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Technical Report

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Approved for Distribution:

James R. Luyten, Chairman
Department of Physical Oceanography

Abstract

Trajectories and time series of velocity, temperature, and pressure are presented for 13 neutrally-buoyant, acoustically tracked (SOFAR) floats that were launched in May and June, 1986 in the Newfoundland Basin by the Woods Hole Oceanographic Institution SOFAR float operations group. The deployment of these floats and the array of Autonomous Listening Stations (ALS's) used to track the floats was designed to investigate the North Atlantic Current and its possible recirculation. Although there were a number of technical difficulties which reduced the data return for this experiment, we have obtained a total of nearly 12 years of float data for the region at three depths, nominally 700, 1200, and 2000 m.

The data obtained from two deployments of ALS's, covering nearly three years, are presented in this report. Of particular note is the strong eddy variability at 700 m depth that is comparable to those found in the Gulf Stream Extension and the entrainment of 2000 m depth floats into the deep western boundary current.

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1 Introduction

The nature of the connection of the North Atlantic Current with the Gulf Stream and its role in the large scale circulation of the North Atlantic has been controversial (Worthington, 1976; Clarke *et al.*, 1980). Since the early work of Iselin (1936) and Dietrich *et al.* (1975), there has been little doubt that part of the surface Gulf Stream feeds into the North Atlantic Current. However, the connection between these two currents at depth and the extent to which the North Atlantic Current advects thermocline water into the eastern basin of the North Atlantic has been subject to debate. Recent SOund Fixing and Ranging (SOFAR) float observations (Schmitz, 1985; Owens, in preparation), demonstrated that within the thermocline the mean Gulf Stream bifurcated at the Grand Banks, feeding both a southern recirculation and the North Atlantic Current. The structure of the mean currents within the Newfoundland Basin was still unclear. The results of a SOFAR float experiment from May 1986 to June 1989 that attempted to address this question are presented in this data report.

Twenty SOFAR floats, half ballasted to be neutrally buoyant at 700 m (Floats 90–99) and the remainder at 2000 m (Floats 100–109), were launched in June 1986 (Figure 1, Table I). They were tracked using one French and an array of five U.S. Autonomous Listening Stations (ALS's) that were also launched at that time. During a cruise in October 1987, the U.S. ALS array was recovered and redeployed for an additional 18 months, until a final recovery in June 1989 (Figure 1, Table II). The two settings are combined into the data set presented here.

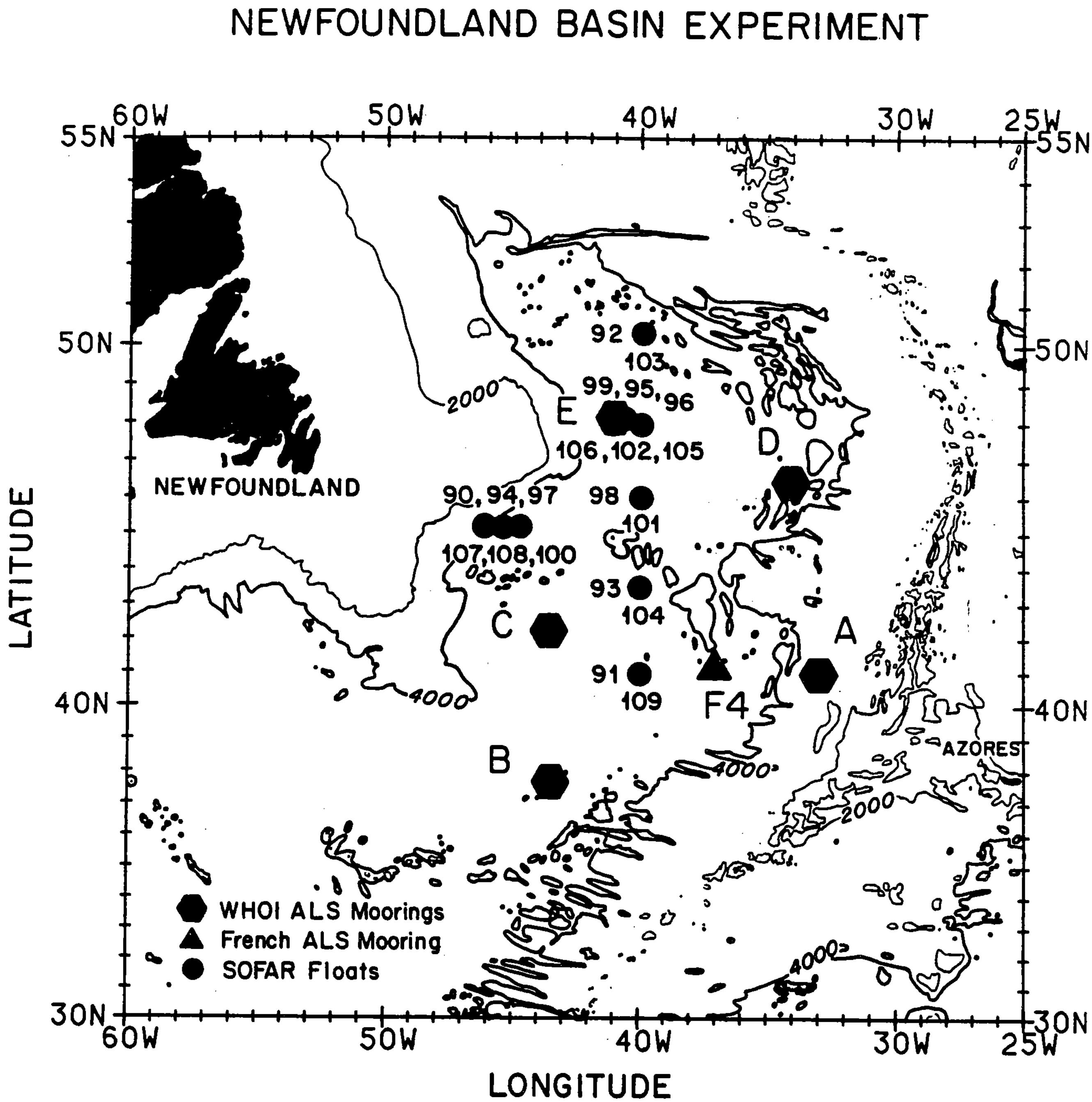

Figure 1: Location of autonomous listening station (ALS) moorings, SOFAR float launch positions and bathymetry in the experimental area.

TABLE I

1986 – 1989 FLOAT FILE STATISTICS

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	INIT. TEMP. deg C	AVE. TEMP. deg C	INIT. PRES. dbars	AVE. PRES. dbars
90A	700	860609	45.238	46.249	861001	42.534	50.911	115	3.74	3.93	760	725
90B	700	861024	42.632	51.440	870423	43.496	36.484	182	4.45	5.84	698	732
91	700	860602	40.910	40.113	860911	39.028	40.848	102	6.48	7.28	757	732
92 *	1100	860606	50.799	39.654	861016	52.608	34.130	133	3.72	3.55	1311	1271
93A	700	860603	43.565	39.735	871017	38.336	44.376	502	6.79	7.55	840	754
93B	700	871107	36.893	43.747	880208	36.331	39.085	94	8.97	8.39	788	757
93C	700	880621	39.932	33.789	880821	39.912	34.044	62	8.50	8.04	717	700
94	700	860609	45.113	45.814	880218	35.318	35.896	620	4.30	8.16	747	695
95	700	860608	48.856	40.859	860806	49.480	43.775	60	3.86	4.19	967	969
96 *	1100	860607	48.854	40.189	870512	43.058	43.113	340	4.10	4.41	1261	1176
98 *	1100	860604	46.560	40.428	861231	49.513	34.754	211	4.54	3.64	1168	1110
99	700	860608	48.321	40.827	890404	42.019	31.207	1032	4.02	6.75	744	702
100	2000	860609	45.158	45.090	870510	42.686	53.175	336	3.33	3.43	2053	2011
104	2000	860603	43.470	39.945	861214	48.750	43.277	195	3.64	3.55	2070	2019
107	2000	860609	45.154	46.296	861207	42.421	51.026	182	3.30	3.31	2046	2012
109	2000	860602	41.004	40.104	861116	44.301	45.440	168	3.68	3.70	2089	2043
							TOTAL	11.9 yrs.				

* Floats with extra weight added.

TABLE II

ALS MOORINGS

ALS SITE	ALS MOORING #	LAUNCH DATE yymmdd	RECOVERY DATE yymmdd	LATITUDE deg N	LONGITUDE deg W	ALS DEPTH (m)
			1986 - 1987			
A	145A	860527	871107	41.007	32.937	1100
B	146A	860529	871109	37.692	43.427	1000
C	147A	860530	871101	42.256	43.544	1000
D	148A	860602	871106	46.497	34.003	800
E	149A	860605	871104	48.213	41.013	700
F4	F08A	850818	860927	41.160	36.978	1500
			1987 - 1989			
A	157A	871107	890620	41.008	32.927	1100
B	158A	871109	890623	37.673	43.413	1000
C	154A	871102	890622	42.234	43.610	1000
D	156A	871106	890619	46.447	34.009	800
E	155A	871104	890618	48.189	40.993	700

Note:
A-E were WHOI moorings and F4 was a mooring maintained by Centre Oceanologique de Bretagne, France.

2 Float and Autonomous Listening Station Deployments

During cruise 144 of the R/V *Endeavor*, 20 SOFAR floats were launched at locations indicated in Figure 1. All the floats were launched in pairs, with one float ballasted to a nominal depth of 700 m and the other to 2000 m. The general strategy for choosing the launch locations was: (1) to seed the hypothesized interior recirculation within the Newfoundland Basin along 40°W and (2) to launch sets of floats across the North Atlantic Current at nominal latitudes of 45°N and 48°N. The launch locations within the North Atlantic Current were chosen using XBT's and ship's drift to indicate that the ship was over the core of the current. The floats at 48°N were launched quite close to 40°W due to an apparent large eastward meandering of the North Atlantic Current.

For reasons discussed in the next section, three sets of floats (98, 101; 96, 105; and 92, 103) were incorrectly reballasted at sea and initially went to much greater depths than was planned. The three deep floats (101, 103, and 105) were never heard after launch, and the shallow floats sank to pressures of approximately 1100–1200 decibars.

