APPEND-IX XI

# STATISTICAL DESCRIPTION OF THE SUMMERTIME ICE EDGE IN THE CHUKCHI SEA

by

W.J. Stringer and J.E. Groves

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# TABLE OF CONTENTS

# LIST OF TABLES

## LIST OF FIGURES

| Date | Path/Row | Minimum Displacement km/day | Maximum Displacement km/day | Number 1-day Observation | [illegible]mber [illegible]ultiday Observations | Maximum Displacement with distance from shore 0-50 km | 50-100 km | 100 km |
|---|---|---|---|---|---|---|---|---|
| 1973 | | | | | | | | |
| March 14-15 | 80/ 10 | 0.0 | 0*0 | | | | | |
| April 13-14 | 74/10 | < 0.5 s | 3,0 s | 18 | | | 1.0 S | 3.0 s |
| April 14-15 | 74/10 | 0.5 s | 1.0s | '12 ] . | 8 | | 0.5 s | 1.0 S |
| May 5-6 | 78/10 | 6.5 W | 19,5 w | 10 | | | | 19.5 w |
| July 16-17 | 79/10 | 14.5 w | 17.0 w | 4 | | | 17.0 w | 15.0 W |
| July 31-Aug 1 | 75/10 | 2.5 E | 7.5 N | 13 | | 4.5 N | 5.0 NE | 7.5 N |
| 1974 | | | | | | | | |
| March 4-5 | 76/10 | < 0.5 E | 0.5 E | 6 | | | < 0.5 E | 0.5 E |
| March 7-9 | 78/10 | < 0.5 E | 0.5 E | 6 | 0 | 0.5 E | 0.5 E | |
| March 9-10 | 80/ 10 | < 0.5 N | 1.0 N | 5 | | | 1.0 N | |
| March 22-24 | 75/10 | 0.0 | 0.5 SE | 4 | 0 } | | | |
| March 24-26 | 78/10 | < 0.5 E | 1.0 E | 10 | 0 | 0.0 | < 0.5 E | 1.0 SE |
| June 21-22 | 76/10 | 1.5s | 7.0 s | 19 | | 7.0 s | 5.0 s | 5.0 s |
| June 25-26 | 80/1 0 | 2.5 W | 15.0 w | 10 | | | 13.5 w | 15.0 w |
| Sept 4-6 | 79/10 | 17.0 w | 50.0 w | 12 | 3 | 32.5 W | 50.0 w | 20.5 W |
| 1975 | | | | | | | | |
| March 18-19 | 76/10 | 0.5 s | 5.5 w* | 27 | | 1.0 W | 3.0 W | 5.5 w |
| April 3-4 | 74/10 | 1.5s | 2.5 S | 18 } | ** 17 | 1.5 S | 2.0 s | 2.5 S |
| April 4-5 | 74/10 | 2.0 w | 16.0 W | 27 | | 16.0 W | 16.0 W | 6.0 W |

* Unusually large movement for March. Average Maximum Displacement = .4 km /day

** Reversal of ice motion direction immediately following collision of large floes off MacKenzie Delta

| Date | Path/Row | Minimum Displacement km/day | Maximum Displacement km/day | Number 1-day Observations | Number Multiday Observations | Maximum Displacement with distance from shore 0-50 km | 50-100 km | 100 km |
|---|---|---|---|---|---|---|---|---|
| **1976** | | | | | | | | |
| Febr 14-15 | 76/10 | 0,0 | 0.0 | | | | | |
| Febr 17-18 | 79/10 | 0.0 | 0.0 | | | | | |
| Febr 18-19 | 80/10 | 0.0 | 0.0 | | | | | |
| March 21-22 | 76/10 | 0.0 | 0.0 | | | 0.0 | 0.0 | 0.0.. |
| April 9-10 | 77/10 | < 0.5 s | 2.5 S | 11 | | < 0.5 s | 0.5 E | 2.5 S |
| May 31-June 1 | 75/10 | 2.5 N | 8.0 w | 20 | 14 | | 7.5 w | 8.0 W |
| June 1-2 | 75/10 | 9.0 w | 12.5 W | 21 | | | 12.5 w | 11. 0 w |
| June 4-5 | 79/10 | 1.5 W | 9.5 w | 13 | 5 | { - | 9.0 w | 7.5 w |
| June 5-6 | | | | | | | 1.5 W | 6.0 W |
| July 23-24 | 74/10 | 3.0 w | 25.0 w | 17 | | 25.0 W | 5.5 w | 4.5 w |
| July 28-29 | 79/10 | 3.0 NW | 10.0 w | 16" | | 10.0 w | 8.0 NW | 5.0 NW |
| **1977** | | | | | | | | |
| Febr. 26-28 | 77/10 | 0.0 | 0.0 | | | | | |
| March 20-21 | 79/10 | 0.0 | 0.0 | | | | | |
| March 21-22 | 80/1 0 | 0.0 | 0.0 | | | | | |
| April 6-7 | 79/10 | 0.5 N | 1.5 NE | 4 | | 0.5 N | | 1.5 NE |
| July 5-6 | 79/10 | 6.0 W | 20.0 w | 11 | 0 | | 16.0 W | 9.5 w |
| July 6-7 | | | | | | | 20.0 W | 13.5 W |
| **1978** | | | | | | | | |
| March 21-22 | 77/10 | < 0.5 S | 0.5 E | 6 | | < 3.5 s | < 0.5 E | 0.5 E |
| May 15-16 | 78/10 | 6.0 W | 9.5 w | 7 | | 8.0 W | 9.5 w | 9.0 W |
| July 7-8 | 77/10 | 1.5s | 6.0 E | 23 | 7 | 6.0 E | 4.5 E | 3.0 S |
| July 8-9 | 78/10 | 2.0 W | 12.0 w | 14 | | 11.0 w | 10.0 w | 11.5 W |
| July 17-18 | 78/10 | 6.0 W | 34.5 w | 20 | | 27.5 W | 3465 W | 12.5 W |

| Date | Path/Row | Minimum Displacement km/day | Maximum Displacement km/day | Number 1-day Observations | Number Multi-day Observations | Maximum Displacement with distance from shore 0-650 km | 50-100 km | 100 km |
|---|---|---|---|---|---|---|---|---|
| 1979 | | | | | | | | |
| March 18-19 | 79/10 | 0.5 S | 1.0s | 9 | | 0.5. s | 1.0 S | 1.0s |
| June 6-7 | 78/10 | 8.5W | 10.5 w | -12 | | 10.5 w | 11.0 W | 10.0 w |
| July 13-14 | 79/10 | 0,5 SE | 3.5 E | 23 | | 3.5 E | 1.5 E | 1.5 E |
| July 14-15 | 79/10 | 3.0 E | 5.0 E | 10 | 10 | 5.0 E | 3.5 E | |
| July 21-22 | 77/10 | 3.0 w | 12.5 W | 19 | | 12.5 W | 12.5 W | 10.0 w |
| 1980 | | | | | | | | |
| March 30-31 | 79/10 | 0.0 | 0.0 | | | | | |
| June 15-16 | 75/10 | 4*OW | 6.5 W | 17 | | 4.0 w | 7.0 W | 7.0 w |
| June 16-17 | | | | | | | 0.5 SE | 0.5 SE |
| June 17-18 | 77/10 | 0.5 s | 1.0 SE | 33 | 19 | 0.5 s | 1.0 SE | 1.0 SE |
| July 2-3 | | | | | | 36.0 W | 70.0 W | 19.5 W |
| July 3-4 | 74/10 | 10.5 w | 70,0 w | 26 | 14 | 33.5 w | 21.5 w | 19.5 w |
| July 4-5 | | | | | | | 18.5 W | 18.5 W |
| July 5-6 | 77/10 | 13.5 w | 19.5 w | 9 | | 19.5 w | 17.0 w | |
| Nov 9-10 | 78/10 | 2.5 S | 29.5 W | 11 *** | | 9.0 E | 29.5 W | 6.5 W |
| Nov 9-10 | 78/ 10 | " 6.0 E | 9,0 E | 5 **** | | | | |

*** Includes two 3-Day measurements

**** Two simultaneous movement patterns

| Date | Path/Row | Minimum Displacement km/day | Maximum Displacement km/day | Number B-day Observations | mber tiday Observations | Maximum Displacement with distance from shore 0-50 km | 50-100 km | 100 km |
|---|---|---|---|---|---|---|---|---|
| 1981 | | | | | | | | |
| March 24-25 | 78/10 | < 0.5 E | < 0.5 E | | | < 0.5 E | < 0.5 E | < 0.5 E |
| April 1-2 | 78/1 0 | 10.0 w | 16.0 W | 12 | | 16.0 W | 15.0 W | 14.0 w |
| April 2-3 | 77/10 | 11.5 w | 13.0 w | 10 | | 11.5 w | 12.5 W | 12.0 w |
| June 12-13 | 77/10 | 11.5 w | 13.0 w | 19 | | 12.5 W | 12.5 W | 12.0 w |
| June 15-16 | 80/1 0 | 7*5W | 11.0 w | 8 | | | 11.0 w | 10.5 w |
| July 21-22 | 80/1 0 | 4.5 E | 10.5 E | 11 | ***** | 9.5 w | 10.5 E | |
| July 21-22 | 80/ 10 | 2.0 s | 9.5 w | 6 | | | | |

Eighteen-Day Displacements

| Date | Minimum | Maximum | Number | Daily Displacement for 18-Day Period Min. | Max. |
|---|---|---|---|---|---|
| 1973 | | | | | |
| June 29-Jul 16 | 30.0 w | 31.0 w | 3 | 1.7 W | 1.7 W |
| July 14-31 | 79.0 E | 70.0 E | 1 | 4.0 E | 4.0 E |
| 1974 | | | | | |
| March 5-23 | 3.5 w | 7.0 w | 5 | 0.2 w | 0.4 W |
| March 7-25 | 6.0 W | 7.0 w | | 0.3 w | 0.4 w |

***** Two simultaneous movement patterns

TABLE II.

Direction Frequency and Average Magnitude of Floe Displacements

Frequencies and (Percent of Occurrences) — Average Magnitude km/day

| | | North | South | East | West | Other | No Movement | West | Non-West |
|---|---|---|---|---|---|---|---|---|---|
| February | Maximum | 0(.00) | 0(.00) | 0(.00) | 0(.00) | 0(.00) | 4(1.00) | - | 0 |
| | Minimum | 0(.00) | 0(.00) | 0(.00) | 0(.00) | 0(.00) | 4(1.00 | - | 0 |
| March | Maximum | (.07) | .07) | 5'.36) | (.07) | 1 .07)SE | 5(.36, | 5.5 | .4 |
| | Minimum | (.07' | 3(.21) | 4(.29) | 0(.00) | 0(.00) | 6(.43) | – | 0.3 |
| April | Maximum | 0(.00) | 4(.50) | 0(.00) | 3(.38) | 1(.13)NE | 0(.00) | 15.0 | 2.1 |
| | Minimum | 1(.13) | 4(.50) | 0(.00) | 3(.38) | 0(.00) | 0(.00) | 7.8 | 0.7 |
| May | Maximum | 0(.00) | 0(.00) | 0(.00) | 3(1.00) | 0(.00) | 0(.00) | 12.3 | - |
| | Minimum | (.33 | 0(.00) | 0(.00) | 2(.66) | 0(.00) | 0(.00) | 6.3 | 2.5 |
| June | Maximum | 0(.00) | 0(.00) | 0(.00) | 7(.77) | 1( )SE | 0(.00) | 11.1 | 4.0 |
| | Minimum | 0(.00) | 2 .22) | 0 .00 | 7(.77' | 0(.00) | 0(.00) | 6.4 | 1.0 |
| July | Maximum | 1(.07) | 0(.00) | 4(.27) | 0(.67' | 0(.00) | 0(.00) | 23.0 | 6.5 |
| | Minimum | 0(.00) | 2 .13) | 3(.20) | 8(.53) | 2(. 3 | 0(.00) | 7.3 | 2.4 |
| September | Maximum | 0(.00) | 0(.00) | 0(.00) | 1(1.00) | 0(.00) | 0(.00) | 50.0 | - |
| | Minimum | 0(.00) | (.50) | 0(.00) | 1(.50) | 0(.00) | 0(.00) | 17.0 | - |
| November | Maximum | 0(.00) | 0(.00) | 1(.50) | 1(.50) | 0(.00) | 0(.00) | 29.5 | 9.0 |
| | Minimum | 0(.00) | (.50) | 1(.50) | 0(.00) | 0(.00) | 0(.00) | - | 4.3 |
| Maximum Frequencies | | 2(.00) | 6(.11) | 10(.18) | 6(.46) | 3(.05) | 9(.16) | | |
| Minimum Frequencies | | 3(.0 ) | 12(.21) | 8(.14) | 1(.38) | 2(.04) | 0(.18) | | |
| Average Max. km/day | | 4.3 | 2.8 | 3.7 | 8.3 | 1.0 | | 8.3 | 2.2 |
| Average Min. Km/day | | 1.2 | 1.0 | 2.3 | 7.4 | 1.8 | - | 7.4 | 1.0 |

TABLE III.

Floe Displacement with Distance from Shore
Direction Frequency and Mean Magnitude

| | W | S | E | N | Other | O | Total | Mean W Only | Mean All |
|---|---|---|---|---|---|---|---|---|---|
| March | | | | | | | | | |
| 0-50 | 1 | 2 | 2 | 0 | 0 | 2 | 7 | 1.0 | <.4 |
| 50-100 | 1 | 1 | 5 | 1 | 0 | 1 | 9 | 3.0 | .8 |
| >100 | 1 | 1 | 4 | 0 | 0 | 1 | 7 | 5.5 | 1.3 |
| April | | | | | | | | | |
| 0“50 | 3 | 2 | 0 | 1 | 0 | 0 | 6 | 14.5 | 7.7 |
| 50”100 | 3 | 3 | 1 | 0 | 0 | 0 | 7 | 14.5 | 6.8 |
| ?100 | 3 | 4 | 0 | 0 | 1 | 0 | 8 | 10.7 | 5.3 |
| May | | | | | | | | | |
| 0-50 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 8.0 | 8.0 |
| 50-100 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 8.5 | 8.5 |
| >100 | 3 | 0 | 0 | 0 | 0 | 0 | 3 | 12.2 | 12.2 |
| June | | | | | | | | | |
| 0-50 | 3 | 2 | 0 | 0 | 0 | 0 | 5 | 9.0 | 6.9 |
| 50-100 | 8 | 1 | 0 | 0 | 2 | 0 | 11 | 9.8 | 7.7 |
| >100 | 8 | 1 | 0 | 0 | 2 | 0 | 11 | 9.9 | 7.8 |
| July | | | | | | | | | |
| 0-50 | 9 | 0 | 3 | 1 | 0 | 0 | 13 | 20.5 | 15.7 |
| 50-100 | 11 | o | 4 | 0 | 2 | 0 | 17 | 22.0 | 16.2 |
| )100 | 10 | 1 | 1 | 1 | 1 | 0 | 14 | 13.4 | 10.8 |
| September | | | | | | | | | |
| 0-50 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 32.5 | 32.5 |
| 50-100 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 50.0 | 50.0 |
| ?100 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 20.5 | 20.5 |
| November | | | | | | | | | |
| 0-50 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | | 9.0 |
| 50-100 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 29.5 | 29.5 |
| >100 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 6.5 | 6.5 |
| Frequency | 72 | 18 | 21 | 4 | 8 | 4 | 127 | 14.9 | 9.4 |
| % Occurrence | 57% | 14% | 17% | 3% | 6% | 3% | | | |
| Freq. 0-50 | 18 | 6 | 6 | 2 | 0 | 2 | | | |
| % Occurrence | 25% | 33% | 29% | 50% | o% | 50% | | 16.5 | 9.9 |
| Freq.50-100 | 27 | 5 | 10 | 1 | 4 | 1 | | | |
| % Occurrence | 38% | 28% | 48% | 25% | 50% | 25% | | 17.2 | 10.7 |
| Freq. ?100 | 27 | 7 | 5 | 1 | 4 | 1 | | | |
| % Occurrence | 38% | 39% | 24% | 25% | 50% | 25% | | 11.6 | 7.8 |

List of Figures (cont.)

# ABSTRACT

Ice edge data has been analyzed for ice recursion analysis in the Chukchi Sea for a twelve year period. A variety of related products have been created. These include: 1) a set of weekly ice-free frequency maps for the Beaufort and Chukchi Seas, 2) graphs of weekly minimum and maximum extent of ice in the Chukchi Sea during the study period, 3) graphs of weekly Chukchi Sea ice extent, 4) weekly Chukchi Sea ice edge frequency maps, 5) station-specific ice presence frequency graphs for 67 Chukchi Sea stations, 6) station-specific ice presence history charts for 67 Chukchi Sea stations, 7) maps of the average and median dates of breakup and freezeup in the Chukchi Sea, 8) maps of the average and median lengths in days of the longest period of continuous ice-free water in the Chukchi Sea, 9) a map of the difference in days between the average and median lengths (skewedness) of the longest period of continuous ice-free water in the Chukchi Sea, 10) a map of the percent frequency of ice recurrence in the Chukchi Sea, 11) a descriptive calendar of significant events related to ice edge behavior in the Chukchi and Beaufort seas, 12) a table of station-specific calculated ice edge behavioral parameters for 67 Chukchi Sea locations, 13) a table of ice recurrence behavior for 67 specific locations in the Chukchi Sea, and 14) a detailed analysis of the influence of melt-back bays in the configuration of the Chukchi Sea ice edge.

Conclusions drawn include: 1) numerous parameter comparisons describing the great variability of ice extent found in the Chukchi Sea, 2) that for a period of80 to 100 days beginning with August and continuing through October, ice-free water will exist in the Chukchi Sea south of 70"N and 175°W. Within these boundaries ice will return (recur)

once after it has retreated in the spring, or it will retreat once after it has returned in the fall, less than 50% of the time, 3) ice in the western Chukchi Sea (along the Siberian coast) may provide multi-year ice to the Bering Sea through Bering Strait starting in late fall, 4) melt-back bays (defined by Paquette and Bourke, 1981) created by warm Bering Sea waters channeled by Chukchi Sea bathymetry are persistent. and significant features of the Chukchi Sea ice edge.

# Statistical Description of the Summertime Ice Edge in the Chukchi Sea

## Introduction

The Chukchi Sea occupies the Chukchi Shelf, a shallow segment of the continental shelf of the Arctic Ocean north of the Bering Strait, south of approximately 73°N, bounded on the west by Wrangel Island and the north coast of Siberia, and on the east by the northwest coast of Alaska.

The bathymetry of the Chukchi Sea is not as well known as that of other coastal areas of Alaska. The conspicuous features are a flat central basin of 50 meters depth; two deep troughs approximately 60 m deep extending into the Arctic Ocean (Herald Canyon near Herald Island, and Barrow Canyon northwest of Pt. Barrow); and a shallow area (Herald Shoal) at approximately 71°N and 171°W.

Scientific expeditions visited the Chukchi Sea in the late 1800's. As early as 1922 Sverdrup observed a north-"flowing current near Herald Island. However, the major research effort took place in the 60's and 70's. In the 60's this effort involved basic research into the mechanism of interaction between the Arctic Ocean and the North Pacific Ocean through Bering Strait. The Bering and Chukchi seas were investigated to aid understanding of the Bering Strait. In the 70's the Chukchi Sea became of interest in its own right due to potential offshore oil development off its Alaskan coast, and to its use as a shipping corridor to the Beaufort Sea.

Studies in the 70's concentrated on the Marginal Ice Zone (MIZ). The Marginal Ice Zone is defined as the region where the ice edge interacts with the water front.

This work further defines statistically the location and time frame of melt-back and freezeup of the ice edge in the Chukchi. It relates the observations to circulation patterns described for the Chukchi by Coachman, Aagaard, and Trip (1975).

## Data and Analysis

Twelve years' (1972 thru 1983) weekly Navy/NOAA Joint Ice Center Analysis Charts of the Southern Ice Limit were assembled for computer analysis. Twenty-seven one-week periods were included, starting from the first week in June and ending with the first week in December. This involved the analysis of 324 individual Ice Analysis Charts. The area covered extended from Banks Island (120°W) to Wrangel Island (170°E) and from approximately 75*N to approximately 64°N, or just south of the Bering Strait (Figure 1).

The location of the ice edge on each chart was digitized to create a computer file. The ice edge was treated as a boundary between water that. contained at least some ice (which includes the NOAA classification category O/W, or open water) and water that was completely ice-free. The twelve years' data available for each week were combined to produce 27 weekly ice-free frequency maps (Figures 2-28), which characterized ice cover in the Chukchi and Beaufort seas into four ice-free frequency categories: water that was completely ice-free for twelve out of twelve years; water that contained at least some ice for twelve out of twelve years; water that contained some ice for one to six years; and water that contained some ice for seven to eleven years.

Ice-free frequency maps are very useful for demonstrating when, where, and how often one is likely to find water which is completely ice-free. They are less useful for predicting how much ice is present, because the ice-present category contains contributions from all the Ice Center Analysis Charts' ice concentrations, from 100% sea ice covered to "sea ice present in concentrations less than one tenth."

Ice concentration frequency maps are practically much more difficult to generate as one is, in essence, faced with the problem of comparing the extent and frequency of the occurrence of each ice concentration subdivision, in turn with all the remaining ice concentrations.

A third type of ice map, the average ice concentration map, is derived from the average of all the ice concentrations observed at a given point over a period of years. This map reveals frequency of occurrence only at the ice-free and 100% ice-covered concentration, unless one takes the trouble to do statistical calculations at station locations. Average ice concentration maps were not made because of the additional complication that would have been added to the project by the necessity of digitizing the individual ice concentrations, as well as the ice edge. Furthermore, the average ice concentration is frequently misleading. For instance, a hi-modal distribution having 0% and 100% concentrations, each half of the time, yields an average concentration of 50%--yet this never occurs.

A smaller study area within the large region described earlier was chosen to facilitate statistical analysis of ice-free conditions in the Chukchi Sea (Figures 29 and 30). Pt. Barrow was selected to mark the eastern border, Wrangel Island for the western border, the most northerly extent of the ice edge observed in the twelve year period for the northern border, and a line drawn along the shortest distance across Bering Strait for the southern border. The actual lines to be used were selected for easy utilization of the product generated by computer from the digitization of the raw Southern Ice Limit data sheets. The studied area was $6X10^5 km^2$ and contained 6081 individual data cells, each representing approximately 100 $km^2$. The resolution of the satellite imagery from which the analysis charts are drawn is 1 km. However, the analysis charts themselves are of a size such that 5 km is the best precision to be expected. Thus, the size of the data cell (10X10 km) is compatible with the precision of the data sheets.

## Results and Conclusions

### 1. General Properties of the Open Water Season in Chukchi Sea

Calculations were made of the percentage of the study area covered by the four ice-free frequency classes. Plots were made of the percentage of maximum ice-free area observed for each week in any one of the twelve years versus time (Figure 32), and of the minimum ice-free area observed for each week (Figure 31). This was done to document the time when the maximum icc-free area occurred, and to give some indication how large the minimum icc-free area was in relation to the maximum ice-free area for each week. These calculations revealed that an ice-free region which is relatively stable in total area (25-30% of the study area) and location, is consistently established for a seven-week period, between the second week in August and the end of September. This area is roughly about one third of the maximum open water area observed. The location of this area can be seen in Figures 55-61, where it appears as the area with a 100% ice-free frequency.

Reference to Figures 31 and 32 allowed the following generalities to be made concerning the appearance and extent of completely ice-free water in the Chukchi Sea. Table 1 summarizes these events. The appearance of ice-free water occurred in the first week in June (Figure 32). Inspection of the individual Southern Ice Limit sheets for the week prior to the first week in June reveals that no ice-free water was present in the Chukchi Sea in the last week in May. The first occurrence of an area which was ice-free for twelve years occurred the second week in July. The maximum ice-free area observed occurred the first week in October and occupied 95% of the study area. The maximum area which was ice-free all twelve years occurred the first week in September and occupied 32% of the study area.

Around the second or third week in October both the maximum ice-free area and the minimum ice-free area began to decrease sharply. After the last week in October there was no area ice-free for all twelve years. However, significant variations took place; at least once in the twelve-year period, an ice-free area was *not* only present into the third week in November, but it was fairly extensive, occupying 20% of the study area.

Plots of ice-free area versus time were made for each of the twelve years (Figures 33-44). These plots allow comparisons to be made between the generalized twelve-year data and individual years.

The years 1975 (Figure 36) and 1983 (Figure 44) emerge as the minimum ice-free years. The years 1978 (Figure 39) and 1979 (Figure 40) emerge as the maximum ice-free years. The individual minimum ice-free years have a larger area of ice-free water than the generalized plots imply, and the individual maximum ice-free years have a somewhat smaller area than implied. This is because the location of the boundaries of the areas of maximum and minimum ice-free water varies from year to year. Thus, while the generalized plot for all-time minimum area of ice-free water was at a maximum of 32% of the study area in the first week in September, the equivalent percentages for 1975 and 1983 are 42% in the first week of September and 48% in the last week of August, respectively.

In the falls of 1972 and 1979 (Figures 33 and 40) a significant decrease in the area of ice-free water occurred, followed by an increase. Our interpretation of this is that conditions occurred to initiate an early freezeup, but these conditions did not persist long enough for freezeup to be completed. The ice-free peak of November 14, 1979 appears to be due to a genuine retreat to nearly 73°N of the ice pack, which had advanced to 72″N prior to November 14.

On the other hand, the event of 1972 appears to have been a rapid freezing of "new ice" followed by an equally rapid "melt back". Inspection of the Southern Ice Limit sheets for September 26 to October 10, 1972, . the weeks immediately preceding and following the week of the decrease in ice-free area, October 3, shows the Southern Ice Limit at roughly 73°N. On October 3 there is an ice category boundary corresponding to the September 26 and October 10 Southern Ice Limits at 73°N, but there is also a large area of "new ice" indicated, which establishes a new Southern Ice Limit at about 71°N. No alternate imagery is available to check the validity of the "new ice" designation.

Interpretation of Southern Ice Limit sheets presents certain difficulties. Some of the 324 Southern Ice Limit sheets are difficult to read. On other Southern Ice Limit sheets, features which look identical have been interpreted differently in different weeks, leading to the suspicion that interpretation is not always consistent. The data sheets for the years 1972-1974 do not possess the intricate detail of the more recent data sheets. Occasionally, the position of the ice edge is estimated. However, the policy for the digitization of the sheets was to regard them as the best and most complete data set available on location of the ice edge in the Chukchi Sea, and to assume that any small errors introduced due to the above problems would be smoothed out in the generalized product from the computer analysis. The only questionable observation this policy produced in the generalized product was the early temporary ice edge advance in October, which may be due to the anomaly of October 1972.

The following generalizations can be made based on the statistical description of the summertime ice edge in the Chukchi Sea:

1) Under optimal melt-back conditions (Figure 32) a significant area of ice-free water (20% or more of the study area) can appear for a 19 week period, starting as early as the third week in June and persisting as late as the third week in November. A period of maximum ice-free conditions (90%′ of the study area) can appear between the second week in September and the third week in October. These conditions describe events in 1979 (Figure 40).

2) Under minimal melt-back conditions (Figure 31) the first ice-free water occurs no earlier than the second week in July (Figure 50), and the last ice-free water disappears in the last week in October (Figure 66). A maximum of only 50% of the study area may become ice-free and the period for which 20% of the study area is ice-free can be as short as 11 weeks.

3) A relatively stable area of dependably ice-free water occurring in 25 to 30% of the study area occurs for a seven-week period between the second week in August and the last week in September (Figures 55-61). It is bordered on the east by the west coast of Alaska from Pt. Lay south to Bering Strait, 70°N latitude on the north, the 174°W meridian on the west, and is closed by the Siberian coast as it approaches Alaska at Bering Strait. However, neither 1975 nor 1983 (the two minimum ice extent years) is completely described by this generalization; both years had somewhat larger areas of open water which persisted for a somewhat longer period of time (Figures 36, 44).

4) The 174°W boundary of the stable area of ice-free water described

in number 3 above appears to coincide with the interface between Bering Sea Water and Eastern Siberian Sea Water described by Coachman, et al. (1975).

2. Station-Specific Ice Incursion Analysis

Ice edge frequency maps for the Chukchi Sea were produced for each week (Figures 45-71). The horizontally shaded area represents the region where the frequency of occurrence of at least some ice is 100%, and the vertically shaded area represents the region where the frequency of occurrence of the ice-free water is 100%. The intermediate area is isolined in intervals of 20%, where the percentage refers to the percentage of years for which the analysis found some sea ice present. These isolines were derived from frequencies calculated for each of the 67 stations located on Figure 30. Thus, the isolines don't have the resolution the borders of the first two ice categories have. These-maps can be used in conjunction with maximum and minimum ice-free water plots (Figures 31 and 32) to determine both the location and extent of ice-free water.

Figures 72 to 138 are station-specific ice presence frequency curves which display the frequency of finding some sea ice present at each of 67 stations for each week of the 27 week period. Figure 72 (the ice presence frequency curve for a station west of the Diomedes) tells us that for the second week in June, some ice was present for 80% of the years. By the second week in July there existed a 100% frequency of ice-free conditions.

Figures 139 to 205 display the ice presence history for each year from 1972 to 1983 at each of the 67 stations. The Figures 72-138 are, in effect, "averages" of these curves. Figures 139 through 205 show the actual variability of the individual years.

Figures 72 through 138, and 139 through 205 permit the calculation of two characteristic numbers--the median and average ice-free periods. From Figures 72 through 138 one can determine the period at each station when, for 50% of the years, the location was ice-free. From Figures 139 through 205 one can calculate the average dates when the water became ice-free and when it froze. These calculations are in Table 2. The length of the period the water was ice-free for six or more years (i.e., the median period) is equal to or greater than the average period the water was ice-free for most stations. Inspection shows that this results because the data set is skewed and includes some years with very short ice-free periods. One should also take note of the standard deviation from the average period of ice-free water at each station. These standard deviations can be as small as two weeks, but they are typically of the order of three weeks to a month.

Based on the data presented in Table 2, Figures 208-209 were prepared, which display the timing of the retreat and advance of the ice edge. Average and median dates of breakup and freezeup for the longest period of ice-free water have been plotted for each station and isolined in roughly two-week intervals. Figures 210 and 211 display the average and median lengths of the longest period of ice-free water.

### 3. Ice Recurrence

In an effort to investigate the chance that ice will recur after ice-free water first appears, Figures 139-205 were examined to produce Table 3. Table 3 records the number of ice-free periods which occurred (x), and the number of years studied which exhibited ice-free conditions for each of the 67 stations (y). An index (x/y - 1) is defined with the property that, if the ice went out each year and never recurred (except for freezeup) for twelve of the twelve years, one arrives at 12/12 - 1 = 0, or 0% intrusion. A value of 50% means that in half the cases where the ice went out, the ice came back before freezeup. This method of measurement does not distinguish between many recurrences in one year and one recurrence each year for many years. Neither does it indicate the duration of the recurrence of ice or whether the recurrence is more likely to take place in the spring or fall. However, inspection of Figures 139 to 205 reveals that typically, recurrence took place only once a year, and it was equally likely to occur in the spring or fall.

Figure 212 displays the frequency of ice intrusion or recurrence. The area between 70°N and 73°N and Long Strait have the highest frequency of ice intrusion.

Figure 213 displays the difference between the median and the average ice-free period using the values for the longest ice-free period observed at each of the 67 stations. As was noted earlier, the median ice-free period is generally longer than the average ice-free period. This is true for nearly all locations, as is displayed by the positive values plotted in Figure 213. Exceptions to this generalization occur at three locations: 1) in Long Strait on the East Siberian Sea side of the interface between East Siberian Sea Water and Bering Sea Water, 2) north of 72°N, and 3) along the Alaskan coast line.

One can make the following generalization about the ice recurrences in the Chukchi Sea. Between the beginning of August and the end of October, for a period of around 80 to 100 days, ice-free water will exist south of 70"N off the Alaskan coast and east of 175°W. Within these boundaries the ice will return once it has retreated in the spring, or the ice will retreat once it has returned in the fall, less than 50% of the time. The majority of these recurrences are associated with the beginning of breakup or freezeup and are characterized by the ice returning for the week following the week the station was first ice-free and vice versa. It should be stressed this is the median case; 50% of the time the characteristics of the ice-free period will be less favorable.

4. Additional Observations

There has been discussion in papers dealing with oceanographic processes in the vicinity of the Bering Strait and in the Chukchi Sea as to whether it is likely multi-year ice from north of the Bering Strait could pass through the Bering Strait into the Bering Sea.

Coachman et al. (1975) describe Siberian Coastal Water which flows southeast along the Siberian coast. They state that in October of 1962, this water mass reached within 80 km of Cape Serdtse Kamen at 172°W, and suggest that under sustained west or northwest winds it may reach Cape Dezhnev. However, they state that there is no documentation that Siberian Coastal Water has ever penetrated into the Bering Sea.

Coachman and Rankin (1968) discuss the current regime in Long Strait from a historical perspective and from current measurements made in the summer of 1968.

With respect to ice movements they observed while aboard the Burton Island that, in August of 1968, a large flux of ice moved south-eastward along the coast near Kolyuchin Bay ("175°W). They cite Gorbunov (1957) in which a description is given of the path of a radio beacon placed on the ice near Wrangel Island and followed from May until September 1956. The beacon moved alternately east and west through Long Strait.

With respect to water movements Coachman and Rankin (1968) draw the following conclusion on currents in Long Strait. The long term mean flow through Long Strait seems to be determined by the continuity requirements of the Chukchi Sea-East Siberian Sea system as it responds to regional winds. When the regional atmospheric pressure gradients dictate southerly winds east of Wrangel Island and/or northerly winds to the west, there is a mean westbound flow through Long Strait, and vice versa.

Figures 2-71 cannot provide documentation for passage of multi-year ice through the Bering Strait; however, they can give some indication of how frequently and when such ice would be in position for passage and where such ice would originate.

Figures 45-71 show that, whereas the ice edge predictably retreated to Icy Cape or approximately 70"N every year along the Alaskan coast, in the same time period it predictably retreated only as far north as 66°30'N along the coast of Siberia (Figure 55). In the peak season for maximum recurring extent of open water, from the second week of August to the last week in September, the ice edge is shown as far south as Cape Dezhnev at 66°N. Inspection of individual Southern Ice Limit sheets reveals that southern extension of the ice edge to 66°N occurred only one year out of the twelve years for each week of this period.

Figures 12 through 18 display the boundary between that area which has at least some ice for 50% or more of the time from an area in the south which is for 50% or more of the time. Along the Siberian coast this boundary line lies between 67"N and 69°N. "Along the Alaskan coast the boundary lies between Pt. Franklin (71°N) and north of Pt. Barrow.

These figures display statistical evidence for the observation that there is always more ice extending further south off the Siberian coast than off the Alaskan coast.

Following the course of freezeup from October on, the pattern repeats itself; the ice is always more extensive and further south along the Siberian coast than for the same time period off the Alaskan coast. In the first and second week of October a tongue of ice appears to block the northern entrance to Bering Strait. This occurred once--in October of 1983 (Figures 61 and 62).

Furthermore, on the most recent Southern Ice Limit sheets which indicate the stage of development of sea ice, there is frequent designation of "old ice" as a constituent of the ice cover present off the Siberian coast. "Old ice" is listed as one of the constituents of the ice cover in the tongue of ice which appears to block the northern entrance to Bering Strait in October 1983.

The conclusion is that, during the ice-free water season, multi-year ice can be a constituent of ice off the coast of Siberia, and this ice can occasionally drift far enough south to be in a position to pass south through Bering Strait.

## 5. Comparison with Other Results

Other investigations have been made of long term sea ice variability. Niebauer (1983) describes a three-year warming trend for 1977-79 in the Bering Sea during the study period 1974-82. Figures 38-39 showing ice-free areas for the Chukchi seem to confirm this trend. Walsh and Johnson (1979) studied the fluctuation of sea ice extent in the Arctic Ocean over the period 1953-77. In this 25 year span fluctuations of the range observed for the 12 years in the present study, and the 3 year warming trend reported by Niebauer, would appear to be merely average and not exceptional. Thus, it would seem likely that in the future, one will not *only* observe ice-free seasons of greater ice-free area than occurred between 1972 and 1983, but one may also observe seasons of lesser extent. Rogers (1978) suggests that the extent of summer ice-free water in the Beaufort Sea has been decreasing over 25 years.

Other investigators have studied the location of the ice edge in the Chukchi and suggested mechanisms for its formation throughout the open water season.

Webster (1982], using both satellite and airborne observations over a period of twenty-nine years, produced maps showing minimum and maximum extent of the ice edge and the location of the border of 50% ice concentration twice a month for all twelve months. His method was to measure the location of the ice edge along lines of longitude and to develop the statistical distribution from these measurements.

Paquette and Bourke (1981) related temperature and salinity measurements to proximity to the ice edge. They found a sharp temperature and salinity front at the edge of the retreating ice pack, formed as a result of ice melt caused by warm surface water from the south. They compared Southern Ice Limit sheets for August of 1976, 1977, 1978, and 1979, and discovered the existence of four major recurring bays and perhaps one minor one. They locate these bays at approximately 170-175°W, 168°W, as the shore lead along the Alaskan coast, and as an embayment W to WNW of Pt. Barrow. They state they must be due to well-defined influences and not a continually changing one like wind stress. They suggest the well-defined influence is steering of currents by bottom bathymetry (as described by Coachman, Aagaard and Trip, 1975) for all bays except the one N to WNW of Pt. Barrow.

Our Figures -28 correspond to Webster's figures for 100% and 0% probability of finding an ice edge. While Webster's data display alternate weeks during the approximately twenty-seven week period of ice-free water in the Chukchi Sea, our data display all 27. While our data span only twelve years and utilize satellite data alone, digitization of the ice edge permits a much finer differentiation of the detail of the ice edge than Webster's method. Thus, our data reveal the bays described by Paquette and Bourke; Webster's do not. Nevertheless, our data reproduce the same general pattern of melt-back and freezeup as Webster documents--especially in the case of the minimum or 0% probability ice edge.

# APPENDIX I

## Detailed Discussion Concerning Formation of Melt-Back Bays

### Introduction

The chief product of this project is the statistical description of ice behavior in the Chukchi Sea in terms of duration of open water and recurrence of ice. These results have been described. However, our data yielded additional information concerning the melt-back bays reported by Paquette and Bourke (1981) that pertained to the configuration of the ice edge in the northern Chukchi Sea. We have been conducting related research for the National Oceanic and Atmospheric Administration in anticipation of the necessity of preparing environmental impact statements in support of federal offshore petroleum leasing in this region. Since the configuration of the melt-back bays and the influence of currents on the ice edge would be useful to those studies as well as this, we combined forces, so to speak, to prepare this appendix supporting and expanding upon the observations of Paquette and Bourke. This appendix, then, was jointly supported by both projects.

Paquette and Bourke based their statement about the recurrence of the four bays on observation of four Southern Ice Limit sheets for August of 1976, 1977, 1978, and 1979. Our data utilize 324 Southern Ice Limit sheets for a period of twelve years over the entire time period which one can expect at least some ice-free water in the Chukchi. Our data not only confirm Paquette and Bourke's observations for August, but reveal the phenomena can be detected by observation of the movement of the ice edge as early as the last week in June (for Herald Canyon only), is common from the second week in July through the end of September, and is occasionally present in October through the first week in November.

Results

Figures 45 to 71 enable more definitive statements to be made concerning the persistence of each of the bays over longer periods of time. As Figures 45 to 71 are essentially "averages" of the ice edge location over twelve years, one can make some predictions concerning the importance of the four embayments to ice movements in the Chukchi Sea. We will refer to the bays as: 1) the Herald Canyon Bay for the bay at 170°W to 175°W; 2) the 168°W Bay; 3) the Alaskan Coastal Bay for the shore lead along the Alaskan Coast; 4) Barrow Canyon Bay for the bay west to WNW of Pt. Barrow; and 5) West Barrow Canyon Bay for a bay hypothesized by Paquette and Bourke to be formed by a branching of the Alaskan Coastal Current at 163°W along the western branch of Barrow Canyon.

Figures 2-28 will be used for the location of the 50% ice edge because the resolution of the 50% ice edge on these figures is equivalent to that of the maximum and minimum melt-back ice edges recorded in Figures 45-71. These ice edges were derived from the complete array of over 6000 digitized cells. The 20%, 40%, 60%, and 80% ice edges in Figures 45-71 were derived from statistical calculations made at 67 individual data stations, selected from the 6081 possible data stations. Thus, the isopleths indicating the location of these ice edges lack the finer definition of the 0%, 50% and 100% ice edges.

On the last week in June, there is the first appearance of the Herald Canyon Bay, the Alaskan Coastal Bay, and possibly the 168°W Bay (Figure 48). Inspection of individual Southern Ice Limit sheets for this week reveals that the Herald Canyon Bay was present only once in the twelve year period--in 1979. The extreme ice edge for this week is the product of one year (1979).

For the first week in July, all bays are present except the Barrow Canyon Bay (Figure 49). Inspection of the individual Southern Ice Limit sheets reveals that all three bays were present simultaneously only-once in twelve years--in 1979. In Figure 6 the location of the ice edge in 50% of the twelve years reveals beginnings of the Herald Canyon Bay and the 168°W Bay.

For the second week in July, all bays are present. except the Barrow Canyon Bay (Figure 50). The isopleths indicating the location of the ice edge in 80% and 60% of the years also reveal the influence of these bays. In Figure 7 the 50% ice edge shows no structure; this means that the four bays were present in less than 50% of the years.

For the third week in July, all four bays are present (Figure 51). The Alaskan Coastal Bay would appear to be the precursor of the Barrow Canyon Bay. At 71°N and 162°W the bottom bathymetry (Figure 29) branches to form two channels. The deepest, most prominent of these is Barrow Canyon. Barrow Canyon Bay appears to be the result of the Alaskan Coastal Current (Coachman, Aagaard and Trip, 1975), following this deeper channel to a point where it encounters the steering action of the westward curving left bank of Barrow Canyon as it encounters the continental slope to the north (Paquette and Bourke, 1981). The Herald Canyon Bay is extremely prominent. Figure 51 shows a small oval which is always ice covered during this week and which is located over Herald Shoal. No individual year reveals such an oval; the oval is the area of overlap common to a peninsula containing Herald Shoal, which is present in several years. In Figure 8, the 50% ice edge shows what could be the beginnings of the Herald Canyon Bay, the 168° W Bay, and the Alaskan Coastal Bay.

In the fourth week in July, all four bays are present. The Herald Canyon Bay is extremely prominent (Figure 52) for the extreme ice edge, and for the 60% and 80% ice edge. The 168°W Bay appears to be centered around 166°W for the extreme ice edge, and in the case of the 80% ice edge, it is centered closer to 165°W. The extreme ice edge east of 168°W was derived from the situation recorded on the Southern Ice Limit sheet for July 25, 1978, which was also observed in the field by Paquette and Bourke on the MIZPAC 1978 cruise. In Figure 9, the 50% ice edge shows only the Alaskan Coastal Bay.

In the last week in July, all four bays are present (Figure 53). In Figure 10, the 50% ice edge shows all the bays except the Barrow Canyon Bay. The Herald Canyon Bay is extremely prominent for the extreme ice edge, and for the 60% and 80% ice edges. Figure 10, the 50% ice edge, and Figure 53, the extreme ice edge, and the 60% and 80% ice edges all show the 168°W Bay centered at 166°W.

In the first week in August, the averaged data do not appear to display the Barrow Canyon Bay (Figure 54). Inspection of individual Southern Ice Limit sheets reveals that this bay was apparently not present at this time during the twelve years examined. However, perhaps the individual sheets for August 4, 1974 and 1981, August 9, 1977, and August 7, 1979 could be interpreted to demonstrate the existence of the West Barrow Canyon Bay hypothesized by Paquette and Bourke to be formed by a branching of the Alaskan Coastal Current at 163°W along the western branch of the Y of Barrow Canyon. Furthermore, in Figure 11, in the 50% ice edge, an indentation at 163*W, which could be statistical confirmation for the above process, is as prominent as an indentation at 166°W, which could be assigned to the more adequately documented 168°W Bay. Melt-back through Herald Canyon is pronounced. In Figure 54, the 80%, 60%, and 40% ice edges all suggest flow through Herald Canyon. In Figure 11, the 50% ice edge also shows all bays except the Barrow Canyon Bay and pronounced melt-back through Herald Canyon.

In the second week in August, all four bays are present (Figure 55). The Herald Canyon Bay is especially prominent. The 60% and 80% ice edges show the 168°W Bay centered at 168°W. In Figure 12, the 50% ice edge shows all bays except the Barrow Canyon Bay.

In the third week in August, all four bays are present. The Herald Canyon Bay is prominent. Furthermore, the boundary enclosing the ice-free water (minimum retreat ice edge) shows all the bays except the Barrow Canyon Bay (Figure 56). This is the first week in which even a year with minimum melt-back has melted back far enough north to exhibit bay formation. In Figure 13, the 50% ice edge shows all bays except the Barrow Canyon Bay. The 40% and 60% ice edges (Figure 56) and the 50% ice edge (Figure 13) show the 168°W Bay centered at roughly 166°W.

In the last week in August, there is some indication of formation of all bays except the Barrow Canyon Bay. The maximum melt-back ice edge is north of 73°N and does not display bay formation (Figure 57). However, the minimum melt-back ice edge (Figure 57) and the 50% ice edge (Figure 14) show all the bays except the Barrow Canyon Bay. The Herald Canyon Bay is prominent. The 168°W Bay appears to be centered around 166°W in Figure 57 and at the 50% ice edge in Figure 14.

In the first week in September, there is some indication of the formation of all the bays except the Barrow Canyon Bay (Figure 58). This week has the maximum ice-free water area observed for minimum melt-back conditions. The minimum melt-back ice edge shows the formation of all the bays except the Barrow Canyon Bay. Individual Southern

Ice Limit sheets for 1972, 1974, and 1977 show the development of Barrow Canyon Bay. In Figure 15 the 50% ice edge displays the first three bays and perhaps also shows formation of the Barrow Canyon Bay. Herald Canyon Bay has ceased to be prominent statistically, although on individual Southern Ice Limit sheets (Sept. 6, 1983) it is present.

In the second week in September, all bays except the Barrow Canyon Bay are present (Figure 59) in the minimum melt-back edge. In Figure 16 the 50% ice edge also shows all the bays except the Barrow Canyon Bay.

In the third week in September, all bays except the Barrow Canyon Bay are evident in the minimum melt-back ice edge (Figure 60). In Figure 17 the 50% ice edge clearly displays the Barrow Canyon Bay.

In the fourth week of September, all bays except the Barrow Canyon Bay and the 168°W Bay are evident in the minimum melt-back ice edge (Figure 61). This week is a maximum melt-back week. In Figure 18 the 50% ice edge shows the Barrow Canyon Bay, and perhaps the 168°W Bay. The Herald Canyon Bay is not prominent.

In the first week in October, there is some indication of the presence of the Herald Canyon Bay and the 168°W Bay on the 60% ice edge (Figure 62). In Figure 19 the 50% ice edge shows the Alaskan Coastal Bay and a lesser indication of the 168°W Bay. This week is also a maximum melt-back week.

The first week in October displays an interesting feature, a tongue of ice extending from the northern coast of Siberia into the Bering Strait. This event was observed only in 1983.

For the second week in October, there is some indication of Alaskan Coastal Bay in the minimum melt-back ice edge (Figure 63). In Figure 20 the 50% ice edge reveals the presence of the Barrow Canyon Bay. The tongue extending from the northern coast of Siberia is still present.

For the third week in October, the Herald Canyon Bay and the 168°W Bay are indicated in the minimum melt-back ice edge (Figure 64). The 60% ice edge displays the Herald Canyon Bay and the Barrow Canyon Bay. The 40% isopleth (Figure 64) and the 50% ice edge (Figure 21) reveal the presence of the Alaskan Coastal Bay. The tongue extending from the northern coast of Siberia into the Bering Strait has receded.

In the fourth week in October, 80% and 60% ice edges indicate the Herald Canyon Bay and the Alaskan Coastal Bay (Figure 65). In Figure 22 the 50% ice edge reveals the bay at 168°W and the Alaskan Coastal Bay.

In the last week in October, the maximum melt-back ice edge gives an indication of the Herald Canyon Bay and the Barrow Canyon Bay (Figure '66).

In the first week in November, the maximum melt-back ice edge reveals the Herald Canyon Bay, and the bay at 168°W (perhaps), and the Alaskan Coastal Bay (Figure 67). The Herald Canyon Bay again becomes a prominent feature of the 40%, 60%, and 80% ice edges (Figure 66) and the 50% ice edge (Figure 24). The 50% ice edge (Figure 24) also delineates a small "island" which is located roughly around Herald Shoal. This implies that Herald Shoal ices over before the water surrounding it.

In the second week in November, the 80% ice edge (Figure 68) shows the Herald Canyon Bay and the Alaskan Coastal Bay still present.

In the third week in November, the maximum melt-back ice edge shows the beginning of the Herald Canyon Bay and the 168°W Bay (Figure 69). The Herald Canyon Bay was still observable this late only in 1979.

Figures 206 through 211, corresponding to the average and median dates of breakup and freezeup, demonstrate that the predominant currents described by Paquette and Bourke, as involved in formation of the different bays, are much more important in influencing the pattern of breakup than that of freezeup. These Figures and Figures 212 and 213 stress again the importance of these currents in effecting oceanographic events in the Chukchi Sea. The current directed by Herald Canyon is particularly obvious in Figures 206-208.

Discussion

Drainage north through Herald Canyon is a conspicuous feature of the summertime melt-back pattern. On-site evidence for the process occurring in the vicinity of Herald Canyon is given by observations in July 1969 by Russian investigators (Nikolaev, 1973). The existence of a surface jet flowing north along the ice edge at a location southeast of Herald Island was described. Two drifting stations moved steadily approximately 90 km along the ice edge, independent of the wind directions, between July 21 and 30. Drainage through Herald Canyon must be at least as important to the mechanism of melt-back and the pattern of circulation within the Chukchi Sea as is drainage through Barrow Canyon.

Paquette and Bourke defined their ice edge as separating 100% ice-free water and the Southern Ice Limit category O/W, or water containing from O-10% sea ice, from water containing greater than 10% sea ice. The digitized data, which were used in the production of Figures 2-71, were based on definition of the ice edge as that which separated 100% ice-free water from water containing any sea ice whatsoever. Using Paquette and Bourke's definition of ice edge for digitization would have produced radically different results for the pattern of melt-back observed for the last week of June and for July. Inspection of individual Southern Ice Limit sheets reveals that open water formation along the Alaskan coast is frequently characterized by a strip of fairly high ice concentration, extending roughly NW from Cape Lisburne and connecting with the main ice pack. This band separates an area of 100% ice-free water in the southern Chukchi Sea from an area of 0-10% sea ice extending off the Alaskan coast from Cape' Lisburne to Pt. Barrow. Thus, melt-back along Herald Canyon and perhaps through the trough parallel to 168°W appears to be a fairly straight-forward process, whereas melt-back along the Alaskan coast is complicated by other processes not addressed by either Paquette and Bourke or this study, because neither study considered processes occurring prior to June.

Carleton (1980) and Stringer (1982) studied springtime polynya formation off the coast of Alaska between Pt. Hope and Pt. Barrow. They discuss mechanisms for the formation of regions of open water which can appear in this area as early as February.

Carleton (1980) studied the growth of polynya in the vicinity of Pt. Hope using Landsat imagery from February to June of 1973 to 1977. He suggests that persistently offshore (northeasterly) winds favor expansion of the polynya early in the season. However, as the season advances, advection of warmer air from the adjacent land surface appears to be the more significant control.

Stringer (1981) studied the width and persistence of Chukchi Polynya for the months of February through October, utilizing measurements of the polynya width at six stations on the coast of Alaska between Pt. Barrow and Pt. Hope for the years 1974-1981. These studies indicate that during May and June the polynya is virtually permanent and wider in the middle (Pt. Lay) than at the north (Pt. Barrow) or the south (Pt. Hope and Cape Lisburne). In July the same pattern continues with the exception that there is now virtual open water at Pt. Hope. Stringer states a qualitative correlation can be found between the average ice motion away from the coast and the mean vector wind for all months except July.

If the sea ice concentrations recorded on Southern Ice Limit sheets for March, April, and May were digitized and subjected to statistical analysis, it is likely that one could quantitatively demonstrate that the average ice concentration off the coast of Alaska is lower than that for the rest of the Chukchi Sea, and that there is a band of high concentration ice that exists off Cape Lisburne.

Figures 45-71 suggest that advection of warmer water from the Bering Sea through the Bering Strait which begins to reach Cape Lisburne in late June and July, could be another factor in the widening of polynya, as well as the advection of warm air off the land surface mentioned by Carleton.

## Conclusions

The following generalizations can be made concerning melt-back bays:

1) The embayments first described by Paquette and Bourke will have a tendency to form at any time of the year the ice edge is located between 70"N and 72° to 73*N. 70°N is roughly the latitude where the 20 fathom isobath delineates Herald Shoal. Herald Shoal is as shallow as 9 fathoms. 70"N is also the latitude which forms the northern border of the maximum area that was ice-free for twelve of twelve years.

2) Drainage north through Herald Canyon and the 25 fathom trough parallel to 168°W are at least as important to the pattern of melt-back of the ice edge that is observed, as is drainage through Barrow Canyon. Given Herald Canyon is such a conspicuous feature, it may be a more important route for transport of water to the Arctic Ocean than the Barrow Canyon. The water mass transported through Herald Canyon has

been designated by Coachman, Aagaard and Trip as Bering Sea Water (Coachman et al. 1975).

3) Drainage through Barrow Canyon appears to be a more complex process than that through Herald Canyon. The water mass transported through Barrow Canyon has been designated by Coachman, Aagaard, and Trip as Alaskan Coastal Water.

4) The 168°W Bay, while likely arising from current directed along a shallow trough at approximately 168°W, as Paquette and Bourke suggest, is much broader than they indicate. The bay frequently centers around 166°W and can form between 168°W and 165°W. Paquette and Bourke's examples of the Southern Ice Limit sheets (July 22, 1978 and August 2, 1977) show the 168°W Bay centered at 166°W.

5) The Barrow Canyon Bay doesn't appear until the ice edge has retreated north to approximately 71°N. Referring to Figures 17 and 18, only in the third and fourth weeks of September was the ice edge that far north in 50% of the years, This bay forms far less frequently than the other three.

6) West Barrow Canyon Bay is hypothesized to form by a branching of the Alaskan Coastal Current at 163°W along the western branch of the Y of Barrow Canyon. The first week in August is the only period which provides any statistical confirmation for the existence of this bay. However, this is not strong confirmation either for the bay's existence or non-existence. West Barrow Canyon Bay appears to be the smallest of the bays which makes it harder to detect in an averaging process, even if it formed frequently. West Barrow Canyon Bay appears to form even less frequently than Barrow Canyon Bay.

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TABLE 1. CALENDAR OF EVENTS FOR THE CHUKCHI AND BEAUFORT SEAS.

JUNE

| WEEK 1 | WEEK 2 | WEEK 3 | WEEK 4 |
|---|---|---|---|
| First appearance of 100% ice-free water in Chukchi occurs prior to this. | | First appearance in Chukchi of at least one year where the 100% ice-free water occupies 20% of the area. | |

JULY

| WEEK 1 | WEEK 2 | WEEK 3 | WEEK 4 | WEEK 5 |
|---|---|---|---|---|
| First appearance in at least one year of 100% ice-free water in Mackenzie Bay. | First week where 100% ice-free water occupies 20% of the area, 50% of the time. | First week 100% ice-free water appears in a region of the Chukchi 100% of the time. An island of 100% ice cover 100% of the time is present over Herald Shoal. This is a statistical artifact which documents the importance of shallow water in keeping the pack ice in place as the ice edge retreats. | First appearance for at least one year of two nearly continuous strip of 100% ice-free water along the Beaufort Coast. | First week where 100% ice-free water occupies 20% of the area 100% of the time. |

TABLE 1. CALENDAR OF EVENTS FOR THE CHUKCHI AND BEAUFORT SEAS.

AUGUST

| WEEK 1 | WEEK 2 | WEEK 3 | WEEK 4 |
|---|---|---|---|
| irst appearance for at east one year of a con-inuous strip of 100% cc-free water along the Beaufort Coast. | Appearance of conspicuous strip of ice present for all 12 years, lying be-tween Prudhoe Bay and Barter Island. First week where an area of Mackenzie Bay is 100% ice-free for 50% of the time. | | First appearance of an al-most continuous band of water which is 100% ice-free for 50% of the time off the Beaufort Coast. |

SEPTEMBER

| WEEK 1 | MEEK 2 | W | WEEK 4 |
|---|---|---|---|
| Maximum area that has 100% frequency of ice-free conditions in the Chukchi. The greatest extent of ice-free water observed in heavy ice years occurs. Interesting “ice shadow” west of Wrangel Island. | Last week for an almost continuous band of water which is 100% ice-free for 50% of the time. | | Maximum extent of area which is ice-free 50% of the time in Chukchi. |

TABLE 1. CALENDAR OF EVENTS FOR THE CHUKCHI AND BEAUFORT SEAS.

OCTOBER

| WEEK 1 | WEEK 2 | WEEK 3 | WEEK 4 | WEEK 5 |
|---|---|---|---|---|
| Maximum ice-free area ever observed in Chukchi. | | In Chukchi, freeze-up accelerates and the area which is 100% ice-free for 12 years and the maximum 100% ice-free areas have shrunk considerably. Some sea ice is always present along the Beaufort Coast over the 12-year period. | Alaskan Beaufort Coast 100% ice covered 100% of the time. Last week where an area which is 100% ice-free is present in the Chukchi Sea. Last week any 100% ice-free water appears off the Mackenzie Delta. | |

NOVEMBER -

| WEEK 1 | WEEK 2 | WEEK 3 | WEEK 4 |
|---|---|---|---|
| | | In Chukchi Sea, maximum ice-free area is still fairly large - 20% of maximum ice-free area ever observed or 2/3 of the maximum area ever expected to be ice-free under minimal conditions. | There is still some ice-free water in the Chukchi Sea. |

TABLE 2. STATION-SPECIFIC ICE-FREE INDICES

| LOCATION | DATES OF AVERAGE ICE-FREE PERIOD | DATES OF MEDIAN ICE-FREE PERIOD | DURATION OF MAXIMUM ICE-FREE PERIOD | DURATION OF AVERAGE ICE-FREE PERIOD | DURATION OF MINIMUM ICE-FREE PERIOD | DURATION OF MEDIAN ICE-FREE PERIOD |
|---|---|---|---|---|---|---|
| #1 | 6/22±13 d. to 11/10±16 d. | 6/18 to 11/15 | 176 d. | 140±25 d. | 76 d. | 151 d. |
| 2 | 6/22±11 d. to 1/6±16 d. | 6/18 to 1 /19 | 61 d. | 137±30 d. | 98 d. | 54 d. |
| 3 | 7/9±11 d. to 0/20±9 d. | 7/9 to 0/22 | 126 d. | 103±16 d. | 77 d. | 05 d. |
| 4 | 6/27±12 d. to 1/7±16 d. | 6/25 to 11/15 | 154 d. | 133±2 d. | 84 d. | 44 d. |
| 5 | 6/30±12 d. to 1/9±11 d. | 6/25 to 11/12 | 154 d. | 131±19 d. | 105 d. | 40 d. |
| 6 | 7/9±11 d. to /2±10 d. | 7/6 to 11/8 | 147 d. | 117+15 d. | 98 d. | 126 d. |
| 7 | 7/12±10 d. to 0/ 2±6 d. | 7/9 to 10/15 | 119 d. | 93±13 d. | 70 d. | 98 d. |
| 8 | 7/30±14 d. to /3±24 d. | 7/26 to 0/15 | 106 d. | 67±29 d. | 1 d. | 8 d. |
| 9 | 7/2±11 d. to / ±25 d. | 6/25 to /8 | 154 d. | 123±26 d. | 63 d. | 137 d. |
| 10 | 7/2±1 d. to 1 /8±9 d. | 6/28 to /12 | 154 d. | 28±16 d. | 105 d. | 137 d. |
| 1 | 7/14±11 d. to 0/27±7 d. | 7/12 to 0/29 | 119 d. | 05±12 d. | 91 d. | 108 d. |
| 12 | 8/8±14 d. to 10/ ±2 d. | 8/2 to 0/8 | 98 d. | 50±33 d. | 0 d. | 67 d. |
| 13 | 7/17±10 d. to 10/20±22 d. | 7/16 to / | 133 d. | 95±30 d. | 35 d. | 108 d. |
| 14 | 7/9±12 d. to 11/3±9 d. | 7/2 to 1 /5 | 154 d. | 8±18 d. | 84 d. | 126 d. |
| 15 | 7/9±11 d. to 11/3±1 d. | 7/9 to 1 /5 | 154 d. | 8±17 d. | 9 d. | 11 d. |
| 16 | 7/12±14 d. to 10/27±11 d. | 7/9 to 10/29 | 140 d. | 107±17 d. | 84 d. | 112 d. |
| 17 | 7/16±1 d. to 10/2 ±6 d. | 7/ 2 to 10/25 | 119 d. | 98±11 d. | 84 d. | 105 d. |
| 18 | 8/18±23 d. to 9/8±24 d. | 8/2 to 10/ 5 | 105 d. | 54±3 d. | 14 d. | 73 d. |
| 19 | 7/19±11 d. to 10/25±2 d. | 7/16 to 11/5 | 133 d. | 98±26 d. | 49 d. | 112 d. |
| 20 | 7/14±11 d. to 11/1±8 d. | 7/ 2 to 11/5 | 140 d. | 109±17 d. | 84 d. | 115 d. |

TABLE 2. STATION-SPECIFIC ICE-FREE INDICES.

| LOCATION | DATES OF AVERAGE ICE-FREE PERIOD | DATES OF MEDIAN ICE-FREE PERIOD | DURATION OF MAXIMUM ICE-FREE PERIOD | DURATION OF AVERAGE ICE-FREE PERIOD | DURATION OF MINIMUM ICE-FREE PERIOD | DURATION OF MEDIAN ICE-FREE PERIOD |
|---|---|---|---|---|---|---|
| #21 | 7/15±14 d. to 11/1±1 d. | 7/16 to 11/5 | 154 d. | 109±21 d. | 84 d. | 112 d. |
| 22 | 7/23±13 d. to 10/26±8 d. | 7/19 to 10/29 | 127 d. | 98±18 d. | 63 d. | 101 d. |
| 23 | 7/24±13 d. to 10/17±12 d. | 7/23 to 10/22 | 105 d. | 85±14 d. | 70 d. | 91 d. |
| 24 | 7/23±14 d. to 10/9±9 d. | 7/23 to 10/15 | 119 d. | 78±17 d. | 56 d. | 84 d. |
| 25 | 8/23±24 d. to 10/8±25 d. | 8/13 to 10/22 | 105 d. | 50±35 d. | 14 d. | 70 d. |
| 26 | 8/3±19 d. to “ 0/25±17 d. | 7/30 to 11/5 | 127 d. | 82±30 d. | 28 d. | 98 d. |
| 27 | 7/25±19 d. to 11/1±11 d. | 7/19 to 11/5 | 133 d. | 99±29 d. | 21 d. | 108 d. |
| 28 | 8/8±12 d. to “ 0/26±12 d. | 8/2 to 10/29 | 112 d. | 78±29 d. | 1 d. | 87 d. |
| 29 | 8/6±21 d. to 10/15±21 d. | 7/30 to 10/29 | 105 d. | 69±26 d. | 21 d. | 87 d. |
| 30 | 8/4±24 d. to 10/6±24 d. | 7/30 to 10/22 | 98 d. | 66±33 d. | 14 d. | 84 d. |
| 31 | 8/16±27 d. to 10/6±24 d. | 7/30 to 10/22 | 91 d. | 55±35 d. | 7 d. | 84 d. |
| 32 | 8/13±25 d. to 9/28±23 d. | 7/30 to 10/15 | 91 d. | 49±30 d. | 7 d. | 77 d. |
| 33 | 8/27±30 d. to 9/26±25 d. | 8/9 to 10/11 | 91 d. | 39±37 d. | 0 d. | 31 d. |
| 34 | 8/25±28 d. to 9/29±20 d. | 9/10 to 10/15 | 84 d. | 37±34 d. | 0 d. | 35 d. |
| 35 | 9/11±24 d. to 10/14±17 d. | 9/10 to 10/1 | 91 d. | 34±34 d. | 0 d. | 21 d. |
| 36 | 8/22±25 d. to 10/11±27 d. | 8/13 to 10/29 | 98 d. | 53±33 d. | 7 d. | 77 d. |
| 37 | 8/8±17 d. to 10/20±19 d. | 7/30 to 10/29 | 112 d. | 72±29 d. | 7 d. | 91 d. |
| 38 | 8/20±31 d. to 10/17±20 d. | 8/13 to 10/25 | 112 d. | 62±34 d. | 0 d. | 74 d. |
| 39 | 8/17±24 d. to 10/10±18 d. | 8/13 to 10/22 | 105 d. | 52±30 d. | 1 d. | 70 d. |
| 40 | 8/25±17 d. to 9/24±24 d. | 8/16 to 10/15 | 84 d. | 36±30 d. | 0 d. | 59 d. |

TABLE 2. STATION-SPECIFIC ICE-FREE INDICES.

| LOCATION | DATES OF AVERAGE ICE-FREE PERIOD | DATES OF MEDIAN ICE-FREE PERIOD | DURATION OF MAXIMUM ICE-FREE PERIOD | DURATION OF AVERAGE ICE-FREE PERIOD | DURATION OF MINIMUM ICE-FREE PERIOD | DURATION OF MEDIAN ICE-FREE PERIOD |
|---|---|---|---|---|---|---|
| #41 | 9/8±17 d. to 10/8±12 d. | 9/13 to 10/11 | 63 d. | 20±23 d. | 0 d. | 28 d. |
| 42 | 9/8±18 d. to 10/12±11 d. | 9/13 to 9/24 | 70 d. | 21±25 d. | 0 d. | 10 d. |
| 43 | 9/5±11 d. to 10/7±11 d. | 9/17 to 9/30 | 56 d. | 19±21 d. | 0 d. | 14 d. |
| 44 | 9/13±25 d. to 10/6±18 d. | 10/8 | 63 d. | 20±24 d. | 0 d. | 1 d. |
| 45 | 8/15±27 d. to 10/3±29 d. | 8/2 to 10/15 | 112 d. | 48±40 d. | 0 d. | 73 d. |
| 46 | 8/24±17 d. to 10/7±23 do | 8/27 to 10/1 | 105 d. | 37±35 d. | 0 d. | 35 d. |
| 47 | 8/26±17 d. to 9/27±24 d. | 8/27 to 10/1 | 84 d. | 30±30 d. | 0 d. | 35 d. |
| 48 | 9/3±13 d. to 9/28±20 d. | 9/10 to 10/1 | 63 d. | 22±24 d. | 0 d. | 21 d. |
| 49 | 9/14±8 d. to10/5±13 d. | 9/24 | 49 d. | 7±14 d.' | 0 d. | 1 d. |
| 50 | 9/10±10 d. to 10/2±11 d. | 9/17 to 9/24 | 49 d. | 11±17 d. | 0 d. | 7 d. |
| 51 | 9/14±17 d. to 9/24±15 d. | | 21 d. | 4± 7 d | 0 d. | 0 d. |
| 52 | 9/11±26 d. to 10/11±13 d. | | 56 d. | 16±21 d. | 0 d. | 0 d. |
| 53 | 8/28±15 d. to 9/13±13 d. | 9/24 | 70 d. | 23±29 d. | 0 d. | 1 d. |
| 54 | 9/1±10 d. to 10/6±16 d. | 9/24 | 63 d. | 17±21 d. | 0 d. | 1 d. |
| 55 | 9/8±14 d. to 10/5±15 d. | | 56 d. | 13±17 d. | o d. | 0 d. |
| 56 | 9/18±16 d. to 10/1±13 d. | | 28 d. | 7±11 d. | 0 d. | 0 d. |
| 57 | 9/14±8 d. to 10/5±13 d. | | 49 d. | 7±14 d. | 0 d. | 0 d. |
| 58 | 9/15±10 d. to 9/29±10 d. | | 35 d. | 5±10 d. | 0 d. | 0 d. |
| 59 | 9/21±15 d. to 9/26±14 d. | | 7 d. | 1± 2d. | 0 d. | 0 d. |
| 60 | 9/10±12 d. to 9/22±20 d. | | 42 d. | 7±13 d. | 0 d. | 0 d. |

TABLE 2. STATION-SPECIFIC ICE-FREE ItIDICES.

| LOCATION | DATES OF AVERAGE ICE-FREE PERIOD | DATES OF MEDIAN ICE-FREE PERIOD | DURATION OF MAXIMUM ICE-FREE PERIOD | DURATION OF AVERAGE ICE-FREE PERIOD | DURATION OF MINIMUM ICE-FREE PERIOD | DURATION OF MEDIAN ICE-FREE PERIOD |
|---|---|---|---|---|---|---|
| #61 | 9/23±13 d. to 10/12±6 d. | | 21 d. | 3±7 d. | 0 d. | |
| 62 | 9/16±13 d. to 9/30±23 d. | | 21 d. | 2±6 d. | 0 d. | |
| 63 | | | 0 d. | 0 d. | 0 d. | |
| 64 | 9/8±4 d. to 9/22±24 d. | | 28 d. | 2±8 d. | 0 d. | |
| 65 | 9/24 | | 1 d. | | 0 d. | |
| 66 | 10/2 and 10/16 | | 1 d. | | 0 d. | |
| 67 | | | 0 d. | 0 d. | 0 d. | |

TABLE 3. PERCENT FREQUENCY OF ICE RECURRENCE AT 67 POINTS IN THE CHUKCHI SEA.

| Point # | Number of Recurrences (x) | Number of Open Water Years (Y) | $(\frac{x}{Y} - 1)100$ = % Ice Recurrence |
|---|---|---|---|
| 1 | 17 | 12 | 42 |
| 2 | 16 | 12 | 33 |
| 3 | 15 | 12 | 25 |
| 4 | 15 | 12 | 25 |
| 5 | 12 | 12 | 0 |
| 6 | 14 | 12 | 17 |
| 7 | 15 | 12 | 25 |
| 8 | 17 | 12 | 42 |
| 9 | 14 | 12 | 17 |
| 10 | 14 | 12 | 17 |
| 11 | 14 | 12 | 17 |
| 12 | 16 | 12 | 33 |
| 13 | 16 | 12 | 33 |
| 14 | 15 | 12 | 25 |
| 15 | 14 | 12 | 17 |
| 16 | 12 | 12 | 0 |
| 17 | 16 | 12 | 33 |
| 18 | 21 | 12 | 75 |
| 19 | 15 | 12 | 25 |
| 20 | 12 | 12 | 0 |
| 21 | 13 | 12 | 8 |
| 22 | 16 | 12 | 33 |
| 23 | 14 | 12 | 17 |
| 24 | 14 | 12 | 17 |
| 25 | 23 | 12 | 92 |
| 26 | 19 | 12 | 58 |
| 27 | 14 | 12 | 17 |
| 28 | 18 | 12 | 50 |
| 29 | 18 | 12 | 50 |
| 30 | 19 | 12 | 58 |
| 31 | 24 | 12 | 100 |
| 32 | 24 | 12 | 100 |
| 33 | 22 | 11 | 100 |
| 34 | 19 | 11 | 73 |
| 35 | 19 | 11 | 73 |
| 36 | 25 | 12 | 108 |
| 37 | 18 | 12 | 50 |
| 38 | 15 | 11 | 36 |
| 39 | 20 | 12 | 67 |
| 40 | 18 | 11 | 64 |
| 41 | 11 | 7 | 57 |
| 42 | 12 | 7 | 71 |
| 43 | 10 | 7 | 43 |
| 44 | 13 | 8 | 63 |
| 45 | 19 | 11 | 73 |
| 46 | 15 | 10 | 50 |
| 47 | 16 | 10 | 60 |
| 48 | 18 | 9 | 100 |
| 49 | 5 | 4 | 25 |
| 50 | 8 | 6 | 33 |
| 51 | 7 | 5 | 40 |
| 52 | 7 | 6 | 17 |
| 53 | 10 | 6 | 67 |
| 54 | 9 | 6 | 50 |
| 55 | 7 | 6 | 17 |
| 56 | 9 | 6 | 50 |
| 57 | 5 | 4 | 25 |
| 58 | 4 | 4 | 0 |
| 59 | 3 | 2 | 50 |
| 60 | 7 | 5 | 40 |
| 61 | 3 | 2 | 50 |
| 62 | 3 | 2 | 50 |
| 63 | 0 | 0 | 0 |
| 64 | 2 | 2 | 0 |
| 65 | 1 | 1 | 0 |
| 66 | 2 | 1 | 100 |
| 67 | 0 | 0 | 0 |

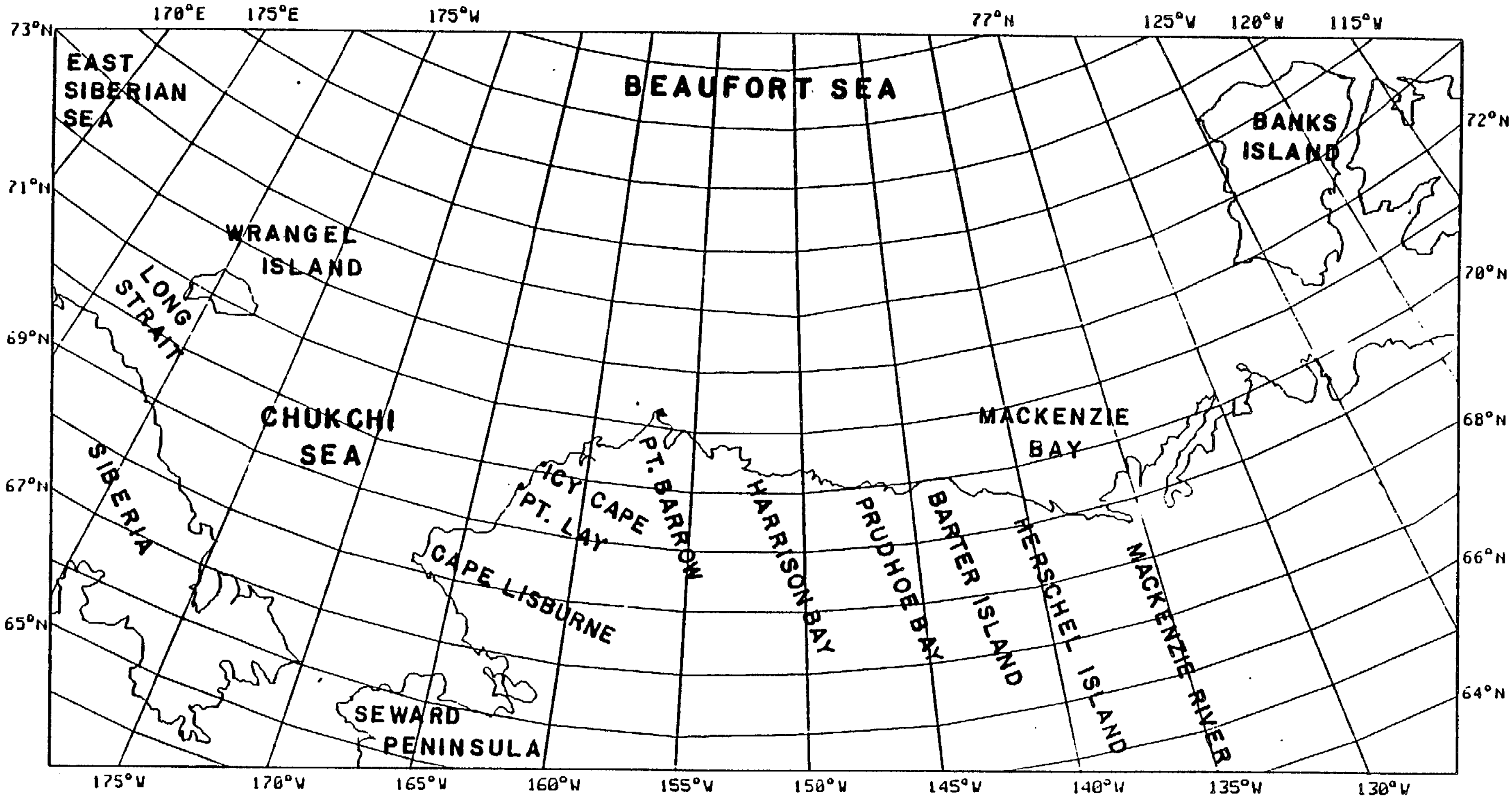



Figure 1. Geographic Location Map of the Beaufort and Chukchi Seas.

Figures 2 through 28. Weekly Ice-Free Frequency Maps for the Beaufort and Chukchi Seas.

Water that contained some ice for all the years examined. (i.e., was never observed to be ice-free)

Water that contained some ice 7 to 11 years. (i.e., was ice-free less than half the years)

Water that contained some ice 1 to 6 years. (i.e., was ice-free more than half the years)

Water that was completely ice-free for all the years examined.

The boundary between water that contained some ice 7 to 11 years and that which contained some ice 1 to 6 years is the 50% ice-free frequency line.

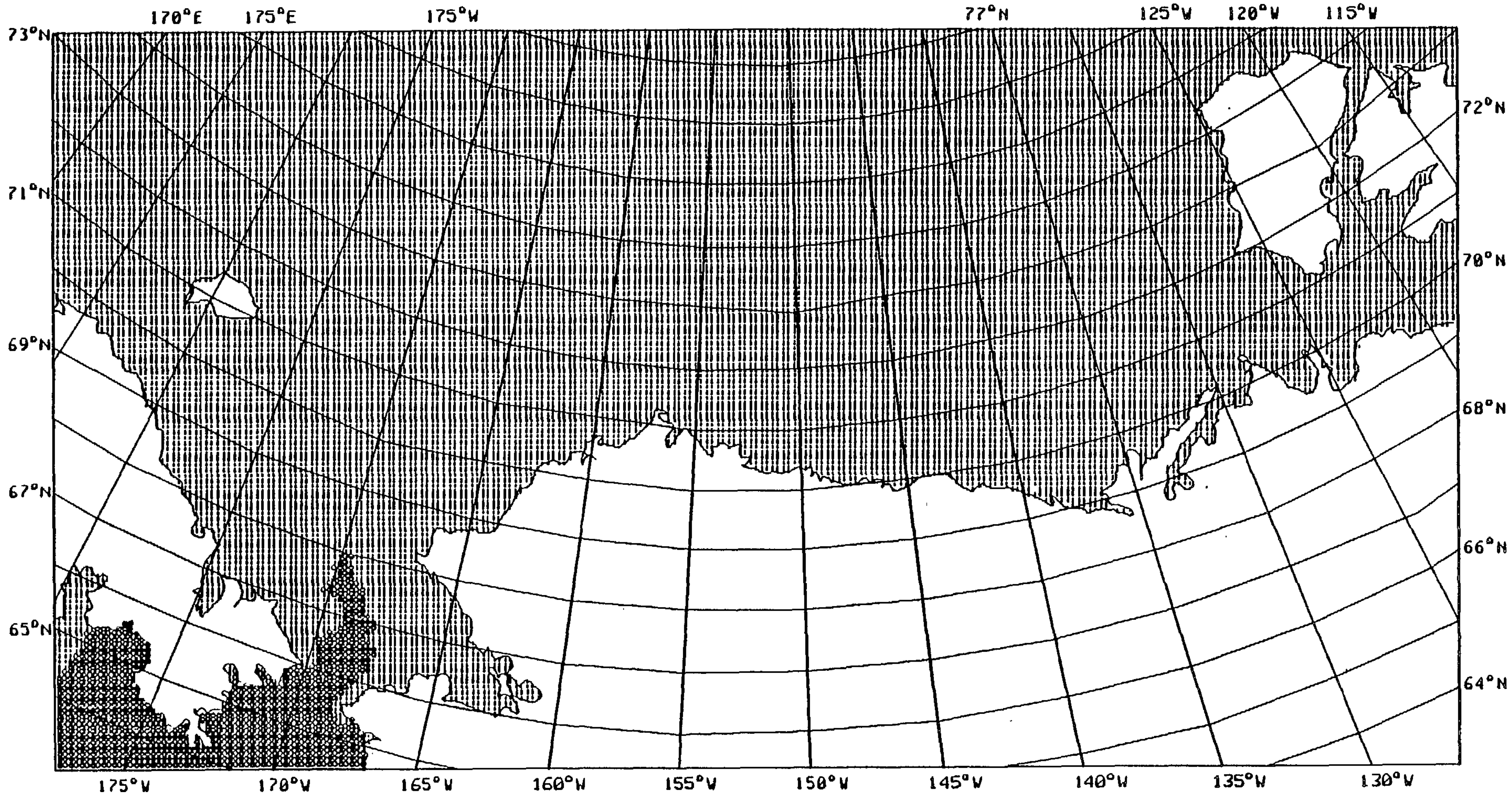
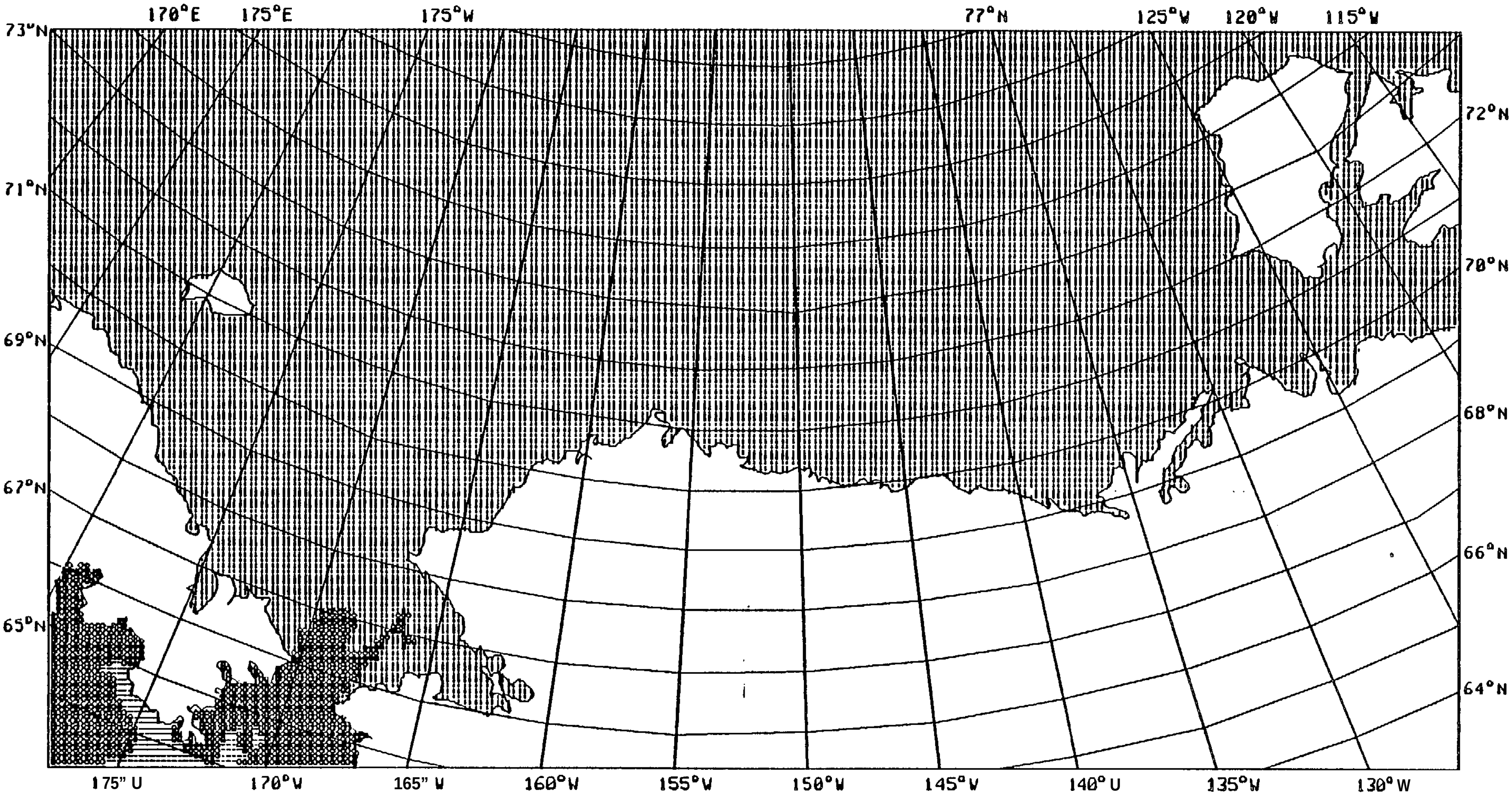



FIGURE 2 ICE FREE FREQUENCY FOR JUNE 7 F°R THE BEAUFORT AND CHUKCHI SE°S




F 1 GURE 3 ICE FREE FREQUENCY FOR JUNE 8-14 FOR THE BEAUFORT AND CHUKCHI SEAS

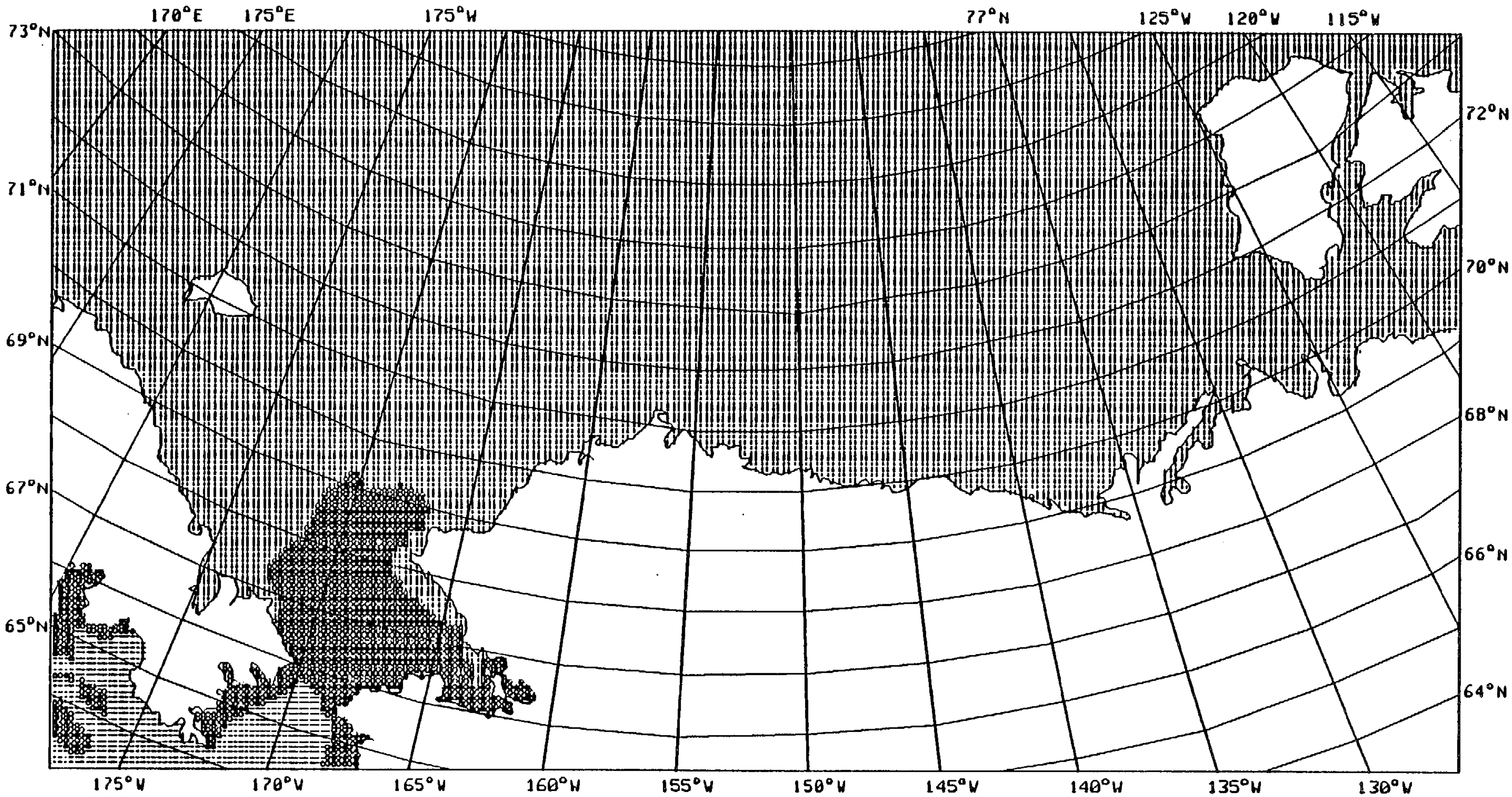



FIGURE 4 ICE FREE FREQUENCY FOR JUNE 5-21 FOR THE BEAUFORT AND CHUKCHI SEAS

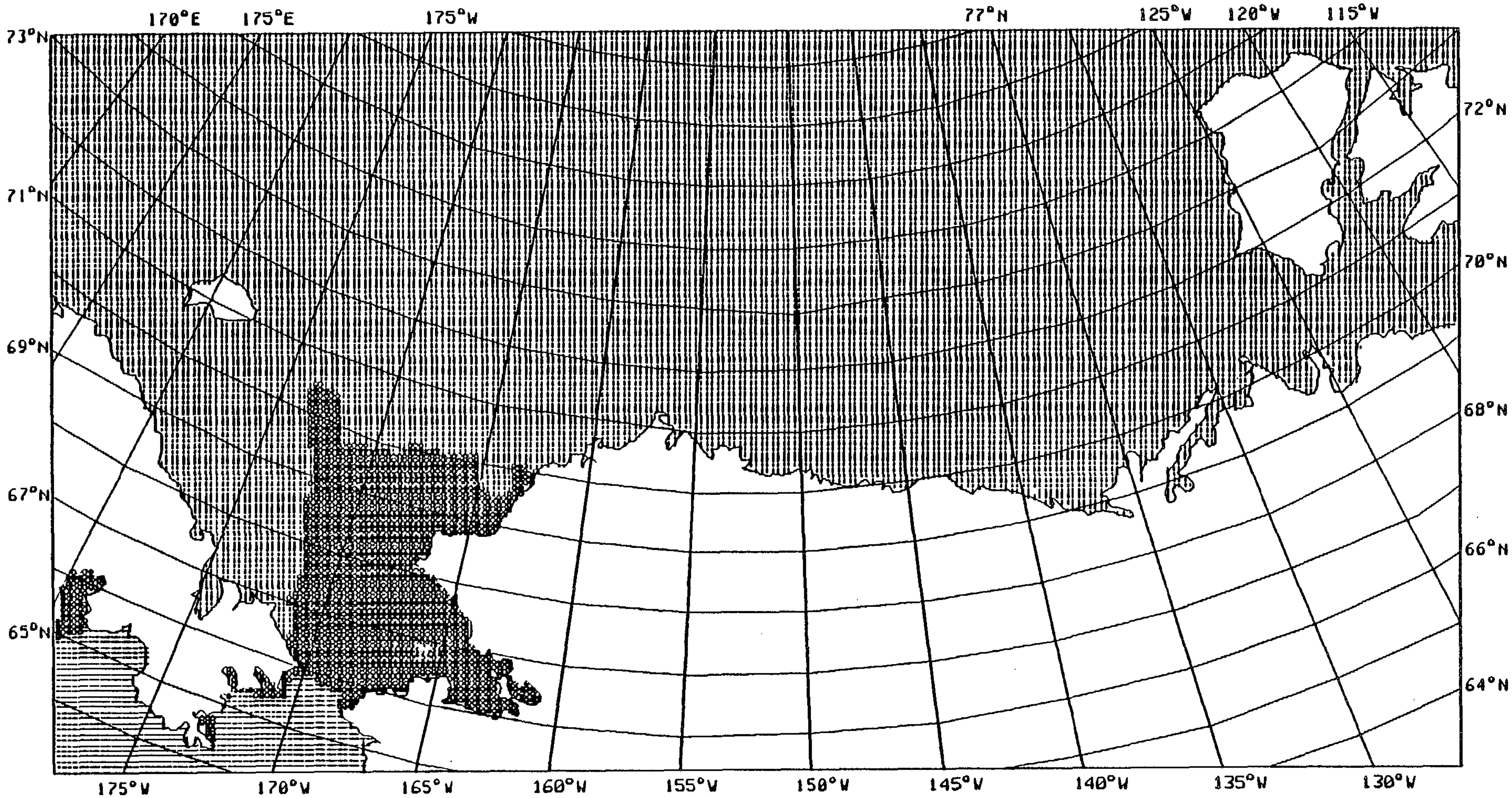
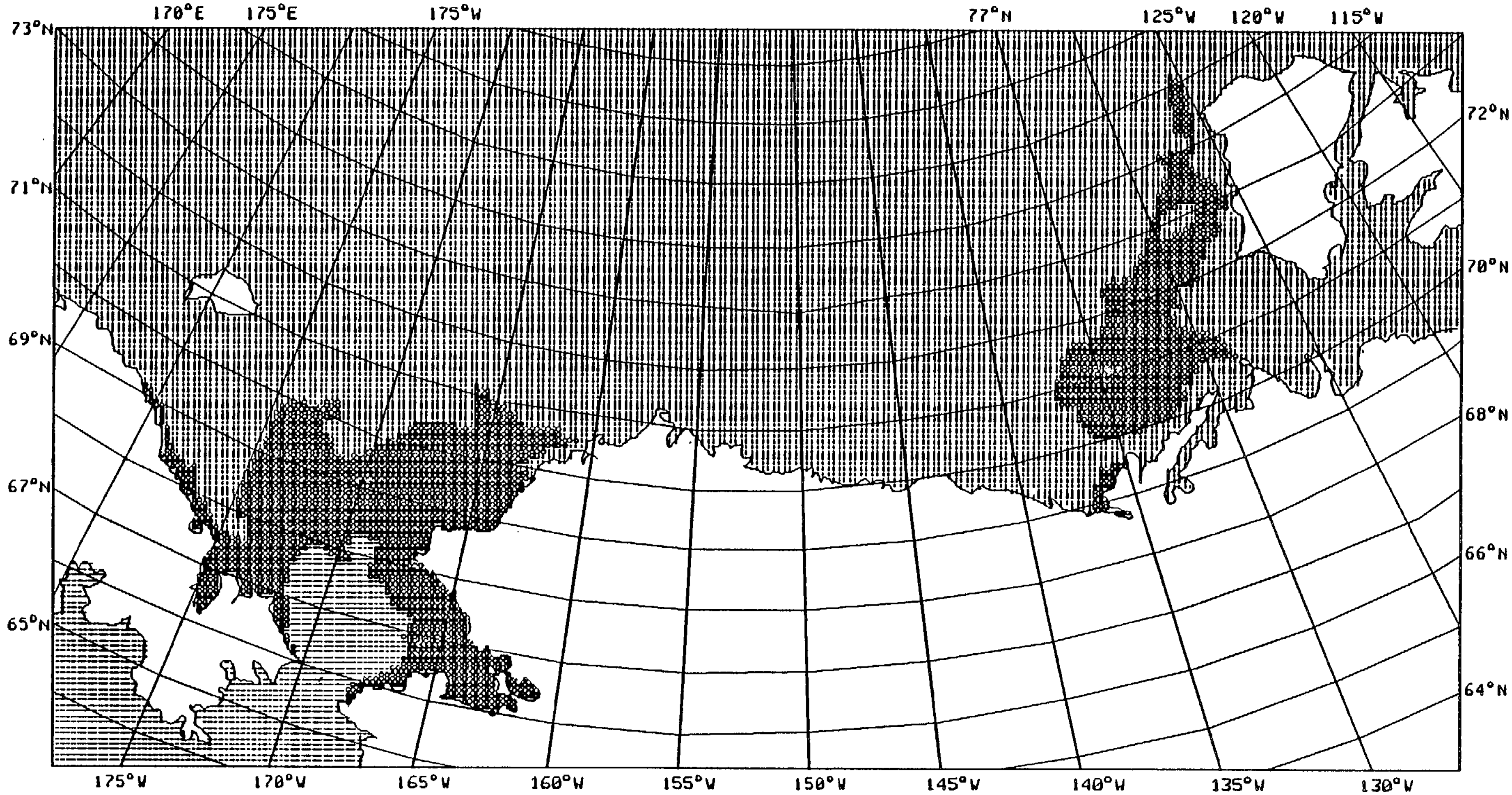
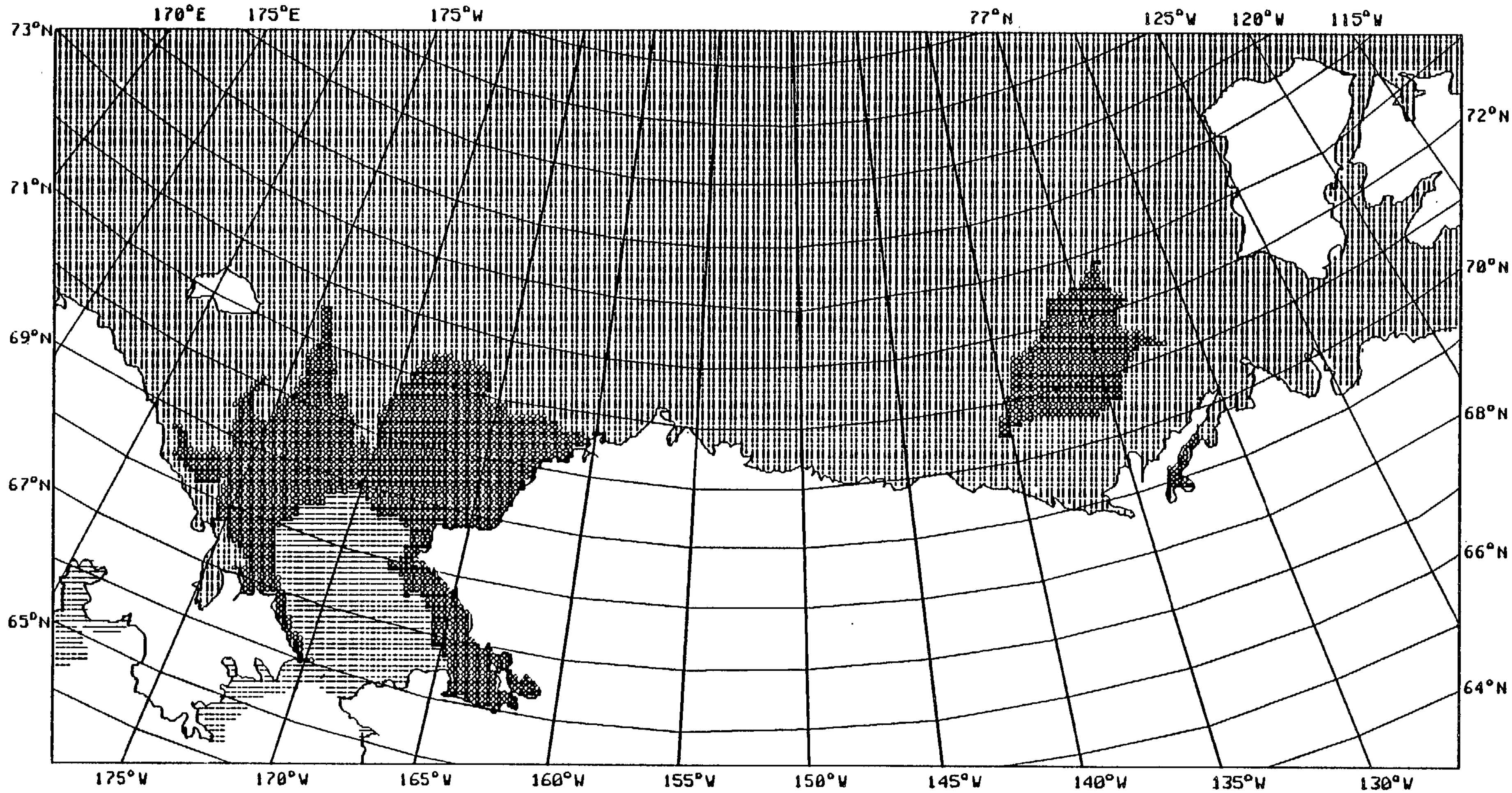


