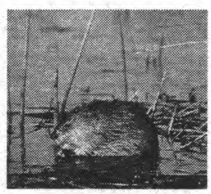
Canada Alberta Northwest Territories

Northern River Basins Study





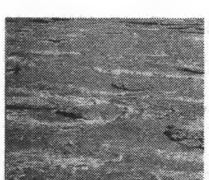




NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 109

PROBABLE AIR PATHWAYS FOR LONG-RANGE TRANSPORT OF AIR POLLUTANTS TO LAKE ATHABASCA:

ANALYSIS USING A LAGRANGIAN BACK TRAJECTORY MODEL






DATE DUE

Prepared for the
Northern River Basins Study
under Project 5316-E1

by

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PREFACE:

The Northern River Basins Study was initiated through the "Canada-Alberta-Northwest Territories Agreement Respecting the Peace-Athabasca-Slave River Basin Study, Phase II - Technical Studies" which was signed September 27, 1991. The purpose of the Study is to understand and characterize the cumulative effects of development on the water and aquatic environment of the Study Area by coordinating with existing programs and undertaking appropriate new technical studies.

This publication reports the method and findings of particular work conducted as part of the Northern River Basins Study. As such, the work was governed by a specific terms of reference and is expected to contribute information about the Study Area within the context of the overall study as described by the Study Final Report. This report has been reviewed by the Study Science Advisory Committee in regards to scientific content and has been approved by the Study Board of Directors for public release.

It is explicit in the objectives of the Study to report the results of technical work regularly to the public. This objective is served by distributing project reports to an extensive network of libraries, agencies, organizations and interested individuals and by granting universal permission to reproduce the material.

NORTHERN RIVER BASINS STUDY
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Whereas the above publication is the result of a project conducted under the Northern River Basins Study and the terms of reference for that project are deemed to be fulfilled,
IT IS THEREFORE REQUESTED BY THE STUDY OFFICE THAT;
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F. J. Wrona
(Dr. Fred J. Wrona, Science Director)

16 May 96
(Date)

Whereas it is an explicit term of reference of the Science Advisory Committee "to review, for scientific content, material for publication by the Board",
IT IS HERE ADVISED BY THE SCIENCE ADVISORY COMMITTEE THAT;
this publication has been reviewed for scientific content and that the scientific practices represented in the report are acceptable given the specific purposes of the project and subject to the field conditions encountered.
SUPPLEMENTAL COMMENTARY HAS BEEN ADDED TO THIS PUBLICATION: [ ] Yes [ ] No

P. A. Larkin
(Dr. P. A. Larkin, Ph.D., Chair)

May 10/96
(Date)

Whereas the Study Board is satisfied that this publication has been reviewed for scientific content and for immediate health implications,
IT IS HERE APPROVED BY THE BOARD OF DIRECTORS THAT;
this publication be released to the public, and that this publication be designated for: **[ ] STANDARD AVAILABILITY [ ] EXPANDED AVAILABILITY**

Lucille Partington
(Lucille Partington, Co-chair)

May 9/96
(Date)

Robert McLeod.
(Robert McLeod, Co-chair)

May 21/96
(Date)

PROBABLE AIR PATHWAYS FOR LONG-RANGE TRANSPORT OF AIR POLLUTANTS TO LAKE ATHABASCA: ANALYSIS USING A LAGRANGIAN BACK TRAJECTORY MODEL

STUDY PERSPECTIVE

The Northern River Basins Study Board identified contaminants as an area requiring significant attention under its science program. The Study focused considerable attention to determining the distribution, concentration and effects to contaminants discharged to the aquatic ecosystem from existing development. In an attempt to differntiate between changes due to upstream sources and those which are a result of natural processes, long range atmospheric transport and other regional non-point sources, NRBS undertook a sediment coring program on selected lakes. To further augment the work, NRBS investigated the probable pathways of airborne contaminants.

The long-range transport of air pollutants (LRTAP) involves the investigation of contaminant transfer by global air circulation. Man-made pollutants, including air toxics, heavy metals and acidifying emissions put into the atmosphere can be carried into the Study area.

Related Study Questions

4a) *What are the contents and nature of the contaminants entering the system and what is their distribution and toxicity in the aquatic ecosystem with particular reference to water, sediments and biota?*

4b) *Are toxins such as dioxins, furans, mercury, etc. increasing or decreasing and what is the rate of change?*

13a) *What predictive tools are required to determine the cumulative effects of man-made discharges on the water and aquatic environment?*

13b) *What are the cumulative effects of man-made discharges on the water an aquatic environment?*

This report describes the results of an investigation into potential atmospheric pathways for air pollutiants. Observed wind data from the Ft. Chipewyan area for the period of October 1991 to September 1992 were selected to run the air circulation model. Results of the analysis reveal that most of the air moving into the Athabasca river basin is coming fromthe easternmost parts of Asia. Researchers concluded that the probabilites for air to be transporting fresh contaminants into the river basin from the East Asian area are relatively large. A smaller fraction is contributed from Eastern North America and Europe. Calculations also showed that these contaminants will come primarily from a polar route rather than a south to nortth route.

NRBS investigations and others, e.g.,Slave River Environmental Quality Monitoring Program, have shown some contaminants occuring within the Study area are coming from atmospheric sources. The identification of the East Asian area as a major contributor of air to the Athabascan basin signals the need to be more knowledgeable of airborne emissions from this area. The East Asian area is experiencing industrial growth and unless significant safeguards are in place to limit the release of contaminants into the air, there is an increased likelihood that these contaminants will find their way into the Study area. The prospect exists that, quite independent of any effort to control contaminant emissions within the Study area, airborne sources may in time become the more significant source of contaminants into the aquatic environments of the Peace, Athabasca and Slave river basins.

Results of this project will be used by the Contaminants component leader in preparing a synthesis report dealing with Contaminant distribution within NRBS. Information from this project is being made available to the Human Health Monitoring Program and the Slave River Environmental Quality Monitoring Program.

Report Summary

Long-range transport of air pollutants (or LRTAP) is the mechanism by which atmospheric contaminants are transported very long distances to be deposited and affect the environment thousands of kilometers away from the source of the emissions. From investigation of lake sediments, chemical species are known to be transported into the river basins of northern Alberta via atmospheric pathways. The Atmospheric Environment Service (AES) Lagrangian back trajectory model was used to identify the potential atmospheric routes for airborne contaminants to the basin. Back trajectory analysis indicates that the possible source areas are more wide-spread in the closed-water season than in the open-water season as may be expected from climatology. Although there are subtle differences between the seasons, generally, the greatest frequency of air passages are from the northern Pacific Ocean (30 to 40%)and western North America (50 to 65%). There is no direct transport from Mexico or South America, little transport from Europe (0 to 1%) and central Asia (0.5 to 0.7%) or eastern North America (2 to 3%), but more transport from eastern Asia (3 to 4%) including Japan, China and northern Russia.

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1.0 Introduction:

Global circulation of air can transport chemical pollutants from around the world to the area of Canada included in the Northern River Basins Study (NRBS). Anthropogenic pollutants, including air toxics, heavy metals, smoke, acidifying emissions, and radiation fall-out, are imported into the area with potentially harmful effects on the environment. To understand all sources of pollutants into an area under study, it is important to identify local and regional emissions but also to be able to identify major atmospheric pathways that may potentially bring contaminants from much further away.

The long-range transport of air pollutants (or LRTAP) depends on the ability of the chemical species to remain in the atmosphere for relatively long periods of time. Chemicals can remain stable in the atmosphere like mercury or lead, react to form new species as when sulphur dioxide becomes sulphuric acid producing acid rain, or physically bond to water or dust particles to form aerosols. Eventually, these compounds will return to the earth as either wet or dry deposition. There is also the possibility of revolatilization and resuspension of these materials. In general, global climatology of wind and precipitation determine where the chemicals finally end up. LRTAP is the principal pathway for contaminants reaching relatively remote locations of the earth.

Sediments from Lake Athabasca (59° 3′N and 110° 13′W) have been chemically analyzed to investigate the depositional history of organic contaminants [Bourbonniere, 1995]. From this study, it was found that atmospheric transport is potentially the main control for distribution of polyaromatic hydrocarbons (PAHs). While the suite of organochlorines (including pesticides, toxaphene and polychlorinated biphenyls PCBs) were at levels below detection in the samples and will require reanalysis with lower detection limits, it is known that these compounds can be transported to the lake atmospherically or through the river system.

A Lagrangian back trajectory model [Olson, 1978] is used to investigate potential atmospheric pathways for air pollutants to the northern river basins. Trajectories were run at four levels in the atmosphere backwards for 5 days and every 6 hours for the closed-water season (October 1991 through March 1992) and the open-water season (April 1992 through September 1992). This analysis will identify the major atmospheric routes by which contaminants undergoing LRTAP can reach the river basin. It cannot address the issues of revolatilization and resuspension but only the paths of "fresh" emissions to the atmosphere of chemicals that are capable of remaining aloft for one to five days.

First, the model is described with a focus on the decisions made in the modeling operations. A brief comparison of the model results from the year of interest with the long-term climate will indicate whether this is a typical meteorological year and when the main differences could be expected. The potential pathways for air transport will be illustrated visually through a series of diagrams picturing daily and seasonal results. Finally, probabilities of trajectory pathways will be compared with known emission source areas in order to provide an overall probability that the atmospheric pathway is a viable one in this watershed.

2.0 Model Description:

The Atmospheric Environment Service (AES) has developed a Lagrangian model for the assessment of the Long-Range Transport of Air Pollutants (LRTAP) [Olson, 1978]. This model has been applied previously to the problems of estimating sulphur and nitrogen budgets for eastern Canada [Olson, 1982, 1990] and Alberta [McDonald, 1993]. Numerical evaluation of the model has been performed [Walmsley, 1983] and no serious deficiencies were identified. While all modelling procedures incur errors especially in light or variable wind flows, the assumption here is that these will tend to compensate over longer time scales such that the average features of the flow over each season will support the basic transport patterns of pollutants reasonably well.

The trajectory model uses wind fields determined at the Canadian Meteorological Centre (CMC). Observed wind data are objectively analyzed at 6-hour intervals onto a 381-km grid superimposed on a polar stereographic projection true at 60°N. By incorporating hydrostatic and height-wind balance routines, the three-dimensional scheme produces gridded wind components both horizontally and vertically [Rutherford, 1977] providing some topographical effects. Analyzed winds are interpolated to a grid length of 127 kilometers. Starting points can be located anywhere in North America and at any pressure level between 1000 and 500 mbar. Trajectories can be calculated from the starting point in either a forward or backward direction for up to 5 days at a specified time-step interval from 6-hours to daily. An iterative procedure assuming constant acceleration between segments is used to determine accurate end-point positions.

For the purposes of this study, trajectory calculations were performed every 6-hours for 5 days backward at four pressure levels: 925, 850, 700, 500 millibar (mb). (The usual surface level at 1000 mb was omitted in this calculation since most of Alberta has elevations that normally lie above that pressure.) Trajectories were run in a backward direction from the end-point shown as a large dot in Figure 1 lying at 59° 3′N and 110° 13′W. Test runs showed little difference in the air trajectories over points in a 200 km range of this point so that most of the NRBS study area can be represented by this one point for larger scale and upper air movements. In addition, this central point of Lake Athabasca is a position used for collection of lake sediments and core samples for chemical analysis [Bourbonniere, 1995]. This point was selected to represent the study area and to compare results with the sediment analyses.

Sampling was performed at the central Lake Athabasca end-point between March 1992 and March 1993 for the purpose of determining the depositional history of the sedimentbound contaminants. Of particular interest are organic compounds produced as by-products from industrial, agricultural and commercial processes. Dioxins, furans, resin acids, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphyenyls (PCBs), organochlorine pesticides, toxaphene, total mercury and petroleum hydrocarbons were analyzed in the surficial sediment. Although deep cores were taken at the same site, the resolution was not sufficient to take advantage of the back trajectory method.

Instead, since the sedimentation rate is on the order of 0.20 cm/yr, the year previous to the sampling year was selected for analysis of the surficial sediments. The calendar year was separated into a closed-water season (October 91 through March 92) and an open-water season (April 92 through September 92) for analysis of the back trajectories. The intent is to show which source areas have the potential for atmospheric deposition to either the lake waters or to the snow pack for later deposition into the sediment.

Climatological normals [AES, 1982] for the wind speed and direction at Fort Chipewyan (58° 46′ N; 111° 7′ W) are given in Table 1 with frequencies and averages for the seasons as defined above and the annual values. This airport site is situated in a low area with ridges to the east and west completely surrounded by trees which results in frequent calm conditions. As a result, this may not be typical of the regional study area. At all times of the year, the prevailing surface wind comes from the east. West winds are the next most common. The lowest frequency wind directions are south and southwest. The greatest windspeeds come from the west and northwest and the lowest from the southeast and southwest. Comparison of these normal values with the same calculations from the surface winds in the model will illustrate whether the year 1991/92 is typical for the area or whether it is an extreme year for wind variables. This comparison is done in the results section.

Figure 1: Northern River Basins Study area showing trajectory end-point in Lake Athabasca.

Table 1: Fort Chipewyan climate wind normals 1951-1980.

(a) Percent frequency of direction

Direction	Closed-water Season (Oct. - Mar.)	Open-water Season (Apr. - Sept.)	Annual Values
N	5.82	7.09	6.45
NE	8.36	10.68	9.50
E	15.74	17.63	16.75
SE	6.99	9.54	8.30
S	5.00	6.37	5.65
SW	5.10	6.23	5.65
W	14.74	13.27	14.00
NW	9.92	8.48	9.20
Calm	28.33	20.72	24.50

(b) Mean wind speed (km/hr)

Direction	Closed-water Season (Oct. - Mar.)	Open-water Season (Apr. - Sept.)	Annual Values
N	12.68	13.86	13.27
NE	11.21	13.51	12.37
E	11.88	12.86	12.37
SE	11.74	11.77	11.73
S	11.96	11.87	11.90
SW	10.71	12.71	11.73
W	12.93	14.46	13.70
NW	14.54	14.40	14.50
All *	9.00	10.62	9.80

* This value also includes the incidents of calm winds above so that it is not an average of the values above it in the table.

3.0 Results and Discussion:

Surface level (925 mb) wind speed and direction from the model runs can be used to compare with the measured climate normals at Fort Chipewyan given in Table 1. Table 2 shows the comparable values from the model. For the frequency of wind directions, the model does not separate those winds that are considered calm (<5 km/hr). Without including this component, it is clear that the prevailing winds from the east and west are represented in the model results. The main difference is that the model differentiates more clearly between a westerly flow in the closed-water season and an easterly flow in the open-water season. The model does not capture very well the northeast component of the wind flow observed at the airport, but this observation may be representative of the particular valley flow around the meteorological site.

With respect to wind speed, the calculation of all wind speeds clearly indicates that the model is not including sufficient calm periods to represent the Fort Chipewyan airport but this may be a good indication that the model is useful at the higher altitudes and as a representation of the whole region rather than specific points like a site appropriately selected for an airport. Overall, western winds are stronger than the eastern ones but the model again shows a clearer distinction between the open and closed-water seasons with east winds becoming the stronger in the open-water season. This is a reasonable result since strong summer storms associated with lows passing to the south of the area will bring winds counterclockwise from the south and to the east while strong winds in the winter will come with a cold front from the northwest and west.

For ease of comparison, Figure 2 compares the modelled wind directions and those from the long-term climate normals with the condition "calm" removed. Generally, the model is able to represent the two main wind flow directions, east and west, in the area quite well. The comparison with the climate station data at Fort Chipewyan, however, is limited because the site may not be representative of the whole region. This is also complicated by the fact that a single year has been modelled and not the entire period of record which would average out the values. While the figure shows that the model has more variation between the seasons than the climate data, this is to be expected as averages over time will smooth out any such differences observed on an annual basis. Overall, however, the model is reasonably representing the main surface observations but may be better at higher altitudes.

Table 2: Model near-surface wind climatology (925 mb).

(a) Percent frequency of direction.

Direction	Closed-Water Season (Oct.91 - Mar.92)	Open-Water Season (Apr.92 - Sep. 92)	Annual Values
N	2.50	2.46	2.48
NE	1.00	1.91	1.50
E	25.00	27.73	26.50
SE	20.83	29.51	25.60
S	5.67	5.19	5.41
SW	7.33	7.51	7.43
W	32.50	22.54	27.03
NW	5.17	3.14	4.05

(b) Mean wind speed (km/hr).

Direction	Closed-Water Season (Oct. 91 - Mar. 92)	Open-Water Season (Apr. 92 - Sep. 92)	Annual Values
N	12.47	10.62	11.54
NE	9.03	9.22	9.13
E	9.57	13.29	11.43
SE	11.64	12.19	11.92
S	11.26	10.44	10.85
SW	15.65	13.05	14.35
W	13.89	12.77	13.33
NW	7.50	7.26	7.38
All	11.36	11.11	11.24

Figure 2: Frequency of occurrence of wind direction from long-term climate and model calculations.

