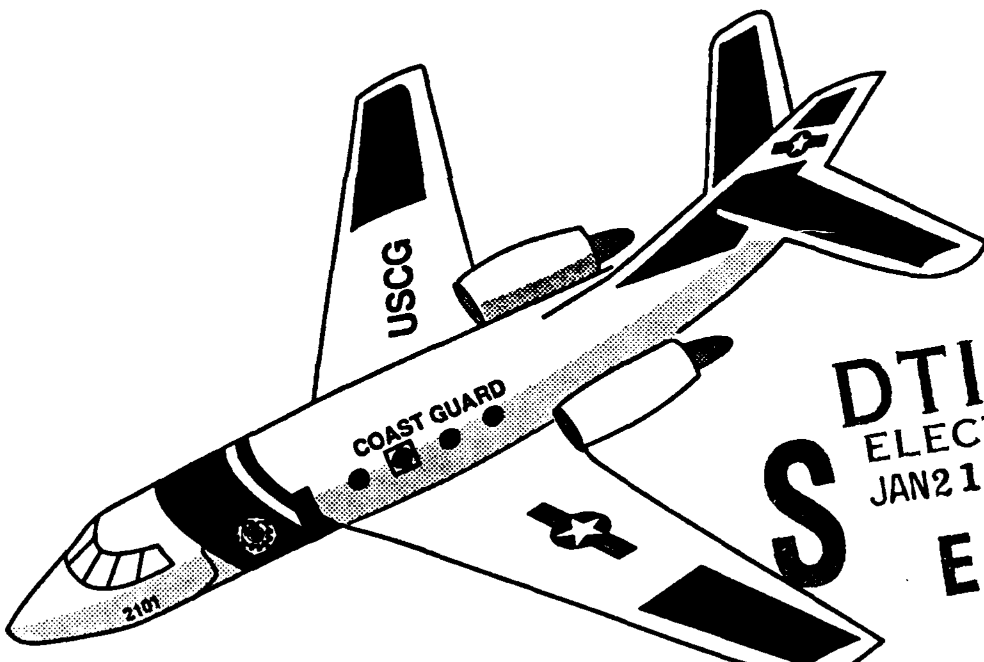
AD-A259 818

U. S. Department of Transportation
United States Coast Guard

Report of the International Ice Patrol in the North Atlantic



HU-25 Aireye Falcon
Introduced to Ice Patrol Service in 1988

1989 Season
Bulletin No. 75
CG-188-44

U.S. Department of Transportation
United States Coast Guard

Commandant
United States Coast Guard

MAILING ADDRESS:
2100 2nd St., S.W.
Washington, D.C. 20593
(202)267-1450

Bulletin No. 75

REPORT OF THE INTERNATIONAL ICE PATROL IN THE NORTH ATLANTIC

Season of 1989

CG-188-44

Forwarded herewith is bulletin No. 75 of the International Ice Patrol, describing the Patrol's services, ice observations and conditions during the 1989 season.

J. W. Lockwood

J. W. LOCKWOOD
Chief, Office of Navigation Safety
and Waterway Services

Accesion For	
NTIS CRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification per AD-A256 161	
By	
Distribution /	
Availability Codes	
Dist	Avail and / or Special
A-1	

DTIC QUALITY INSPECTED 5

DISTRIBUTION—SDL No. 129

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z
A																										
B	3*	1*	1*		2					1				2	2		1									
C	1*																1*									
D																							60			
E																										
F																										
G																										
H																										

NON-STANDARD DISTRIBUTION: B:a G-NIO only; B:b LANTAREA (5), PACAREA (1); B:c First Fifth Districts only; C:a CGAS Elizabeth City only; C:q LANTAREA only; SML CG-4

INTERNATIONAL ICE PATROL 1989 ANNUAL REPORT

CONTENTS

Introduction

This is the 75th annual report of the International Ice Patrol (IIP). It contains information on Ice Patrol operations, environmental conditions, and ice conditions for the 1989 IIP season. The U.S. Coast Guard conducts the International Ice Patrol Service in the North Atlantic under the provisions of U.S. Code, Title 46, Sections 738, 738a through 738d, and the International Convention for the Safety of Life at Sea (SOLAS), 1974, regulations 5-8. This service was initiated shortly after the sinking of the RMS TITANIC on April 15, 1912 and has been provided annually since that time.

Commander, International Ice Patrol, working under Commander, Coast Guard Atlantic Area, directs the IIP from offices located in Groton, Connecticut. IIP analyzes ice and environmental data, prepares daily ice bulletins and facsimile charts, and replies to requests for ice information. IIP uses aerial Ice Reconnaissance Detachments and surface patrol cutters to survey the southeastern, southern, and southwestern regions of the Grand Banks of Newfoundland for icebergs. IIP makes twice-daily radio broadcasts to warn mariners of the limits of all known ice.

Vice Admiral J. C. Irwin was Commander, Atlantic Area until March 31, 1989, and Vice Admiral H. B. Thorsen was Commander, Atlantic Area, from March 31, 1989, to the end of the 1989 ice year. CDR S. R. Osmer was Commander, International Ice Patrol until July 31, 1989. CDR J. J. Murray commanded Ice Patrol for the remainder of the 1989 ice year.

Summary of Operations, 1989

The 1989 IIP year (October 1, 1988 - September 30, 1989) marked the 75th anniversary of the International Ice Patrol, which was established February 7, 1914. IIP's operating area is delineated by 40°N - 52°N, 39°W - 57°W (Figure 1). During 1989, Coast Guard HC-130H aircraft equipped with the AN/APS-135 Side-Looking Airborne Radar (SLAR) flew 44 ice reconnaissance sorties, logging over 207 flight hours, and Coast Guard HU-25B aircraft equipped with the AN/APS-131 SLAR flew 27 reconnaissance sorties, logging over 84 flight hours.

Aircraft deployments were made from January 26 to 31 and February 16 to 25 to determine the preseason iceberg distribution. Based on the latter preseason deployment, the 1989 IIP season was opened on 1 March. From this date until August 9, 1989, an aerial Iceberg Reconnaissance Detachment (ICERECDET) operated from Newfoundland one week out of every two. The IIP base of operations in Newfoundland shifted from Gander to St. John's during the 1989 season. The season officially closed on July 28, 1989.

Watchstanders at IIP's Operations Center in Groton, Connecticut analyze the iceberg sighting information from the ICERECDETs, along with sighting information from commercial shipping and Atmospheric Environment Service (AES) of Canada sea ice/iceberg reconnaissance flights. In 1989, IIP actively pursued obtaining iceberg sighting information from additional sources, such as the Canadian Department of Defense, the Canadian Department of Fisheries and Oceans, and the commercial offshore fishing industry.

The IIP Operations Center received a total of 5,154 iceberg sightings in 1989, compared to 35,129 in 1988. The decrease is explained by cutbacks in AES Canada's iceberg flights and curtailment of offshore oil industry operations. Only those iceberg sightings made during the ice season and within IIP's operations area (40°N - 52°N, 39°W - 57°W) are entered into the IIP iceberg drift prediction computer model (ICEPLOT). 1184 sightings were in IIP's operations area in 1989, compared to 1340 in 1988, and 1098 of these were entered into IIP's computer model, compared to 1160 in 1988. Watchstanders determine whether each sighting is a resight of an iceberg IIP already has on ICEPLOT or a new iceberg. Iceberg sightings near the Newfoundland coast are not entered into the computer model due to a lack of ocean current information in these areas.

IIP's computer model consists of one routine which predicts the drift of each iceberg and another which predicts the deterioration of each. The drift prediction program uses a historical current file which is modified weekly using satellite-tracked ocean drifting buoy data, thus taking into account local, short-term, current fluctuations. Murphy and Anderson (1985) describe the IIP drift model in more detail, along with an evaluation of the model.

The IIP iceberg deterioration program uses daily wind, sea surface temperature, and wave height information from the U.S. Navy Fleet Numerical Oceanography Center (FNOC) to melt the ice-

Table 1
Sources of International Ice Patrol Iceberg Sightings By Size

Sighting Source	Growler	Small	Medium	Large	Radar Target	Total	Percent of Total
Coast Guard (IIP)	70	335	347	205	82	1039	34.8
Commercial Ship	23	213	383	177	26	873	29.2
Offshore Oil Industry	74	110	84	28	0	269	9.0
DOD Sources	47	62	122	66	6	256	8.6
Canadian AES	0	117	79	26	8	253	8.5
BAPS	7	66	102	29	1	205	6.9
Lighthouse/Shore	0	4	13	10	0	27	0.9
Other	4	15	26	14	5	64	2.1
Total	225	922	1156	555	128	2986	100.0

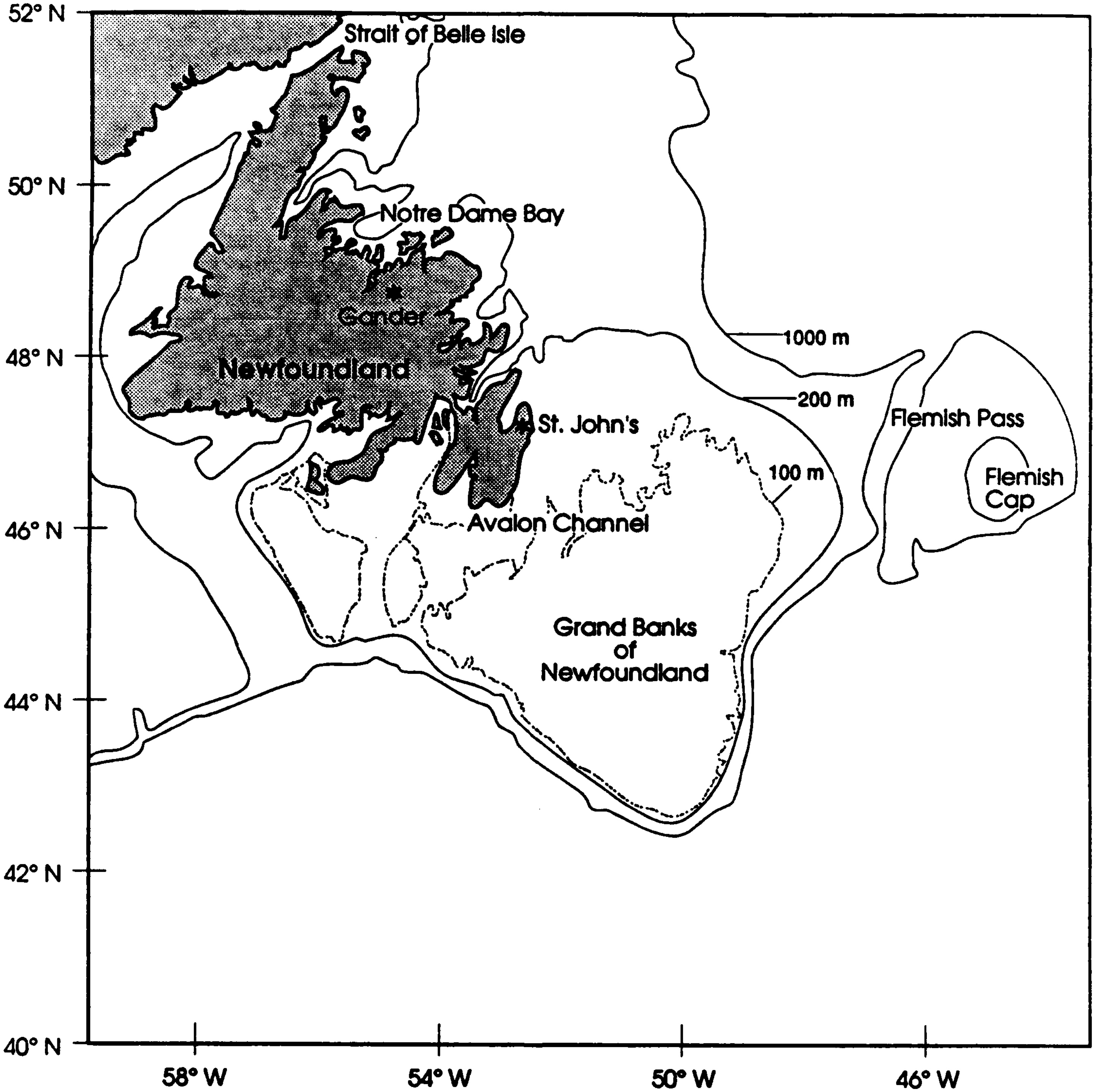


Figure 1. Bathymetry of the Grand Banks of Newfoundland.

bergs. Anderson (1983) and Hanson (1987) describe the IIP deterioration model in detail. It is the combined ability of the SLAR to detect icebergs in all weather and IIP's computer models to estimate iceberg drift and deterioration which has enabled IIP to reduce its ICERECDET operations from overlapping weekly deployments to every other week deployments.

Table 1 shows the total iceberg sightings reported to IIP in 1989 (including resights) which were in IIP's operations area and away from the Newfoundland coast. Sightings are broken down by the sighting source and iceberg size. IIP ICERECDET and commercial shipping were the major sources of iceberg sighting reports this season. AES of Canada was not able to provide as many reports this season as last. Appendix A lists all iceberg sightings received from commercial shipping, regardless of the sighting location.

Table 2 lists monthly estimates of the total number of icebergs that crossed 48°N during the various reconnaissance eras: pre-International Ice Patrol, ship, aircraft visual, and aircraft SLAR eras. Table 3 compares the estimated number of icebergs crossing 48°N for each month of 1989 with the monthly mean number of icebergs crossing 48°N for each of the four different eras.

During the 1989 ice year, an estimated 301 icebergs drifted south of 48°N latitude, compared to 187 during 1988. The average number of icebergs drifting south of 48°N per year from 1900 to 1987 is 403 icebergs (Alfultis, 1987). IIP defines those ice years with less than 300 icebergs crossing 48°N as light ice years; those with 300 to 600 crossing 48°N as average; those with 600 to 900 crossing 48°N as heavy; and those with more than 900 crossing 48°N as extreme. Thus, 1989 was an average year.

Table 2: Total Icebergs South of 48°N - The four periods shown are pre-International Ice Patrol (1900-1912), ship reconnaissance (1913-45), aircraft visual reconnaissance (1946-82), and SLAR reconnaissance (1983-88).

	Total 1900-12	Total 1913-45	Total 1946-82	Total 1983-88	1989
OCT	27	80	2	3	3
NOV	13	93	4	11	0
DEC	38	42	11	14	0
JAN	33	87	65	13	0
FEB	79	372	273	239	19
MAR	898	1204	1172	450	127
APR	1537	3308	3131	1731	68
MAY	1611	5472	2993	1275	39
JUN	1004	2514	1865	813	35
JUL	423	773	489	586	10
AUG	160	229	100	148	0
SEP	58	188	10	43	0
Total	5,881	14,362	10,115	5,326	301

Nine satellite-tracked ocean drifting buoys were deployed to provide operational data for IIP's iceberg drift model. These buoys were the same standard size drifting buoys IIP has been deploying for fourteen years. In addition, several of these buoys were, for the first time, equipped with barometric pressure sensors. The U.S. Naval Oceanographic Command provided the funding for these barometric sensors. Drift data from these buoys are discussed in Appendix B.

Prior to the start of the 1989 season, IIP modified its Air-deployed eXpendable BathyThermograph (AXBT) system which was first used in 1988 (Alfultis, 1988). During the 1989 season, IIP operationally deployed 40 AXBT's which were provided by the U.S. Naval Oceanographic Command. The AXBT measures temperature with depth and transmits the data back to the aircraft.

Temperature data from the AXBTs were sent to the Canadian Meteorological and Oceanographic Center (METOC) in Halifax, Nova Scotia, Canada, the U.S. Naval Eastern Oceanography Center (NEOC) in Norfolk, Virginia, and FNOC for use as inputs into ocean temperature models. IIP directly benefits from its AXBT deployments by having improved ocean temperature data provided to its iceberg deterioration model. To further enhance the quality of environmental data used in its iceberg models, IIP also provided weekly drifting buoy sea surface temperature (SST) and drift histories and SLAR ocean feature analyses to METOC and NEOC for use in water mass and SST analyses.

IIP SLAR-equipped HC-130 and HU-25 aircraft participated in the Labrador Ice Margin Experiment (LIMEX) 1989. IIP's goals in participating in LIMEX 89 were to investigate SLAR detection of icebergs and vessels near the ice margin and SLAR detection of oceanic fronts. In addition, IIP used satellite-tracked beacons to monitor iceberg drift in the sea ice. Appendix C discusses IIP's participation in this experiment.

No U. S. Coast Guard cutters were deployed to act as surface patrol or oceanographic vessels this year.

On April 15, 1989, IIP paused to remember the 77th anniversary of the sinking of the RMS TITANIC. During an ice reconnaissance patrol, two memorial wreaths were placed near the site of the sinking to commemorate the nearly 1500 lives lost.

Table 3: Average Number of Icebergs South of 48°N - The four periods shown are pre-International Ice Patrol (1900-1912), ship reconnaissance (1913-45), aircraft visual reconnaissance (1946-82), and SLAR reconnaissance (1983-88).

	Avg 1900-12	Avg 1913-45	Avg 1946-82	Avg 1983-88	1989
OCT	2	2	0	1	3
NOV	1	3	0	2	0
DEC	3	1	0	2	0
JAN	2	3	2	2	0
FEB	6	11	7	40	19
MAR	69	36	32	75	127
APR	118	100	85	288	68
MAY	124	166	81	212	39
JUN	77	76	50	136	35
JUL	32	23	13	98	10
AUG	12	7	3	25	0
SEP	4	6	0	7	0
Era Average	450	434	273	888	301

Iceberg Reconnaissance and Communications

During the 1989 Ice Patrol year, 139 aircraft sorties were flown in support of IIP. These included preseason flights, ice observation flights during the season, , and SLAR research flights. The purpose of preseason flights was to determine iceberg concentrations north of 48°N in order to predict when icebergs would threaten the North Atlantic shipping lanes. During the active season, ice observation flights were made to locate the southwestern, southern, and southeastern limits of icebergs. Postseason flights were made to survey the iceberg distribution and perform logistics and liaison in St. John's. The SLAR research flights were in support of LIMEX '89.

Aerial ice reconnaissance was conducted with SLAR-equipped U. S. Coast Guard HC-130H and HU-25B aircraft. The HC-130H aircraft deployed from Coast Guard Air Station Elizabeth City, North Carolina, and HU-25B aircraft deployed from Coast Guard Air Station Cape Cod, Massachusetts. Both aircraft participated in LIMEX '89, and both were used on logistics flights. Tables 4, 4a, and 4b show aircraft use during the 1989 ice year.

The HC-130 'Hercules' aircraft has been the platform for Ice Patrol aerial reconnaissance since 1963. This was the second year for the HU-25B to serve as an Ice Patrol platform. Although the HU-25B does not have the range of the HC-130, it can serve as an excellent complement and is capable of covering a majority of the IIP operations area.

Each day during the ice season, IIP prepares the 0000Z and 1200Z ice bulletins warning mariners of the southwestern, southern, and southeastern limits of icebergs. U.S. Coast Guard Communications Station Boston, Massachusetts, NMF/NIK, and Canadian Coast Guard Radio Station St. John's/VON were the primary radio stations responsible for the dissemination of the ice bulletins. Other transmitting stations for the bulletins included Canadian Forces Meteorological and Oceanographic Center (METOC) Halifax, Nova Scotia/CFH, and U.S. Navy LCMP Broadcast Stations Norfolk/NAM, Thurso, Scotland, and Keflavik, Iceland.

IIP also prepares a daily facsimile chart graphically depicting the limits of all known ice for broadcast at 1600Z. U. S. Coast Guard Communications Station Boston assisted with the transmission of these charts. Canadian Forces METOC, Halifax/CFH, and AM Radio Station Bracknell/GFE, United Kingdom used Ice Patrol limits in their broadcasts. Canadian Coast Guard Radio Station St. John's/VON and U.S. Coast Guard Communications Station Boston/NIK provided special broadcasts.

Table 4 - Aircraft Use During the 1989 IIP Year (1 October 1988 - 30 September 1989)

Aircraft Deployment	Sorties	Flight Hours
Preseason	12	44.6
Regular Season	120	411.1
Post Season	7	15.8
Total	139	471.5

Iceberg Reconnaissance Sorties by Month

Month	Sorties	Flight Hours
Jan	2	9.8
Feb	3	13.4
Mar	19	78.9
Apr	7	44.5
May	9	45.2
Jun	13	44.8
Jul	16	49.5
Aug	2	5.3
Total	71	291.4

Table 4a - HC-130H Aircraft Use During the 1989 IIP Year (1 October 1988 - 30 September 1989)

Aircraft Deployment	Sorties	Flight Hours
Preseason	12	44.6
Regular Season	74	306.7
Post Season	7	15.8
Total	93	367.1

Iceberg Reconnaissance Sorties by Month

Month	Sorties	Flight Hours
Jan	2	9.8
Feb	3	13.4
Mar	8	44.4
Apr	7	44.5
May	9	45.2
Jun	13	44.8
Jul	0	0.0
Aug	2	5.3
Total	44	207.4

The International Ice Patrol requested that all ships transiting the area of the Grand Banks report ice sightings, weather, and sea surface temperatures via Canadian Coast Guard Radio Station St. John's/VON or U. S. Coast Guard Communications Station Boston/NIK. Response to this request is shown in Table 5, and Appendix A lists all contributors. Although St John's/VON remained the primary source of relayed information, IIP received more relayed information from the following sources during the 1989 ice year than in previous years: ECAREG Halifax, Canada; U.S. Coast Guard Communications and Master Station Atlantic, Norfolk, Virginia; and U.S. Coast Guard Automated Merchant Vessel Emergency Response/Operational Computer Center, New York.

Table 4b - HU-25B Aircraft Use During the 1989 IIP Year (1 October 1988 - 30 September 1989)

Aircraft Deployment	Sorties	Flight Hours
Preseason	0	0
Regular Season	46	104.4
Post Season	0	0.0
Total	46	104.4

Iceberg Reconnaissance Sorties by Month

Month	Sorties	Flight Hours
Mar	11	34.5
Apr	0	0.0
May	0	0.0
Jun	0	0.0
Jul	16	49.5
Aug	0	0.0
Total	27	84.0

Table 5
Iceberg and SST Reports

Number of ships furnishing Sea Surface Temperature (SST) reports	97
Number of SST reports received	376
Number of ships furnishing ice reports	255
Number of ice reports received	1032
First Ice Bulletin	010000Z MAR 89
Last Ice Bulletin	281200Z JUL 89
Number of facsimile charts transmitted	150

Environmental Conditions, 1989 Season

The wind direction along the Labrador and Newfoundland coasts can affect the iceberg severity of each ice year since the mean wind flow can influence iceberg drift. Dependent upon wind intensity and duration, icebergs can be accelerated along or driven out of the main flow of the Labrador Current. Departure from the Labrador Current normally slows their southerly drift and, in many cases, speeds up their rate of deterioration.

The wind direction and air temperature indirectly affect the iceberg severity of each ice year by influencing the extent of sea ice. Sea ice protects the icebergs from wave action, the major agent of iceberg deterioration. If the air temperature and wind direction are favorable for the sea ice to extend to the south and over the Grand Banks of Newfoundland, the icebergs will be protected longer as they drift south. When the sea ice retreats in the spring, large numbers of icebergs will be left behind on the Grand Banks. Also, if the time of sea ice retreat is delayed by below normal air temperatures, the icebergs will be protected longer, and a longer than normal ice season can be expected. The opposite is true if the southerly sea ice extent is minimal, or if above normal air temperatures cause an early retreat of sea ice from the Grand Banks.

The following discussion summarizes the environmental conditions along the Labrador and Newfoundland coasts for the 1989 ice year.

January: The monthly mean pressure of the Icelandic Low was about 18 mb lower in January than normal (Figure 2). The winds for the month were from the northwest over the Labrador Coast (AES, 1989).

February: The mean Icelandic Low for the month was northeast of Iceland and lower than normal. The Azores-Bermuda High was 10 mb higher than normal (Figure 3). As a result, the mean winds over Newfoundland and Labrador during the month were colder and more westerly than normal (AES, 1989).

March: The monthly mean pressure for the month shows a summer-time Azores-Bermuda High and a winter-time Icelandic Low (Figure 4), and thus both were more intense than normal (Mariner's Weather Log, 1989a). This resulted in 20 mb negative anomalies over Iceland and 10mb positive anomalies in the mid North Atlantic. The prevailing winds continued to be more westerly than normal along the Labrador and east Newfoundland coasts (AES, 1989).

April: The Azores-Bermuda High covered a large part of the North Atlantic and was 5 mb higher than normal (Figure 5). As expected, the Icelandic Low spread out from Labrador to Iceland, but, unexpectedly, it also covered Europe, creating negative anomalies (Mariner's Weather Log, 1989b). Moderate northwest to westerly winds prevailed over east Newfoundland waters (AES, 1989) rather than the normal northerly winds.

May: The Azores-Bermuda High had an extension covering from Nova Scotia to eastern Europe (Fibure 6). This extension covered the area usually occupied by the Icelandic Low, resulting in a band of positive anomalies (Mariner's Weather Log, 1989b). The mean windflow was from the southwest for the first part of the month and then shifted to northwesterly (AES, 1989). Light southwesterlies usually prevail throughout the month.

June: Although the Azores-Bermuda High was weaker than normal, it still covered most of the North Atlantic (Figure 7). The Icelandic Low was over Greenland, north of its normal position, resulting in a slightly higher than normal pressure off Labrador. Winds were very light over the region during the month.

July: The Azores-Bermuda High covered most of the North Atlantic, and it also extended over the United Kingdom, thus creating positive anomalies in this region (Figure 8). Although a weak high normally exists over Greenland, a mild Icelandic Low persisted in this area during July (Mariner's Weather Log, 1990). The winds were typical southwesterlies.

August: The Icelandic Low was centered over Iceland and much more intense than normal, creating up to 10-mb negative anomalies (Figure 9). The mean pressures for the region were abnormal due to the intense low and a midsummer Azores-Bermuda High (Mariner's Weather Log, 1990).

September: The Icelandic Low usually reappears during September, but this year it was already present in August (Mariner's Weather Log, 1990). The Icelandic Low was more extensive than normal, though, and thus created negative anomalies (Figure 10). The Azores-Bermuda High was approximately normal, but slightly more intense than normal around the edges. There was a normal westerly flow over Newfoundland.

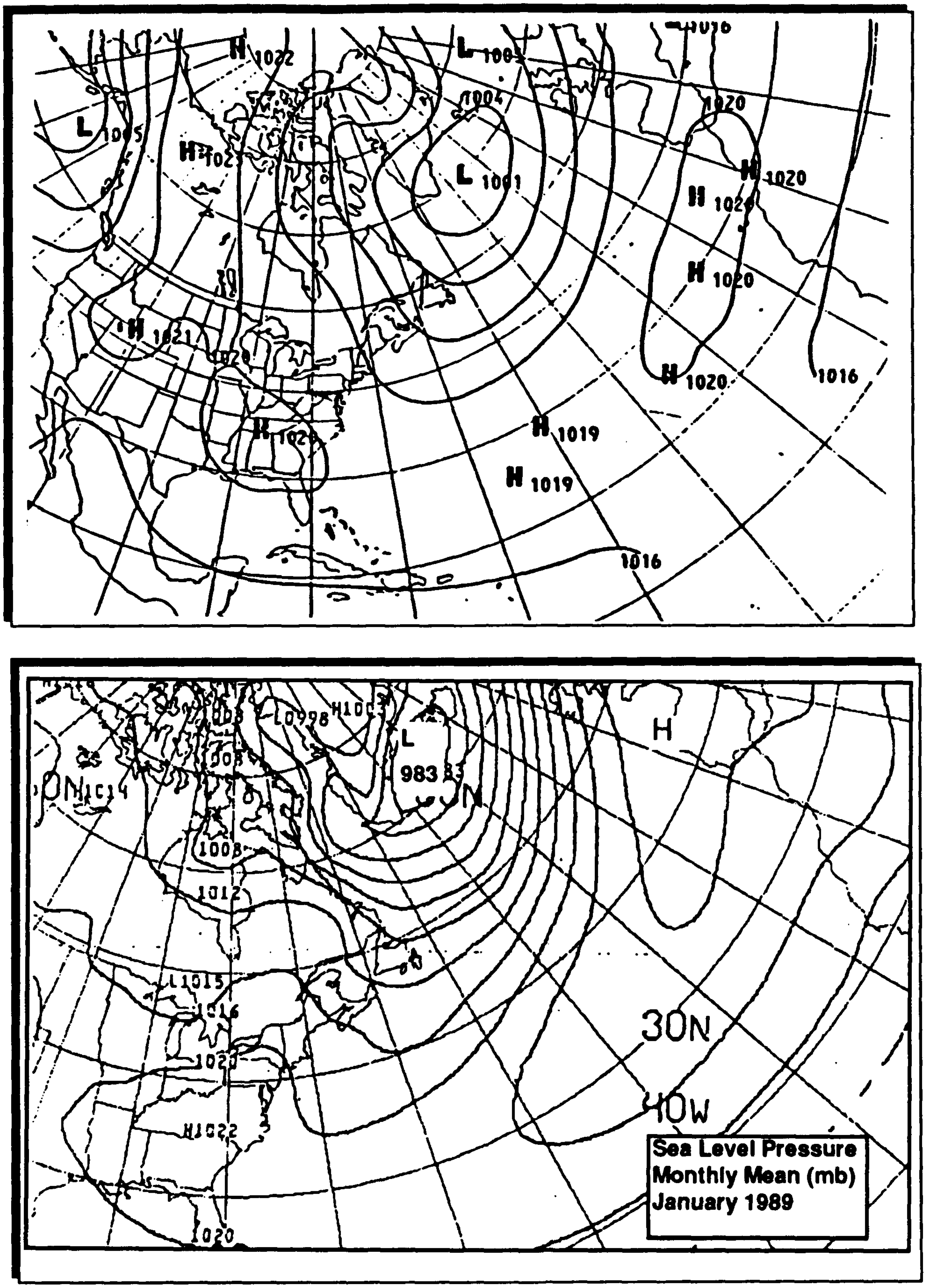
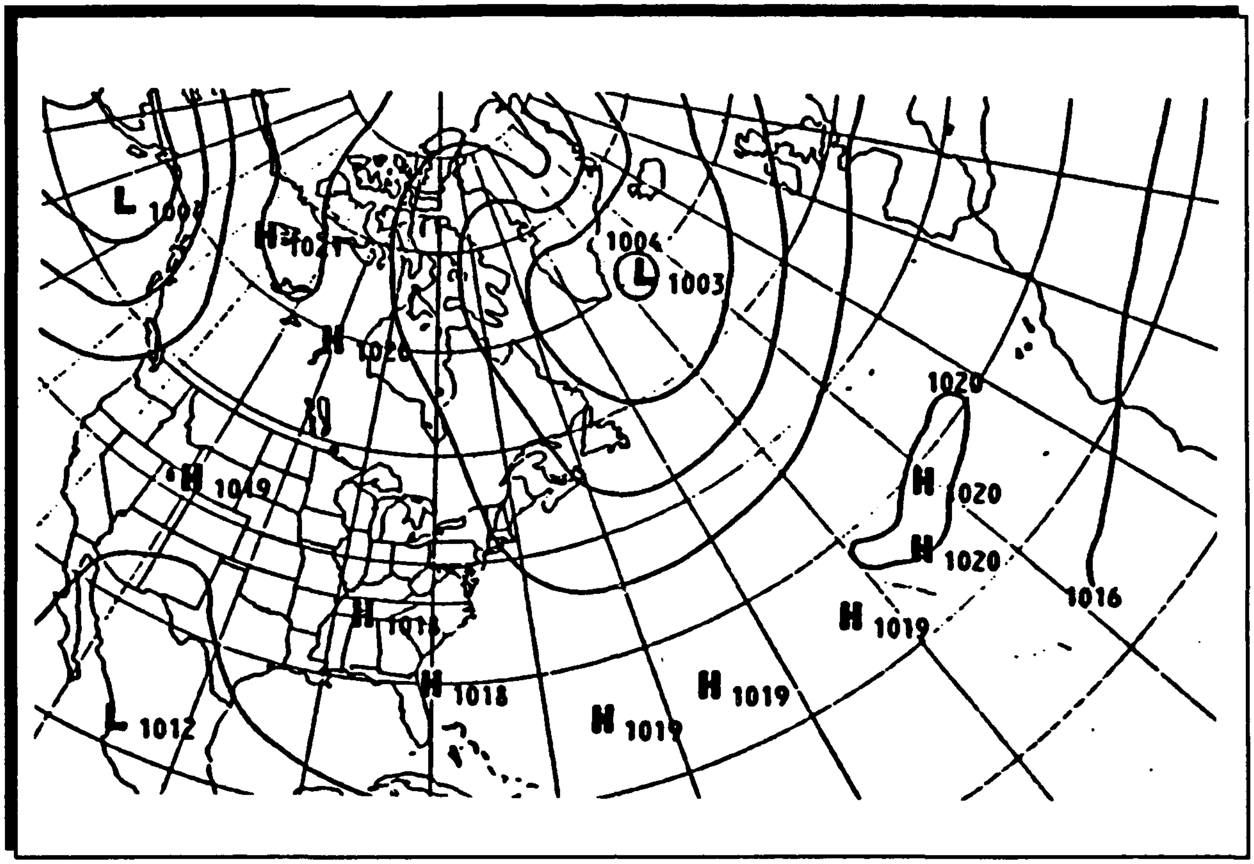


Figure 2. Comparison of January 1989 monthly mean surface pressure in mb (bottom, from Mariner's Weather Log, 1989a) with March historical average, 1948-1970 (top).



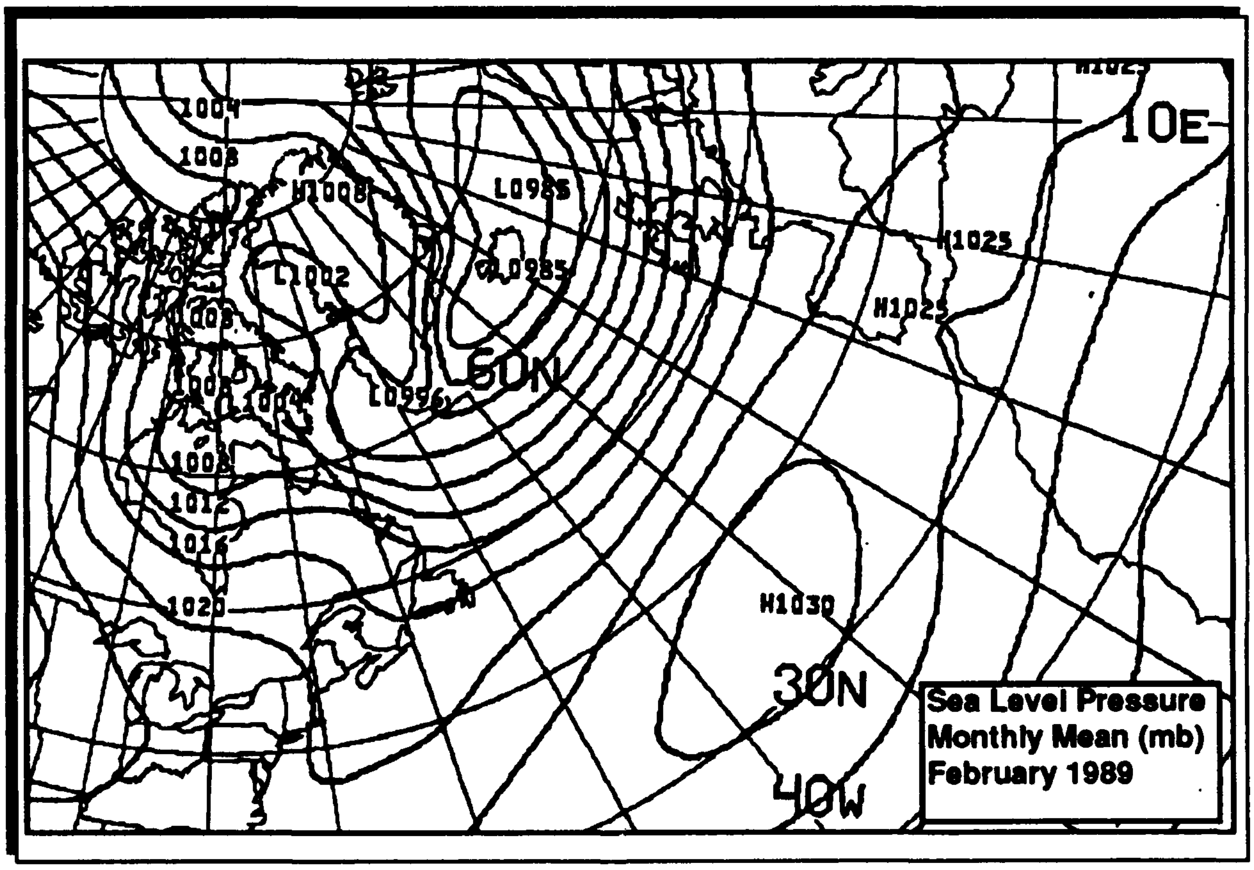


Figure 3. February 1989 (from Mariner's Weather Log, 1989a).

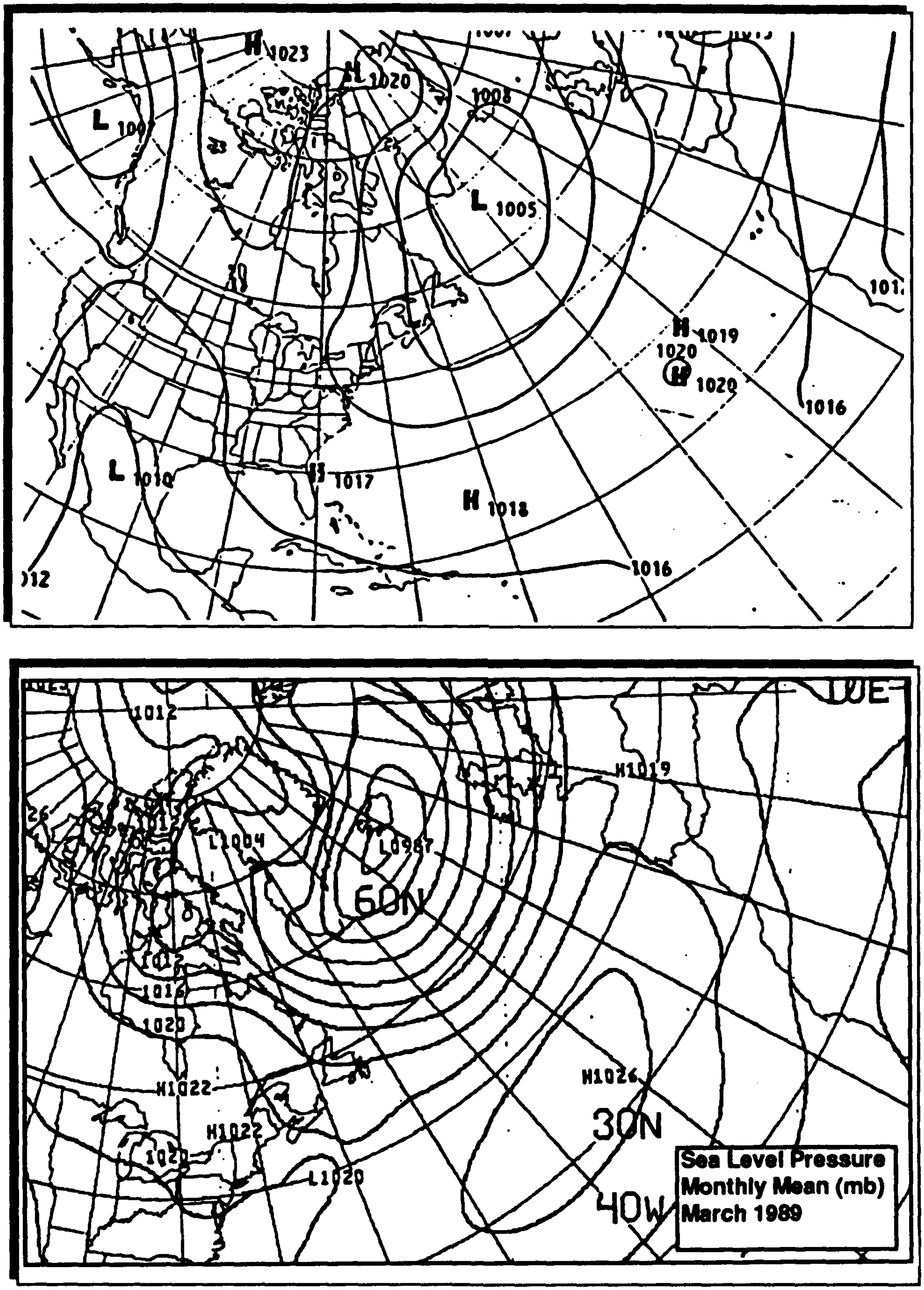


Figure 4. March 1989 (from Mariner's Weather Log, 1989a).

