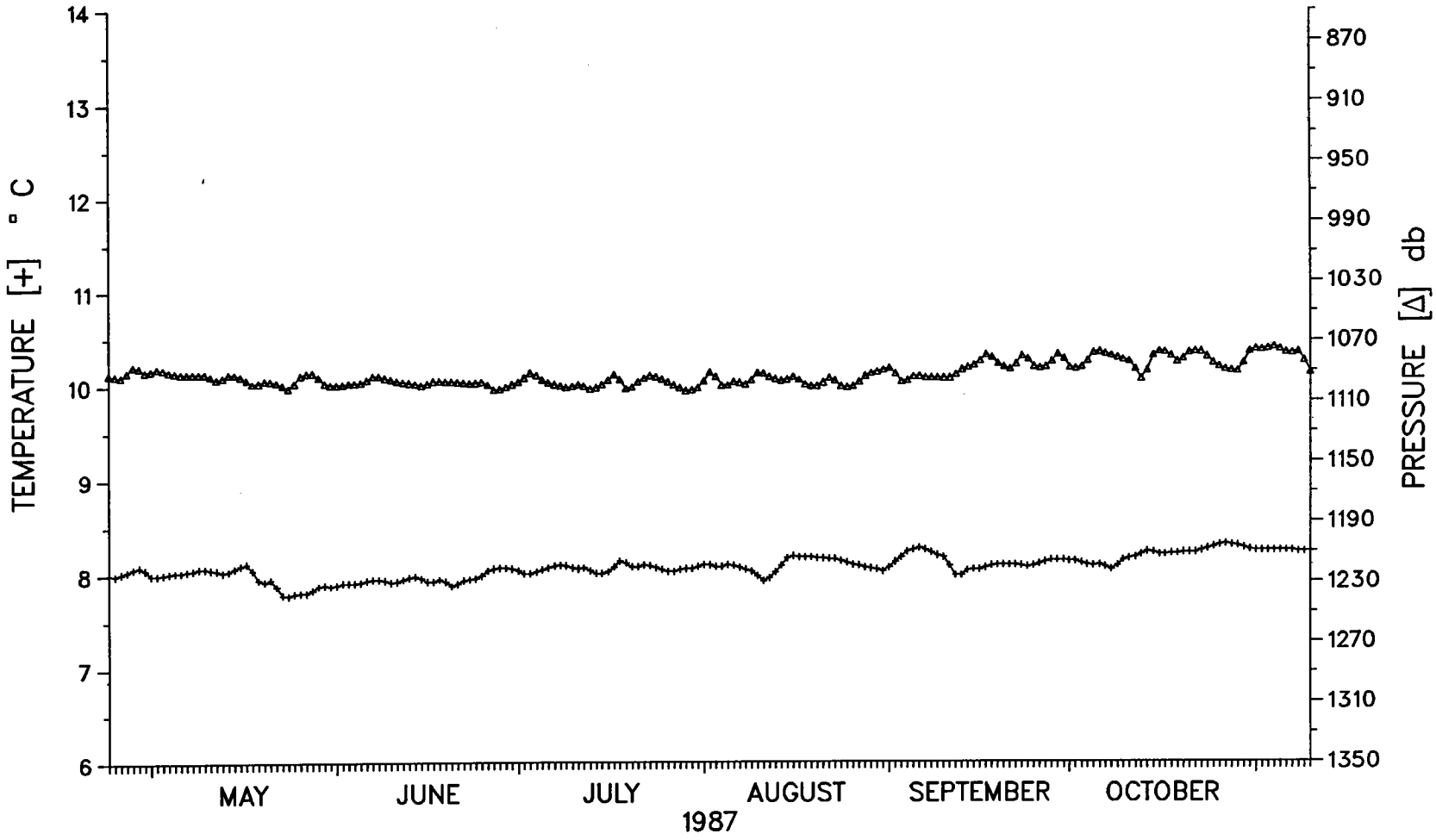
PLOT 4 OF 4
.SPL

EASTERN BASIN 131



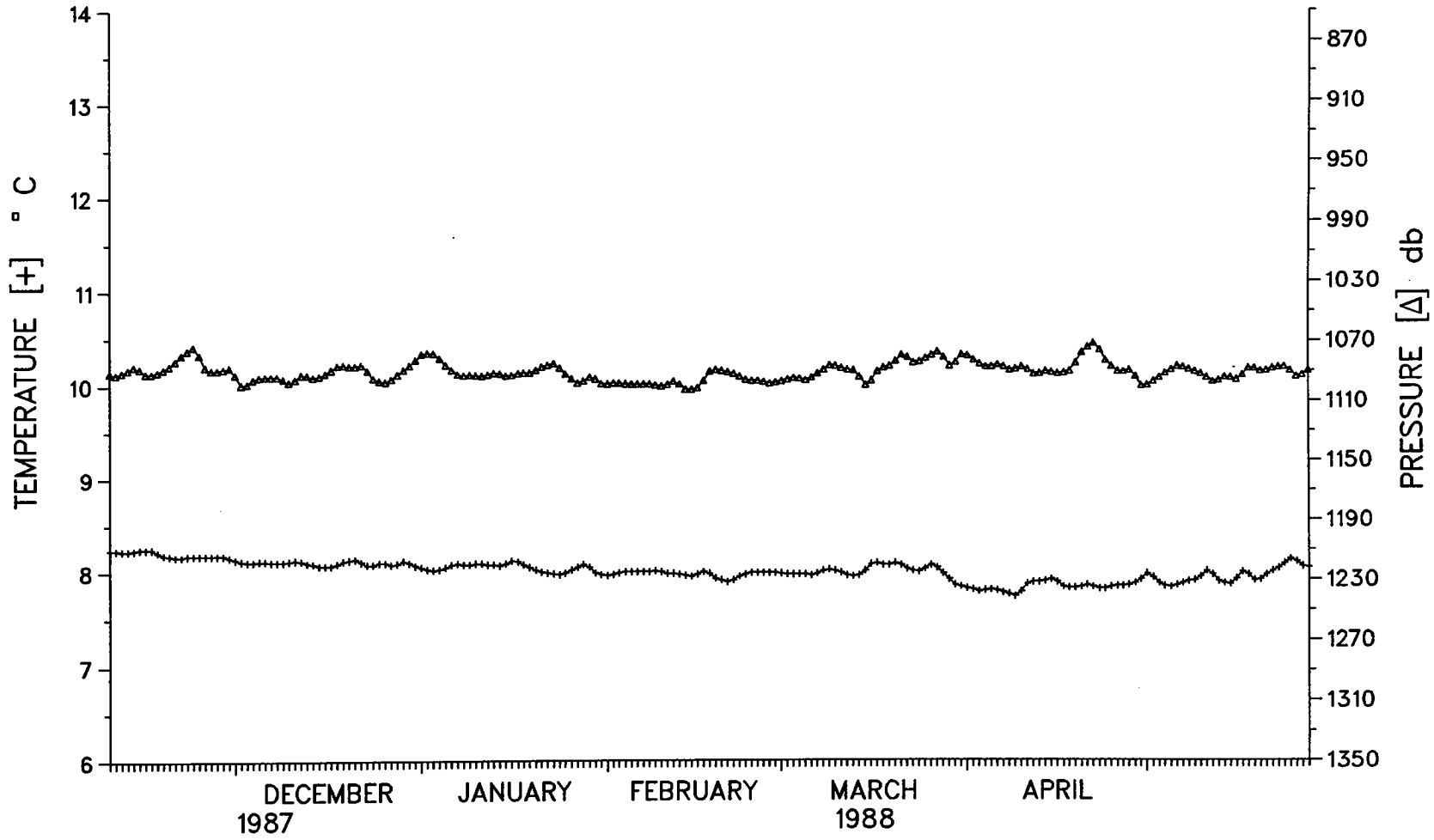
PLOT 1 OF 4
.SPL

EASTERN BASIN 131



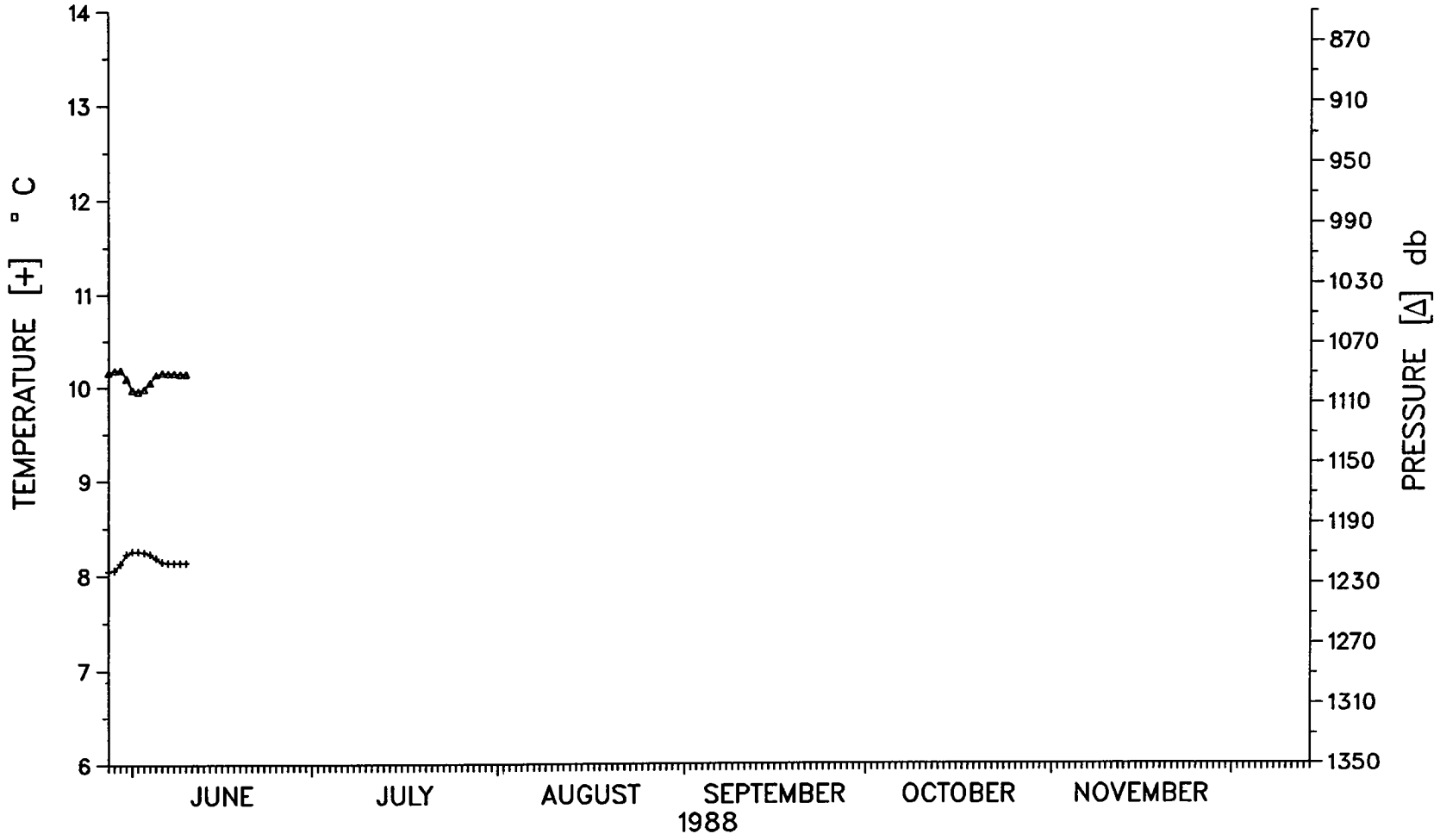
PLOT 2 OF 4
.SPL

EASTERN BASIN 131



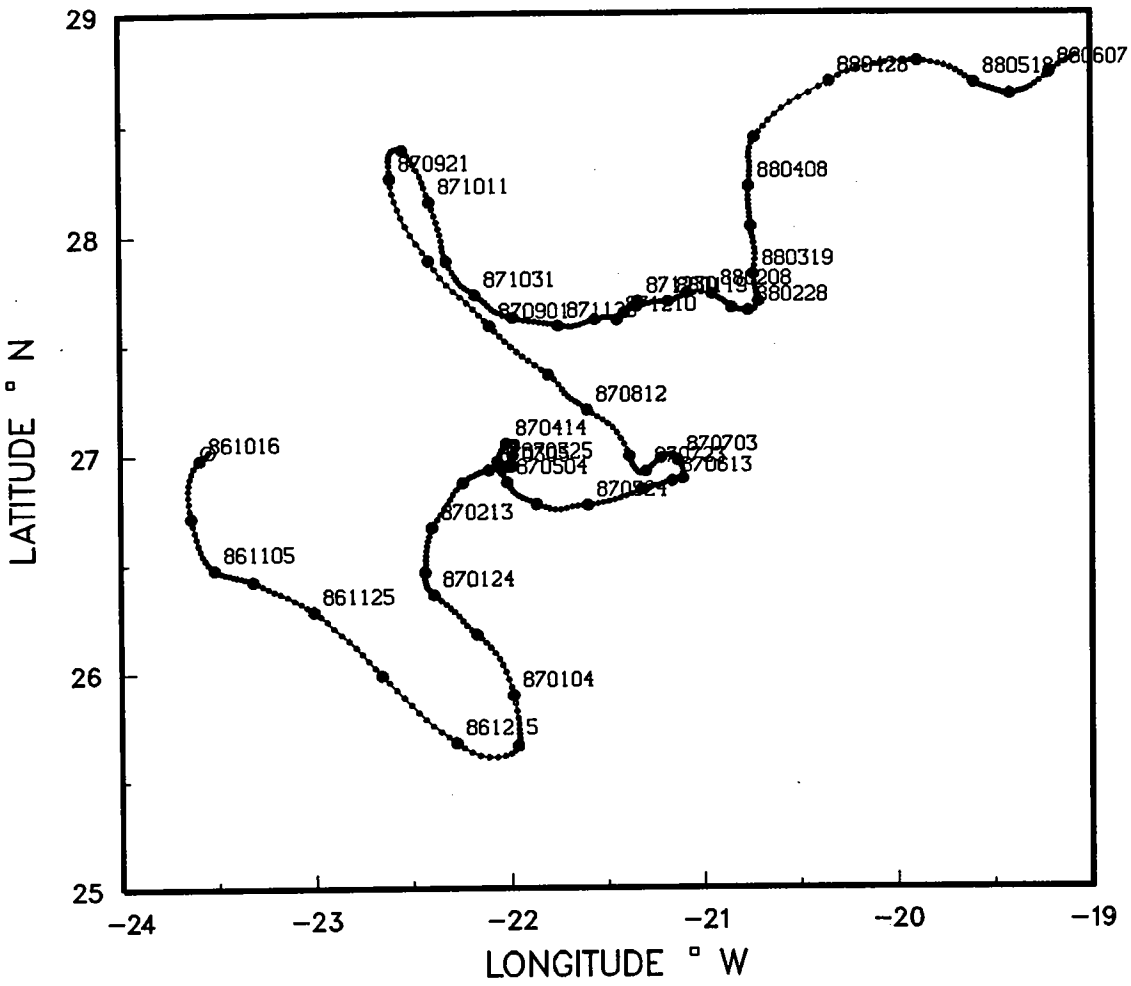
PLOT 3 OF 4
.SPL

EASTERN BASIN 131



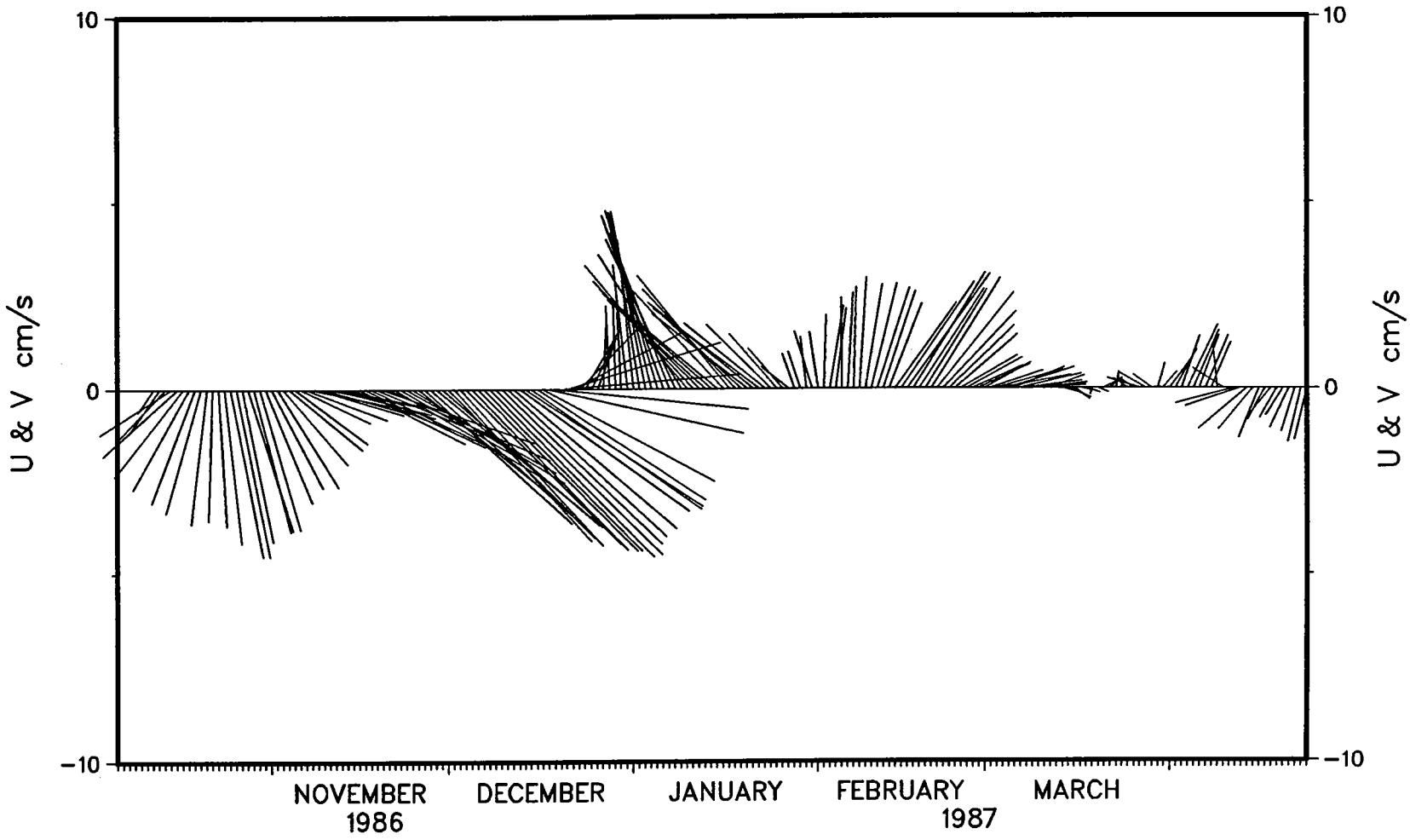
PLOT 4 OF 4
.SPL

EASTERN BASIN 132



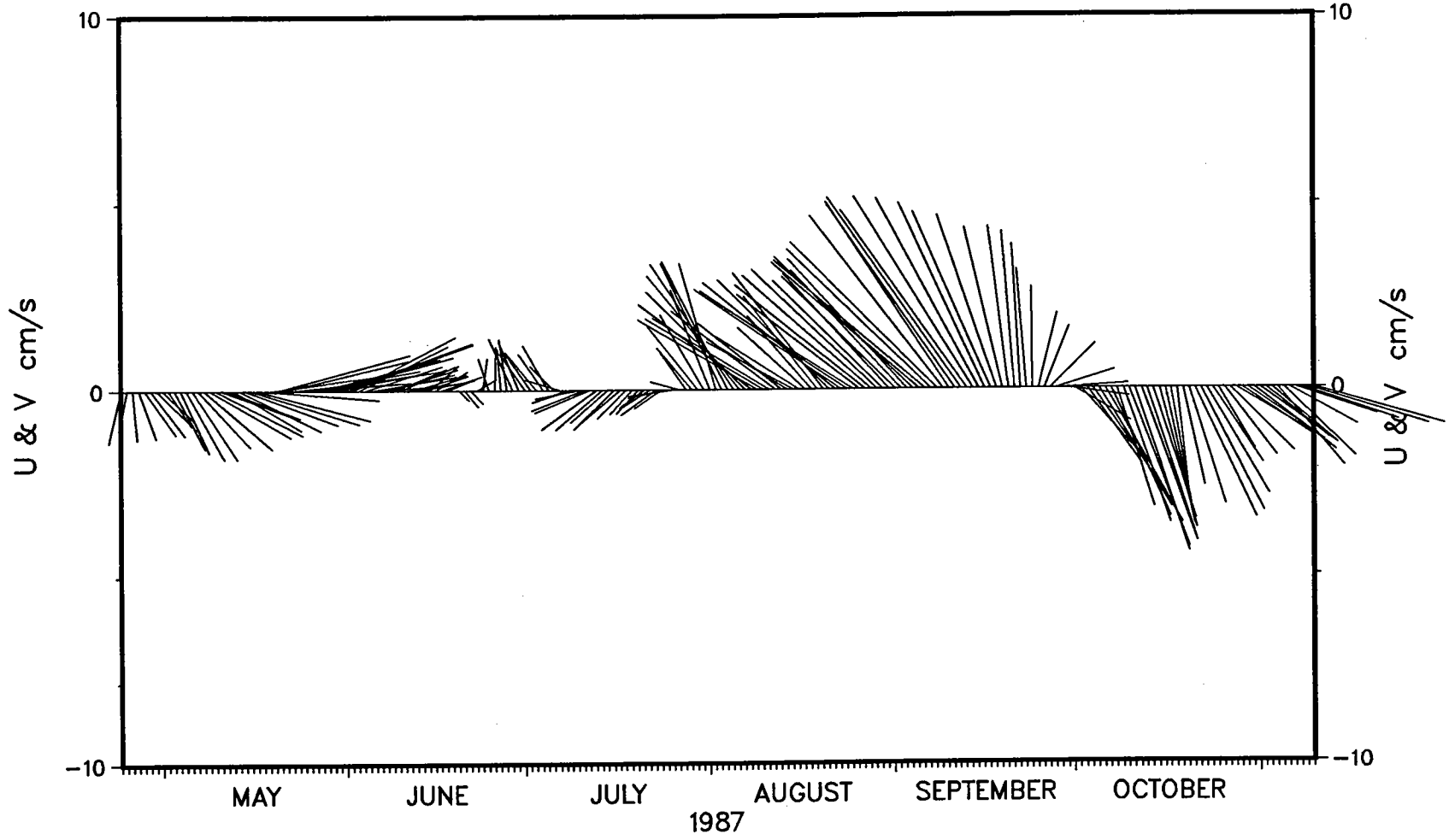
PLOT 1 OF 1
.SPL

EASTERN BASIN 132



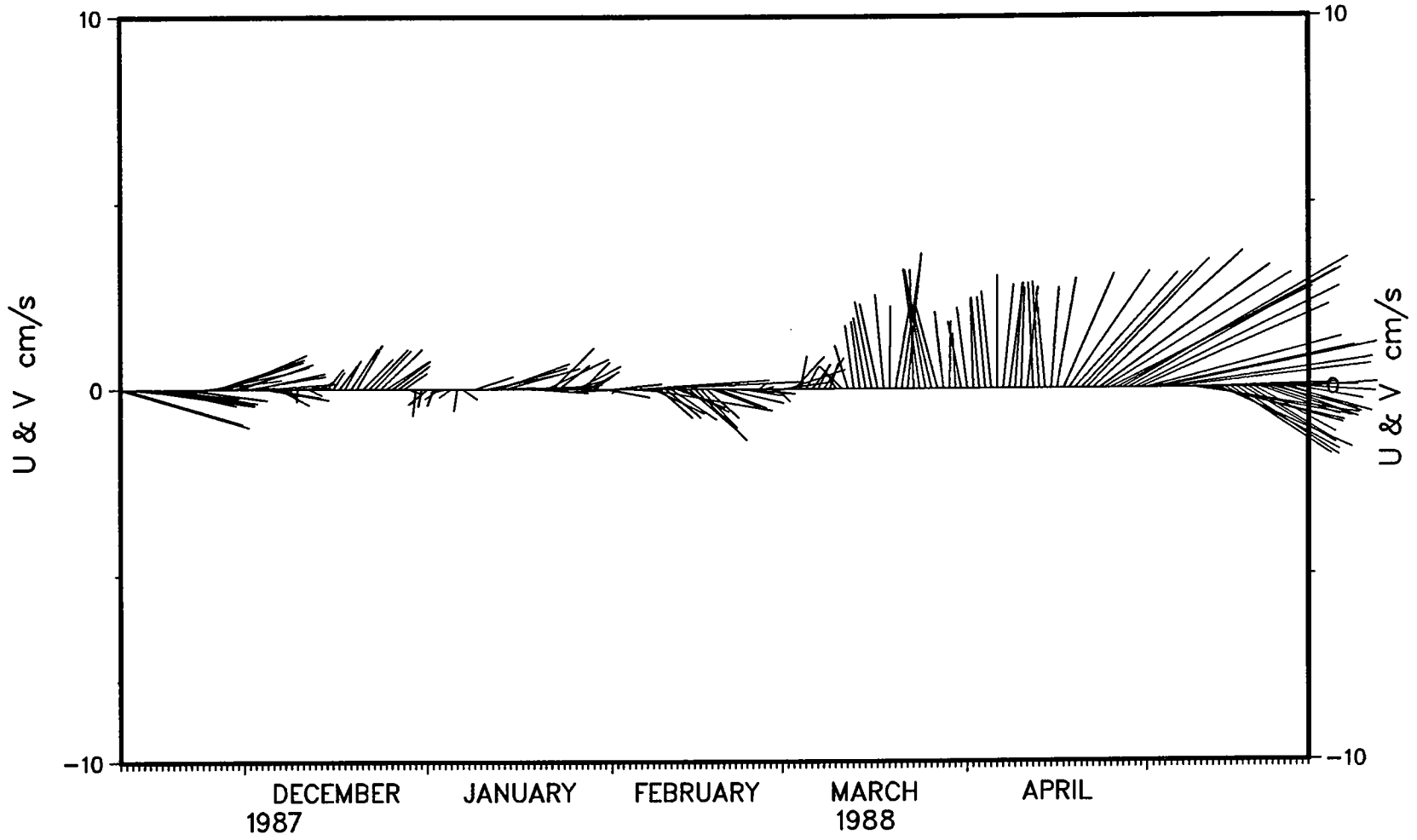
PLOT 1 OF 4
.SPL

EASTERN BASIN 132



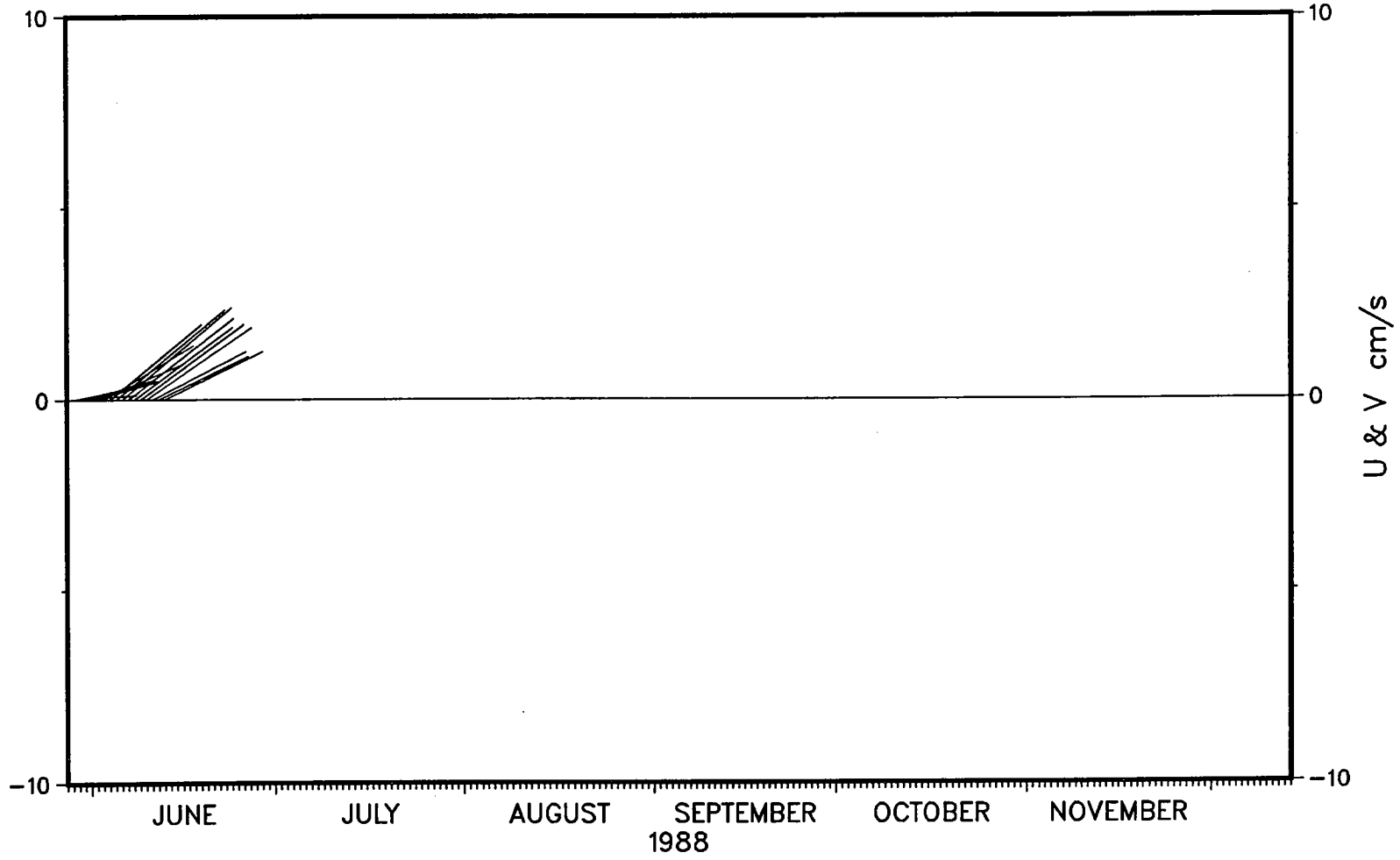
PLOT 2 OF 4
.SPL

EASTERN BASIN 132



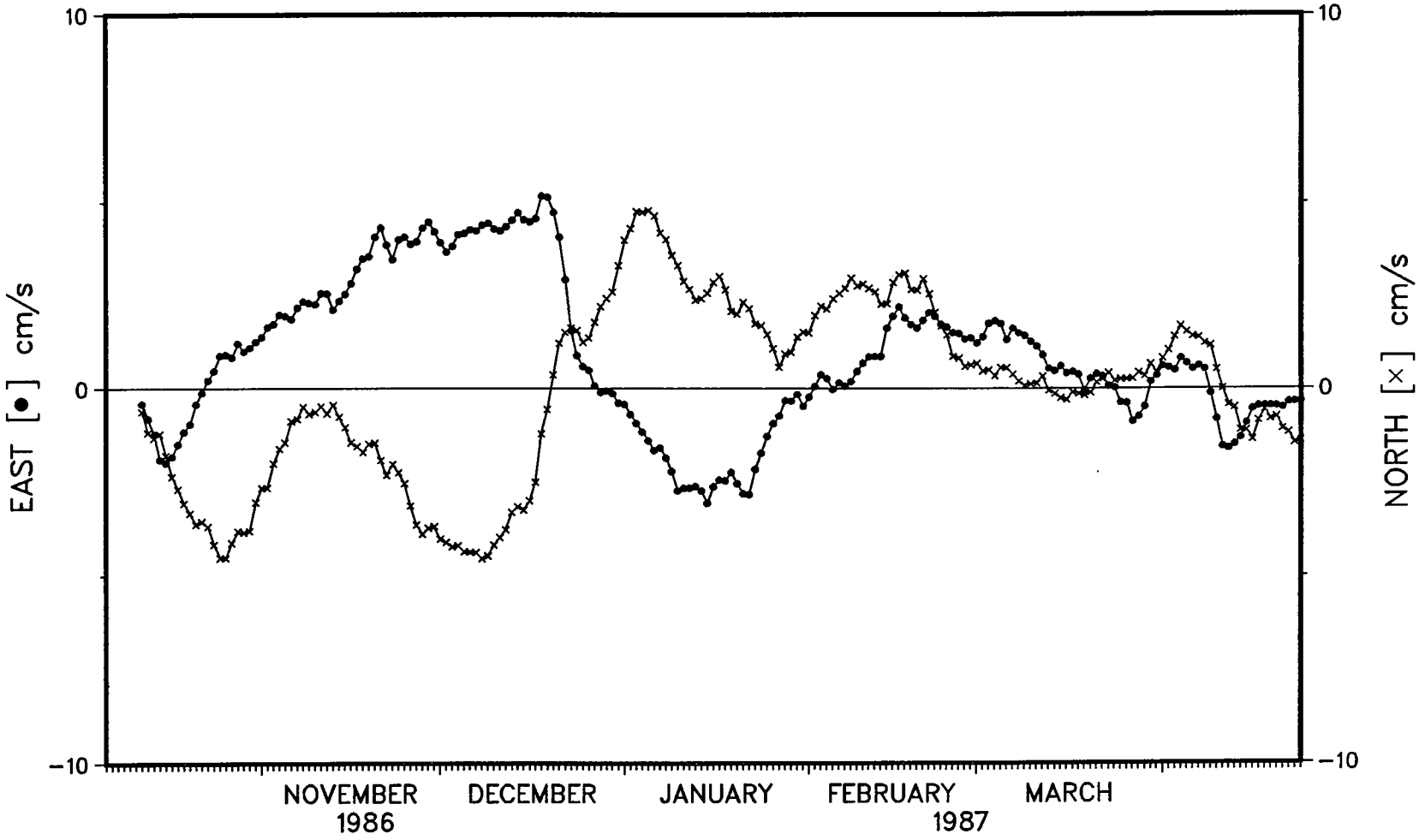
PLOT 3 OF 4
.SPL

EASTERN BASIN 132



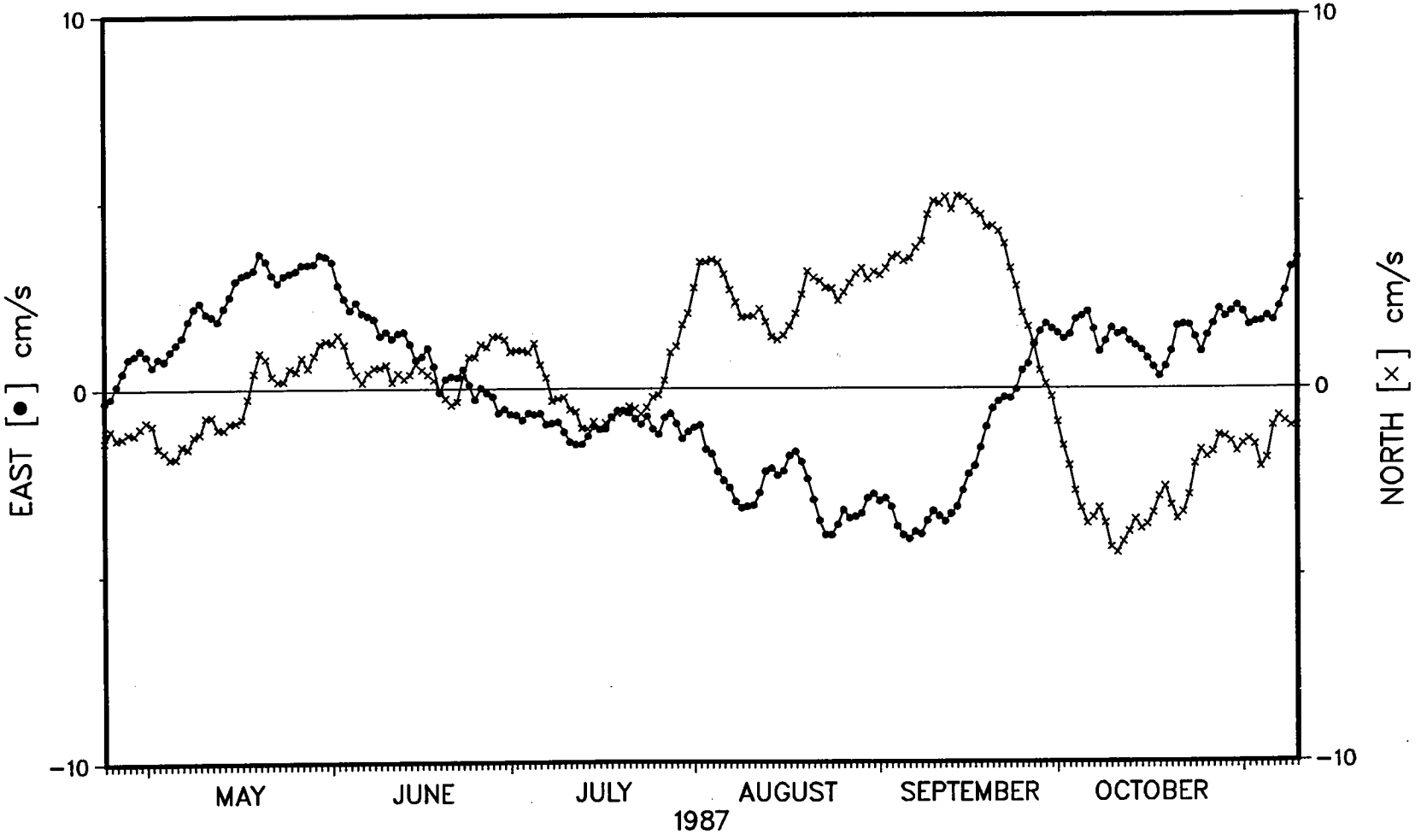
PLOT 4 OF 4
.SPL

EASTERN BASIN 132