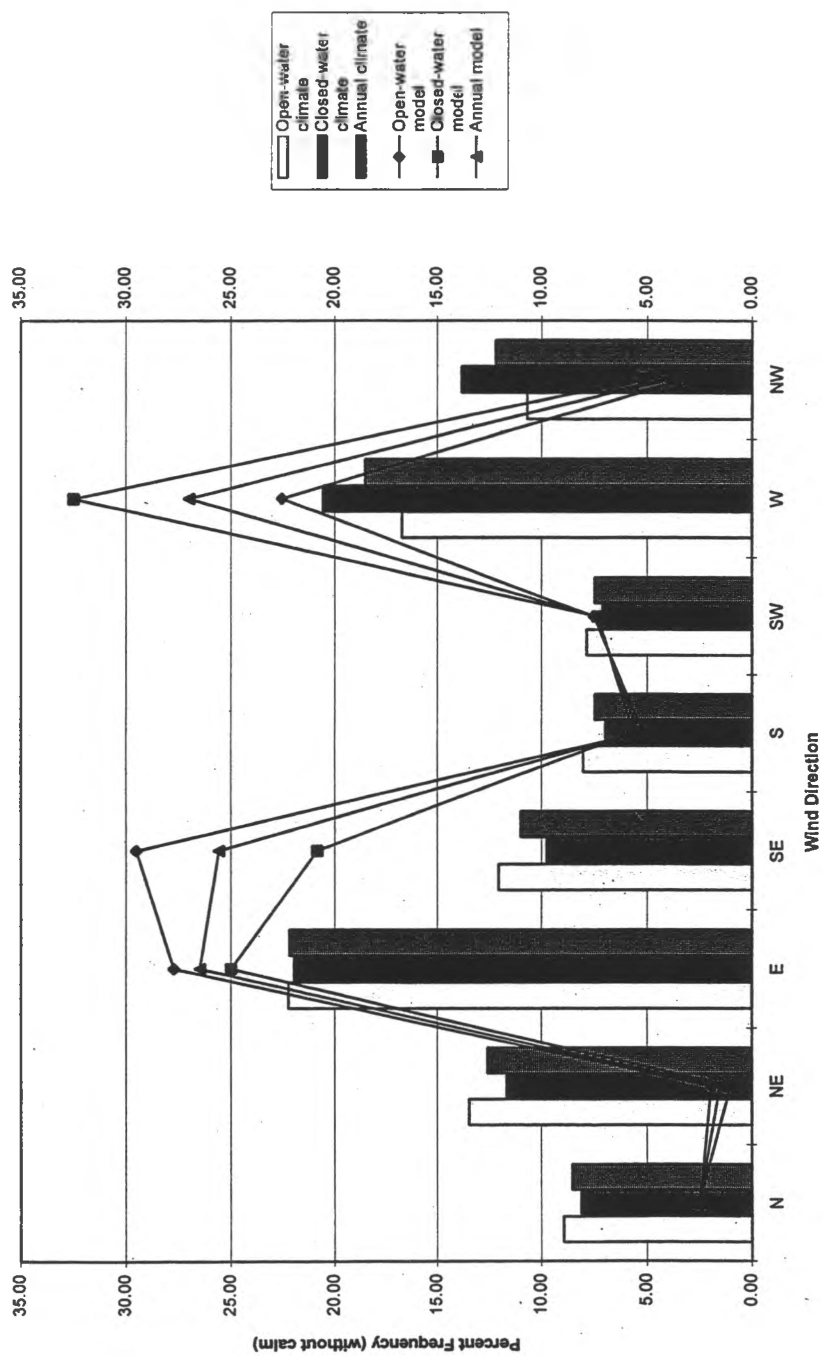
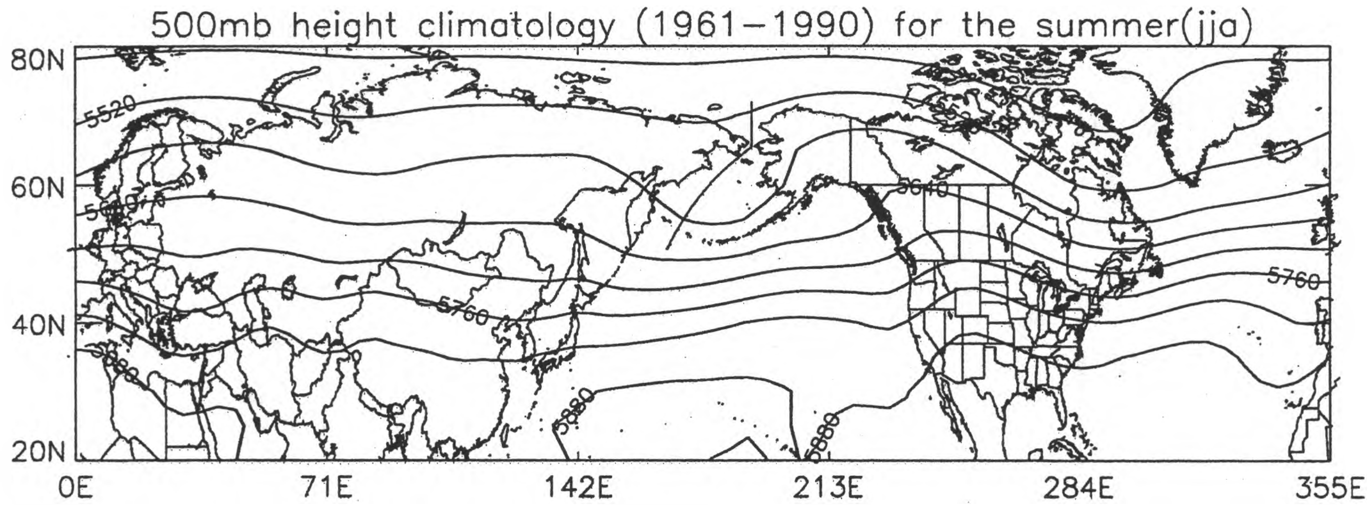


Figure 3(a): Upper-air wind climatology at 500 mb for summer and winter (1961-1990).



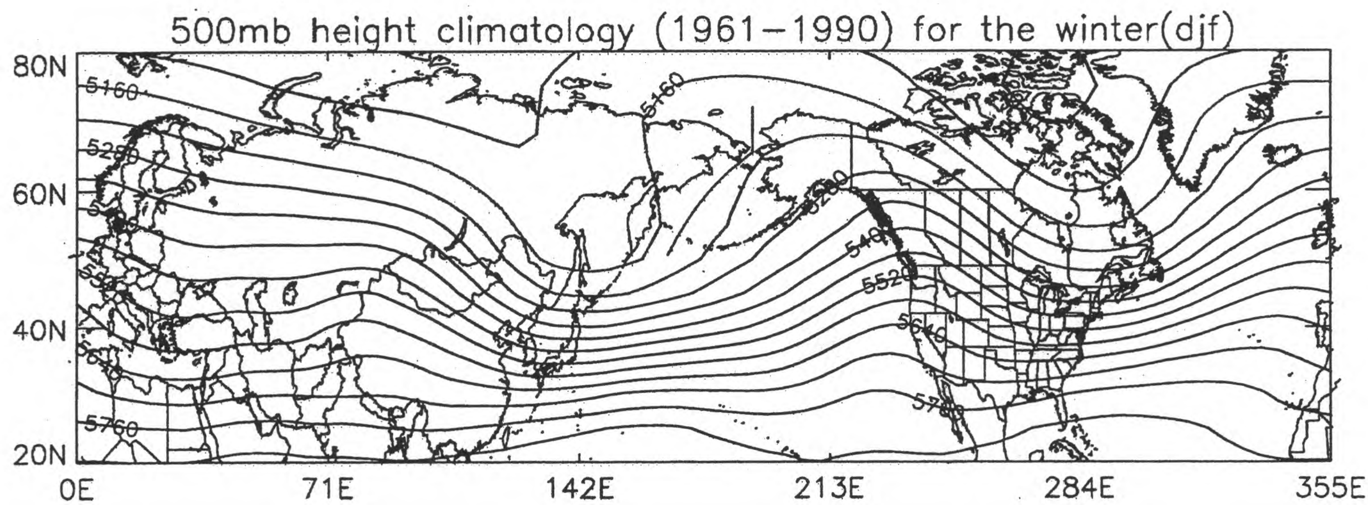
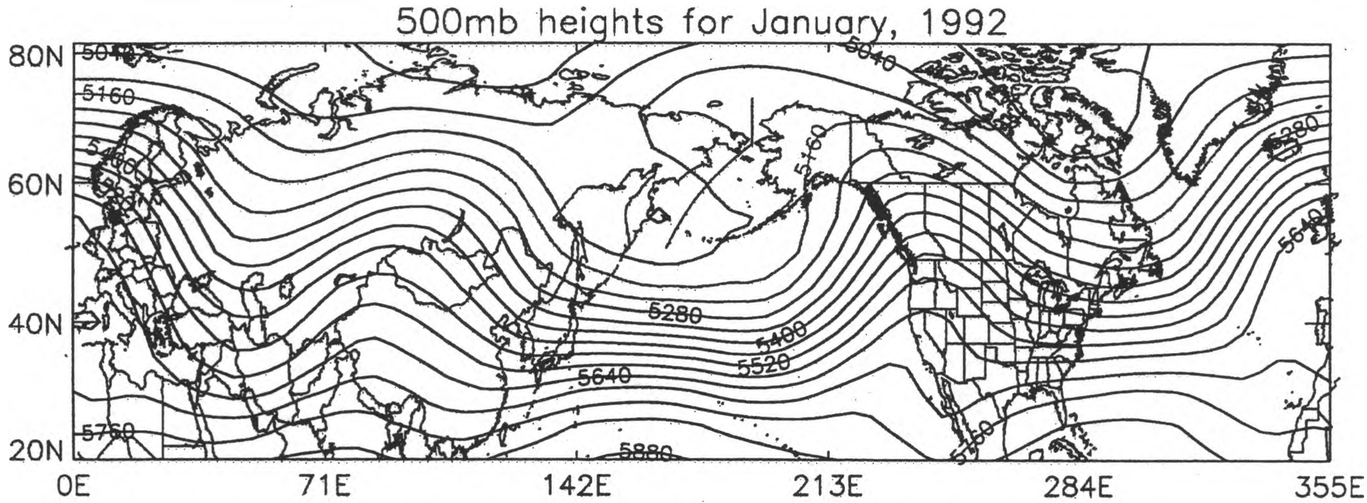


Figure 3(b): Upper-air wind height and anomally plots at 500 mb for January 1992.



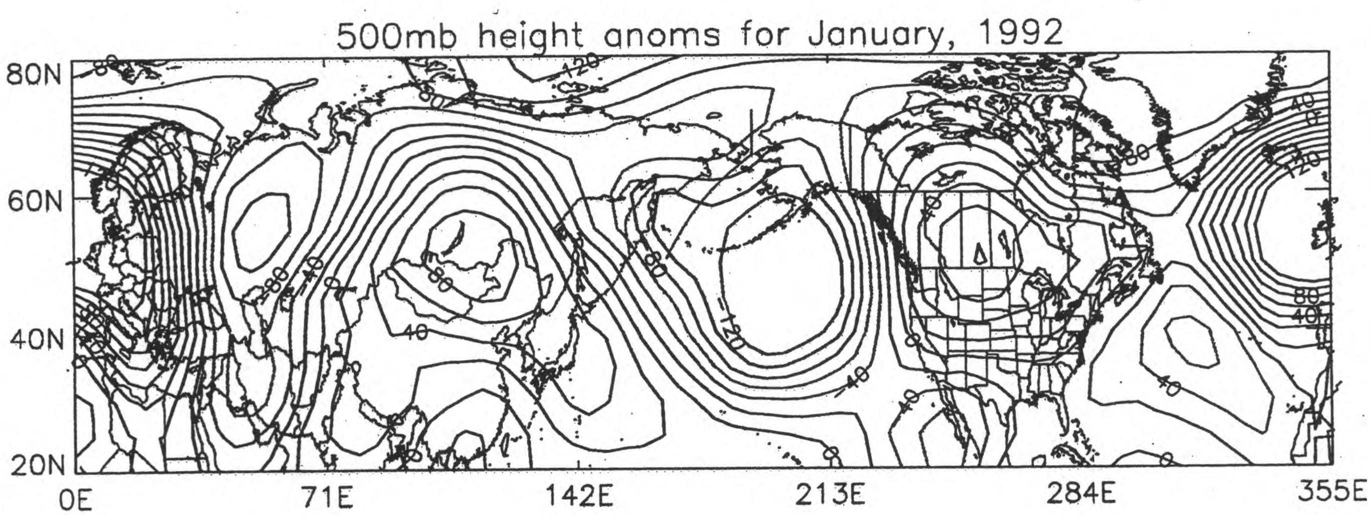
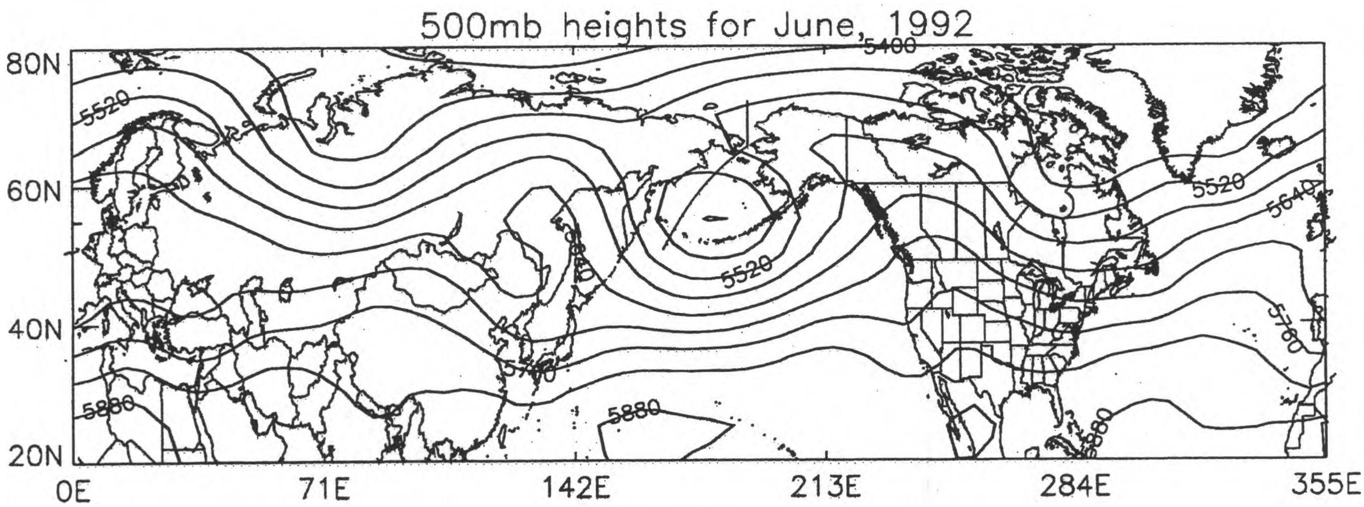
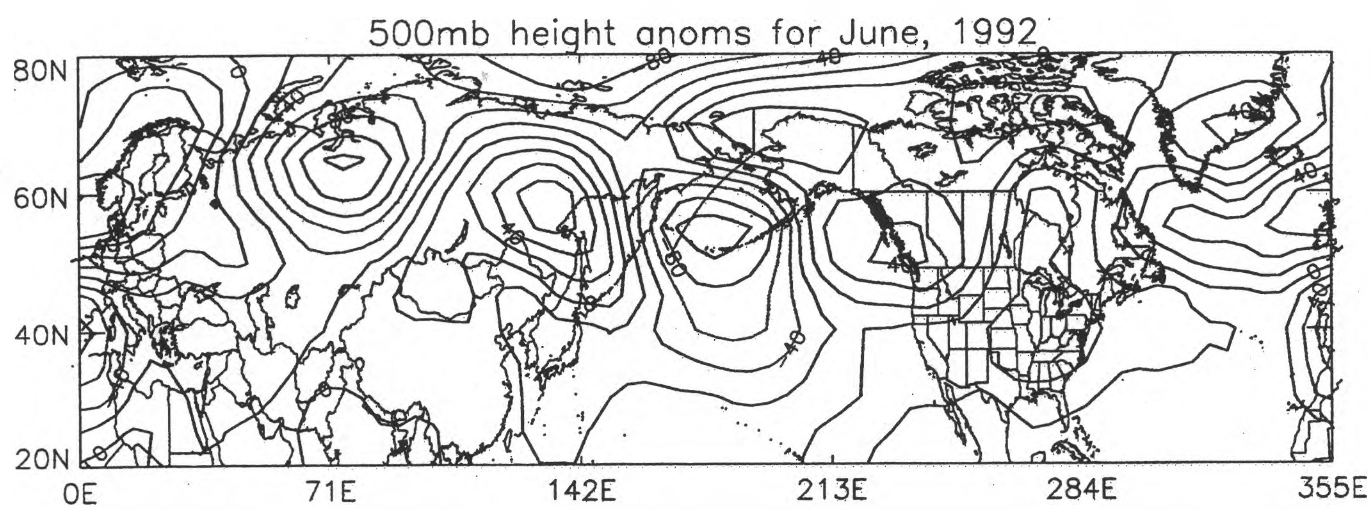


Figure 3(c): Upper-air wind height and anomally plots at 500 mb for June 1992.





The model's success representing the upper air flow can be discussed by comparing the 500 mb wind height long-term climatology plots for the winter and summer pictured in Figure 3(a) with the 500 mb wind height and anomally plots in Figures 3(b) and 3(c). The latter are for one month in each of the closed (January) and open-water (June) periods of 1991/92, respectively. In the winter months, the wind heights tend to be lower and with a steeper gradient than in the summer. Both maps features a ridge over western North America and a trough in the east but the winter is much more defined. The upper-air heights for January and June of 1992 indicate that the winter is quite similar to the long-term climatology but show a steeper ridge from Alaska and down to California in both seasons. The upper air anomalies better illustrate the difference between the actual wind flow and the long-term climatological flow patterns. Although the summer season is very nearly a so-called normal year as seen from the very shallow variations in the patterns, there is a low in the north Pacific Ocean and a corresponding high along the Pacific coast of North America. The year 1991/92 was an El Nino year which implies a somewhat anomalous closed-water season climate. This is evident in the relatively large high in central North America and a deep low in the Pacific Ocean. Air mass flow around this high will bring air from further south in the Pacific bringing warm conditions to the western part of North America. These conditions are observed in the trajectory end-points which are plotted in Figure 4(a) and 4(b) described below. This implies that the model has relatively successfully reproduced the 1991/92 specific climatology for the upper winds.

The model provides point-wise data for every 6-hour time step backwards for 5 days. By plotting these points on a map of the area of interest, it is possible to visualize the major pathways of air movements into the river basin. In Figure 4(a) and Figure 4(b), the 500 mb end-points are plotted for the closed-water and open-water seasons, respectively. It is difficult to interpret the information near to the basin but some conclusions become immediately clear. First, there is no transport evident from the Southern Hemisphere including Mexico and South America nor is much arriving from most of Europe and southern Asia. There is very little transport from the industrialized eastern part of North America, but more transport comes from this area in the open-water season than in the closed-water season.

Most of the air into the Athabasca river basin is coming from the easternmost parts of Asia, passing over the northern Pacific Ocean and making landfall along the west coast of North America. This landfall can be as far south as southern California especially in the closed-water season which is to be expected since in El Nino winters, the atmospheric jetstream over the Pacific Ocean tends to be displaced southward. In the closed-water season, the areal spread of points is greater than in the open-water season indicative of the seasonal differences in the large-scale meteorology. Also evident in the winter months to the west of Alaska is an area of lower density of points representing an area of relatively stable low pressure which causes winds to travel around the area without passing over it. This is a well-known climatological feature in northern hemisphere.

Figure 4(a): End-points at 500 mb during the closed-water season with latitudes every 10° beginning at 20°N and longitudes every 15° with 0° at the far right.