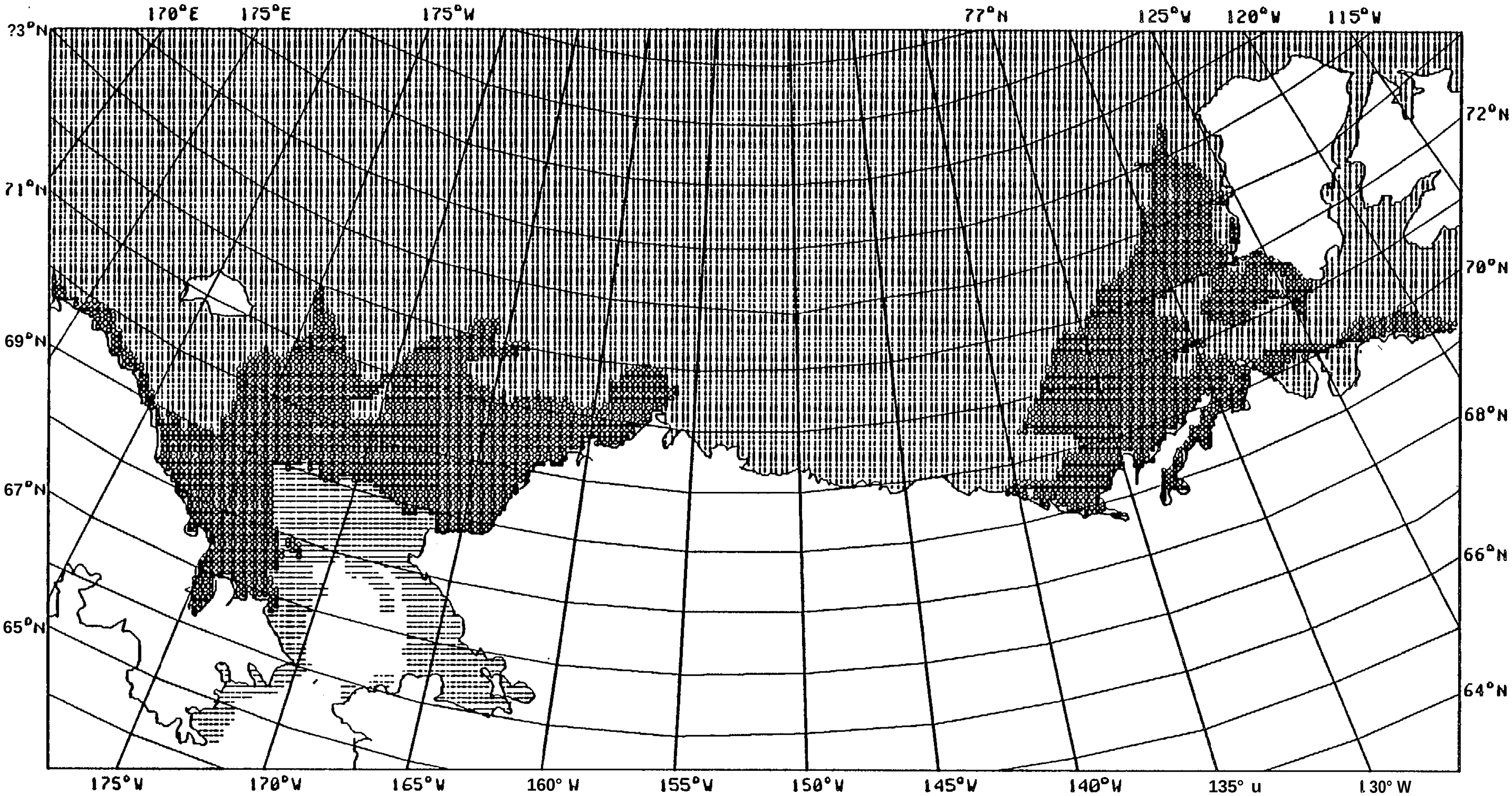

FIGURE 5 ICE FREE FREQUENCY FOR JUNE 22-28 FOR THE BEAUFORT AND CHUKCHI SEAS



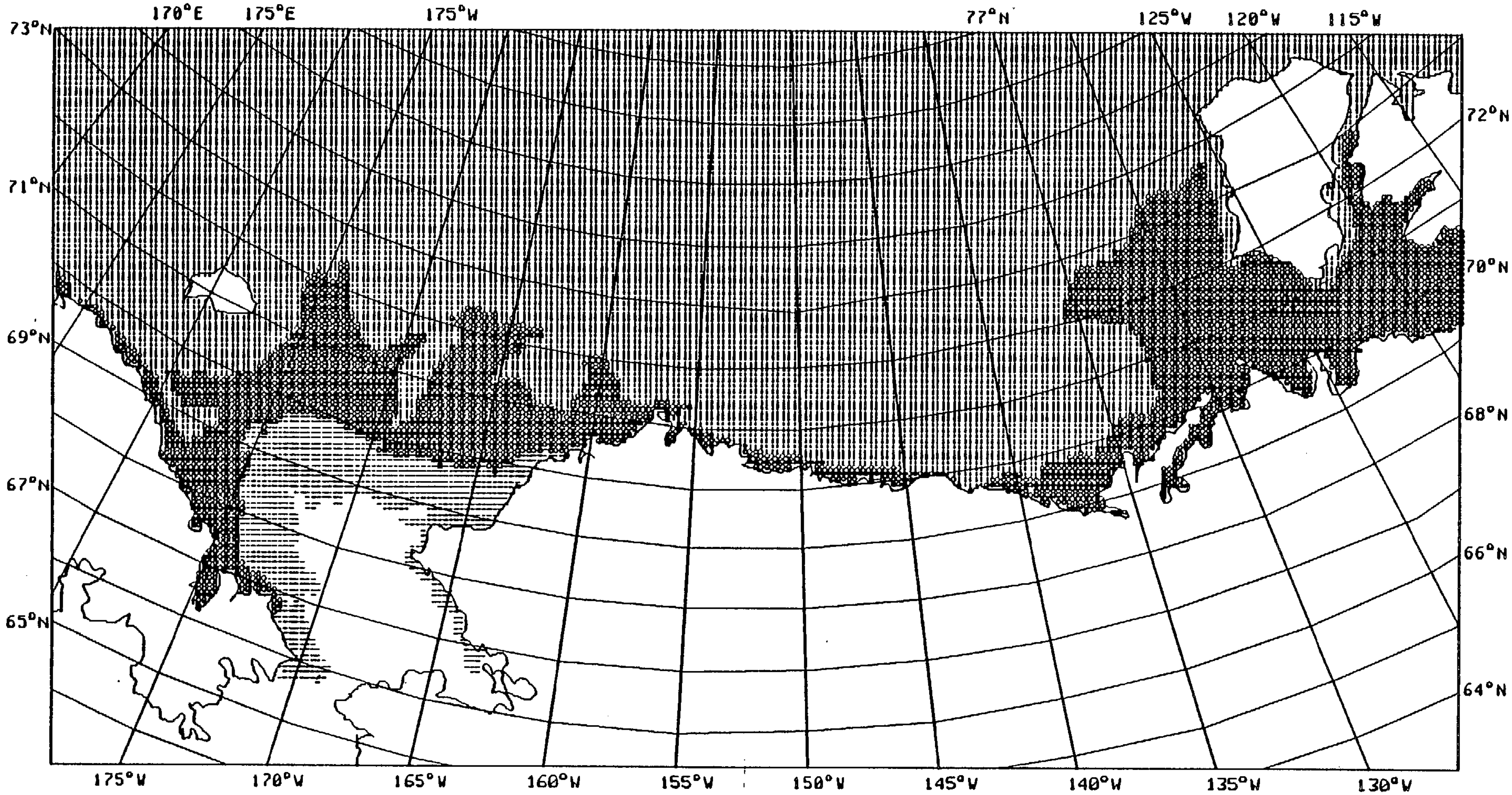

F GURE 6 ICE FRE= FREQUENCY FOR JUNE 29-JUL 5 FOR THE BEAUFORT AND CHUKCHI SEAS




FI=URE 7 C≤ FREE FREQUENCY FOR JULY 6-'2 FOR THE BEAUFORT AND CHUKCHI SEAS




F 1 GURE 8 ICE FREE FREQUENCY FOR JULY 13-19 FOR THE BEAUFORT AND CHUKCHI SEAS




F 1 GURE 9 ICE FREE FREQuENCY FOR JULY 20-26 FOR THE BEAUFORT AND CHUKCHI SEAS

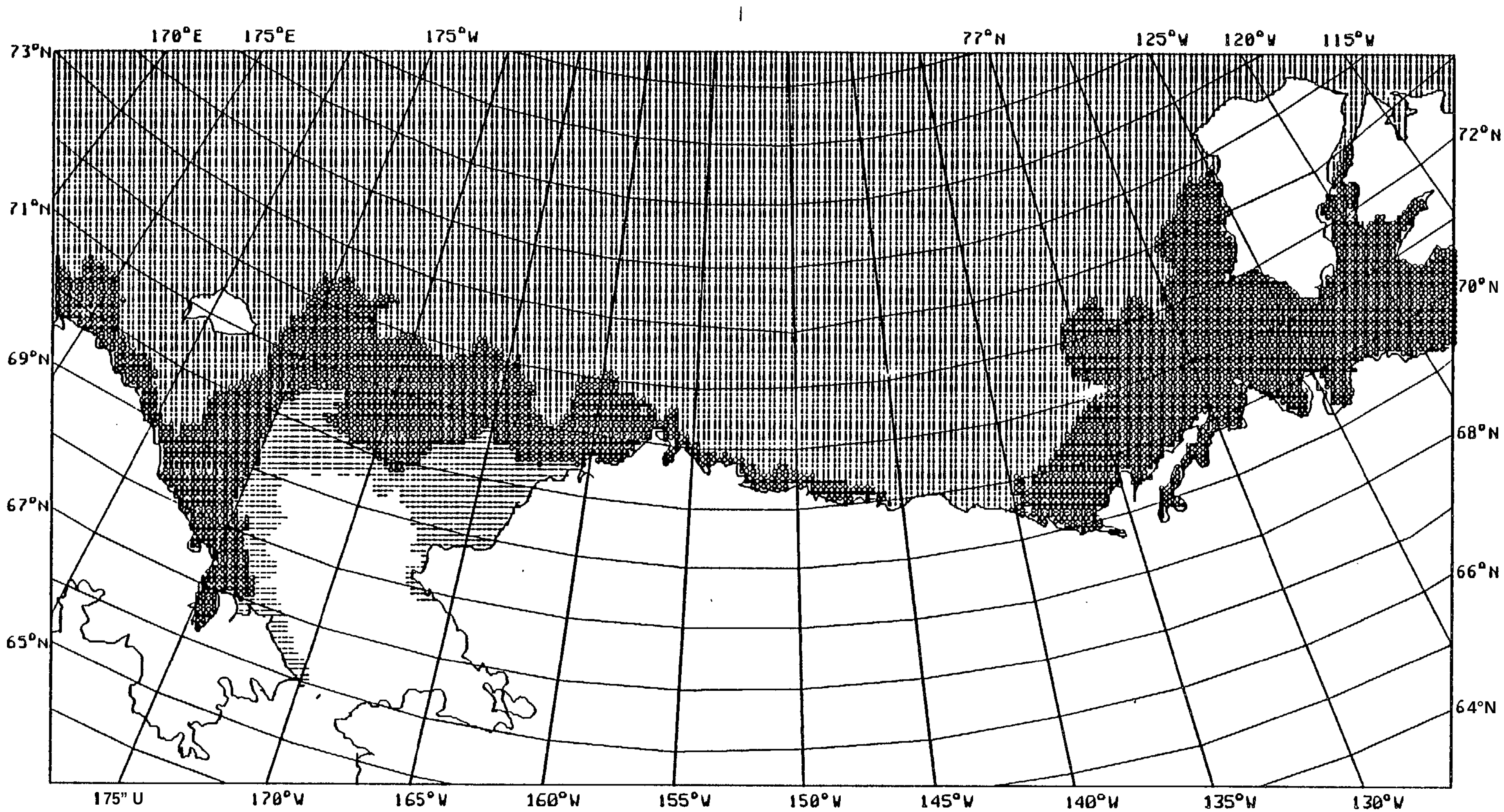



**FIGuRE 10 ICE FREE FREQUENCY FOR JULY 27-AUG 2 FOR THE BEAUFORT AND CHUKCHI SEAS**

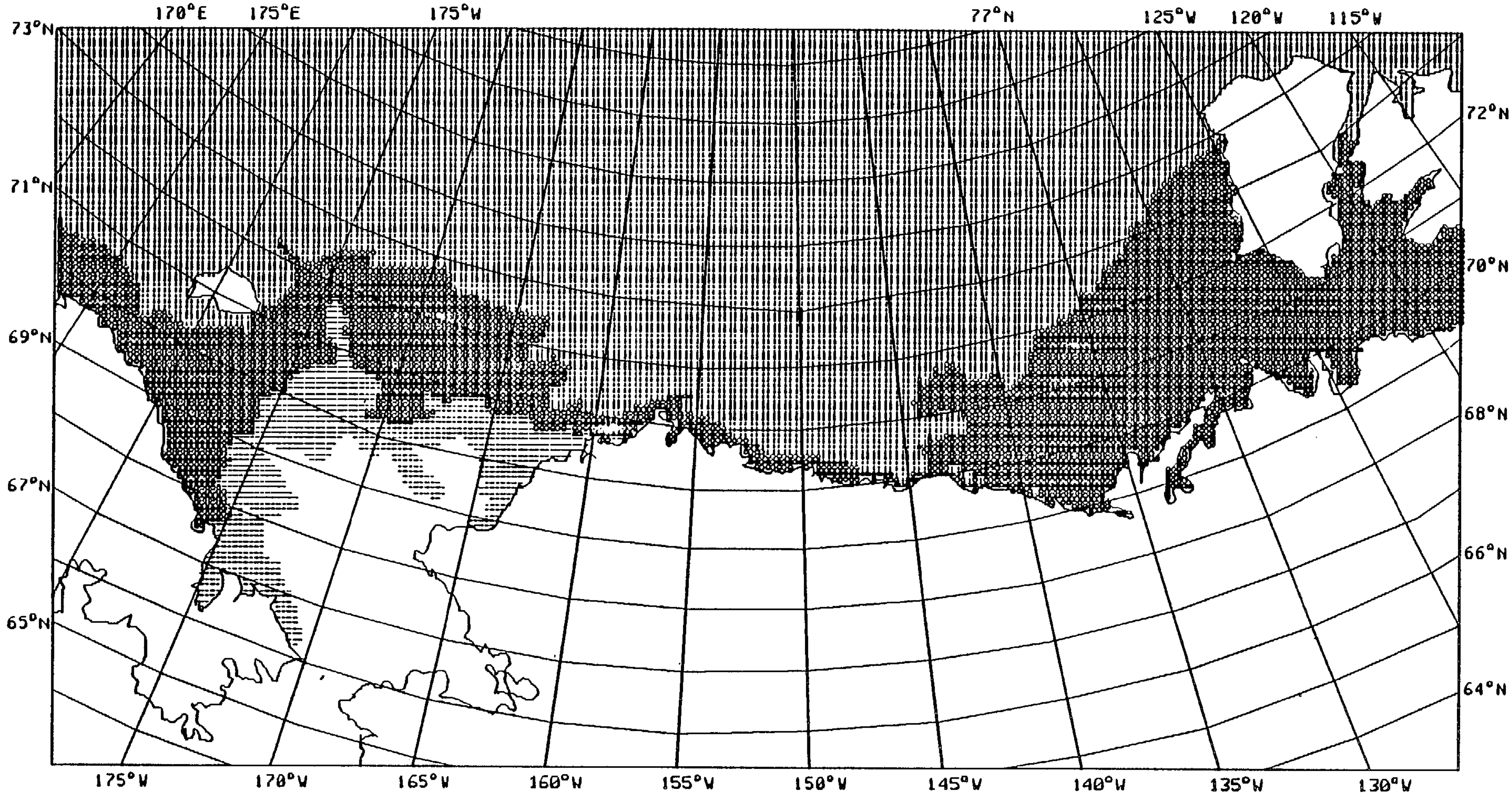



FIGURE 11 ICE FREE FREQUENCY FOR AUGUST 3-9 FOR THE BEAUFORT AND CHUKCHI SEAS

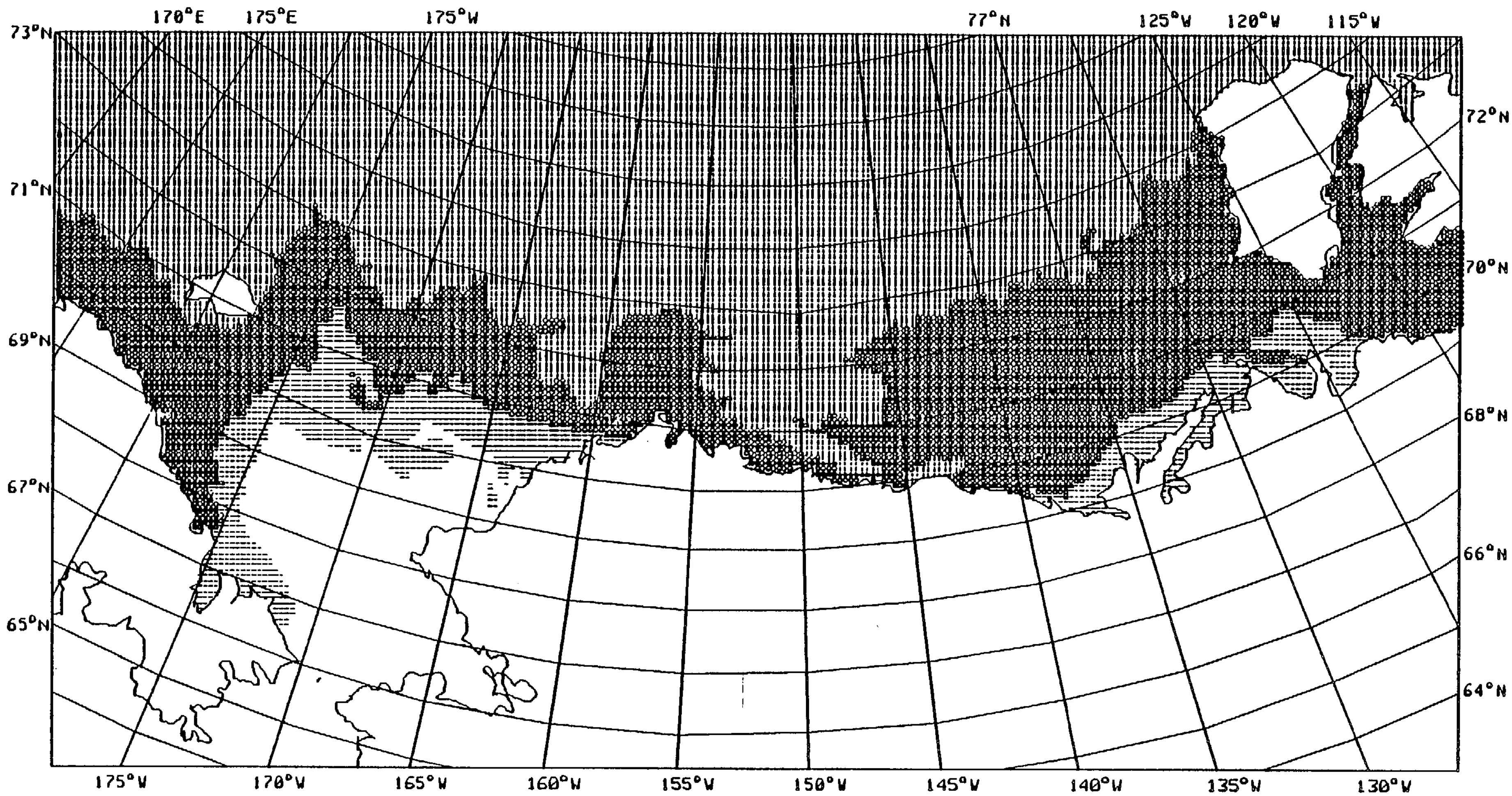



FIGURE 2 ICE FREE FREQUENCY FOR AUGUST 10-16 FOR THE BEAUFORT AND CHUKCHI SEAS

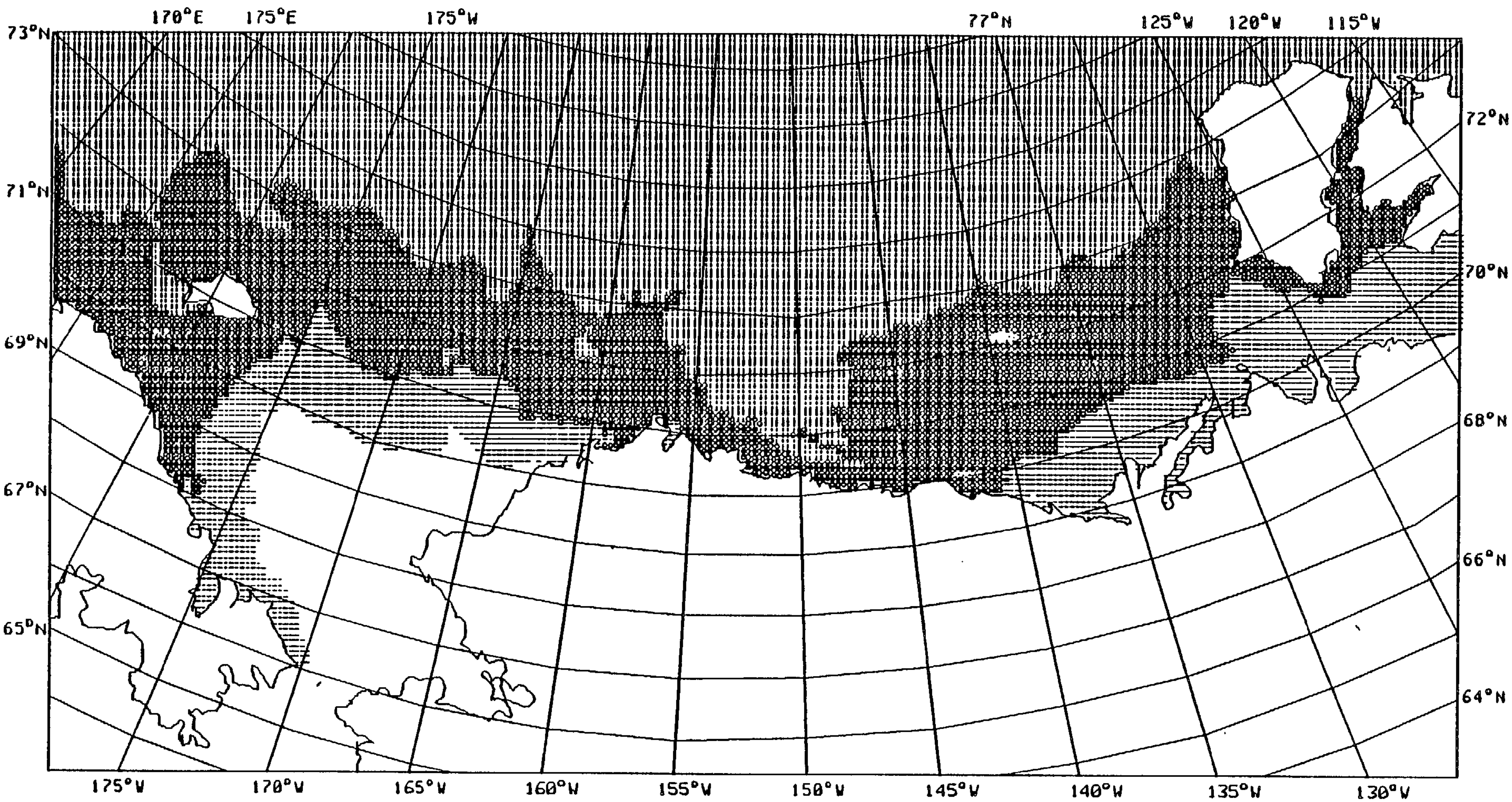



FIGURE 3 ICE FREE FREQUENCY FOR AUGUST 17-23 FOR THE BEAUFORT AND CHUKCHI SEAS

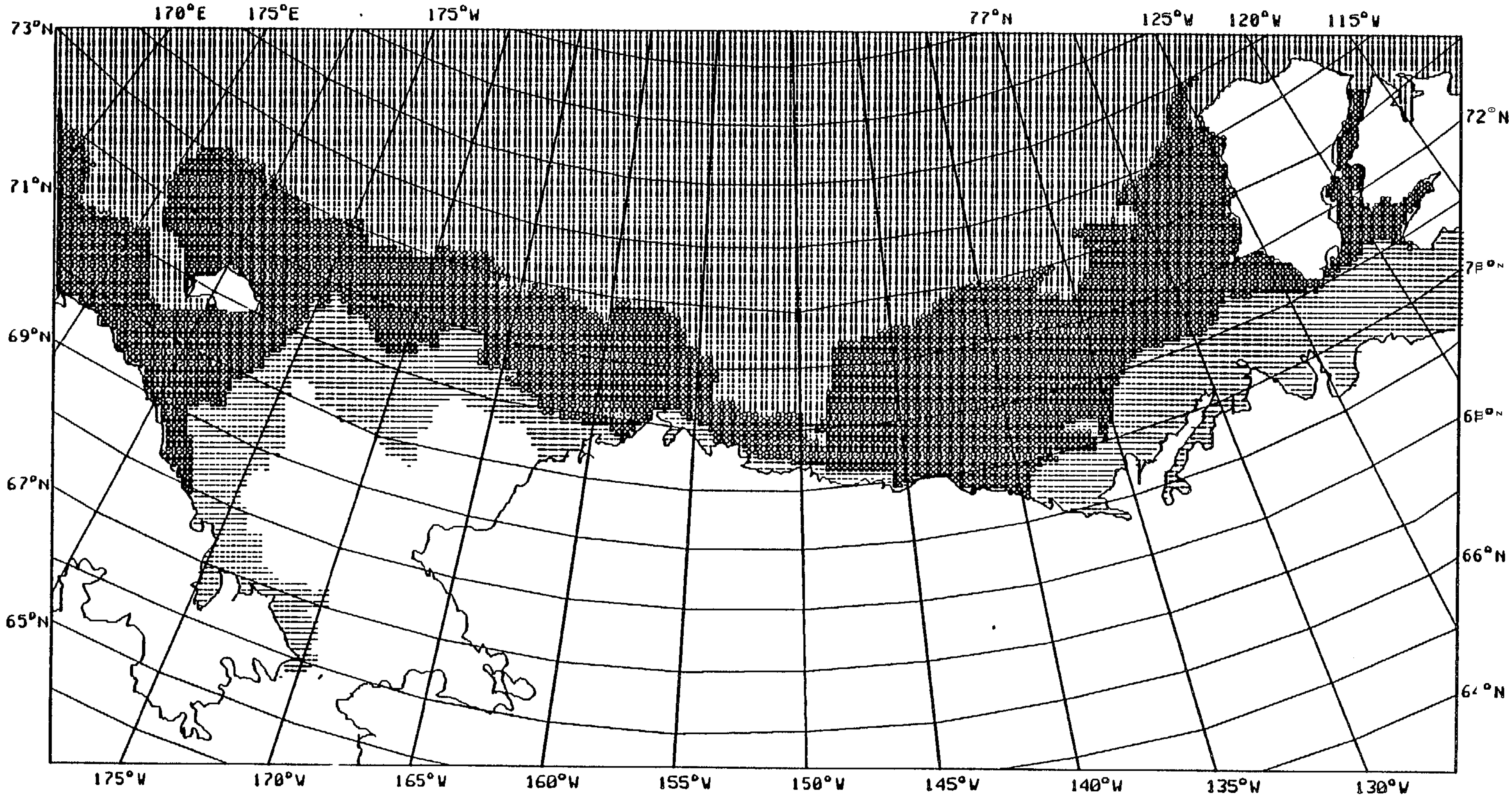



FIGURE 14 ICE FREE FREQUENCY FOR AUGUST 24-30 FOR THE BEAUFORT AND CHUKCHI SEAS

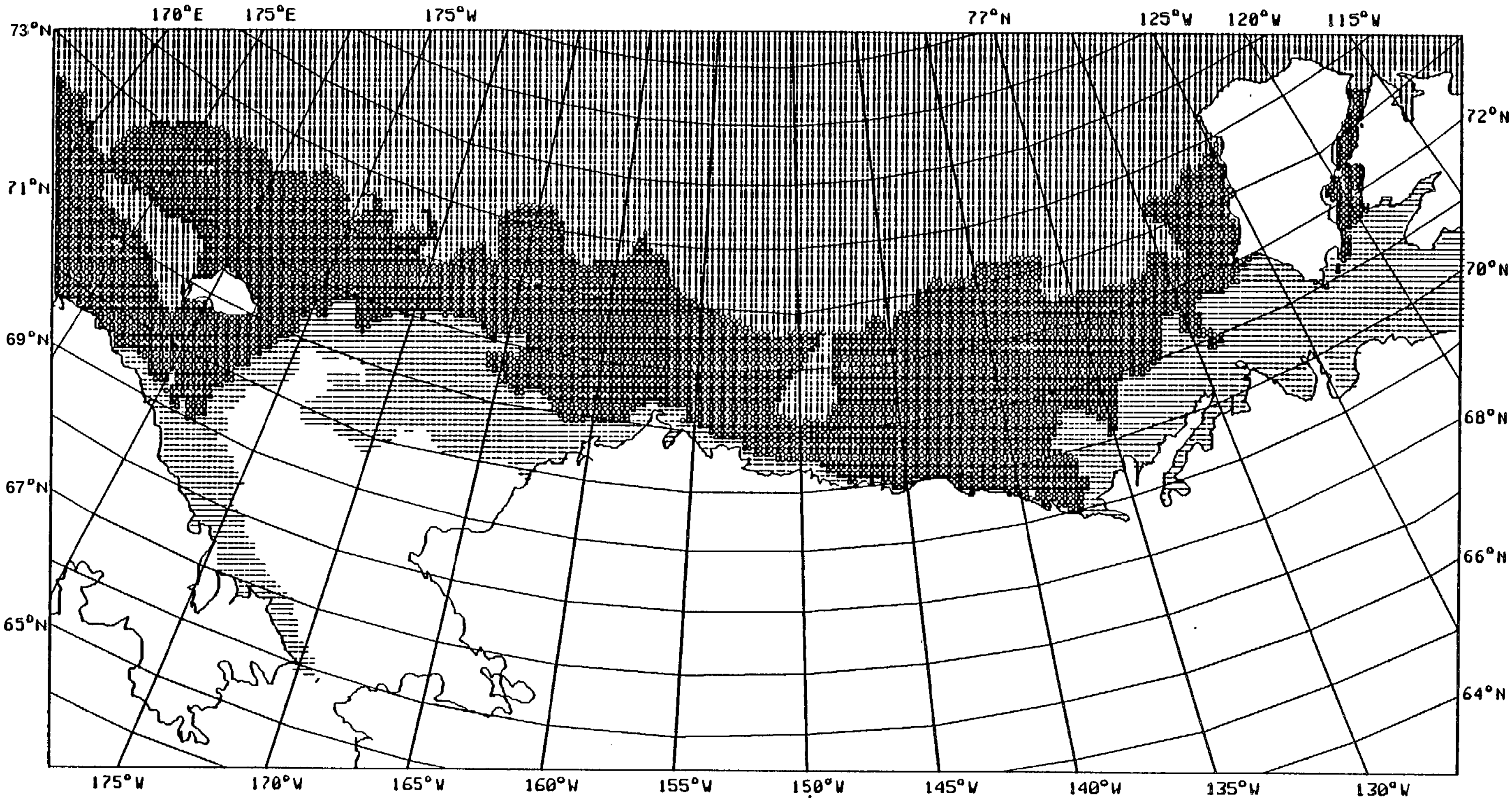



FIGuRE 15 ICE FREE FREQUENCY FOR AUGUST 31-SEP 6 FOR THE BEAUFORT AND CHUKCHI SEAS

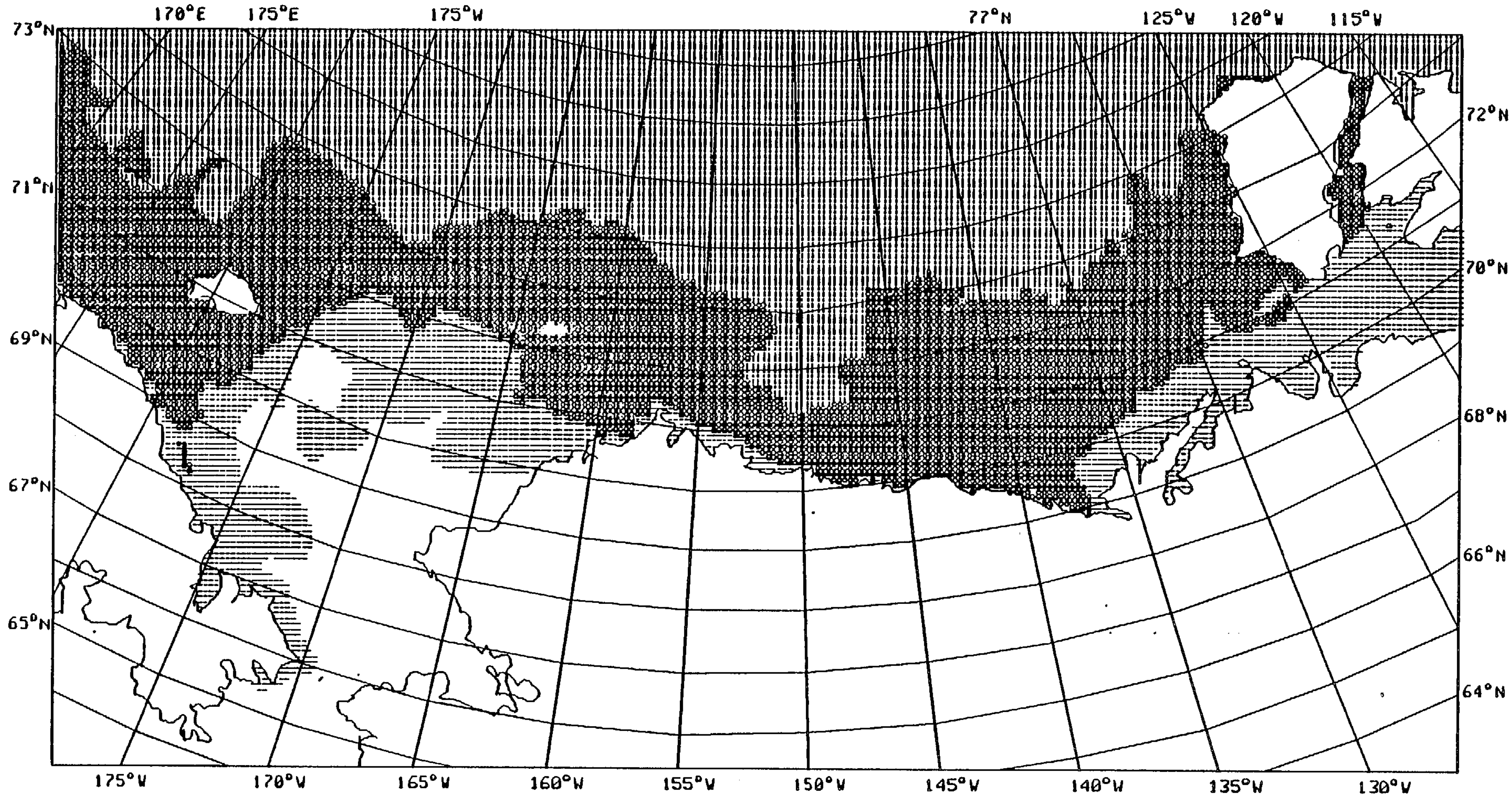



FIGURE 6 ICE FREE FREQUENCY FOR SEPTEMBER 7-13 FOR THE BEAUFORT AND CHUKCHI SEAS

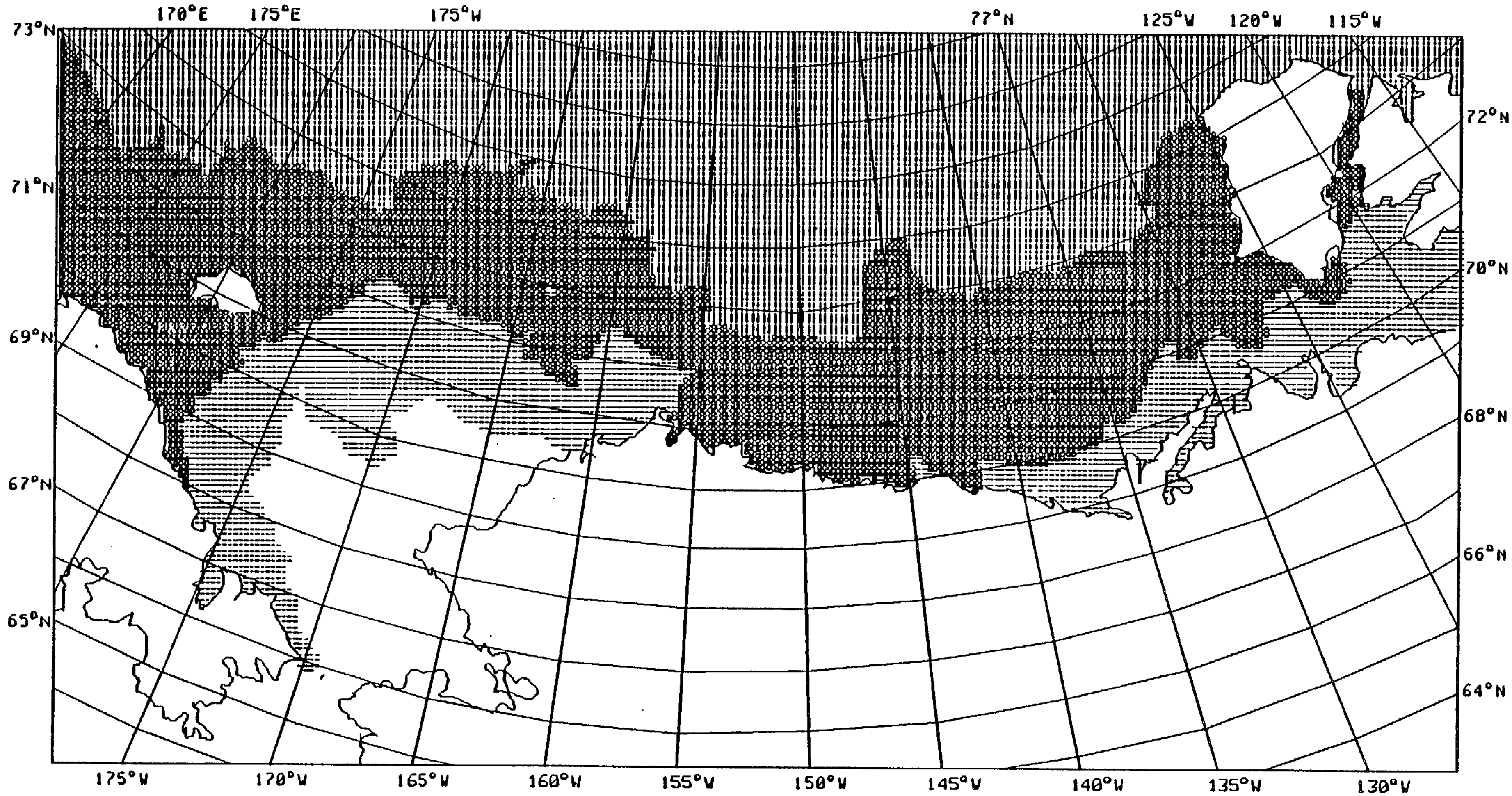



FIGURE 17 ICE FREE FREQUENCY FOR SEPTEMBER 15-17 FOR THE BEAUFORT AND CHUKCHI SEAS

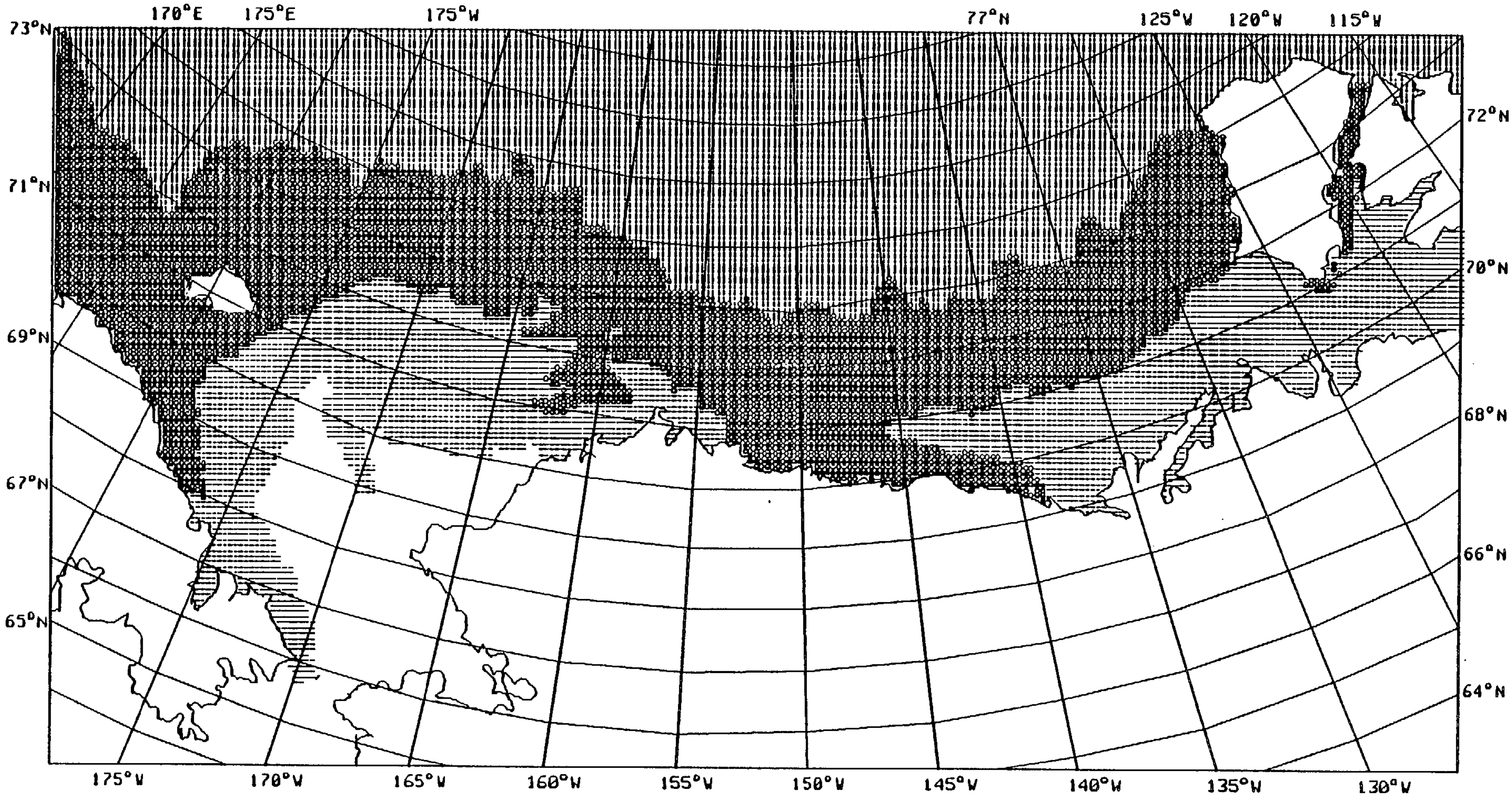



**FIGURE 18** ICE FREE FREQUENCY FOR SEPTEMBER 21-27 FOR THE BEAUFORT AND CHUKCHI SEAS

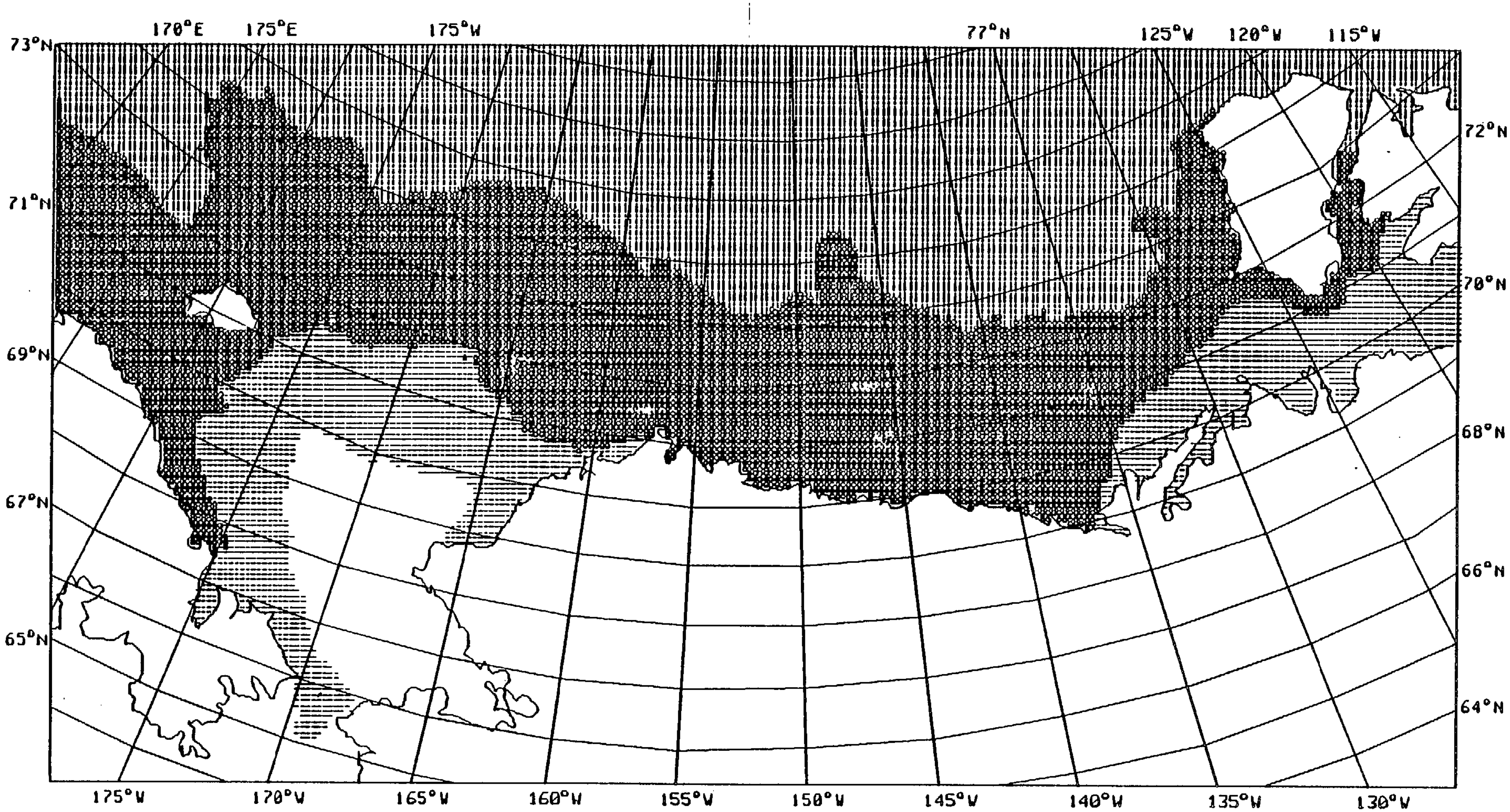
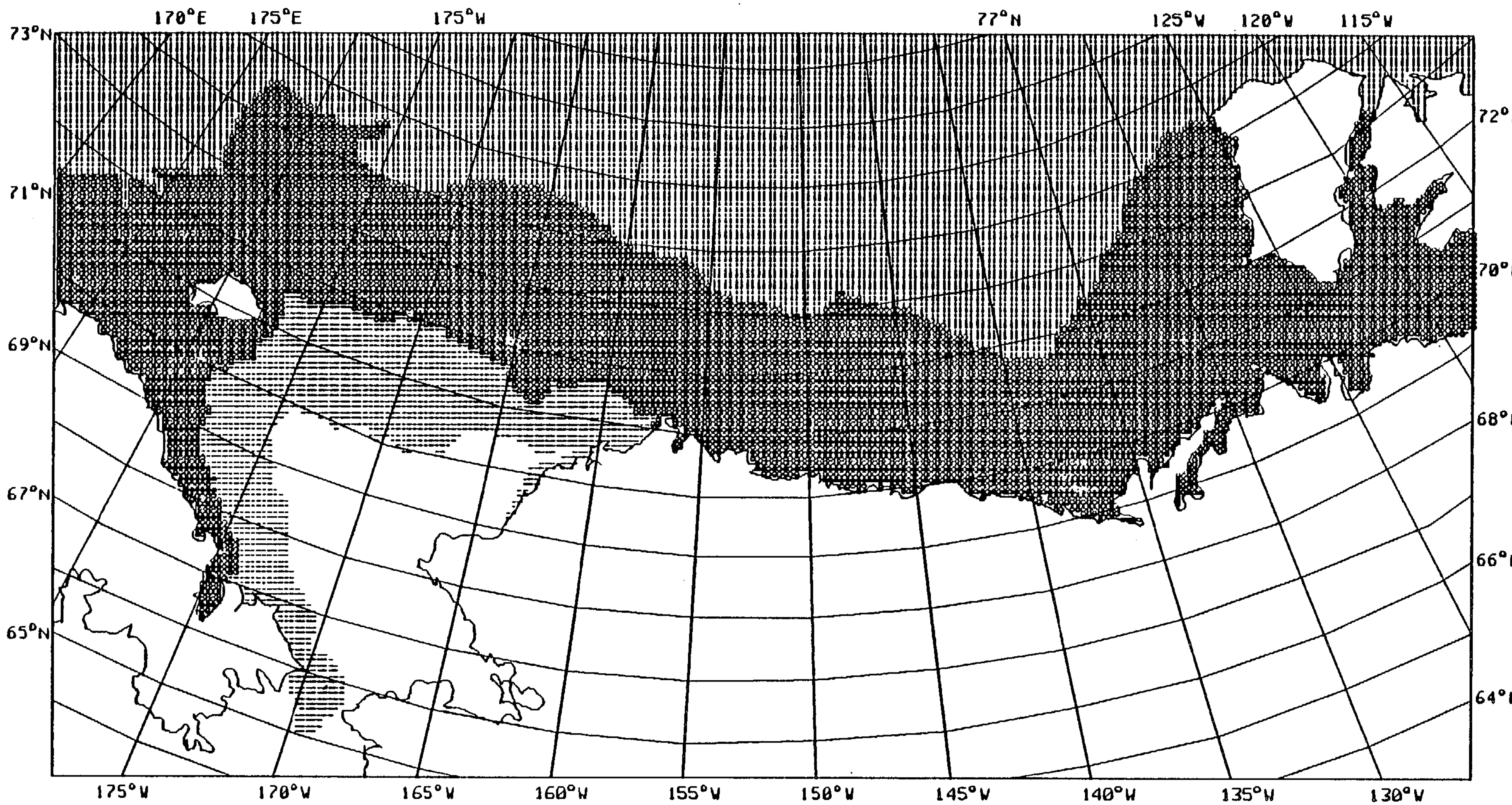



**FIGuRE 19 ICE FREE FREQUENCY FOR SEPTEMBER** 28-OCT 4 **FOR THE** BEAUFORT AND CHUKCHI SEAS




F GURE 20 ICE FREE FREQUENCY FOR OCTOBER 5-11 FOR THE BEAUFORT AND CHUKCHI SEAS

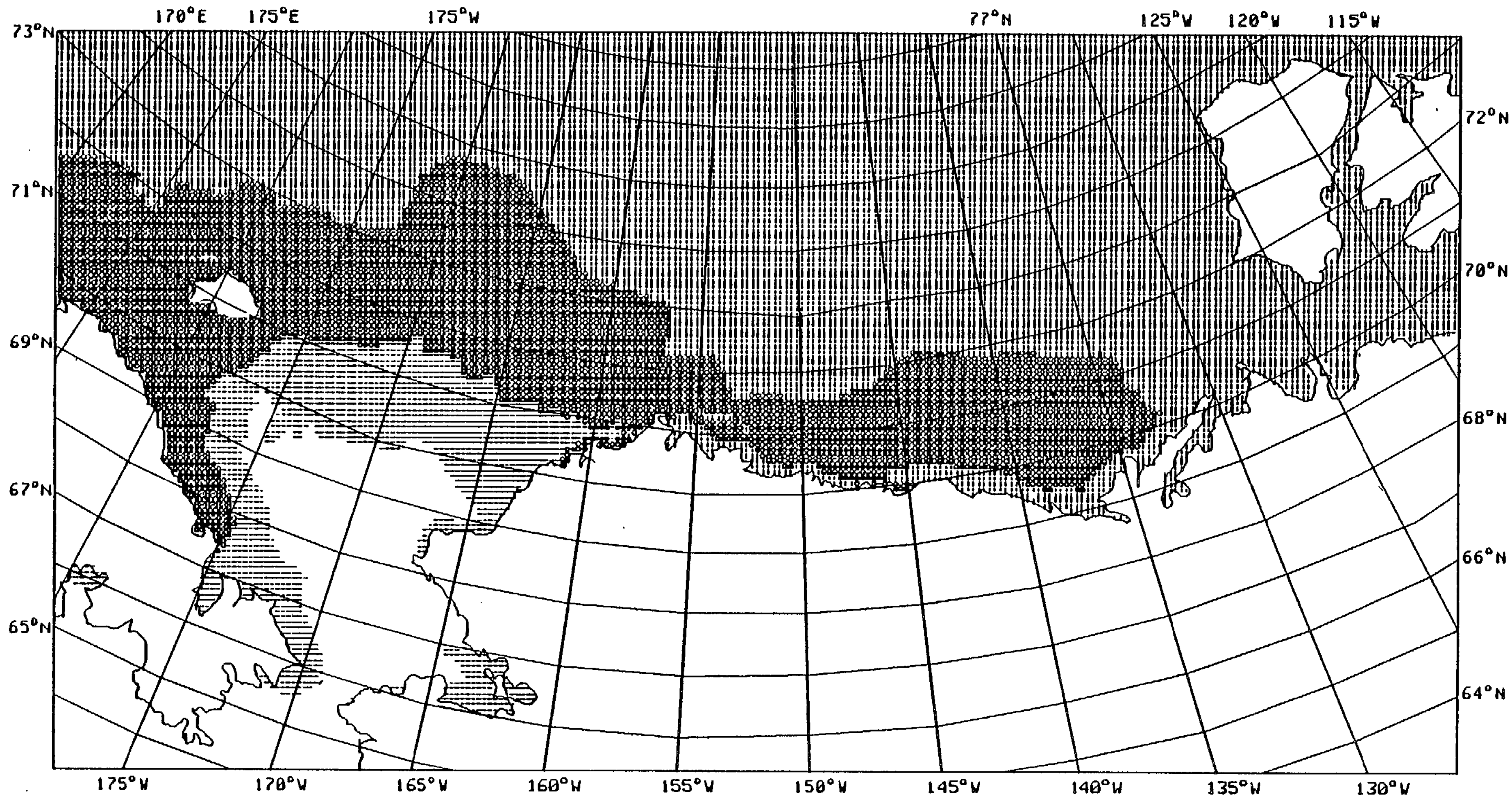
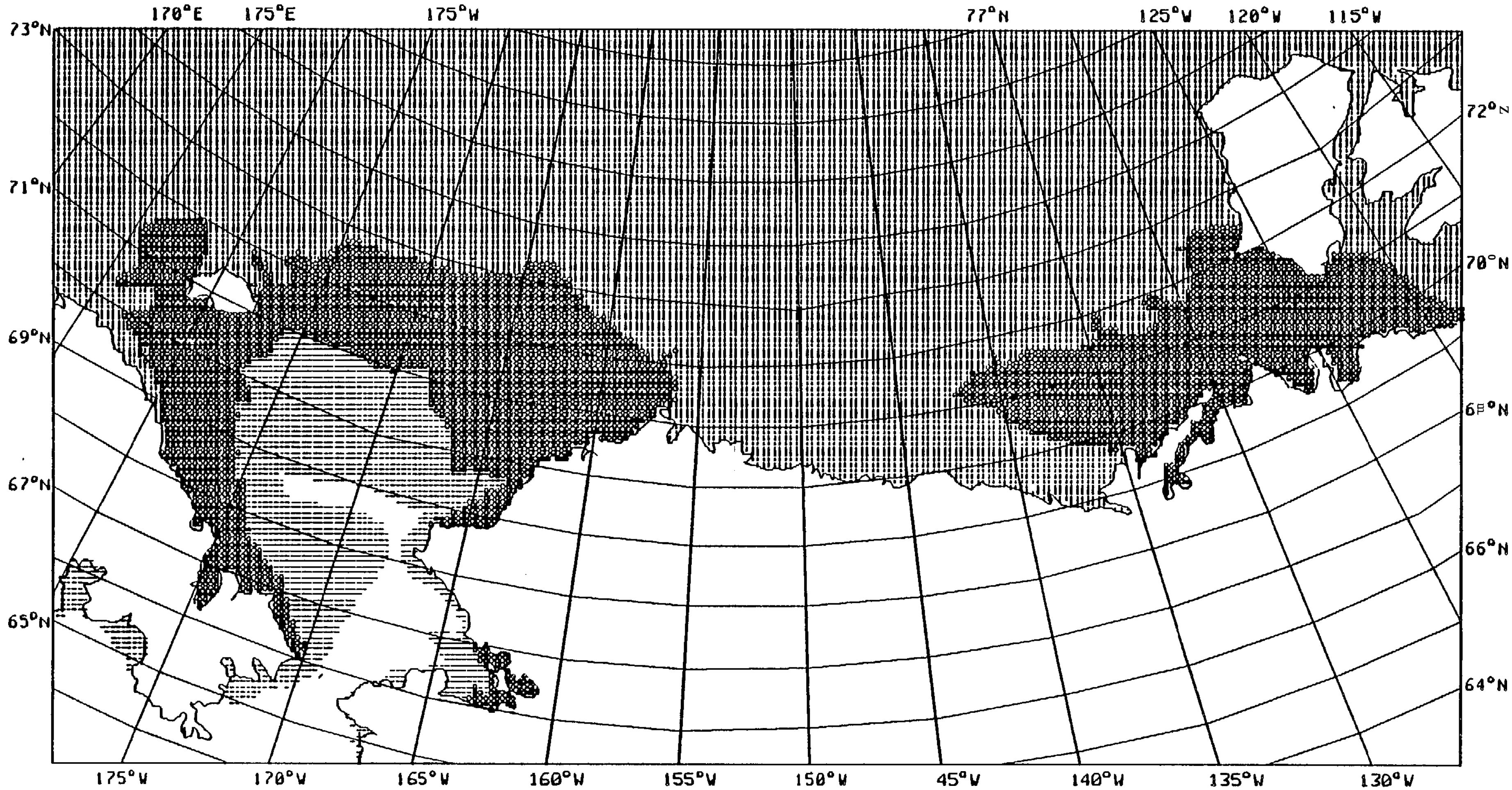



FIGURE 21 ICE FREE FREQUENCY FOR OCTOBER 12-18 FOR THE BEAUFORT AND CHUKCHI SEAS




F GURE 22 ICE FREE FREQUENCY FOR OCTOBER 9-25 FOR THE BEAUFORT AND CHUKCHI SEAS

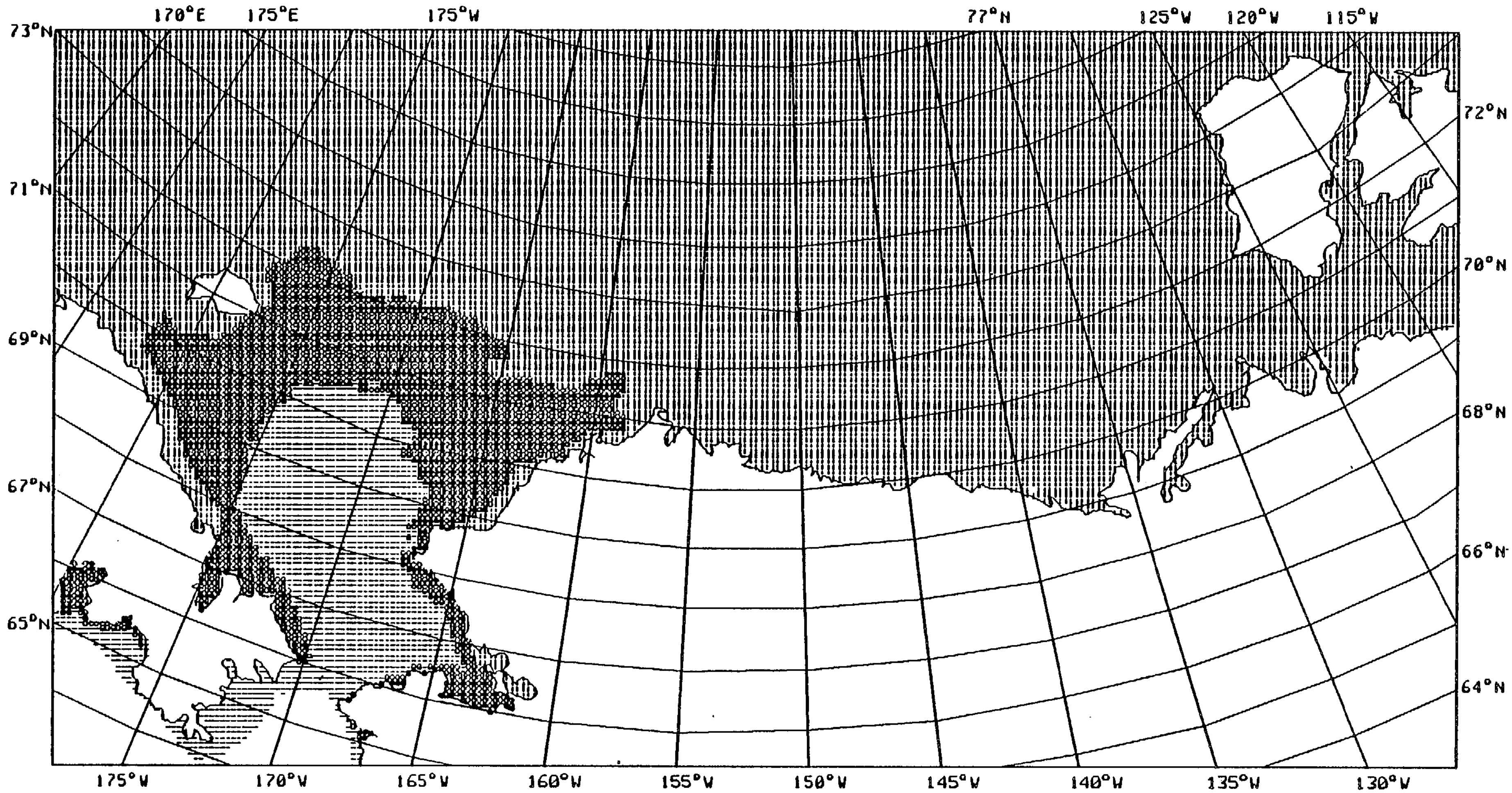



**FIGURE 23** ICE **FREE FREQUENCY** FOR **OCTOBER** 26-NOV1 **FOR THE** BEAUFORT AND CHUKCHI SEAS

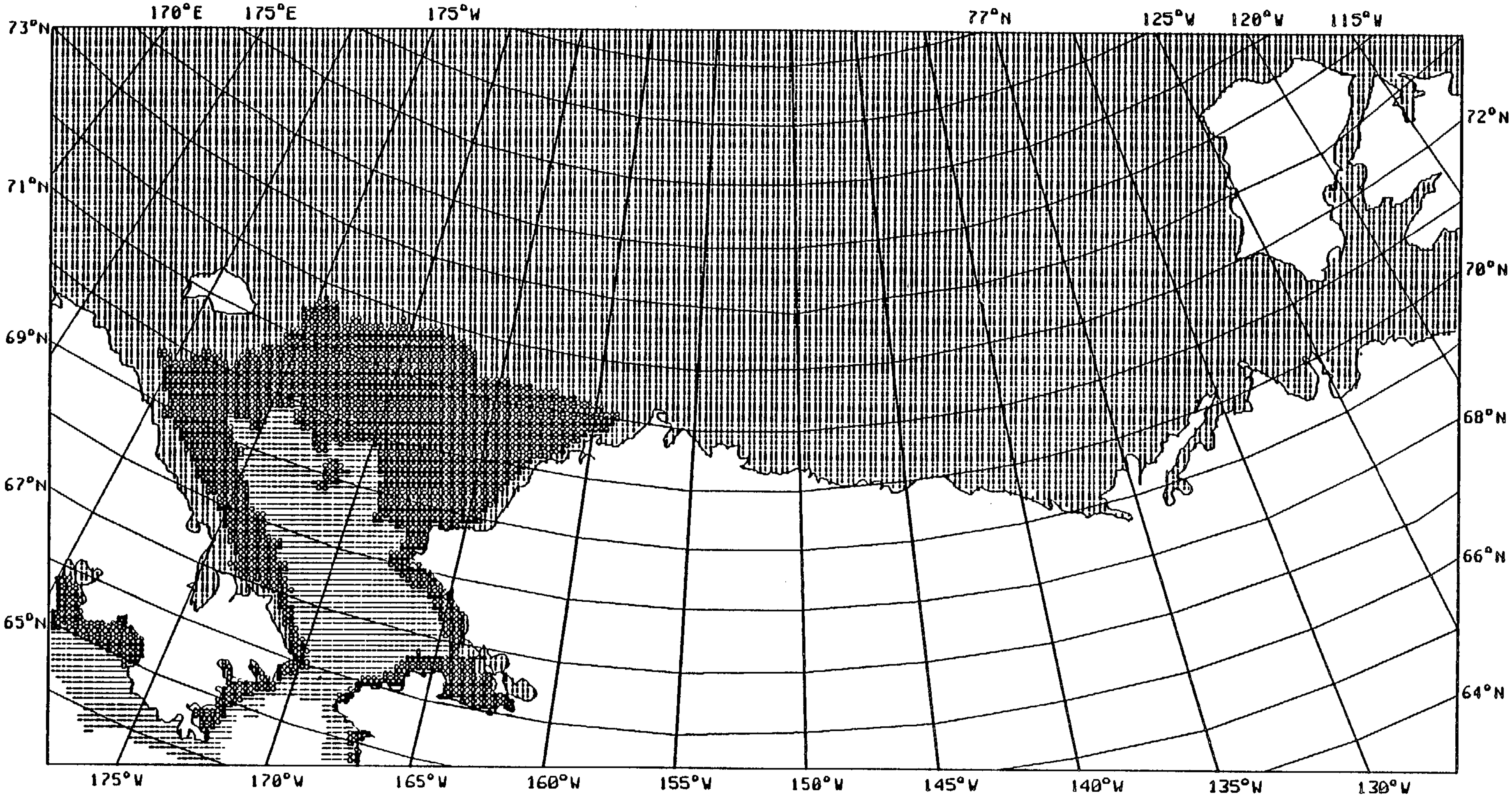



**FIGURE 24** ICE FREE FREQUENCY FOR NOVEMBER 2-8 FOR THE BEAUFORT AND CHUKCHI SEAS

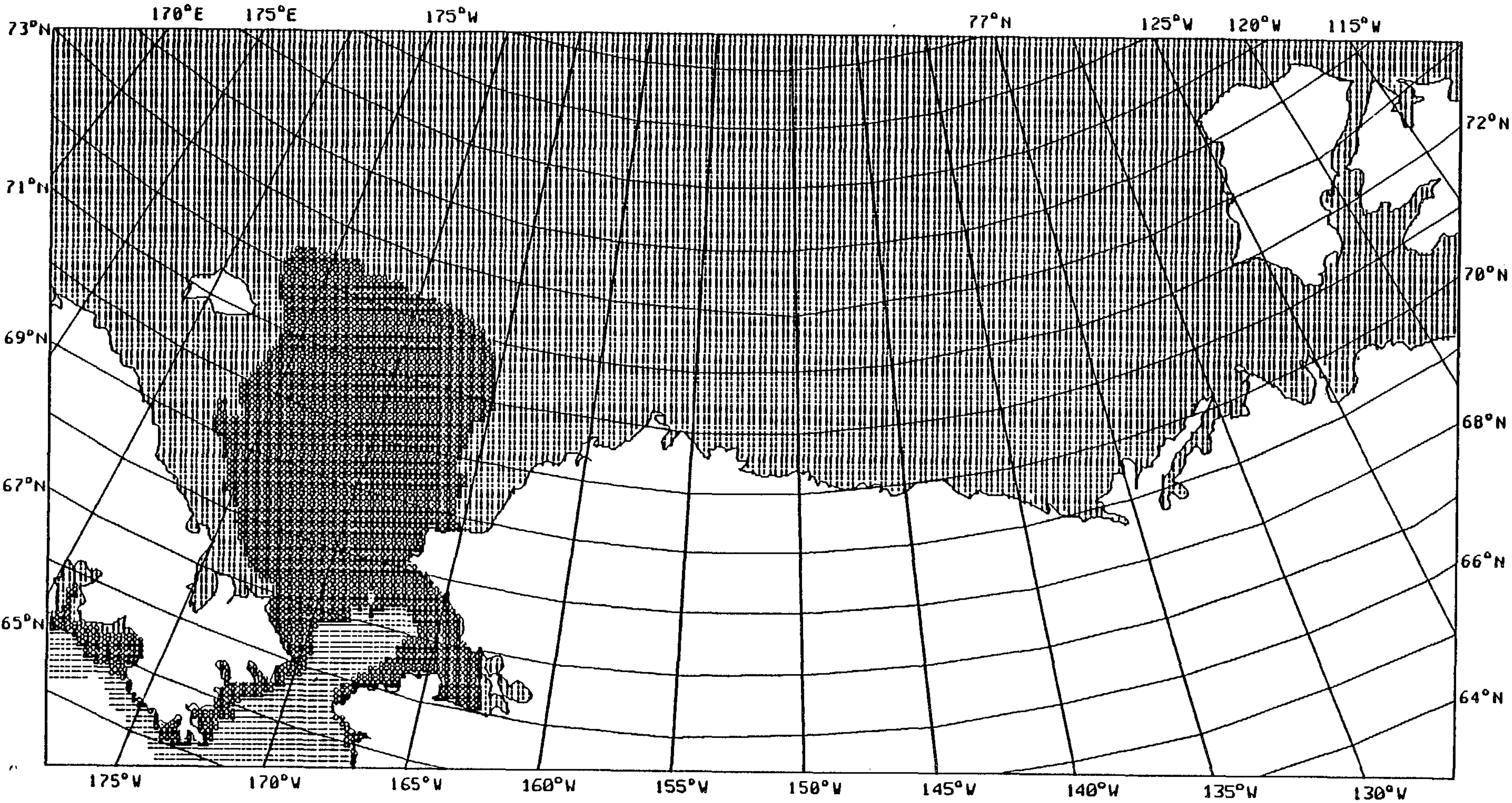



FIGURE 25 ICE FREE FREQUENCY FOR NOVEMBER 9-15 FOR THE BEAUFORT AND CHUKCHI SEAS

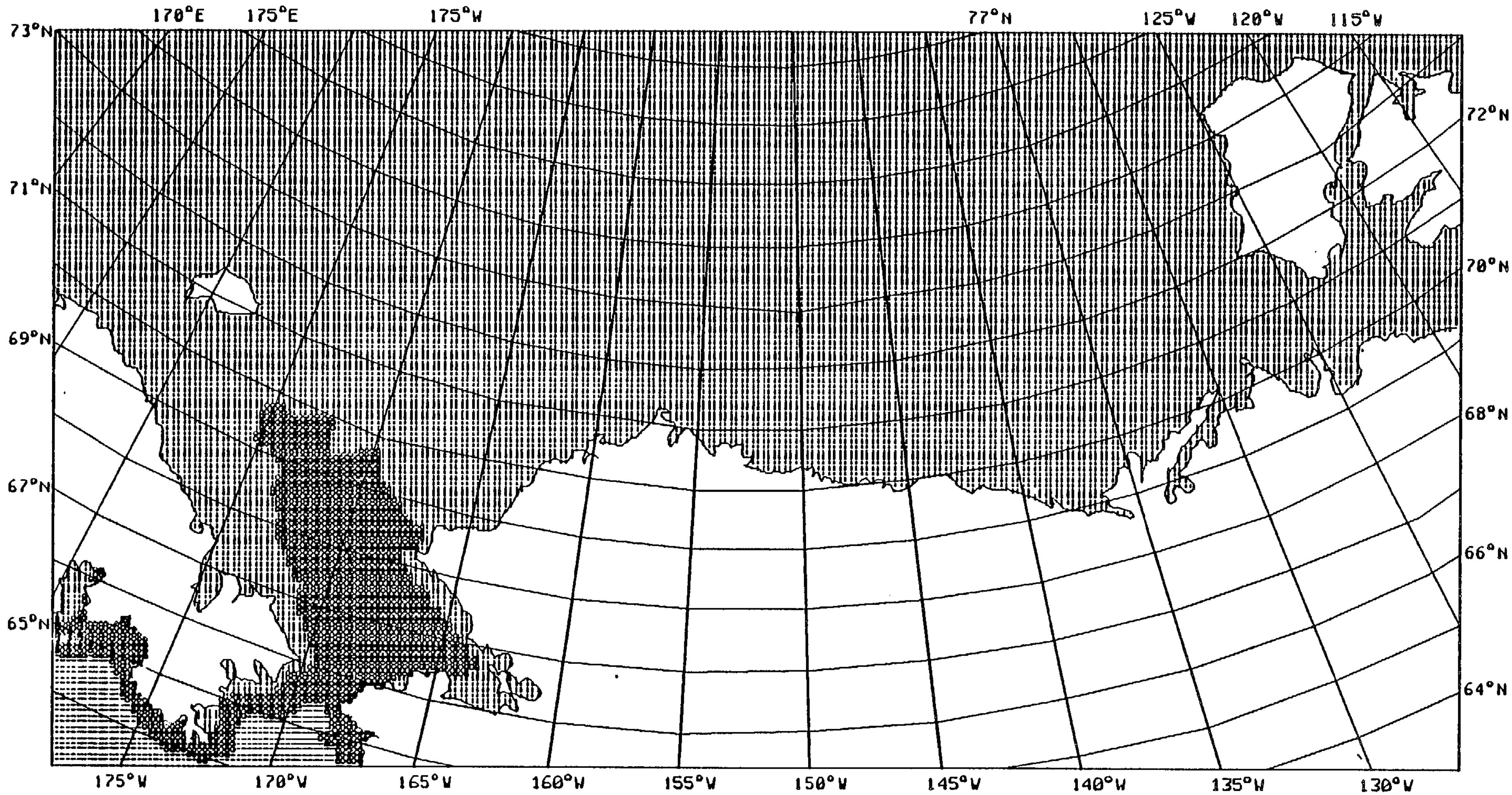
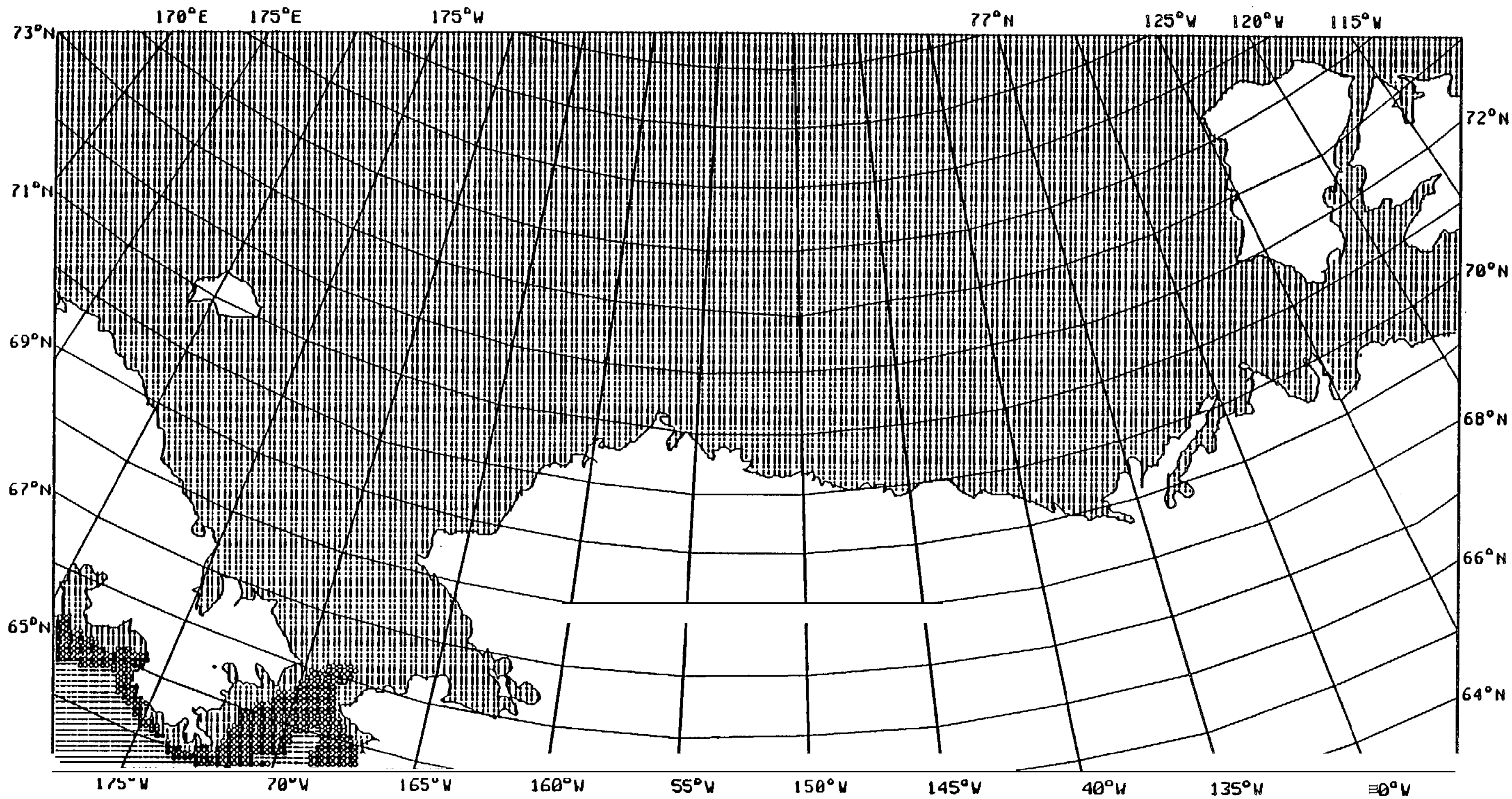



FIGURE 26 ICE FREE FREQUENCY FOR NOVEMBER 16-22 FOR THE BEAUFORT AND CHUKCHI SEAS




F GURE 27 ICE FR=E FREQUENCY FOR NOVEMBER 23 29 FOR THE BEAUF°°T AND CHUKCHI SEAS

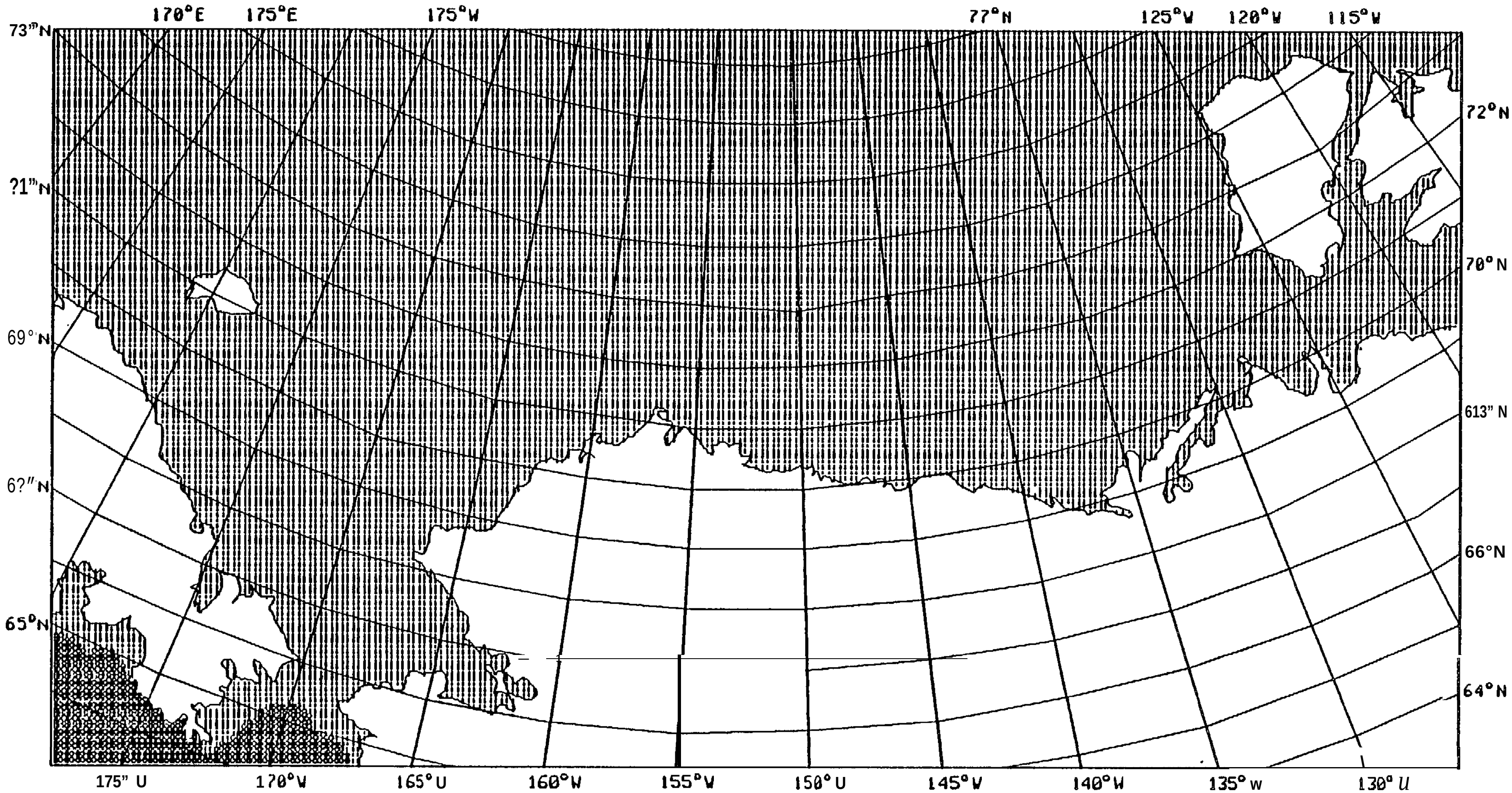
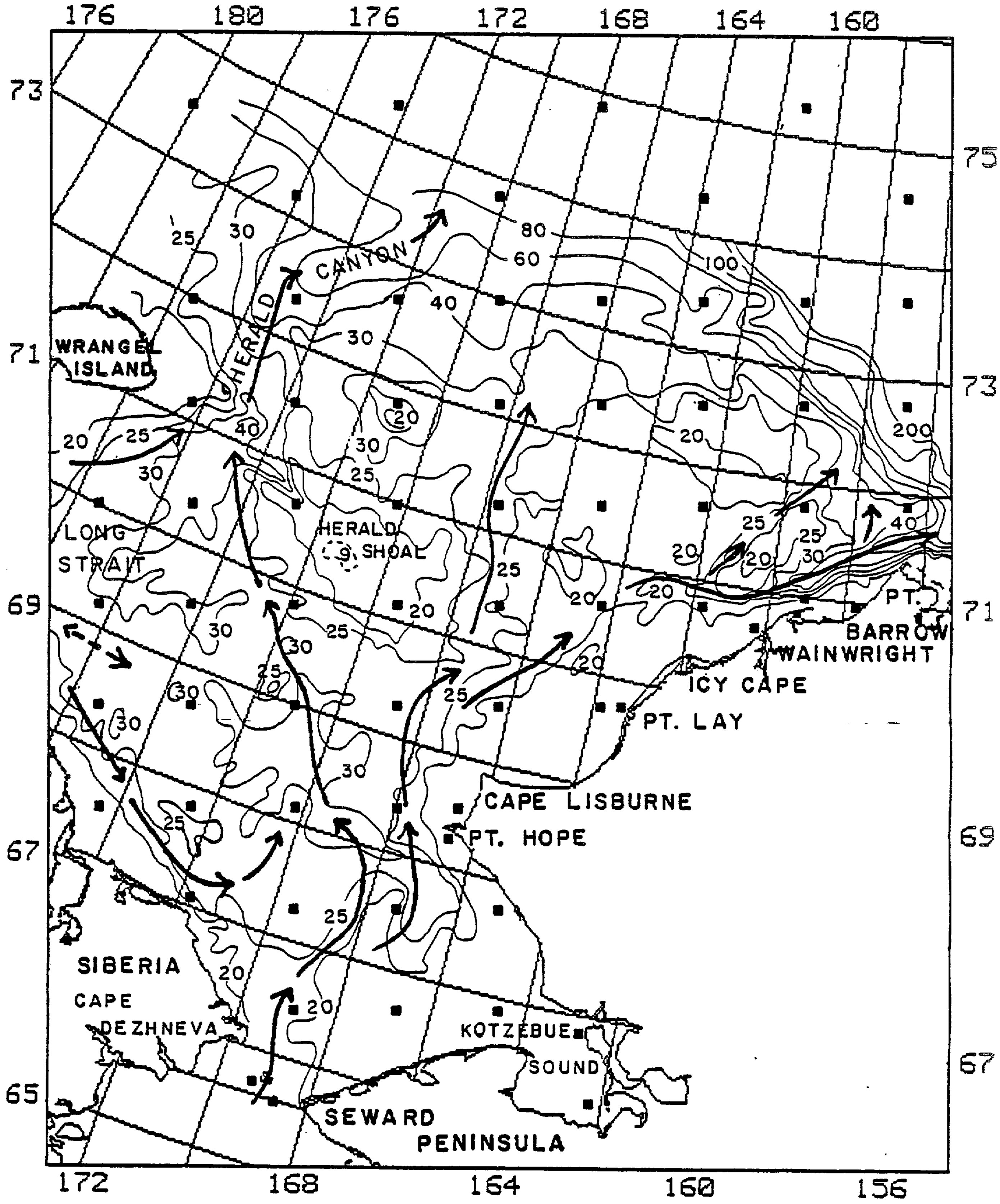



FIGURE 28 [CE FREE FREQUENCY FOR NOVEMBER 30-DEC 6 FOR THE BEAUFORT AND CHUKCHI SEAS




Figure" 29. Bathymetry and Major Currents in the Chukchi Sea (Adopted from Coachman, Aagaard and Trip [1975] and Paquette and Bourke[1981]. Depths given are in fathoms [1 fathom = 1.83m]).

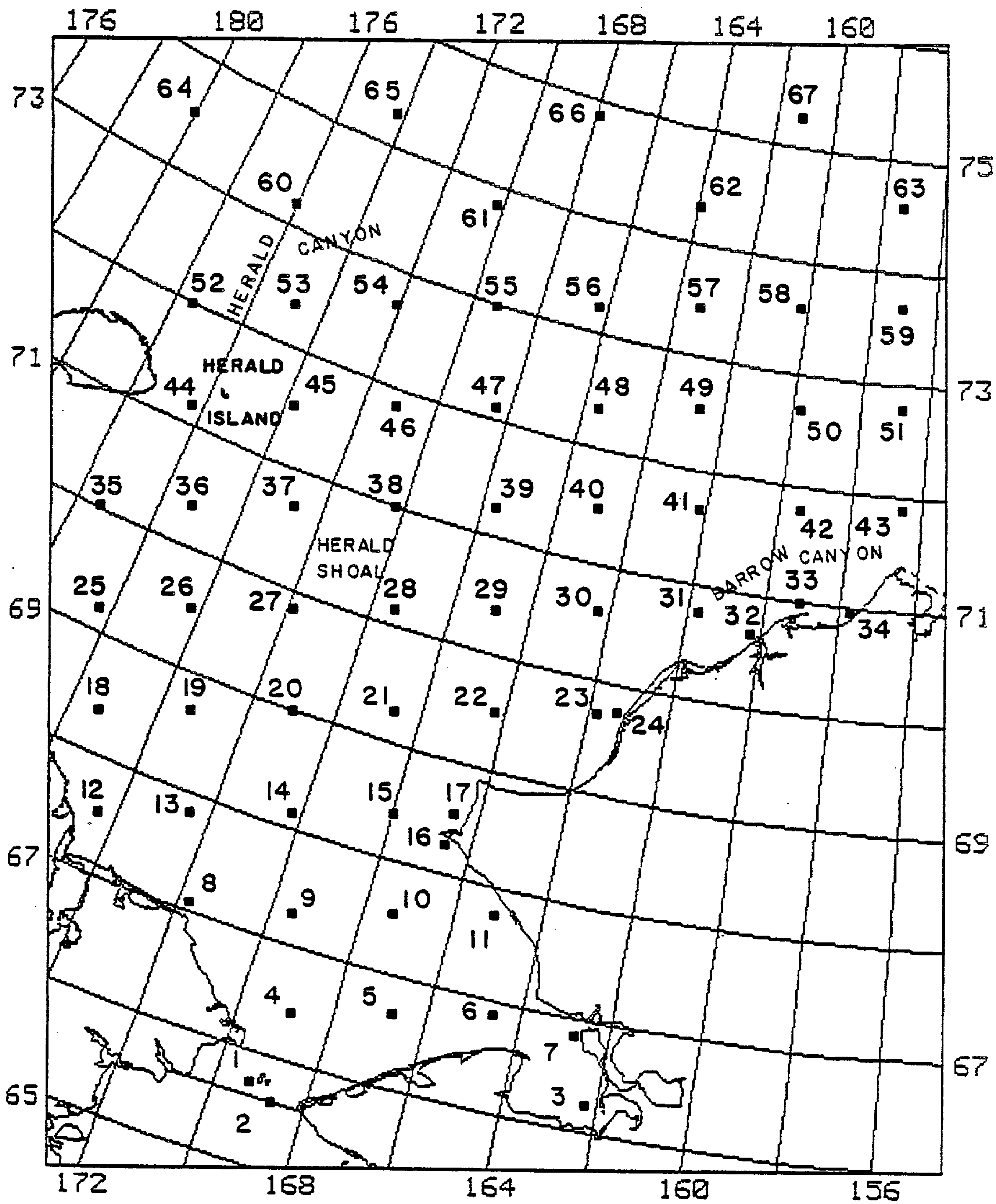



Figure 30. Location of 67 Stations selected for statistical analysis.