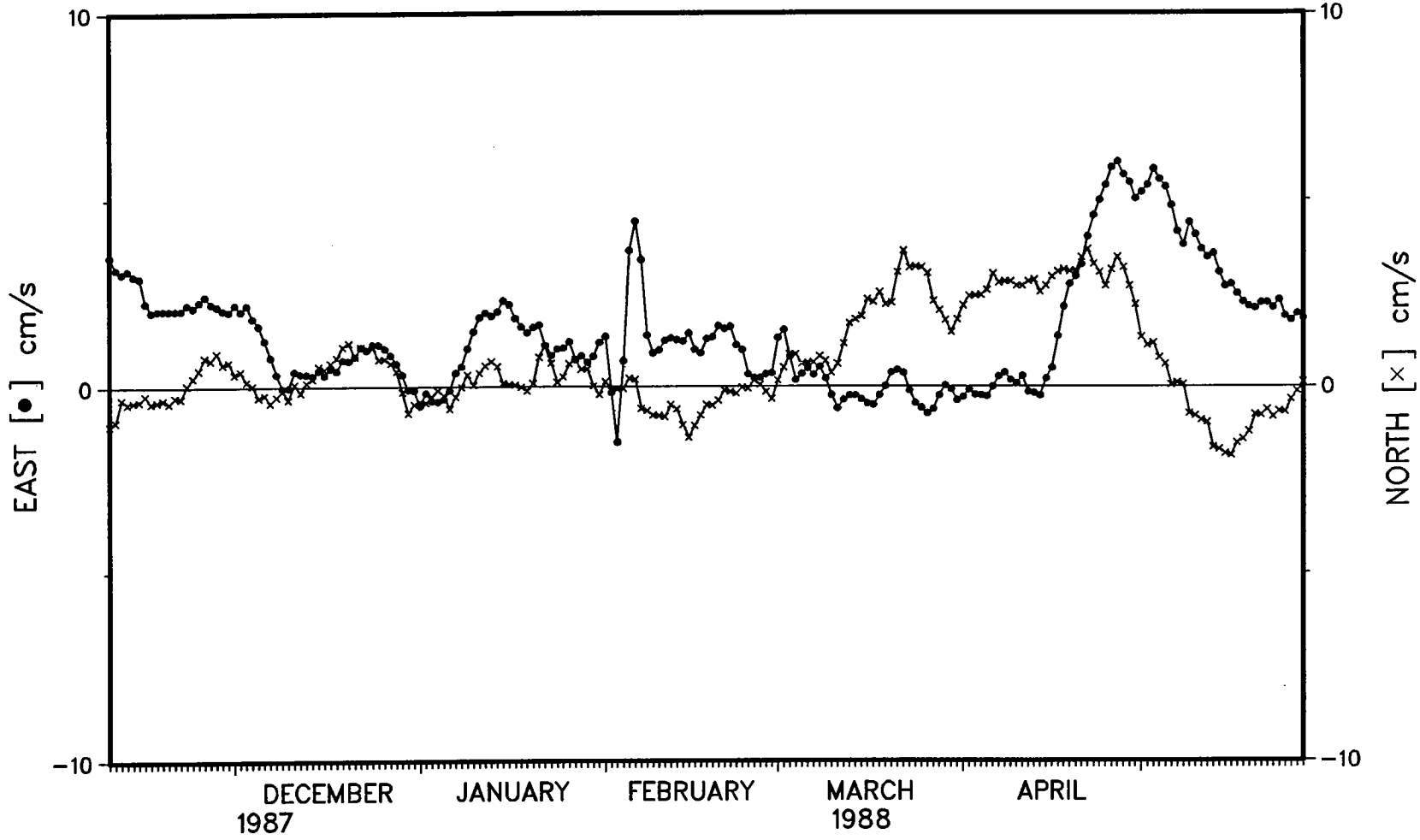
PLOT 1 OF 4
.SPL

EASTERN BASIN 132



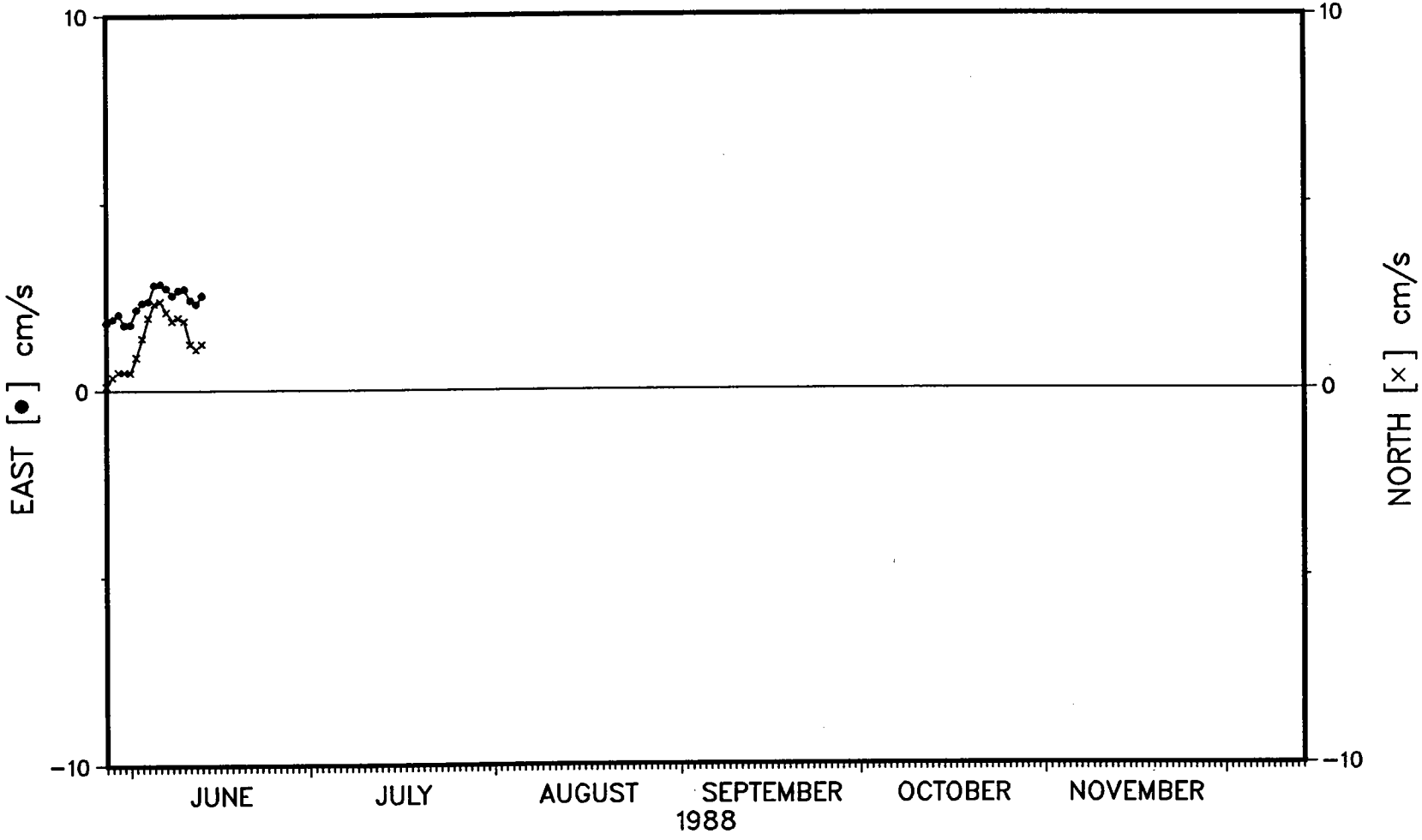
PLOT 2 OF 4
.SPL

EASTERN BASIN 132



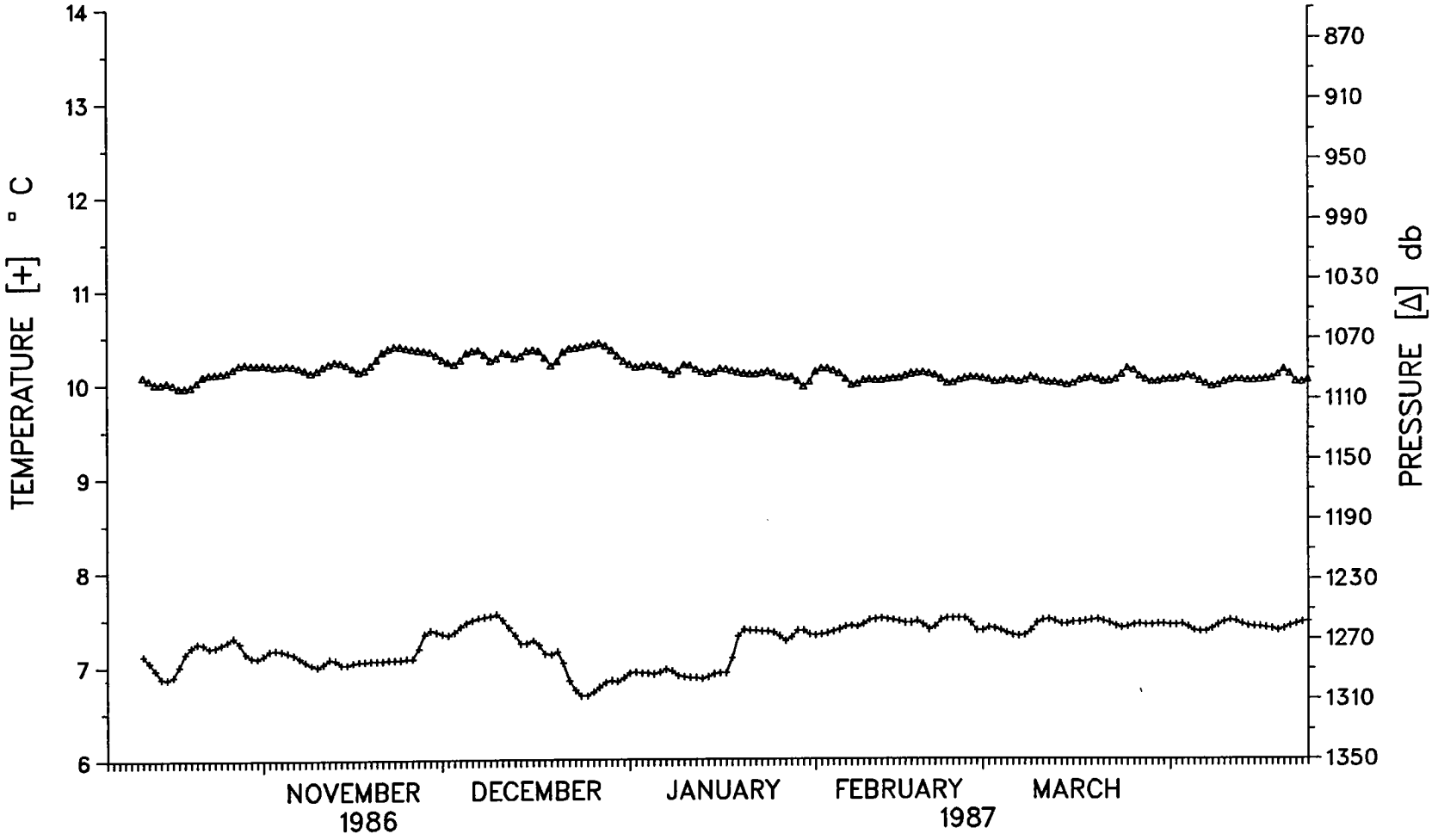
PLOT 3 OF 4
.SPL

EASTERN BASIN 132



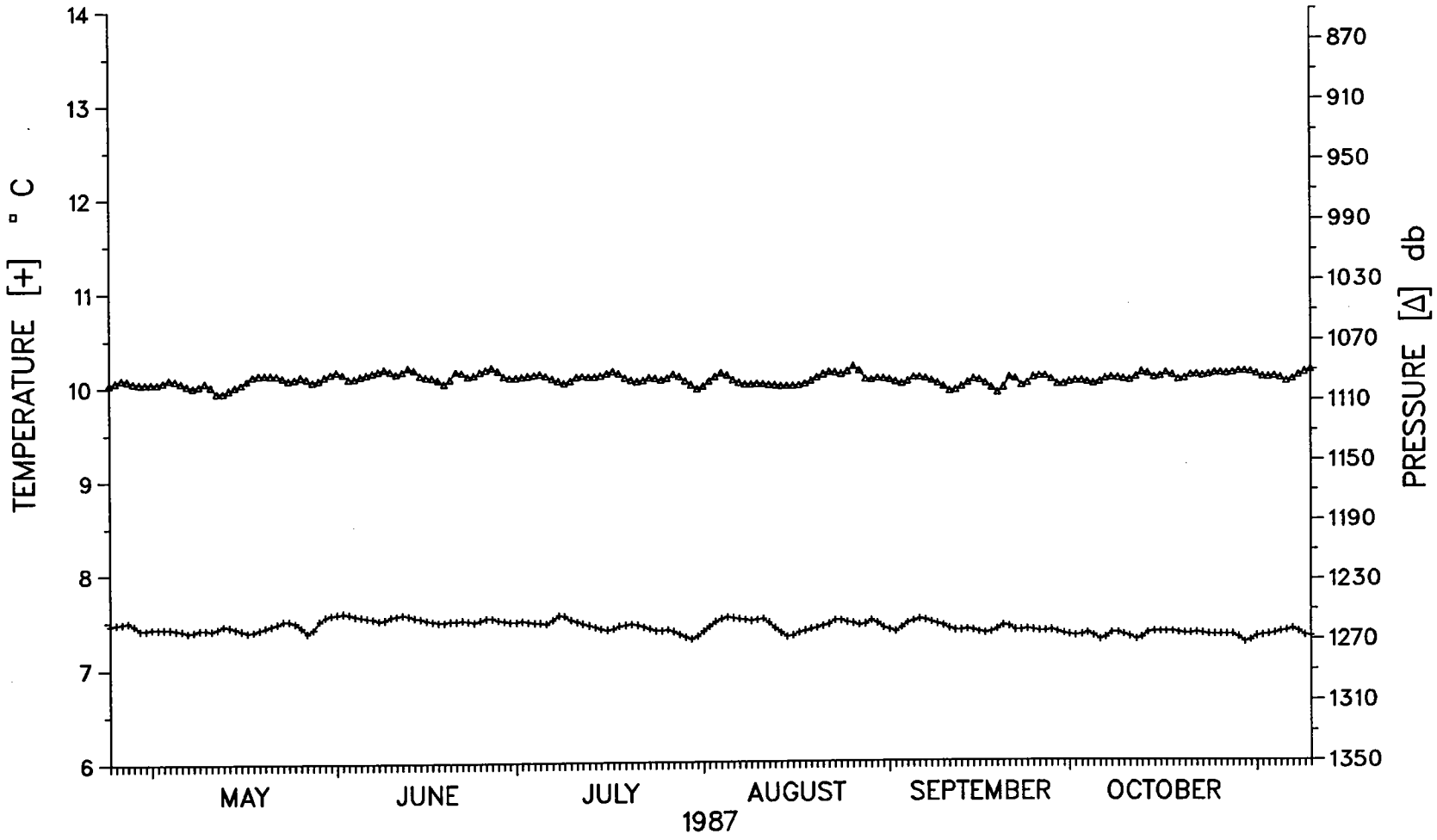
PLOT 4 OF 4
.SPL

EASTERN BASIN 132



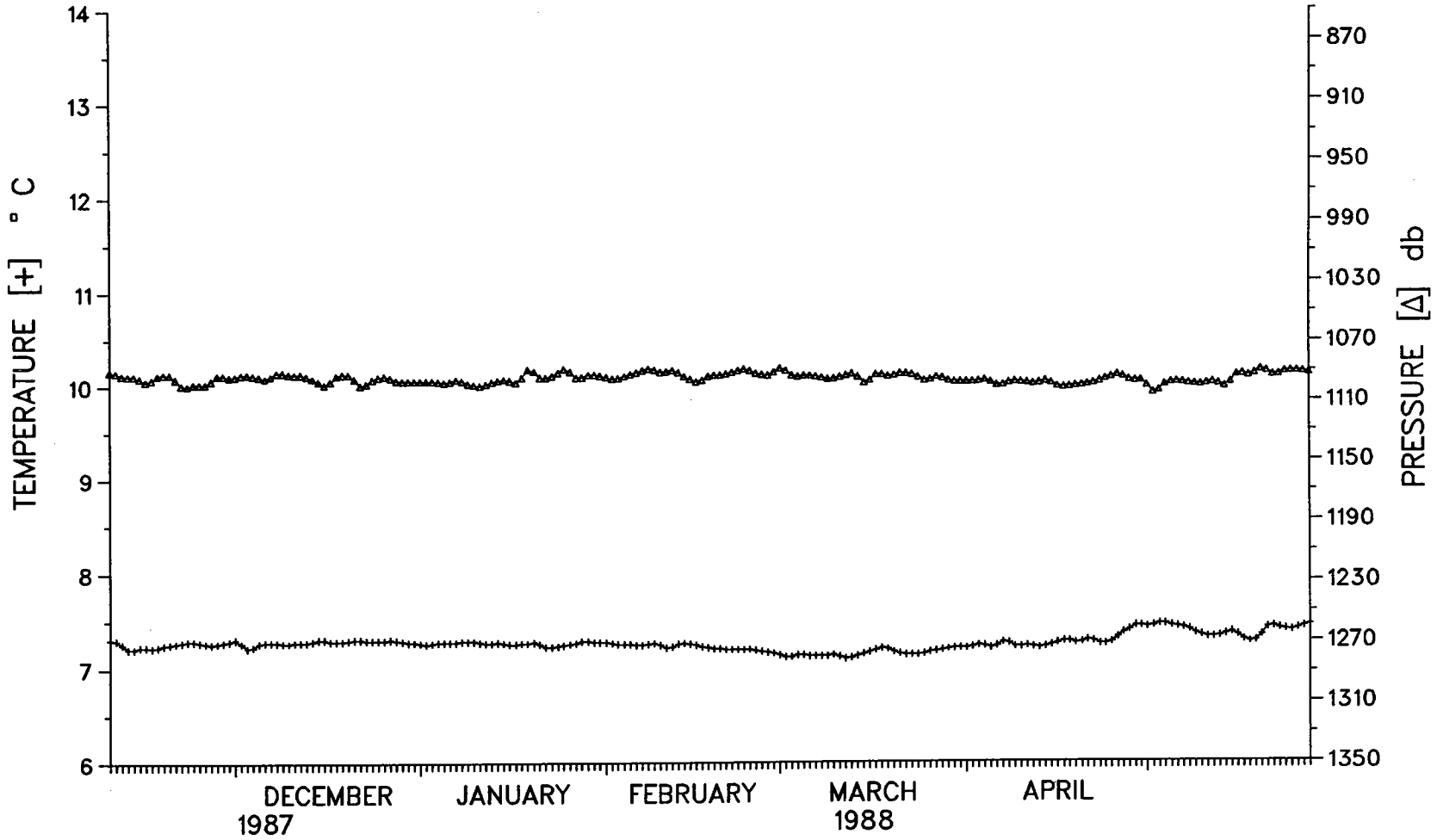
PLOT 1 OF 4
.SPL

EASTERN BASIN 132



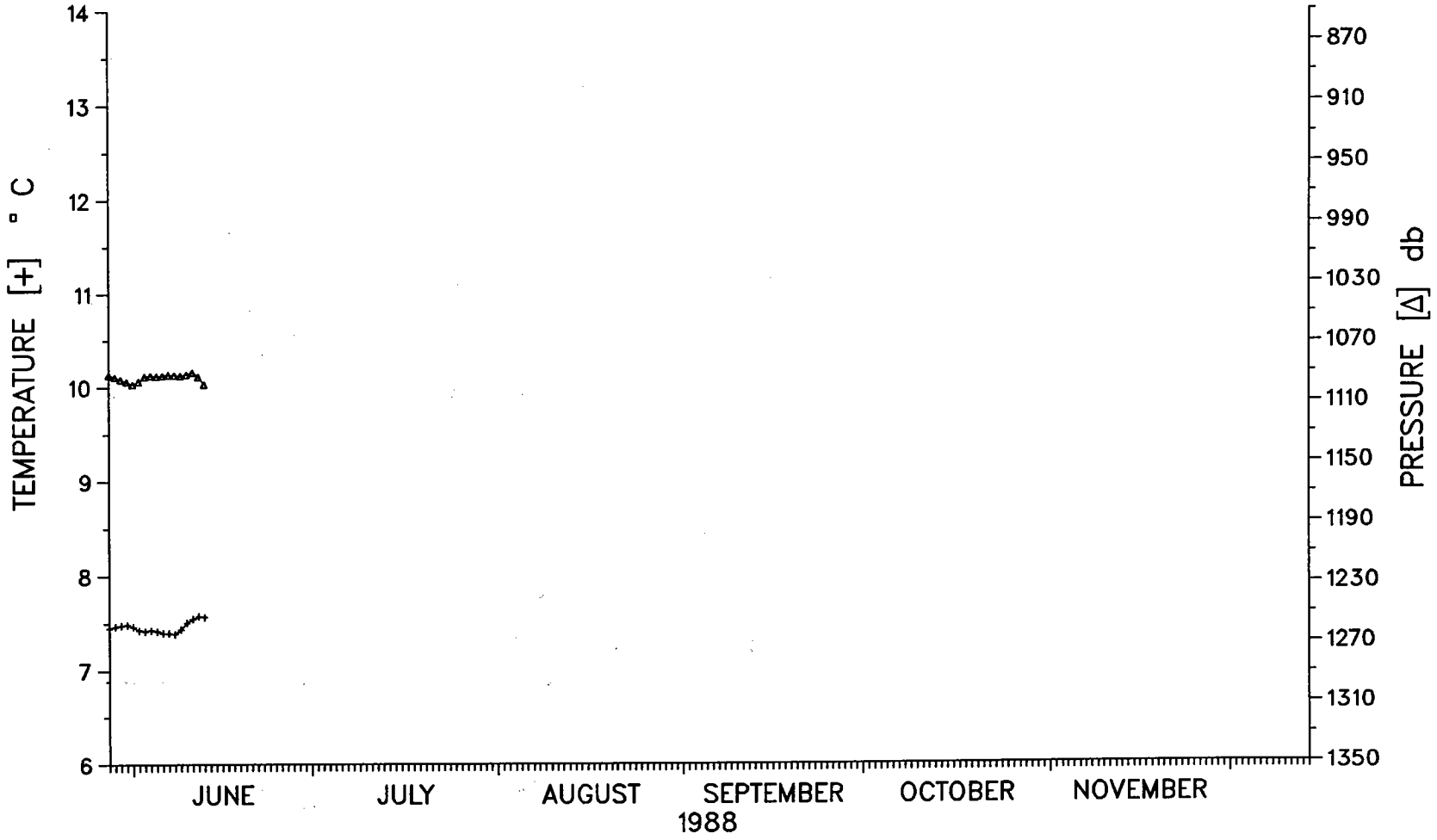
PLOT 2 OF 4
.SPL

EASTERN BASIN 132



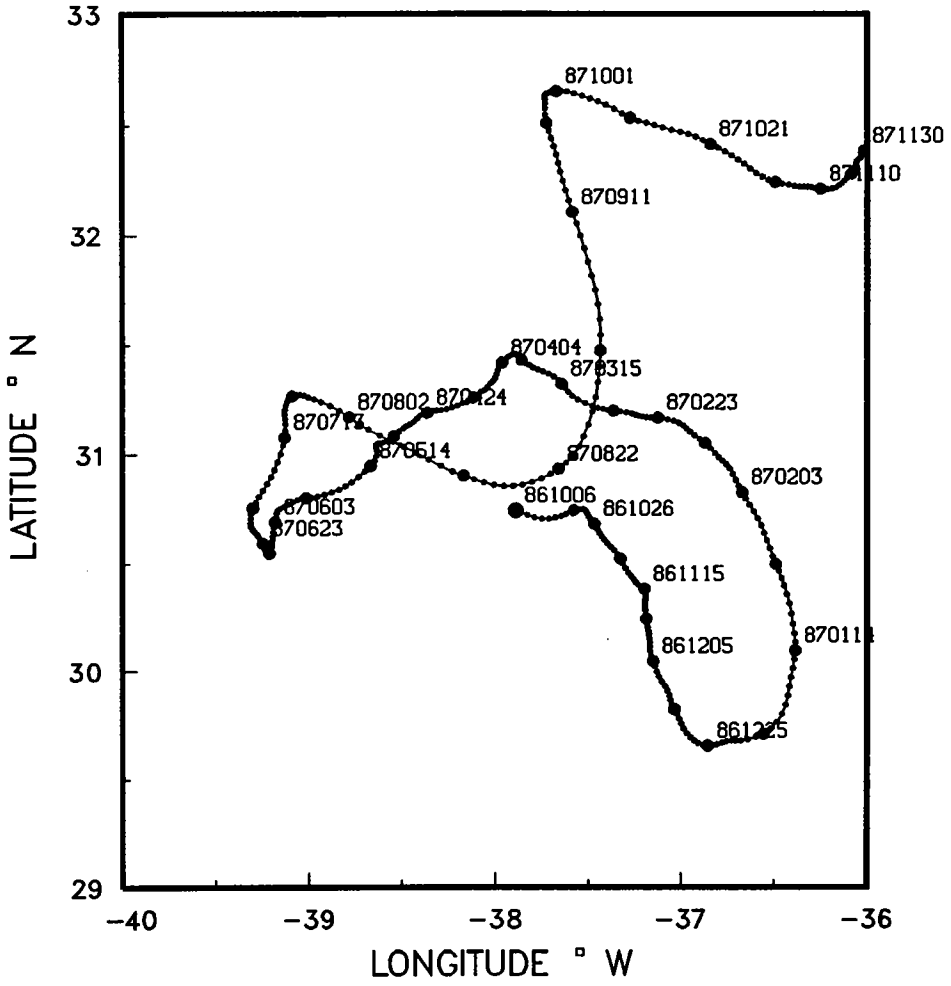
PLOT 3 OF 4
.SPL

EASTERN BASIN 132



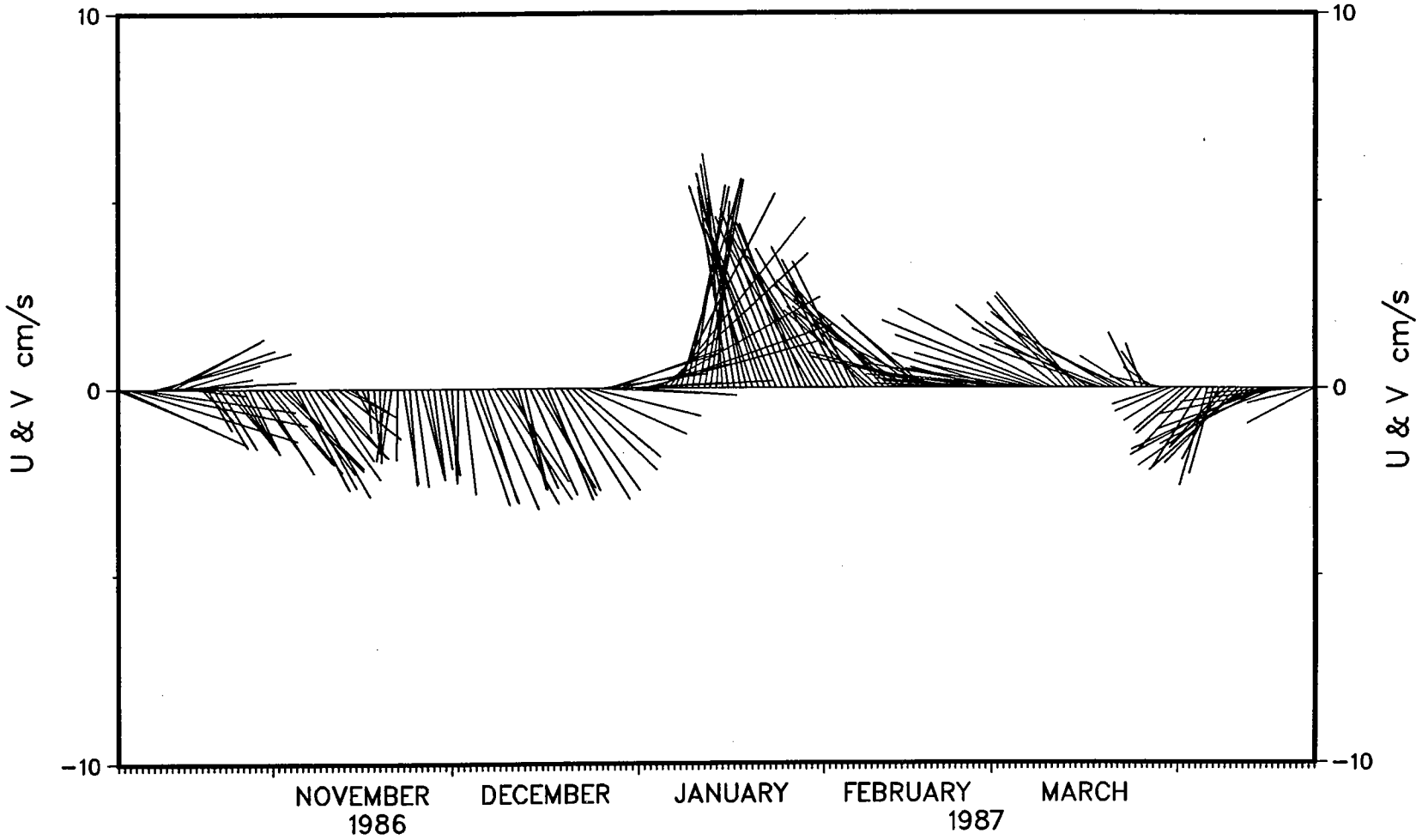
PLOT 4 OF 4
.SPL

EASTERN BASIN 133



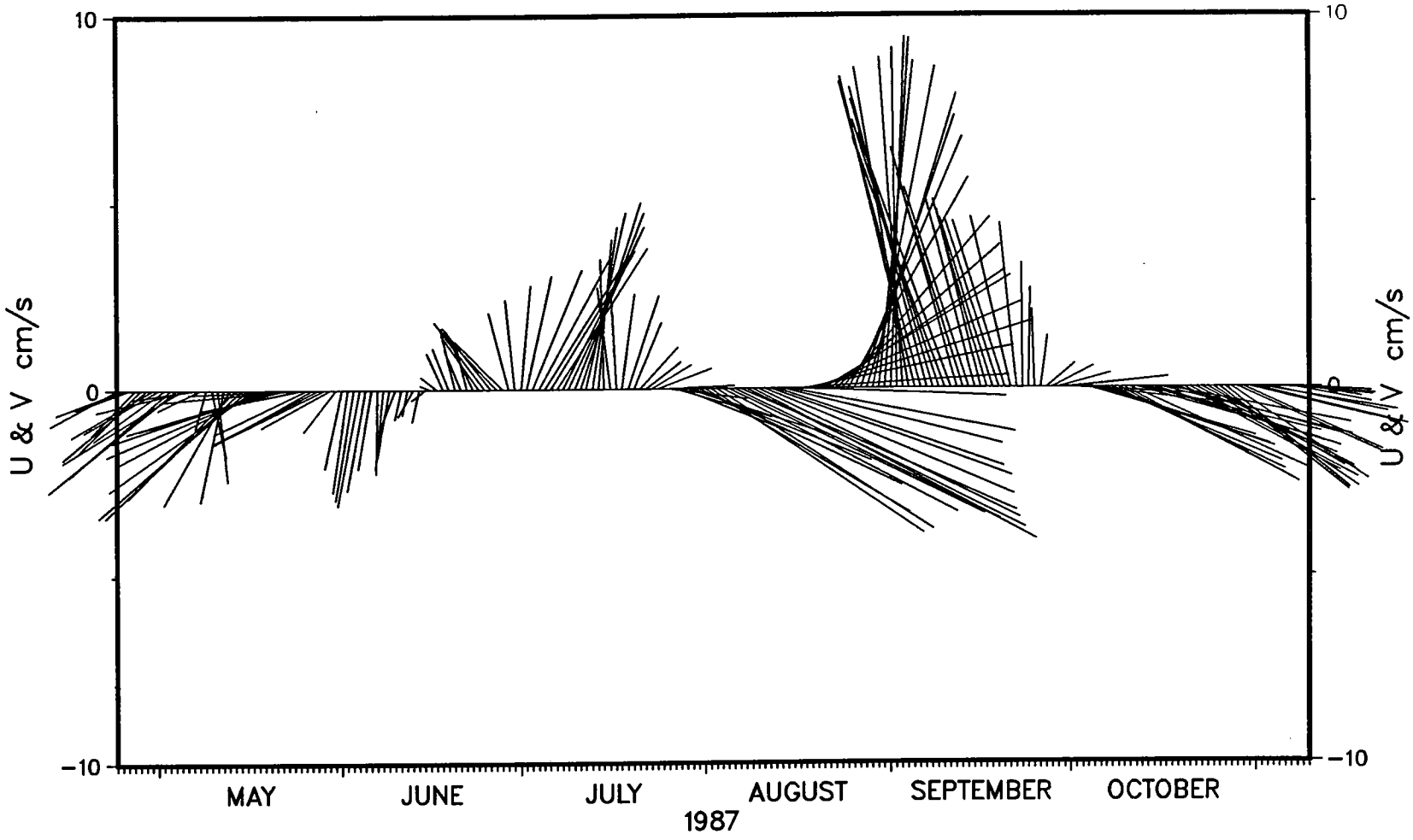
PLOT 1 OF 1
.SPL

EASTERN BASIN 133



PLOT 1 OF 3
.SPL

EASTERN BASIN 133

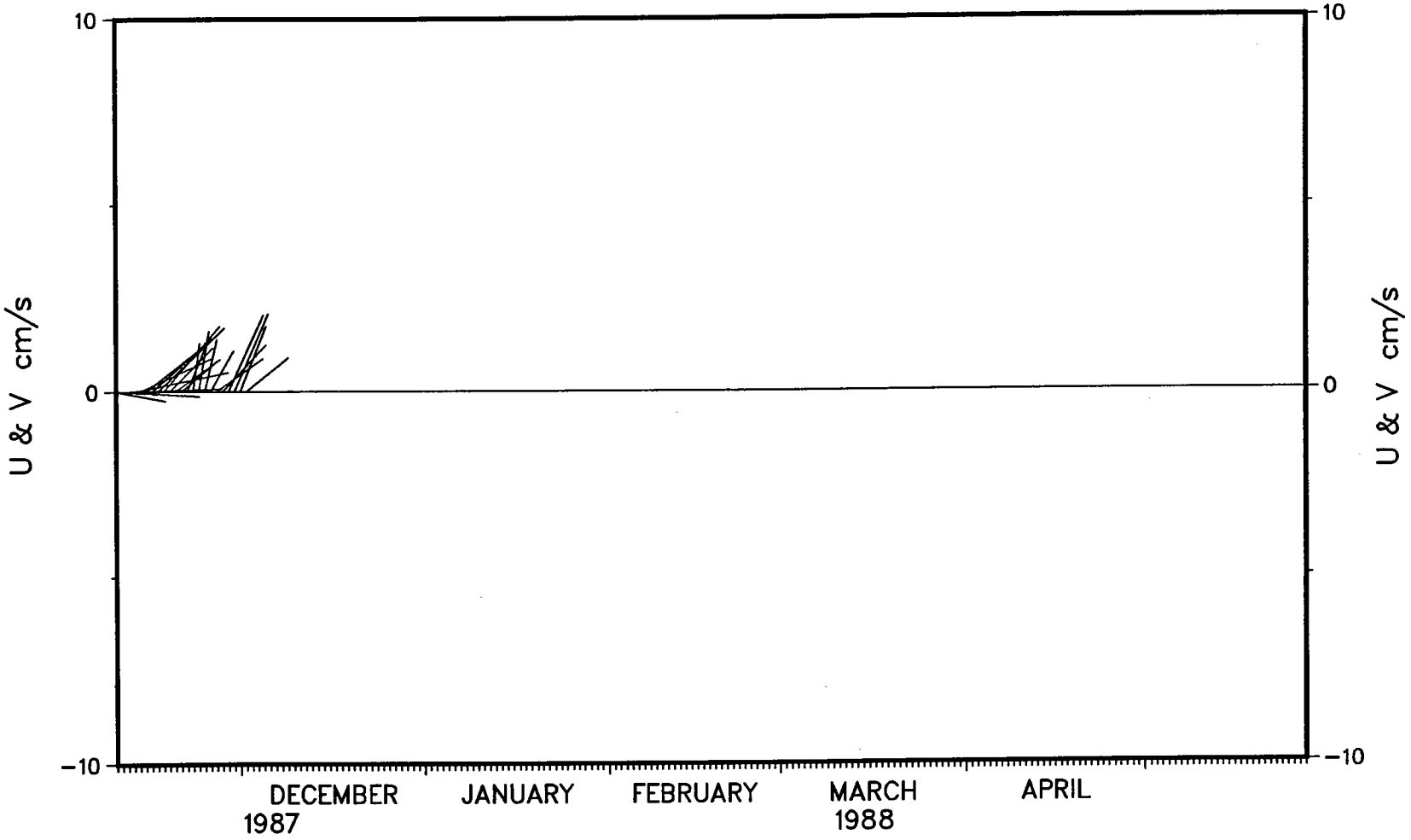