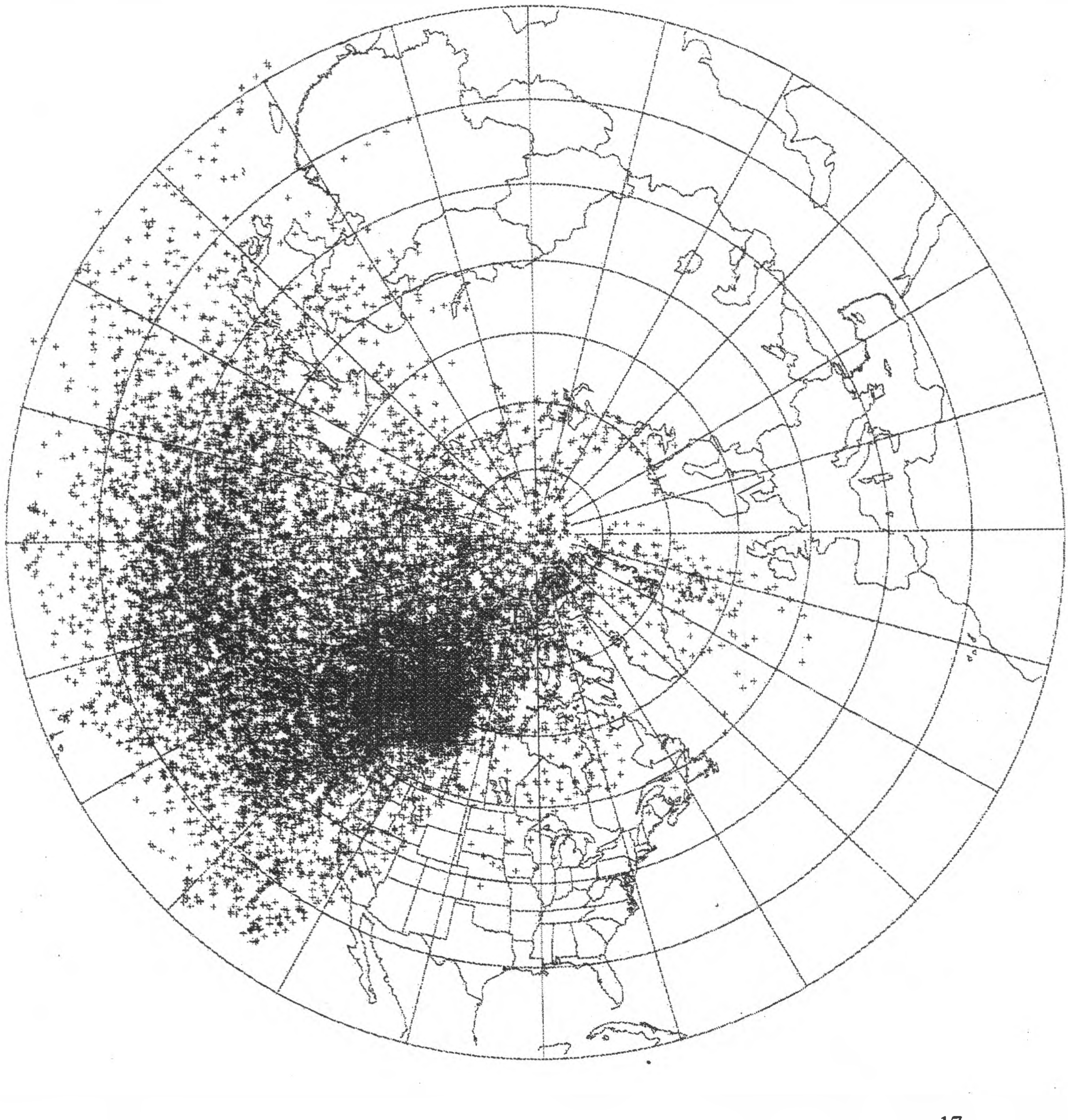


Figure 4(b): End-points at 500 mb during the open-water season with latitudes every 10° beginning at 20°N and longitudes every 15° with 0° at the far right.

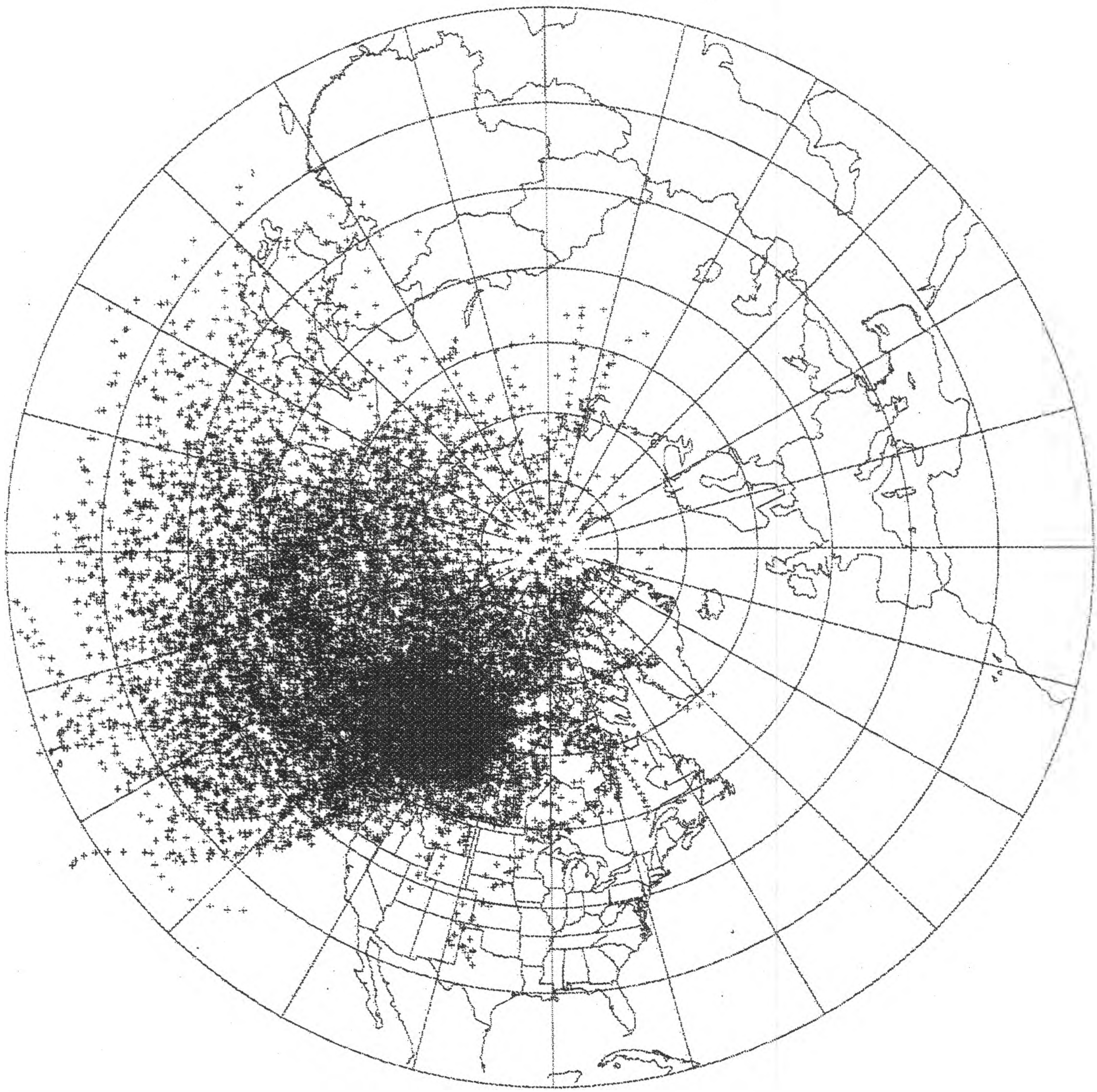


Figure 5(a): End-points at 700 mb during the closed-water season with latitudes every 10° beginning at 20°N and longitudes every 15° with 0° at the far right.

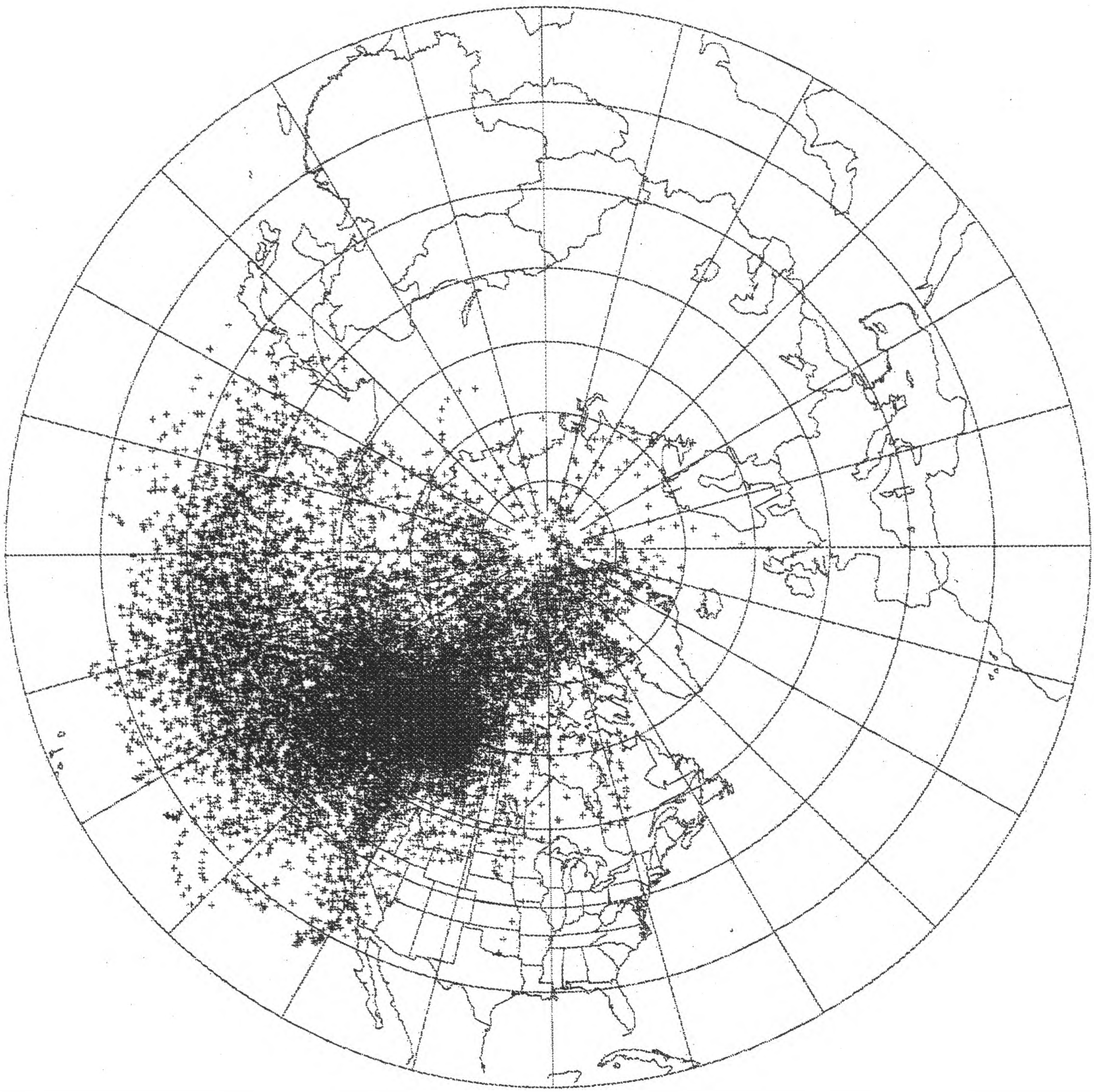


Figure 5(b): End-points at 700 mb during the open-water season with latitudes every 10° beginning at 20°N and longitudes every 15° with 0° at the far right.

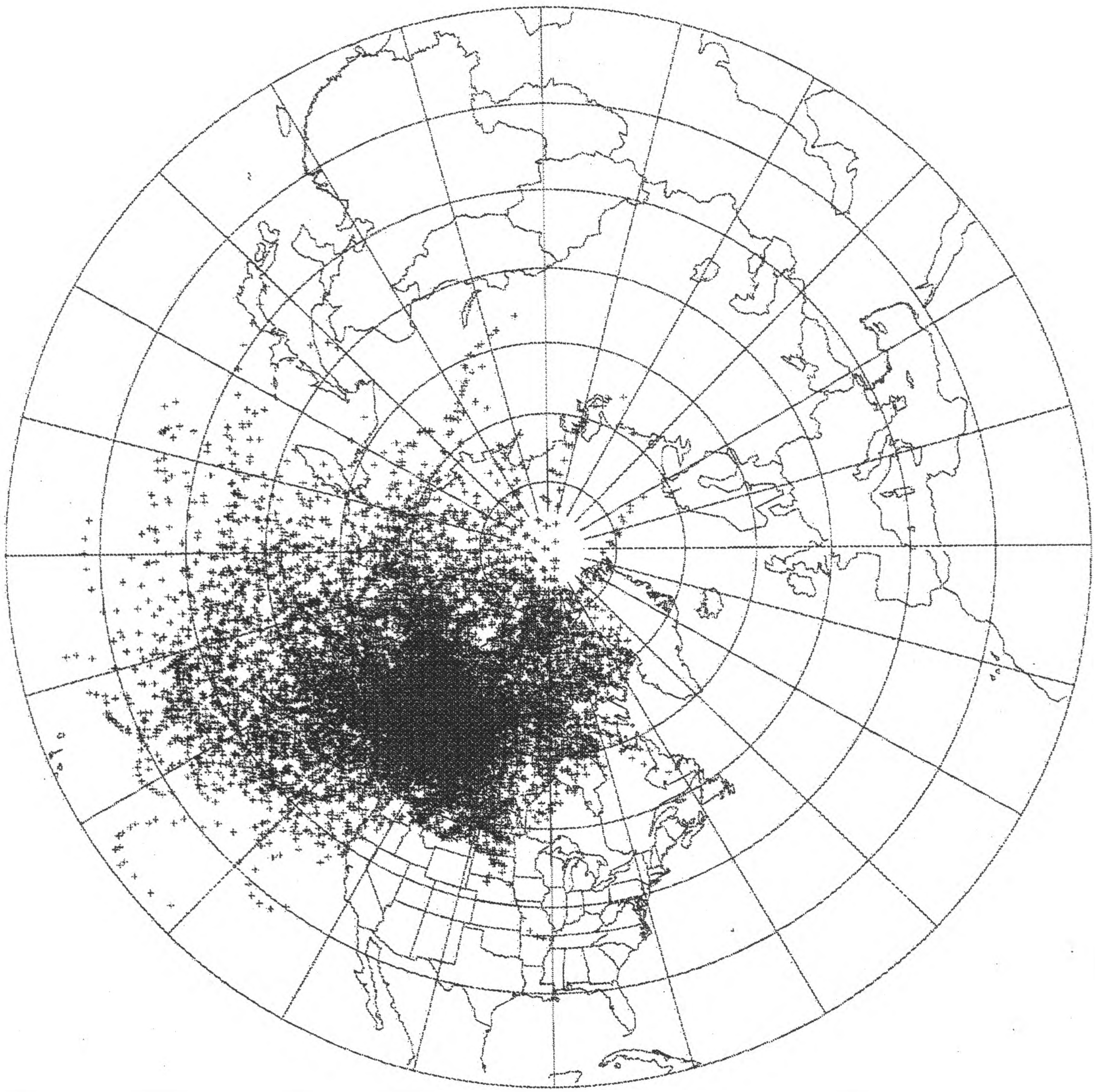


Figure 6(a): End-points at 850 mb during the closed-water season with latitudes every 10° beginning at 20°N and longitudes every 15° with 0° at the far right.

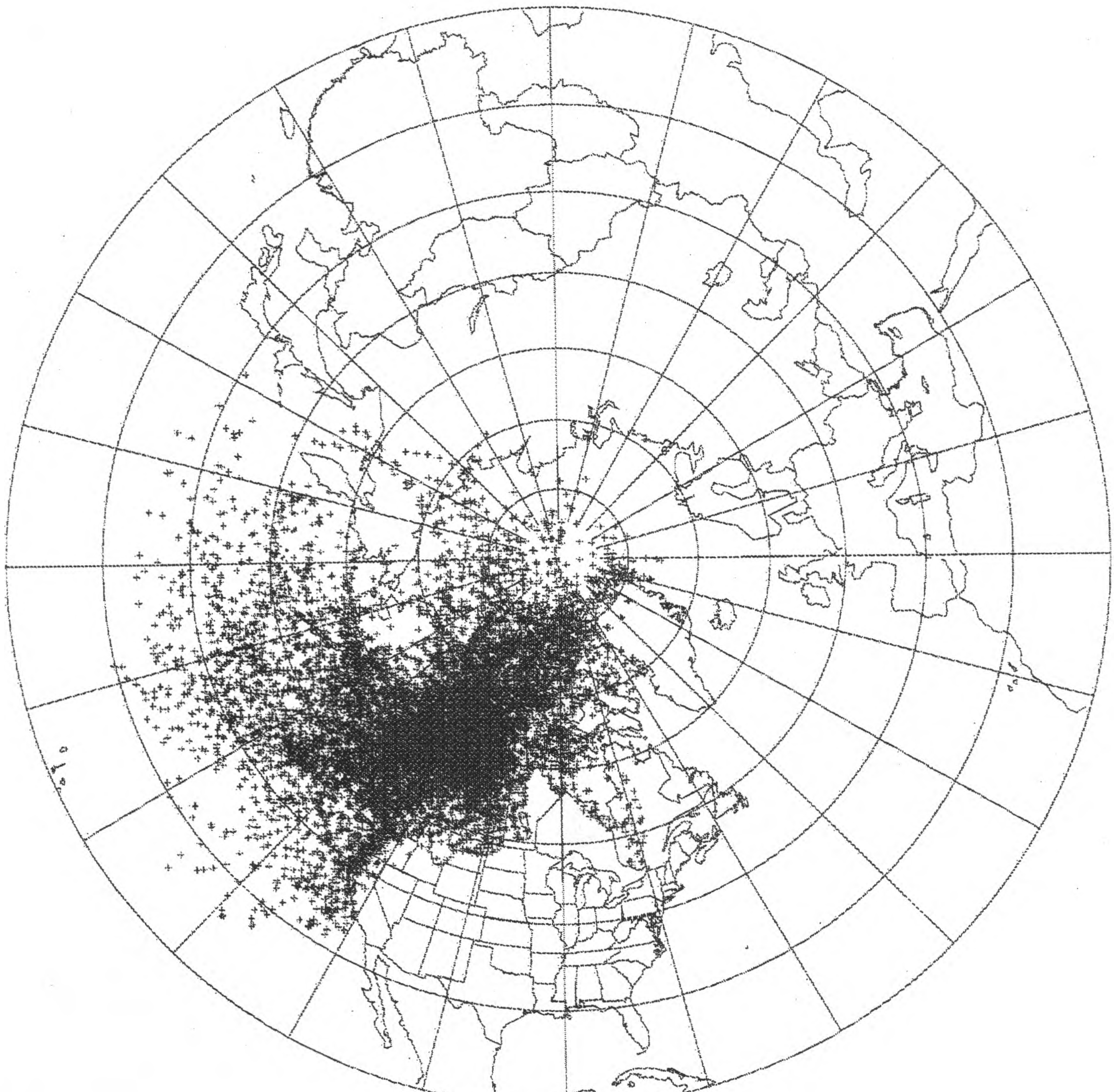


Figure 6(b): End-points at 850 mb during the open-water season with latitudes every 10° beginning at 20°N and longitudes every 15° with 0° at the far right.