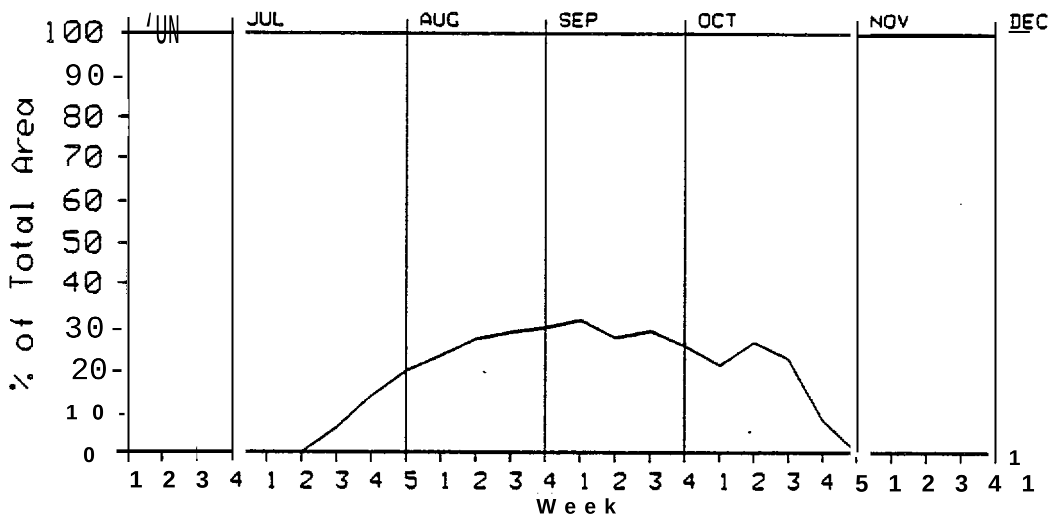



FIGURE 31 MINIMUM EXTENT Of ICE FREE WATER AS A PERCENTAGE OF THE TOTAL CHUKCHI SEA STUDY AREA

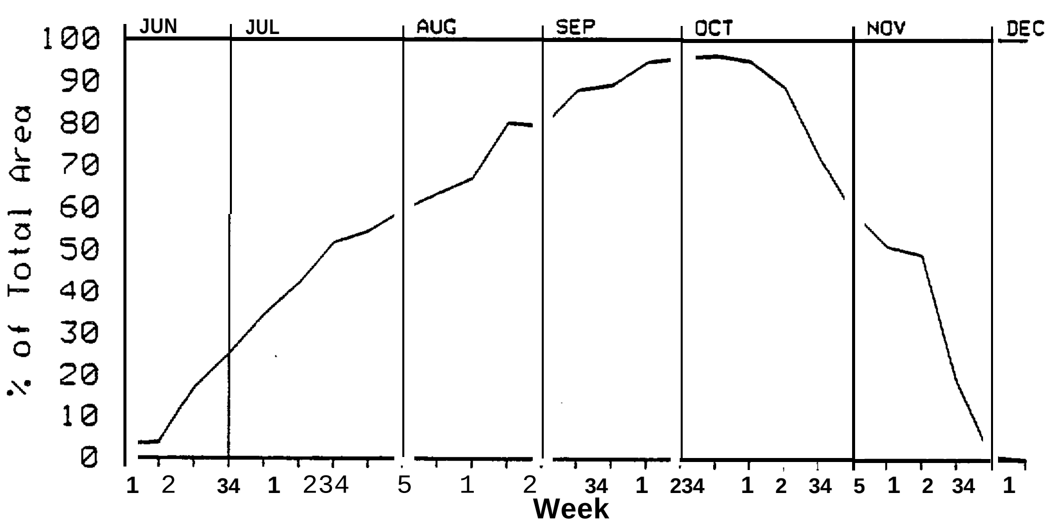



FIGURE 32 MAXIMUM EXTENT Of ICE FREE WATER AS A PERCENTAGE OF THE TOTAL CHUKCHI SEA STUDY AREA

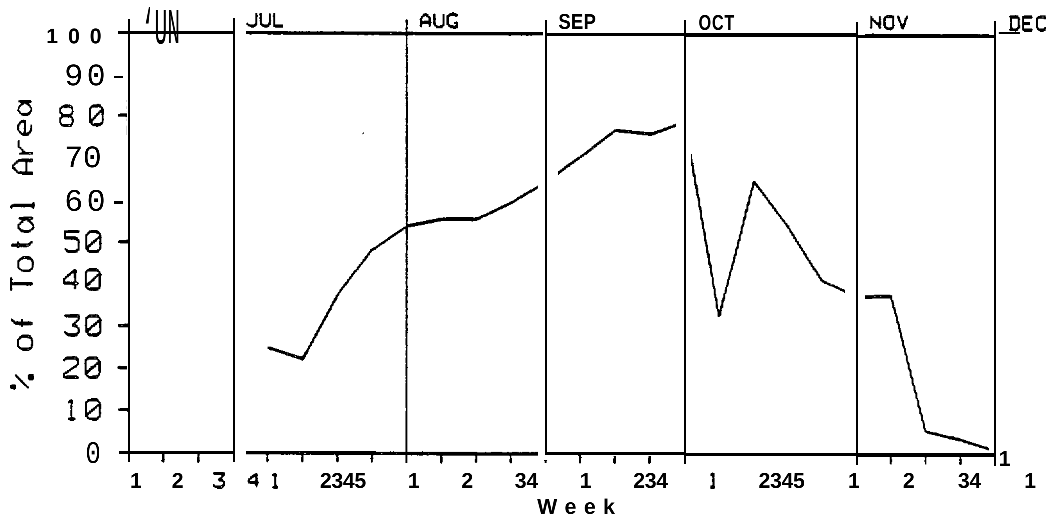



FIGURE 33 EXTENT OF ICE FREE WATER AS PERCENTAGE OF TOTAL CHUKCHI SEA AREA FOR 1972

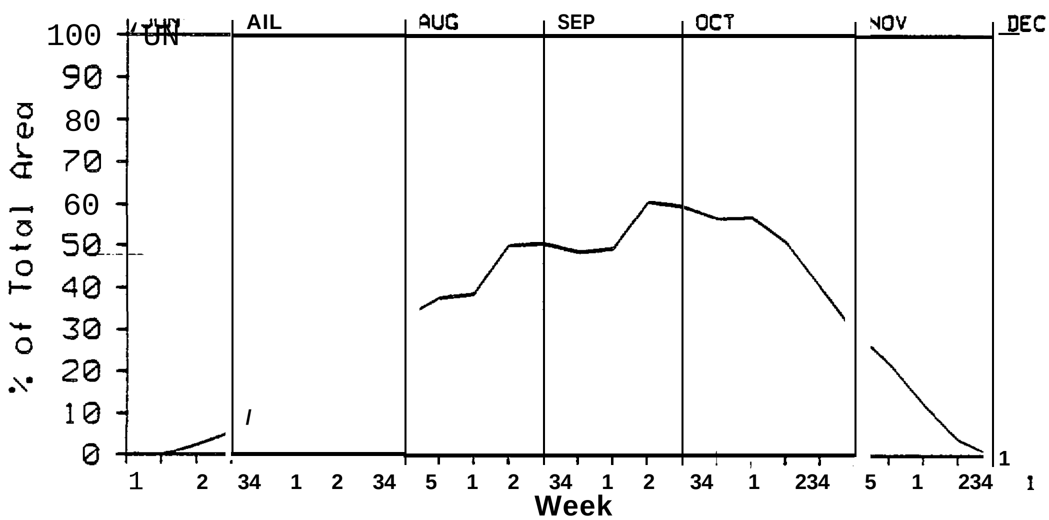



FIGURE 34 EXTENT OF ICE FREE WATER AS PERCENTAGE OF TOTAL CHUKCHI SEA AREA FOR 1973

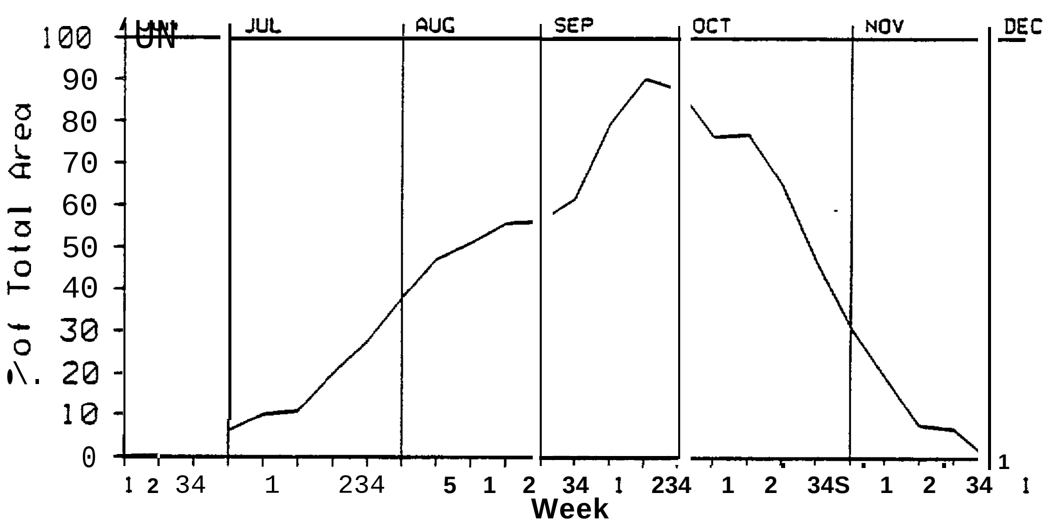



FIGURE 35 EXTENT OF ICE FREE WATER AS PERCENTAGE OF TOTAL CHUKCHI SEA AREA FOR 1974

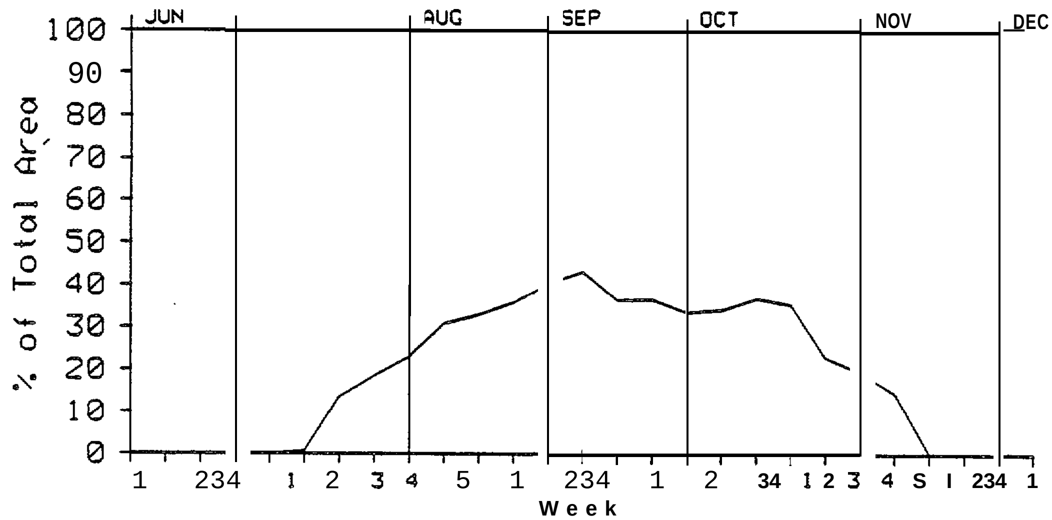



FIGURE 36 EXTENT Of ICE FREE WATER AS PERCENTAGE OF TOTAL CHUKCHI SEA AREA FOR 1975

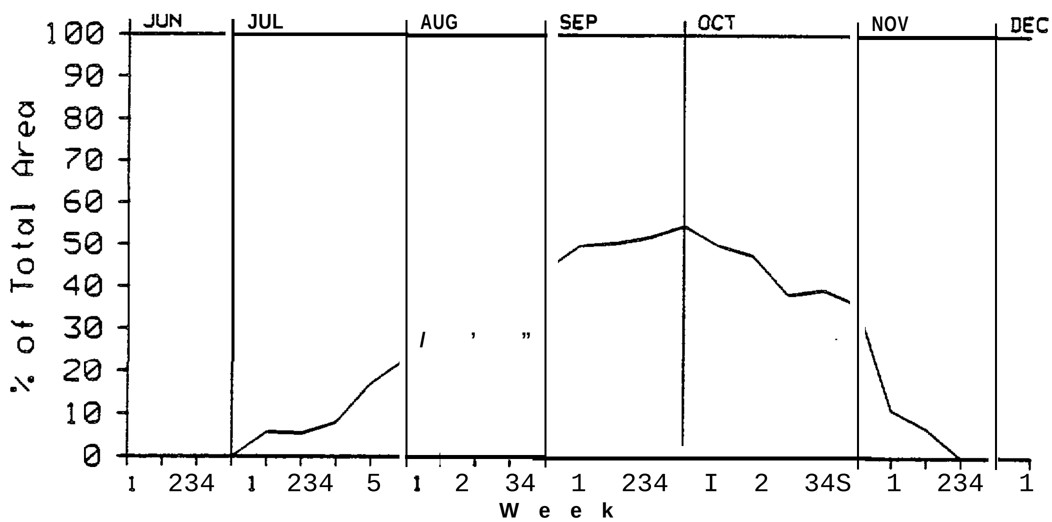



FIGURE 37 EXTENT OF ICE FREE WATER AS PERCENTAGE OF TOTAL CHUKCHI SEA AREA FOR 1976

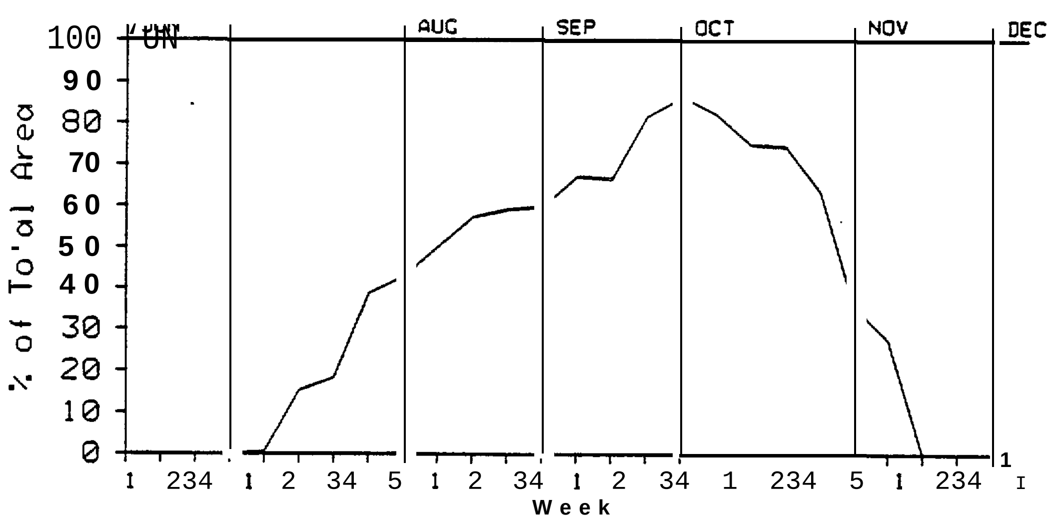



FIGURE 38 EXTENT OF ICE FREE WATER AS PERCENTAGE OF TOTAL CHUKCHI SEA AREA FOR 1977

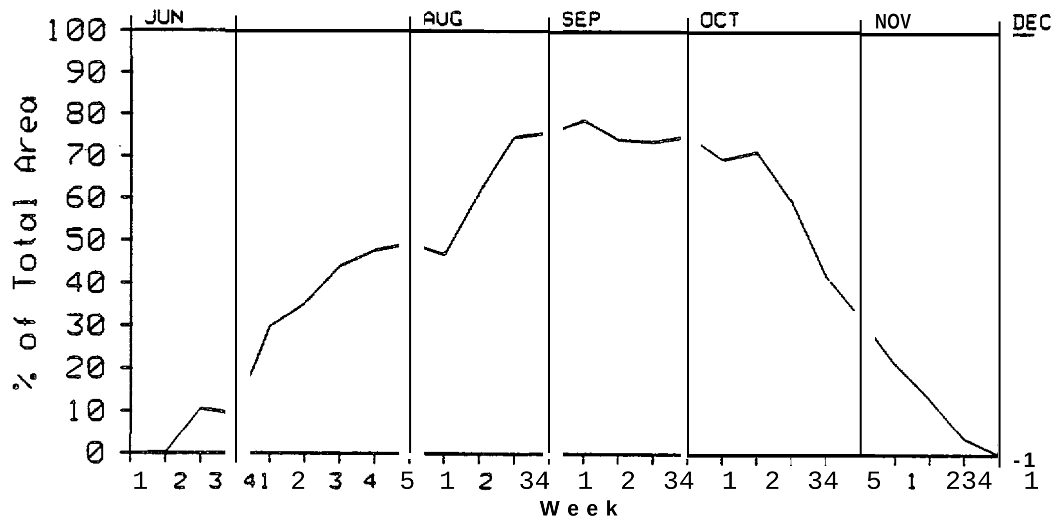



FIGURE 39 EXTENT OF ICE FREE WATER AS PERCENTAGE OF TOTAL CHUKCHI SEA AREA FOR 1978

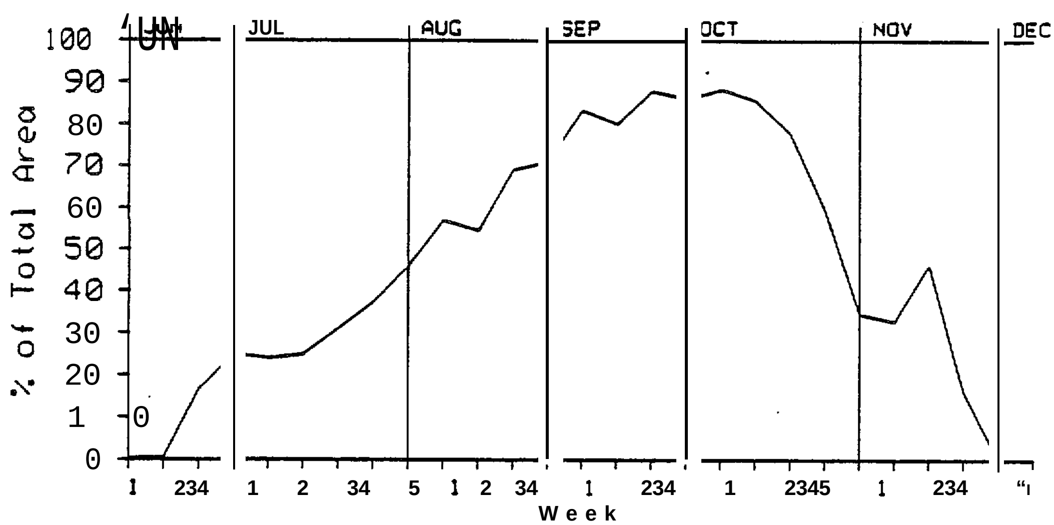



FIGURE 40 EXTENT OF ICE FREE WATER AS PERCENTAGE OF TOTAL CHUKCHI SEA AREA FOR 1979

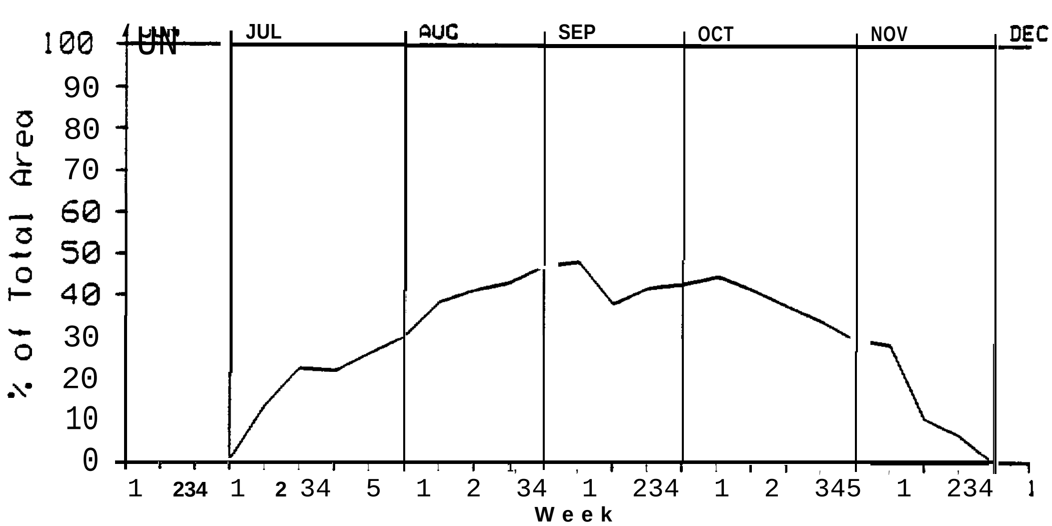



FIGURE 41 EXTENT OF ICE FREE WATER AS PERCENTAGE OF TOTAL CHUKCHI SEA AREA FOR 1980

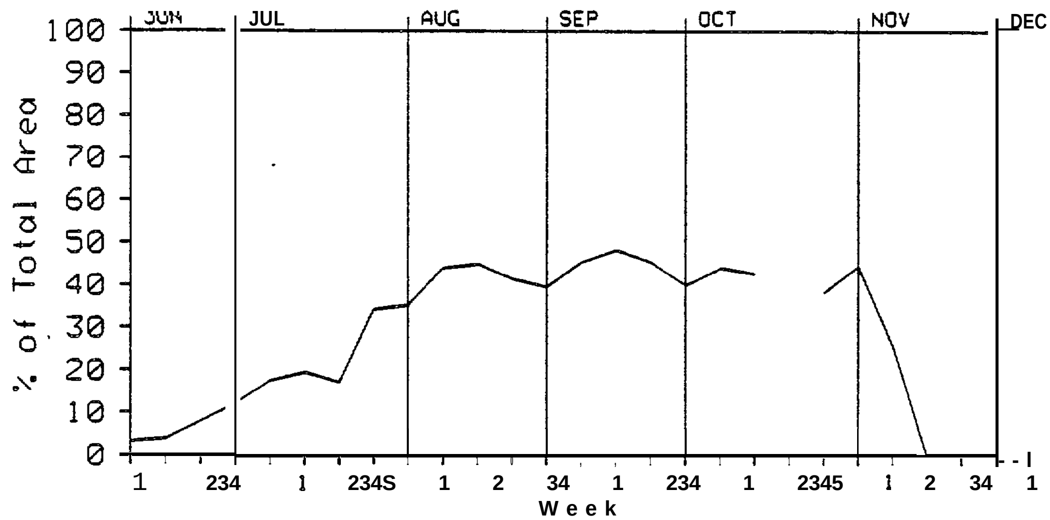



FIGURE 42 EXTENT OF ICE FREE WATER AS PERCENTAGE OF TOTAL CHUKCHI SEA AREA FOR 1981

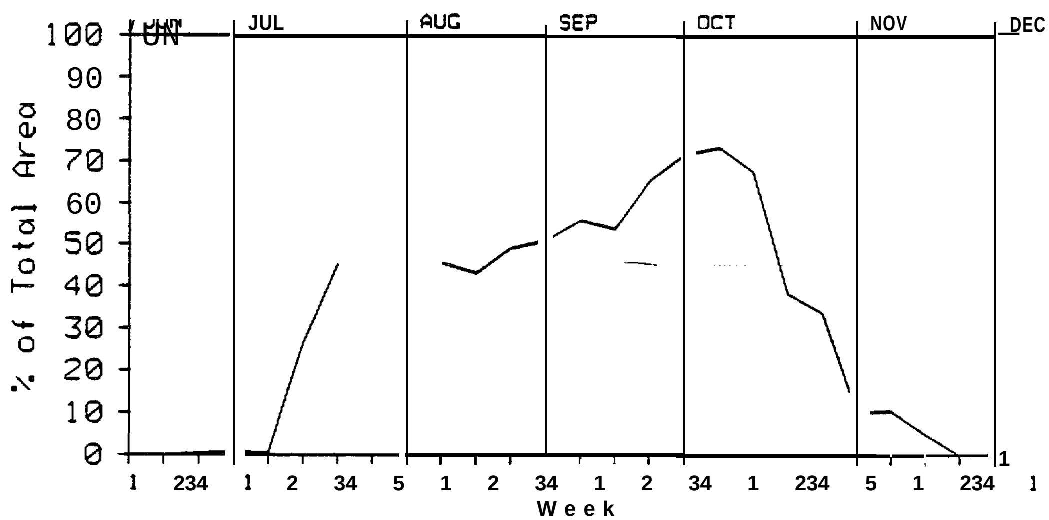



FIGURE 43 EXTENT OF ICE FREE WATER AS PERCENTAGE OF TOTAL CHUKCHI SEA AREA FOR 1982

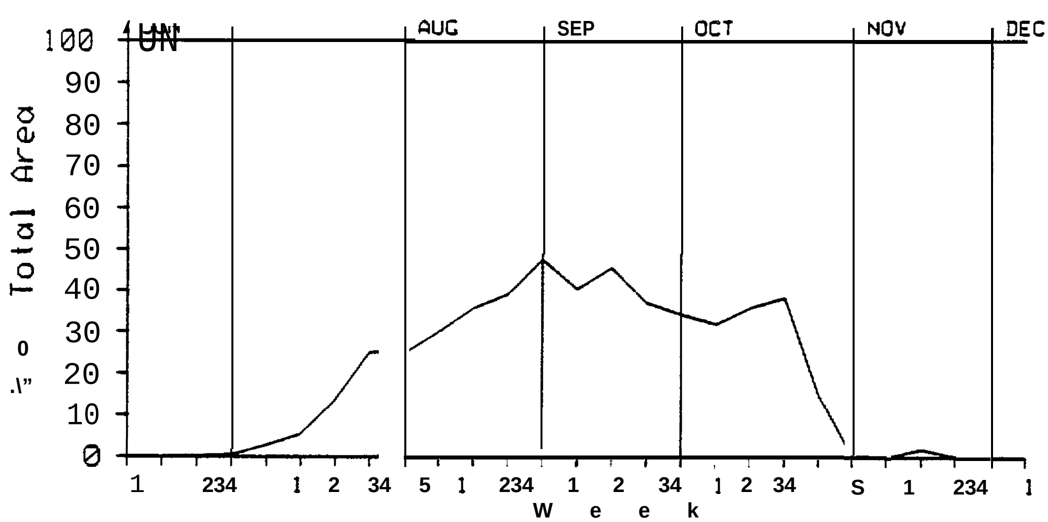



FIGURE 44 EXTENT Of ICE FREE WATER AS PERCENTAGE OF TOTAL CHUKCHI SEA AREA FOR 1983

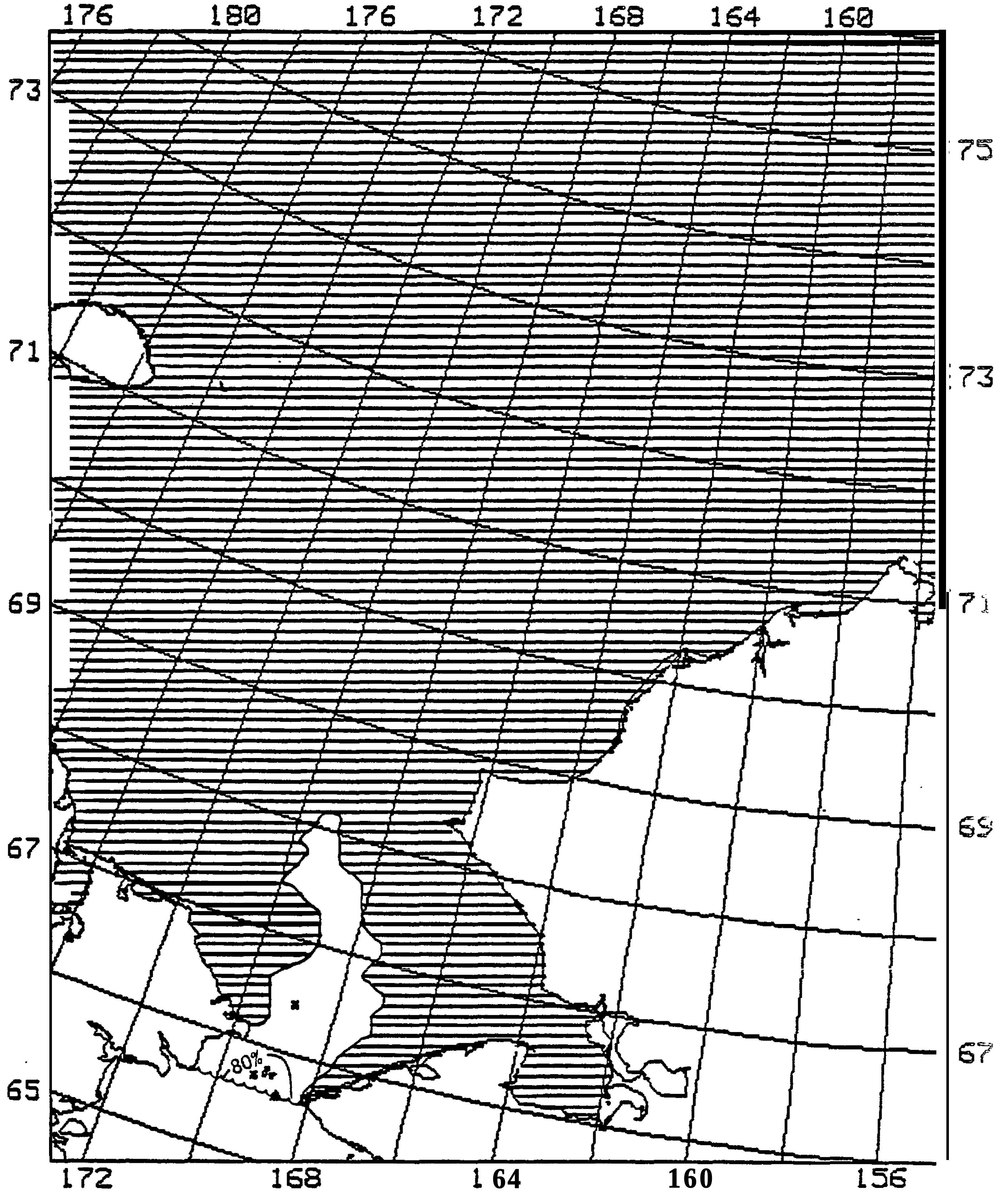



Figure 45. **Chukchi** Sea Ice Edge Frequency Map for June 1-7. The **isopleths** on this map define the relative frequency with which oceanic **locations** have been within the ice edge on this date. The area containing vertical **lines** was ice-free on **all** years studied, while the area containing horizontal lines had ice present on all years.

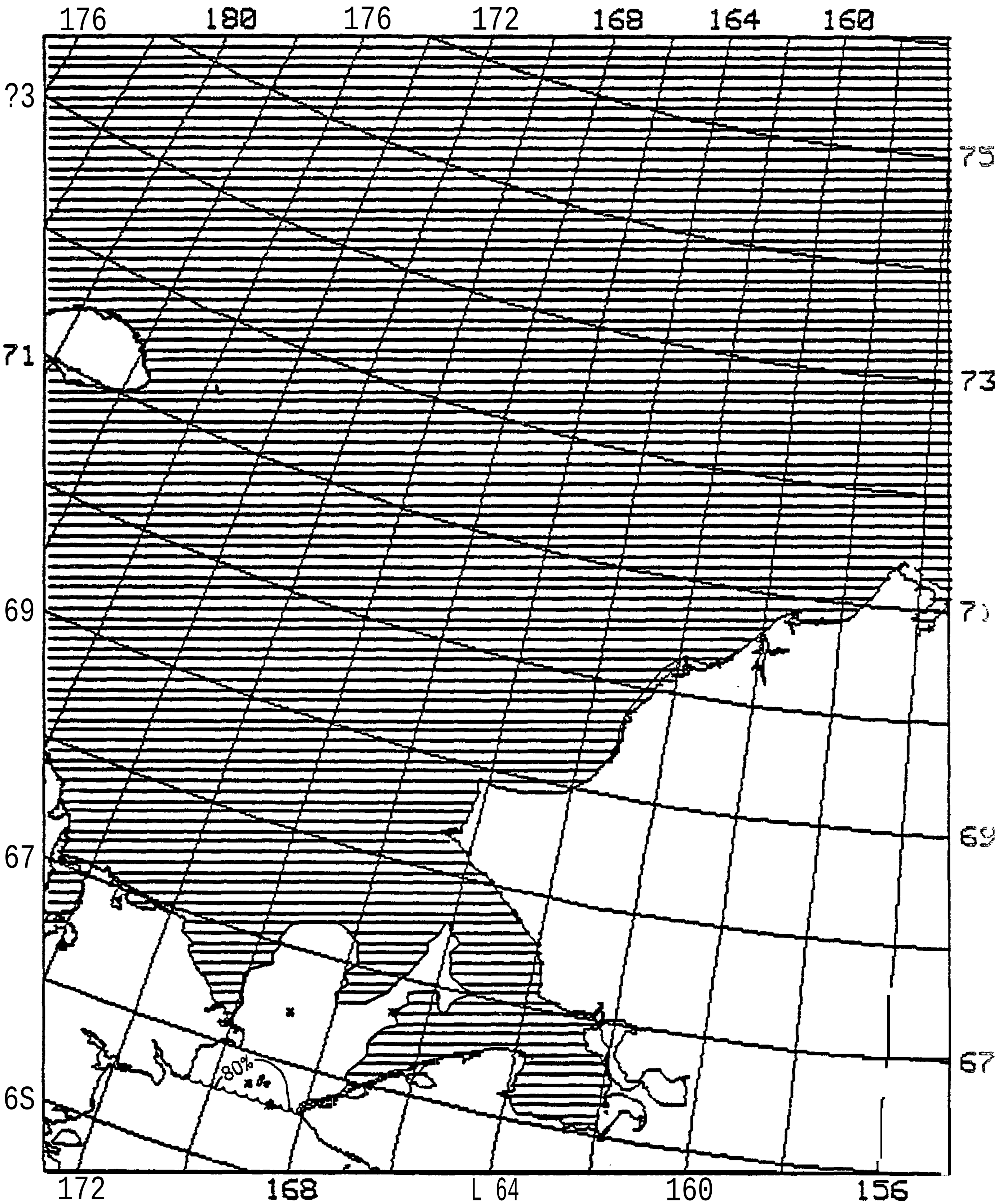



Figure 46. **Chukchi** Sea Ice Edge Frequency Map for June 8-14. - The **isopleths** on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

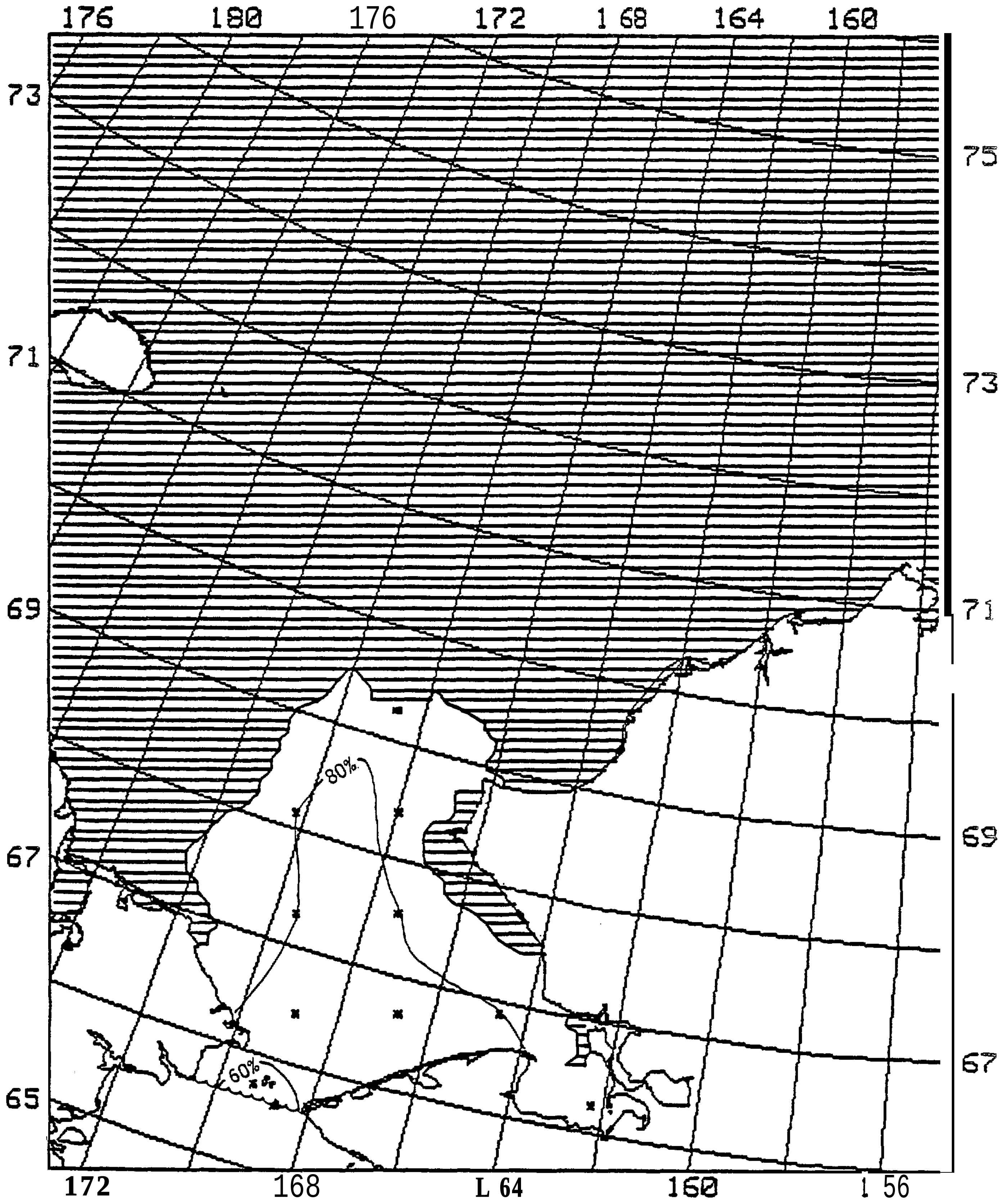



Figure 47. Chukchi Sea Ice Edge Frequency Map for June 15-21. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

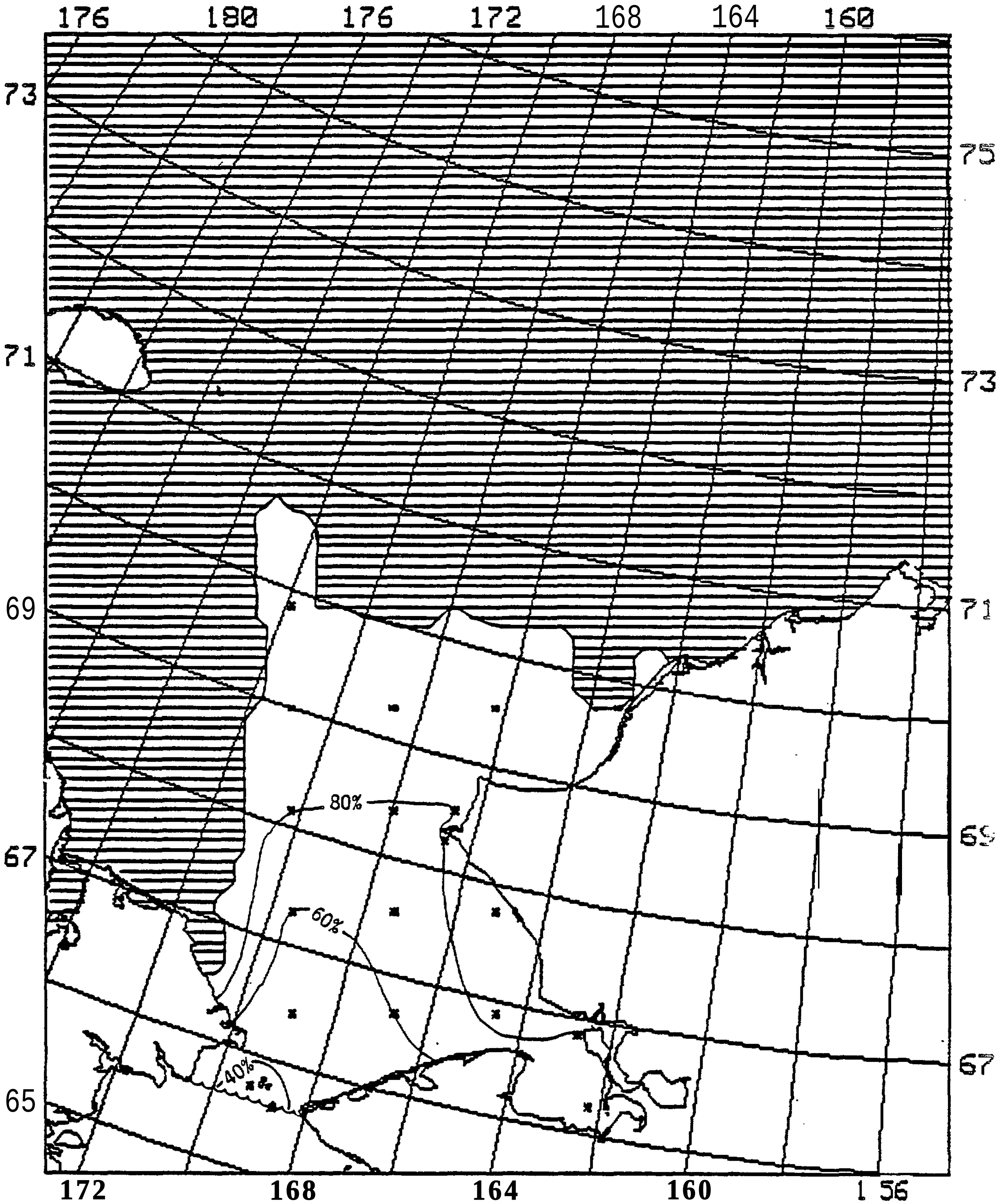



Figure 48. Chukchi Sea Ice Edge Frequency Map for June 22-28. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

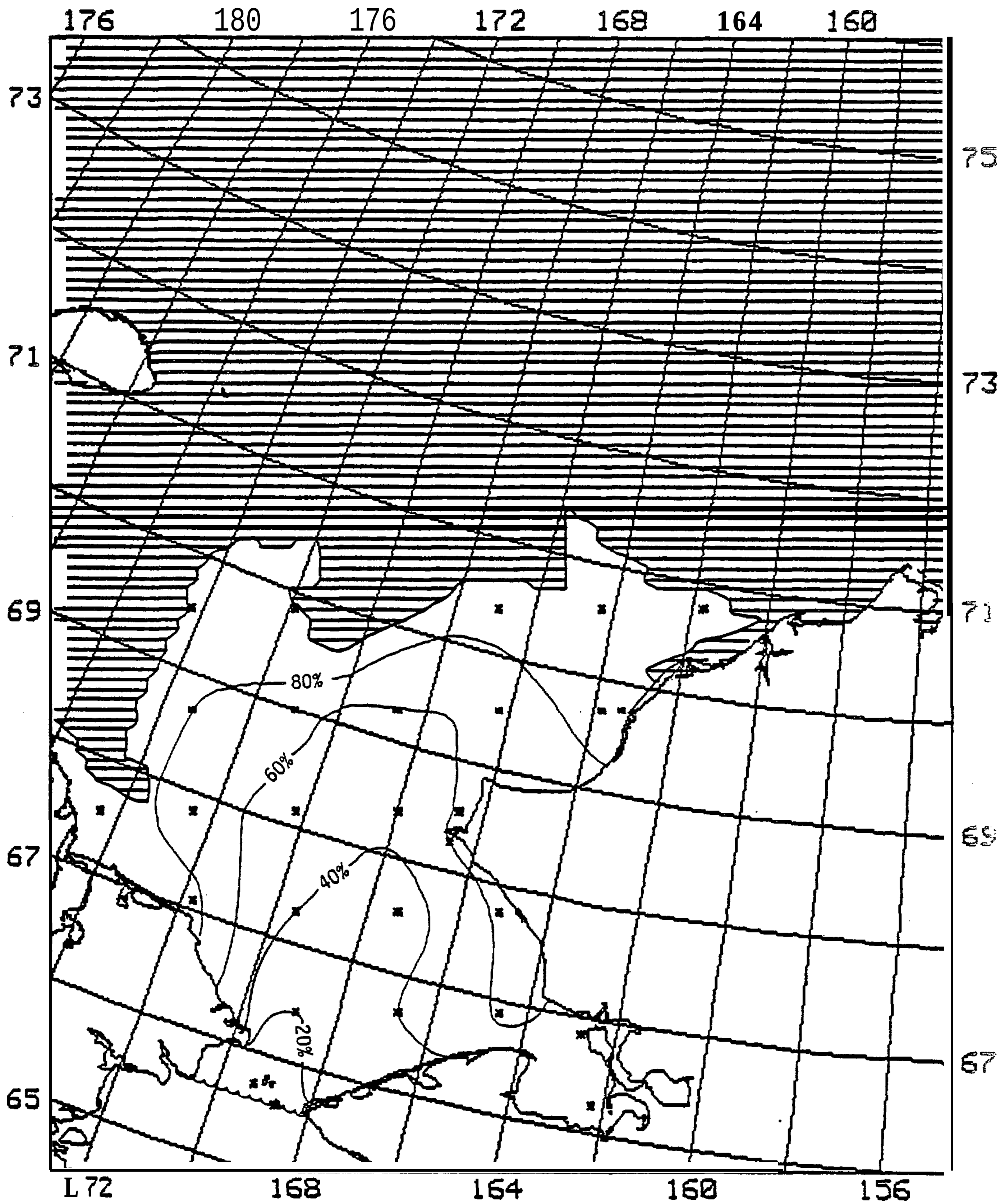



Figure 49. Chukchi Sea Ice Edge Frequency Map for June 29-July 5. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

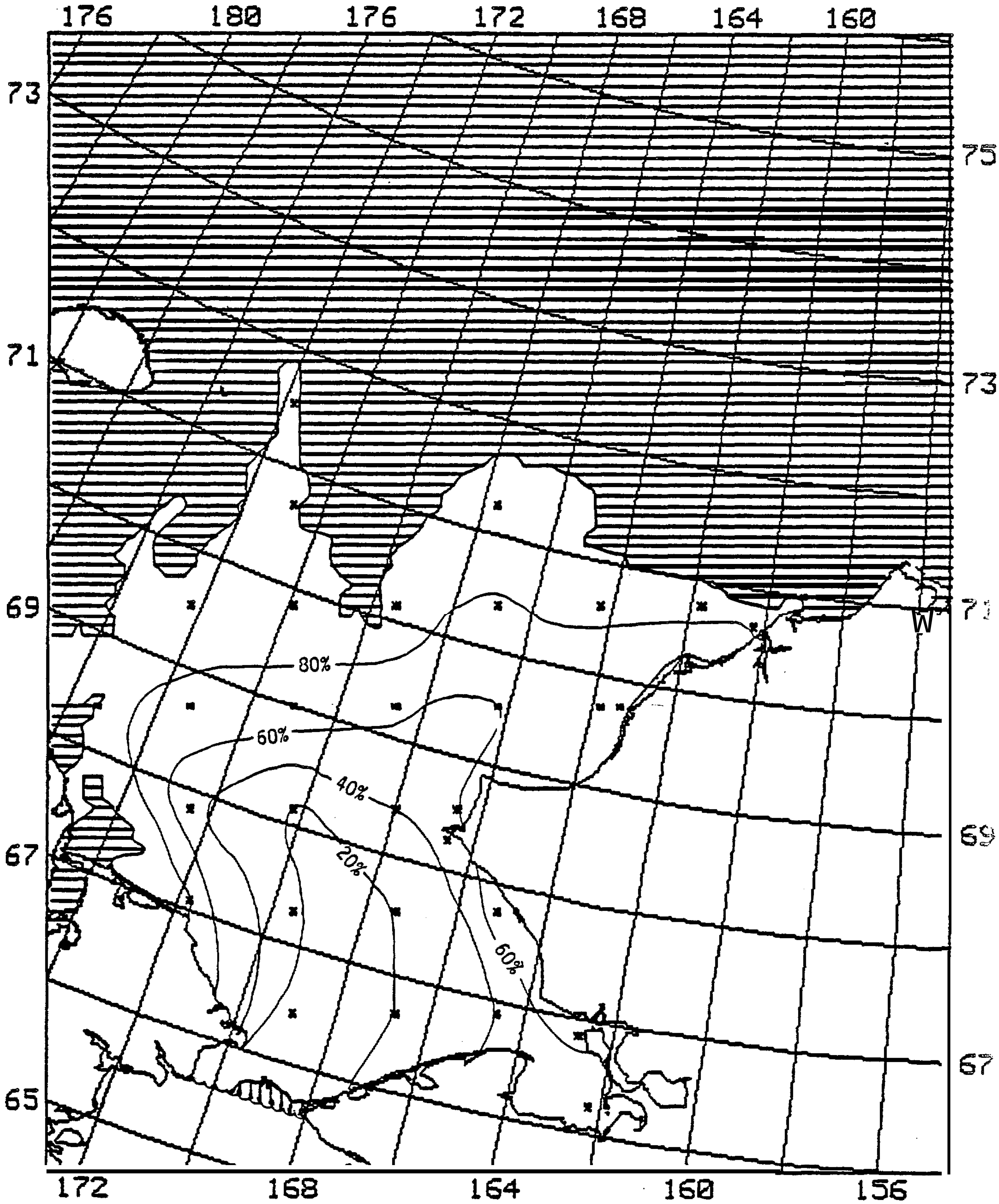



Figure 50. Chukchi Sea Ice Edge Frequency Map for July 6-12. The **isopleths** on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

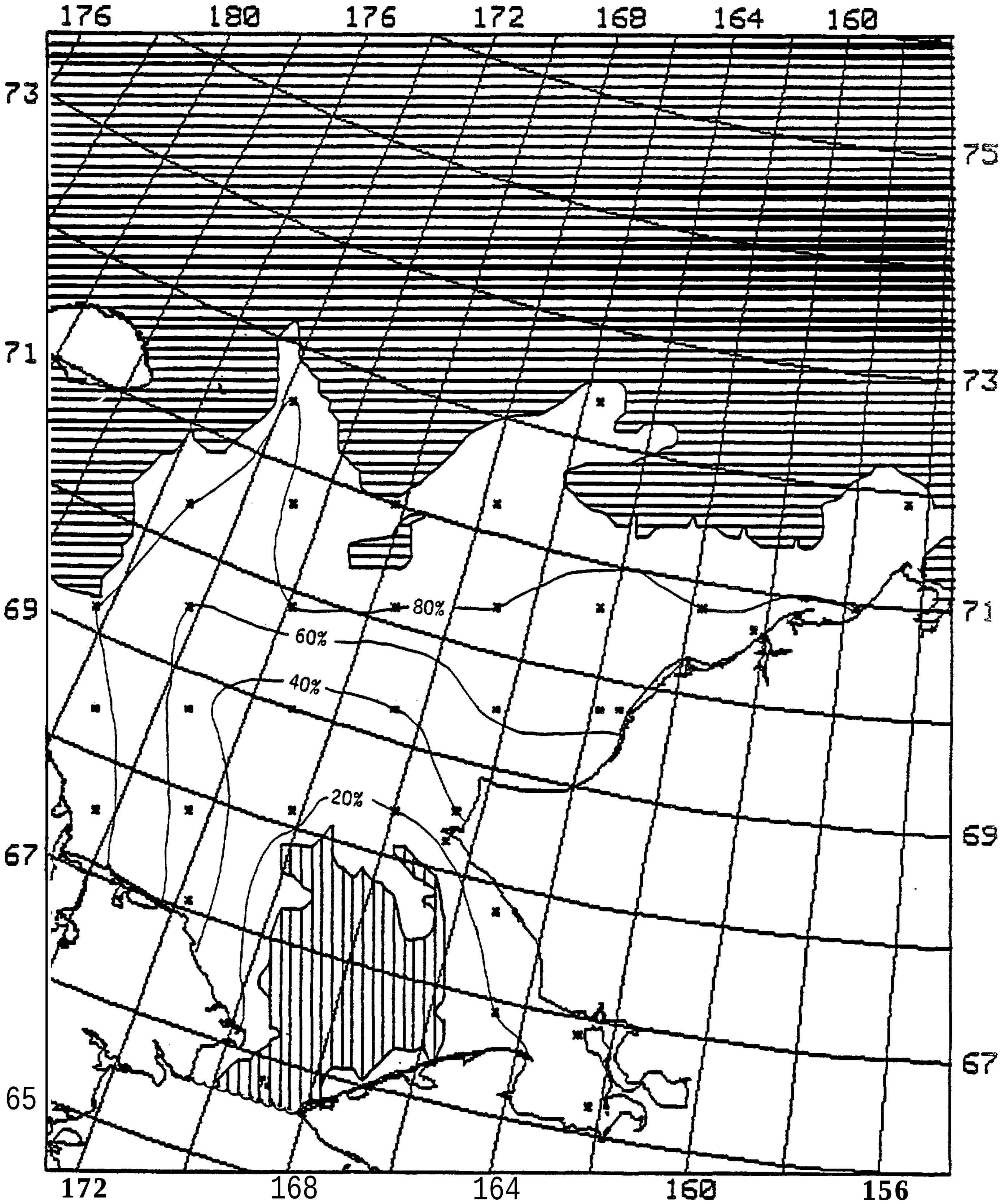



Figure 51. Chukchi Sea Ice Edge Frequency Map for July 13-19. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

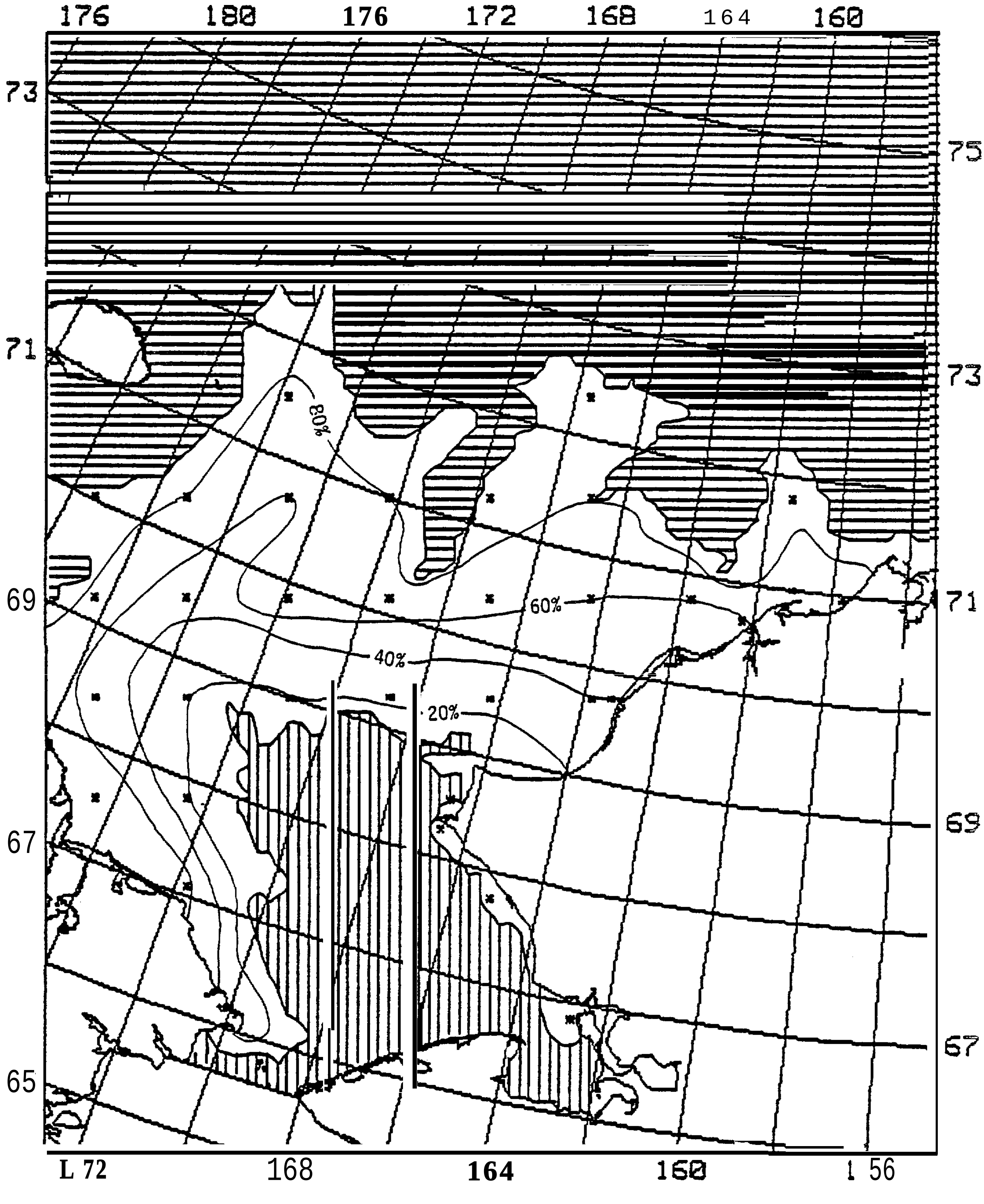



Figure 52. Chukchi Sea Ice Edge Frequency Map for July 20-26. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

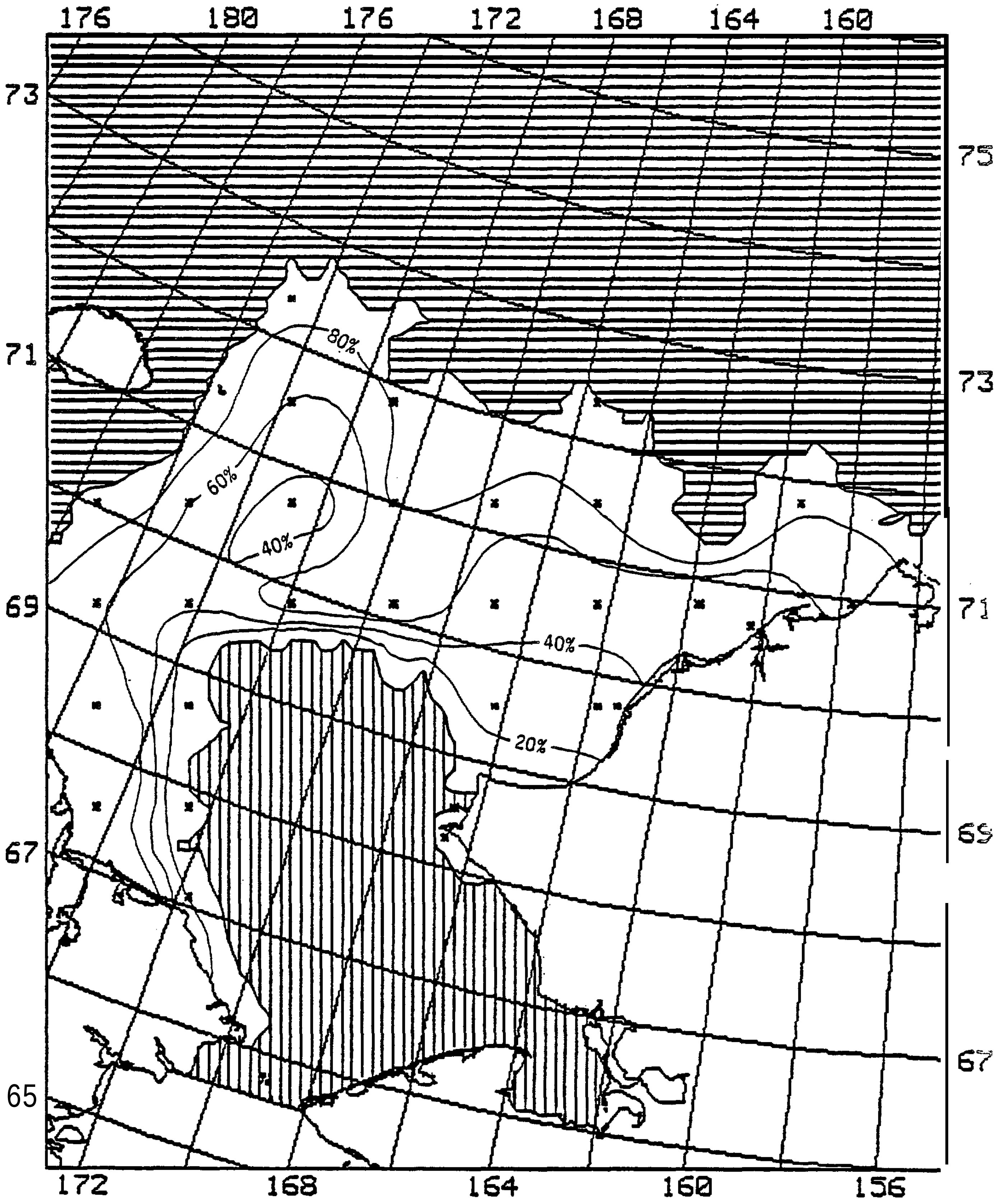



Figure 53. Chukchi Sea Ice Edge Frequency Map for July 27-Aug. 2. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

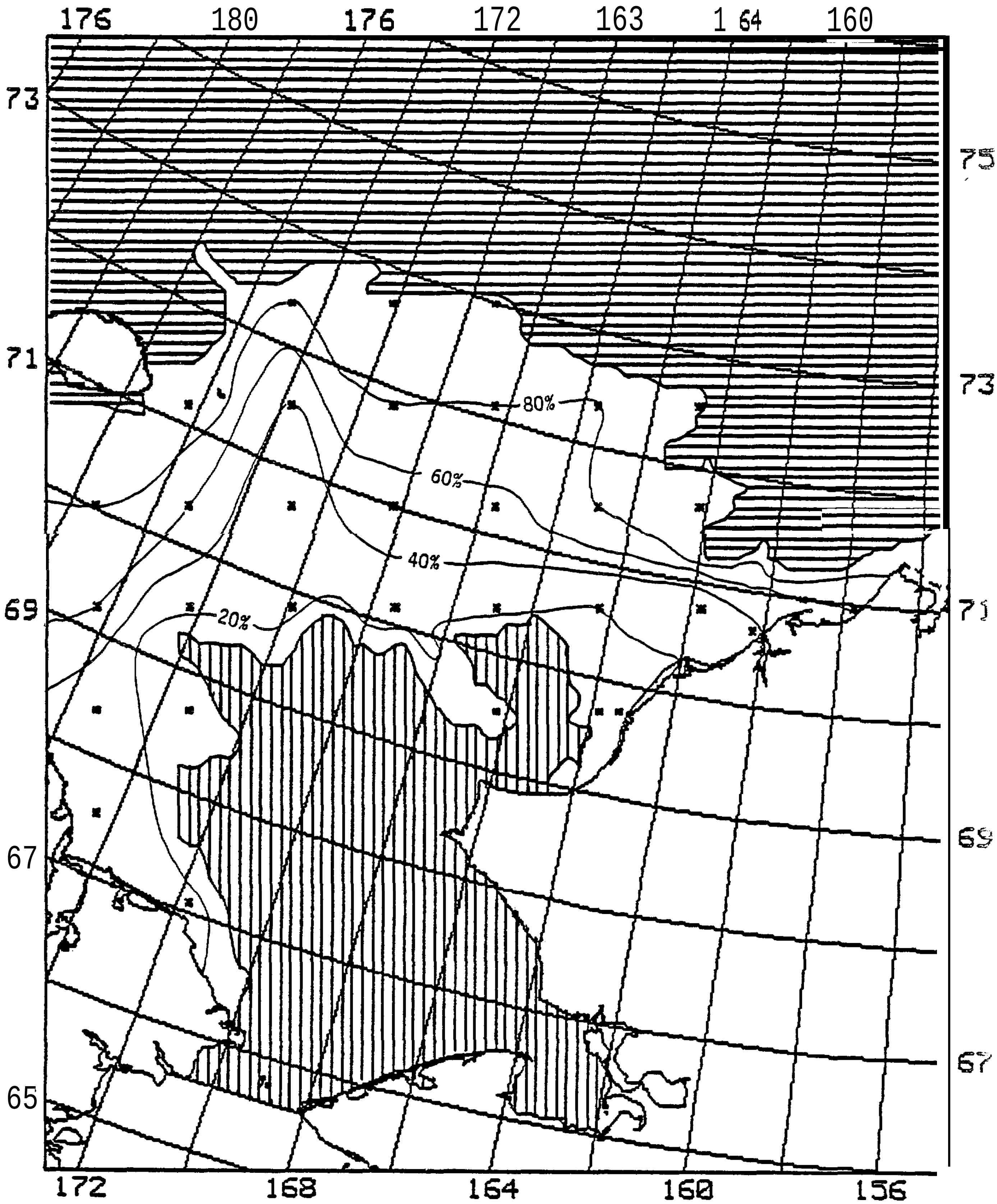



Figure 54. Chukchi Sea Ice Edge Frequency Map for August 3-9. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

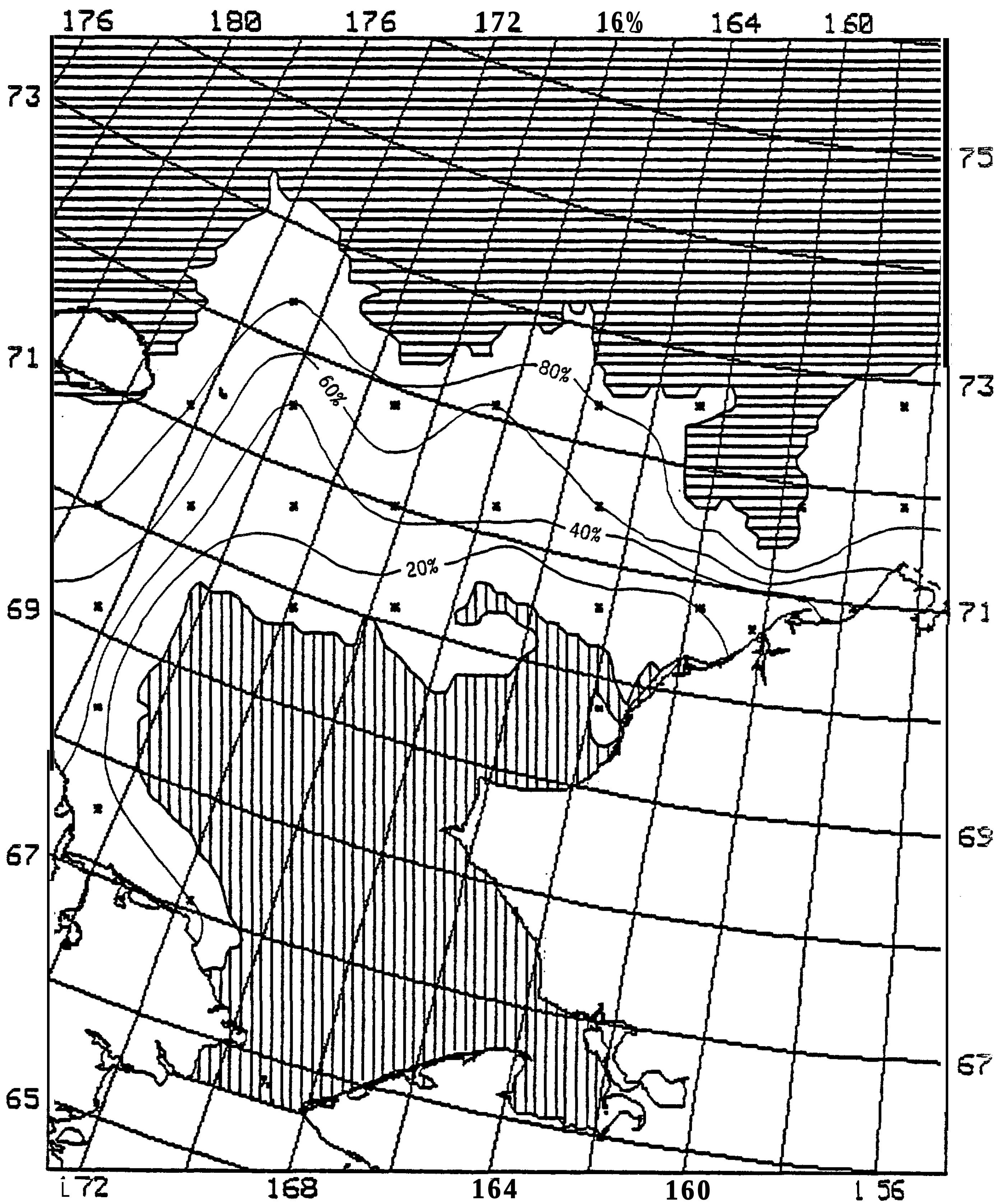



Figure 55. Chukchi Sea Ice Edge Frequency Map for August 10-16. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

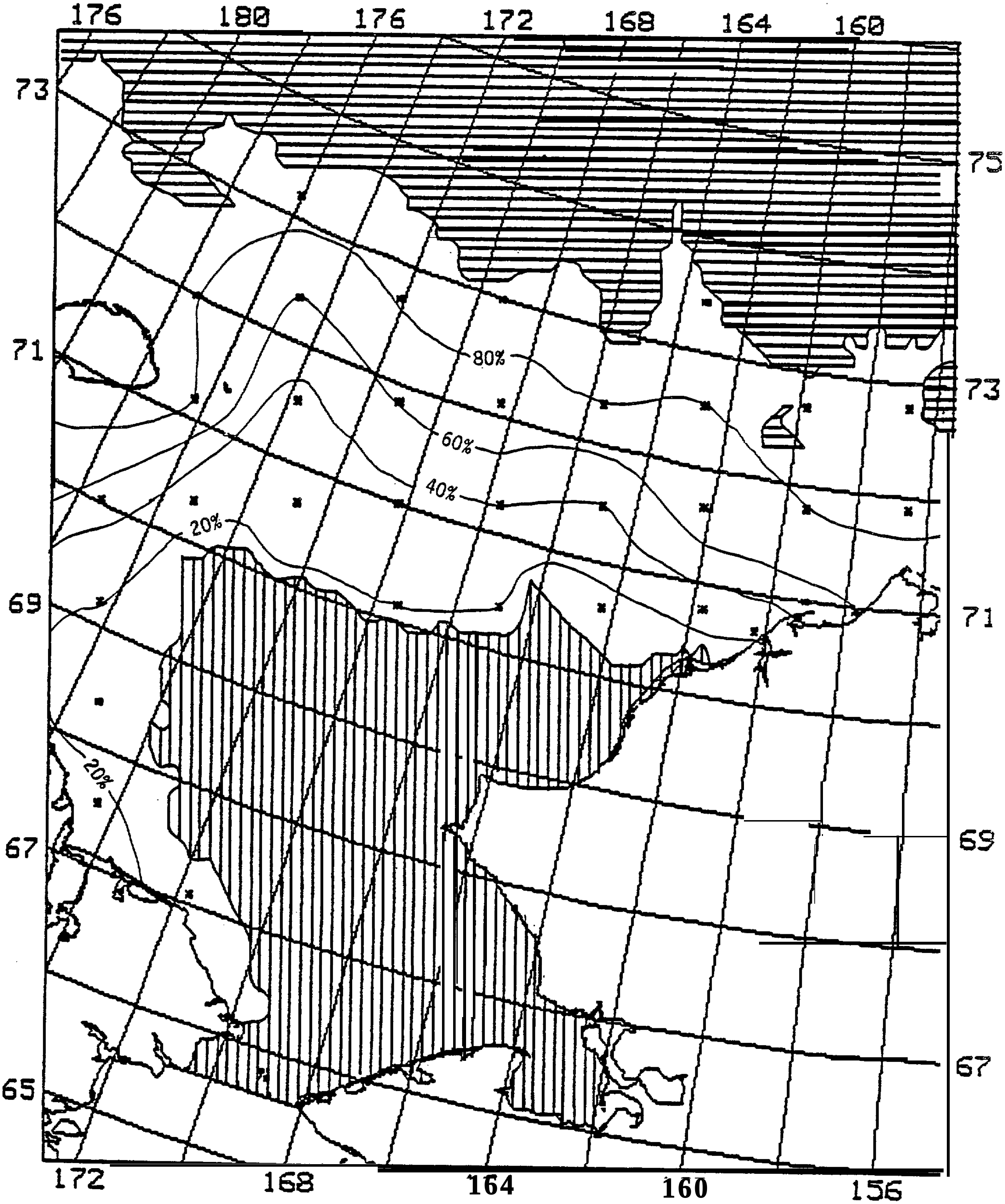


Figure 56. Chukchi Sea Ice Edge Frequency Map for August 17-23. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

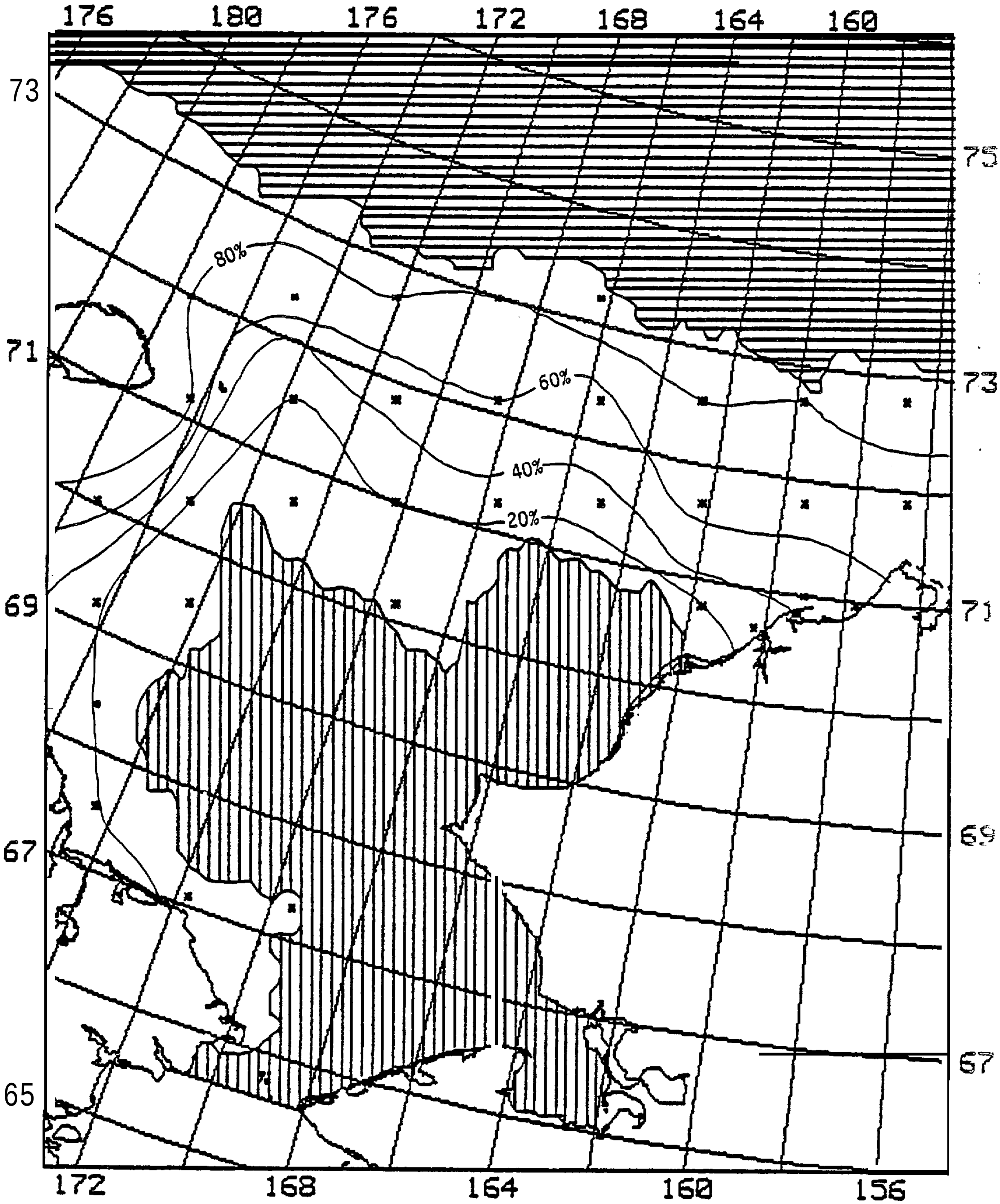



Figure 57. Chukchi Sea Ice Edge Frequency Map for August 24-30. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

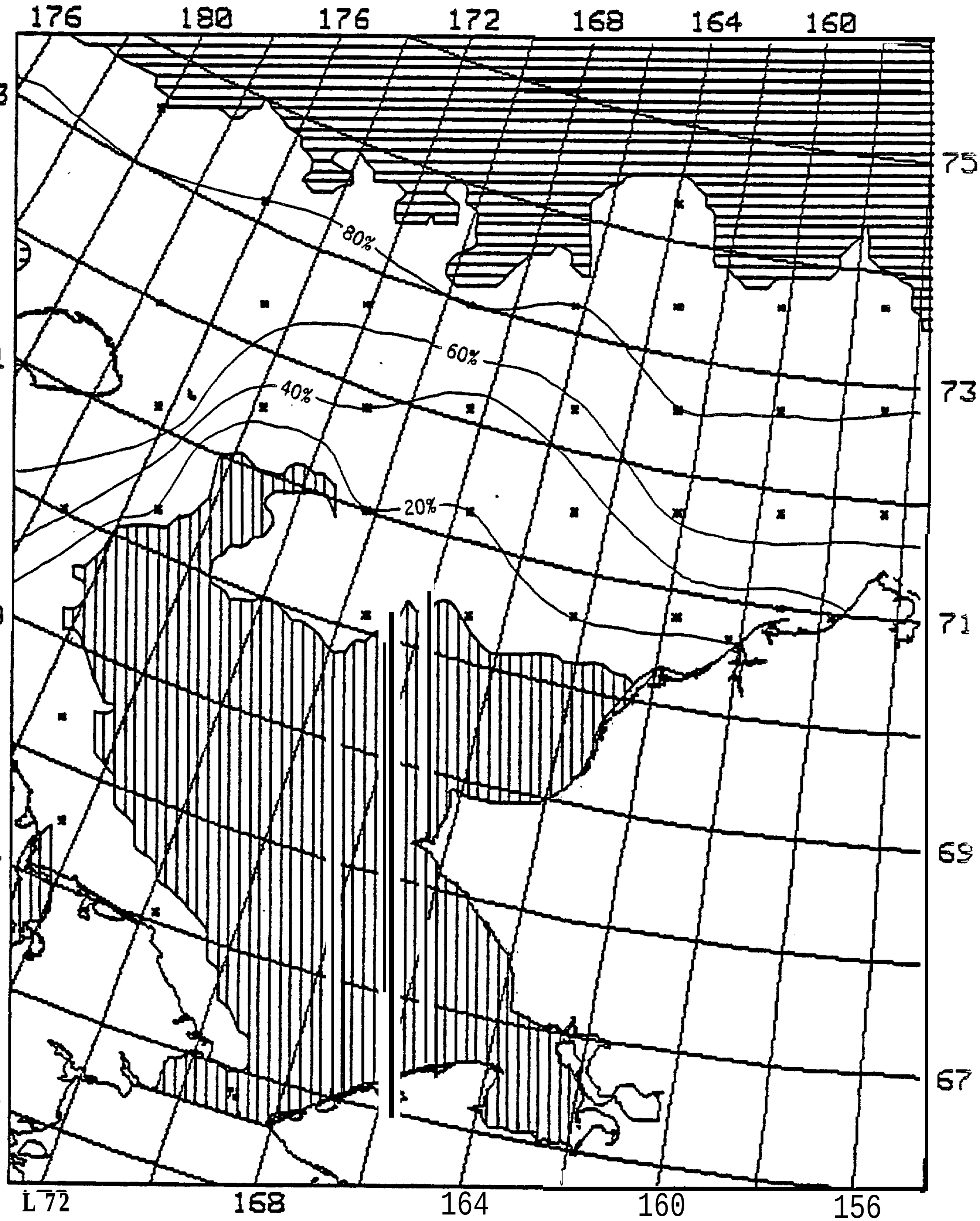



Figure 58. Chukchi Sea Ice Edge Frequency Map for Aug. 31-Sept. 6. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

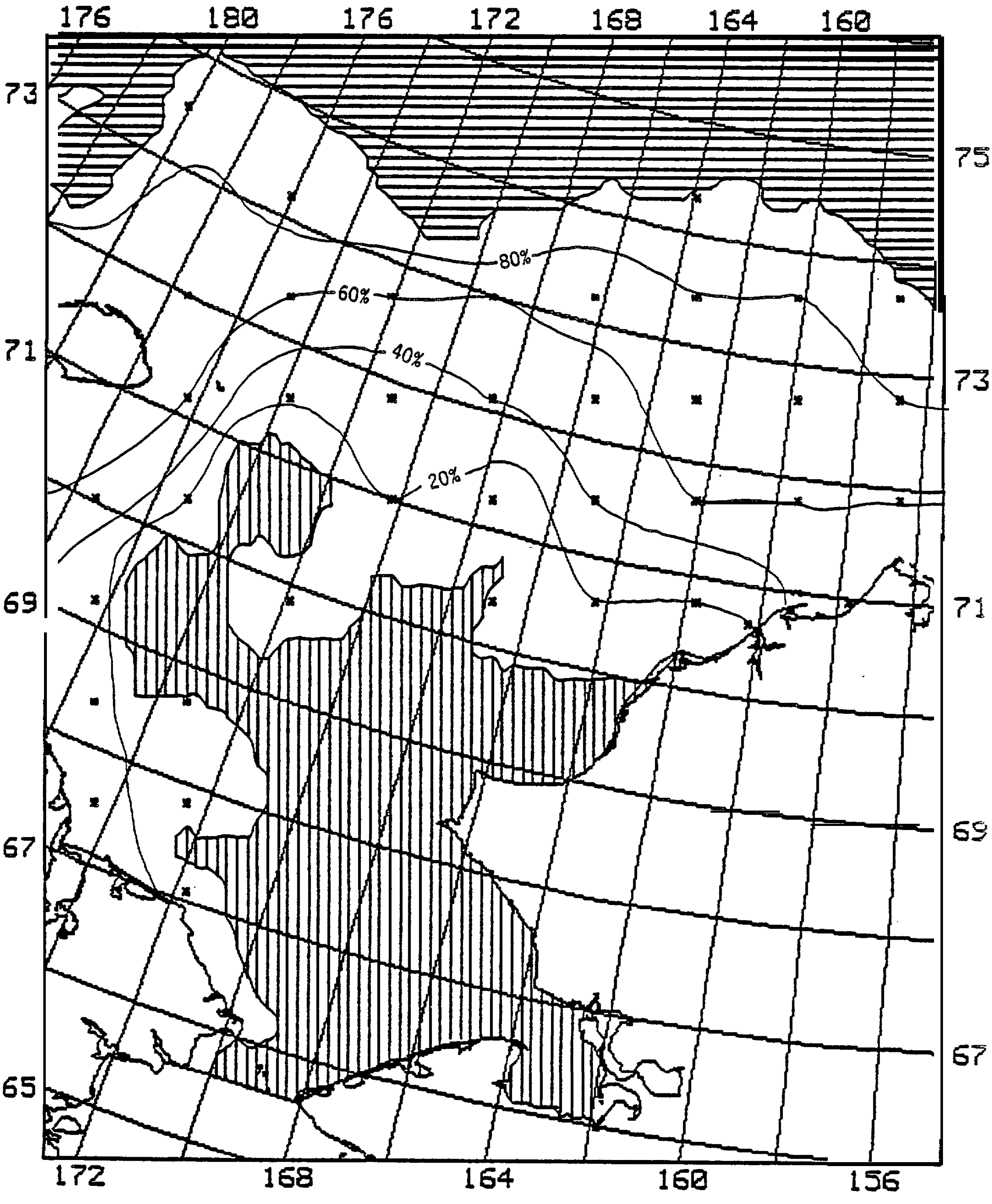



Figure 59. Chukchi Sea Ice Edge Frequency Map for Sept. 7-13. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

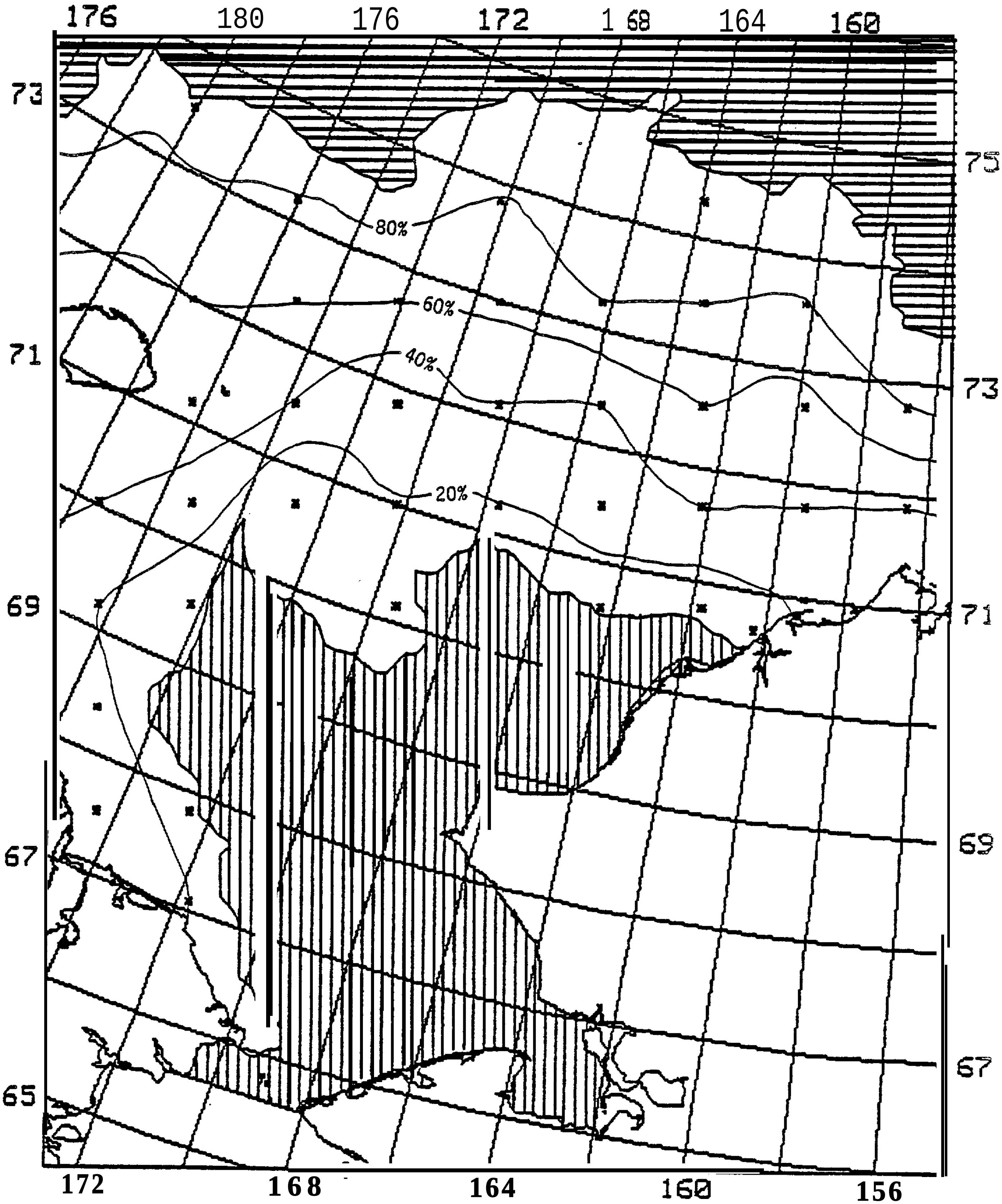



Figure 60. Chukchi Sea Ice Edge Frequency Map for Sept. 14-20. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal. lines had ice present on all years.