178

26-JUN-89 19:32:12

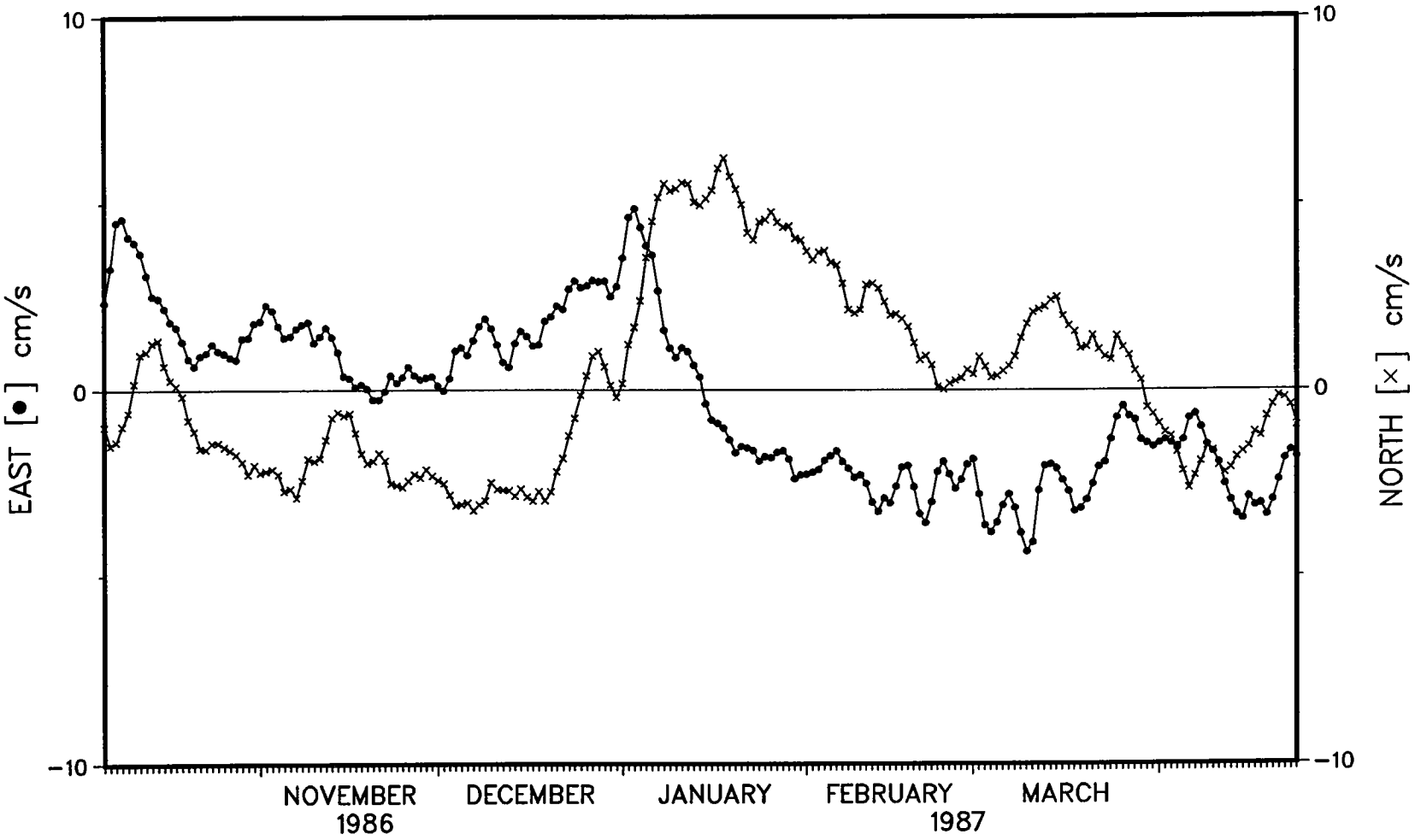
PLOT 2 OF 3
.SPL

EASTERN BASIN 133



PLOT 3 OF 3
.SPL

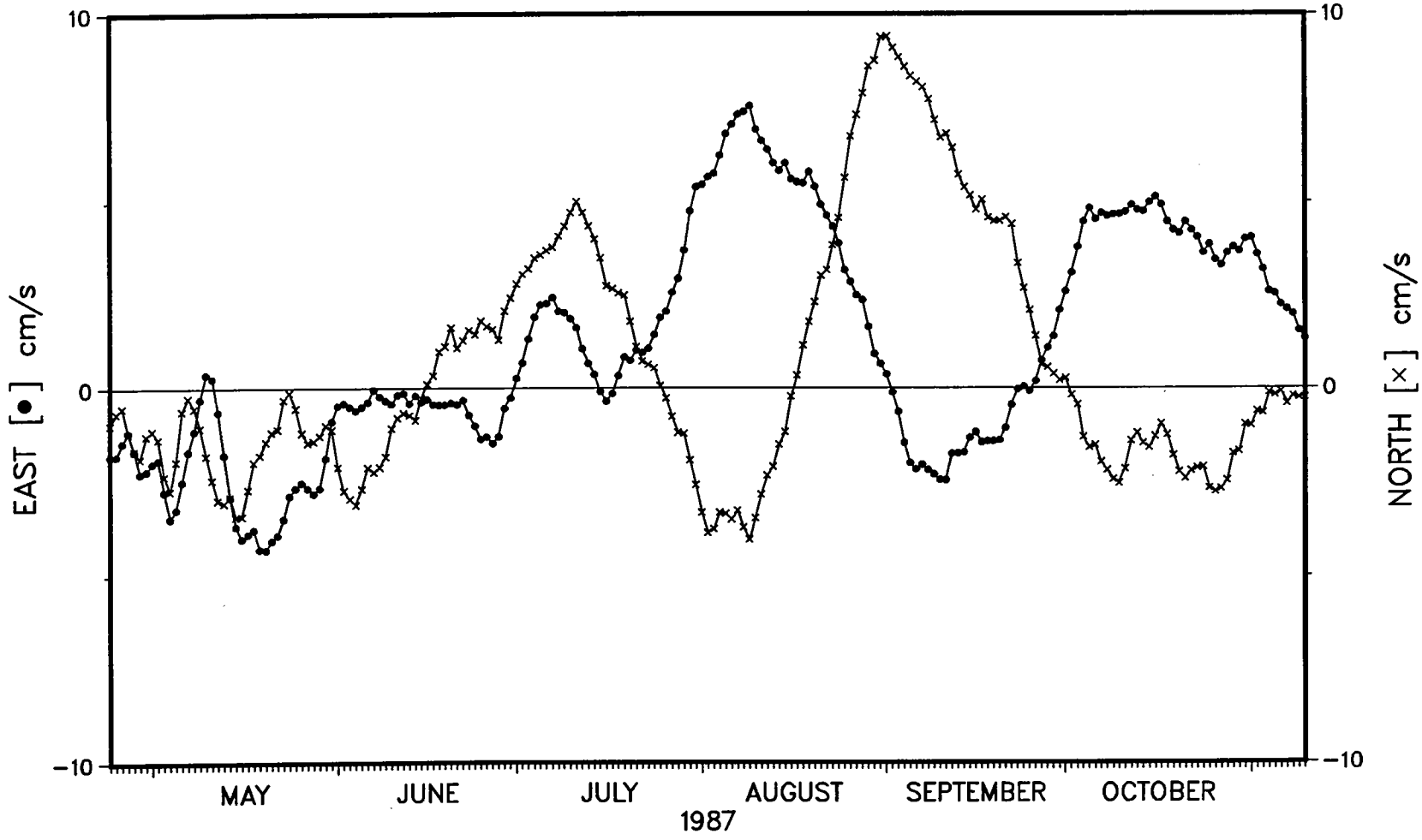
EASTERN BASIN 133



180

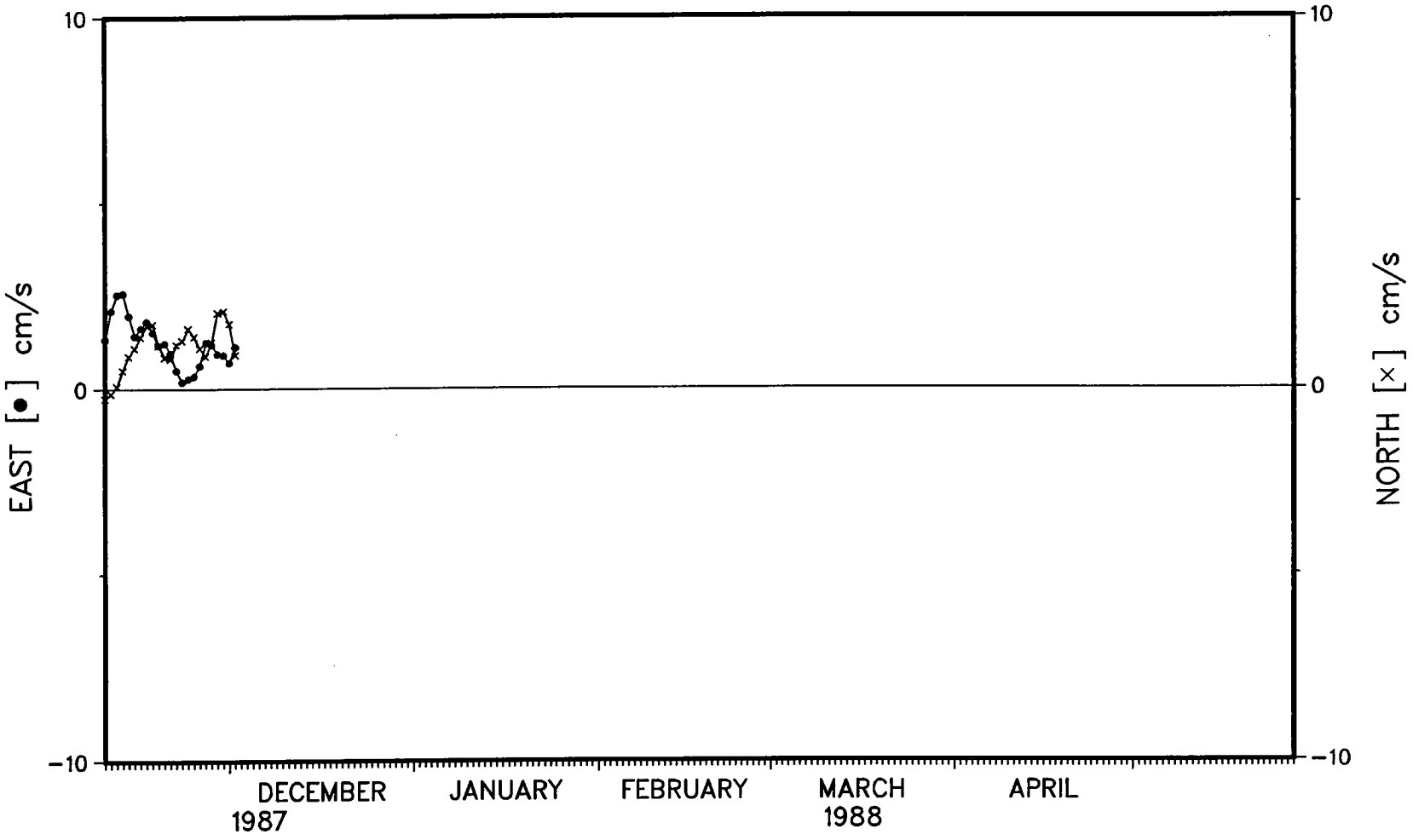
PLOT 1 OF 3
.SPL

EASTERN BASIN 133



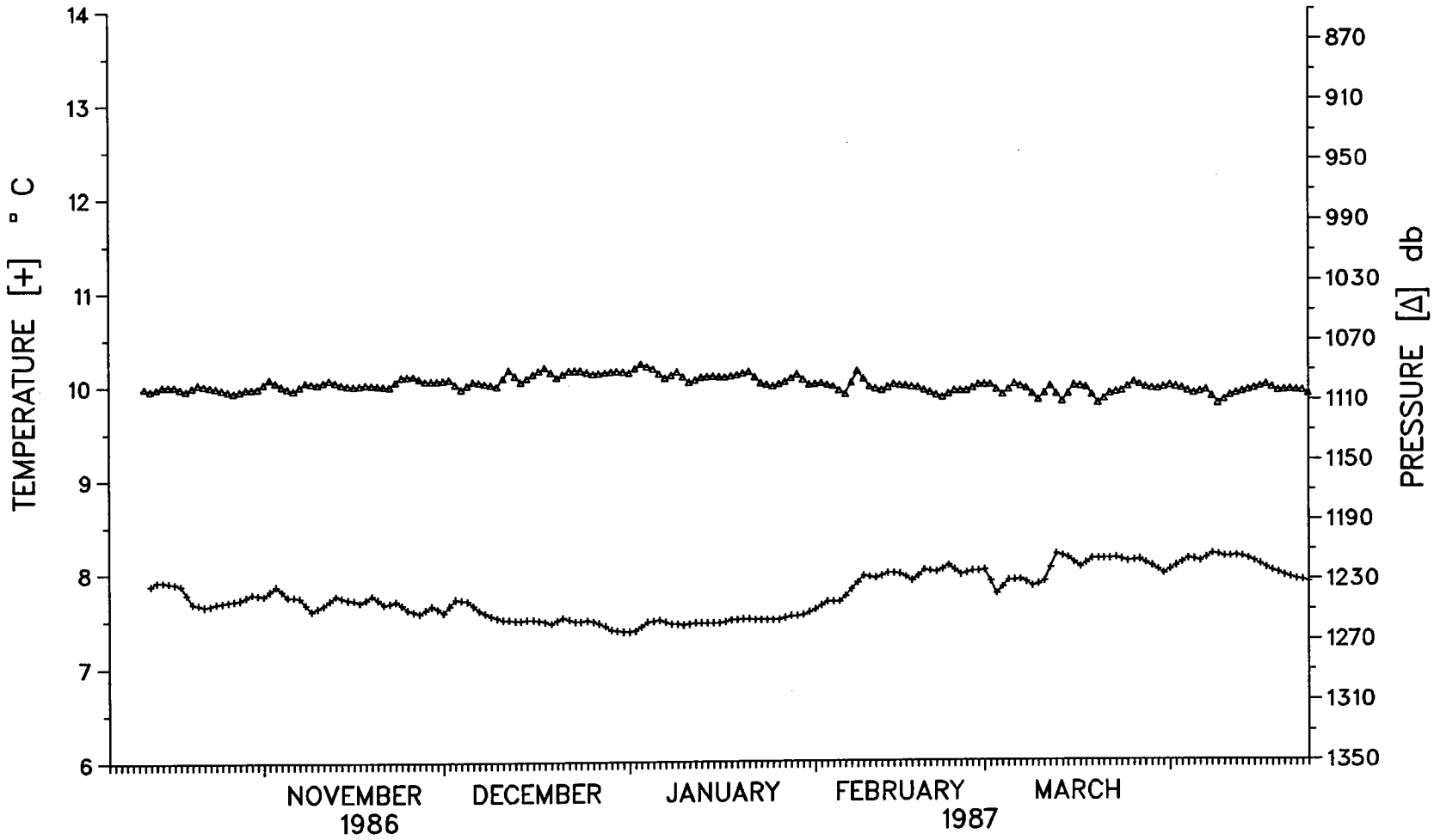
PLOT 2 OF 3
.SPL

EASTERN BASIN 133



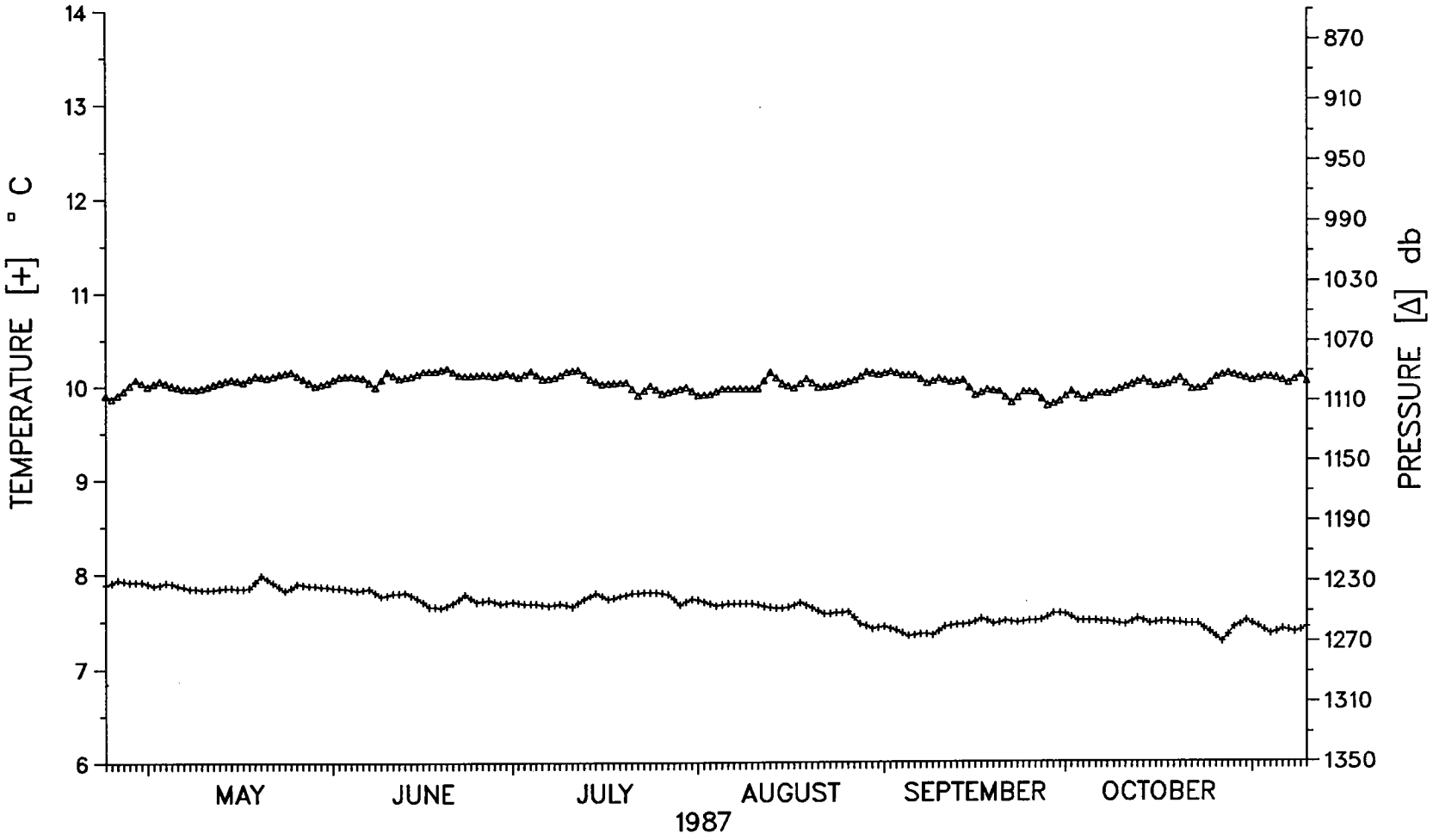
PLOT 3 OF 3
.SPL

EASTERN BASIN 133



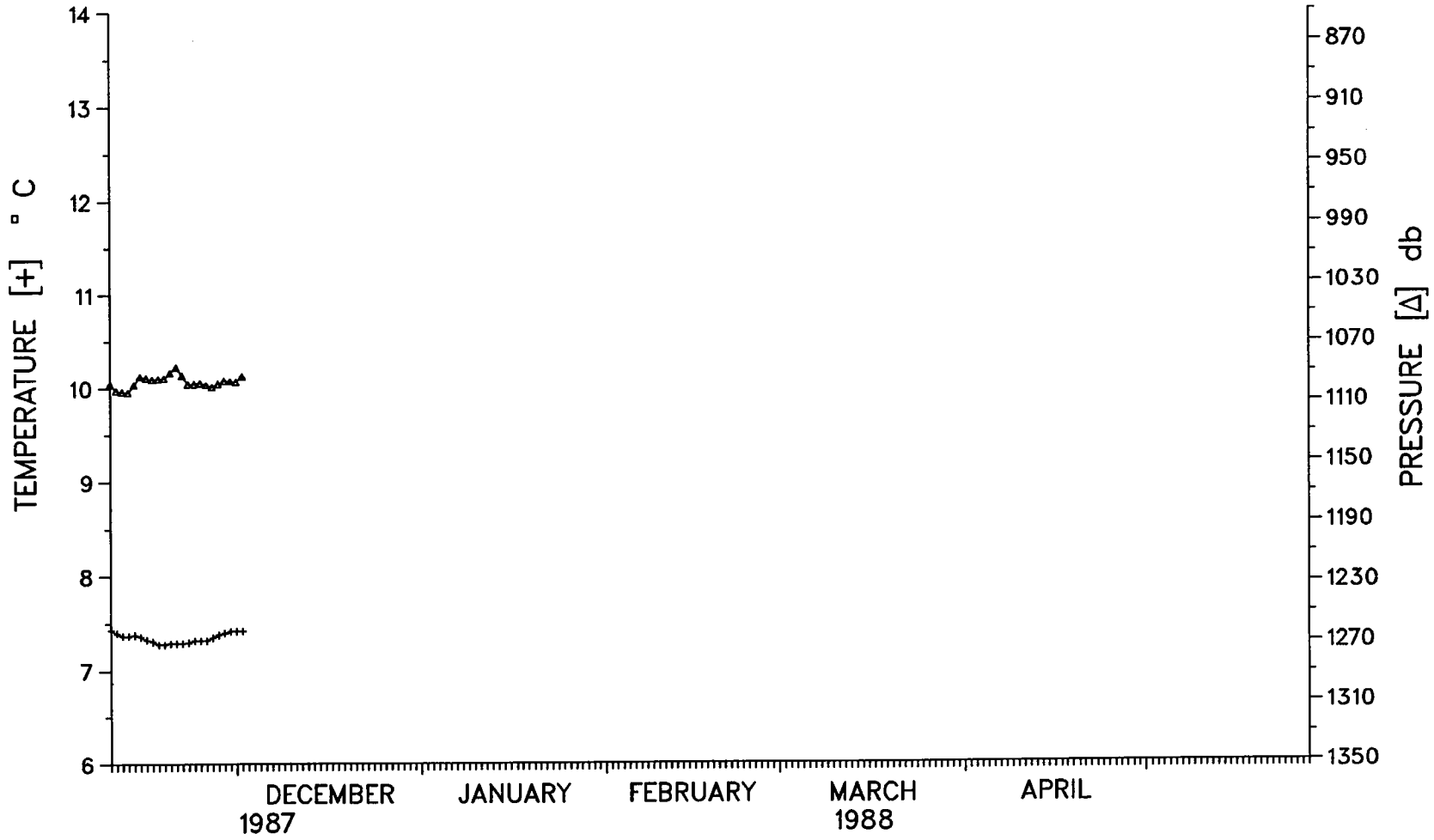
PLOT 1 OF 3
.SPL

EASTERN BASIN 133



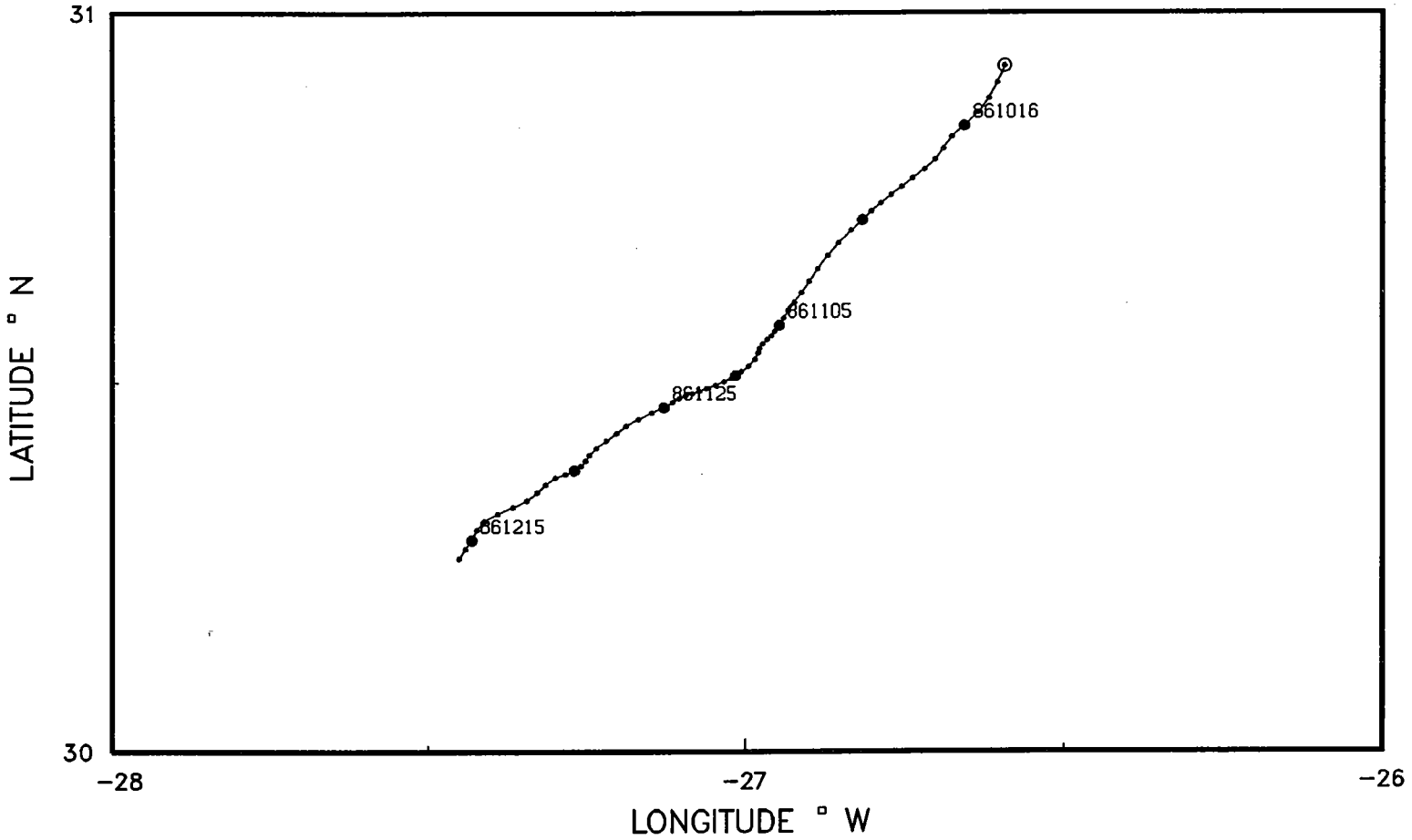
PLOT 2 OF 3
.SPL

EASTERN BASIN 133



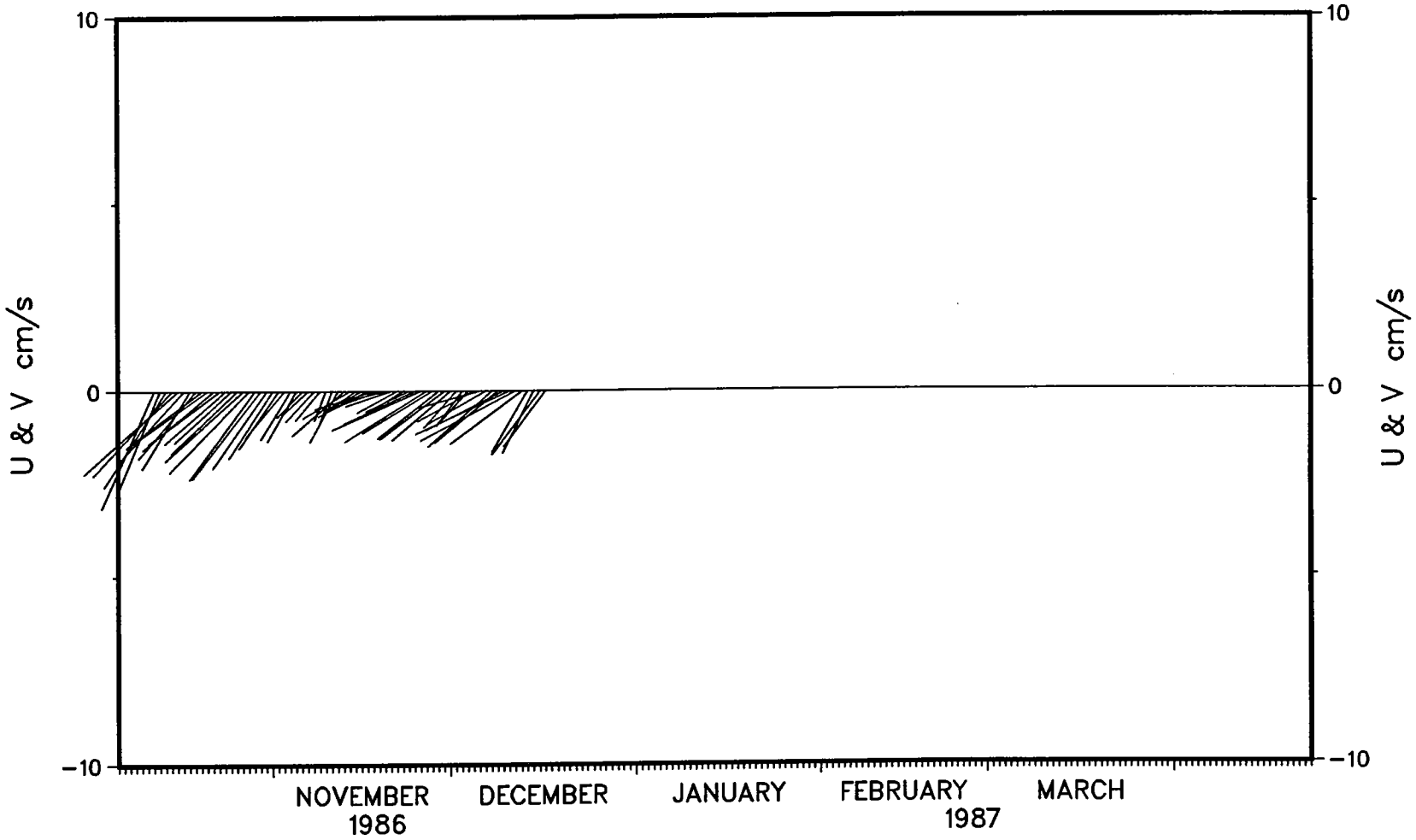
PLOT 3 OF 3
.SPL

EASTERN BASIN 135B



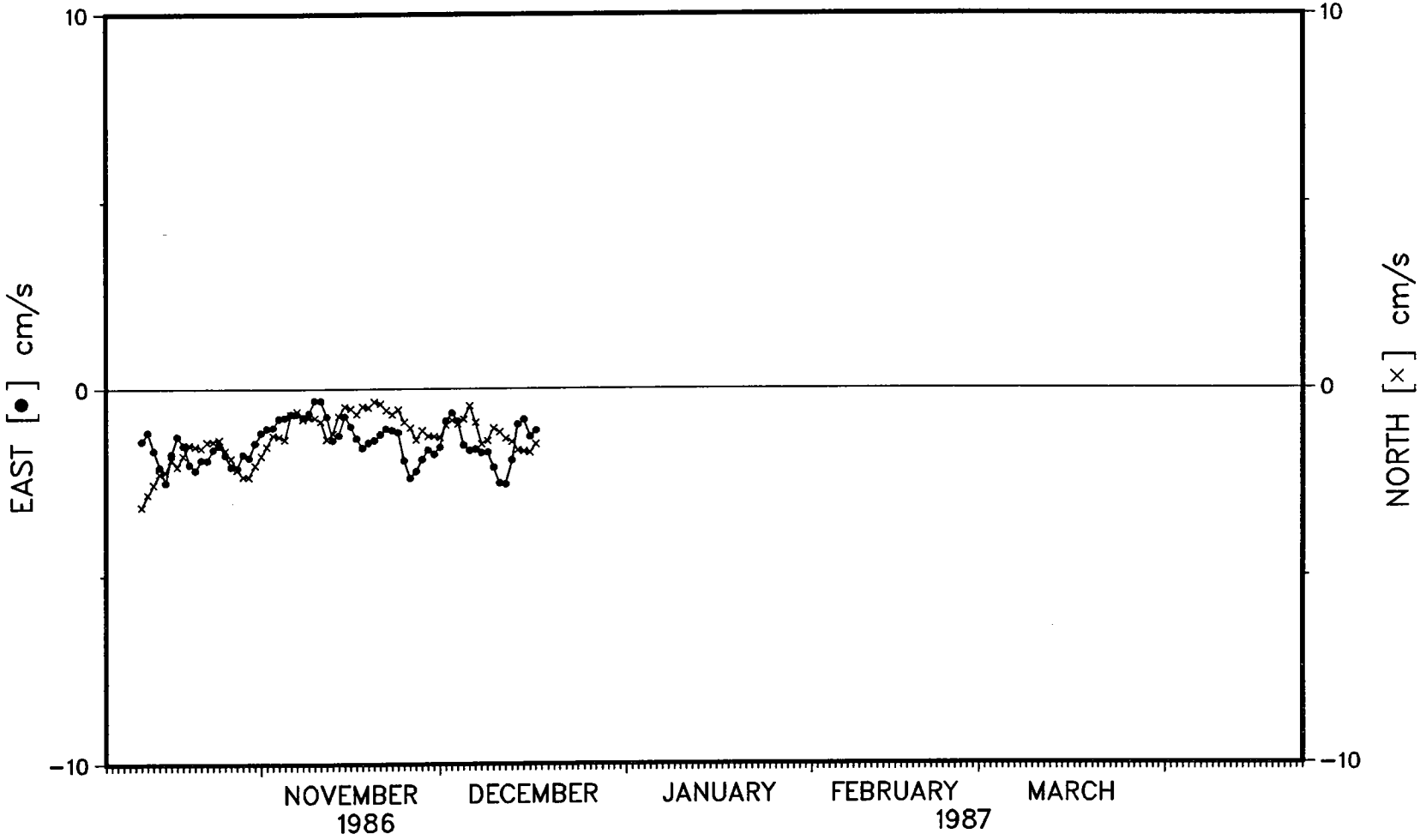
PLOT 1 OF 1
.SPL

EASTERN BASIN 135B



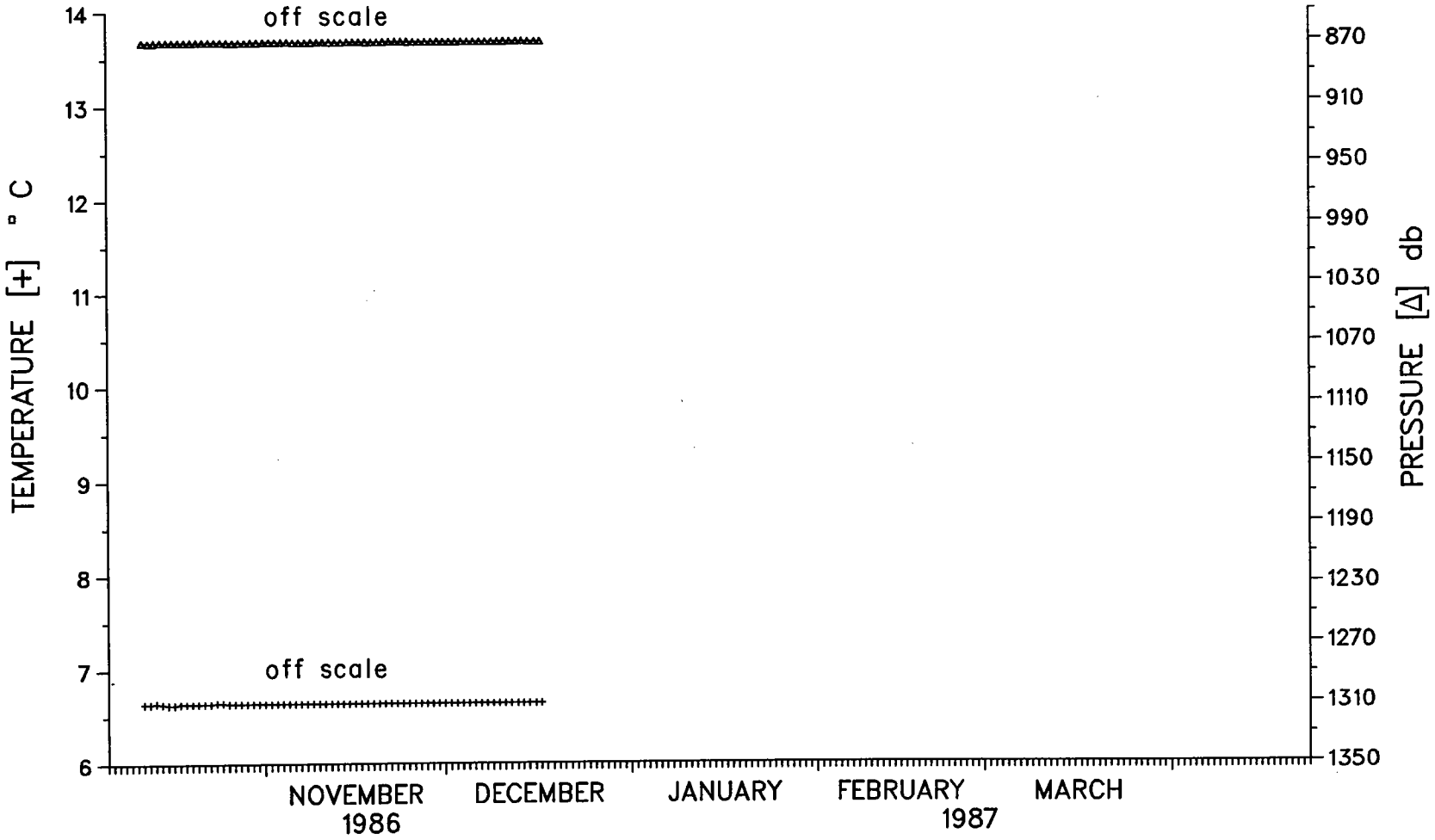