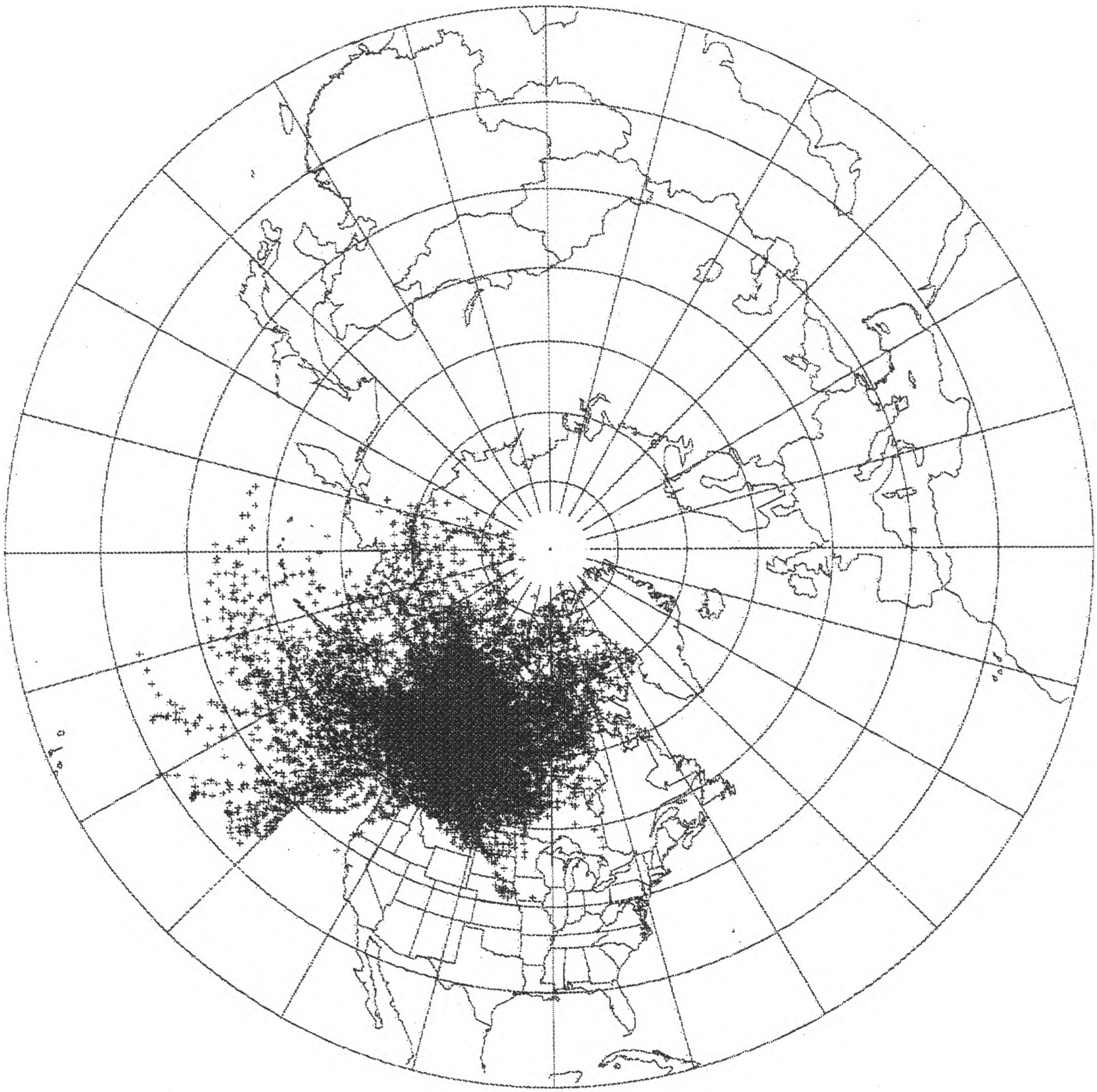


Figure 7(a): End-points at 925 mb during the closed-water season with latitudes every 10° beginning at 20°N and longitudes every 15° with 0° at the far right.

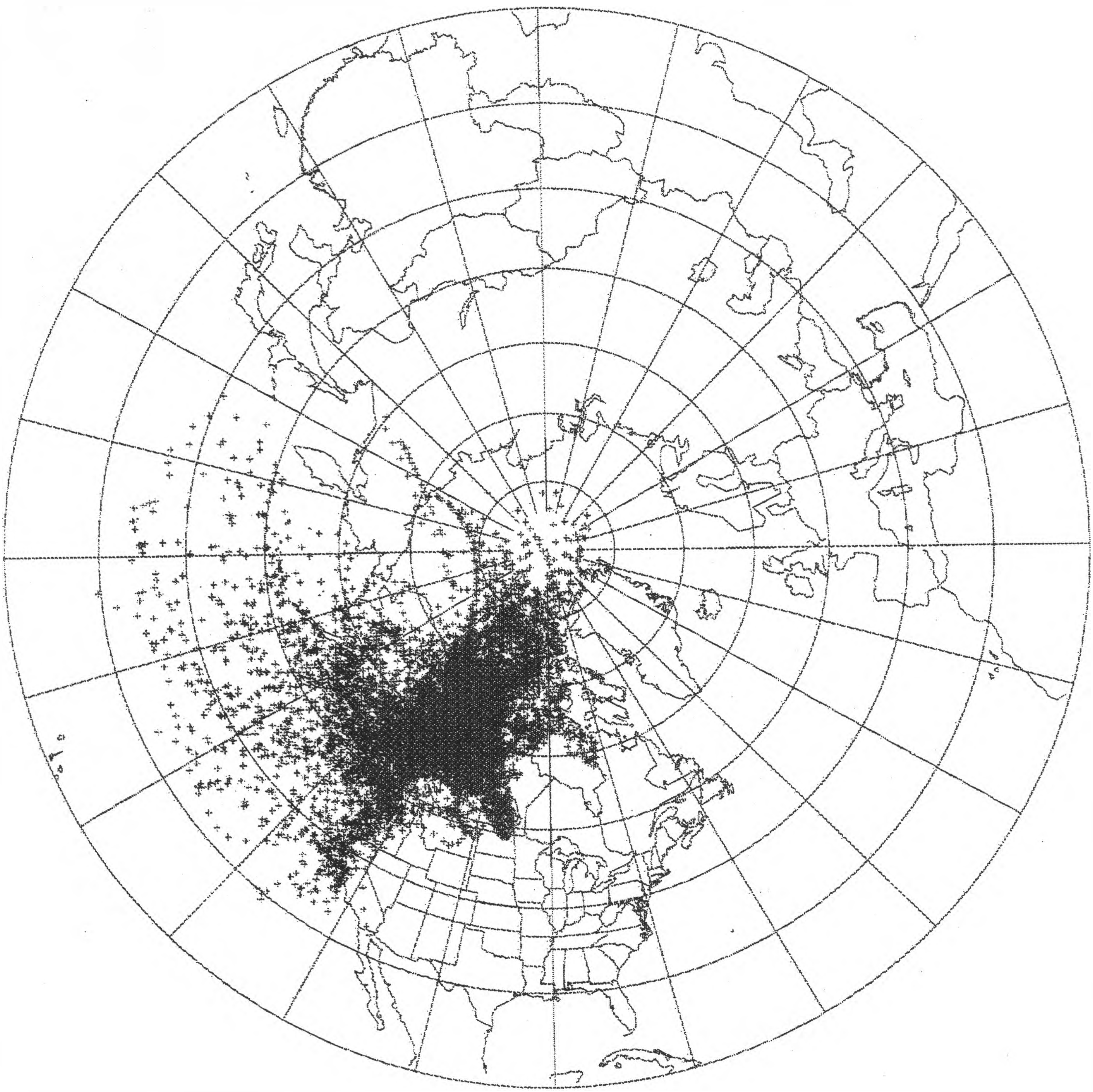
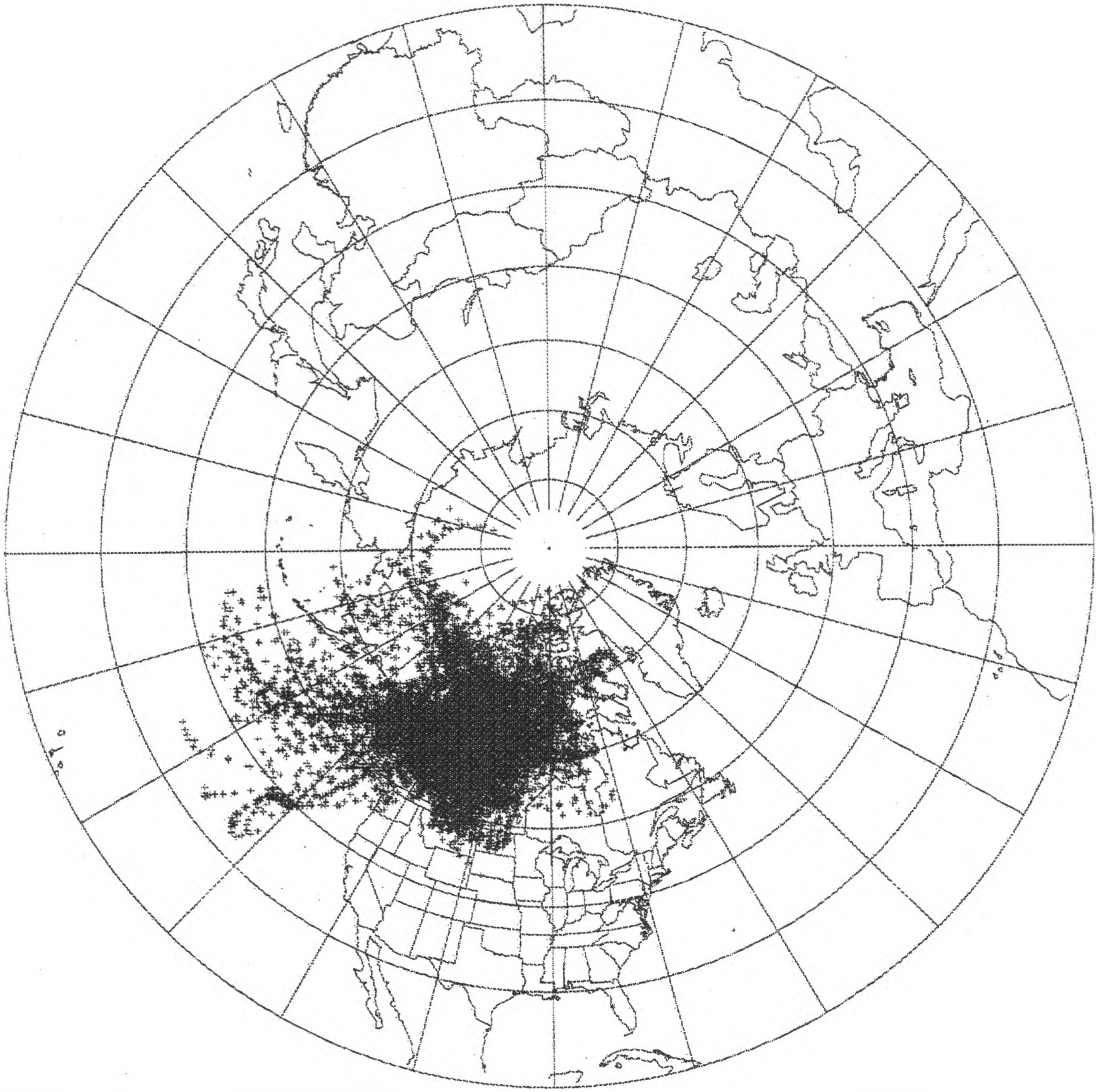


Figure 7(b): End-points at 925 mb during the open-water season with latitudes every 10° beginning at 20°N and longitudes every 15° with 0° at the far right.



Less information is obtained about LRTAP from the 700, 850 and 925 mb end-point plots which are given in Figures 5 through 7 for completeness. As the pressure levels near the surface, the areal spread of the points decreases substantially as would be expected due to topographical effects. The differences between the closed and open-water seasons, however, become slightly more pronounced at the lower levels. These plots give some indication of the extent of the lower level winds which may bring shorter-lived contaminants into the river basin.

In order to better observe the transport through time, similar plots are obtained for each one-day step backwards from the river basin for the 500 mb cases only. Figures 8(a) through 8(e) show points for only periods of one day back at a time during the closed-water season. Obviously, the distance covered by the trajectories increases as the numbers of days backwards increases. The day-one points do not vary further than North America while day-two and day-three include north-east Asia and the northern Pacific Ocean. By day-four, points are observed as far as Japan and more spread is evident in all directions especially around the North Pole with some points from western Europe. Day-five shows the widest spread with much of the Pacific Ocean covered north of 20°N.

Similar plots are given for the open-water season in Figures 9(a) through 9(e). As with the open-water season, by day-four points are observed in Japan and on the Asian coast. More points are seen in the interior of Asia but none in Europe. The open-water season shows less spread and the day-five plot shows that the Pacific Ocean is covered only to 30°N although some points are found further south due likely to the deep low observed in the Pacific that year.

By simply counting the air trajectory end-points and segregating them into parcels that are 15° longitude by 10° latitude, the absolute number of events that air has passed over these areas can be derived from the parcel counts. These frequencies are contoured in Figures 10(a) and 10(b) for the closed and open-water seasons. They follow the major flow patterns around the north pole toward western North America and into the river basin. In the closed-water season, there is a clear flow directly from the west and one that comes up slightly from the southwest along the coast of North America. There is a significant frequency of points from eastern Asia as well as from northern Europe. In the open-water season, the southwest flow is not observed but instead flow is evident from the southeast part of North America. There is practially no frequency of points in Europe and the spread into Asia is more northerly avoiding most of the heavily populated areas of China.

The frequency contours do not, however, provide specific probabilities for specific source regions; for this the globe was segmented into sectors of similar emission histories. From the count information used in the contours above, it is possible to provide a probability that the air arriving at Lake Athabasca has passed over a given segment of the globe in a given period of time up to five days. While this cannot include the processes of revolatilization and resuspension following deposition, it does include direct air emissions transport over a five day period. This information is summarized in Table 3. Naturally, the probabilities from Western North America are the largest in either season but there are differences in the relative probabilites. In particular, there is a greater probability of air from the Pacific and East Asia in the closed-water season than in the open-water season which shows greater probabilities from within North America. Upon removing those points within the Western North America grouping, the seasons' probabilities are much more even with more than 82% of the points coming from the Pacific, 8.6% from East Asia, and 1.5% from Central Asia in both seasons. In the closed-water season, Europe shows the greater probability at 2.2% with 4.8% from Eastern North America while, in the open-water season, only 0.4% arrive from Europe with 8.3% from Eastern North America.

Table 3: Probabilities for air passage from specific emission area around the Northern Hemisphere during the closed and open-water seasons.

Emission Area	Global Longitudes	Closed-Water Season Oct 91 to March 92	Open-Water Season April 92 to Sept 92
Pacific	150W to 150E	0.41	0.29
East Asia	150E to 90E	0.04	0.03
Central Asia	90E to 30E	0.01	0.01
Europe	30E to 30W	0.01	0.00
Eastern N.A.	30W to 90W	0.02	0.03
Western N.A.	90W to 150W	0.51	0.64

Contouring the frequency counts of occurrence of these points on a smaller scale will show the dominating areas in the one to two day regime. Figures 11(a) through 11(d) show these contours at the four atmospheric levels for the closed-water season. Figures 12(a) through 12(d) show the same contours for the open-water season. Again, the spread is larger as the height of the contours increases from 925 to 500 mb. The contours become less circular at the higher altitudes because the flow is less dominated by variable surface meteorology and shows the prevailing flow better. All of the contours are shifted to the north of the site indicating that the windspeeds are greater from the north and airborne particles can travel more distance in the same time frame.

The open-water season shows very little flow from southern and eastern North America while the closed-water sheason shows more probability of flow from the west coast of the United States. In the closed-water season, contours are shifted to the north as before but also to the west indicating that winds off of the Pacific are stronger than those from inland during the winter months. Generally, airborne contaminants into the area will come from a polar route from east to west rather than a south to north route.

Figure 8(a): End-points at 500 mb during the closed-water season for one-day step with latitudes every 10° beginning at 20°N and longitudes every 15° with 0° at the far right.

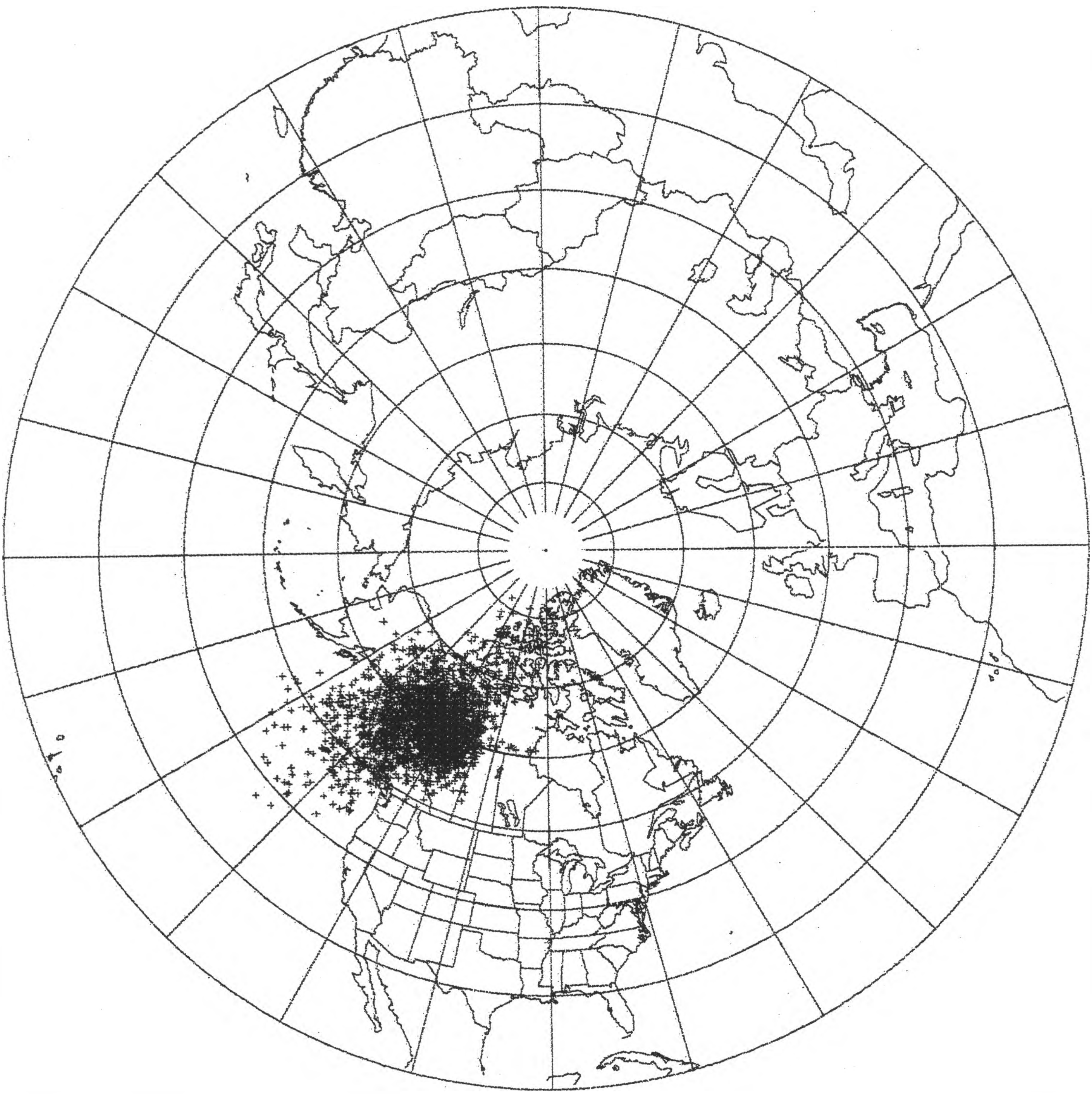


Figure 8(b): End-points at 500 mb during the closed-water season for two-day step with latitudes every 10° beginning at 20°N and longitudes every 15° with 0° at the far right.