In May and June 1986, at the same time that the 20 SOFAR floats were launched, five ALS's were deployed at the positions shown in Figure 1. These instruments were recovered and replaced by five more ALS's in November 1987 on cruise 195 of the R/V *Oceanus* and final recovery of the ALS array was completed in June 1989 on cruise 119 of the R/V *Atlantis II* (Table II). Except for one ALS, which was on mooring 145A, these instruments had a 100% data return. No data were obtained from mooring 145A due to a low pressure leak which caused the electronics to fail shortly after launch.

3 Float Failure Analysis

Although we have obtained 11.9 years of float data, a number of floats failed either at deployment or prematurely during the first year after launch. These floats were equipped with new Tillier-designed microprocessor-based electronics, which had been used successfully by the French in an experiment in the eastern North Atlantic, but appeared to have four problems in this experiment.

The first problem was that the part of the float computer program that telemetered the float's pressure during launch had been incorrectly entered. As a result, the data suggested that the floats were going to a depth approximately one half of their target depth. Before this problem was discovered, six floats were reballasted at sea incorrectly and settled to depths much greater than their targeted ones. Of these six, the three originally ballasted to 2000 m apparently failed before starting their mission.

The second problem occurred when the float program entered an indefinite loop waiting for a character from the SAIL loop used to interrogate the float before launch. During inclement weather, the SAIL interface was powered down before physically disconnecting the SAIL connection from the float. Due to the capacitance of the SAIL interface, the float mistook the transient current drop as the start of a character. Consequently, the float failed to enter its normal signaling schedule. After this was discovered, the float launch procedures were modified to eliminate this problem.

Several floats appeared to fail after six to eight months. This was discovered when the first set of ALS's was recovered and was the subject of an extensive postmortem analysis. A SOFAR float was set up to signal on a rapid schedule and then deployed at the Buoy Farm off Martha's Vineyard and under the Woods Hole dock in two separate tests. It repeatedly failed after signalling for a period of time comparable to the early failures seen in the ocean. At the level of acoustic output chosen for the Newfoundland Basin Experiment, a mechanical resonance between the main float housing and the acoustic resonator caused excessive vibration. This caused a capacitor to break away from the float electronics board causing the float to fail. In subsequent float deployments these capacitors have been rigidly attached to the circuit boards.

Finally, at least one float, Float 100, appeared to have a sudden drop in acoustic output, halving its effective tracking range. This sudden loss of acoustic output had been observed in Float 123 launched as part of the Site L Experiment (Price *et al.*, 1987). Although there are several possible causes, such as the loss of the resonating tube or partial failure of the output amplifier, we have been unable to reproduce this failure mode and have no definitive explanation at this time.

A summary of the lifetimes of those floats that did not fail at launch is shown in Figure 2. The float failures within six to eight months are presumably due to the mechanical resonance problem.

4 Float Data Processing

These floats have been processed using the same software as was used for several previous float experiments, such as the Gulf Stream Recirculation Experiment (GUSREX) (Wooding *et al.*, 1989), Site L (Price *et al.*, 1987), and the Mediterranean Outflow Experiment (Price *et al.*, 1986; Zemanovic *et al.*, 1988 and 1990). This is a three step process involving: (1) converting the raw data recorded on the cassette tapes into time series of possible times of arrival and strengths of

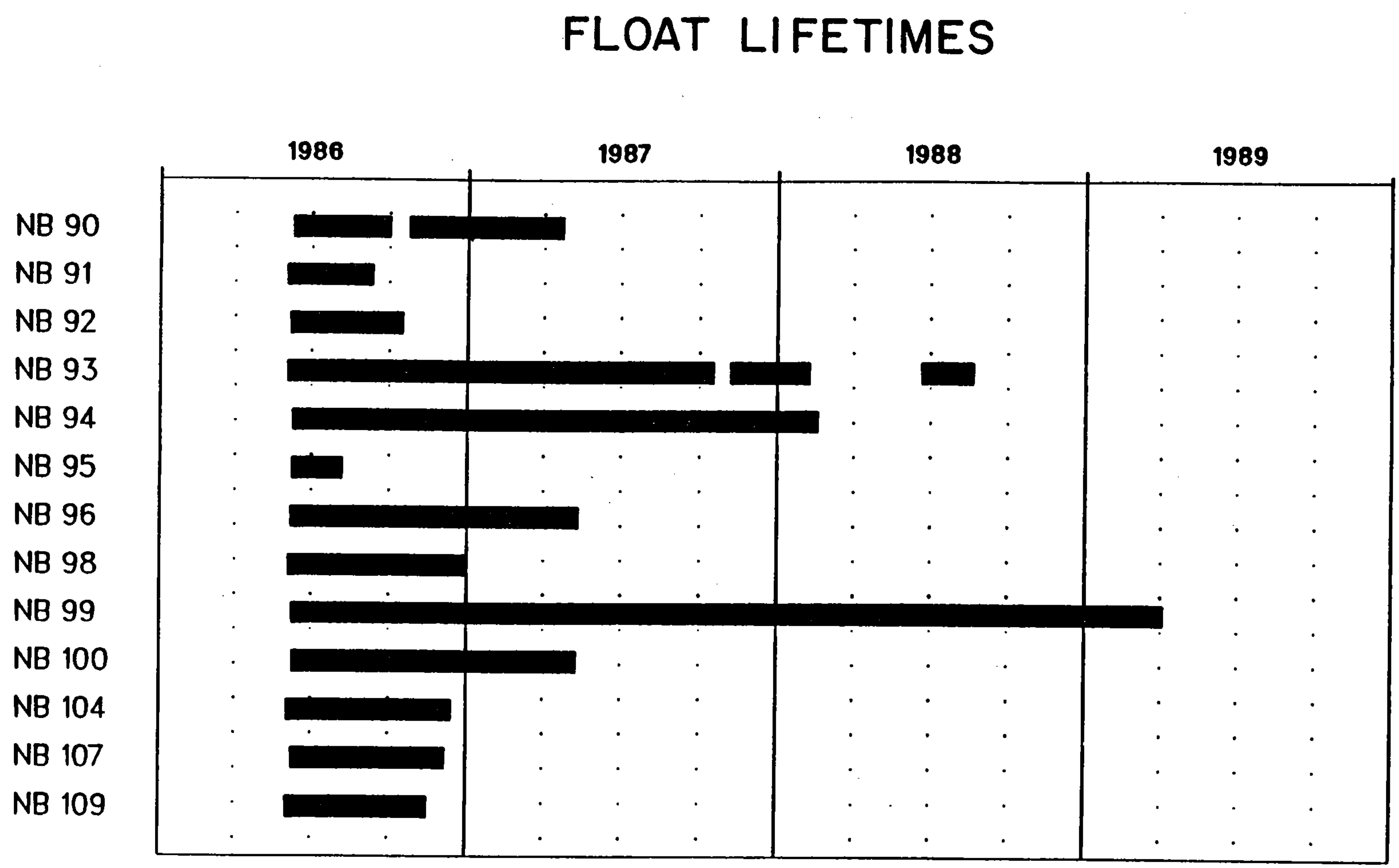

Figure 2: Bar graph showing the time that each float was tracked.

the signal; (2) extraction of the signals for each float and the computation of a time series of its position and temperature and pressure telemetry; and (3) editing, interpolation, and smoothing of the data to produce the final float trajectories as well as velocity, temperature, and pressure time series. After the second step preliminary positions were obtained every twelve hours. From the telemetry signal sent once per day two day averages of temperature and pressure on alternating days are available. Editing consists of eliminating obvious outliers. Linear interpolation is used to fill in any gaps in the initial data which are less than ten days. These gaps may be due to either editing or loss of data due to loss of signals at the ALS's which could be caused by various effects, such as topographic blocking or loss of the acoustic channel to some of the ALS's. If a gap is greater than ten days, the float trajectory is broken into separate pieces. Smoothing was achieved using a five point one-day half-width Gaussian filter. A cubic spline was then fitted to the filtered positions and east and north components of velocity calculated to coincide with the positions. Subsampling at twenty-four hour intervals was then used to produce the data presented in this report.

5 Discussion

Despite the technical difficulties discussed above, the float data has still produced some interesting results. These results are presented in Figure 3 as displacement vectors over the lifetime of the floats, in Figure 4 as a composite of all the trajectories, and in Figures 5–7 which show the trajectories broken into the different float depths. Additional presentations of the data are given in the Appendices: net displacements over the lifetimes of the floats in Appendix A, two month composites of trajectories in Appendix B, and the trajectories and time series of east and north velocities, temperature, and pressure in Appendix C.