PLOT 1 OF 1
.SPL

EASTERN BASIN 135B



PLOT 1 OF 1
.SPL

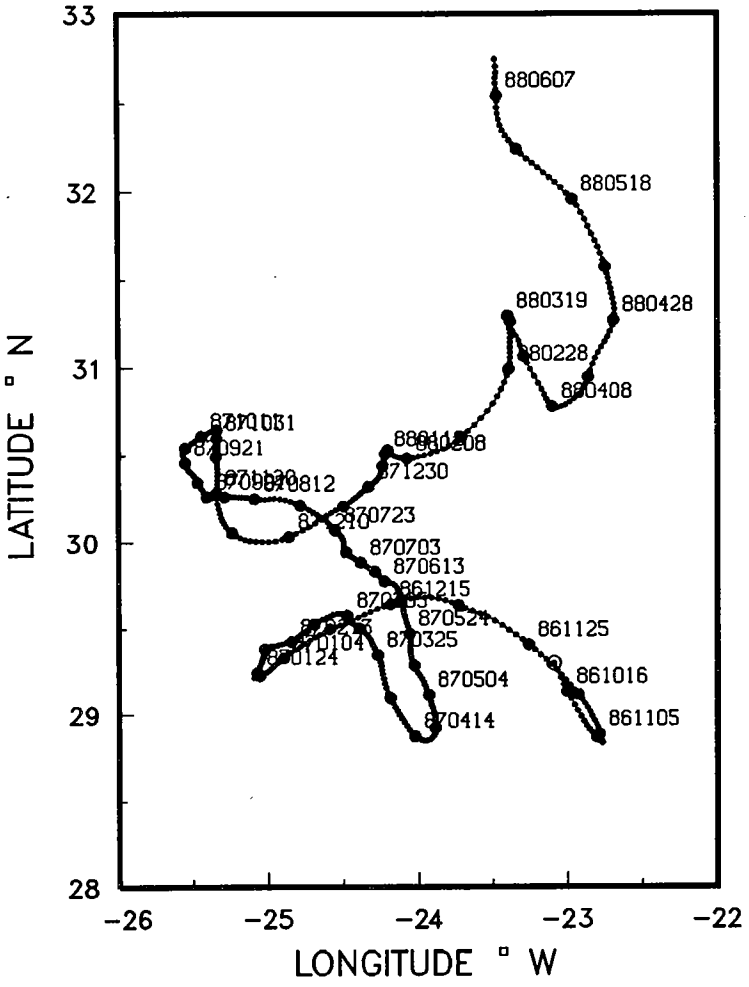
EASTERN BASIN 135B



189

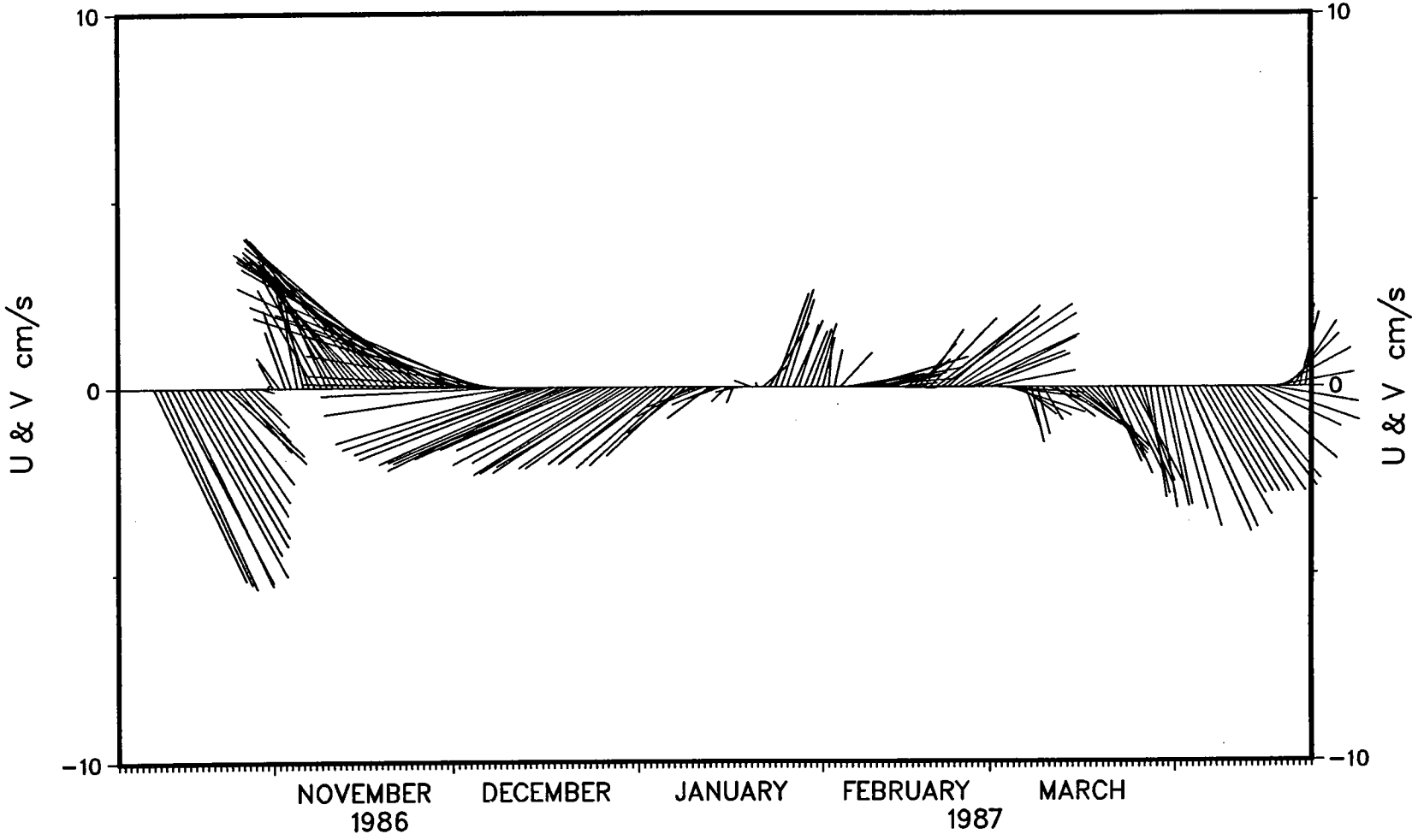
PLOT 1 OF 1
.SPL

EASTERN BASIN 136



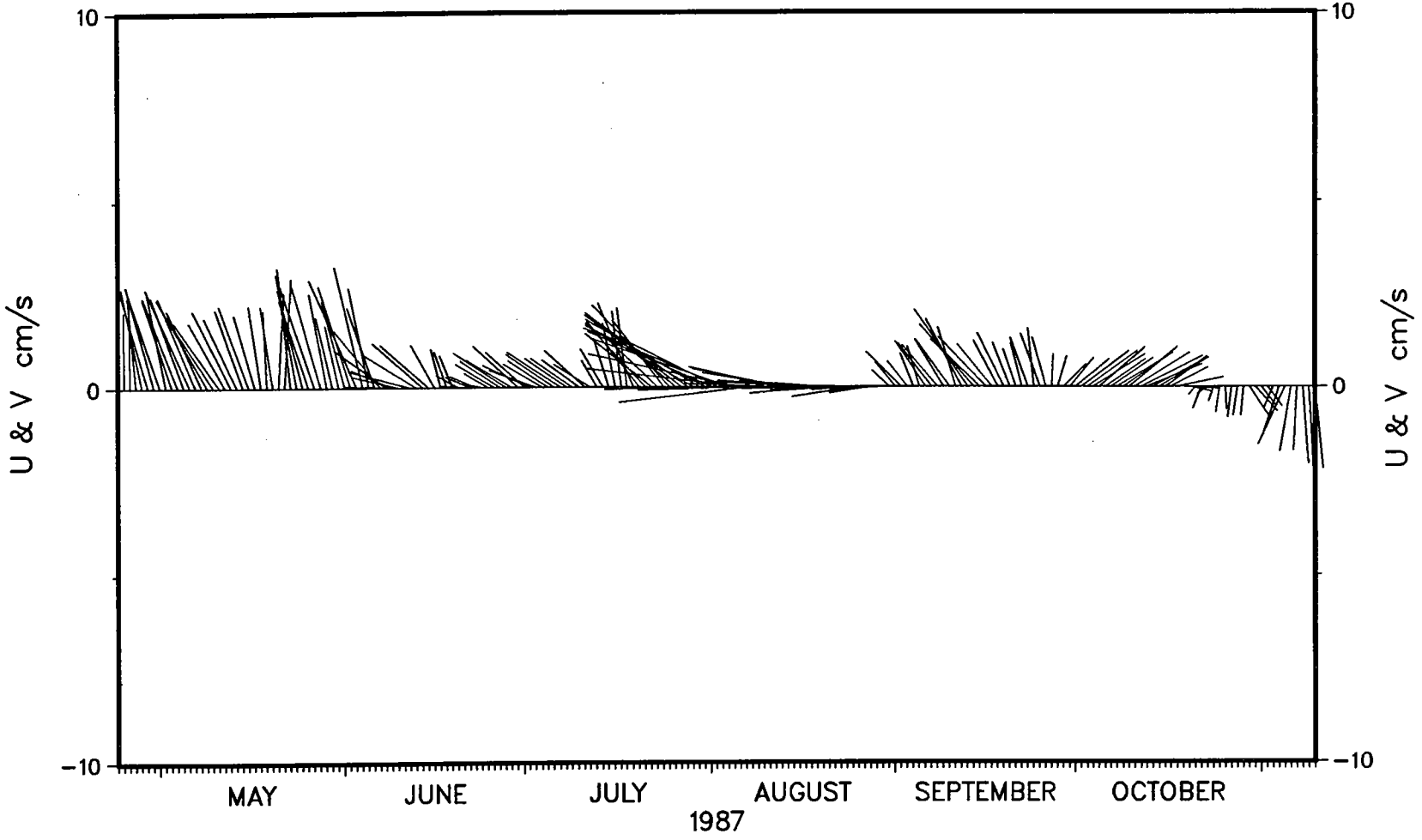
PLOT 1 OF 1
.SPL

EASTERN BASIN 136



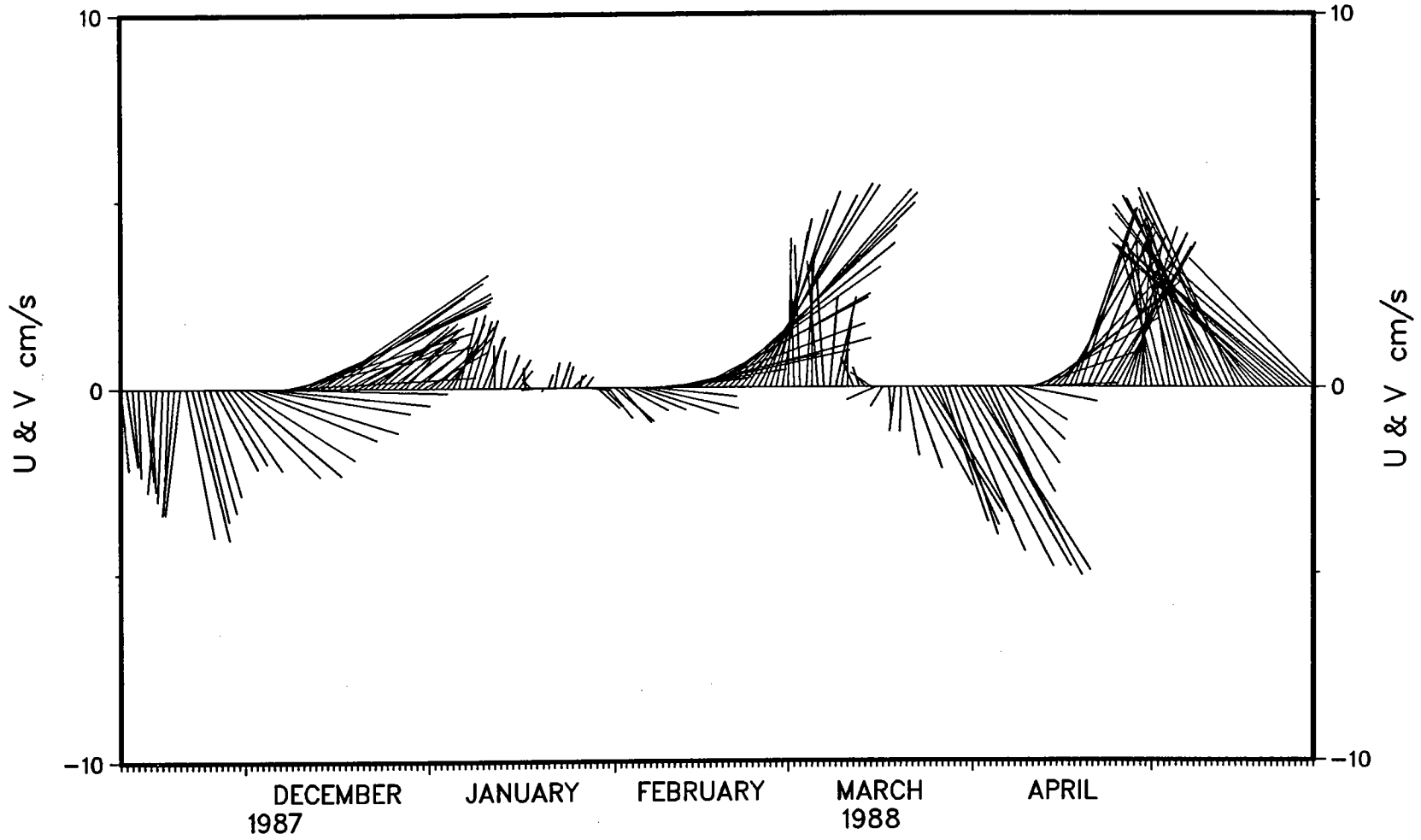
PLOT 1 OF 4
.SPL

EASTERN BASIN 136



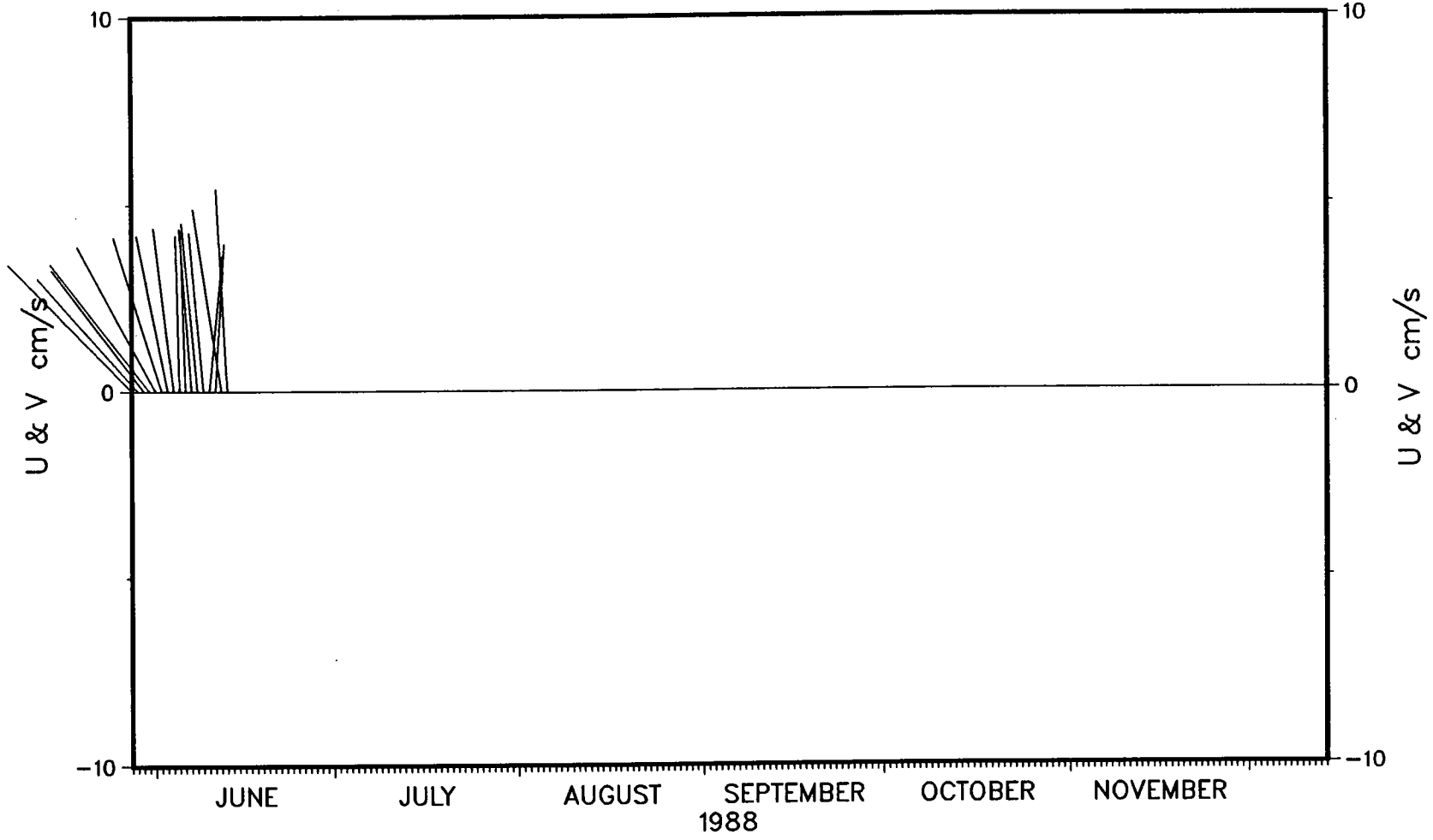
PLOT 2 OF 4
.SPL

EASTERN BASIN 136



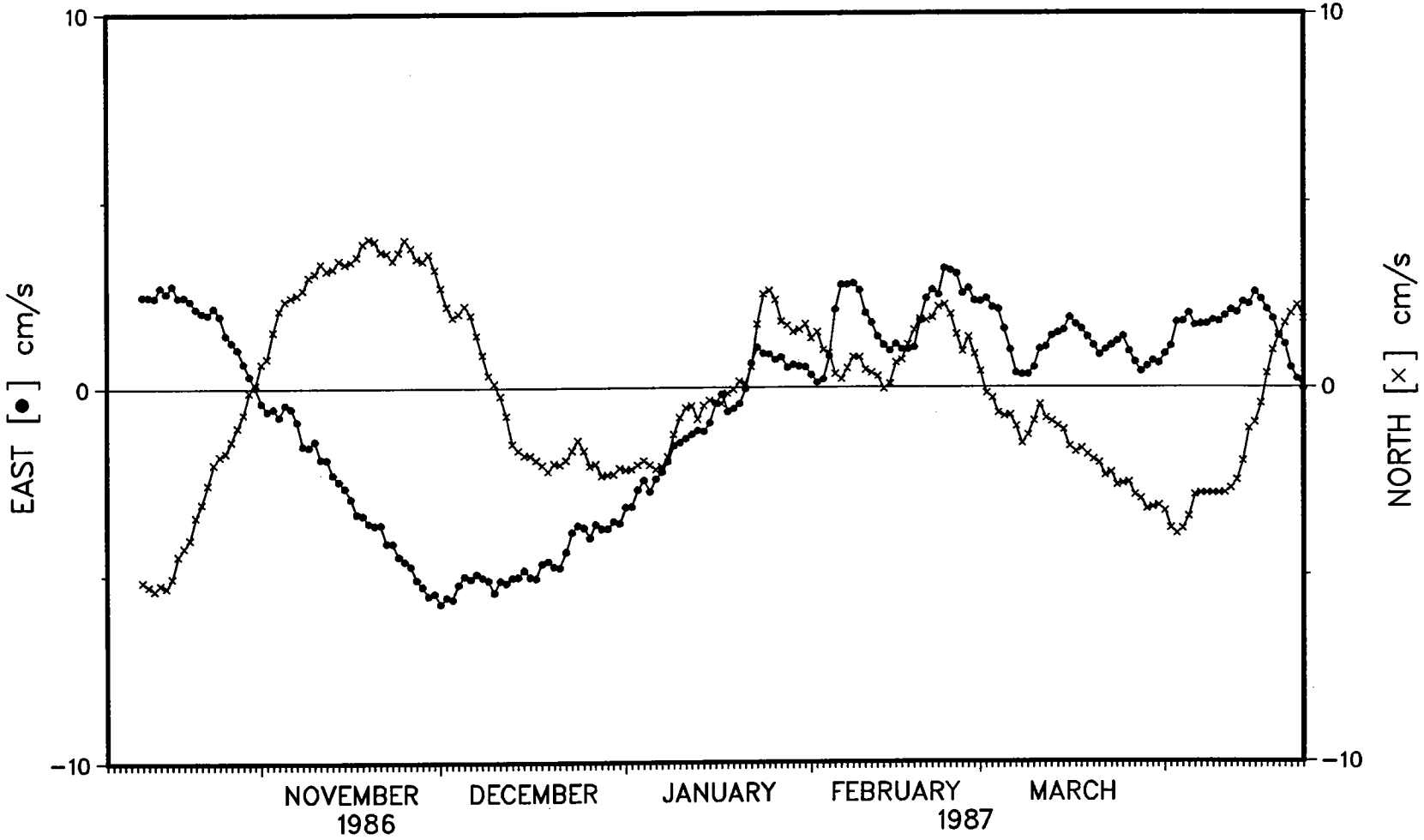
PLOT 3 OF 4
.SPL

EASTERN BASIN 136



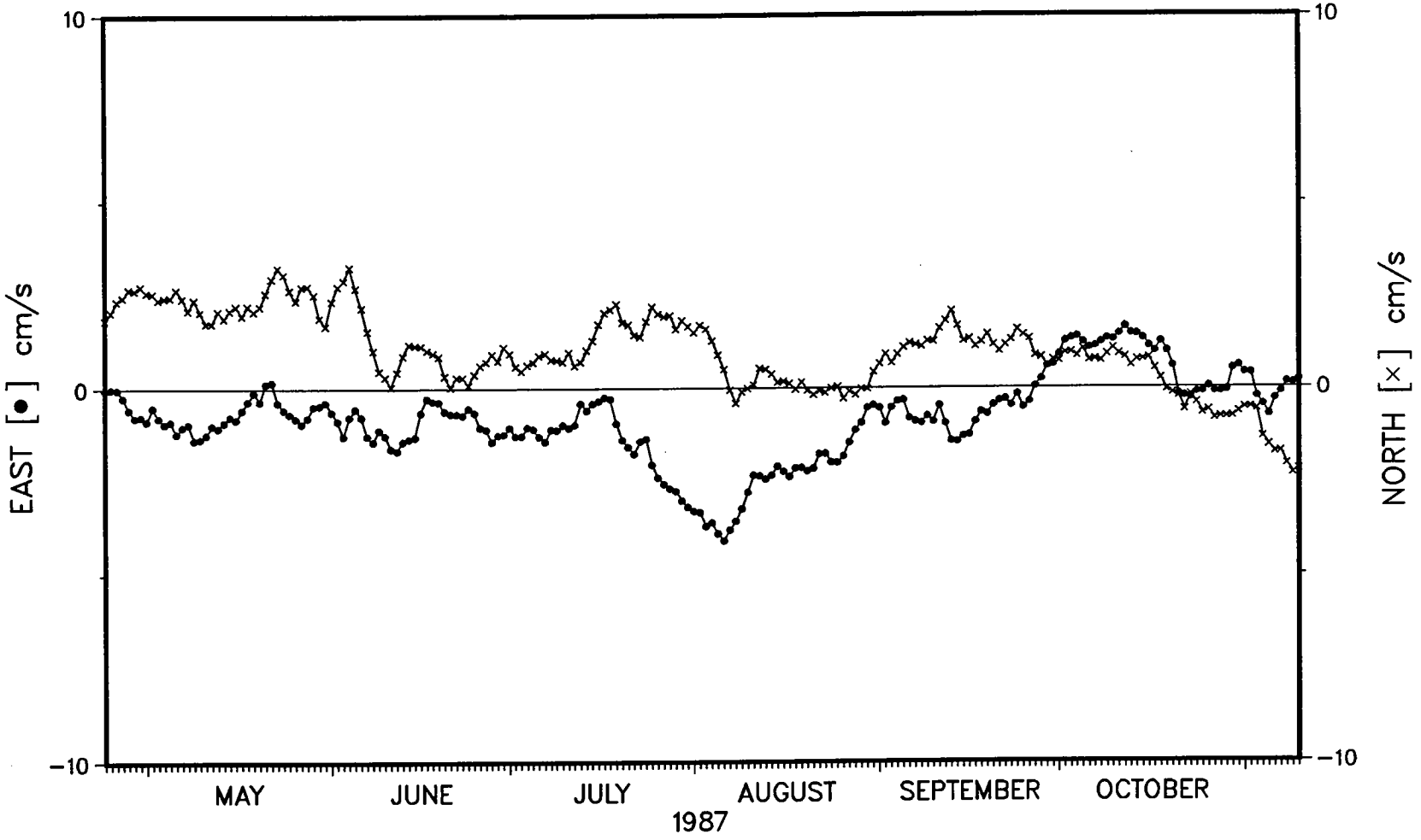
PLOT 4 OF 4
.SPL

EASTERN BASIN 136



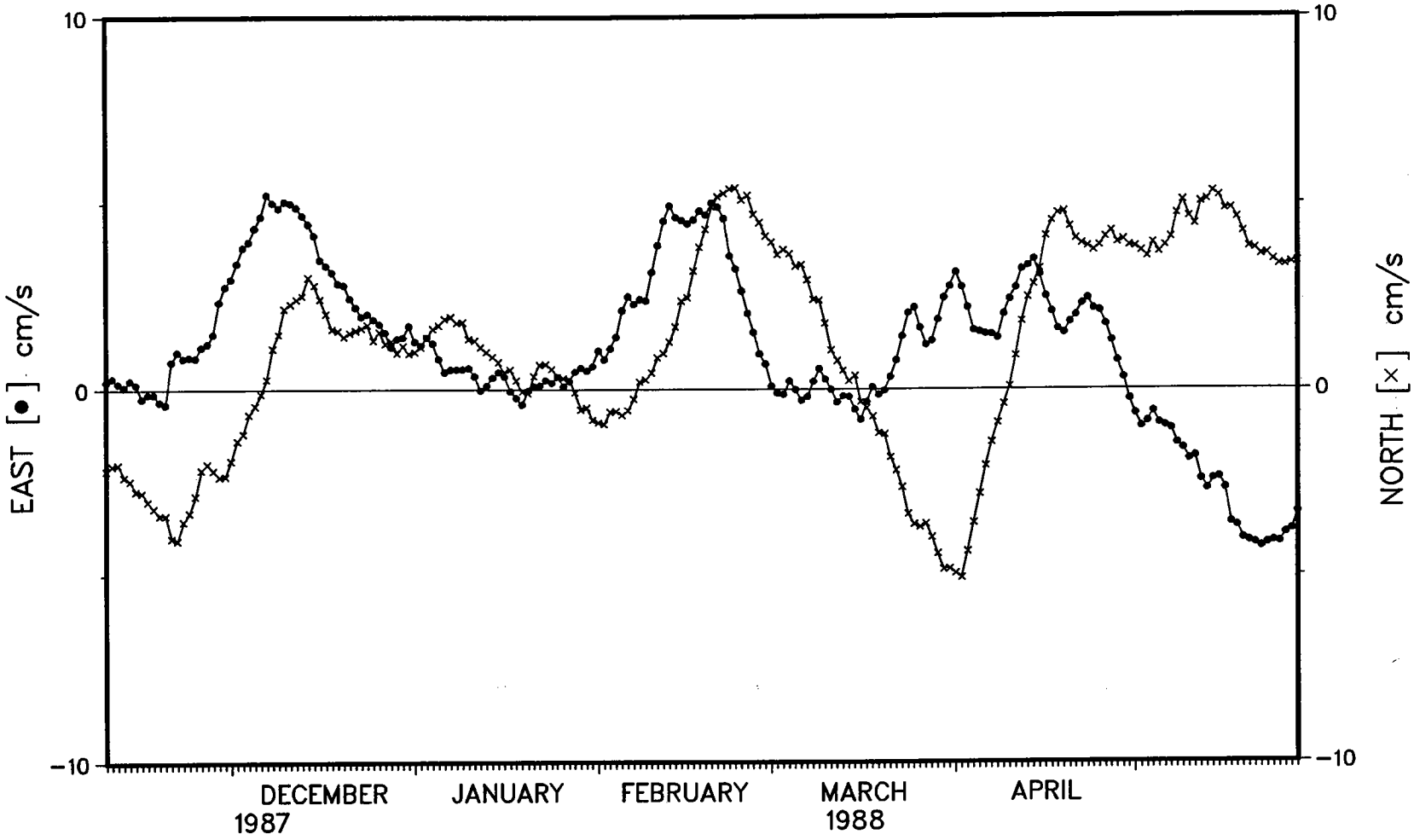
PLOT 1 OF 4
.SPL

EASTERN BASIN 136



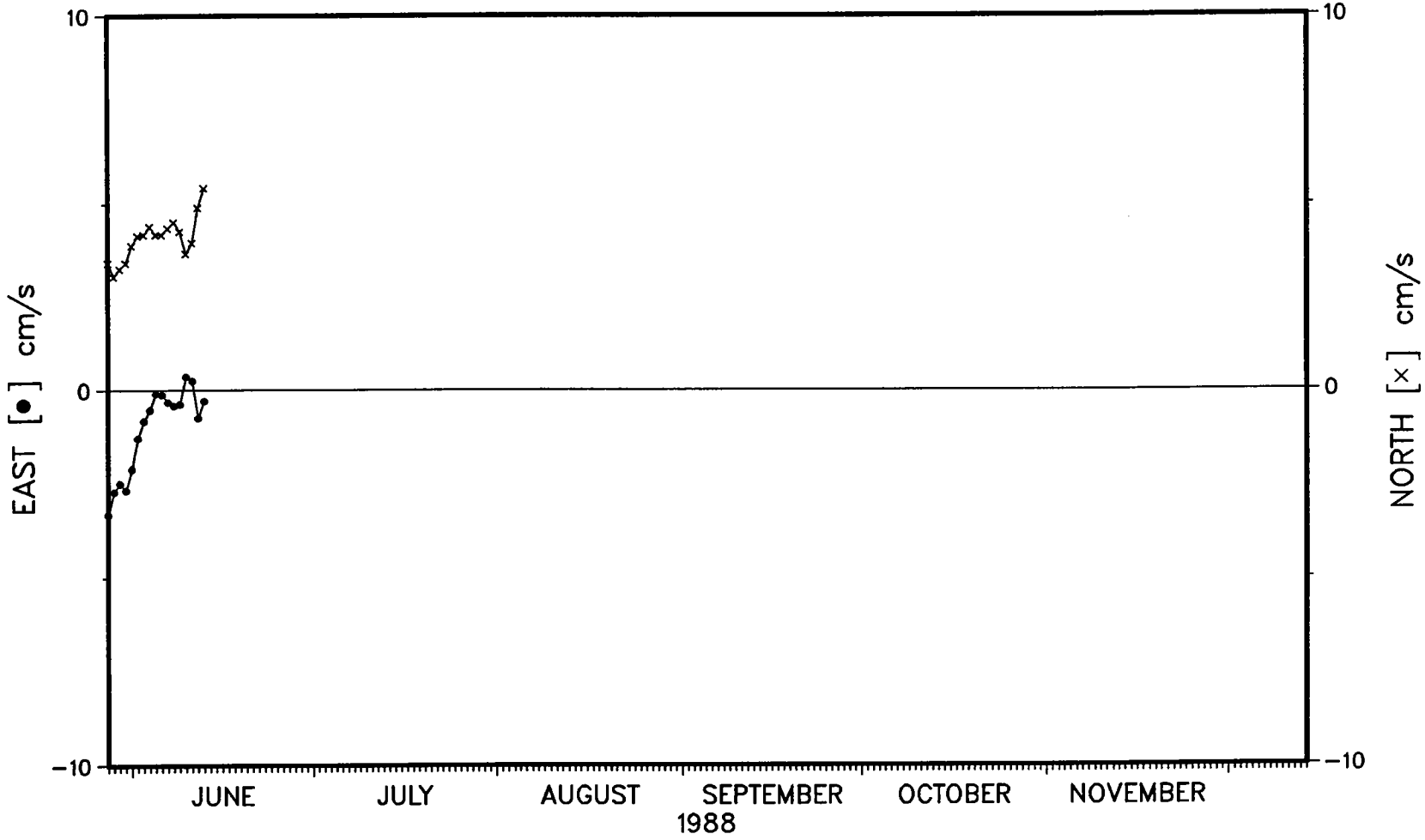
PLOT 2 OF 4
.SPL

EASTERN BASIN 136



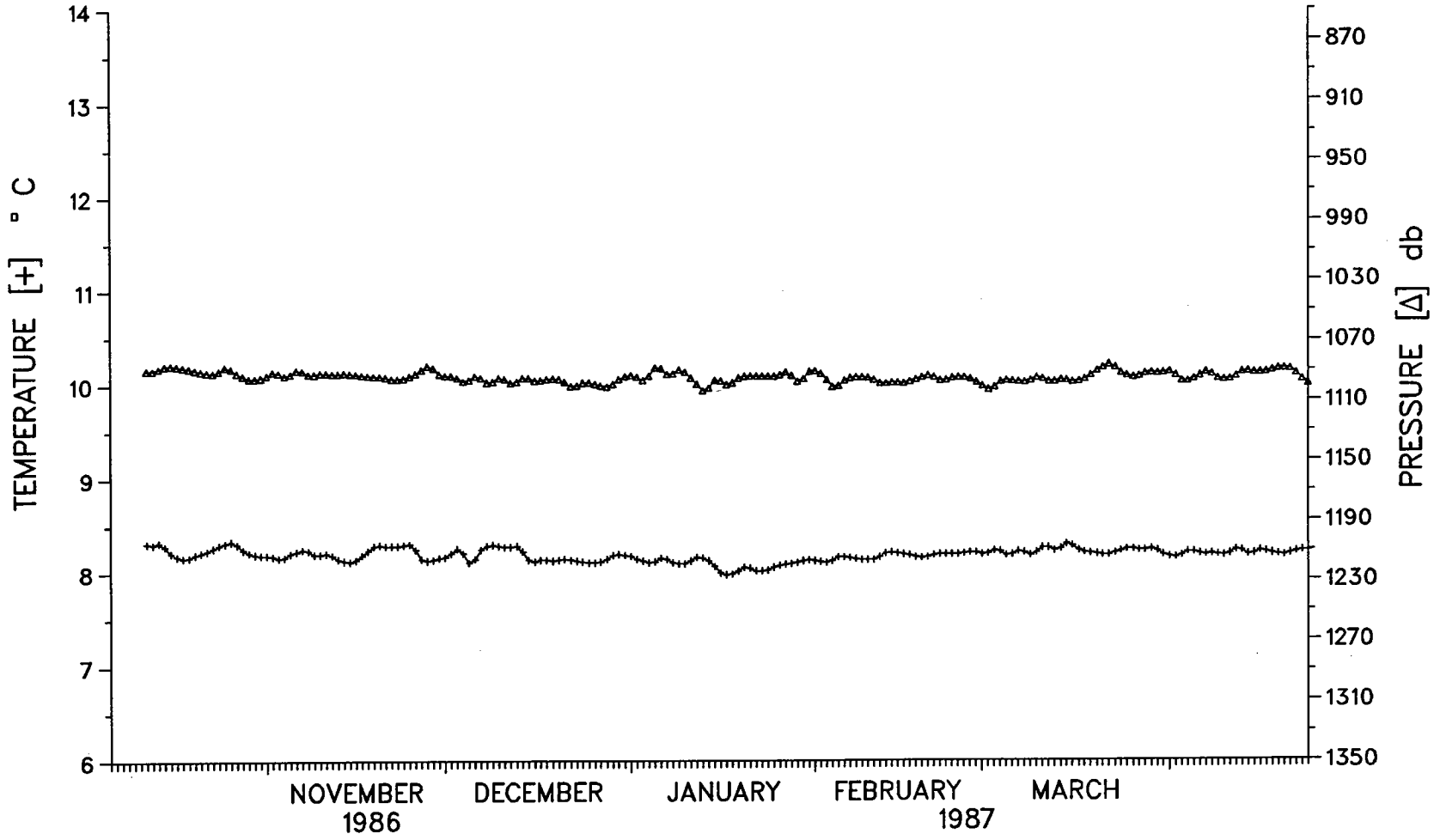