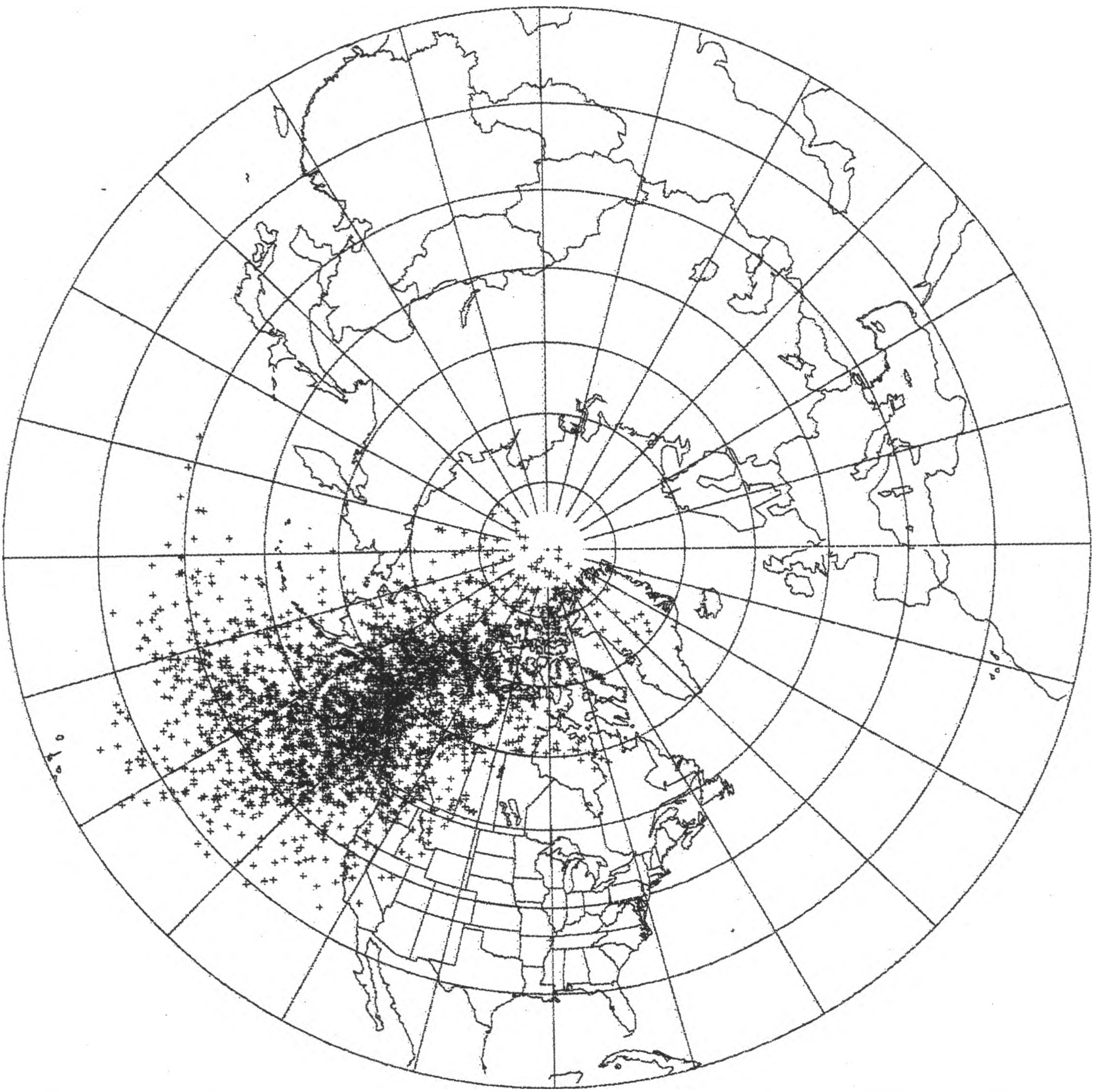


Figure 8(c): End-points at 500 mb during the closed-water season for three-day step with latitudes every 10° beginning at 20°N and longitudes every 15° with 0° at the far right.

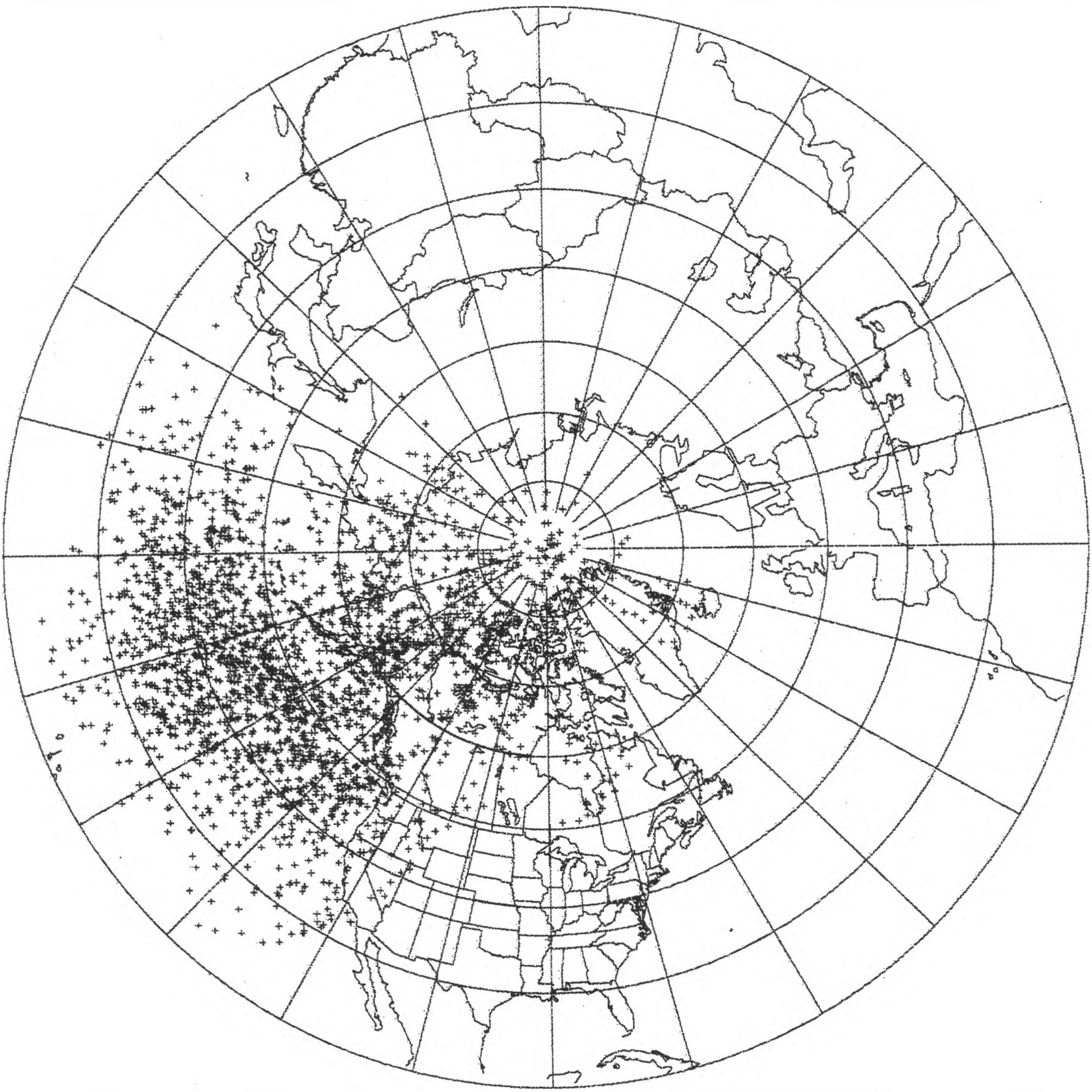


Figure 8(d): End-points at 500 mb during the closed-water season for four-day step with latitudes every 10° beginning at 20°N and longitudes every 15° with 0° at the far right.

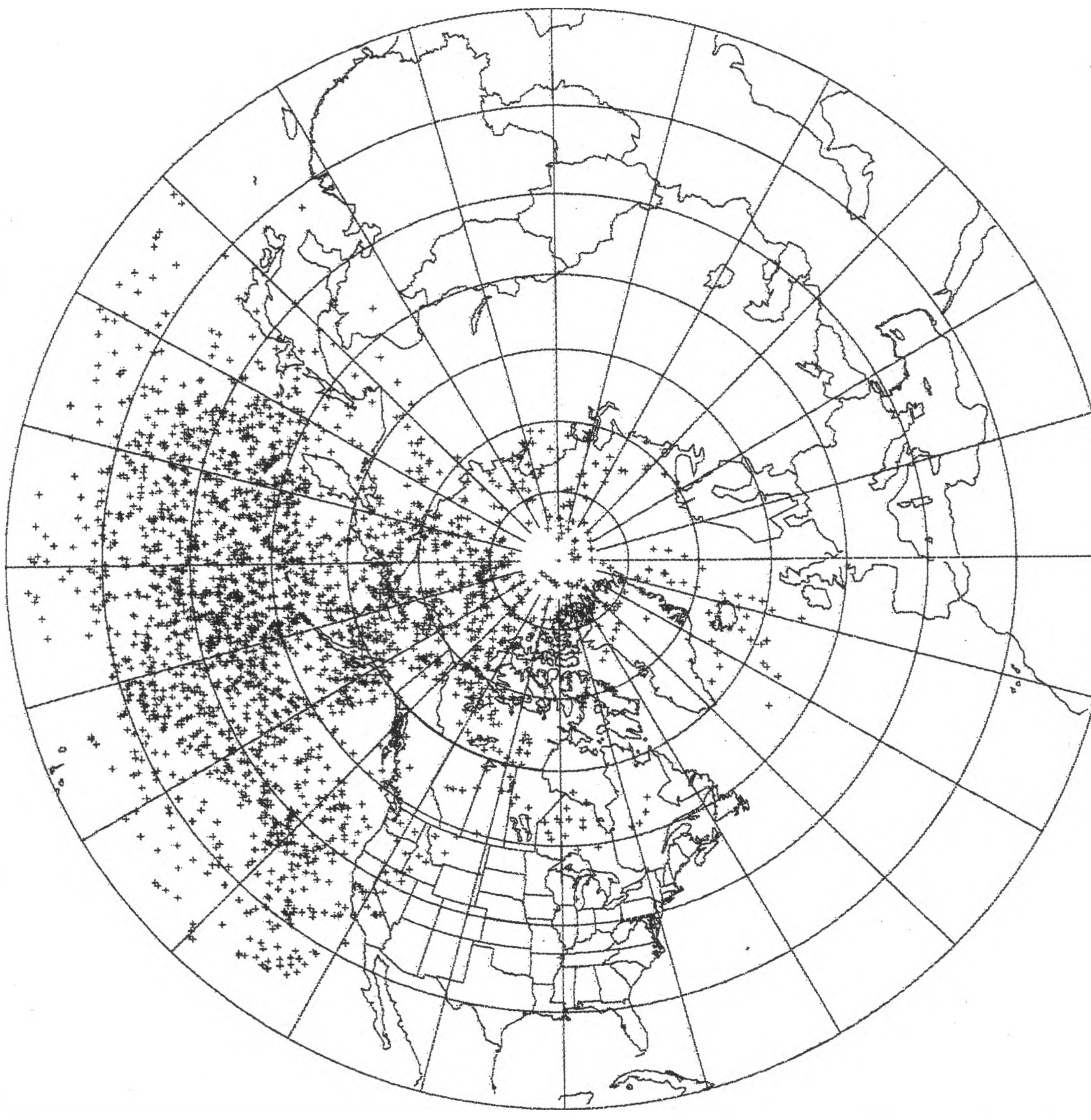


Figure 8(e): End-points at 500 mb during the closed-water season for five-day step with latitudes every 10° beginning at 20°N and longitudes every 15° with 0° at the far right.

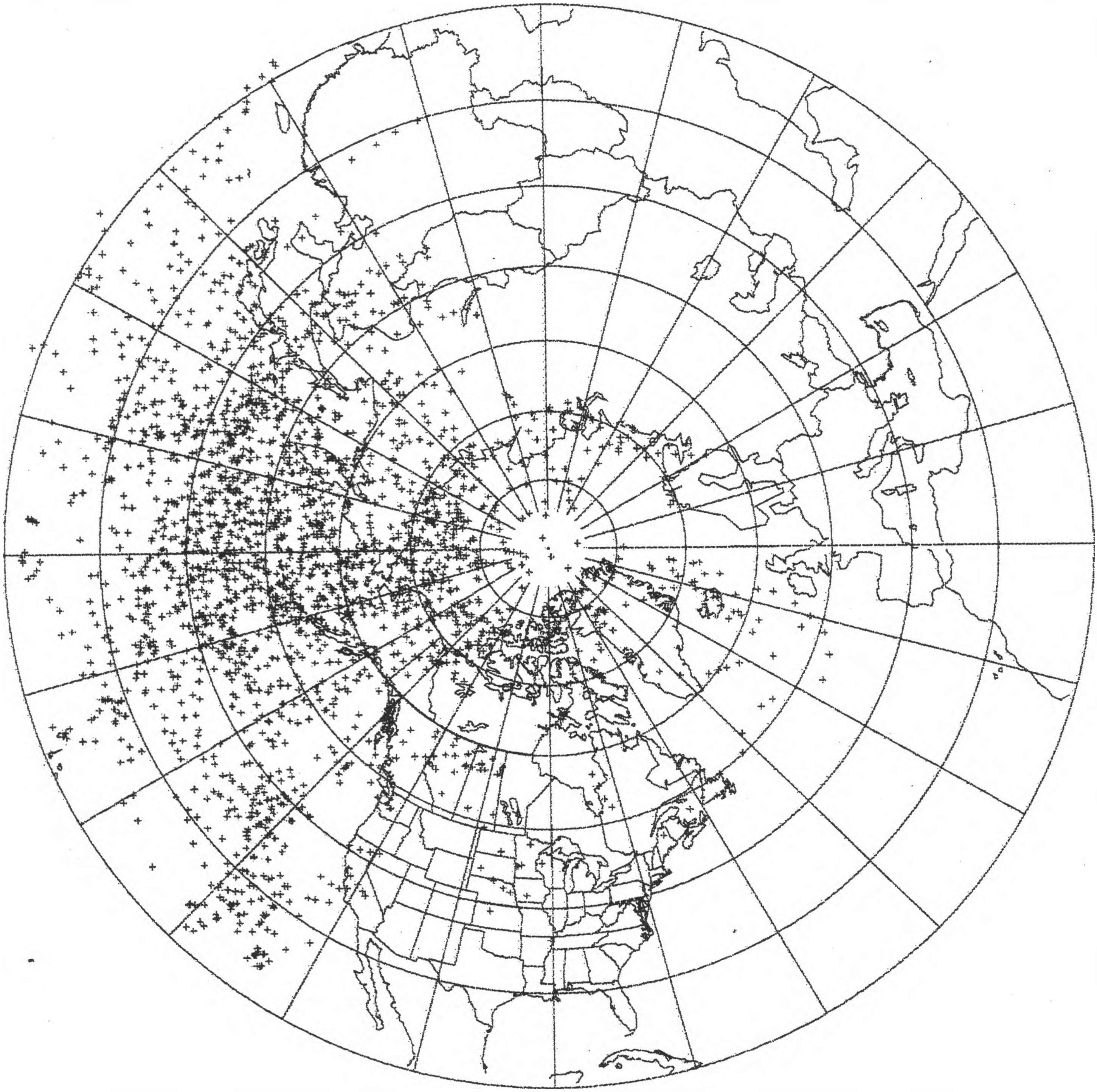


Figure 9(a): End-points at 500 mb during the open-water season for one-day step with latitudes every 10° beginning at 20°N and longitudes every 15° with 0° at the far right.

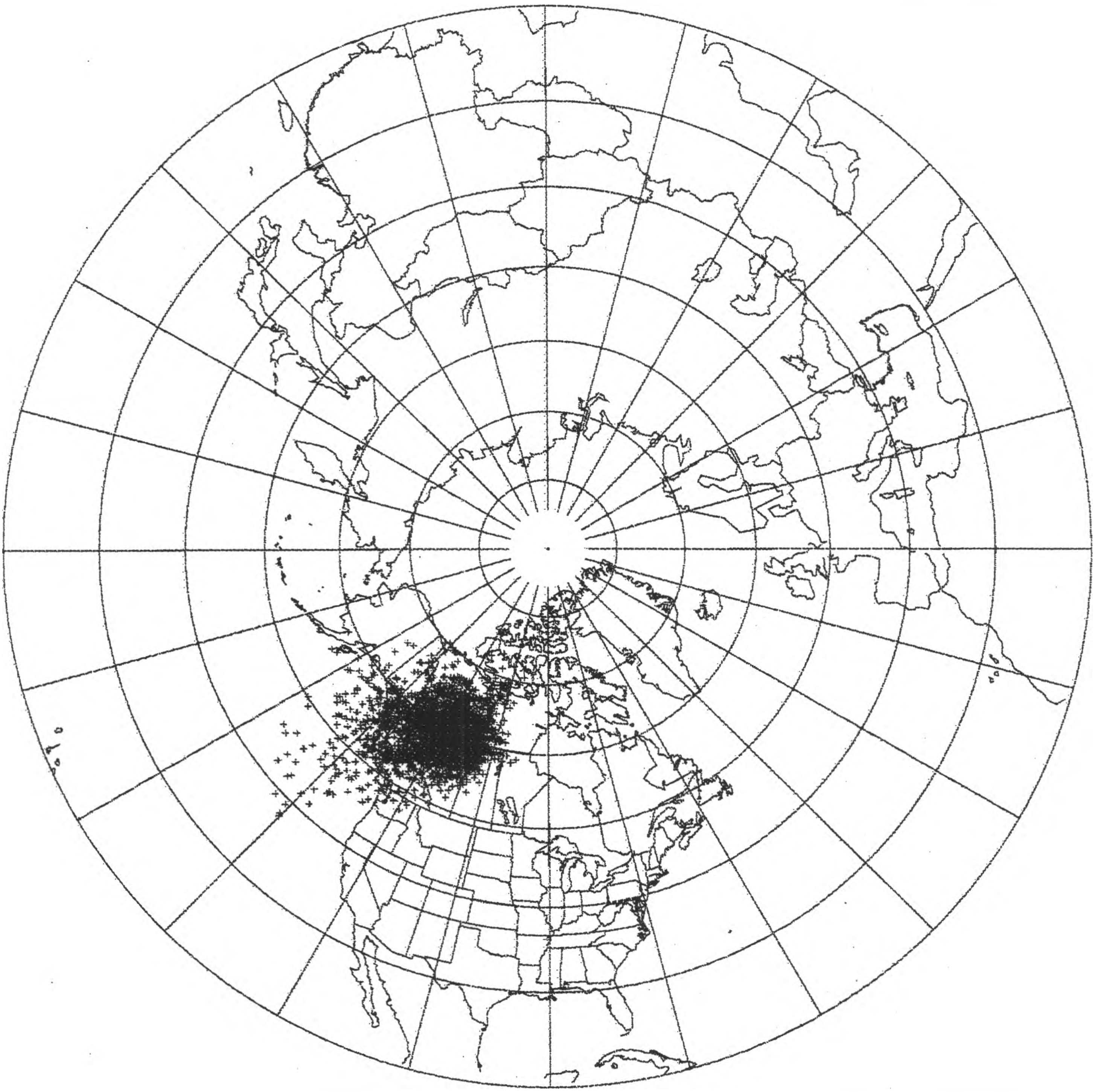


Figure 9(b): End-points at 500 mb during the open-water season for two-day step with latitudes every 10° beginning at 20°N and longitudes every 15° with 0° at the far right.