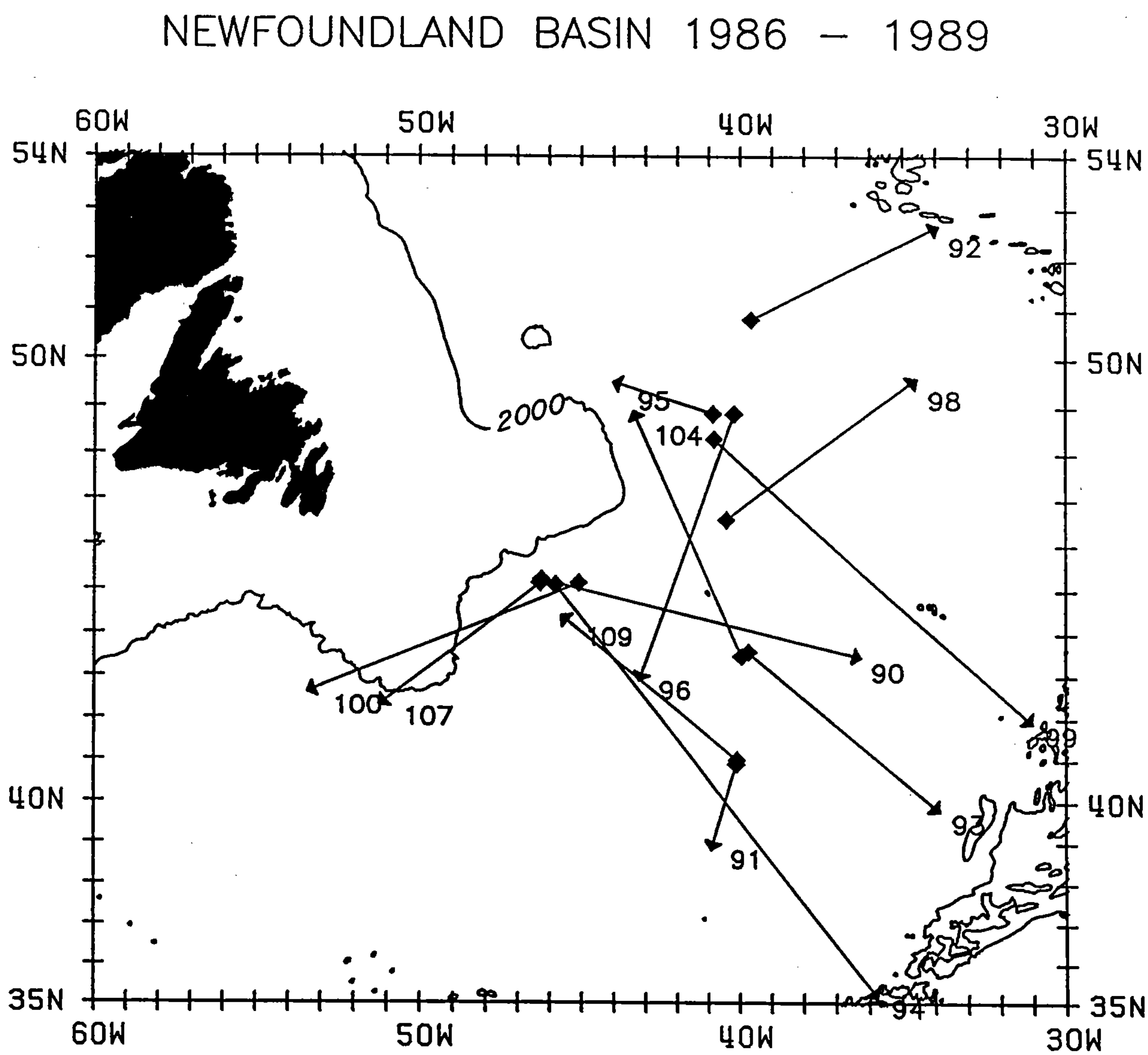

Figure 3: Displacement vectors from the first to last position of each float (1986–1989).

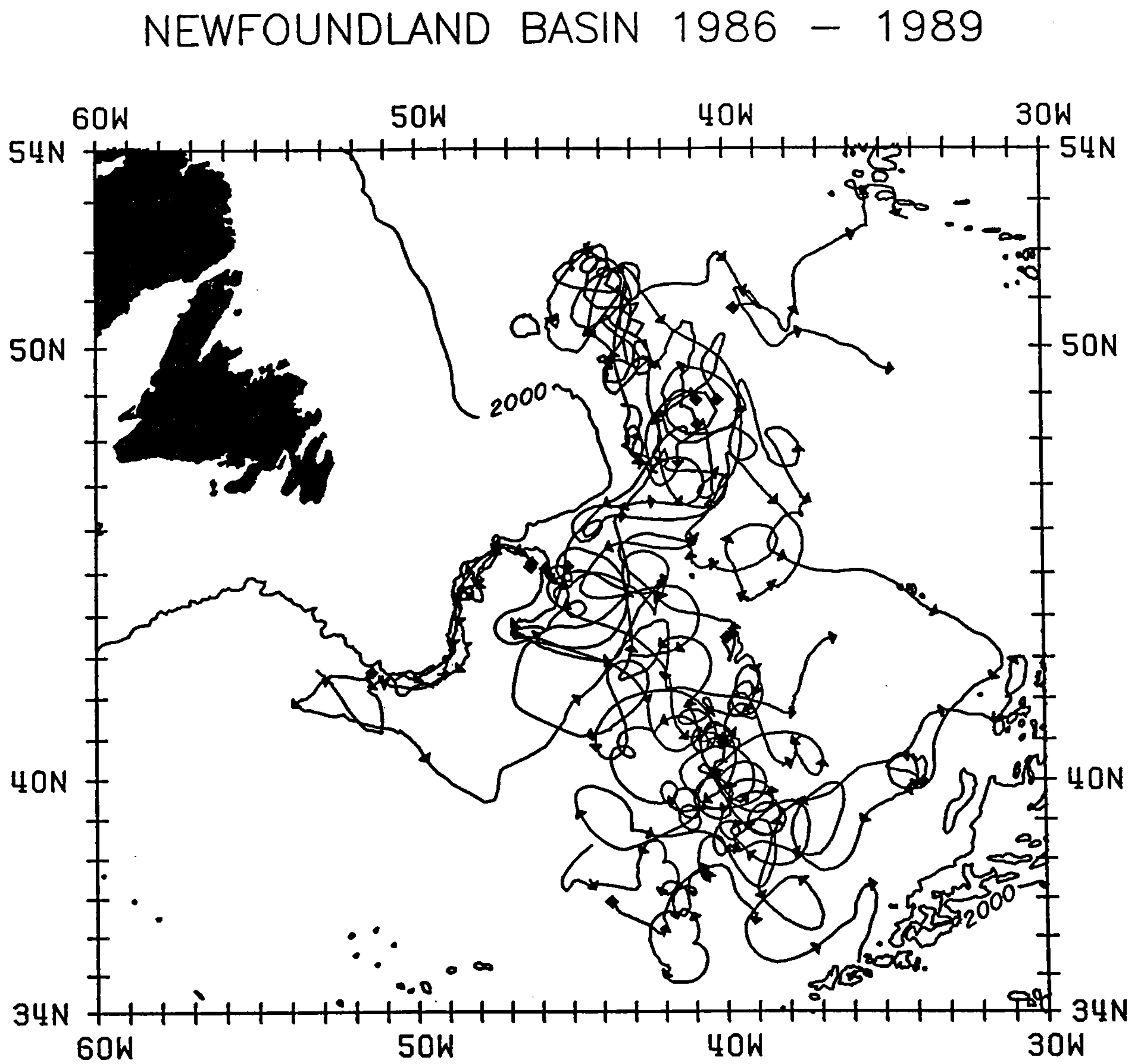

Figure 4: A composite of 13 float trajectories between 1986–1989. Arrowheads are located at 30-day intervals along the trajectories.

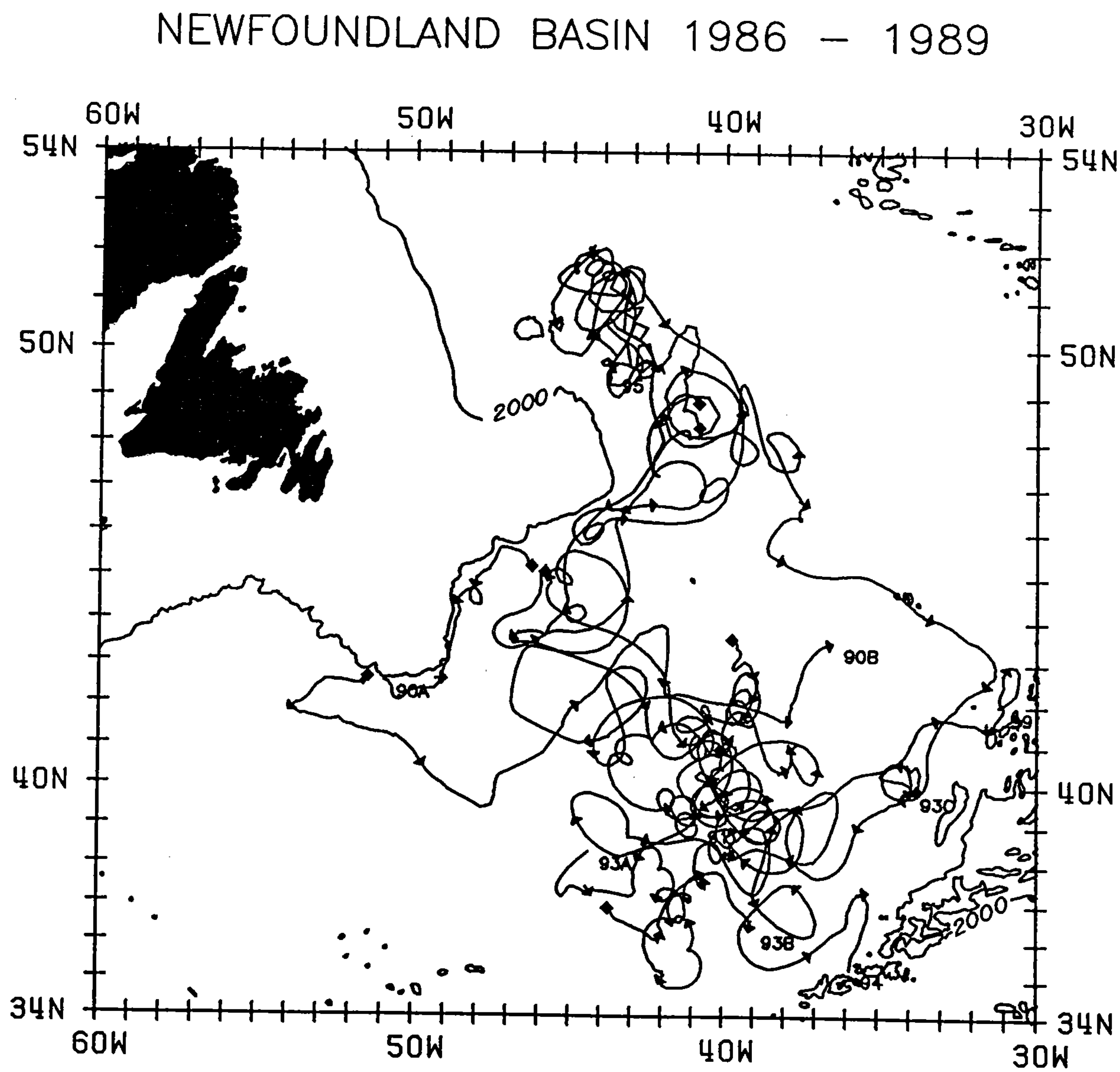

Figure 5: A composite of six float trajectories at 700 m between 1986–1989. Arrowheads are located at 30-day intervals along the trajectories.