PLOT 3 OF 4
.SPL

EASTERN BASIN 136



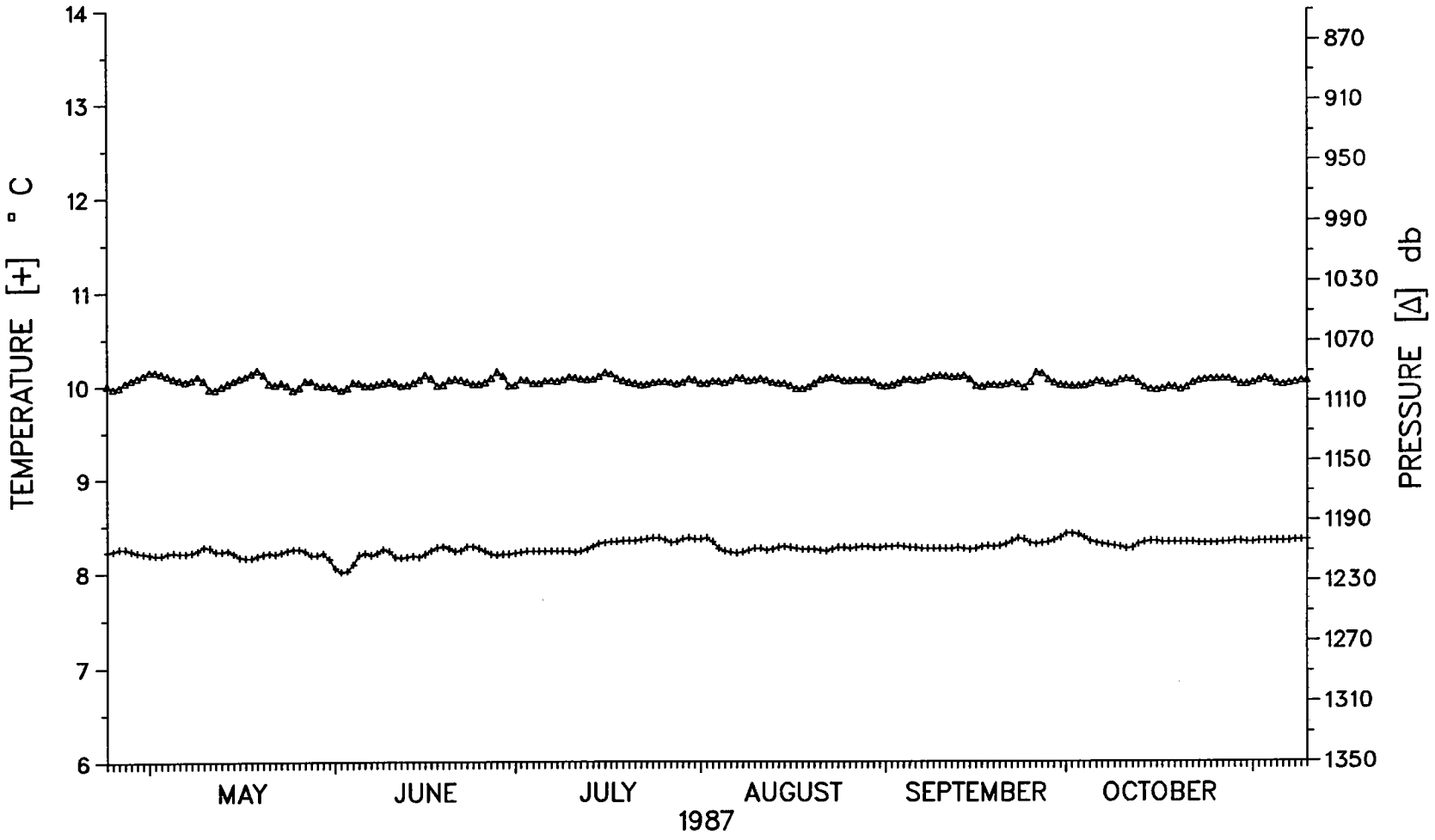
PLOT 4 OF 4
.SPL

EASTERN BASIN 136



PLOT 1 OF 4
.SPL

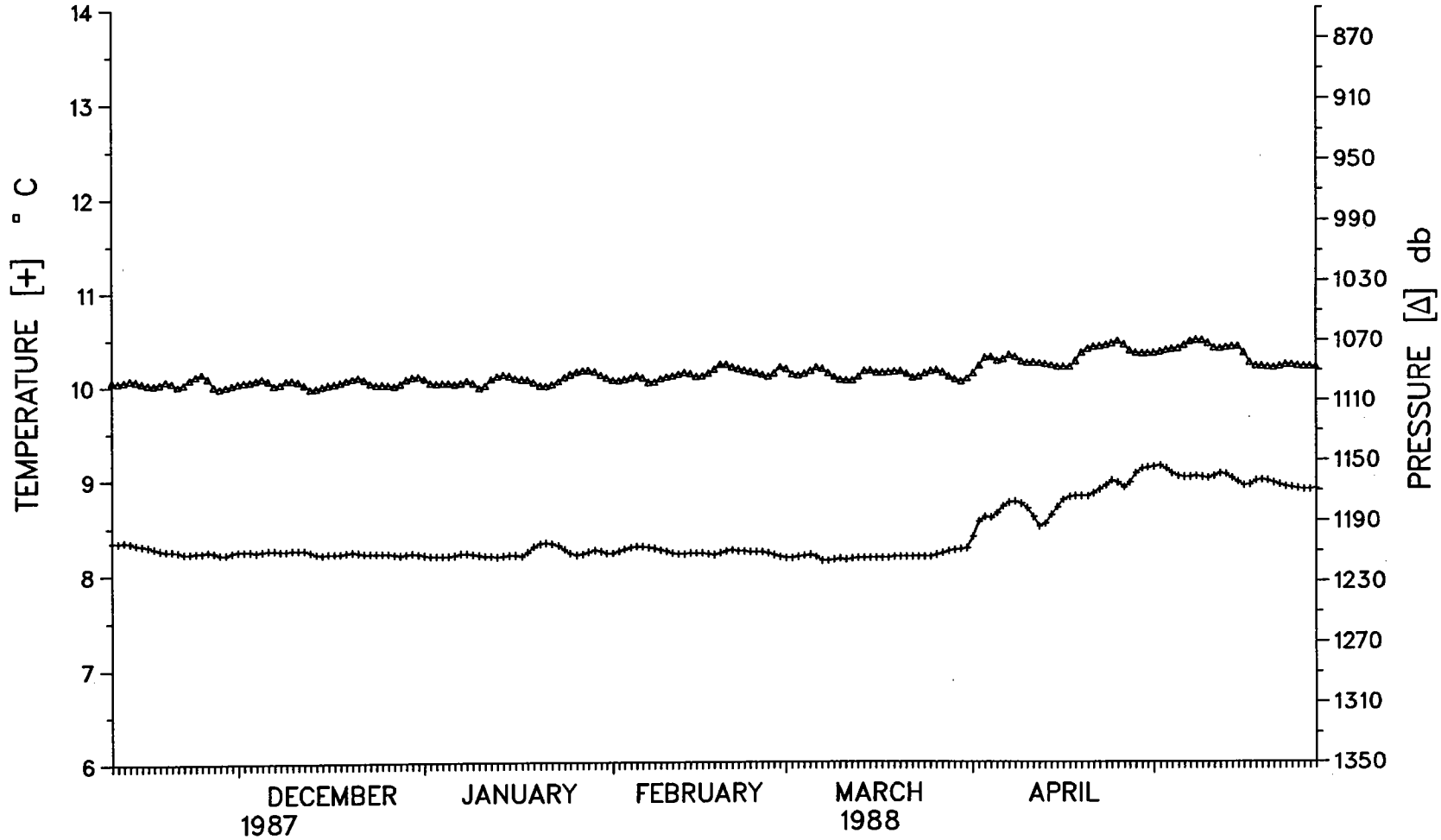
EASTERN BASIN 136



200

PLOT 2 OF 4
.SPL

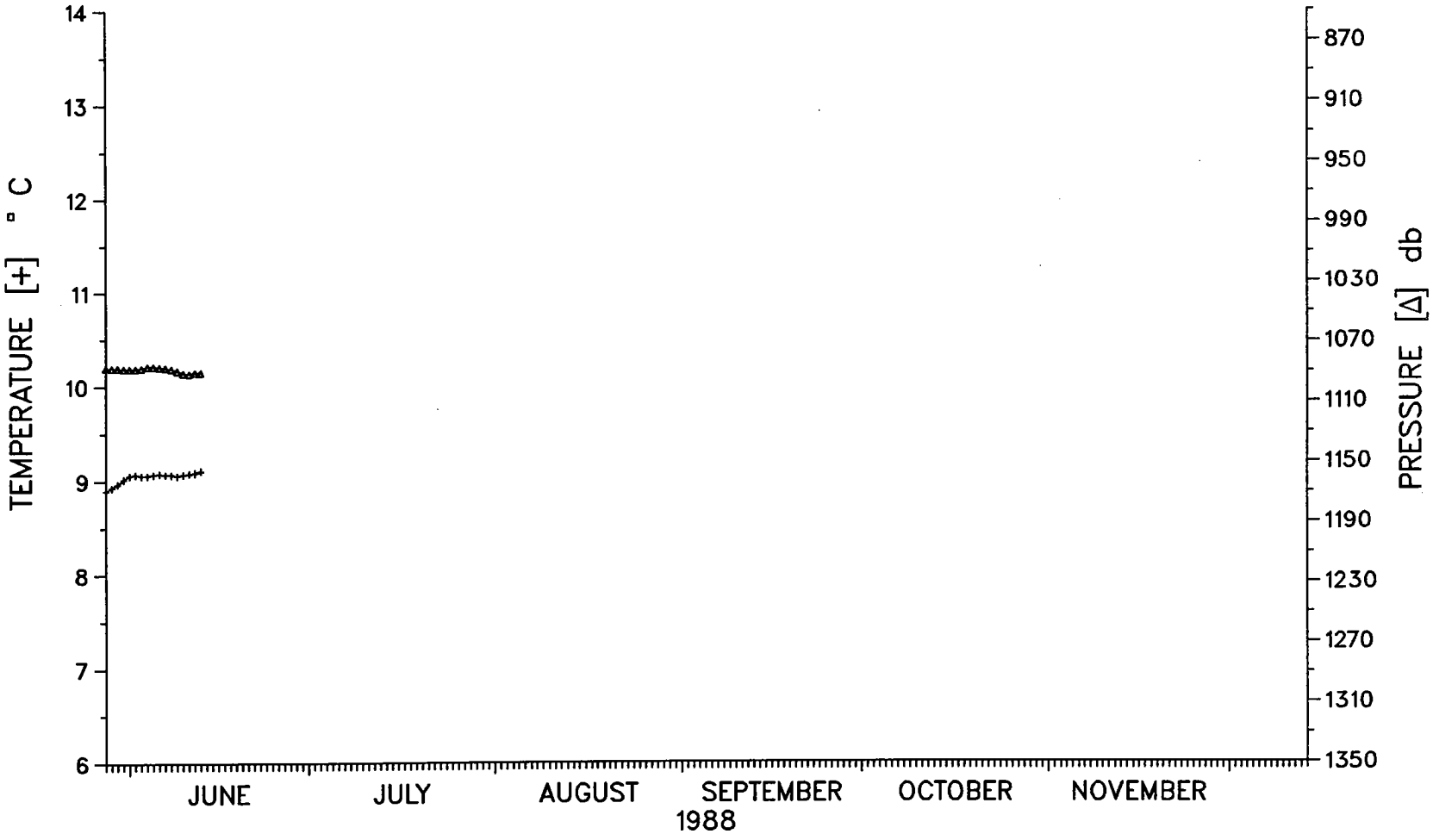
EASTERN BASIN 136



26-JUN-89 19:32:45

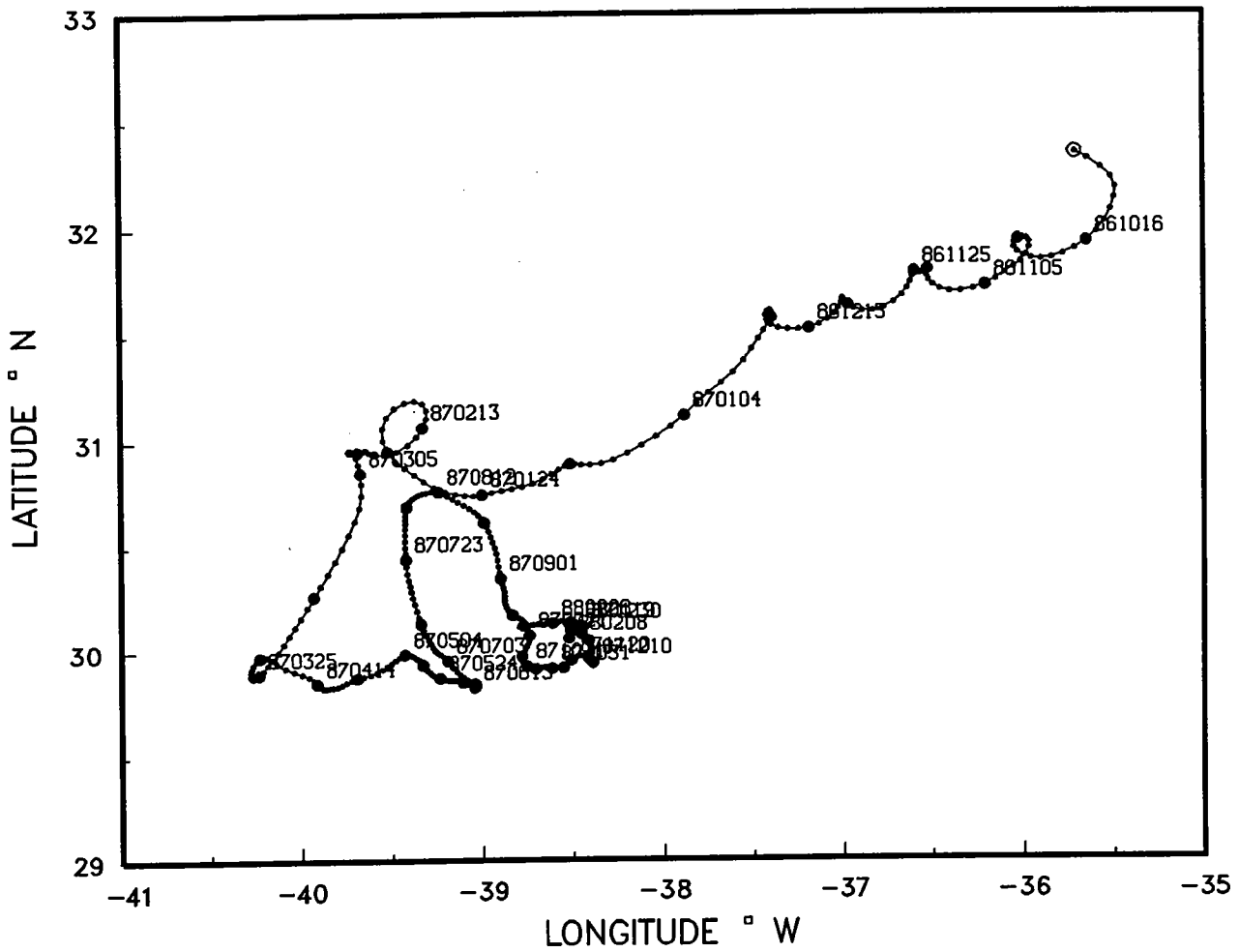
PLOT 3 OF 4
.SPL

EASTERN BASIN 136



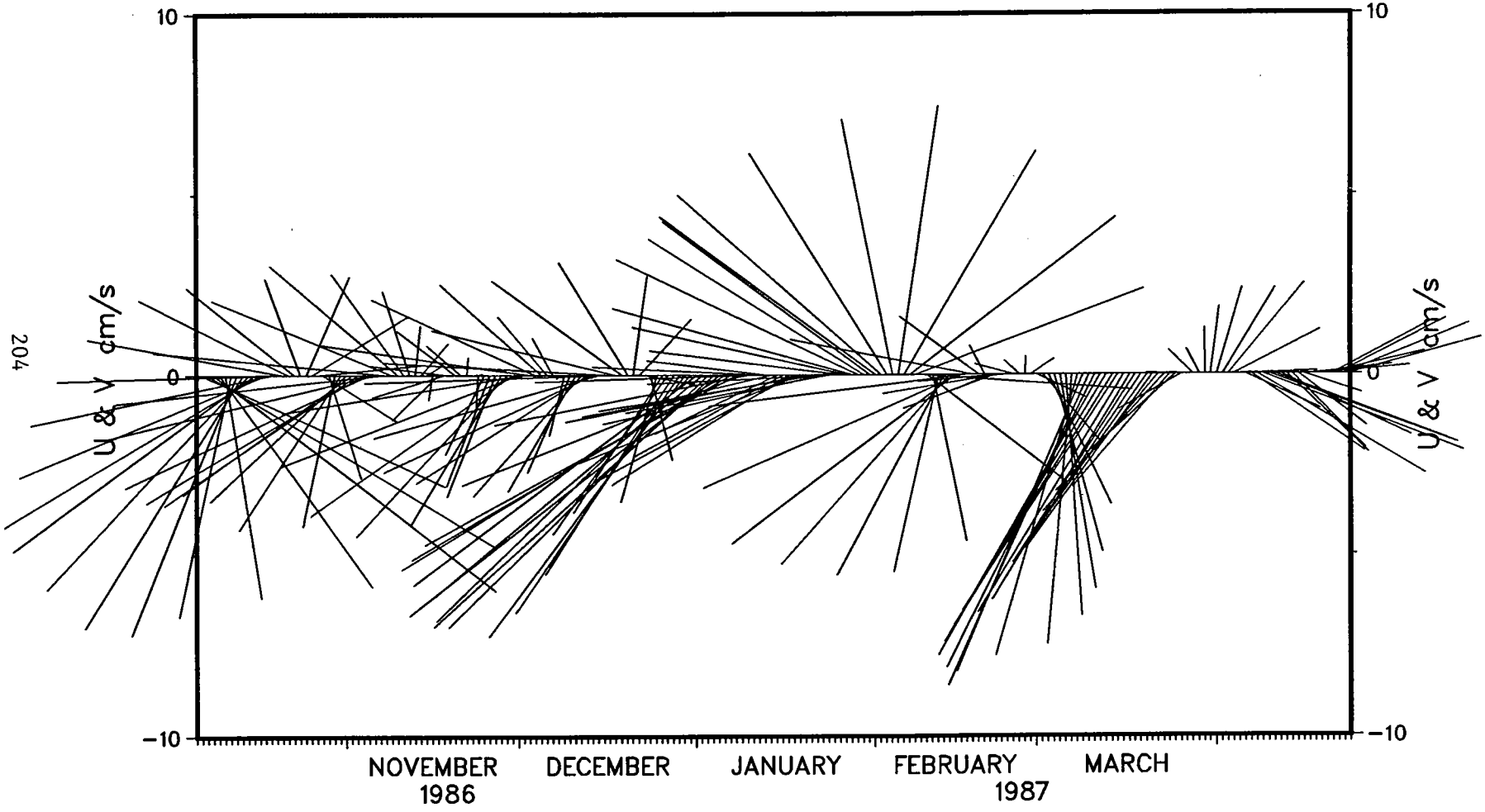
PLOT 4 OF 4
.SPL

EASTERN BASIN 137



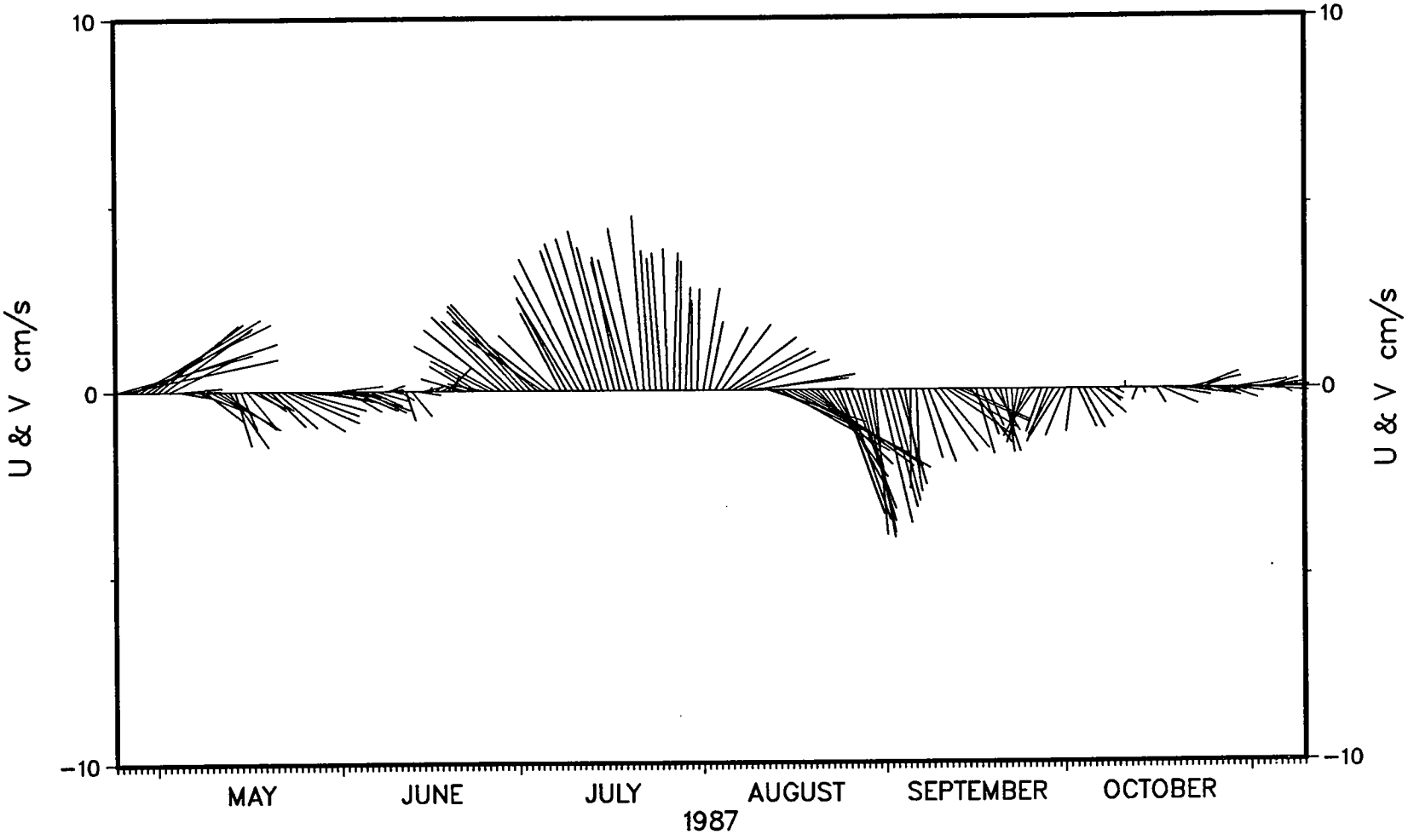
PLOT 1 OF 1
.SPL

EASTERN BASIN 137



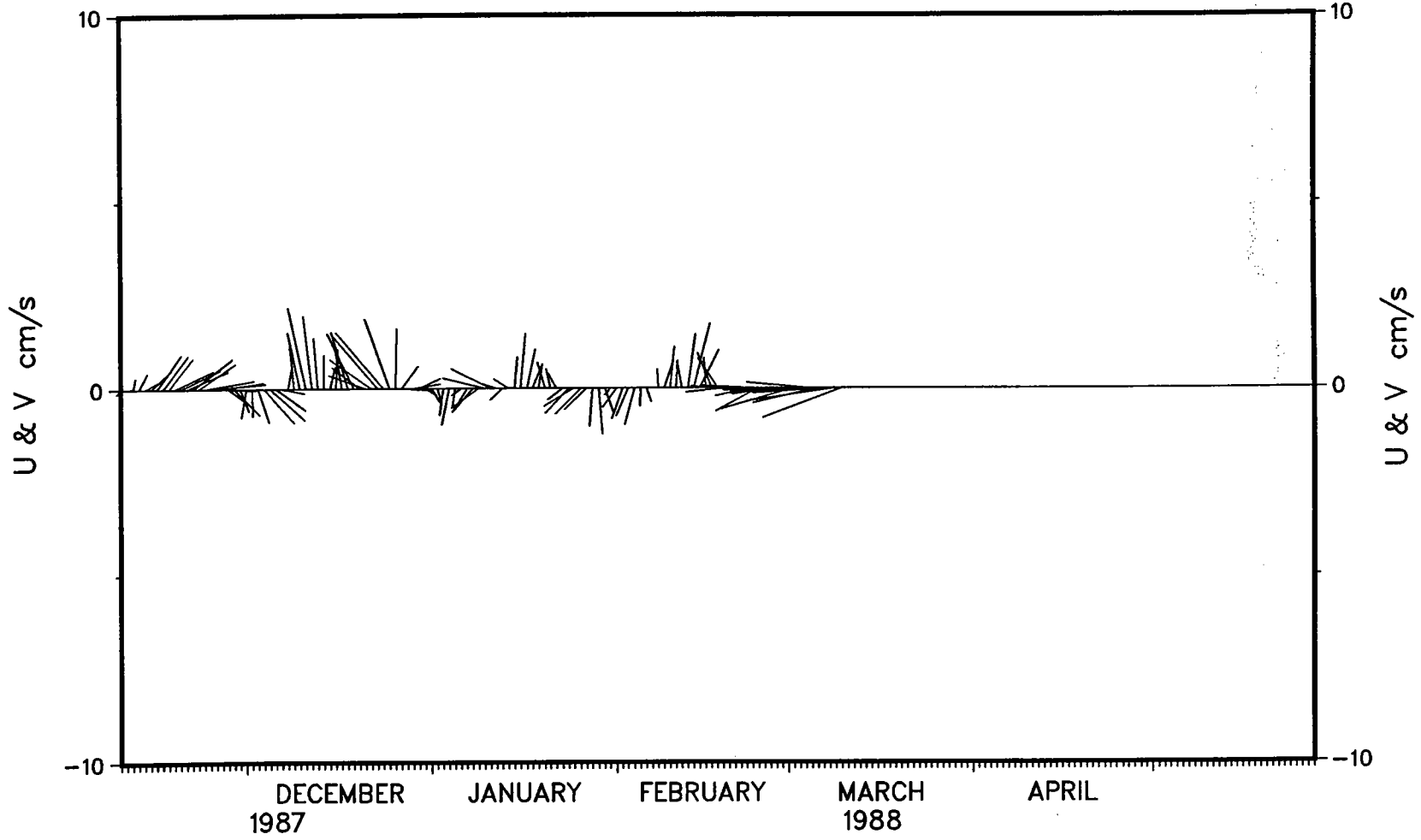
PLOT 1 OF 3
.SPL

EASTERN BASIN 137



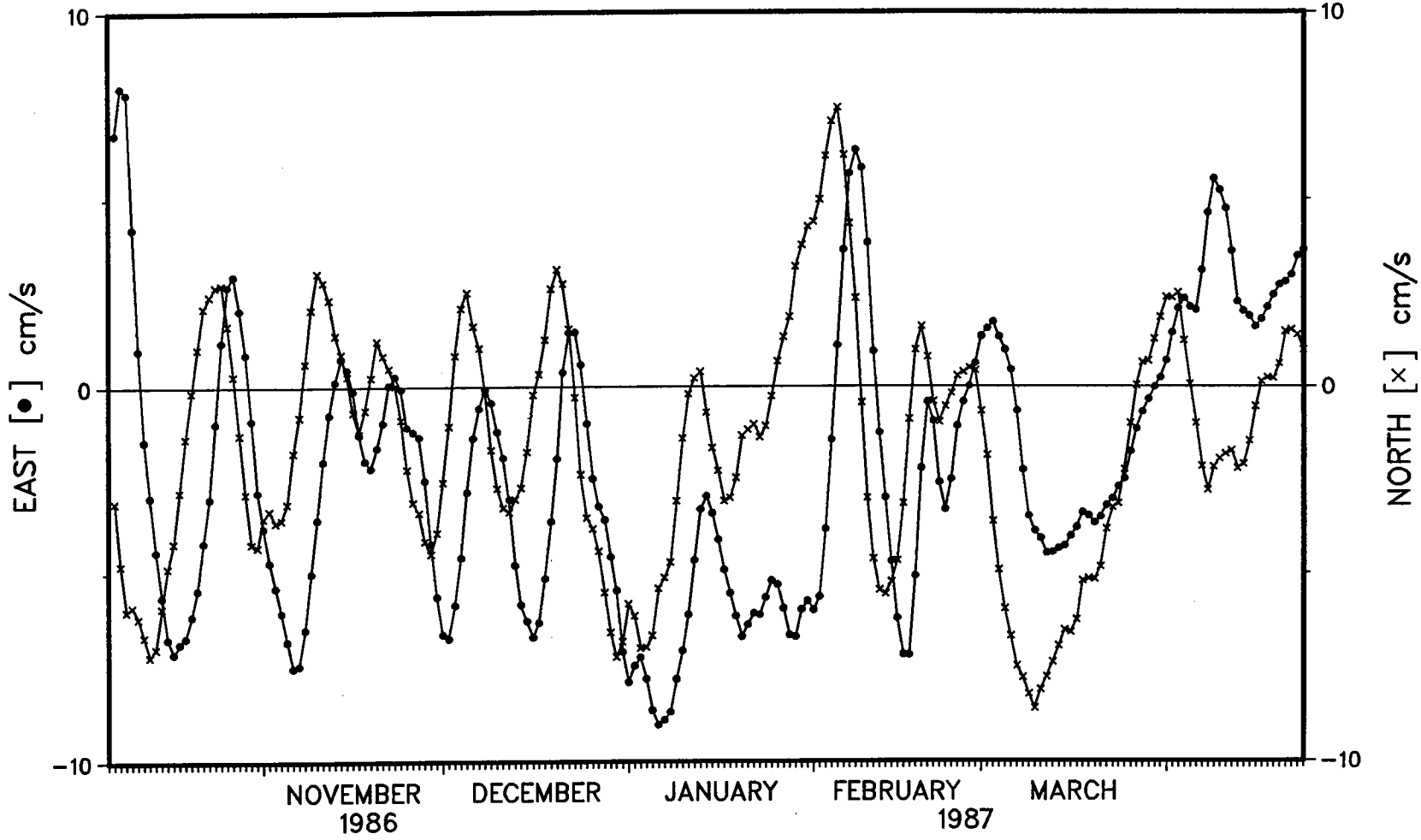
PLOT 2 OF 3
.SPL

EASTERN BASIN 137



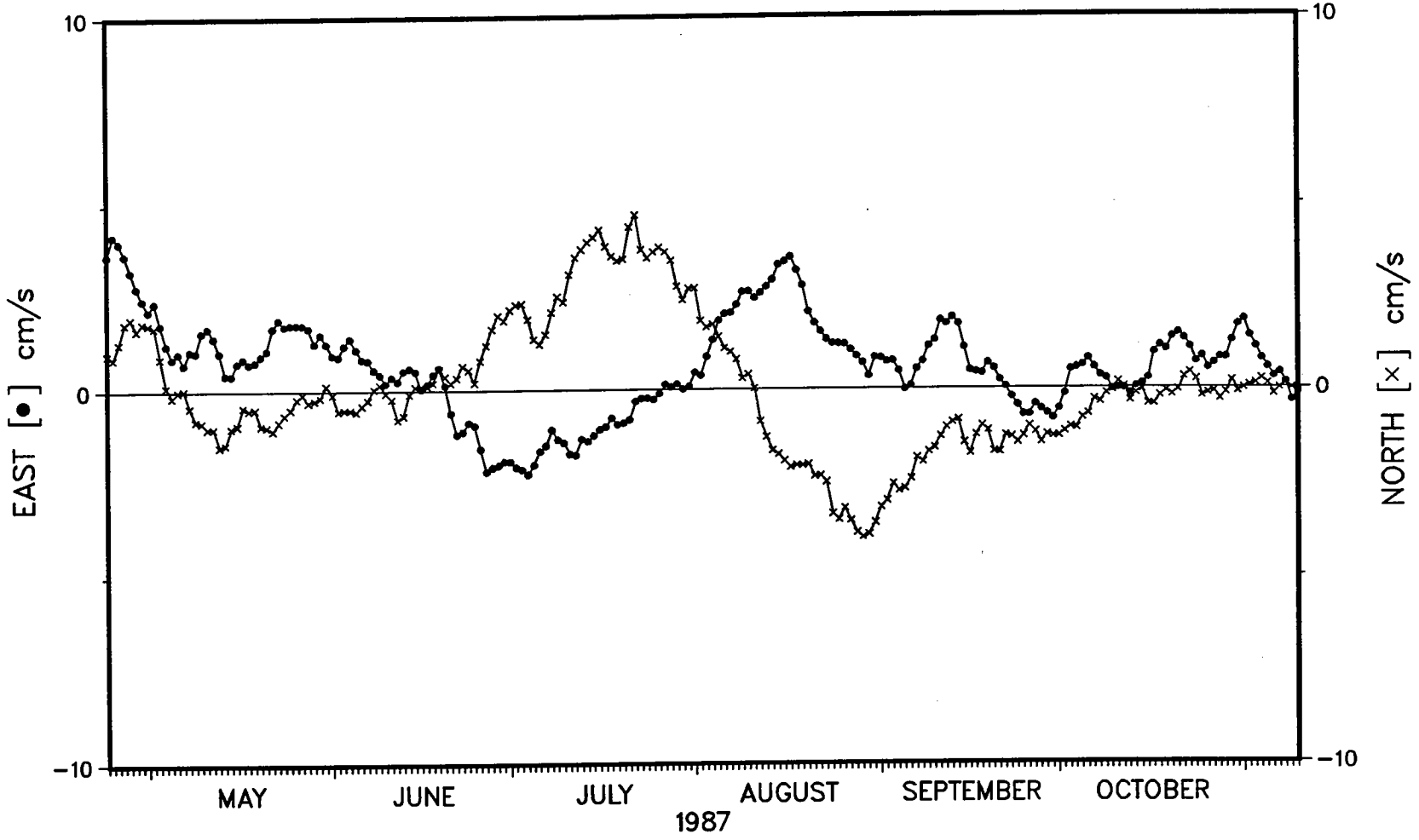
PLOT 3 OF 3
.SPL

EASTERN BASIN 137