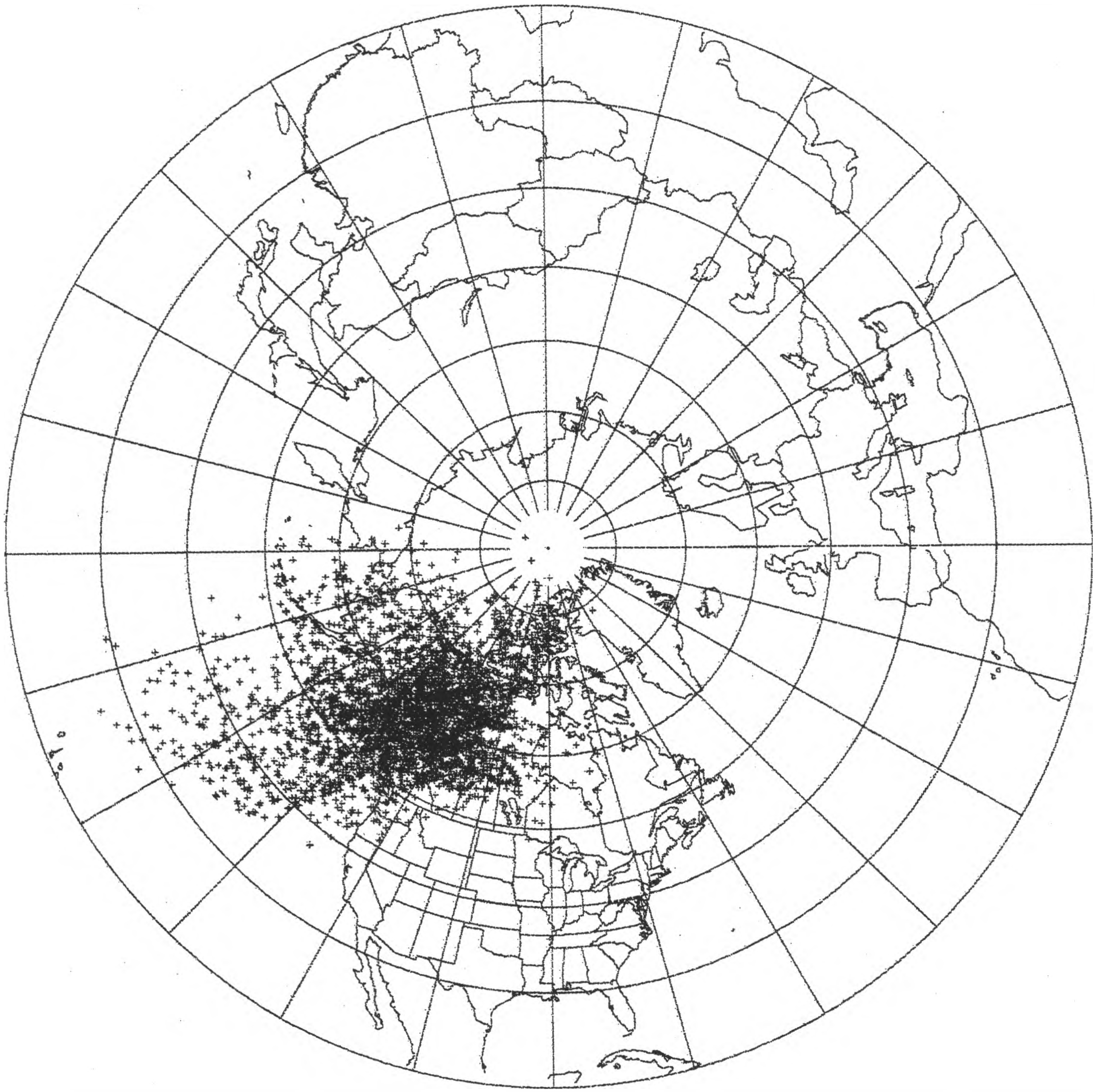


Figure 9(c): End-points at 500 mb during the open-water season for three-day step with latitudes every 10° beginning at 20°N and longitudes every 15° with 0° at the far right.

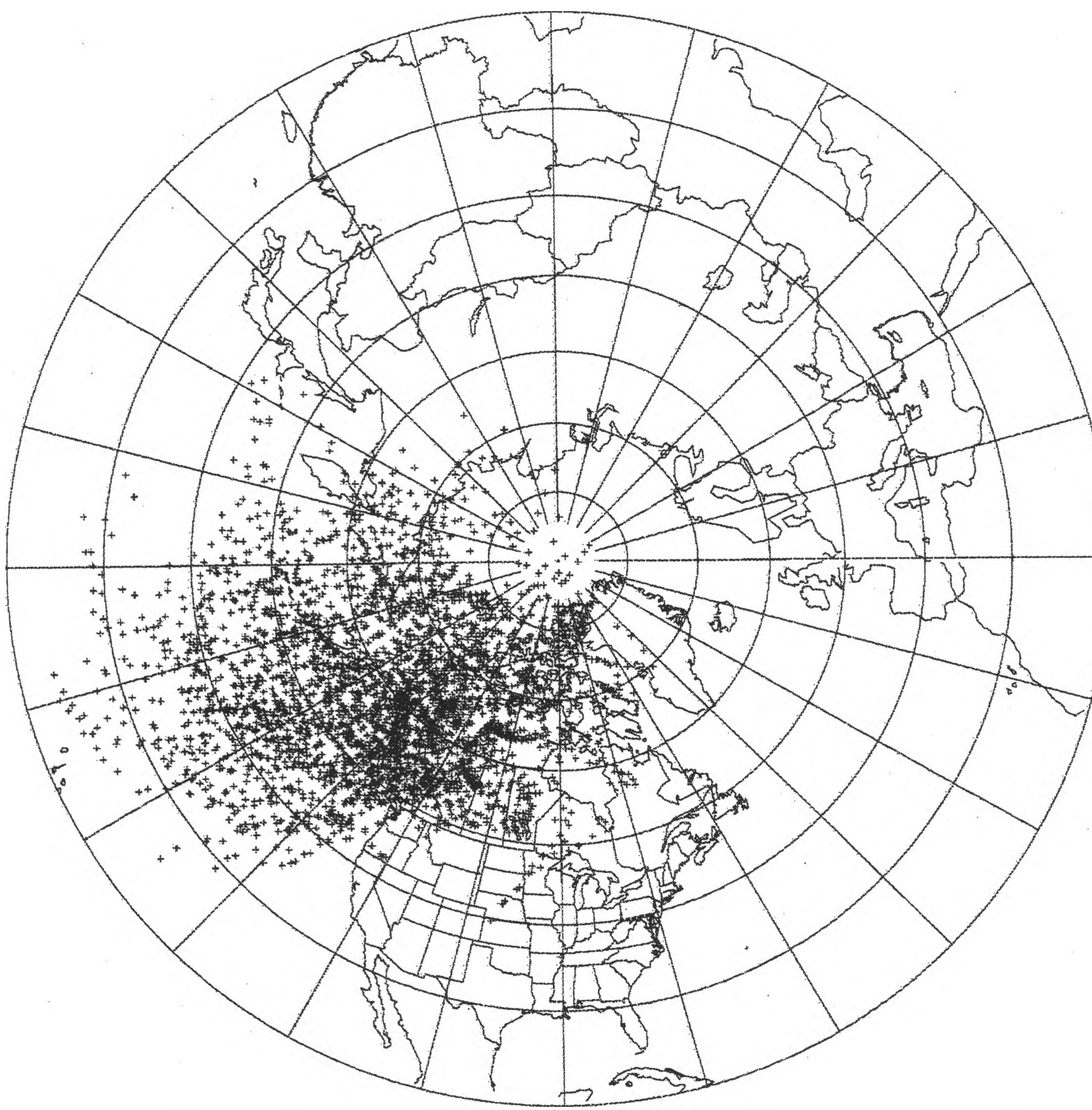


Figure 9(d): End-points at 500 mb during the open-water season for four-day step with latitudes every 10° beginning at 20°N and longitudes every 15° with 0° at the far right.

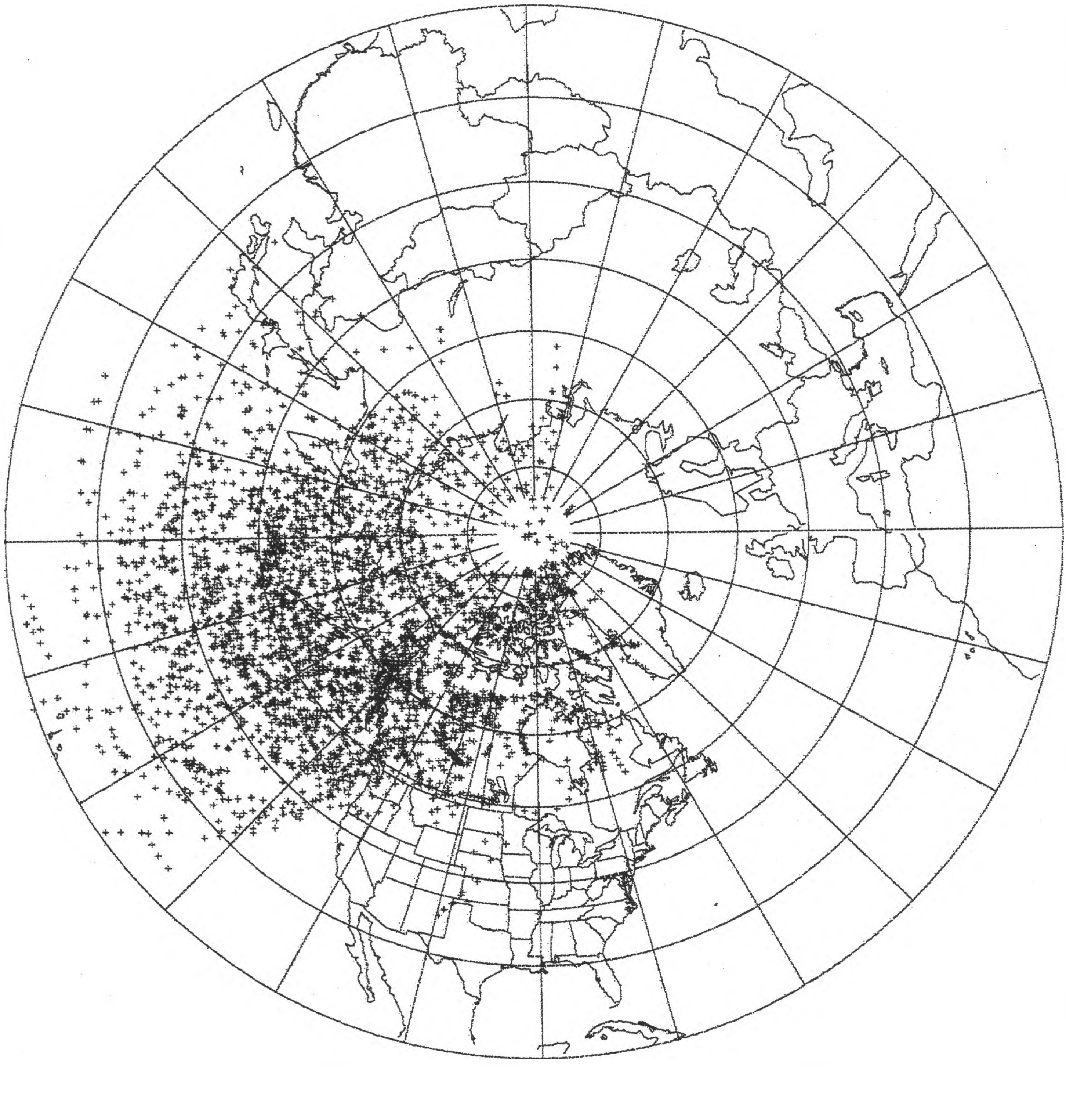


Figure 9(e): End-points at 500 mb during the open-water season for five-day step with latitudes every 10° beginning at 20°N and longitudes every 15° with 0° at the far right.

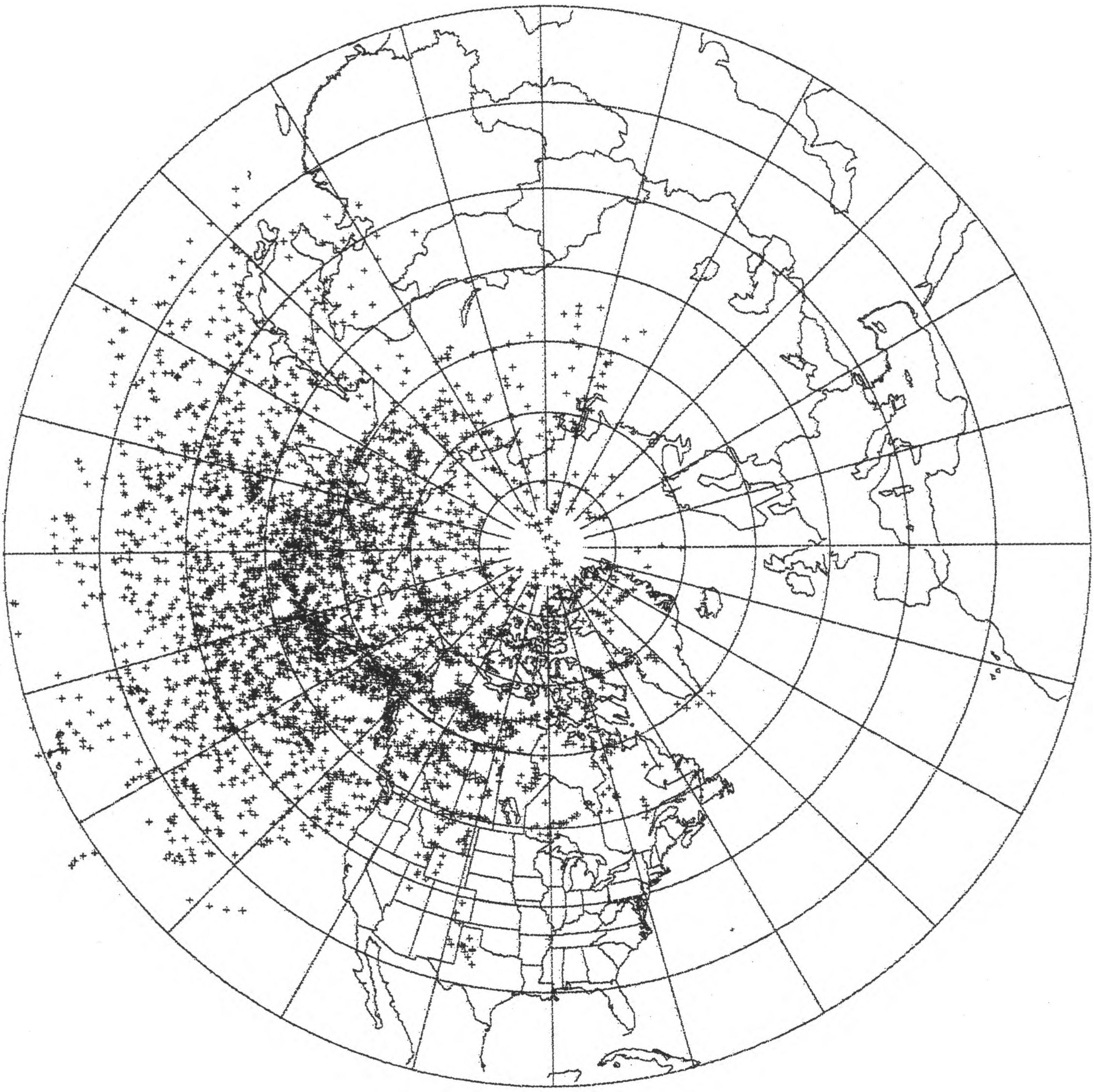


Figure 10(a): Contours of end-point frequency counts for air passage to the river basin at 500 mb during the closed-water season.

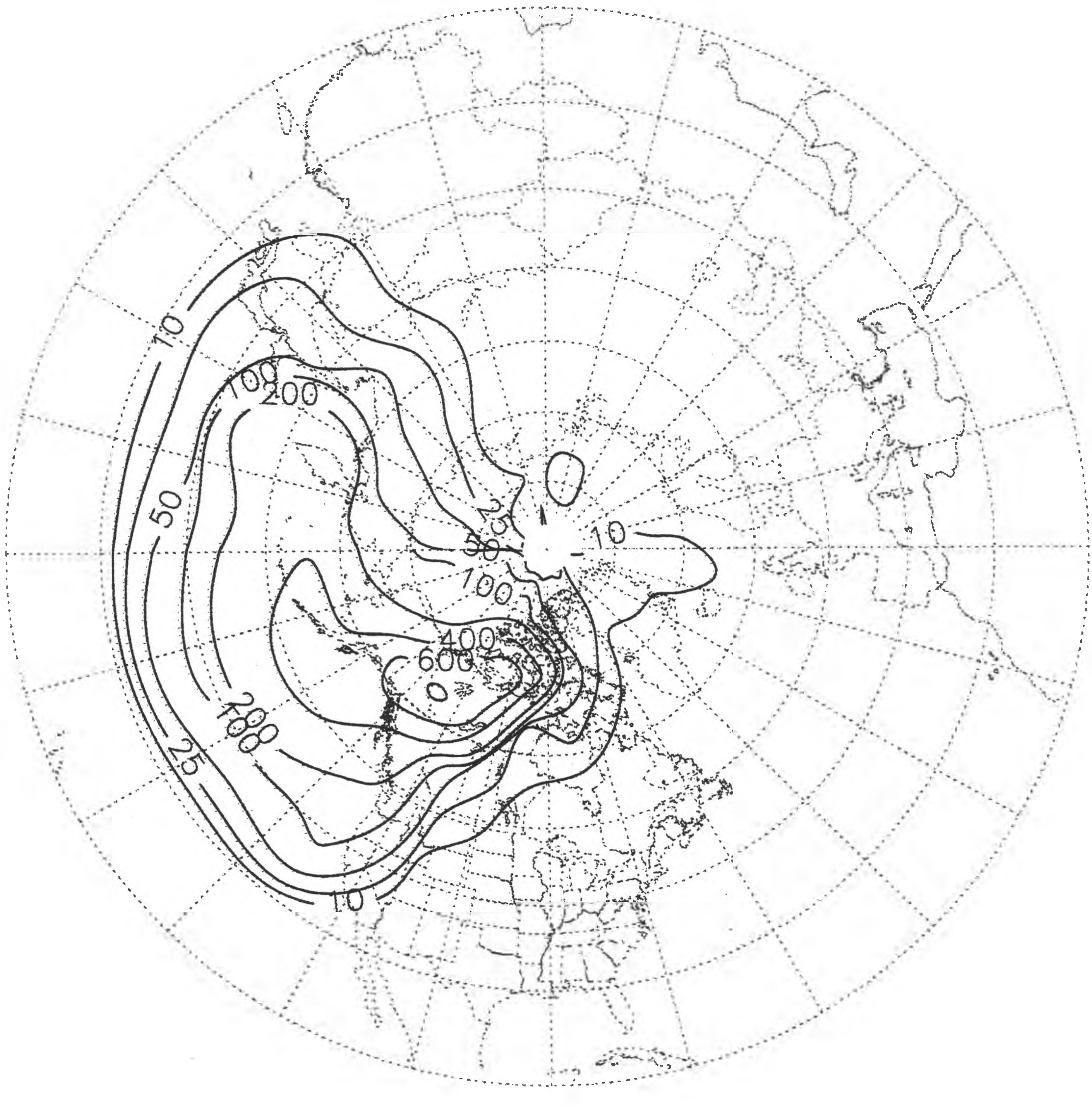


Figure 10(b): Contours of end-point frequency counts for air passage to the river basin at 500 mb during the open-water season.