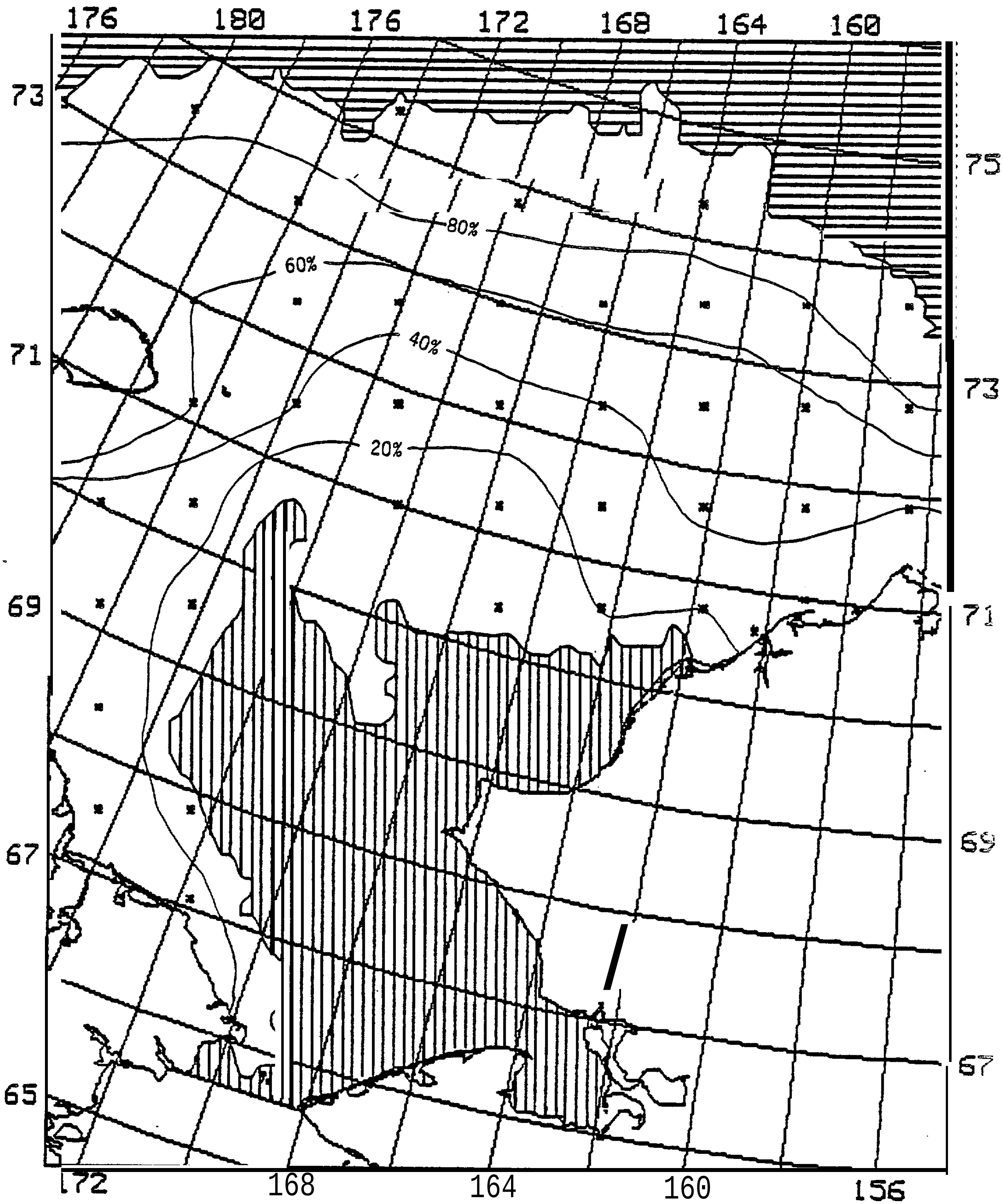



Figure 61. Chukchi Sea Ice Edge Frequency Map for Sept. 21-27. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

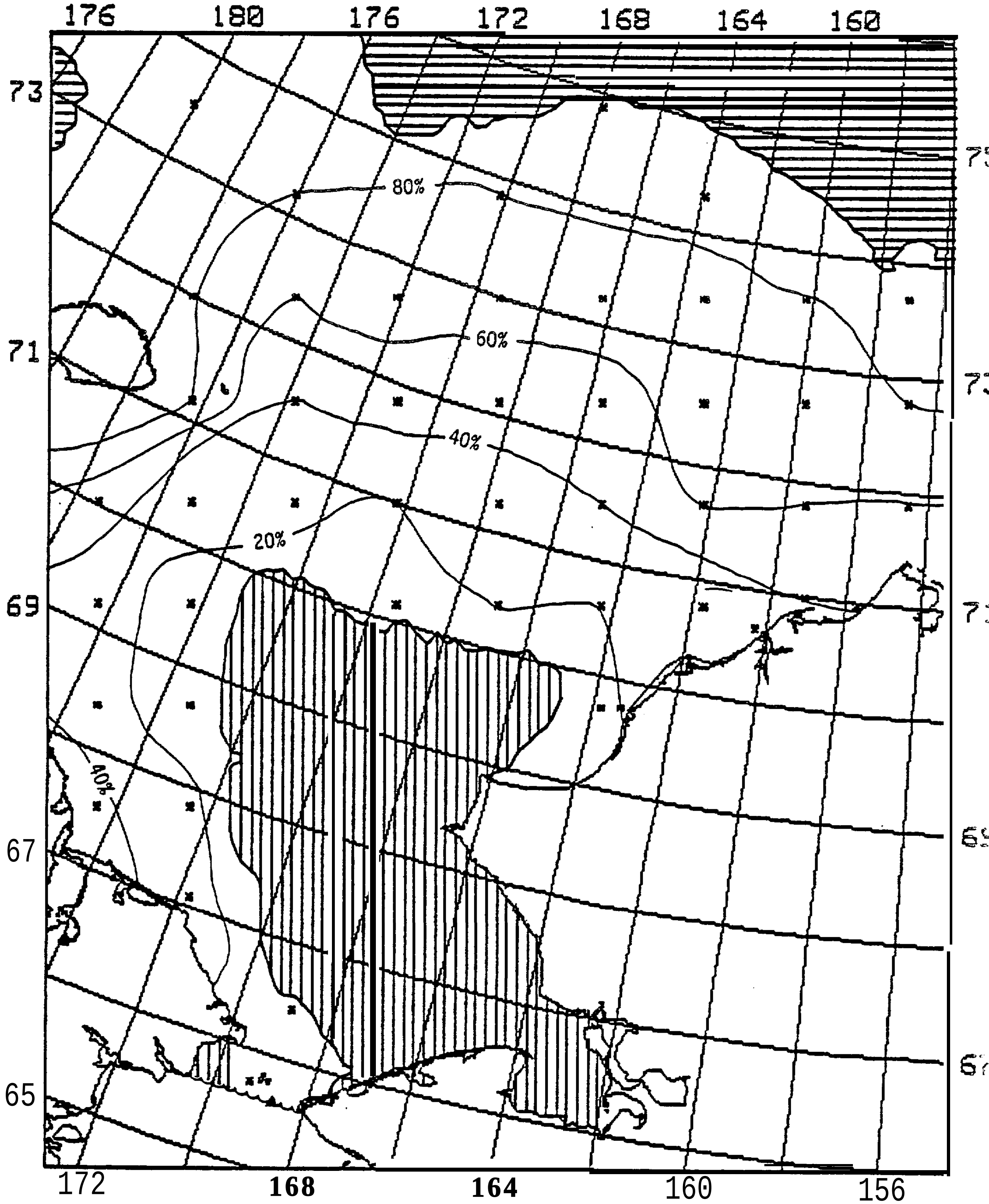



Figure 62. Chukchi Sea Ice Edge Frequency Map for Sept. 28-Ott. 4. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

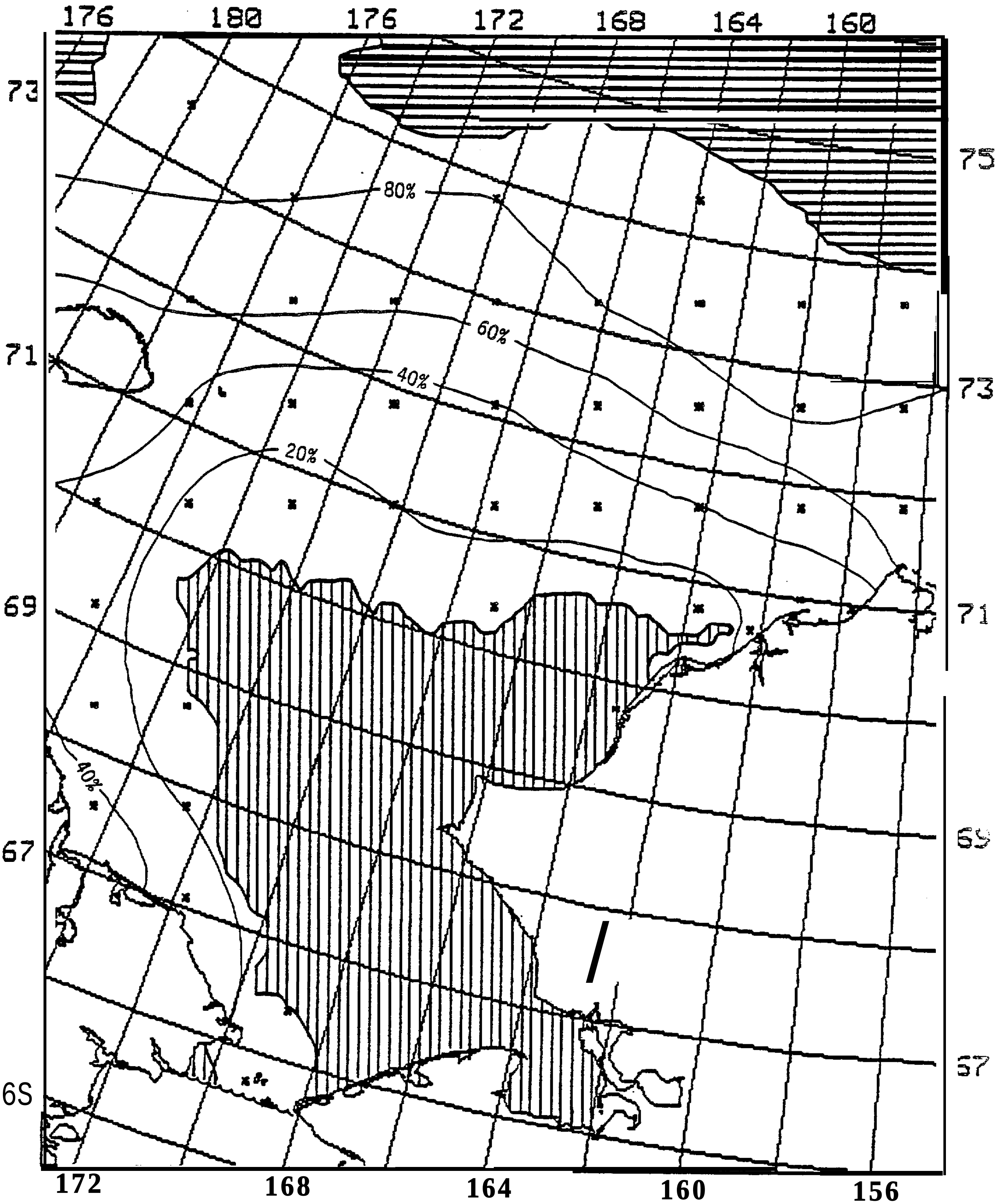



Figure 63. Chukchi Sea Ice Edge Frequency Map for Oct. 5-11. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

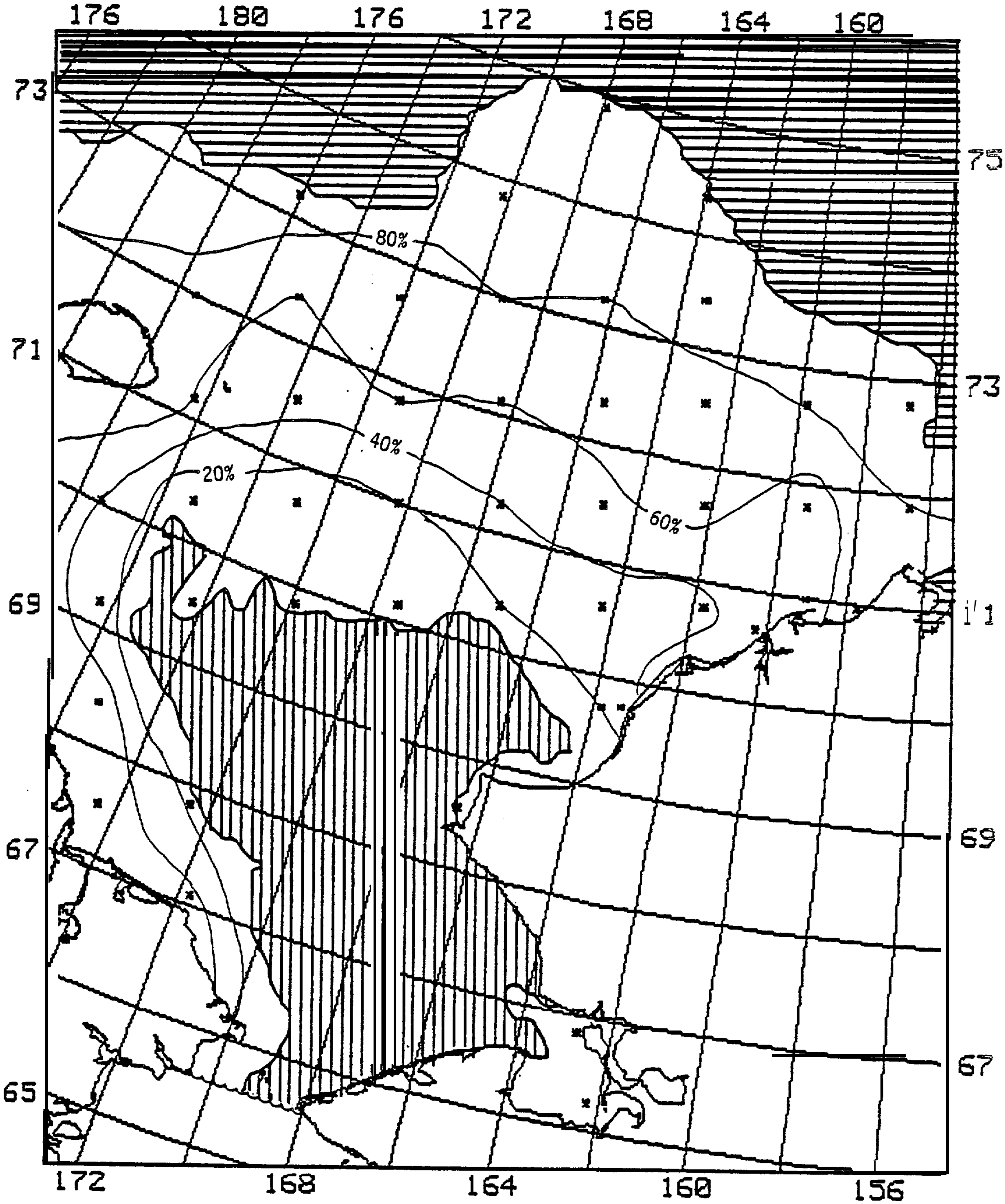



Figure 64. Chukchi Sea Ice Edge Frequency Map for Oct. 12-18. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

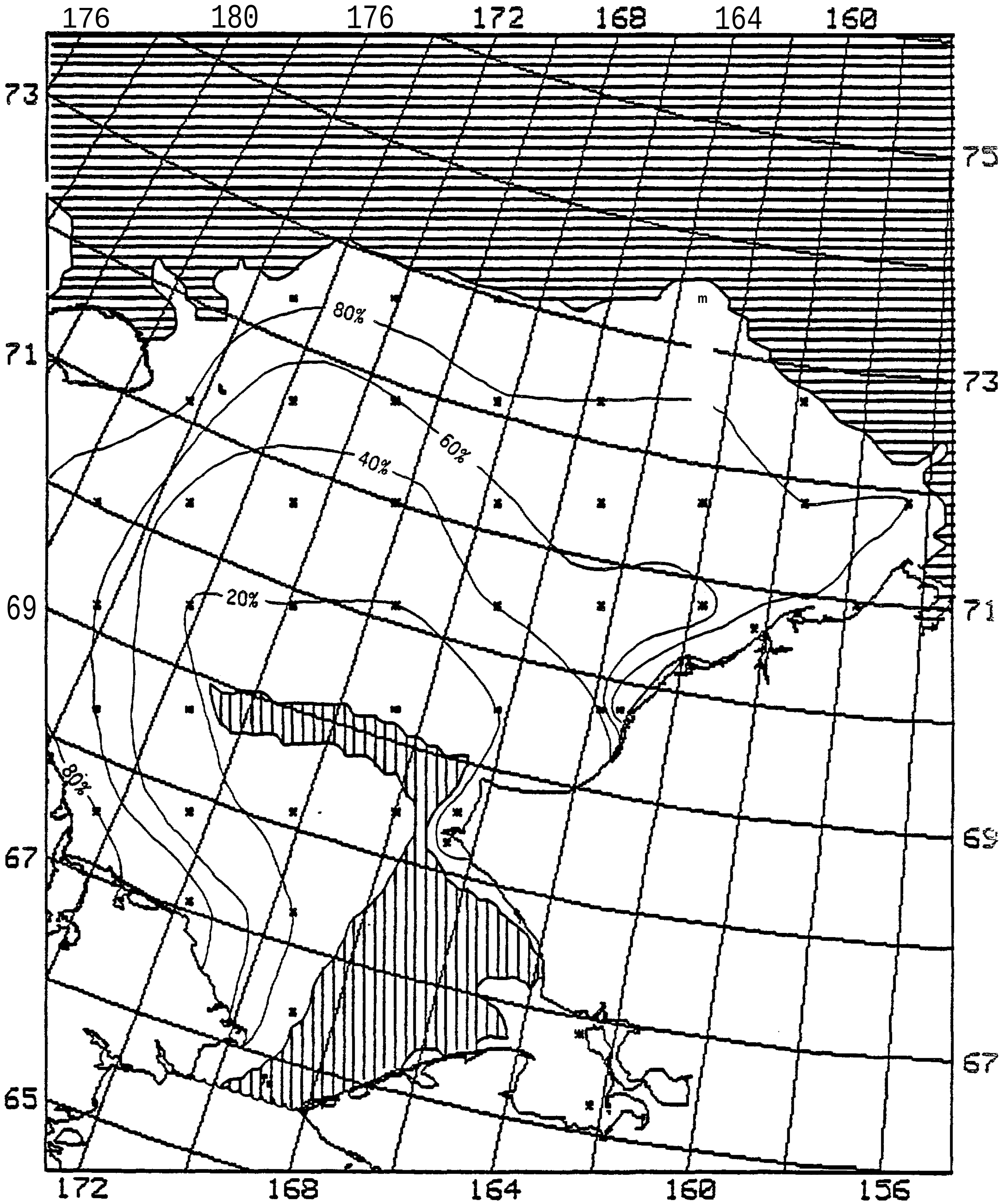



Figure 65. Chukchi Sea Ice Edge Frequency Map for Oct. 19-25. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

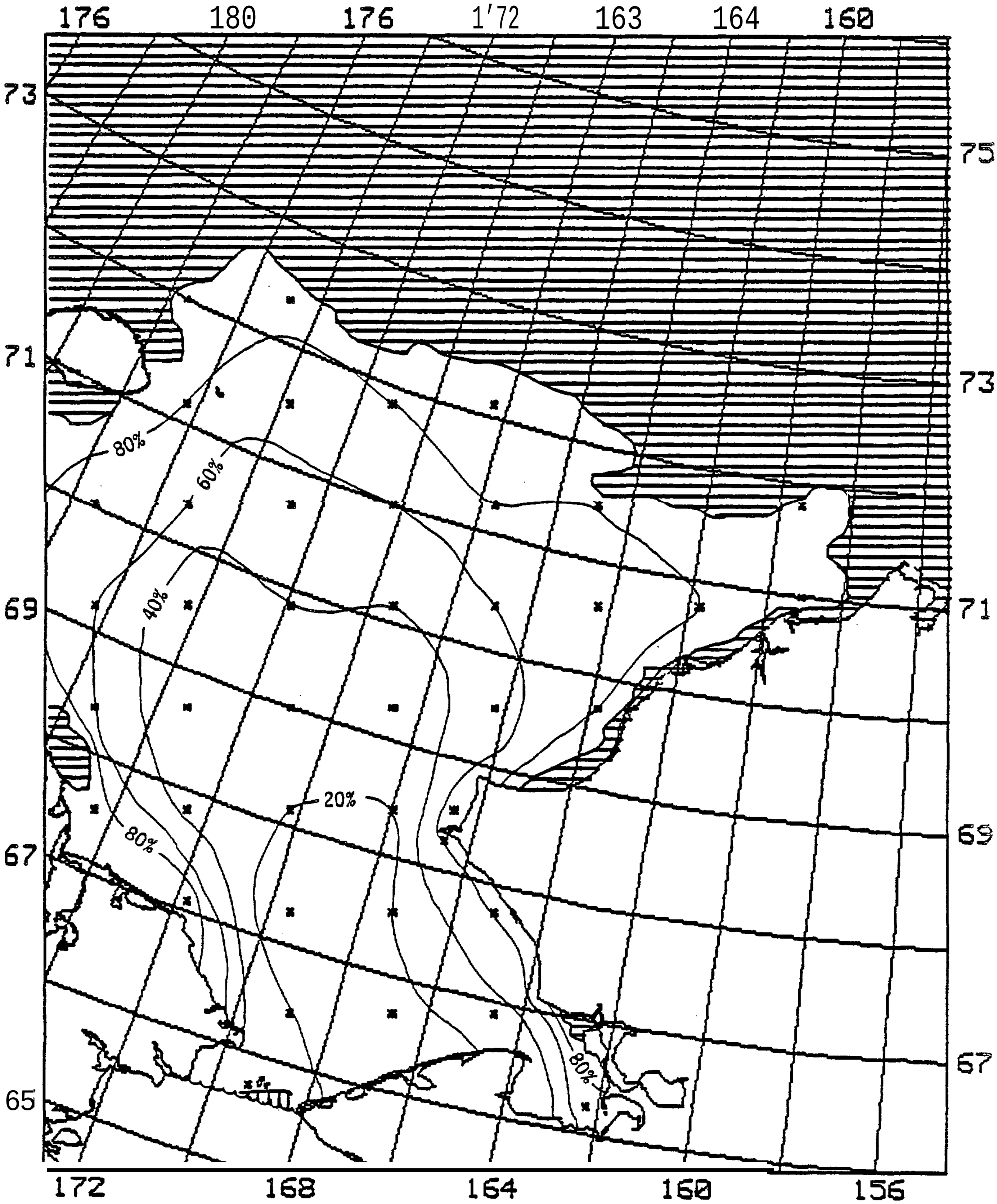



Figure 66. Chukchi Sea Ice Edge Frequency Map for Oct. 26-Nov. 1. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

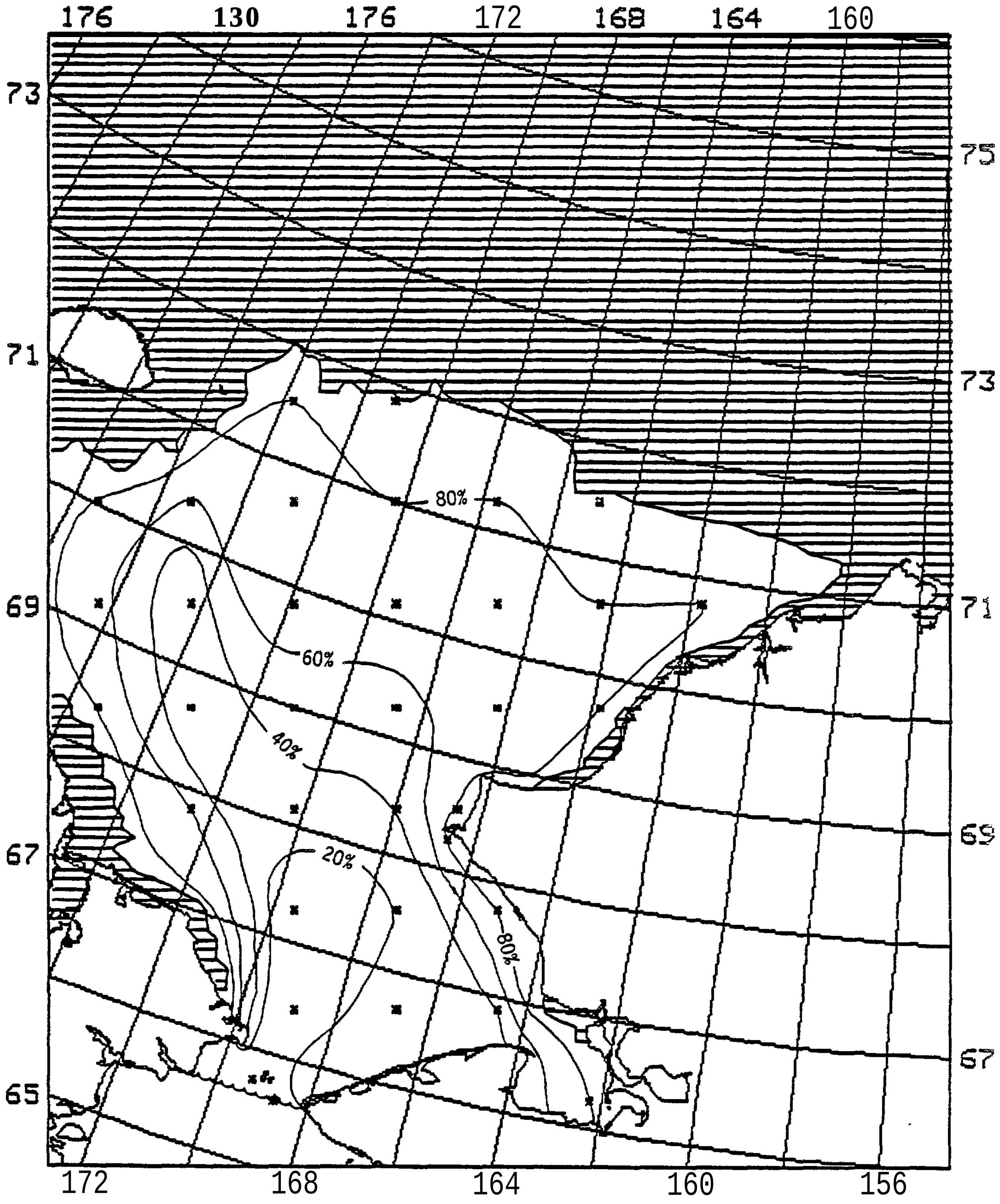



Figure 67. Chukchi Sea Ice Edge Frequency Map for Nov. 2-8. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

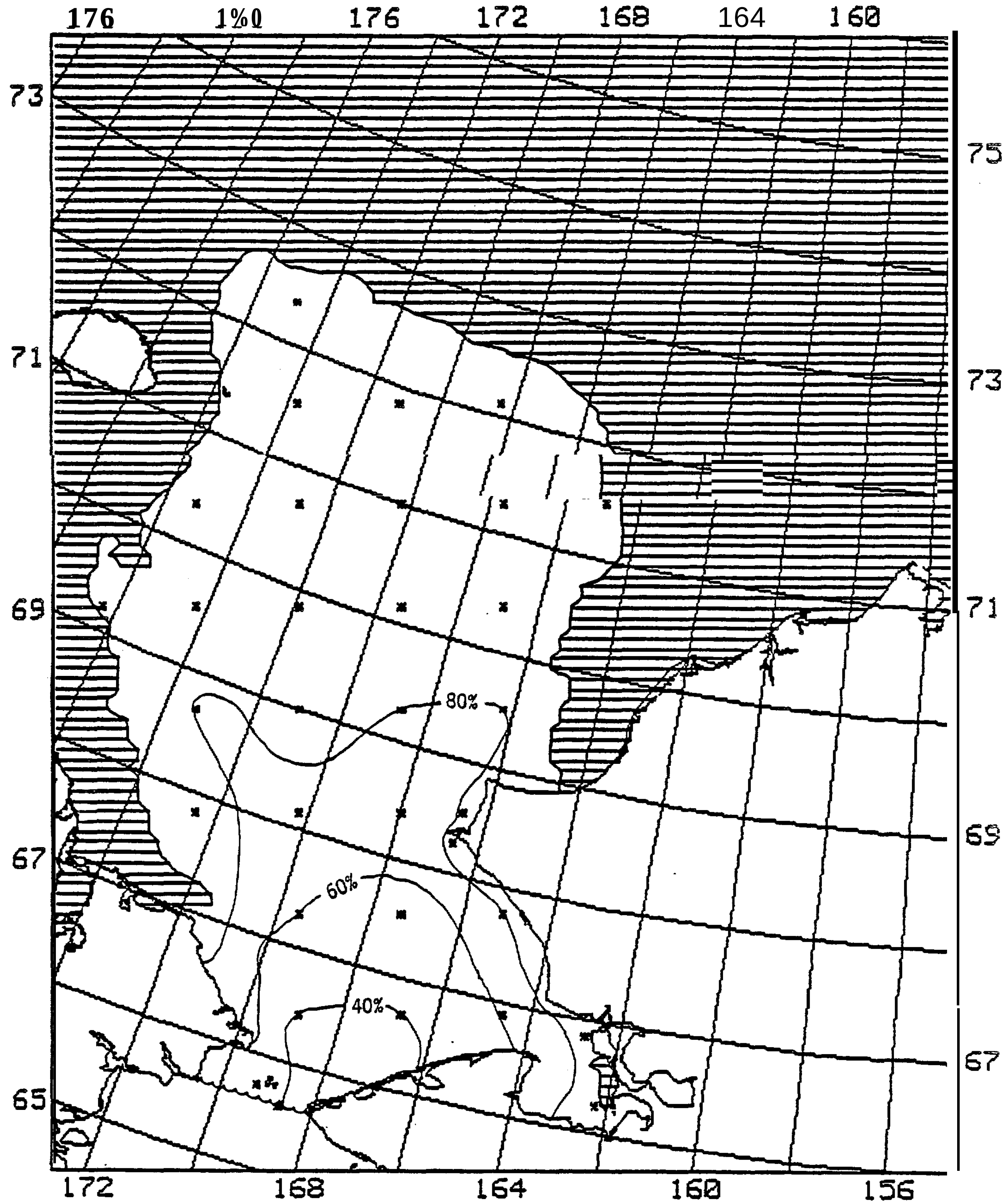



Figure 68. Chukchi Sea Ice Edge Frequency Map for Nov. 9-15. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

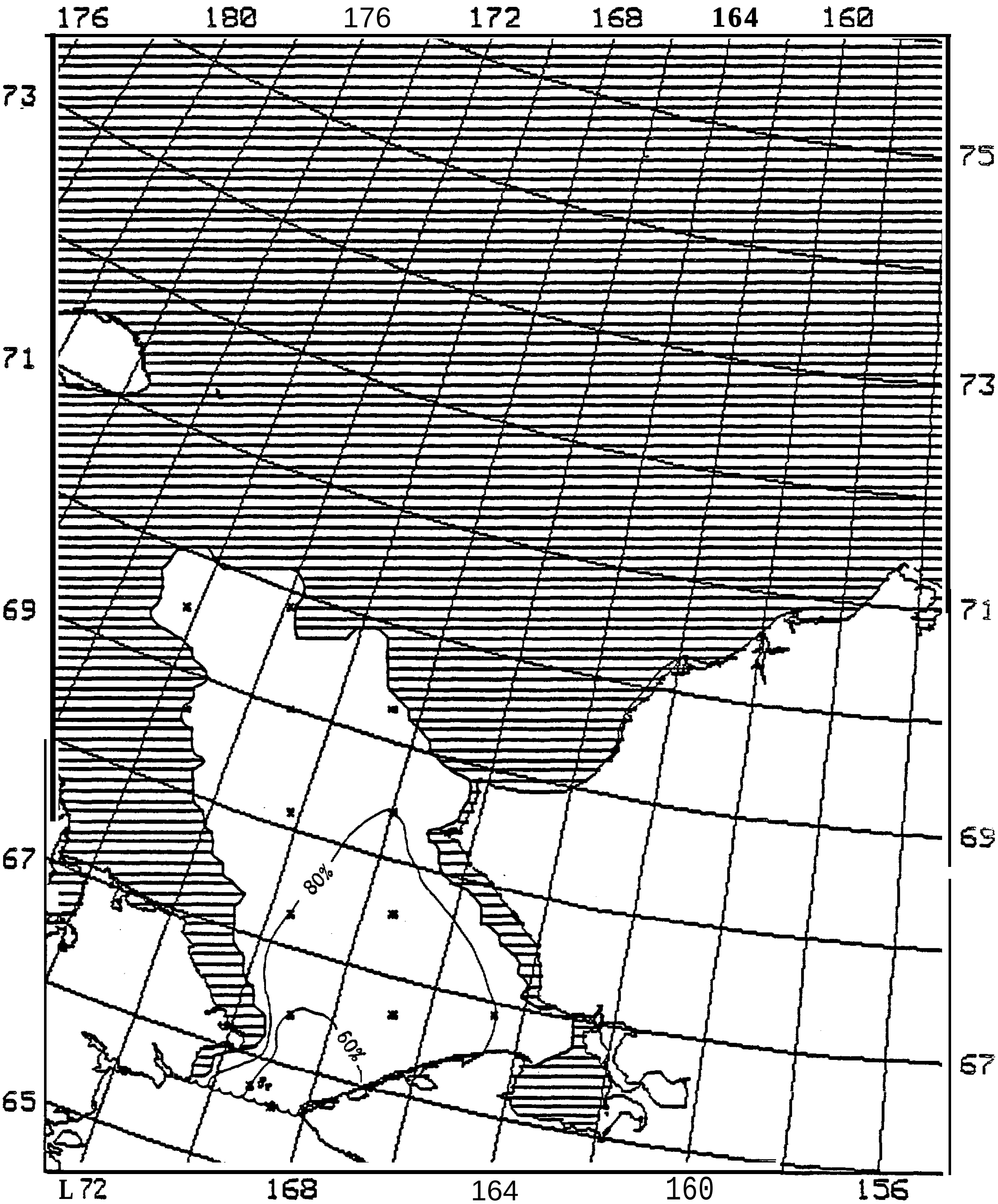



Figure 69. Chukchi Sea Ice Edge Frequency Map for Nov. 16-22. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

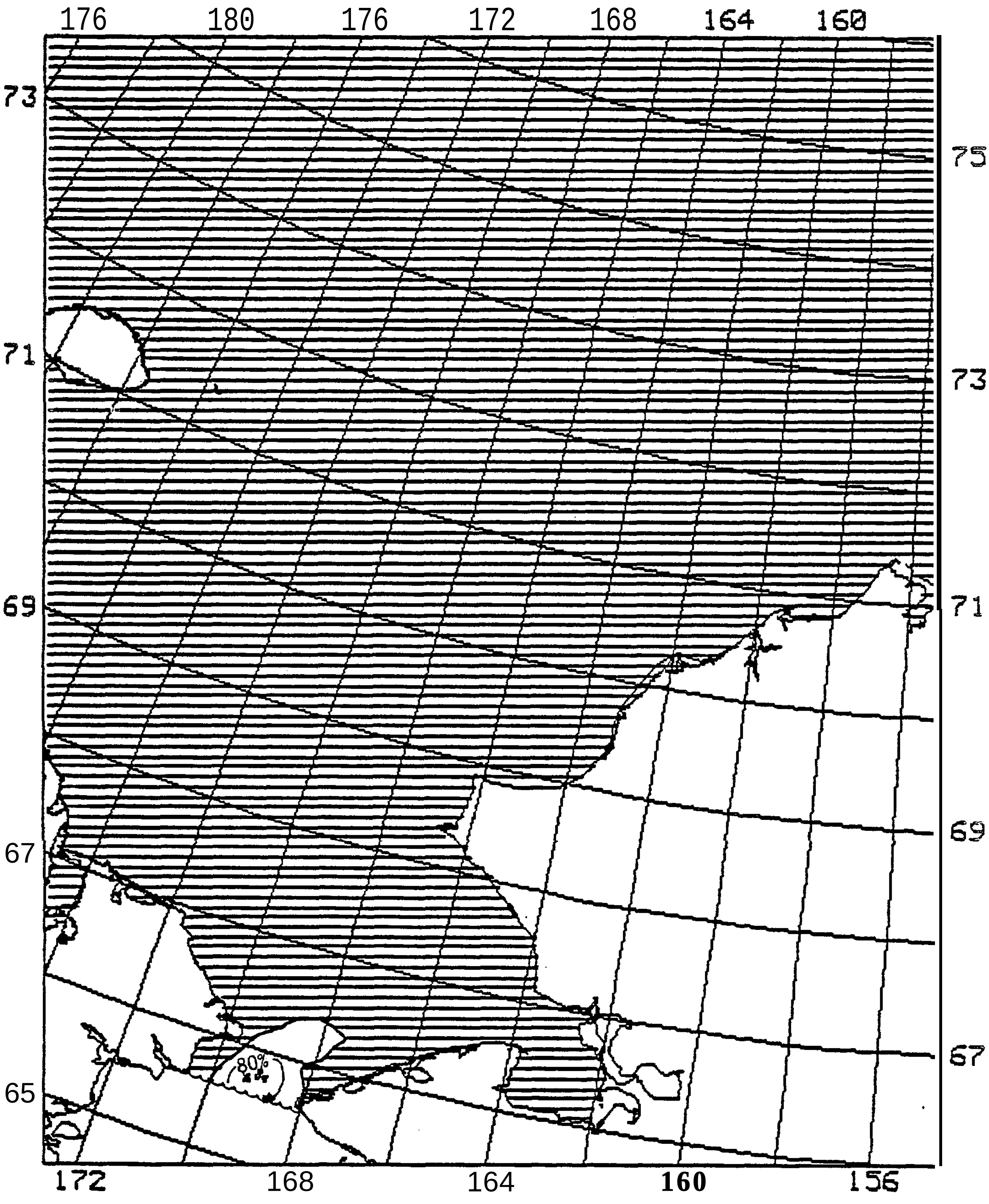



Figure 70. Chukchi Sea Ice Edge Frequency Map for Nov. 23-29. The isopleths on this map define the relative frequency with which oceanic locations have been within the ice edge on this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present on all years.

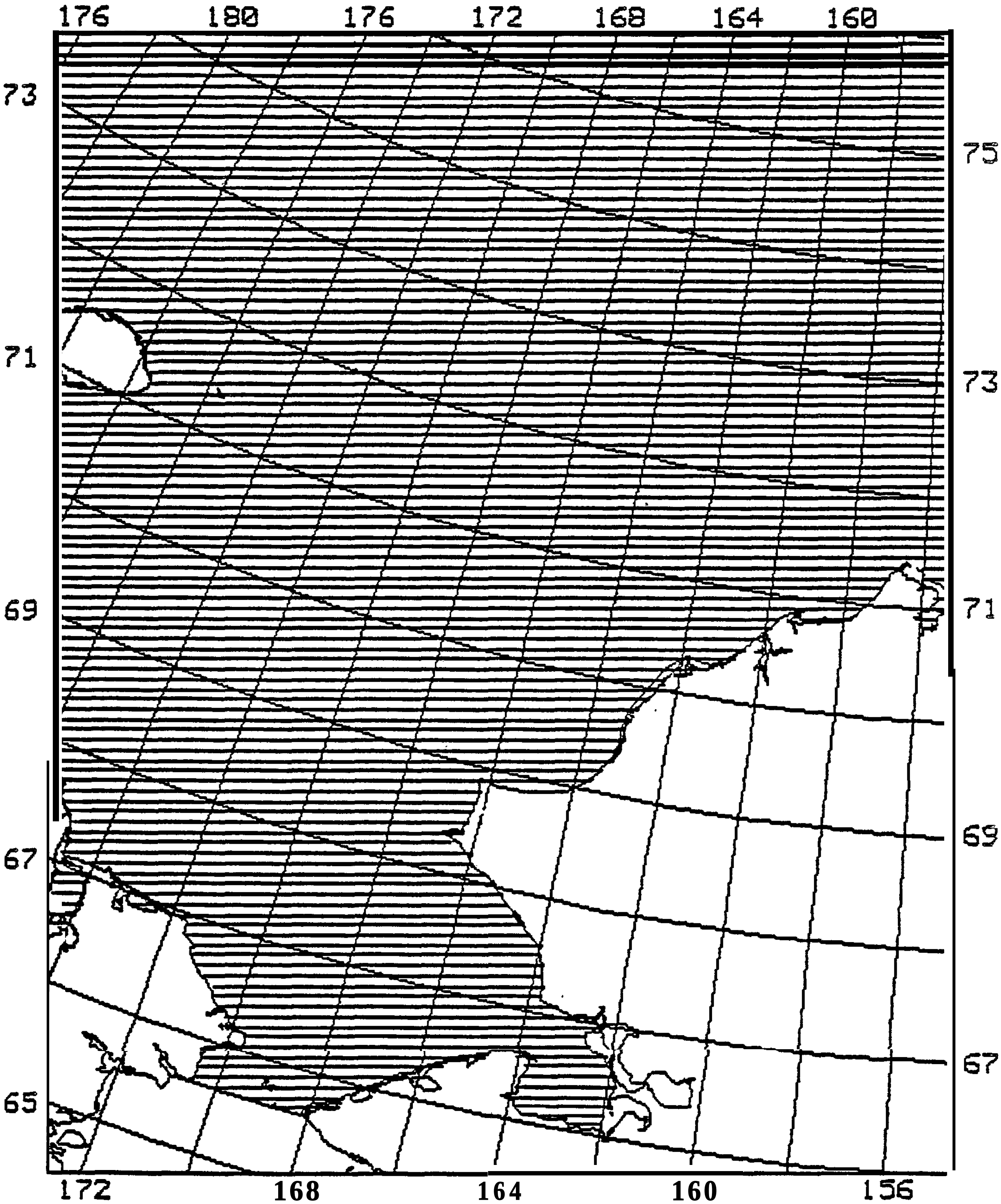



Figure 71. **Chukchi** Sea Ice Edge Frequency Map for Nov. 30-Dec. 6. The **isopleths** on this map define the relative frequency with which oceanic locations have been within the ice edge *on* this date. The area containing vertical lines was ice-free on all years studied, while the area containing horizontal lines had ice present *on* all years.

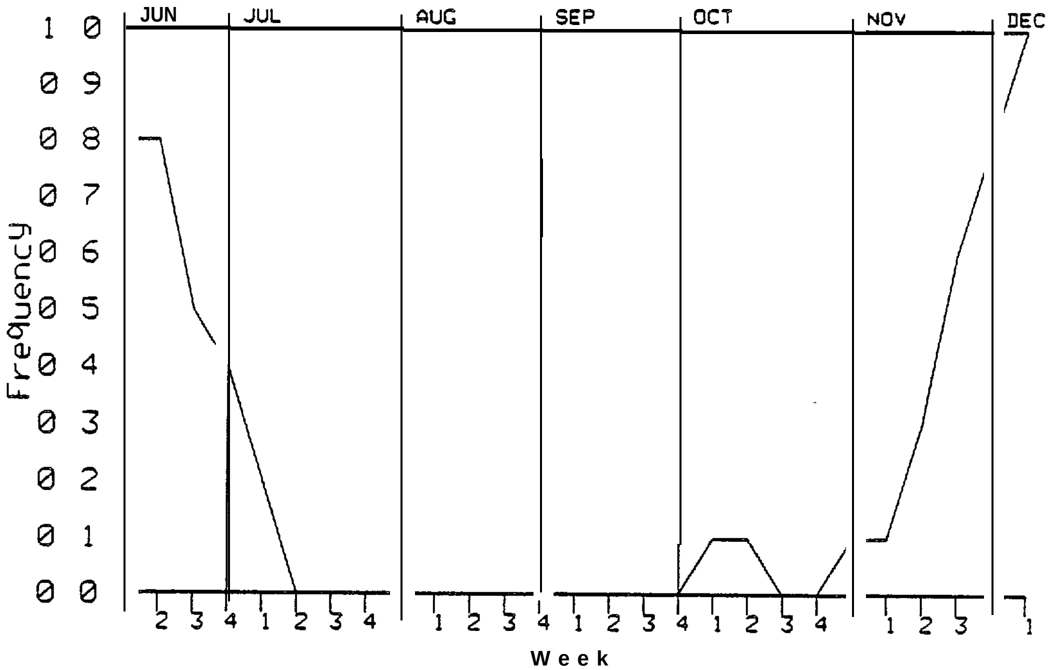



FIGURE 72 ICE PRESENCE FREQUENCY ASA FUNCTION OF DATE AT STATION 1

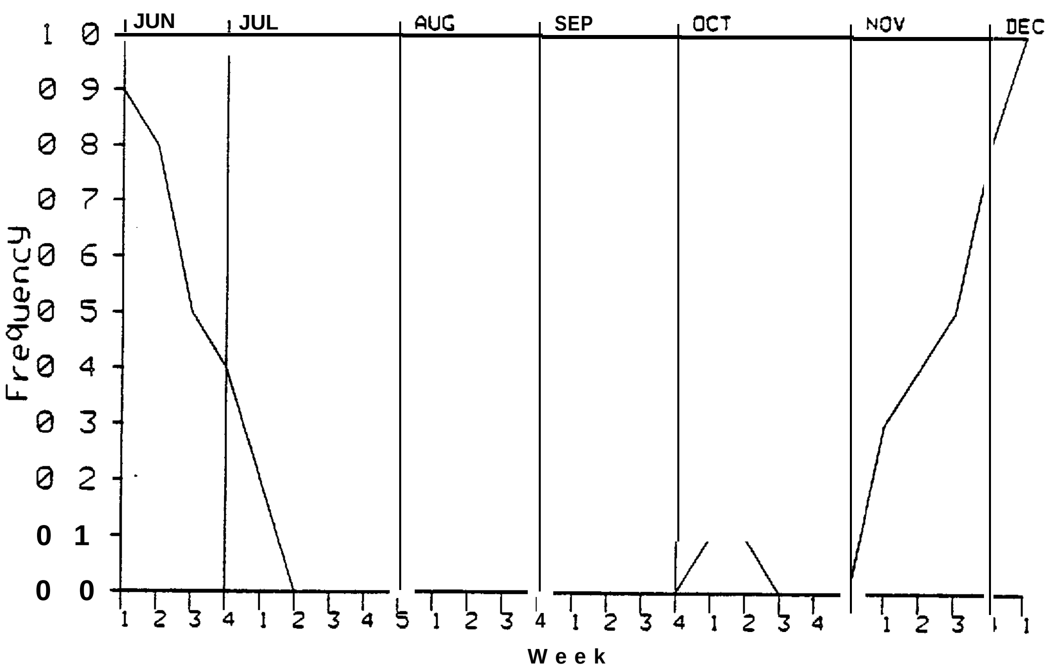



FIGURE 73 ICE PRESENCE FREQUENCY ASA FUNCTION Of DATE AT STATION 2

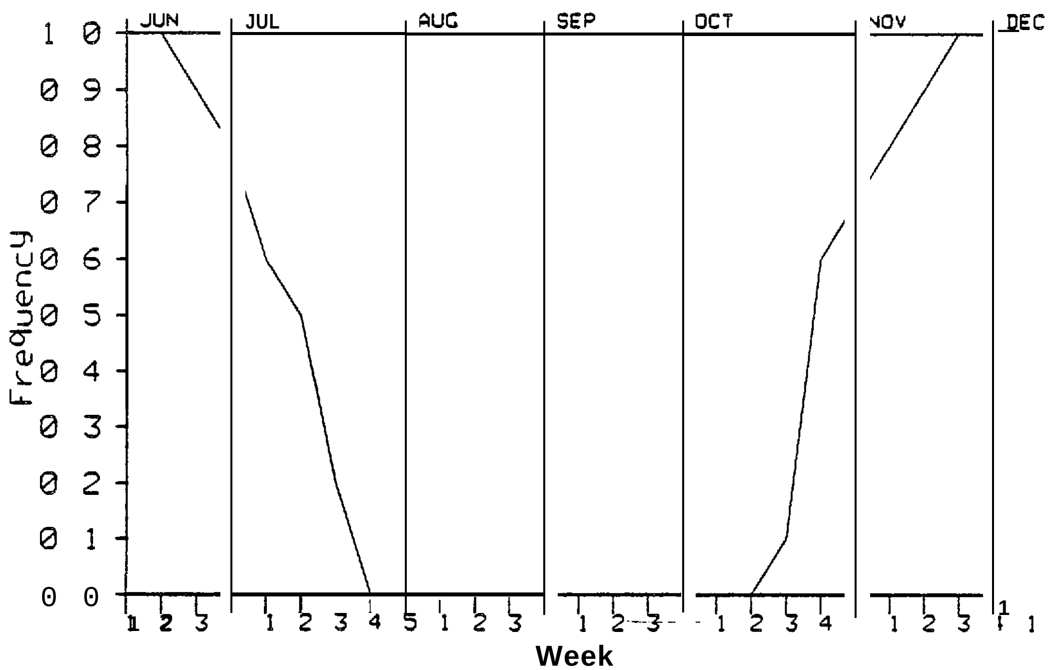



FIGURE 74 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 3

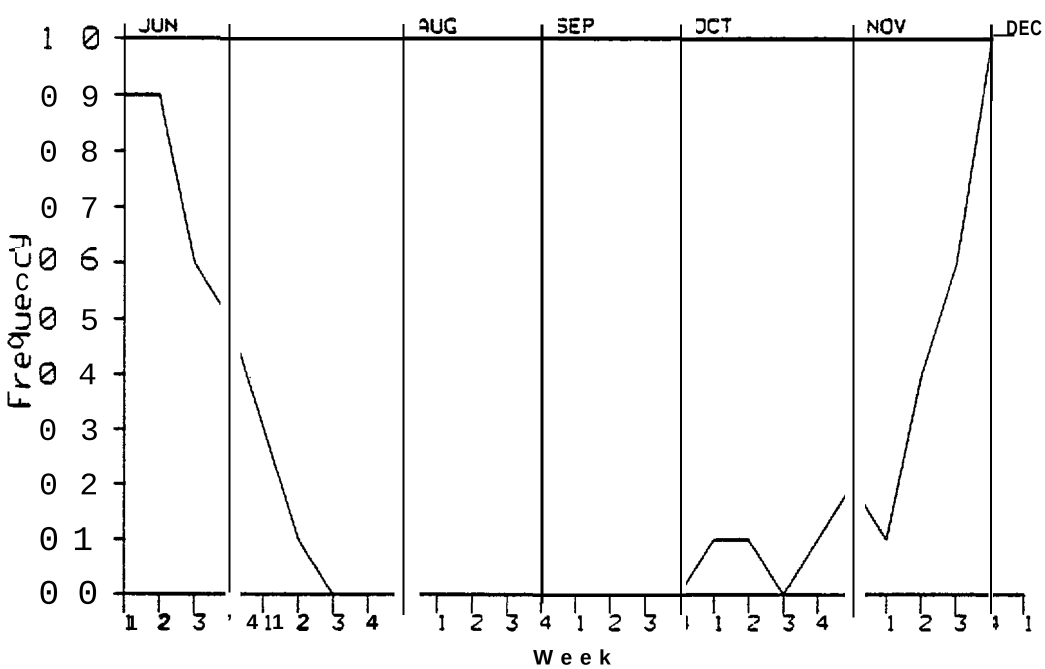



FIGURE 75 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 4

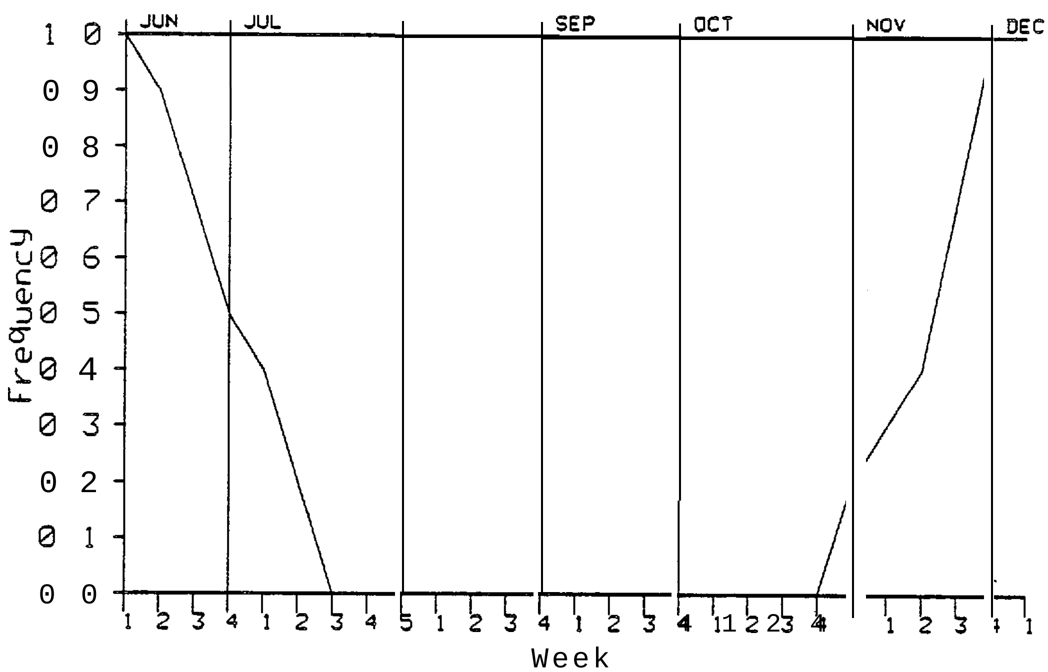



FIGURE 76 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 5

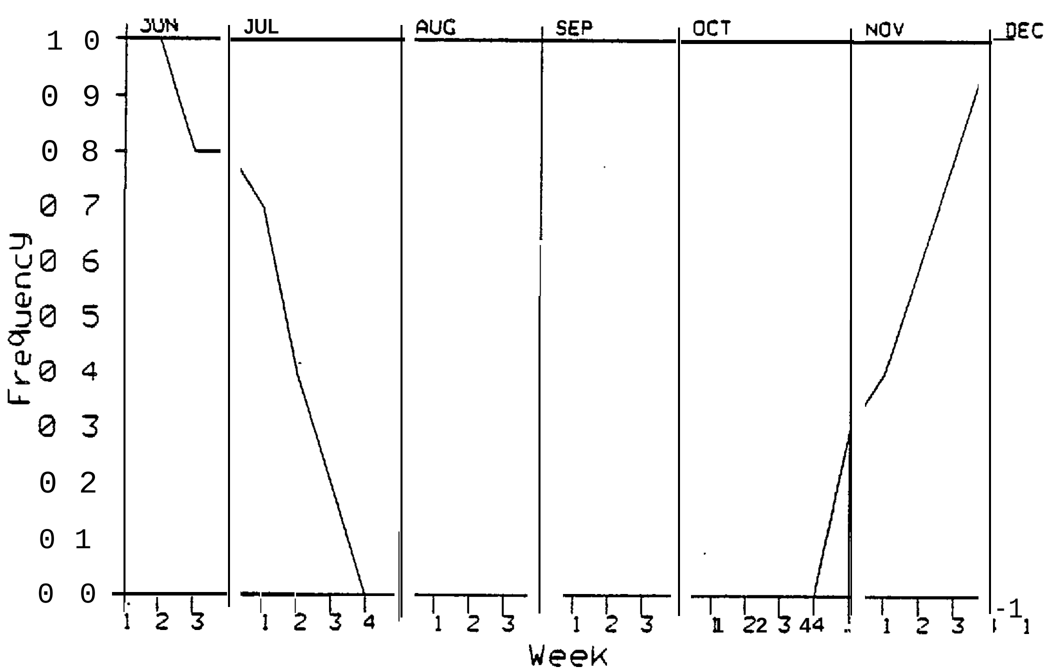



FIGURE 77 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 6

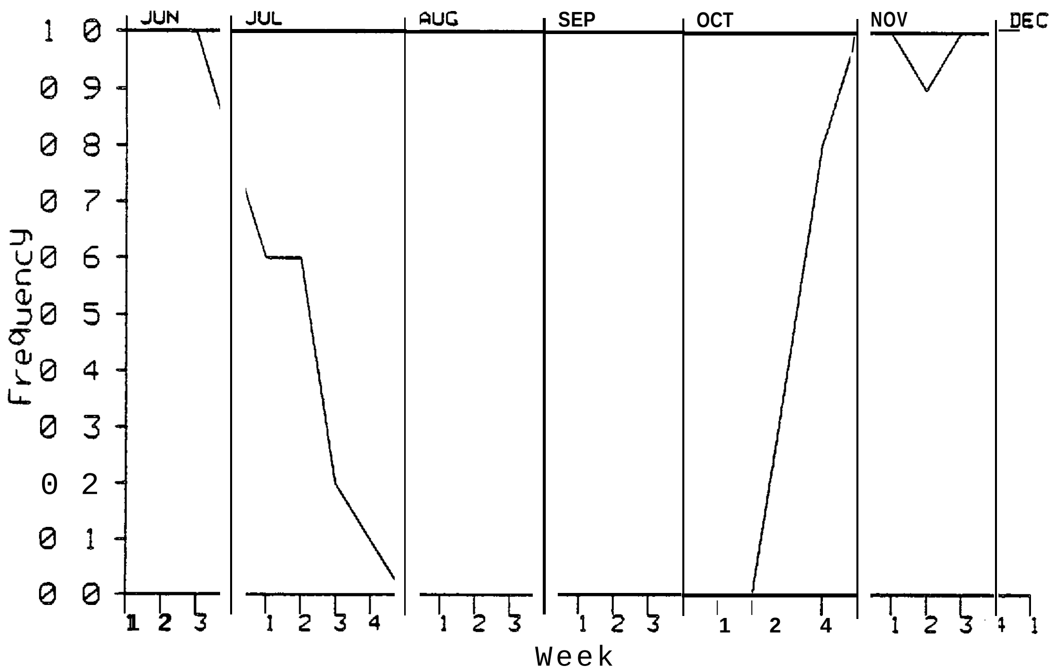



FIGURE 78 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 7

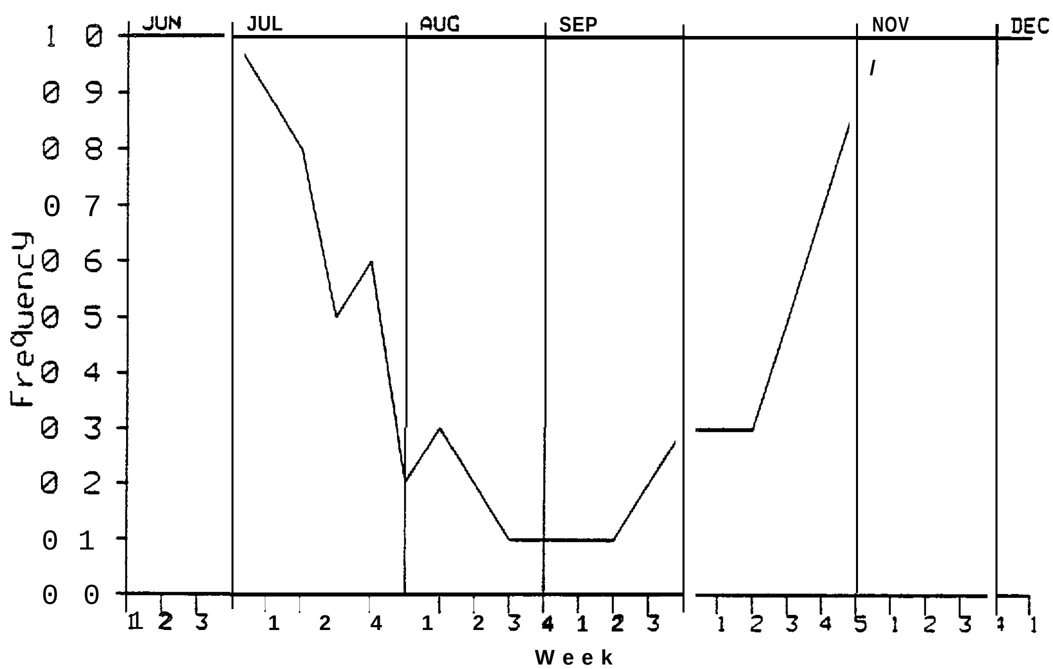



FIGURE 79 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 8

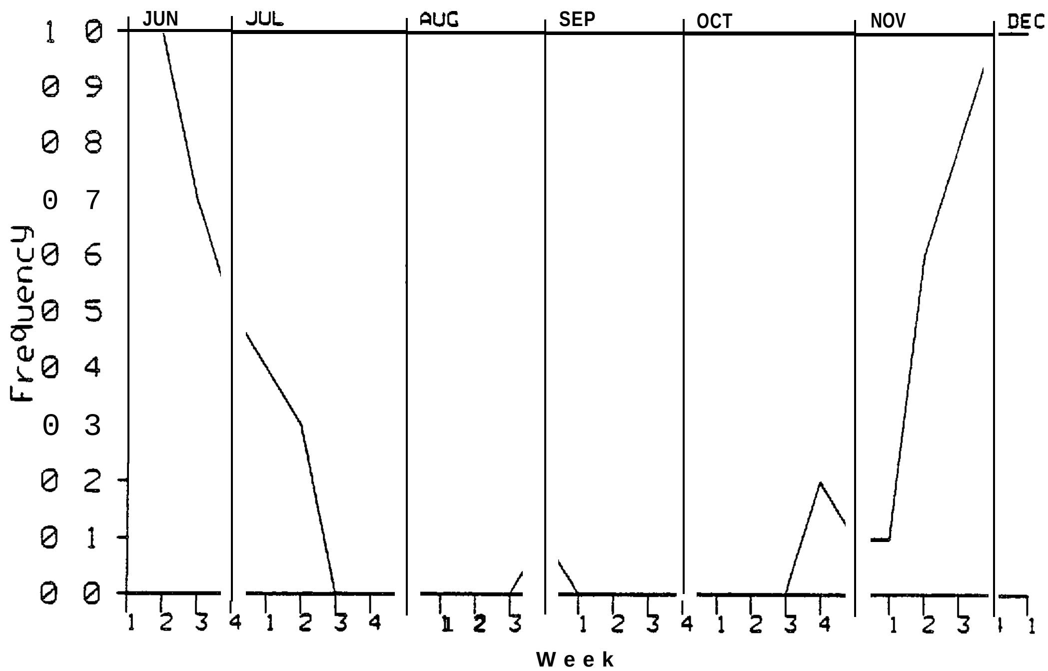



FIGURE 80 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 9

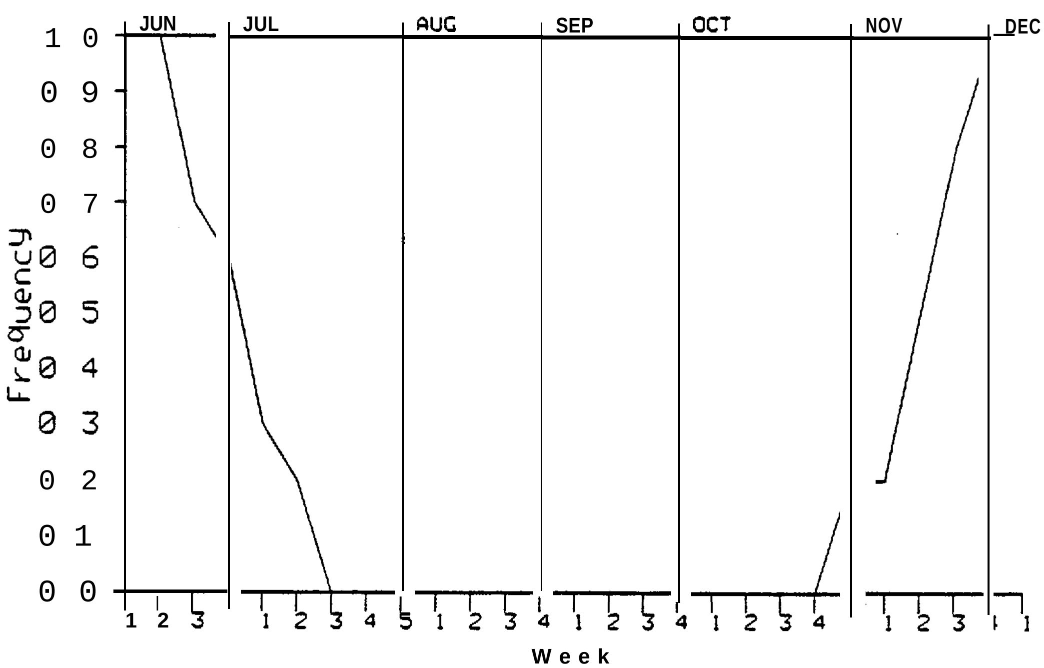



FIGURE 81 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 10

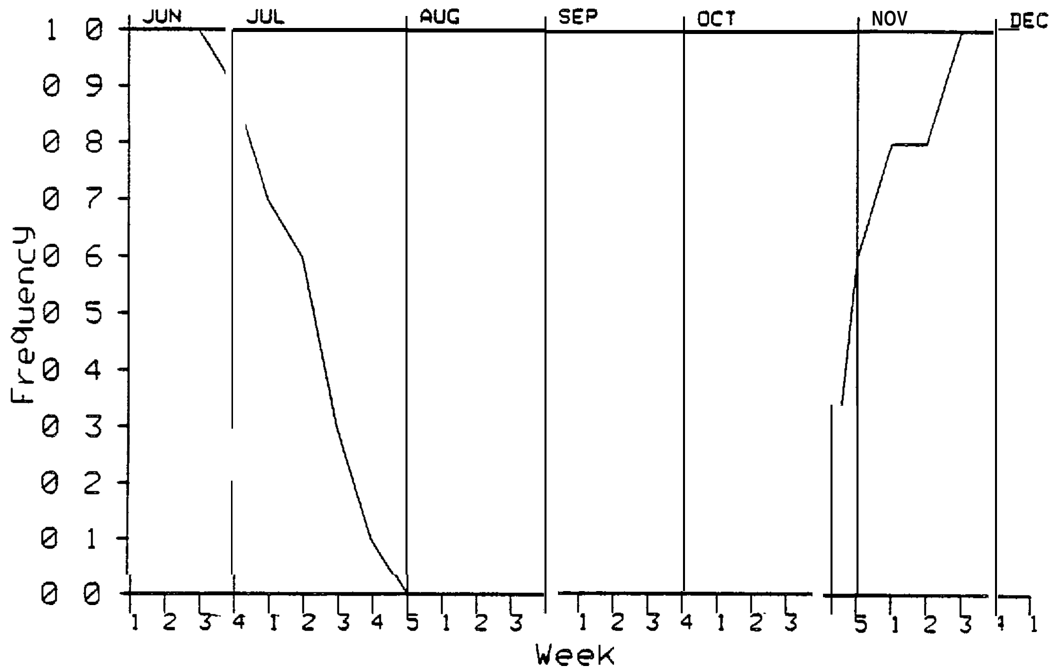



FIGURE 8 2 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 11

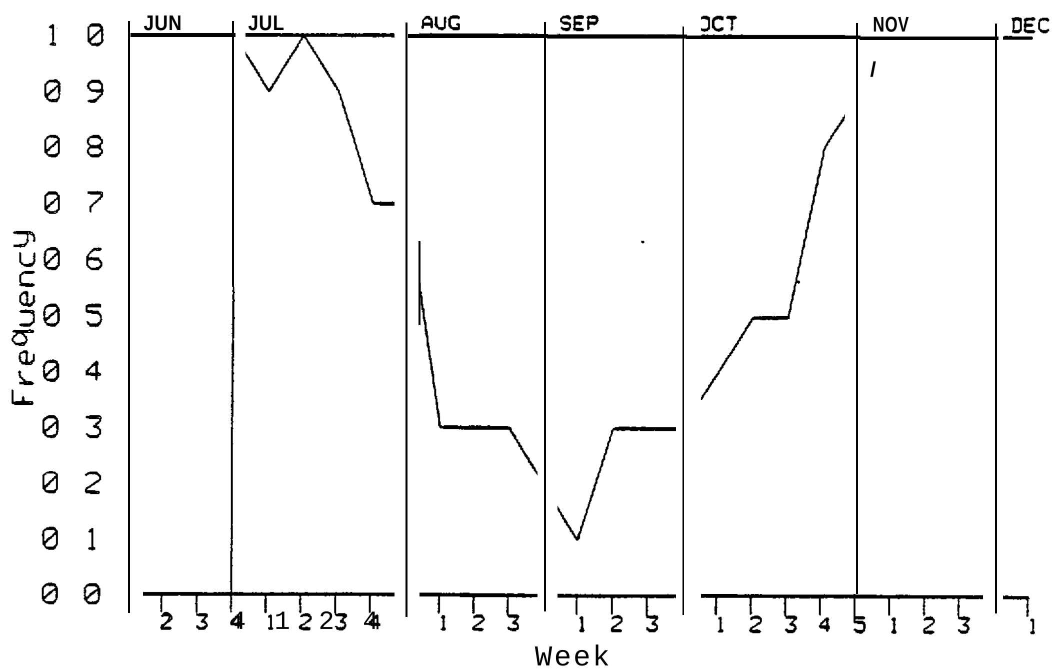



FIGURE 8 3 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 12

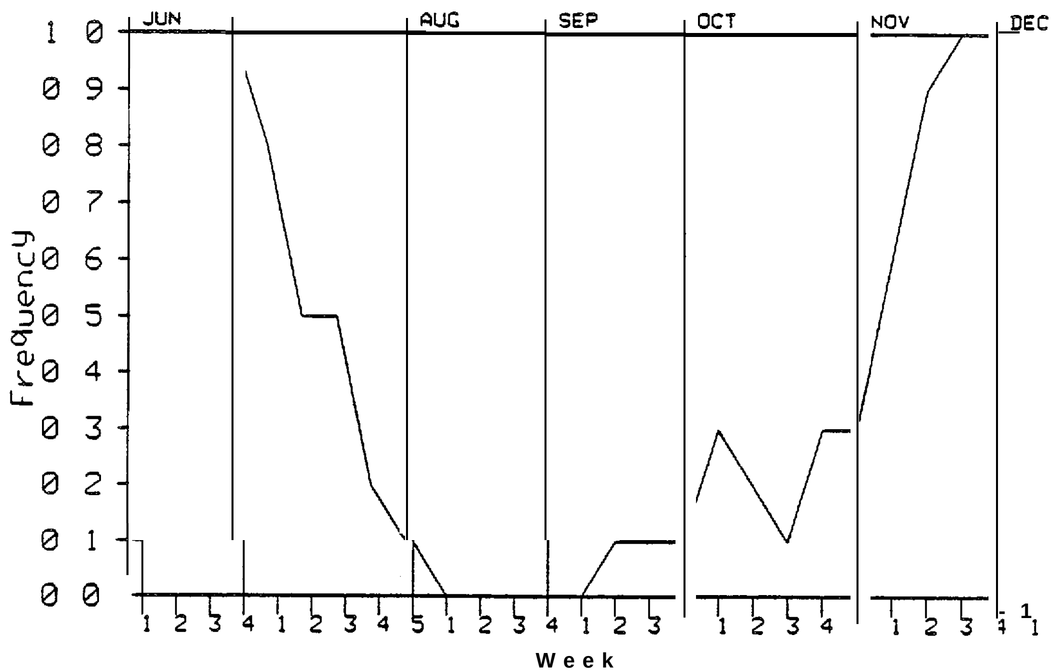



FIGURE 84 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 13

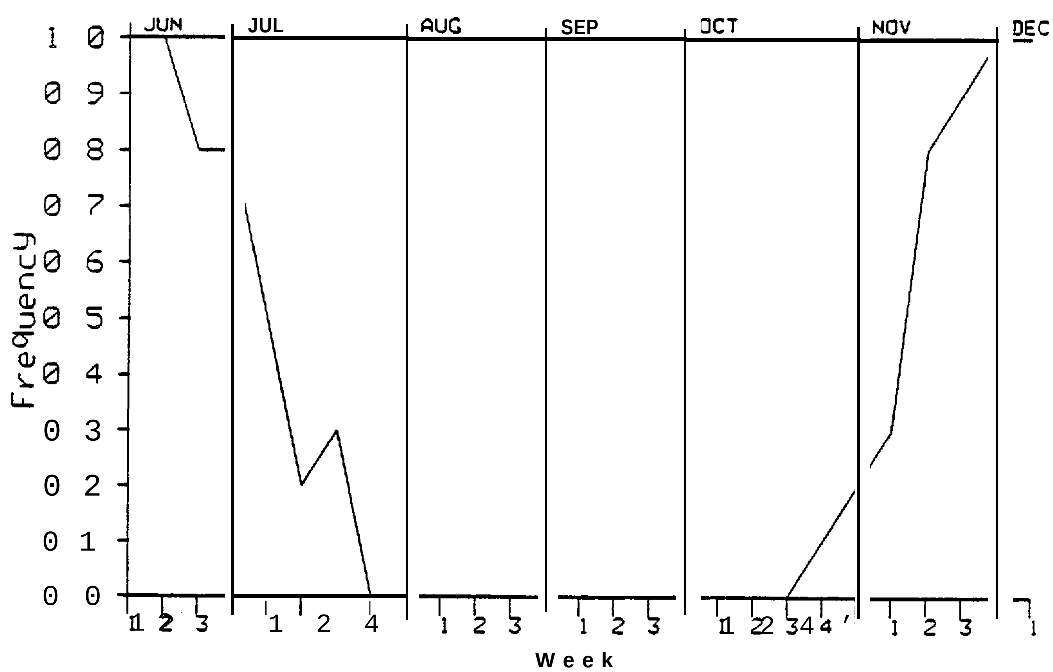



FIGURE 85 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 14

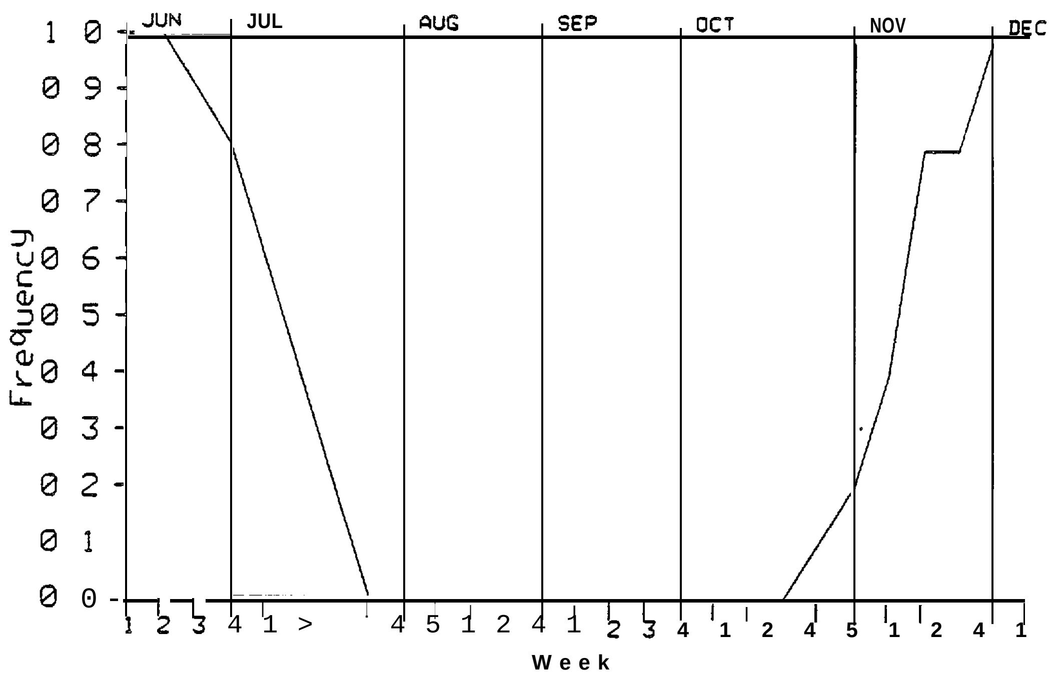



FIGURE 86 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 15

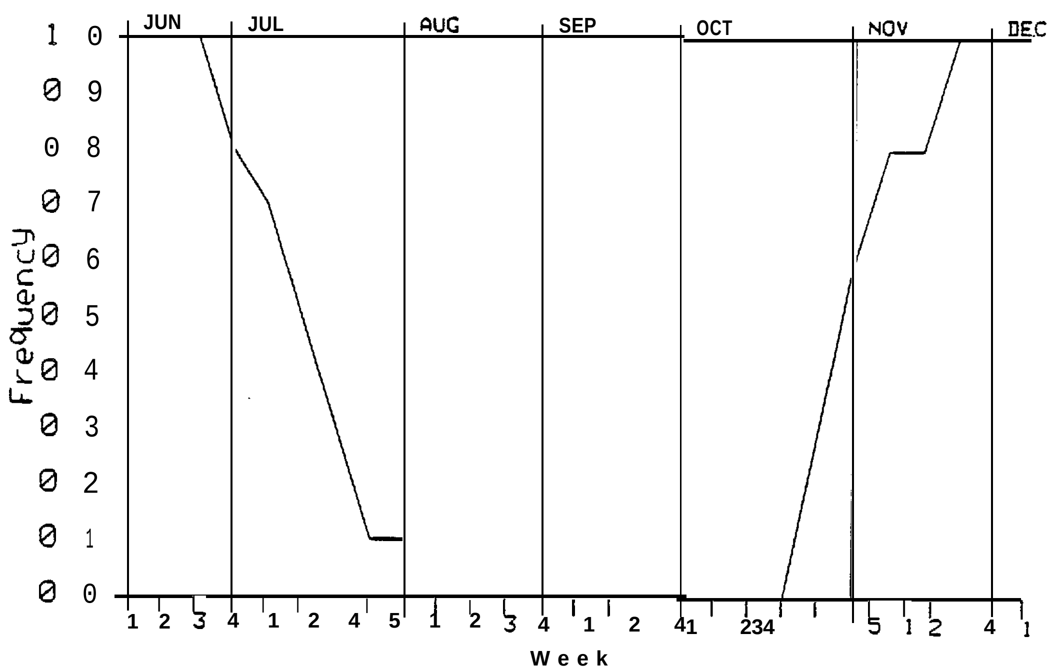



FIGURE 87 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 16

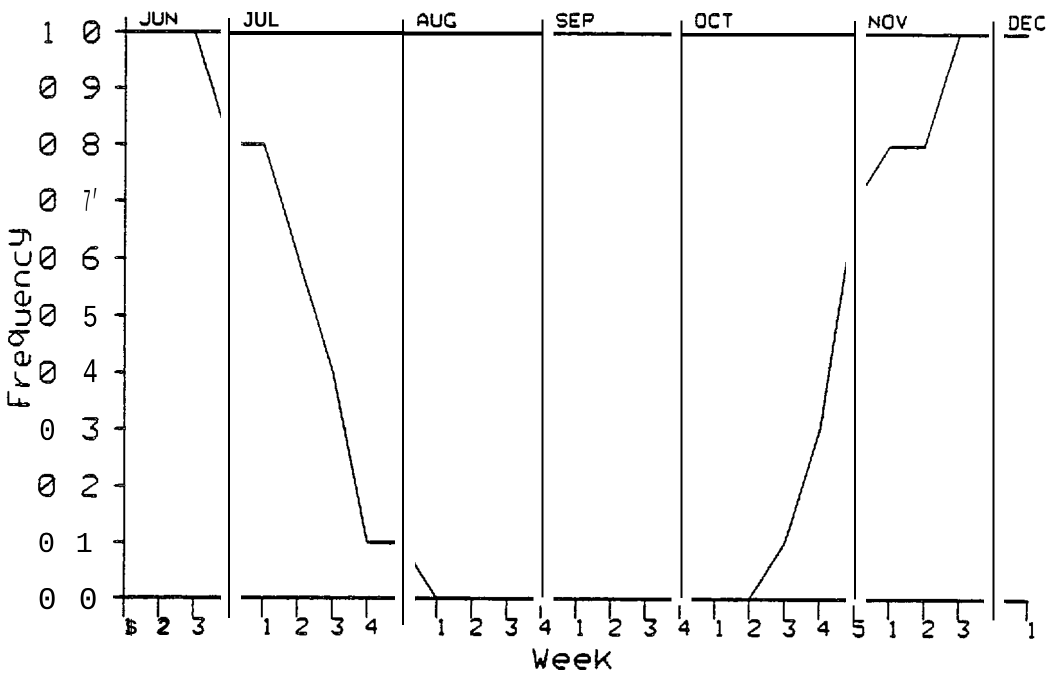



FIGURE 8 8 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE
AT STATION 17

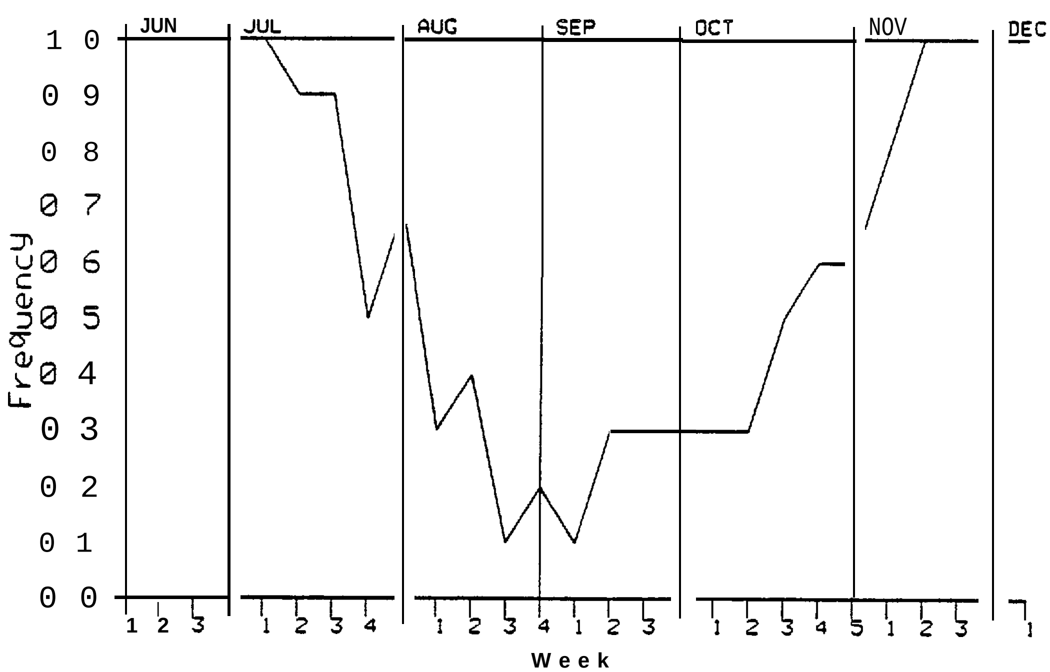



FIGURE 89 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE
AT STQTION 18

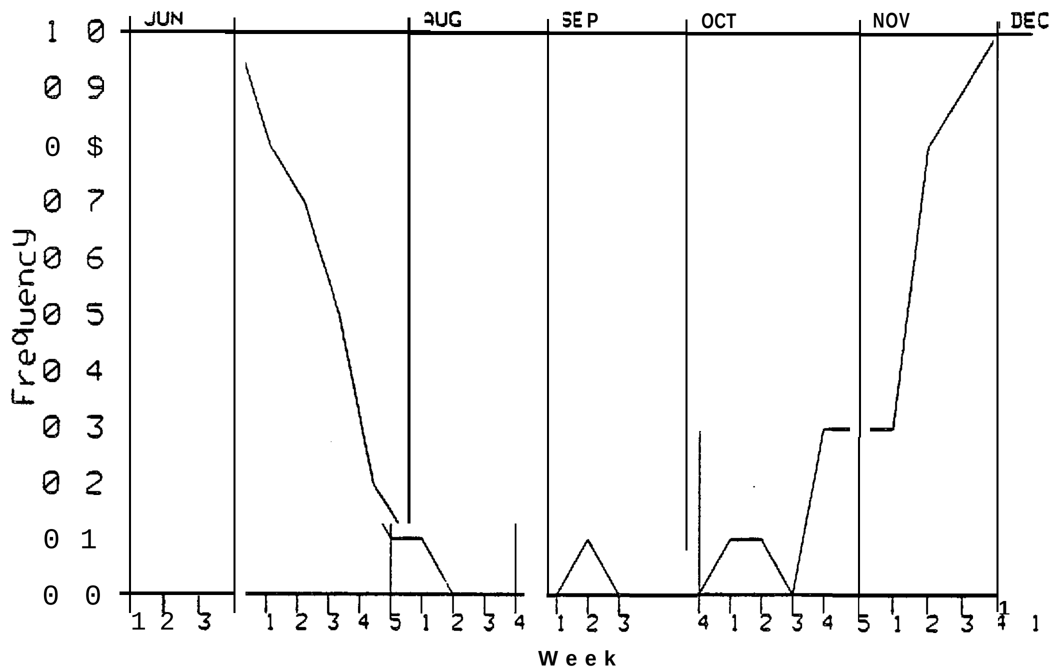



FIGURE 90 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 19

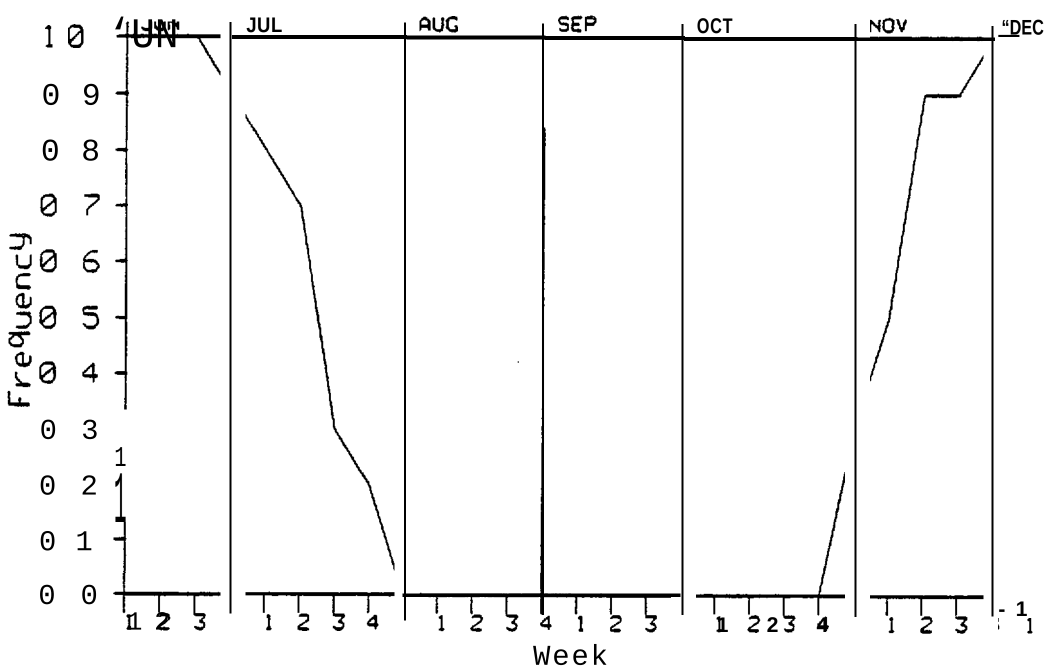



FIGURE 91 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 20

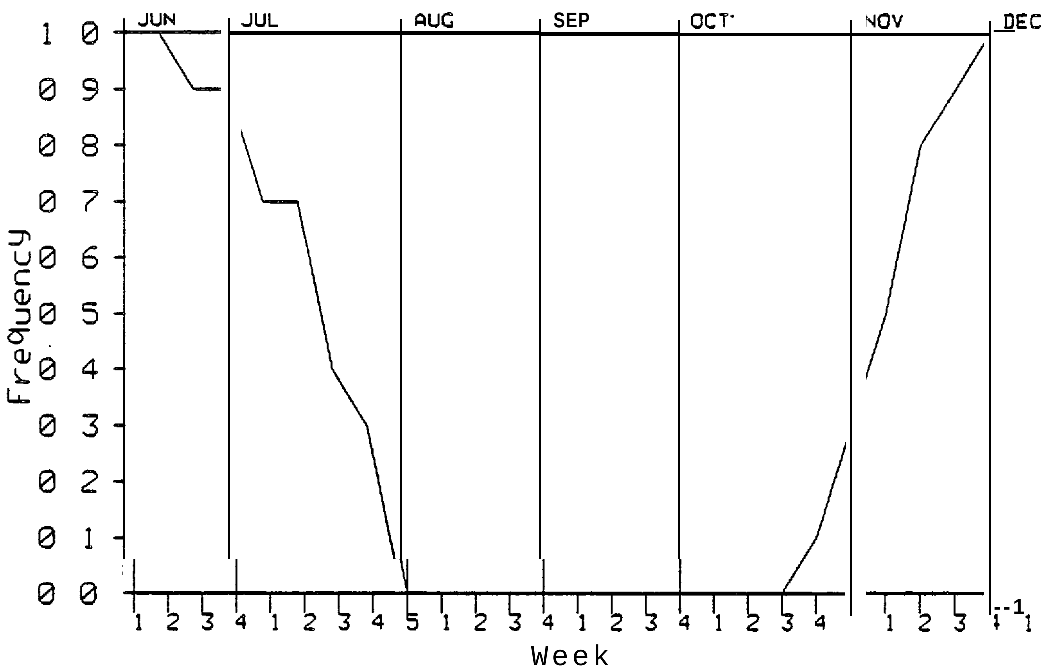



FIGURE 92 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 21

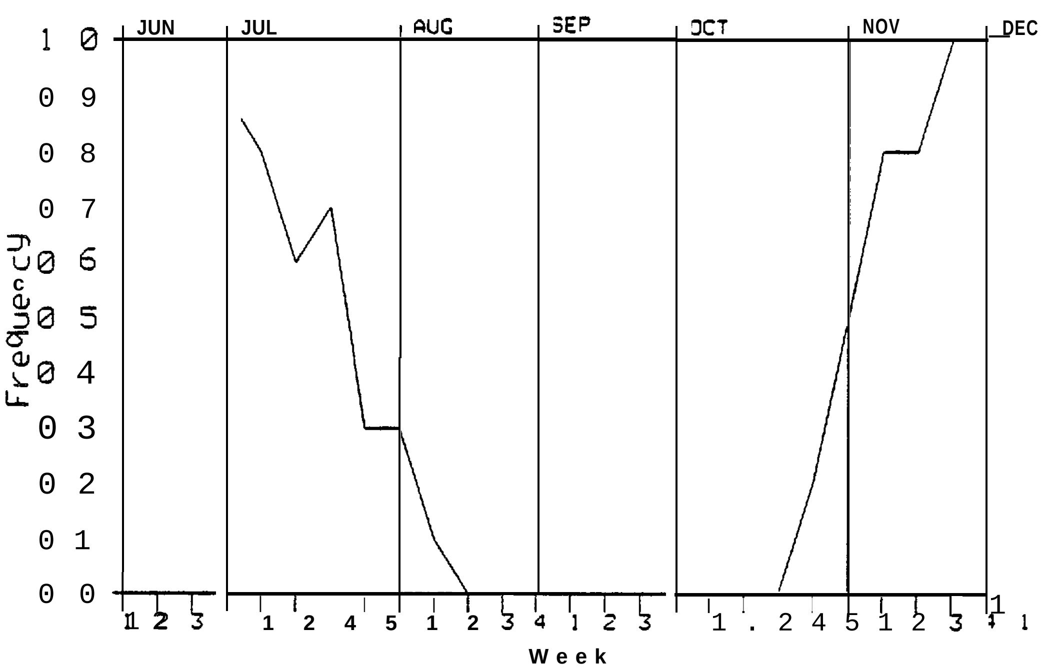



FIGURE 93 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 22

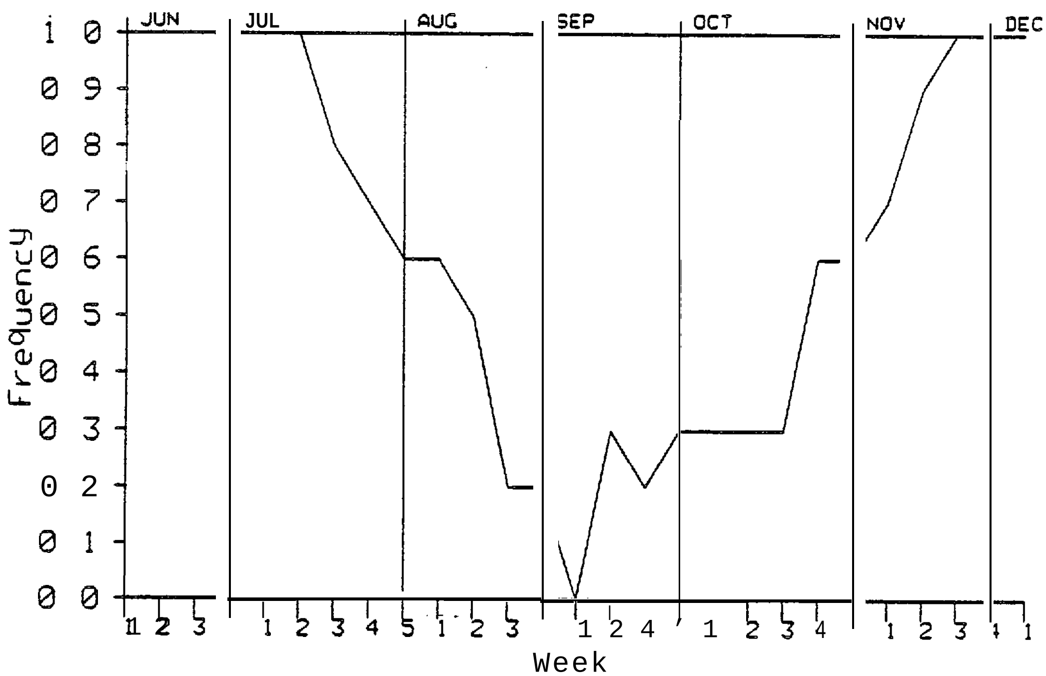



FIGURE 9 6 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 25

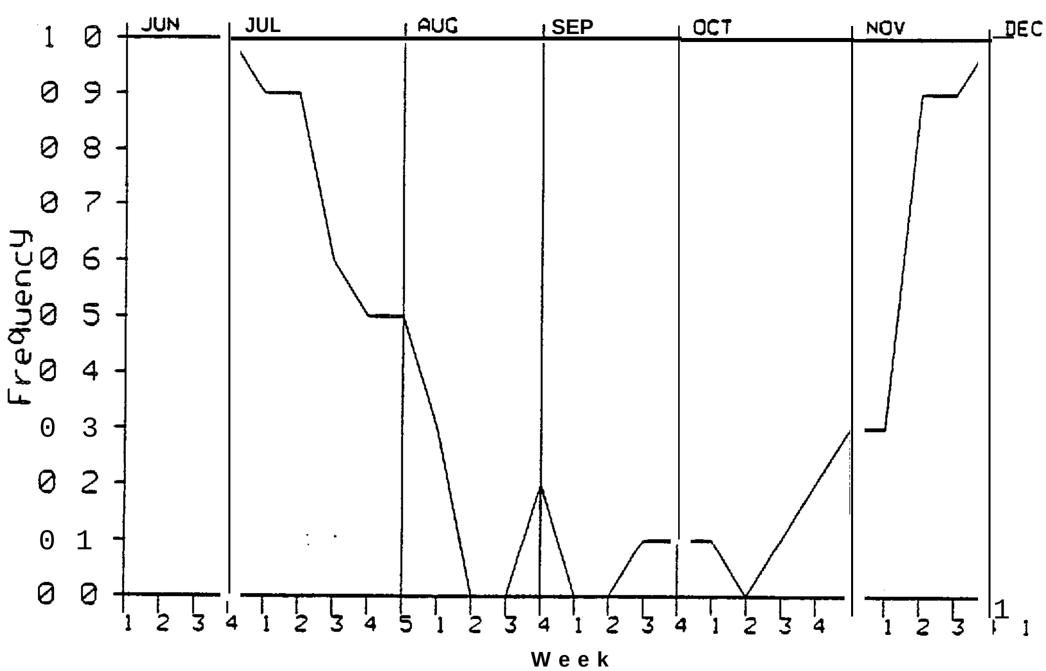



FIGURE 9 7 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 26

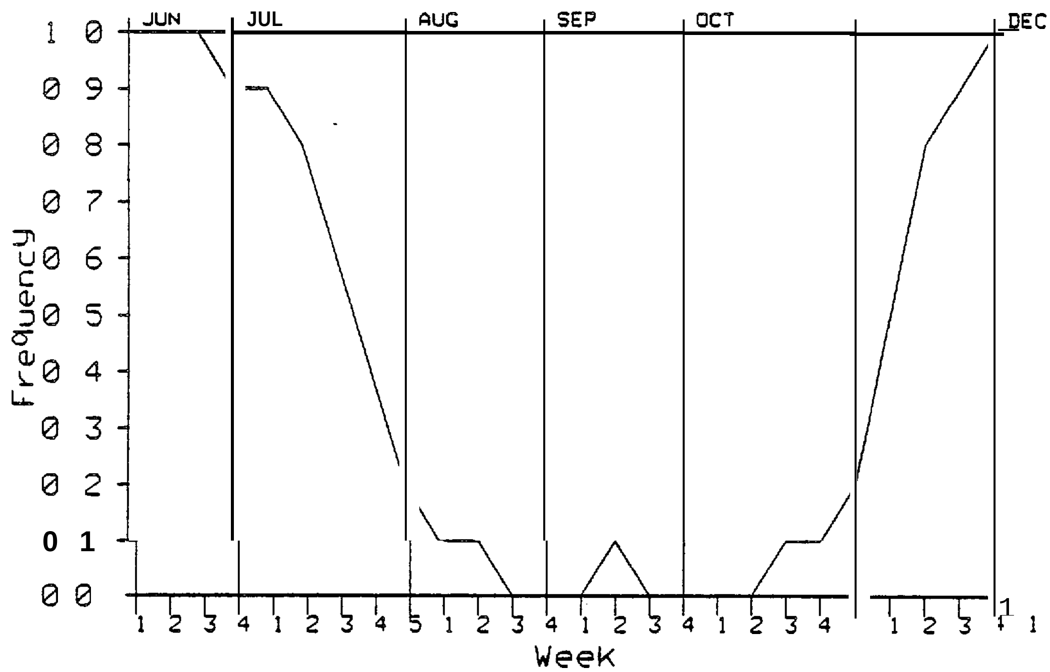



FIGURE 98 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 27

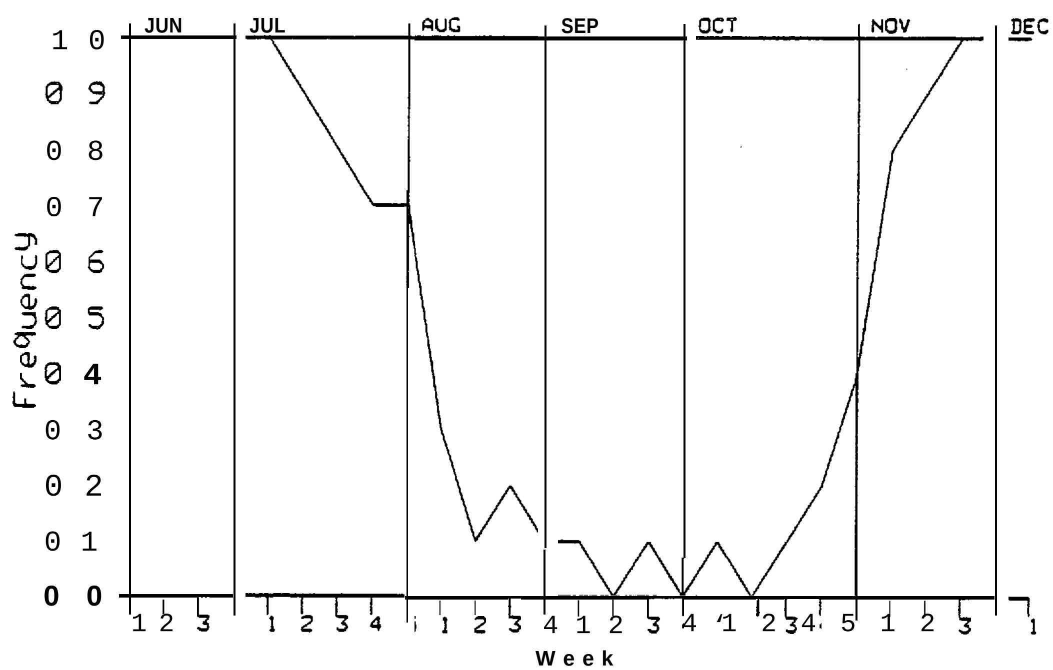



FIGURE 99 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 28

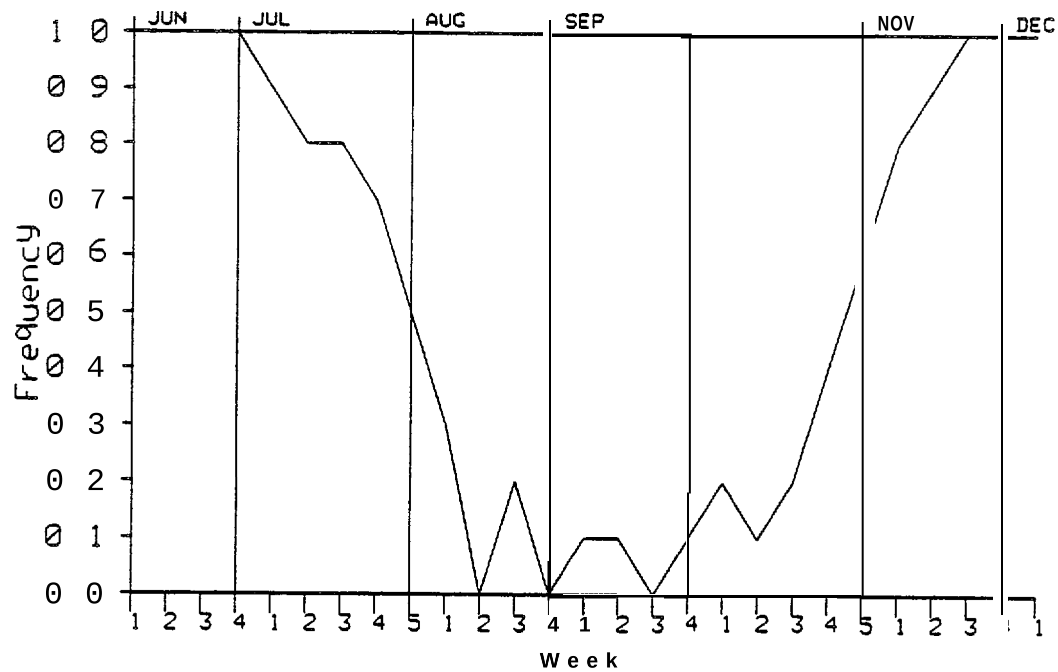



FIGURE 100" ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 29

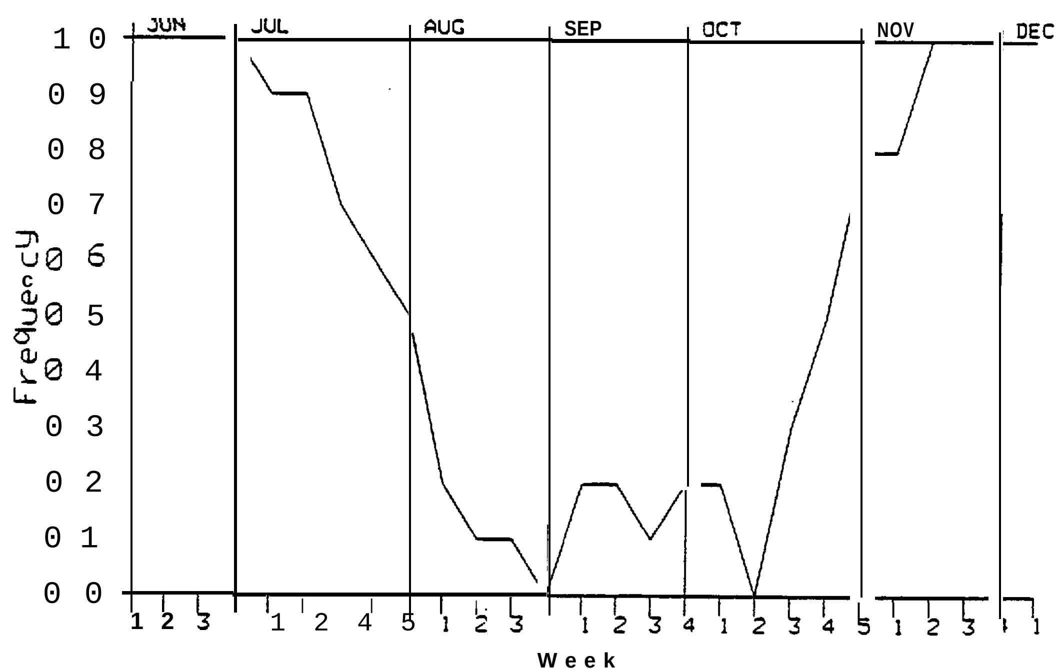



FIGURE 101 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 30

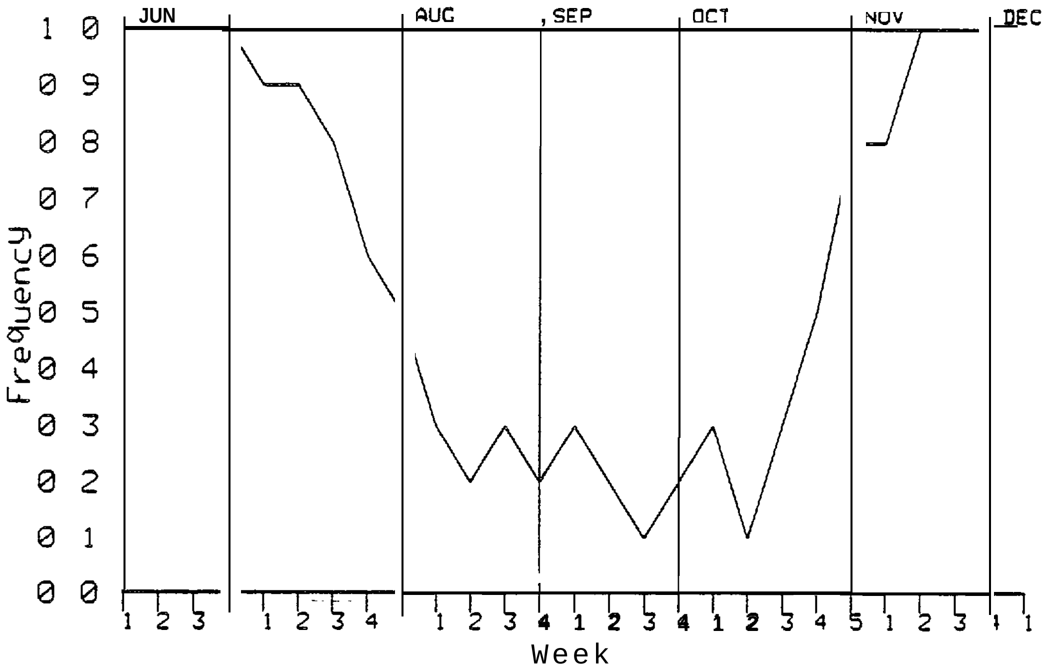



FIGURE 102 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 31

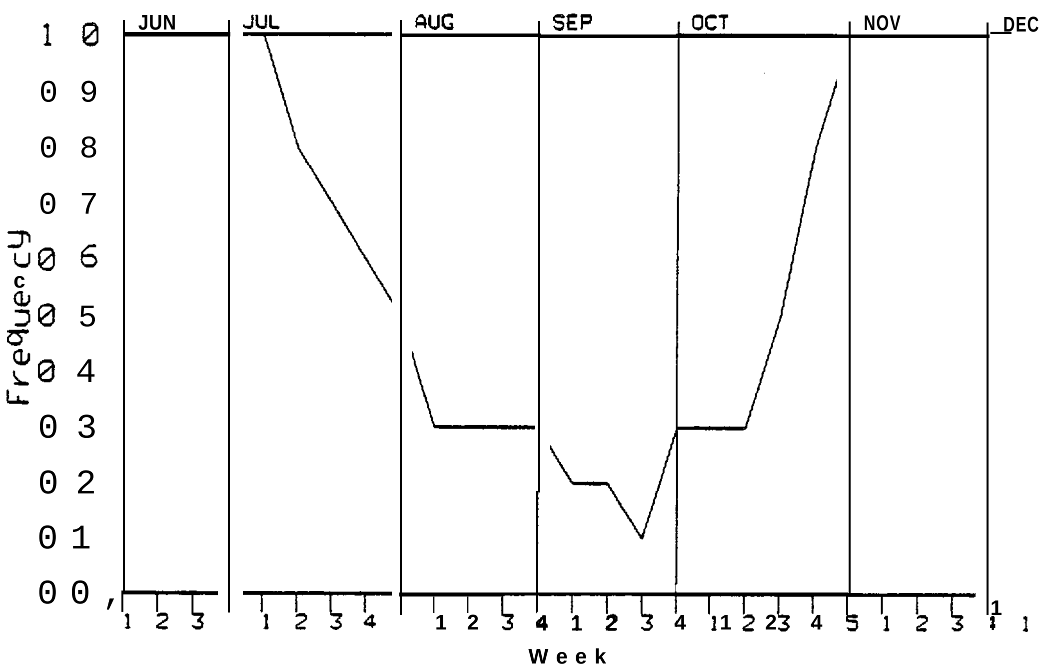



FIGURE 103 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 32

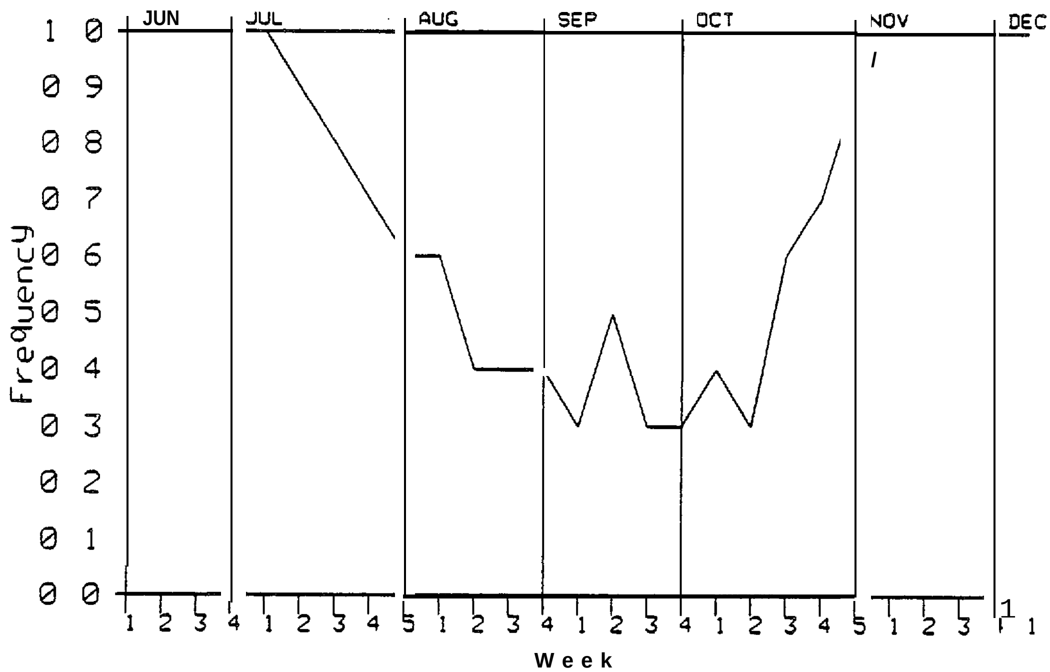



FIGURE 104 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE
AT STATION 33

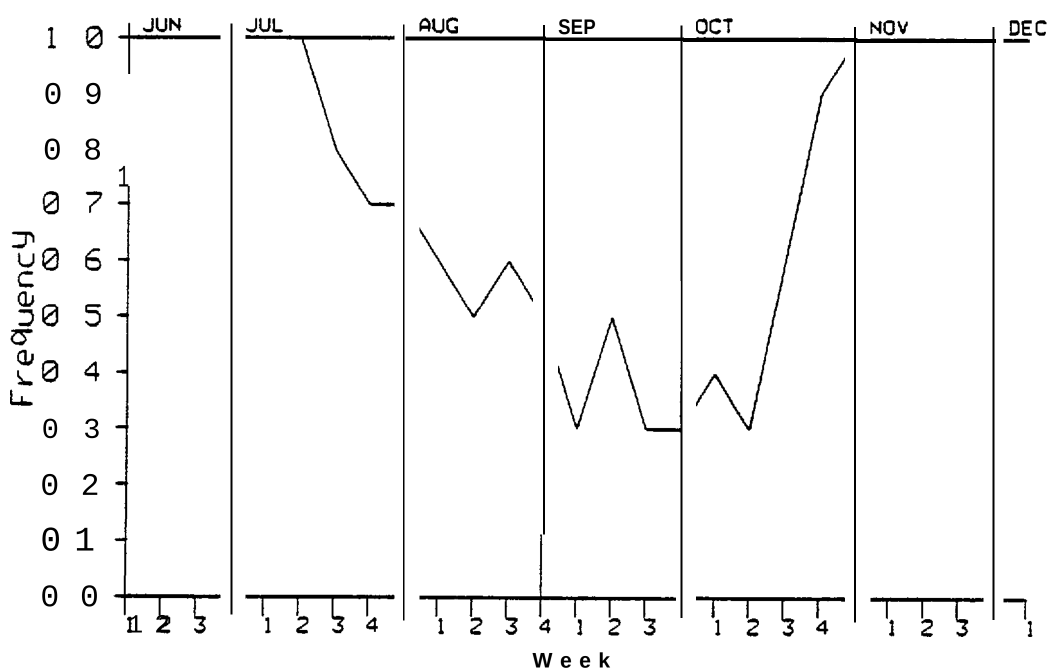



FIGURE 10S ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE
AT STATION 34

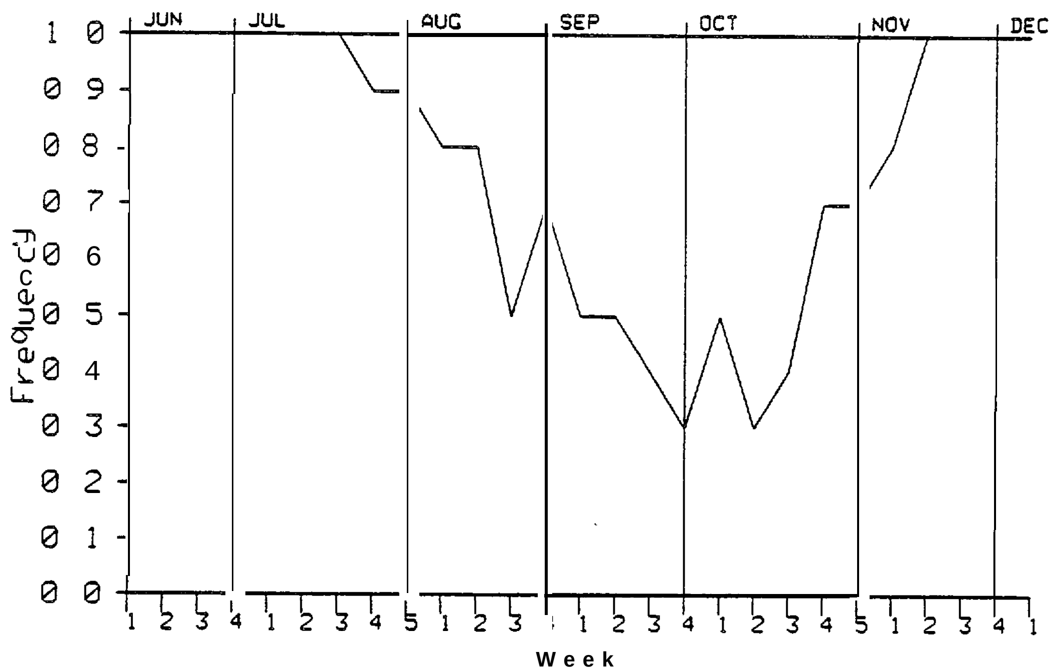



FIGURE 106 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 35

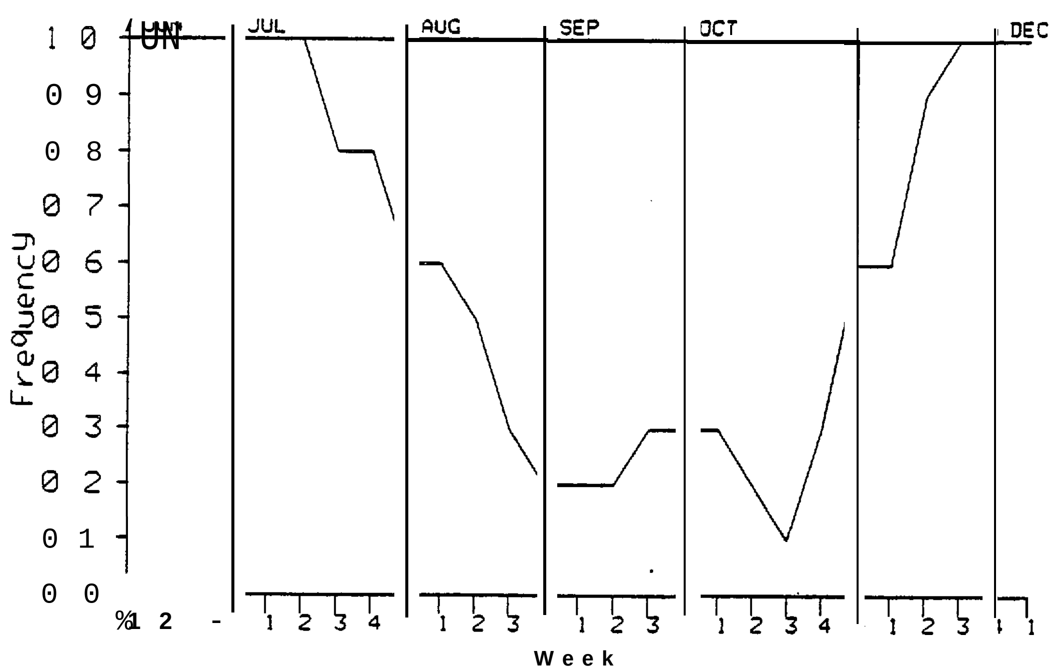



FIGURE 107 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 36

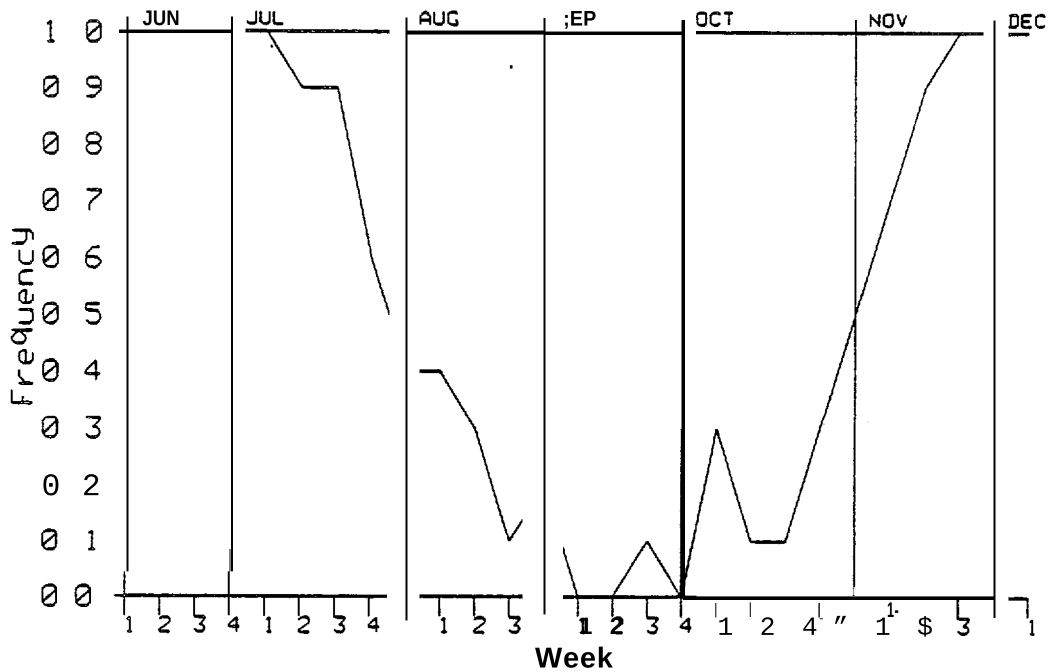



FIGURE 108 ICE PRESENCE FREQUENCY ASA FUNCTION OF DATE AT STATION 37

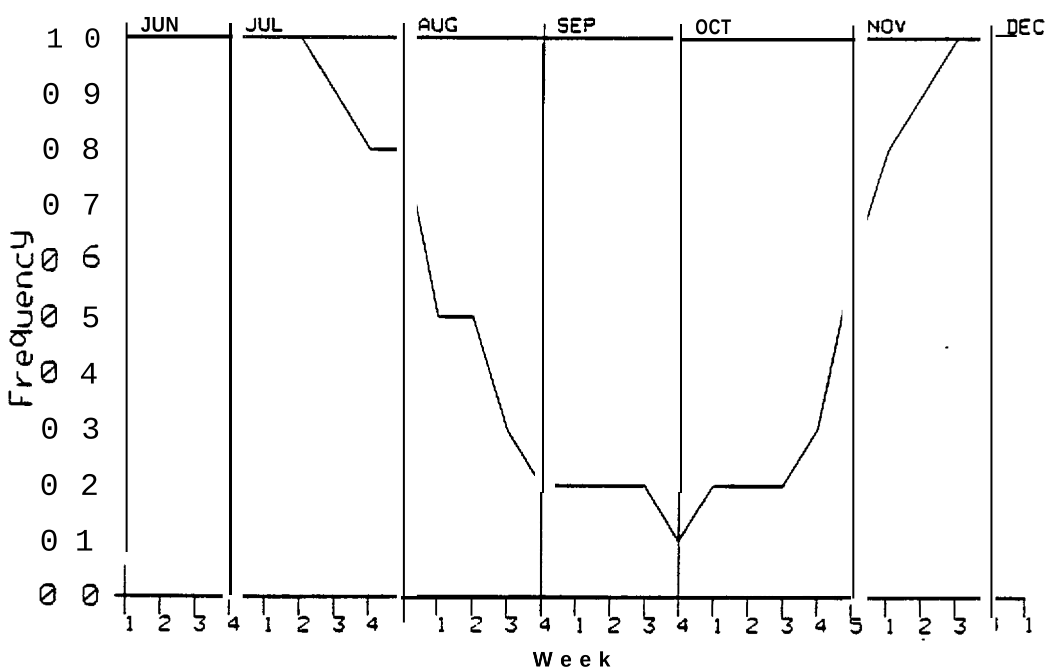



FIGuRE 109 ICE PRESENCE FREQUENCY ASA FUNCTION Of DATE AT STQTION 3S

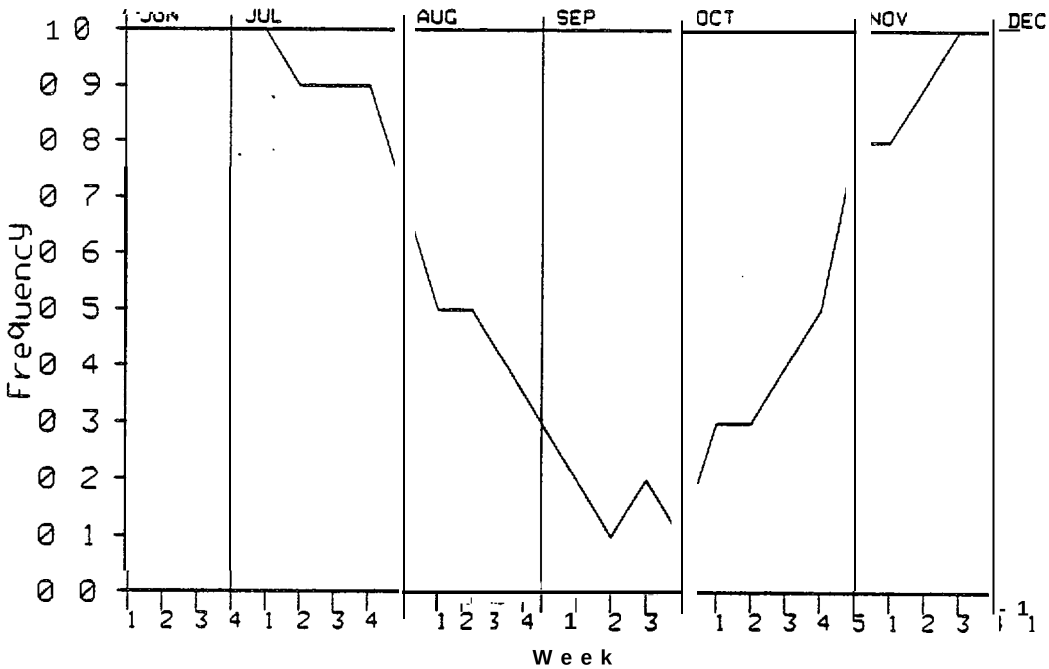



FIGURE 110 ICE PRESENCE FREQUENCY ASA FUNCTION Of DATE AT STATION 39

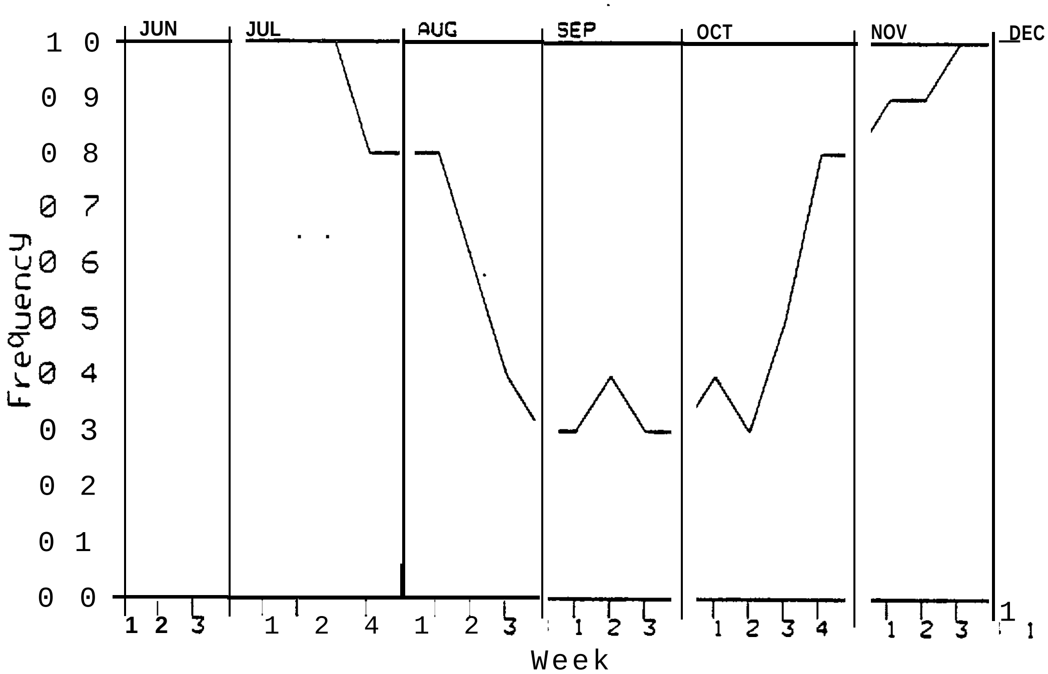



FIGURE 111 ICE PRESENCE FREQUENCY ASA FUNCTION OF DATE AT STATION 40

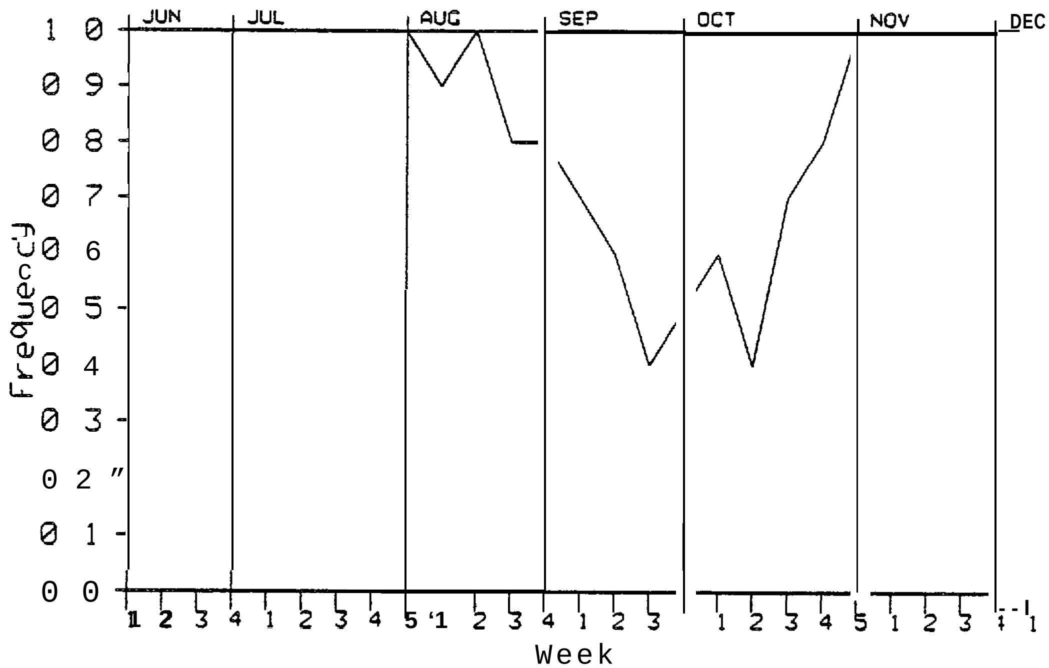



FIGURE 112 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 41

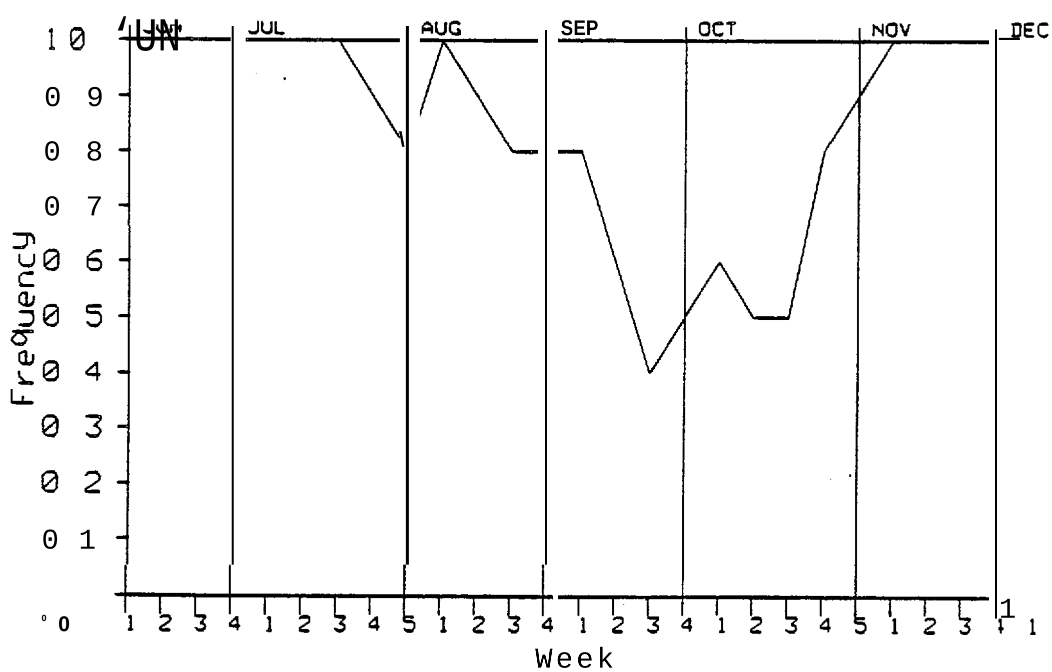



FIGURE 113 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 42

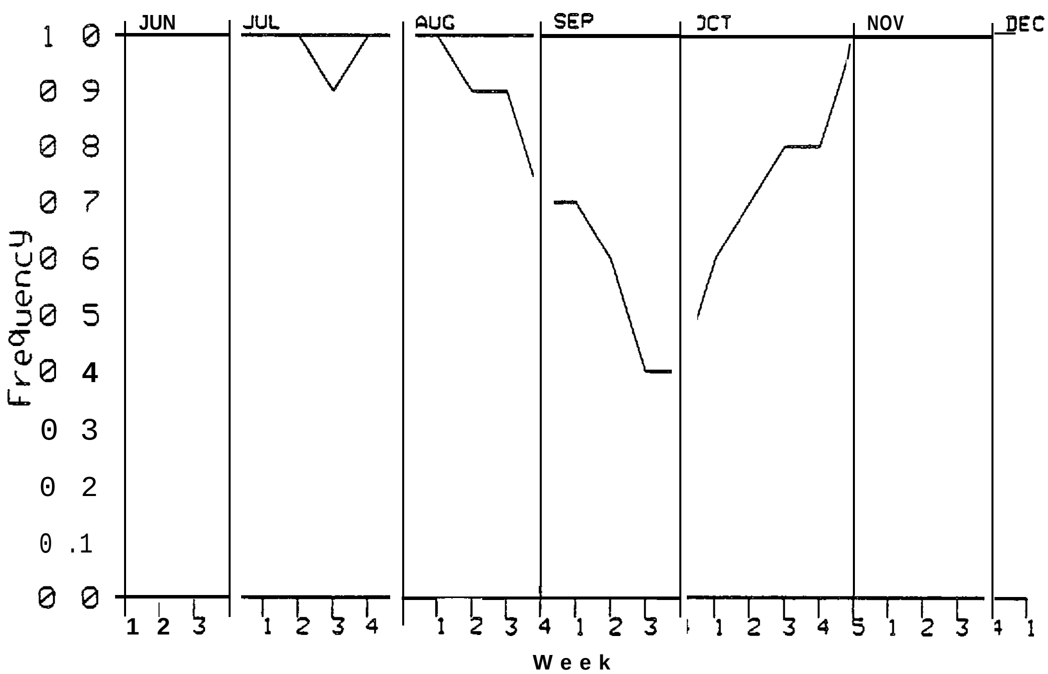



FIGURE 114 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 43

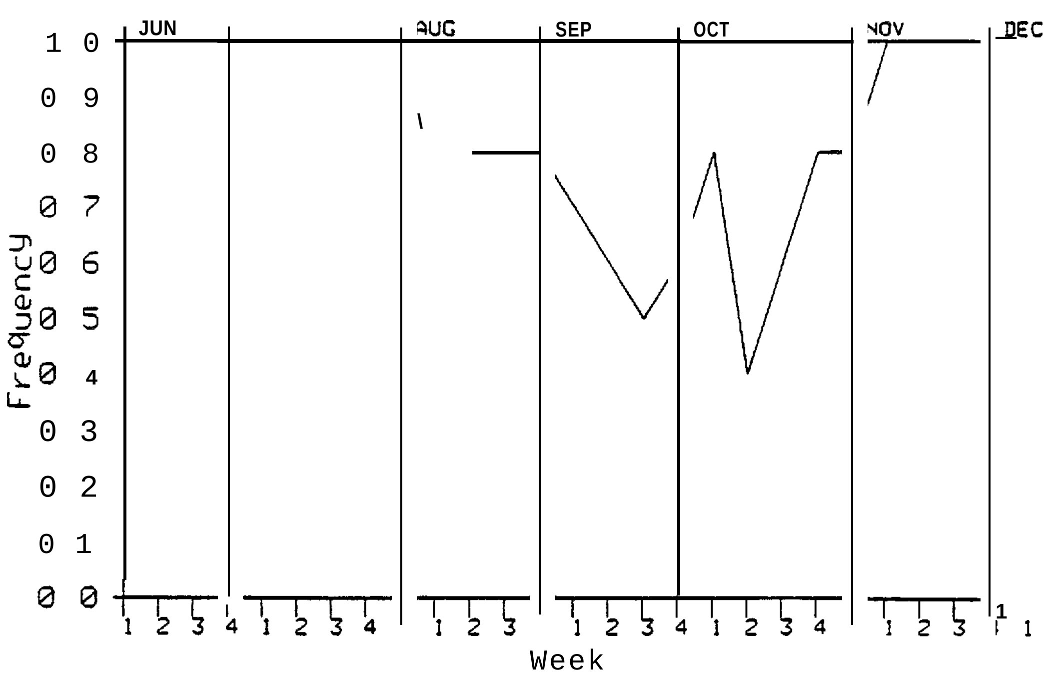



FIGURE 115 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 44

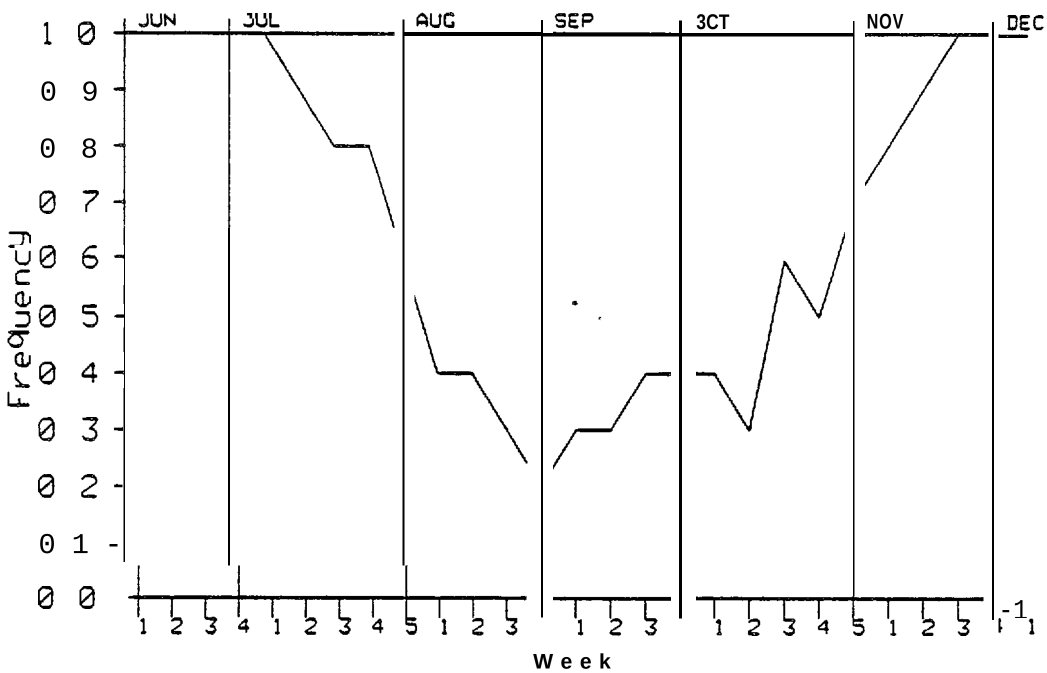



FIGURE 116 ICE PRESENCE FREQUENCY ASA FUNCTION OF DATE AT STATION 45

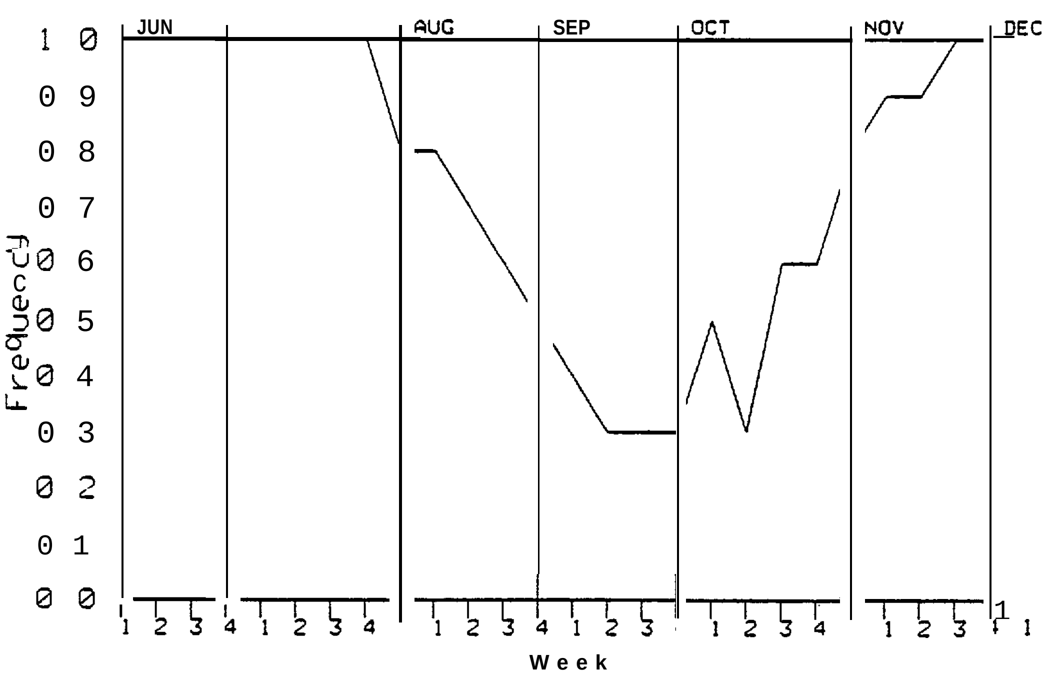



FIGuRE 117 ICE PRESENCE FREQUENCY ASA FUNCTION OF DATE AT STATION 46

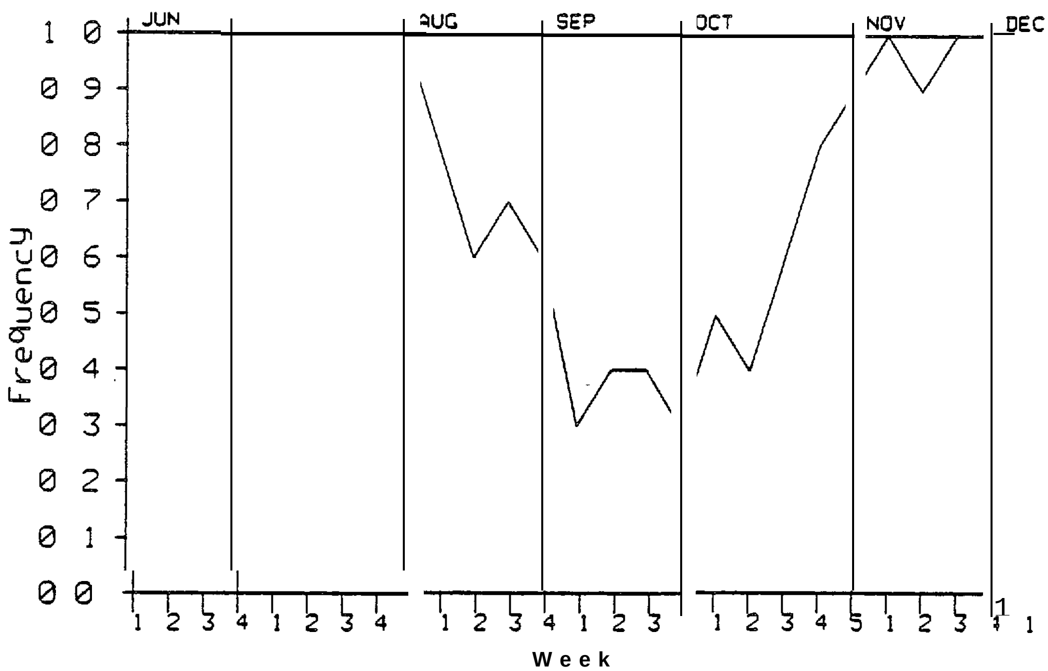



FIGURE 118 ICE PRESENCE FREQuENCY AS A FUNCTION OF DATE AT STATION 47

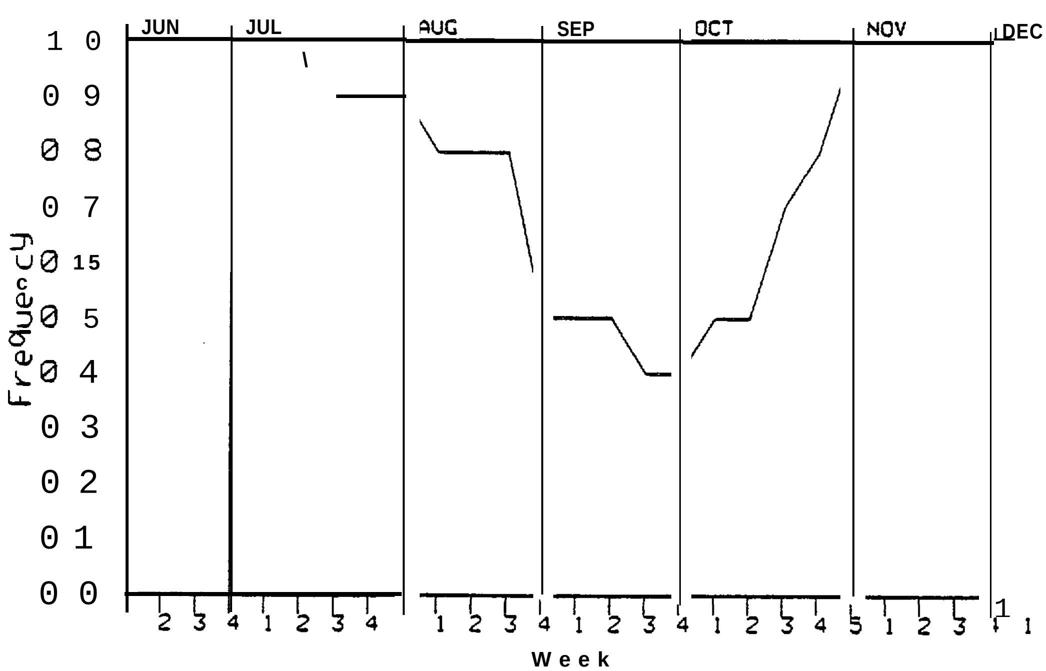
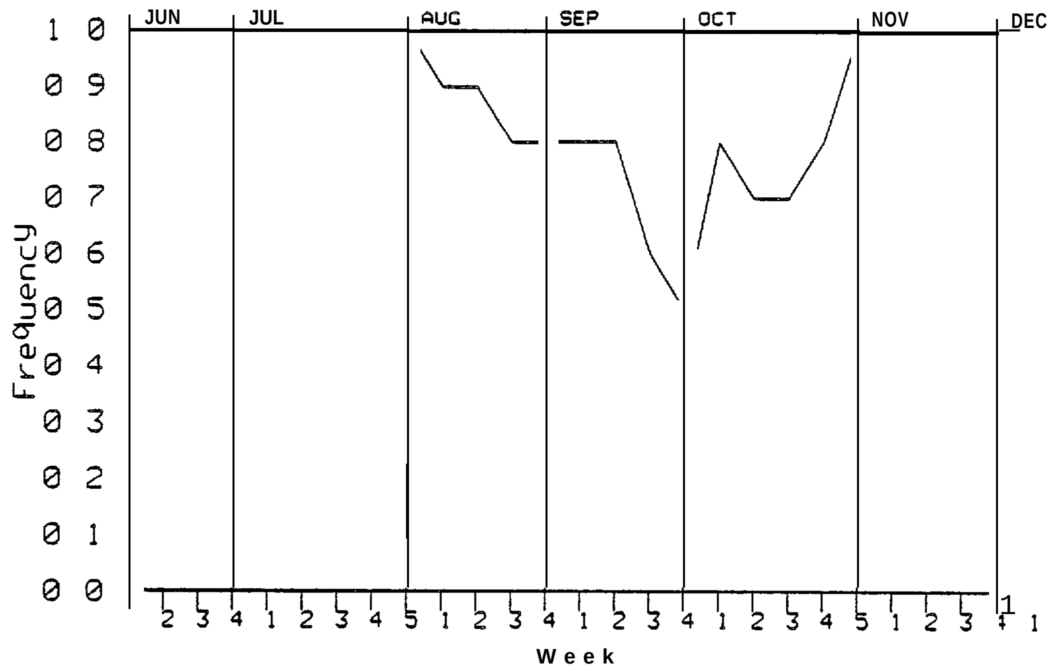



FIGURE 119 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 48




FI GURE 120 ICE PRESENCE FREQUENCY ASA FUNCTION OF DATE
AT STATION 49

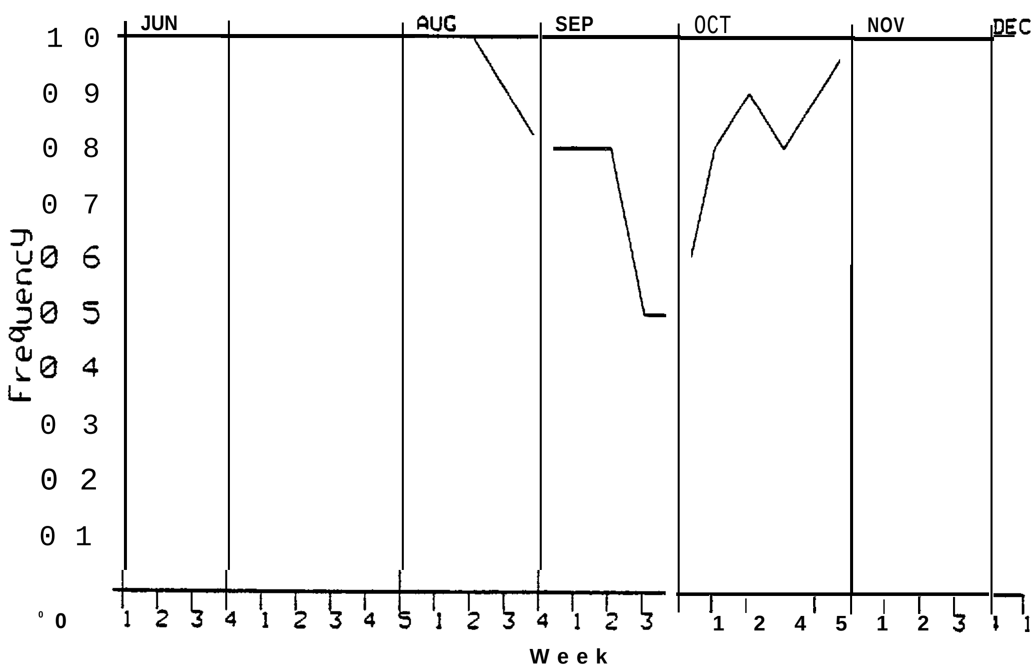



FIGURE 121 ICE PRESENCE FREQUENCY ASA FUNCTION Of DATE
AT STATION 50

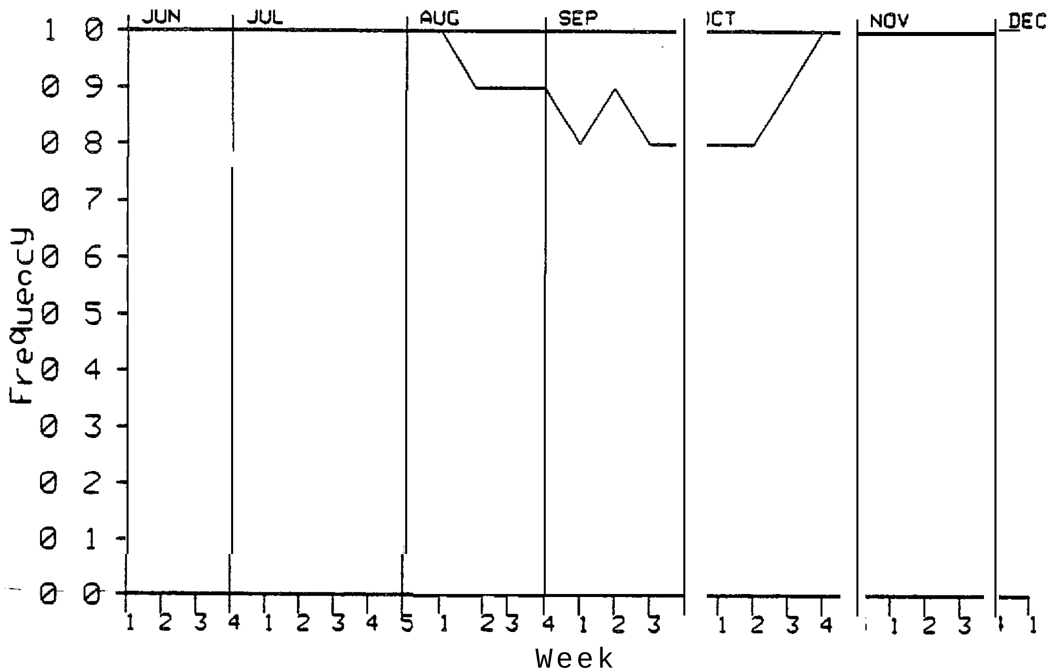



FIGURE 122 ICE PRESENCE FREQUENCY ASA FUNCTION OF DATE AT STATION 51

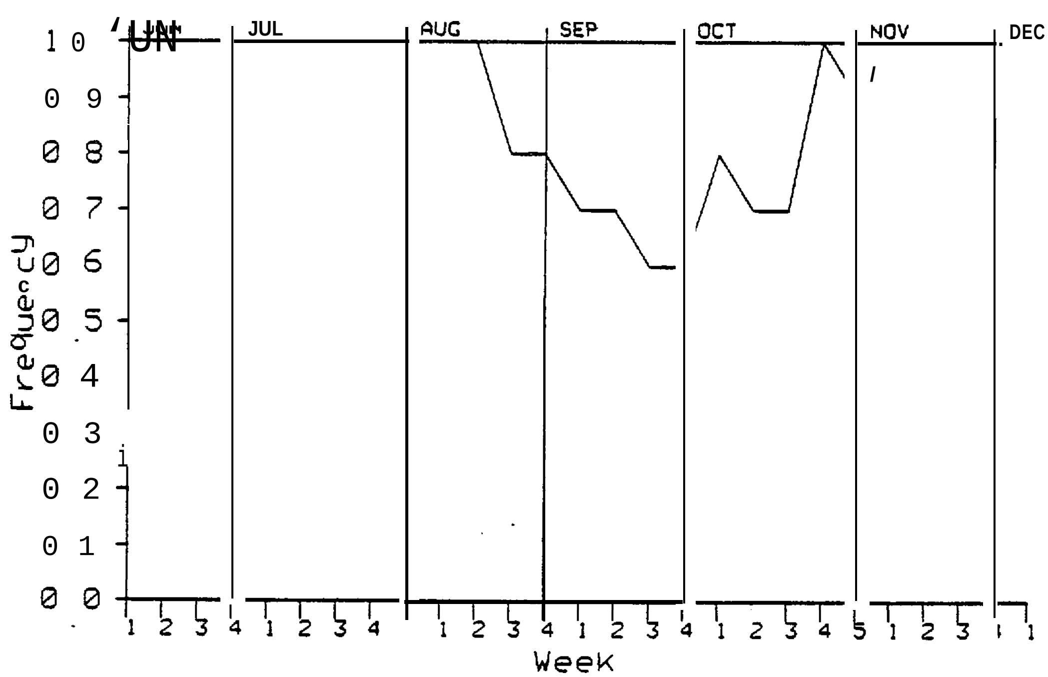



FIGURE 123 ICE PRESENCE FREQUENCY ASA FUNCTION OF DATE AT STATION 52

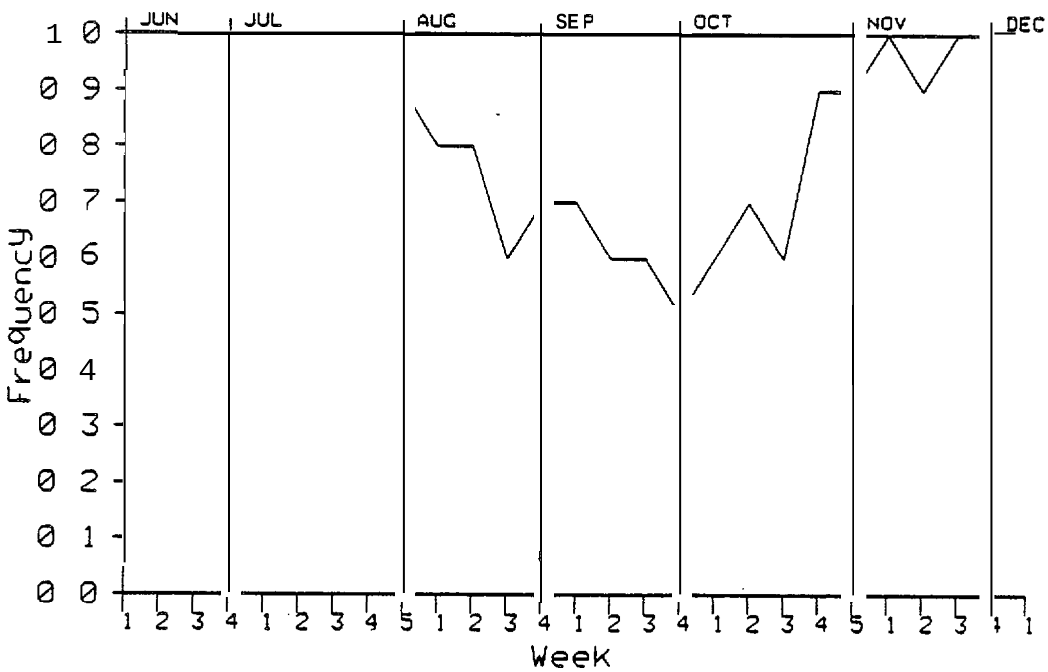



FIGURE 124 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 53

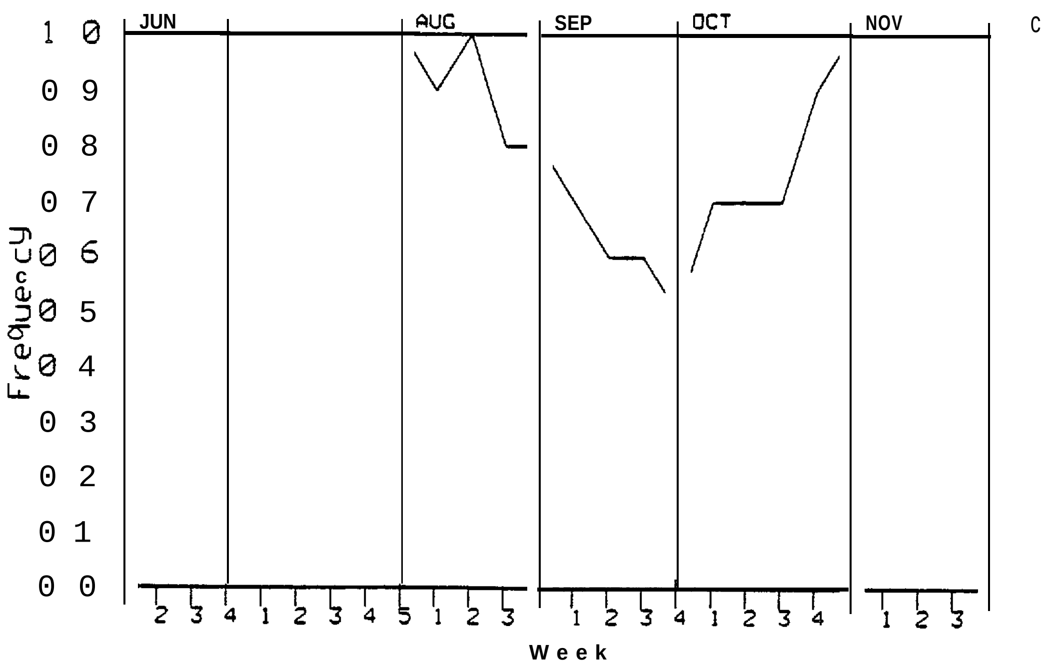



FIGURE 125 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 54

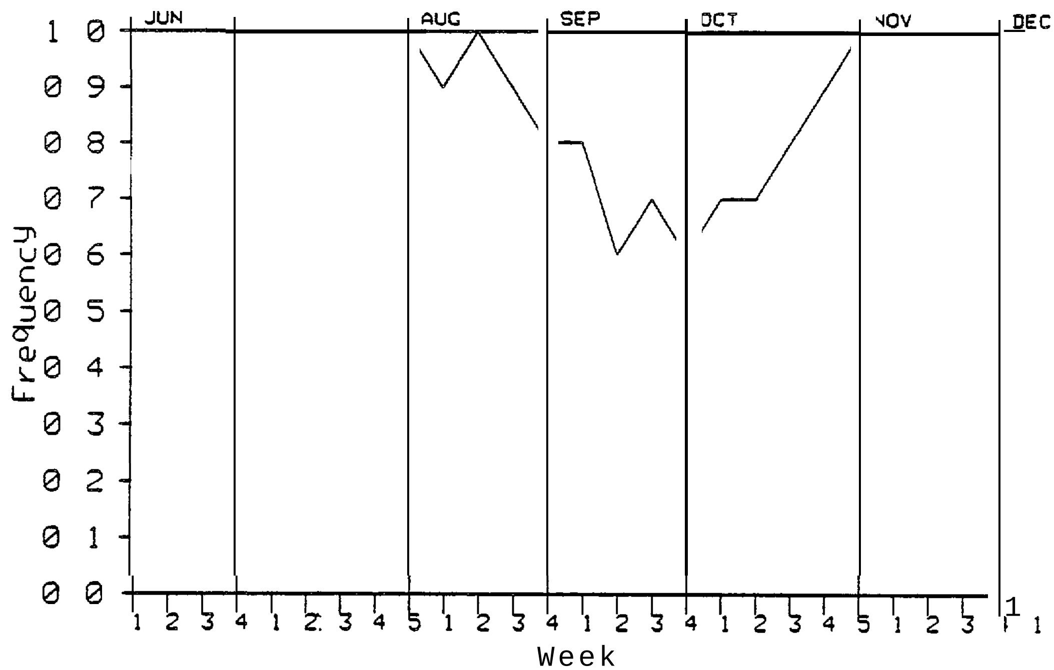



FIGURE 126 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 55

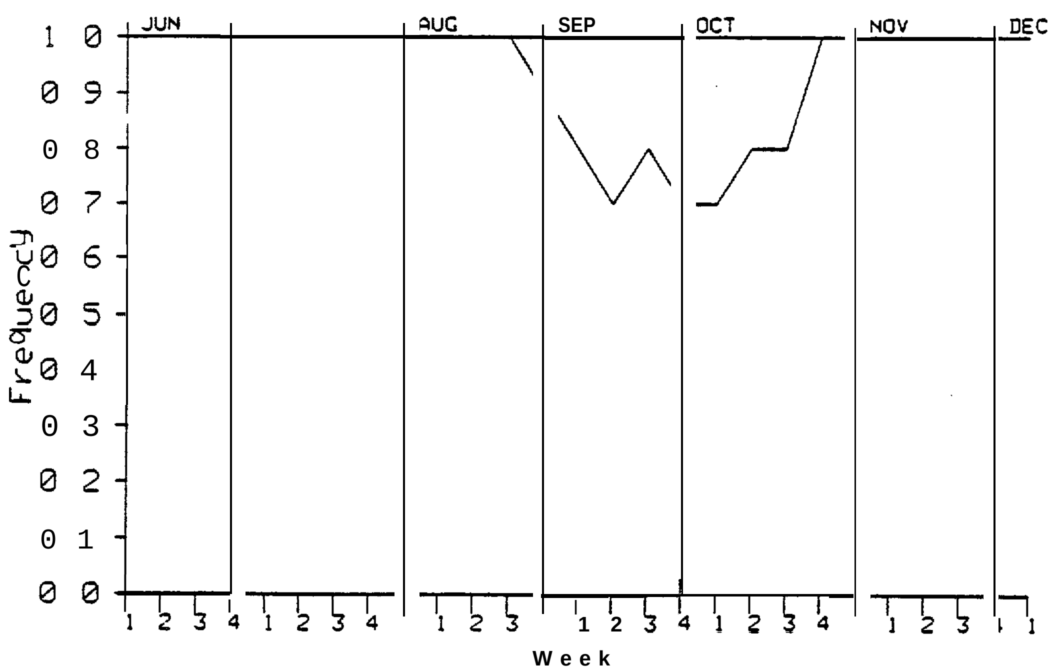



FIGURE 127 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 56

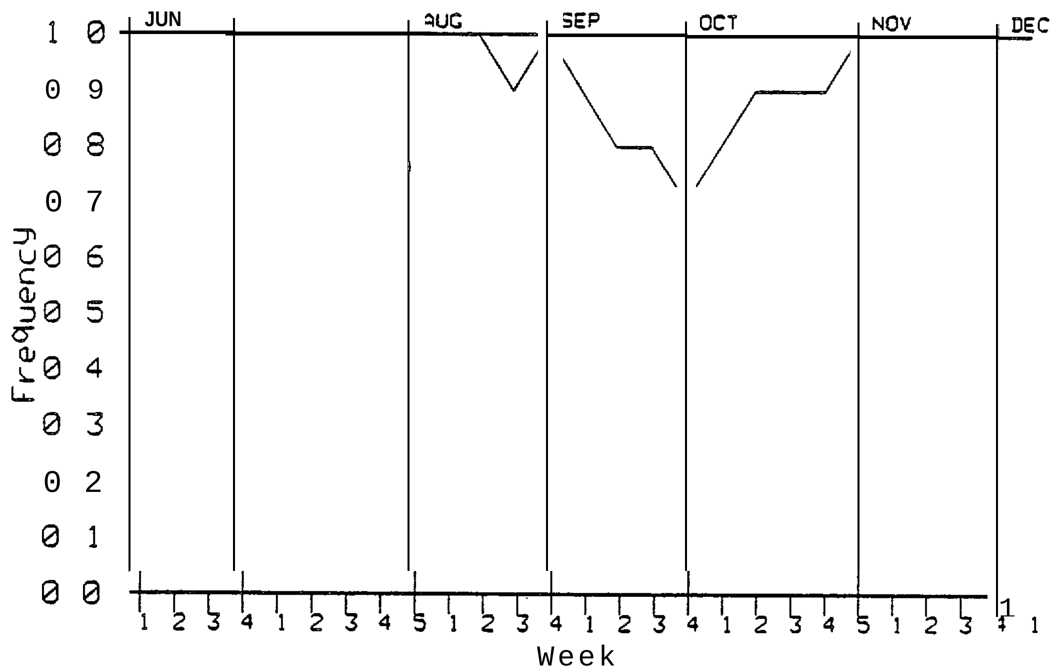



FIGURE 128 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 57

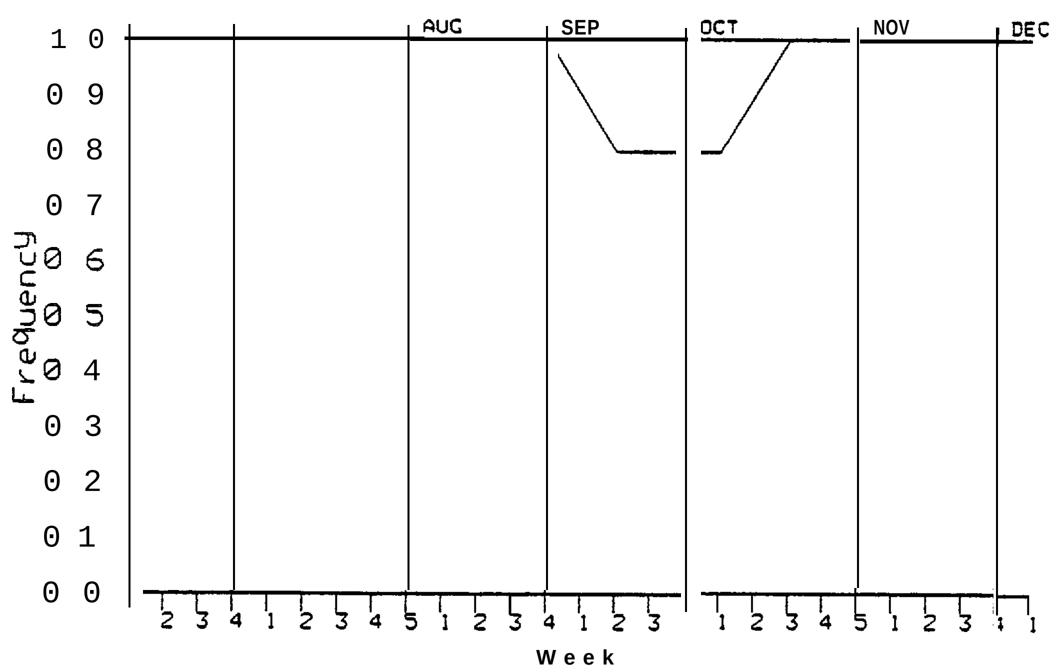



FIGURE 129 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 58

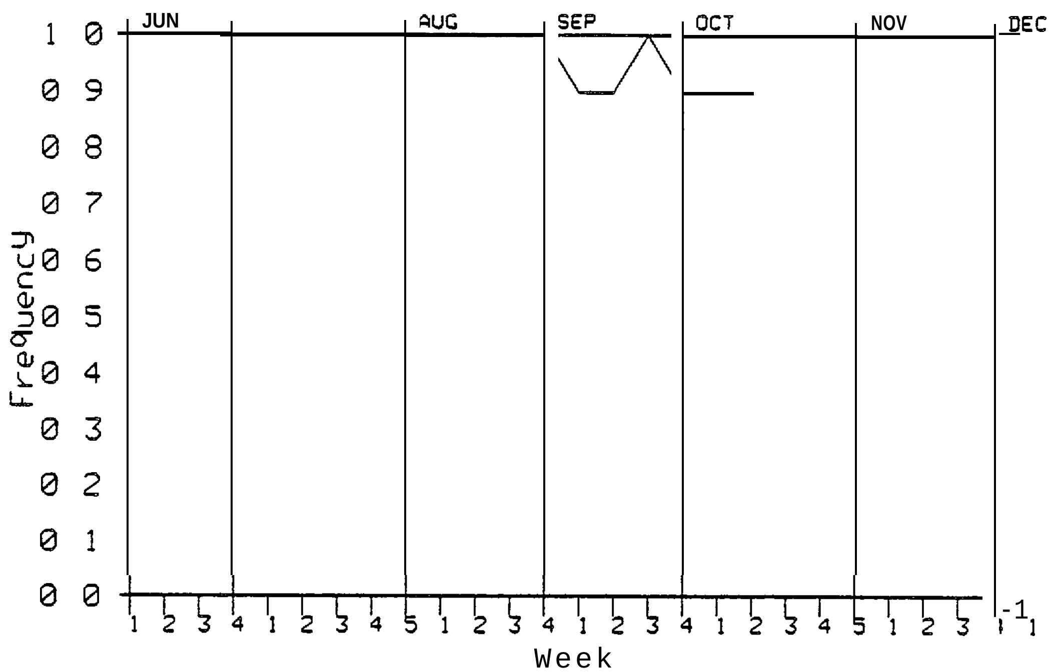



FIGURE 130 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION S 9

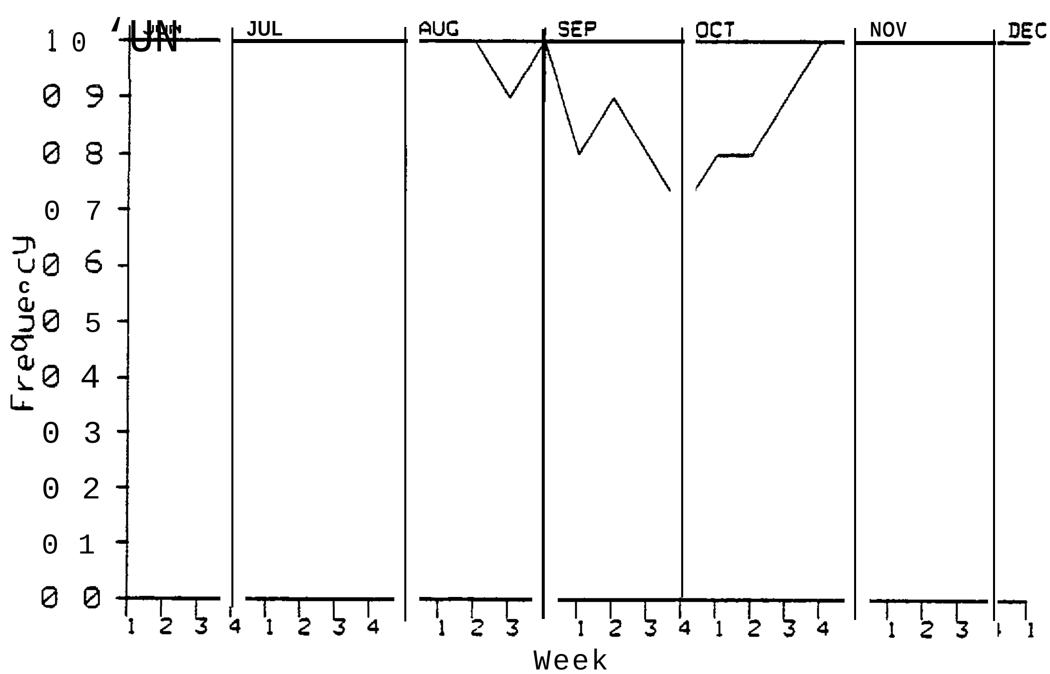



FIGURE 131 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 6 0

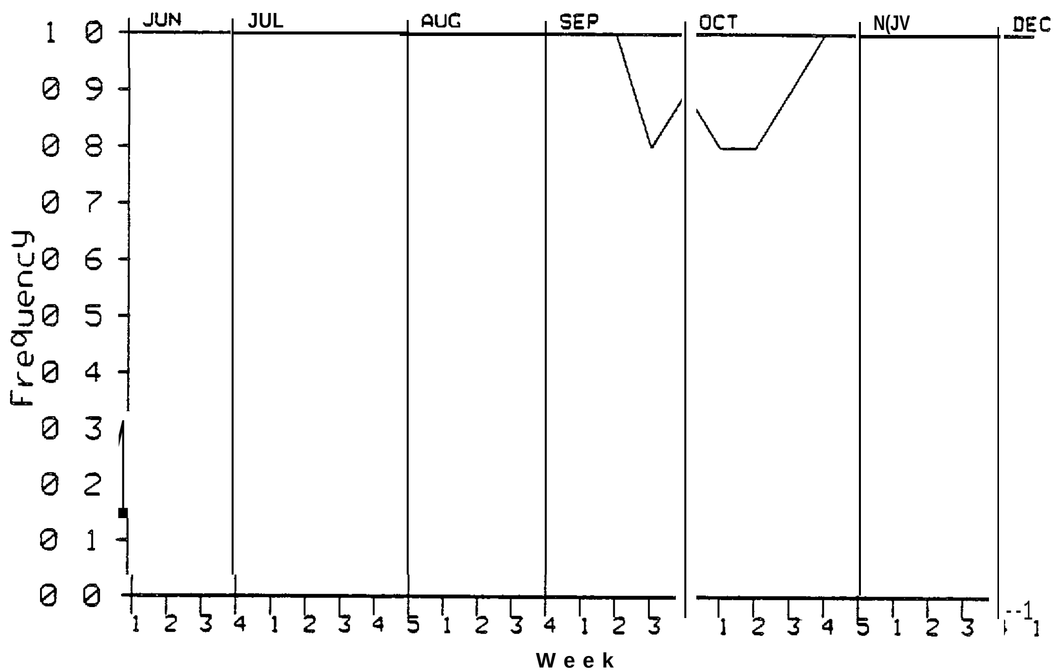



FIGURE 132 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 61

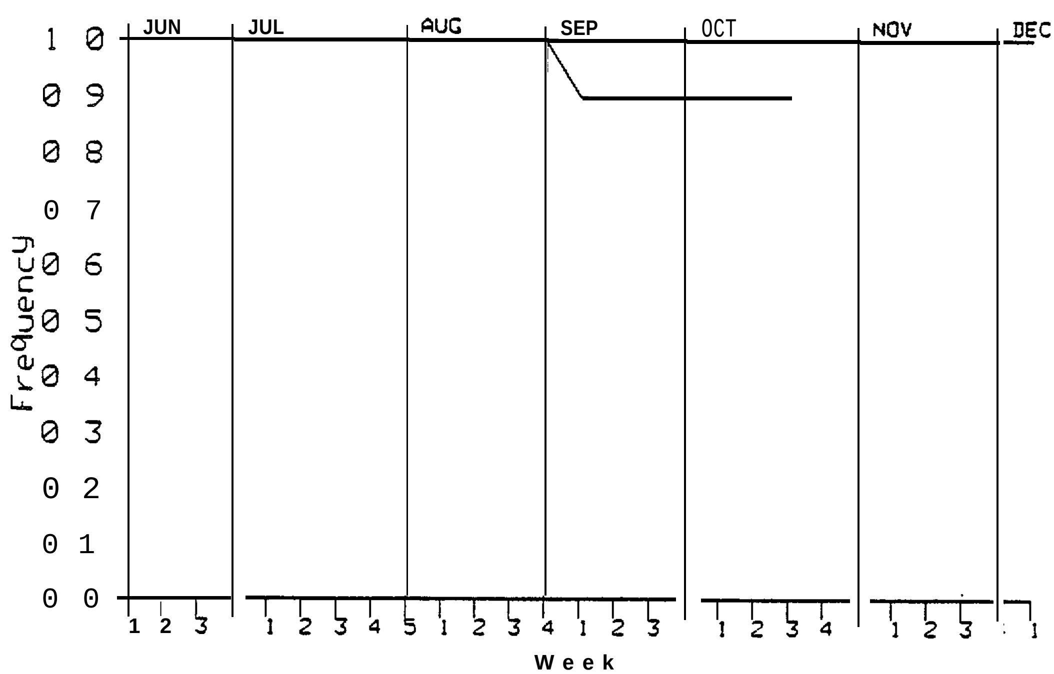



FIGURE 133 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 62

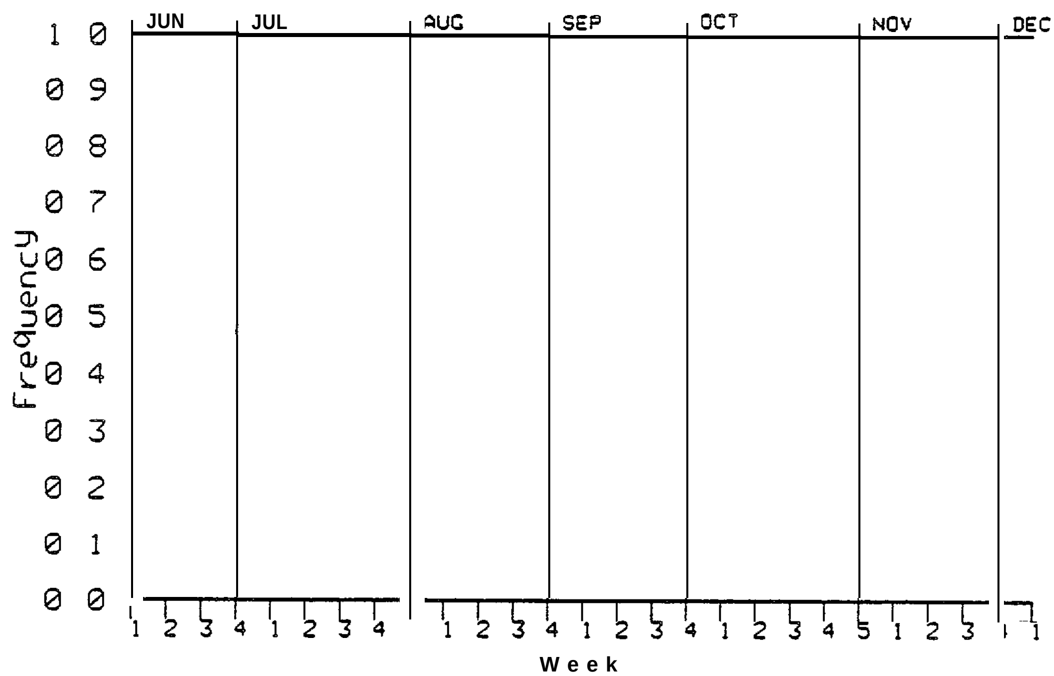



FIGURE 134 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 63

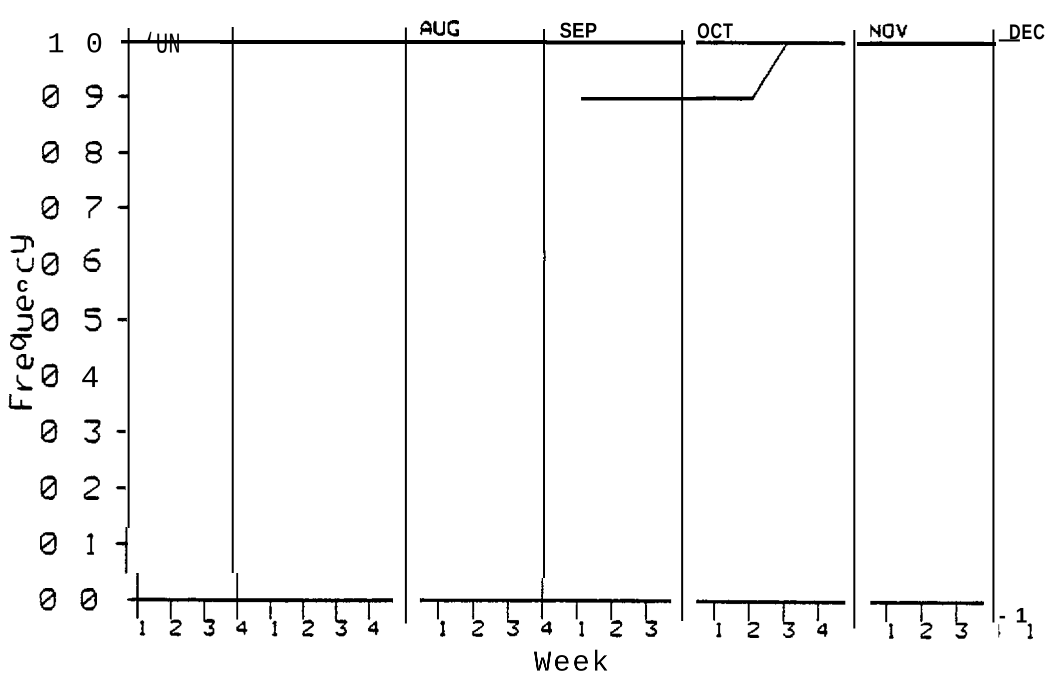



FIGURE 135 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 64

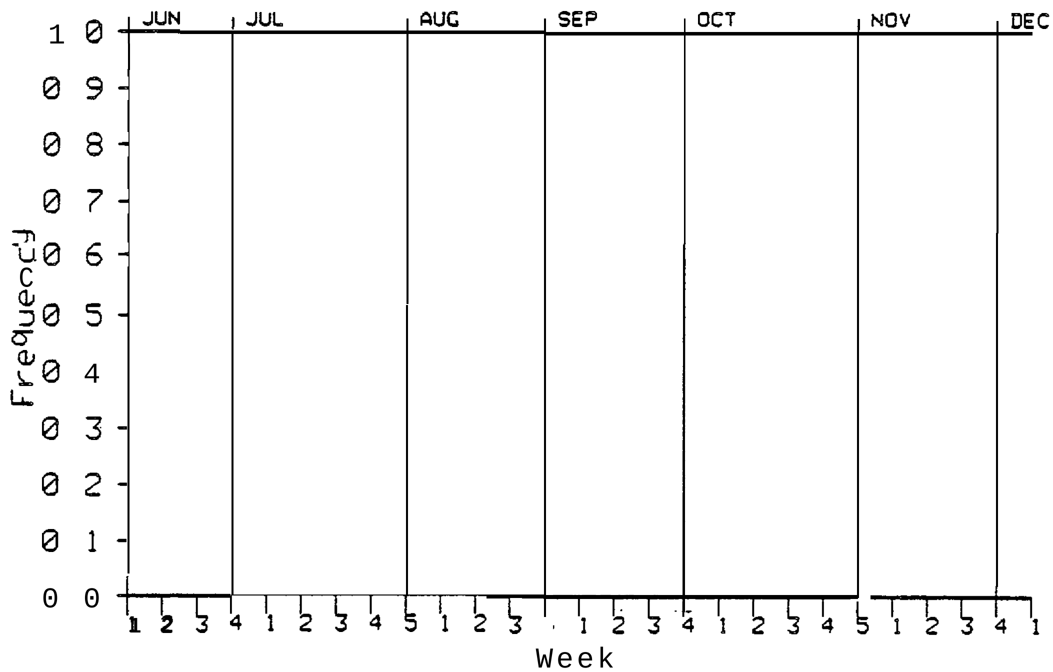



FIGURE 136 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 65

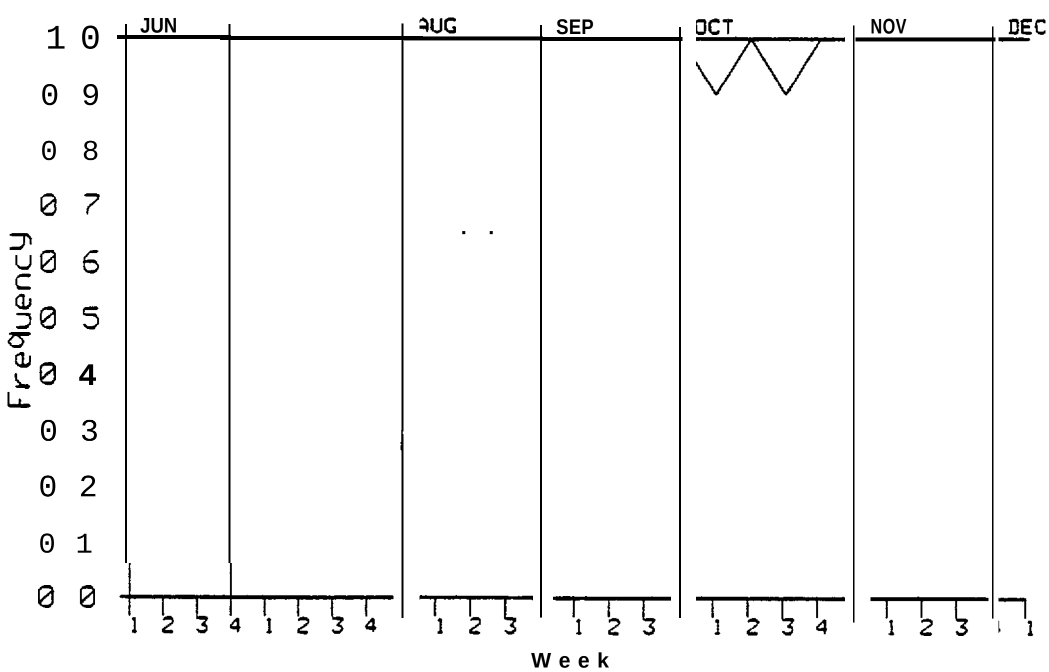



FIGURE 137 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 66

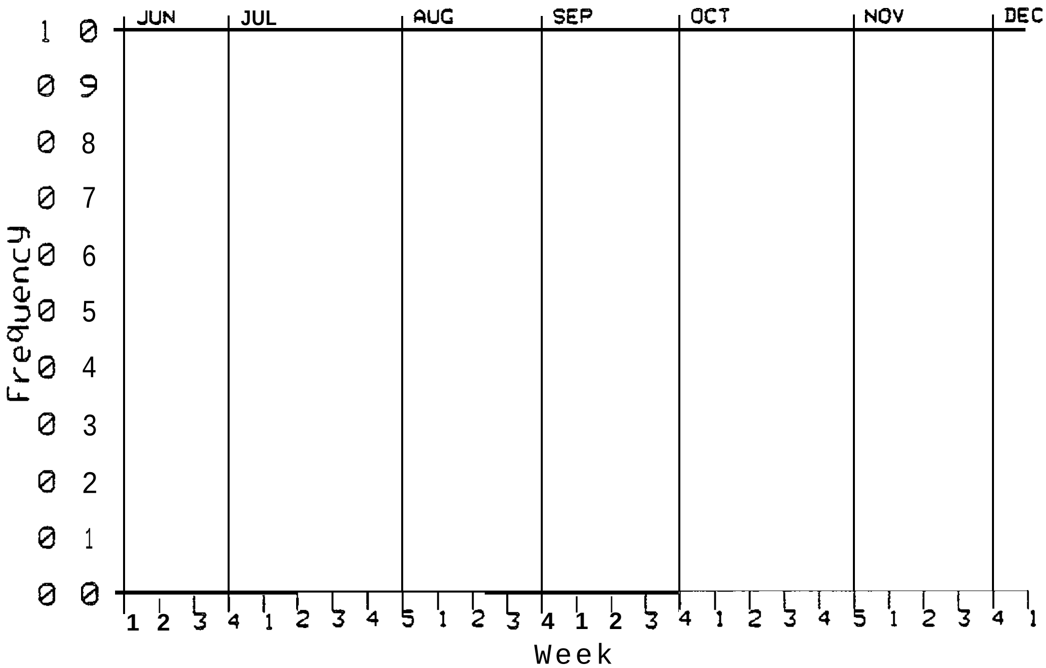



FIGURE 138 ICE PRESENCE FREQUENCY AS A FUNCTION OF DATE AT STATION 67

Figures 139 through 205. Ice presence history for each year at each of the 67 stations located on Figure 30.

Data for the following weeks was not available:

Week. 3; 1972
Week 4; 1974
Weeks 8 and 9; 1982
Week 20; 1981

Gaps appear in the following plots for these weeks.

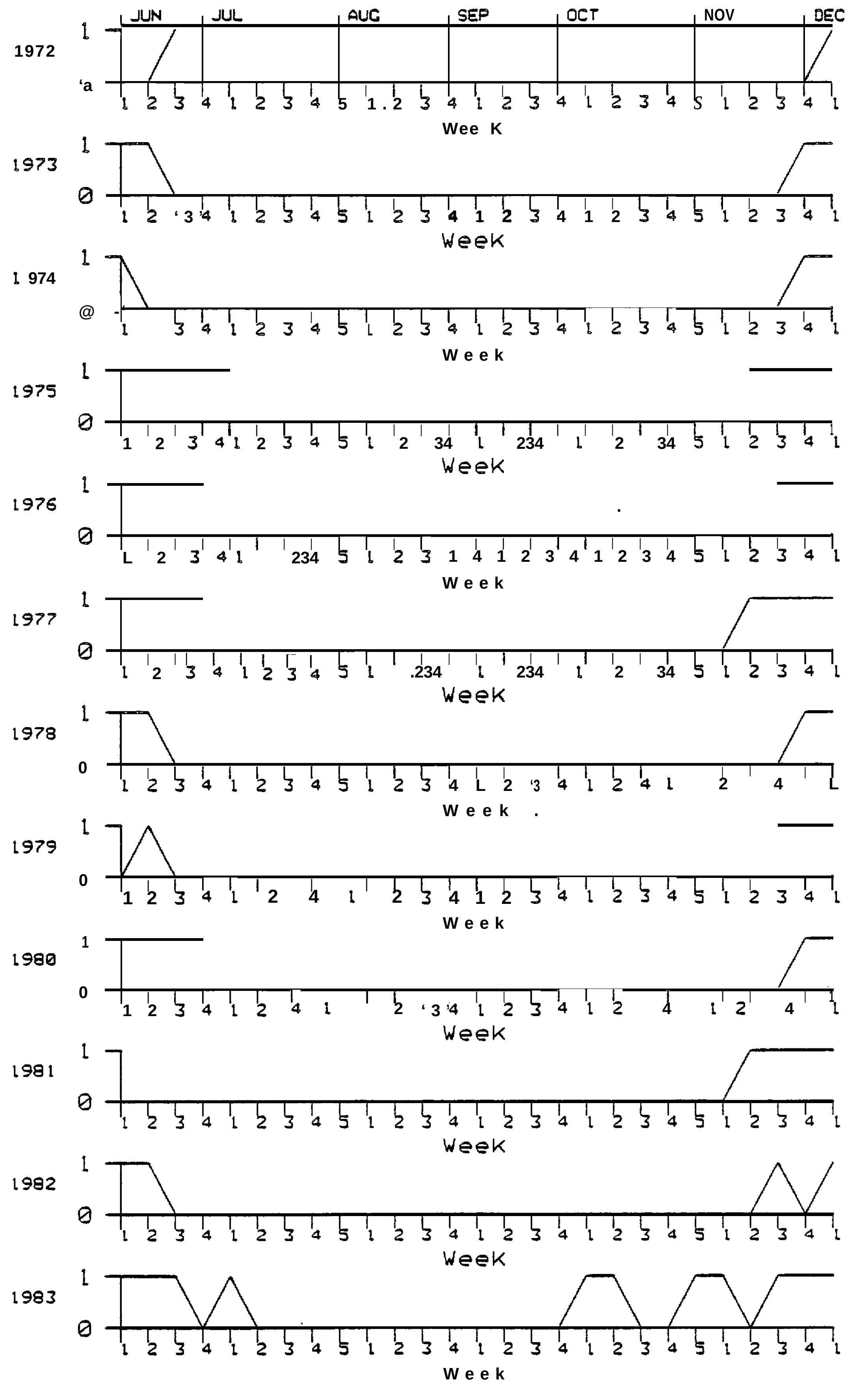



FIGURE 139 ICE PRESENCE HISTORY AT STATION 1 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

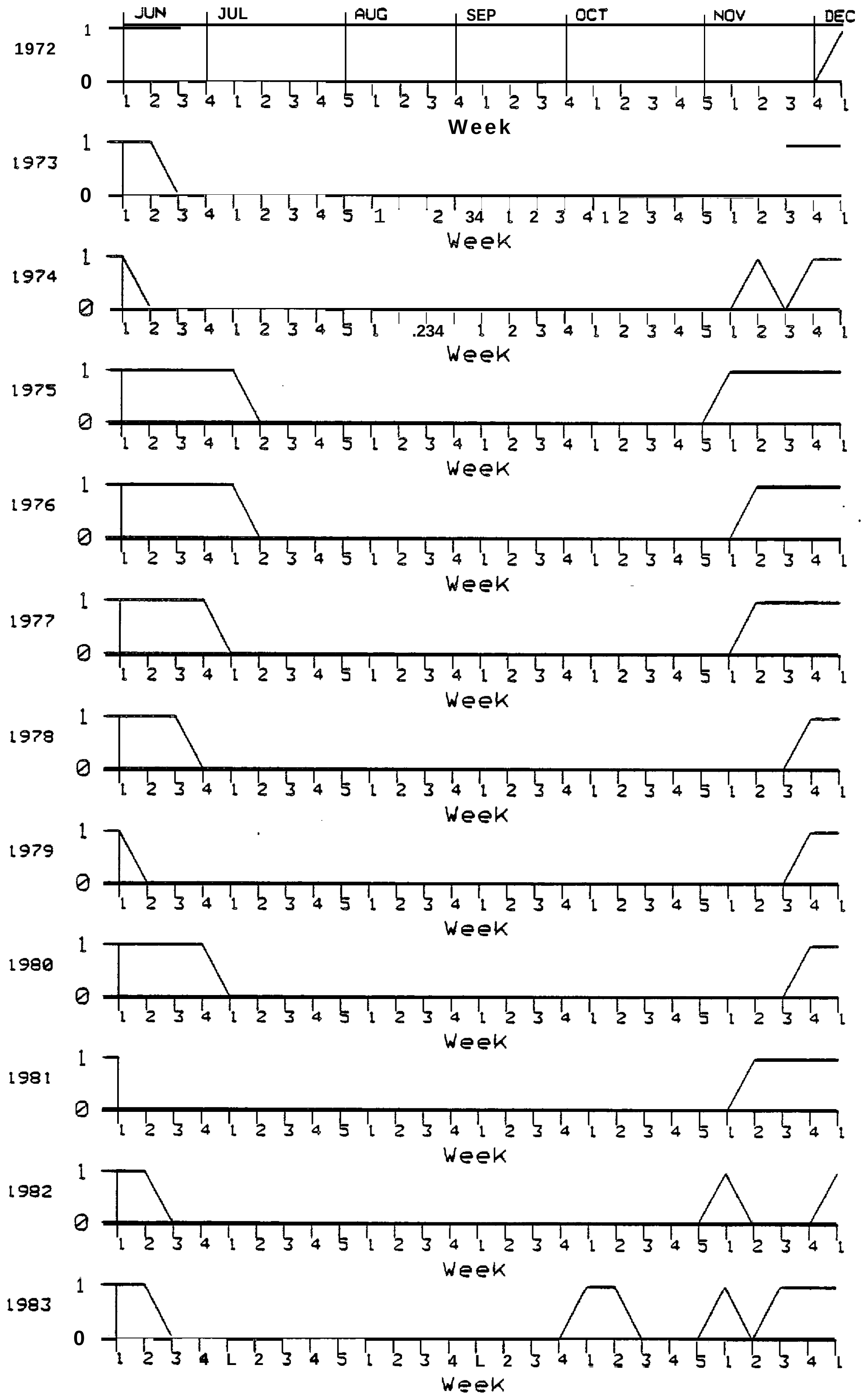



FIGURE 140 ICE PRESENCE HISTORY AT STATION 2 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE T(WJIATION [s BINARY. ICE [S EITHER PRESENT OR IT IS NOT

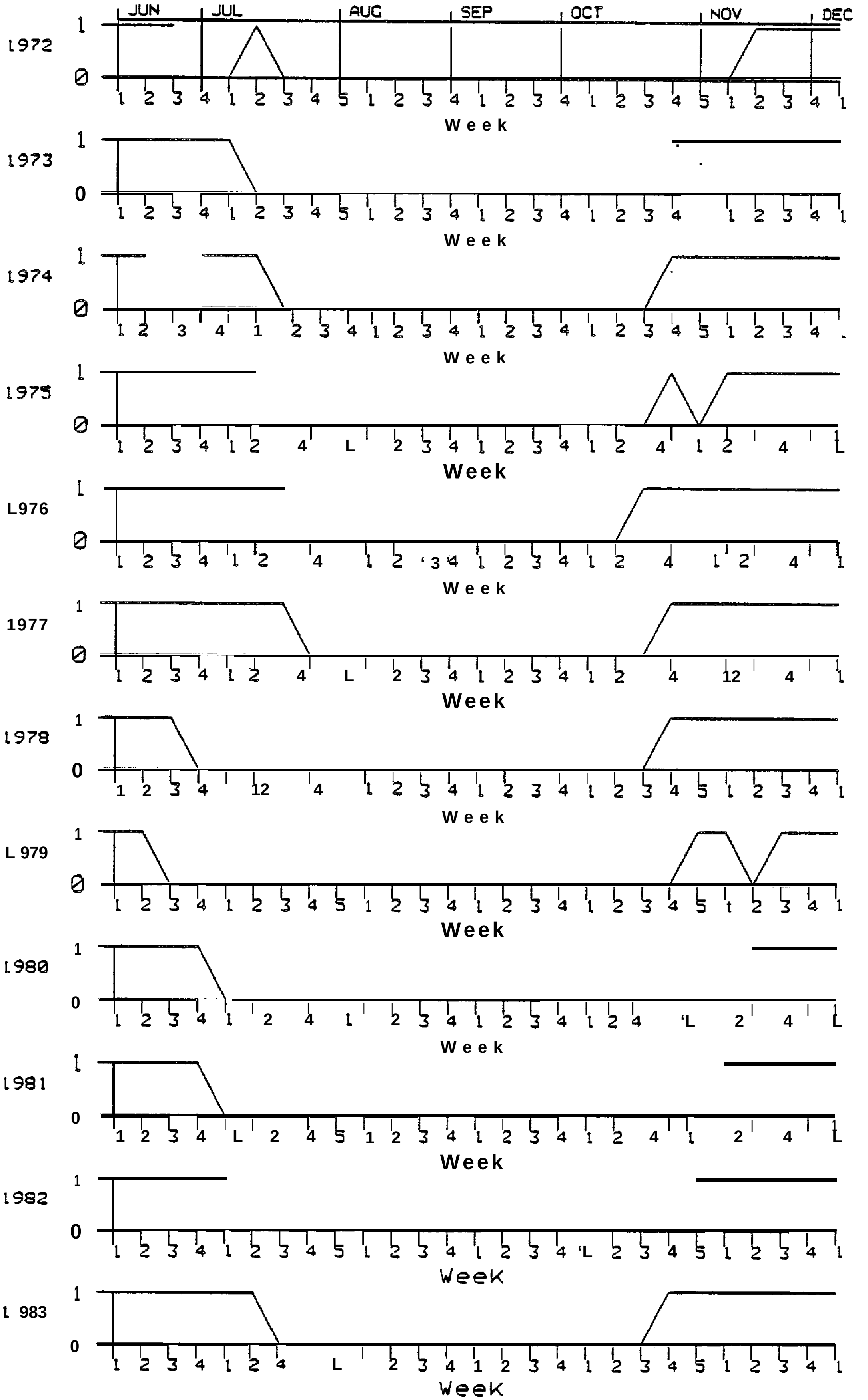
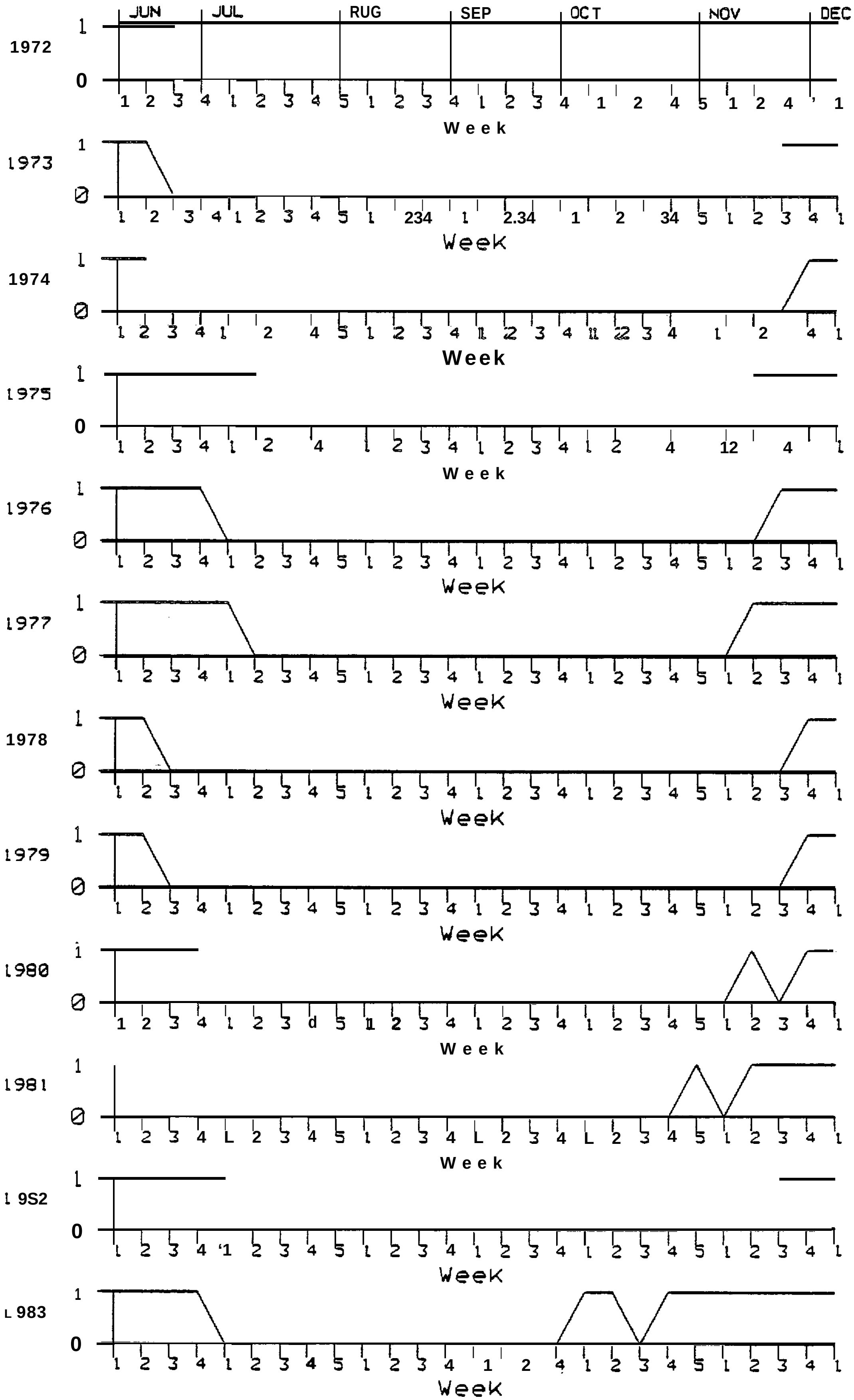



FIGURE 141 ICE PRESENCE HISTORY AT STATION 3 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT




F IGURE 142 ICE PRESENCE HISTORY AT STATION 4 THE DATA REPRESENT THE WEEKLY SAMPLING Of ICE PRESENCE THE TABULATION Is BINARY, ICE IS EITHER PRESENT OR IT IS NOT

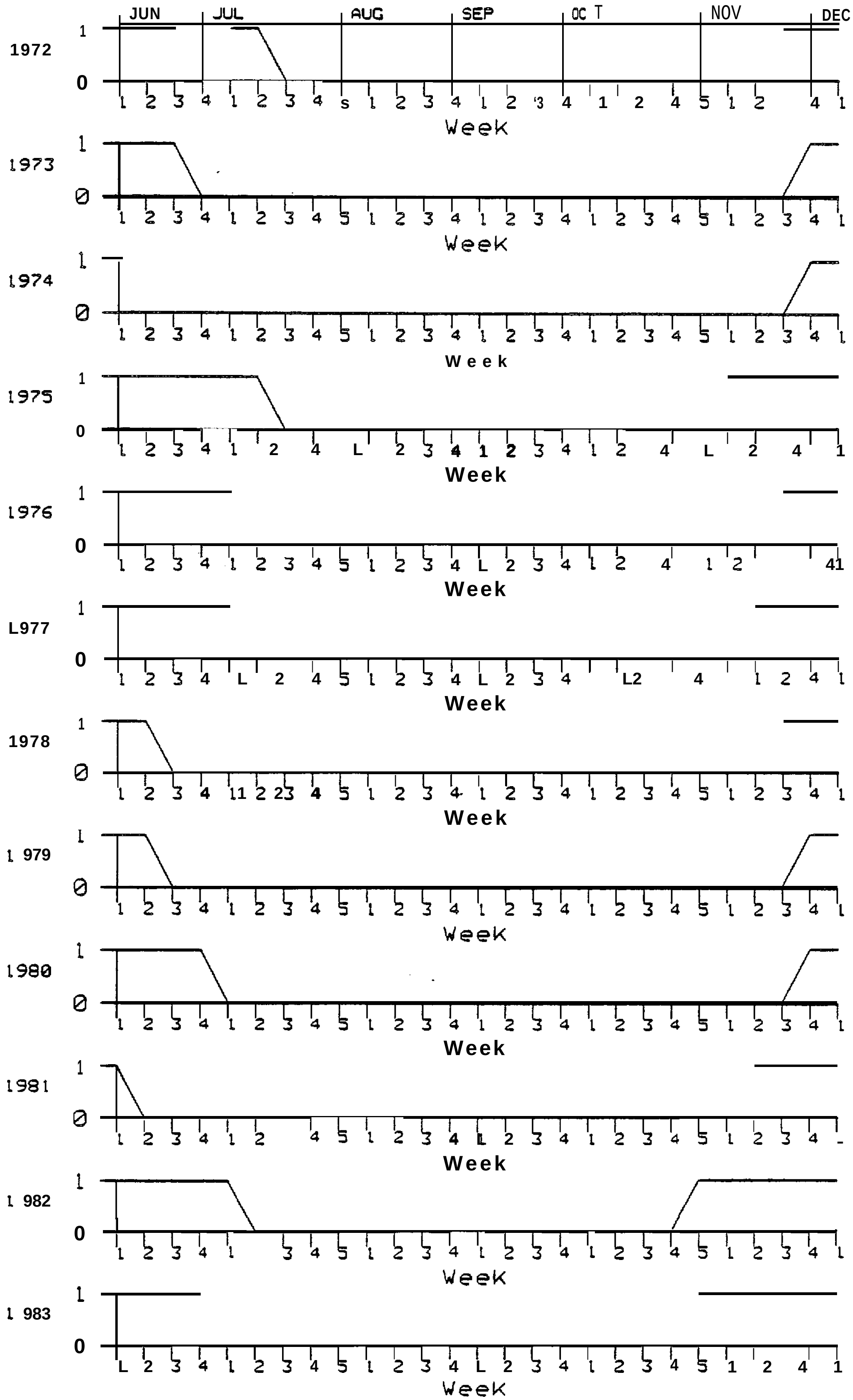



FIGURE 143 ICE PRESENCE HISTORY AT STATION 5 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE [S EITHER PRESENT OR [T IS NOT

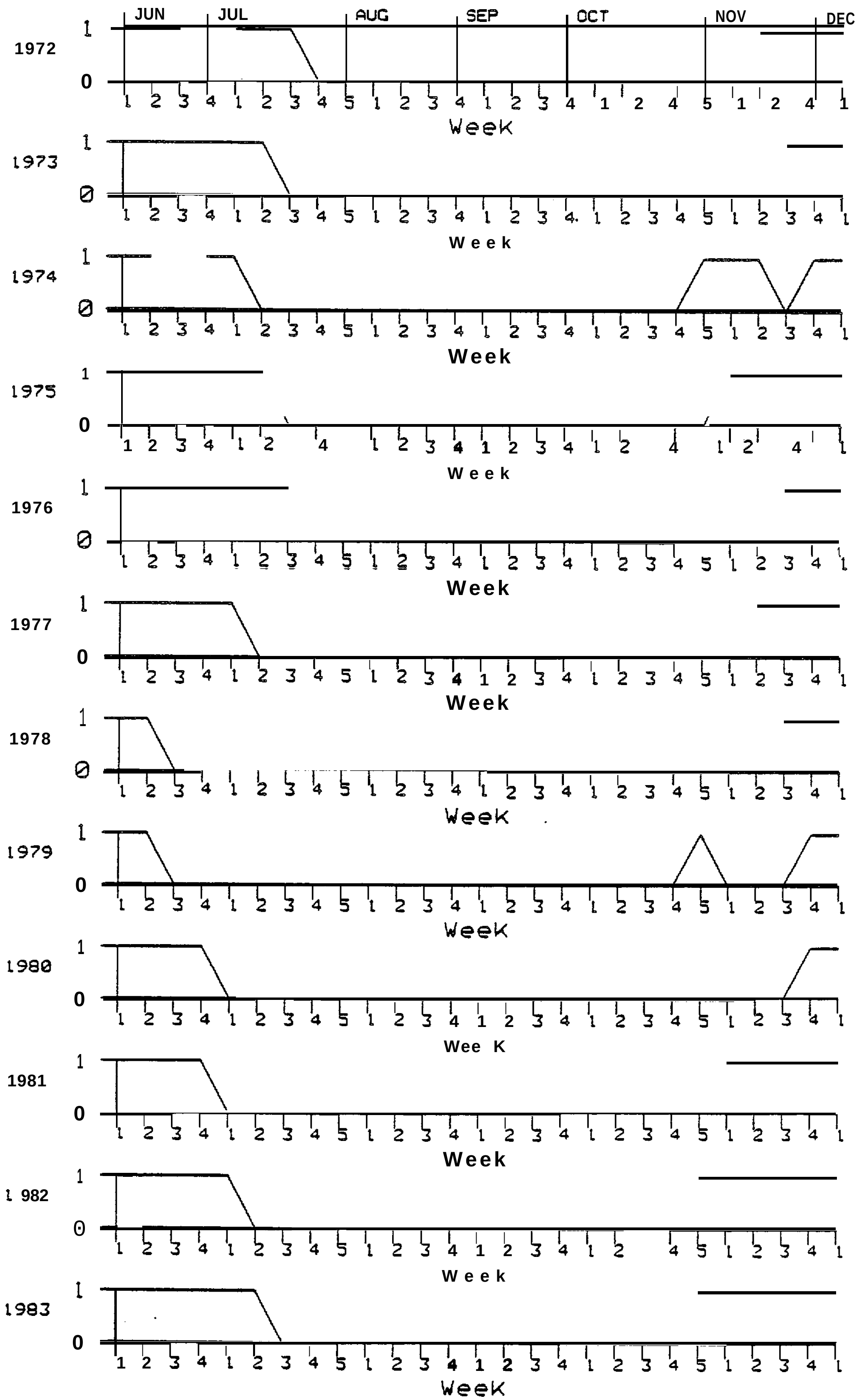



FIGURE 14 4 ICE PRESENCE HISTORY AT STATION 6 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

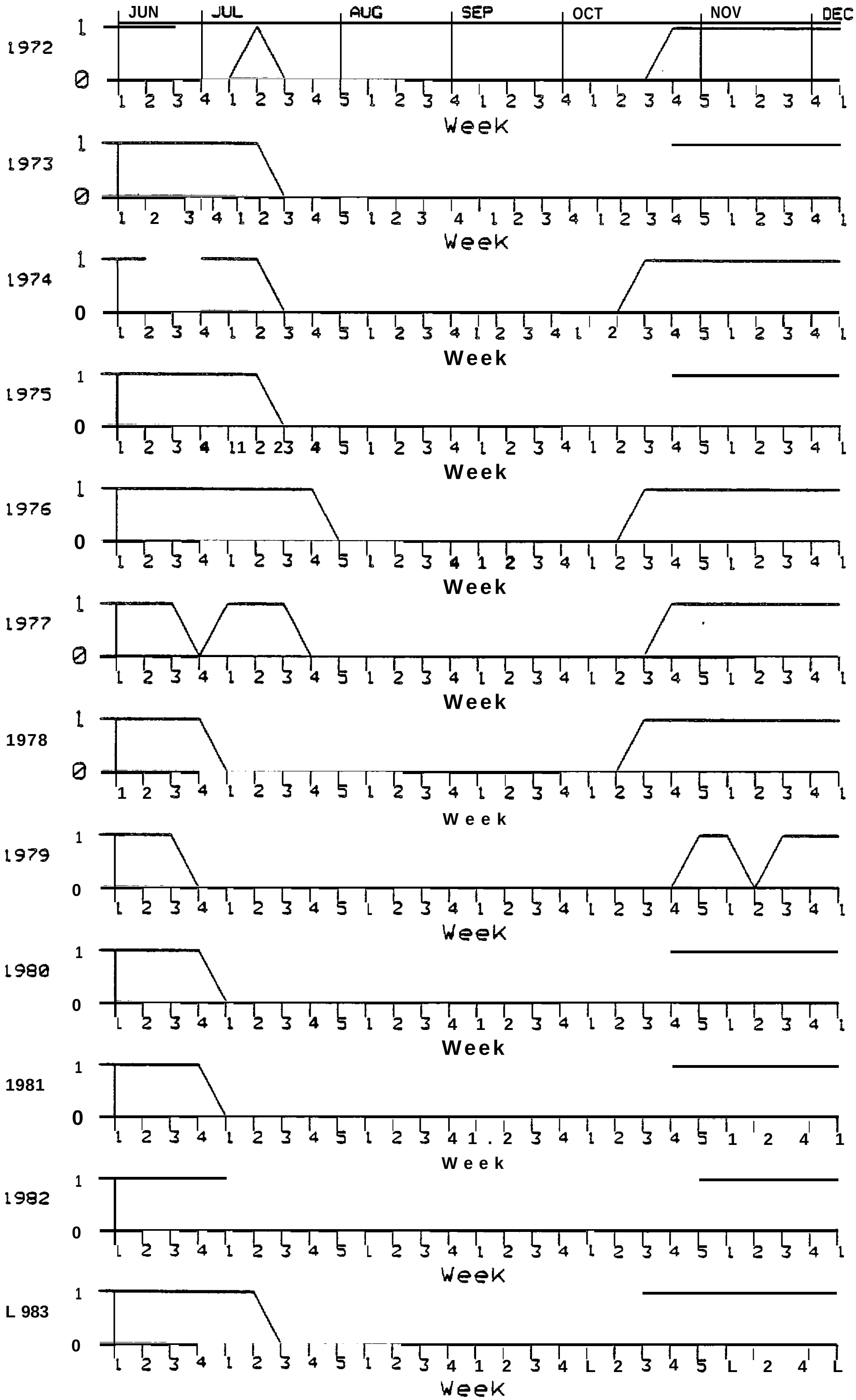



FIGURE 145 ICE PRESENCE HISTORY AT STATION 7 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

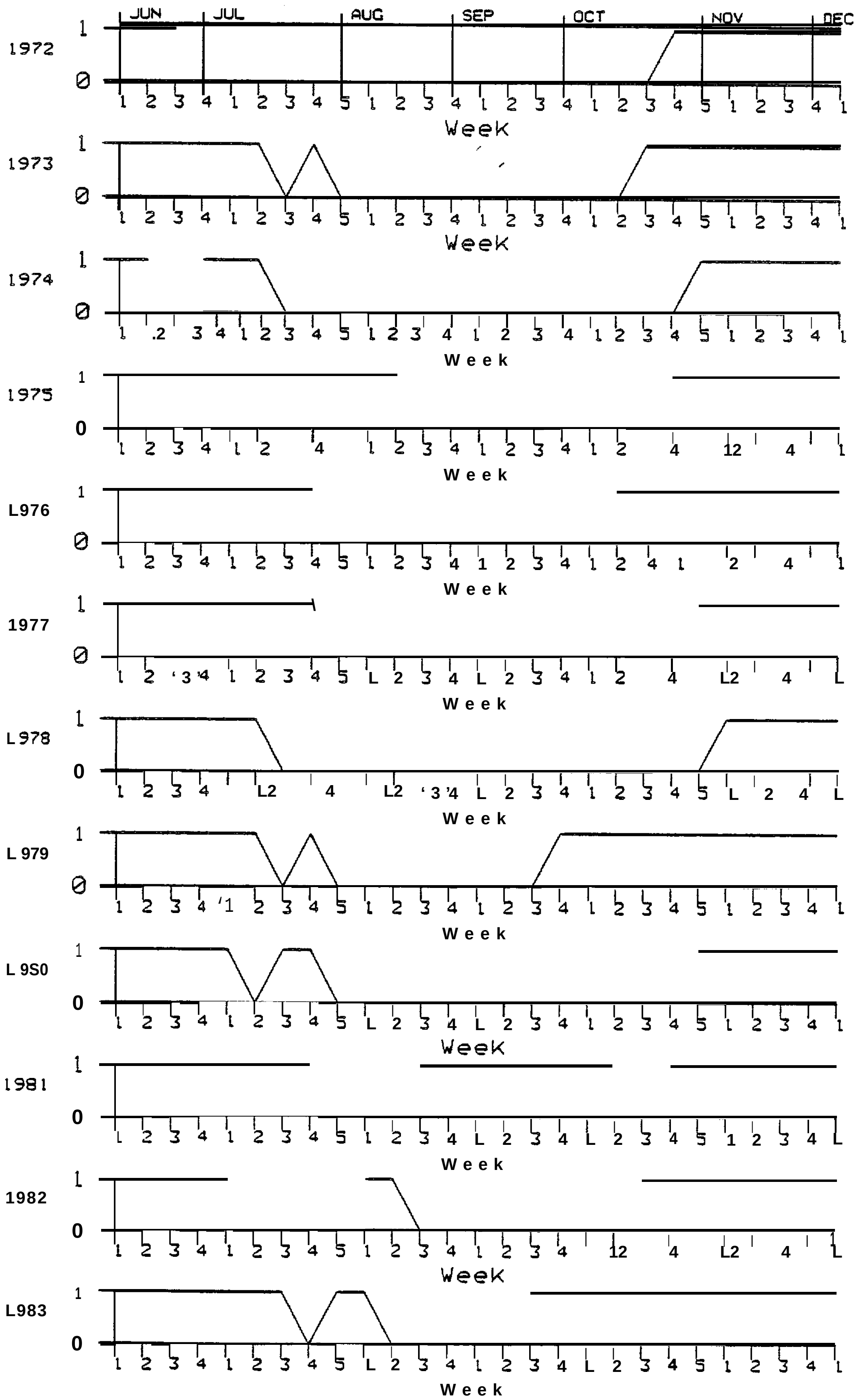



FIGURE 146 ICE PRESENCE HISTORY AT STATION 8 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

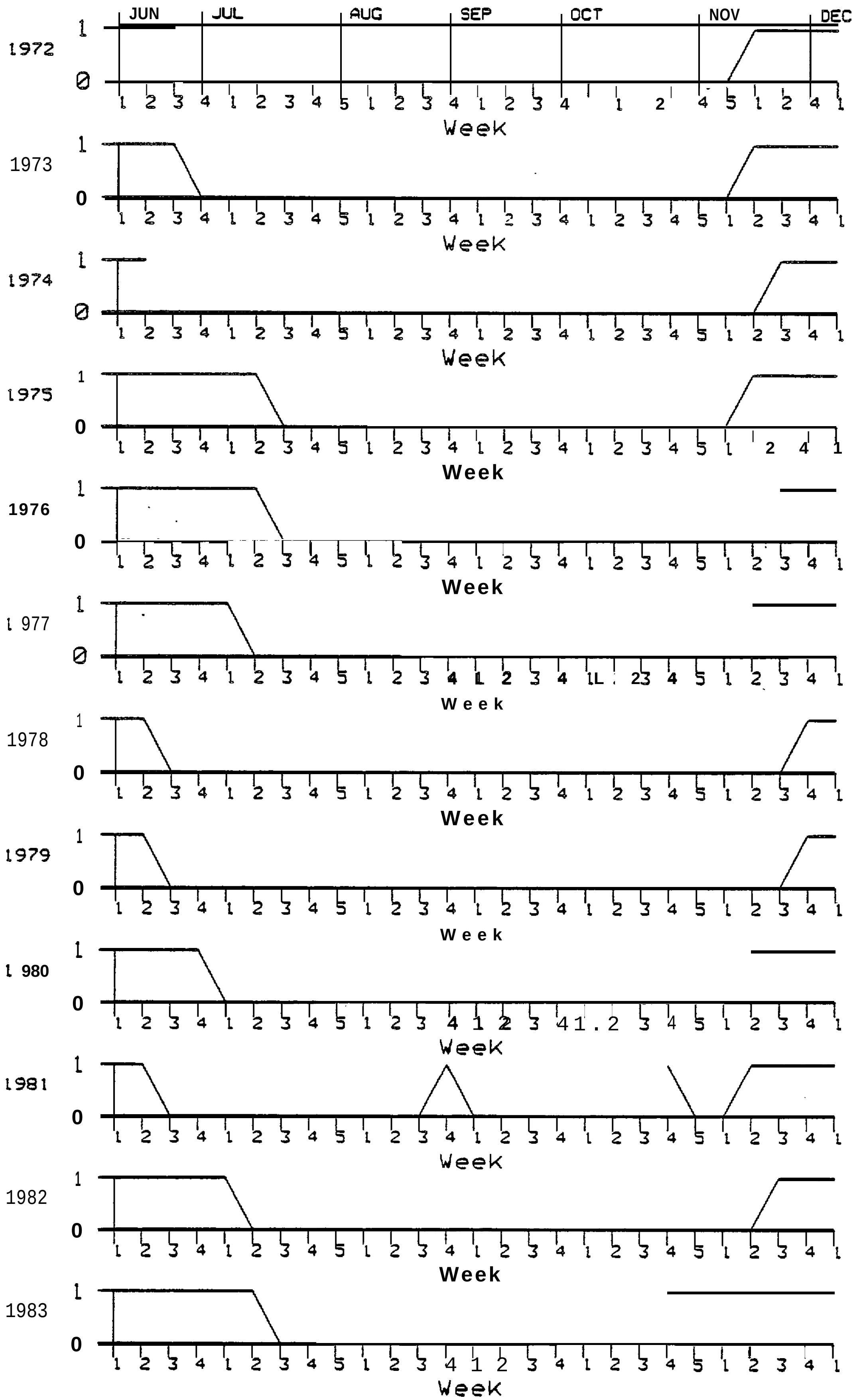



FIGURE 147 ICE PRESENCE HISTORY AT STATION 9 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY, ICE IS EITHER PRESENT OR IT IS NOT

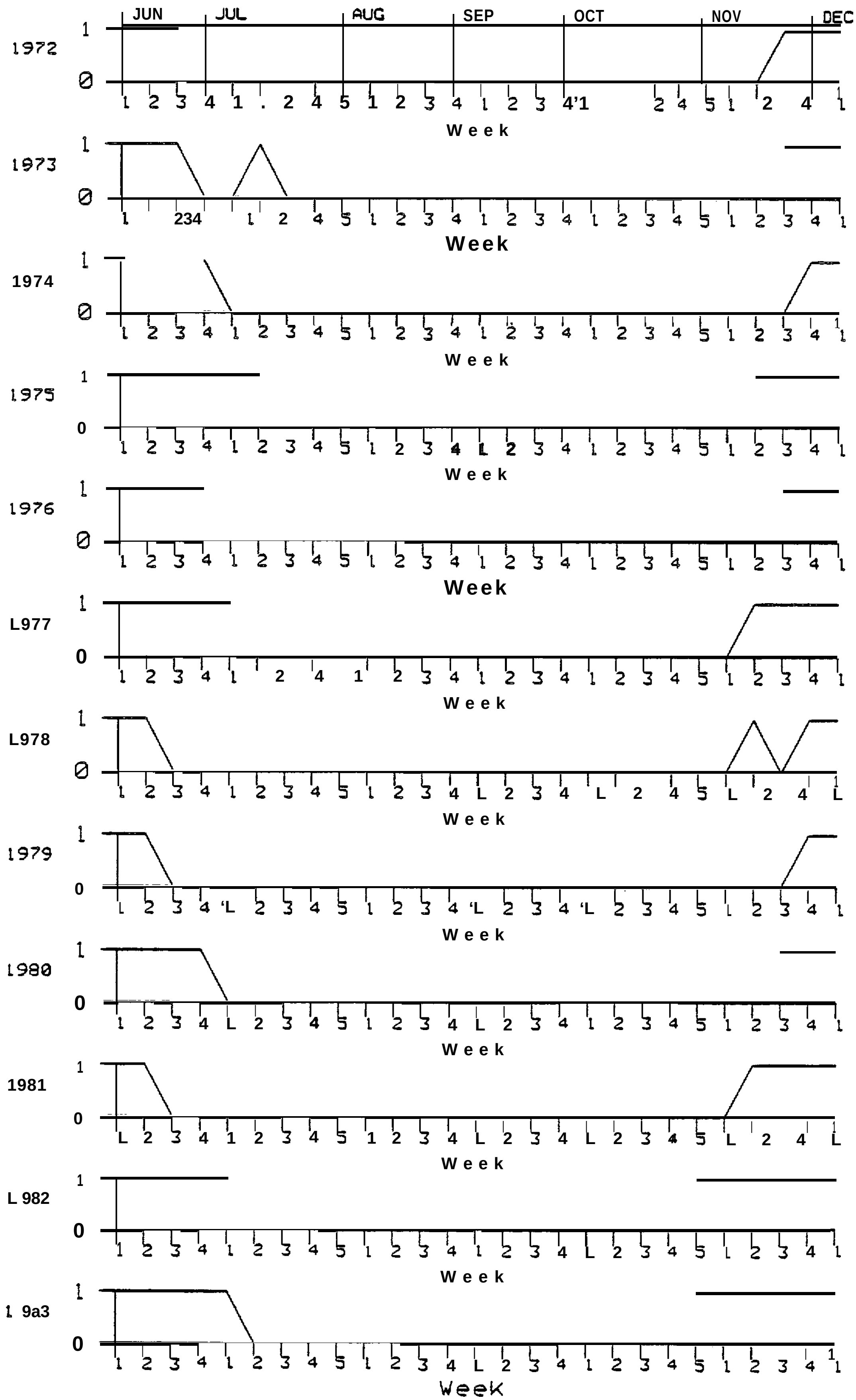



FIGURE 148 ICE PRESENCE HISTORY AT STATION 10 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

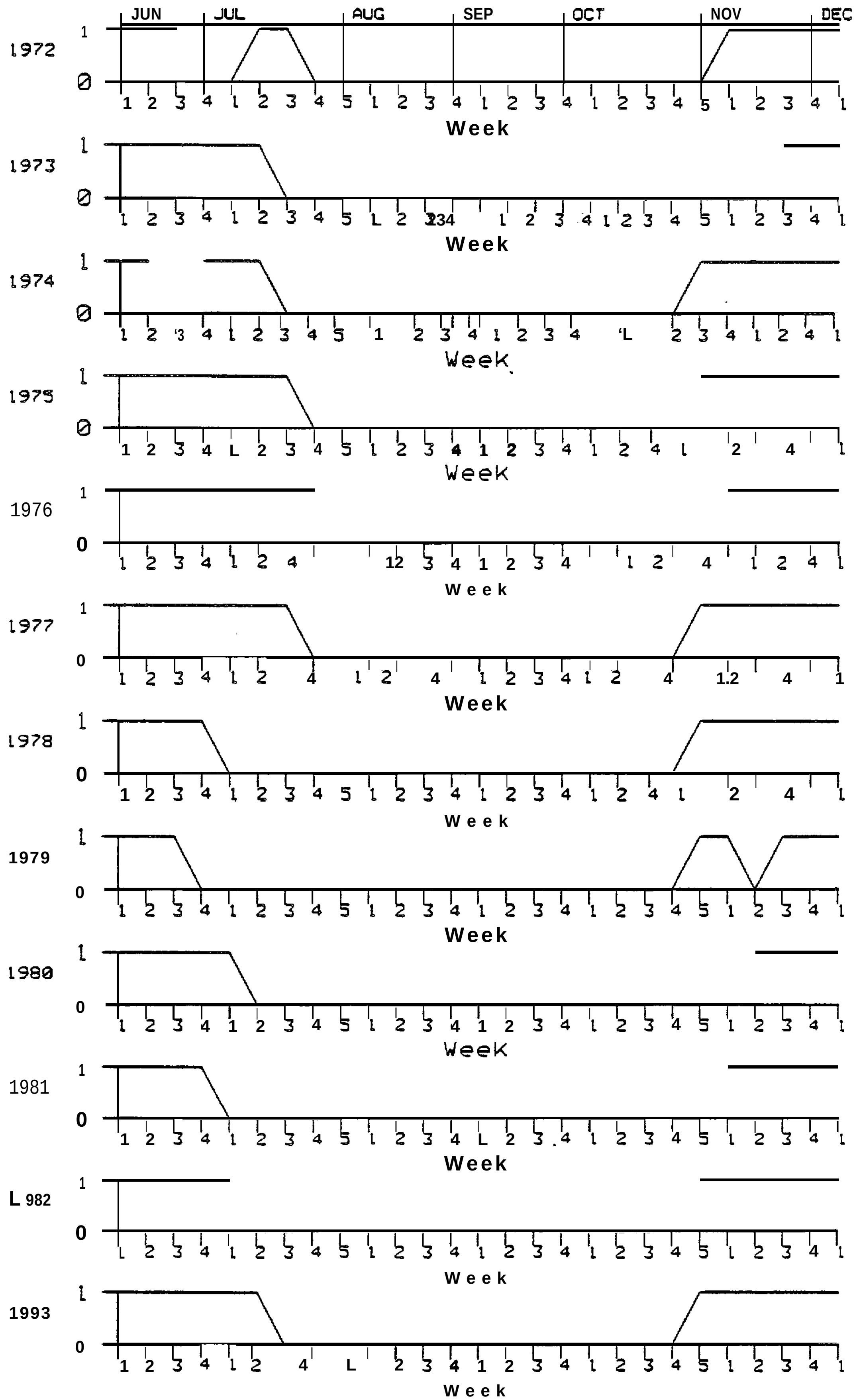



FIGURE 149 ICE PRESENCE HISTORY AT STATION 11 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

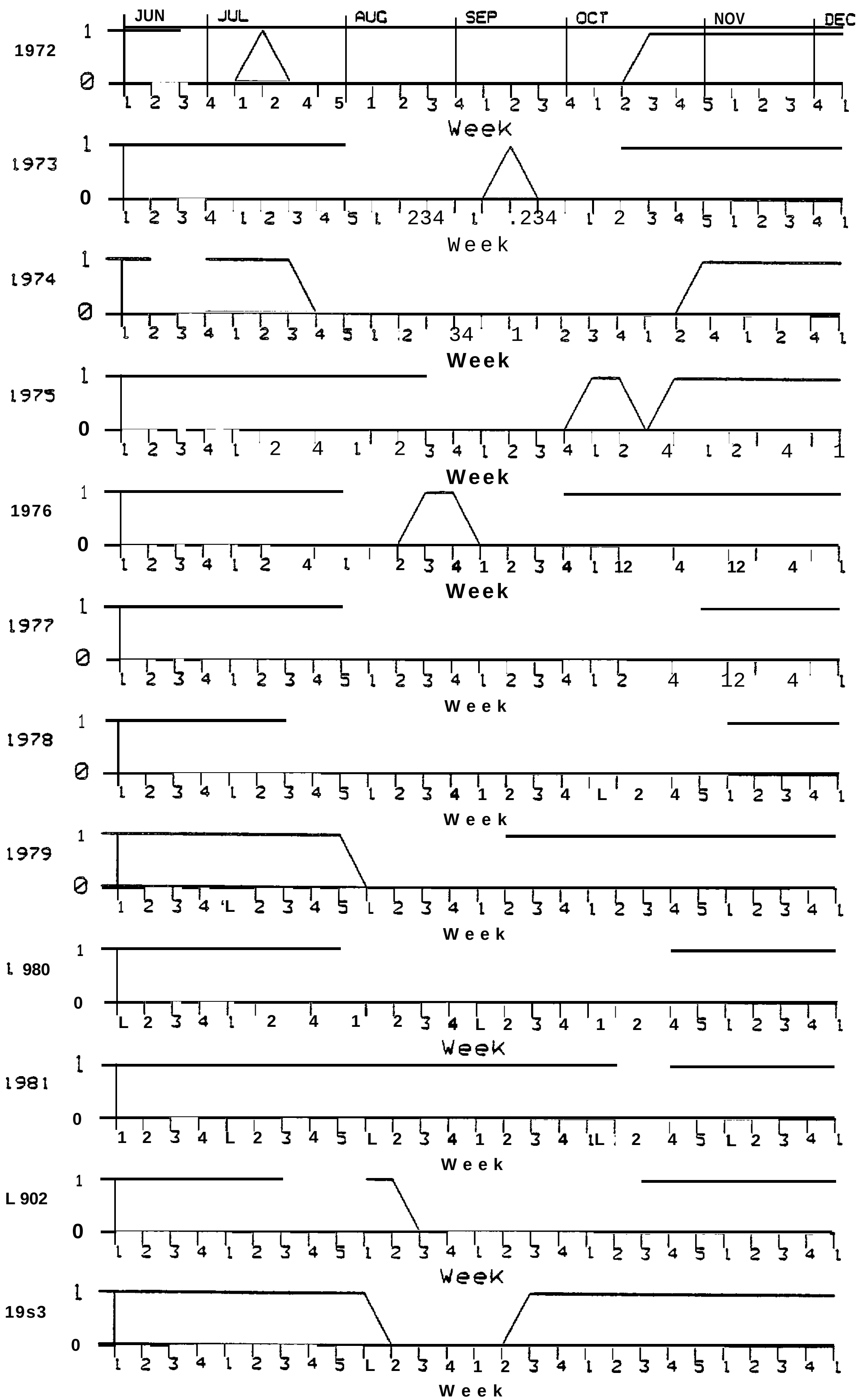



FIGURE 150 ICE PRESENCE HISTORY AT STATION 12 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY, ICE IS EITHER PRESENT OR IT IS NOT

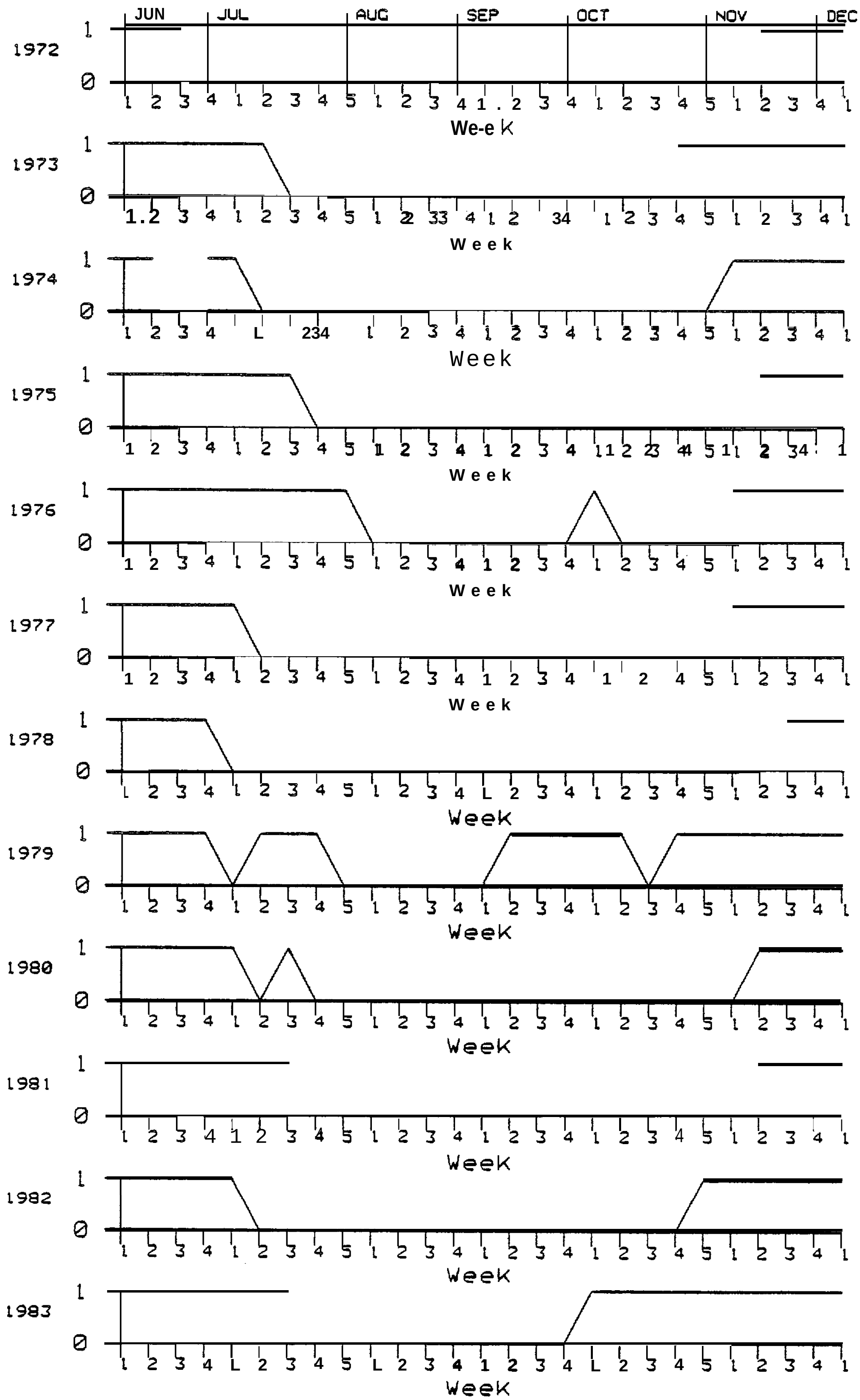



FIGURE 151 ICE PRESENCE HISTORY AT STATION 13 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY, ICE IS EITHER PRESENT OR IT IS NOT

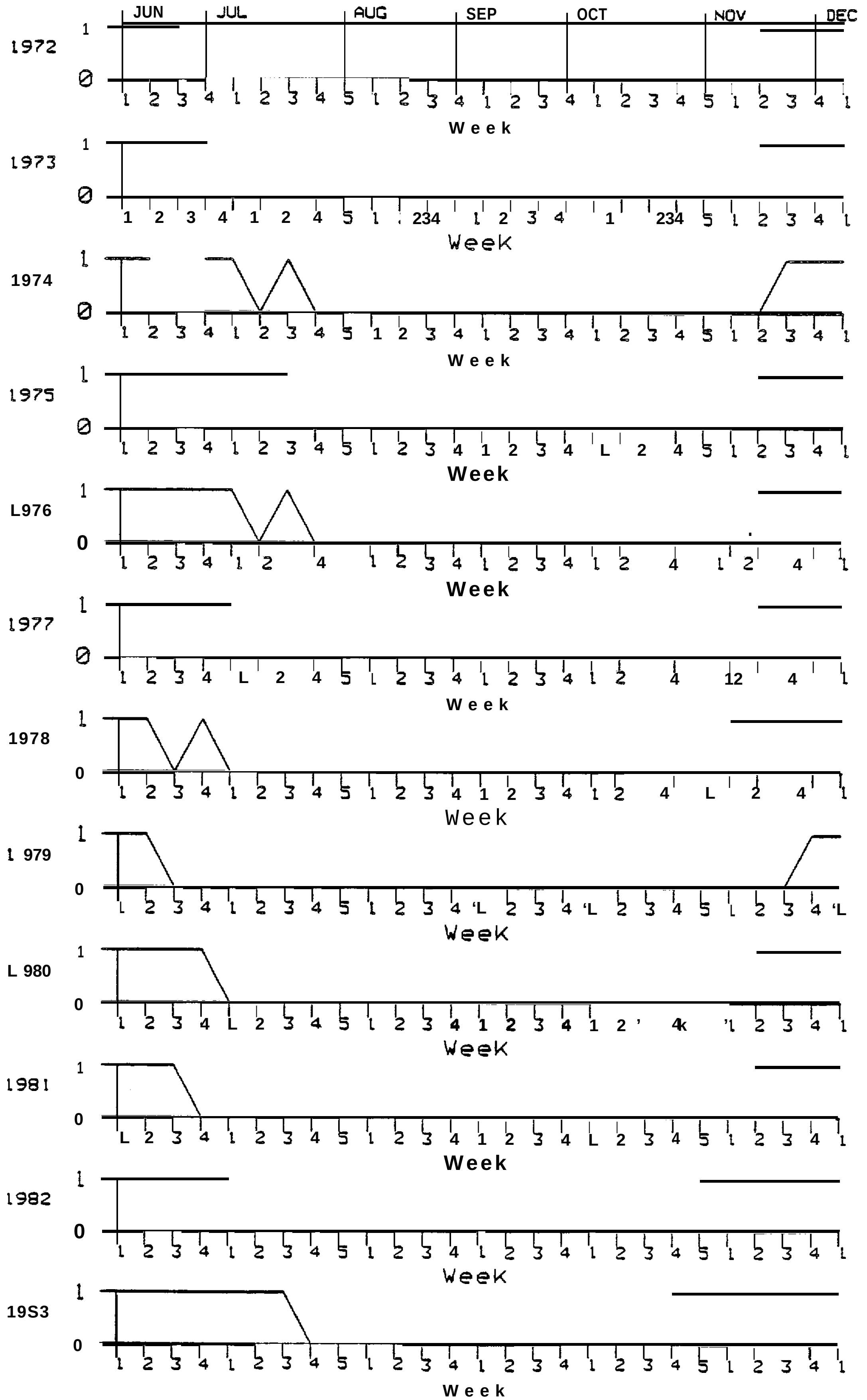



FIGURE 152 ICE PRESENCE HISTORY AT STATION 14 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

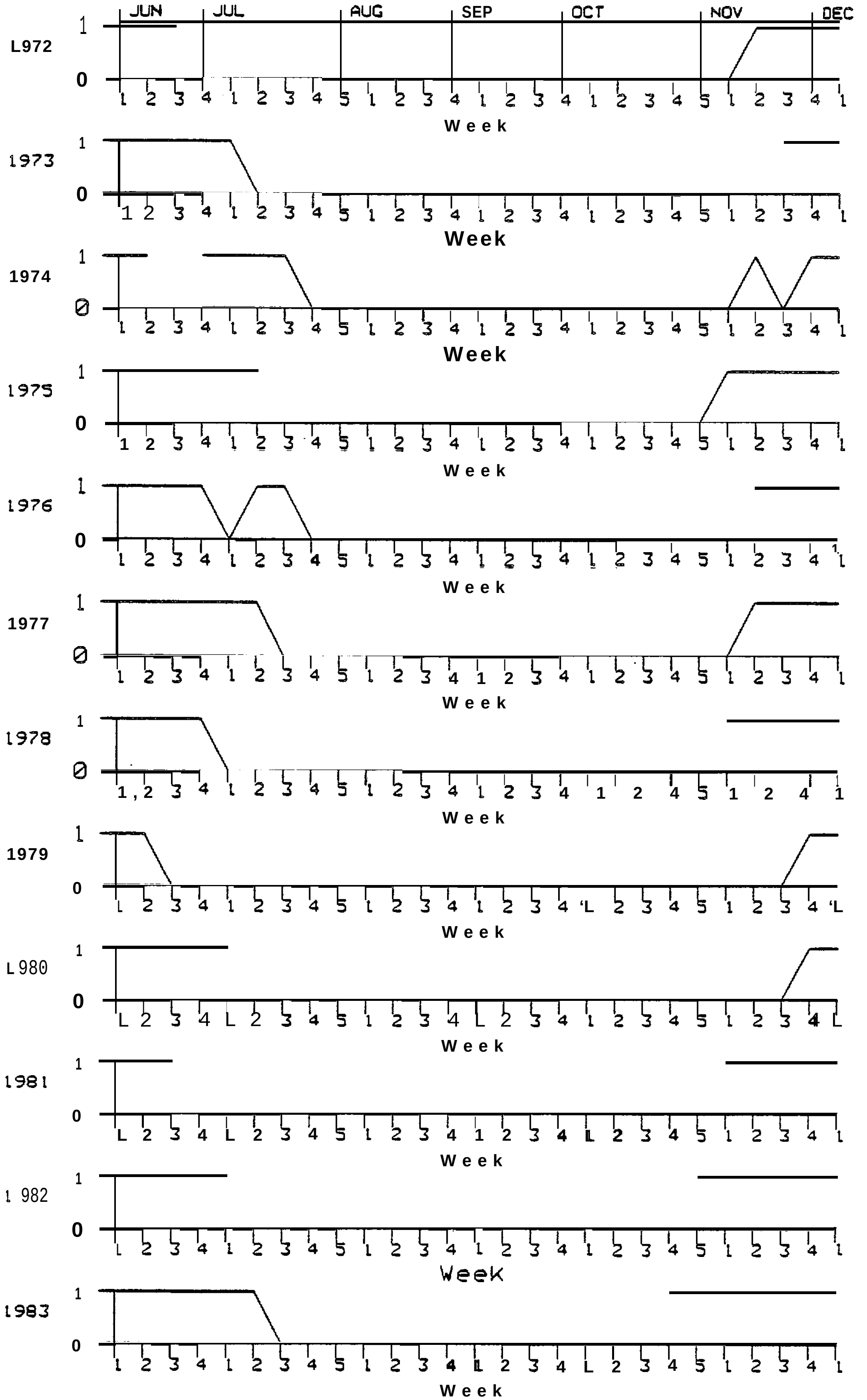



FIGURE L53 ICE PRESENCE HISTORY AT STATION 1S THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

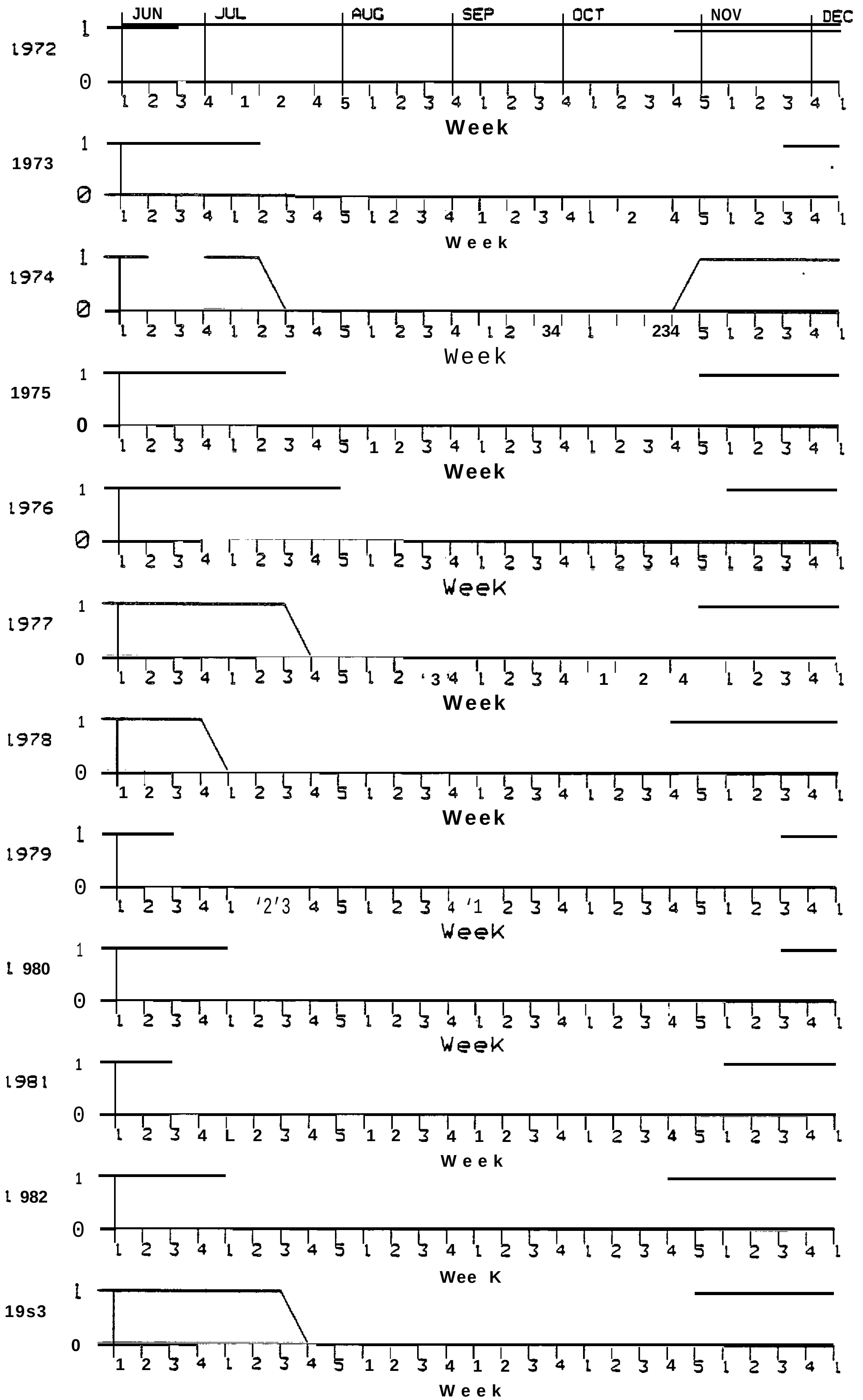



FIGURE 154 ICE PRESENCE HISTORY AT STATION 16 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

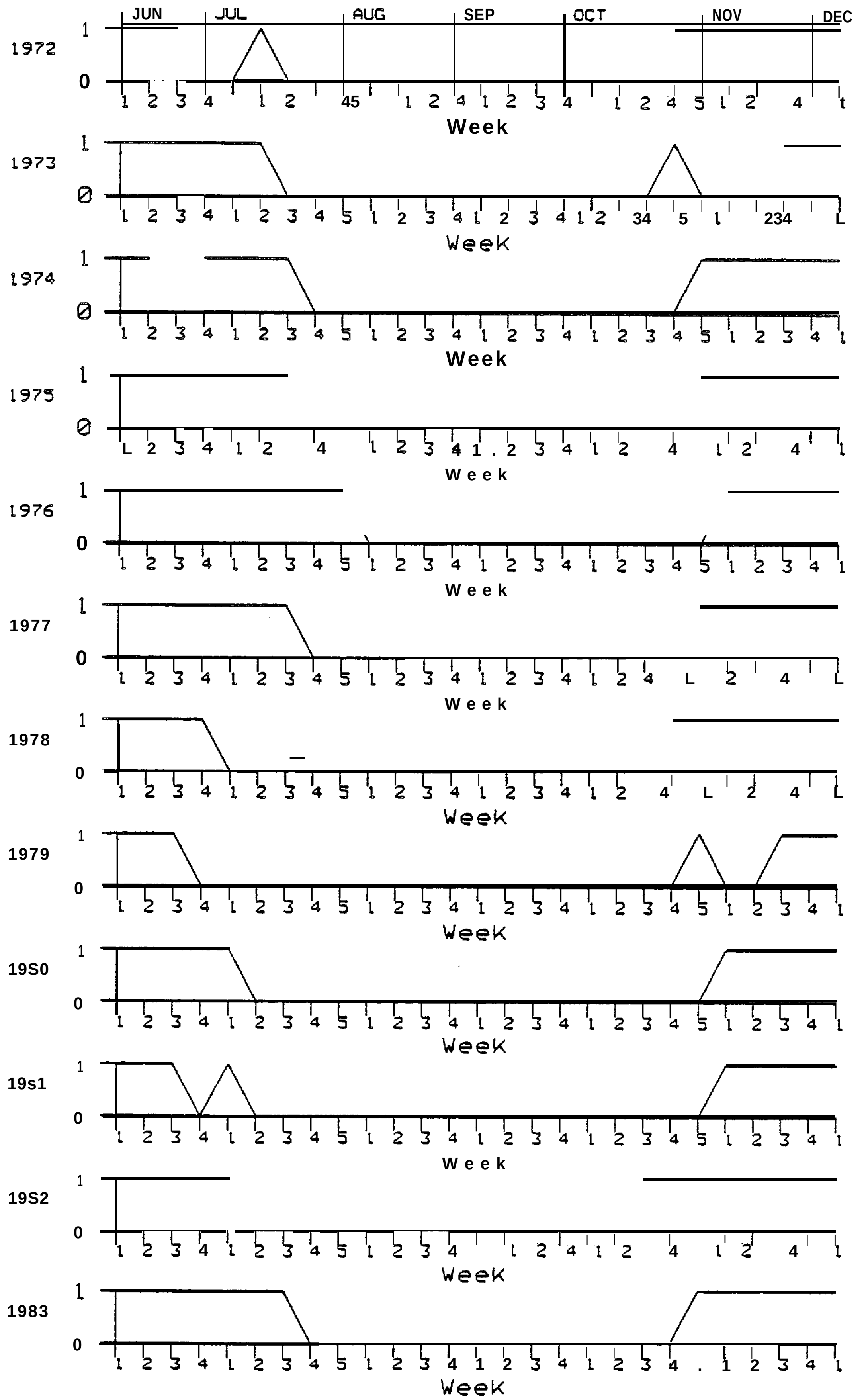



FIGURE 155 ICE PRESENCE HISTORY AT STATION 17 THE DATA REPRESENT THE WEEKLY SAMPLING Of ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

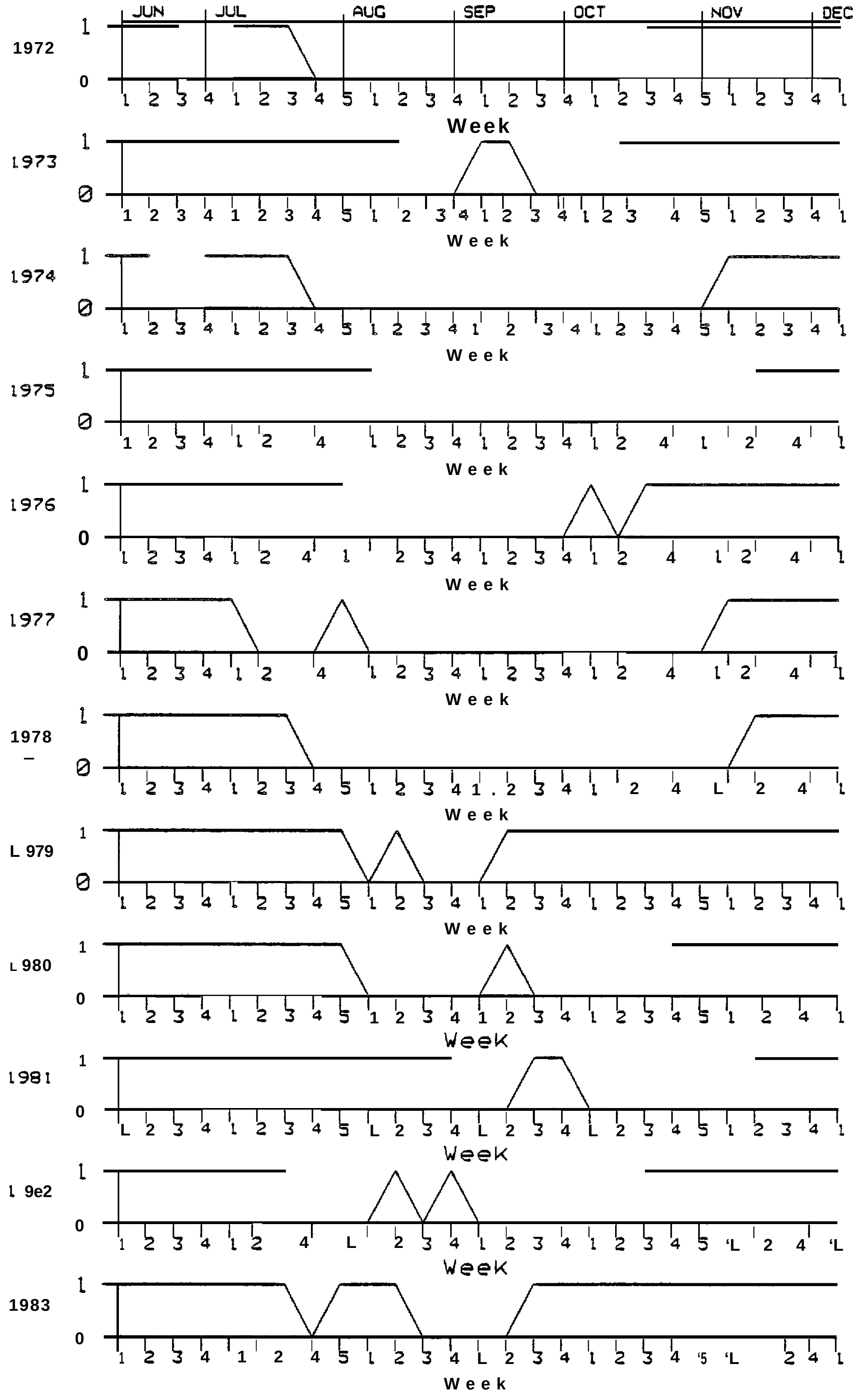



FIGURE 156 ICE PRESENCE HISTORY AT STATION 18 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

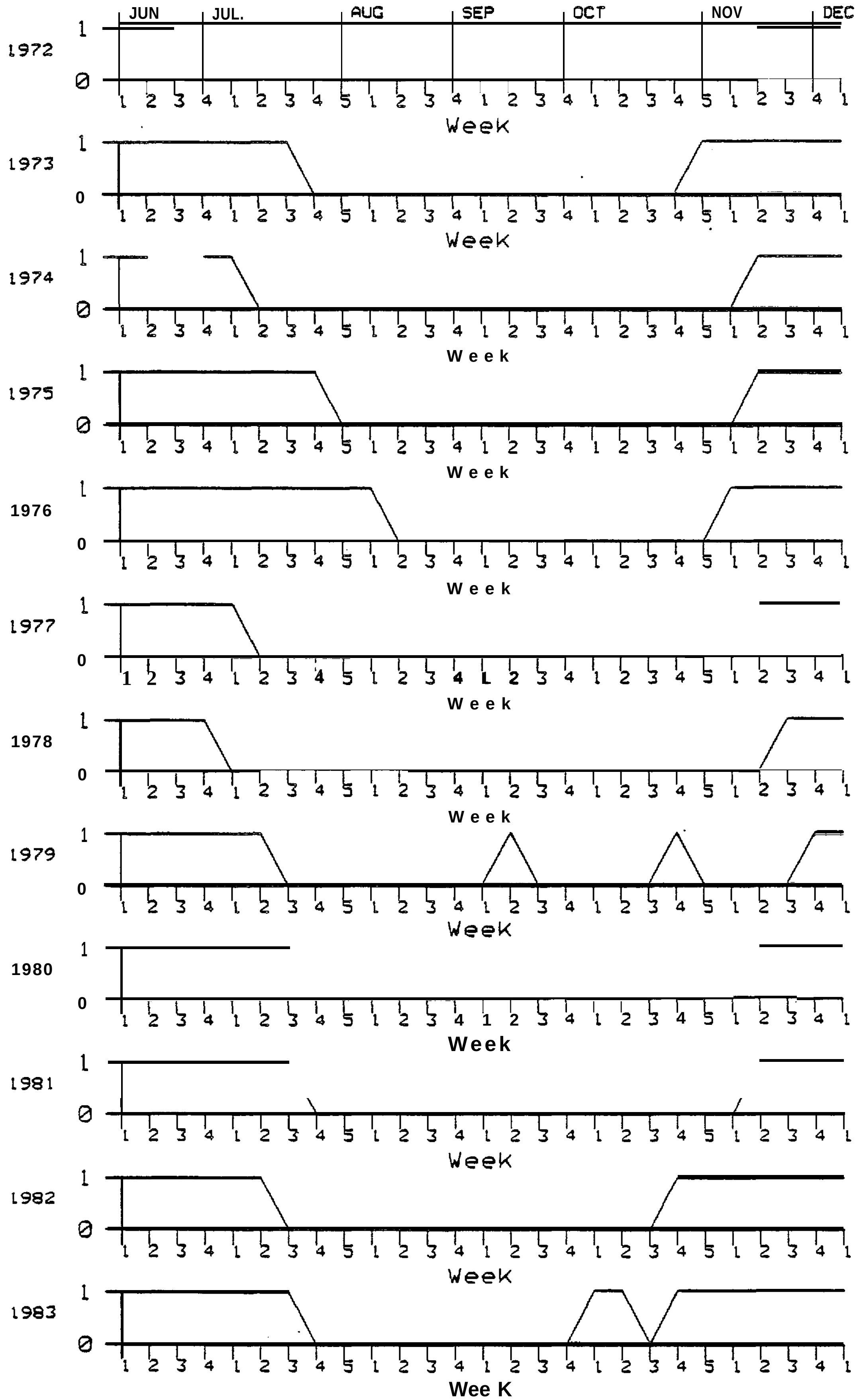



FIGURE 157 ICE PRESENCE HISTORY AT STATION 19 THE DATA
REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION
IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

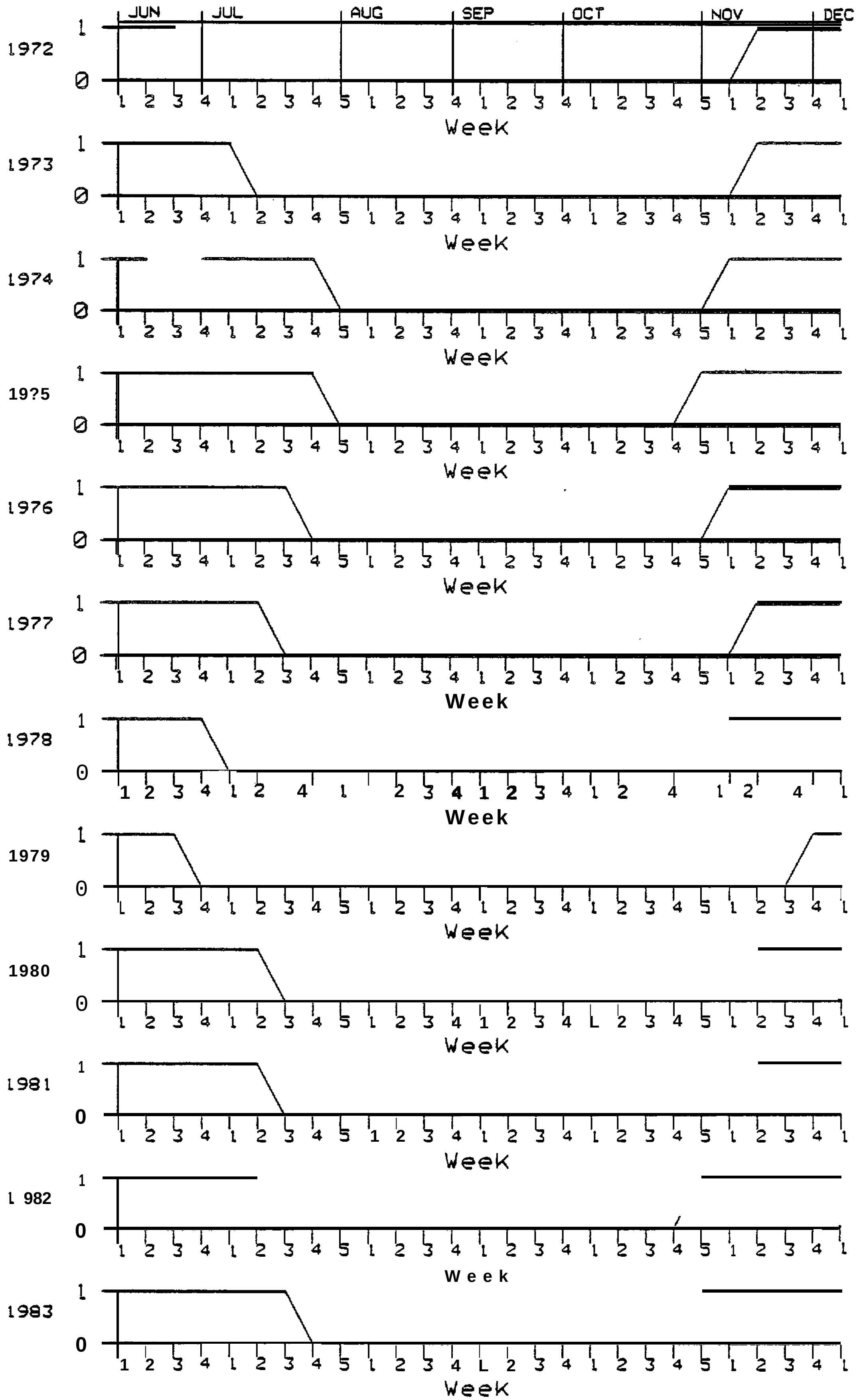



FIGURE 158 ICE PRESENCE HISTORY AT STATION 20 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

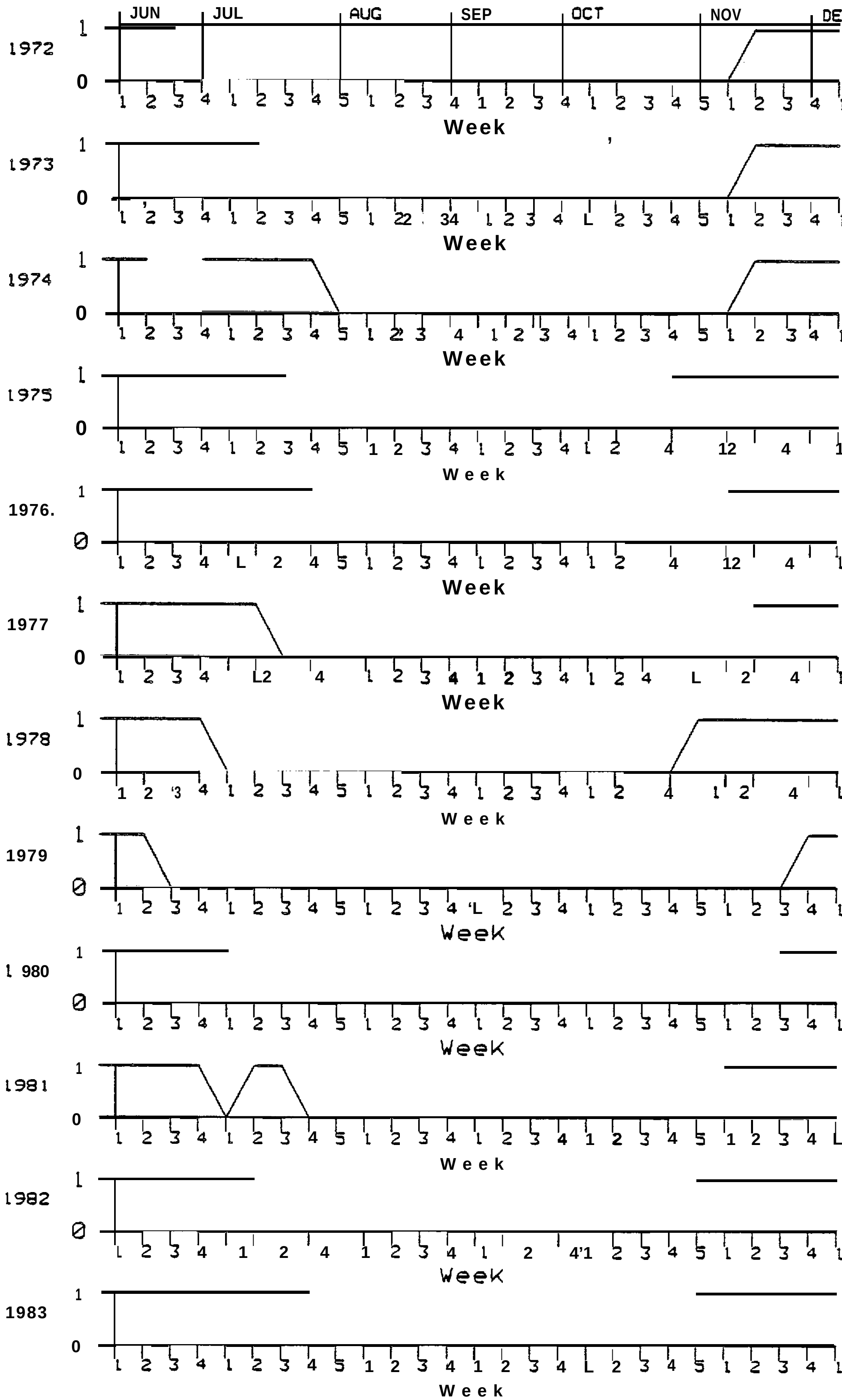
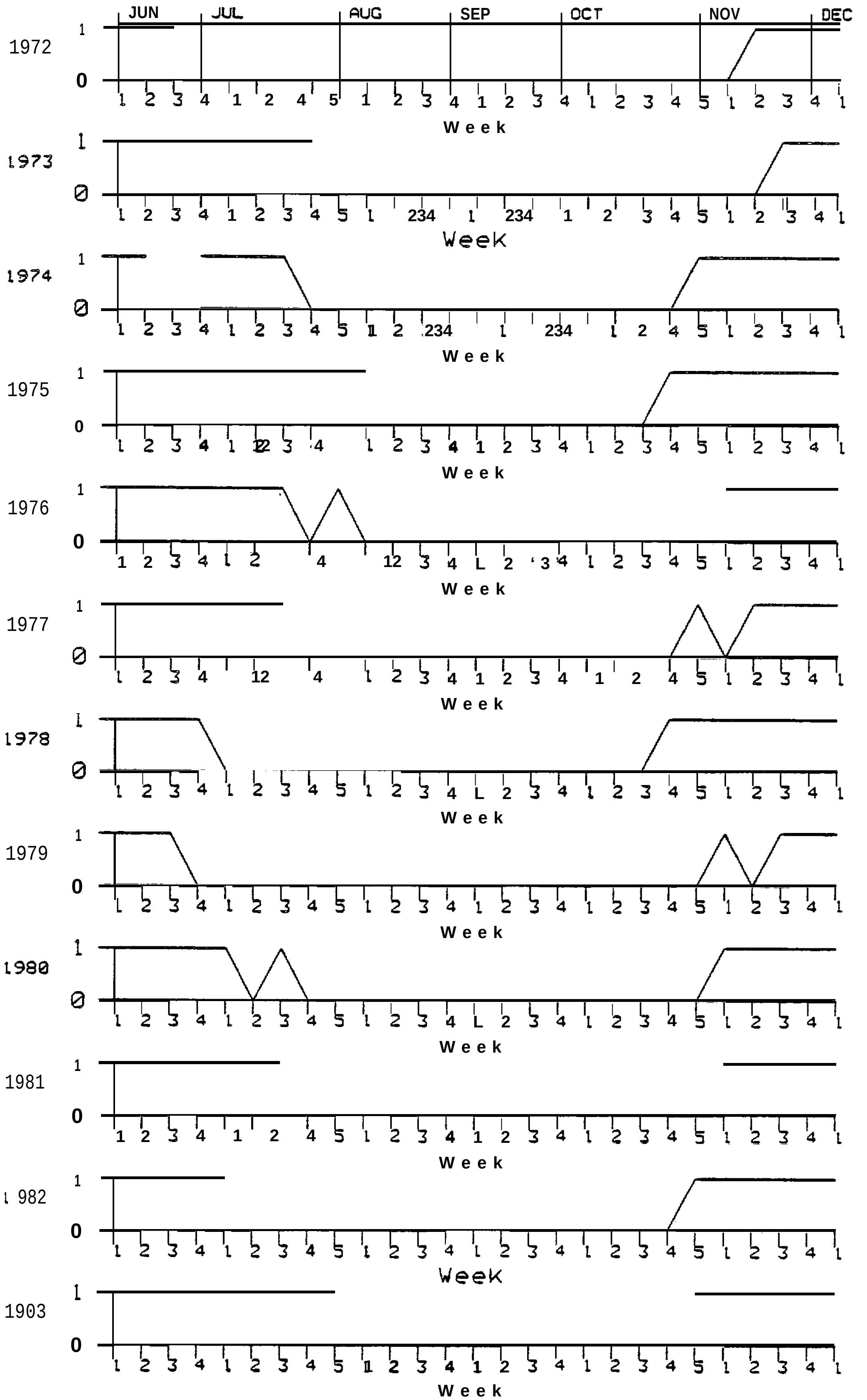



FIGURE 159 ICE PRESENCE HISTORY AT STATION 21 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY ICE IS EITHER PRESENT OR IT IS NOT




f IGURE 160 ICE PRESENCE HISTORY AT STATION 22 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION [S BINARY, ICE [S EITHER PRESENT OR [T IS NOT

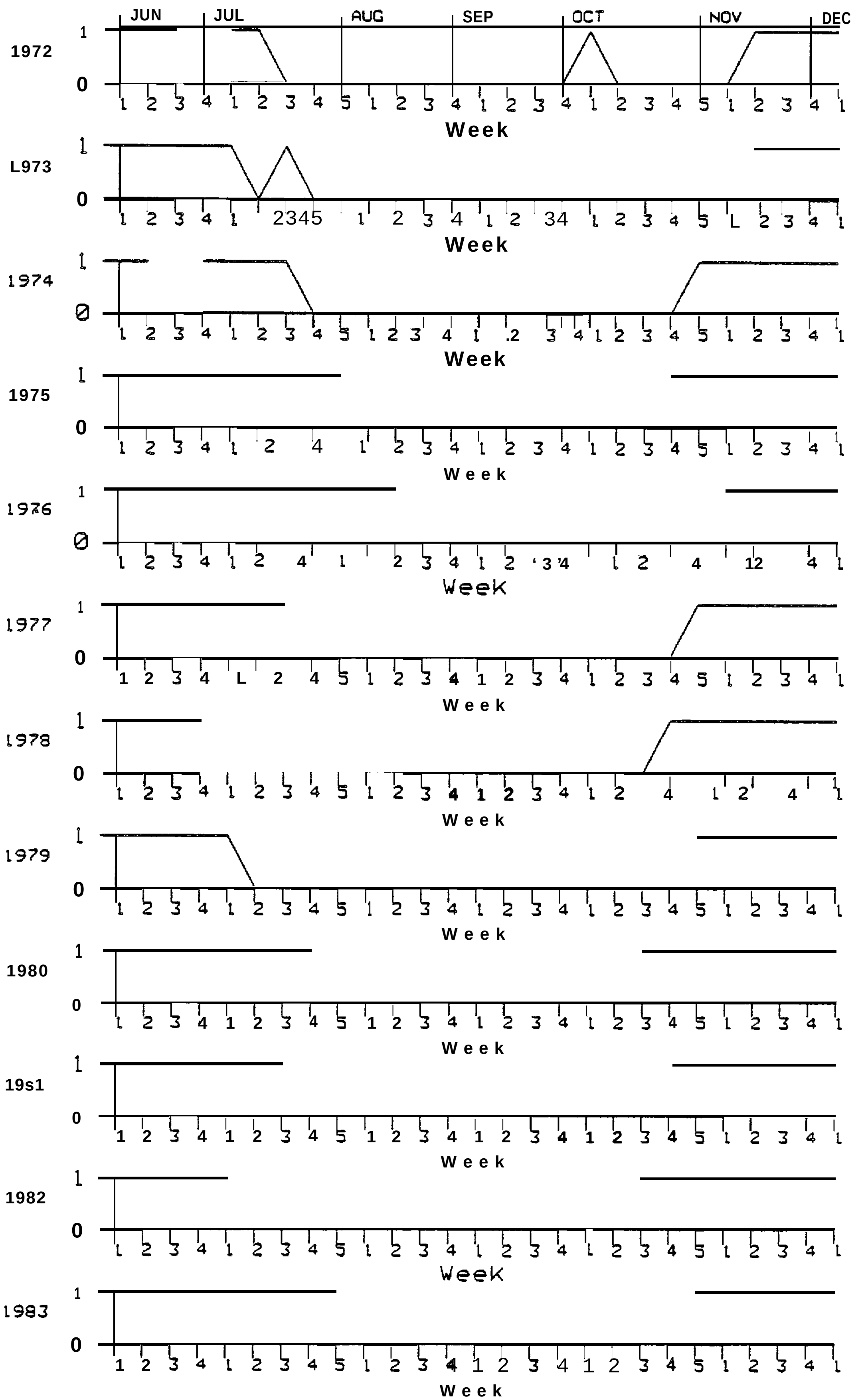



FIGURE 161 [CE PRESENCE HISTORY AT STATION 23 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

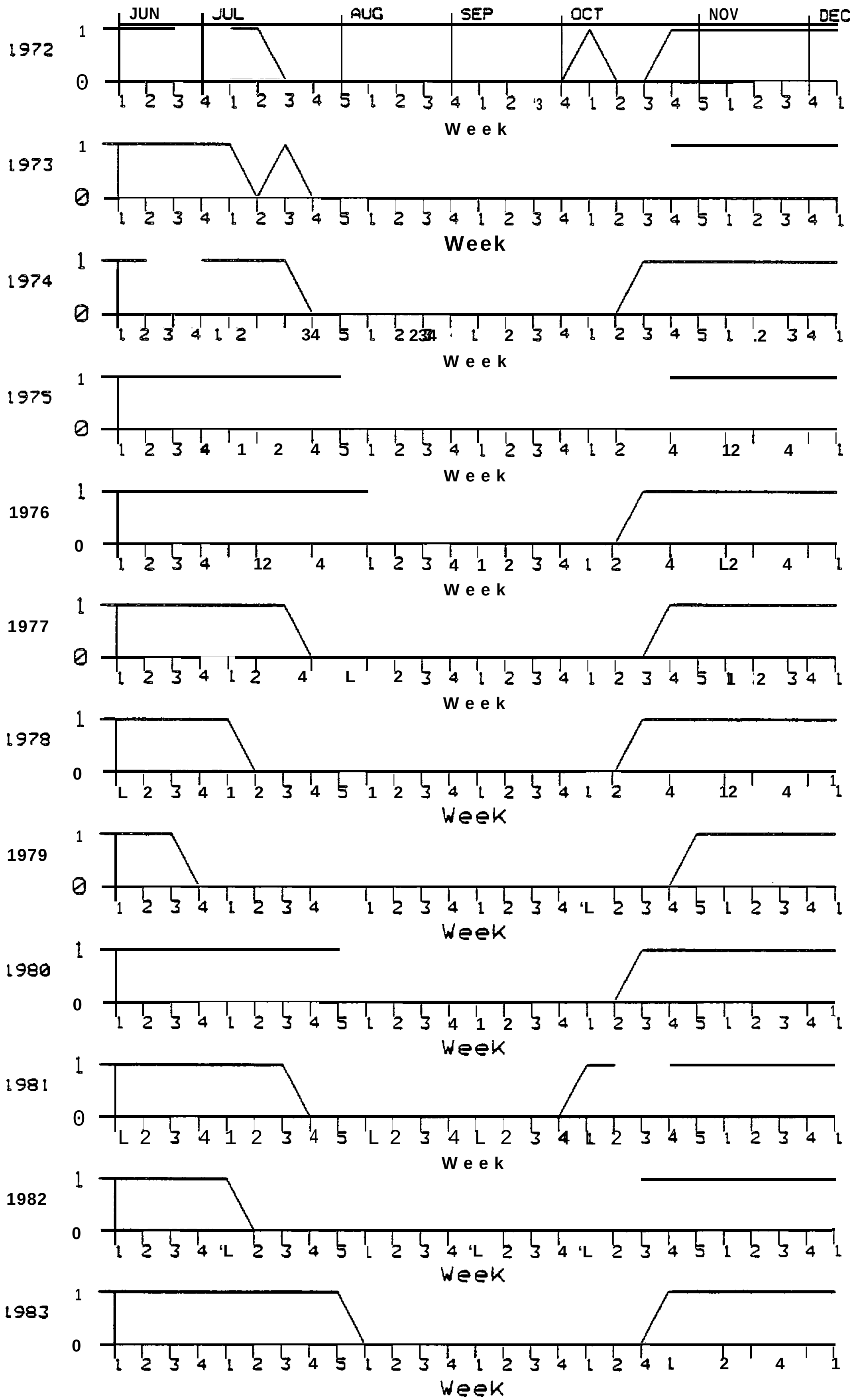



FIGURE 162 ICE PRESENCE HISTORY AT STATION 24 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

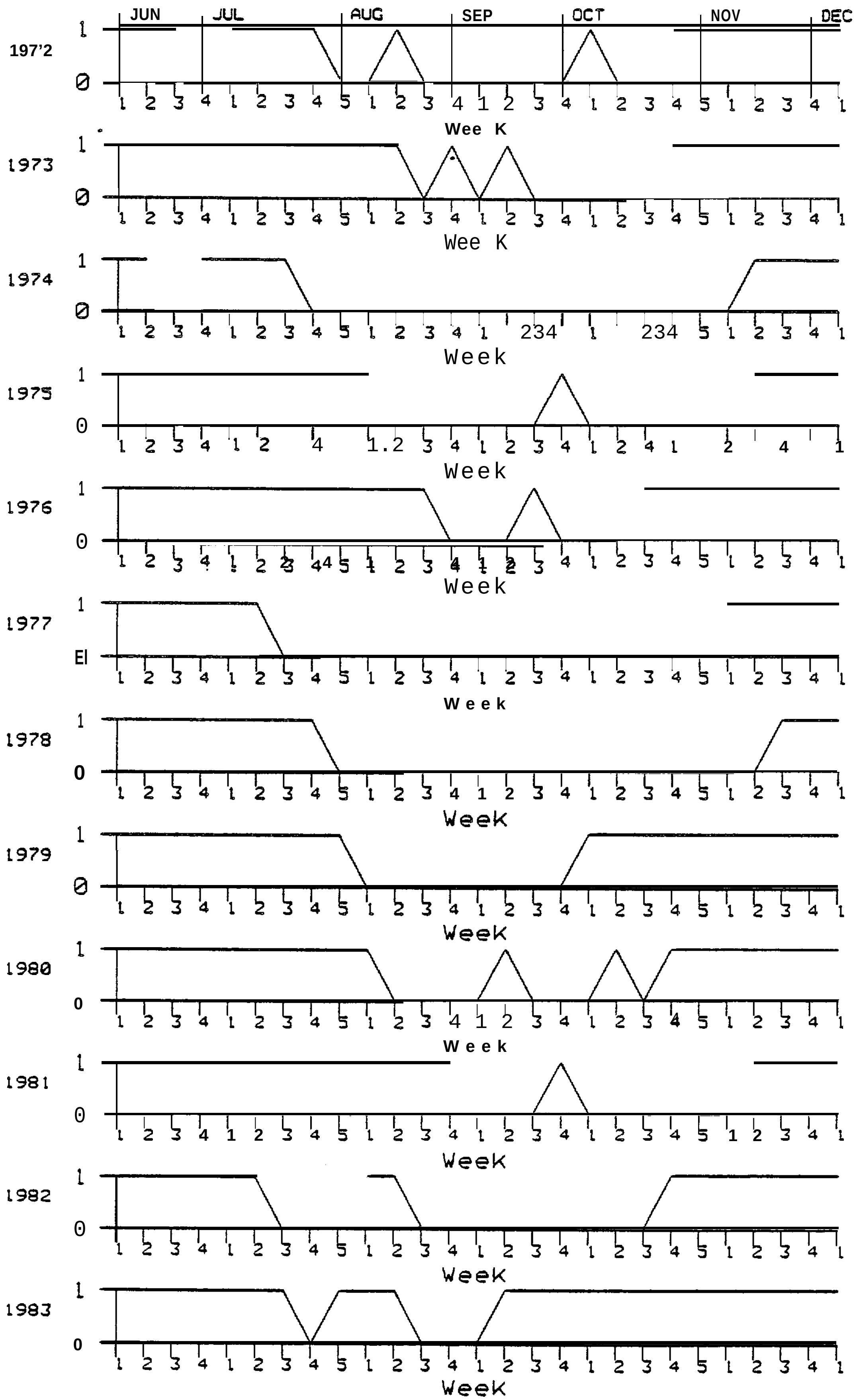



FIGURE 163 ICE PRESENCE HISTORY AT STATION 25 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY ICE IS EITHER PRESENT OR IT IS NOT

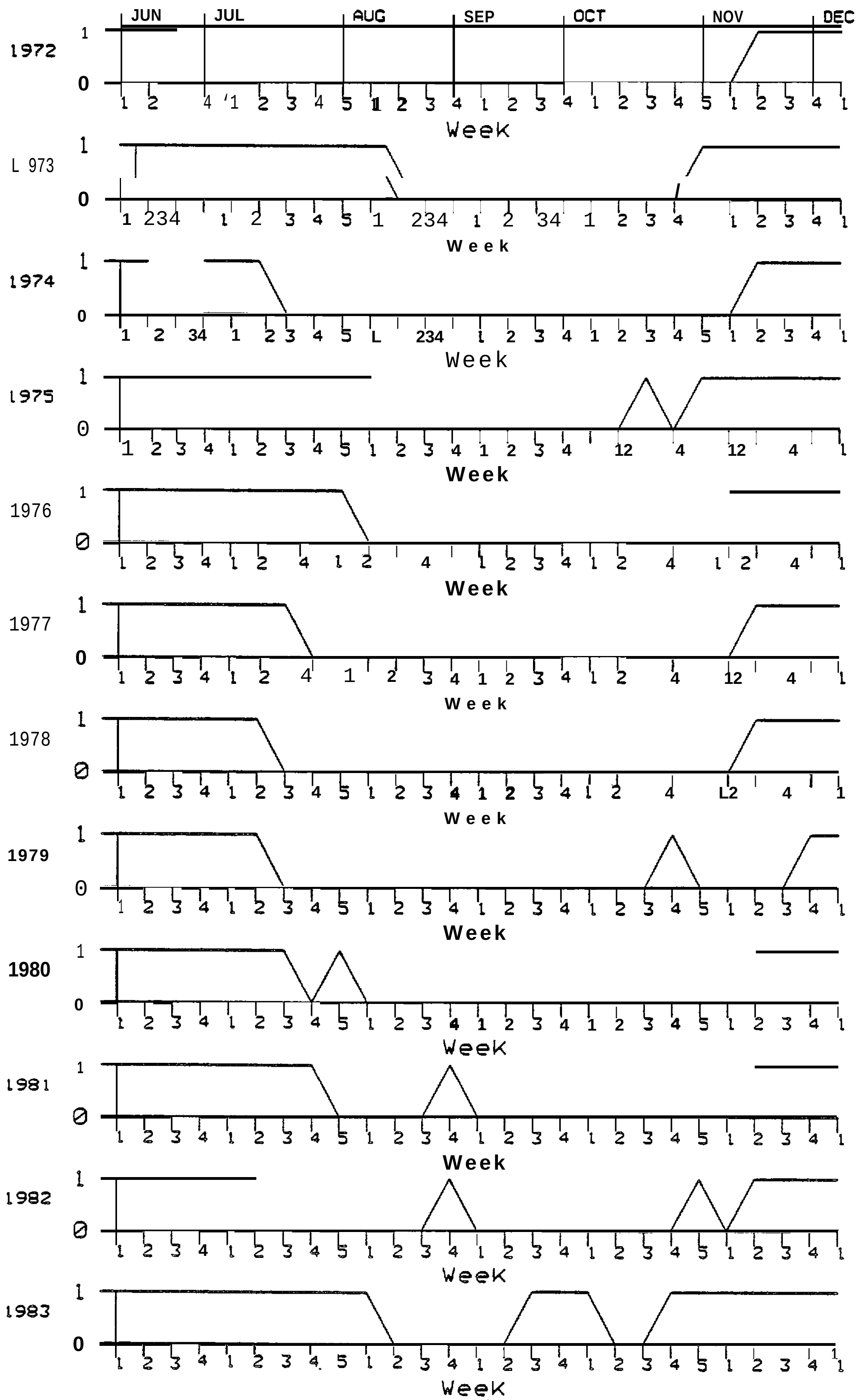



FIGURE 164 ICE PRESENCE HISTORY AT STATION 26 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

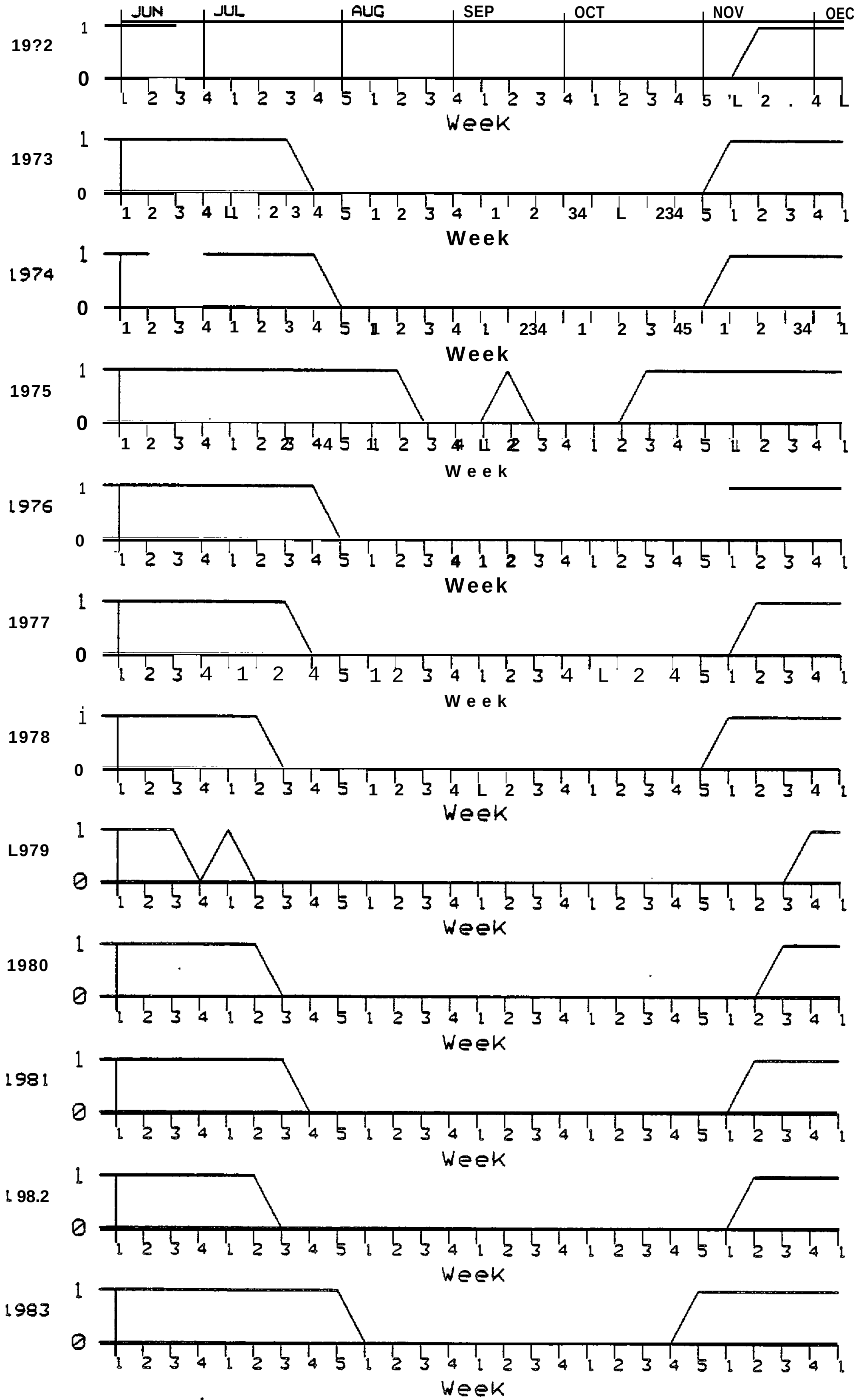
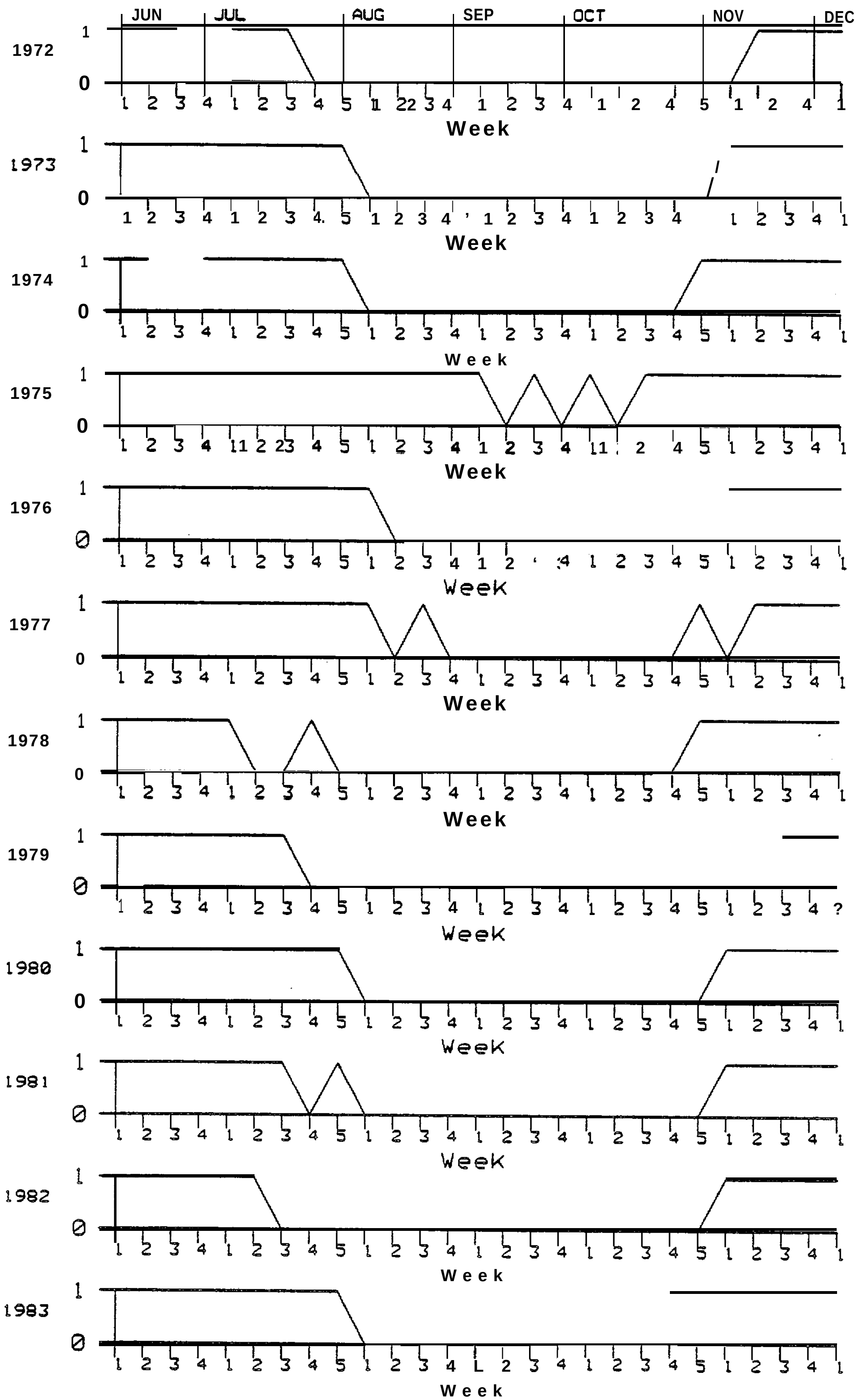



FIGURE 165 ICE PRESENCE HISTORY AT STATION 27 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT




FI CURE 166 ICE PRESENCE" HISTORY AI' STATION 2S THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

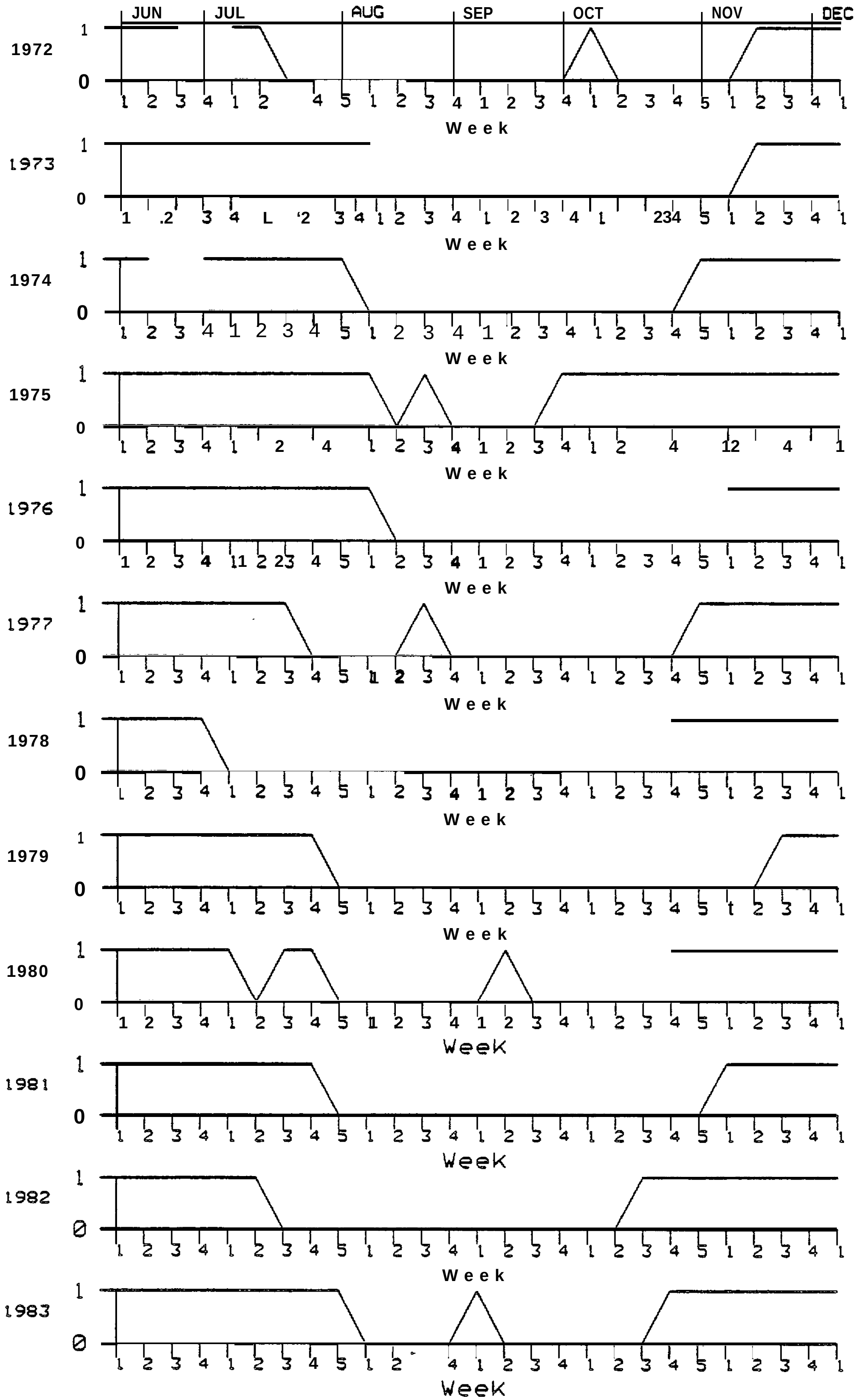



FIGURE 167 ICE PRESENCE HISTORY AT STATION 29 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY, ICE IS EITHER PRESENT OR IT IS NOT

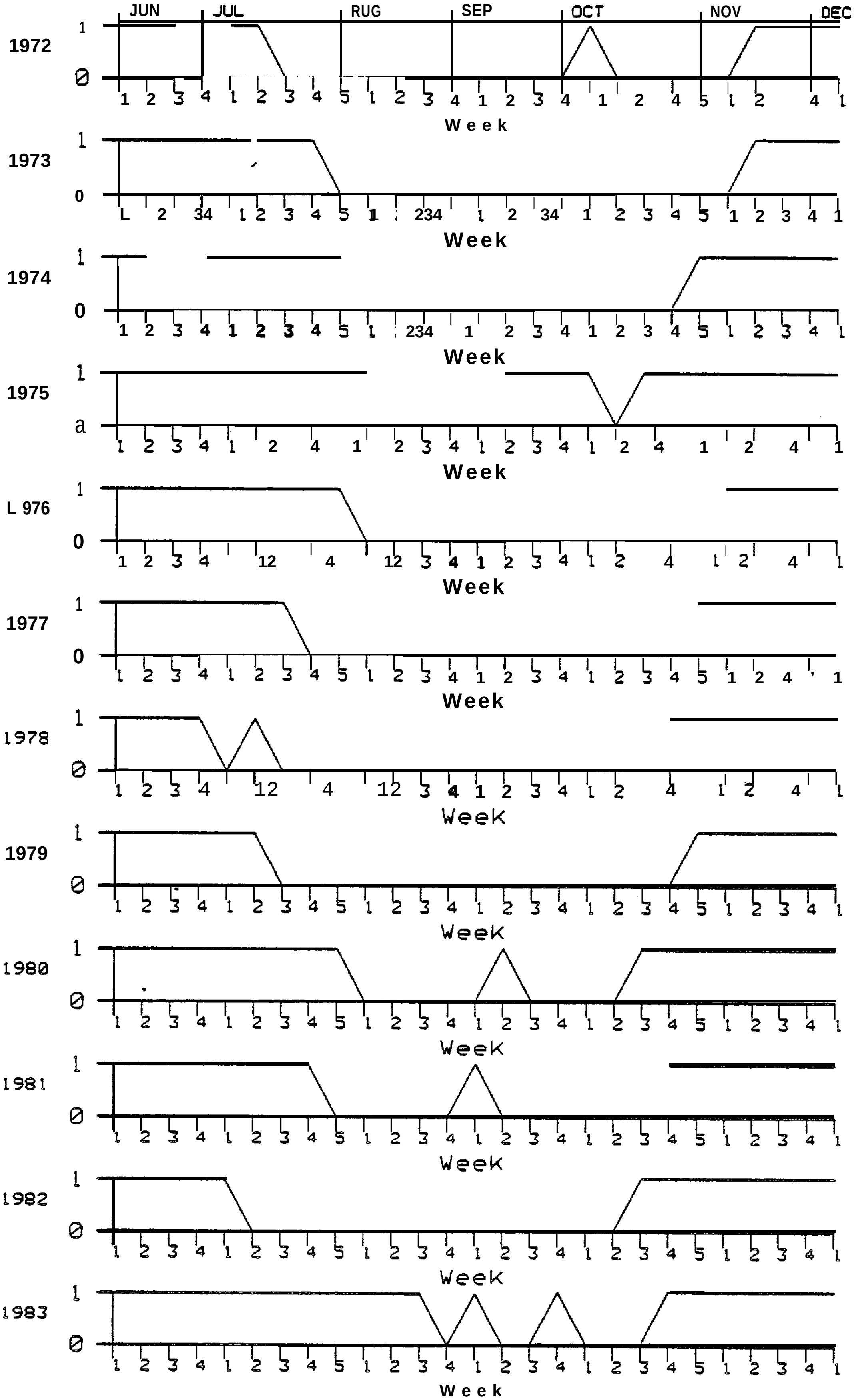



FIGURE 168 ICE PRESENCE HISTORY AT STATION 30 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

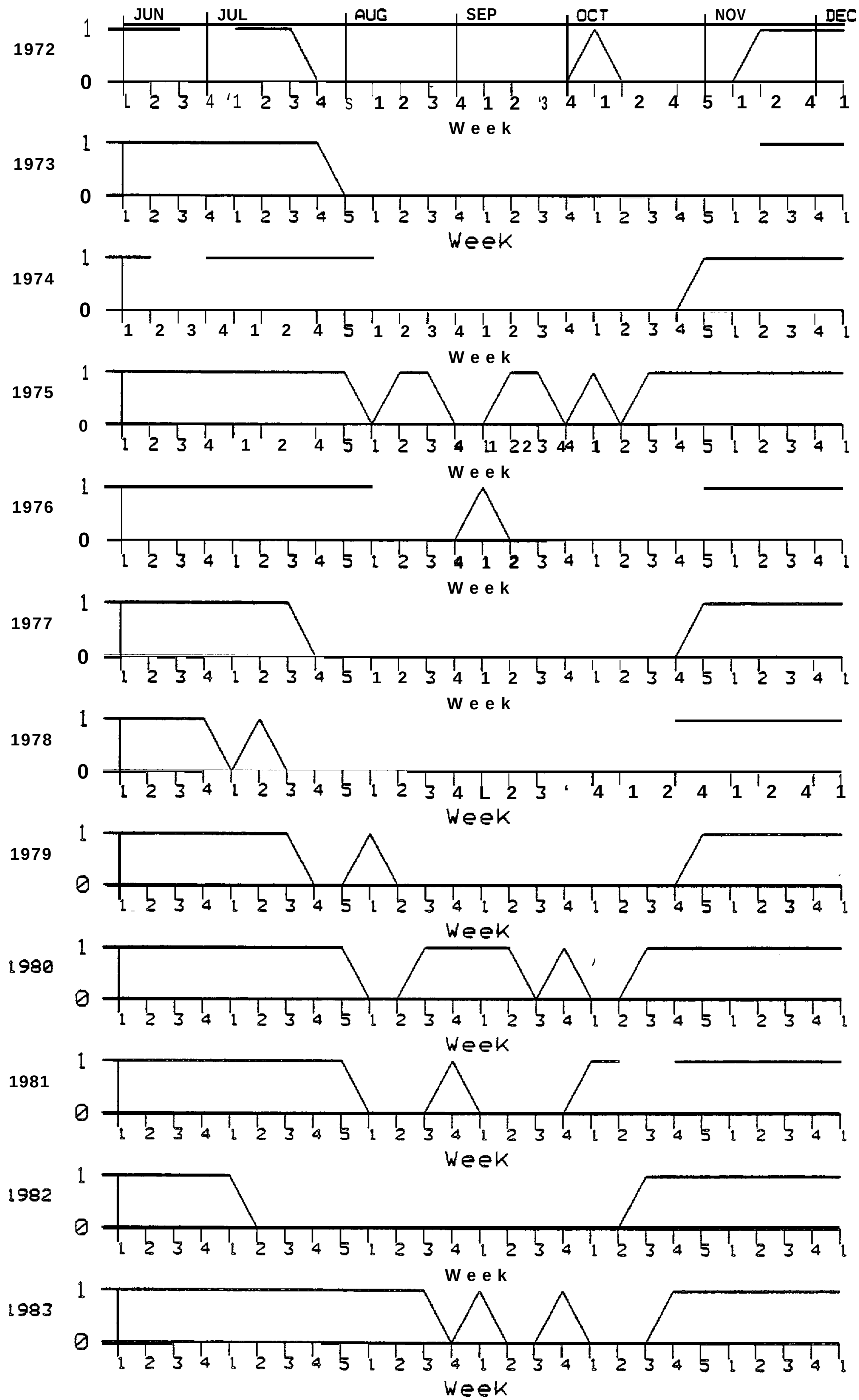



FIGURE 169 ICE PRESENCE HISTORY AT STATION 31 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY, ICE IS EITHER PRESENT OR IT IS NOT

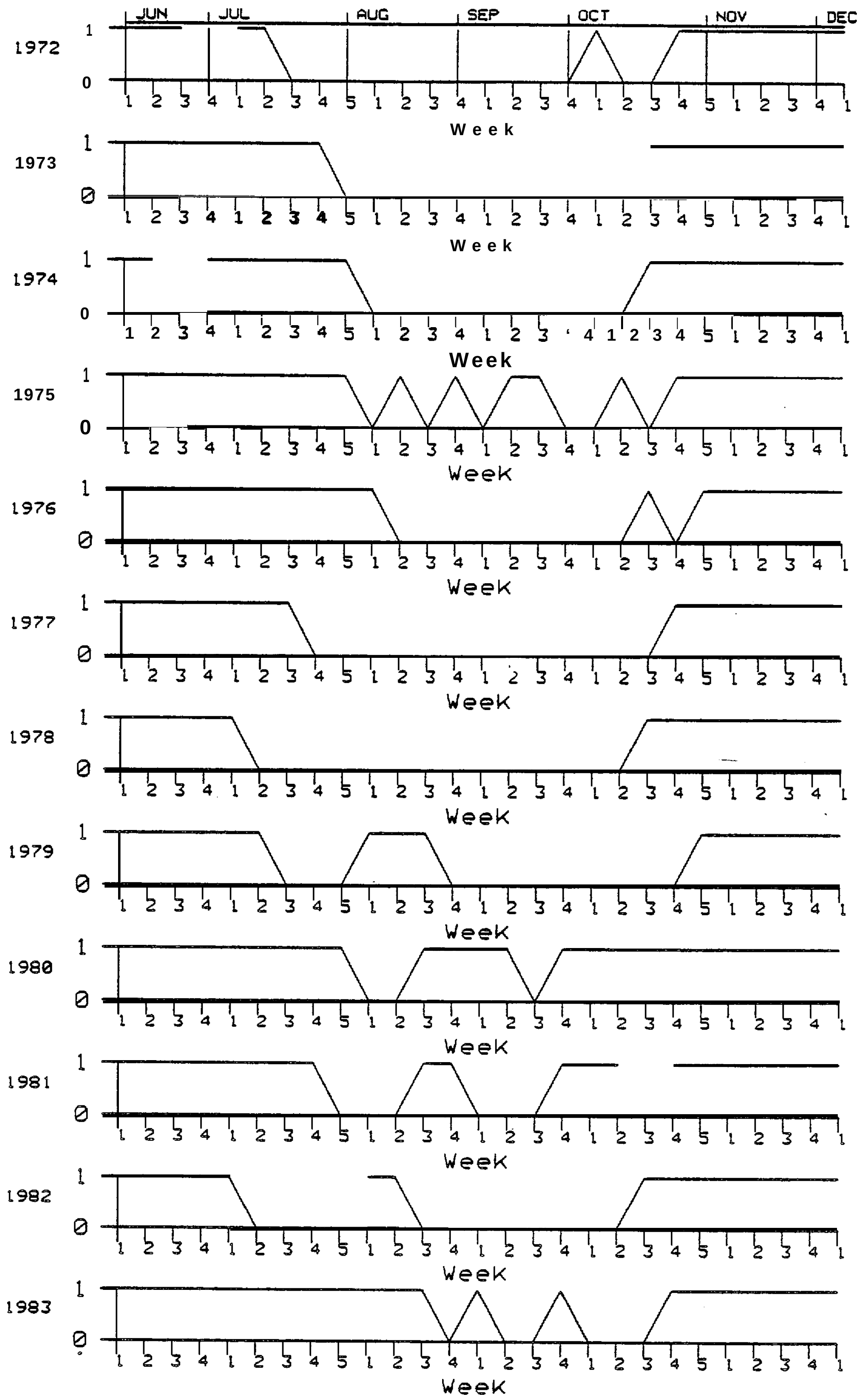



FIGURE 170 ICE PRESENCE HISTORY AT STATION 32 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

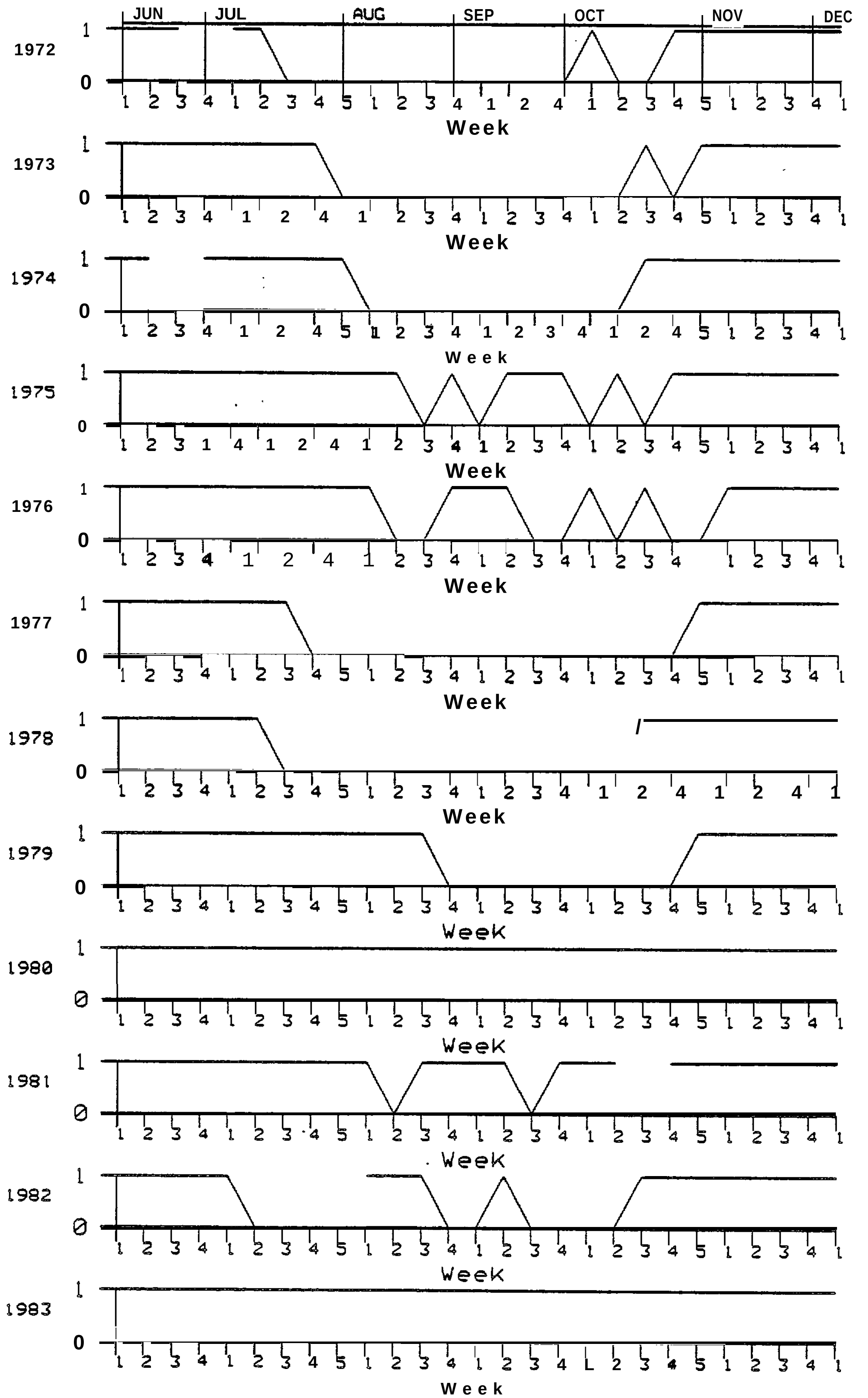



FIGURE 171 ICE PRESENCE HISTORY AT STATION 33 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

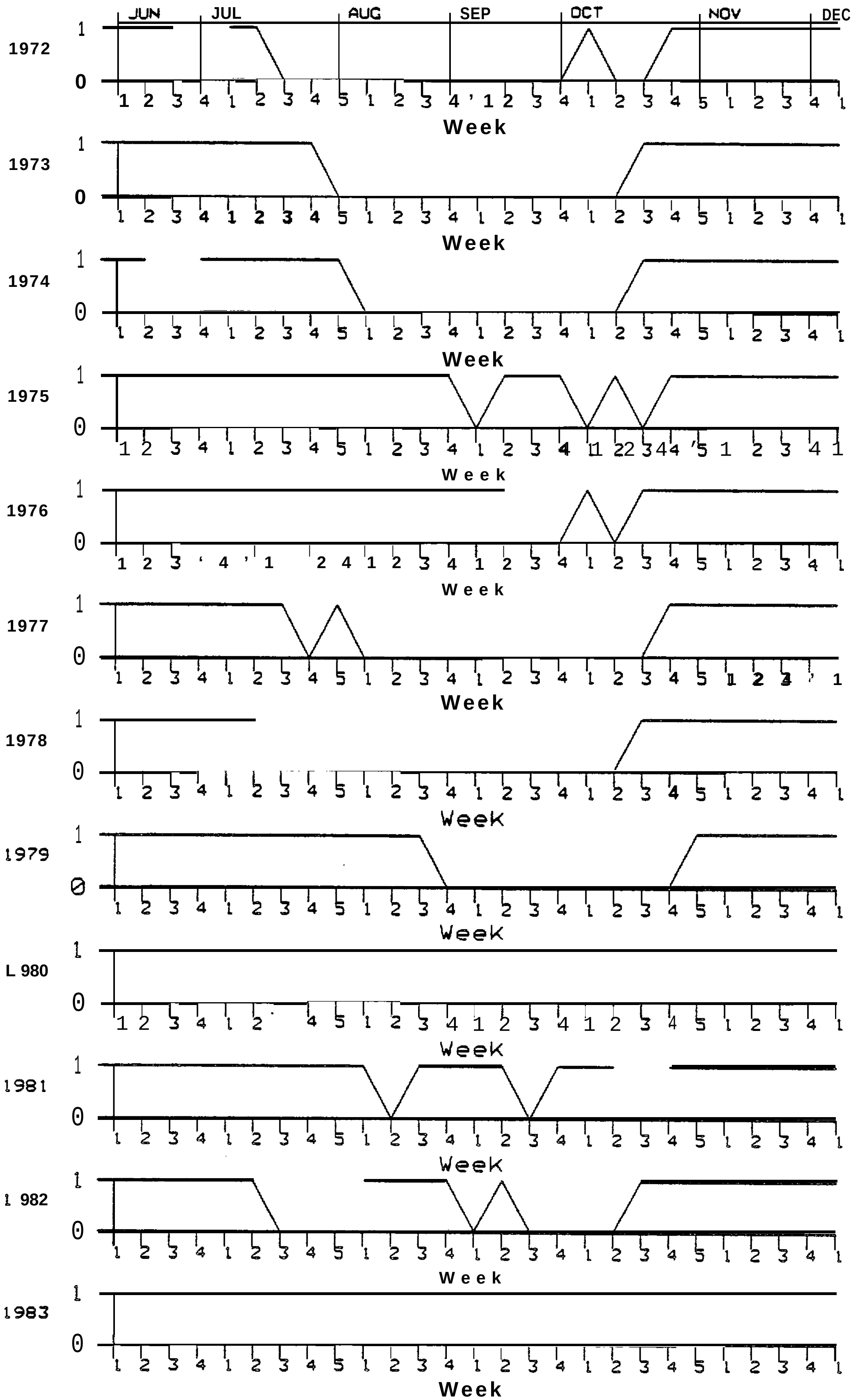



FIGURE 172 ICE PRESENCE HISTORY AT STATION 34 THE DATA REPRESENT THE WEEKLY SAMPLING Of ICE PRESENCE THE TABULATION Is BINARY, ICE IS EITHER PRESENT OR IT IS NOT

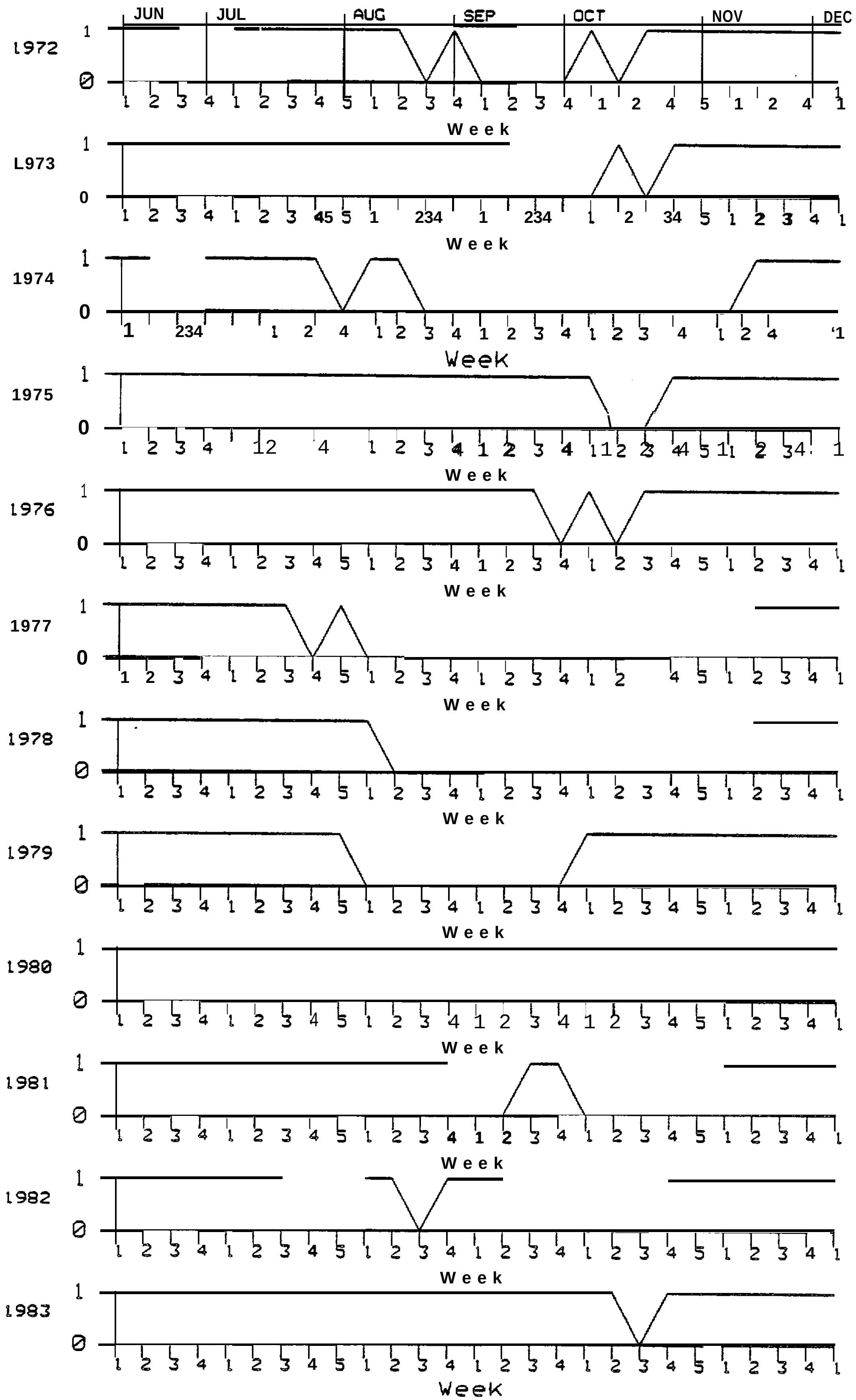



FIGURE 173 ICE PRESENCE HISTORY AT STATION 35 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY, ICE IS EITHER PRESENT OR IT IS NOT

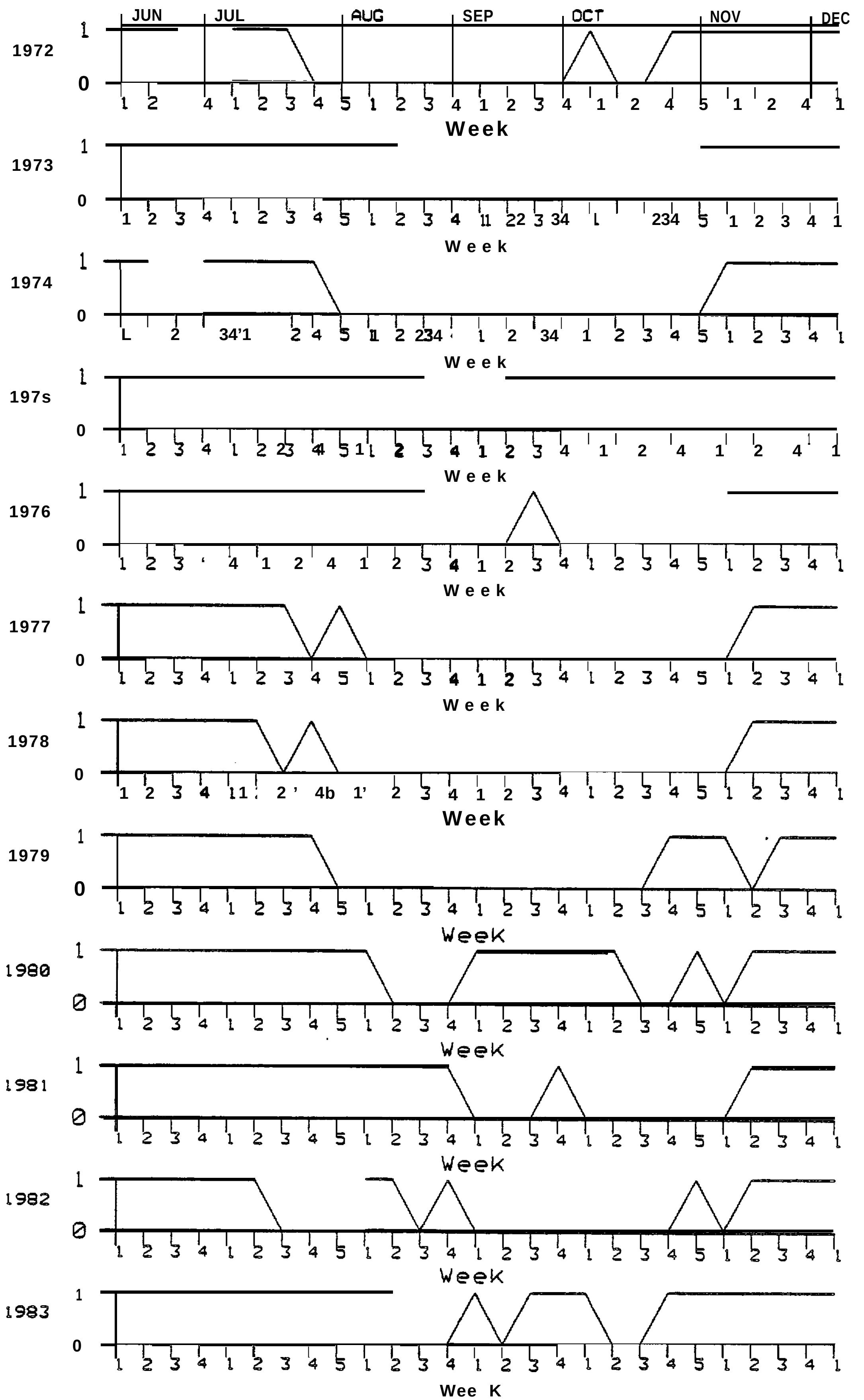



FIGURE 1.74 ICE PRESENCE HISTORY AT STATION 36 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

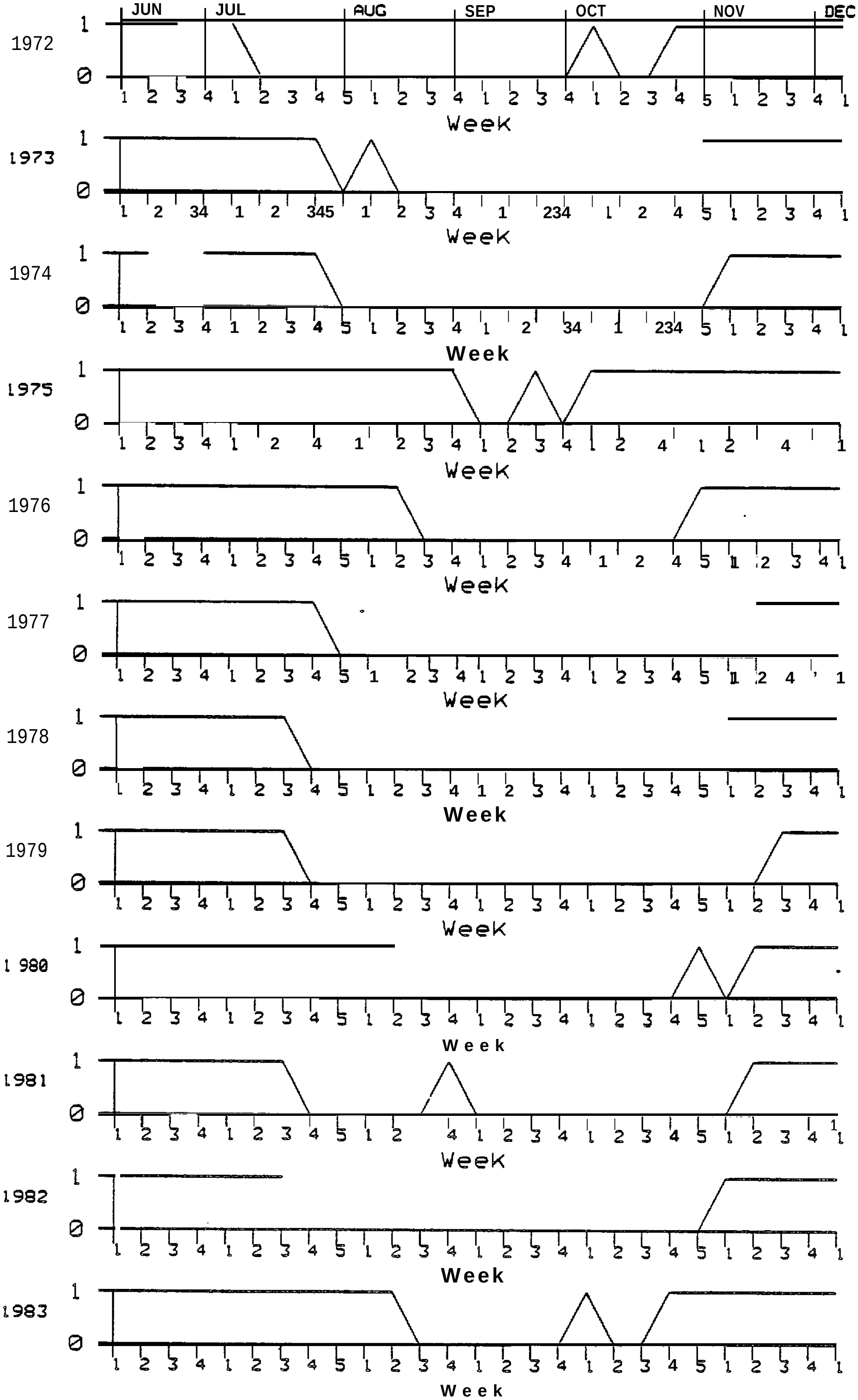



FIGURE 175 ICE PRESENCE HISTORY AT STATION 37 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY, ICE IS EITHER PRESENT OR IT IS NOT

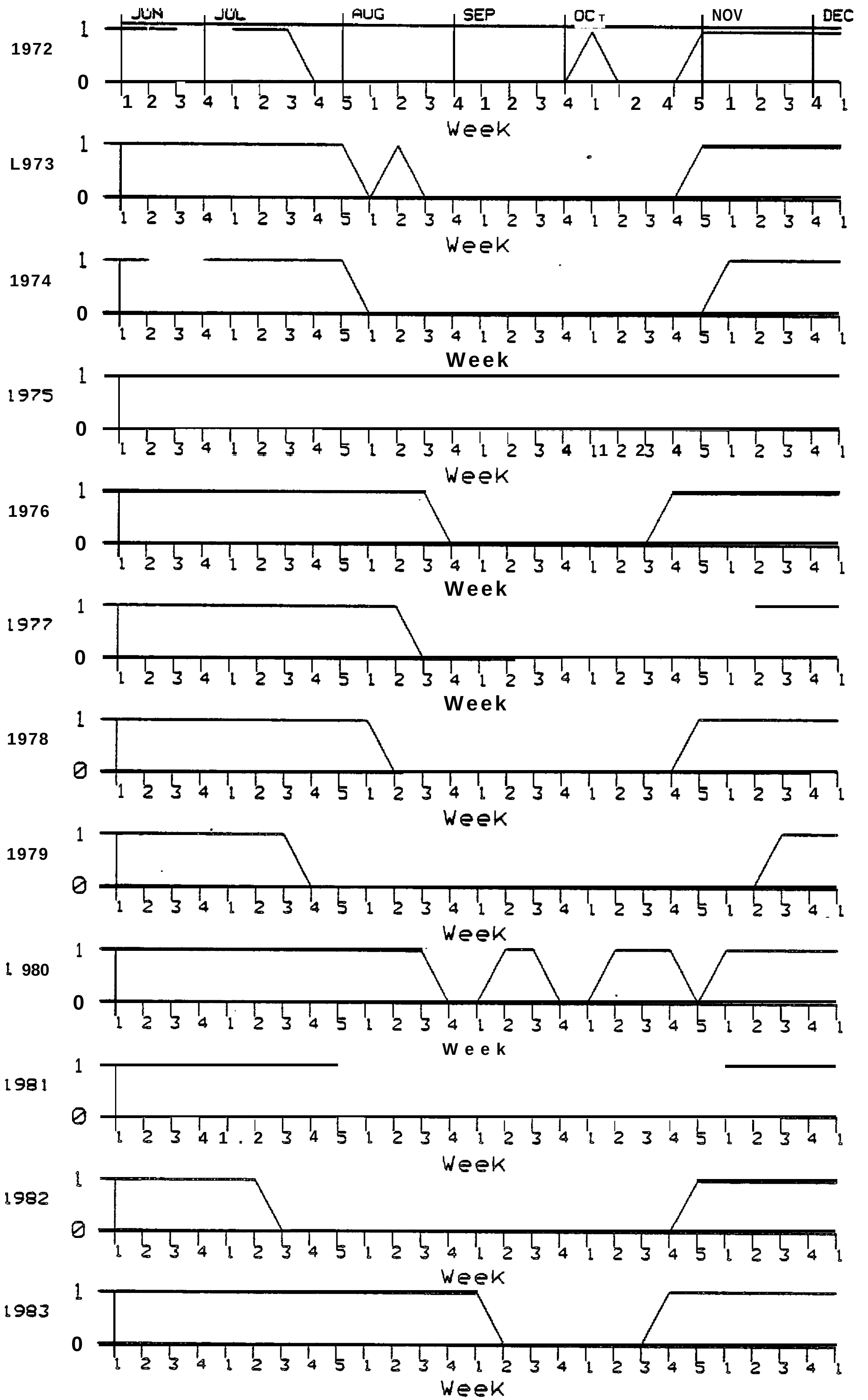



FIGURE 176 ICE PRESENCE HISTORY AT STATION 38 THE DATA Represent THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

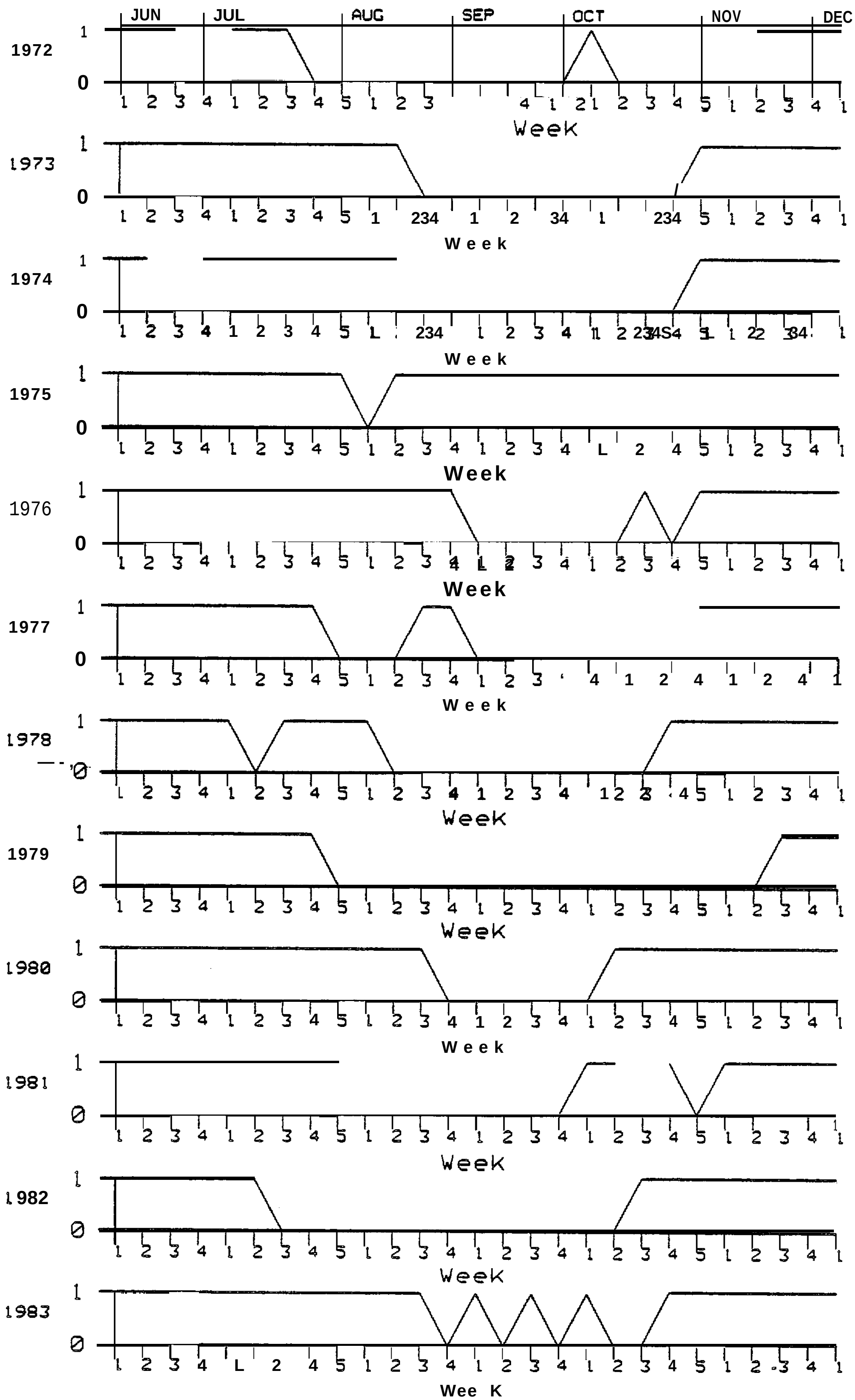
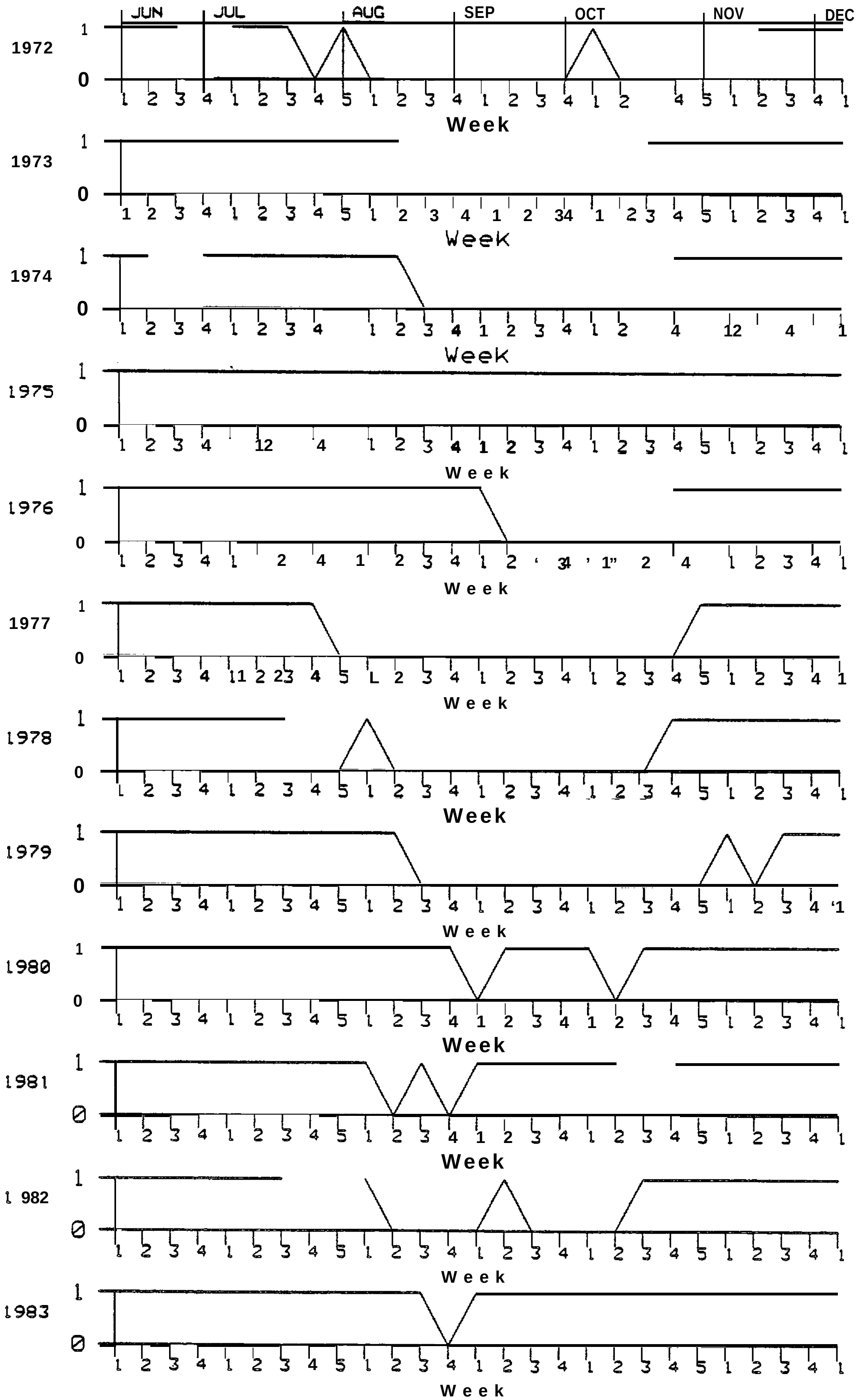



FIGURE 177 ICE PRESENCE HISTORY AT STATION 39 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT




FIGUREl 78 ICE PRESENCE HISTORY AT STATION 40 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY, ICE IS EITHER PRESENT OR IT IS NOT

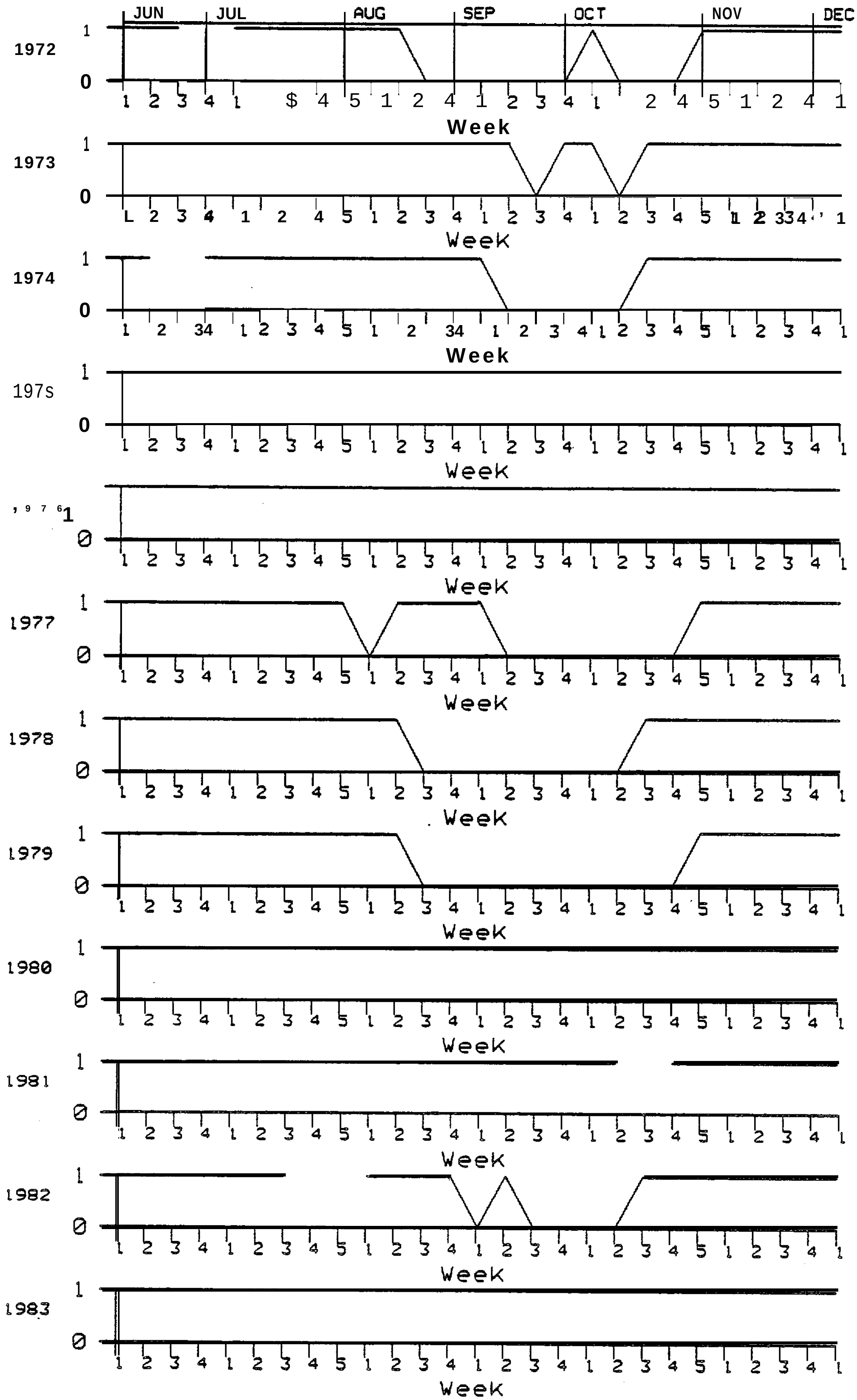



FIGURE 179 ICE PRESENCE HISTORY AT STATION 41 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

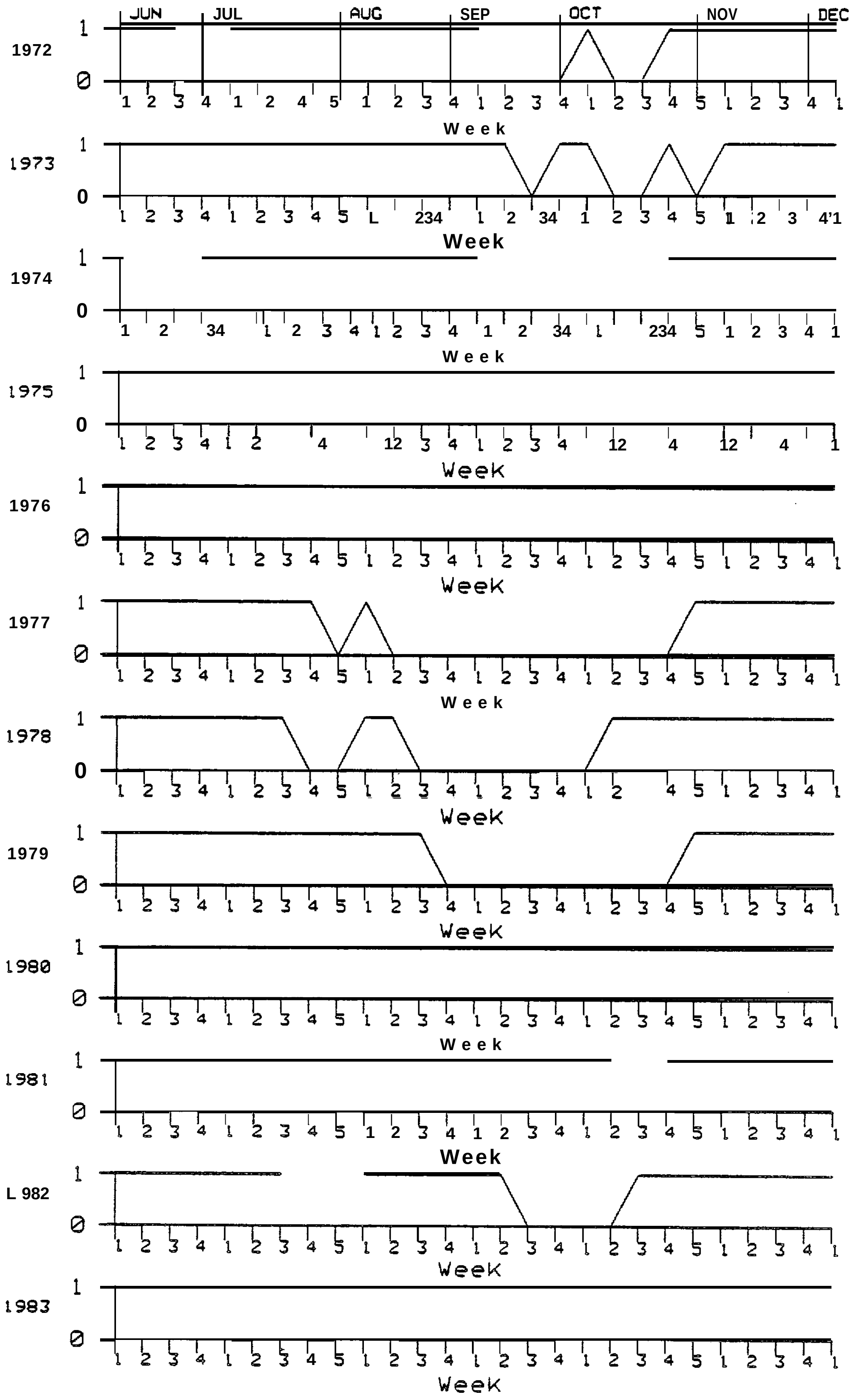



FIGURE 180 ICE PRESENCE HISTORY AT STATION 42 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

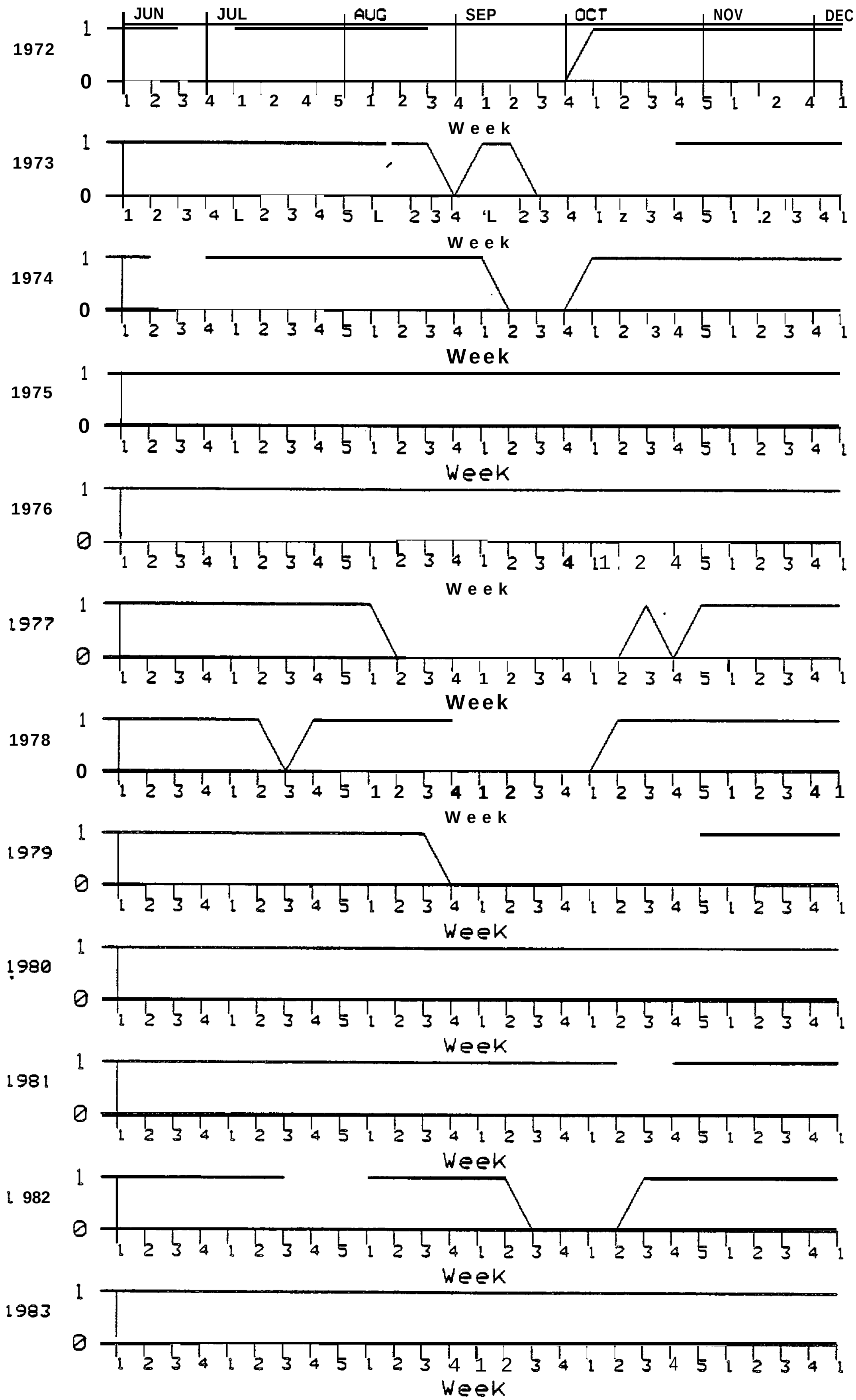



FIGURE 181 ICE PRESENCE HISTORY AT STATION 43 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

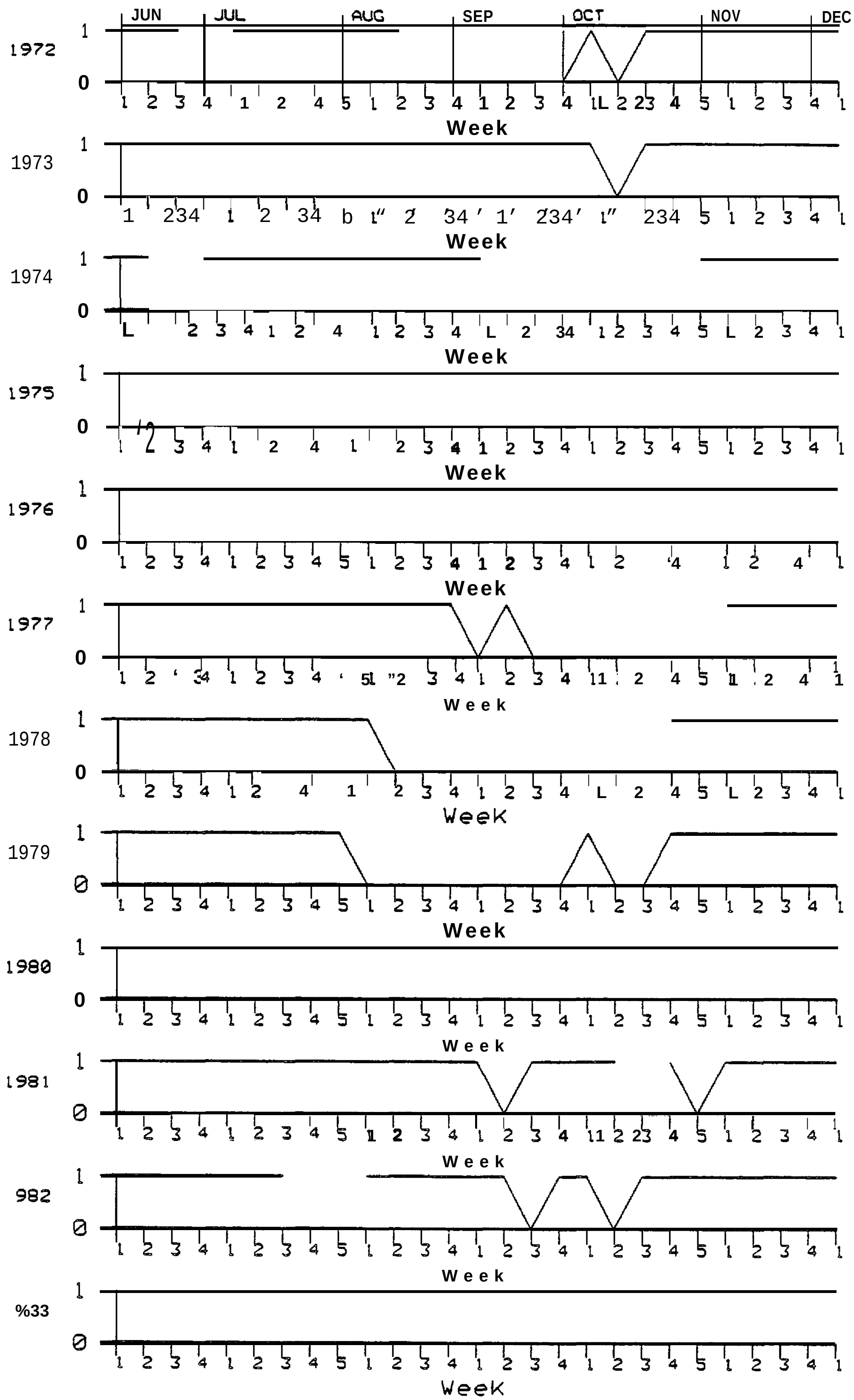



FIGURE 182 ICE PRESENCE HISTORY AT STATION 44 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY, ICE IS EITHER PRESENT OR IT IS NOT

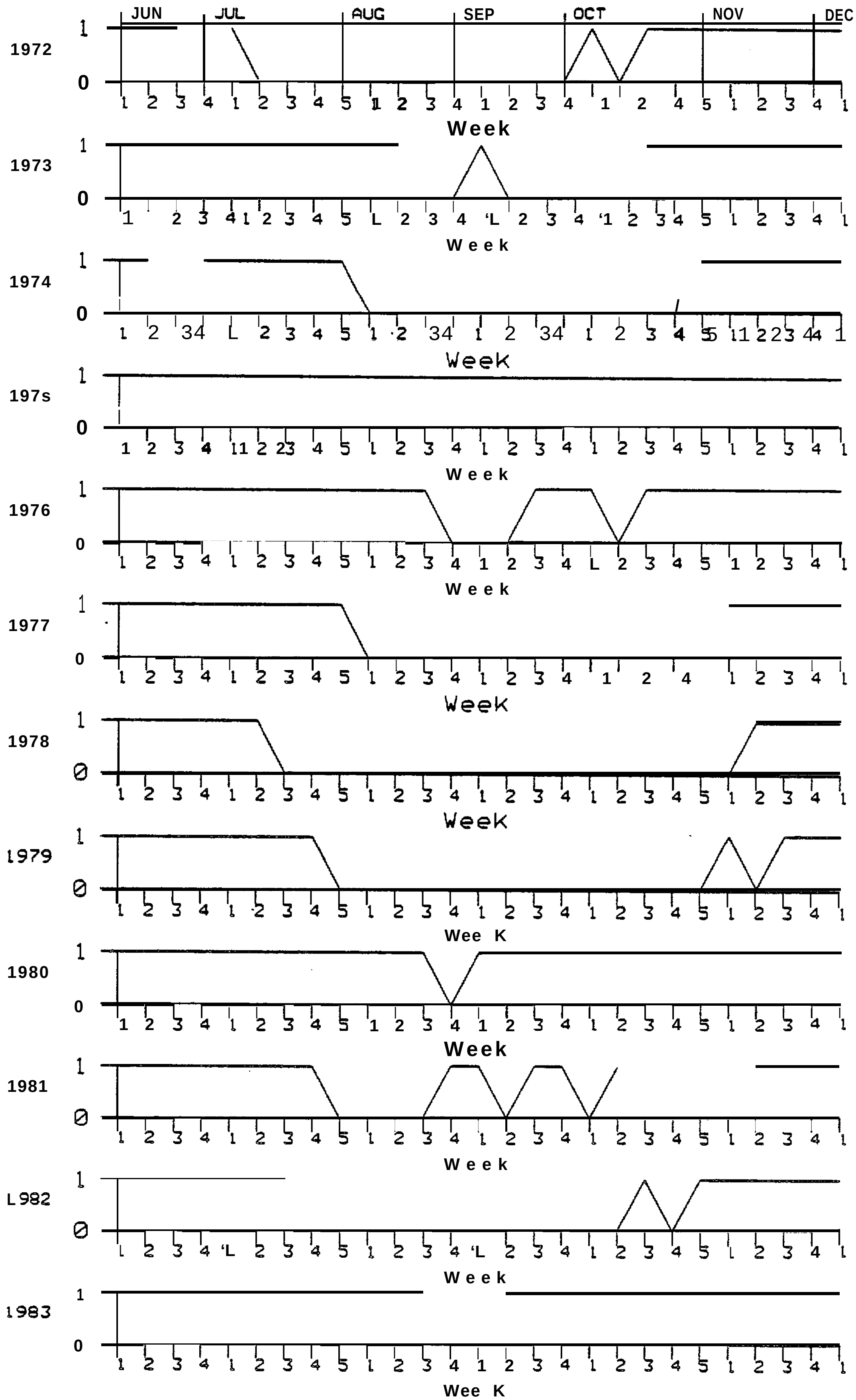



FIGURE 183 ICE PRESENCE HISTORY AT STATION 45 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY, ICE IS EITHER PRESENT OR IT IS NOT

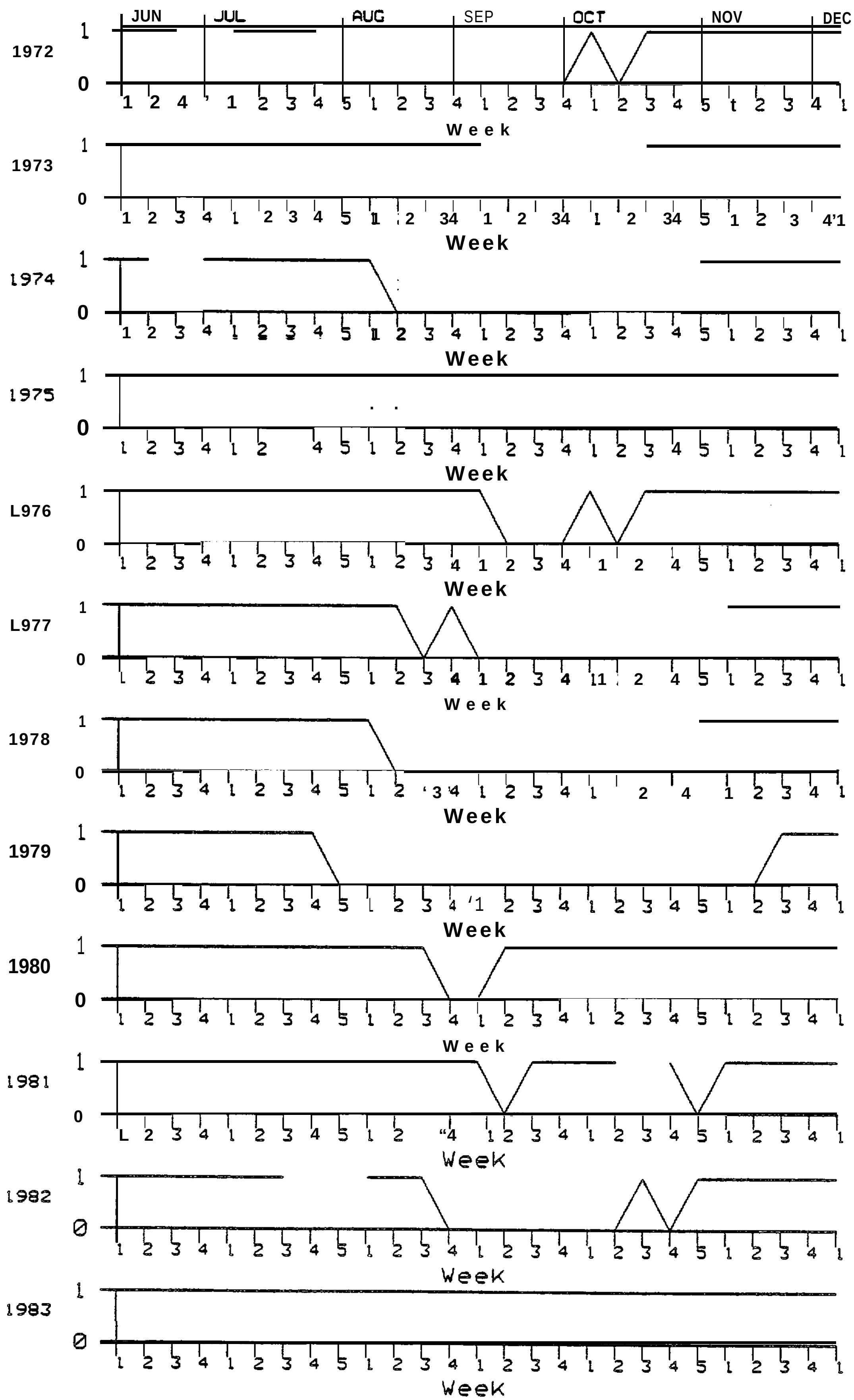



FIGURE 1 84 ICE PRESENCE HISTORY AT STATION 46 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

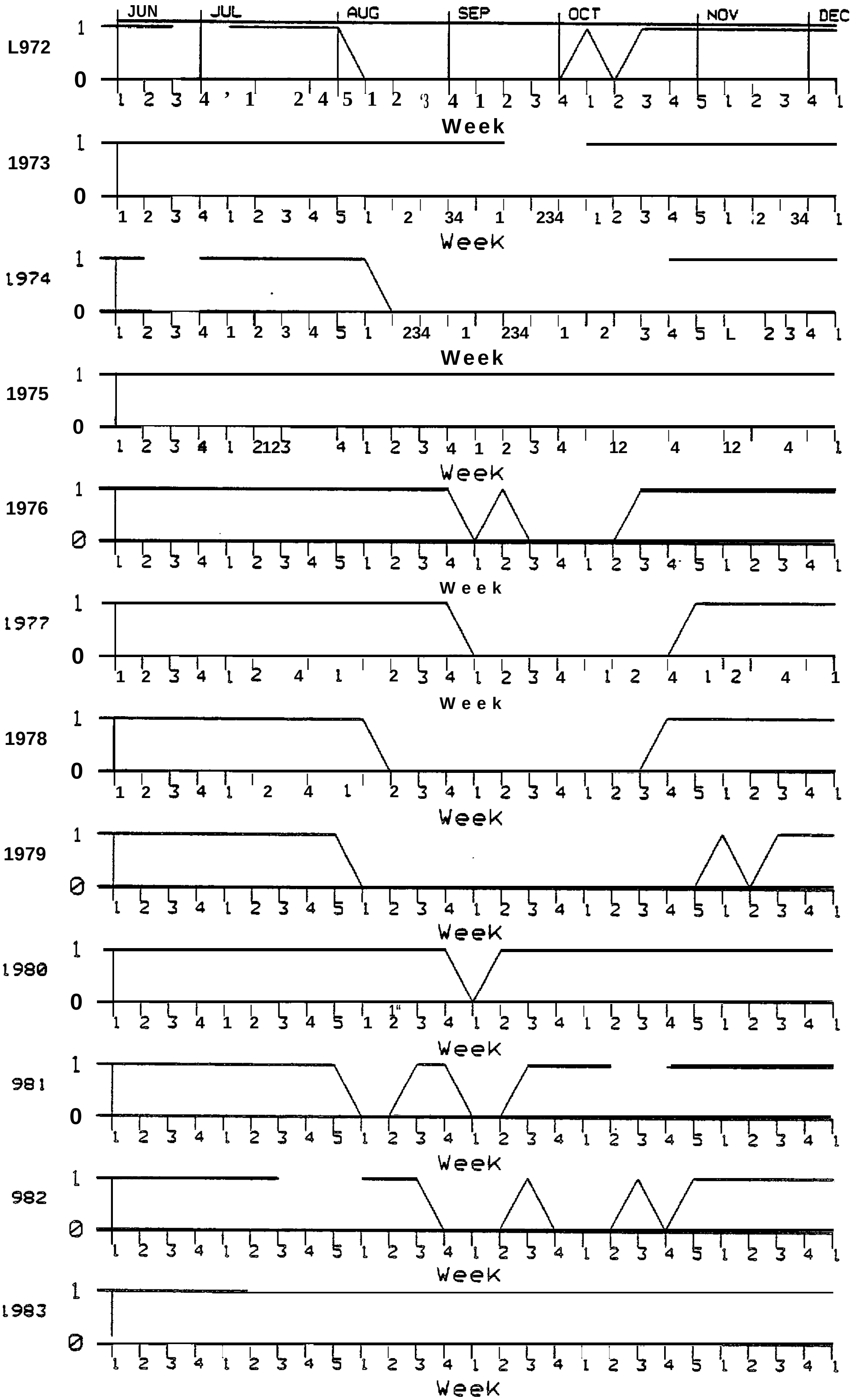



FIGURE 185 ICE PRESENCE HISTORY AT STATION 4-7 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULAT ON IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

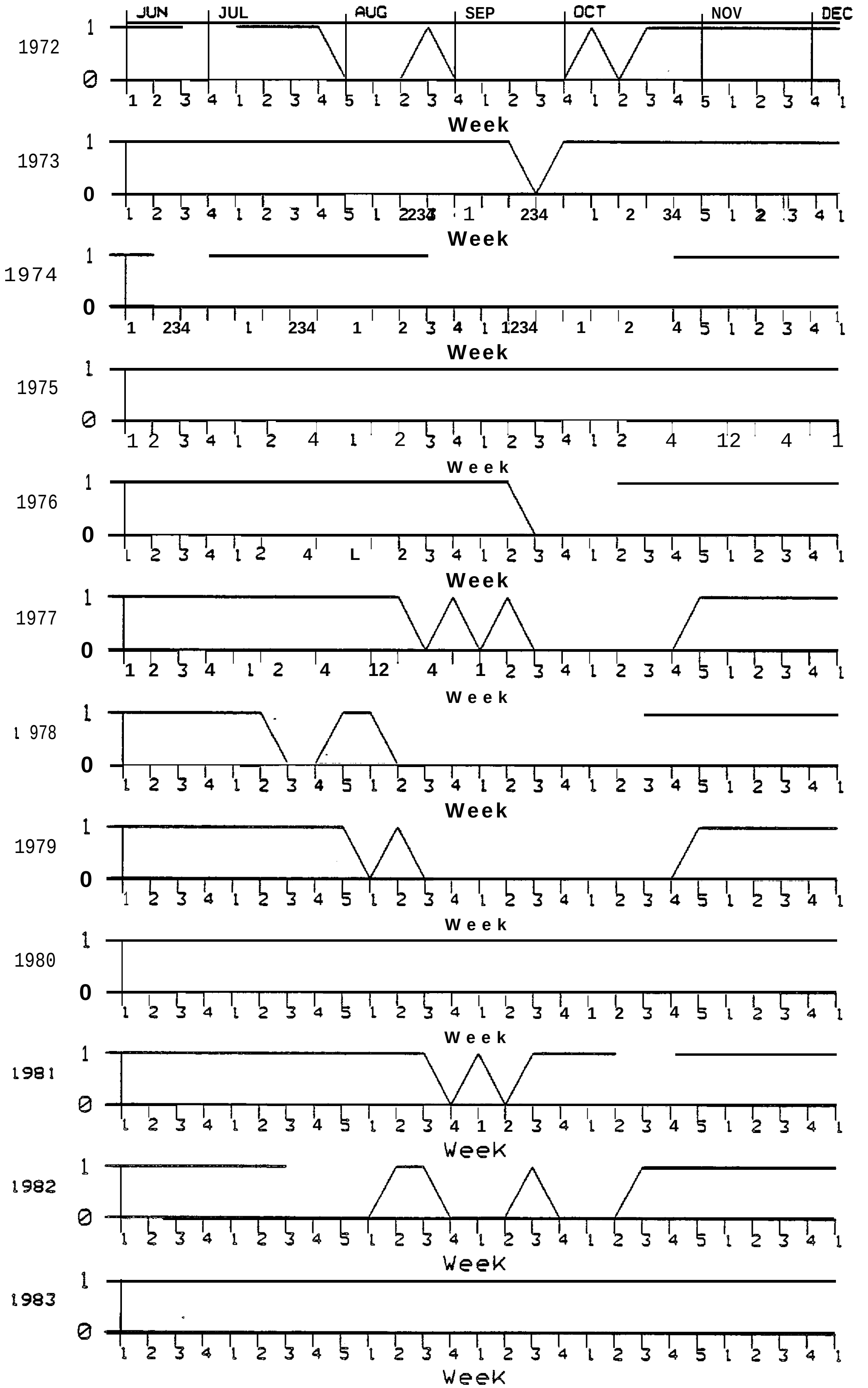



FIGURE 186 ICE PRESENCE HISTORY AT STATION 43 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

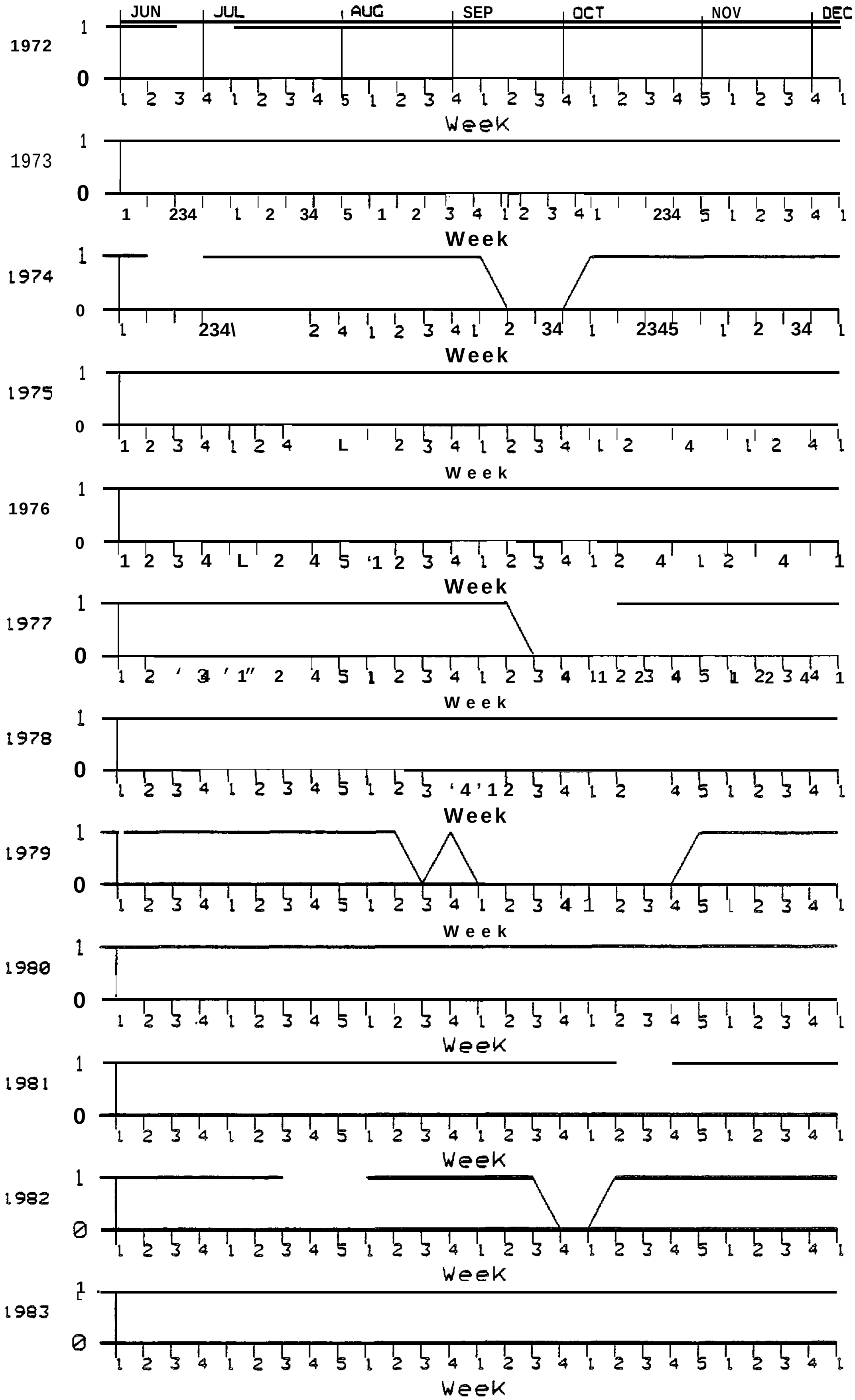



FIGURE 187 ICE PRESENCE HISTORY AT STATION 49 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

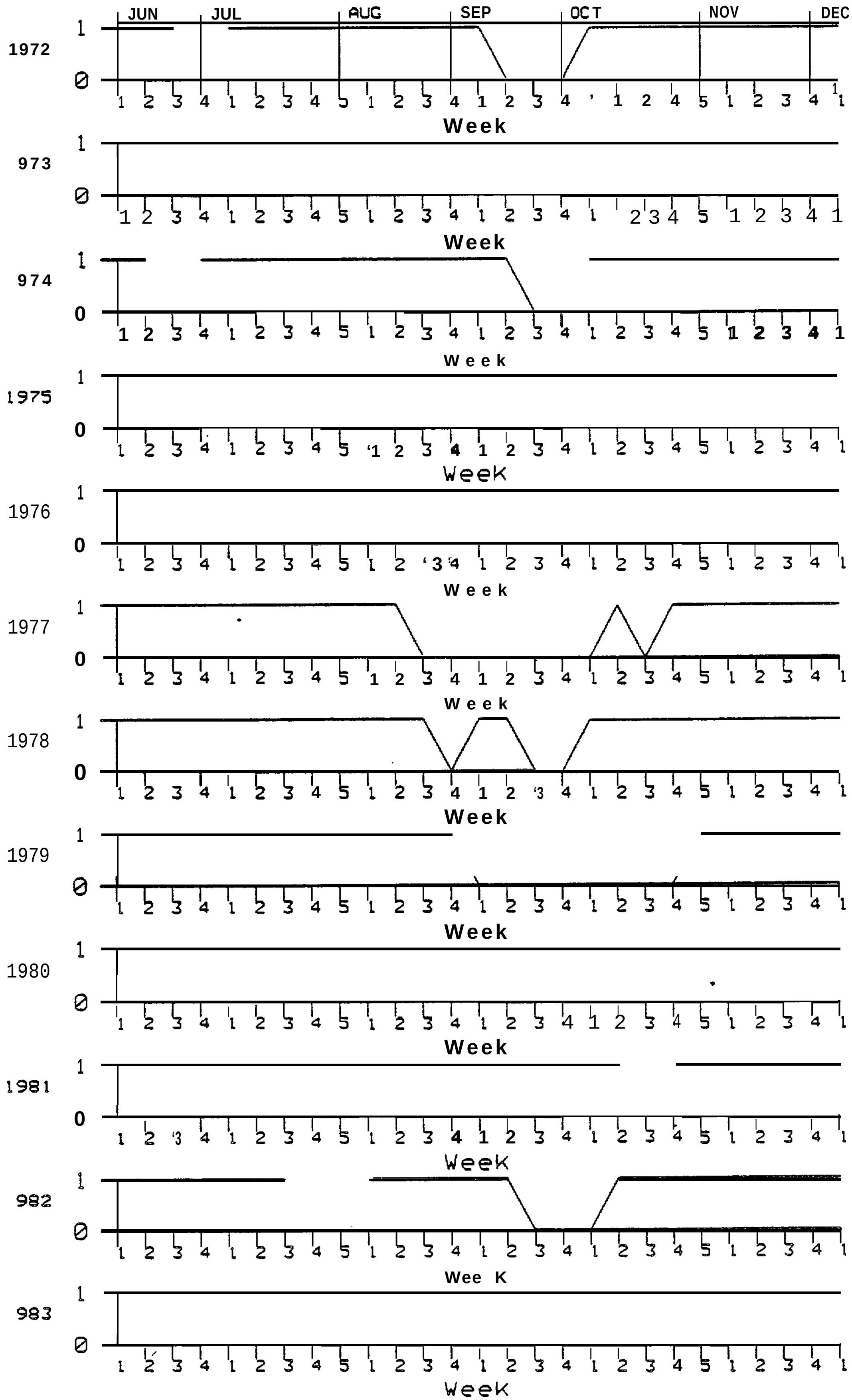
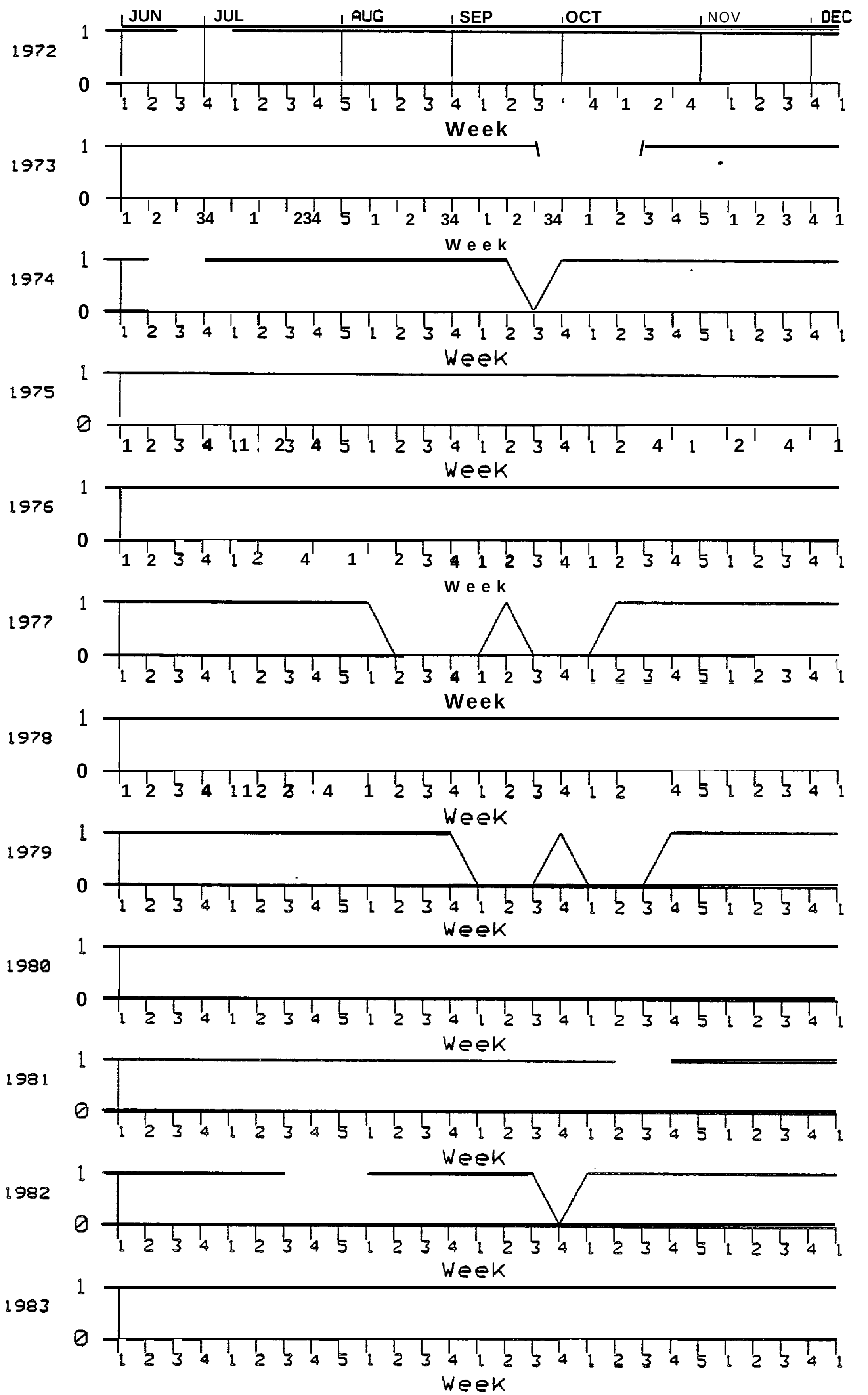



FIGURE 188 ICE PRESENCE HISTORY AT STATION 5 0 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT




FI CURIE 189 ICE PRESENCE HISTORY AT STATION 51 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

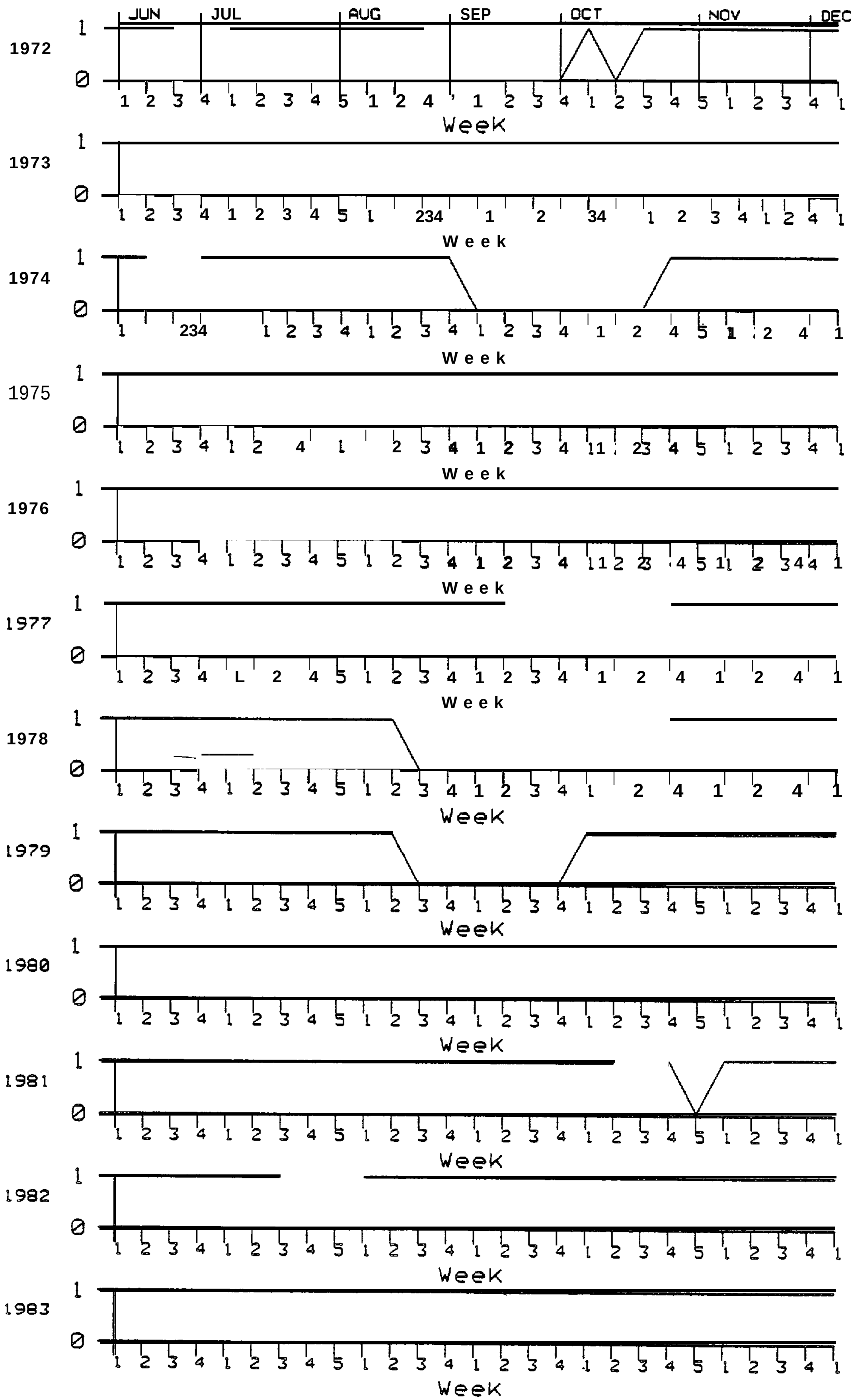



FIGURE 190 ICE PRESENCE HISTORY AT STATION 52 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

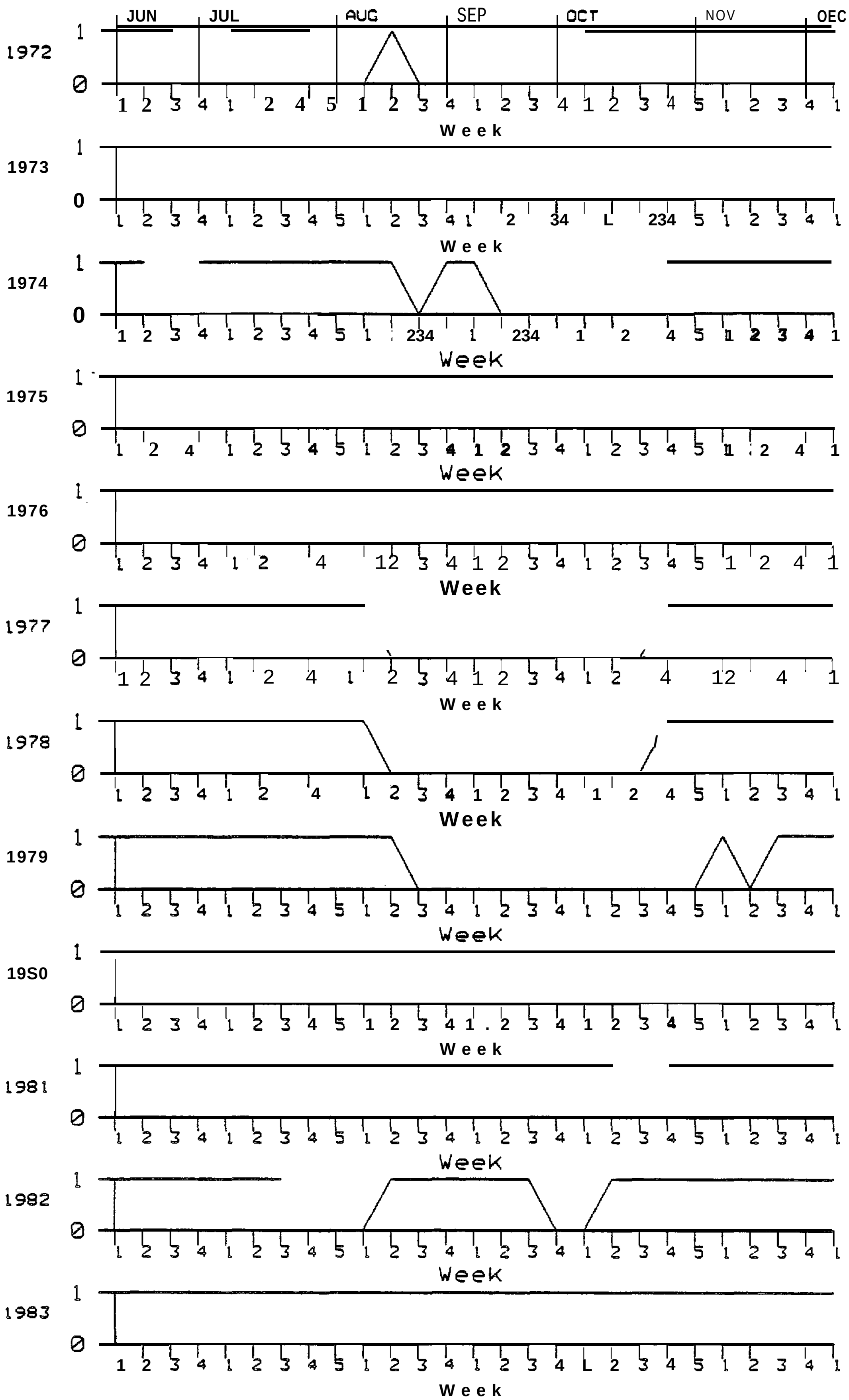



FIGURE 191 ICE PRESENCE HISTORY AT STATION 53 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

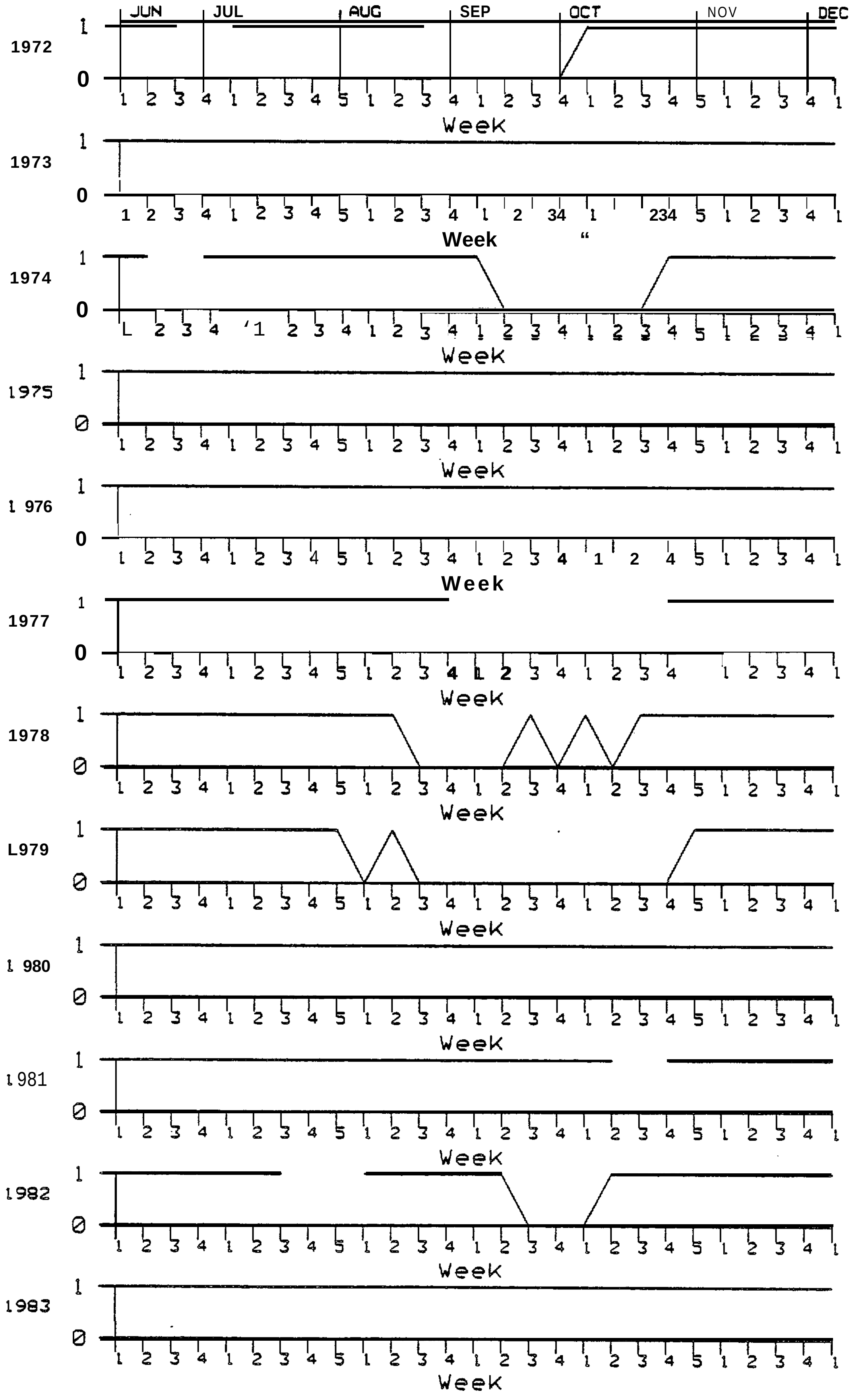



FIGURE 192 ICE PRESENCE HISTORY AT STATION 54. THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

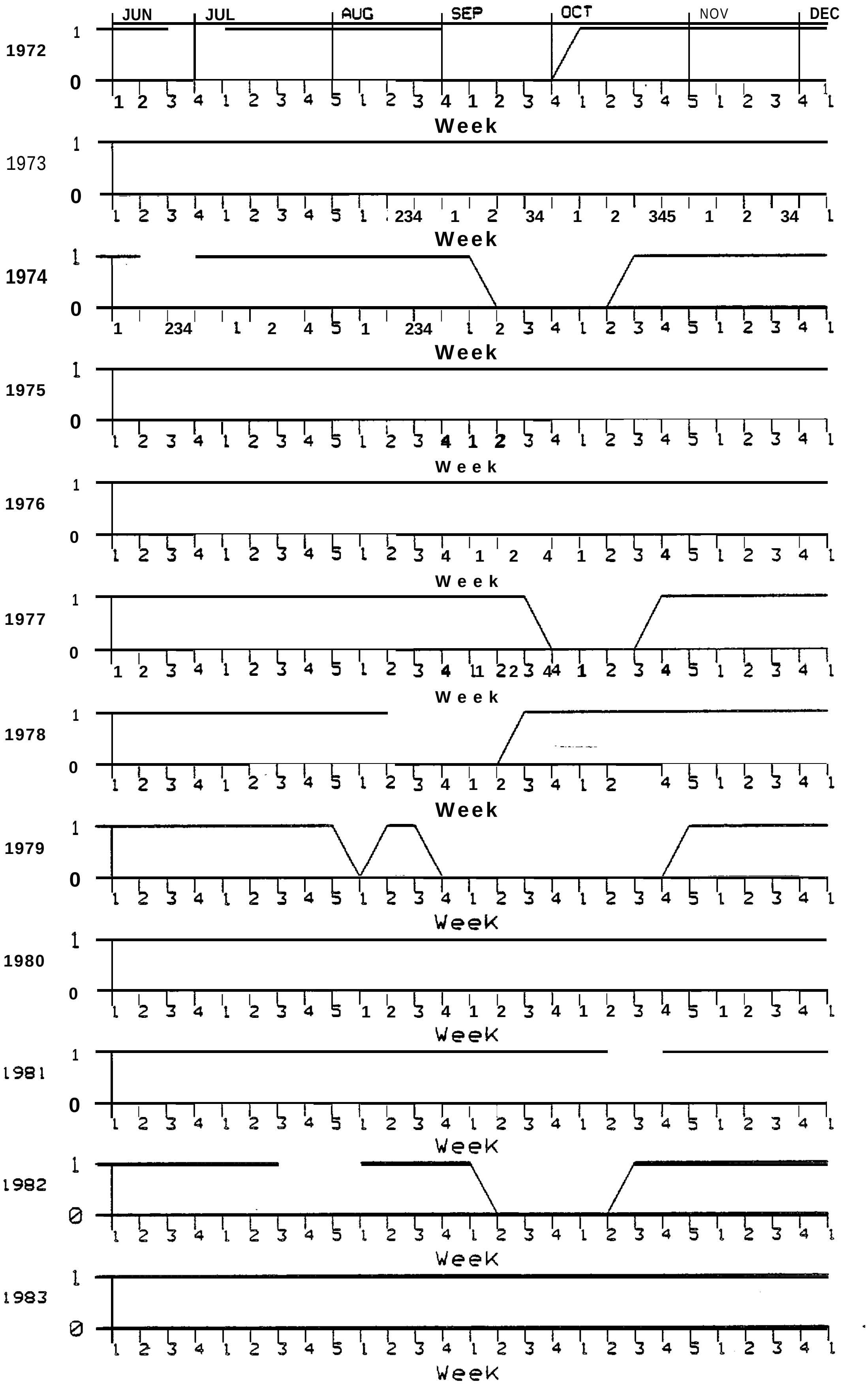



FIGURE 193 ICE PRESENCE HISTORY AT STATION 55 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

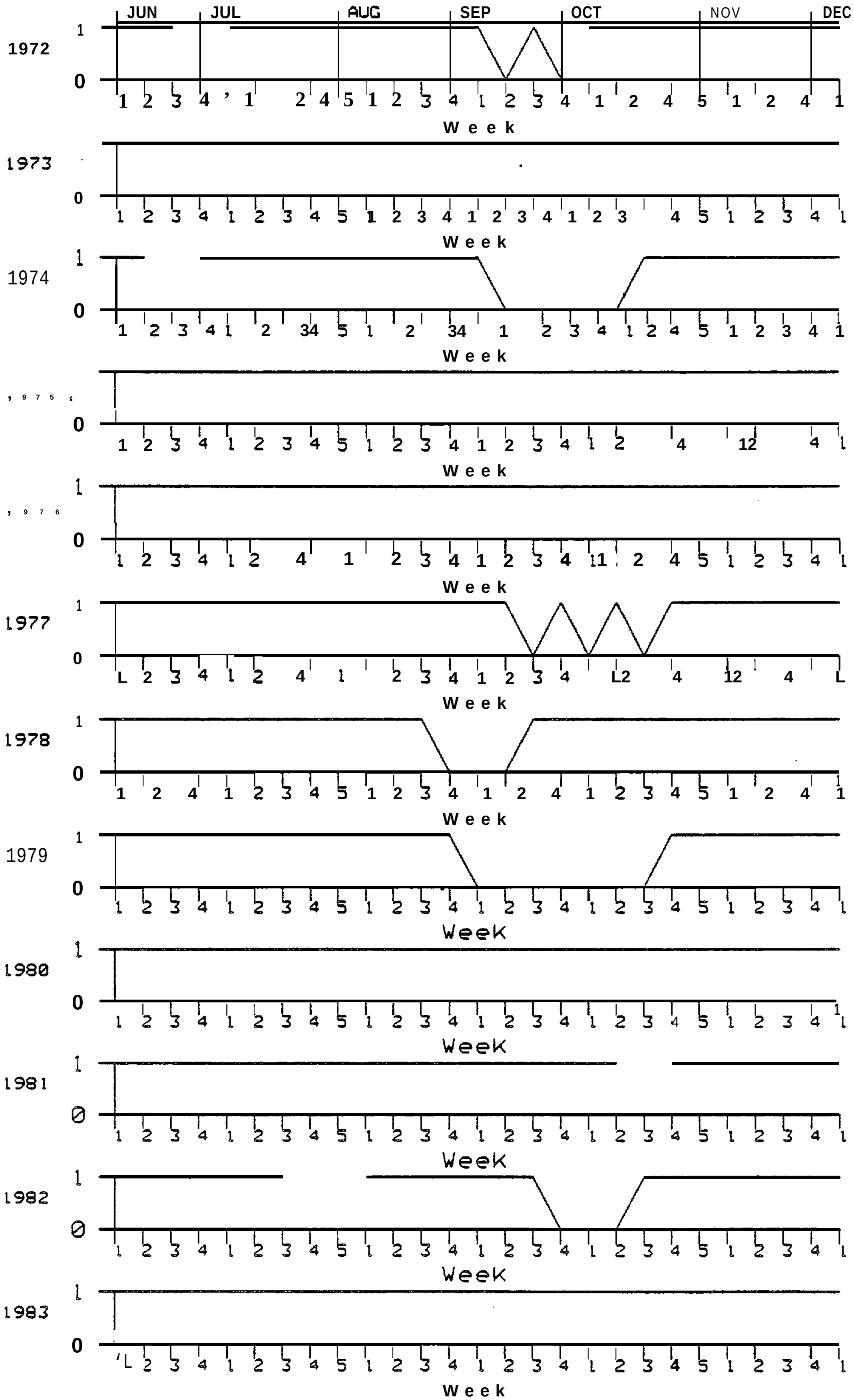



FIGURE 194 ICE PRESENCE HISTORY AT STATION 56 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

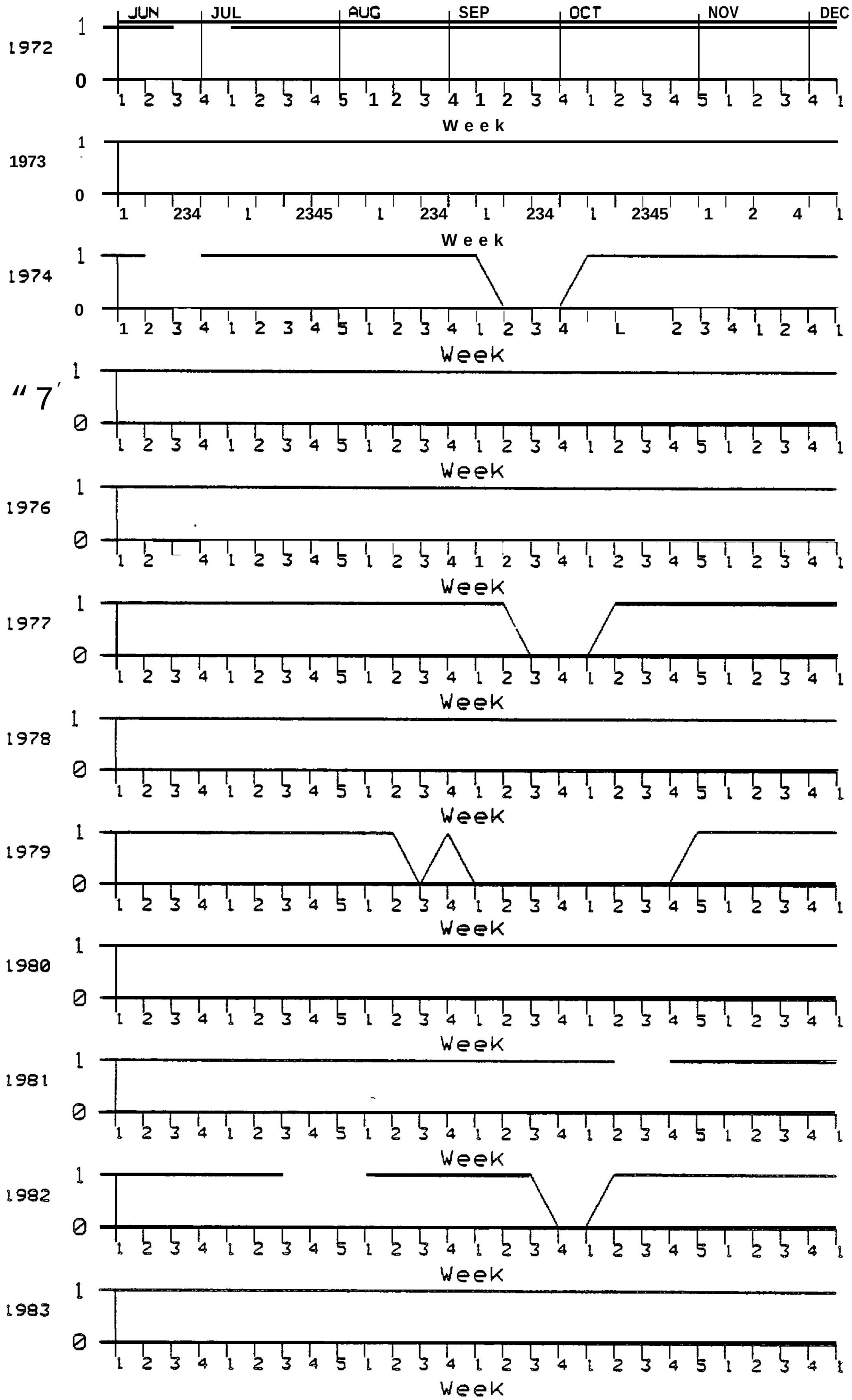



FIGURE 195 ICE PRESENCE HISTORY AT STATION 57 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

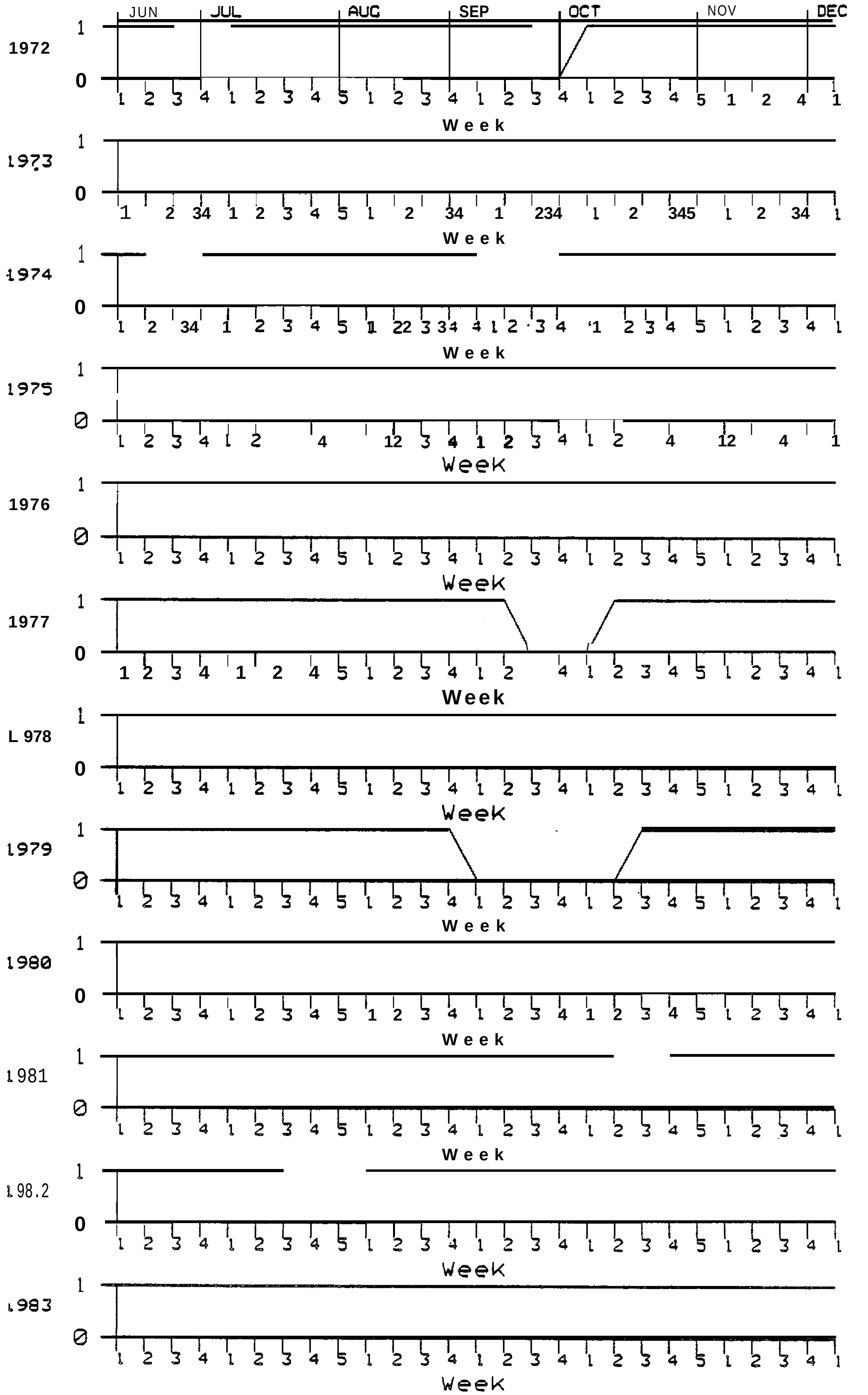



FIGURE 196 ICE PRESENCE HISTORY AT STATION 5$ THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

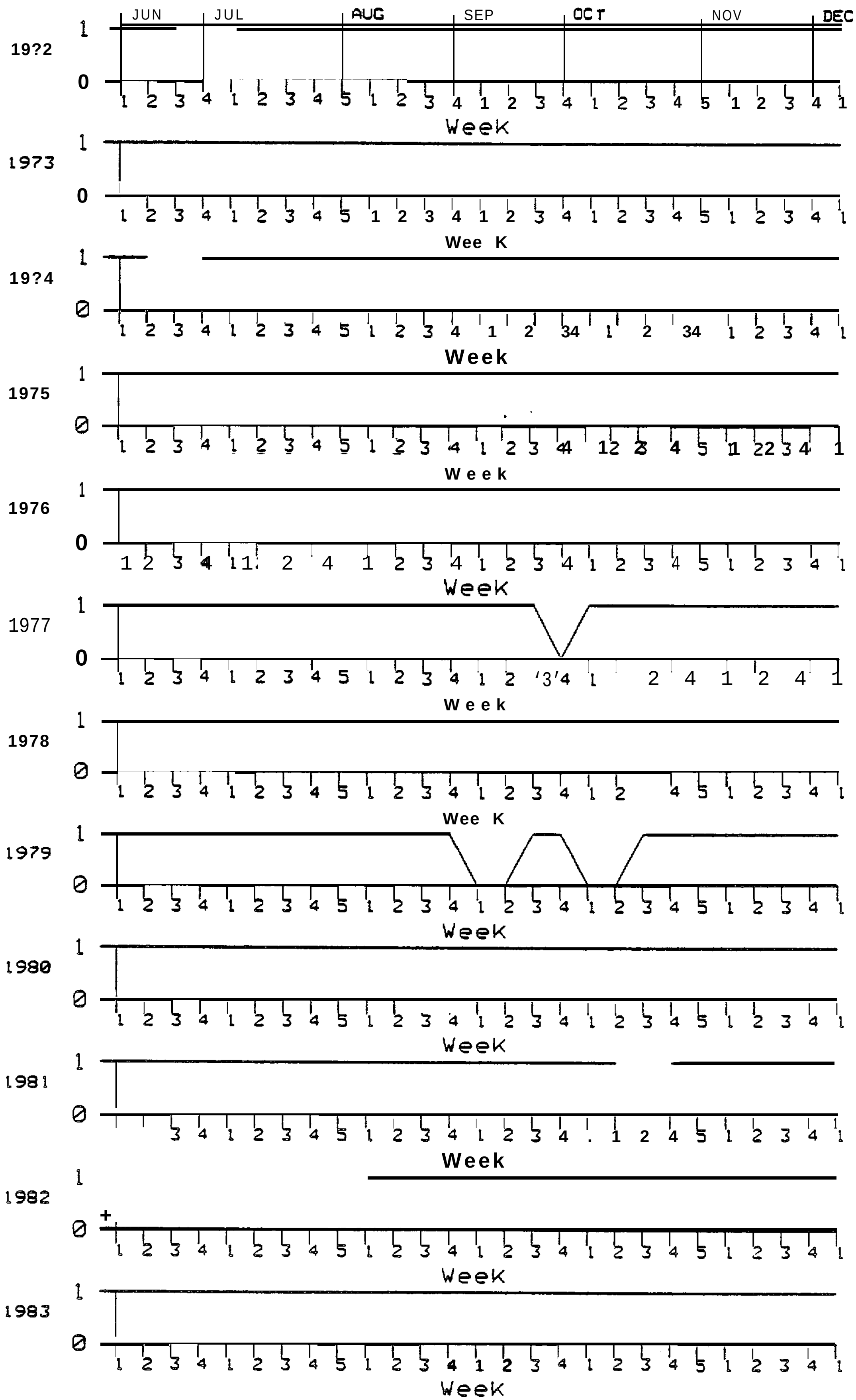



FIGURE 197 ICE PRESENCE HISTORY AT STATION 59 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

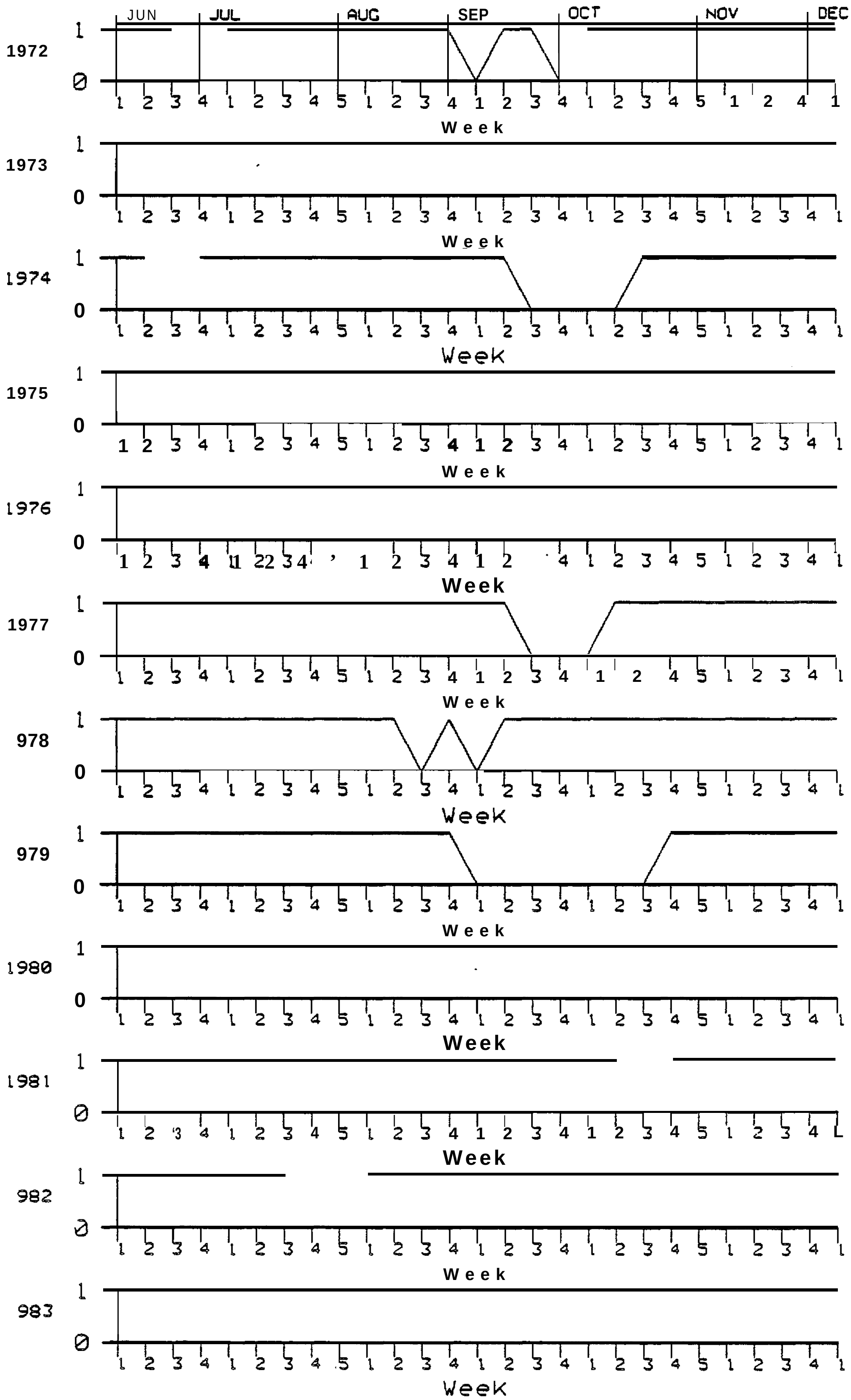



FIGURE 198 ICE PRESENCE HISTORY AT STATION 60 THE DATA REPRESENT THE WEEKLY SAMPLING of ICE PRESENCE THE TABULATION IS BINARY ICE IS EITHER PRESENT OR IT IS NOT

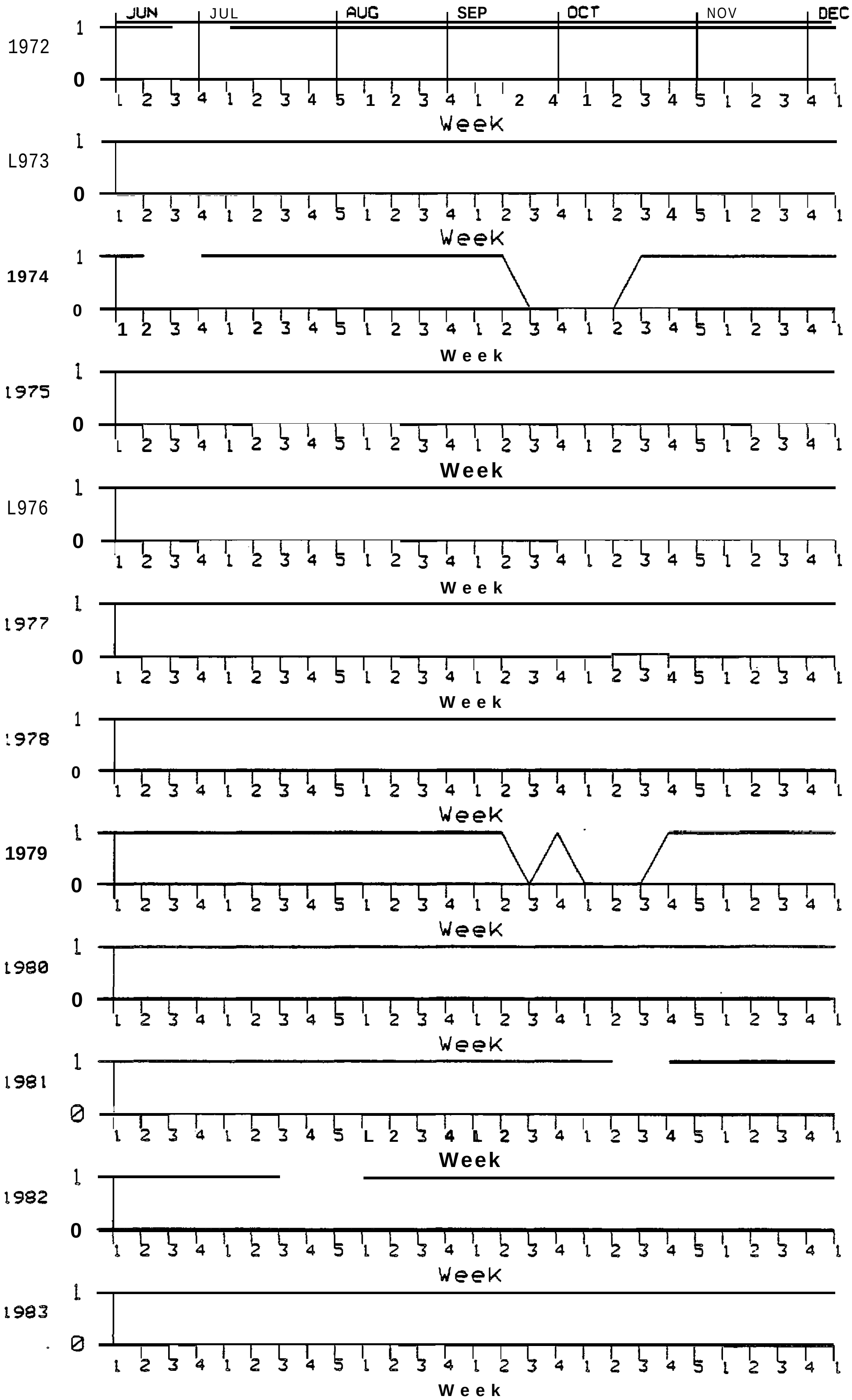



FIGURE 199 ICE PRESENCE HISTORY AT STATION 61 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

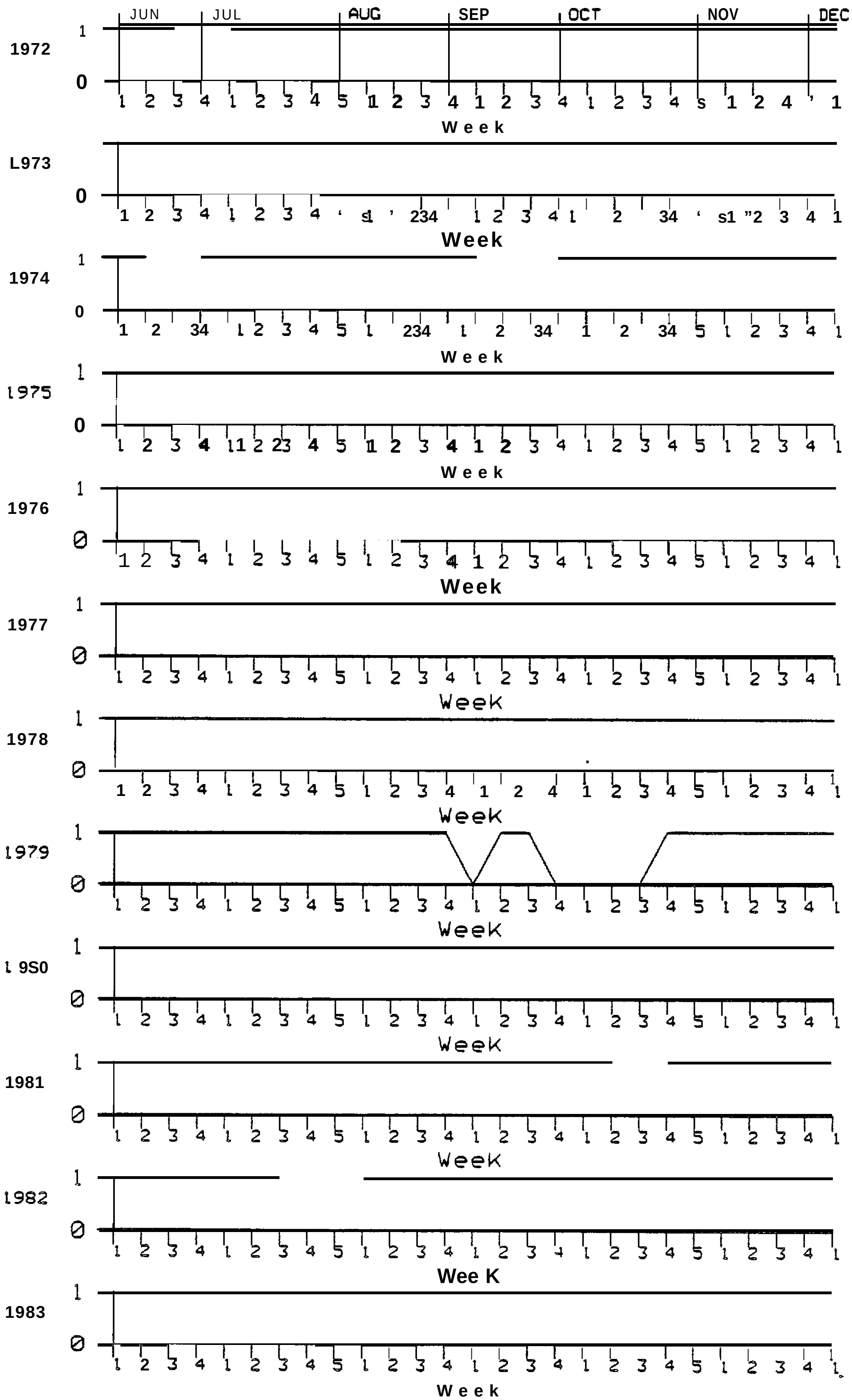



FIGURE 200 ICE PRESENCE HISTORY AT STATION 62 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

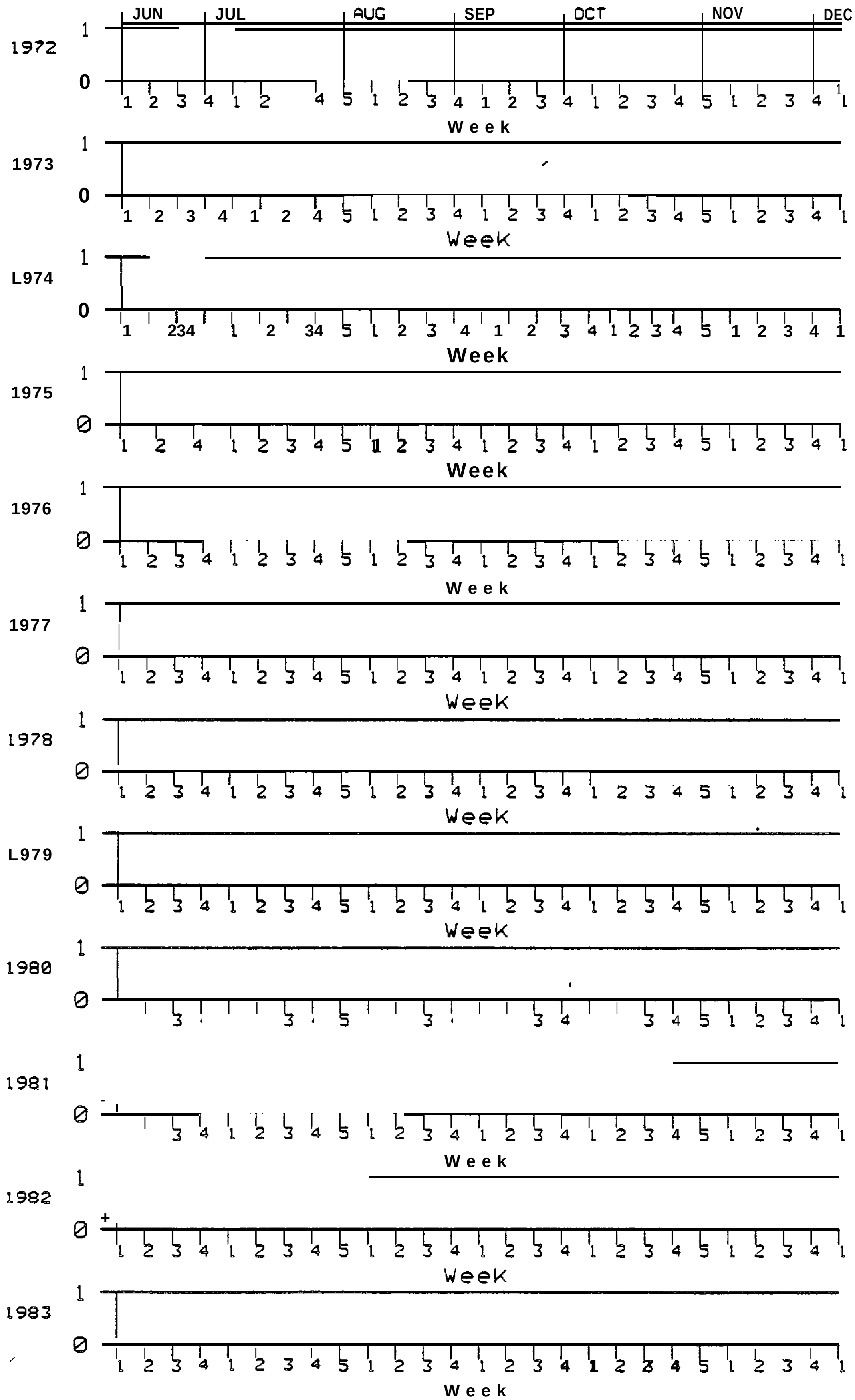



FIGURE 201 ICE PRESENCE HISTORY AT STATION 63 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

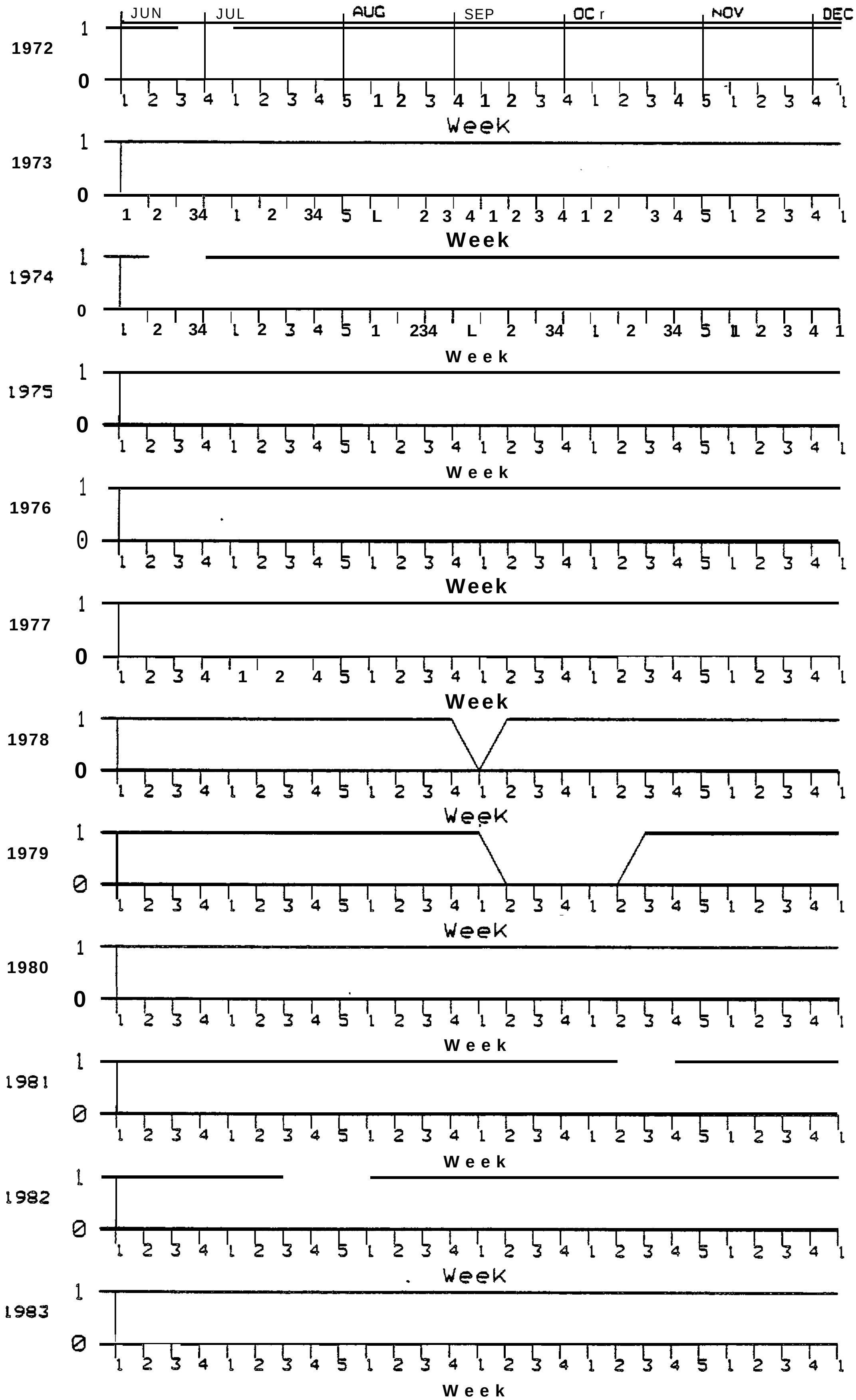



FIGURE 202 ICE PRESENCE HISTORY AT STATION 64 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY. ICE IS EITHER PRESENT OR IT IS NOT

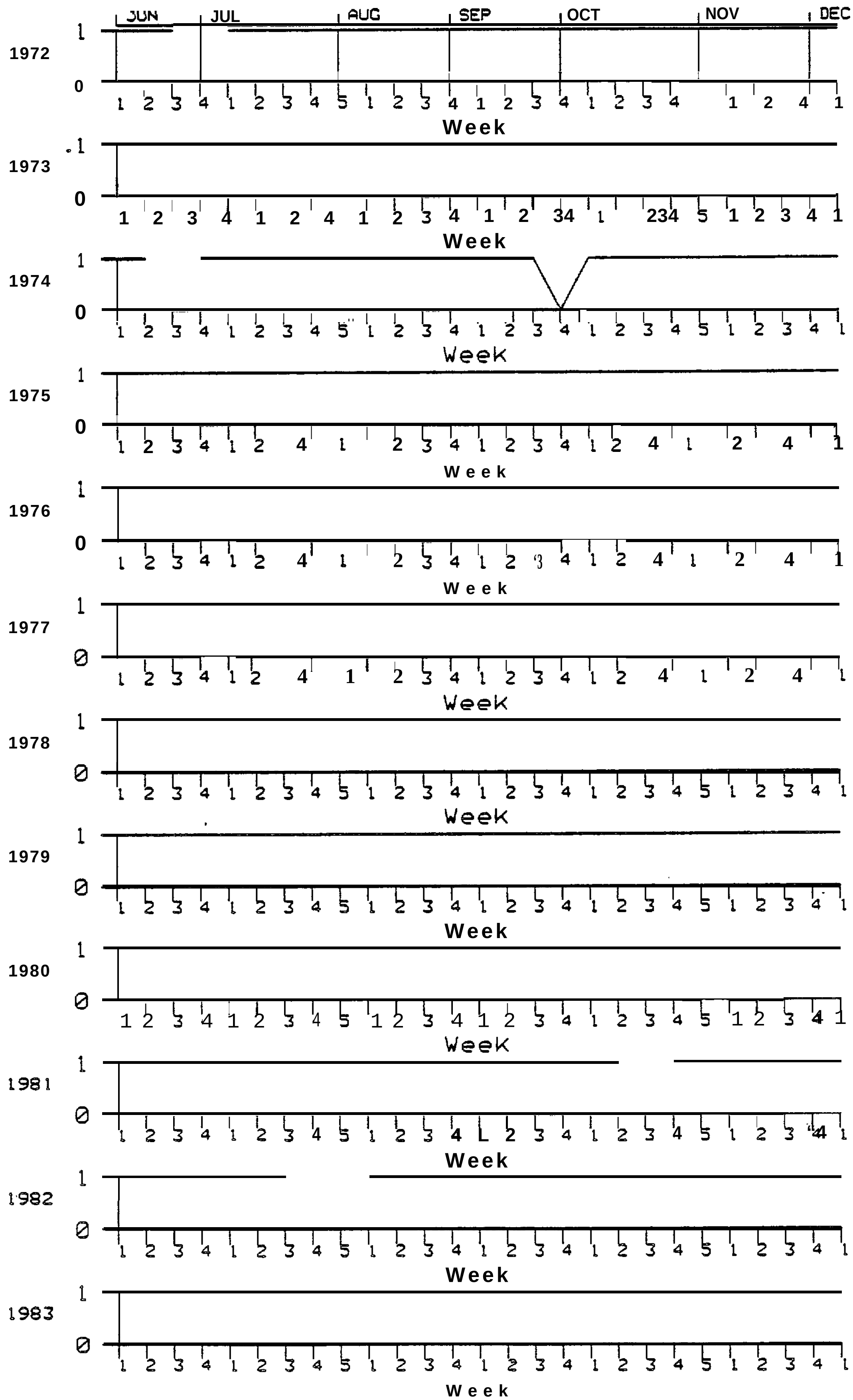



FIGURE 20.3 ICE PRESENCE HISTORY AT STATION 6 5 THE DATA REPRESENT THE WEEKLY SAMPLING OF' ICE PRESENCE THE TABULATION IS BINARY, ICE IS EITHER PRESENT OR IT IS N O T

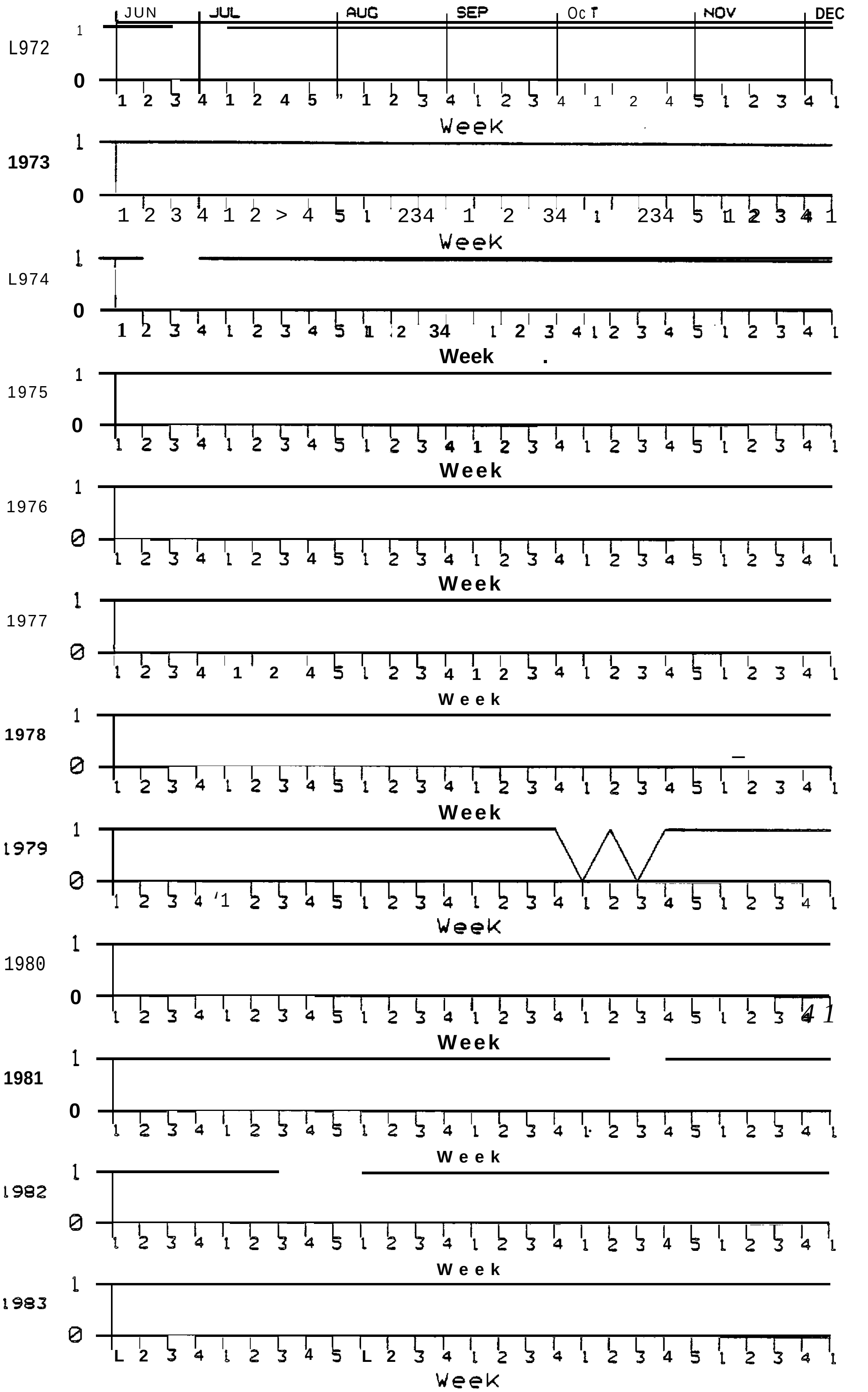



FIGURE 204 ICE PRESENCE HISTORY AT STATION 66 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY ICE IS EITHER PRESENT OR IT IS NOT

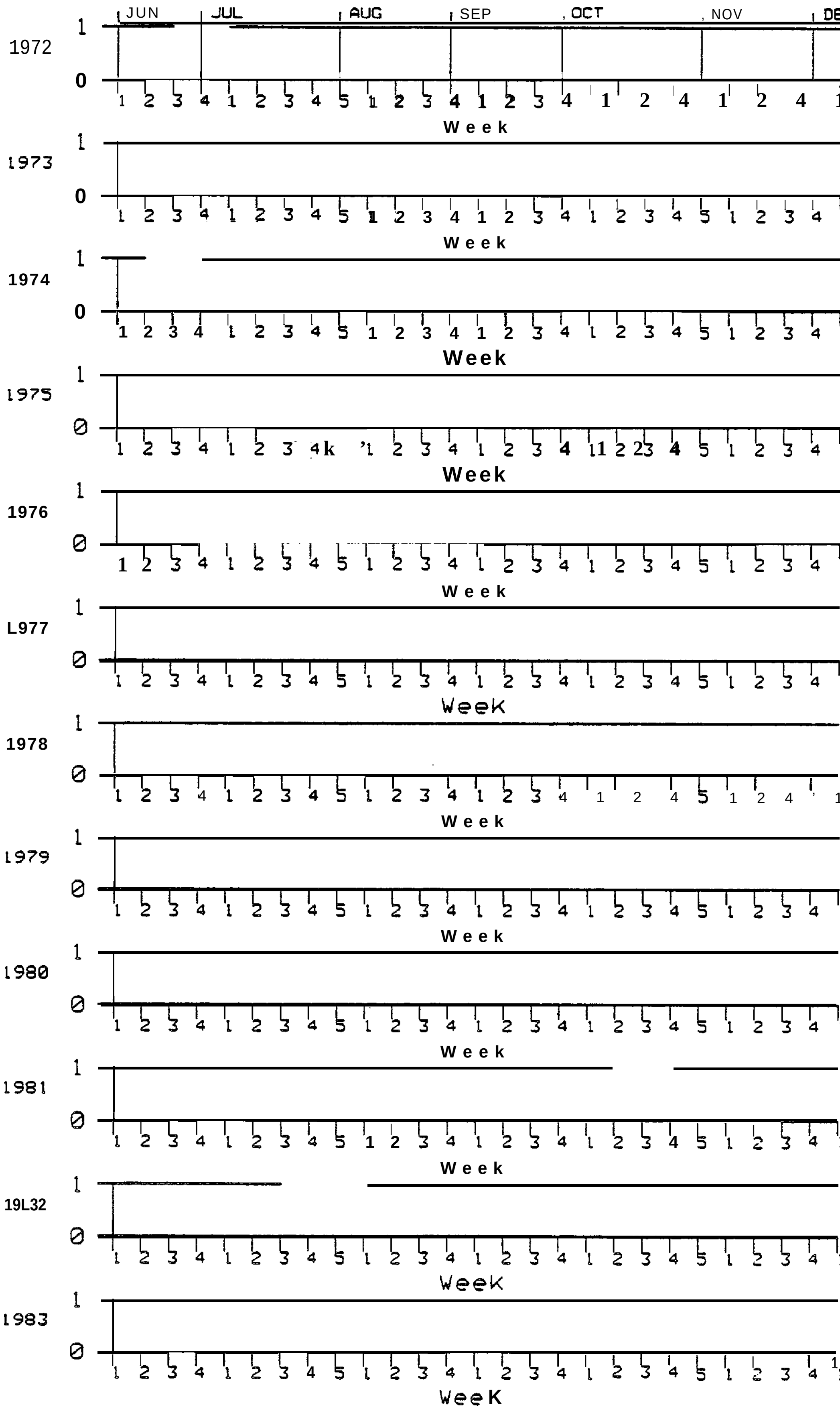



FIGURE 205 ICE PRESENCE HISTORY AT STATION 67 THE DATA REPRESENT THE WEEKLY SAMPLING OF ICE PRESENCE THE TABULATION IS BINARY, ICE IS EITHER PRESENT OR IT IS NOT

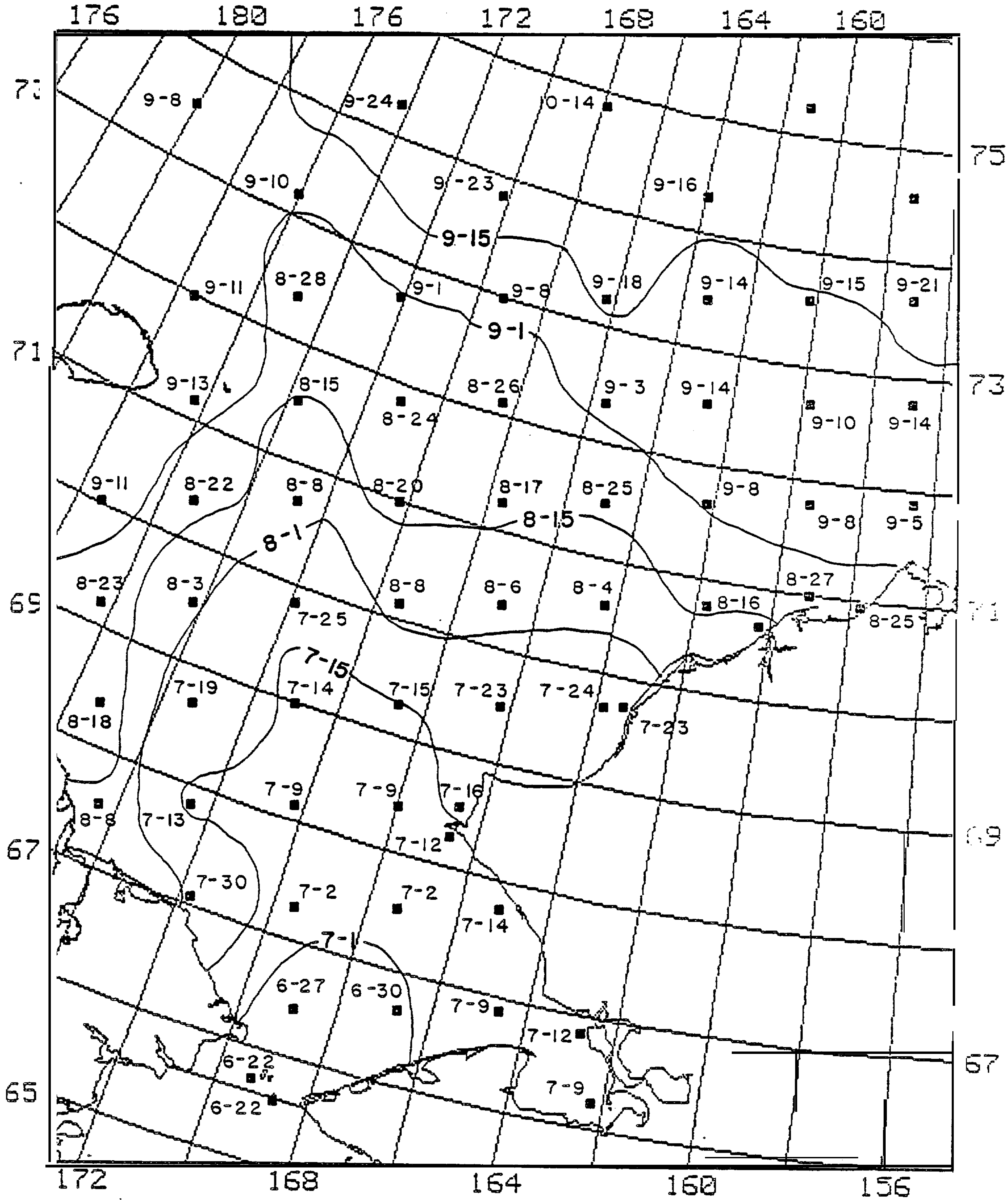



Figure 206. Average date of Breakup calculated at 67 stations in the Chukchi Sea. (Where Breakup is defined as the beginning of the longest period of continuous ice-free water.)

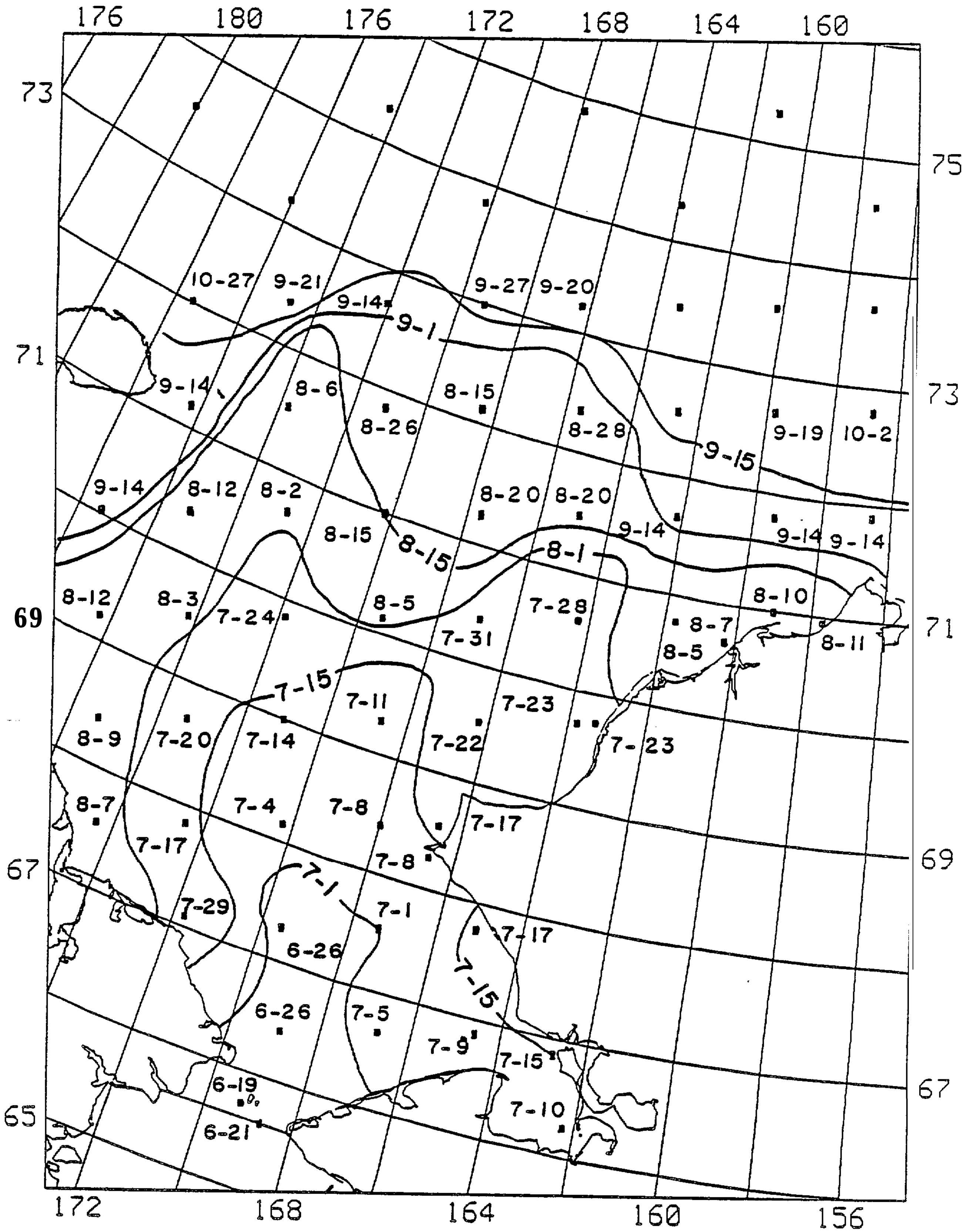



Figure 207. Median date of Breakup determined for 67 stations in the Chukchi Sea. (Where Breakup is defined as the beginning of the longest period of continuous ice-free water.)

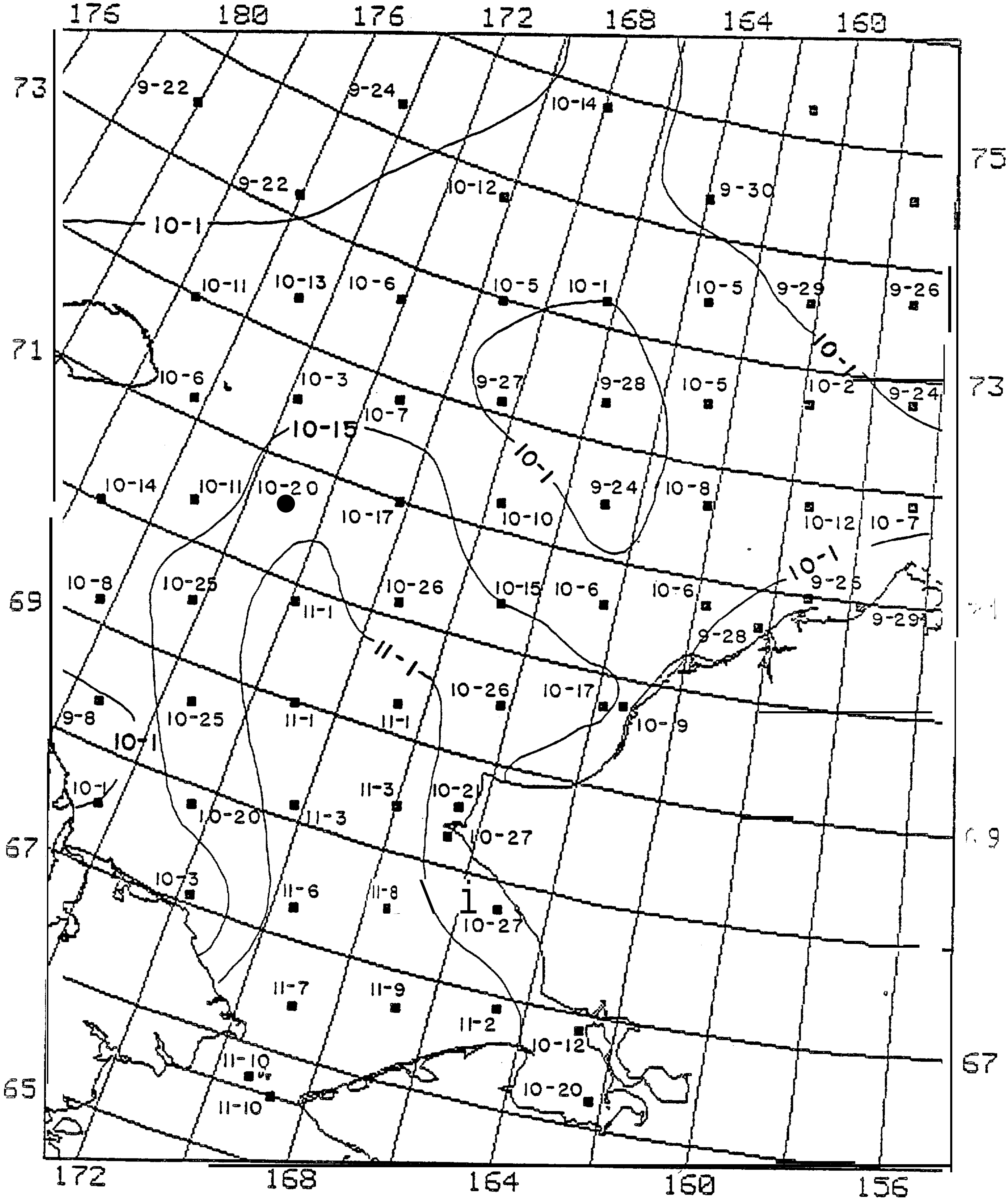



Figure 208. Average date of Freezeup calculated at 67 stations in the Chukchi Sea. (Where Freezeup is defined by the termination of the longest period of ice-free water.) .

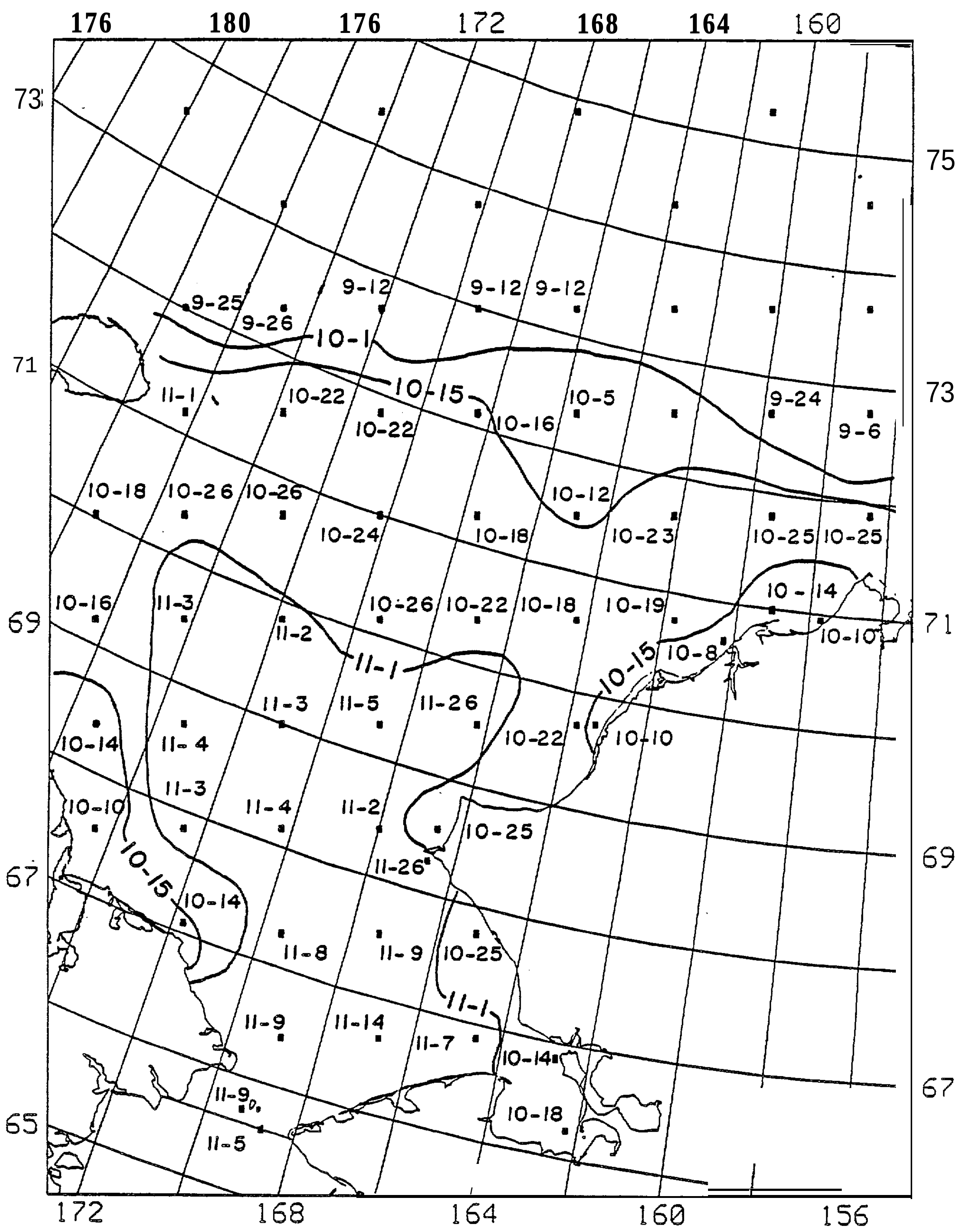



Figure 209. Median date of Freezeup determined for 67 stations in the Chukchi Sea. (Where Freezeup is defined by the termination of the longest period of ice-free water.)

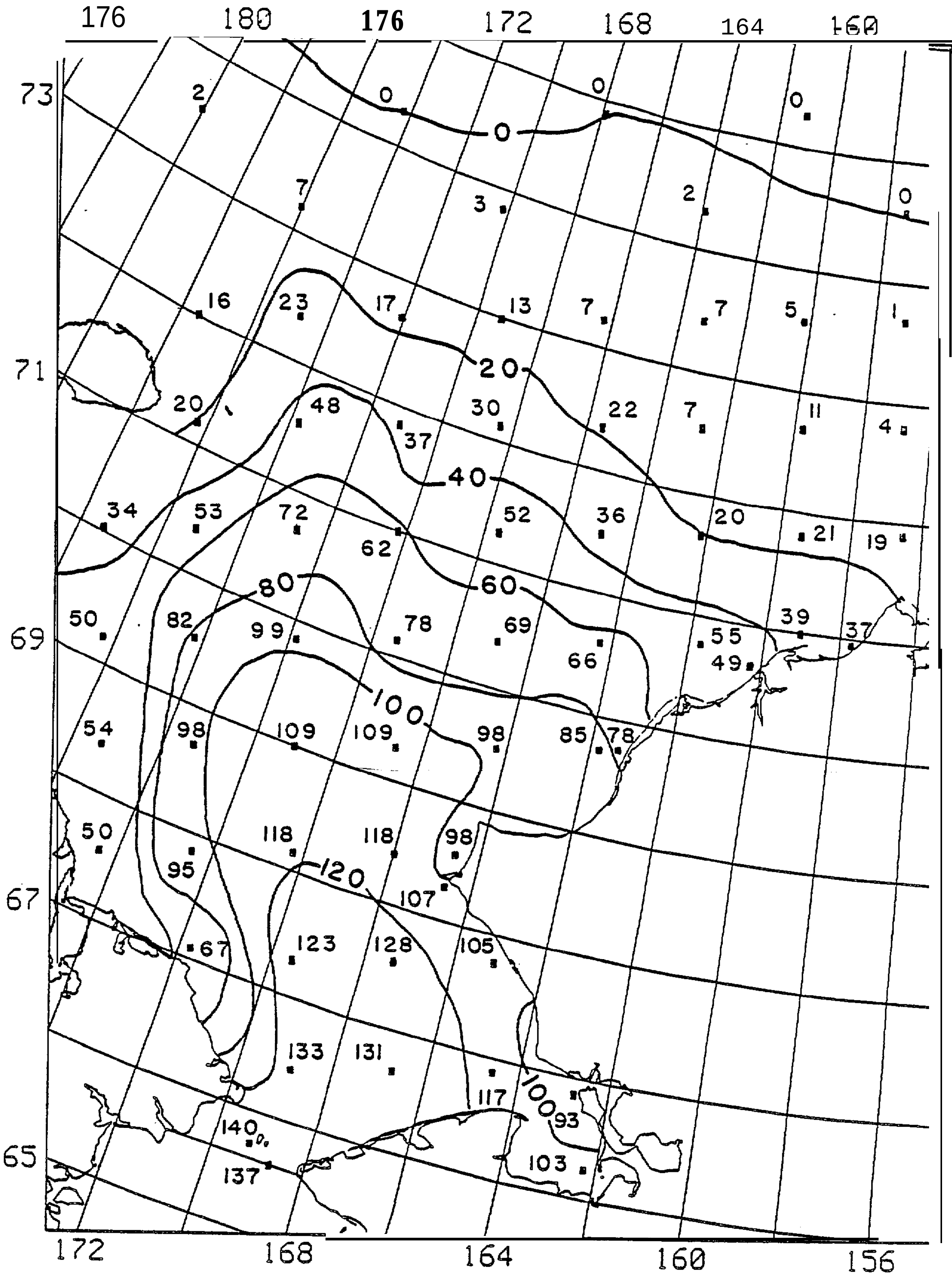



Figure 210. Average length in days of the longest period of continuous ice-free water calculated at 67 stations in the Chukchi Sea.

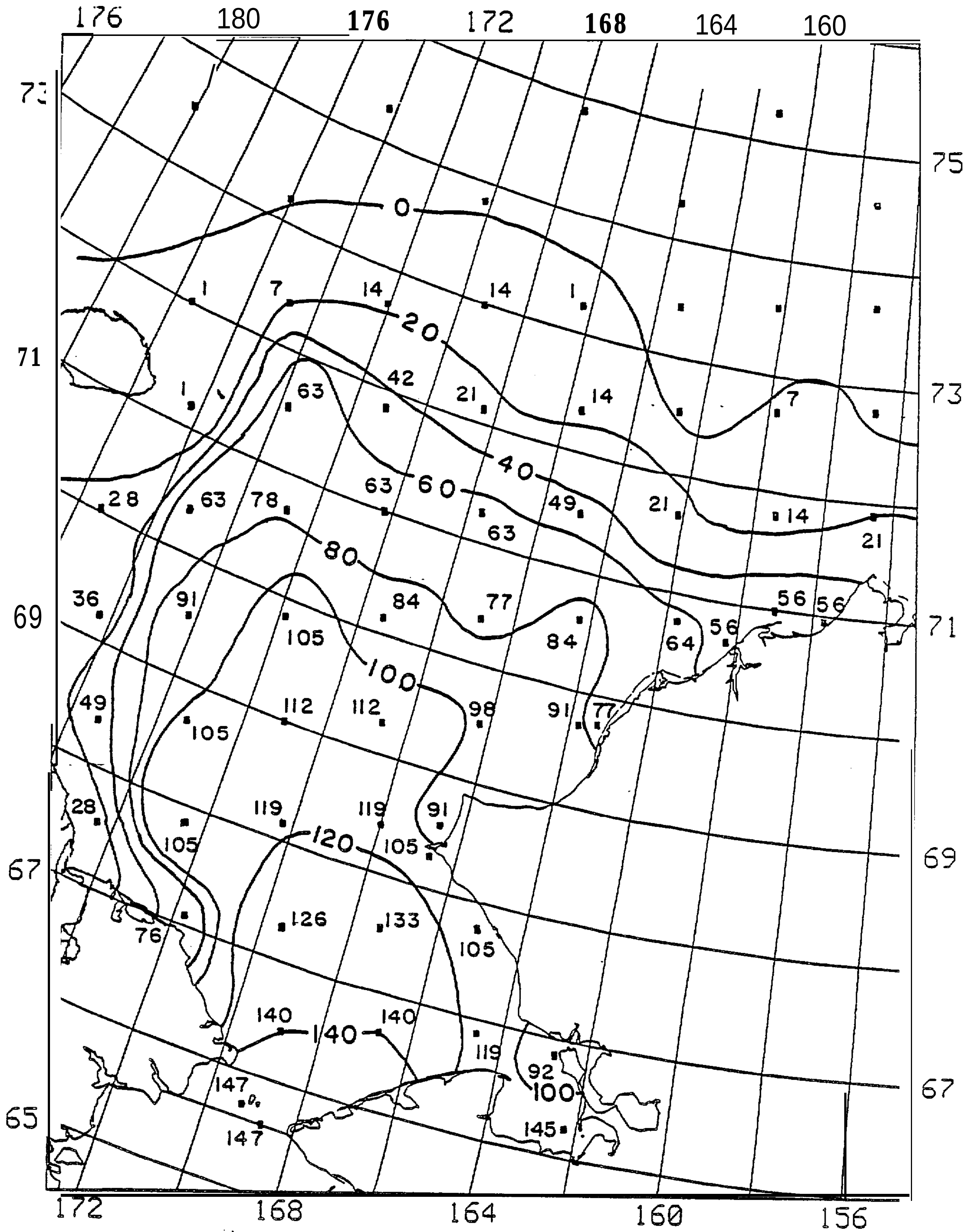



Figure 211. Median length in days of the longest period of continuous ice-free water determined for 67 stations in the Chukchi Sea.

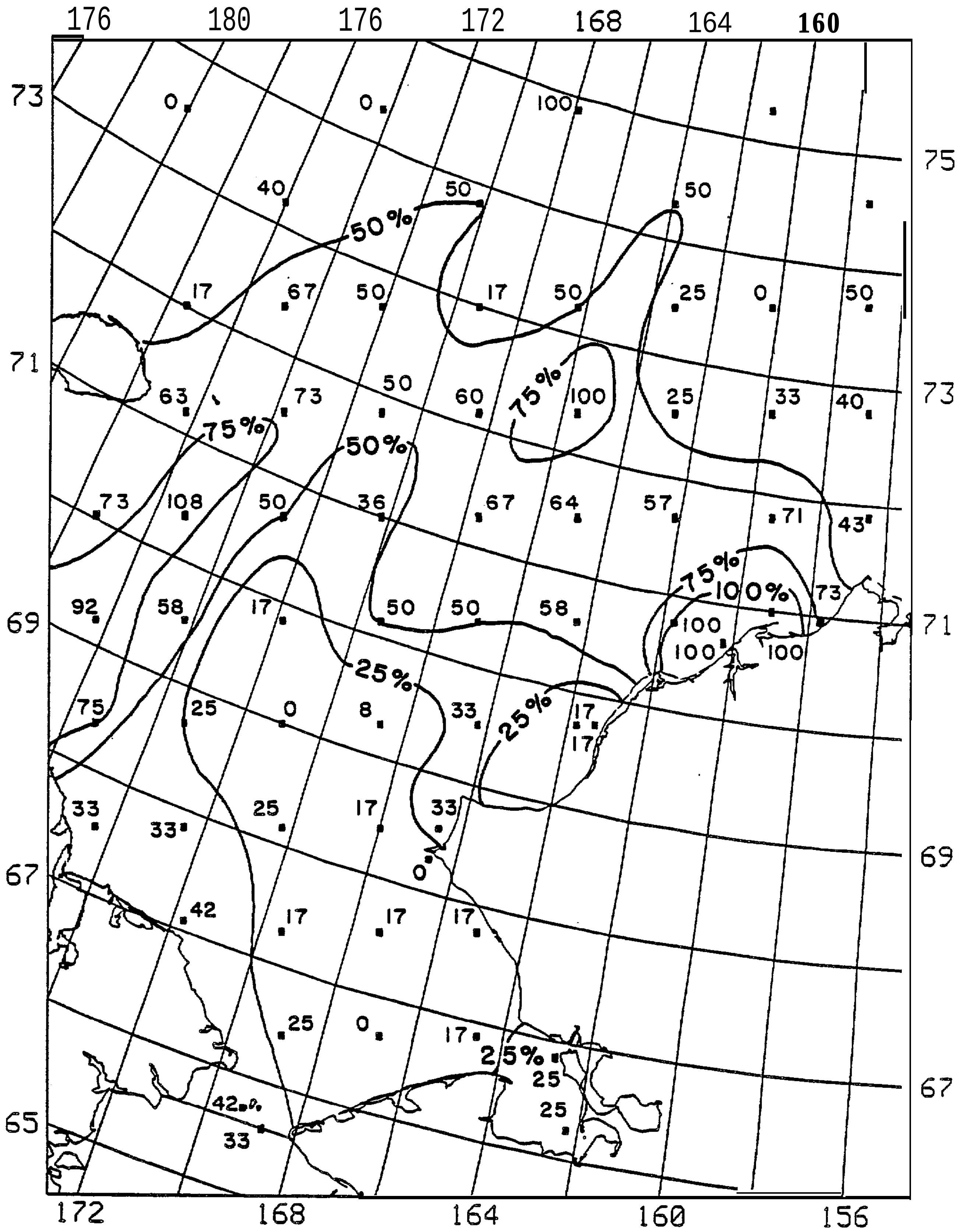



Figure 212. Percent frequency of ice recurrence at 67 stations in the Chukchi Sea.

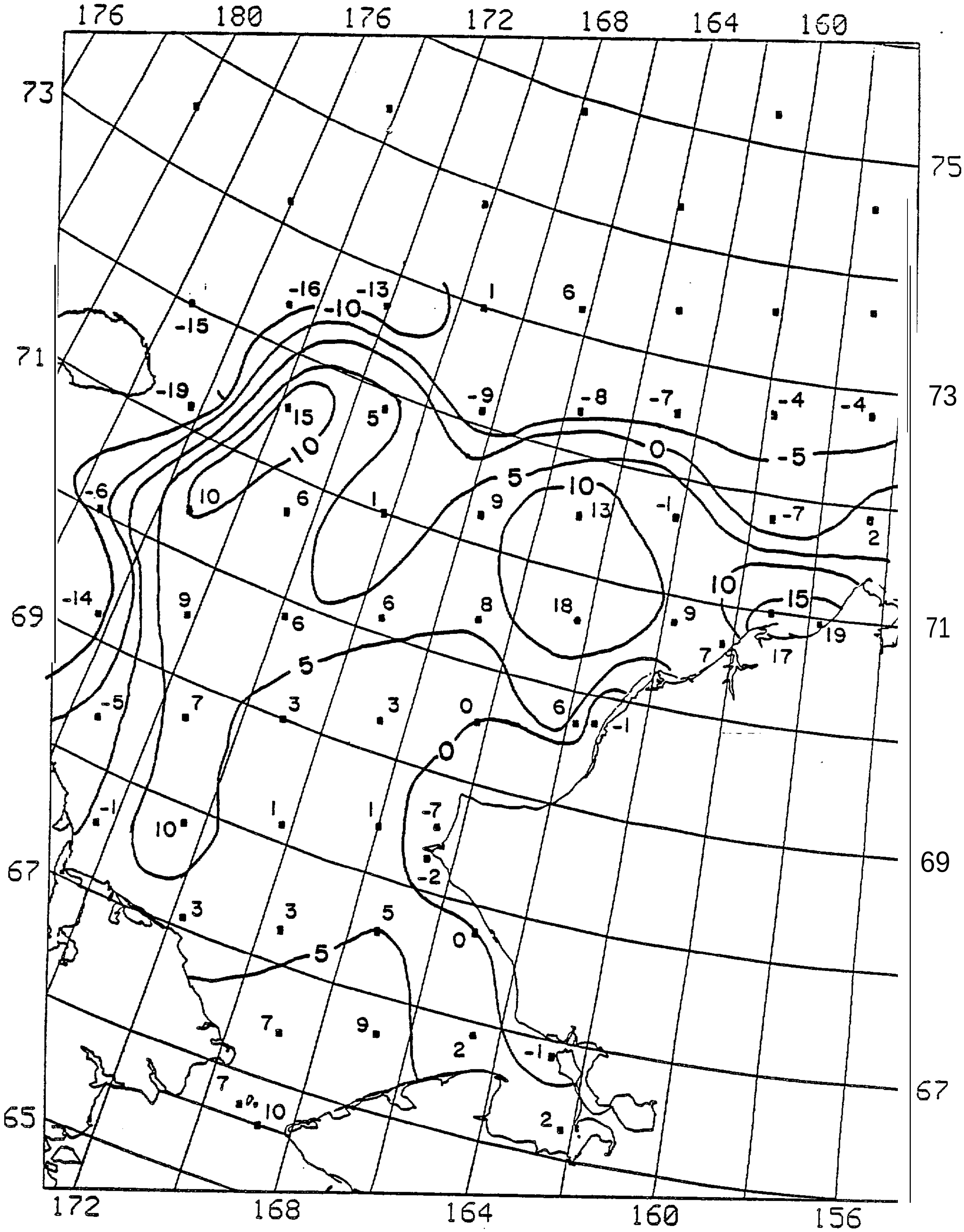



Figure 213. Period in days of the difference between the median ice-free water period and the average ice-free water period. Positive values mean the median period is longer than the average period.