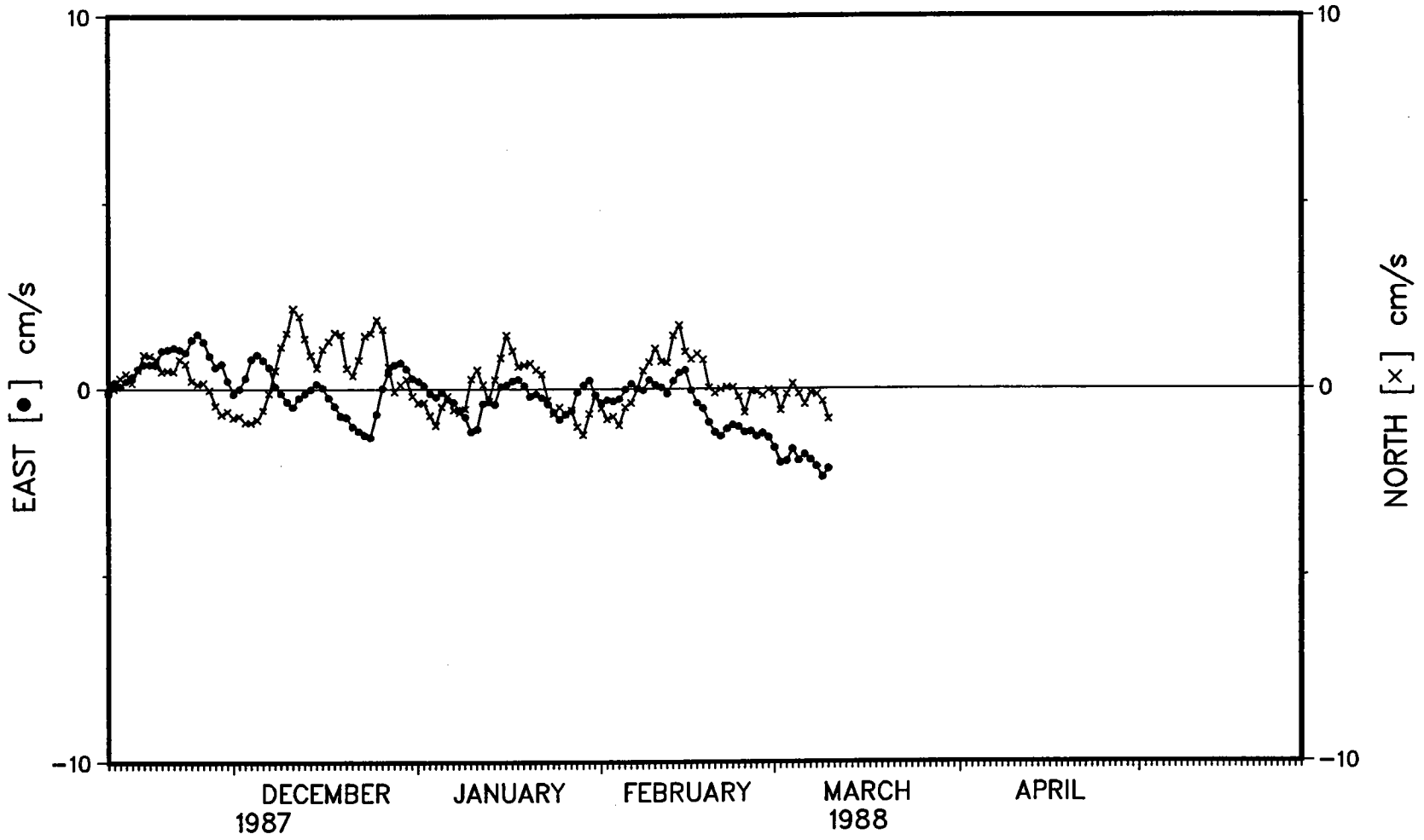
PLOT 1 OF 3
.SPL

EASTERN BASIN 137



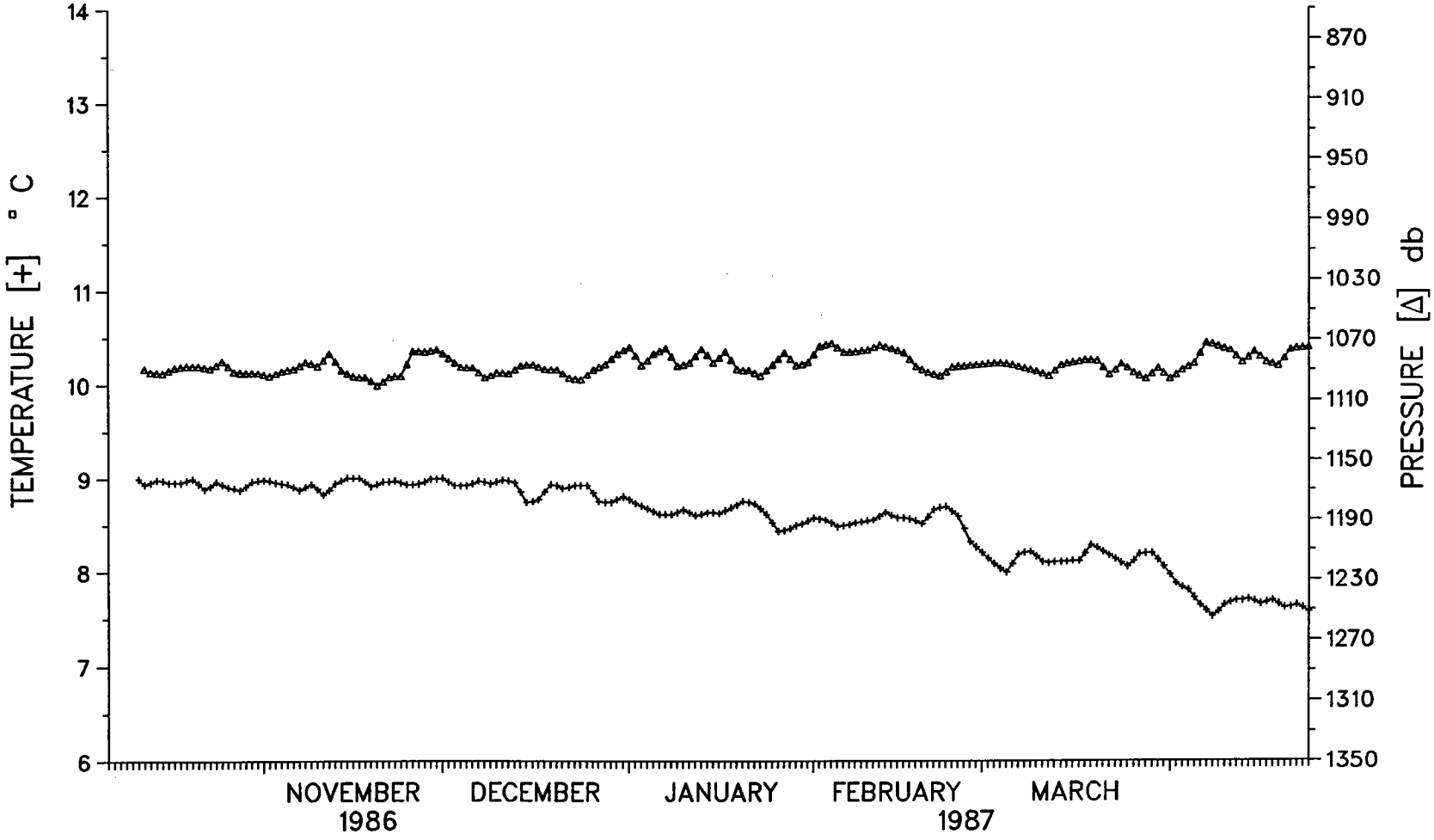
PLOT 2 OF 3
.SPL

EASTERN BASIN 137



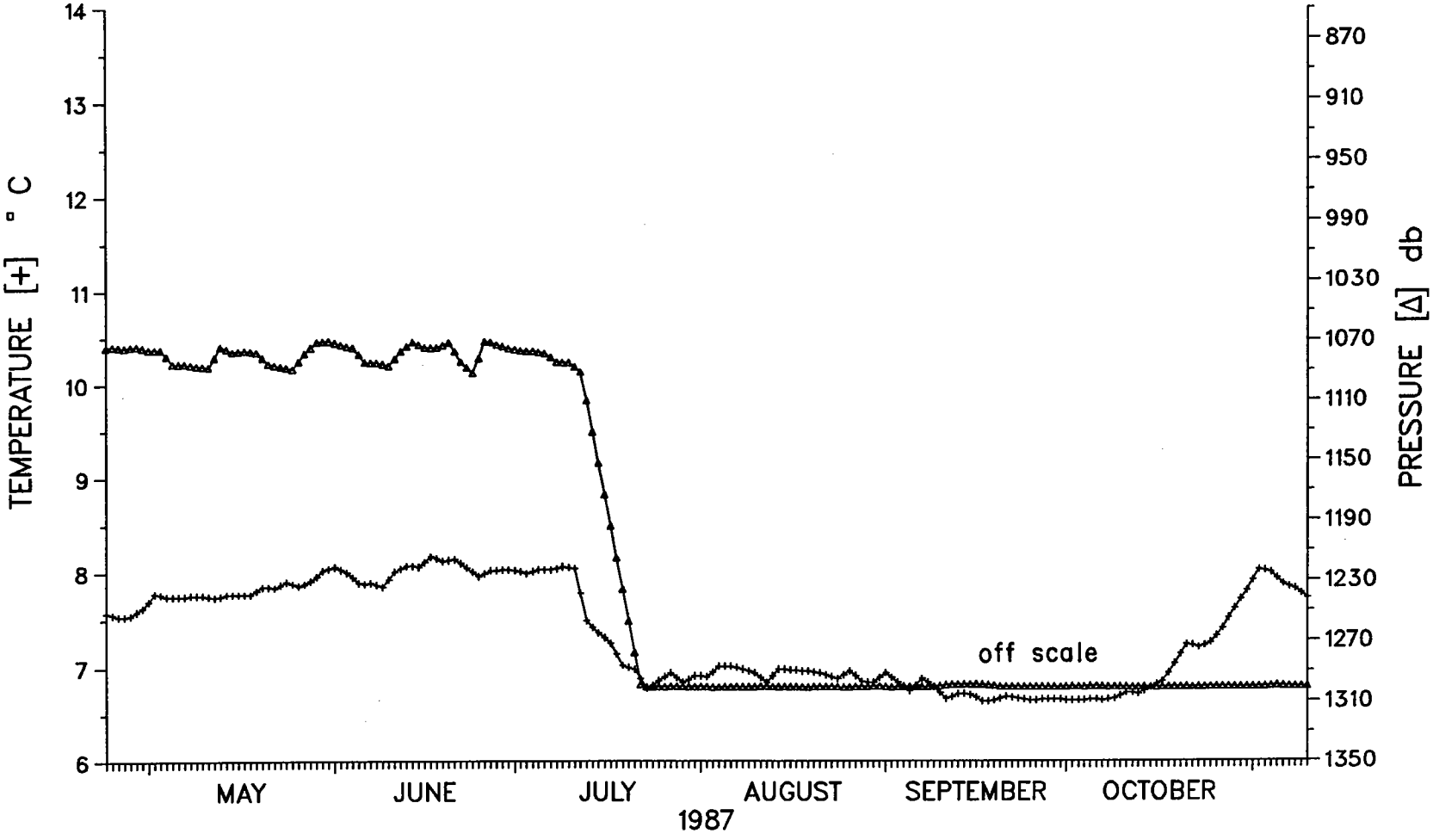
PLOT 3 OF 3
.SPL

EASTERN BASIN 137



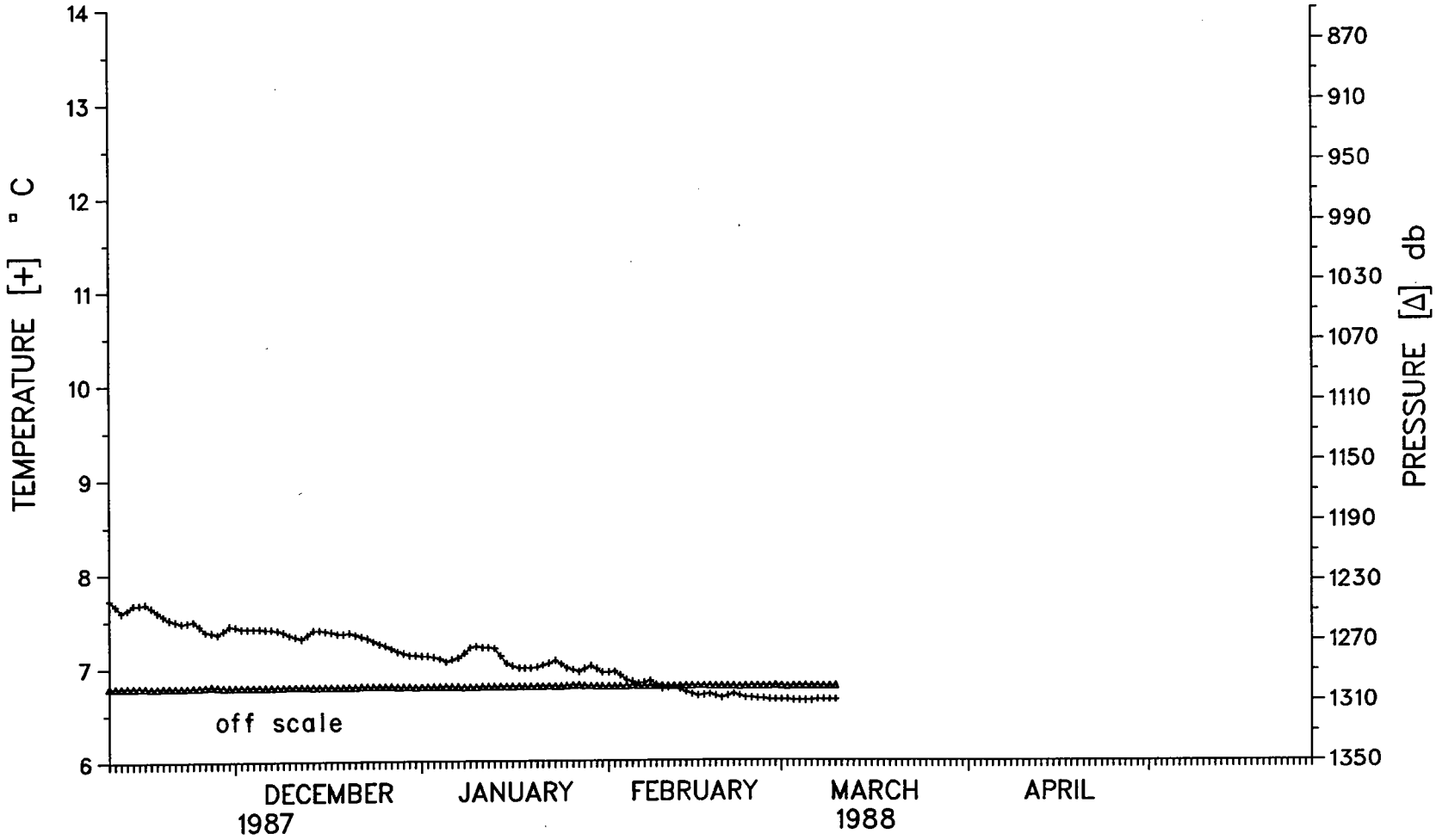
PLOT 1 OF 3
.SPL

EASTERN BASIN 137



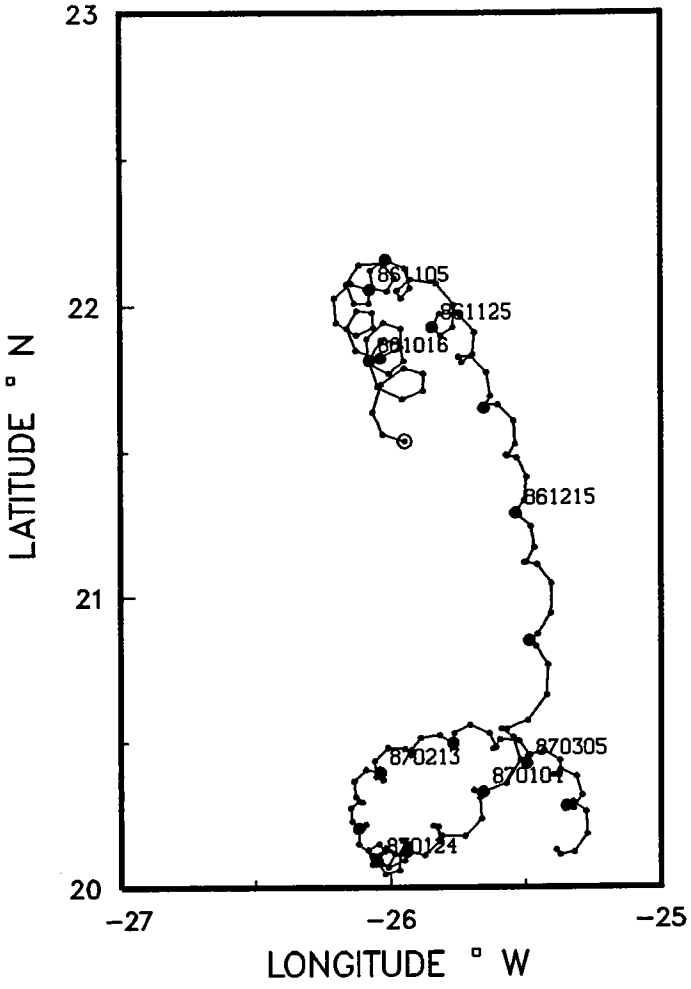
PLOT 2 OF 3
.SPL

EASTERN BASIN 137



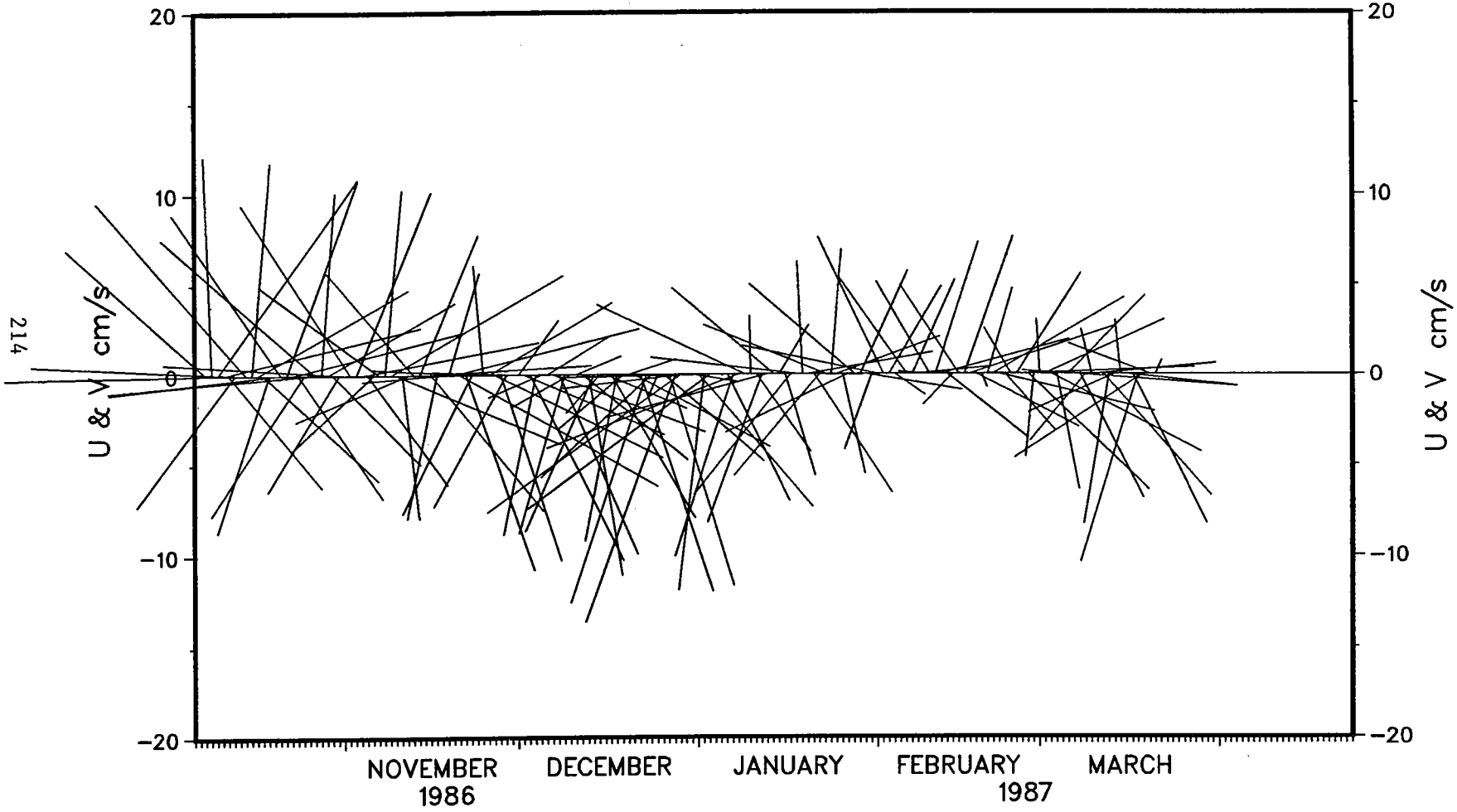
PLOT 3 OF 3
.SPL

EASTERN BASIN 145

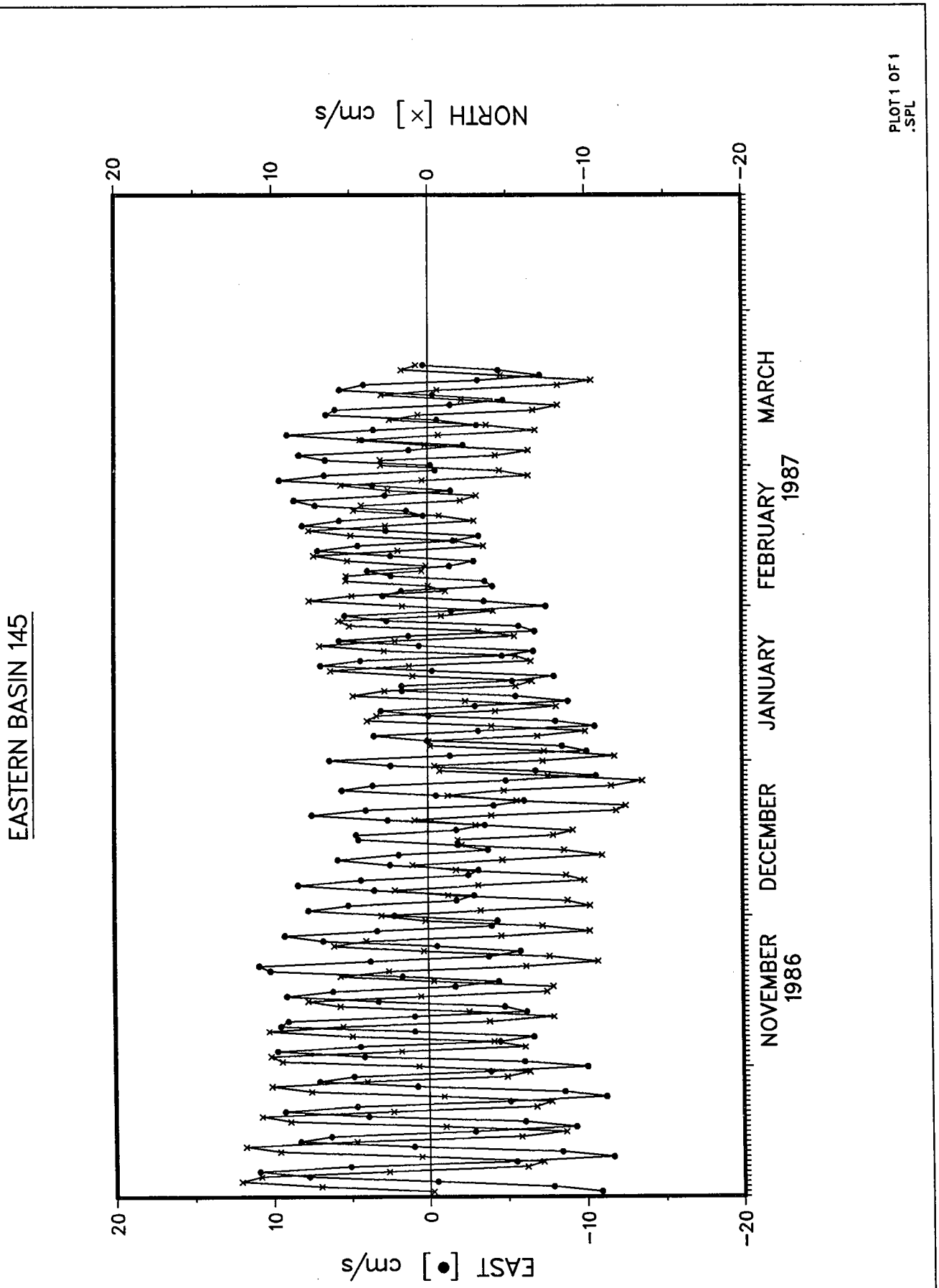


PLOT 1 OF 1
.SPL

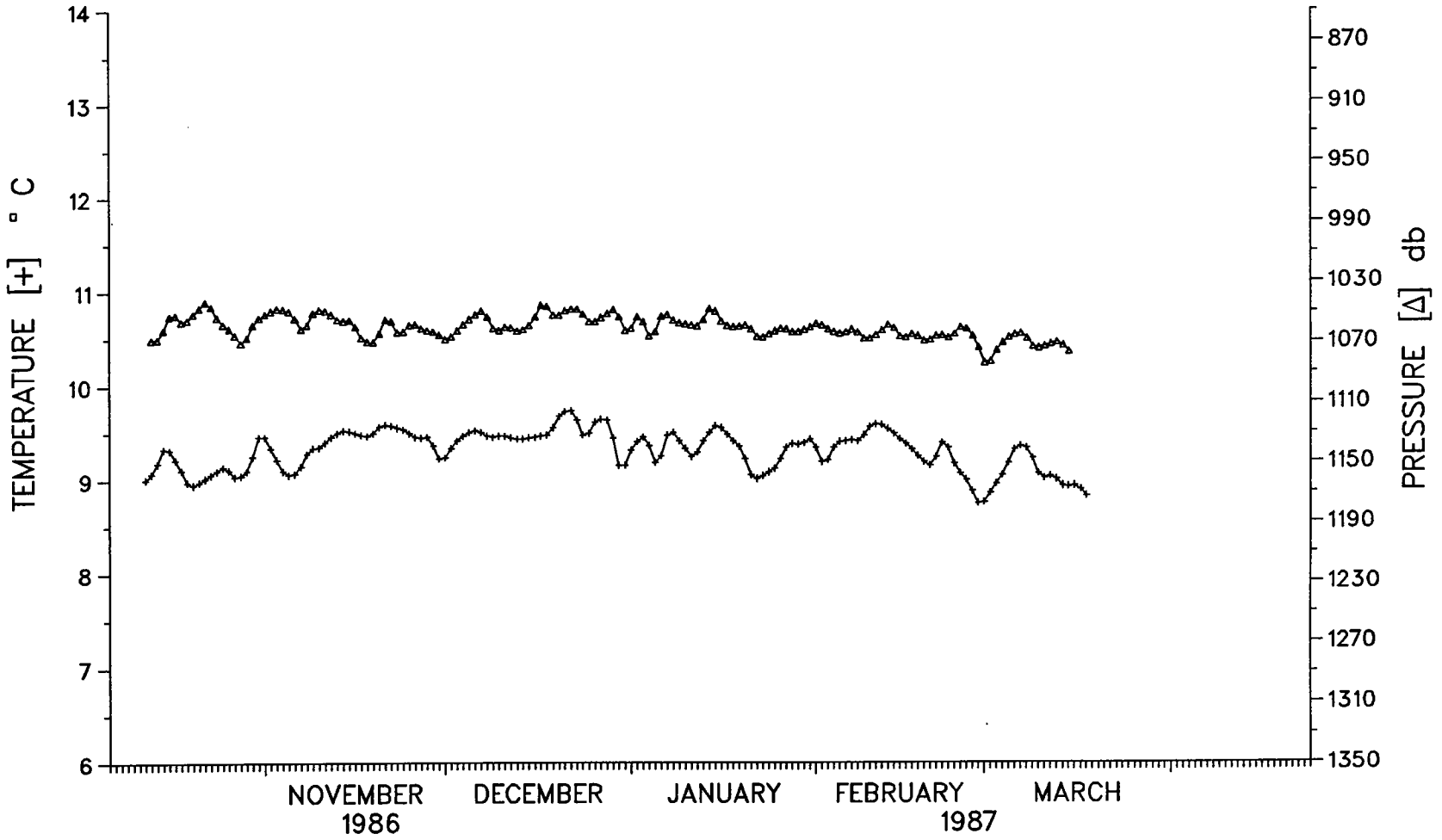
EASTERN BASIN 145



PLOT 1 OF 1
.SPL

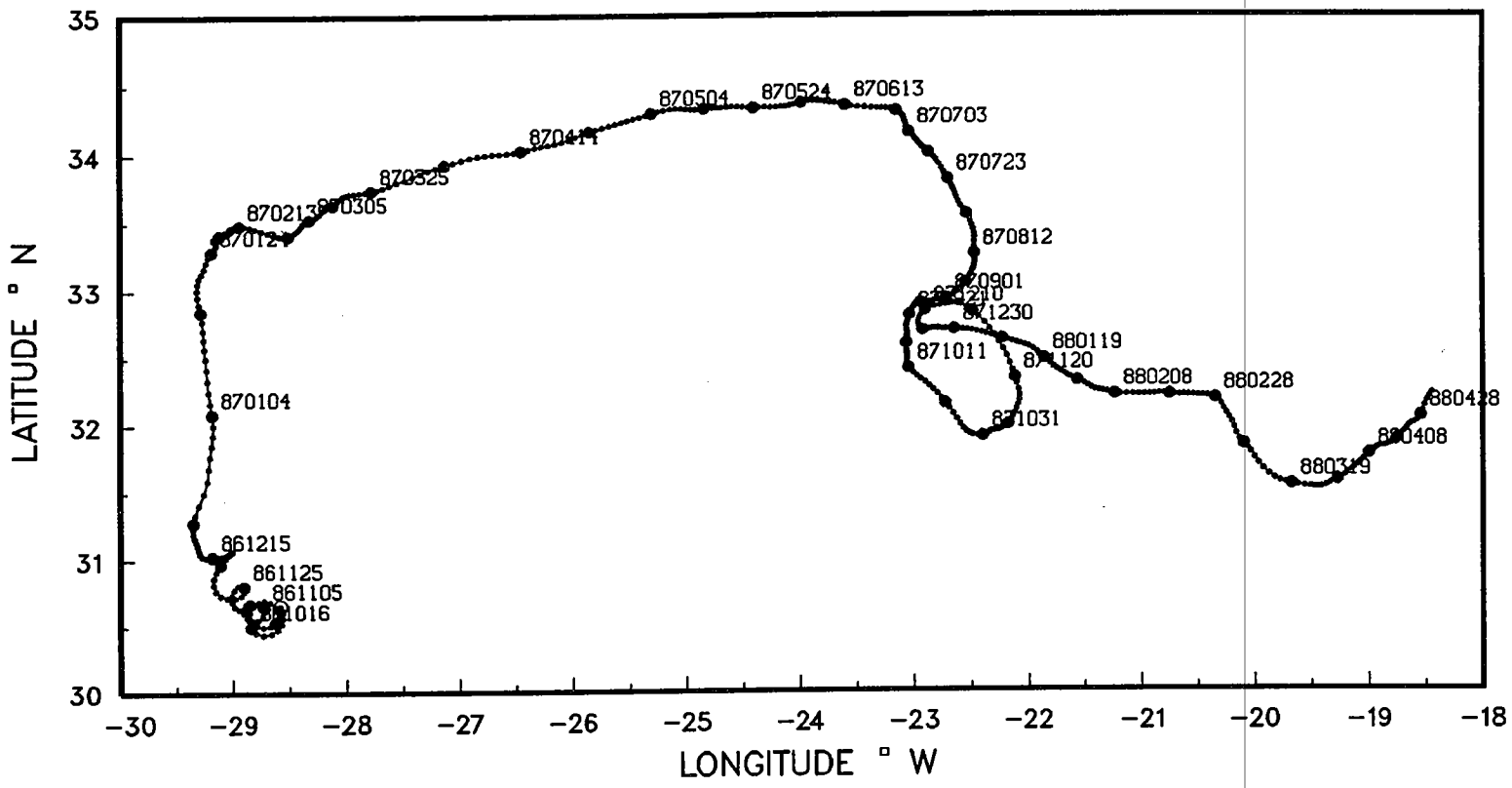

EASTERN BASIN 145
NORTH [×] cm/s
EAST [•] cm/s
20
10
0
−10
−20
NOVEMBER 1986
DECEMBER
JANUARY
FEBRUARY 1987
MARCH
PLOT 1 OF 1
.SPL