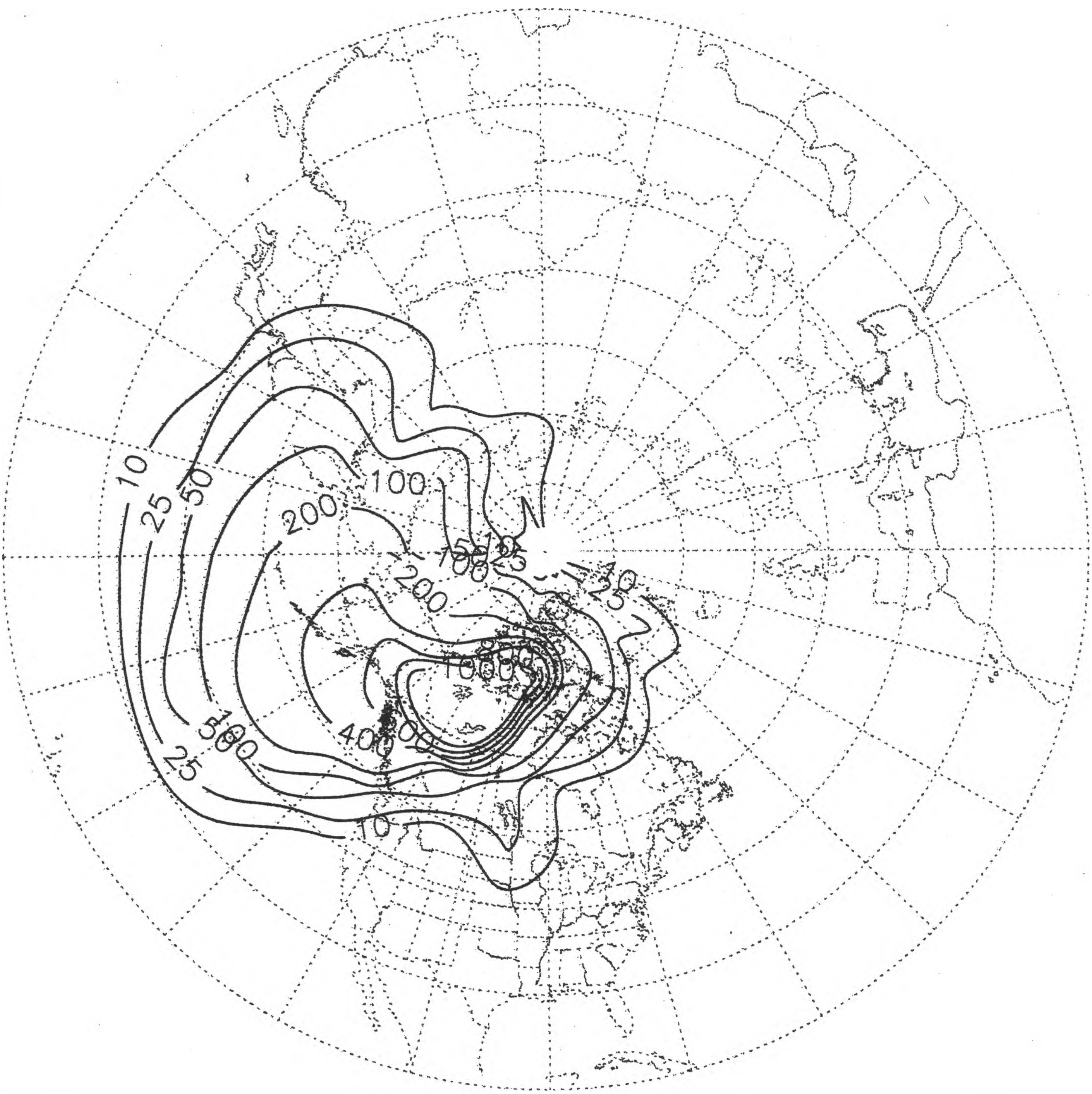


Figure 11(a): Contours of the frequency counts of winds to Lake Athabasca at 500 mb in the closed-water season.

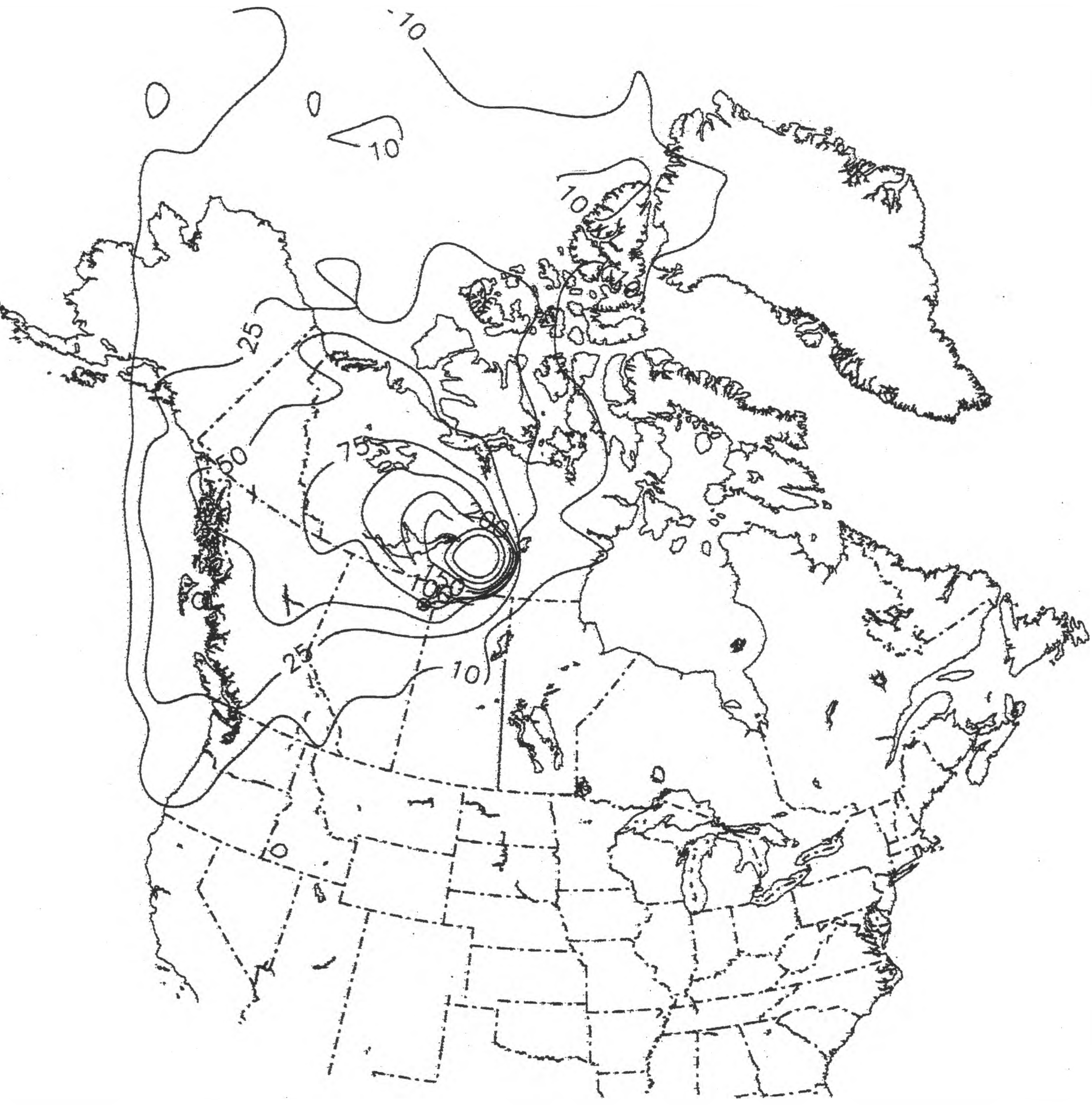


Figure 11(b): Contours of the frequency counts of winds to Lake Athabasca at 700 mb in the closed-water season.

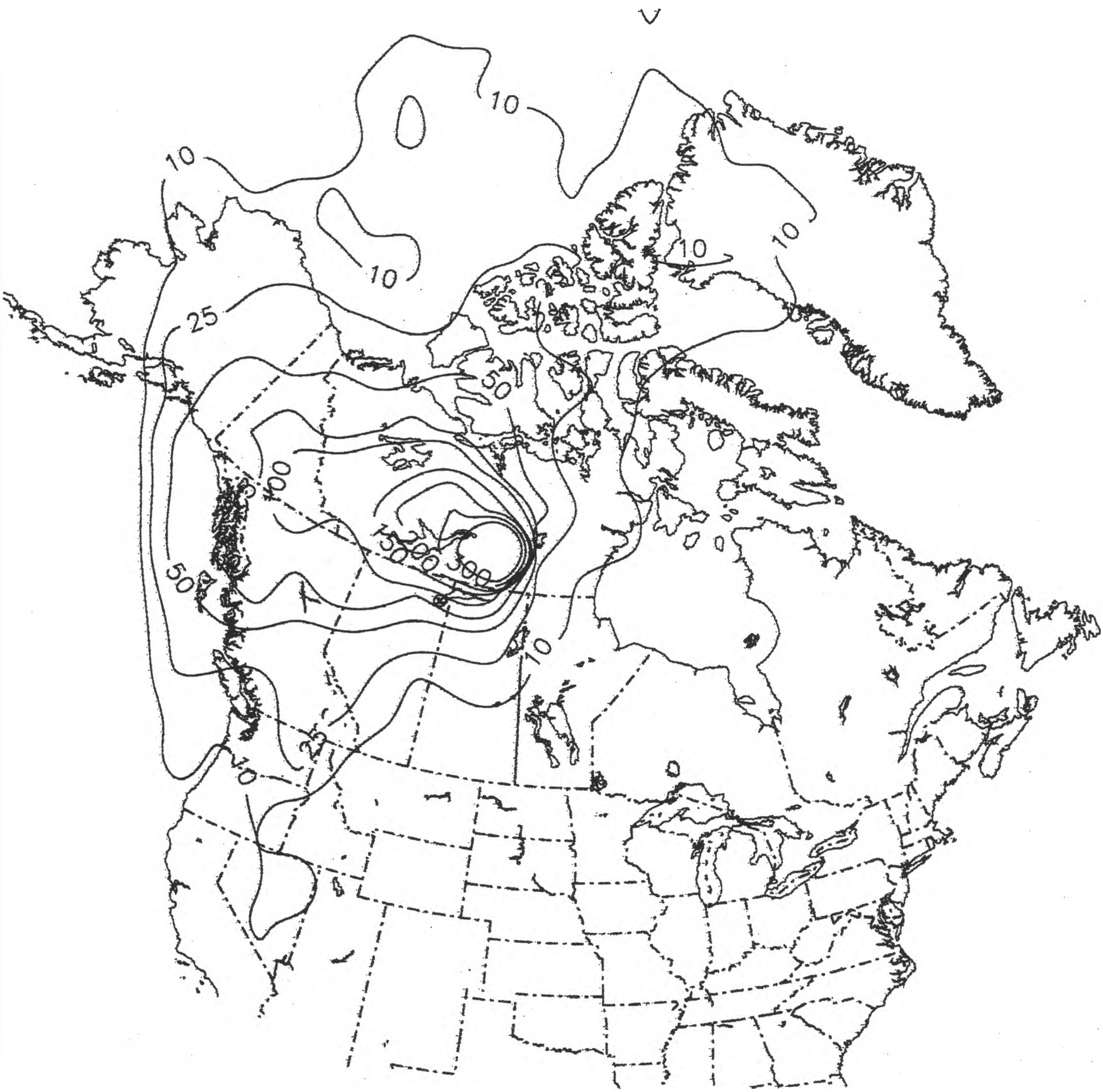


Figure 11(c): Contours of the frequency counts of winds to Lake Athabasca at 850 mb in the closed-water season.

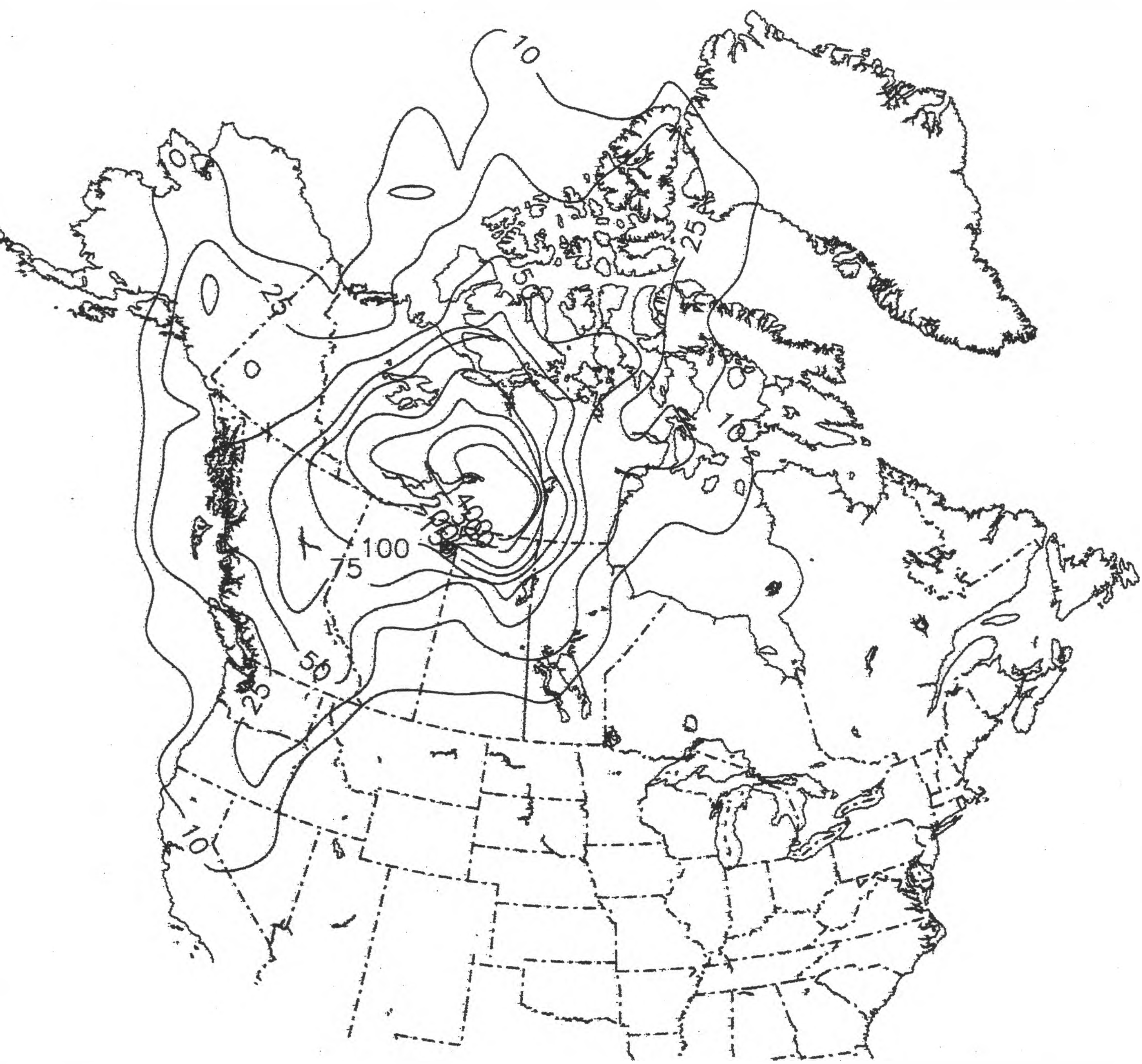


Figure 11(d): Contours of the frequency counts of winds to Lake Athabasca at 925 mb in the closed-water season.

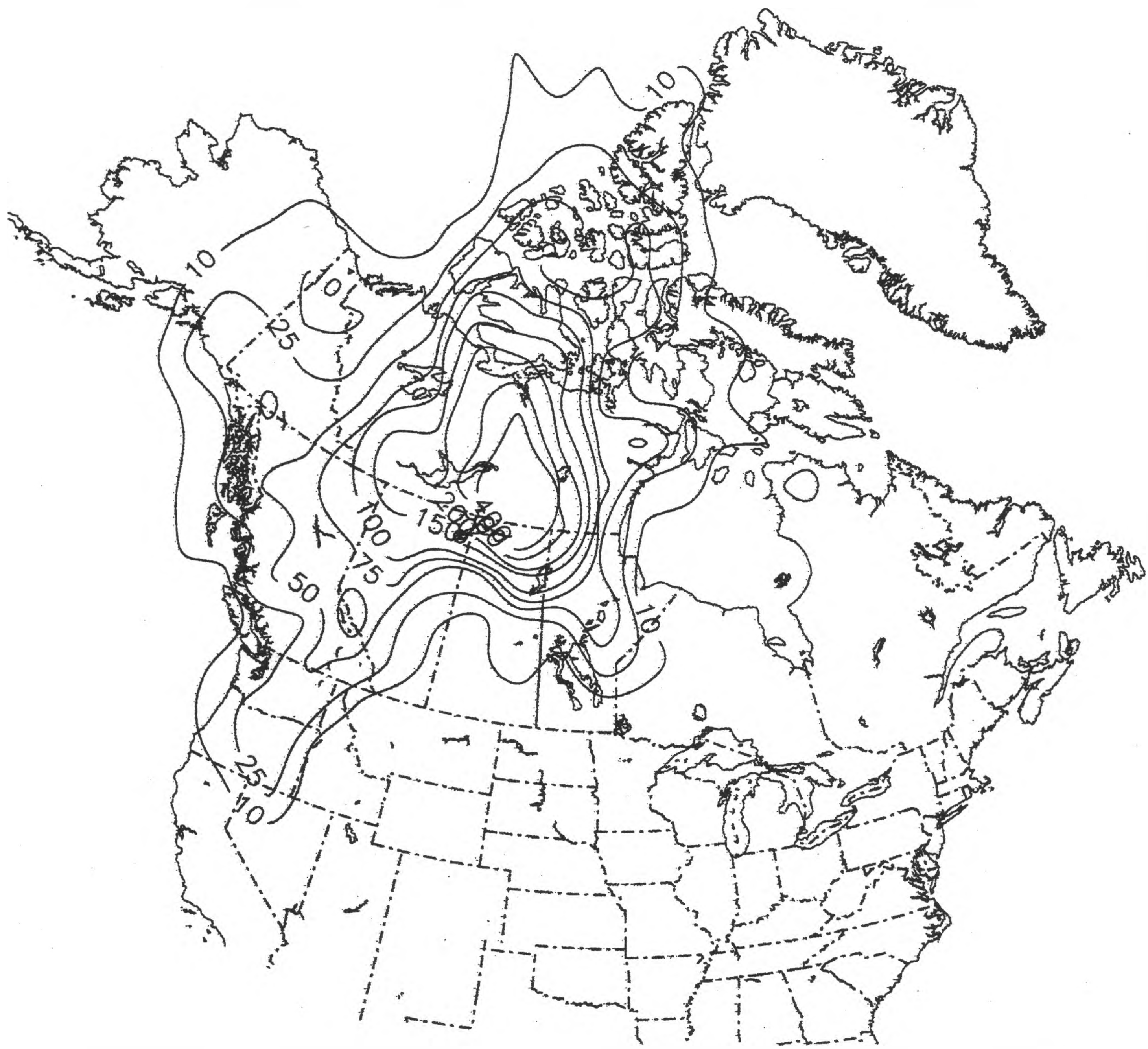


Figure 12(a): Contours of the frequency counts of winds to Lake Athabasca at 500 mb in the open-water season.