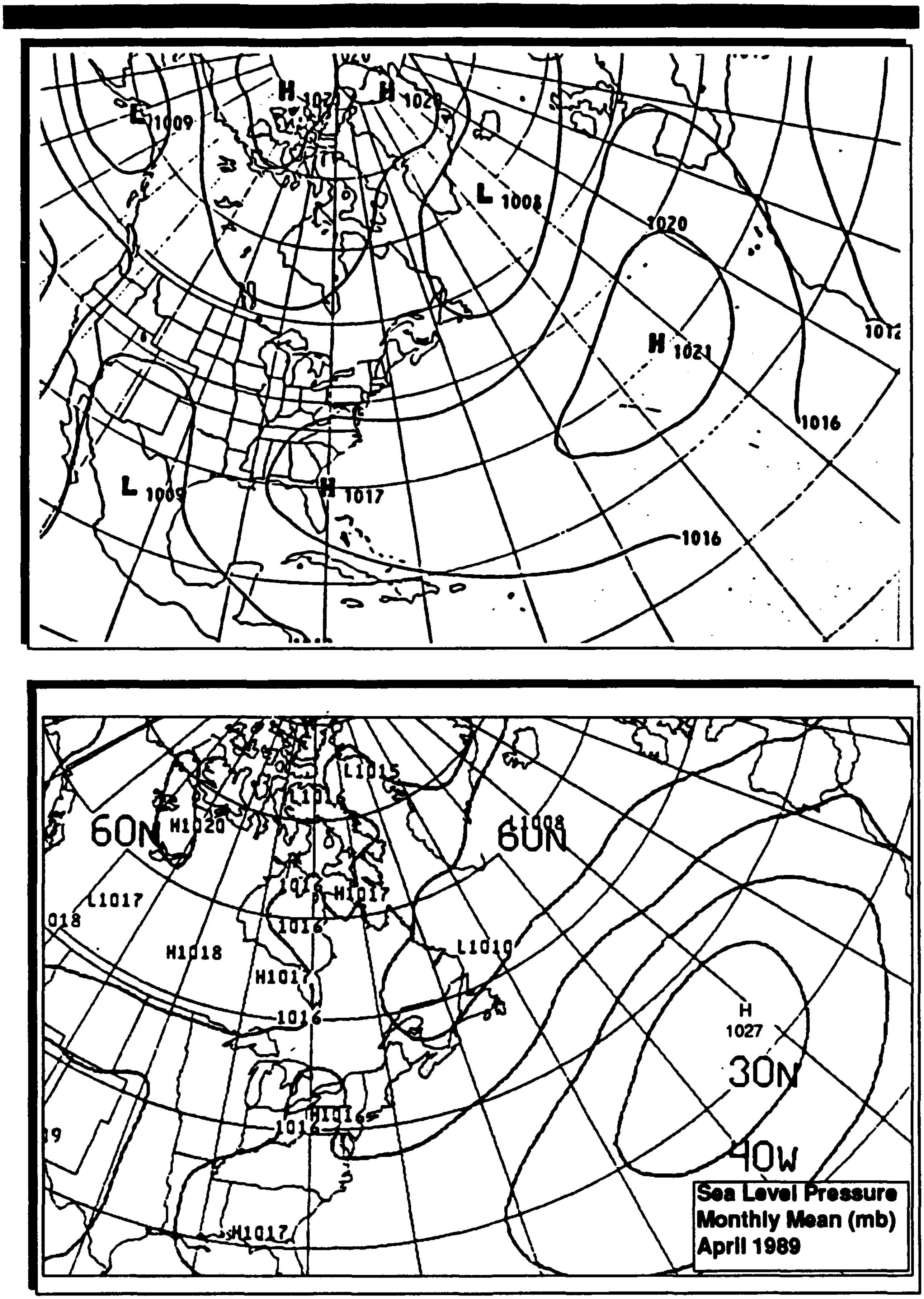


Figure 5. April 1989 (from Mariner's Weather Log, 1989b).

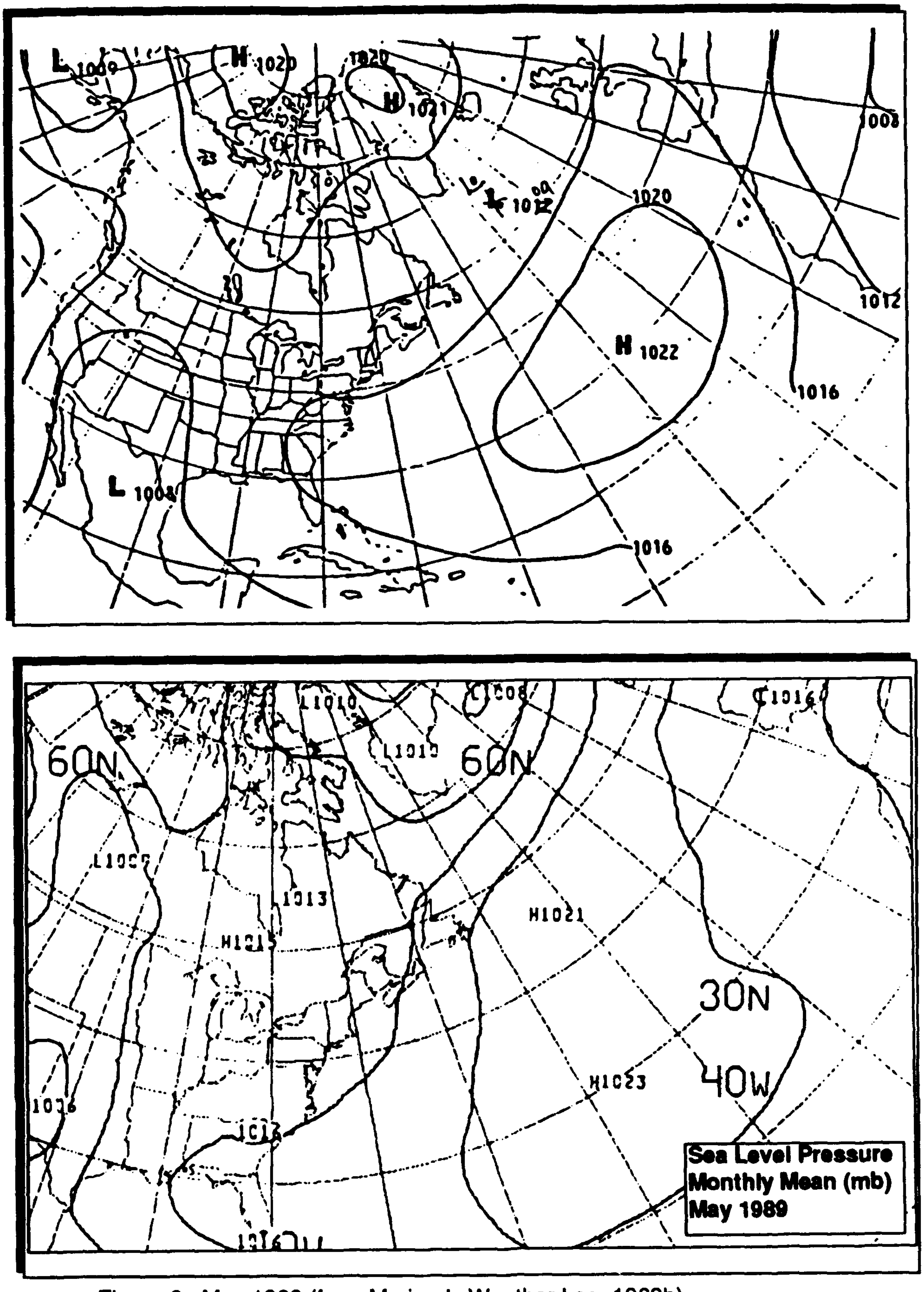


 Figure 6. May 1989 (from Mariner's Weather Log, 1989b).

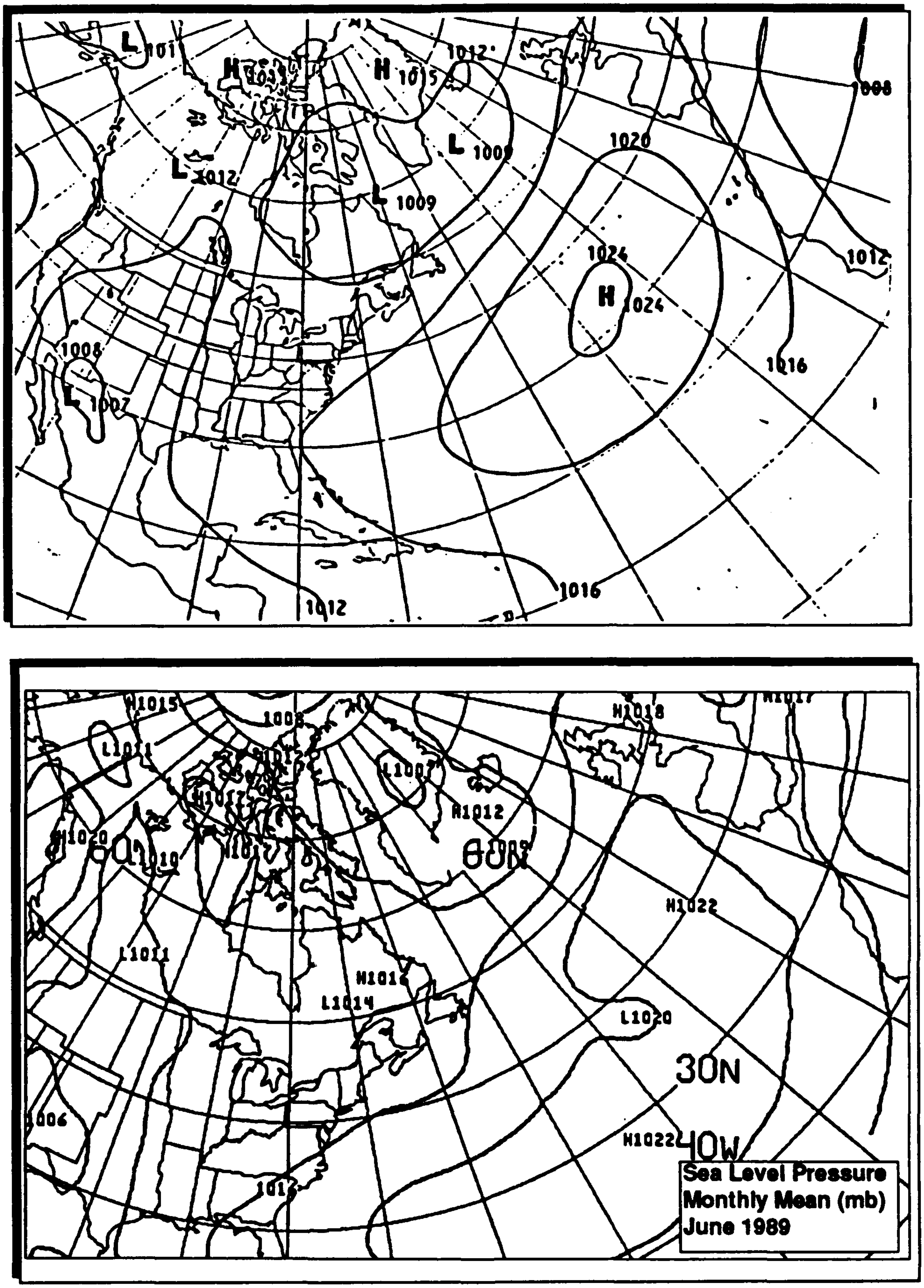


Figure 7. June 1989 (from Mariner's Weather Log, 1989b).

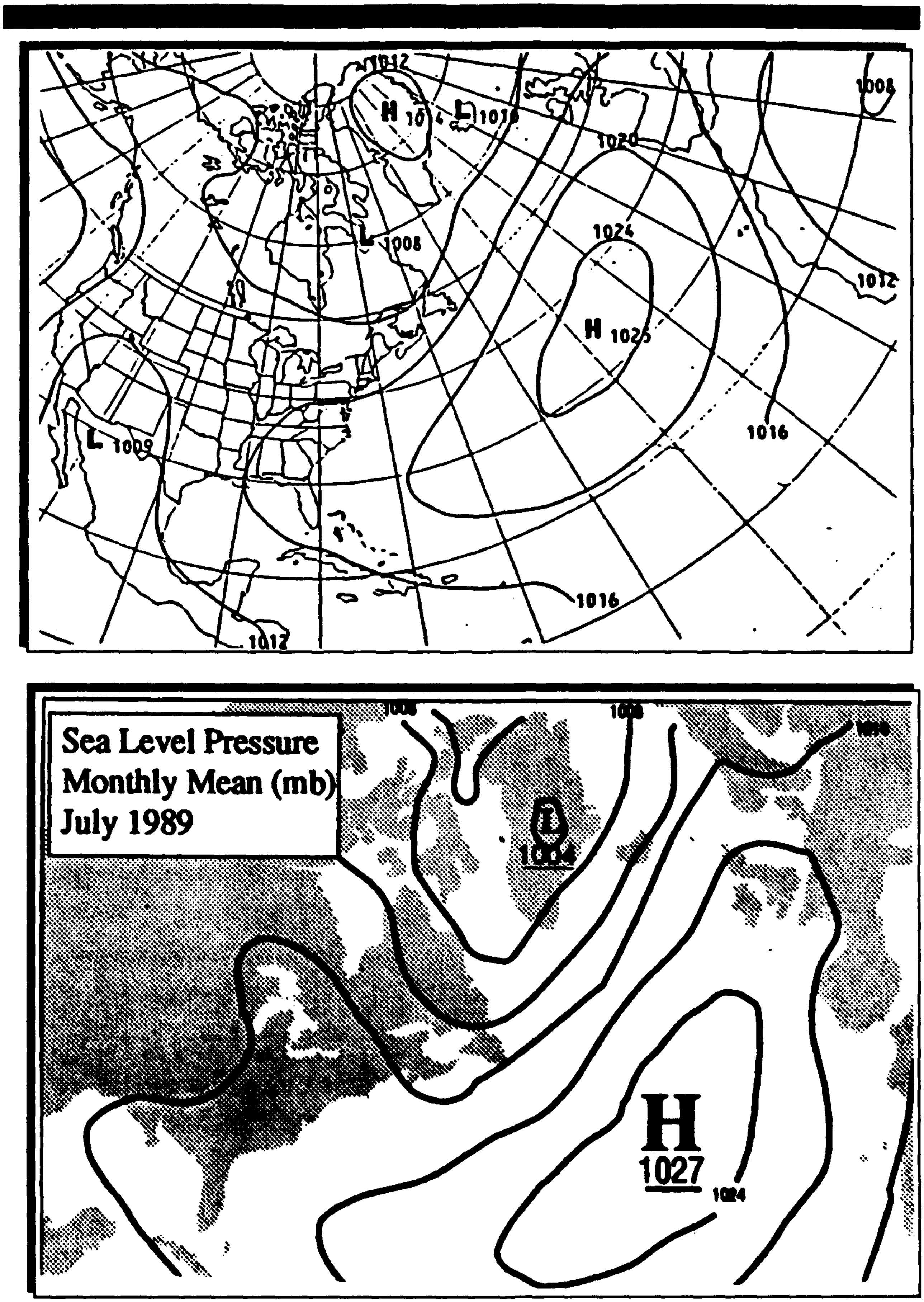


 Figure 8. July 1989 (from Mariner's Weather Log, 1990).

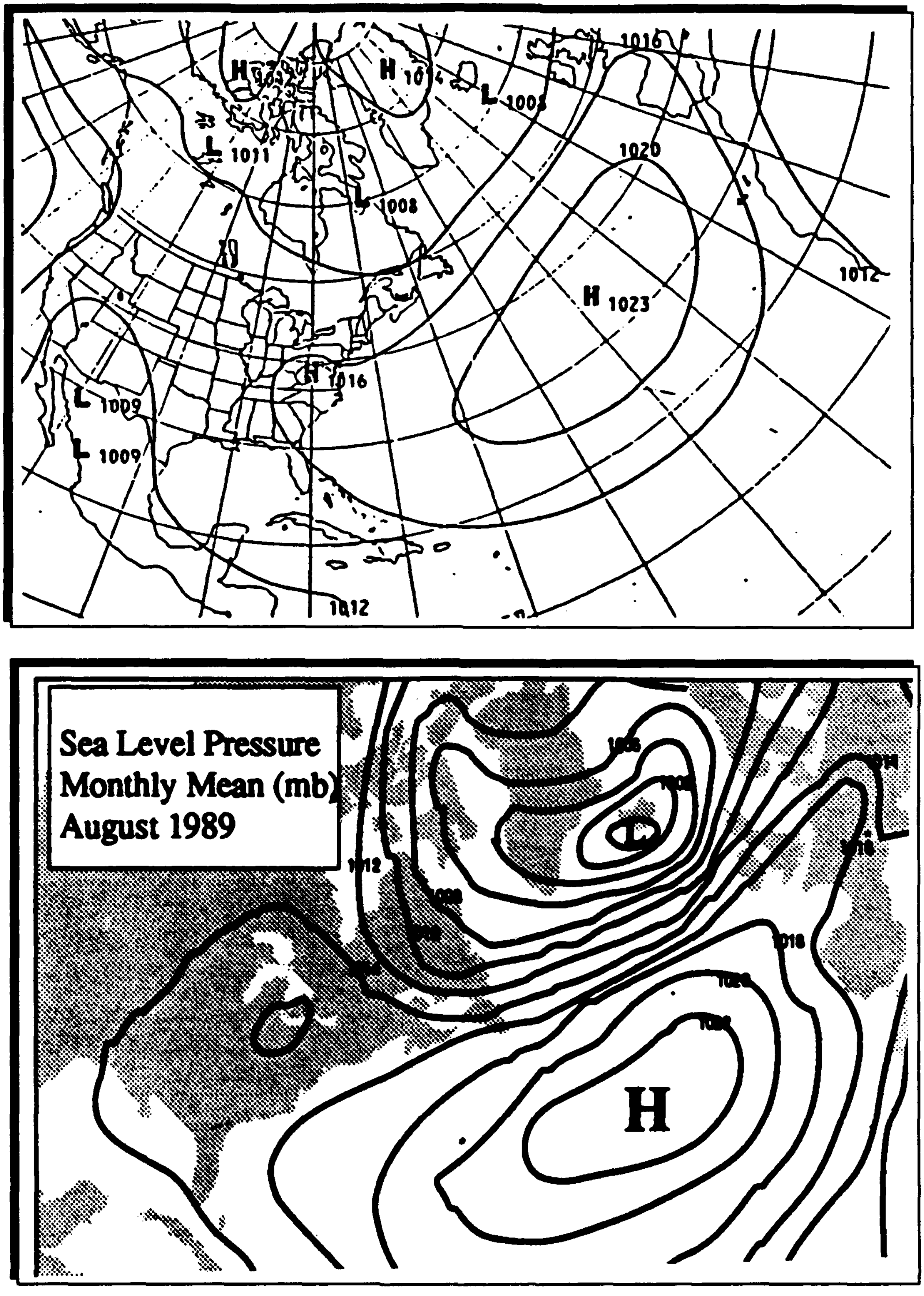


Figure 9. August 1989 (from Mariner's Weather Log, 1990).

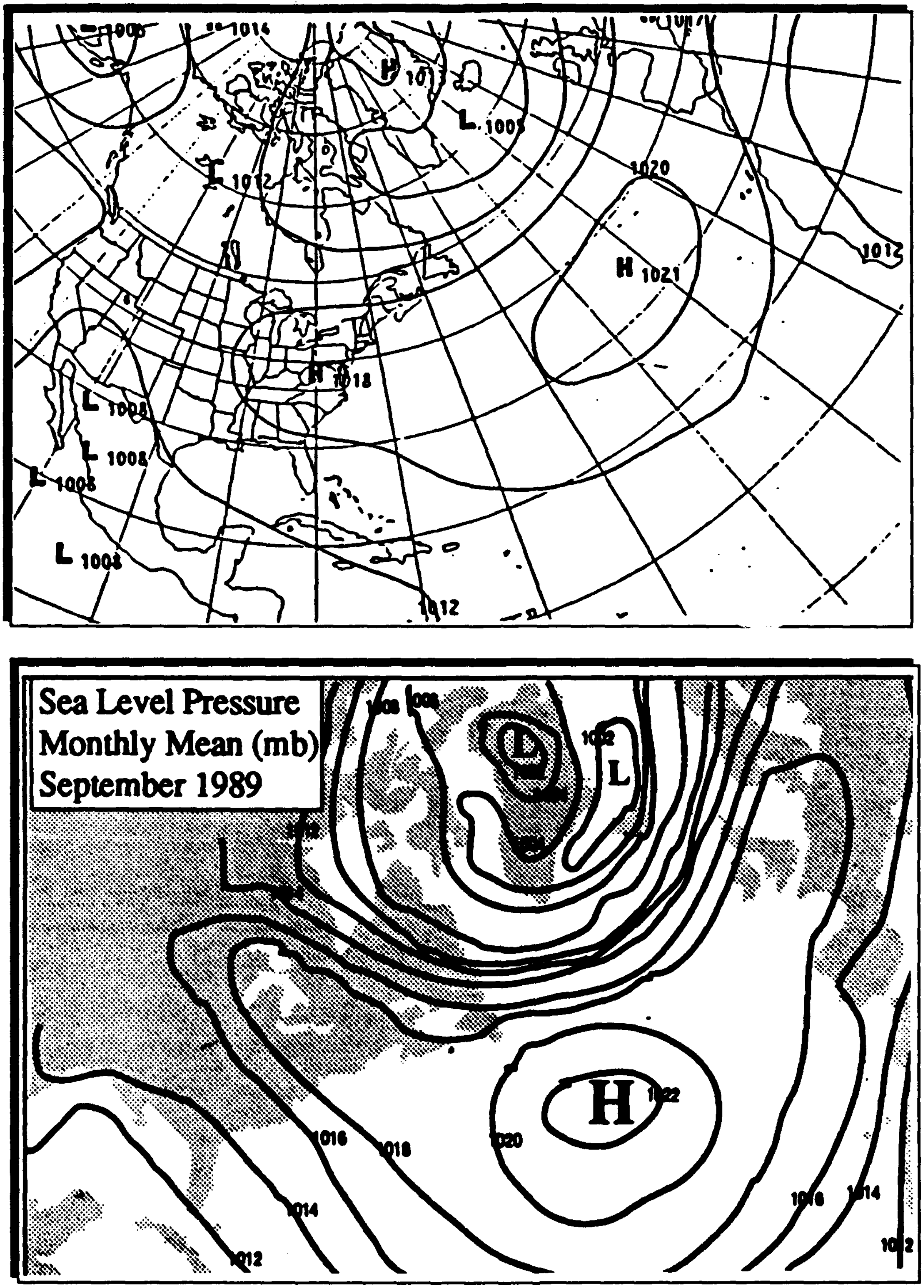


Figure 10. September 1989 (from Mariner's Weather Log, 1990).

Ice Conditions, 1989 Season

The following discussion summarizes the sea ice and iceberg conditions along the Labrador and Newfoundland coasts and on the Grand Banks of Newfoundland for the 1989 ice year. The sea ice information is derived from the Thirty-Day Ice Forecast for Northern Canadian Waters published monthly by the Atmospheric Environment Service (AES) of Canada and the Southern Ice Limit published twice-monthly by the U.S. Navy-NOAA Joint Ice Center. Information on the mean sea ice extent was obtained from the Naval Oceanography Command, 1986.

October 1988: Although sea ice does not normally extend south of 65°N in October (Naval Oceanographic Command, 1986), it was seen as far south as Resolution Island, approximately 62°N (Figure 11). There were 43 icebergs reported south of 52° N in October, and 3 of these were south of 48° N.

November 1988: By mid-November, there was no sea ice south of 65°N (Figure 12). The mean extent of sea ice in November is confined to the southern tip of Baffin Island with the maximum sea ice extent covering Hudson Strait, and Ungava Bay (Naval Oceanographic Command, 1986). The ice edge in November 1988 was less than average. There were no icebergs reported south of 52° N in November.

December 1988: The sea ice edge extended to the southern tip of Labrador by mid-December (Figure 13). The sea ice edge usually extends only as far south as Hamilton inlet in December. Temperatures over the area during the first half of December averaged 3.6 °C below normal (AES, 1989). These colder than normal temperatures enhanced the sea ice growth along the Labrador coast. There was only one iceberg reported south of 52° in December, and it was not south of 48 °N.

January 1989: Temperatures in Labrador and Newfoundland continued to be 3-5 °C below normal in January (AES, 1989). As a result, the growth and spread of sea ice along the Labrador and Newfoundland coasts were about a week and a half ahead of normal, and the ice was thicker than normal (AES, 1989). By mid-January, the sea ice extended along the east coast of Newfoundland into Notre Dame Bay to Cape Freels (Figure 14). By the end of January, the freezing degree days were double that usually observed, and the ice extent and thickness were about that expected in mid-February, or two weeks ahead of normal (AES, 1989). There were 105 icebergs reported south of 52° N in January, but none of these were south of 48° N

February 1989: Colder than normal temperatures continued through February, averaging about 5° C below normal (AES, 1989). In addition, the winds were more westerly than normal in February. This resulted in the sea ice edge being farther south than normal due to enhanced ice growth and farther east than normal due to ice drift (Figure 15). There were 74 icebergs observed south of 52° N in February, and 19 of these were south of 48° N.

March 1989: The sea ice edge continued to be farther south than normal in March (Figure 16). The 1989 International Ice Patrol Season opened on March 1, 1989. Figure 23 depicts the initial iceberg distribution. The icebergs were distributed mainly north of Flemish Cap and into Flemish Pass. Only one or two icebergs were near the Tail of the Grand Banks. By mid-March, large numbers of icebergs were being reported along the sea ice edge with most of the icebergs in open water in Flemish Pass (Figure 24). Most of the icebergs seemed to be located in the Labrador Current (Figure34). By the end of March, large numbers of icebergs were distributed between the Grand Banks and south of Flemish Pass (Figure 25). These icebergs appeared to be moving east rather than south with the Labrador Current. There were 189 icebergs on plot the end of March. For the whole month, there were 259 icebergs south of 52° N, and 127 of these were south of 48° N.

April 1989: The sea ice edge began to retreat northward in April. By mid-April, open water existed along the eastern coast of Newfoundland due to the easterly drift created by the westerly winds (Figure 17). The ice edge was near its mean southern and eastern positions. By mid-April, the large numbers of icebergs became more widely distributed to the east with small numbers of icebergs drifting south along the Grand Banks (Figure 26). There were still large numbers of icebergs north of 48° N which appeared to be drifting in the eastern branch of the Labrador Current. Not as many icebergs were to the east at the end of April, but there were still large numbers north of Flemish Pass (Figure 27). There were 216 icebergs on plot the end of April. There were 193 icebergs south of 52° N in April, and 68 of these were south of 48° N .

May 1989: The sea ice continued to retreat northward in May, but at a faster than normal rate. By mid-May, only patches of sea ice existed off the Strait of Belle Isle, and open water existed along the Labrador coast up to Hamilton Inlet (Figure 18). Above normal temperatures over Newfoundland and Labrador along with southwesterly winds the first half of May enhanced the sea ice deterioration. The iceberg distribution increased both in numbers and extent by mid-May with the icebergs widely scattered over most of the International Ice Patrol area (Figure 28). The icebergs seemed to be drifting both south through Flemish Pass and east north of Flemish Pass. The icebergs remained widely distributed at the end of May (Figure 29). There were 250 icebergs on plot the end of May. There were 197 new icebergs south of 52° N, but only 39 of these were south of 48° N in May.

June 1989: Temperatures averaged close to normal along the Labrador Coast, and ice conditions were also close to normal. Sea ice extended along the Labrador Coast to Hamilton Inlet at mid-month. There were 130 icebergs on plot the end of June. There were 148 new icebergs south of 52° N in May, and only 35 of these were south of 48° N.

July 1989: Temperatures averaged near normal for the month, and sea ice deteriorated, extending south only to Cumberland Peninsula. The 1989 International Ice Patrol Season closed on July 28, 1989. Figure 33 depicts the iceberg distribution at the end of the IIP season. There were 30 icebergs on plot the end of July. There were 78 new icebergs south of 52° N in July. Only 10 of these were south of 48° N.

August 1989: Except for some sea ice south of Greenland, there was none south of 65° N by mid-August (Figure 21). Normally, there is no sea ice south of 65° N in August. There were 73 icebergs south of 52° N in August, and none of these were south of 48° N. There were 37 icebergs on plot at the end of the month.

September 1989: There was no sea ice south of 65° N in September, which is normally the case (Figure 22). There were 13 new icebergs south of 52° N in September, and none of these were south

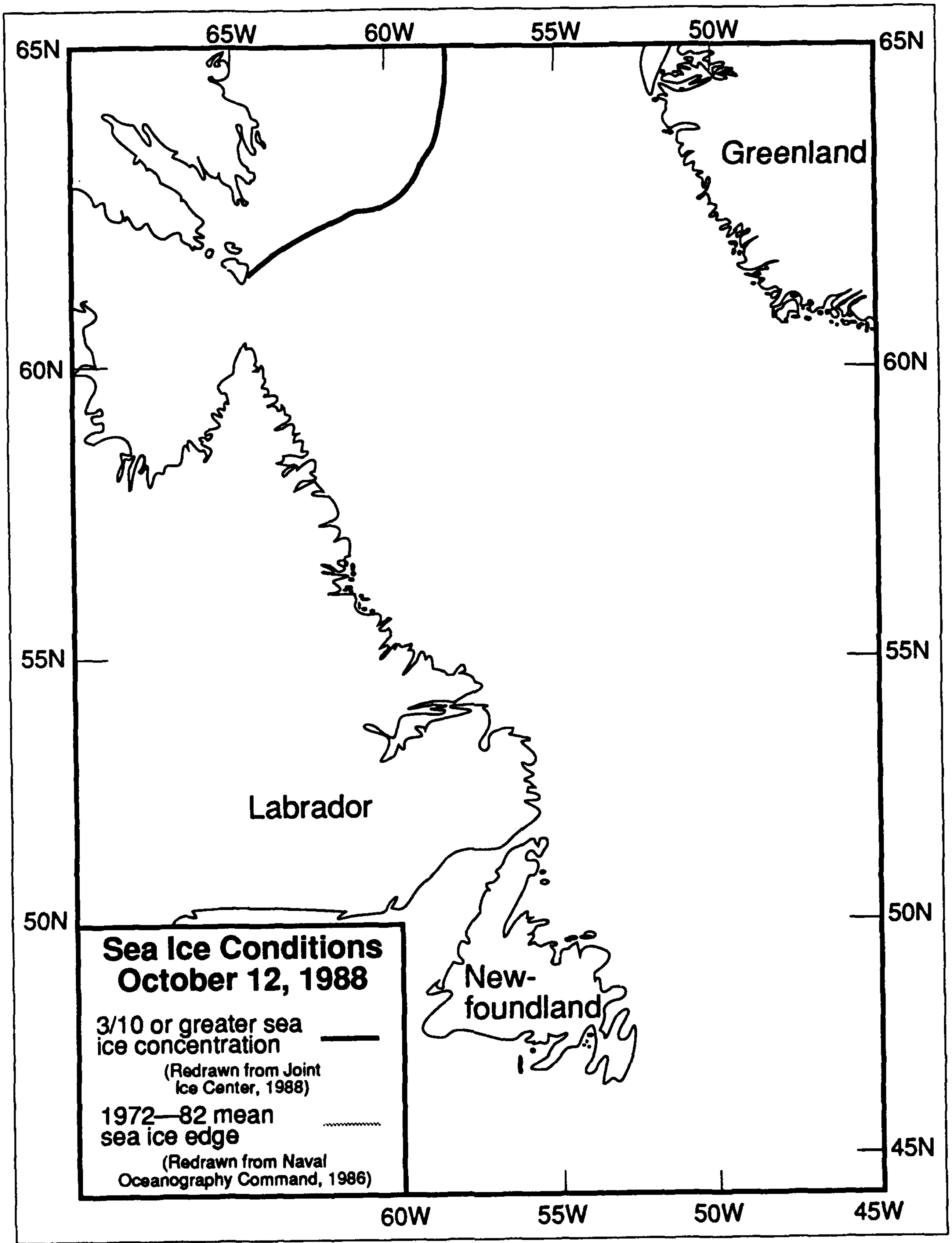

65N
65W
60W
55W
50W
65N
Greenland
60N
60N
55N
55N
Labrador
50N
50N
Sea Ice Conditions
October 12, 1988
3/10 or greater sea ice concentration
(Redrawn from Joint Ice Center, 1988)
1972—82 mean sea ice edge
(Redrawn from Naval Oceanography Command, 1986)
New-
foundland
45N
60W
55W
50W
45W

Figure 11.

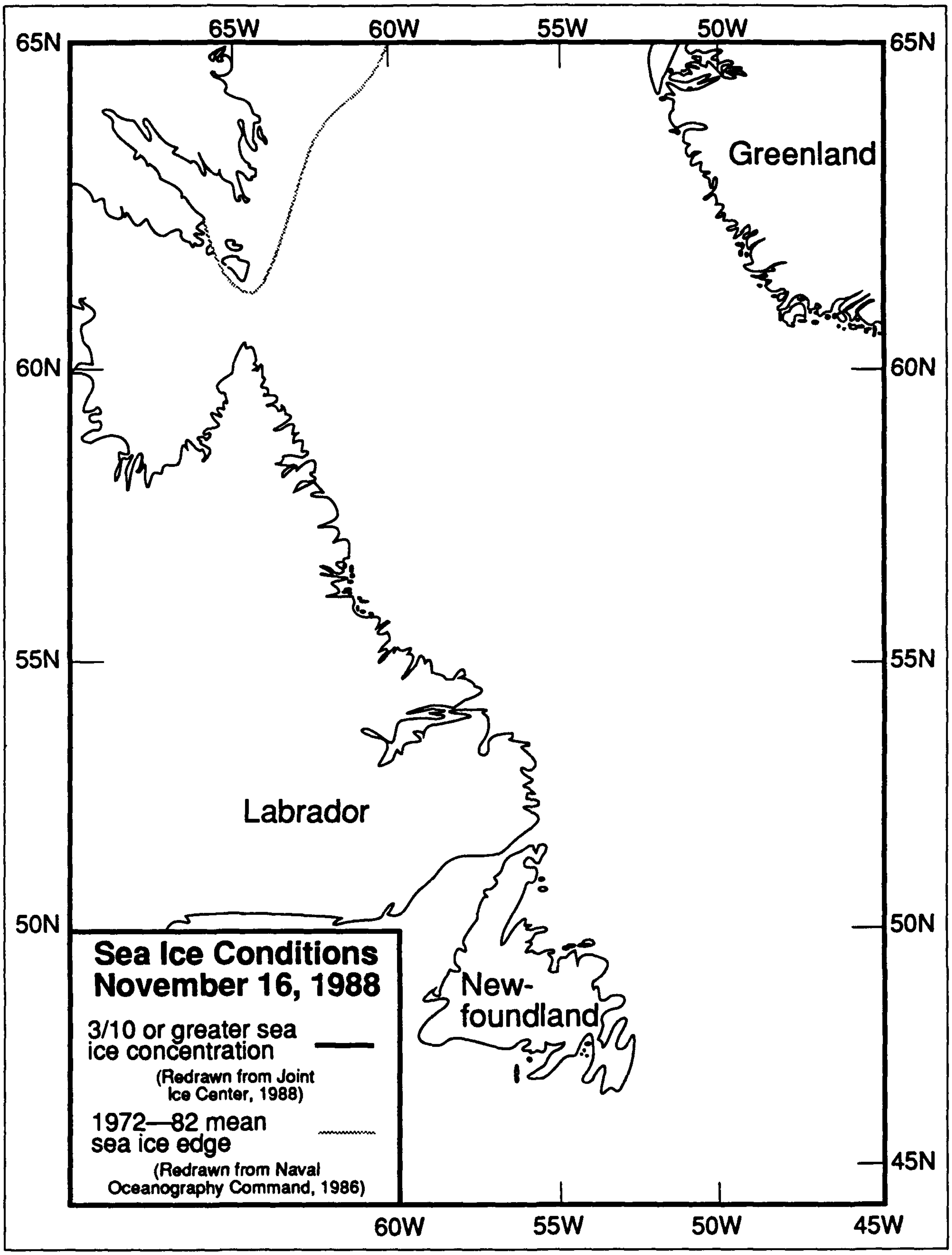

65W
60W
55W
50W
65N
60N
55N
50N
45N
60W
55W
50W
45W
Greenland
Labrador
New-
foundland
Sea Ice Conditions
November 16, 1988
3/10 or greater sea ice concentration
(Redrawn from Joint Ice Center, 1988)
1972—82 mean sea ice edge
(Redrawn from Naval Oceanography Command, 1986)

Figure 12.