EASTERN BASIN 145



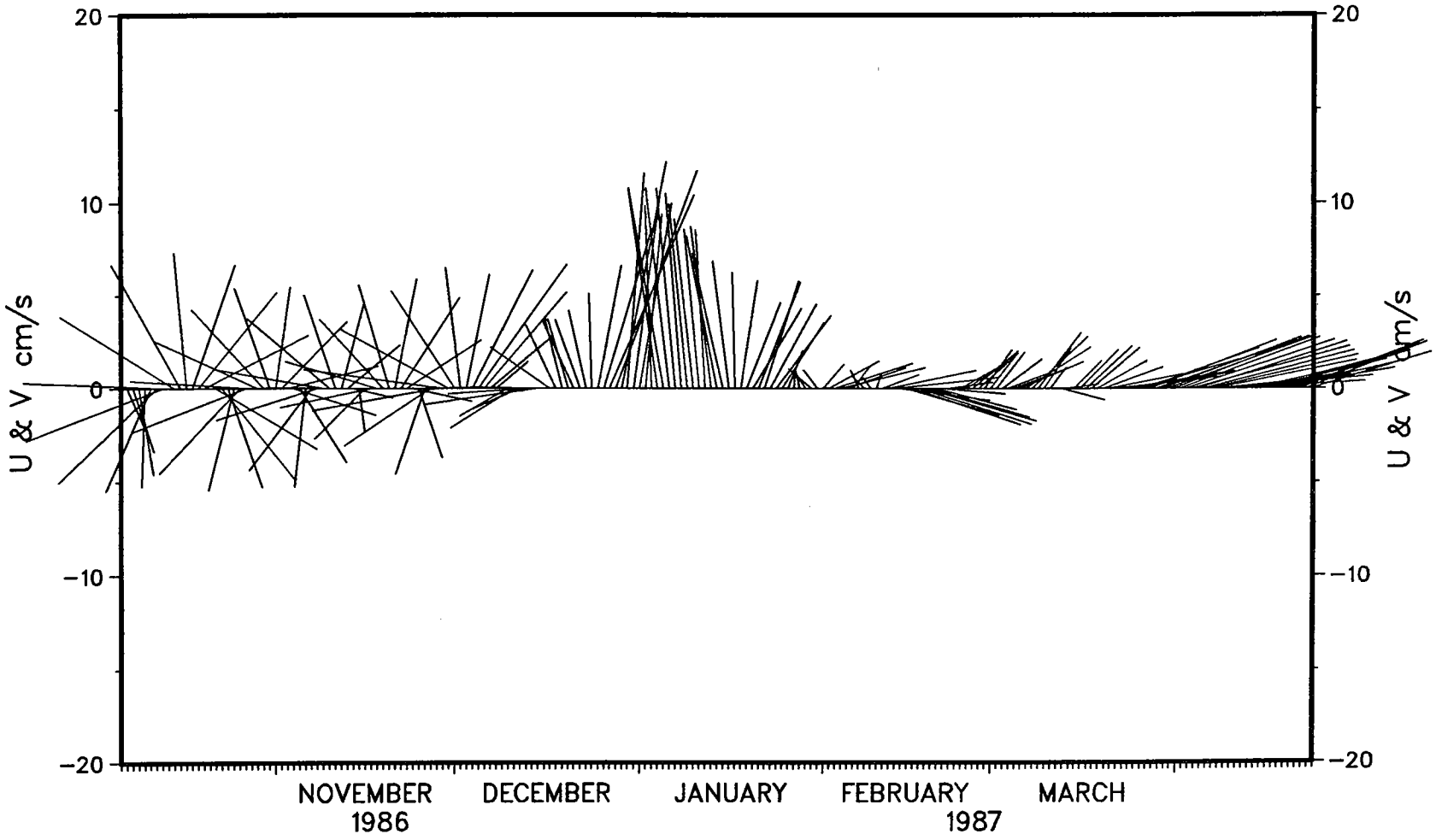
PLOT 1 OF 1
.SPL

EASTERN BASIN 148



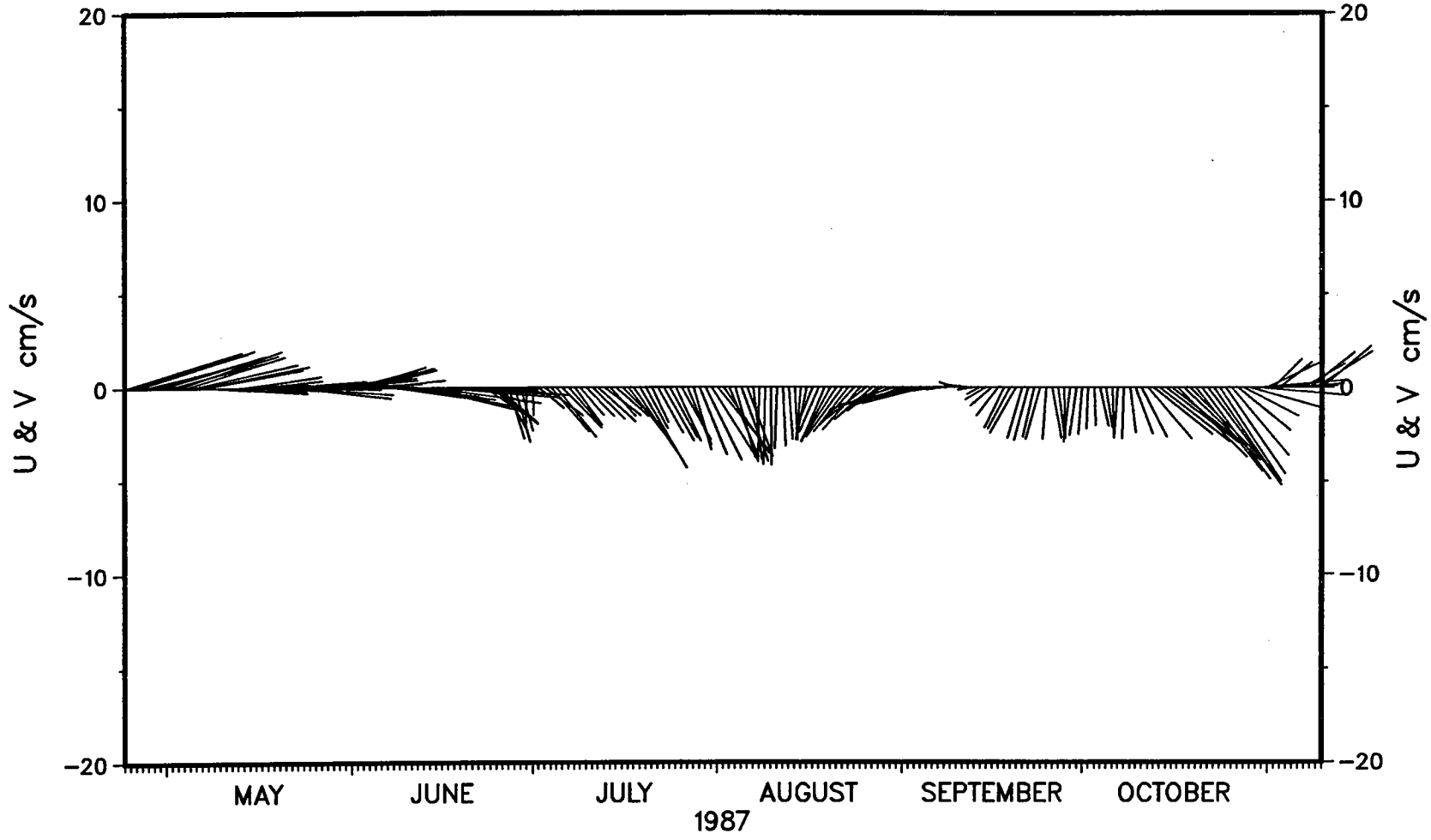
PLOT 1 OF 1
.SPL

EASTERN BASIN 148



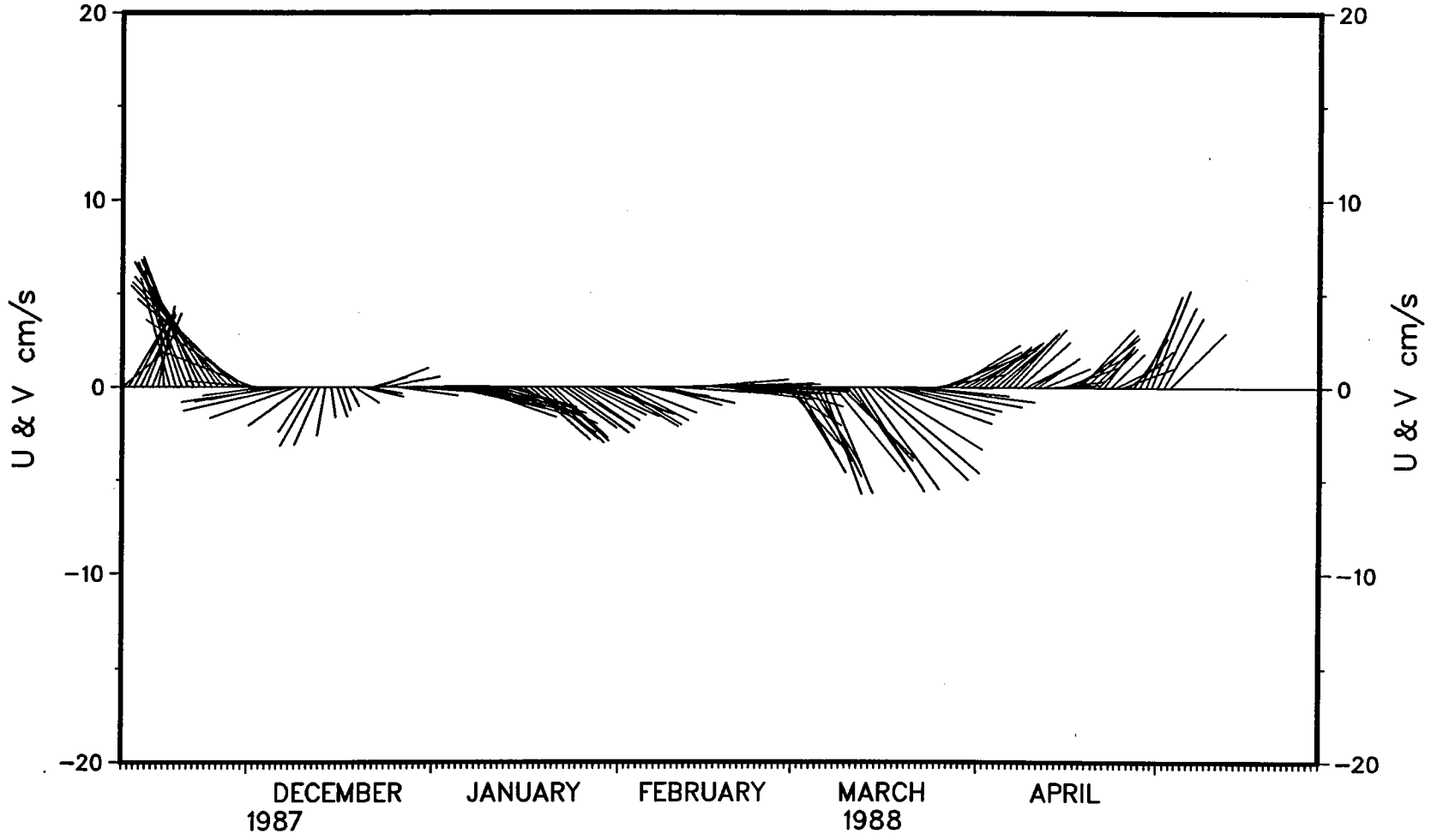
PLOT 1 OF 3
.SPL

EASTERN BASIN 148



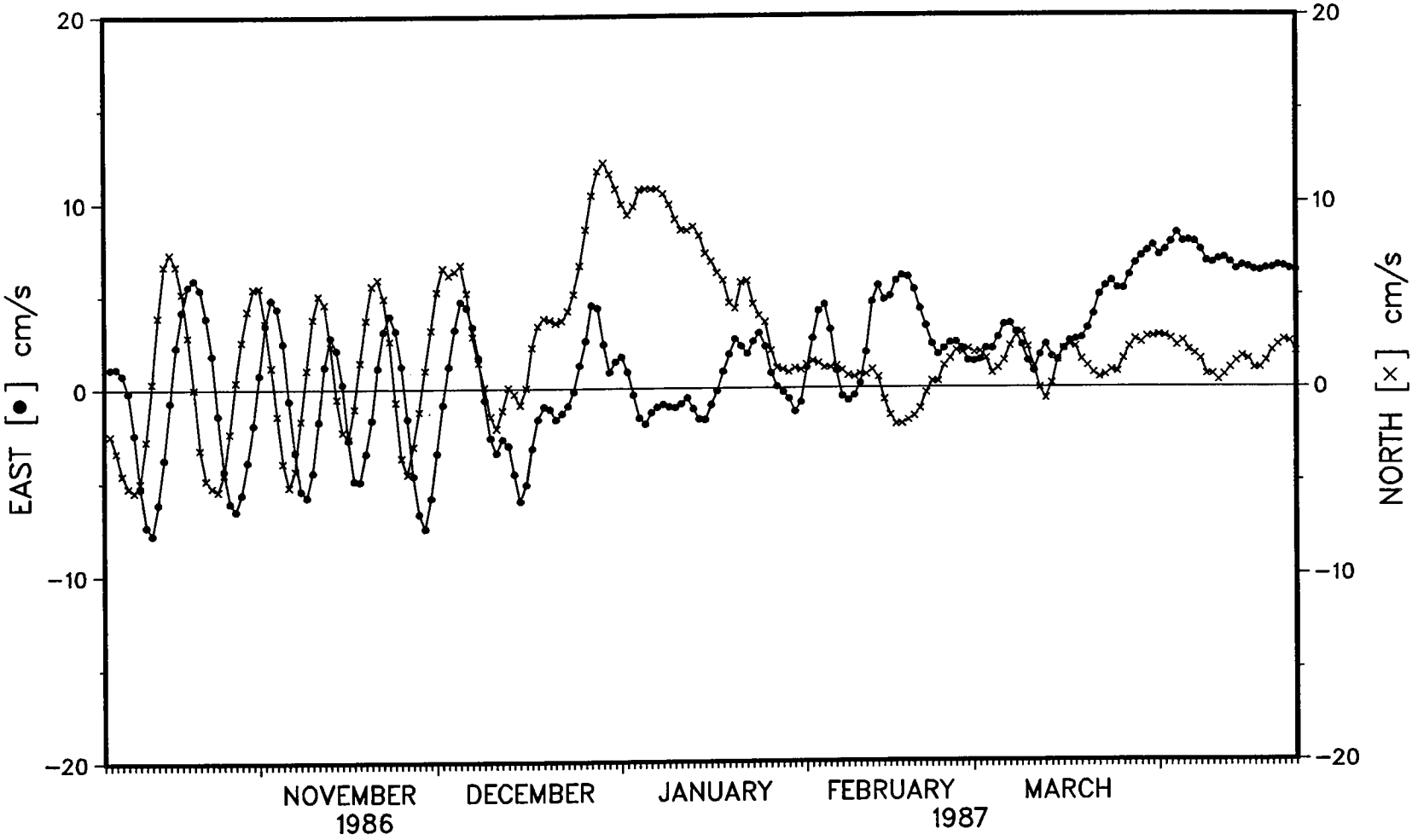
PLOT 2 OF 3
.SPL

EASTERN BASIN 148



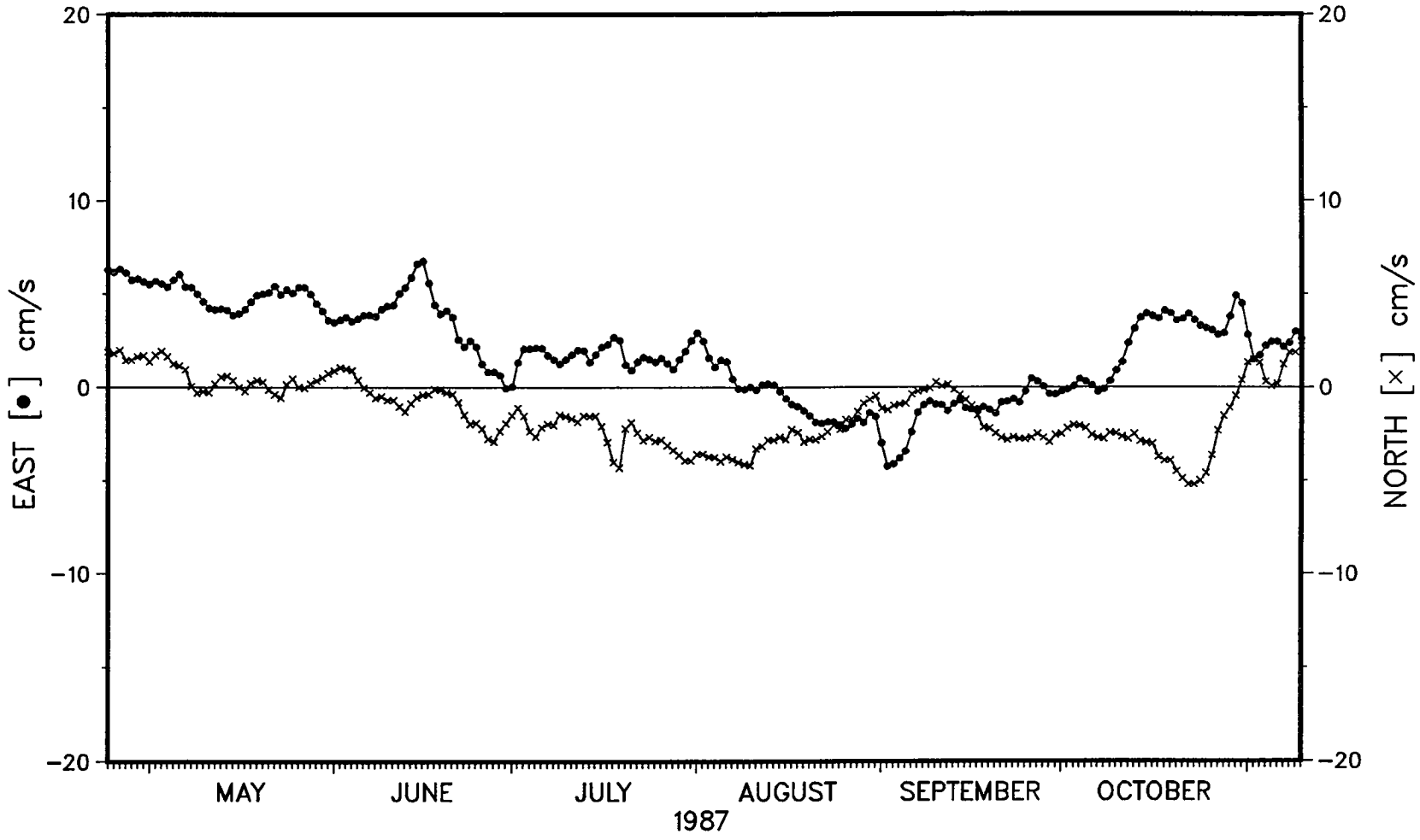
PLOT 3 OF 3
.SPL

EASTERN BASIN 148



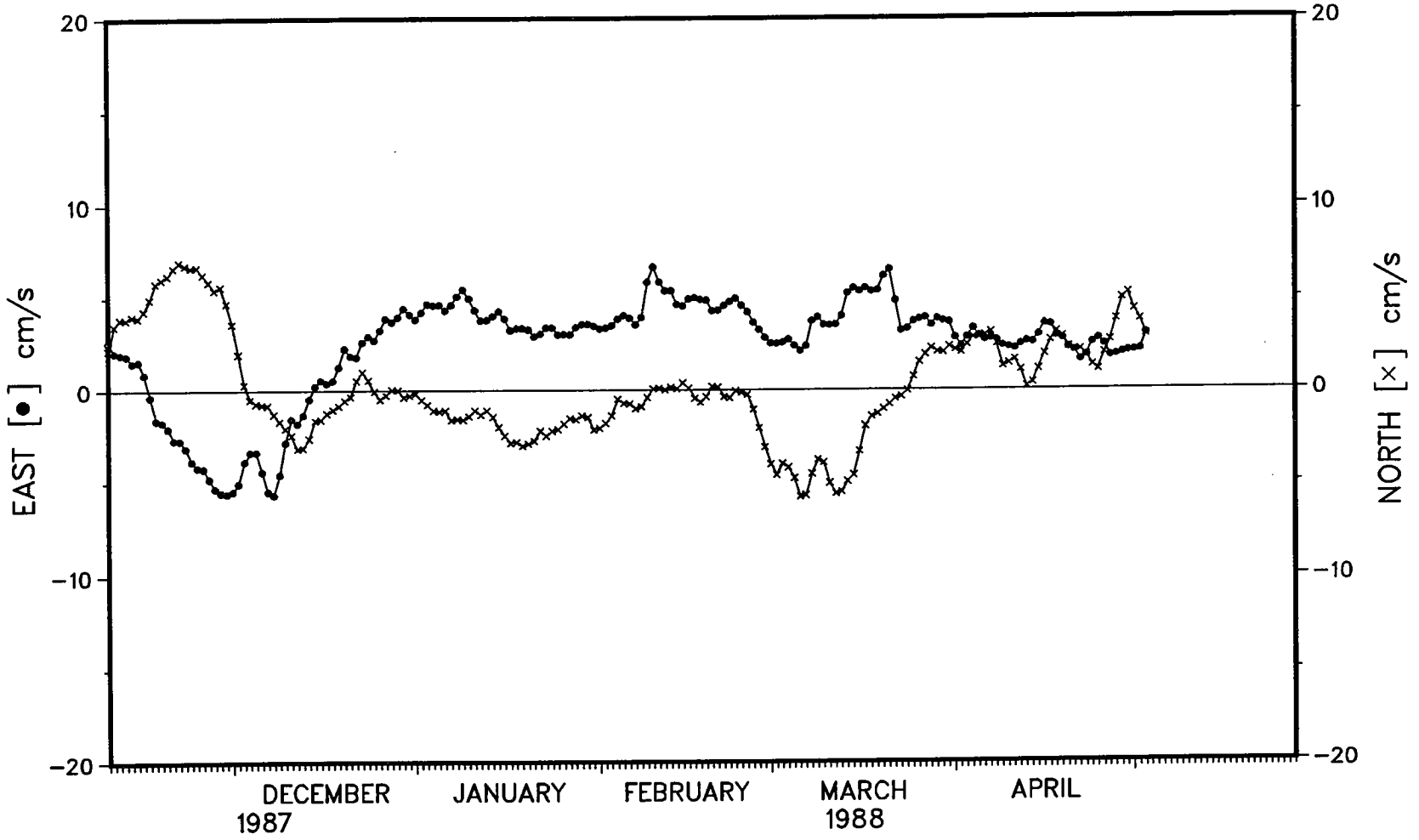
PLOT 1 OF 3
.SPL

EASTERN BASIN 148



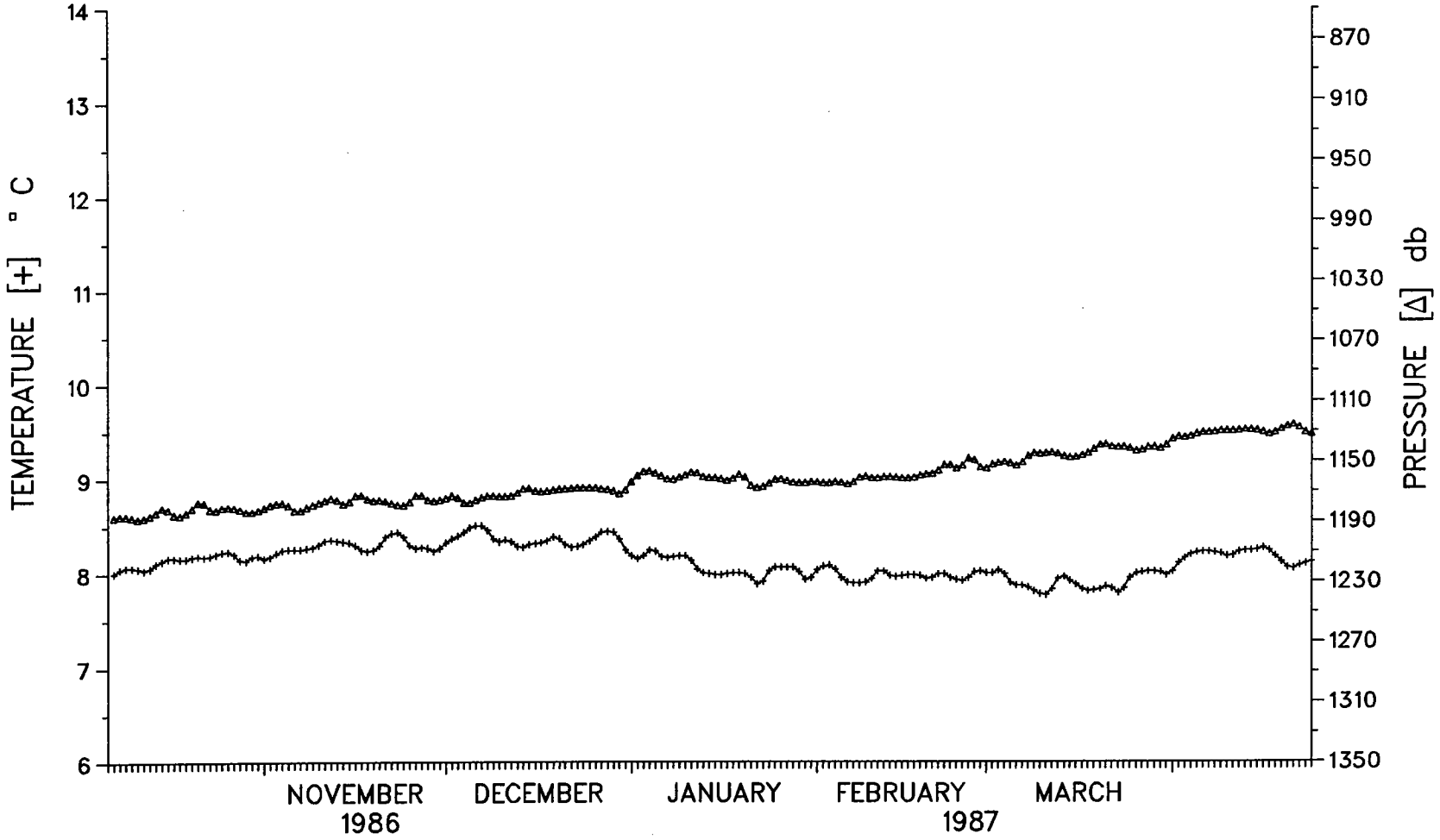
PLOT 2 OF 3
.SPL

EASTERN BASIN 148



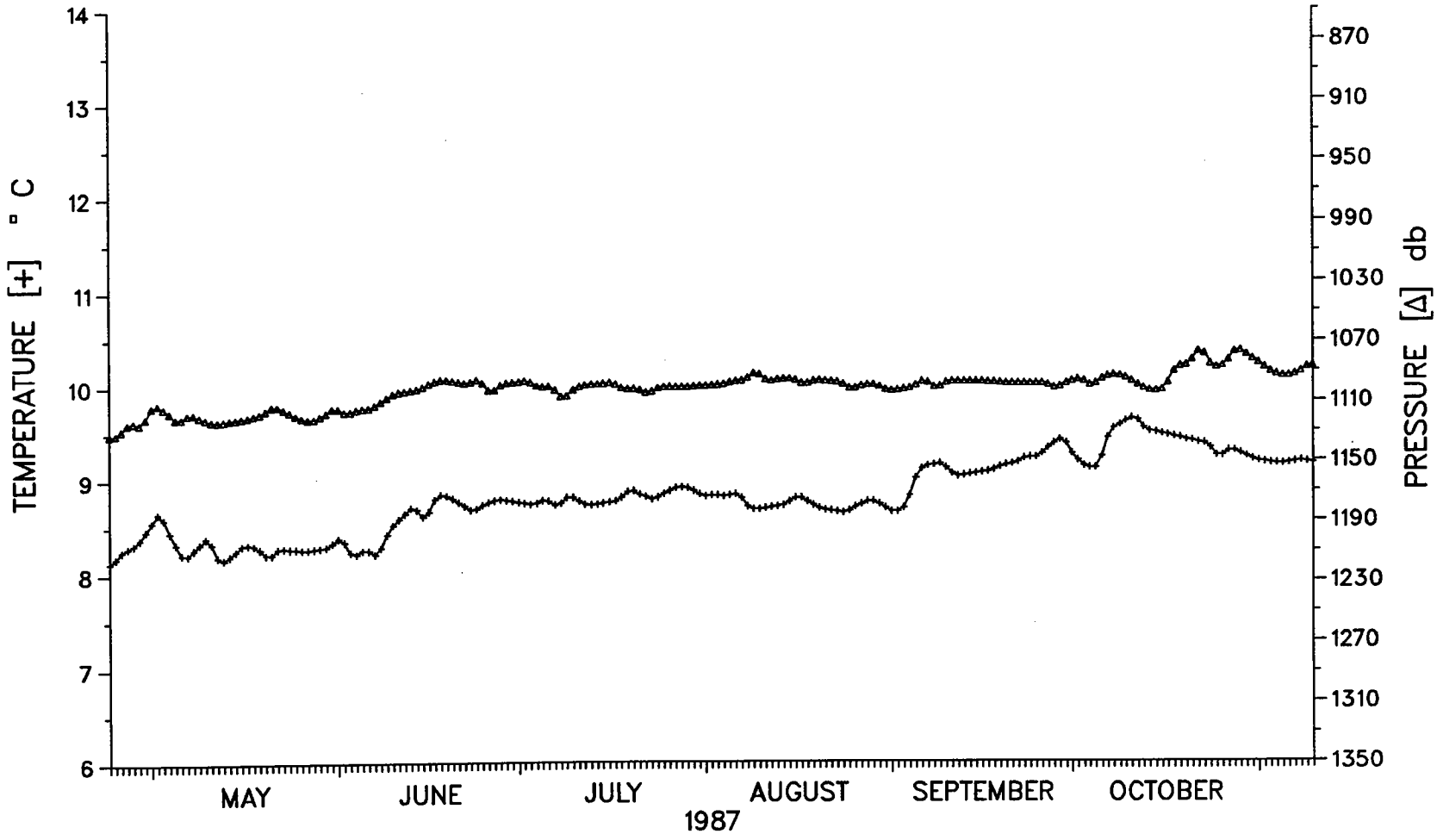
PLOT 3 OF 3
.SPL

EASTERN BASIN 148



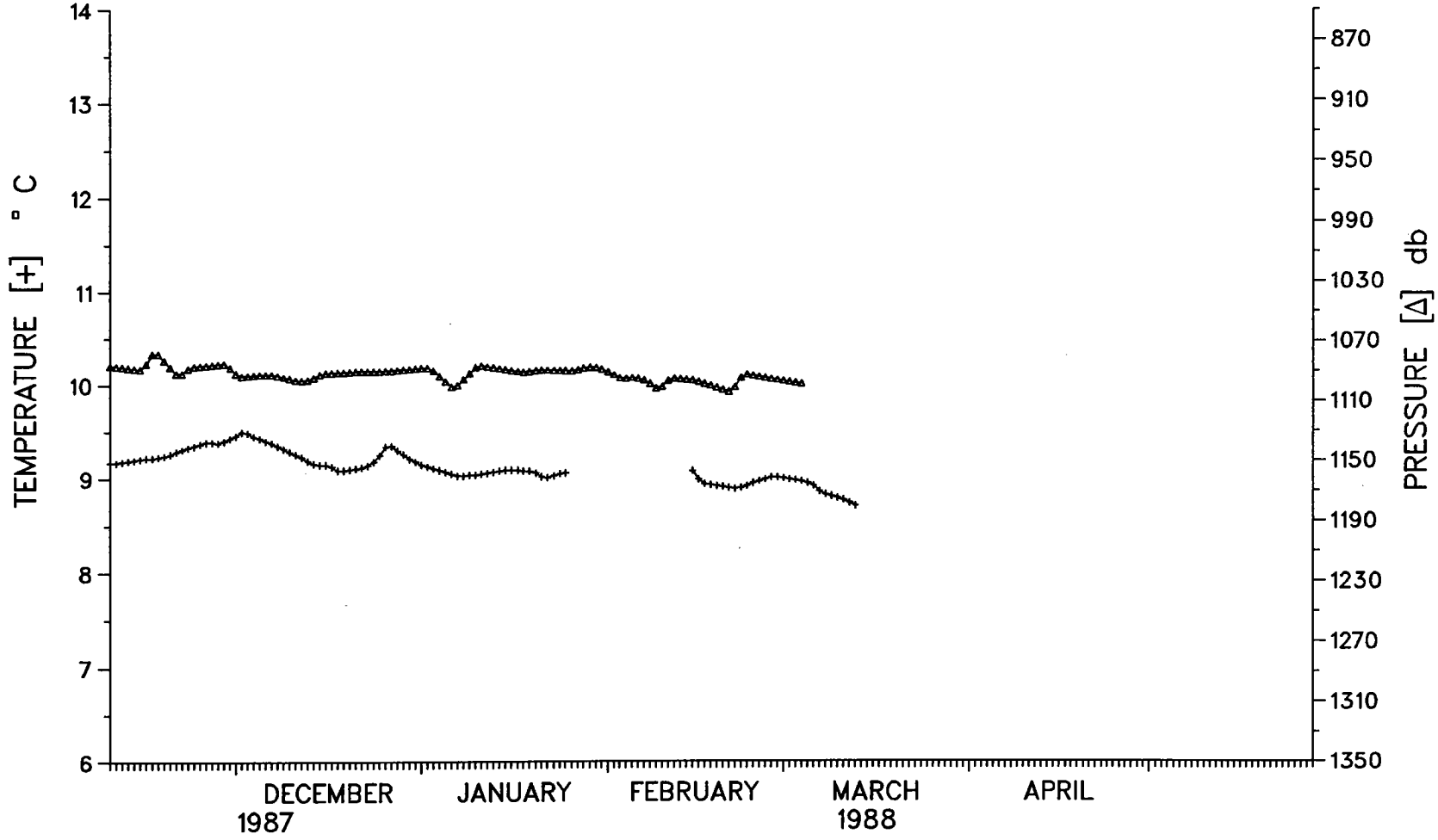
PLOT 1 OF 3
.SPL

EASTERN BASIN 148



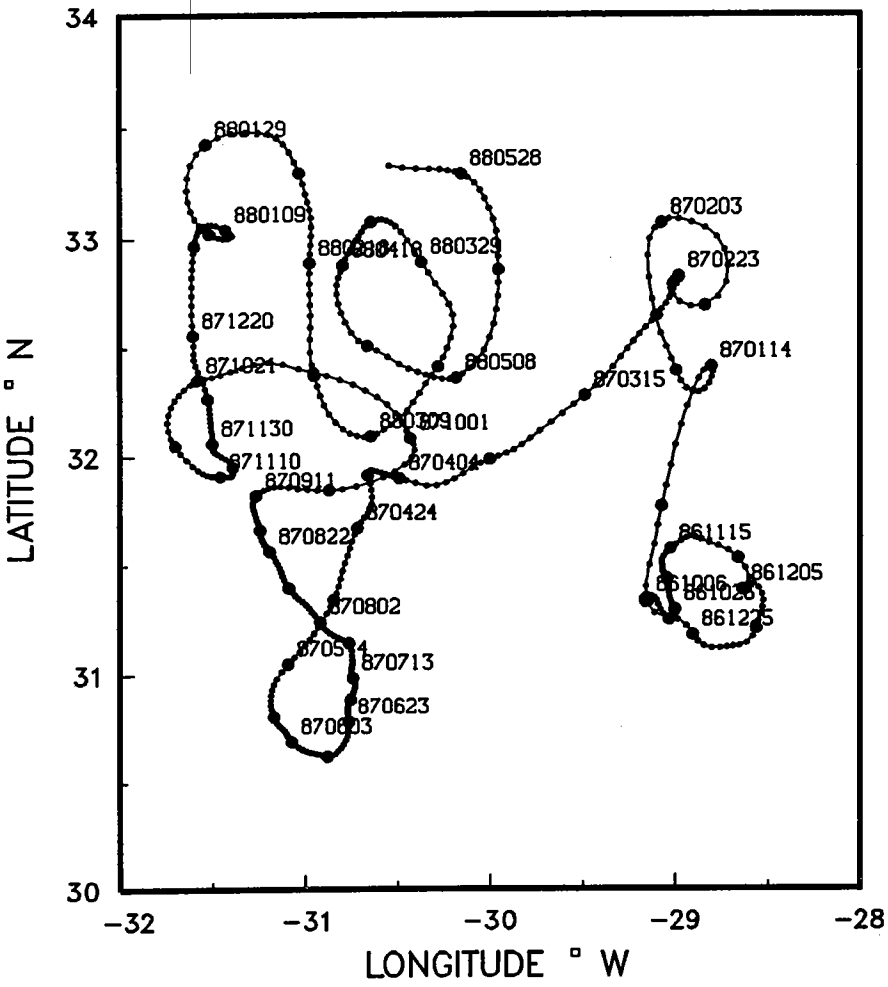
PLOT 2 OF 3
.SPL

EASTERN BASIN 148



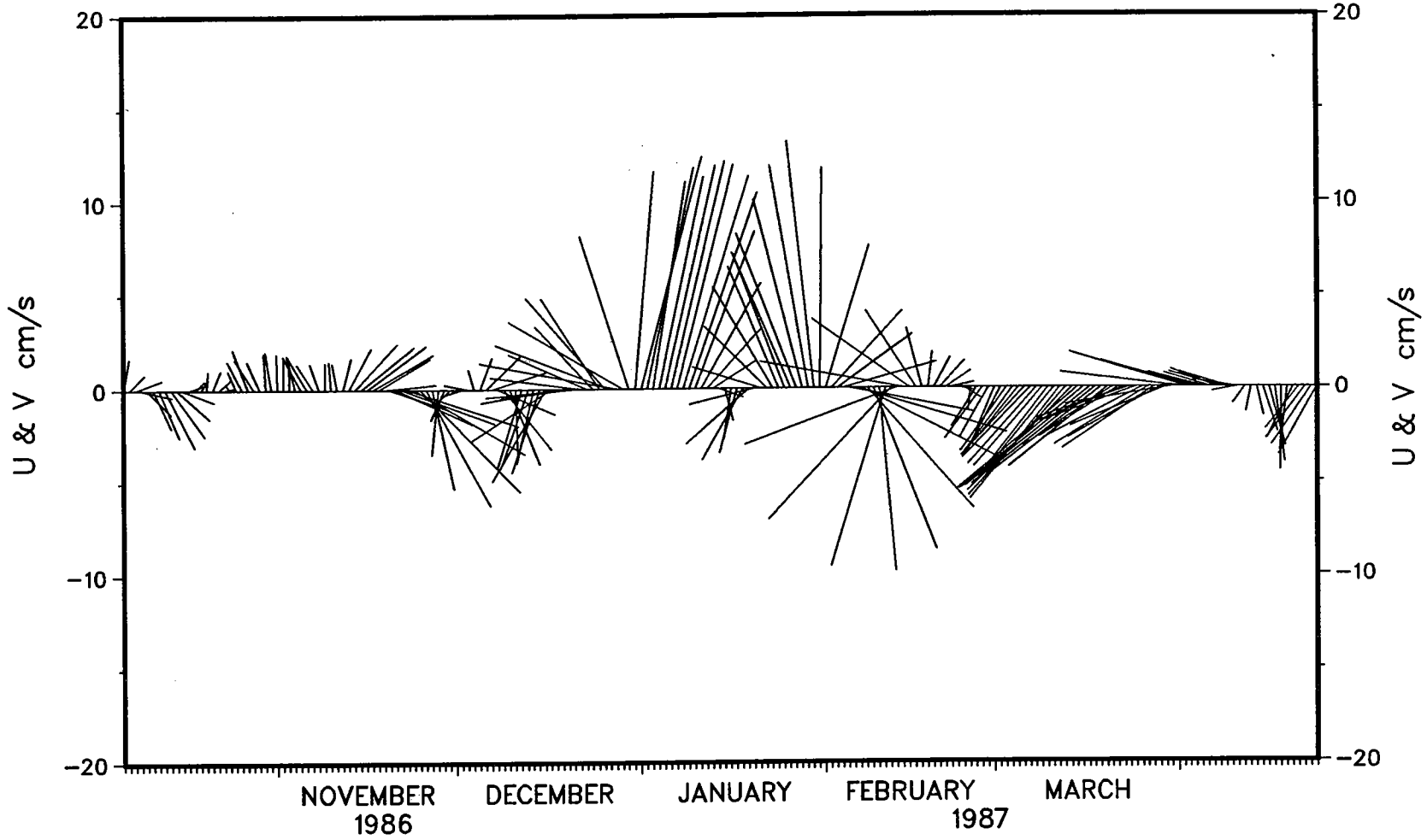
PLOT 3 OF 3
.SPL

EASTERN BASIN 149



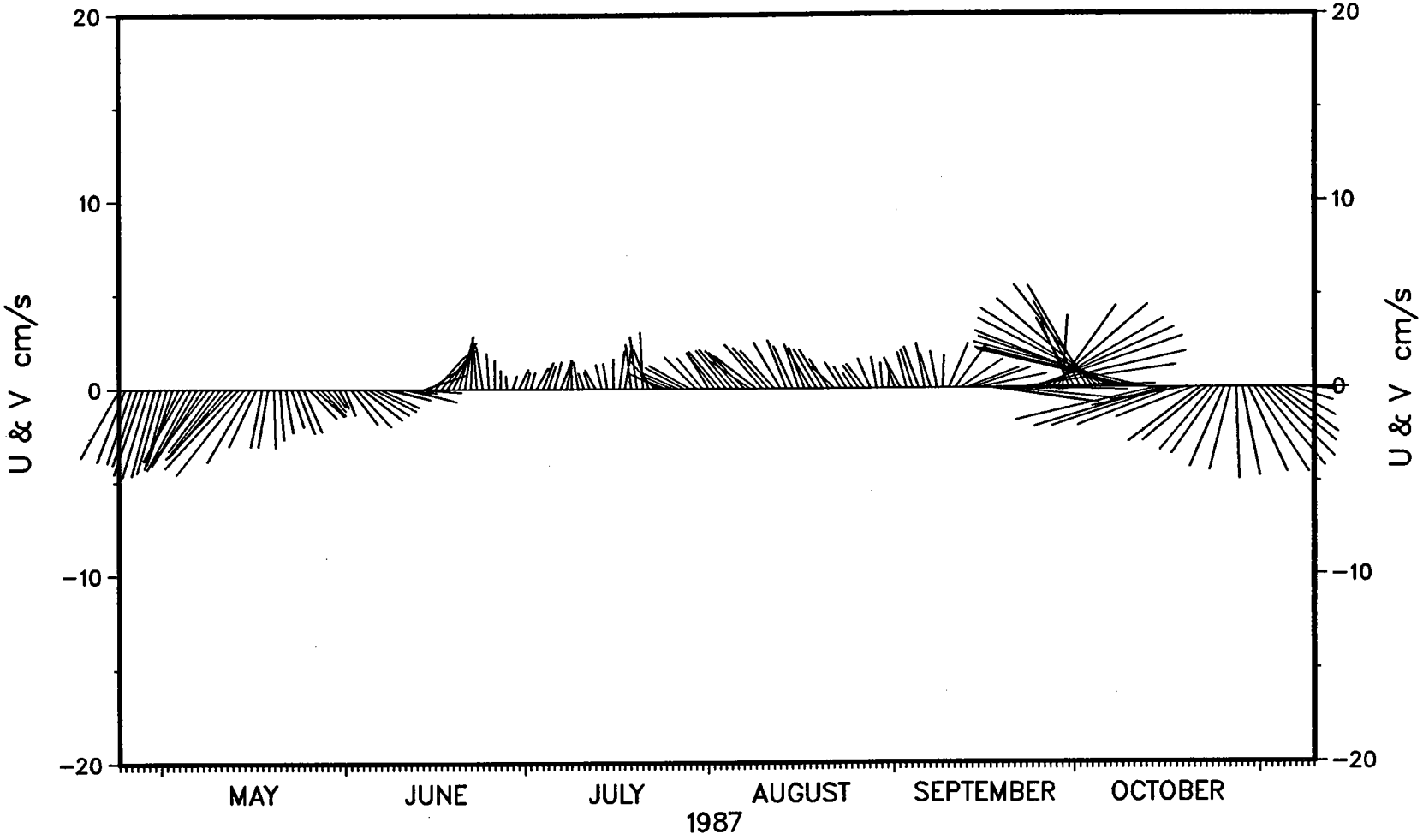
PLOT 1 OF 1
.SPL

EASTERN BASIN 149



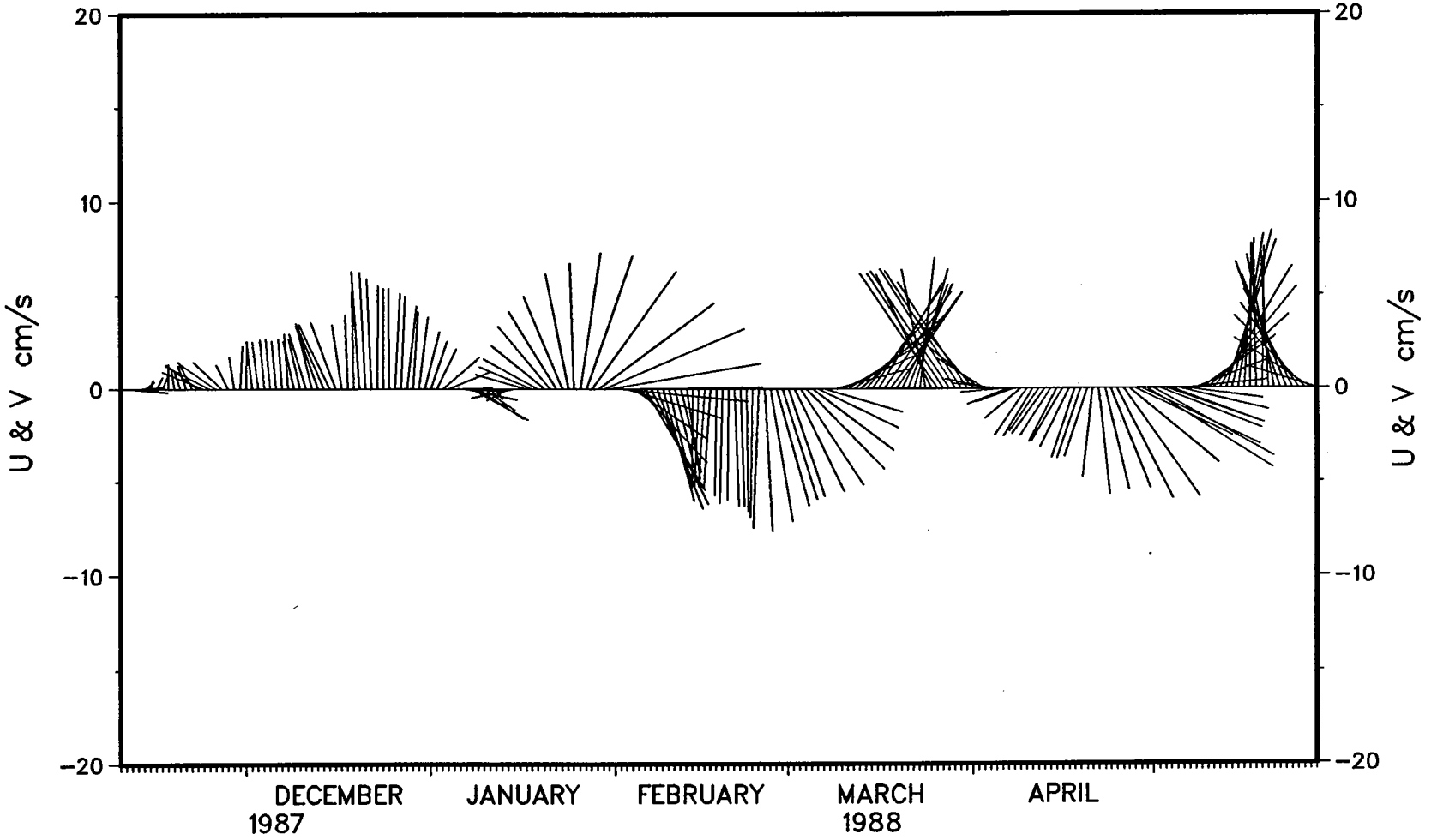
PLOT 1 OF 4
.SPL

EASTERN BASIN 149



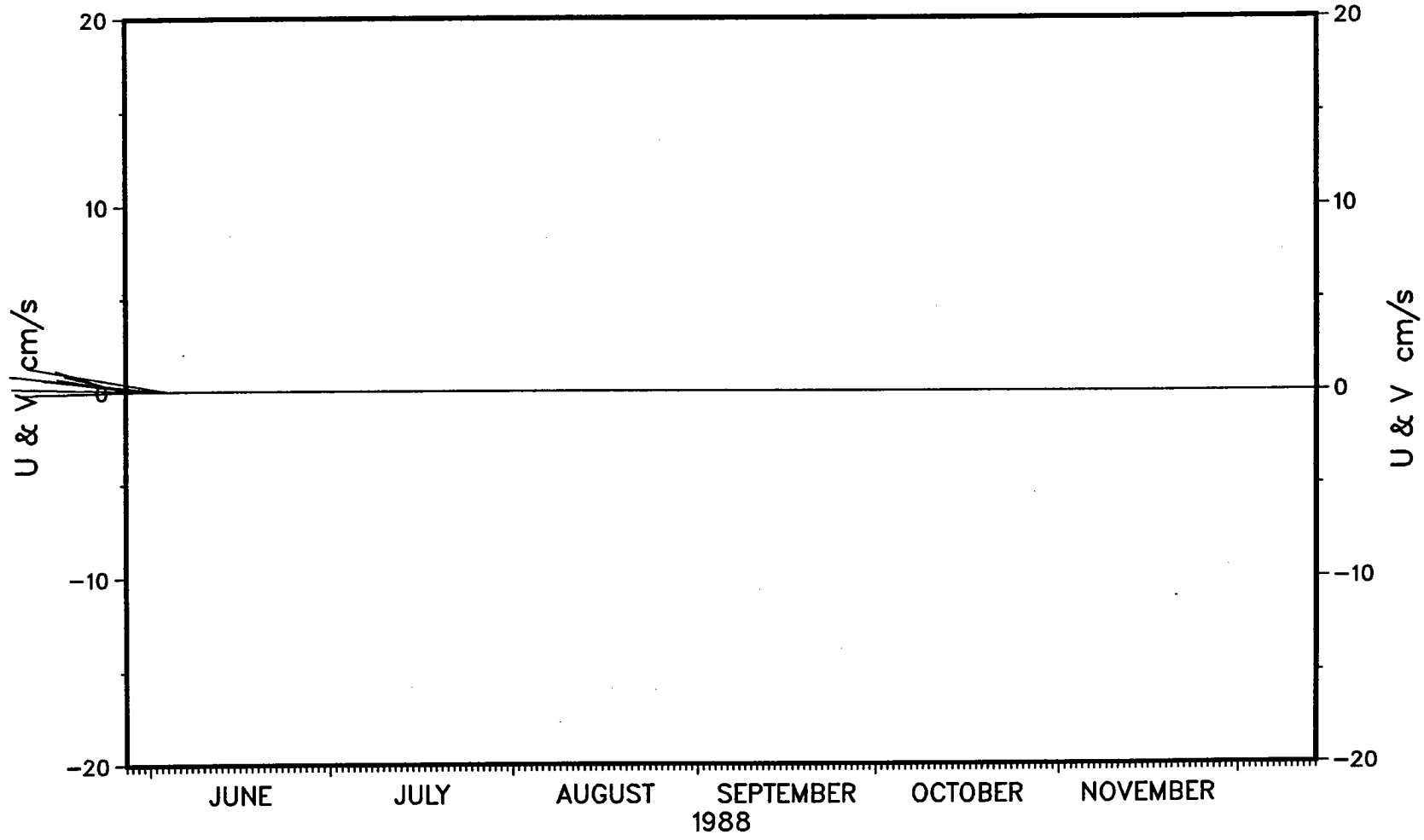
PLOT 2 OF 4
.SPL

EASTERN BASIN 149



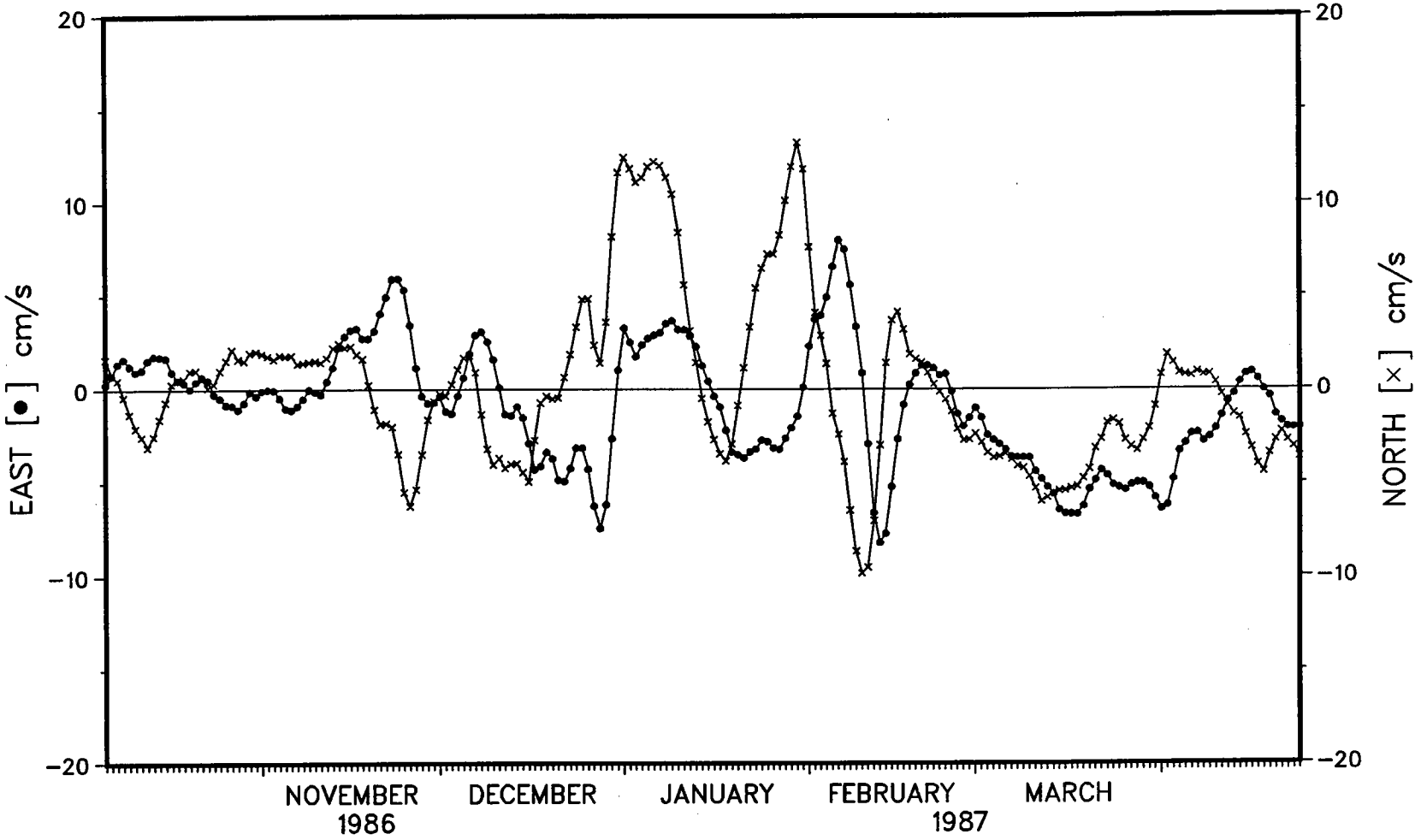
PLOT 3 OF 4
.SPL

EASTERN BASIN 149



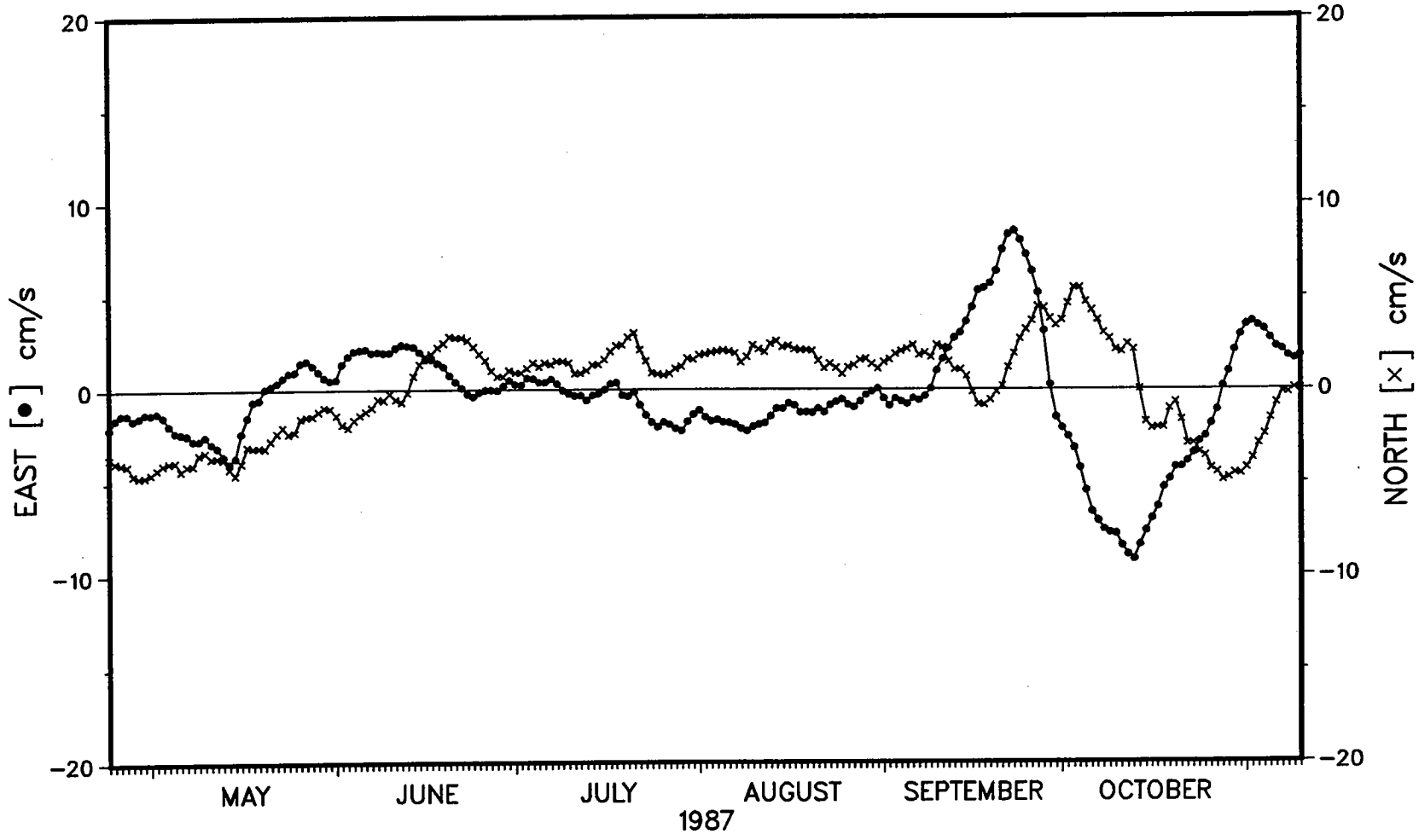
PLOT 4 OF 4
.SPL

EASTERN BASIN 149



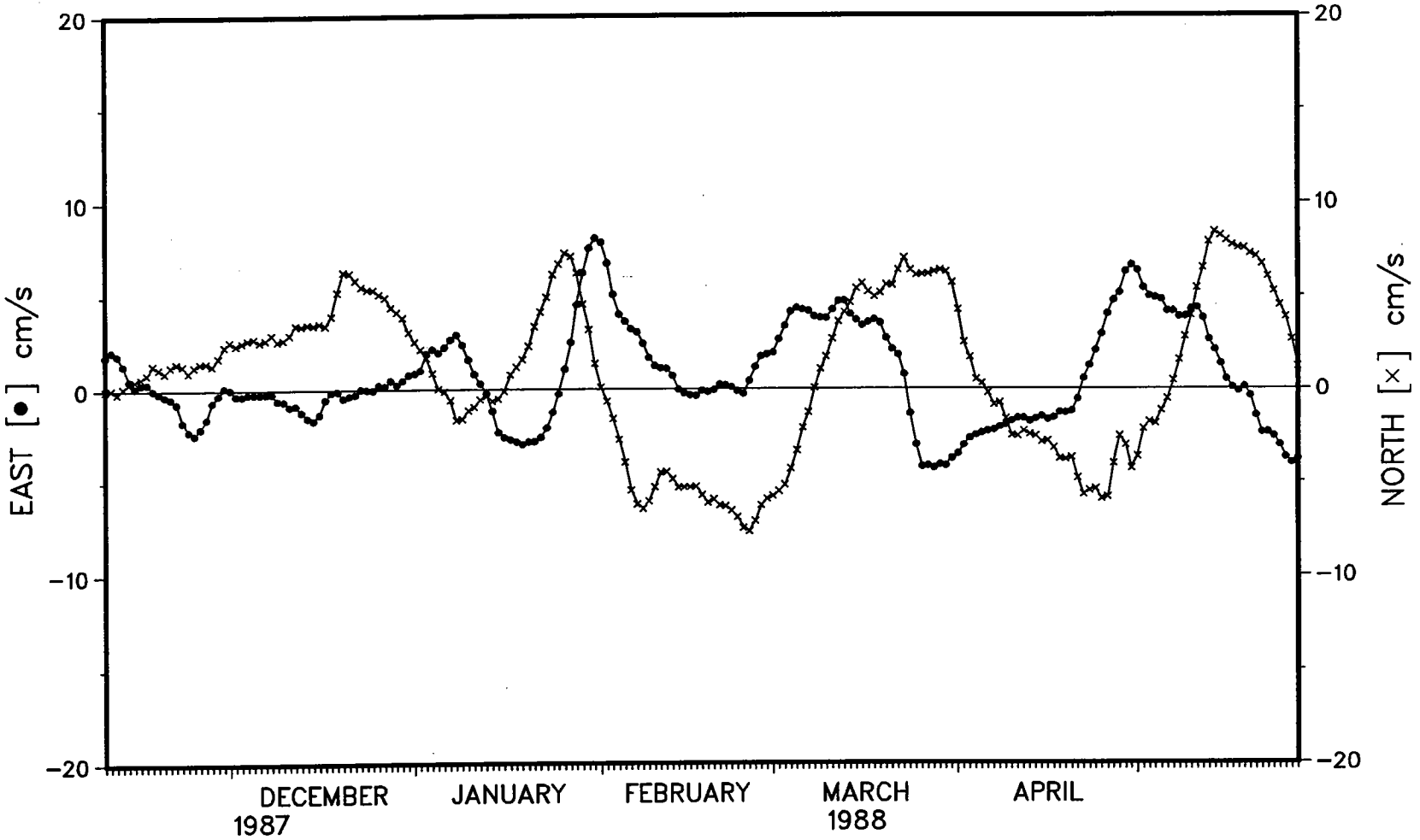
PLOT 1 OF 4
.SPL

EASTERN BASIN 149



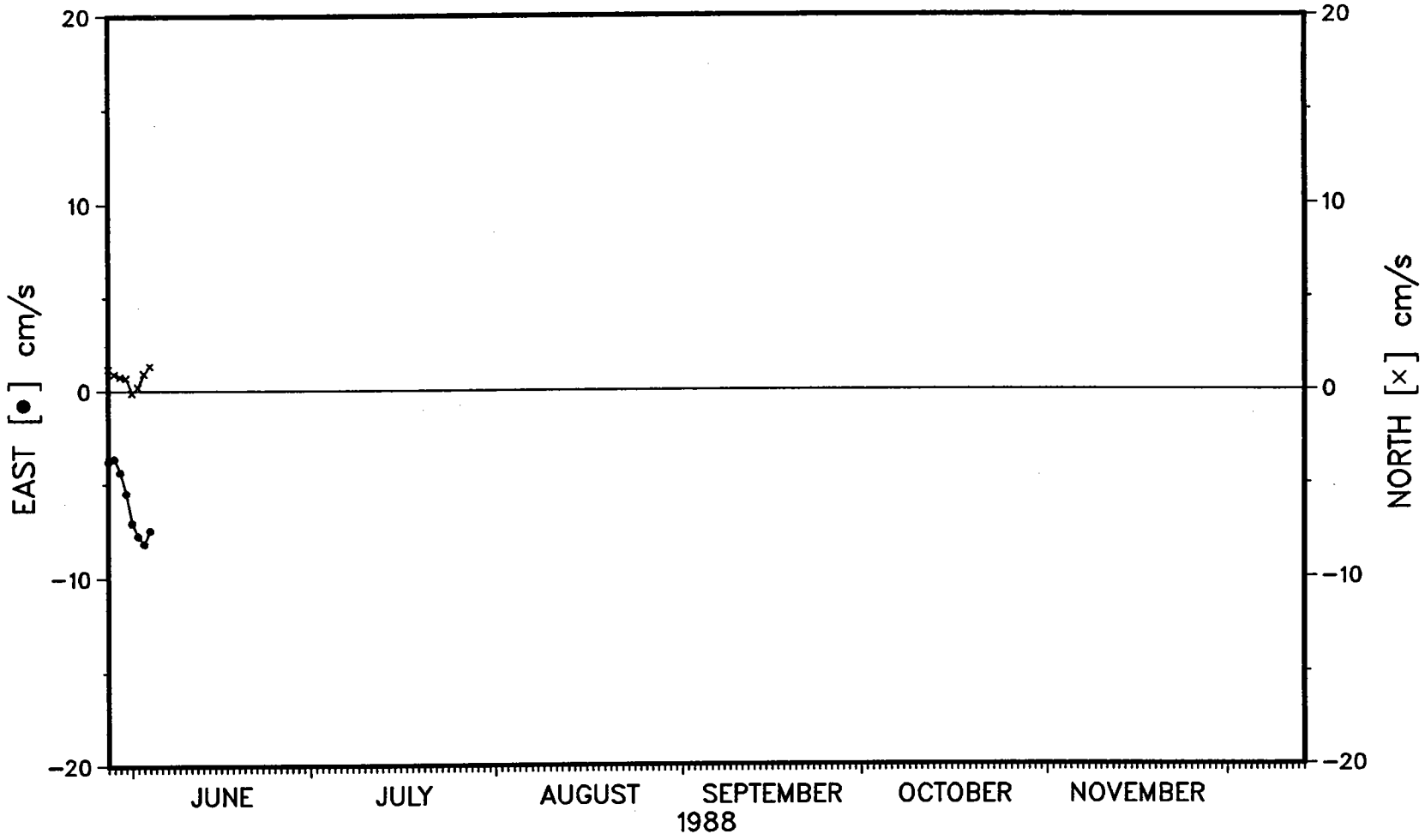
PLOT 2 OF 4
.SPL

EASTERN BASIN 149



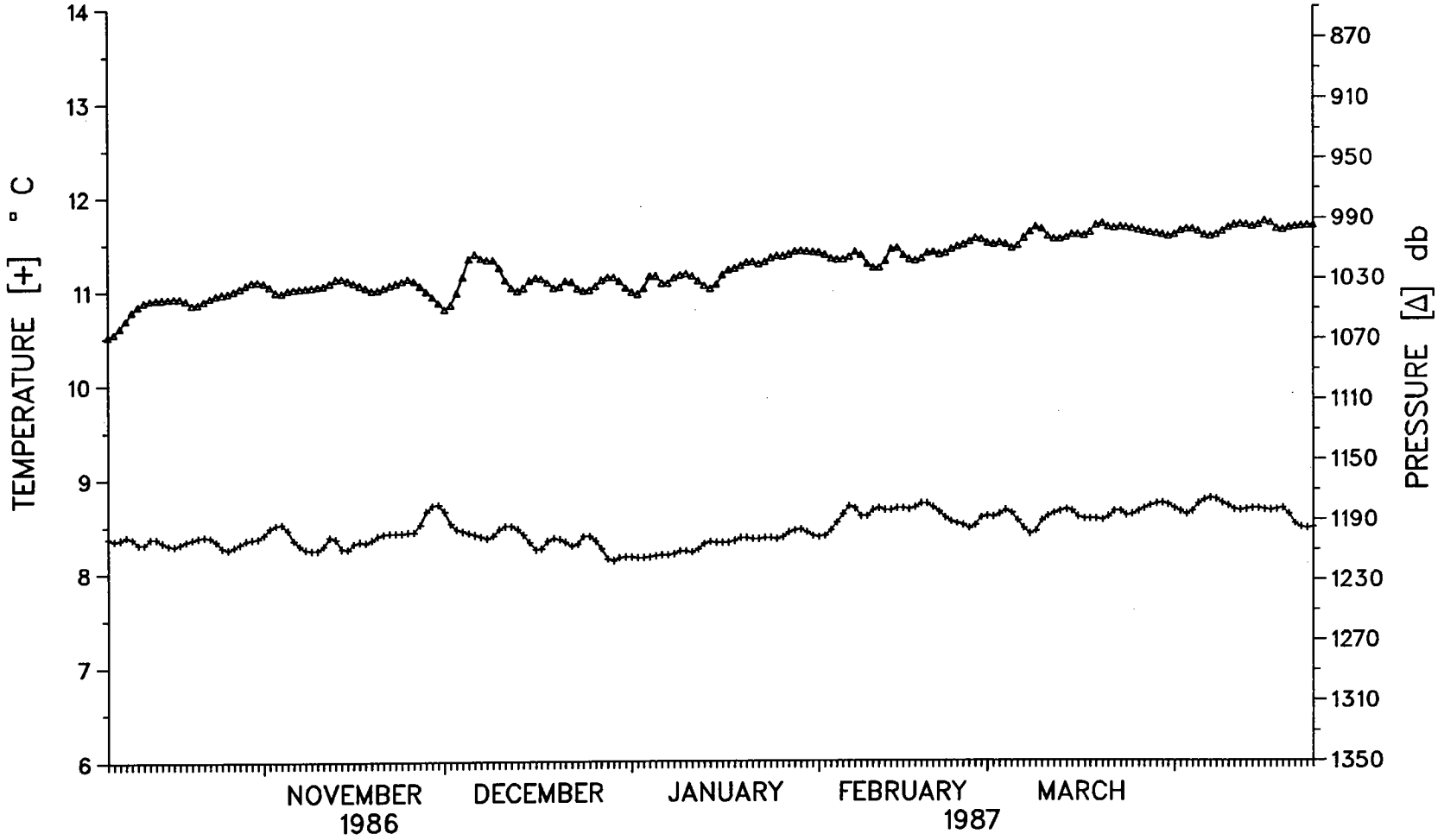
PLOT 3 OF 4
.SPL

EASTERN BASIN 149



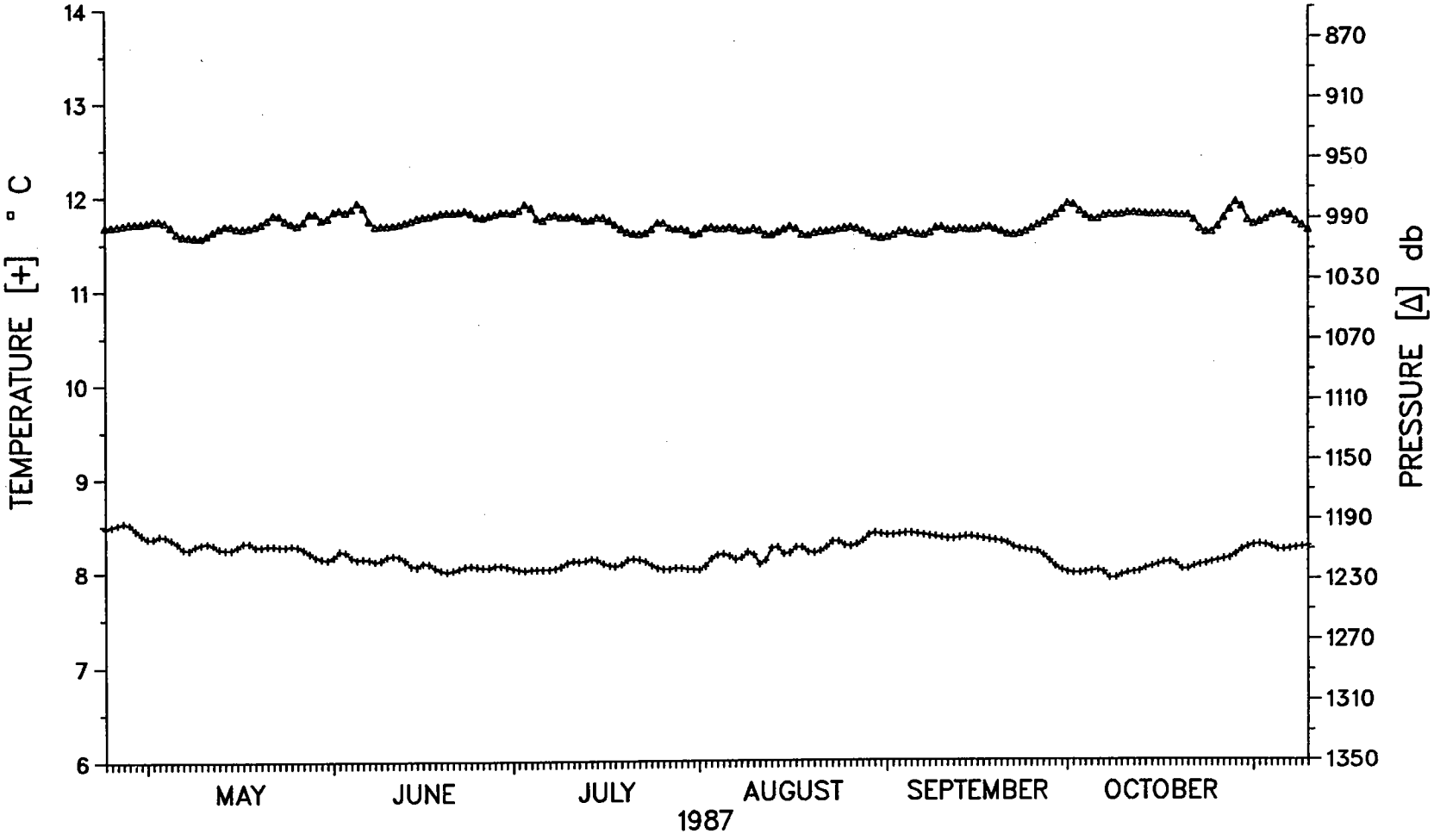
PLOT 4 OF 4
.SPL

EASTERN BASIN 149



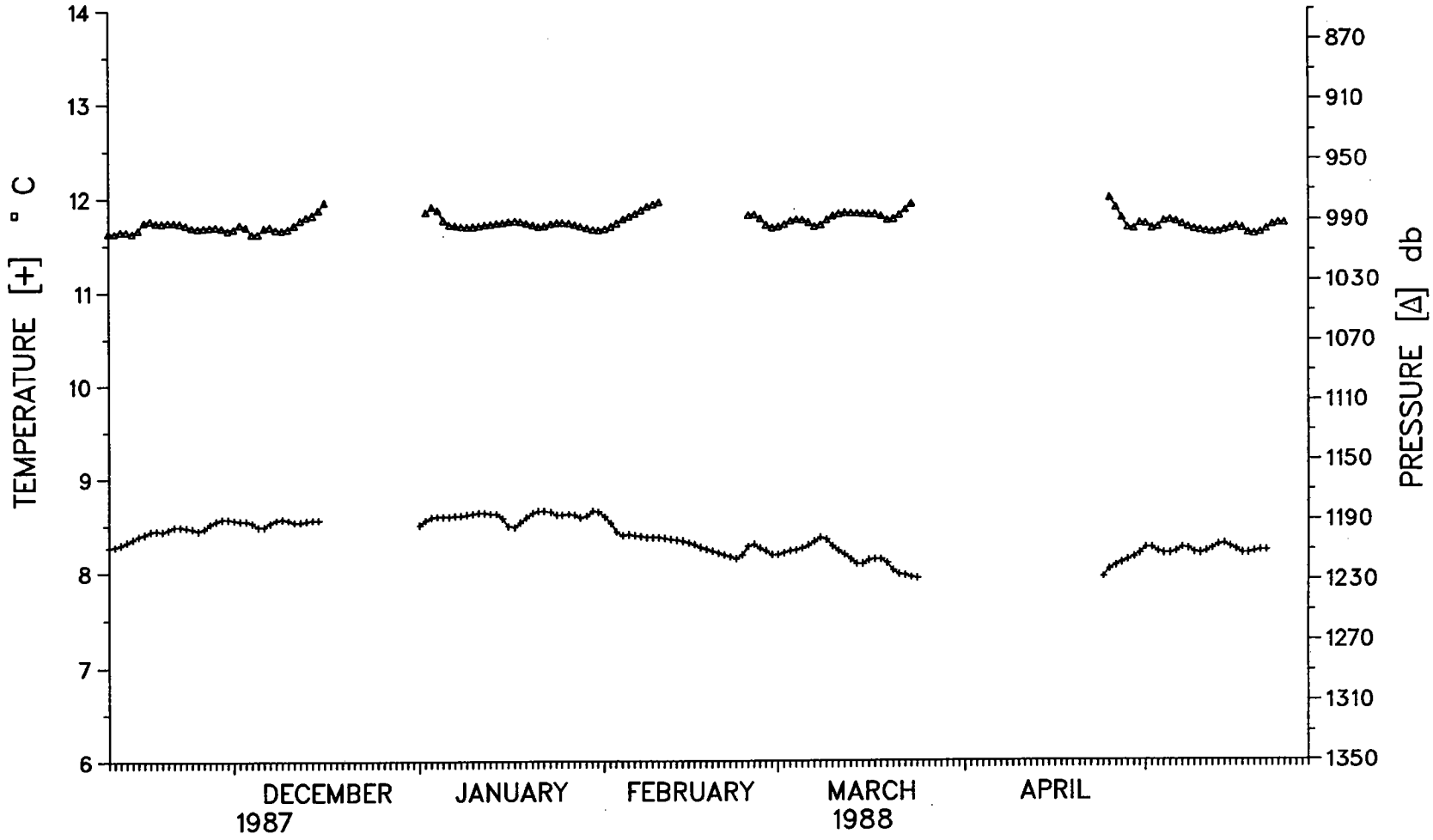
PLOT 1 OF 4
.SPL

EASTERN BASIN 149



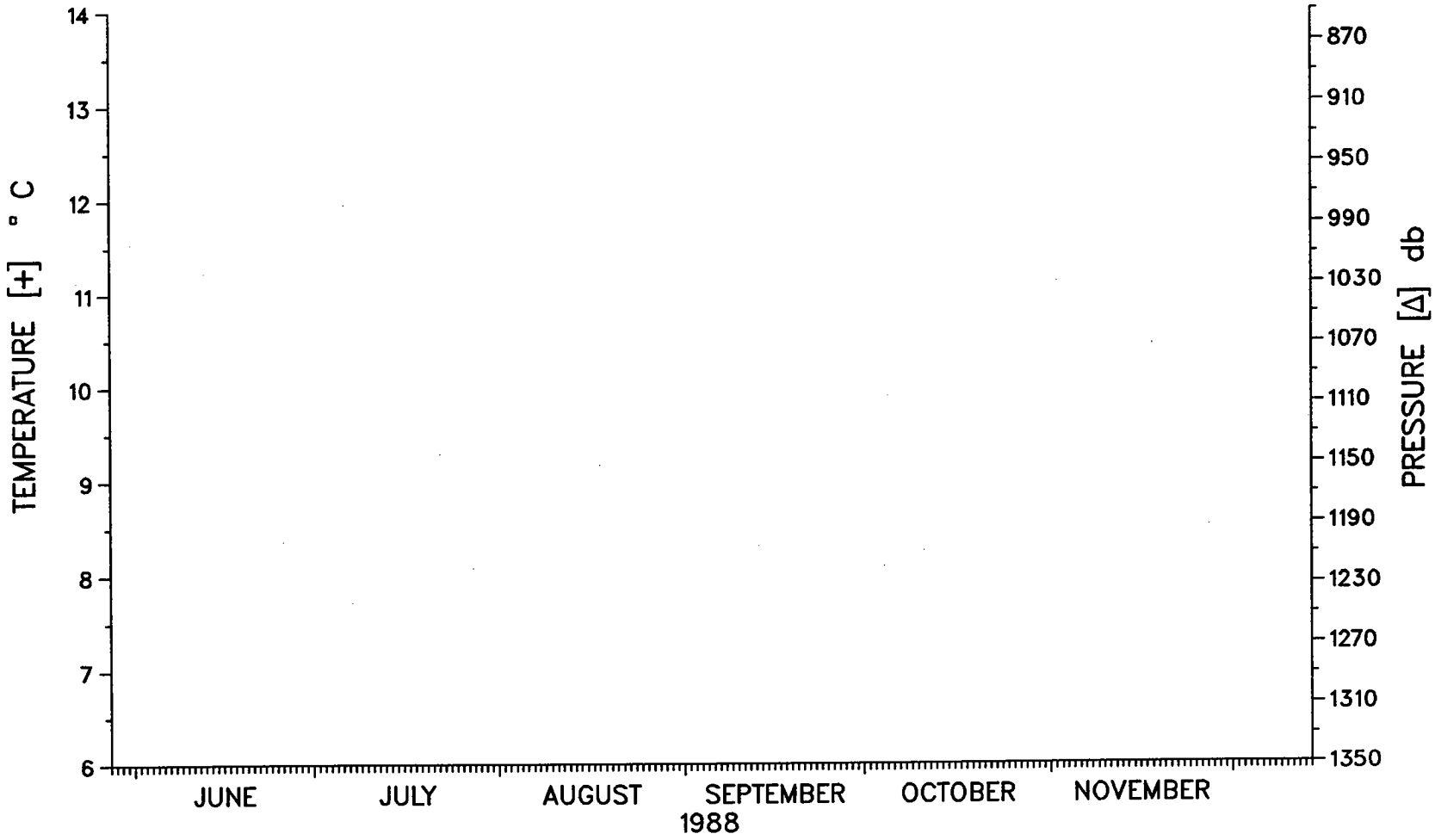
PLOT 2 OF 4
.SPL

EASTERN BASIN 149



PLOT 3 OF 4
.SPL

EASTERN BASIN 149



PLOT 4 OF 4
.SPL

DOCUMENT LIBRARY

January 17, 1990

Distribution List for Technical Report Exchange

Attn: Stella Sanchez-Wade
Documents Section
Scripps Institution of Oceanography
Library, Mail Code C-075C
La Jolla, CA 92093

Hancock Library of Biology &
Oceanography
Alan Hancock Laboratory
University of Southern California
University Park
Los Angeles, CA 90089-0371

Gifts & Exchanges
Library
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, NS, B2Y 4A2, CANADA

Office of the International
Ice Patrol
c/o Coast Guard R & D Center
Avery Point
Groton, CT 06340

NOAA/EDIS Miami Library Center
4301 Rickenbacker Causeway
Miami, FL 33149

Library
Skidaway Institute of Oceanography
P.O. Box 13687
Savannah, GA 31416

Institute of Geophysics
University of Hawaii
Library Room 252
2525 Correa Road
Honolulu, HI 96822

Marine Resources Information Center
Building E38-320
MIT
Cambridge, MA 02139

Library
Lamont-Doherty Geological
Observatory
Colombia University
Palisades, NY 10964

Library
Serials Department
Oregon State University
Corvallis, OR 97331

Pell Marine Science Library
University of Rhode Island
Narragansett Bay Campus
Narragansett, RI 02882

Working Collection
Texas A&M University
Dept. of Oceanography
College Station, TX 77843

Library
Virginia Institute of Marine Science
Gloucester Point, VA 23062

Fisheries-Oceanography Library