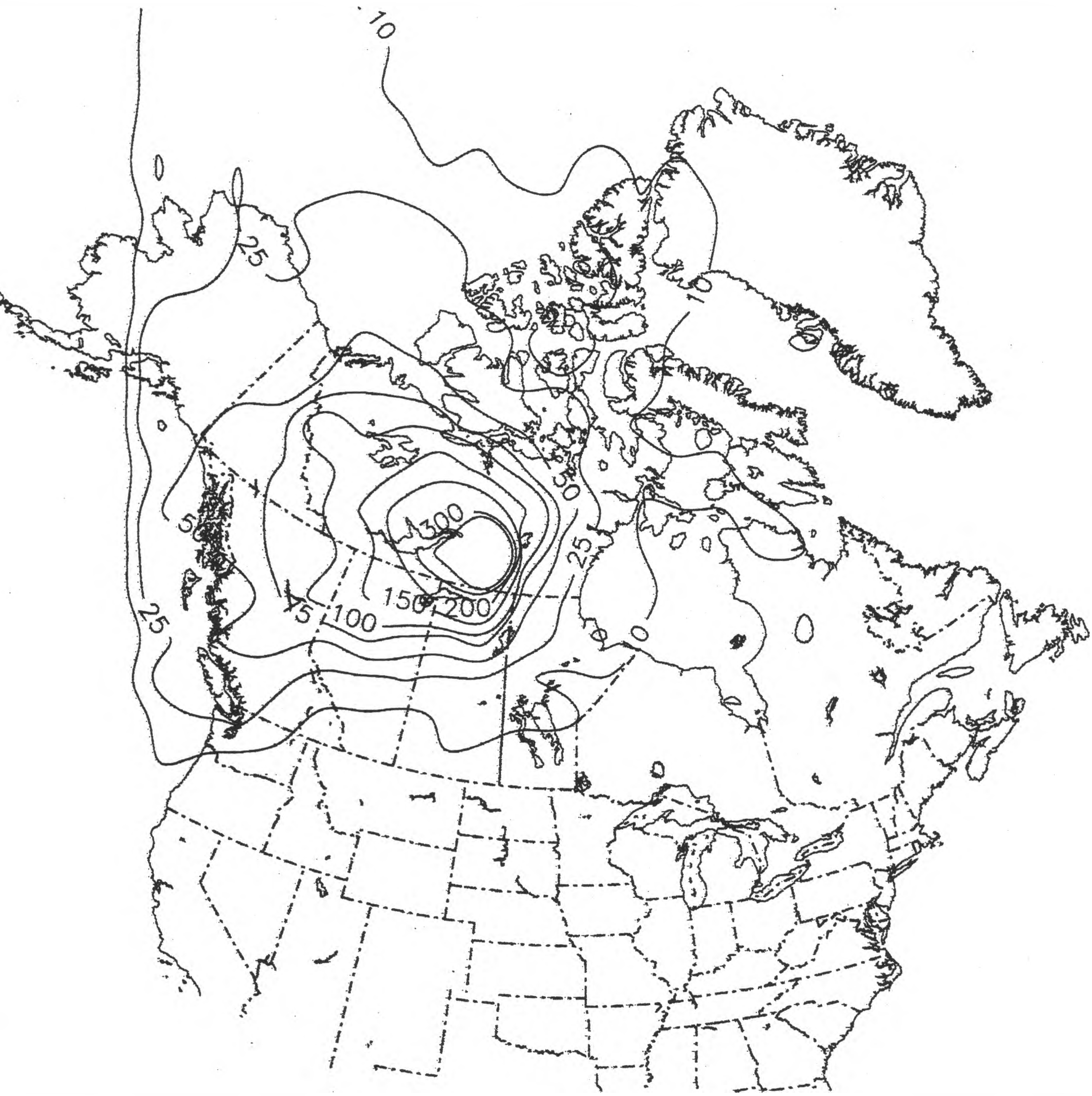


Figure 12(b): Contours of the frequency counts of winds to Lake Athabasca at 700 mb in the open-water season.

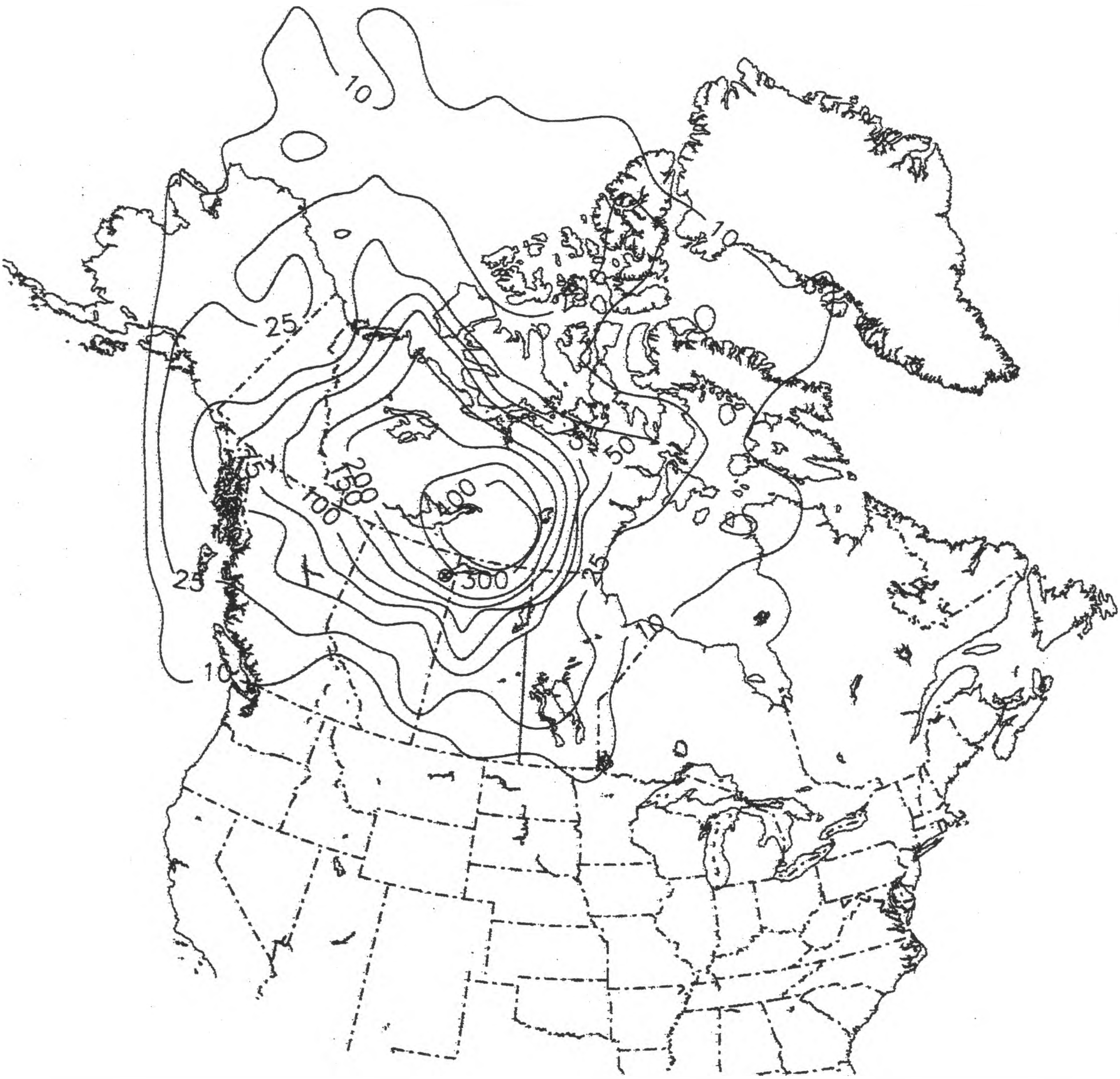


Figure 12(c): Contours of the frequency counts of winds to Lake Athabasca at 850 mb in the open-water season.

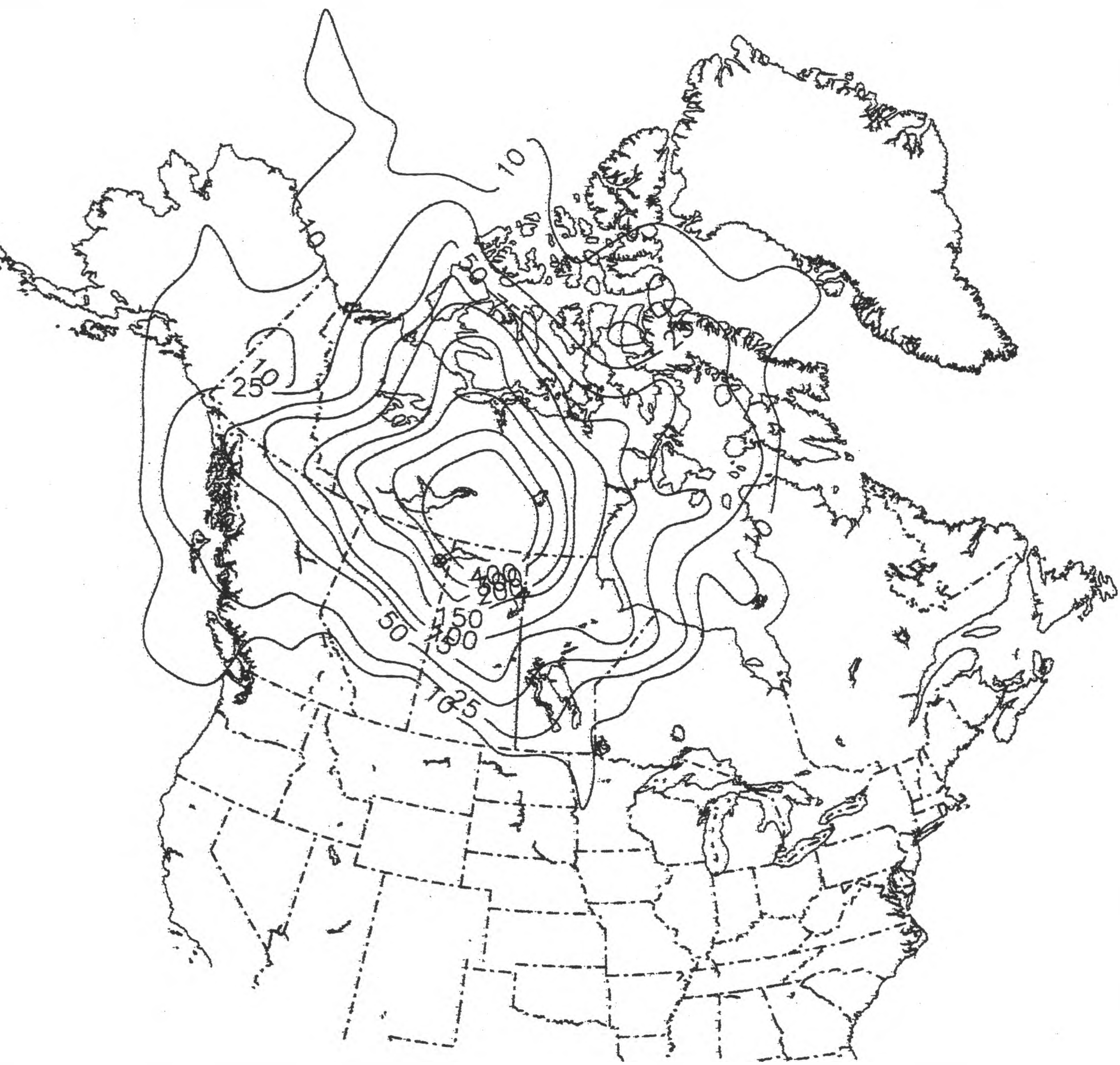
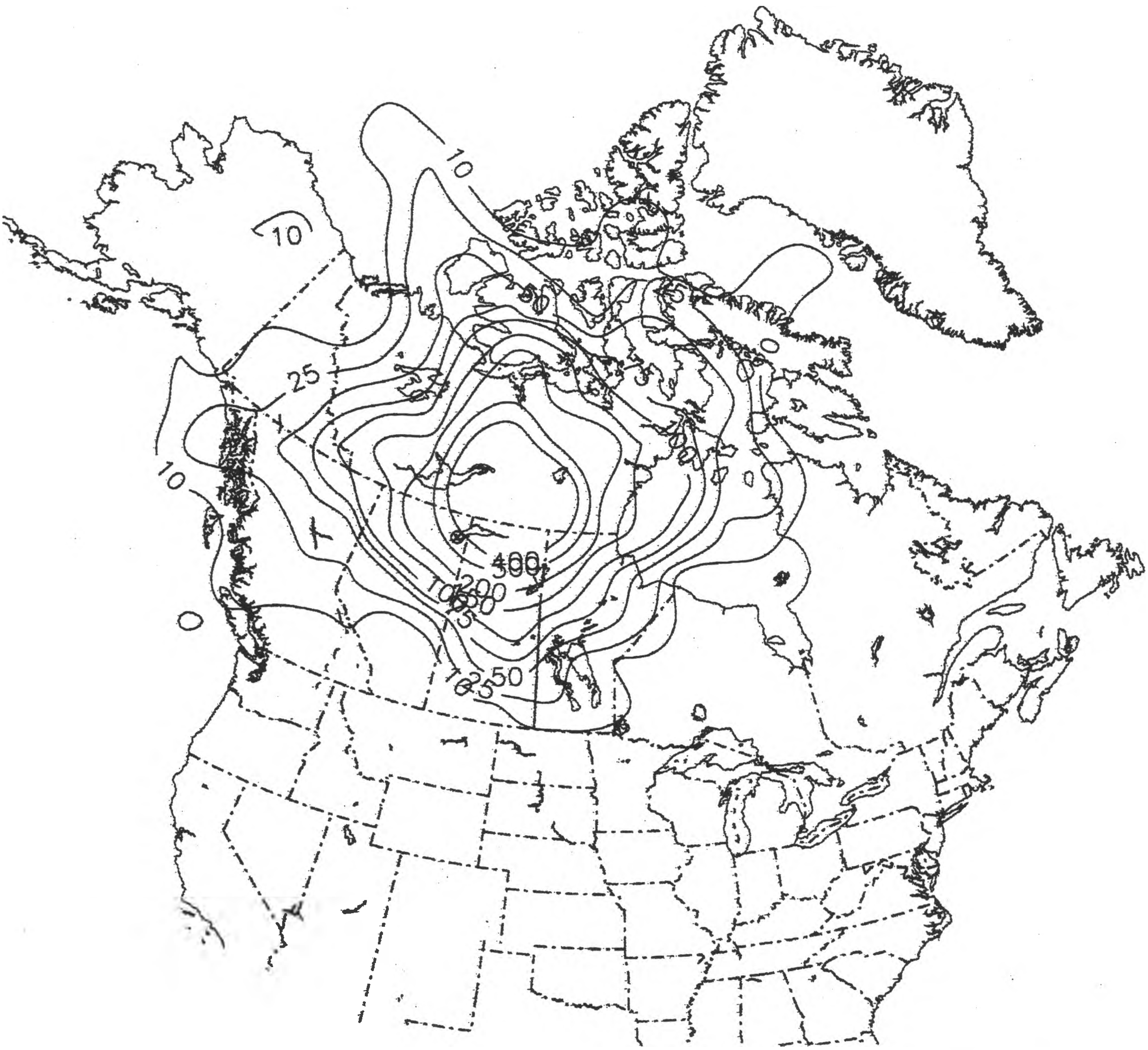


Figure 12(d): Contours of the frequency counts of winds to Lake Athabasca at 925 mb in the open-water season.



4.0 Conclusions:

The Atmospheric Environment Service (AES) Lagrangian model for the assessment of the Long-Range Transport of Air Pollutants (LRTAP) has been applied to the problem of identifying major global atmospheric pathways for air arriving at Lake Athabasca at 59° 3′N and 110° 13′W. The calendar year was separated into a closed-water season (October 91 through March 92) and an open-water season (April 92 through September 92) for analysis of the back trajectories. Generally, the model is capable of representing the two main wind flow directions, east and west, in the area quite well. The point-wise model data for every 6-hour time step backwards for 5 days were plotted on a map of the area of interest to visualize the major pathways of air movements into the river basin.

There is no transport evident from the Southern Hemisphere including Mexico and South America nor is there much arriving from most of Europe and southern Asia. There is very little transport from the industrialized eastern part of North America but more transport comes from this area in the open-water season than in the closed-water season. Most of the air into the Athabasca river basin is coming from the easternmost parts of Asia, passing over the northern Pacific Ocean and making landfall along the western coast of North America. While this analysis does not include the processes of revolatilization and resuspension following deposition, it does include direct air emissions transport over a five day period.

The probabilities that air is transporting fresh pollutants into the river basin are relatively large from the East Asian area with a small fraction arriving from Eastern North America and Europe. Generally, all calculations show that airborne contaminants into the area will come from a polar route from east to west rather than a south to north route.

Acknowledgements:

The author acknowledges the contribution of Trudy Wholleben for producing the 500mb height wind anomally plots.

5.0 References:

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Appendix A: Terms of Reference

No contractual Terms of Reference were prepared for the work documented in this report. The work was done by the author as a contribution in kind from her employing agency and represents a part of her responsibilities to the working committee of the Synthesis and Modelling Component of the Northern River Basins Study.