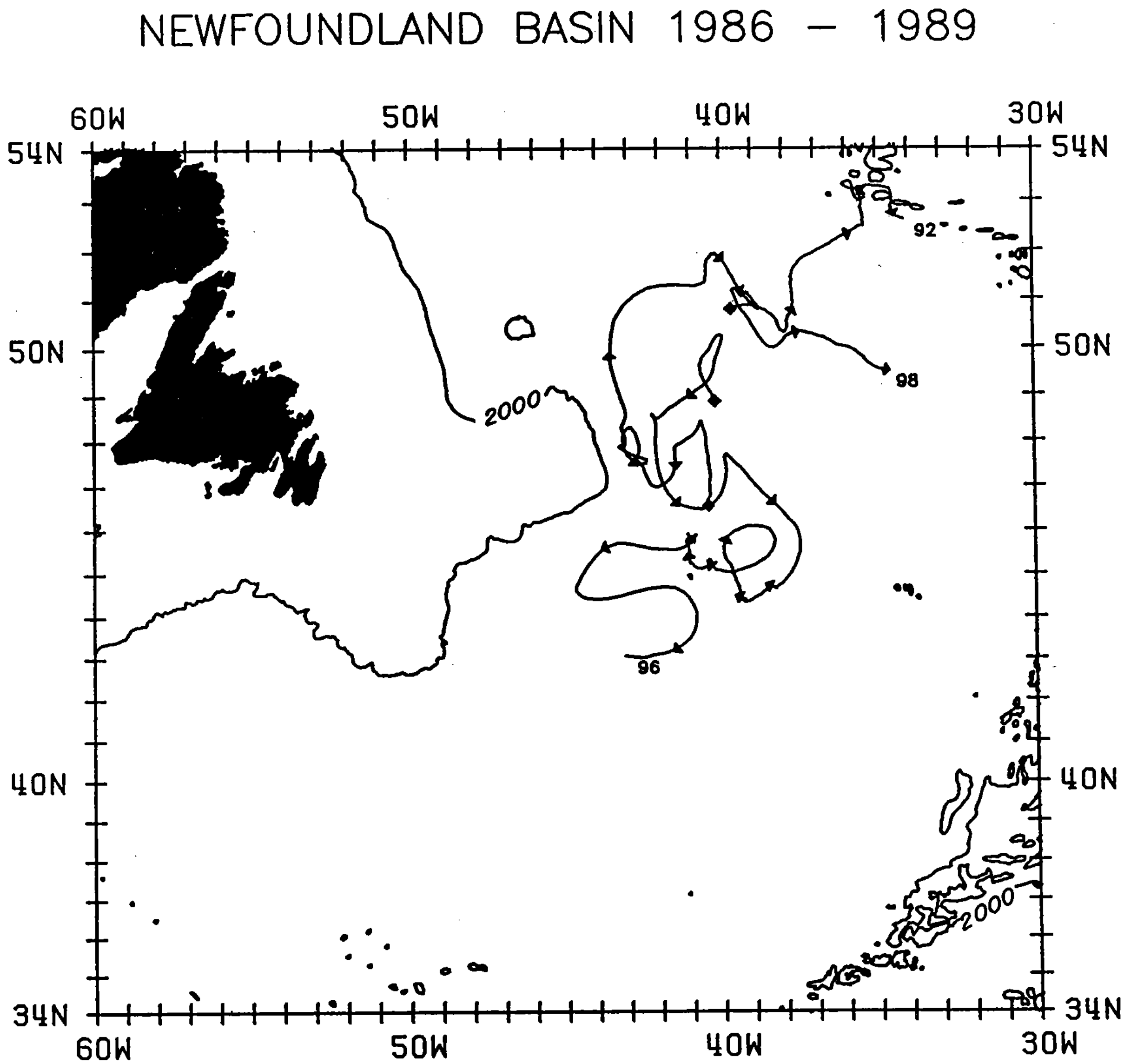

Figure 6: A composite of three float trajectories at 1100 m between 1986–1989. Arrowheads are located at 30-day intervals along the trajectories.

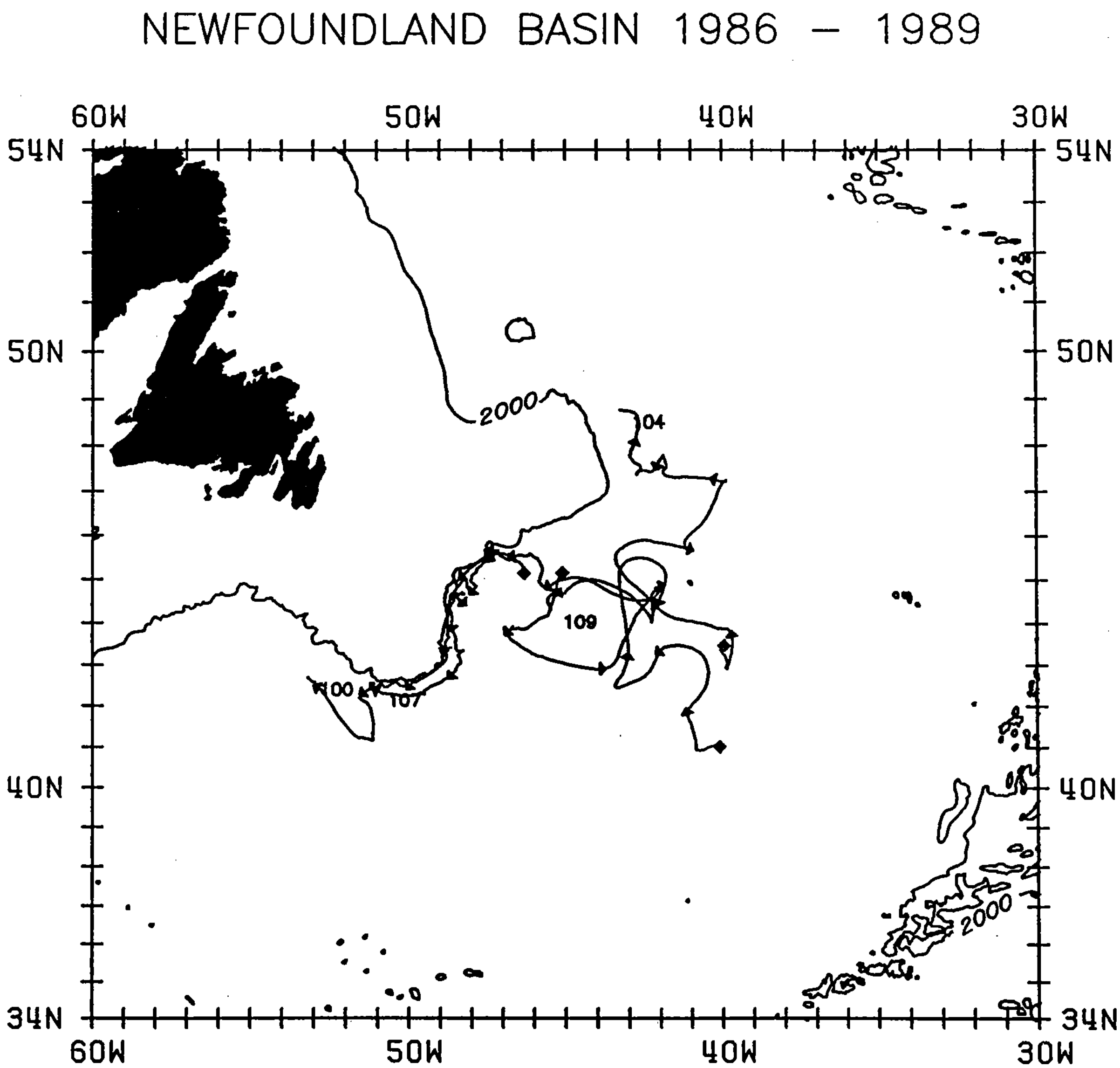

Figure 7: A composite of four float trajectories at 2000 m between 1986–1989. Arrowheads are located at 30-day intervals along the trajectories.

At 700 m depth the float trajectories clearly demonstrate the strong eddy variability of the region, including sufficiently strong eddies to produce a number of trajectories with closed loops. Particularly noticeable is Float 99 which has velocities comparable to those found in Gulf Stream Rings. Eddy kinetic energies, calculated from averages over approximately 200 by 300 kilometer boxes, for this region (approximately 300–400 cm^2/sec^2) are comparable to those found in the Gulf Stream Extension, on the southwestern side of the Tail of the Grand Banks, but are significantly less than those found in the Gulf Stream at 70°W.

Particularly noticeable in the 2000 m float data is the entrainment of two floats into the southward flowing deep western boundary current (Figure 7).

6 Acknowledgements

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The floats were purchased from Webb Research Corporation. They were ballasted, prepared for sea and launched by the WHOI float operations group consisting of J. R. Valdes, R. D. Tavares and B. J. Guest. The operations group also maintained, moored and retrieved the ALS's. The floats were tracked by M. E. Zemanovic at the Woods Hole Oceanographic Institution using a system developed by W. B. Owens. M. A. Lucas typed the manuscript.

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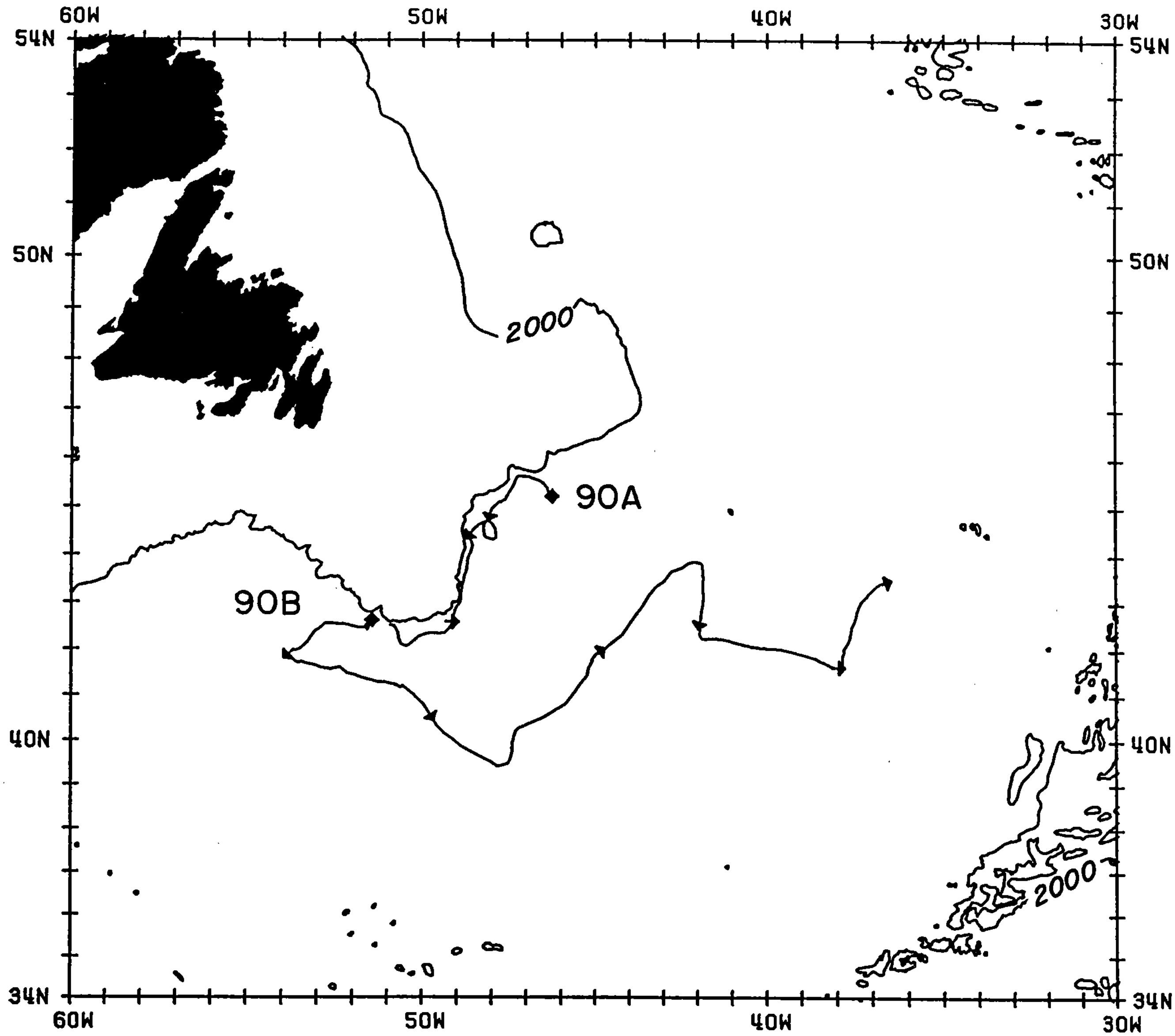
APPENDIX A:

Net Displacements Over Float Lifetimes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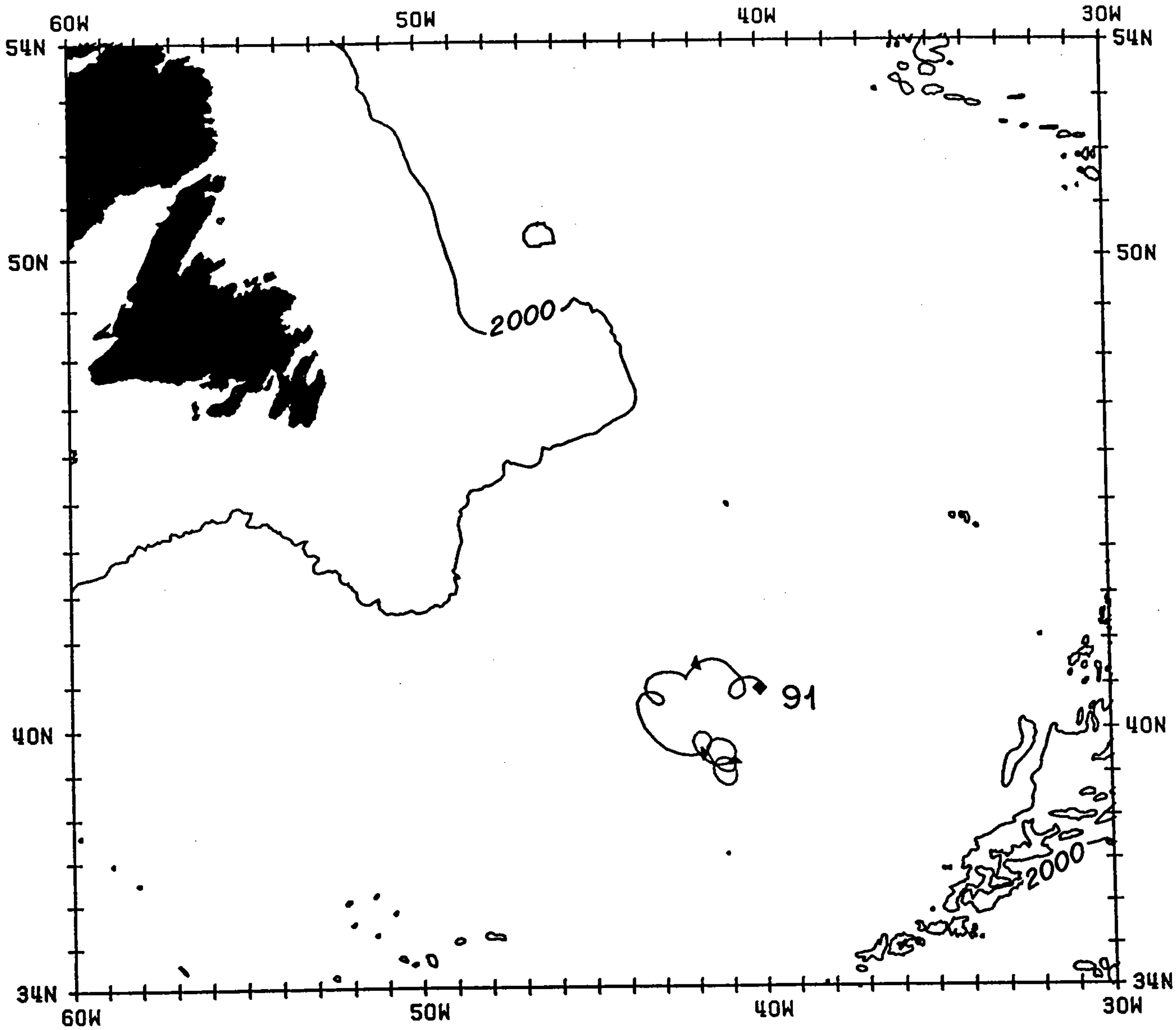
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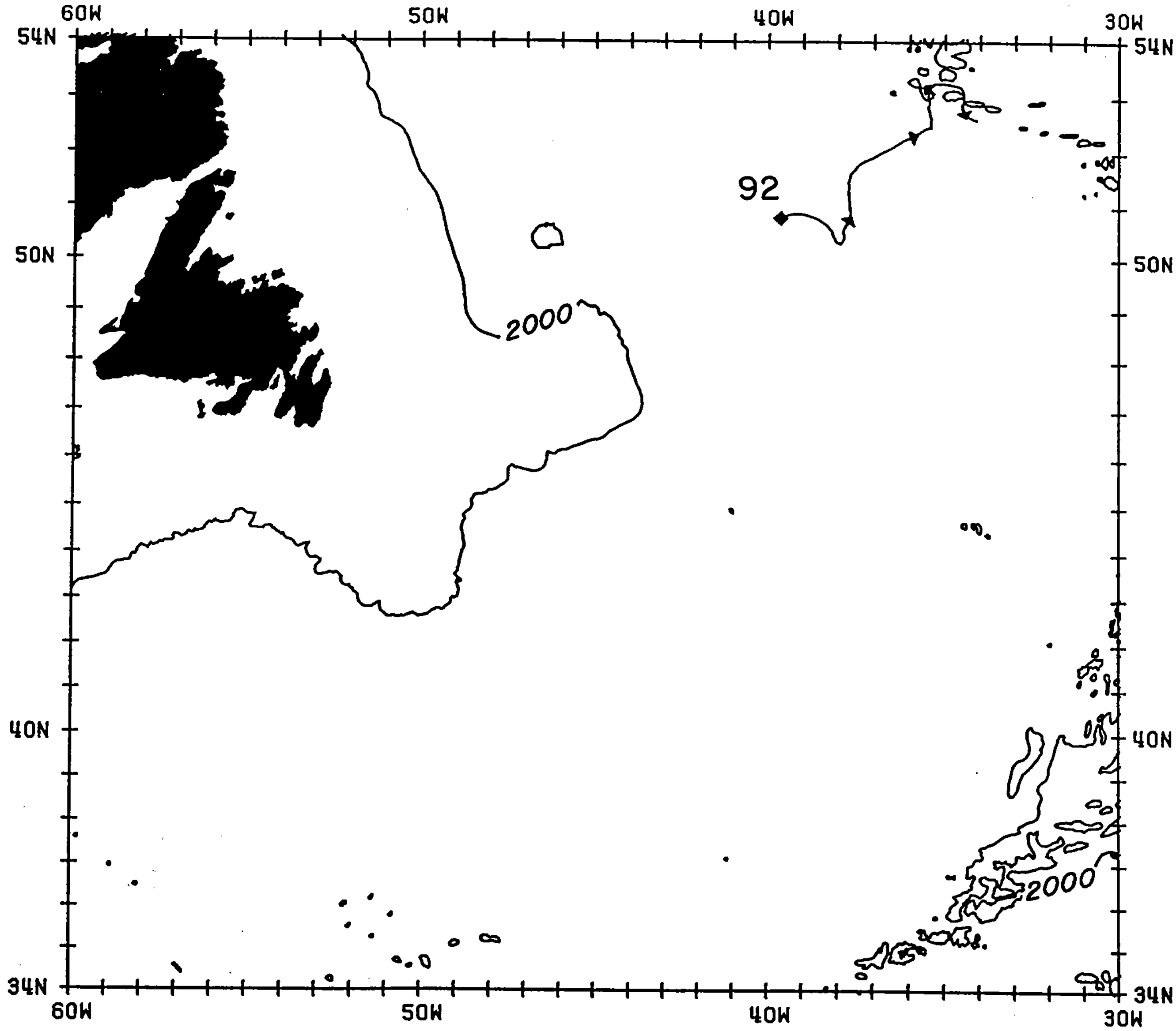
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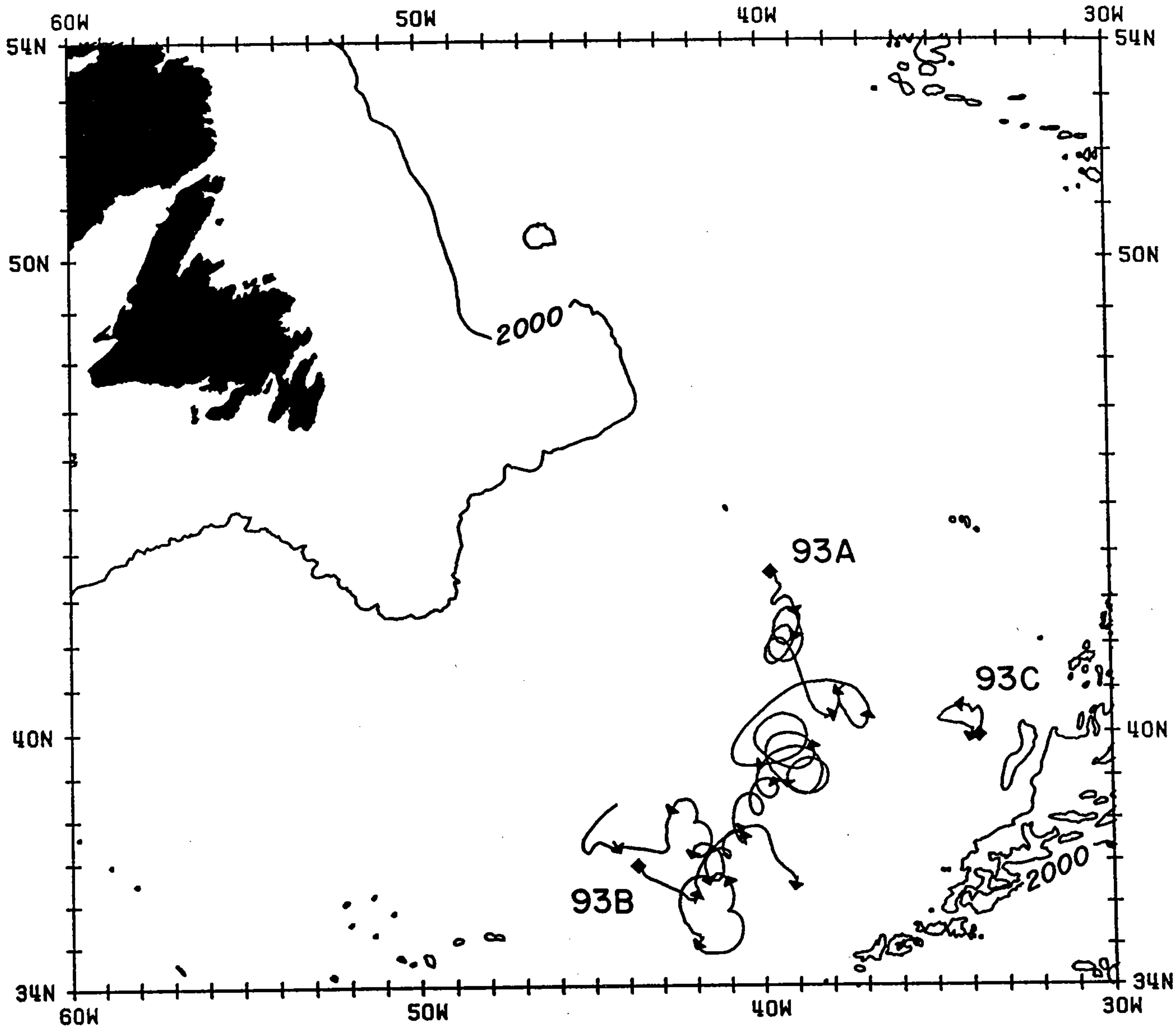
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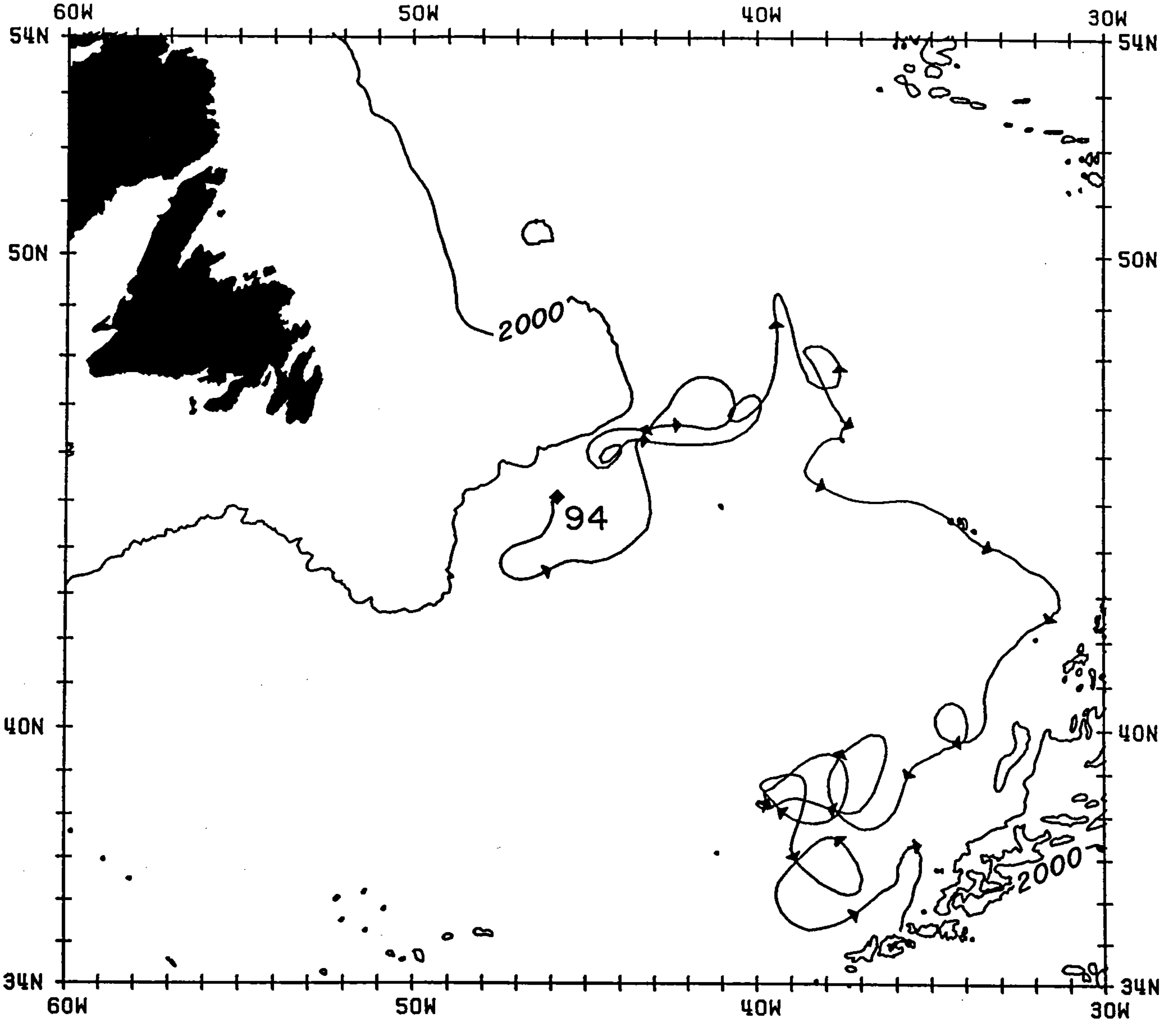
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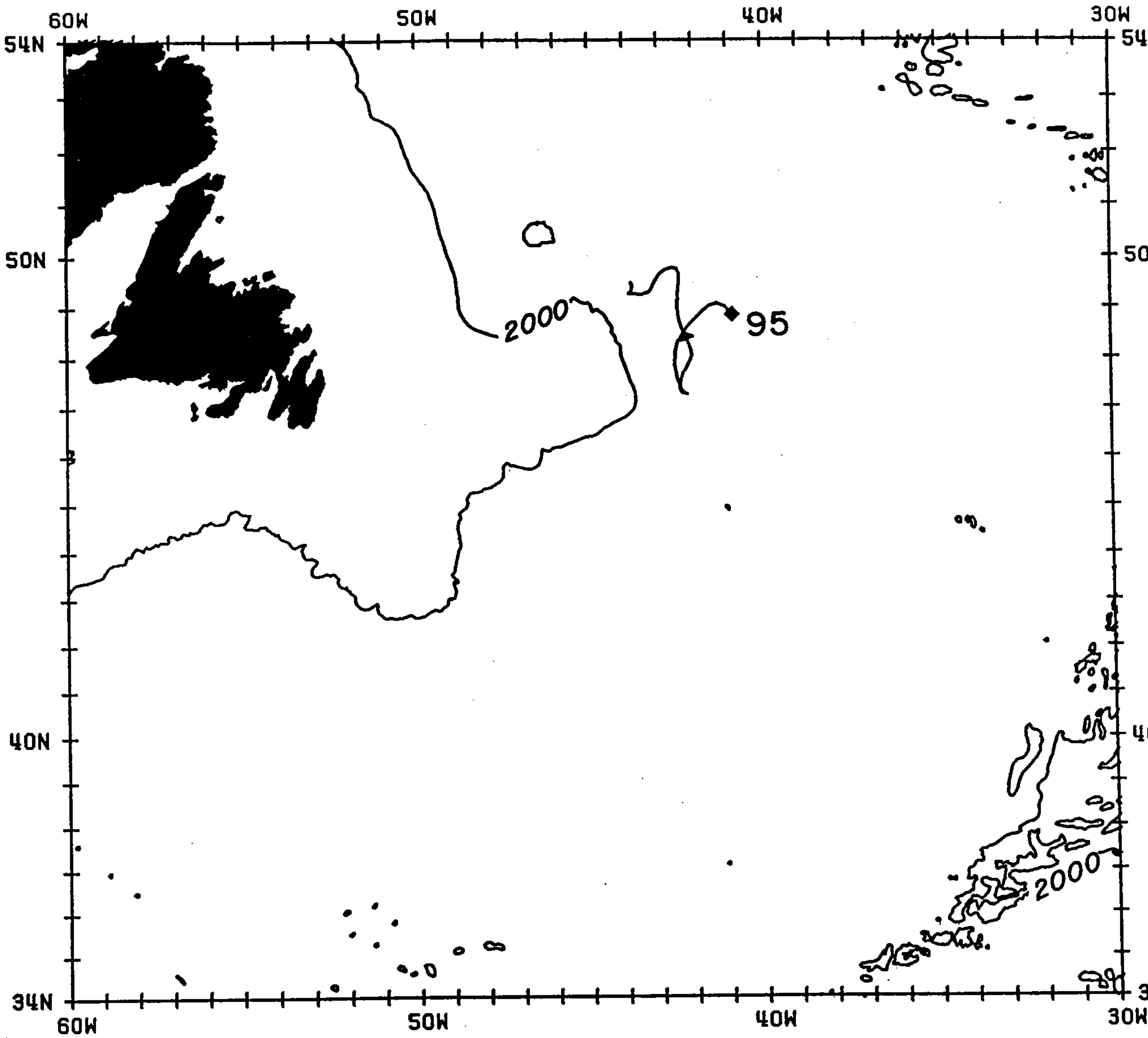
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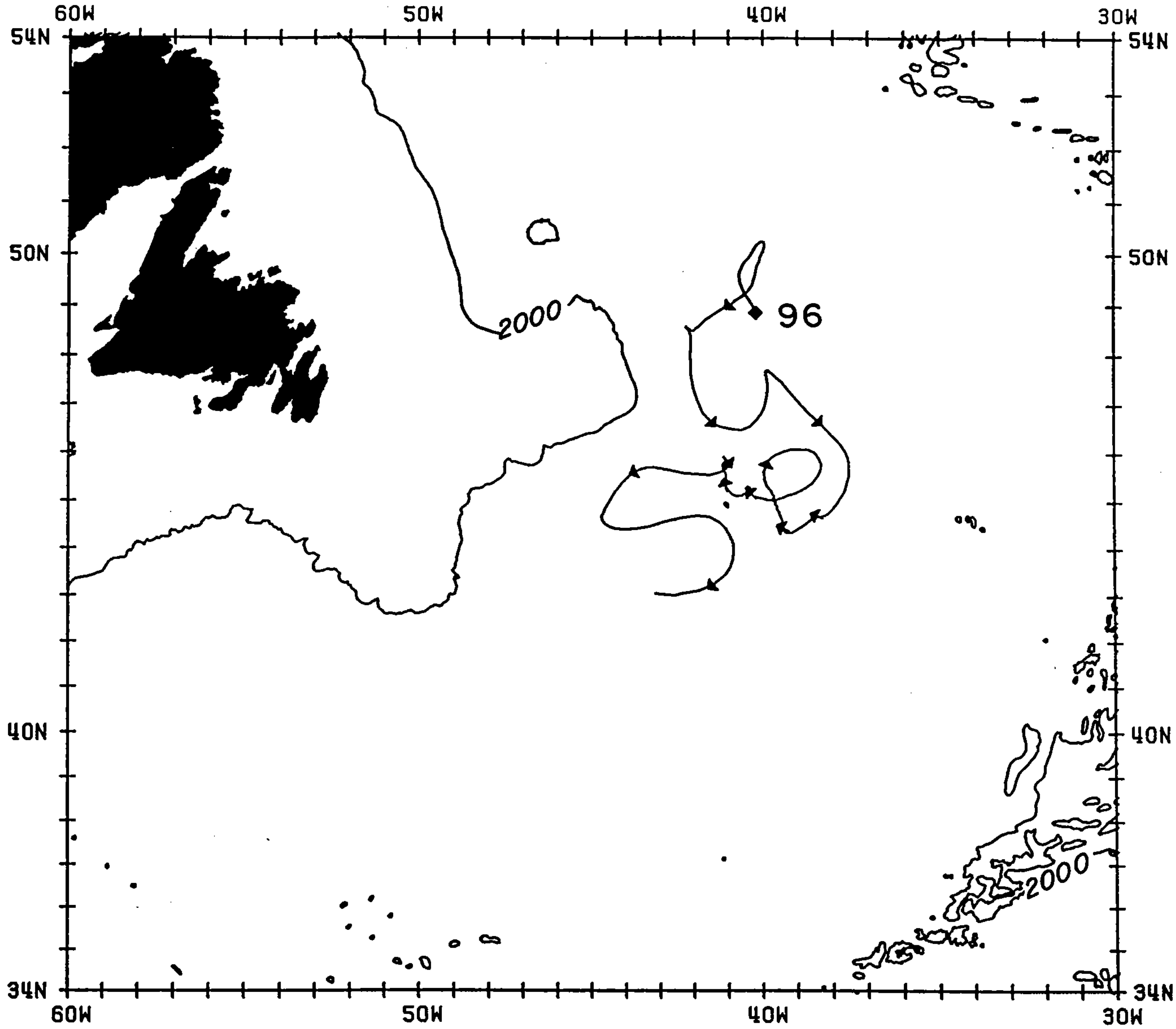
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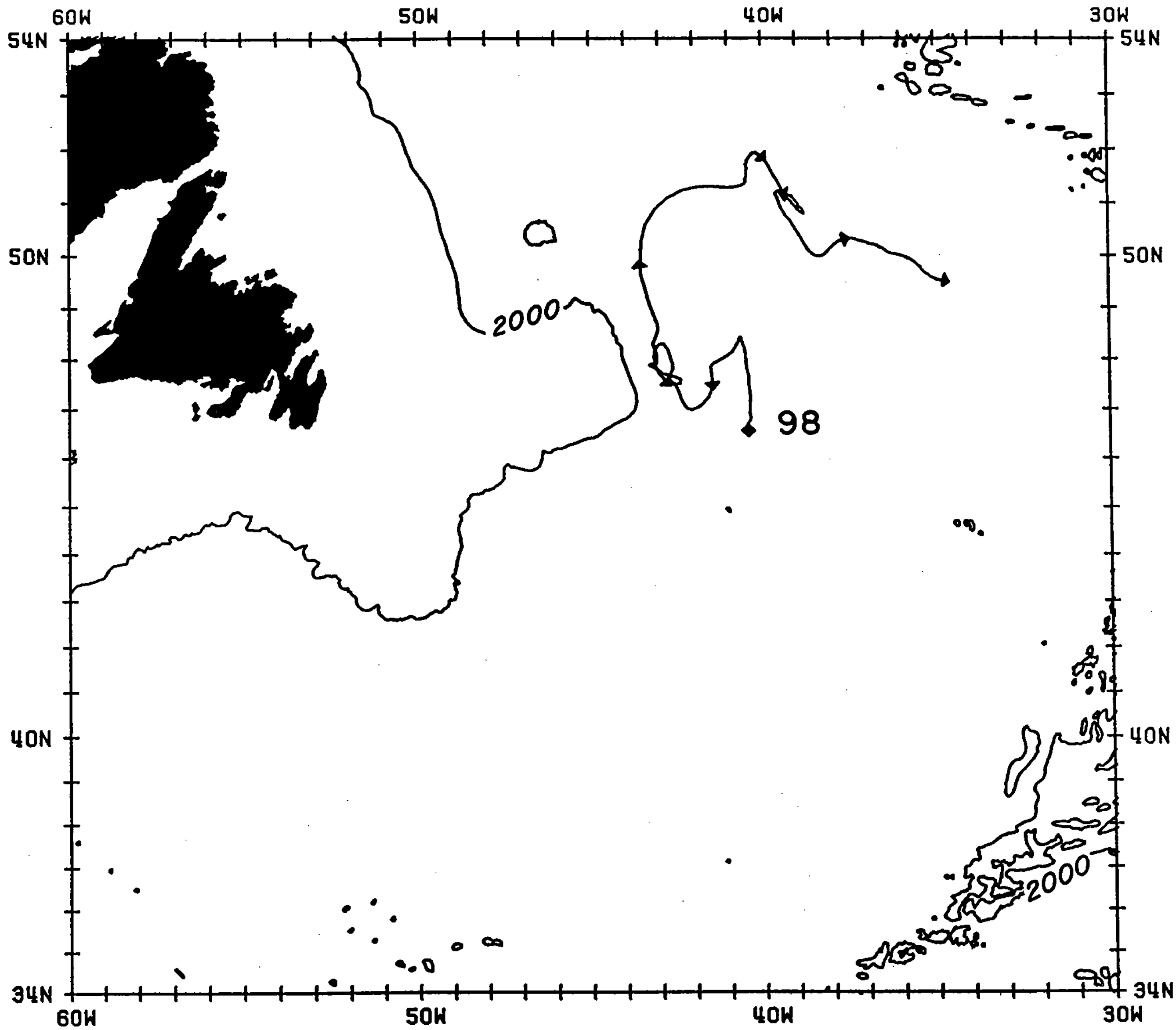
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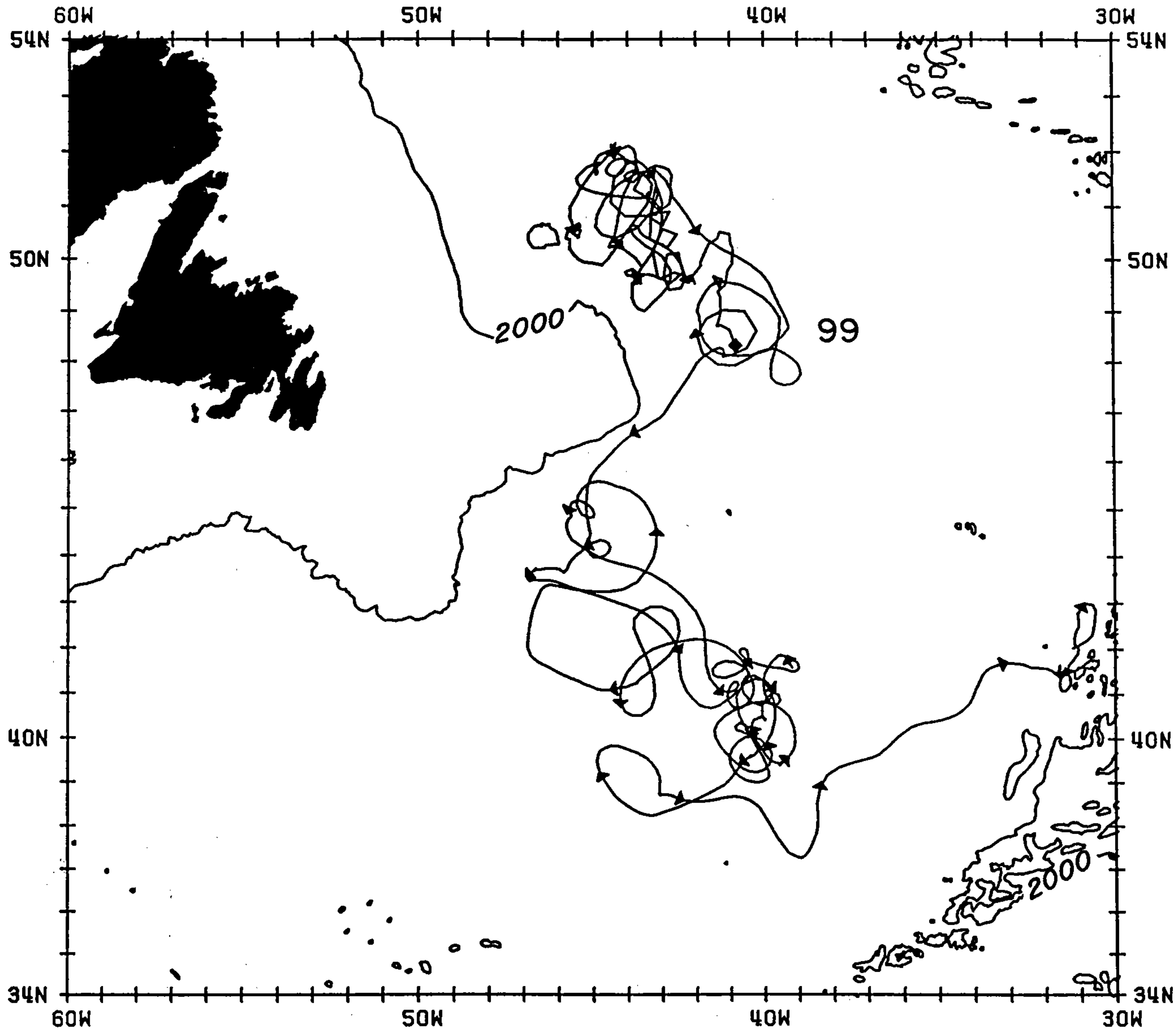
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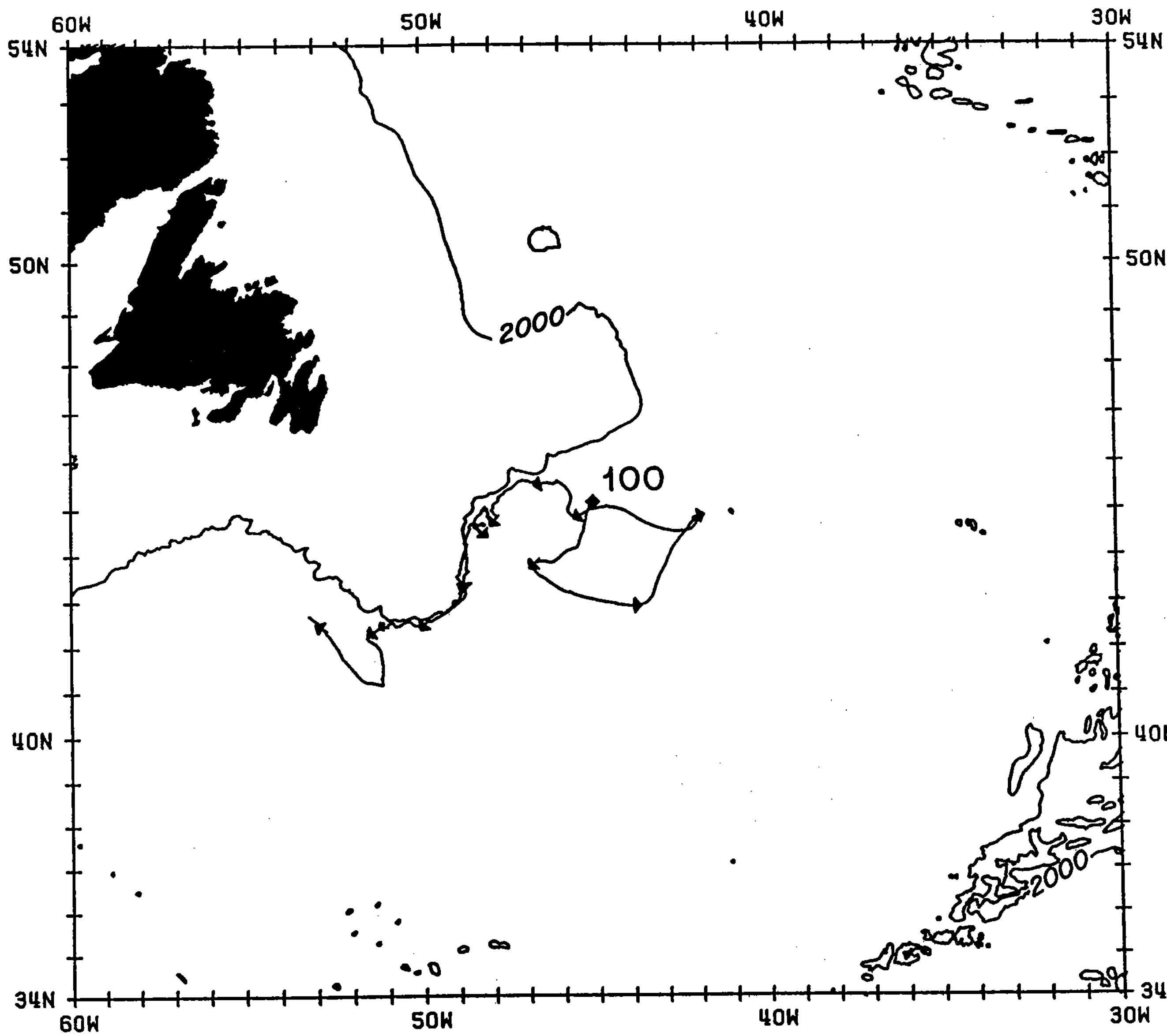
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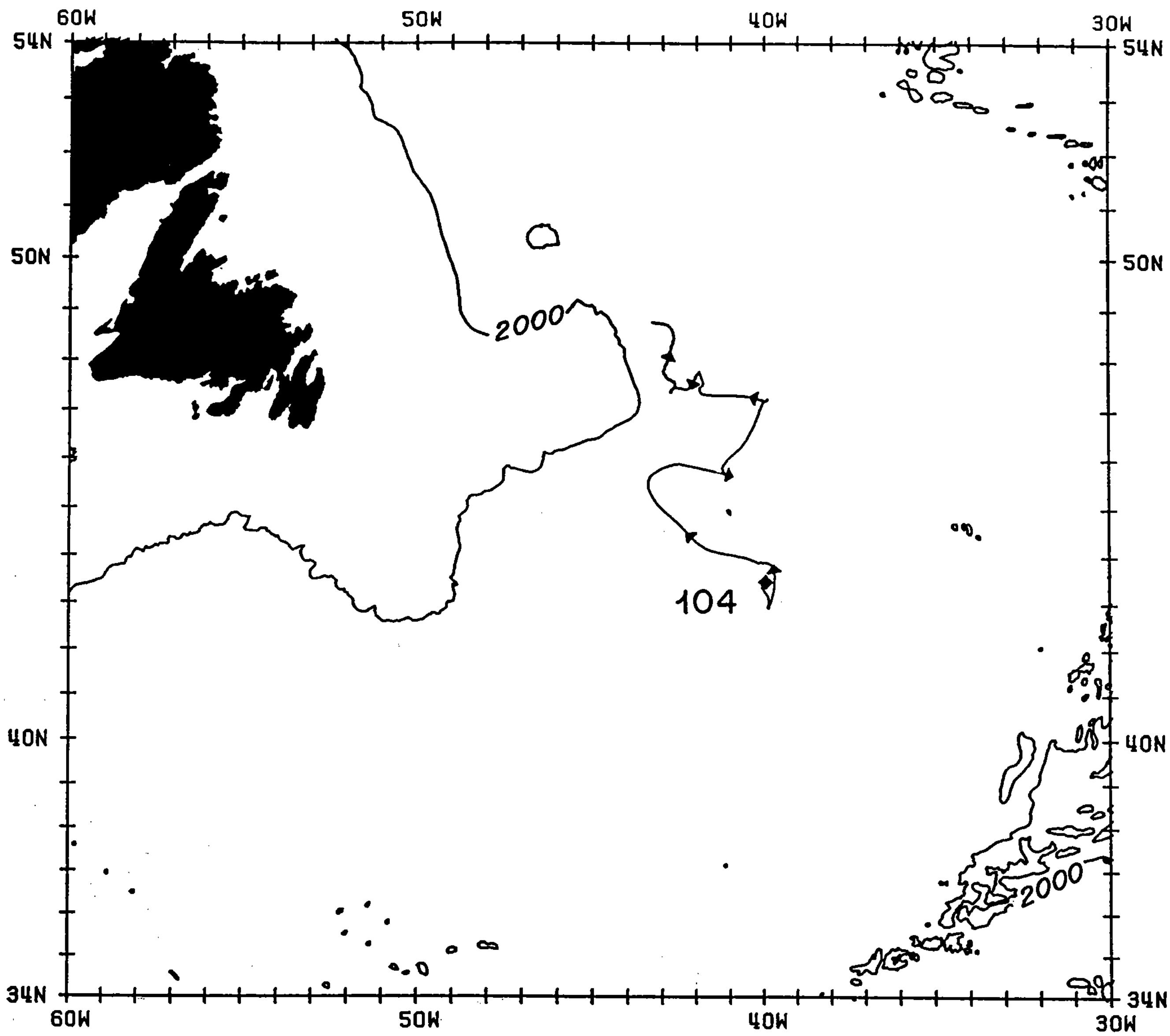
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