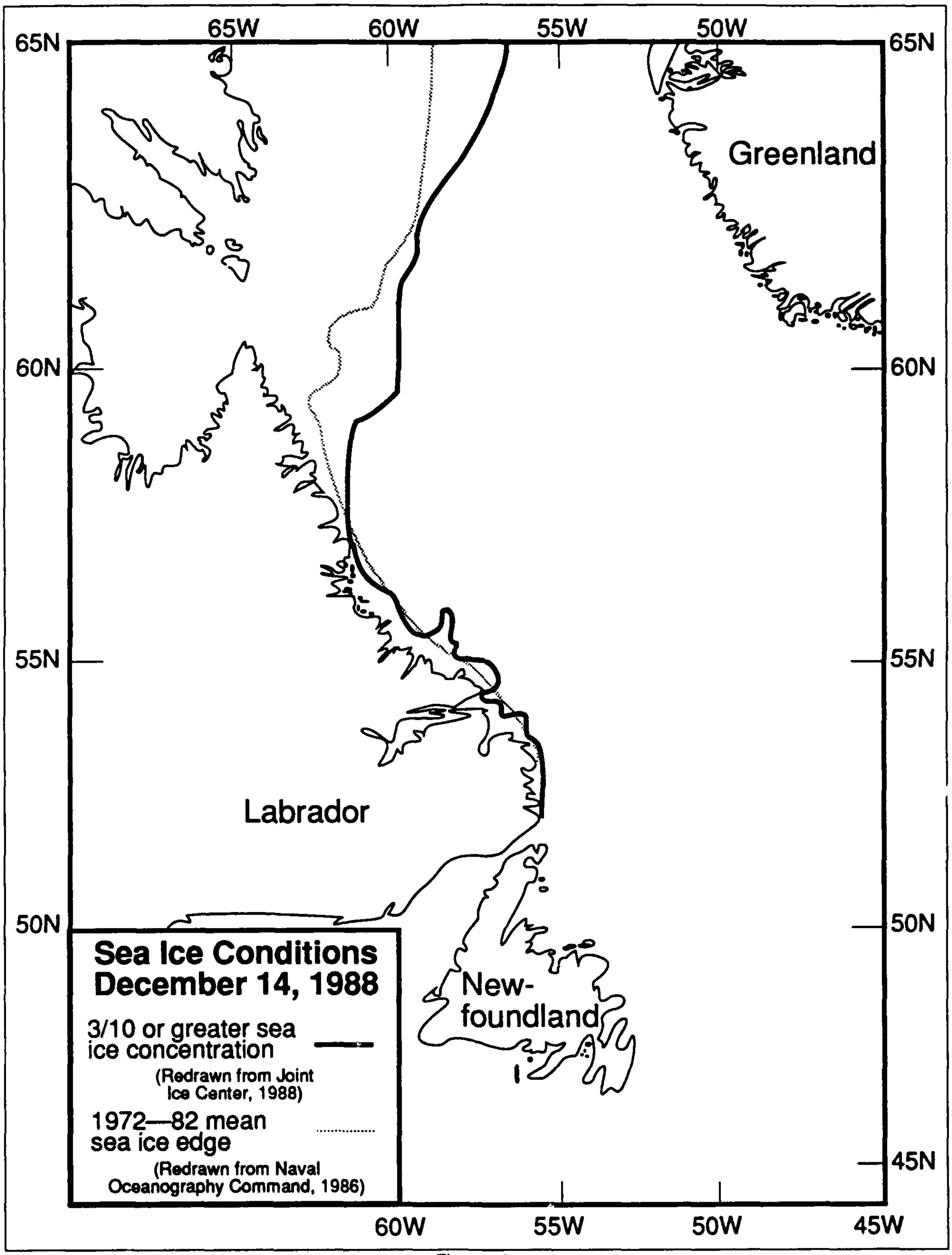

65W
60W
55W
50W
65N
60N
55N
50N
45N
60W
55W
50W
45W
Greenland
Labrador
New-
foundland
Sea Ice Conditions
December 14, 1988
3/10 or greater sea
ice concentration
(Redrawn from Joint
Ice Center, 1988)
1972—82 mean
sea ice edge
(Redrawn from Naval
Oceanography Command, 1986)

Figure 13.

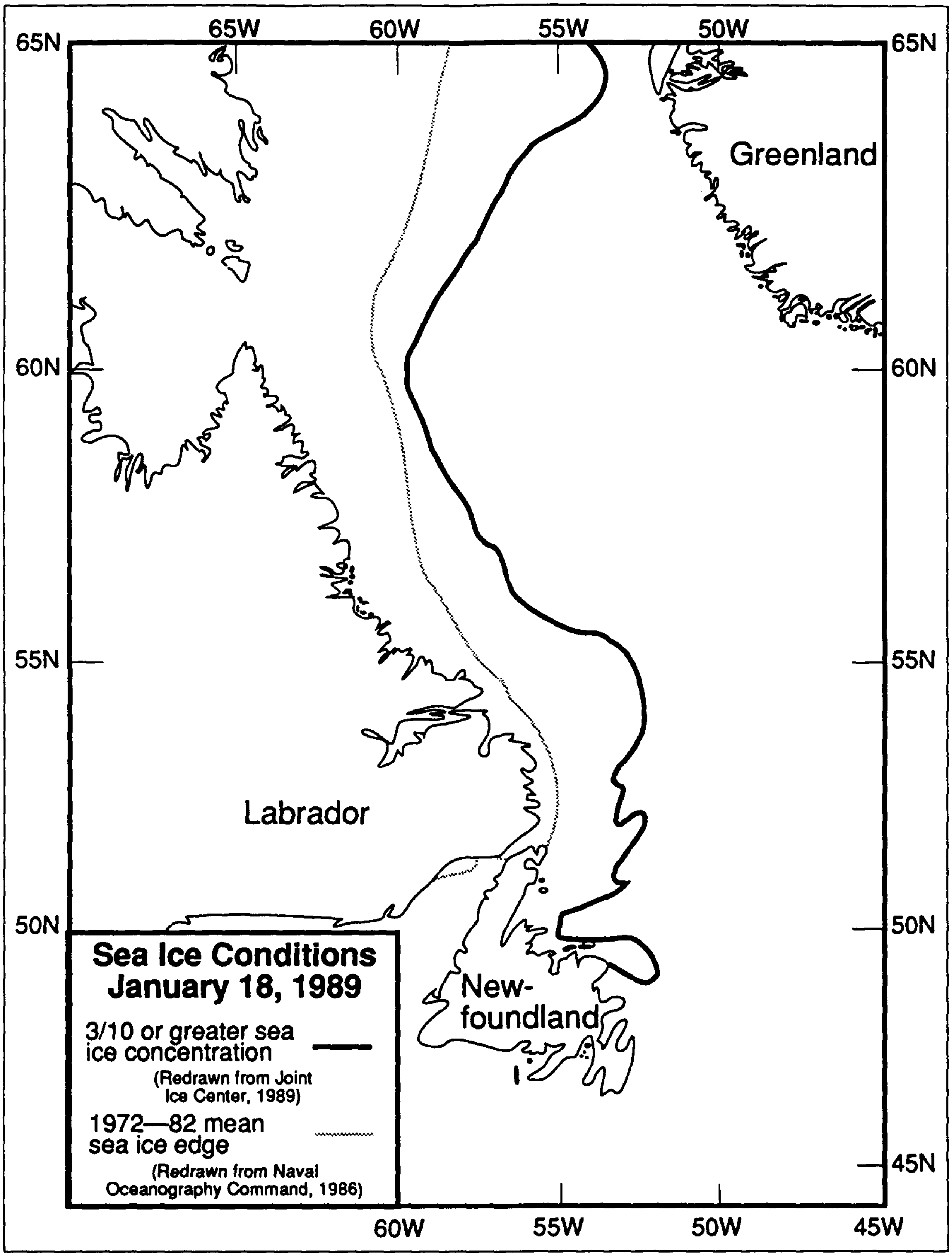

65W
60W
55W
50W
65N
60N
55N
50N
45N
Greenland
Labrador
New-
foundland
Sea Ice Conditions
January 18, 1989
3/10 or greater sea ice concentration
(Redrawn from Joint Ice Center, 1989)
1972—82 mean sea ice edge
(Redrawn from Naval Oceanography Command, 1986)
60W
55W
50W
45W

Figure 14.

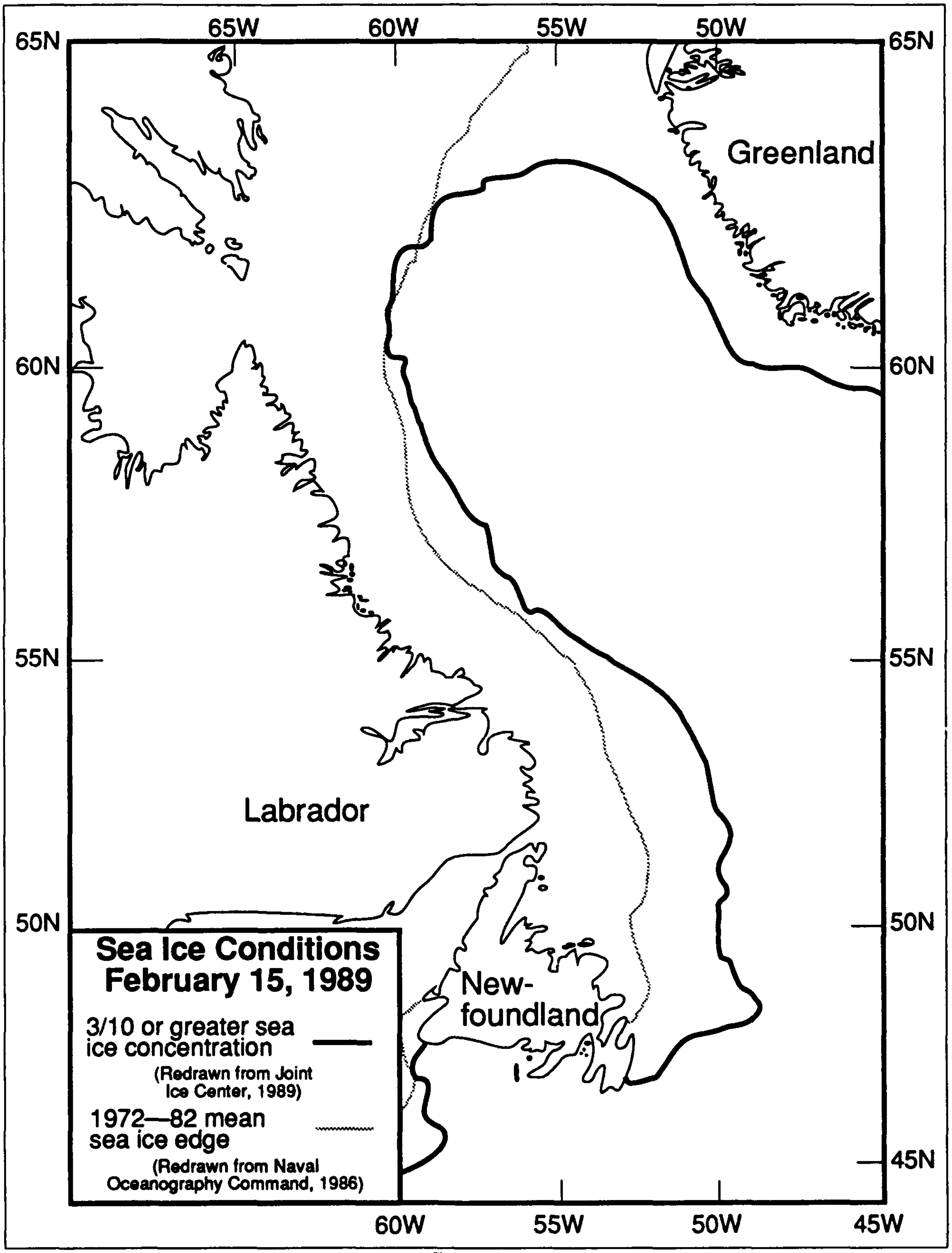
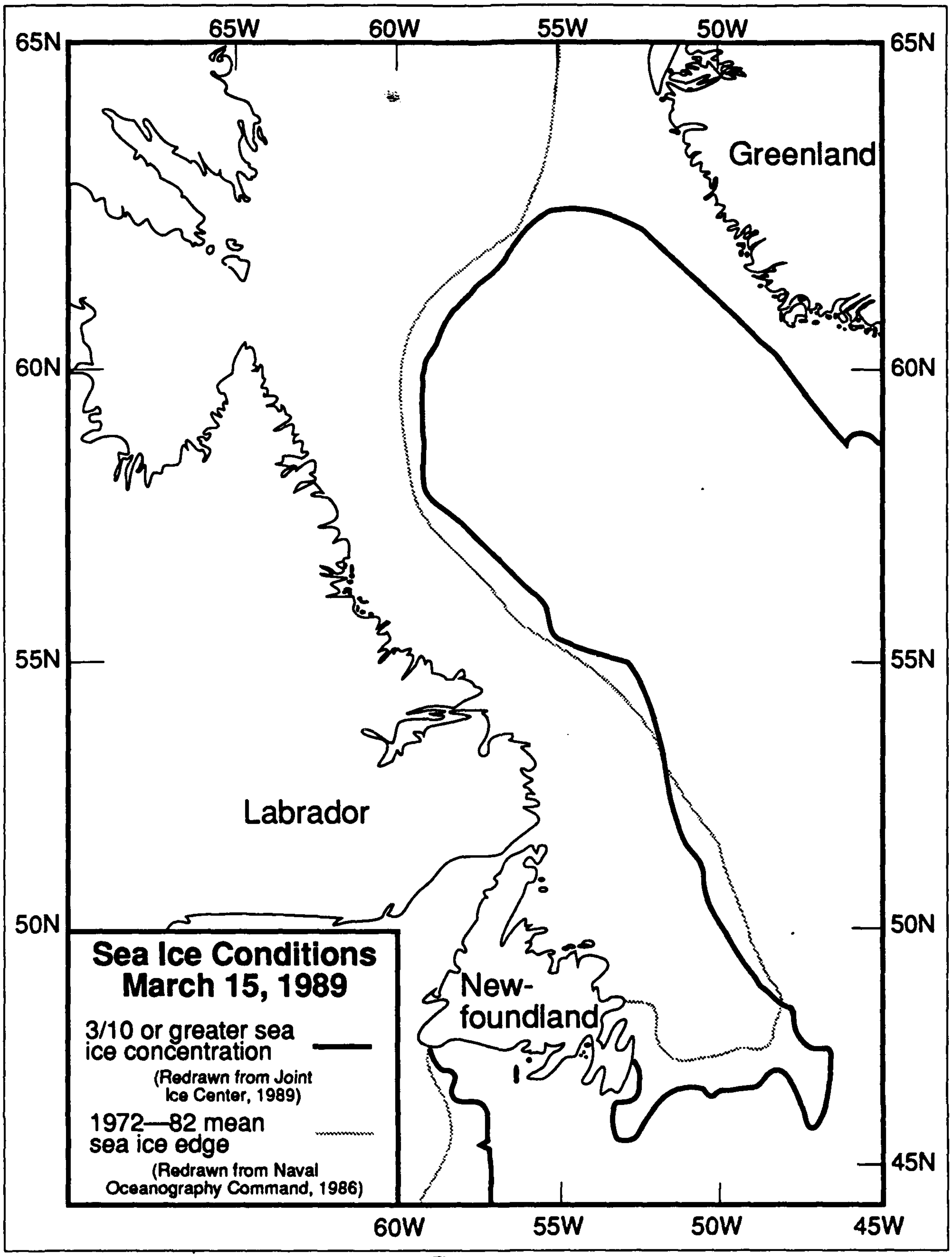

65W
60W
55W
50W
65N
65N
60N
60N
55N
55N
50N
50N
45N
60W
55W
50W
45W
Greenland
Labrador
New-
foundland
Sea Ice Conditions
February 15, 1989
3/10 or greater sea
ice concentration
(Redrawn from Joint
Ice Center, 1989)
1972—82 mean
sea ice edge
(Redrawn from Naval
Oceanography Command, 1986)

Figure 15.



65W
60W
55W
50W
65N
65N
Greenland
60N
60N
55N
55N
Labrador
50N
50N
New-
foundland
45N
60W
55W
50W
45W
Sea Ice Conditions
March 15, 1989
3/10 or greater sea
ice concentration
(Redrawn from Joint
Ice Center, 1989)
1972—82 mean
sea ice edge
(Redrawn from Naval
Oceanography Command, 1986)

Figure 16.

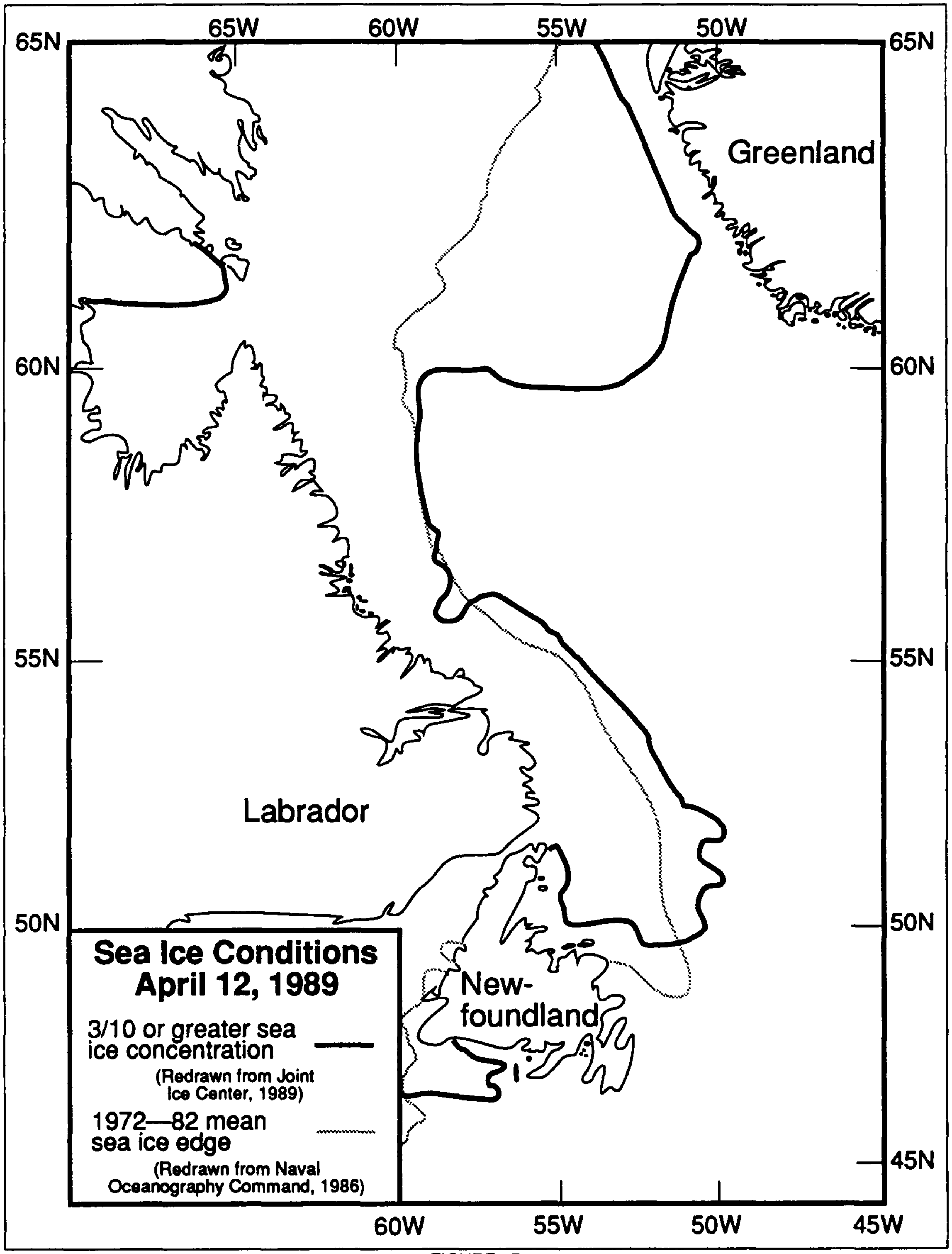

65W
60W
55W
50W
65N
65N
60N
60N
55N
55N
50N
50N
45N
60W
55W
50W
45W
Greenland
Labrador
New-
foundland
Sea Ice Conditions
April 12, 1989
3/10 or greater sea
ice concentration
(Redrawn from Joint
Ice Center, 1989)
1972—82 mean
sea ice edge
(Redrawn from Naval
Oceanography Command, 1986)

FIGURE 17.

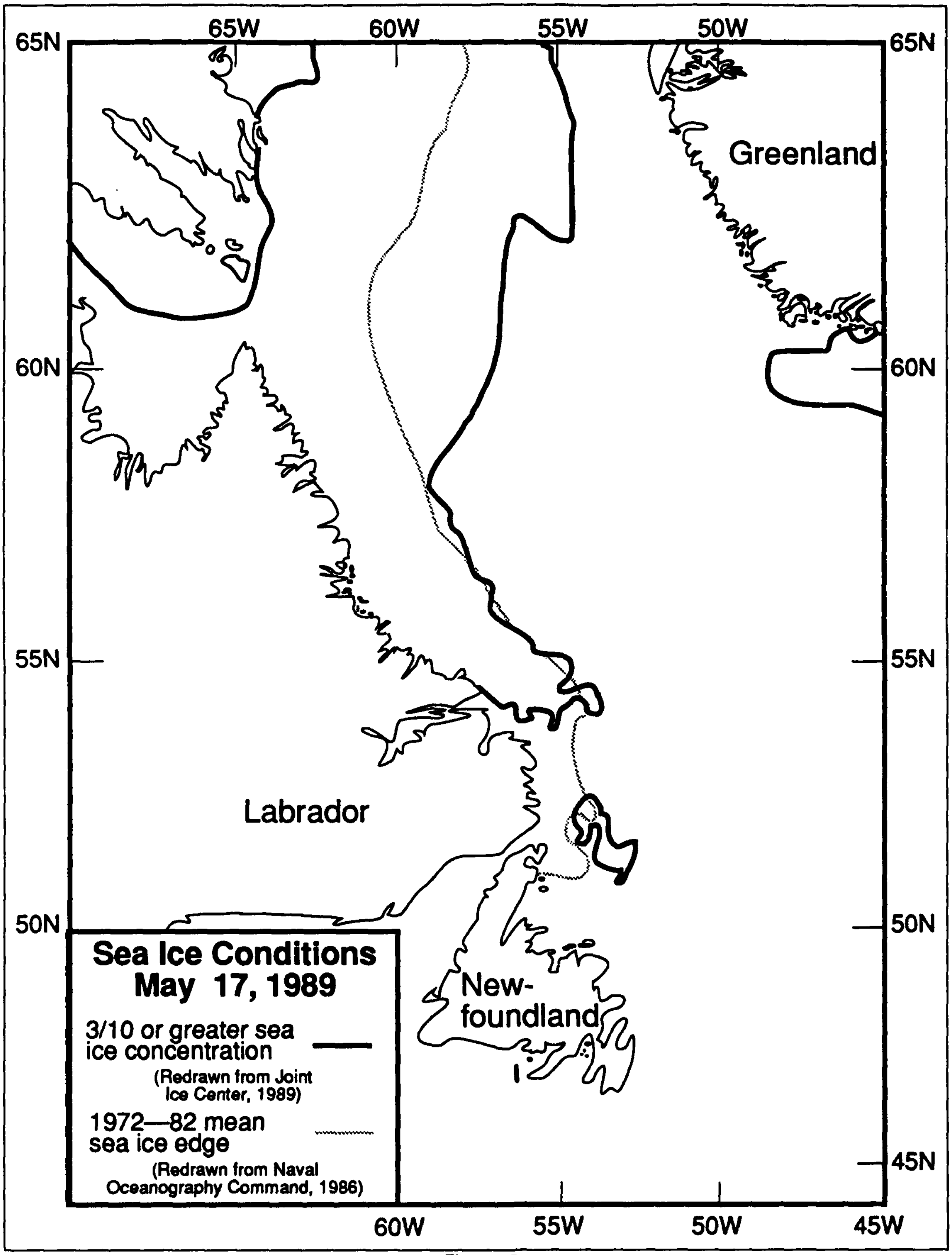
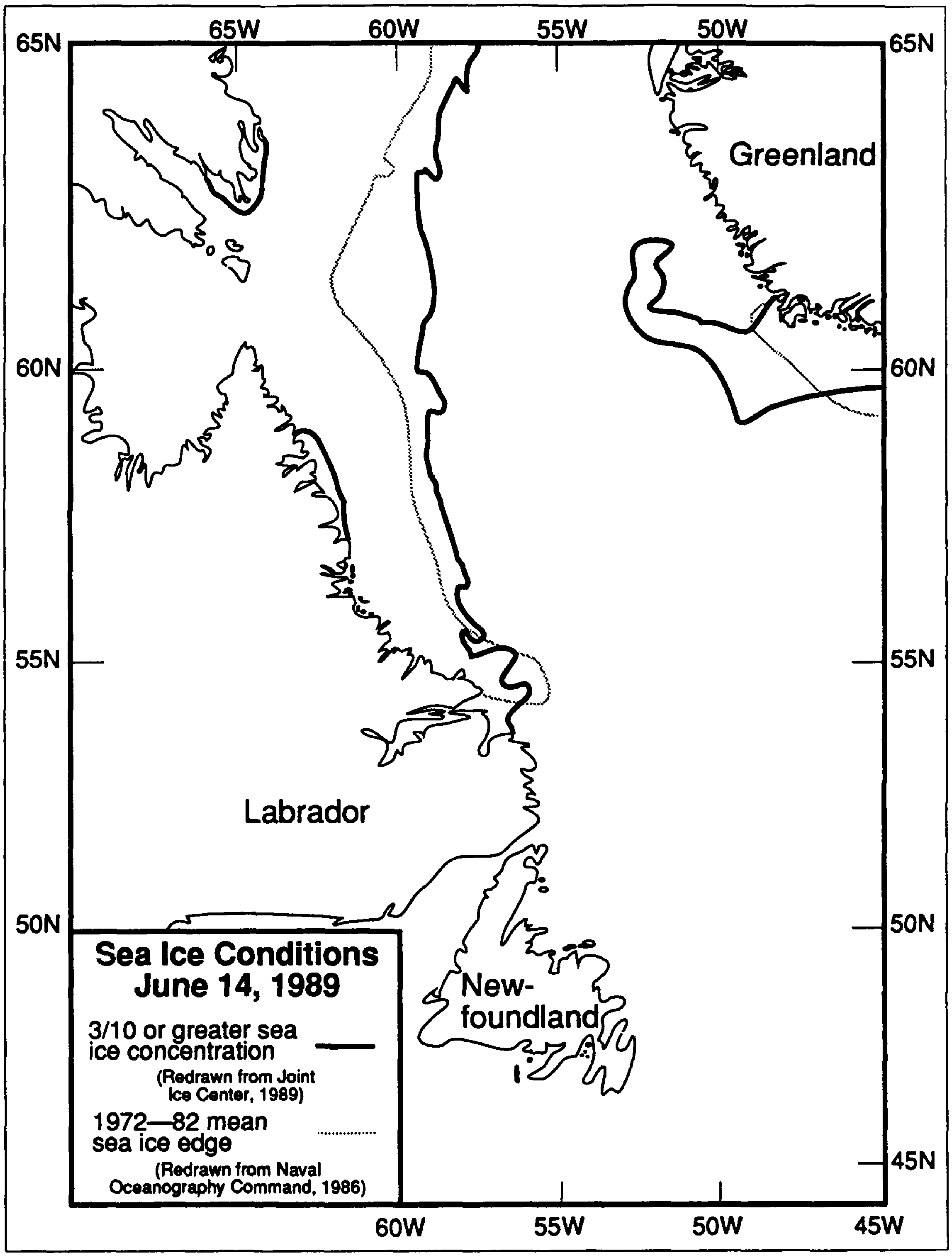

65W
60W
55W
50W
65N
60N
55N
50N
45N
60W
55W
50W
45W
Greenland
Labrador
New-
foundland
Sea Ice Conditions
May 17, 1989
3/10 or greater sea ice concentration
(Redrawn from Joint Ice Center, 1989)
1972—82 mean sea ice edge
(Redrawn from Naval Oceanography Command, 1986)

Figure 18.



65W
60W
55W
50W
65N
65N
Greenland
60N
60N
55N
55N
Labrador
50N
50N
New-
foundland
45N
60W
55W
50W
45W
Sea Ice Conditions
June 14, 1989
3/10 or greater sea
ice concentration
(Redrawn from Joint
Ice Center, 1989)
1972—82 mean
sea ice edge
(Redrawn from Naval
Oceanography Command, 1986)

Figure 19.

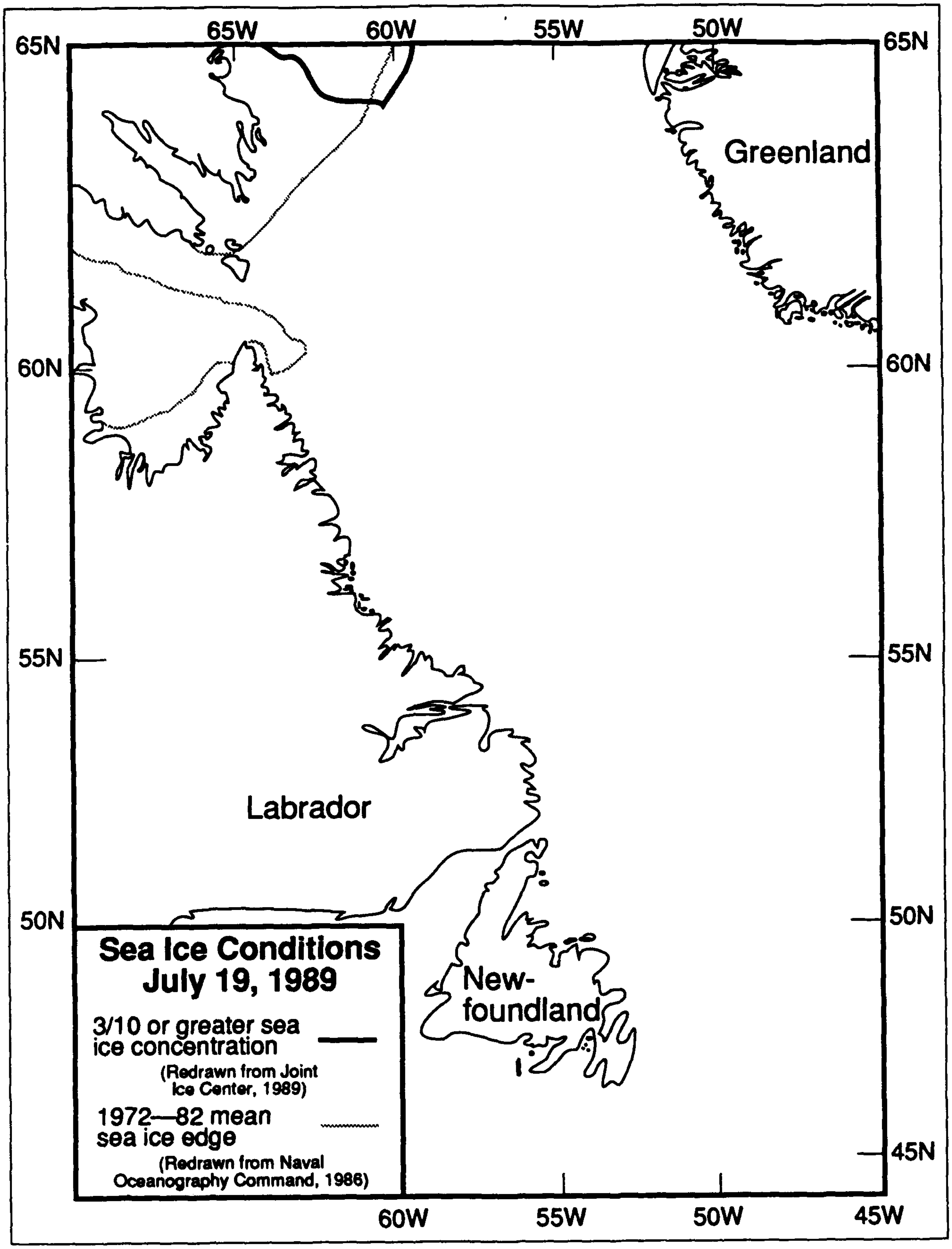

65W
60W
55W
50W
65N
65N
Greenland
60N
60N
55N
55N
Labrador
50N
50N
Sea Ice Conditions
July 19, 1989
3/10 or greater sea ice concentration
(Redrawn from Joint Ice Center, 1989)
1972—82 mean sea ice edge
(Redrawn from Naval Oceanography Command, 1986)
New-foundland
45N
60W
55W
50W
45W

Figure 20.

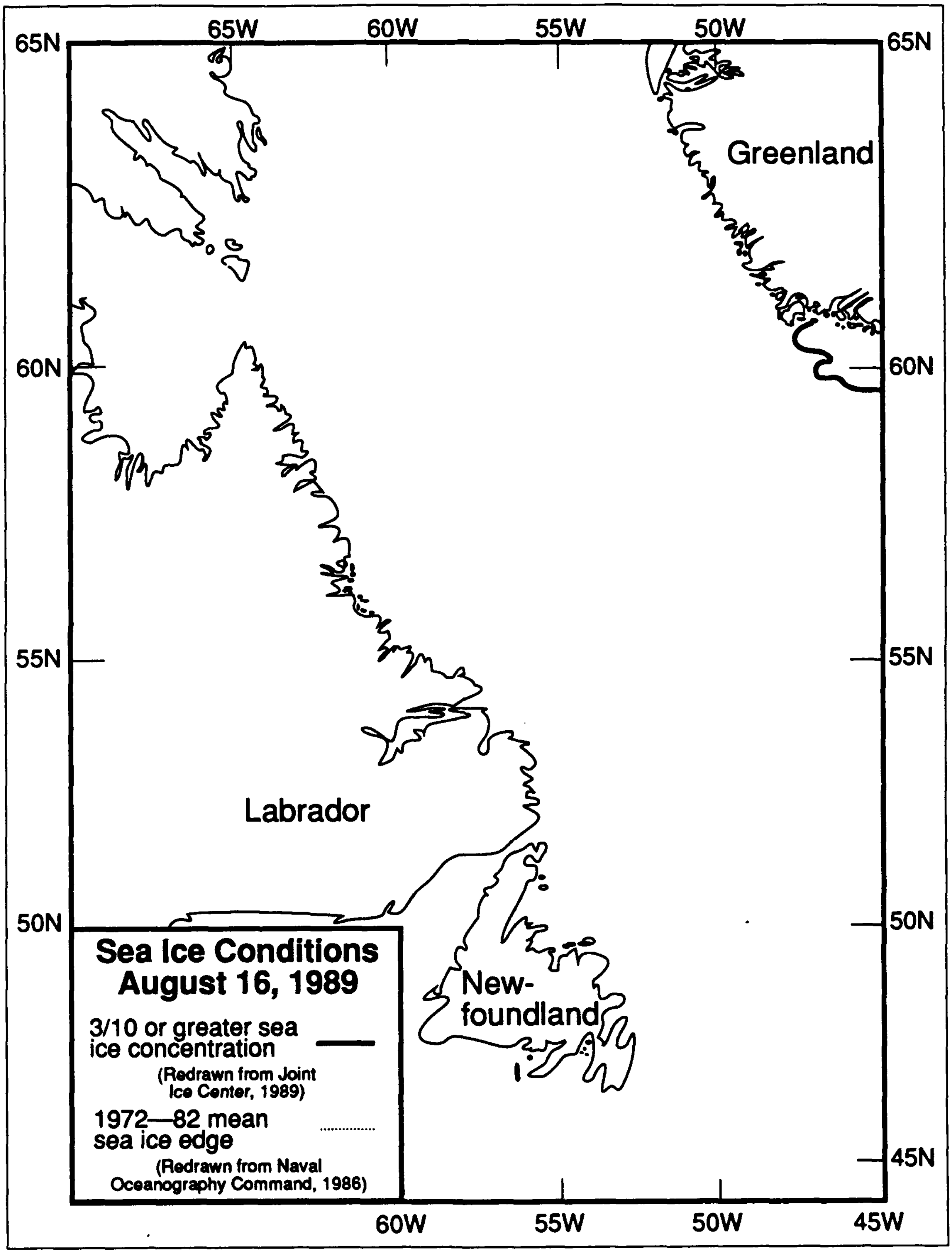

65W
60W
55W
50W
65N
65N
60N
60N
55N
55N
50N
50N
45N
60W
55W
50W
45W
Greenland
Labrador
New-
foundland
Sea Ice Conditions
August 16, 1989
3/10 or greater sea
ice concentration
(Redrawn from Joint
Ice Center, 1989)
1972—82 mean
sea ice edge
(Redrawn from Naval
Oceanography Command, 1986)

Figure 21.

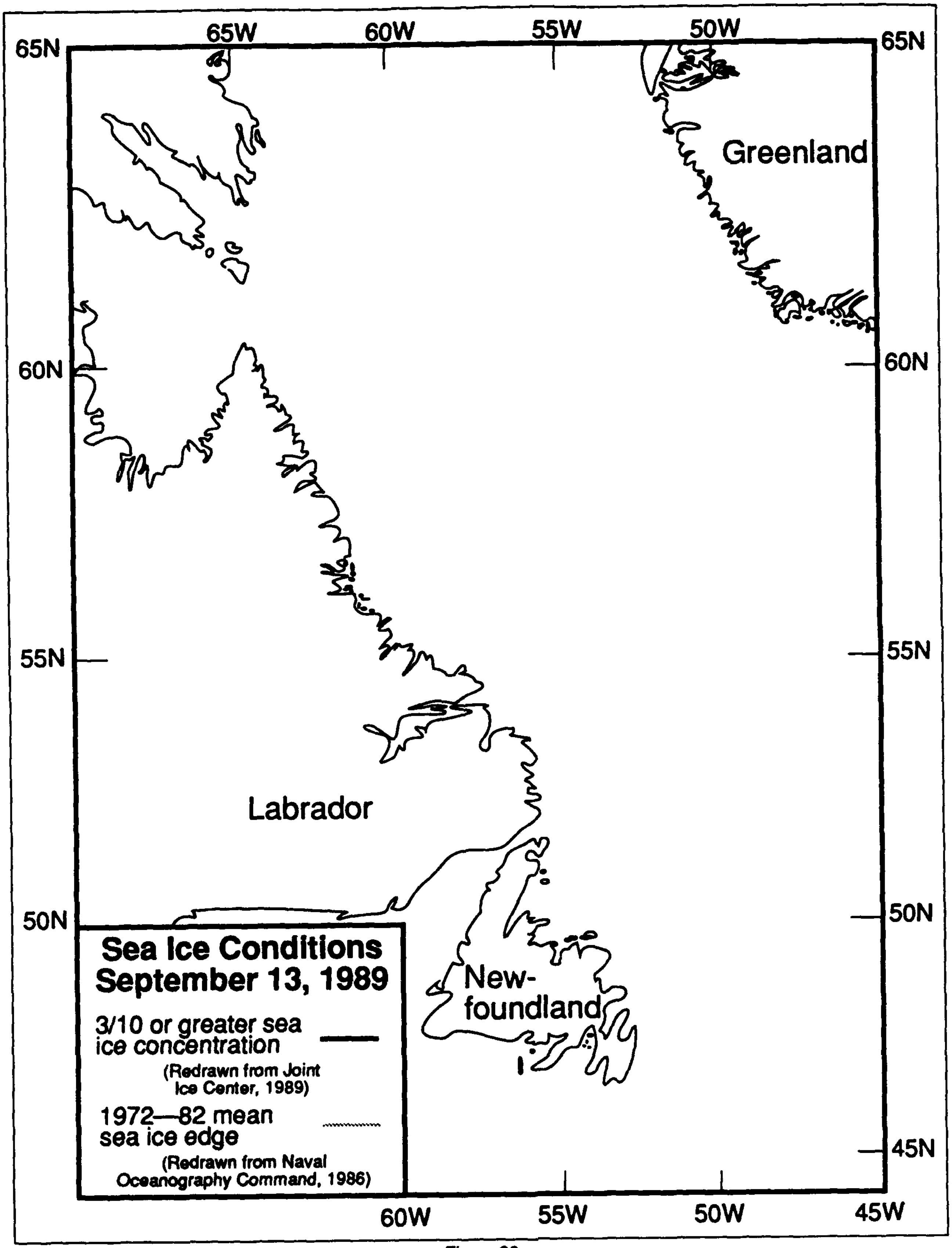
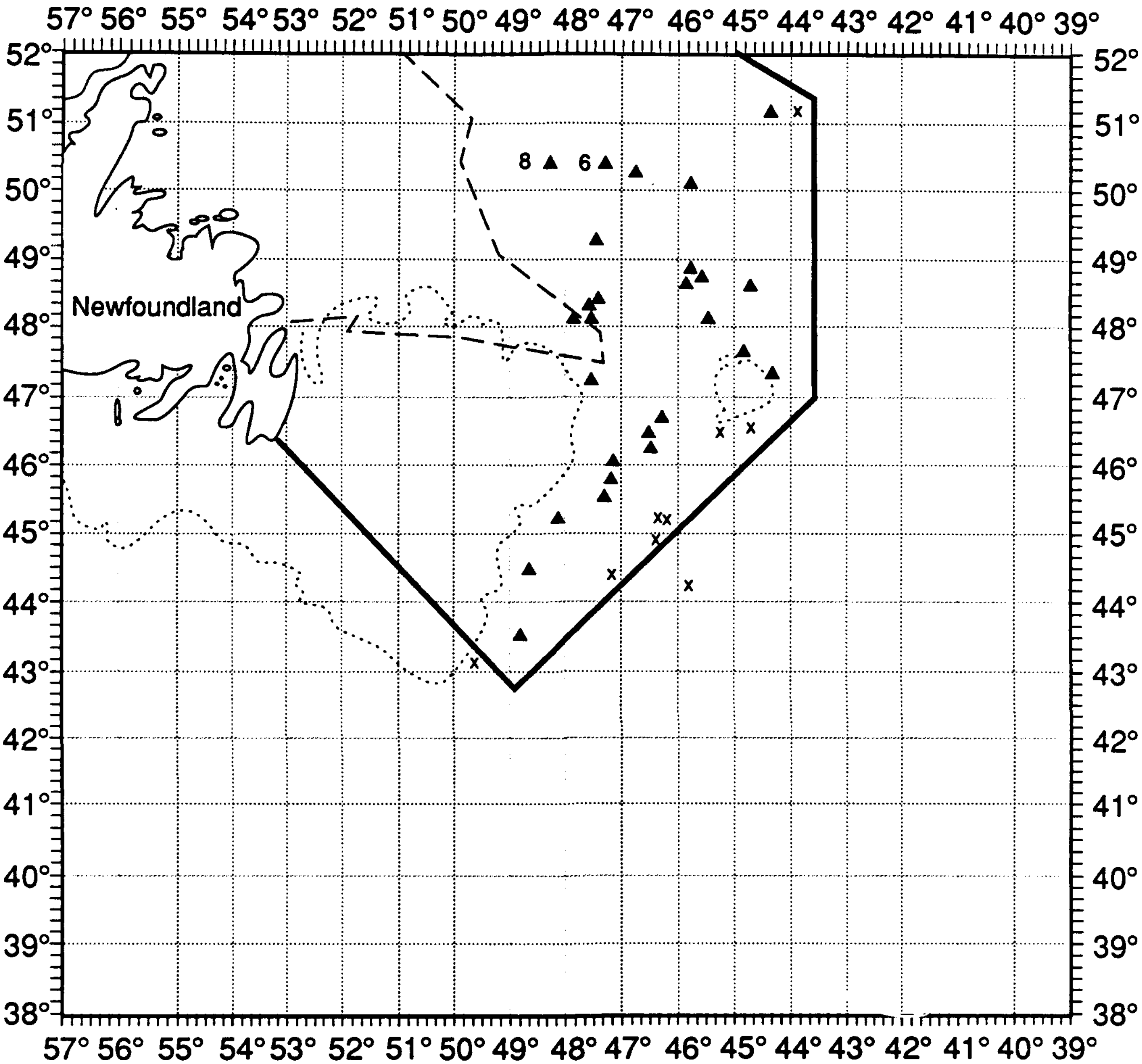

65W
60W
55W
50W
65N
65N
Greenland
60N
60N
55N
55N
Labrador
50N
50N
New-
foundland
45N
60W
55W
50W
45W
Sea Ice Conditions
September 13, 1989
3/10 or greater sea
ice concentration
(Redrawn from Joint
Ice Center, 1989)
1972—82 mean
sea ice edge
(Redrawn from Naval
Oceanography Command, 1986)

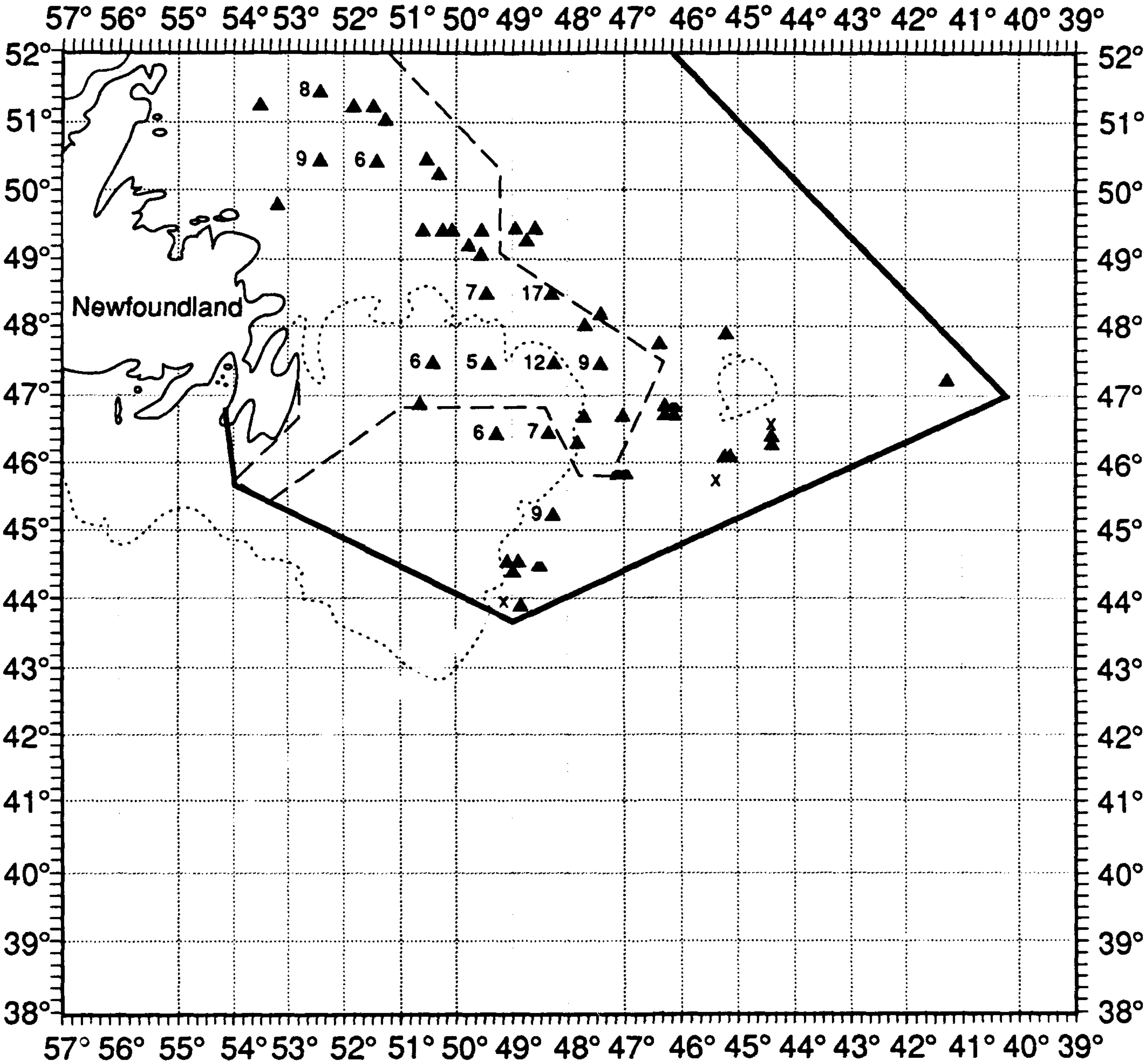
Figure 22.



N ▲ Berg
N ▲ Growler
N X Radar Target / Contact
Where "N" Is The Number Of Designated Targets In A One Degree Rectangle

——— Estimated limit of all known ice
– – – – Estimated limit of sea ice
.... 200 Meter bathymetric curve

Figure 23. Graphic Depiction Of International Ice Patrol Ice Plot For 1200 GMT 01MAR89 Based On Observed And Forecast Conditions



N ▲ Berg

N ▲ Growler

N X Radar Target / Contact

Where "N" Is The Number Of Designated Targets In A One Degree Rectangle

——— Estimated limit of all known ice

– – – – Estimated limit of sea ice

·········· 200 Meter bathymetric curve

Figure 24. Graphic Depiction Of International Ice Patrol Ice Plot For 1200 GMT 15MAR89 Based On Observed And Forecast Conditions

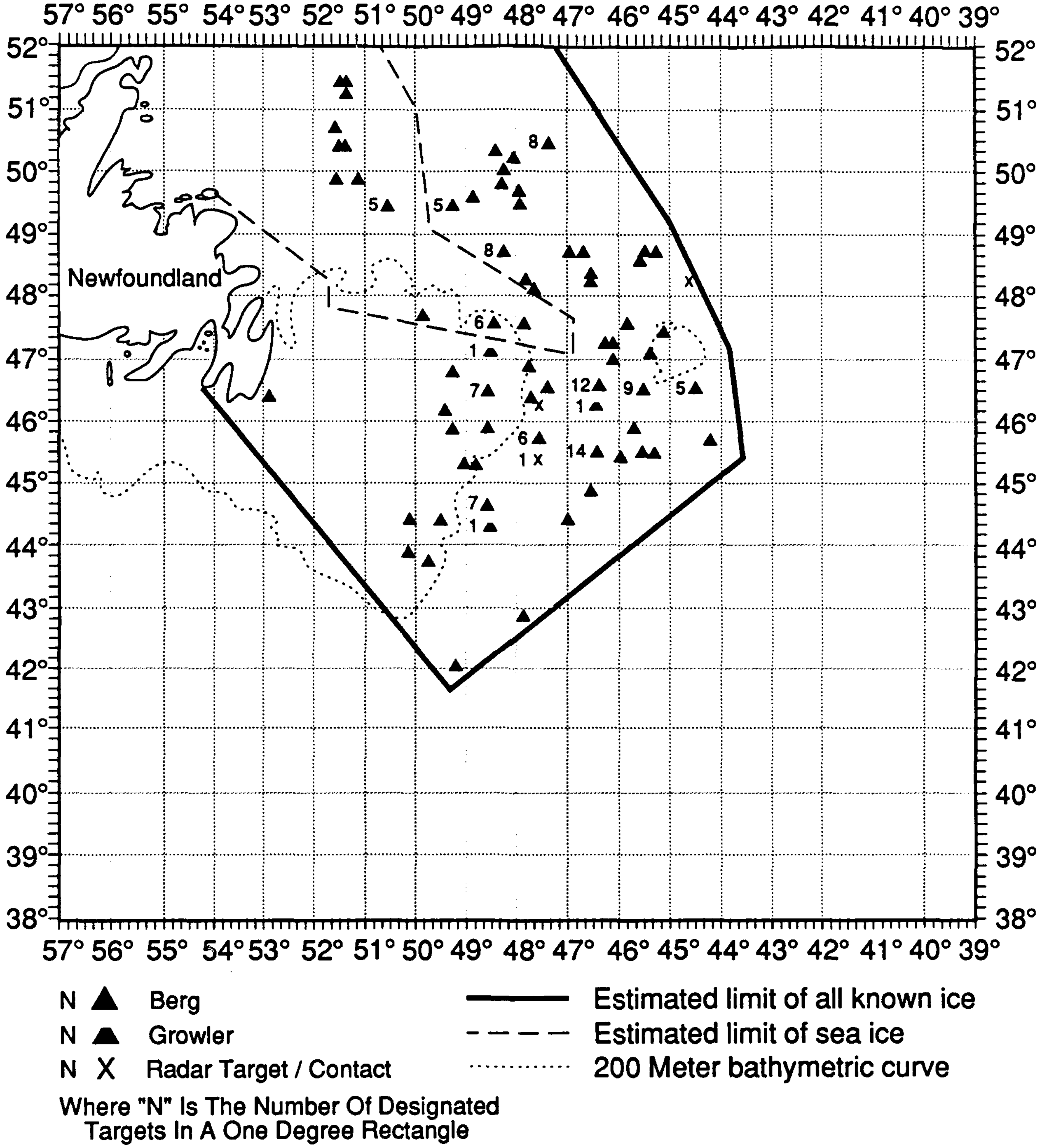
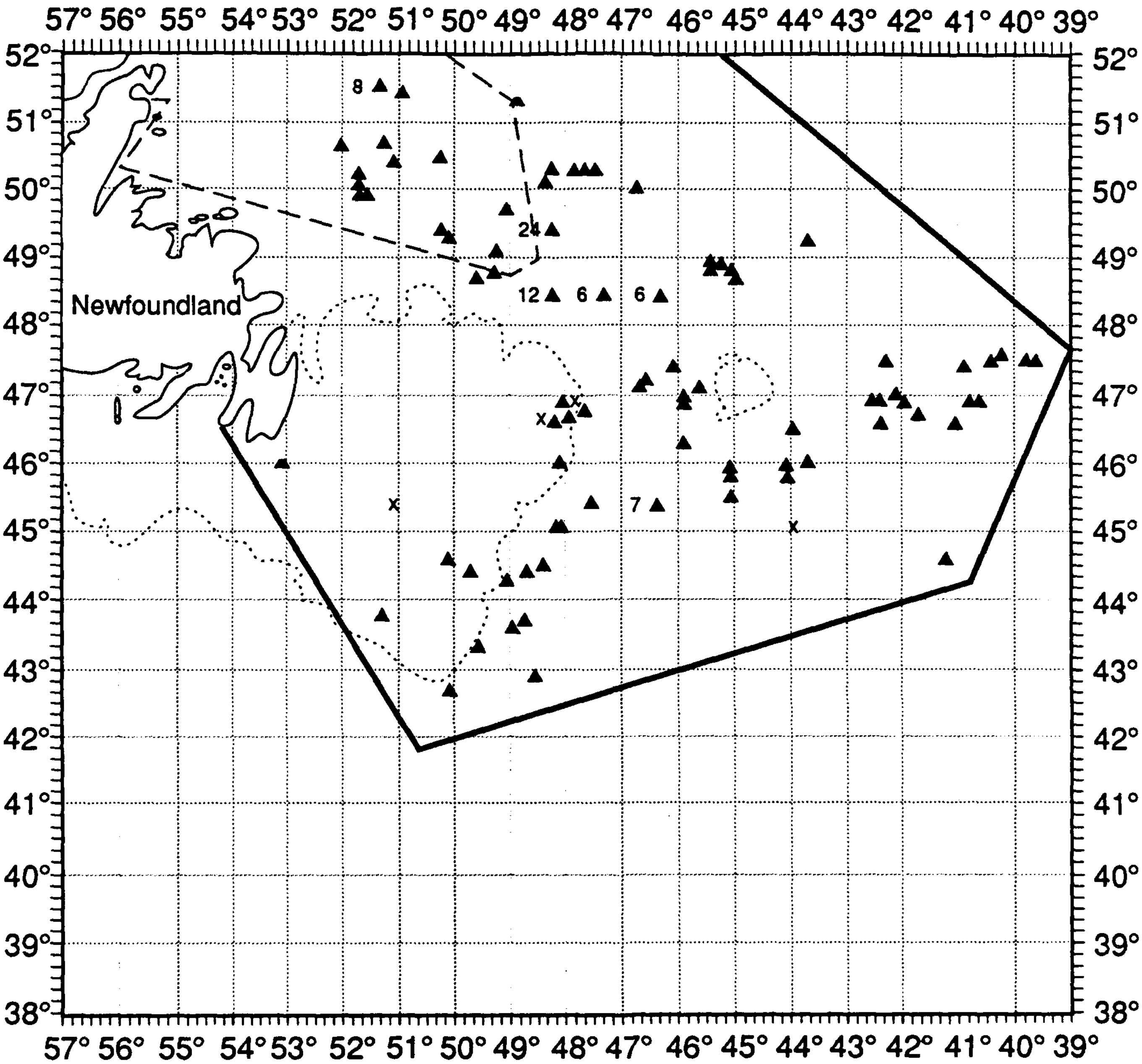


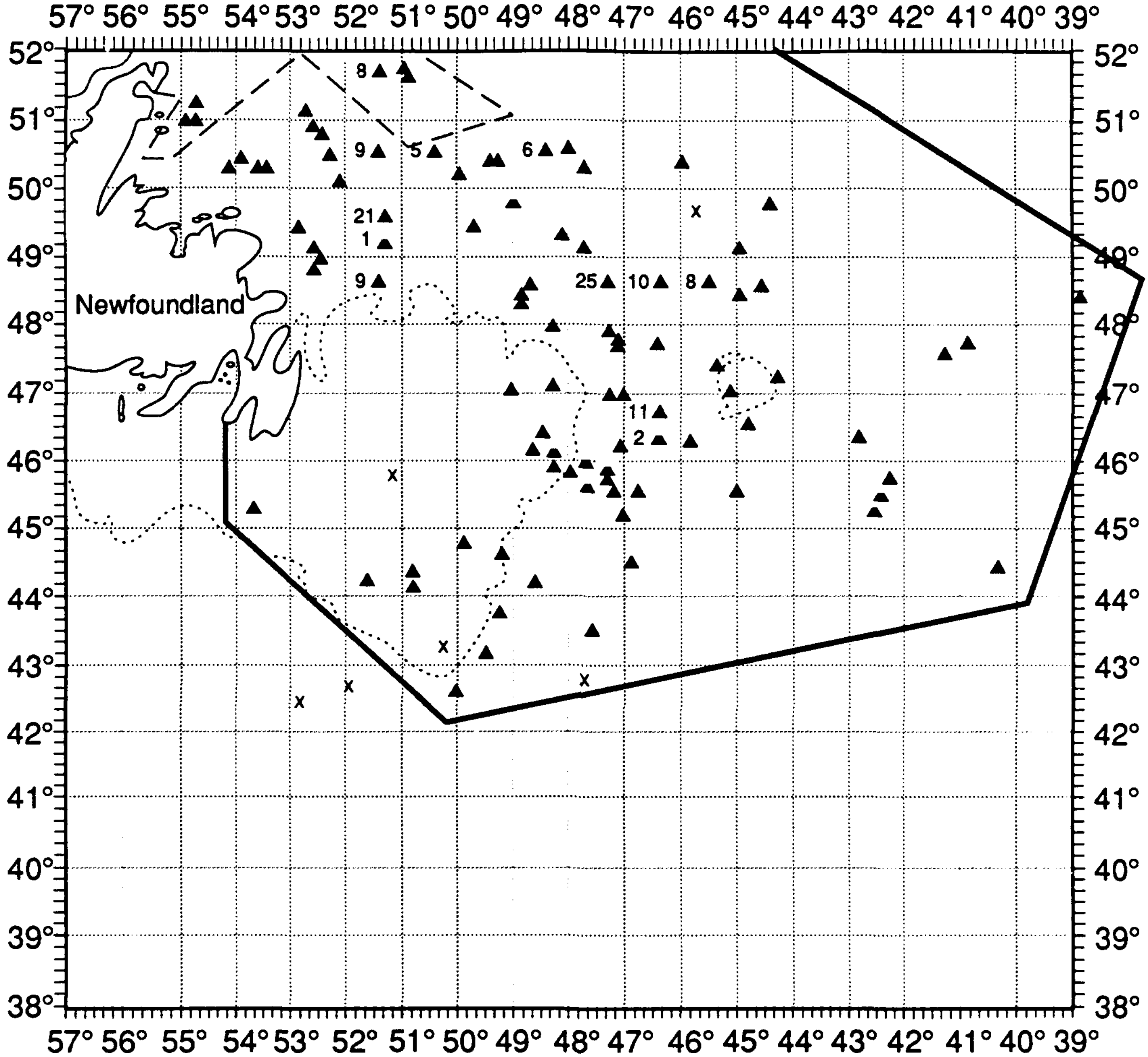
Figure 25. Graphic Depiction Of International Ice Patrol Ice Plot
For 1200 GMT 30MAR89 Based On Observed And Forecast Conditions



N ▲ Berg
N ▲ Growler
N X Radar Target / Contact
Where "N" Is The Number Of Designated Targets In A One Degree Rectangle

——— Estimated limit of all known ice
– – – – Estimated limit of sea ice
············ 200 Meter bathymetric curve

Figure 26. Graphic Depiction Of International Ice Patrol Ice Plot For 1200 GMT 15APR89 Based On Observed And Forecast Conditions



N ▲ Berg
N ▲ Growler
N X Radar Target / Contact
Where "N" Is The Number Of Designated Targets In A One Degree Rectangle

——— Estimated limit of all known ice
– – – – Estimated limit of sea ice
·········· 200 Meter bathymetric curve

Figure 27. Graphic Depiction Of International Ice Patrol Ice Plot For 1200 GMT 30APR89 Based On Observed And Forecast Conditions

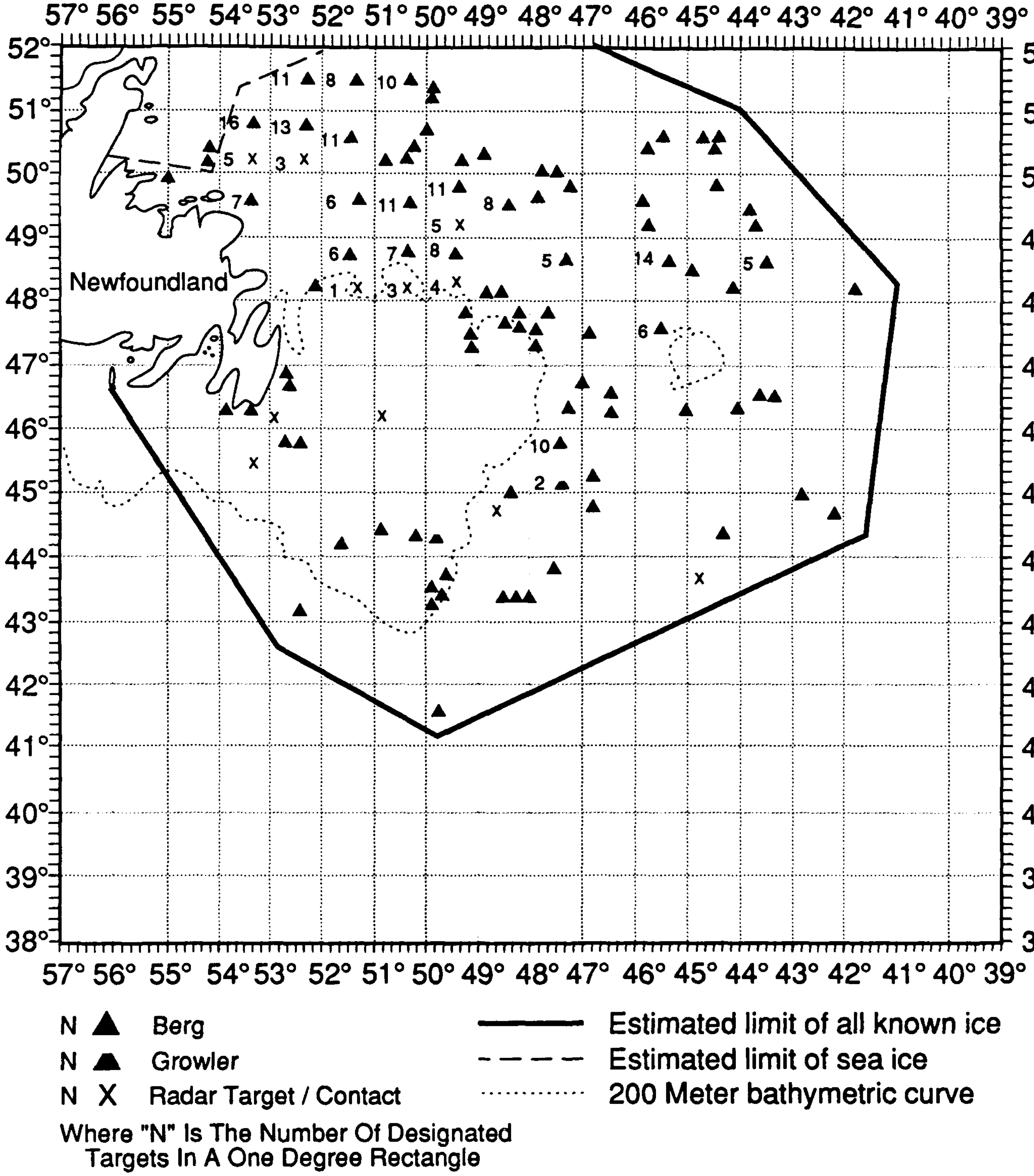


Figure 28. Graphic Depiction Of International Ice Patrol Ice Plot For 1200 GMT 15MAY89 Based On Observed And Forecast Conditions

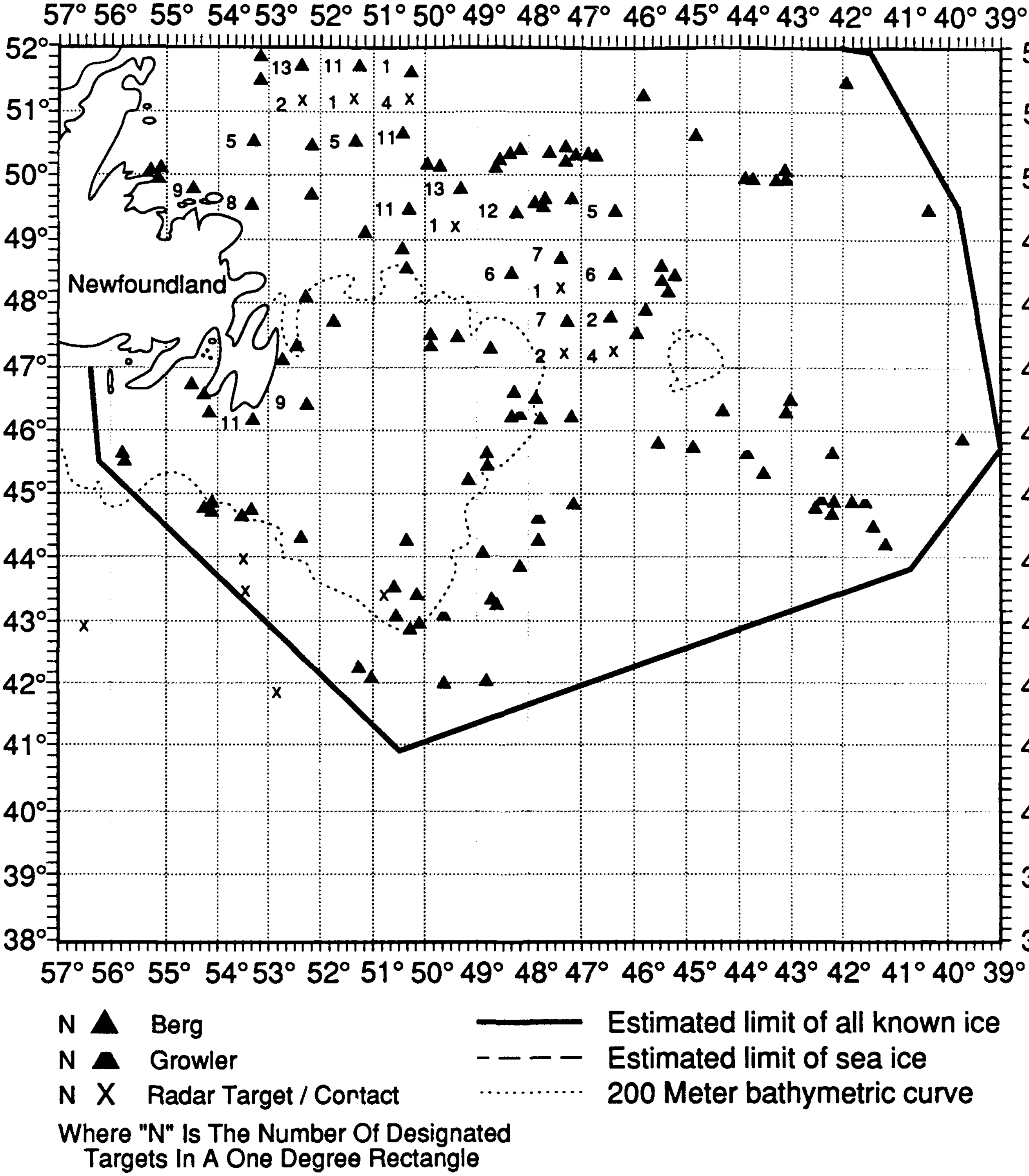


Figure 29. Graphic Depiction Of International Ice Patrol Ice Plot For 1200 GMT 30MAY89 Based On Observed And Forecast Conditions

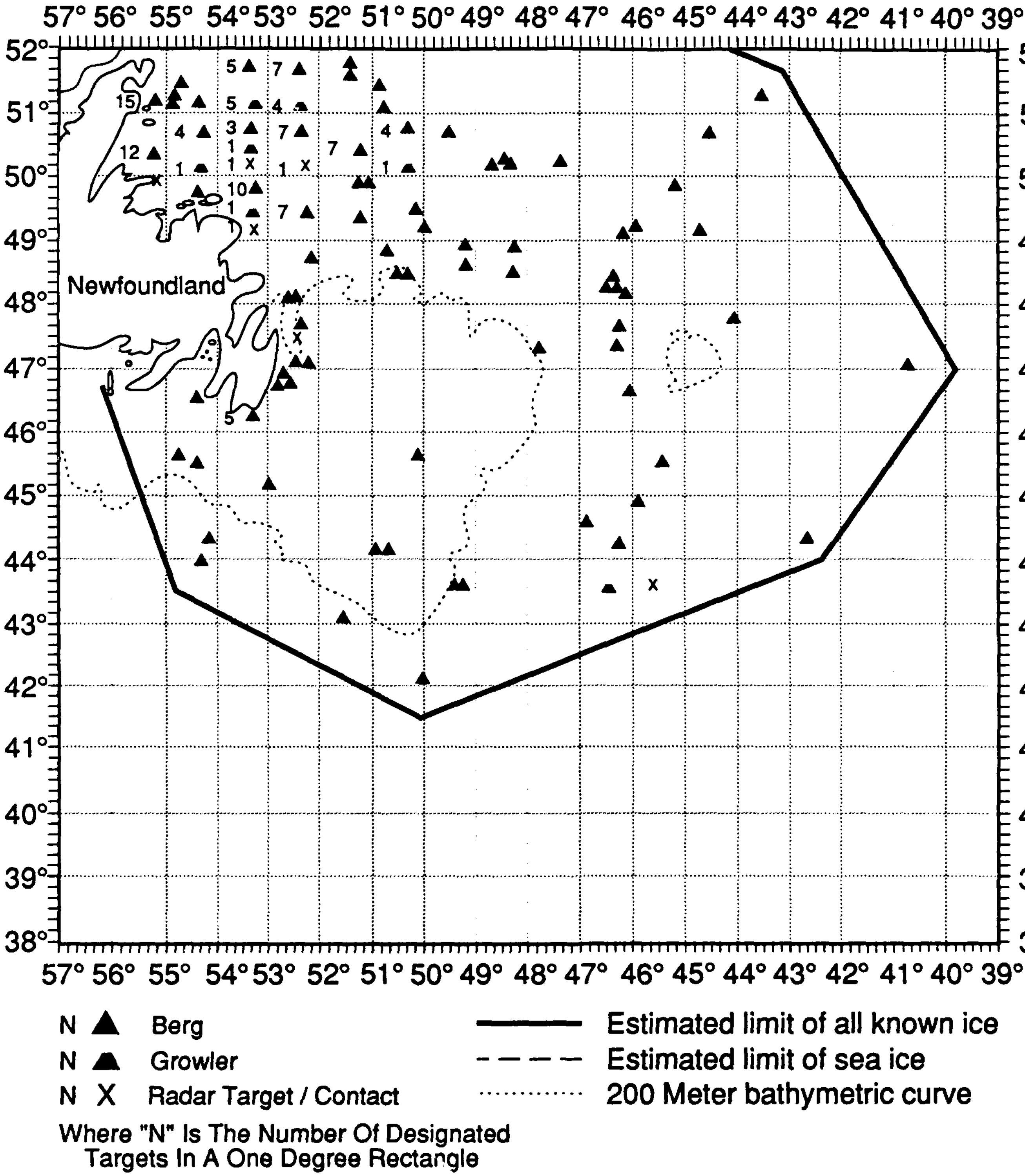


Figure 30. Graphic Depiction Of International Ice Patrol Ice Plot
For 1200 GMT 15JUN89 Based On Observed And Forecast Conditions

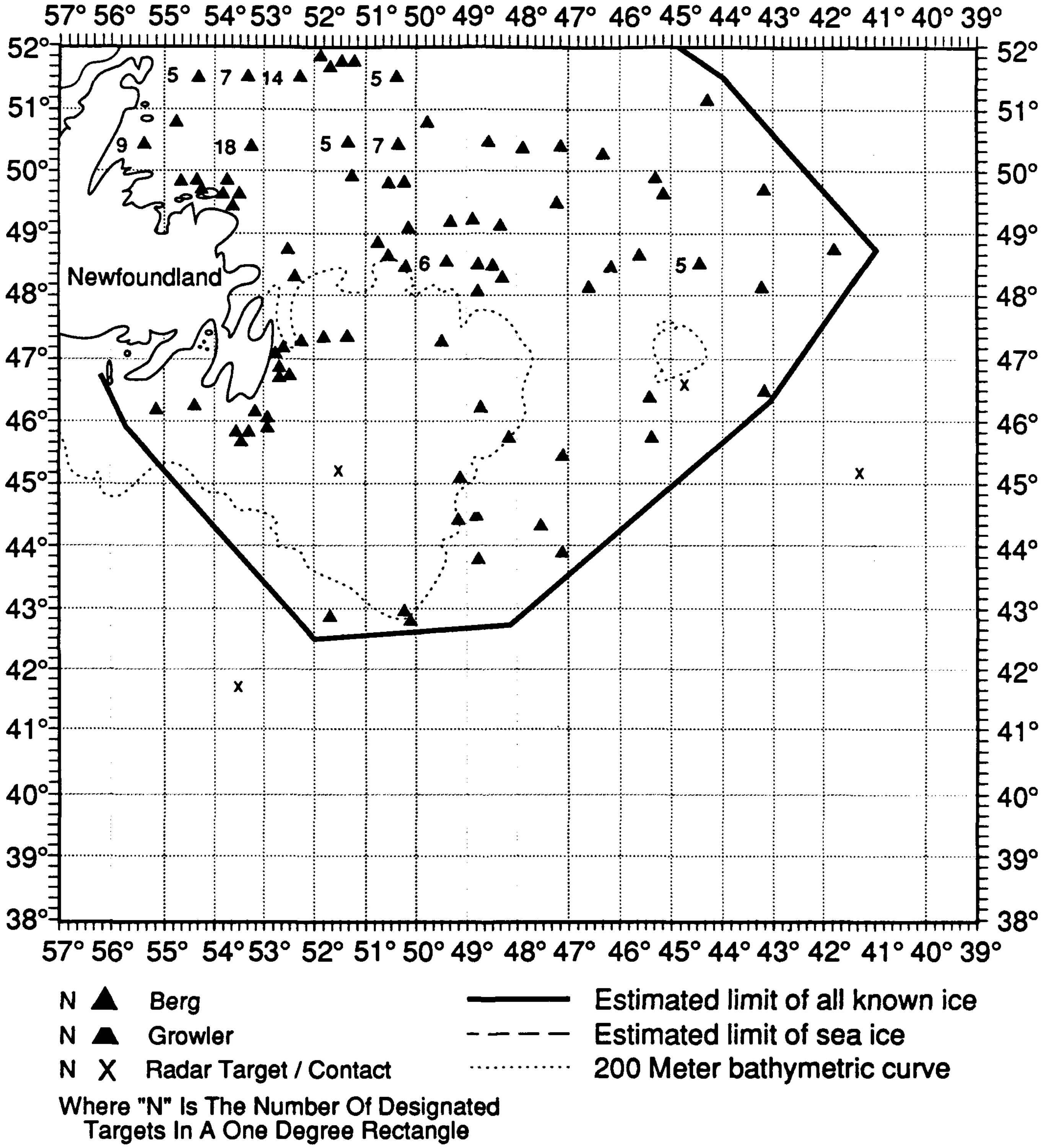
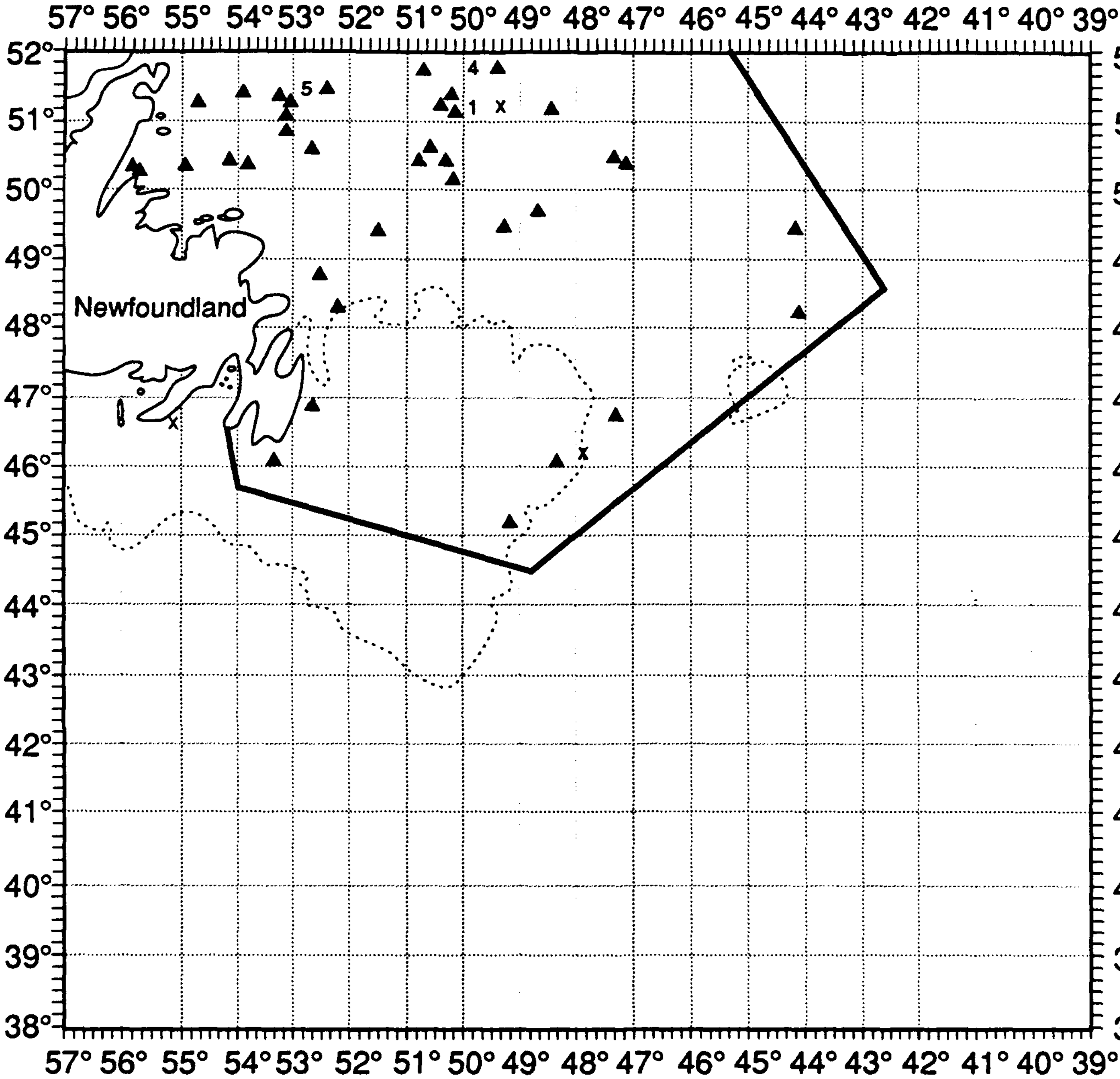


Figure 31. Graphic Depiction Of International Ice Patrol Ice Plot
For 1200 GMT 30JUN89 Based On Observed And Forecast Conditions



N ▲ Berg

N ▲ Growler

N X Radar Target / Contact

Where "N" Is The Number Of Designated Targets In A One Degree Rectangle

——— Estimated limit of all known ice

– – – – Estimated limit of sea ice

··········· 200 Meter bathymetric curve

Figure 32. Graphic Depiction Of International Ice Patrol Ice Plot For 1200 GMT 15JUL89 Based On Observed And Forecast Conditions

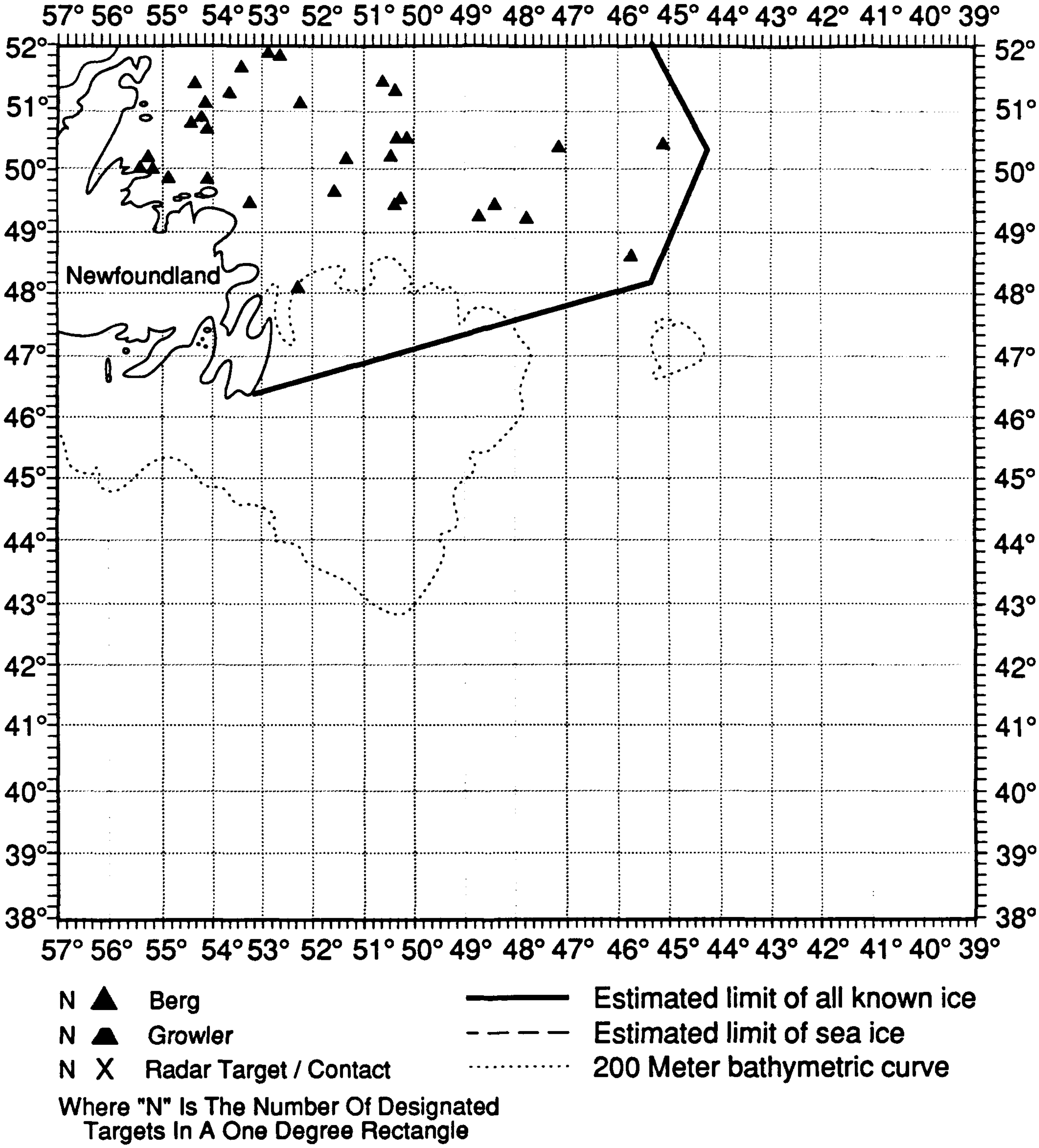


Figure 33. Graphic Depiction Of International Ice Patrol Ice Plot
For 1200 GMT 28JUL89 Based On Observed And Forecast Conditions

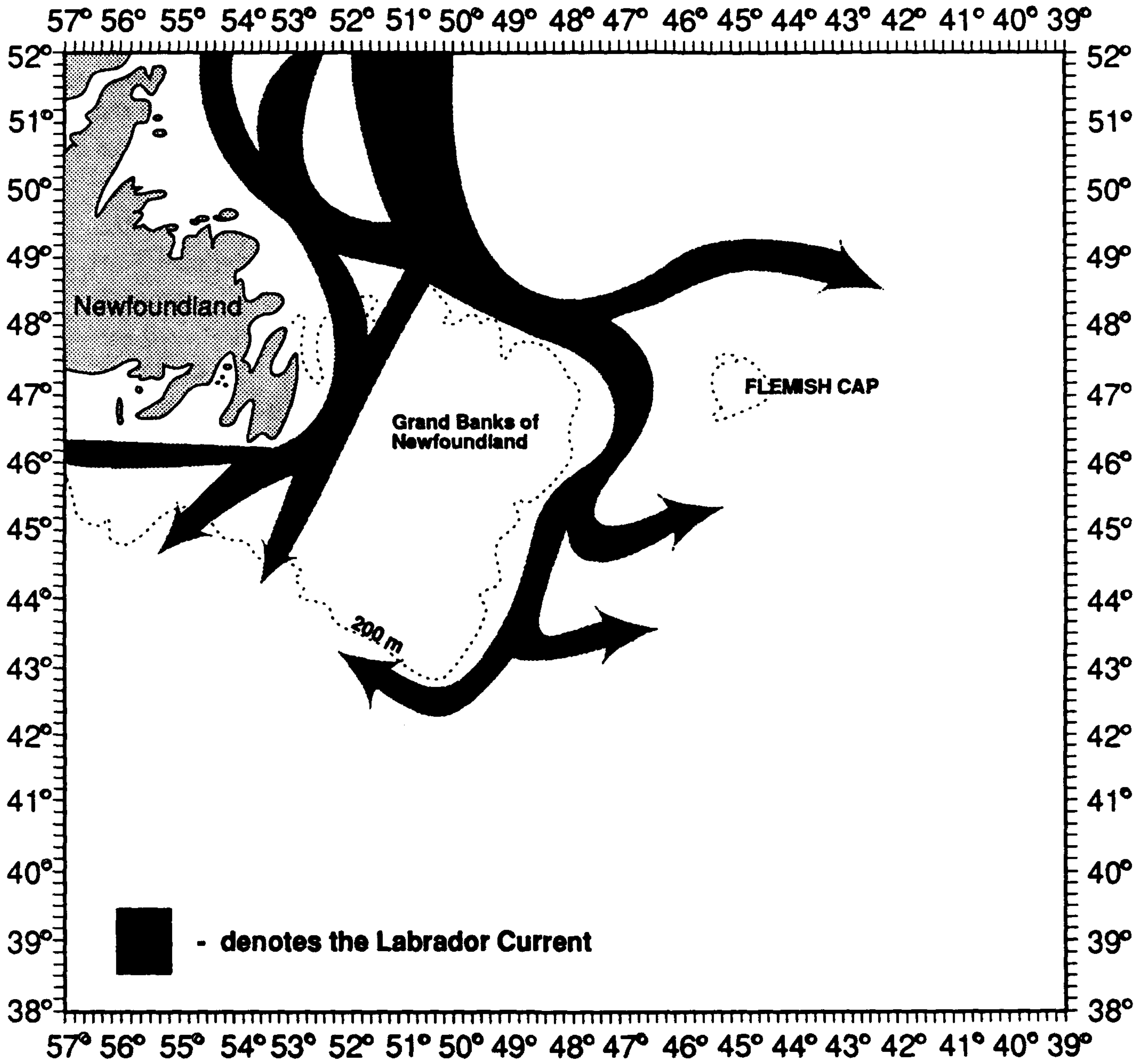


Figure 34: This figure depicts the Labrador Current, the main mechanism for transporting icebergs South to the Grand Banks.

DISCUSSION OF ICE AND ENVIRONMENTAL CONDITIONS

Since more than 10,000 icebergs are calved by Greenland's glaciers into the Baffin Bay each year (Knutson and Neill, 1978), annual fluctuations in the generation of Arctic icebergs are not a significant factor influencing the number of icebergs passing south of 48° N annually. The factors that determine the number of icebergs passing south of 48° N each season are the supply of icebergs available to drift south onto the Grand Banks, those factors affecting iceberg transport (currents, winds, and sea ice), and those affecting the rate of iceberg deterioration (wave action, sea surface temperature, and sea ice).

Sea ice acts to impede the transport of icebergs by winds and currents and also protects icebergs from wave action, the major agent of iceberg deterioration. Although it slows current and wind transport of icebergs, sea ice is itself an active medium, continually moving toward the ice edge where melt occurs. Therefore, icebergs in sea ice will eventually reach open water unless grounded. The melting of sea ice is affected by snow cover (which slows melting) and air and sea water temperatures. As sea ice melt accelerates in the spring and early summer, trapped icebergs are rapidly released and then become subject to normal transport and deterioration.

The Labrador Current, aided by northwesterly winds in winter, is the main mechanism transporting icebergs south to the Grand Banks. In addition to transporting icebergs south, the relatively cold waters of the Labrador Current keep the deterioration of icebergs in transit to a minimum.

During December, 1988, a more intense than normal low pressure to the south of Greenland resulted in stronger than normal northwesterly winds over eastern Canadian waters. This combined with below normal temperatures to produce an early freeze-up. During January, February, and March, temperatures continued to be below normal for Newfoundland and Labrador, and freezing degree accumulations were higher than normal. Therefore, the growth and spread of ice were ahead of normal, and mean pack ice was thicker and extended further south than normal for these three months. More westerly than normal winds during February and March also caused the ice to extend further east than normal off the Newfoundland and Labrador coasts.

Because sea ice conditions were above normal for the first part of the 1989 season and the sea ice edge was farther south than normal, icebergs were protected from deterioration longer and released farther south than normal. As expected, this resulted in a fairly large number of icebergs south of 48°N during February and March, and the season opened on 1 March 1989.

Although sea ice conditions were greater than normal during the first three months of the year, 1989 was only an average iceberg year. Slightly warmer than normal temperatures and a southwesterly wind during the first part of May caused the sea ice to retreat faster than normal along the Labrador Coast at the end of May. Slightly warmer than normal temperatures persisted throughout the remainder of the ice season as well.

In summary, ice conditions during the first few months of 1989 were more severe than normal, but those toward the end of the ice season were less severe, resulting in an average iceberg year.

References

Alfultis, M.A., Iceberg Populations South of 48 N Since 1900, Report of the International Ice Patrol in the North Atlantic, CG-188-42.

Anderson, I. Iceberg Deterioration Model, Report of the International Ice Patrol in the North Atlantic, CG-188-38.

Atmospheric Environment Service (AES), Thirty Day Ice Forecast for Northern Canadian Waters, October 1988 to September 1989.

Hanson, W.E., Operational Forecasting Concerns Regarding Iceberg Deterioration, Report of the International Ice Patrol in the North Atlantic, 1987 Season, CG-188-42, U.S. Coast Guard, Washington D.C., 1987.

Knutson, K.N. and T.J. Neill, Report of the International Ice Patrol Service in the North Atlantic for the 1977 Season, CG-188-32, U.S. Coast Guard, Washington D.C., 1978.

Mariners Weather Log, Summer 1989, Vol. 33, Number 3, 1989a.

Mariners Weather Log, Fall 1989, Vol 33, Number 4, 1989b.

Mariners Weather Log, Winter 1989, Vol. 34, Number 1, 1990.

Murphy, D.L. and I. Anderson. Evaluation of the International Ice Patrol Drift Model, Report of the IInternational Ice Patrol in the North Atlantic, 1985 Season, CG-188-40, U.S. Coast Guard, Washington D.C., 1985.

Naval Oceanography Command, Sea Ice Climatic Atlas: Volume II Arctic East, 1986.

Navy-NOAA Joint Ice Center, Naval Polar Oceanography Center, Southern Ice Limit, Published Bi-monthly, 1989.

Acknowledgements

Commander, International Ice Patrol acknowledges the assistance and information provided by the Atmospheric Environment Service of Environment Canada, U.S. Naval Fleet Numerical Oceanography Center, U.S. Naval Eastern Oceanography Center, the U.S. Coast Guard Research and Development Center, the Coast Guard Atlantic Area Staff, and the First Coast Guard District Communications Center.

We extend our sincere appreciation to the staffs of the Canadian Coast Guard Radio Station St. John's, Newfoundland/VON, Ice Operation St John's, Newfoundland, Air Traffic Control Gander, Newfoundland, Canadian Forces Gander and St John's, Newfoundland, and the Gander Weather Office, and to the personnel of U.S. Coast Guard Air Station Elizabeth City, U.S. Coast Guard Air Station Cape Cod, and U.S. Coast Guard Communications Station Boston for their excellent support during the 1989 International Ice Patrol season.

It is also important to recognize the efforts of the personnel at the International Ice Patrol: CDR S. R. Osmer, LCDR W. A. Hanson, Dr. D. L. Murphy, LCDR R.L. Tuxhorn, LT M. A. Alfultis, LTJG M. B. Christian, MSTCM G. F. Wright, MSTC M. F. Alles, MSTC R. H. Eckenrode, YN1 P. G. Thibodeau, MST1 M. G. Barrett, MST1 C. R. Moberg, MST2 J. L. Perdue, MST2 J. R. Shuberth, MST2 D. D. Beebe, MST2 D. A. Hutchinson, MST2 J. C. Myers, MST3 M. E. Petrick, MST3 P. J. Reilley, MST3 R. C. Lenfenstey, MST3 N. A. Capobianco, MST3 M. D. Baechler, and MST3 C. F. Weiller.

APPENDIX A
SHIP REPORTS

VESSEL NAME	FLAG	SST	ICE REPORTS
A. G. FARQUHARSON	CANADA		6
ABEL EGEDE	GREENLAND		1
ABITIBI CLAIRBORNE	FED. REP. OF GERMANY		1
ABITIBI MACADO	FED. REP. OF GERMANY		2
ABITIBI ORINOCO	FED. REP. OF GERMANY		5
ADA GORTHON	BAHAMAS		3
AINO	NORWAY	5	
AKADEMIK ROFFE	U.S.S.R.		1
AL REHMAN	PANAMA	4	
ALAM TELADAN	MALAYSIA		3
ALBERTA	GREECE		1
ALBRIGHT PIONEER	UNITED KINGDOM		3
ALEKSANDR STAROSTENKO	U.S.S.R.		4
ALEXANDROS	BAHAMAS		1
ALIBAK JOSEFSEN	GREENLAND		1
ALIDA GORTHON	BAHAMAS		1
ALMARE QUARTA	ITALY		1
AMELIA	DENMARK		1
AMERLOQ	GREENLAND		1
AMFRITRITI	GREECE		1
AMSTELWAL	NETHERLANDS		1
ANANGEL APOLLO	GREECE		1
ANANGEL SKY	GREECE		7
ANNA	ST. VINCENT GRENADINES		2
APJ SUSHMA	INDIA	9	
ARCTIC	CANADA		3
ARCTIC VIKING	CANADA		1
ARI	LIBERIA		1
ARROW COMBINER	NORWAY		1
ARROW PEARL	NORWAY		2
ARUNACHAL PRADESH	INDIA		2
ASPHALT TRADER	GREECE	5	2
ASTART	LIBERIA	4	3
ATLANTIC CARTIER	FRANCE		3
ATLANTIC CONFIDENCE	PANAMA		1

SST = SEA SURFACE TEMPERATURE

VESSEL NAME	FLAG	SST	ICE REPORTS
ATLANTIC CONVEYOR	UNITED KINGDOM		3
ATLANTIC LINK	BAHAMAS		4
ATLANTIC NORMA	CANADA		1
ATLANTIC TREASURE	CANADA		1
ATLANTIS A	CYPRUS	2	2
AZALEA	SOUTH KOREA		4
BADAK	LIBERIA		1
BAFFIN	CANADA		4
BAFFIN RESOLUTEBAY	ANTIGUA - BARBUBA		3
BALSA 8	PHILLIPINES		1
BALTASAR ALVARES	POLAND	13	
BALTIC SUN	NETHERLANDS		2
BARON TRADER	PHILLIPINES		1
BELLE ETOILE	MAURTIUS		1
BENSKOU	DENMARK		1
BENSKOV VENTURE	DENMARK		3
BHAWANI	BAHAMAS		1
BIJELO POLJE	YUGOSLAVIA		5
BLACK SEA	NETHERLANDS		1
BMD NO. 400	CANADA		1
BOSPORUS	CYPRUS		2
BOW FOREST	NORWAY		1
BOXY	SWEDEN		2
BP ENERGY	BAHAMAS		1
BRAGE VIBEKE	NORWAY		6
BRANDAL	CANADA		1
BRIDGEWATER	FED. REP. OF GERMANY		1
BRITISH STEEL	UNITED KINGDOM		1
BRUSSEL	BELGIUM		2
CABEL VENTURE	FED. REP. OF GERMANY	1	1
CANADA MARQUIS	CANADA		1
CANADIAN EXPLORER	UNITED KINGDOM		9
CANMAR AMBASSADOR	UNITED KINGDOM		9
CANMAR EUROPE	BELGIUM		15
CANMAR SPIRIT	PANAMA		3

VESSEL NAME	FLAG	SST	ICE REPORTS
CANMAR SWIFT	SINGAPORE		3
CANMAR VENTURE	UNITED KINGDOM		4
CAPE ROGER	CANADA		8
CAPE ROSEWAY	CANADA		1
CARL EGEDE	GREENLAND		1
CASPIAN TRADER	LIBERIA		1
CAST BEAVER	YUGOSLAVIA		1
CAST CARIBOU	YUGOSLAVIA		4
CAST HUSKY	BAHAMAS		5
CAST MUSKOX	BAHAMAS		3
CAST OTTER	BAHAMAS		2
CAST POLARBEAR	LIBERIA	18	20
CATHERINE VENTURE	LIBERIA		2
CECILIA DESGAGNES	CANADA		4
CIELO DI MILANO	ITALY		2
CLARIDGE	SINGAPORE		2
CLARITA	HONG KONG		1
CLIPPER MARIGAYA	PHILLIPINES	1	1
CLIPPER SPIRIT	PANAMA		2
CONCERT EXPRESS	SWEDEN		1
CONTI ALMANIA	ANTIGUA - BARBUBA	2	2
CORNER BROOK	LIBERIA		4
CORYTON	CYPRESS	2	2
CREDO	SWEDEN		1
CRYSTAL B	CYPRESS		1
CYROS	FRANCE		1
DAISHOWA VOYAGEUR	PANAMA	3	3
DAMODAR KRISHNA	INDIA	4	9
DARA	NORWAY	5	
DAWSON	CANADA	1	4
DELPHINUS	ITALY	2	2
DES GROSEILLIES	CANADA		7
DISKO	DENMARK		1
DOCK EXPRESS 20	NETHERLANDS		1
DOCK EXPRESS FRANCE	NETHERLANDS		1

VESSEL NAME	FLAG	SST	ICE REPORTS
DUKE OF TOPSAIL	UNITED KINGDOM		1
EL AMAAN	LIBERIA		1
ELISABETH	PORTUGAL		1
ELITA	PANAMA		2
ELLEN HUDIG	BELGIUM		3
ELSAM JYLLAND	DENMARK	4	
ENDEAVOUR	U. S. A.		1
ENDURANCE	SINGAPORE	3	4
ENERCHEM FUSION	CANADA		1
ERIN T	CANADA		1
ETABHYDROC BREST	UNKNOWN		1
EURO PRIDE	SINGAPORE		1
EVER GALLANT	TAIWAN	2	
EVER LYRIC	TAIWAN		1
FALCON	NORWAY		4
FALKNES	PHILLIPINES		3
FASTNES	PHILLIPINES		1
FAUST	U. S. A.	3	3
FEDERAL AGNO	PHILLIPINES		2
FEDERAL CALUMET	LIBERIA		1
FEDERAL DANUBE	CYPRUS		3
FEDERAL INGER	NORWAY	2	
FEDERAL MAAS	CYPRUS		5
FEDERAL OTTAWA	BELGIUM	1	6
FEDERAL POLARIS	JAPAN		2
FEDERAL SCHELDE	LIBERIA		1
FEDERAL ST LAURENT	LIBERIA	1	1
FEDERAL THAMES	CYPRUS		4
FERMUSE	CANADA		1
FINNARCTIS	BAHAMAS		4
FINNFIGHTER	FINLAND	12	11
FINNPOLARIS	BAHAMAS		1
FINNTRADER	BAHAMAS		2
FORT RAMEZAY	CANADA		2
FRASER	UNKNOWN		11

VESSEL NAME	FLAG	SST	ICE REPORTS
FREENES	LIBERIA	1	3
FRITHJOF	FED. REP. OF GERMANY		22
FULLNES	LIBERIA		1
GENERAL LUNA	PHILLIPINES		1
GENERAL PAPA	PHILLIPINES		1
GENERAL PRADZYNSKI	POLAND		1
GEORGE L	GREECE	1	1
GLENTROOL	BAHAMAS		1
GREEN WAVE	U. S. A.	1	1
GREENLAND SAGA	DENMARK		3
GULF GRAIN	LIBERIA	2	
GULF SPIRIT	NETHERLANDS	1	1
H. FAVOUR	UNKNOWN		3
HANS LEONHARDT	FED. REP. OF GERMANY		2
HAPPY CHANCE	SINGAPORE	10	9
HAPPY VALLEY	LIBERIA		2
HARP	CANADA		10
HENRY LARSEN	CANADA		1
HIGH LIGHT	PANAMA	1	1
HOEGH DANAOS	GREECE	4	4
HOFSJOKULL	ICELAND	1	1
HOLCAN MAAS	NORWAY	5	11
HOLCAN RIJN	GREECE		1
HOLOCK-LARSEN	INDIA		3
HONORIO BARRETO	PORTUGAL	2	13
HUBERT GAUCHER	CANADA		1
HUMBER ARM	LIBERIA	1	11
HVILVTENNI	DENMARK		1
ICE BERG	U. S. A.		5
ICE FLOWER	DENMARK		2
ICE PEARL	DENMARK		6
IDEAL GAVEL	PANAMA		1
IGLOO FLAKE	CYPRESS		1
IMPERIAL ST. CLAIR	CANADA		1
INDEPENDENT SPIRIT	NETHERLANDS		1

VESSEL NAME	FLAG	SST	ICE REPORTS
INDIAN NO. 38	PANAMA		1
INDIRA MAHAL	NEW HEBRIDE	4	4
INES	FED. REP. OF GERMANY	1	3
IRON MASTER	PANAMA		1
IRVING CANADA	CANADA		1
IRVING FOREST	UNITED KINGDOM		2
IRVING OURS POLAIRE	CANADA		6
IVAN AIVAZOVSKIY	U. S. S. R.		2
IVAN DERBENYEV	U. S. S. R.		1
IVO VOJNOVIC	YUGOSLAVIA	1	1
J. A. Z. DESGAGNES	CANADA		1
JACKMAN	CANADA		3
JACOB DJ	FED. REP. OF GERMANY		1
JAHRE ENERGY	LIBERIA	1	1
JOANN M	BAHAMAS		1
JOH. GORTHON	SWEDEN		5
JOHAN PETERSEN	DENMARK		9
JOHANNA KRISTINA	GREENLAND		2
JUNGE GARDE	GERMAN DEMOCRATIC REP.	1	1
JUPITER	CYPRESS		1
KANGILINEQ	GREENLAND		4
KANGUK	CANADA		9
KAPITAN KHROMTSOV	U. S. S. R.		1
KARAYEL I	TURKEY		1
KARINA	LIBERIA		1
KAZIMIERZ PULASKI	POLAND		1
KENNETH E. HILL	BAHAMAS	4	4
KHUDOZHNIK PAKHOMOV	U. S. S. R.	1	4
KHUDOZHNIK PAYHOMOU	U. S. S. R.		1
KHUDOZHNIK REPIN	U. S. S. R.		6
KIVIUG (1)	CANADA		2
KOLN ATLANTIC	FED. REP. OF GERMANY	2	6
KOREAN TRADER	LIBERIA	4	
KOTA HARTA	SINGAPORE	1	
KOYO SPIRIT	LIBERIA	8	3

VESSEL NAME	FLAG	SST	ICE REPORTS
KRISTJAN PARLUSALU	U. S. S. R.	4	5
KRITI SEA	GREECE		1
KYUSHU	LIBERIA	1	
L'ORME #1	UNKNOWN		1
LA RICHARDAIS	FRANCE		1
LACKENBY	UNITED KINGDOM		1
LADY FRANKLIN	CANADA		1
LADY HAMMOND	ANTIGUA - BARBUBA		1
LAPPONIA	BAHAMAS		2
LAUSANNE	SWITZERLAND	1	2
LE BRAVE	CANADA		1
LE CHENE NO. 1	CANADA		1
LEDE MAERSK	DENMARK		1
LENINSK	U. S. S. R.	1	
LEONARD J. COWLEY	CANADA		4
LEXA MAERSK	DENMARK		1
LICA MAERSK	DENMARK		1
LIONESS	LIBERIA		1
LIONS GATE BRIDGE	PANAMA	1	1
LONGEVITY	PHILLIPINES		2
LOOIERSGRACHT	NETHERLANDS	6	8
LOTILA	BAHAMAS		1
LOUIS MAERSK	DENMARK		1
LT ODYSSEY	INDIA	2	
LUCTOR	SINGAPORE		1
LUNA	SINGAPORE	1	
LUUTIVIK	GREENLAND		1
M. RAKEL	GREENLAND		2
MAERSK CHIGNECTO	CANADA		1
MAERSK GABARUS	CANADA		3
MAERSK PLACENTIA	CANADA		3
MAERSK VINLANDER	CANADA		1
MAGIC SKY	LIBERIA		1
MAGNISTA	PANAMA		1
MAGNUS JENSEN	DENMARK		10

VESSEL NAME	FLAG	SST	ICE REPORTS
MALINSKA	YUGOSLAVIA		2
MALOJA II	CYPRUS		8
MARGRETHE MAERSK	DENMARK	1	1
MARIA GORTHON	SWEDEN		3
MARIGOLA	ITALY		1
MARITA	PHILLIPINES		6
MARQUES DE BOLARQUE	SPAIN	1	2
MARSHAL BUDYONNYY	U. S. S. R.		1
MATHILDA DESGAGNES	CANADA		3
MAUREEN	LIBERIA	28	3
MEERKATZE	FED. REP. OF GERMANY		5
MELA	PANAMA	1	1
MISTRAL	LIBERIA		1
MORIS BISHOP	U. S. S. R.		3
MUEGGELSEE	REP. OF EL SALVADOR	7	
NAJA ITTUK	DENMARK		6
NARA	BELGIUM		1
NARSSALIK	GREENLAND		1
NATAARNAQ	GREENLAND		1
NEPTUNE JADE	SINGAPORE		1
NEWFOUNDLAND ARROW	CANADA		1
NIKKI ITTUK	DENMARK	1	5
NIKOLAY GOLOVANOV	U. S. S. R.		2
NIVI ITTUK	DENMARK		3
NOKASA	GREENLAND		1
NORD OCEAN	SINGAPORE		1
NORDIC	LIBERIA		3
NORLANDIA	DENMARK		1
NORMAN MCLEOD ROGERS	CANADA	3	8
NORTHERN STAR	CYPRUS		2
NORTHGATE	LIBERIA		1
NUKA ITTUK	DENMARK		9
NUNGU ITTUK	DENMARK		14
NURNBERG ATLANTIC	FED. REP. OF GERMANY		3
OCEAN COMMANDER	NORWAY		1

VESSEL NAME	FLAG	SST	ICE REPORTS
OCEAN PRIDE	CYPRUS	1	4
OCEANIC MINDANAO	PANAMA	5	
ODET	FRANCE		2
OHYO MARU	JAPAN		1
OMEGAVENTURE L	GREECE		1
OMISALJ	YUGOSLAVIA		4
ONTADOC	CANADA		2
OOCL ATLANTIC	LIBERIA	1	2
OOCL CHALLENGE	UNITED KINGDOM		13
ORASUND	DENMARK		9
ORATANK	DENMARK		5
OREO	GREECE	1	
OT MOONLIGHT	SWEDEN		2
OTTO DANIELSEN	PANAMA		1
PACIFICO	ITALY		1
PALMAGRACHT	NETHERLANDS	7	5
PAN OAK	BAHAMAS	5	
PANKAR INDOMITABLE	GREECE		1
PARKGRACHT	NETHERLANDS	1	1
PATMOS	GREECE	13	14
PATSY AND SONS	CANADA		1
PELJESAC	YUGOSLAVIA		1
PERSEUS	ITALY		1
PETKA	YUGOSLAVIA	4	5
PETROLAB	CANADA		1
PFC. EUGENE A. OBREGON	U. S. A.	5	5
PIERRE RADISSON	CANADA		1
POKKINEN	BAHAMAS		2
POLAR NANOQ	GREENLAND		2
POLAR STAR	U. S. A.		10
POLYTRAVELLER	NORWAY		2
POS-AMT761	UNKNOWN		1
PREBLE	UNKNOWN	6	6
PROTEKTOR	SINGAPORE	1	
QAASUIT	GREENLAND		3

VESSEL NAME	FLAG	SST	ICE REPORTS
QASIGIAQ	GREENLAND		1
QUEEN ELIZABETH II	UNITED KINGDOM		1
REEFER KNIGHT	CYPRUS	6	8
RENTALA	SINGAPORE	13	14
REUTERSHAGEN	GERMAN DEMOCRATIC REP.		1
RIXTA OLDENDORFF	HONG KONG	2	2
ROMANDIE	SWITZERLAND	3	2
ROMEO NOVEMBER	UNKNOWN		1
SAINT JOHN	GREECE		2
SAINT VASSILIOS	CYPRUS	7	1
SALLEQ	GREENLAND		3
SAMSON	LIBERIA		1
SAMUEL H ARMACOST	BAHAMAS	5	5
SAN LORENZO	UNITED KINGDOM		4
SARAH	LIBERIA		1
SASKATCHEWAN PIONEER	CANADA		4
SCHWANENTOR	UNKNOWN		1
SEAPROGRESS	CYPRUS	7	
SELKIRK SETTLER	UNITED KINGDOM		4
SEXI REX	JAPAN		1
SIR JOHN FRANKLIN	CANADA		8
SIR WILFRED GRENFELL	CANADA		8
SKOGAFOSS	ANTIGUA - BARBUBA		2
SKYRON	LIBERIA	4	3
SOKOLICA	LIBERIA		2
SPICA	LIBERIA		1
SPIRE	NEW HEBRIDE	1	1
SPLIT	YUGOSLAVIA	7	5
ST JEAN	CANADA	1	1
STAR CASTOR	NORWAY	1	
STAR FINLANDIA	DENMARK		1
STAR RANGER	NORWAY		2
STAR ROVER	NORWAY		1
STEFAN STARZYNSKI	POLAND		1
STELLANOVA	NETHERLAND ANTILLES		1

VESSEL NAME	FLAG	SST	ICE REPORTS
STOLT ASPIRATION	PANAMA		3
STOLT CASTLE	LIBERIA		2
STOLT CROWN	LIBERIA		1
STOLT SYDNESS	LIBERIA	4	4
STUTTGART EXPRESS	FED. REP. OF GERMANY		3
SUNSTINNES	CYPRUS		2
TAISETSU MARU	JAPAN		2
TASERMIUT	GREENLAND		1
TERRA NORDICA	CANADA		1
TEXACO ALABAMA	BAHAMAS		2
TEXACO TEXAS	BAHAMAS		1
TIIRA	FINLAND		3
TIM BUCK	U. S. S. R.		1
TINGANES	NORWAY		2
TOBRUK	POLAND		1
TOVE COB	SINGAPORE	7	
TRADER 1	PHILLIPINES	2	2
TRAVE ORE	TAIWAN		8
TREBIZOND	LIBERIA	1	2
TROMAAS	ANTIGUA - BARBUBA		1
TRONES	NORWAY	3	
UAL MONTREAL	GREECE		2
UNIJE	PANAMA		1
URDULTZ	ANTIGUA - BARBUBA	8	1
VARJAKKA	BAHAMAS		4
VAYGACH	U. S. S. R.		1
VENASSA	UNITED KINGDOM		2
VIHREN	BULGARIA		1
VIKTOR BUGAEV	U. S. S. R.		1
VIVA 1	SINGAPAORE	4	4
WALTER LEONHARDT	CYPRUS		1
WILFRED TEMPLEMAN	CANADA		4
WILOM TANA	LIBERIA	2	
WLAYSLAW SIKORSKI	POLAND		1
WORLD AMPHION	GREECE	6	

VESSEL NAME	FLAG	SST	ICE REPORTS
WORLD RADIANCE	LIBERIA		1
ZAGLEBIE MIEDZIOWE	POLAND		3
ZARNATA	LIBERIA		4
ZIEMIA BIALOSTOCKA	POLAND		1
ZIEMIA CHELMINSKI	POLAND		2
ZIEMIA SUWALSKA	POLAND	5	11
ZIYAD	PANAMA		2

APPENDIX B

INTERNATIONAL ICE PATROL'S 1989 DRIFTING BUOY PROGRAM

MICHAEL B. CHRISTIAN
DONALD L. MURPHY

INTRODUCTION

The 1989 iceberg season was the fourteenth consecutive year that the International Ice Patrol (IIP) used satellite-tracked buoys to measure currents in its operations area in the western North Atlantic Ocean. The buoy trajectories are used to provide near realtime current data to the Ice Patrol iceberg drift model. The currents derived from the buoy trajectories are used to modify the mean currents temporarily in the region through which the buoy is moving. Shortly after a buoy departs the region, the current is reverted to its mean value (Summy and Anderson, 1983).

During 1989 Ice Patrol deployed nine satellite tracked buoys (Table B-1). Three of the buoys deployed in 1989 eventually beached in Europe.

The standard configuration for the operational buoys was a 3-m long spar hull with a 1 m diameter flotation collar. Each buoy was equipped with a 2-m by 10-m window-shade drogue attached to the buoy with a 50 m tether of 1/2 in (1.3 cm) nylon. The center of the drogue was at a nominal depth of 58 m. Each buoy had a temperature sensor (accurate to approximately 1°C) mounted approximately 1 m below the waterline, a drogue tension monitor, and a battery voltage monitor. Three of the buoys deployed during 1989 (9875, 9876, and 9879) were equipped with barometric pressure sensors funded by the U. S. Navy.

The data from the buoys are acquired and processed by Service ARGOS. Ice Patrol queries the ARGOS data files and stores the buoy data once daily. Most of the buoy position data fall within the standard accuracy provided by Service ARGOS (~350 m). All of the buoy data were entered onto the Global Telecommunications System (GTS). Each buoy, except 9876, was assigned a World Meteorological Organization (WMO) number.

BUOY DEPLOYMENT STRATEGY

Monitoring the currents with drifting buoys in the entire Ice Patrol operations area (40N to 52N; 39W to 57W) for the entire iceberg season is impractical. A recent study (FENCO, 1987), funded by Canada's Atmospheric Environment Service, showed that at least 400 buoys per year would be required to resolve the eddy field in a 250-km by 250-km area, a small fraction of IIP's area of responsibility.

Ice Patrol's buoy deployment strategy focuses on the Labrador Current. The southward-flowing offshore branch of the Labrador Current is the major conduit of icebergs into the North Atlantic shipping lanes. IIP monitors this current by keeping one or two buoys drifting in it throughout the iceberg season.

Buoys are deployed as far north (north of 50N) as possible because the southward mean flow of the Labrador Current carries the buoys into the southern areas of interest. Ice Patrol's experience has shown that this approach is reasonable with two important limitations. The first is

Table B-1. Summary of 1989 Deployments

ARGOS ID	WMO ID	DEPLOYMENT DATE	DEPLOYMENT POSITION	REMARKS
9875	44510	25 MAR (084)	48-30N 48-00W	Departed OPAREA 26 MAY (146)
9876	None Assigned	25 MAR (084)	48-00N 48-59W	Failed in OPAREA 30 MAR (089)
4565	44507	29 MAR (088)	50-43N 50-40W	Departed OPAREA 04 JUL (185)
9879	44509	08 APR (098)	52-03N 49-59W	Departed OPAREA 19 MAY (139)
4537	44508	10 APR (100)	47-00N 47-20W	Failed In OPAREA 14 OCT (287)
4569	44511	24 APR (114)	51-58N 50-48W	Departed OPAREA 20 SEP (263)
4568	44512	24 APR (114)	49-30N 50-40W	Departed OPAREA 11 JUL (192)
4567	44501	05 MAY (125)	47-10N 46-59W	Failed in OPAREA 04 JUL (185)
4570	44502	05 JUN (156)	47-41N 47-01W	Departed OPAREA 19 NOV (323)

that early in the iceberg season (March and April), buoys are not deployed in areas with significant concentrations of sea ice (> 3/10) because wind-driven movement of the sea ice contaminates the drifter data, and sea ice can damage the buoy. In many cases buoys deployed between 50°N to 52°N move eastward to the north of Flemish Cap, and hence do not enter the region south of Flemish Pass. Because Ice Patrol requires drift data in this area, it is frequently necessary to deploy buoys directly in the Pass to ensure that the buoy will move to the south. In this case the buoys are deployed at 47N between 46-30W and 47-30W.

Despite concerns over deployment in sea ice mentioned above, during the early part of the 1989 season buoy deployment was pushed to the north to support LIMEX '89 (see Appendix C).

AIRCRAFT DEPLOYMENTS

Ice Patrol has deployed satellite-tracked buoys from HC-130's since 1979. The buoy is strapped into an air-deployment package and launched out the rear door of an HC-130 flying at an altitude of 500 ft (150 m) at 150 kts (77 m/s). The air-deployment package consists of a wooden pallet and a parachute, both of which separate from the buoy after it enters the water. The parachute riser is cut by a cable-cutter that is activated by a battery energized when immersed in salt water. The pallet separates when salt tablets dissolve and release straps holding the buoy to the pallet. The buoy then floats free and the drogue falls free and unfurls.

The manufacturer redesigned the air deployment package for use in the 1989 season following a 50 percent failure rate in 1988. None of the re-designed air deployment packages failed during 1989.

DATA PROCESSING

Although the raw position and temperature data are relatively noise free, all records are reviewed before processing to ensure quality control. First, duplicate positions and positions with time separations of less than 30 minutes are deleted. Then, positions less than 700 m from adjacent positions are deleted, unless the deletion results in a time separation of 4 or more hours.

The quality-controlled position data are then fitted to a cubic spline curve to arrive at an evenly spaced record with time intervals of 3 hours. This process results in a slight reduction in the number of fixes per day (from 10 to 8). Next, the position records are filtered using a low-pass cosine filter with a cut-off of 1.16 x 10-5 Hz (one cycle per day). This filter removes most tidal and inertial effects. Finally, the buoy drift speeds are calculated at three-hour intervals using a two-point backward differencing scheme.

The trajectory plots presented in this report are from the filtered records. Also presented for each buoy is a plot of the time history of the U (east is positive) and V (north is positive) components of velocity from the filtered records. Finally, a time history of the raw sea surface temperature data is plotted for each buoy. The dates used in all of the plots are year-days, which are numbered sequentially starting at 1 on January 1. In the text, the year-days are included parenthetically.

BUOY TRAJECTORIES

The following sections discuss each buoy trajectory in chronological order by buoy deployment date. The discussions summarize each buoy's performance and the data that it contributed to Ice Patrol operations. It is not intended to be an exhaustive data analysis. The buoy data outside of the Ice Patrol operations area, east of 39W and north of 52N, are not presented. The data from the IIP buoy program are archived at the IIP office in Groton, Connecticut and the Marine Environmental Data Service (MEDS), Department of Fisheries and Oceans, Halifax, N.S..

Buoy 9875

Buoy 9875 was deployed at 1937Z on 25 March (84) at 48-30N, 48-00W. It remained within the Ice Patrol operations area for 62 days, passing north of 52°N on 26 May (146) (Figure B-1a). The drogue sensor indicated that the drogue was connected until 15 October (288). The buoy stopped transmitting on 23 December (357).

From deployment until day 96 the buoy drifted eastward north of the 1000-m contour at roughly 20 cm/s (Figure B-1b). Between days 96 and 134 the motion of the buoy was complex. Speeds varied from 2 to 25 cm/s, and the temperature ranged from 3°C to 7°C. On day 134 the buoy began a northward drift with speeds increasing up to 100 cm/s and temperature increasing from 4.5°C to 9°C.

Buoy 9876

Buoy 9876 was deployed at 2027Z on 25 March (84) at 48-00N, 48-59W. It failed on 30 March (89) while still within the Ice Patrol operations area. The early failure of 9876 could have been caused by sea ice. It was deployed into an area with 2/10 sea ice cover, and remained within or near the ice edge for its 5-day drift. The drogue sensor indicated that the drogue was connected throughout its 5 operational days.

During the 5 days for which drift data are available, 9876 drifted eastward between the 200-m and 1000-m isobaths (Figure B-2a). Temperature was fairly constant at about -1.6°C. Speeds varied between 10 cm/s and 70 cm/s and often changed abruptly (Figure B-2b).

Bouy 4565

Buoy 4565 was deployed at 1523Z on 29 March (88) at 50-43N, 50-40W. It remained within the Ice Patrol operations area for 97 days, drifting east of 39W on 4 July (185) (Figure B-3a). The drogue sensor indicated that the drogue was connected while in the Ice Patrol area, disconnecting on 19 September (262). The buoy stopped transmitting on 28 January 1990.

After deployment, buoy 4565 drifted southeastward off the shelf and continued its southeastward drift until 20 April (110). The eastward component of this drift could have been caused by wind-driven ice drift. It was deployed in a region of 2/10 sea ice cover. Until mid April it was near or within the sea ice edge, typically in not more than 2/10 sea ice cover. The eastward drift was sufficient to drive this buoy out of the Labrador Current. Following a cyclonic loop between days 111 and 129, the buoy drifted northeastward and then northward. From day 91 to day 130 the temperature increased from 0°C to 6.4°C (0.16°C/day). Speeds were 10 to 20 cm/s from days 129 to 139, then slowed to less than 10 cm/s until day 150 when the speed started to increase, reaching 90 cm/s on day 158 (Figure B-3b). Temperatures also started to increase on day 150, indicating that the buoy entered the North Atlantic Current. Between day 150 and 185, temperatures increased from 6°C to 14°C. Between days 160 and 170, during which speeds varied between 45 and 80 cm/s and temperatures were between 9°C and 10.8°C, the buoy made an anticyclonic loop.

Buoy 9879

Buoy 9879 was deployed at 1515Z on 8 April 1989 (98) at 52-03N, 49-59W. It remained within the Ice Patrol operations area for 41 days, departing to the north on 19 May (139) (Figure B-4a). The drogue sensor indicated that the drogue was never connected. It beached in Macrihanish, Scotland around 15 April 1990 (105).

Buoy 9879 initially drifted southward at 18 to 30 cm/s east of the 1000-m isobath. After 4 days it turned eastward and slightly increased speed (25 to 35 cm/s) before slowing (1 to 10 cm/s) between days 110 and 116 when its eastward drift was interrupted (Figure B-4b). Its eastward drift out of the Labrador Current suggests that its drogue was not connected, and it was more influenced by wind-driven surface currents. From day 117 until 139, the buoy resumed its drift eastward and then northward out of Ice Patrol's area.

Temperatures were uniform (about 3°C) until day 121 when the buoy turned northward and temperatures increased approximately 3°C and became more variable.

Buoy 4537

Buoy 4537 was deployed at 1906Z on 10 April (100) at 47-00N, 47-20W. It failed within the Ice Patrol operations area on 14 October (287). The drogue sensor indicated that the drogue was connected throughout its operational period.

Buoy 4537 (Figure B-5a) drifted southward along the 1000-m contour at speeds of 9 to 25 cm/s until day 121 when it moved offshore, possibly under the influence of a warm-core eddy. Sea surface temperature charts produced by the Canadian Meteorological and Oceanographic Centre (METOC) in Halifax show the existence of such a warm-core eddy during the same period. It then drifted southward into the North Atlantic Current which transported it to the northeast. The temperature record shows an increase on day 129 (FigureB-5b) shortly after the buoy left the shelf. Between days 133 and 161 the buoy appeared to be in a rapidly advecting cyclonic eddy. During this period (days 132 to 154), the temperature increased from 1°C to 12°C. Then, between days 180 and 226 the buoy made 11 cyclonic loops (20 km - 60 km diameter), and during this time the temperature ranged from 9°C to 15.8°C. It then travelled to the southwest between days 226 and 250, contrary to the mean direction of the North Atlantic Current. Speeds during this period ranged from 1 to 31 cm/s, decreasing toward day 250. It then reversed direction and travelled to the northeast and then northwest at increasing speeds (up to 110 cm/s).

Buoy 4569

Buoy 4569 was deployed near the sea ice edge at 1500Z on 24 April (114) at 51-58N, 50-48W. It remained within the Ice Patrol operations area for 149 days, departing on 20 September (263) (Figure B-6a). The drogue sensor indicated that the drogue disconnected on 29 September (272). The buoy was still transmitting when it beached near Cornwall, England on 2 August 1990.

Buoy 4569 drifted southward in the Labrador Current through the Flemish Pass until 9 July (190) when it reached the North Atlantic Current and then travelled to the northeast. Speeds in Flemish Pass ranged from 20 to 50 cm/s, and those between southern Flemish Pass and day 190 were 36 to 50 cm/s. Temperatures increased from -2°C to 9°C while the buoy travelled southward in the Labrador Current. After passing east of Flemish Cap, buoy speeds in the North Atlantic Current increased, reaching up to 100 cm/s. Once in the North Atlantic Current, temperatures only varied between 12°C and 16°C (Figure B-6b). The buoy made an anticyclonic loop between days 244 and 250. Speeds during this period were 64 to 92 cm/s, and temperatures were 12.6°C to 14.6°C.

Buoy 4568

Buoy 4568 was deployed at 1628Z on 24 April (114) at 49-30N, 50-40W. It remained within the Ice Patrol operations area for 78 days, departing on 11 July (192) (Figure B-7a). The drogue sensor indicated that the drogue disconnected on 10 August (222). The buoy was still transmitting when it beached in Ireland on 11 February 1990.

After being deployed over the shelf, buoy 4568 drifted offshore until reaching the Labrador Current. Speeds over the shelf were less than 15 cm/s, but gradually increased starting on day 134. Speeds through Flemish Pass increased from 30 to 60 cm/s, and those south of Flemish Pass (days 148 to 154) decreased from 60 to 34 cm/s. It followed a trajectory similar to that of buoy 4569, but with higher speeds (up to 60 cm/s) in the Labrador Current (Figure B-7b). The temperature record shows an increase throughout the buoy's transit through the Ice Patrol area.

Buoy 4567

Buoy 4567 was deployed at 1753Z on 5 May (125) at 47-10N, 46-59W. It failed within the Ice Patrol area on 4 July (185) (Figure B-8a). The drogue sensor indicated that the drogue disconnected on 29 June (180).

Buoy 4567 was deployed in the Flemish Pass and drifted southward along the 1000-m contour until 16 May (136) when it turned offshore. From deployment until day 139, speeds were between 36 cm/s and 50 cm/s. It drifted southeastward until being influenced by the North Atlantic Current and turning to the northeast. Between days 150 and 170 the buoy made a cyclonic loop southwest of Flemish Cap before resuming its journey to the northeast. Speeds within the cyclonic loop were less than 30 cm/s, but increased upon exiting the loop, reaching nearly 100 cm/s. The buoy made another cyclonic loop between days 175 and 184 with speeds varying from 3 to 64 cm/s.

The temperature record shows three stages, each warmer than the previous. The first stage lasts from deployment until day 139, the second from 146 to 161, and the third from 172 until failure.

Buoy 4570

Buoy 4570 was deployed at 2127Z on 5 June (156) at 47-41N, 47-01W. It remained within the Ice Patrol operations area for 167 days, departing on 19 November (323) (Figure B-9a). The drogue sensor indicated that the drogue was connected until 27 November (331).

The trajectory of buoy 4570 was unusual. On day 164 the buoy stopped travelling southward through Flemish Pass and started drifting eastward, passing just north of Flemish Cap. Speeds across the Cap (days 164 to 204) were slow (3 to 15 cm/s). The buoy trajectory to the north and west of Flemish Cap extends much further to the north and west than would be expected. The reason for this abnormal trajectory is not known. The temperature record is not noteworthy, but shows a general increase until day 218 and then a decrease.

BUOY PERFORMANCE

The performance of the nine operational buoys deployed during the 1989 season was adequate for IIP use (Table B-2). The average number of days a buoy remained within the IIP area was 94. Although 4537 failed within the IIP area, it provided the longest period of information on the area.

The average number of days the buoys transmitted data (as of 1 September 1990) was 271, 304 if 9876 is excluded. The failure of 9876 could have been due to its deployment near sea ice since wind-driven

BUOY PERFORMANCE

TABLE B-2 . 1989 Operational Buoy Performance

BUOY	NUMBER OF DAYS IN IIP OPERA	NUMBER OF DAYS DROGUE CONNECTED	NUMBER OF DAYS BUOY TRANSMITTED (AS OF 1 SEP 90)
9875	62	204	273
9876	5*	5	5
4565	97	174	305
9879	41	0	372 (beached Scotland)
4537	187*	187	187
4569	149	158	465 (beached England)
4568	78	108	316 (beached Ireland)
4567	60*	55	60
4570	167	175	453 (still transmitting)
Average	94	118	271

* Failed within IIP OPAREA

compaction of sea ice could damage a buoy. The period of transmission of three buoys was ended not due to failure but by beaching in Europe, and 4570 was still transmitting on 1 September 1990. Three of the nine buoys (9876, 4537, 4567) failed prematurely (transmitted less than 90 days). Data transmitted from these three indicated that the battery voltage was within the operational limits at the time of failure. The cause of the failures is unknown.

Data from the drogue sensors indicated that the average number of days a drogue remained connected was 118. The average is 125 if 9876 and 4537 are excluded since these buoys stopped transmitting before the drogues disconnected, and the average is 146 if 9879 is also excluded since its sensor indicated that the drogue was never connected. Data from buoy 9879 is viewed as suspicious.

Although the data on buoy performance show that the drogues disconnect much sooner than the buoys stop transmitting, the average number of days the drogue is connected is sufficient for IIP purposes since this is greater than the average time the buoy remains within the IIP area.

SUMMARY AND CONCLUSIONS

Contrary to the 1988 season, none of the buoys deployed during 1989 were recovered at sea.

Most of the 1989 buoy trajectories followed familiar patterns. For example, buoys drifting within the 1000-m contour (4569, 4568) passed through the Flemish Pass along this contour. However, buoys offshore of the 1000-m contour (9875, 4565) did not pass through Flemish Pass but curved northward and moved north of Flemish Cap.

The Labrador Current's temporal variability resulting from a warm-core eddy near 44N and the eastern Grand Banks was observed again in 1989. A warm-core eddy appeared to deflect the Labrador Current eastward in early May (buoys 4537 and 4567), but there was no evidence of such an eddy in July (buoy 4569). METOC Sea surface temperature charts for 9 to 18 May (129 to 138) also suggest the existence of a warm-core eddy which could have influenced the buoys. A warm-core eddy has been observed in the same position, deflecting the Labrador Current, in May during previous IIP seasons and is discussed in more detail in Murphy (1987).

The trajectories of buoys 4565 and 4569 both had anticyclonic loops of similar size in nearly the same location north of Flemish Cap. Speeds for the two buoys while in these loops were also comparable. The temperatures for 4565 were lower than those for 4569. This temperature difference is probably due to 4565 making its loop about 80 days earlier. Note that the two buoys made these loops in approximately the same location despite taking very different paths prior to that.

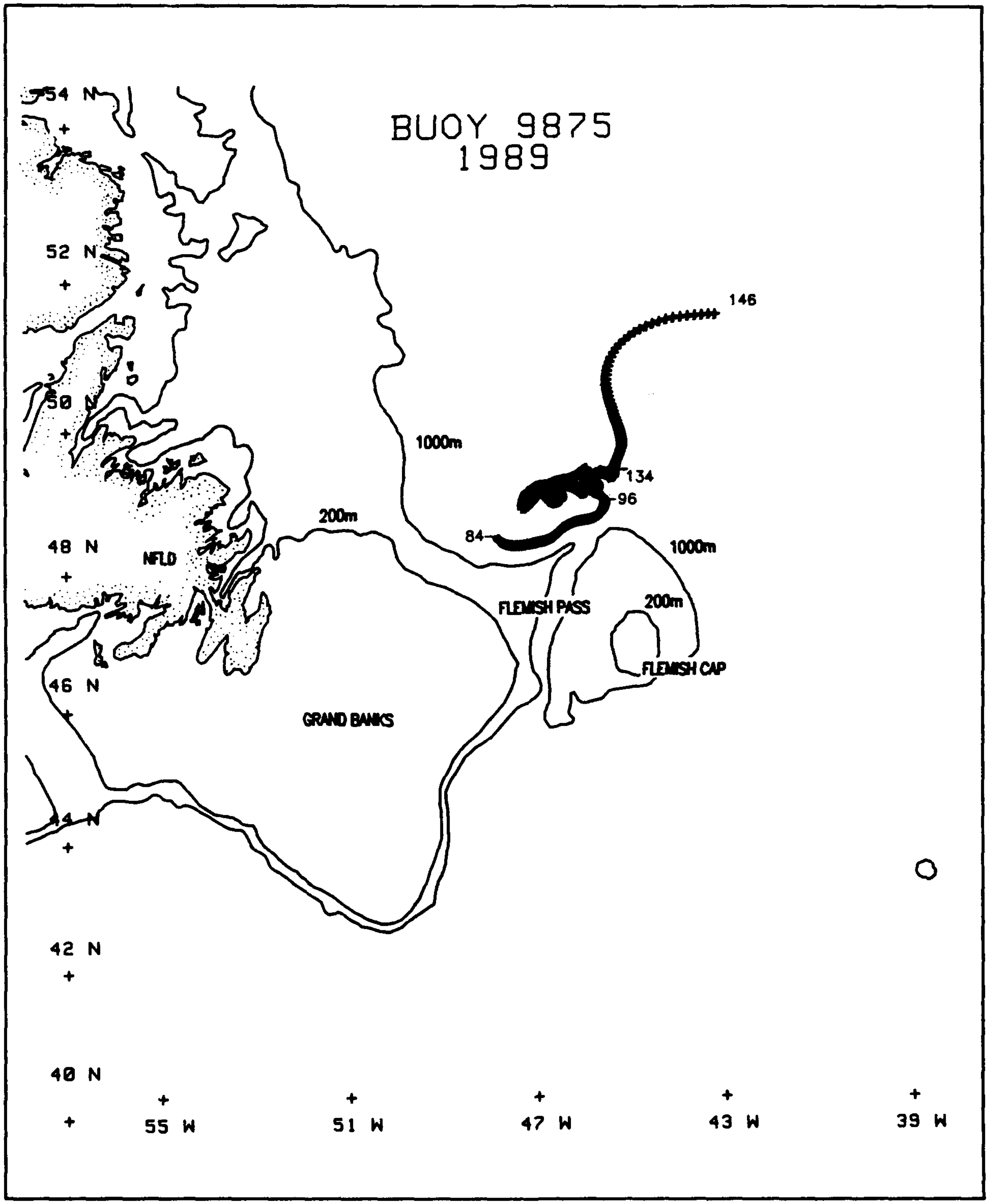


Figure B-1a. Trajectory for 9875.

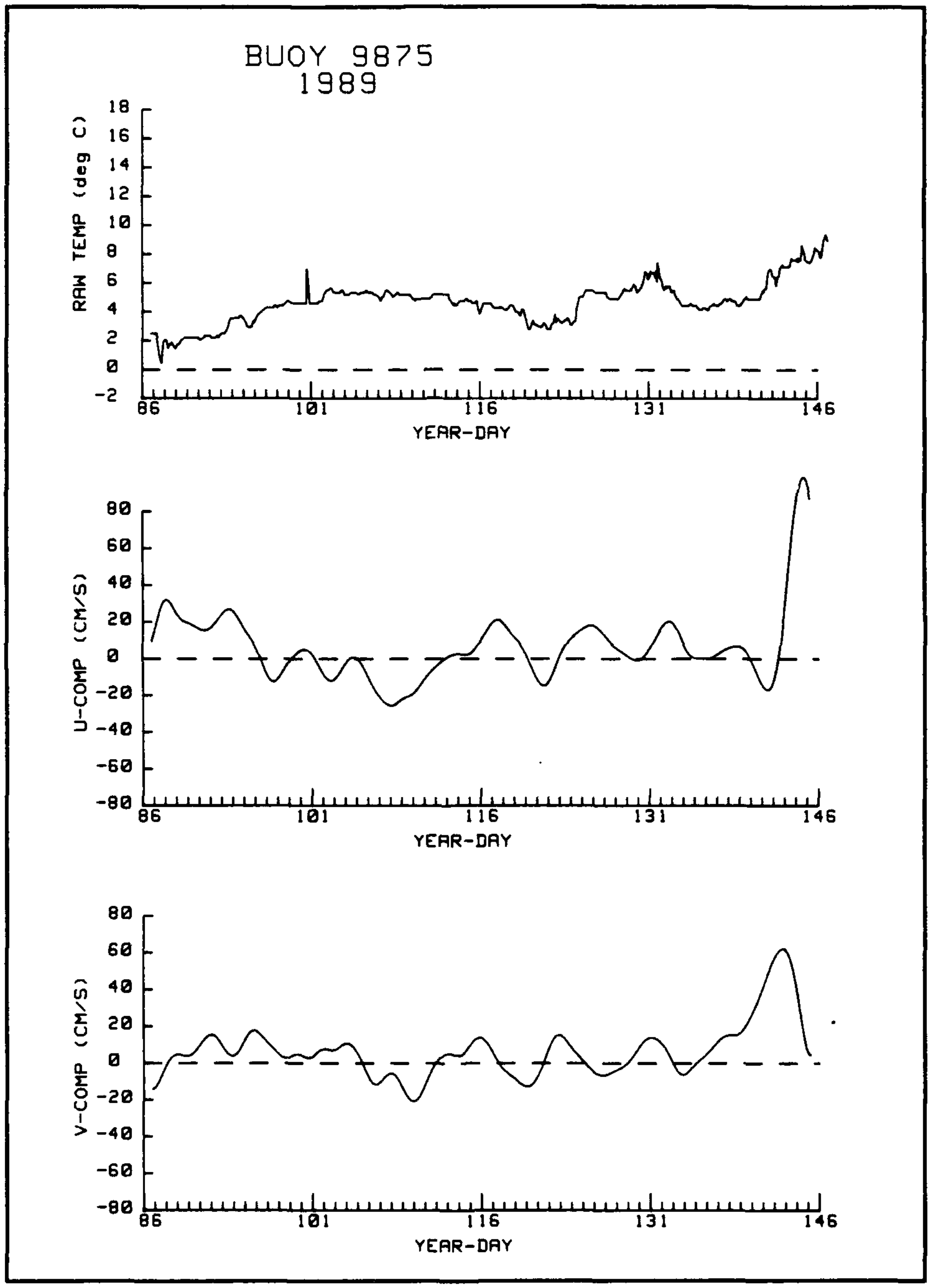


Figure B-1b. Time history of sea surface temperature, U, and V velocity components (filtered) for 9875.

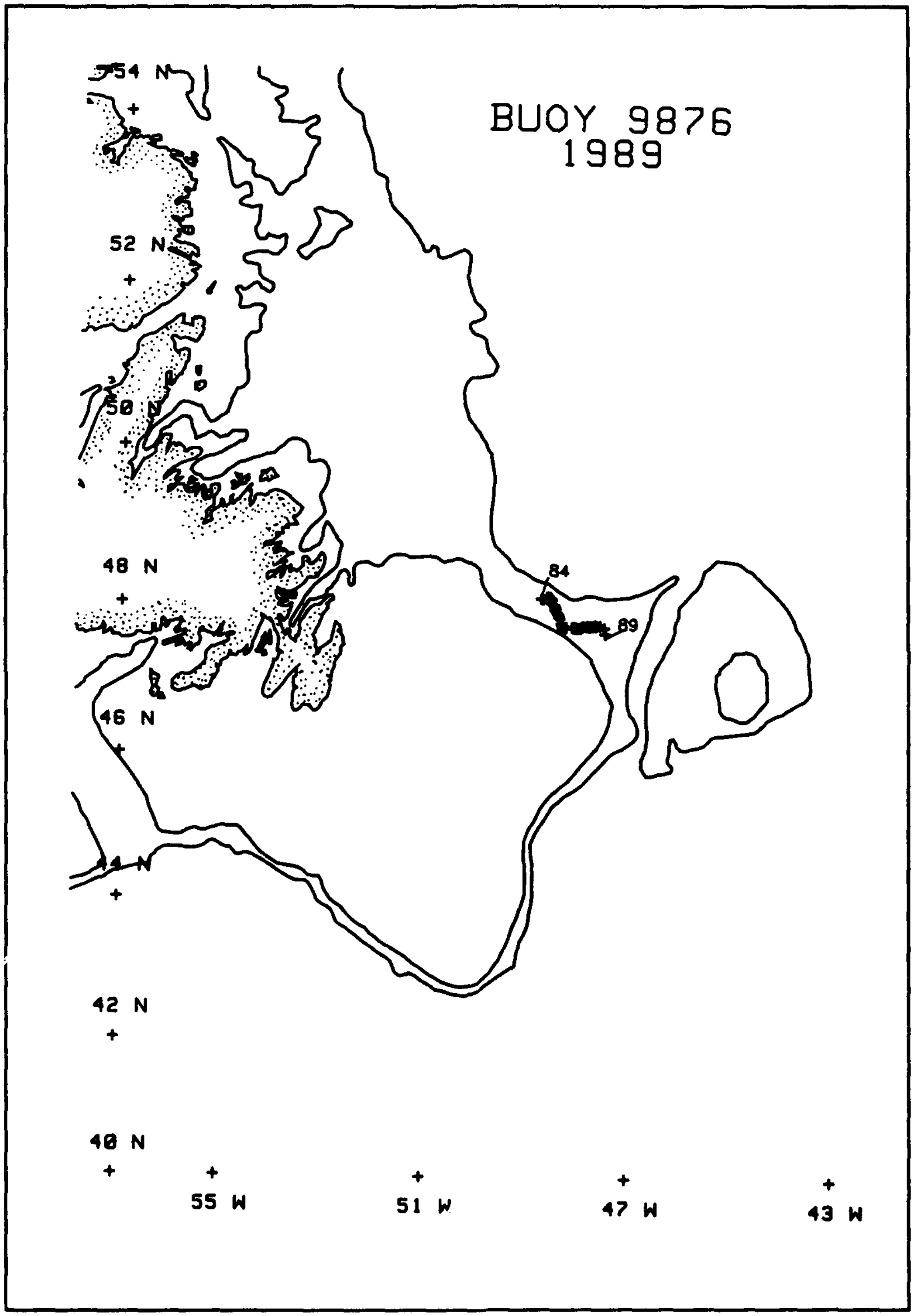


Figure B-2a. Trajectory for 9876.

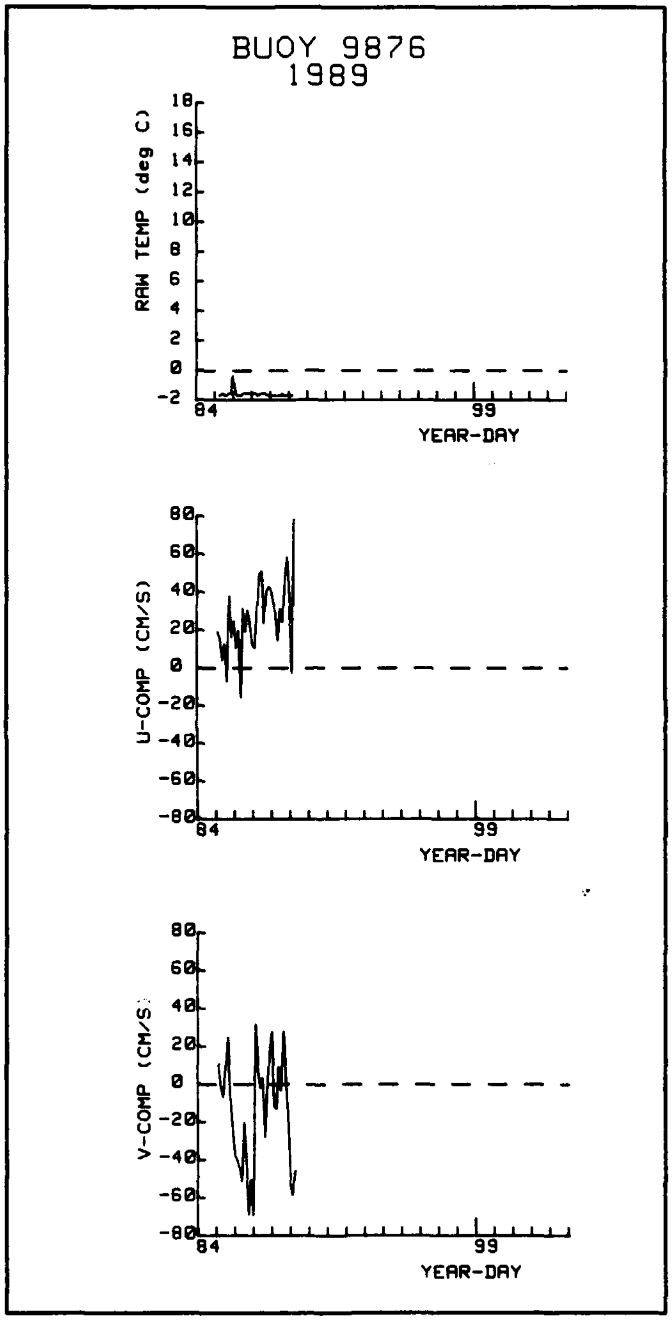


Figure B-2b. Time history of sea surface temperature, U, and V velocity components (filtered) for 9876.

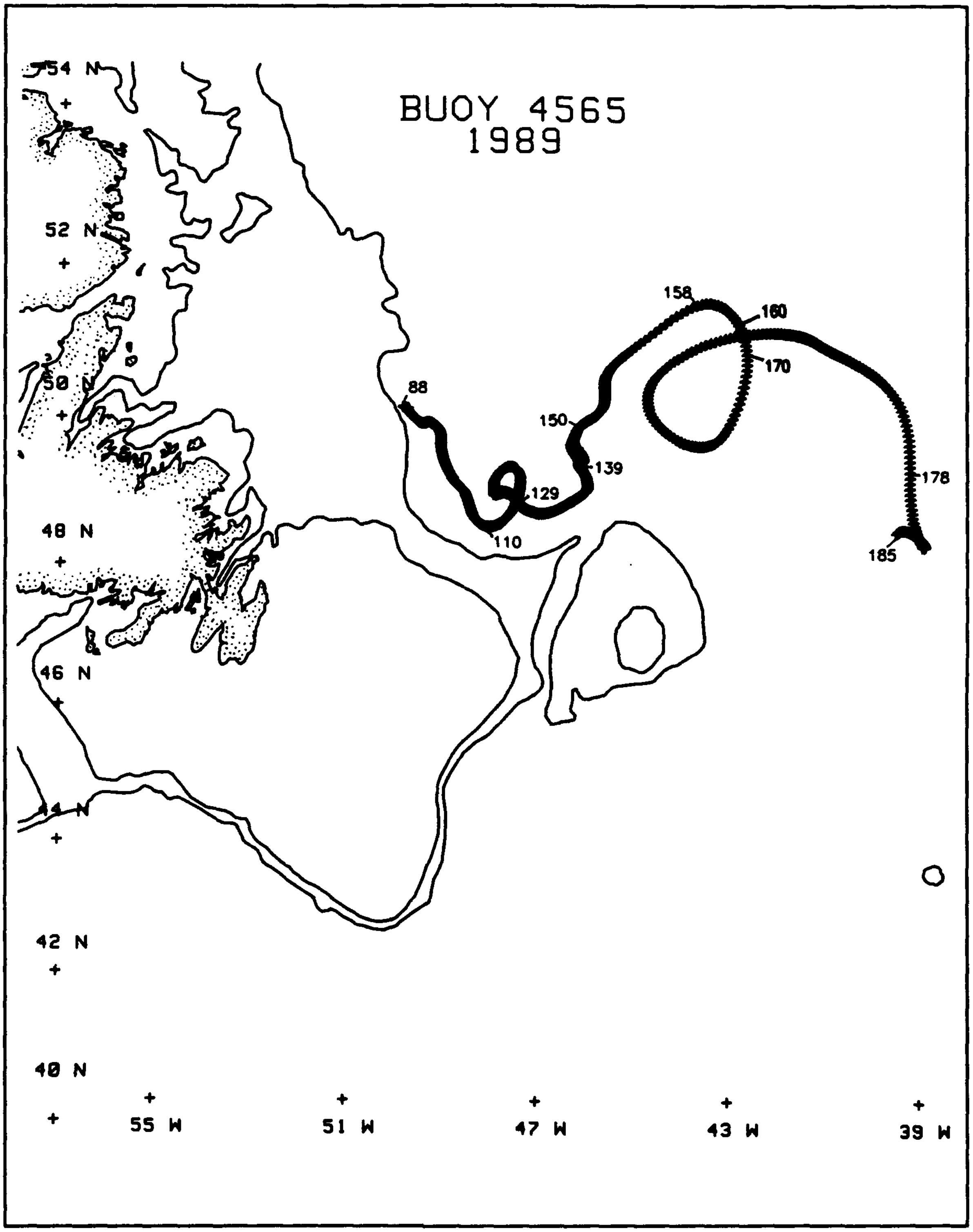


Figure B-3a. Trajectory for 4565.

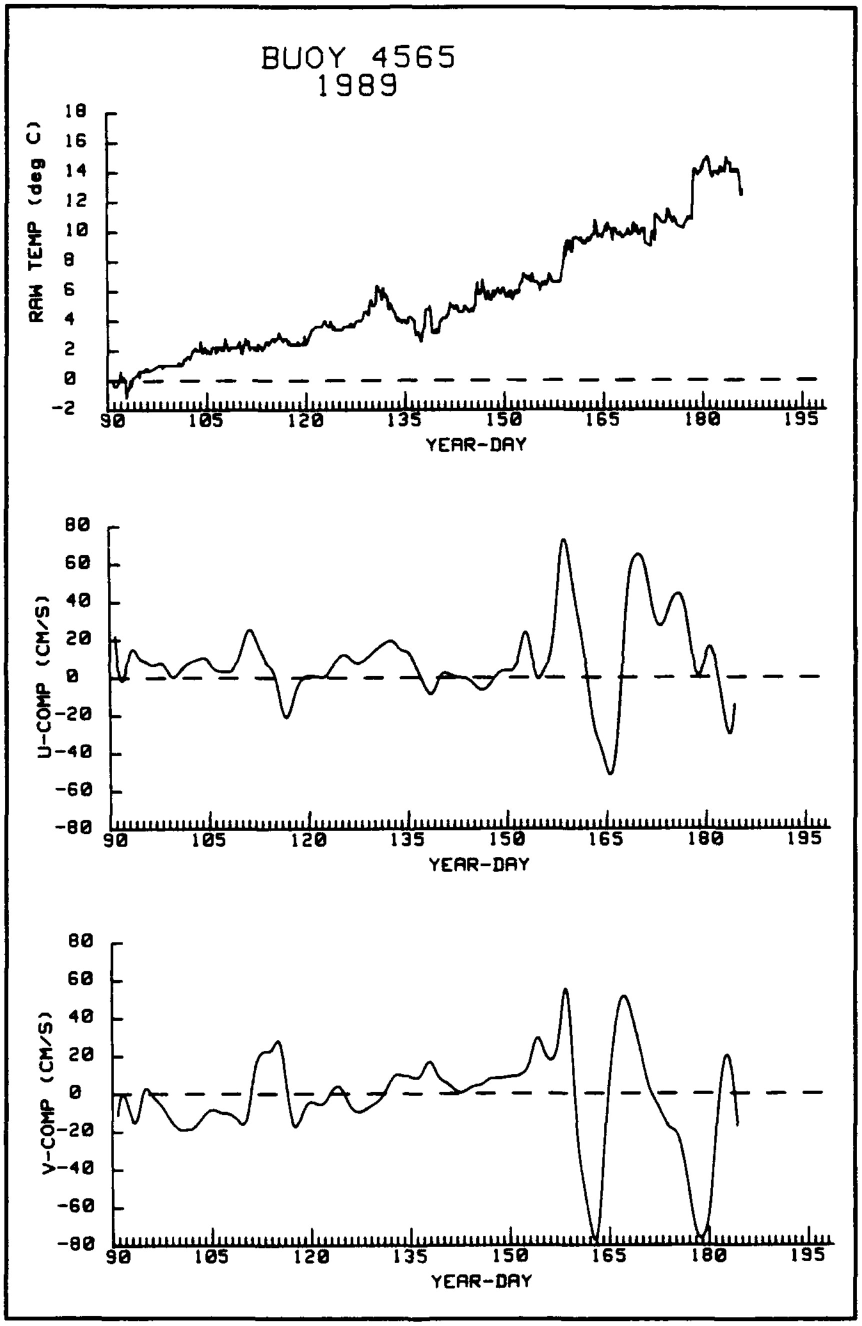


Figure B-3b. Time history of sea surface temperature, U, and V velocity components (filtered) for 4565.

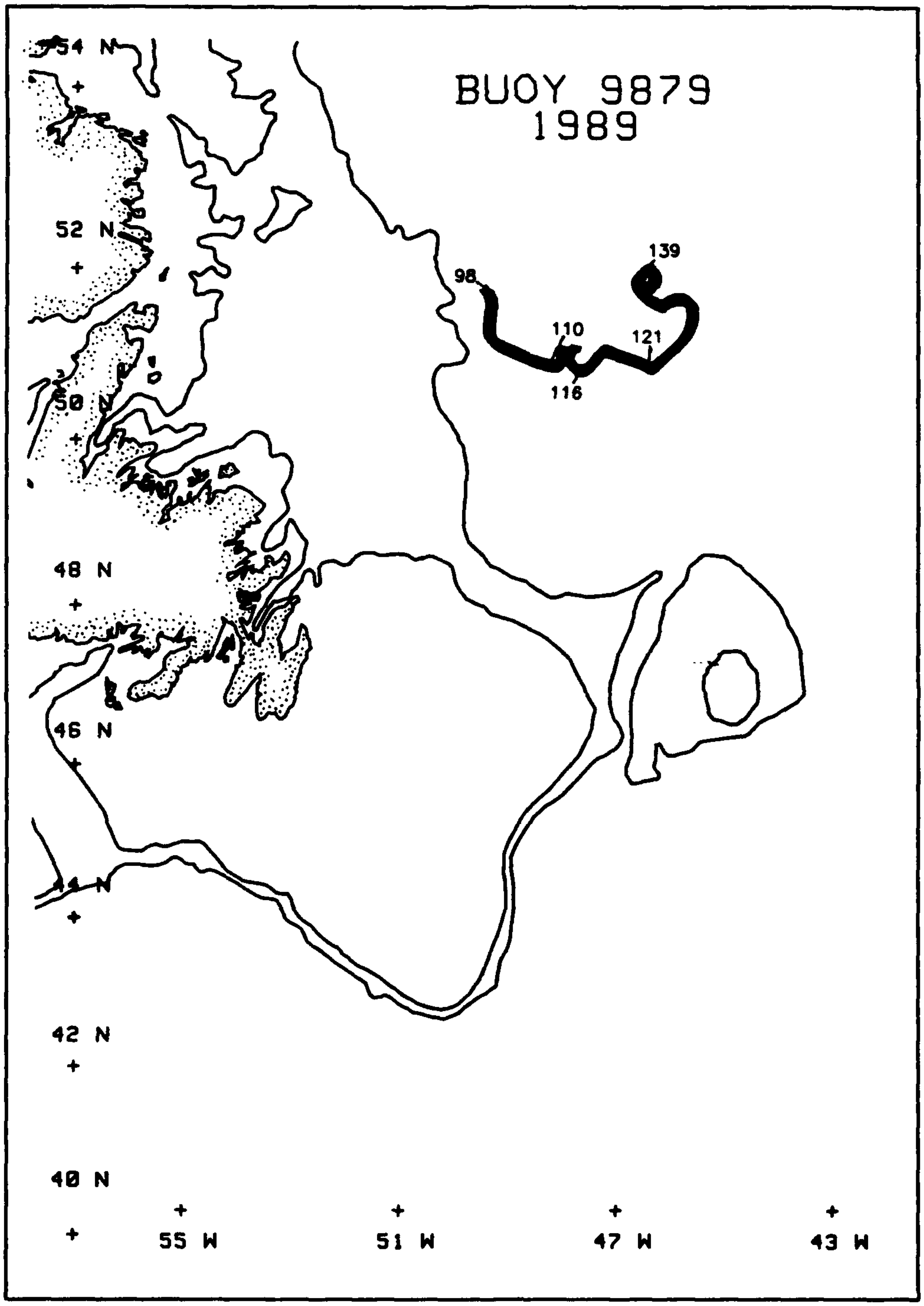


Figure B-4a. Trajectory for 9879.

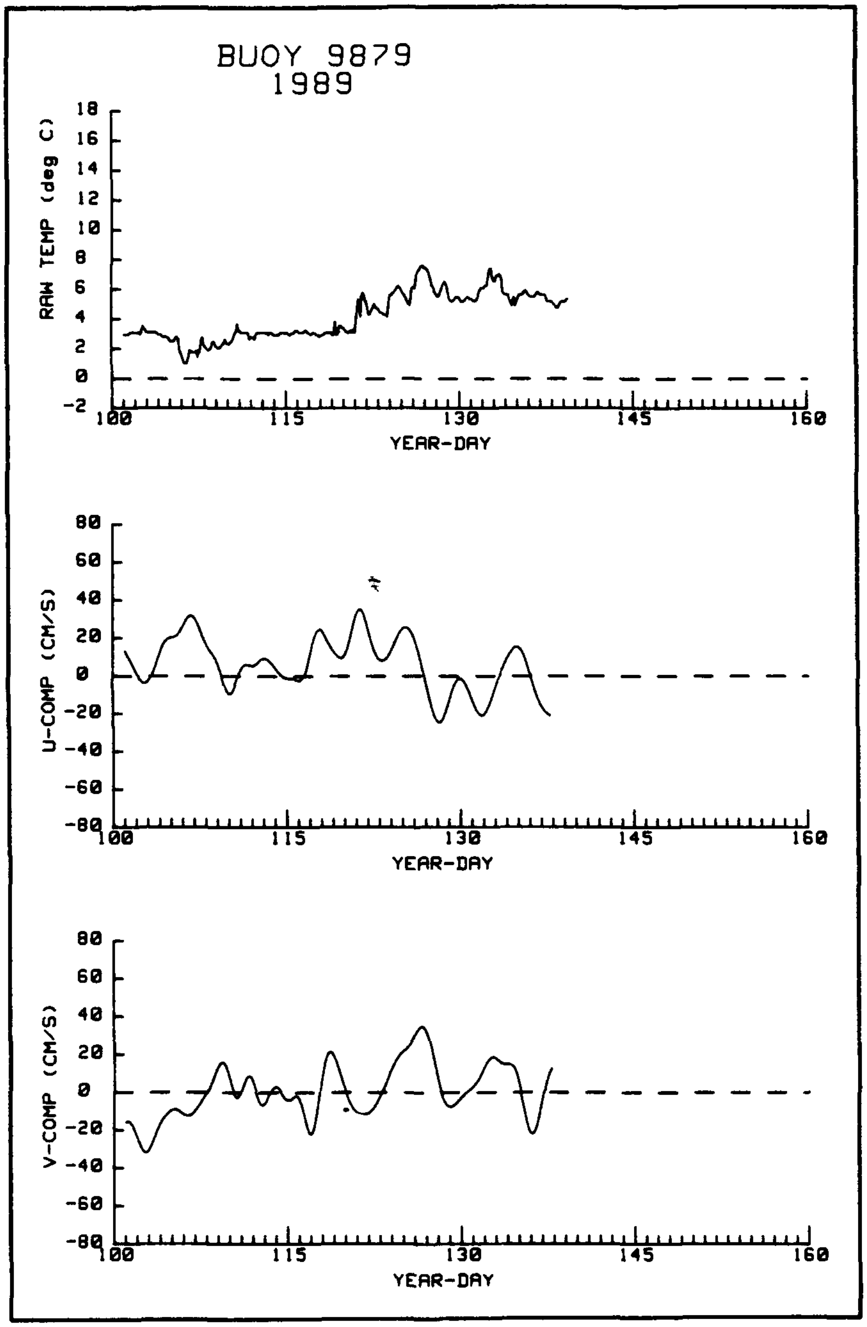


Figure B-4b. Time history of sea surface temperature, U, and V velocity components (filtered) for 9879.

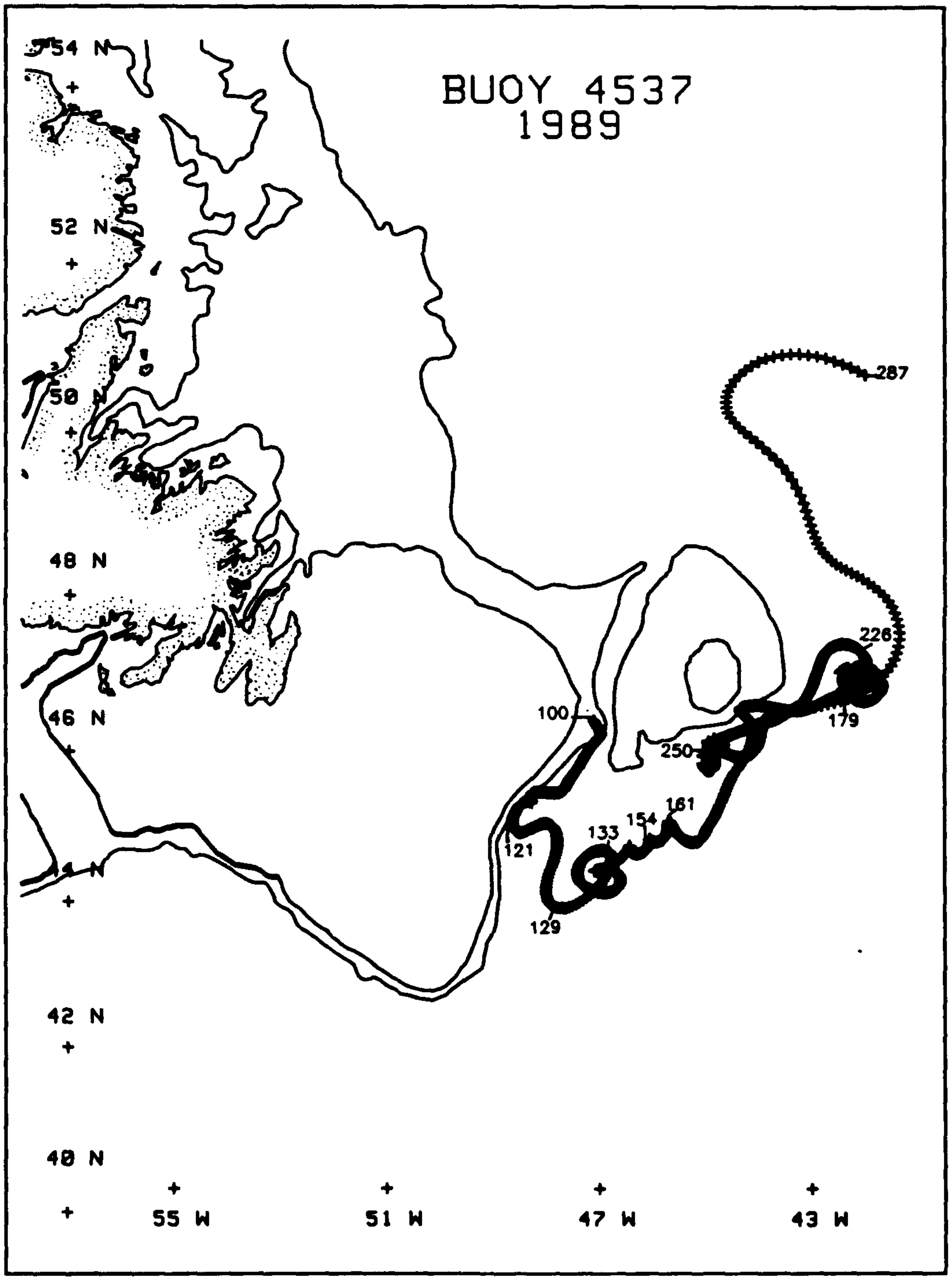


Figure B-5a. Trajectory for 4537.

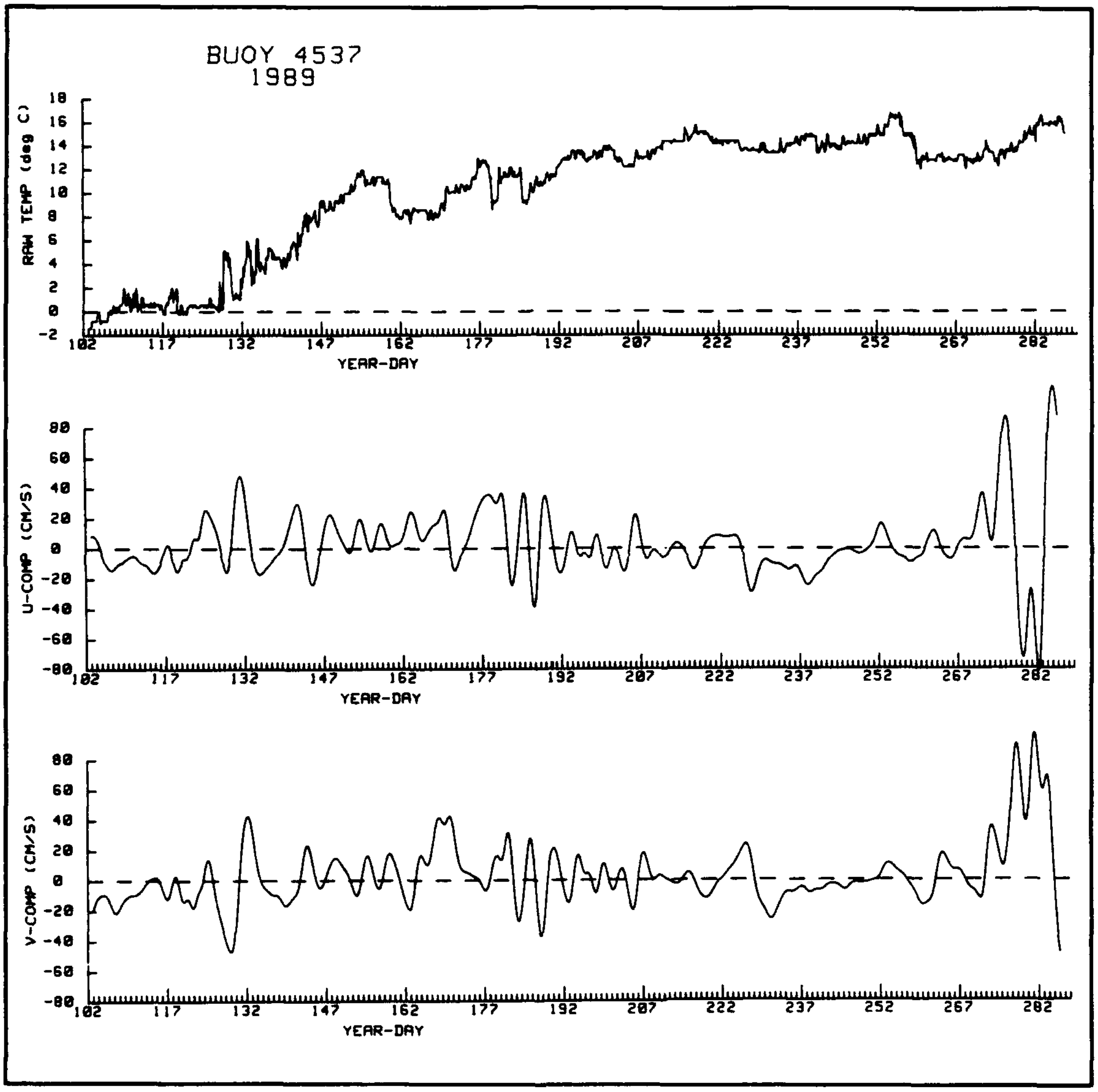


Figure B-5b. Time history of sea surface temperature, U, and V velocity components (filtered) for 4537.

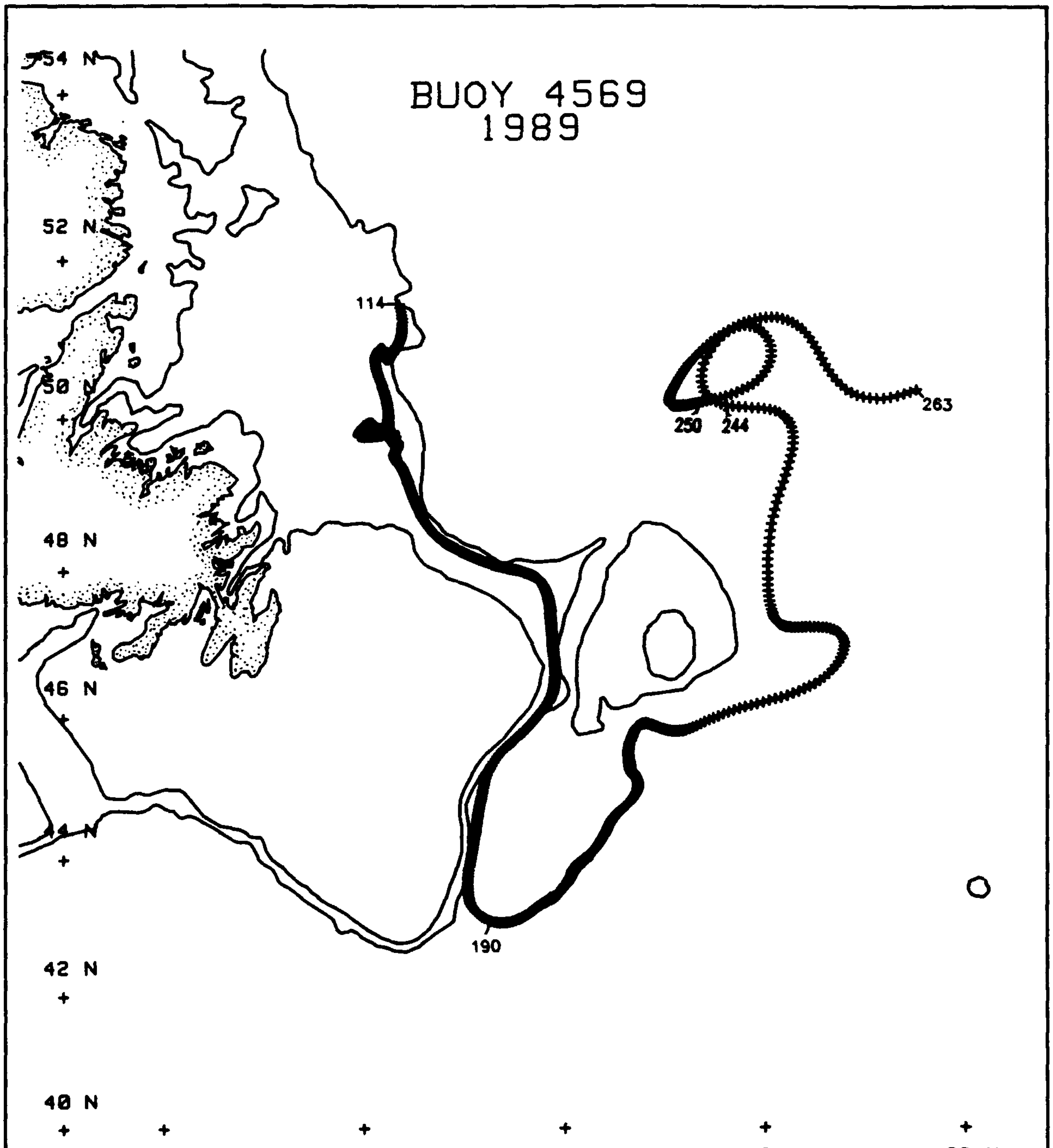


Figure B-6a. Trajectory for 4569.

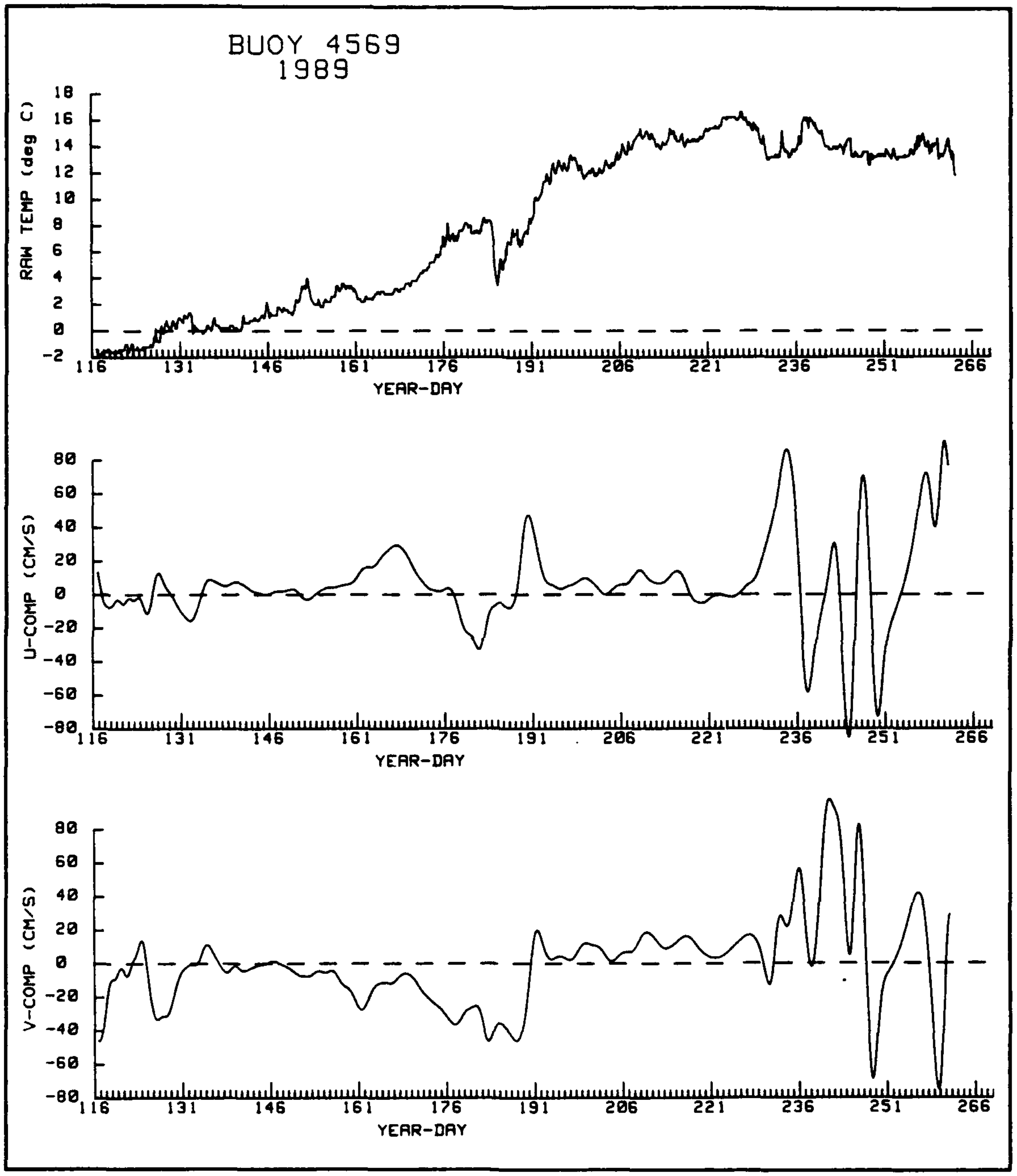


Figure B-6b. Time history of sea surface temperature, U, and V velocity components (filtered) for 4569.

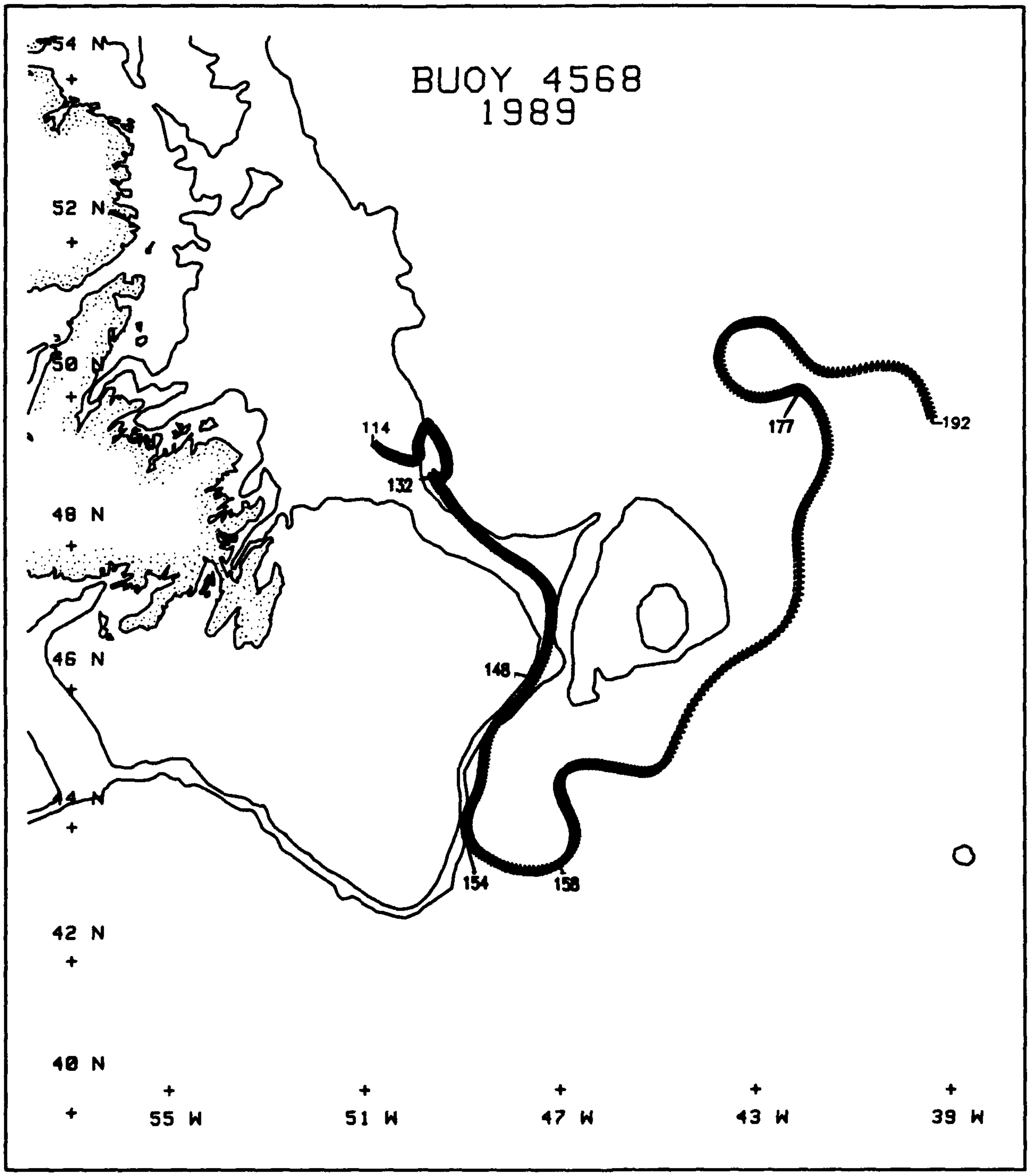


Figure B-7a. Trajectory for 4568.

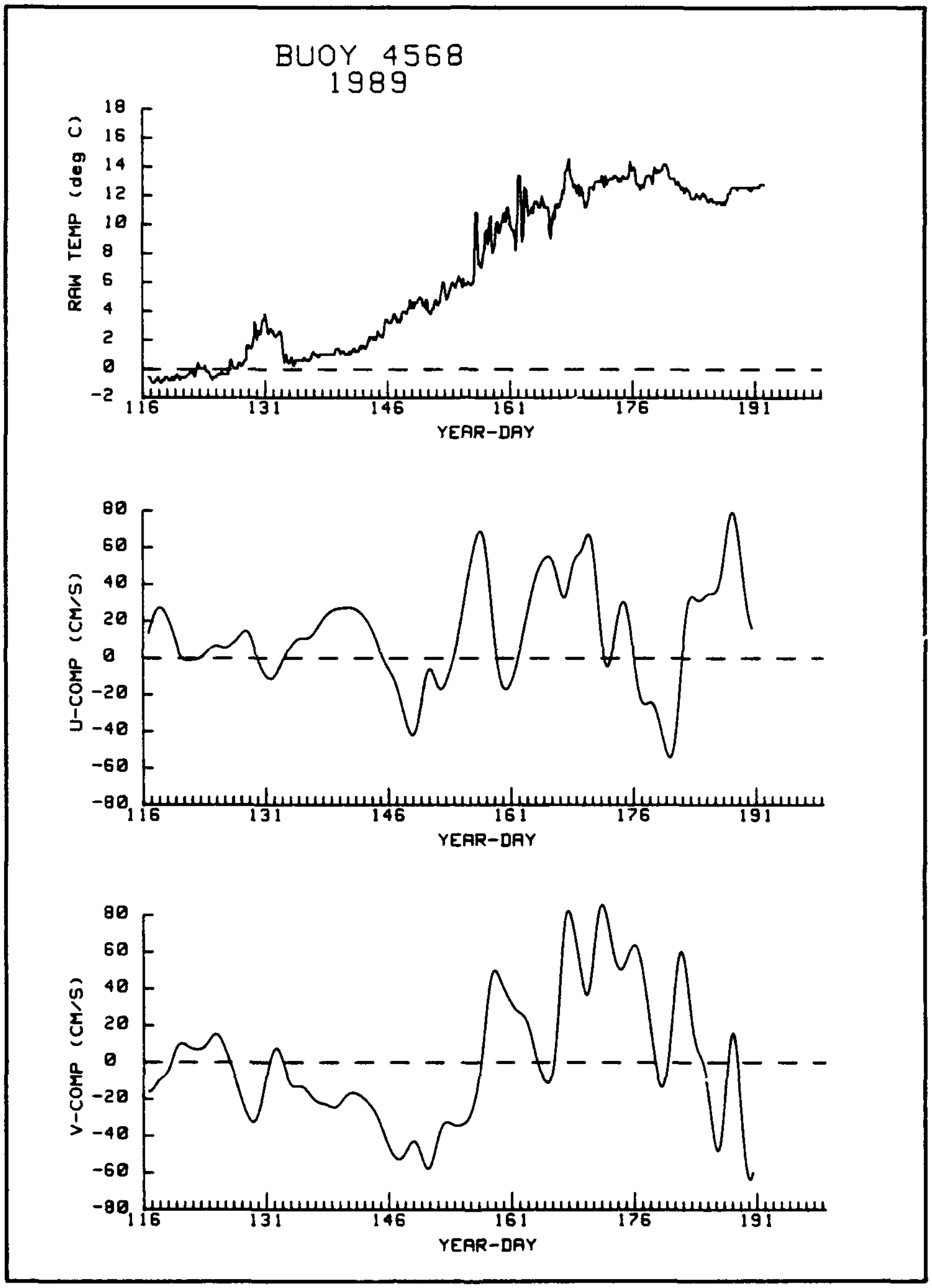


Figure B-7b. Time history of sea surface temperature, U, and V velocity components (filtered) for 4568.

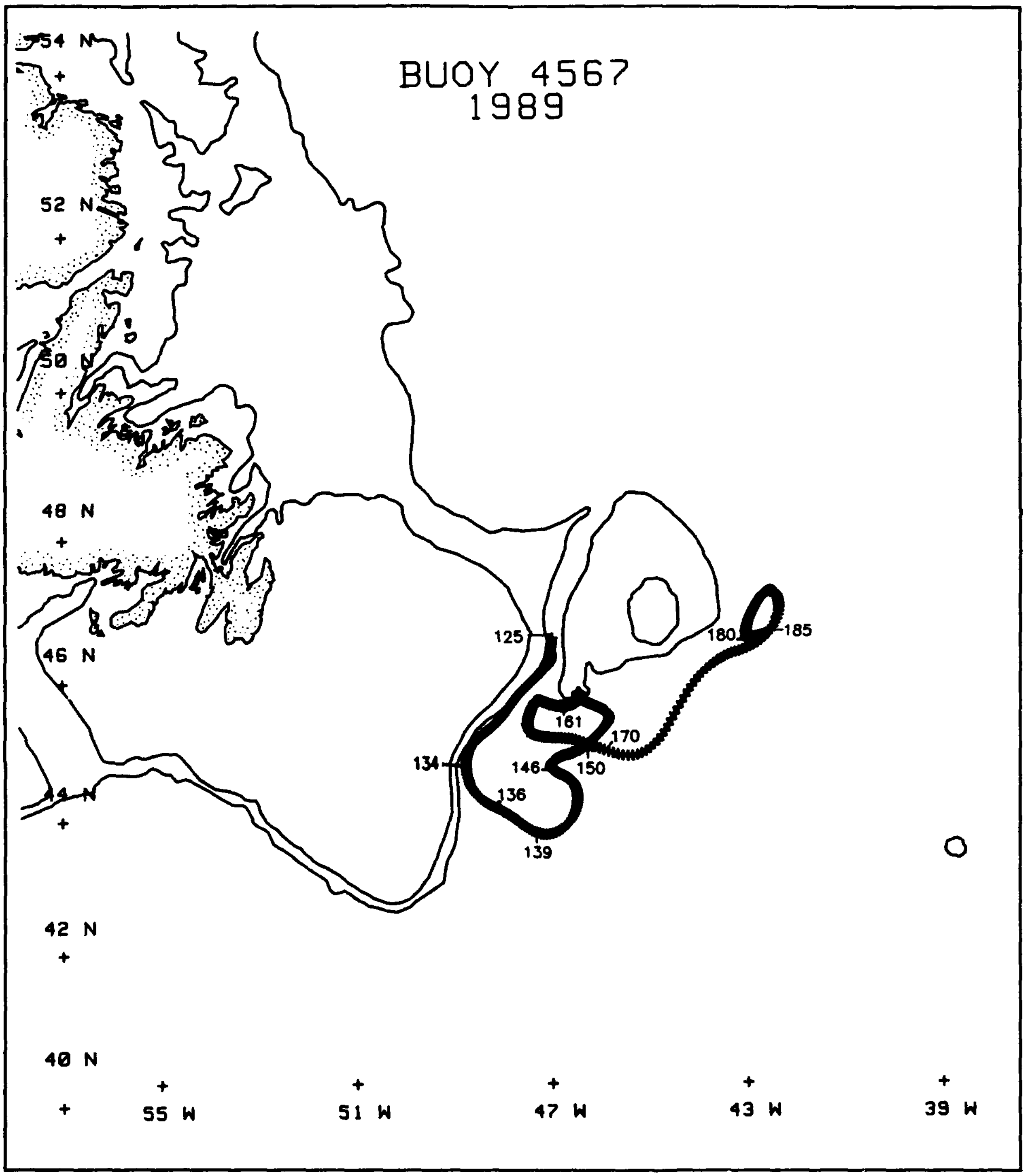


Figure B-8a. Trajectory for 4567.

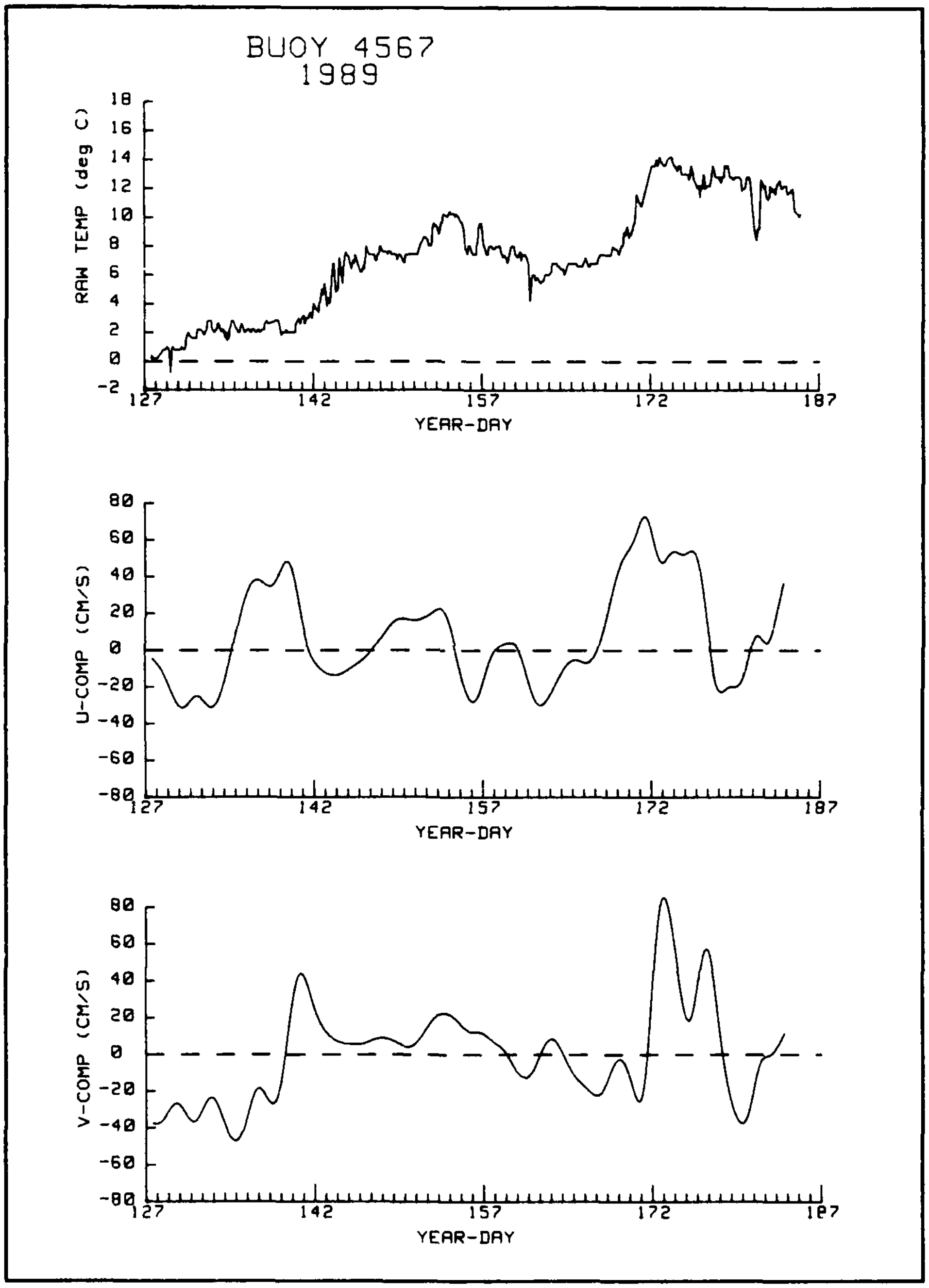


Figure B-8b. Time history of sea surface temperature, U, and V velocity components (filtered) for 4567.

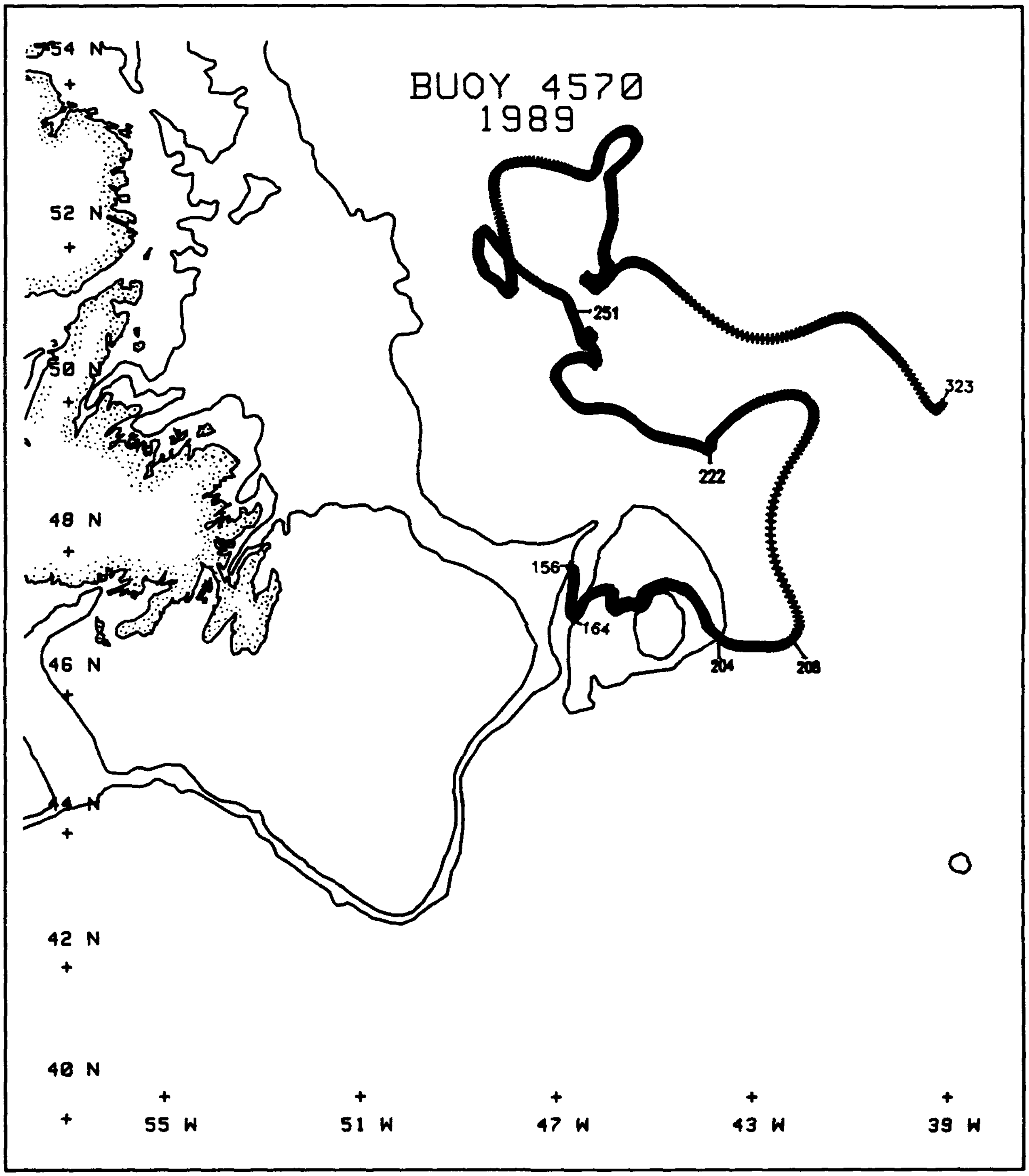


Figure B-9a. Trajectory for 4570.

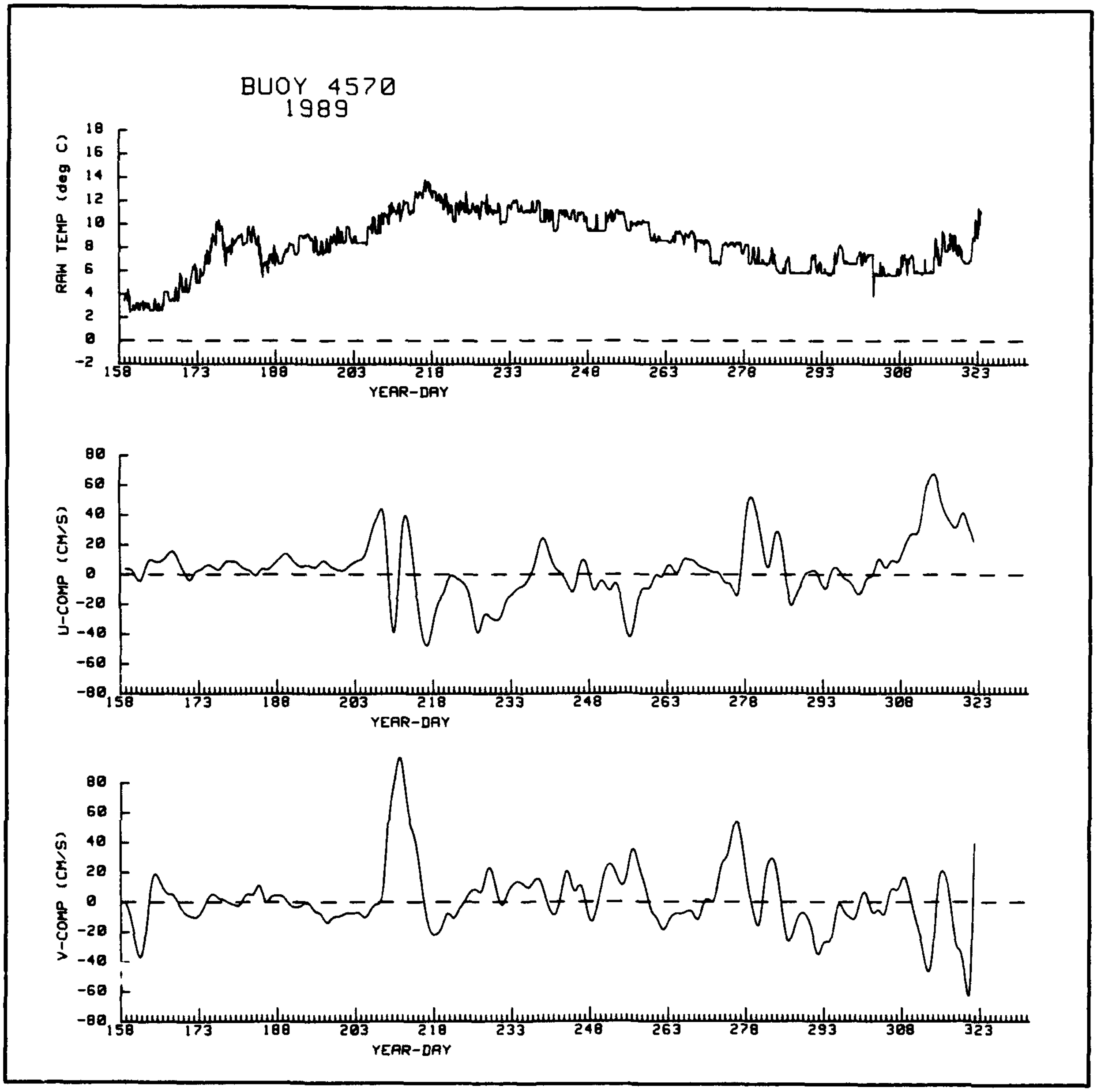


Figure B-9b. Time history of sea surface temperature, U, and V velocity components (filtered) for 4570.

REFERENCES

FENCO, 1987. Optimum Deployment of TOD's (TIROS Ocean Drifters) to Derive Ocean Currents for Iceberg Drift Forecasting. Final Report Submitted by FENCO Newfoundland, Ltd. to Meteorological Ser vices Research Branch, Atmospheric Environment Service, 4905 Dufferin Street, Downsview, Ontario, Canada M3H 5T4.

Murphy, D.L., 1987. Observations of a Warm-Core Eddy Neat the Grand Banks of Newfound!and. Report of the International Ice Patrol in The North Atlantic, 1987 Season. International Ice Patrol, Avery Point, Groton, Connecticut 06340-6096

Summy, A.D. and I. Anderson, 1983. Operational Use of TIROS Oceanographic Drifters by International Ice Patrol (1978-1982). Proceedings of the 1983 Symposium on Buoy Technology. Marine Technology Society, 1825K Street, N.W., Suite 203, Washington, D.C. 20593, pp. 246-250.

ICEBERG MOVEMENT DETERMINED BY SATEL- LITE TRACKED PLATFORMS

By

D. L. MURPHY
and
G. F. WRIGHT

Introduction

The International Ice Patrol (IIP) deployed four satellite-tracked platforms on icebergs drifting east of Newfoundland and Labrador, Canada during the 1989 iceberg season. Two were deployed on icebergs located in sea ice east of Newfoundland in March as part of Ice Patrol's participation in the 1989 Labrador Ice Margin Experiment (LIMEX '89). Two were also deployed on icebergs floating in open water east of Hamilton Inlet in Labrador in mid-June.

The satellite-tracked platforms were TIROS Arctic Drifters (TADs), manufactured by Polar Research Laboratory of Carpenteria, California. They were tracked using the ARGOS Data Collection and Location System carried on two NOAA satellites of the TIROS family, which are polar orbiters. The system position accuracy is about 350 m. Typically, 6-10 fixes per day were received for each TAD. The number of fixes per day is directly proportional to the latitude, so the TADs deployed farther to the north typically provide more positions each day.

The TADs, which were powered by lithium batteries, were designed to withstand the cold temperatures of the high arctic. However, because the TADs were deployed at a relatively low latitude (south of 55°N) and in late winter and spring, alkaline batteries also would have been satisfactory. The TADs were sealed to prevent water damage to the electronics, and as a result they floated. Therefore, they could continue to transmit even after falling off an iceberg. As a result, additional effort is required to ensure that the drift data represent iceberg movement and not a TAD floating in the ocean, but even with the best efforts, this leads to much uncertainty. This issue is discussed in detail later.

All four TADs were deployed from a ship-based helicopter. The TADs were fitted with slings to lower them onto the icebergs from the helicopter. They were also fitted with pointed steel legs to reduce sliding once they were on the icebergs. Figure 1 shows the configuration of TAD 2612. The other three were essentially the same, although there were some minor differences in the physical dimensions. The approximate weight of each TAD was 25 kg.

Data Processing

The position data were fitted to a cubic spline curve to obtain a record with evenly-spaced intervals of 3 hours. The interpolated position records were then filtered using a low-pass cosine filter with a cut-off of 1.16 x 10^5 Hz (about one cycle per day). This filtering removed most tidal and inertial effects. From the filtered position data, speed and direction were calculated using a simple backward-differencing scheme.

The following sections describe the two deployments and present the iceberg tracks. For convience, the dates listed in this report are accompanied in parenthesis by the year dates, the sequential date numbers starting with 1 on 1 January.

LIMEX

TAD Deployments

The two LIMEX TADs (4500 and 2612) were deployed as part of a pilot experiment to examine differential iceberg/sea ice movement during early spring conditions. The iceberg drift data were collected in the context of LIMEX, a large, multidisciplinary, international experiment designed to investigate the physical properties and dynamics of sea ice near the Labrador ice margin in the early spring. Other LIMEX investigators collected data such as sea ice distribution and movement that will support the analysis of the iceberg drift data. As these data are not yet available, so only the iceberg tracks are presented here.

The strategy was to deploy the TADs on apparently stable icebergs (medium to large) far enough offshore to minimize the possibility of grounding. They were deployed using a twin-engine Messerschmitt helicopter, which was based on the CCGC SIR JOHN FRANKLIN. On 11 March (70), one TAD was placed on each of two medium icebergs, which were approximately 20 and 40 km, respectively, northeast of the CCGC SIR JOHN FRANKLIN.

In both cases, the TAD was attached to a hook on the underside of the helicopter by a short length of line. After arriving at the iceberg, the helicopter hovered 5-10 m above it and lowered the TAD to the surface. The helicopter then circled the iceberg so that the ice observers could photograph it and estimate its size. The maximum height of the iceberg

(ID 2612)

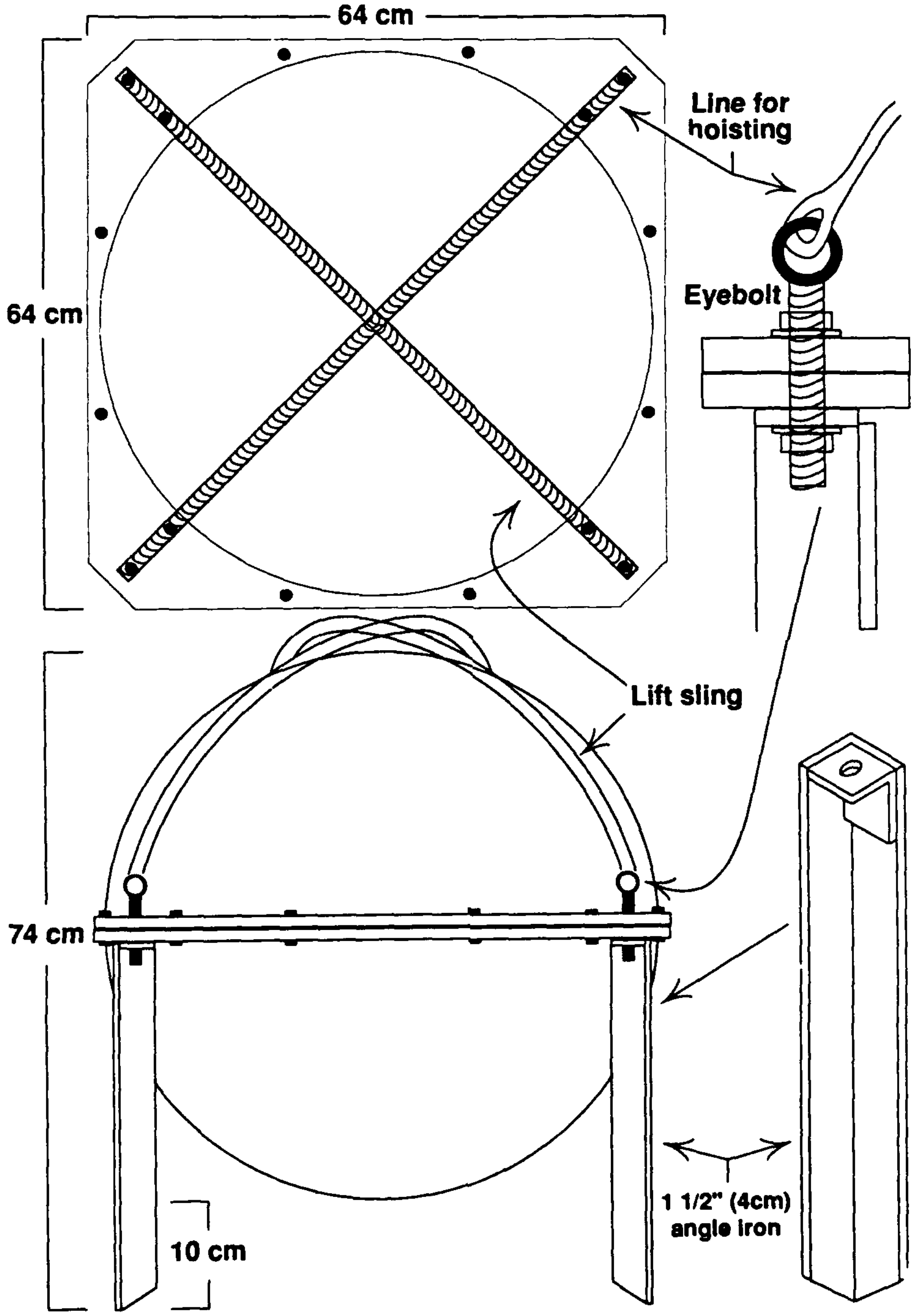


Figure C-1.

above the sea surface was measured using the altimeter on the helicopter.

Table 1 lists the original locations and estimated dimensions of the two icebergs tracked during the study.

Figure 2 shows the results of the aerial sea ice reconnaissance from the flights made when the TADs were deployed. Both icebergs were in sea ice with concentrations > 9/10, which consisted of grey ice and medium and thin first year ice. The predominant form was ice cake, which was approximately 8/10 snow-covered.

Reconnaissance

For two months following the deployments of 4500 and 2612 onto icebergs, IIP periodically attempted to relocate the icebergs during routine aerial iceberg patrols. The intent was twofold: first, to verify that the TADs were still on the icebergs and, second, to determine the extent of sea ice in the vicinity of the icebergs. On the dates of the flights, the ice observers obtained the most recent satellite-derived TAD positions, usually about 3-6 hours old at flight time. In addition, they reviewed the photographs and video tapes of the icebergs onto which the TADs had been deployed.

Search for the icebergs on 29 March (88) was hampered by low clouds and poor visibility. A survey of area with IIP's AN/APS-135 Side Looking Airborne Radar (SLAR) showed several icebergs near each of the satellite-determined positions. In neither case was it possible to identify which iceberg had the TADs. The sea ice cover at both sites, as determined by the SLAR, was approximately 8/10.

On 8 April (98), twenty-eight days after the TAD deployments, an Ice Patrol flight photographed both TADs, verifying that they were still aboard the icebergs. Although reliable measurements could not be made, there was little apparent change in the shape or size of the icebergs. The sea ice concentration in the vicinity of each of the icebergs on this date was about 8/10.

The results of the next attempt, which was made with good visibility on 24 April (114), were not as conclusive. One of the TADs (4500), which was located at 50-20 N, 53-03 W, had stopped transmitting late on 23 April (113). Near the location of the last position transmitted, the ice observers saw a blocky iceberg that had recently broken into two sections, neither of which had the TAD. Several other icebergs which were within a 20 km radius were examined closely, but the TAD was not located.

At the transmitted position of TAD 2612, an iceberg similar in size and shape to that filmed on 8 April was seen. However, the TAD, which was mostly white, could not be seen on the iceberg. The TAD was not evident on the video tape taken during the flight. Also, it was not possible to identify the iceberg positively because of a narrow field of view of the video tape. However, the ice observers were confident that the iceberg at 2612's position was the same iceberg as that in the 11 March photographs and the 8 April video tapes. By 24 April, however, it had developed a large melt pond in its center. Several other icebergs in the vicinity were also examined, but no TAD was sighted. There was no sea ice near either 2612 or 4500.

During the period 4-10 May two attempts were made to search for TAD 2612, but both were limited by low ceilings and poor horizontal visibility. A thorough radar search of the area around 2612's reported position on 9 May (48-46.2 N, 49-35.3 W) revealed one radar target that could not be identified with any confidence. There was no sea ice in the vicinity.

From the flights we conclude that the entire 63-day track of 4500 represents iceberg motion. The silencing of its transmitter on 23 April (113) probably was due to a major calving event which crushed the TAD. The only evidence that supports this conclusion is the existence of a large blocky iceberg, recently broken into two pieces, at the last known position of 4500.

It is likely that 2612 was on its iceberg on 24 April (114). Although the ice observers did not see the TAD on this date, they were confident that the iceberg closest to the TAD posi-

Table 1. Data for LIMEX '89 TAD Deployments onto Icebergs Drifting in Sea Ice

ARGOS ID	DEPLOYMENT DATE	DEPLOYMENT TIME	DEPLOYMENT LOCATION	SIZE Height x Length (in meters)
4500	11 MAR (70)	1330Z	51-39N, 53-06W	MEDIUM 27 m x 120 m
2612	11 MAR (70)	1400Z	51-49N, 53-08W	MEDIUM 34 m x 100 m

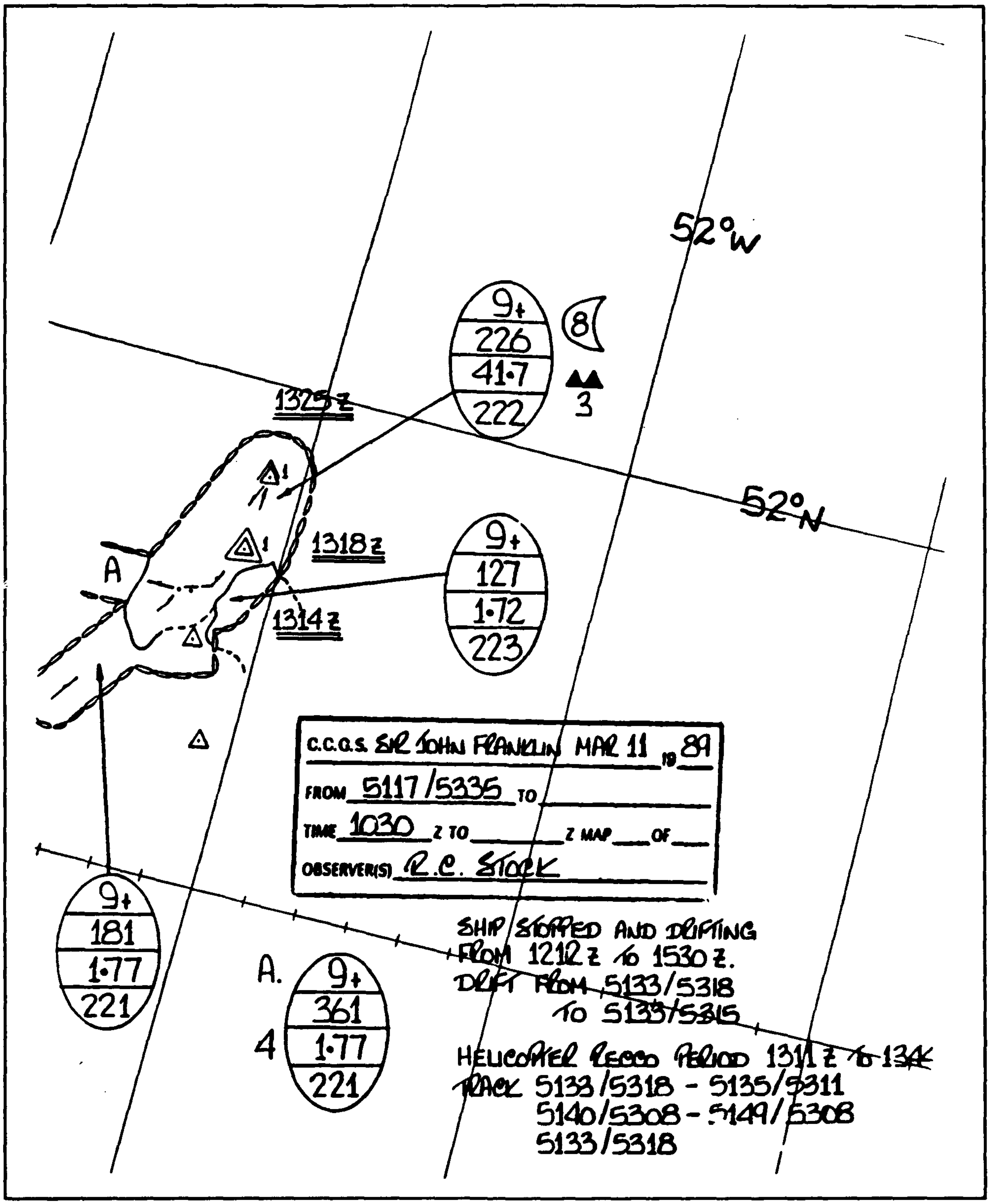

52°W
52°N
9+
226
41·7
222
8
3
1325 z
1318 z
1314 z
9+
127
1·72
223
A
9+
181
1·77
221
A.
4
9+
361
1·77
221
C.C.G.S. SIR JOHN FRANKLIN MAR 11 19 89
FROM 5117/5335 TO
TIME 1030 Z TO Z MAP OF
OBSERVER(S) R.C. STOCK
SHIP STOPPED AND DRIFTING
FROM 1212 Z TO 1530 Z.
DRIFT FROM 5133/5318
TO 5135/5315
HELICOPTER RECCO PERIOD 1311 Z TO 134
TRACK 5133/5318 - 5135/5311
5140/5308 - 5149/5308
5133/5318

Figure C-2.

Table 2. Data for Spring Deployments onto Icebergs in Open Water East of Hamilton Inlet, Labrador				
ARGOS ID	DEPLOYMENT			SIZE (ESTIMATED)
	DATE	TIME	LOCATION	
4504	16 JUNE (167)	1415Z	54-01.5N, 54-30.5W	Large
2580	16 JUNE (167)	1500Z	53-22.1N, 55-29.4W	Large

tion was the iceberg they had seen in the previous photographs. It is best to assume that 24 April was the last day of useful iceberg movement data reported by 2612 because of the lack of any evidence to the contrary.

Figures 3 and 4 present the filtered position data and velocity components of TADs 4500 and 2612. The reason for the short gap between the deployment position and the first plotted filtered position for each is that several points were lost filling the filter. This is also true at the end of the position records. The entire record of 4500 represents iceberg movement. The filled triangle along 2612's track and in the plot of the velocity components marks the date when the TAD was last thought to have been on the iceberg (24 April, 114). There was one short period, from 6 to 7 April (96-97), when the data return was poor, with only one fix for each buoy over a 40-hour period. TAD 2612 transmitted positions until 16 September (259) as it moved eastward across the north Atlantic.

Spring Deployments

The goal of the spring deployments was to study the summer movement of icebergs from the southern Labrador coast to the Ice Patrol operations area, the northern boundary which is at 52° N. There are few long-term (>10 days) iceberg tracks reported in the literature. Using satellite-tracked platforms, Robe (1979) tracked two icebergs and Anderson (1983) three in the region. Of the five, four moved eastward to the north of Flemish Cap, never crossing south of 48°N. This eastward movement is consistent with the observation that, in some years, few icebergs are encountered south of 48°N despite large pre-season iceberg populations along the Labrador coast.

Ice Patrol deployed a TAD on each of two large blocky icebergs along the Labrador Coast east of Hamilton Inlet. The deployments were made with the cooperation of the Canadian Coast Guard, in particular the CCGS ANN HARVEY, whose helicopter made the deployments. The deployments were coordinated by the Canadian Coast Guard Regional Ice Operations Center in St. John's, Newfoundland. Detailed measurements of the icebergs were not made. Both icebergs were in water less than 200 m deep when the TADs were placed aboard. Table 2 summarizes the deployment data.

TAD 4504 provided a 38-day position record (Figure 5), and it is likely that the entire record represents iceberg movement. The data return was excellent, with 8-12 positions recorded on most days. The iceberg tracked by TAD 4504 spent the entire 38-day period on or near Hamilton Bank, mostly in water less than 200 m deep.

After its deployment, 4504 moved northward until 27 June (178), mostly at speeds of about 10 cm/s. The fastest iceberg movement recorded by 4504 occurred during the subsequent southward track (27 June - 3 July, 178-184), most of which was in slightly deeper water (~ 230 m). During this period the iceberg moved at 10-30 cm/s.

After this period, the iceberg returned to the shallow water on Hamilton Bank, where for a 10-day period (3-13 July, 184-194) it moved very slowly. It is likely that the iceberg during this period was dragging intermittently along the bottom. The water depth in the vicinity was about 150 m. Because there were no detailed size measurements taken, it is not possible to say with certainty that the iceberg was grounded. However, for a large iceberg (123-213 m long), a keel depth of about 150 m is a reasonable figure, so grounding was possible.

On 6 July (187) 4504 began a persistent southward movement over Hamilton Bank, beginning at speeds less than 10

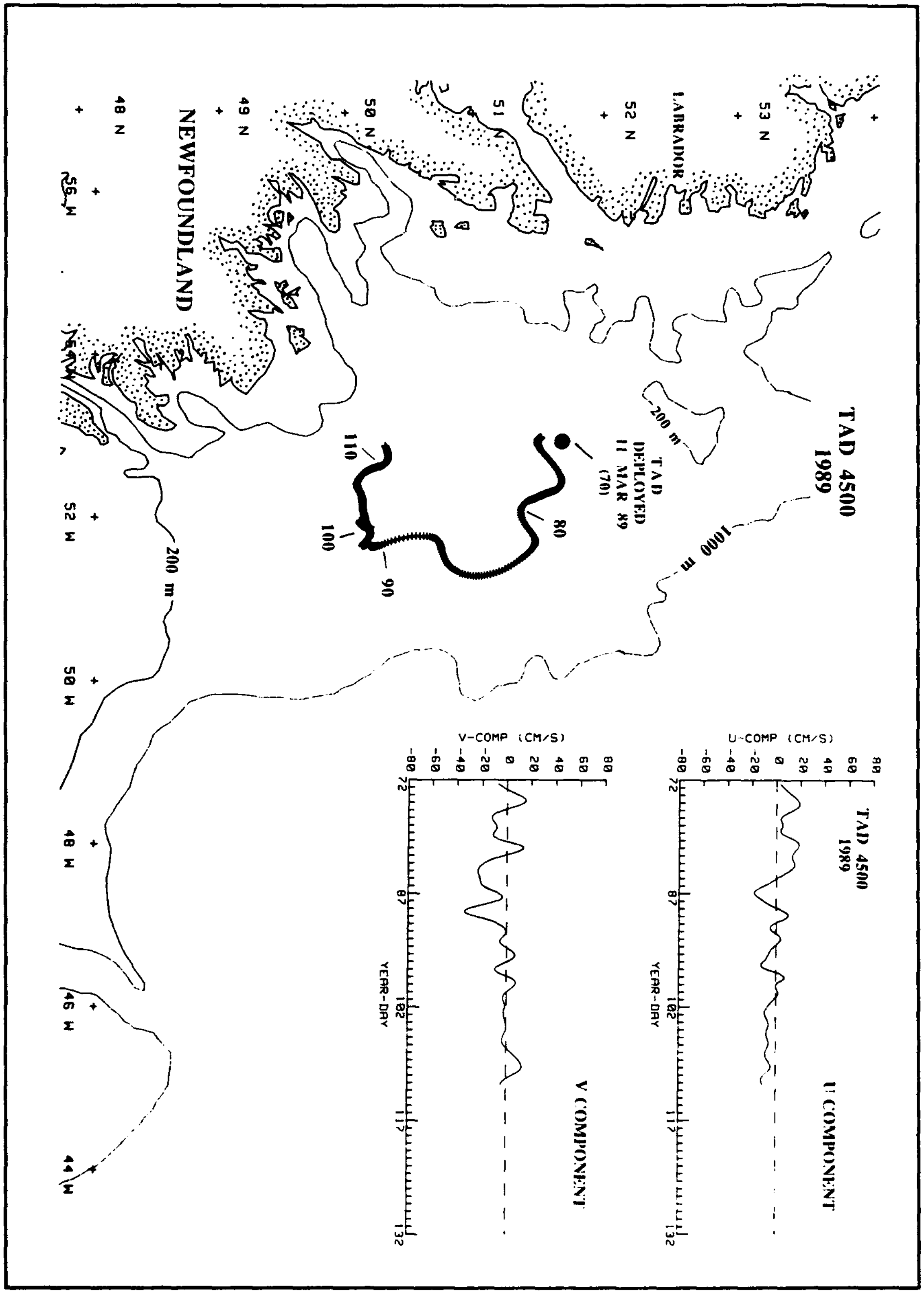

TAD 4500
1989
LABRADOR
NEWFOUNDLAND
53 N
52 N
51
50 N
49 N
48 N
56 W
52 W
50 W
48 W
46 W
44 W
200 m
1000 m
TAD
DEPLOYED
11 MAR 89
(70)
80
90
100
110
U-COMP (CM/S)
V-COMP (CM/S)
YEAR-DAY
U COMPONENT
V COMPONENT

Figure C-3.

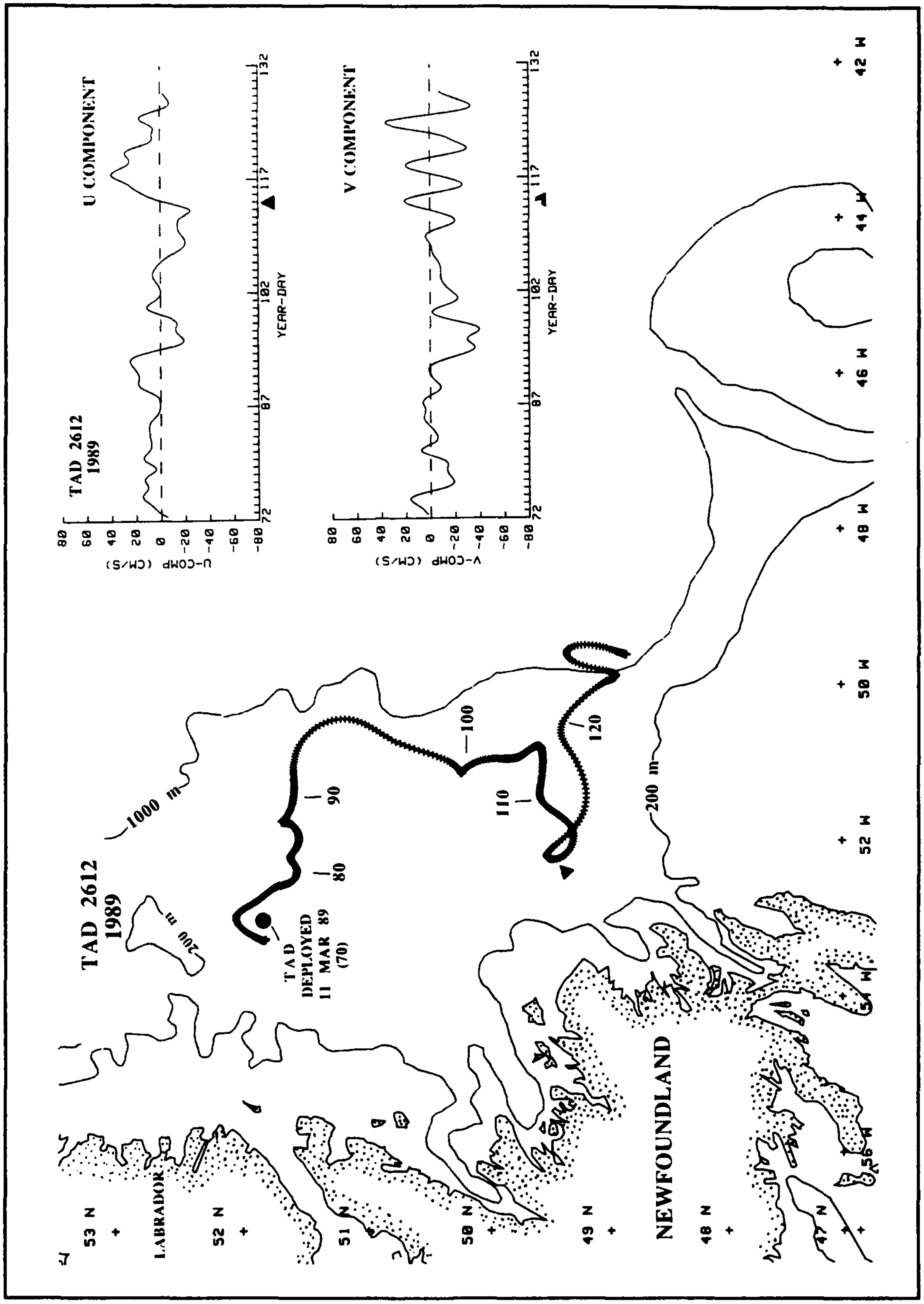

TAD 2612
1989
U COMPONENT
V COMPONENT
U-COMP (CM/S)
V-COMP (CM/S)
YEAR-DAY
TAD
DEPLOYED
11 MAR 89
(70)
1000 m
200 m
LABRADOR
NEWFOUNDLAND

Figure C-4.

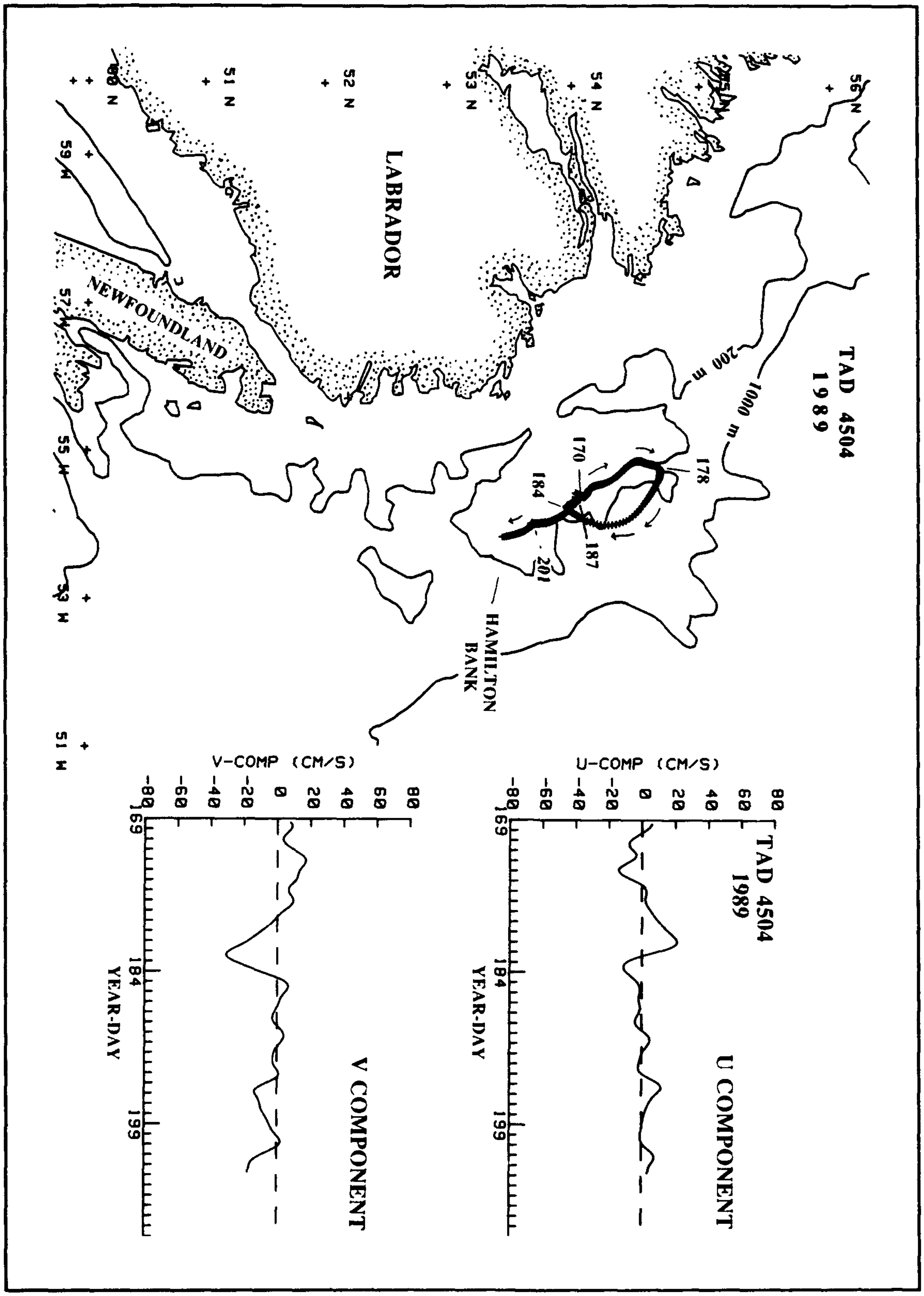

TAD 4504
1989
LABRADOR
NEWFOUNDLAND
HAMILTON
BANK
200 m
1000 m
U COMPONENT
V COMPONENT
U-COMP (CM/S)
V-COMP (CM/S)
YEAR-DAY

Figure C-5.

cm/s. On 20 July (201) the iceberg increased speed to 10-20 cm/s. The TAD failed on 24 July (205).

One attempt was made to relocate and re-sight TAD 4504, but it occurred four hours after its failure on 24 July. Three icebergs were located in the vicinity (within 20 km) of 4504's last known position, the closest of which was a large blocky iceberg, which fit the description of the iceberg on which the TAD had been placed. However, the TAD could not be seen on the iceberg.

TAD 2580 provided a 7-day track before it ceased transmitting on 23 June (174). Because of the short record, the position data were not filtered. The track presented in Figure 6 is plotted using positions interpolated at 24 hour intervals (at 00Z for each date). The U and V components represent 3 hourly averaged values.

During most of the 7-day period, 2580 moved southward. In the first half of the period it averaged 10-20 cm/s, while in the second half it slowed to 5-8 cm/s. On the day that 2580 failed it reversed direction.

Unfortunately, the tracks provided by 2580 and 4504 are not very useful additions to the data set desired by Ice Patrol. Future deployments should be made south of Hamilton Bank and in water depths greater than 200 m deep.

Discussion

Determining how long TADs remain on icebergs is not always easy. Because TADs must survive in the iceberg melt ponds, they are designed not to sink when they fall into the sea. Using the qualitative changes in the TAD's trajectory, such as an increased responsiveness to wind forcing, as an indicator that the TAD is freely drifting is sometimes useful but not conclusive. The internal temperature sensor can sometimes be used to infer that the TAD has entered the sea. However, it is not always possible to distinguish between a TAD in a melt pond and one floating in cold surface water using temperature . Currently, relocating the iceberg and visually confirming that the TAD is still aboard is the only certain method. To this end, painting some bright stripes on the TAD would help the ice observers see it. In fog, a radar survey of the area is useful, but not conclusive evidence that the TAD is on an iceberg. If there are no radar targets in the area it is quite certain that the TAD is no longer on an iceberg. The existence of a radar target in the area is, however, not conclusive evidence that the TAD is on an iceberg. Using the SLAR, it is not always possible to distinguish between an iceberg and a ship passing through the area. Moreover, there are navigational errors associated with the aircraft's inertial navigation system that introduce additional uncertainty into the target identification process.

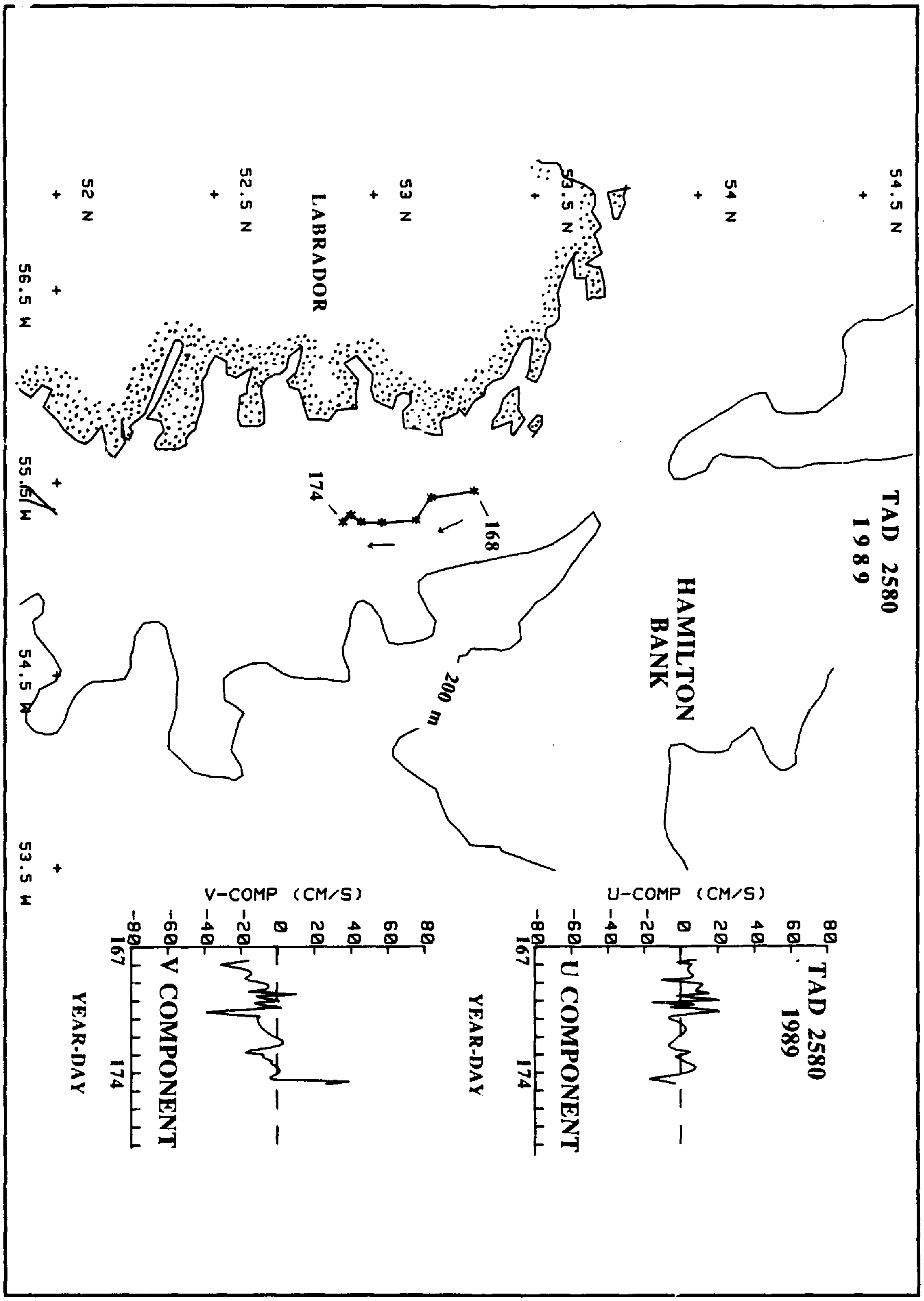

TAD 2580
1 9 8 9
HAMILTON
BANK
200 m
LABRADOR
168
174
54.5 N
54 N
53.5 N
53 N
52.5 N
52 N
56.5 W
55.5 W
54.5 W
53.5 W
TAD 2580
1989
U-COMP (CM/S)
U COMPONENT
YEAR-DAY
V-COMP (CM/S)
V COMPONENT
YEAR-DAY
167
174
80
60
40
20
0
-20
-40
-60
-80

Figure C-6.

References

Anderson, I., 1983. Oceanographic Conditions on the Grand Banks During the 1983 International Ice Patrol Season. Report of the International Ice Patrol in the North Atlantic, 1983 Season, CG-188-38, U. S. Coast Guard, Washington, DC, 1983.

Robe, R.Q. and D. C. Maier, 1979. Long-Term Tracking of Arctic Icebergs. Report CG-D-36-79. U.S. Coast Guard Research and Development Center, Avery Point, Groton, CT 06340-6096, 35 pp.

Robe, R. Q. and D. C. Maier, 1980. Long-Term Drift of Icebergs in Baffin Bay and the Labrador Sea. Cold Regions Science and Technology, Vol. 1, p 183-193.