151 Oceanography Teaching Bldg.
University of Washington
Seattle, WA 98195

Library
R.S.M.A.S.
University of Miami
4600 Rickenbacker Causeway
Miami, FL 33149

Maury Oceanographic Library
Naval Oceanographic Office
Bay St. Louis
NSTL, MS 39522-5001

Marine Sciences Collection
Mayaguez Campus Library
University of Puerto Rico
Mayagues, Puerto Rico 00708

Library
Institute of Oceanographic Sciences
Deacon Laboratory
Wormley, Godalming
Surrey GU8 5UB
UNITED KINGDOM

The Librarian
CSIRO Marine Laboratories
G.P.O. Box 1538
Hobart, Tasmania
AUSTRALIA 7001

Library
Proudman Oceanographic Laboratory
Bidston Observatory
Birkenhead
Merseyside L43 7 RA
UNITED KINGDOM

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. WHOI-90-01	2.	3. Recipient's Accession No.

4. Title and Subtitle

SOFAR Float Mediterranean Outflow Experiment
Summary and Data from 1986 – 1988

5. Report Date
January, 1990

6.

7. Author(s)
Marguerite E. Zemanovic, Philip L. Richardson, and James F. Price

8. Performing Organization Rept. No.
WHOI 90-01

9. Performing Organization Name and Address

The Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C) OCE 82-14066, OCE 85-17375,
(G) OCE 86-00055, OCE 88-22826

12. Sponsoring Organization Name and Address

Funding was provided by the National Science Foundation

13. Type of Report & Period Covered
Technical Report

14.

15. Supplementary Notes

This report should be cited as: Woods Hole Oceanog. Inst. Tech. Rept., WHOI-90-01.

16. Abstract (Limit: 200 words)

In October, 1984, the Woods Hole Oceanographic Institution SOFAR float group began a three and a half year field program to measure the velocity field of the Mediterranean water in the eastern North Atlantic. The principal scientific goal was to learn how the Mediterranean salt tongue is produced by the general circulation and the eddy diffusion of the Canary Basin. Thirty-two floats were launched at depths near 1100 m: 14 in a cluster centered on 32°N, 24°W, with nearest neighbors at 20 km spacing, 10 at much wider spacing to explore regional variations of first order flow statistics, and 8 in three different Meddies (Mediterranean water eddies) in collaboration with investigators from Scripps Institution of Oceanography and the University of Rhode Island.

The floats were launched in 1984 and 1985, and tracked with U.S. and French ALSs (moored listening stations) from October 1984 to June 1988. This report includes a summary of the whole three and a half year experiment, the final year and a half of data processed from the third ALS setting (October 1986-June 1988), and the first deep sea test of Bobber EB014 in the eastern subtropical North Atlantic (May 1986-May 1988). Approximately 60 years of float trajectories were produced during the three and a half years of the experiment.

17. Document Analysis a. Descriptors

1. SOFAR floats
2. Canary basin
3. Mediterranean outflow

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Approved for publication; distribution unlimited.	UNCLASSIFIED	239
	20. Security Class (This Page)	22. Price

(See ANSI-Z39.18) *See Instructions on Reverse*

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce