A CLIMATOLOGY OF LOW-LEVEL AIR TRAJECTORIES IN THE ALBERTA OIL SANDS AREA

by

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for

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
METEOROLOGY AND AIR QUALITY SECTOR

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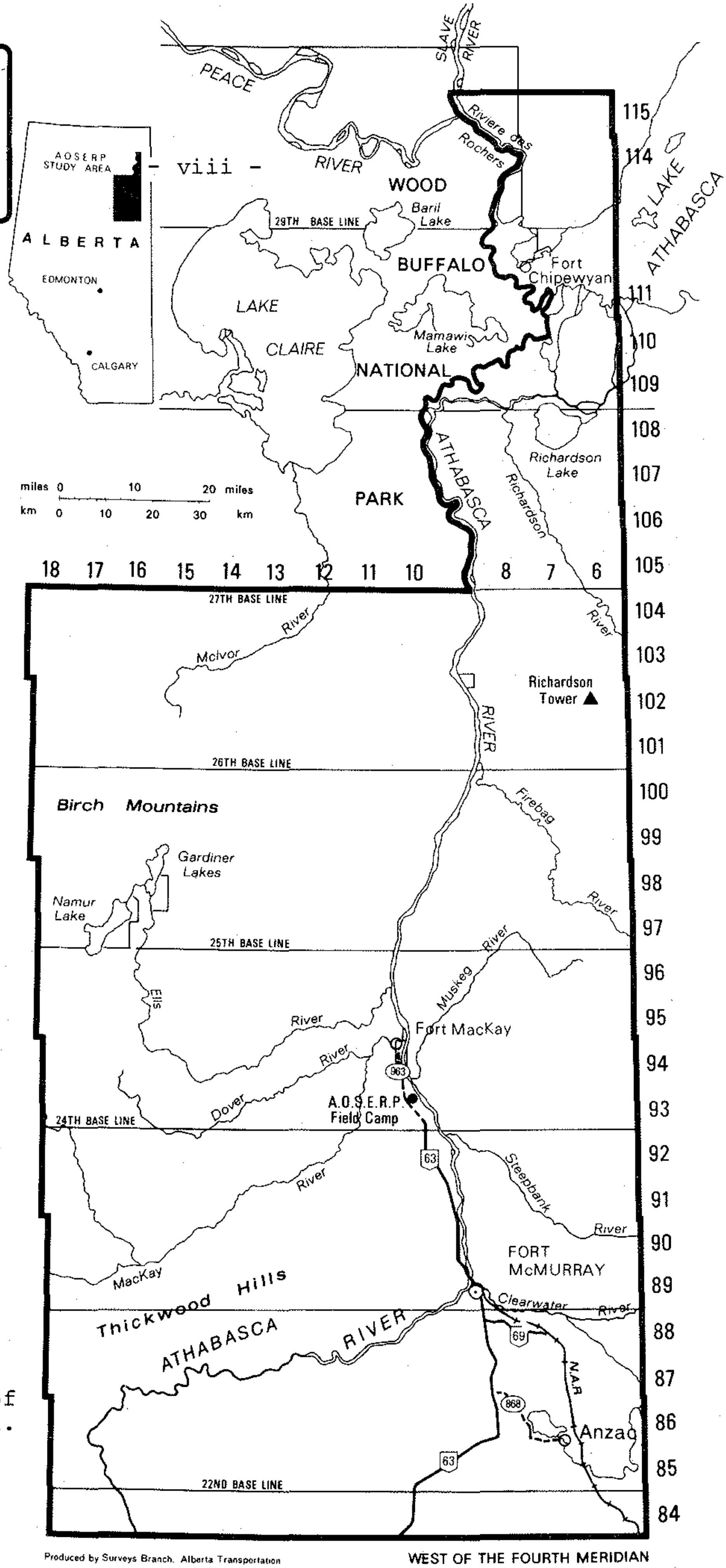
Alberta ENVIRONMENT

Environment Canada Environnement Canada



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1 - INTRODUCTION

By contract dated April 23, 1976 (Supply and Services Canada 04SZ. KM 601-5-1157) Acres Consulting Services was authorized to make the study, "A Climatology of Low-Level Air Trajectories in the Alberta Oil Sands Area". The study is part of the Alberta Oil Sands Environmental Research Program (AOSERP) sponsored jointly by Alberta Environment and Fisheries and Environment Canada. The Scientific Authority responsible for all matters concerning the scientific and technological content of the work was Mr. M. P. Olson, Atmospheric Environment Service (AES). The principal investigator on the project was Mr. P. J. Denison, Acres Consulting Services (ACS). One initiation and three progress meetings were held during the course of studies.

2 - OBJECTIVES

In the AOSERP First Annual Report, 1975, the objective of this subproject was defined as follows:

"to develop a trajectory analysis capability and provide a statistical compilation of horizontal trajectories for the oil sands area, computed on the basis of synoptic wind observations and/or geostrophically computed winds".

The annual report further states that "Information generated by this study will contribute to the best design for air and precipitation sampling networks and in the selection of the best locations for sampling soils and lakes to monitor long-term trends in emission deposition. In addition, it may serve as the basis for a statistical regional dispersion and deposition model."

3 - SCOPE OF WORK

The work requirements given in the Request for Proposal on this project included the following:

(a) Review existing trajectory analysis techniques with the objective of developing a suitable procedure for use here;

(b) Use existing meteorological data (upper air soundings, maps etc.) for a climatologically representative period to calculate air parcel trajectories arriving at and leaving the oil sands area (AOSERP study area).

Required also was a description of the period chosen for analysis and a demonstration that it is of sufficient length from which to compile statistics and is representative climatologically.

A statistical description of the computation results was required for the following cases:

- Trajectories arriving at and leaving the oil sands area

- Stratified by seasons (as appropriate from data)

- At the 1,000- (surface), 925- and 850-mb levels*

- Stratified by precipitation conditions (e.g. dry, showery, rain).

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*1,000, 925 and 850 mb are constant pressure surfaces, the heights of which vary in space and time. Height contours drawn on these surfaces are approximately equivalent to pressure contours (isobars) drawn at the surface, 2,500 feet (750 m) above surface, and 5,000 feet (1,500 m) above surface.

These work requirements were expanded upon and detail was added in the ACS response to the Request for Proposal, as well as in meetings with the Scientific Authority and other AES personnel subsequent to the award of contract.

Budget constraints limited the length of record which could be analyzed. However, previous studies, such as the development of wind-wave climatologies in a number of areas, have suggested that a 4-year period provides sufficient data to reach a climatologically stable result. It was decided that 3 of these years should be the most recent for which complete and readable microfilmed data were available, viz. 1973, 1974 and 1975, and that the fourth year, to serve also as a test year, should be at least 5 years earlier with the same requirement for complete and readable microfilmed data. The year 1968 best met these latter requirements.

The scope of work agreed upon divided into the following tasks:

- Analysis of 72-hour surface and 850-mb trajectories for the 4 years, 1968, 1973-1974-1975, and interpolation for the 925-mb level;

- Grouping of trajectories according to precipitation conditions, nil-light-moderate-heavy;

- Computation of the frequencies of occurrence of air parcels determined by sixteen directional sectors from and circumferences drawn at successive 150-mile radii around the study area;

- Comparison of annual frequencies as determined above for 1968 and 1973-1974-1975 at the surface and 850-mb level to assess representativeness of study period; it was decided that a difference of less than 90 degrees in the dominant trajectory directions would indicate stability in the data sample;

- Analysis of total annual frequencies for the 4 study years;

- Analysis of seasonal frequencies for the 4 study years for conditions of nil and light precipitation and for the surface and 850-mb levels only;

- Spot checks on the reproducibility of 25 trajectory analyses.

Figure 1 is a location map showing the general study area in relation to geographical features and place names.

The actual steps in analysis and documentation of results are detailed in Sections 4 and 5 following.

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LOCATION MAP

NOVEMBER 1976	FIGURE 1

4 - TRAJECTORY ANALYSES

4.1 - Analytical Procedures

A review of trajectory analysis techniques included the following:

Bolin B. and C. Persson. Regional Dispersion and Deposition of Atmospheric Pollutants with Particular Application to Sulfur Pollution over Wester Europe. *Tellus XXVII (1975), 3. pp 284 - 310.*

Godske C. L., T. Bergeron, J. Bjerknes, R. C. Bundgaard. *Dynamic Meteorology and Weather Forecasting.* American Meteorological Society and Carnegie Institution of Washington, 1957.

Smith F. B., and F. G. Jeffrey. Airborne Transport of Sulphur Dioxide from the U.K. *Atmospheric Environment June/July 1975.*

Wendell, L., Model of Northeastern U.S.A. Sulfur Trajectories. *Symposium on Atmospheric Turbulence and Diffusion, Raleigh, N.C., October 1976.*

Rao, K.S., J. S. Legue and B. A. Egan. Air Trajectory Model for Regional Transport of Atmospheric Sulphates. *Symposium on Atmospheric Turbulence and Diffusion, Raleigh, N.C., October 1976.*

The large number of microfilmed weather maps that required individual viewing and analysis suggested that the trajectories can be constructed manually as described following, and as used in the Acres study for Environment Canada "Atmospheric Loading of the Upper Great Lakes" and the extension of that project in the study now nearing completion, "Atmospheric Loading of the Lower Great Lakes and the Great Lakes Drainage Basin". This same technique has been used by the principal investigator in developing wave climatologies for Quebec Cartier Mining Company at Port Cartier, P.Q., and for the Asbestos Corporation in Deception Bay, P.Q. The technique has been used in air pollution studies involving trajectory analyses, e.g. Smith and Jeffries, and Wendell above.

The data sources for this work item were AES microfilms of the historical weather map series as analyzed by the Central Analysis Office in Montreal for the surface and 850-mb levels in the years 1968, 1973, 1974 and 1975. This form of data storage provided major advantages over the more conventional paper map series for both handling and speed of viewing of the approximately 8,800 analyzed weather maps from which the 72-hour trajectories were constructed.

Four 6-hour trajectories at the surface level and two 12-hour trajectories at the 850-mb level were determined each day, both for air parcels leaving the study area and air parcels arriving at the study area. These were composited over successive 72-hour periods, so that once daily at 0000 GMT 72-hour trajectories were drawn for air moving in to and out from the study area at the two levels. Trajectories of air parcels moving in to the study area were obtained by back-tracking from the end of the analysis period. Trajectories at the 925-mb level were obtained by interpolation between the surface and 850-mb levels.

On the surface level maps, measured winds were normally plotted in the general vicinity of the study area. Where the isobaric or height contour gradients drawn on the weather maps agreed with the plotted winds, allowing for the normal cross isobaric flows and frictional reduction in wind speeds, the plotted winds were accepted in the trajectory analysis. As a consequence, topographical effects on airflows such as by valleys, ridges, changes in land cover type, have been factored into the analysis.

At the 850-mb level, the same general approach was followed as in the surface level case, except that no boundary layer effects were allowed for, so that an 850-mb plotted wind that was judged to be representative of the study area on the basis of the 850-mb height contour pattern was accepted in the trajectory analysis.

In the few cases where no winds were plotted or when the plotted winds did not conform at one or both of the levels to the height contour patterns, the latter were used in the trajectory analysis, allowing for the usual boundary layer effects on surface level wind speeds and directions.

Examples are shown in Figures 2 to 11 selected at random from the approximate total of 8,800 trajectories analyzed.

4.2 - Reproducibility

In order to provide a measure of accuracy of the analysis of individual 72-hour trajectories, a randomly selected sample of 25 cases was reanalyzed two months after and without later reference to the original analyses. The differences in each set of trajectories were measured as differences in orientation expressed as degrees, and as differences in travel distance expressed as miles. The results given in Table 1 show an acceptable level of accuracy with relatively small differences in both trajectory orientation and length. The signs of differences in angle of trajectory orientation are positive when the second analysis gave an orientation that was in a clockwise direction from the first, and vice versa. Distance differences are marked positive when the second trajectory was longer than the first. As can be seen, these differences are random and tend to cancel over time.

TABLE 1

RESULTS OF REANALYSIS OF RANDOMLY SELECTED 72-HOUR TRAJECTORIES

Difference in Trajectory Angle (°)*		Difference in Trajectory Length**	
Surface	850 mb	Surface	850 mb
+10	+ 5	+15	+30
+15	0	+30	+75
- 5	-10	0	-15
0	+ 5	+45	+45
-15	- 5	-15	-60
0	-10	+45	+30
-10	0	+15	+45
+ 5	- 5	-60	-75
+20	0	0	-15
-10	-15	-30	-60
+10	+10	+75	+90
+ 5	+20	+45	+30
0	+ 5	-15	-45
0	-10	-60	0
+ 5	+10	+15	+75
+15	+20	-30	-45
-10	- 5	-15	-60
-20	0	-75	-90
+ 5	+15	0	+30
0	- 5	-30	0
-10	-20	+45	+75
+ 5	0	+30	+60
+15	+15	-90	-30
0	-15	+45	+15
-10	-10	- 0	-45
AM = 0.8 SD = 10	AM = -0.2 SD = 11	AM = -0.6 SD = 42	AM = 7.2 SD = 53

* To the nearest 5°
**To the nearest 15 miles

LEGEND

SURFACE

925 mb

850 mb

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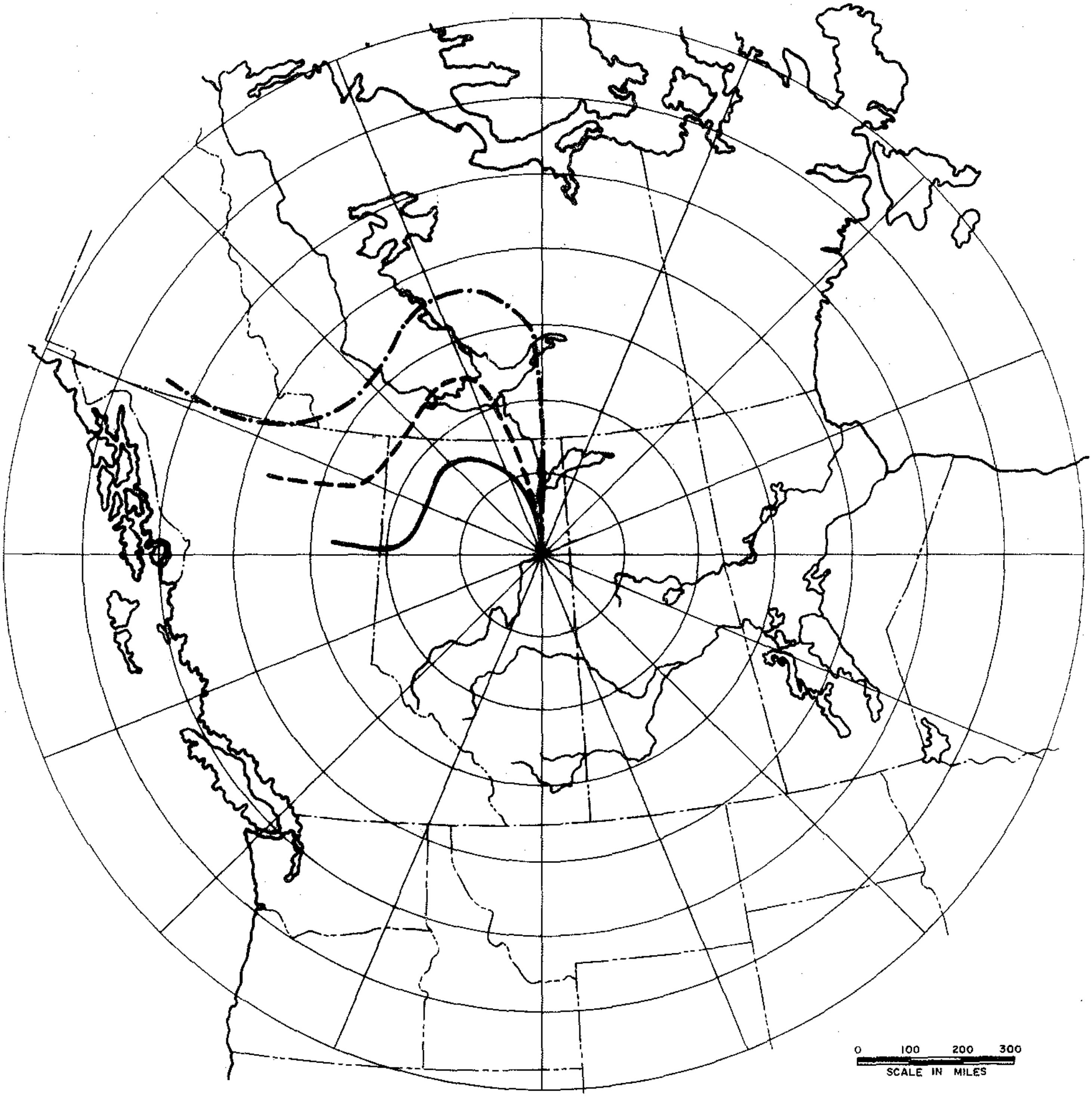
AOSERP - 72 HOUR AIR TRAJECTORY ANALYSIS

EXAMPLE TRAJECTORY
72 HOUR ENDING
0000 GMT - AUGUST 11, 1968
DIRECTION - IN TO STUDY AREA

NOVEMBER 1976	FIGURE 2



LEGEND

SURFACE

925 mb

850 mb

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EXAMPLE TRAJECTORY
72 HOUR ENDING
0000 GMT - FEBRUARY 4, 1968
DIRECTION - OUT FROM STUDY AREA

NOVEMBER 1976 | FIGURE 3

LEGEND

SURFACE

925 mb

850 mb

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AOSERP - 72 HOUR AIR TRAJECTORY ANALYSIS

EXAMPLE TRAJECTORY
72 HOUR ENDING
0000 GMT - FEBRUARY 8, 1973
DIRECTION - OUT FROM STUDY AREA

NOVEMBER 1976	FIGURE 4

LEGEND

SURFACE

925 mb

850 mb

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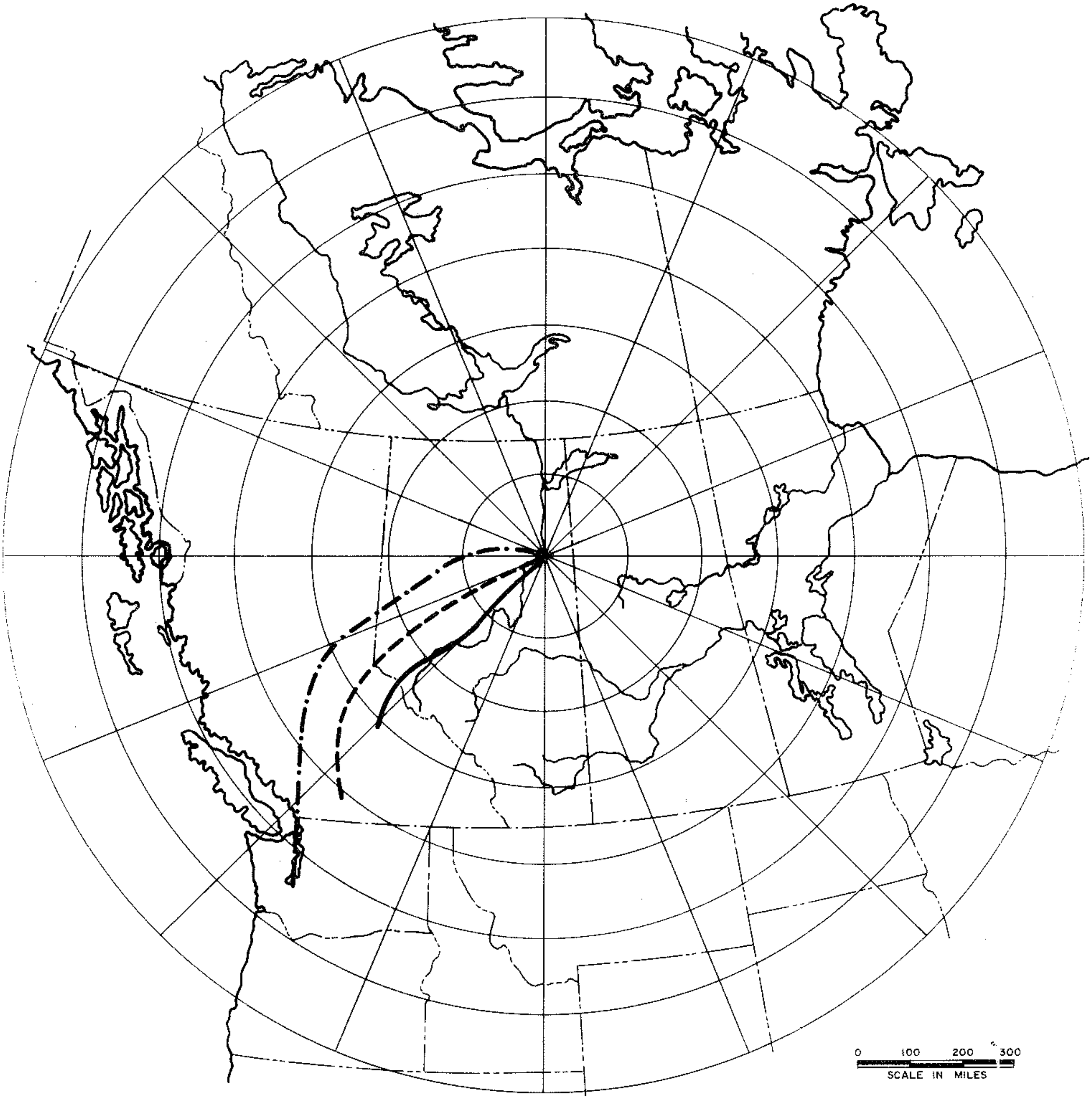
AOSERP - 72 HOUR AIR TRAJECTORY ANALYSIS

EXAMPLE TRAJECTORY
72 HOUR ENDING
0000 GMT - MARCH 11, 1973
DIRECTION - OUT FROM STUDY AREA

NOVEMBER 1976 | FIGURE 5



LEGEND

SURFACE

925 mb

850 mb

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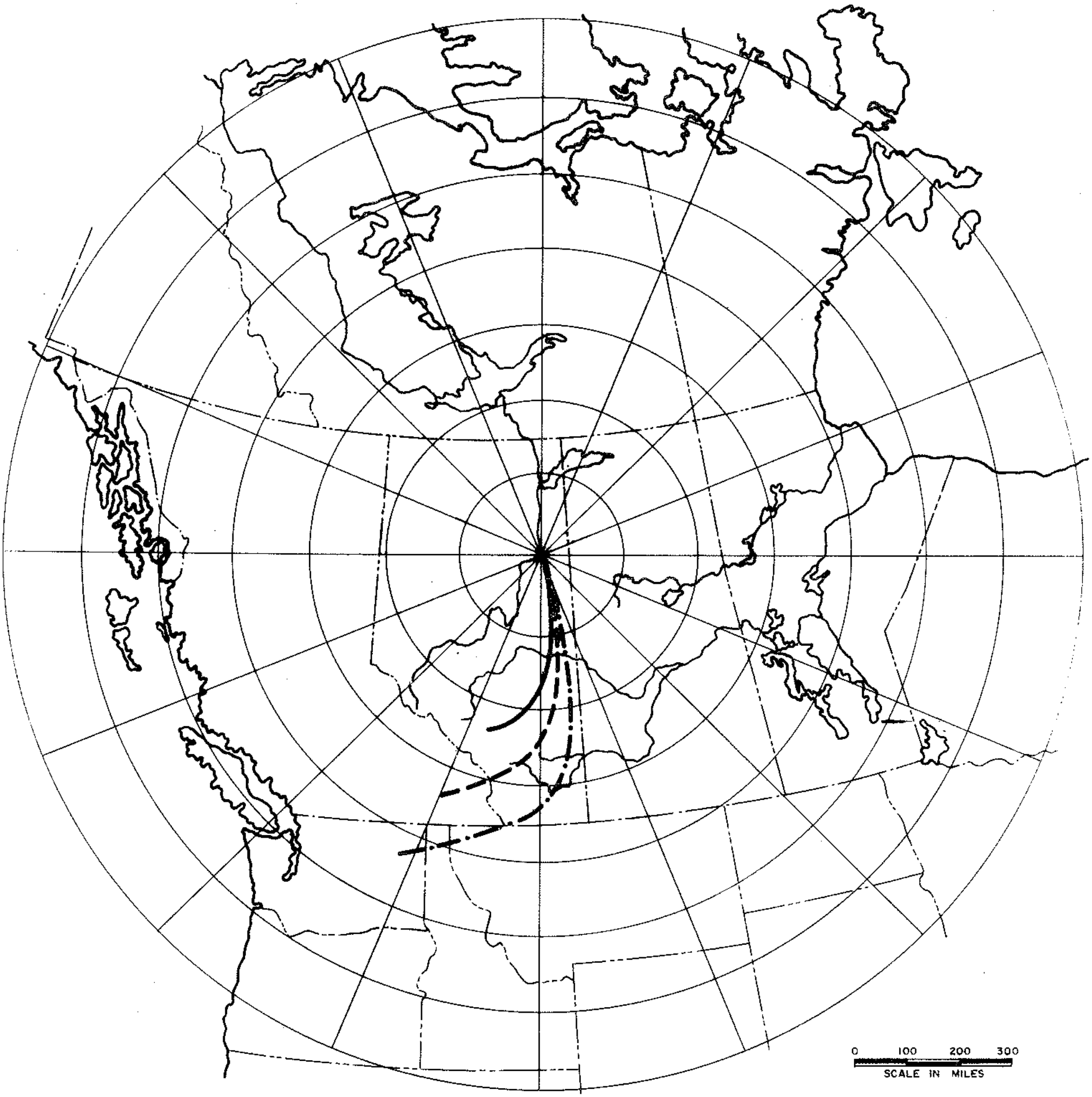
AOSERP - 72 HOUR AIR TRAJECTORY ANALYSIS

EXAMPLE TRAJECTORY
72 HOUR ENDING
0000 GMT - MARCH 31, 1973
DIRECTION - IN TO STUDY AREA

NOVEMBER 1976 | FIGURE 6



LEGEND

SURFACE

925 mb

850 mb

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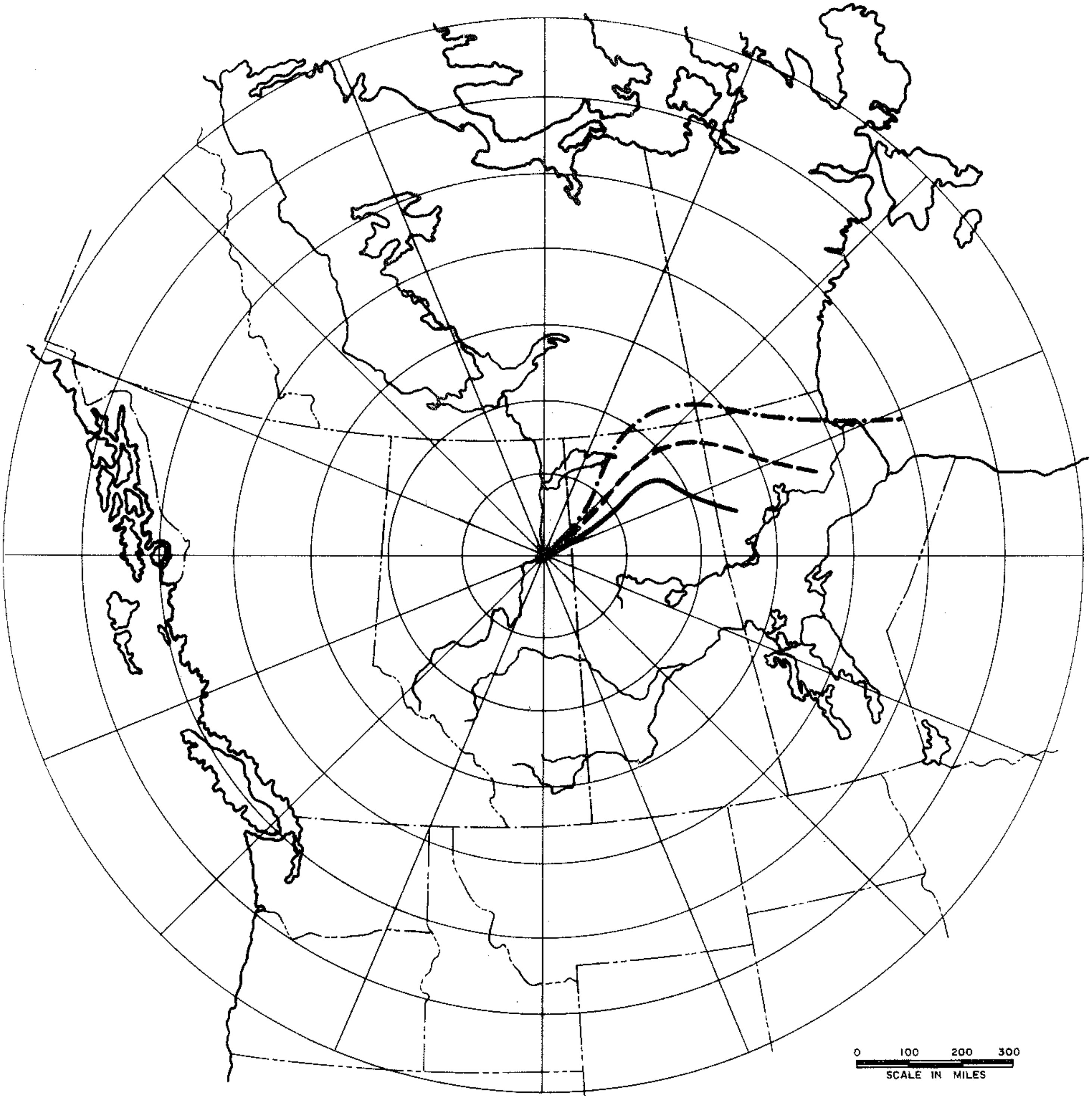
AOSERP - 72 HOUR AIR TRAJECTORY ANALYSIS

EXAMPLE TRAJECTORY
72 HOUR ENDING
0000 GMT - MAY 7, 1973
DIRECTION - IN TO STUDY AREA

NOVEMBER 1976

FIGURE 7



LEGEND

SURFACE

925 mb

850 mb

ACRES

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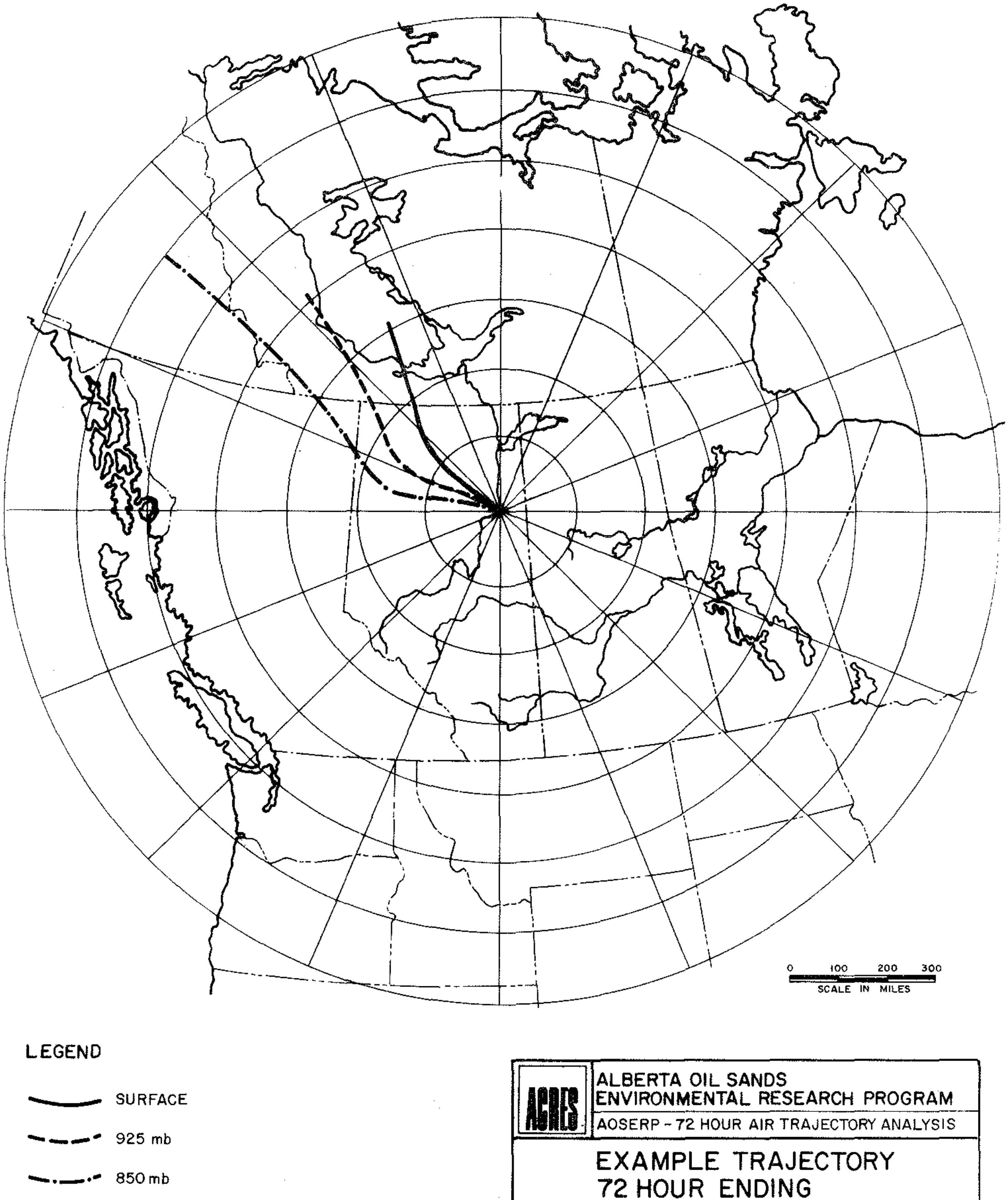
AOSERP - 72 HOUR AIR TRAJECTORY ANALYSIS

EXAMPLE TRAJECTORY
72 HOUR ENDING
0000 GMT - JULY 23, 1974
DIRECTION - OUT FROM STUDY AREA

NOVEMBER 1976

FIGURE 8



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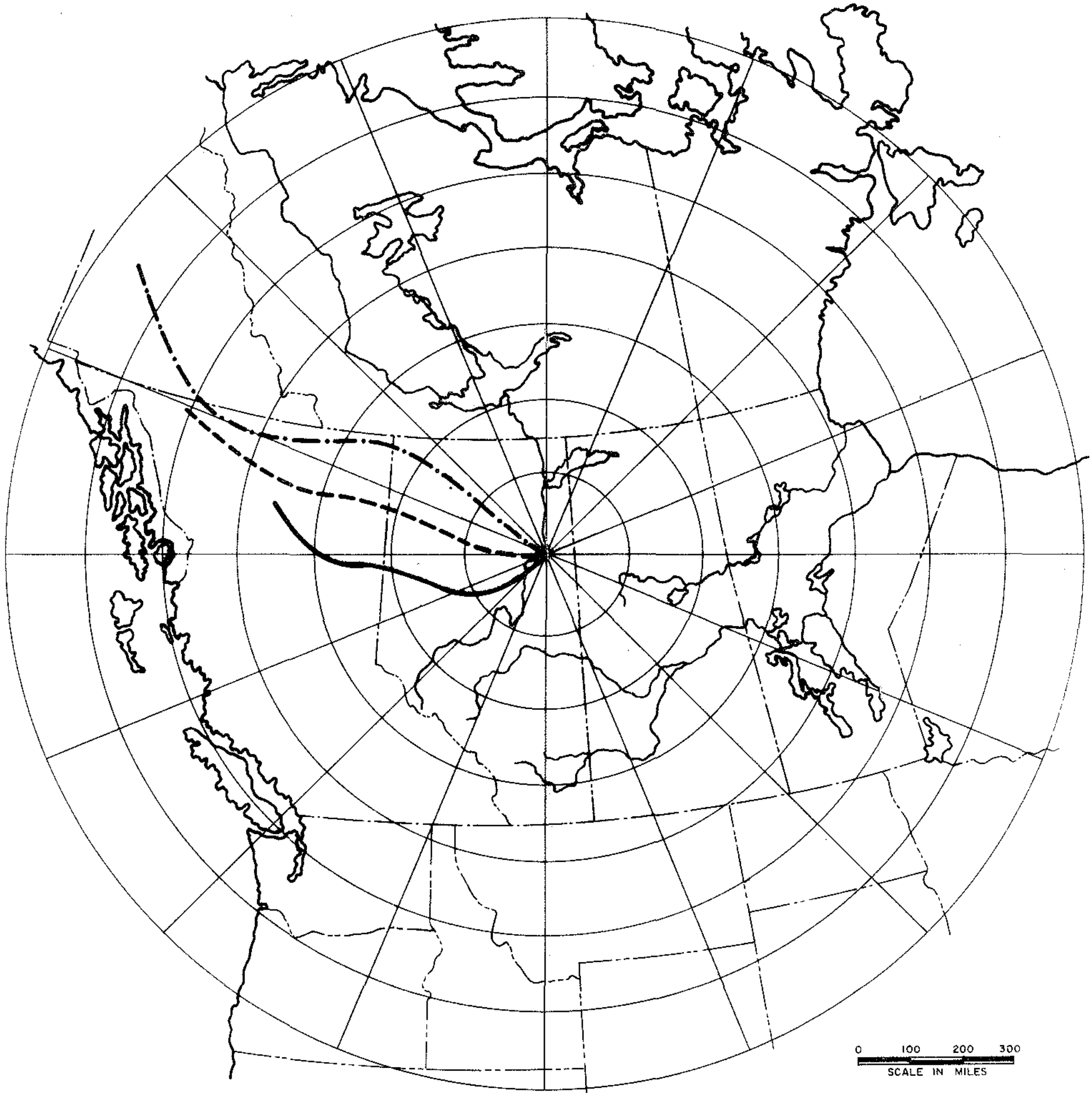
AOSERP - 72 HOUR AIR TRAJECTORY ANALYSIS

EXAMPLE TRAJECTORY
72 HOUR ENDING
0000 GMT - SEPTEMBER 8, 1974
DIRECTION - IN TO STUDY AREA

NOVEMBER 1976

FIGURE 9



LEGEND

SURFACE

925 mb

850 mb

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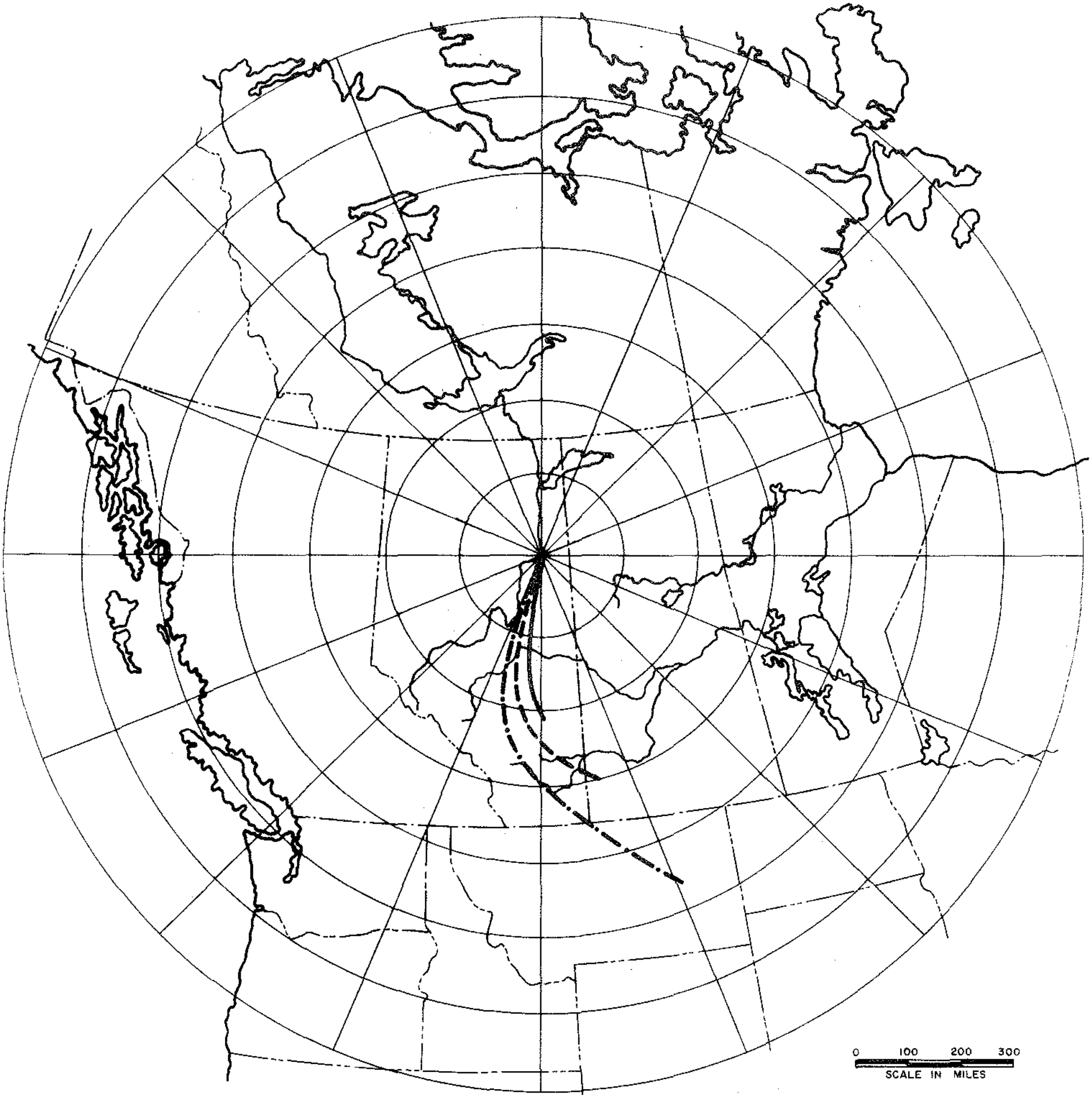
AOSERP - 72 HOUR AIR TRAJECTORY ANALYSIS

EXAMPLE TRAJECTORY
72 HOUR ENDING
0000 GMT - FEBRUARY 24, 1975
DIRECTION - IN TO STUDY AREA

NOVEMBER 1976

FIGURE 10



LEGEND

SURFACE

925 mb

850 mb

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AOSERP - 72 HOUR AIR TRAJECTORY ANALYSIS

EXAMPLE TRAJECTORY
72 HOUR ENDING
0000 GMT - DECEMBER 10, 1975
DIRECTION - OUT FROM STUDY AREA

NOVEMBER 1976

FIGURE 11

5 - FREQUENCY ANALYSIS

5.1 - Analytical Procedures

The 72-hour trajectories were grouped according to four conditions of precipitation during the 72-hour period; these were nil, trace to .25 inch (light), .26 to .50 inch (moderate), over .50 inch (heavy), based on measurements at the Fort McMurray Weather Office. Each 72-hour trajectory map was overlaid with a transparency on which sectors defined by 22.5-degree quadrants and incremental 150-mile radii circles from the study area were labeled. Each time that an air parcel on a trajectory moved through any labeled sector was noted.

The number of occurrences of air parcels in each sector were summed by precipitation groups to give monthly frequencies for each of the 4 years studied, 1968-1973-1974-1975. The monthly frequencies were also summed by precipitation groups to give the annual total for 1968 alone and the 3-year total for 1973-1974-1975, for comparative purposes, in order to assess the climatological stability of the 4-year data base.

The seasonal frequencies were then summed by precipitation groups to give the annual totals for the entire 4-year study period.

Finally the monthly frequencies were summed to give seasonal values by precipitation groups for the total of the 4 study years, where seasons were defined as: December-January-February, March-April-May, June-July-August, September-October-November.

The results of these analyses are shown in map form as isolines of frequency of occurrence (motion) of air parcels by direction and distance from the study area in Subsections 5.2, 5.3 and 5.4 following. The isolines have been drawn so that the numbers plotted in each sector apply at the geometric center of that sector. It should be noted that in the inner ring the numbers are positioned nearer the outside of the sectors to avoid overcrowding; this gives the casual appearance of incorrect contouring which is not the case.

5.2 - Comparison of 1968 and 1973-1974-1975 Total Annual Frequencies

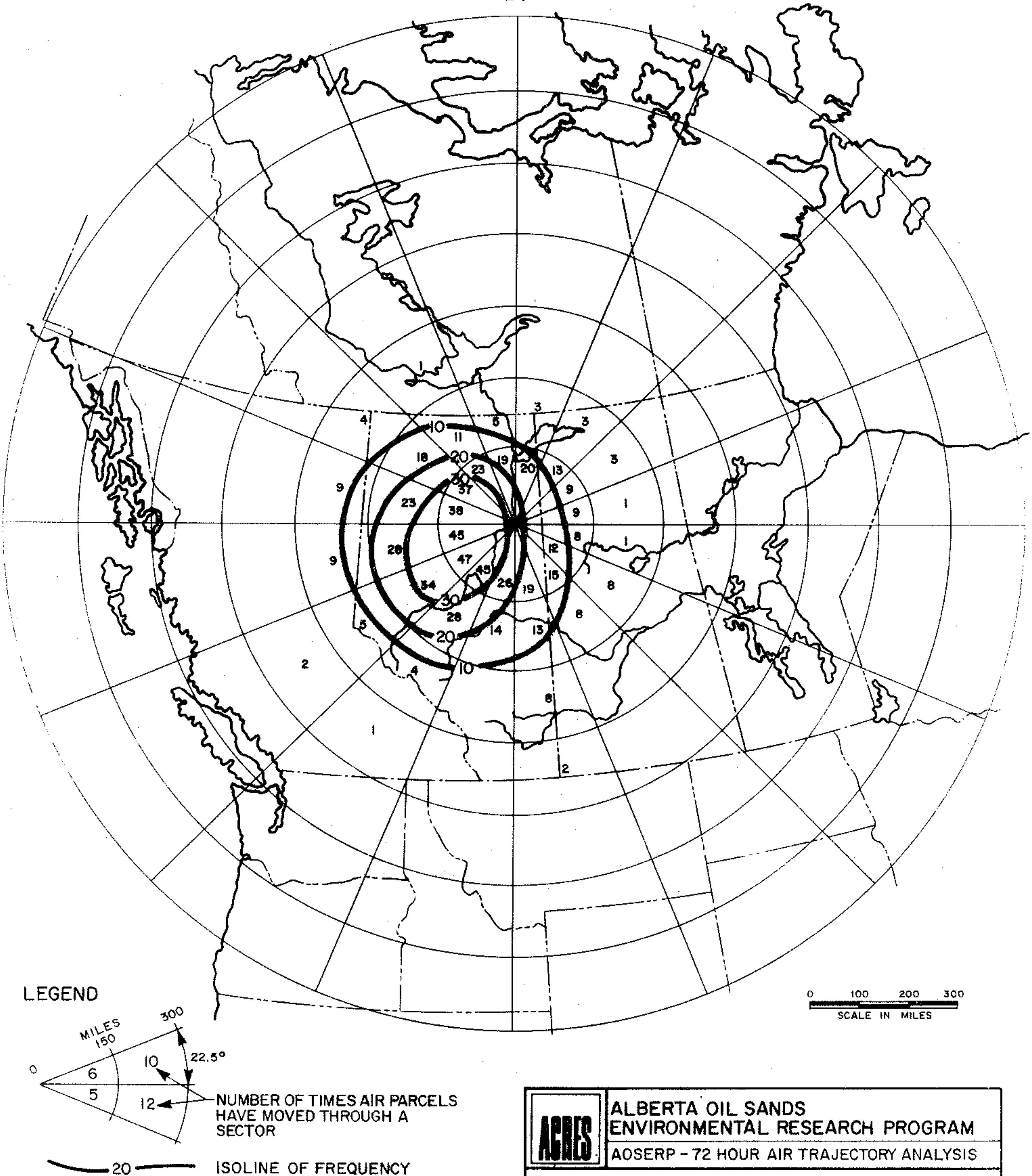
Figures 12 to 19 show the annual air parcel frequency patterns in 1968 and the sum of those over the three year period 1973-1974-1975, at the surface and 850-mb levels, for the conditions of nil precipitation and light precipitation, and for trajectories in to the study area.

For the case of nil precipitation, the patterns are similar with higher frequencies in the general westerly quadrant at both the surface and 850-mb levels. The maximum frequency at the surface shifts from the southwest for the 1973-1974-1975 period to about south-southwest in 1968. At the 850-mb level, the maximum frequency for the 1973-1974-1975 period is from the west-northwest and in 1968 is west-northwest to west-southwest.

For the case of light precipitation, the patterns are very similar, with highest frequencies in the general westerly quadrant at both the surface and 850-mb levels. The maximum frequency at the surface again shifts from about west-southwest for the 1973-1974-1975 period to south-southwest in 1968. At the 850-mb level, the maximum frequency is from the west-northwest both in the 1973-1974-1975 period and in 1968.

Since the dominant trajectory directions differ by not more than 45 degrees in the data sets for 1968 and 1973-1974-1975, that is by half the criterion selected (see page 5), it is concluded that the results of frequency analyses made on the 4-year totals for 1968-1973-1974-1975 should reasonably approach climatological stability for the 72-hour air trajectory parameter under study. Also of interest is the secondary component from the south to southeast at the surface level in both sets of data.

COMPARISON OF 1968 AND 1973-1974-
1975 TOTAL ANNUAL FREQUENCIES



LEVEL – SURFACE

72 HOUR PRECIPITATION – NIL

DIRECTION – IN TO STUDY AREA

PERIOD – 1973, 74, 75 ANNUAL TOTALS

ACRES

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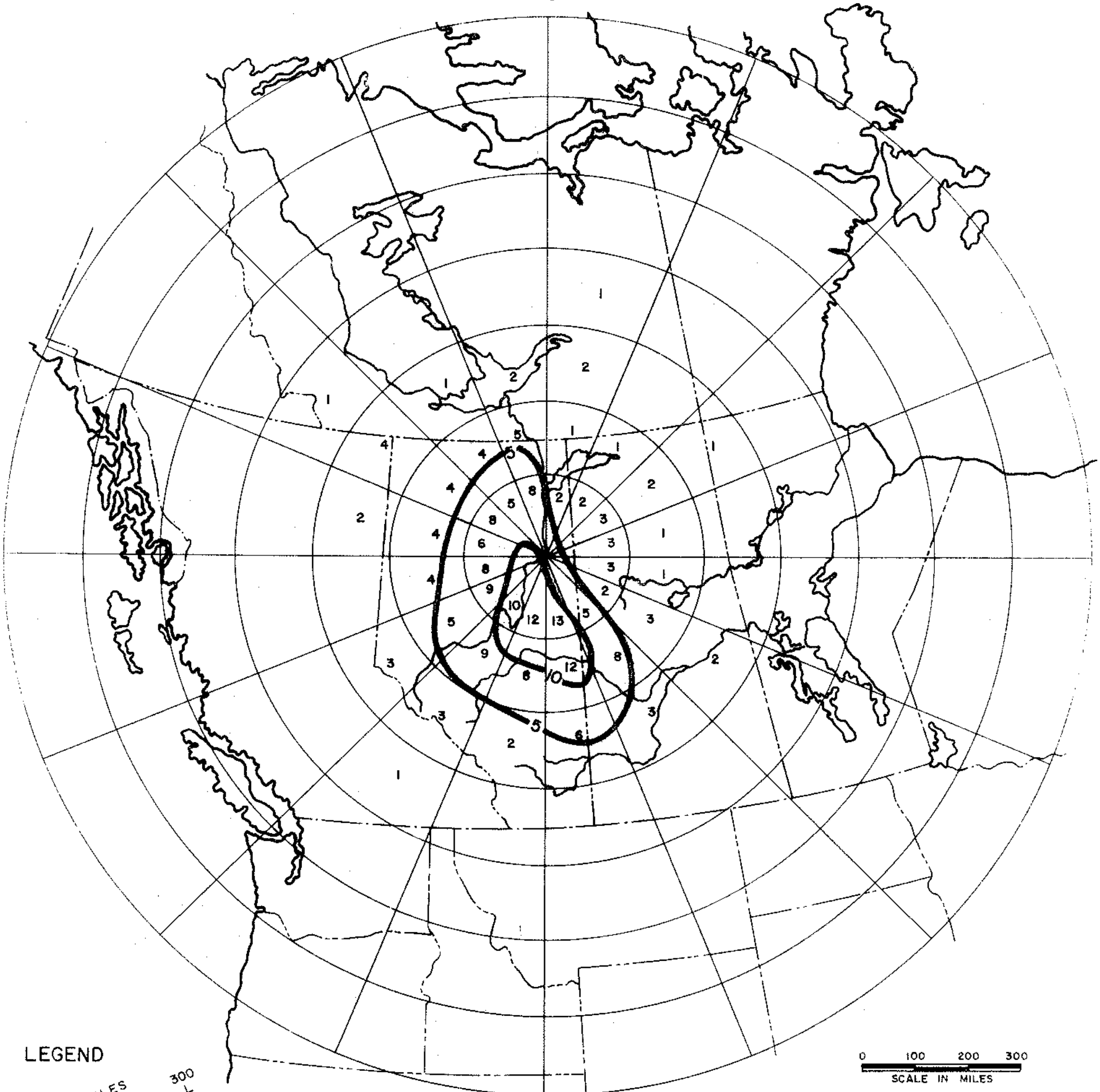
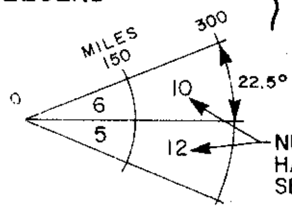
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976 | FIGURE 12



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR

20 ISOLINE OF FREQUENCY

LEVEL - SURFACE

72 HOUR PRECIPITATION - NIL

DIRECTION - IN TO STUDY AREA

PERIOD - 1968 ANNUAL TOTAL

ACRES

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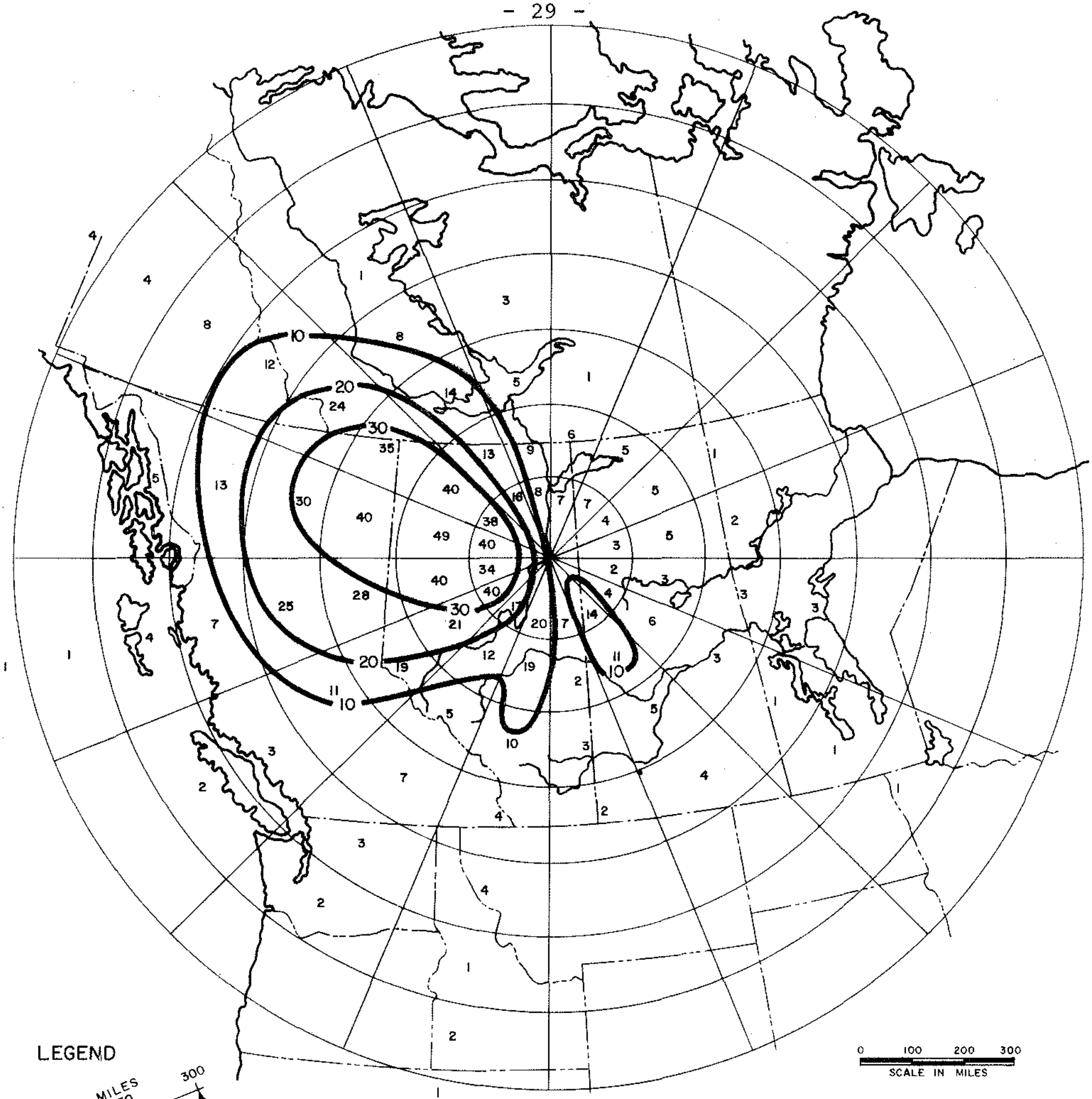
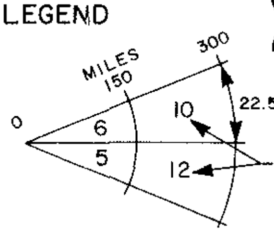
AOSERP - 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 13



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR

20 ISOLINE OF FREQUENCY

LEVEL – 850 mb

72 HOUR PRECIPITATION – NIL

DIRECTION – IN TO STUDY AREA

PERIOD – 1973, 74, 75 ANNUAL TOTALS

ACRES

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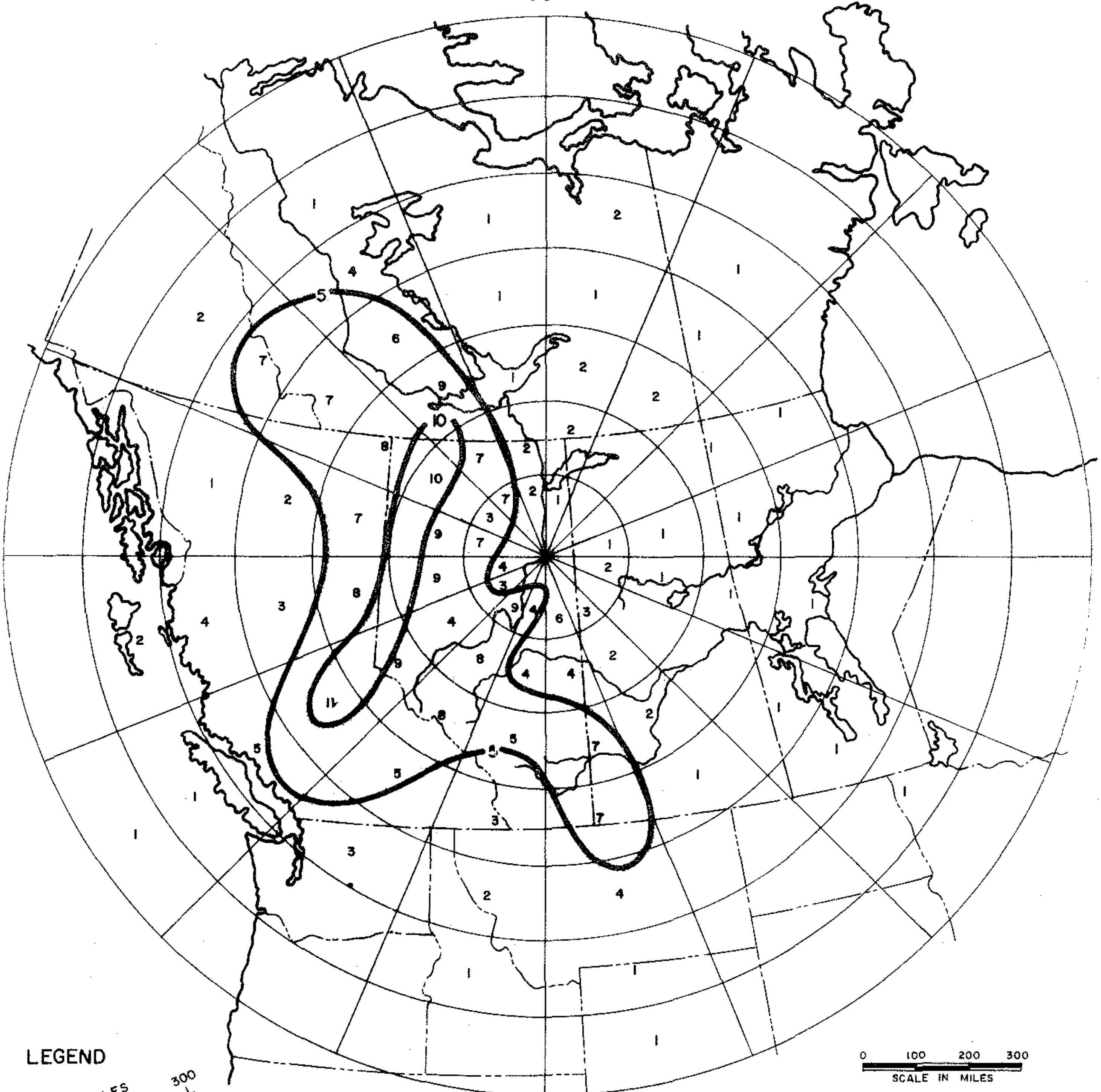
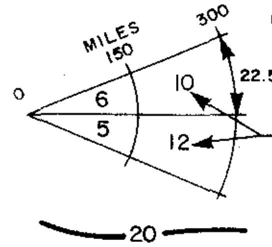
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976 | FIGURE 14



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR

ISOLINE OF FREQUENCY

LEVEL – 850 mb

72 HOUR PRECIPITATION – NIL

DIRECTION – IN TO STUDY AREA

PERIOD – 1968 ANNUAL TOTAL

ACRES

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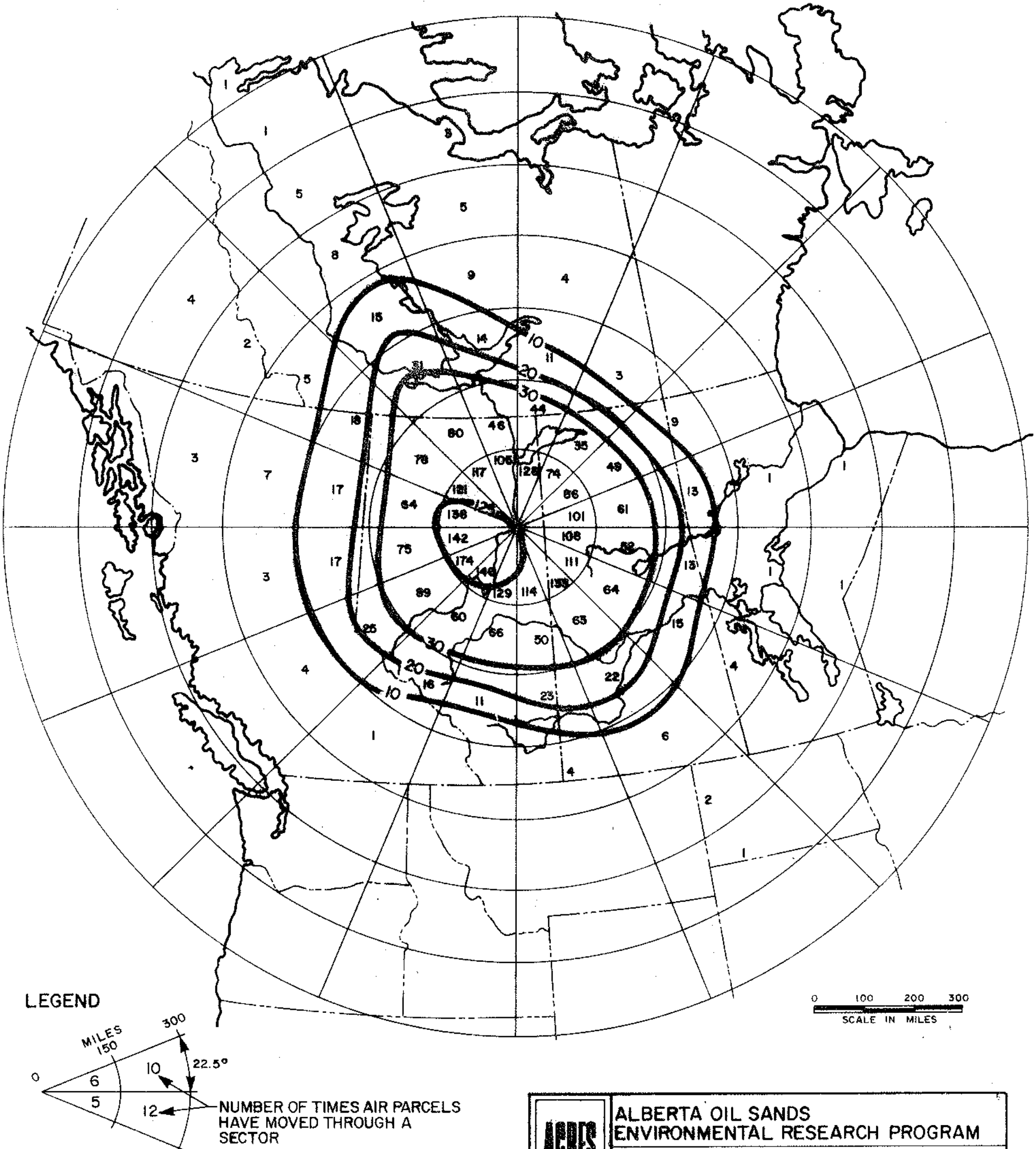
ENVIRONMENTAL RESEARCH PROGRAM

AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 15



LEGEND

NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR

20 ISOLINE OF FREQUENCY

LEVEL – SURFACE

72 HOUR PRECIPITATION – LIGHT

DIRECTION – IN TO STUDY AREA

PERIOD – 1973, 74, 75 ANNUAL TOTALS

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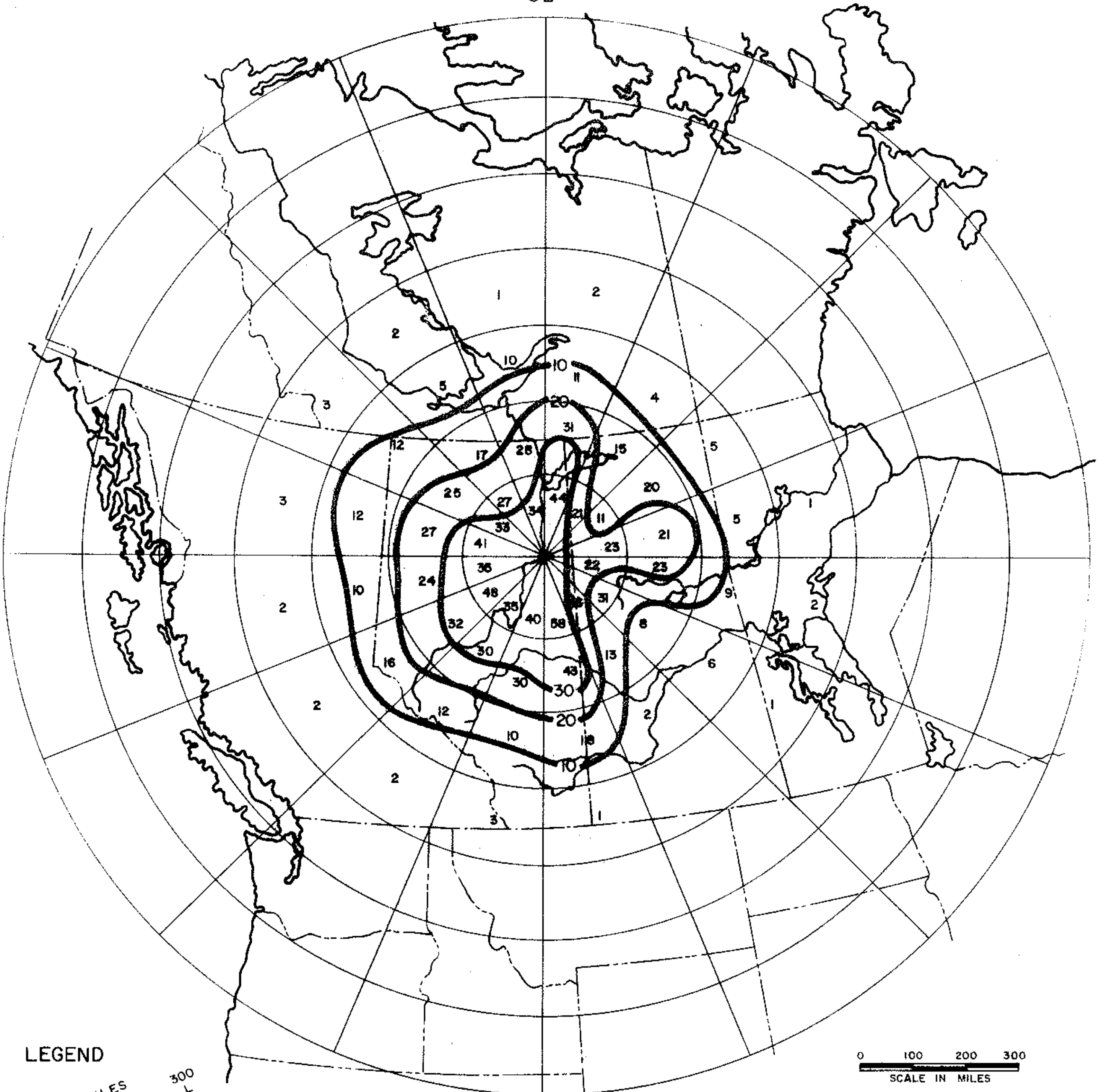
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

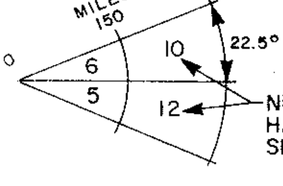
FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976

FIGURE 16



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR

20 ISOLINE OF FREQUENCY

LEVEL – SURFACE

72 HOUR PRECIPITATION – LIGHT

DIRECTION – IN TO STUDY AREA

PERIOD – 1968 ANNUAL TOTAL

ACRES

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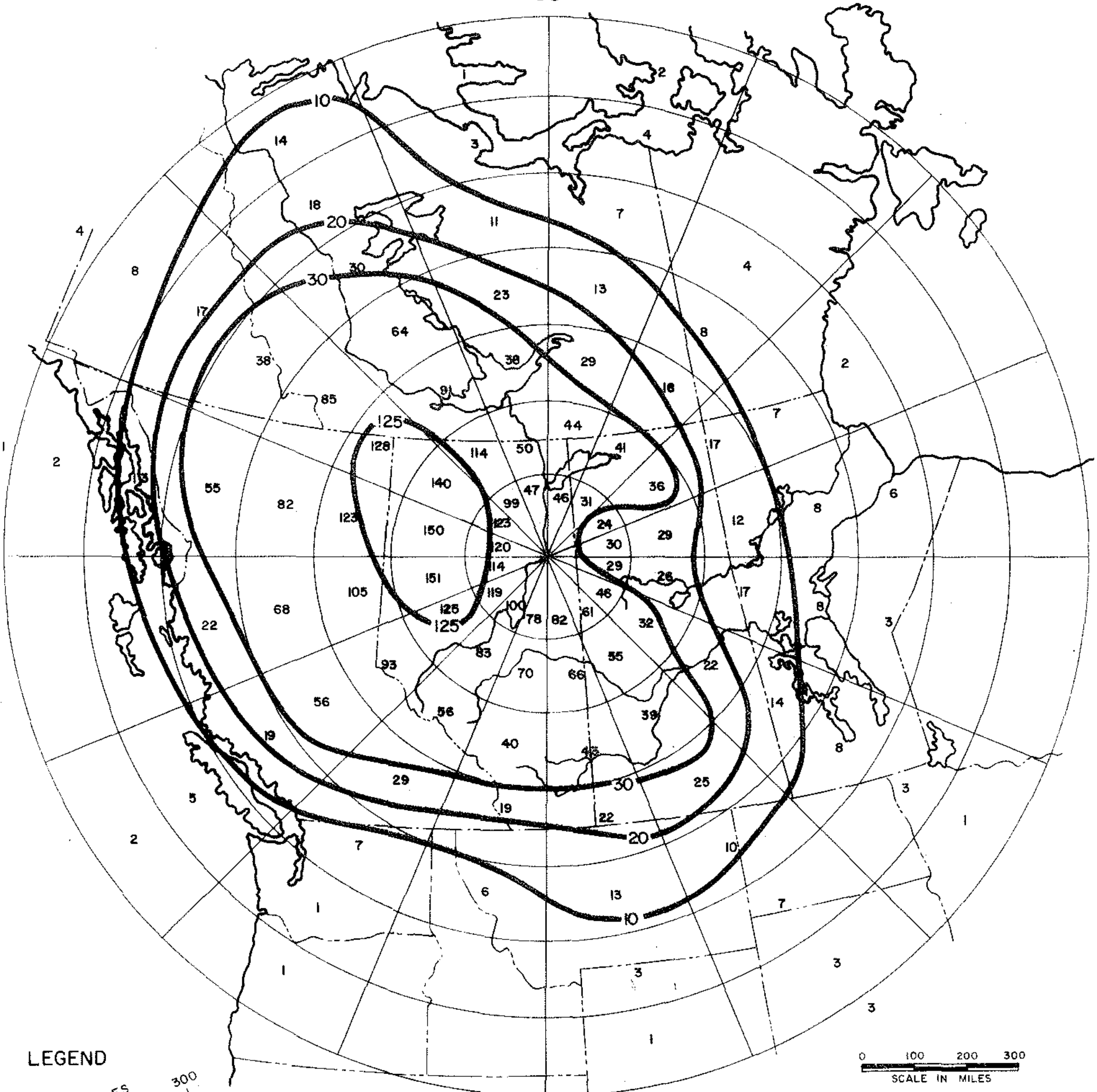
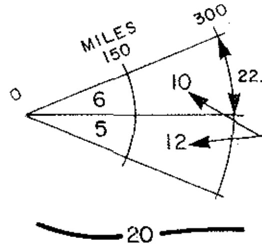
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 17



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR

20 ISOLINE OF FREQUENCY

LEVEL – 850 mb

72 HOUR PRECIPITATION – LIGHT

DIRECTION – IN TO STUDY AREA

PERIOD – 1973, 74, 75 ANNUAL TOTALS

AOSERP

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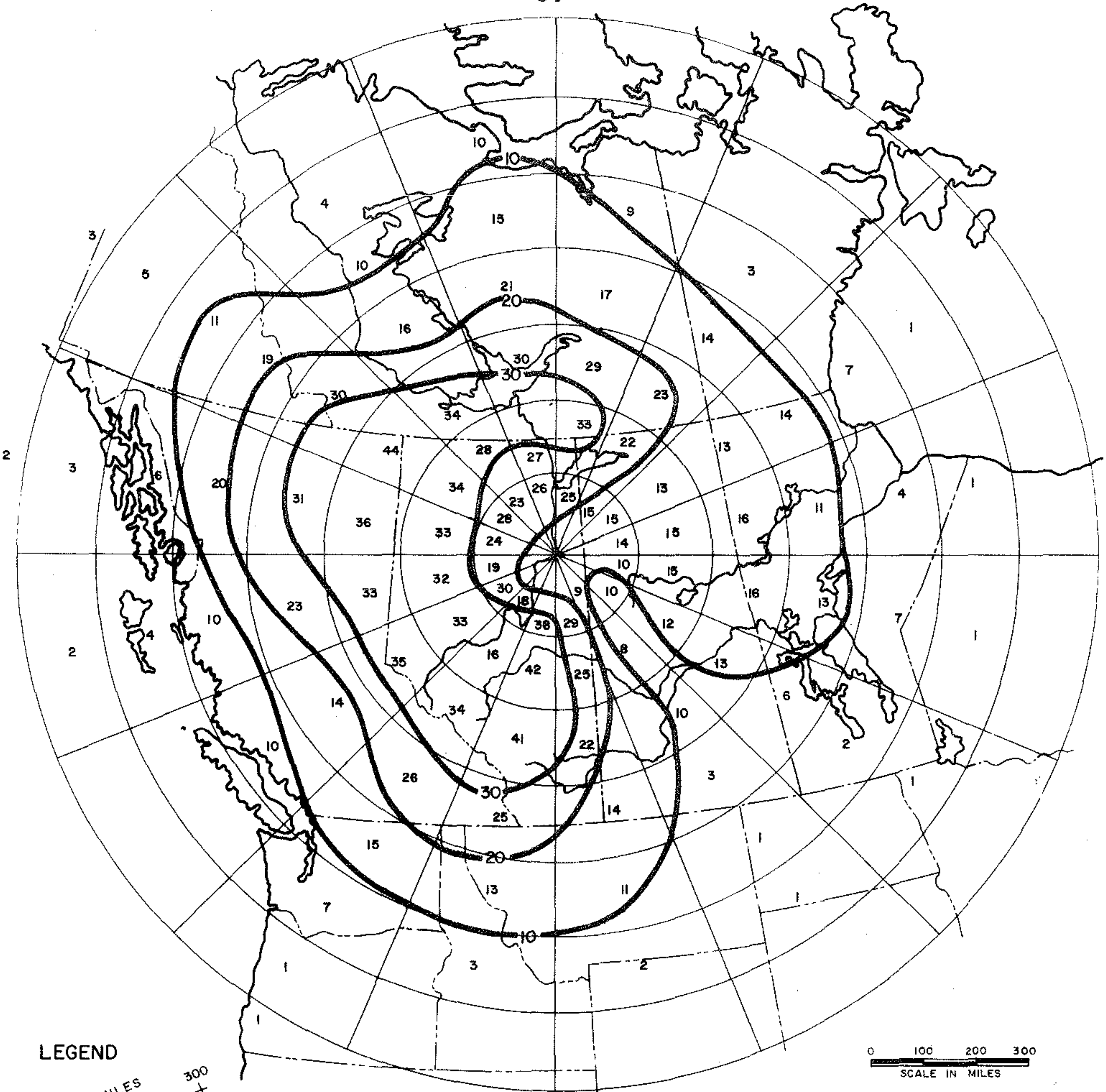
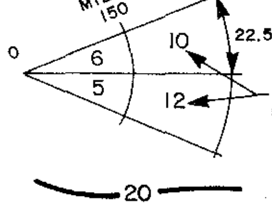
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 18



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR

20 ISOLINE OF FREQUENCY

LEVEL – 850 mb

72 HOUR PRECIPITATION – LIGHT

DIRECTION – IN TO STUDY AREA

PERIOD – 1968 ANNUAL TOTAL

AOSERP

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AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976 | FIGURE 19

5.3 - Total Annual Frequencies for the 4-year Study Period

Figures 20 to 43 show the annual patterns of frequency of air parcel motions, summed over the 4 years, 1968-1973-1974-1975, for four precipitation conditions, nil-light-moderate-heavy, as previously defined, at three levels, surface-925 mb-850 mb. These are discussed by precipitation conditions.

In the case of nil precipitation over the 72-hour trajectory period, the patterns are consistent at all three levels for air parcels moving both in to and out from the study area. The dominant frequencies for motions in to the study area are from northwest to southwest at all three levels, with frequencies increasing in distance from the study area with increasing height, and thus increasing wind speeds. The dominant frequencies for motions out from the study area are to northeast to southeast at all three levels, with the frequencies again increasing in distance from the study area with height. There are secondary components from the south-southeast for air moving in to the study area and to the north-northwest for air moving out from the study area.

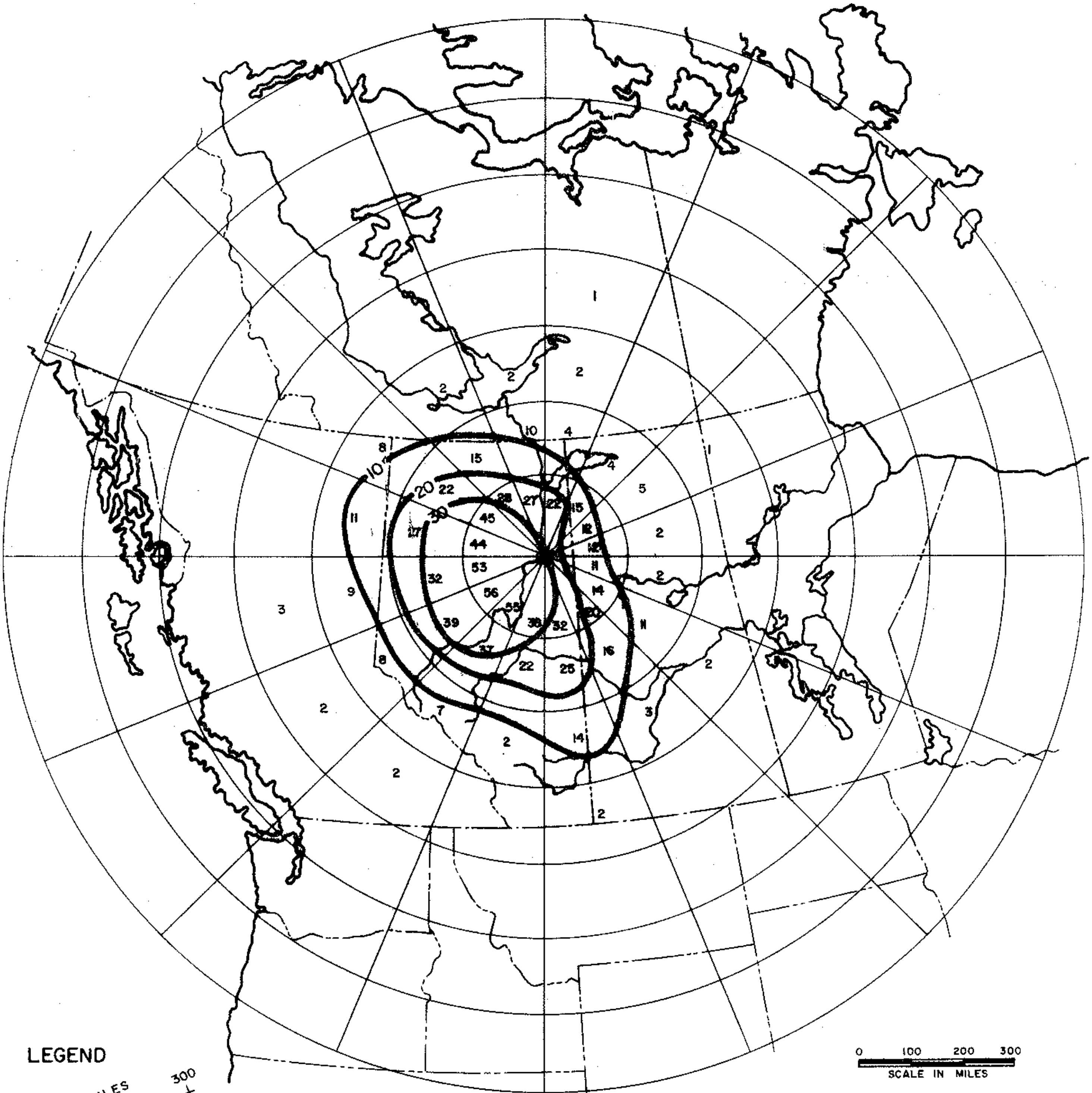
In the case of light precipitation, the frequency distribution patterns also are consistent at all three levels for air parcels moving both in to and out from the study area. The dominant frequencies for motions in to the study area are from the west southwest at the surface level, the west at 925 mb and the west-northwest at 850 mb. For air parcel motions out from the study area, the dominant frequencies are to the east at the surface level, to the north-northwest and east-southeast at 925 mb and to the east-southeast at 850 mb.

In the case of moderate precipitation, the frequency distribution patterns at the surface level do not show any dominant directional bias for air parcel motions in to and out from the study area, although there is some bias in both cases along a northwest-southeast axis. For motions in to the study area, the dominant frequencies are from the northwest at both 925 and 850 mb. For motions out from the study area, the dominant frequencies are to the southeast at these levels.

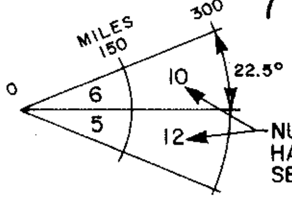
In the case of heavy precipitation, there again is no dominant directional bias for air parcel motions in to and out from the study area at any level. For both in and out motions there is a directional bias along a northwest-southeast axis at all levels. For motions in to the study area, there is a second directional bias in the north-northeast direction, and for motions out from the study area in the south-southwest direction at all three levels. At the 850-mb level, the second directional bias seems to tend to a northeast-southwest axis for both motions in to and out from the study area.

TOTAL ANNUAL FREQUENCIES

NIL PRECIPITATION
Surface - 925 mb - 850 mb Levels
In To and Out From Study Area



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

20 ISOLINE OF FREQUENCY

LEVEL – SURFACE

72 HOUR PRECIPITATION – NIL

DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

ACRES

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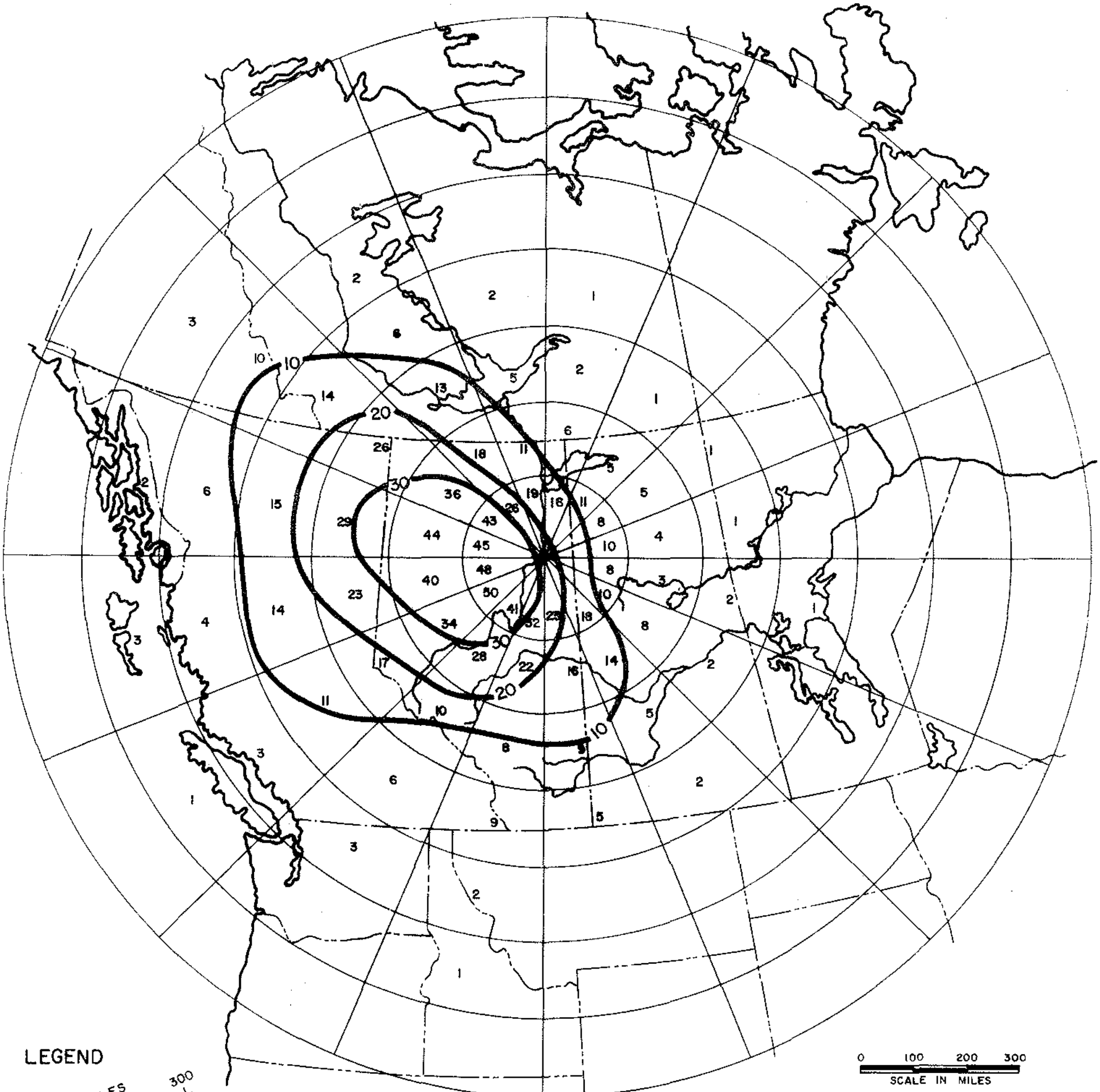
ENVIRONMENTAL RESEARCH PROGRAM

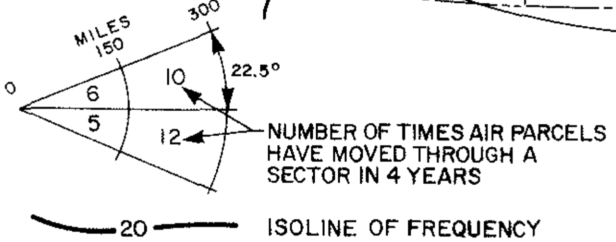
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 20



LEGEND



LEVEL – 925 mb

72 HOUR PRECIPITATION – NIL

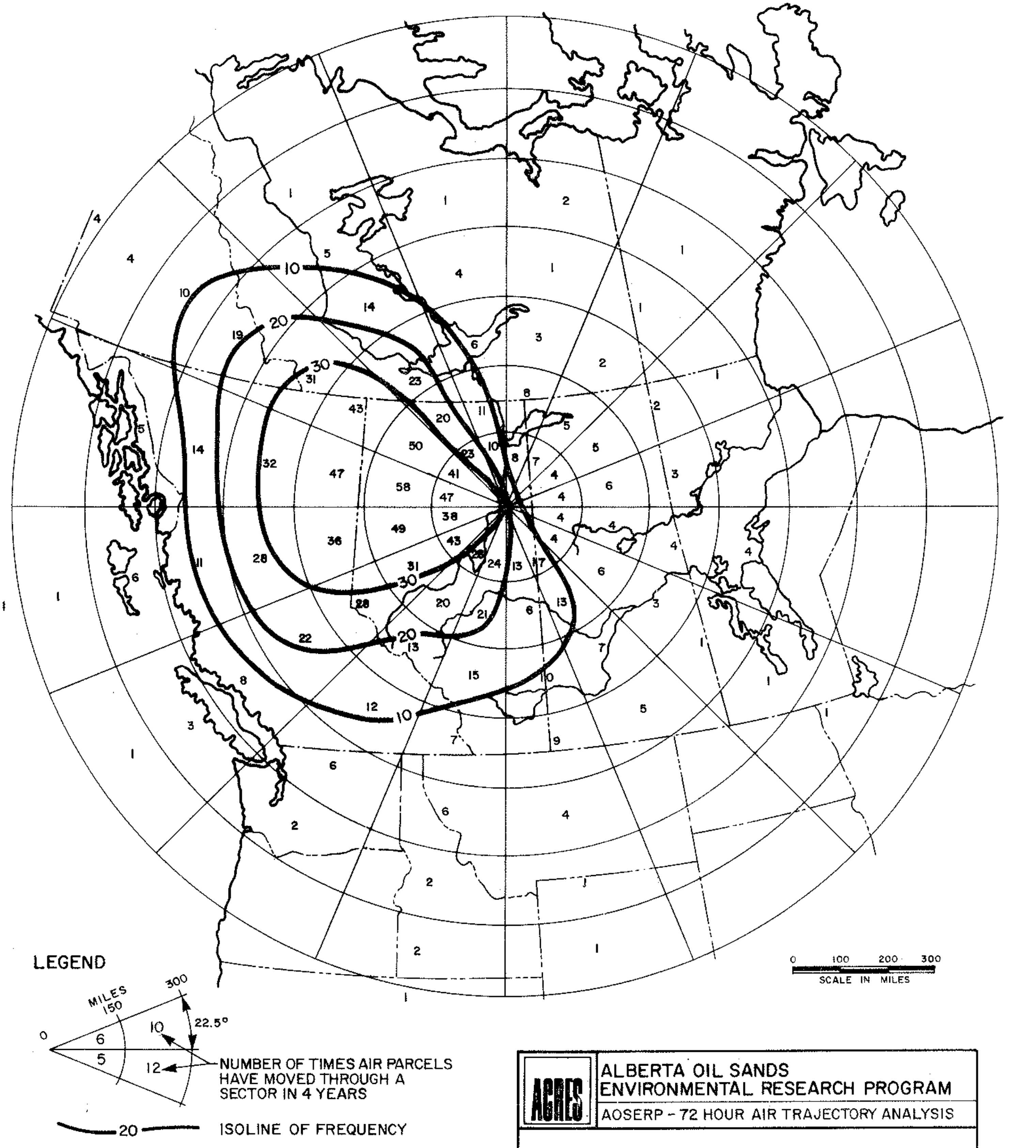
DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

ACRES	ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
	AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 21



LEVEL – 850 mb

72 HOUR PRECIPITATION – NIL

DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

ACRES

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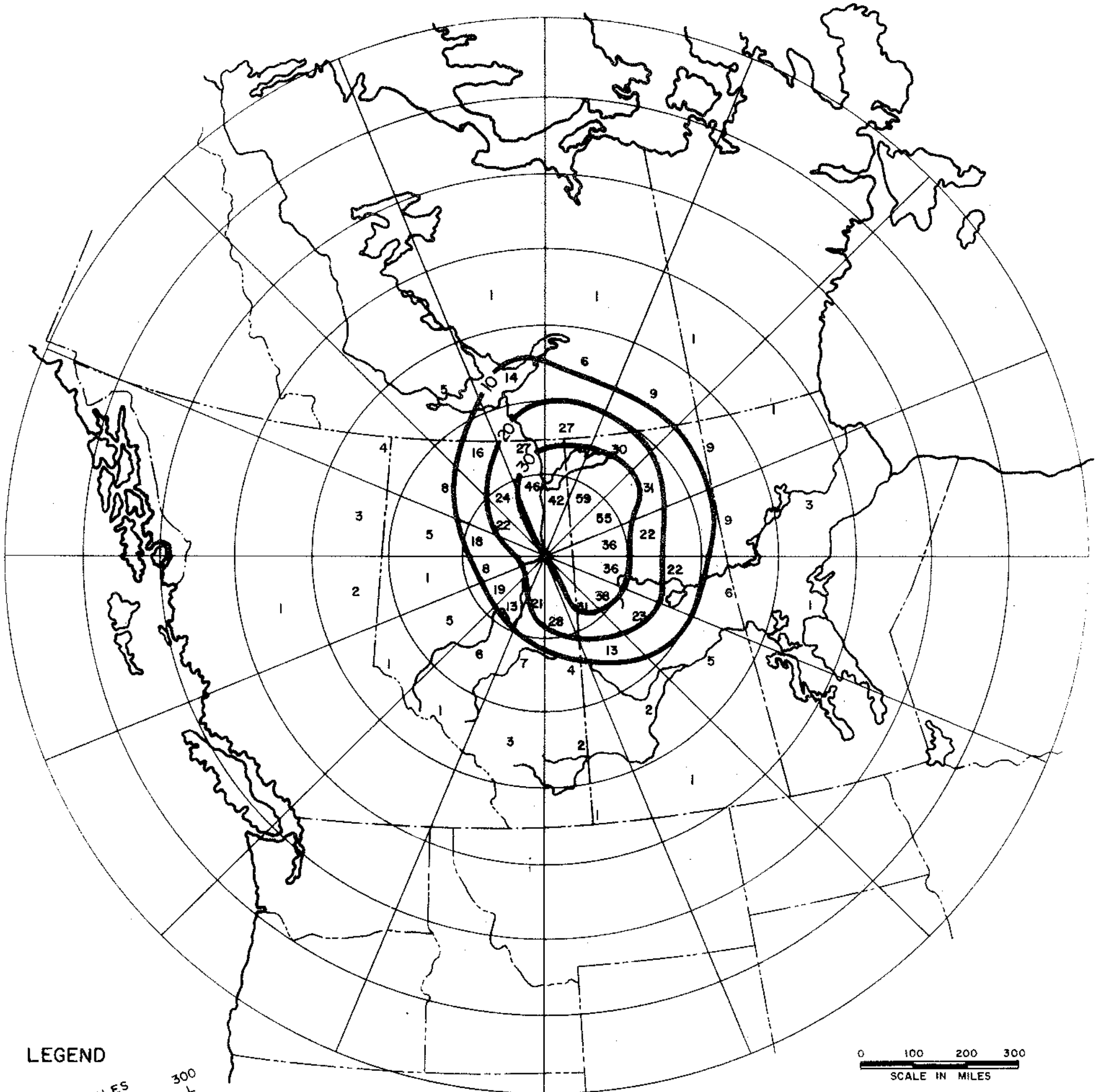
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

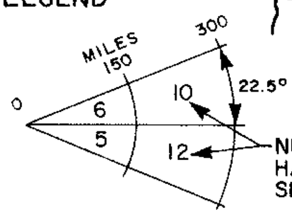
FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976

FIGURE 22



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

20 ISOLINE OF FREQUENCY

LEVEL – SURFACE

72 HOUR PRECIPITATION – NIL

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

ACRES

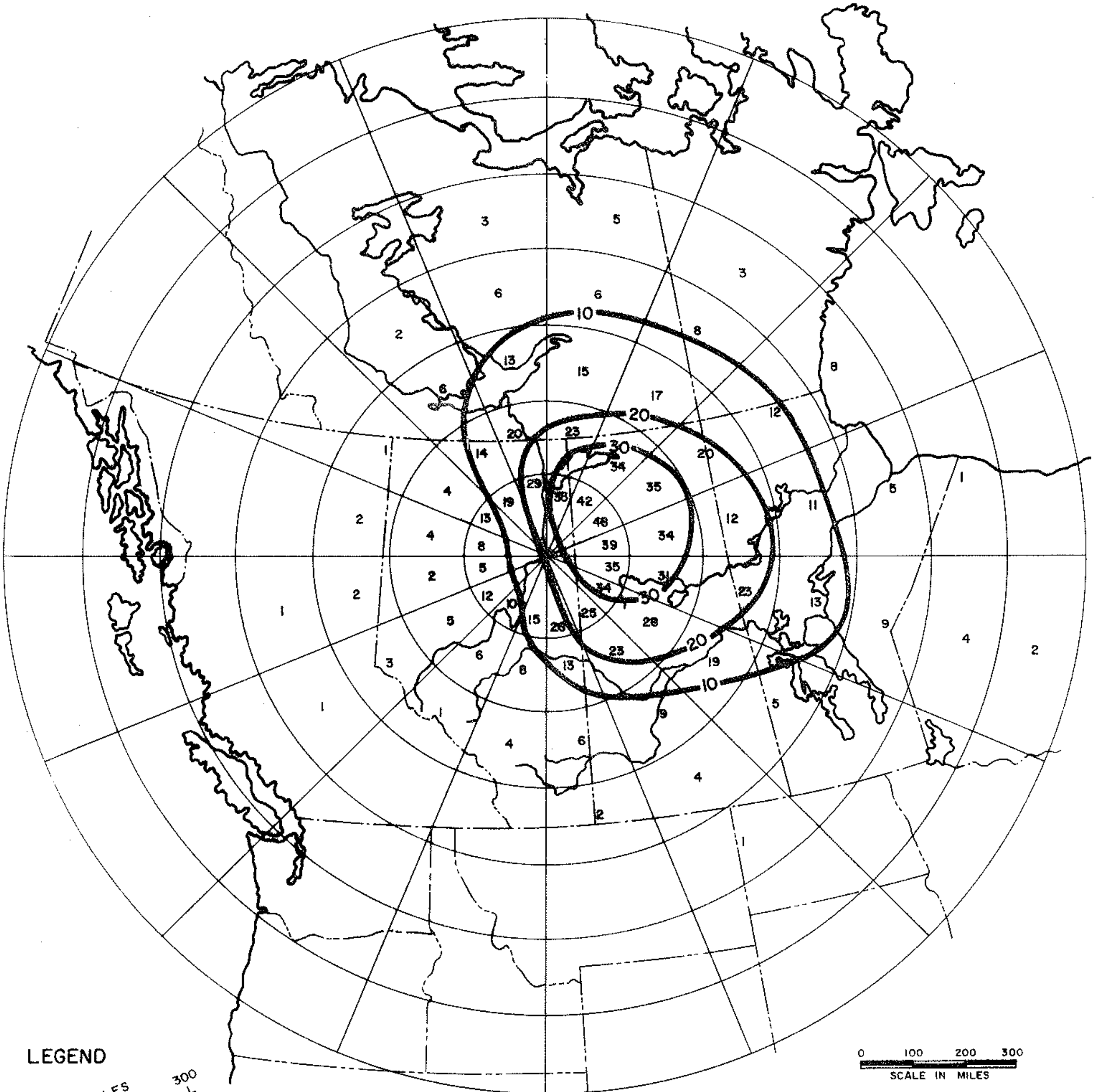
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

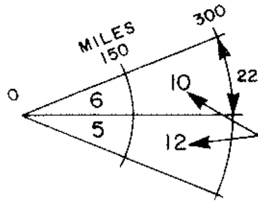
FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976

FIGURE 23



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

20 ISOLINE OF FREQUENCY

LEVEL – 925 mb

72 HOUR PRECIPITATION – NIL

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

ACRES

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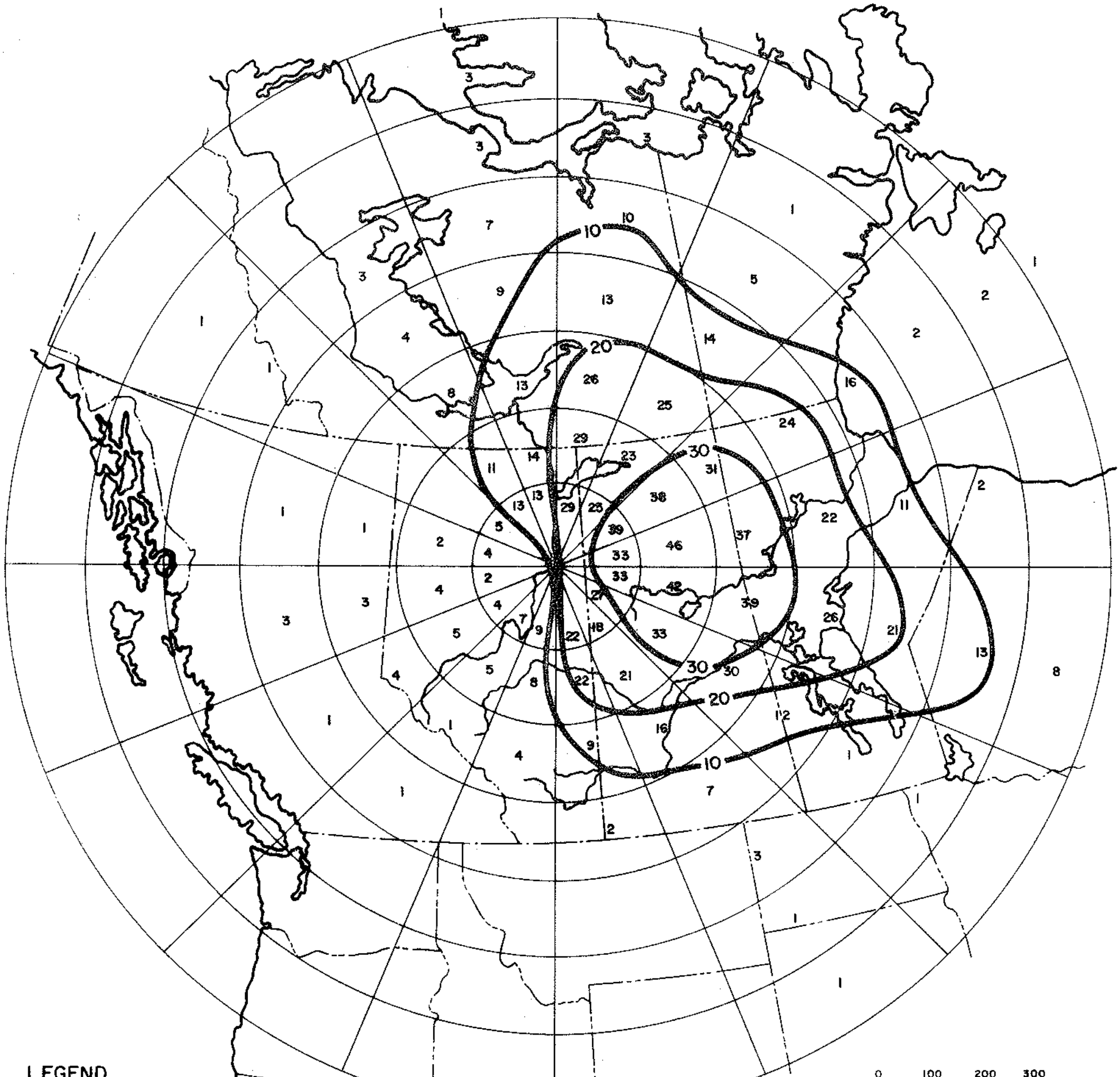
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

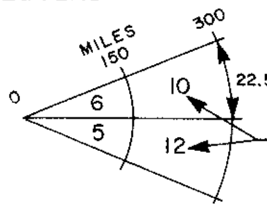
FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976

FIGURE 24



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

20 ISOLINE OF FREQUENCY

LEVEL – 850 mb

72 HOUR PRECIPITATION – NIL

DIRECTION – OUT FROM STUDY AREA

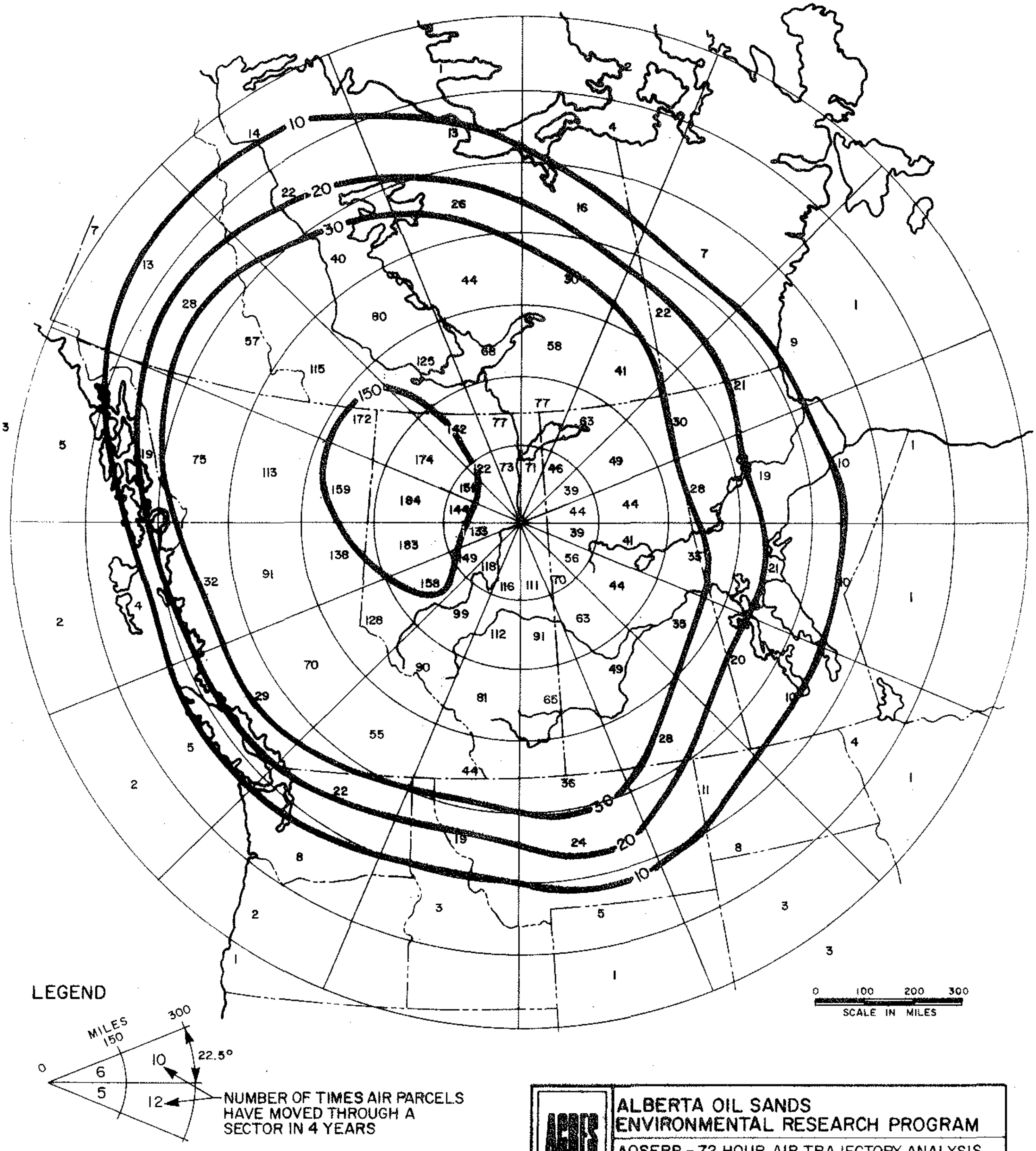
PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

AOSERP	ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
	AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 25

LIGHT PRECIPITATION
Surface - 925 mb - 850 mb Levels
In To and Out From Study Area



LEVEL – 850 mb

72 HOUR PRECIPITATION – LIGHT

DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

ACRES

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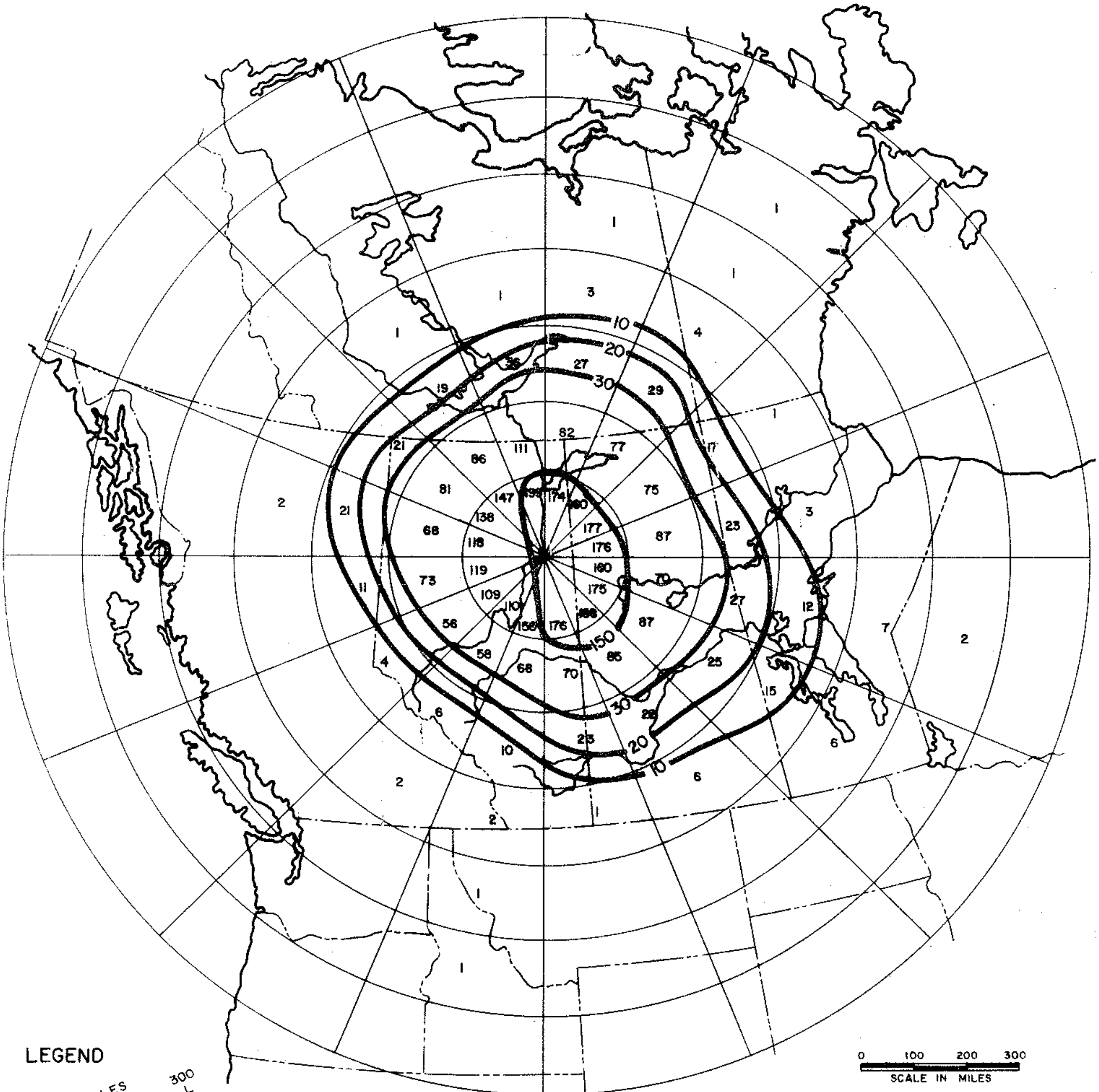
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 28



LEGEND

MILES 150 300

0 6 5 10 12 22.5°

NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

20 ISOLINE OF FREQUENCY

LEVEL – SURFACE

72 HOUR PRECIPITATION – LIGHT

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

ACRES

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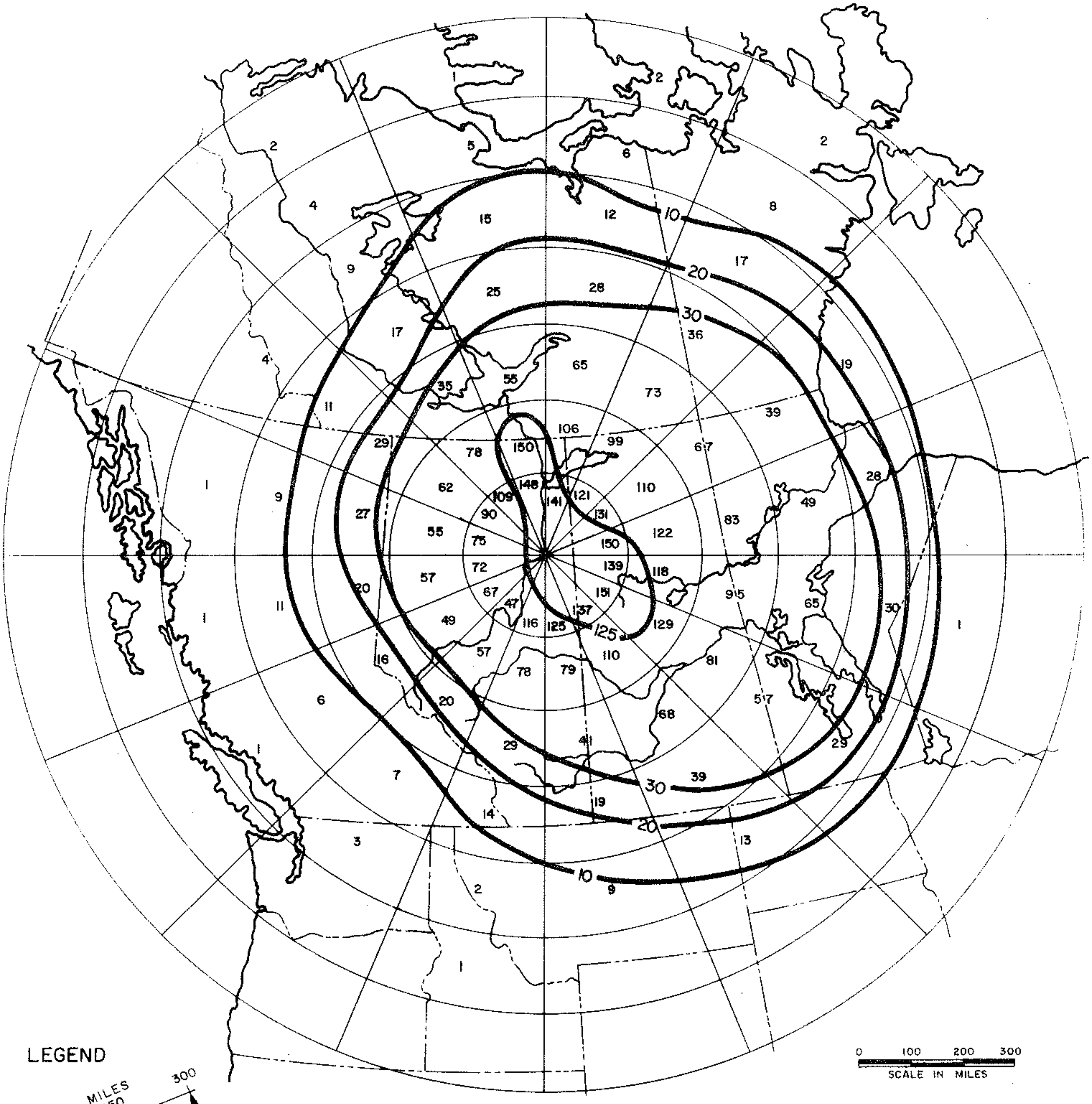
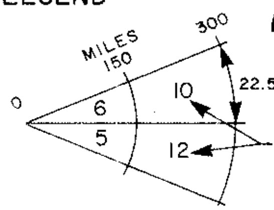
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 29



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

20 ISOLINE OF FREQUENCY

LEVEL – 925 mb

72 HOUR PRECIPITATION – LIGHT

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

ACRES

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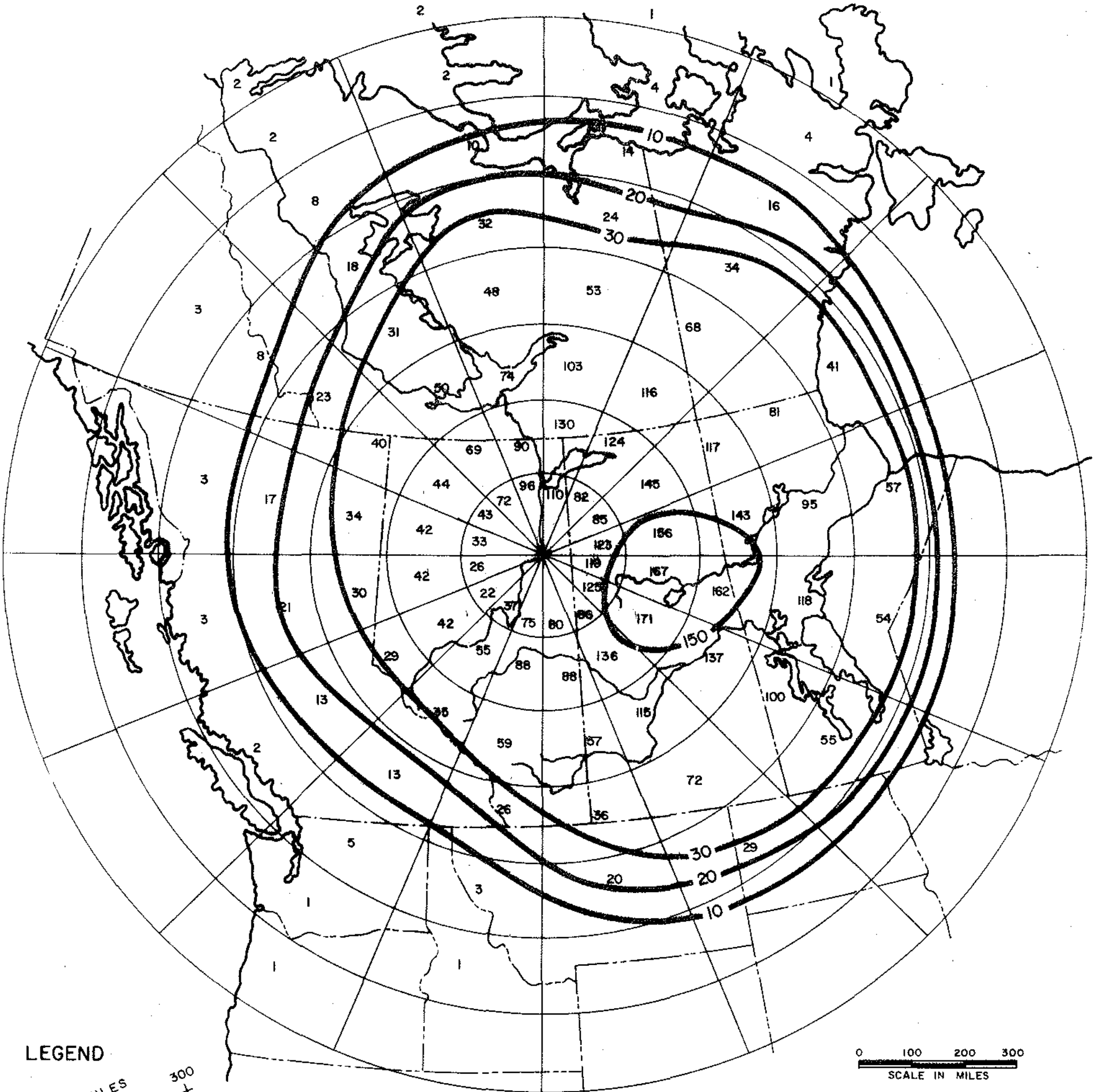
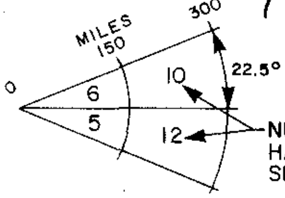
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 30



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

20 ISOLINE OF FREQUENCY

LEVEL – 850 mb

72 HOUR PRECIPITATION – LIGHT

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

ACRES

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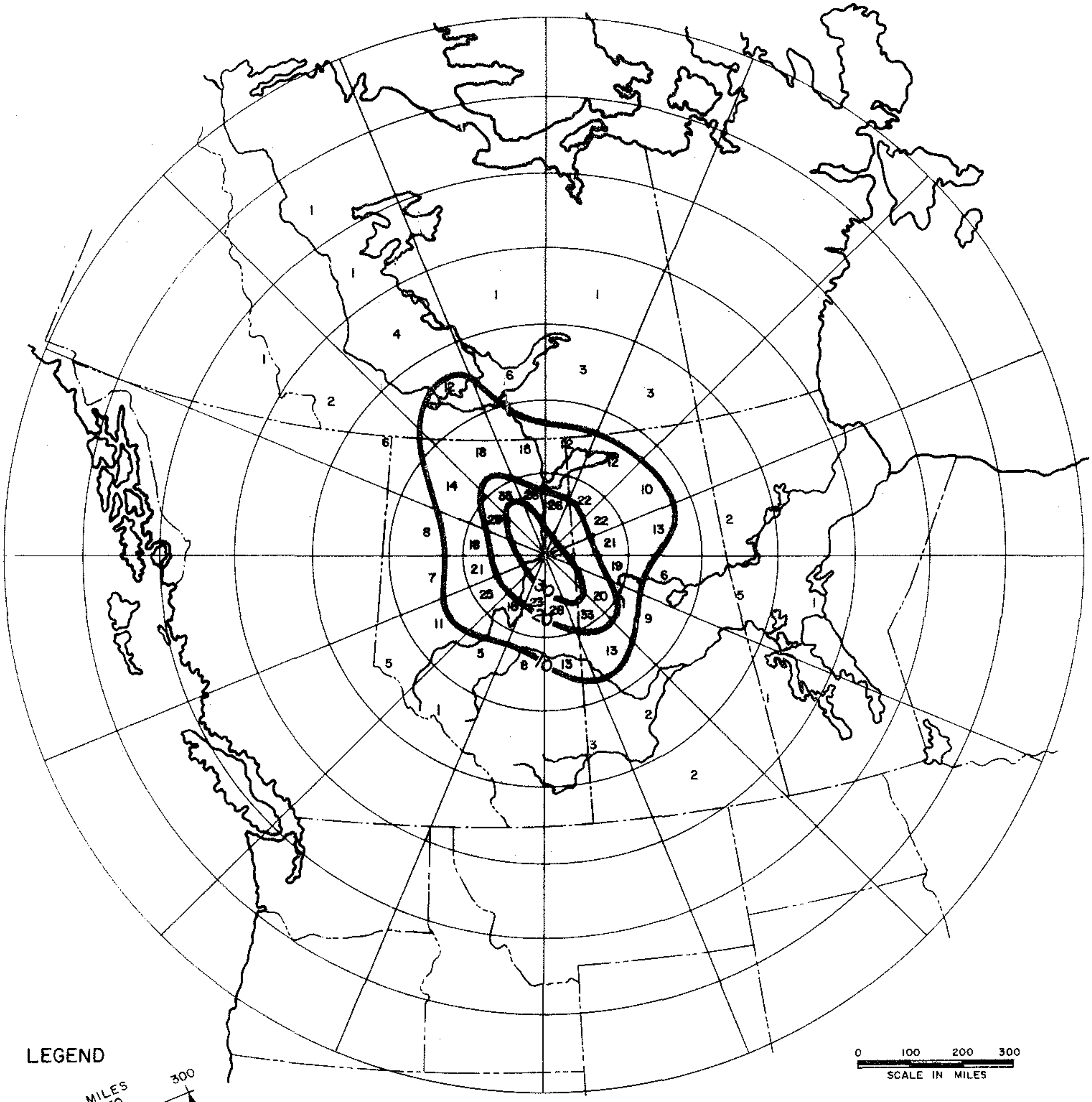
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

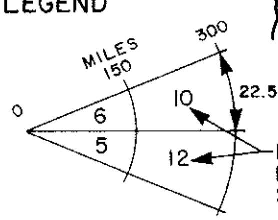
FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 31

MODERATE PRECIPITATION
Surface - 925 mb - 850 mb Levels
In To and Out From Study Area



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

20 ISOLINE OF FREQUENCY

LEVEL – SURFACE

72 HOUR PRECIPITATION – MODERATE

DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

ACRES

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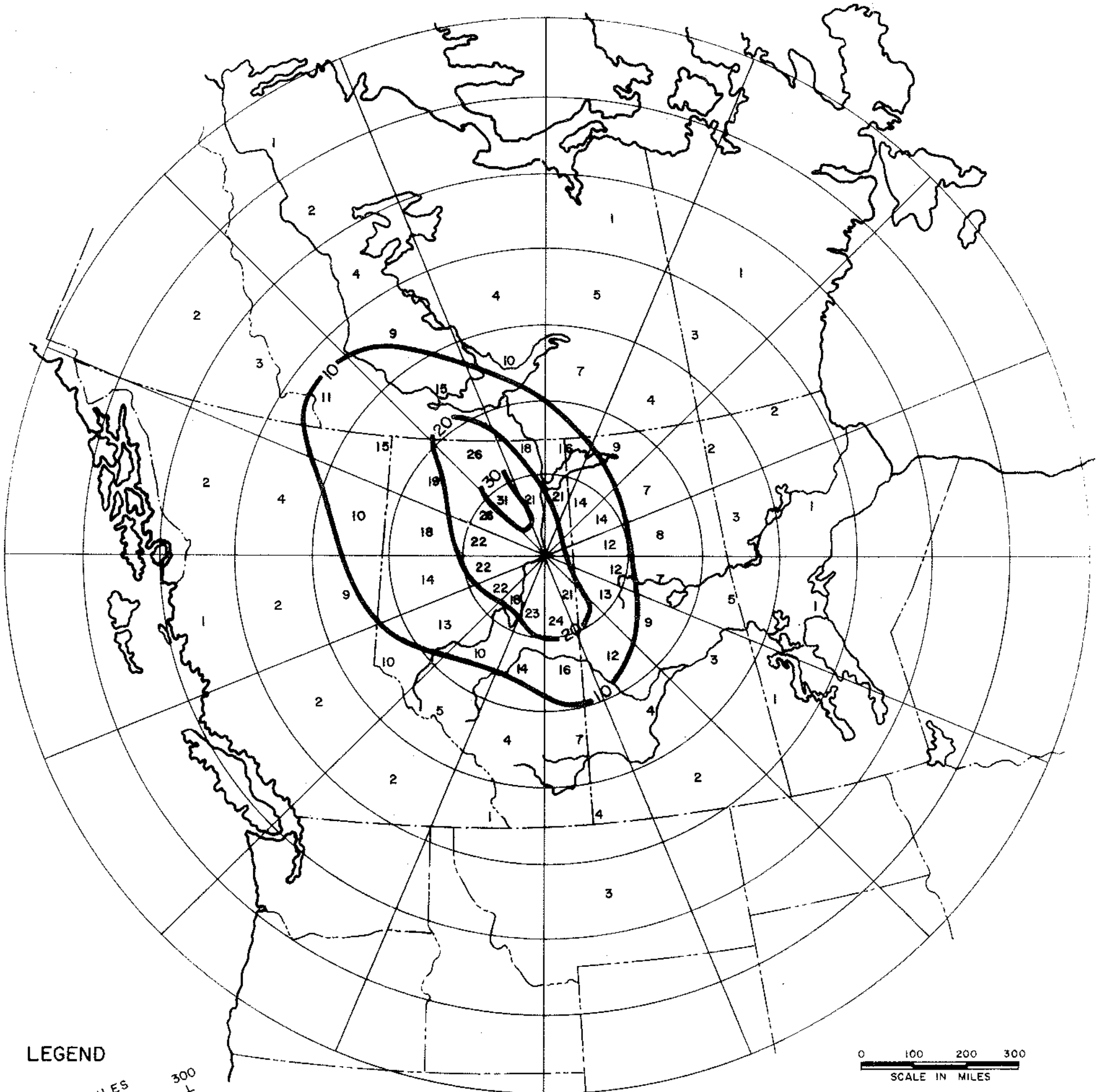
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

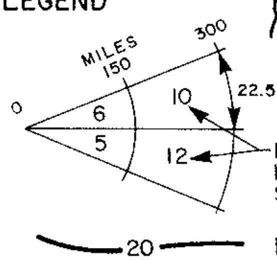
FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976

FIGURE 32



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

—20— ISOLINE OF FREQUENCY

LEVEL – 925 mb

72 HOUR PRECIPITATION – MODERATE

DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

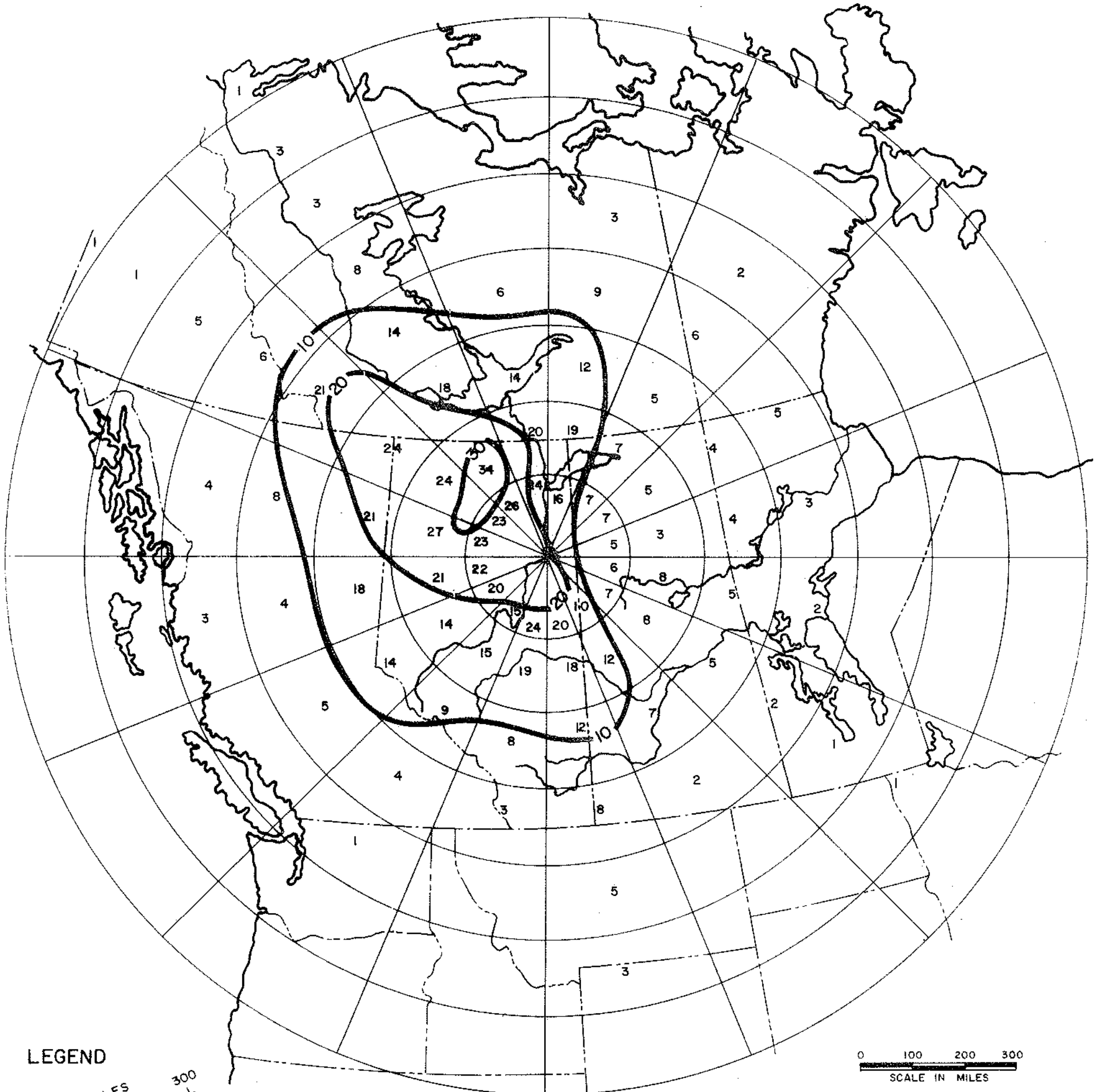
ACRES

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

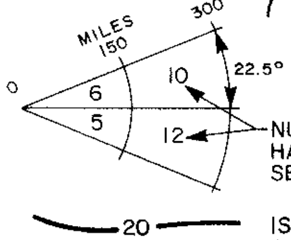
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 33



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

20 ISOLINE OF FREQUENCY

LEVEL – 850 mb

72 HOUR PRECIPITATION – MODERATE

DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

ACRES

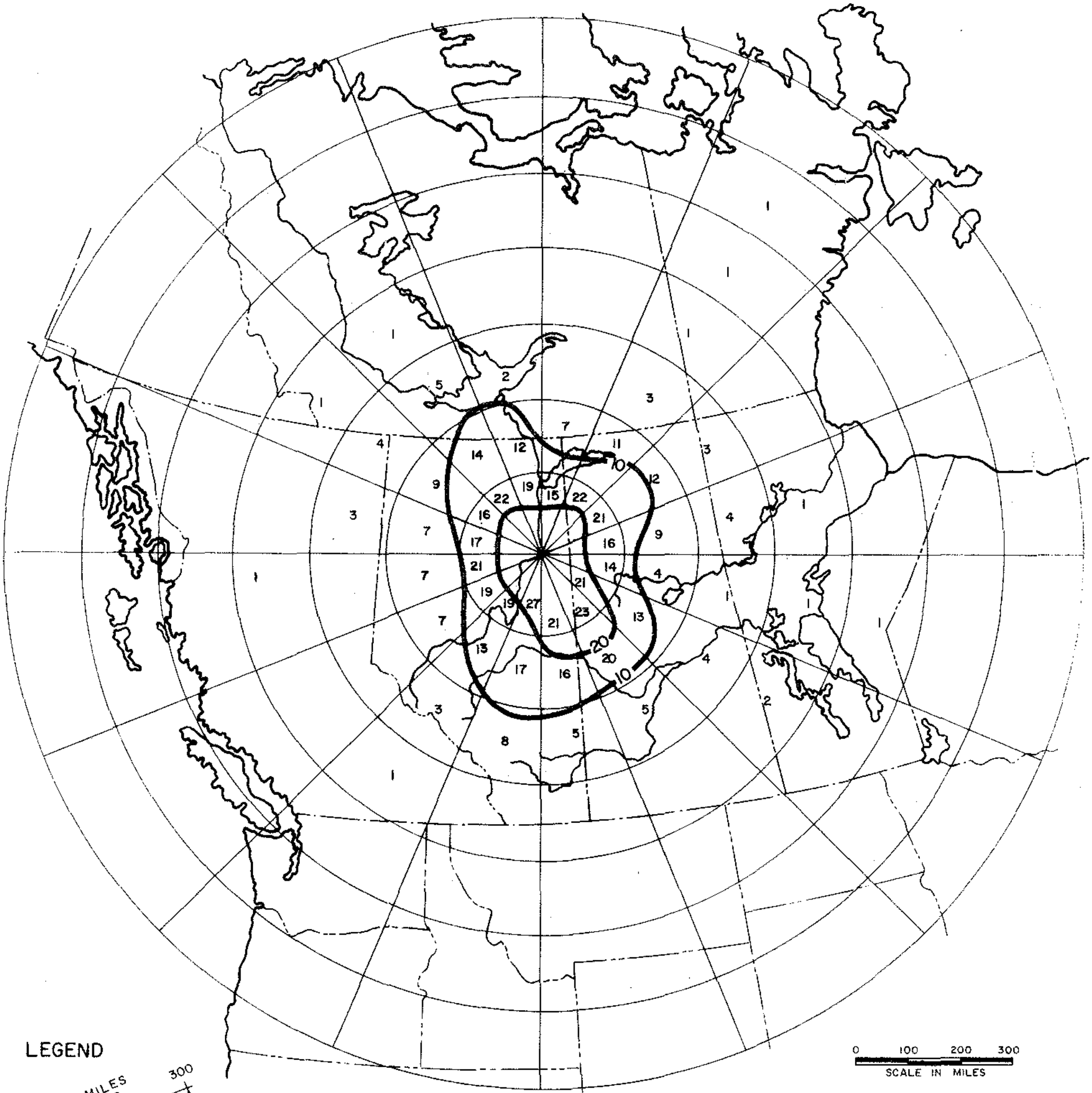
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

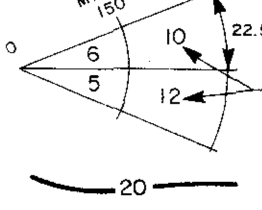
FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976

FIGURE 34



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

—— 20 —— ISOLINE OF FREQUENCY

LEVEL – SURFACE

72 HOUR PRECIPITATION – MODERATE

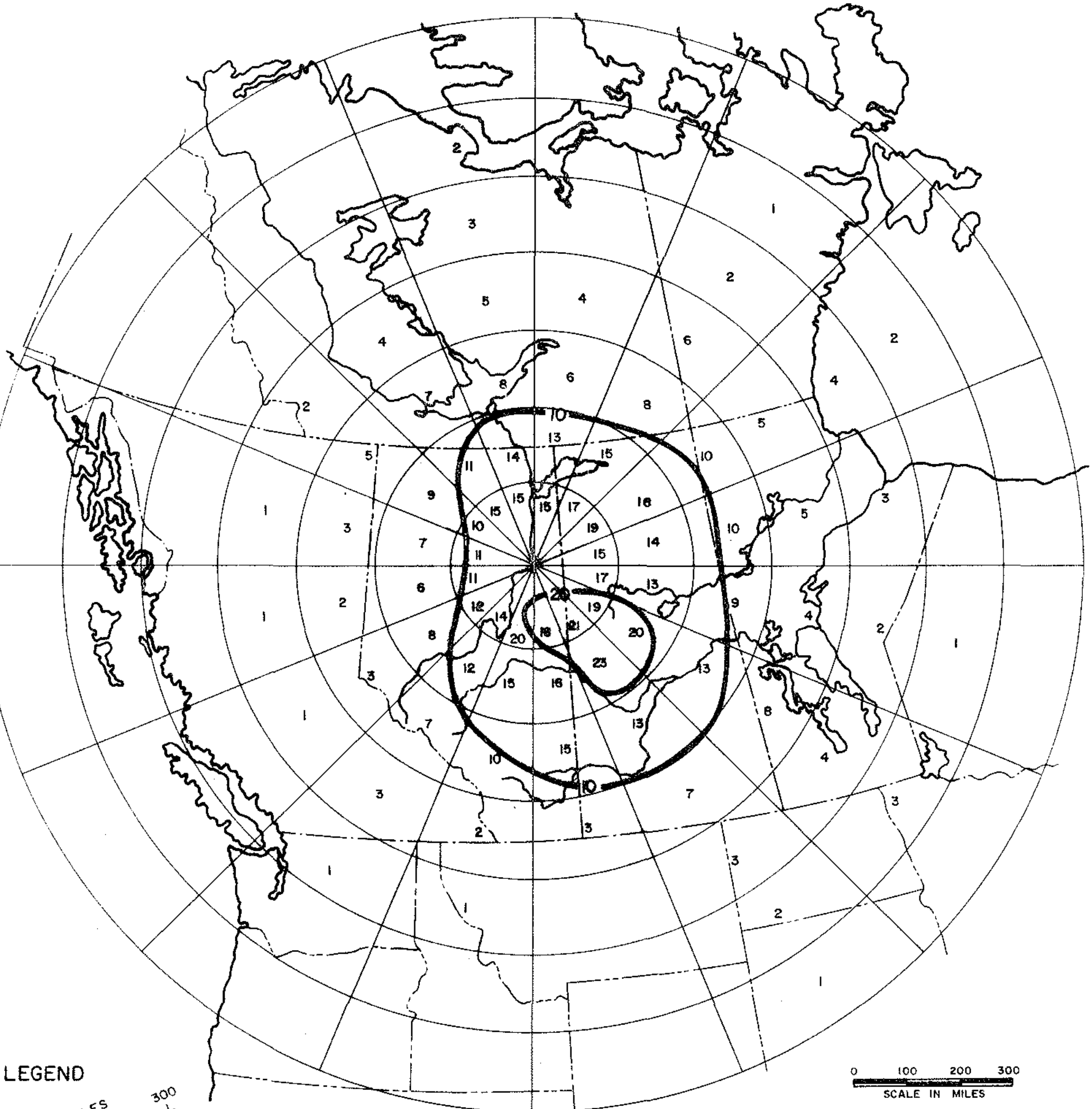
DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

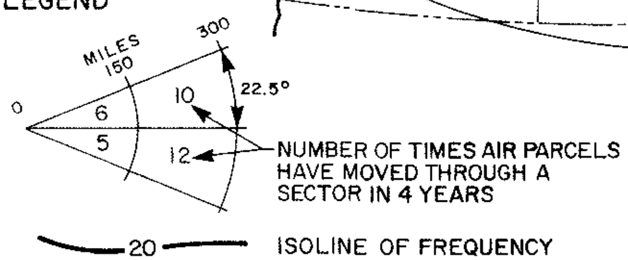
AGRES	ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
	AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 35



LEGEND



LEVEL — 925 mb

72 HOUR PRECIPITATION — MODERATE

DIRECTION — OUT FROM STUDY AREA

PERIOD — 1968, 73, 74 AND 75 ANNUAL TOTALS

ACRES

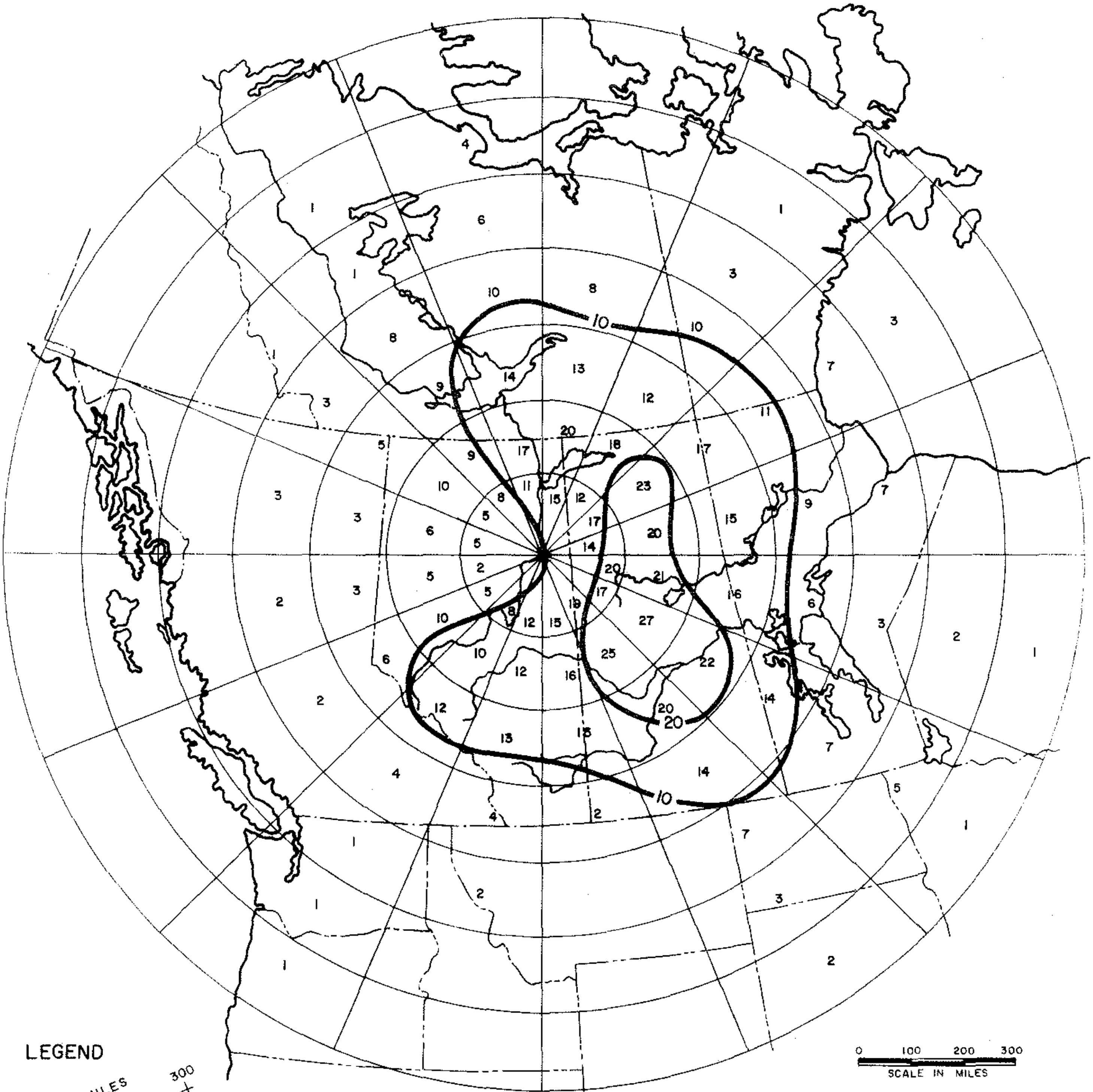
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

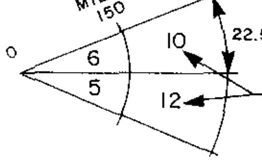
FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976

FIGURE 36



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

20 ISOLINE OF FREQUENCY

LEVEL – 850 mb

72 HOUR PRECIPITATION – MODERATE

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

ACRES	ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

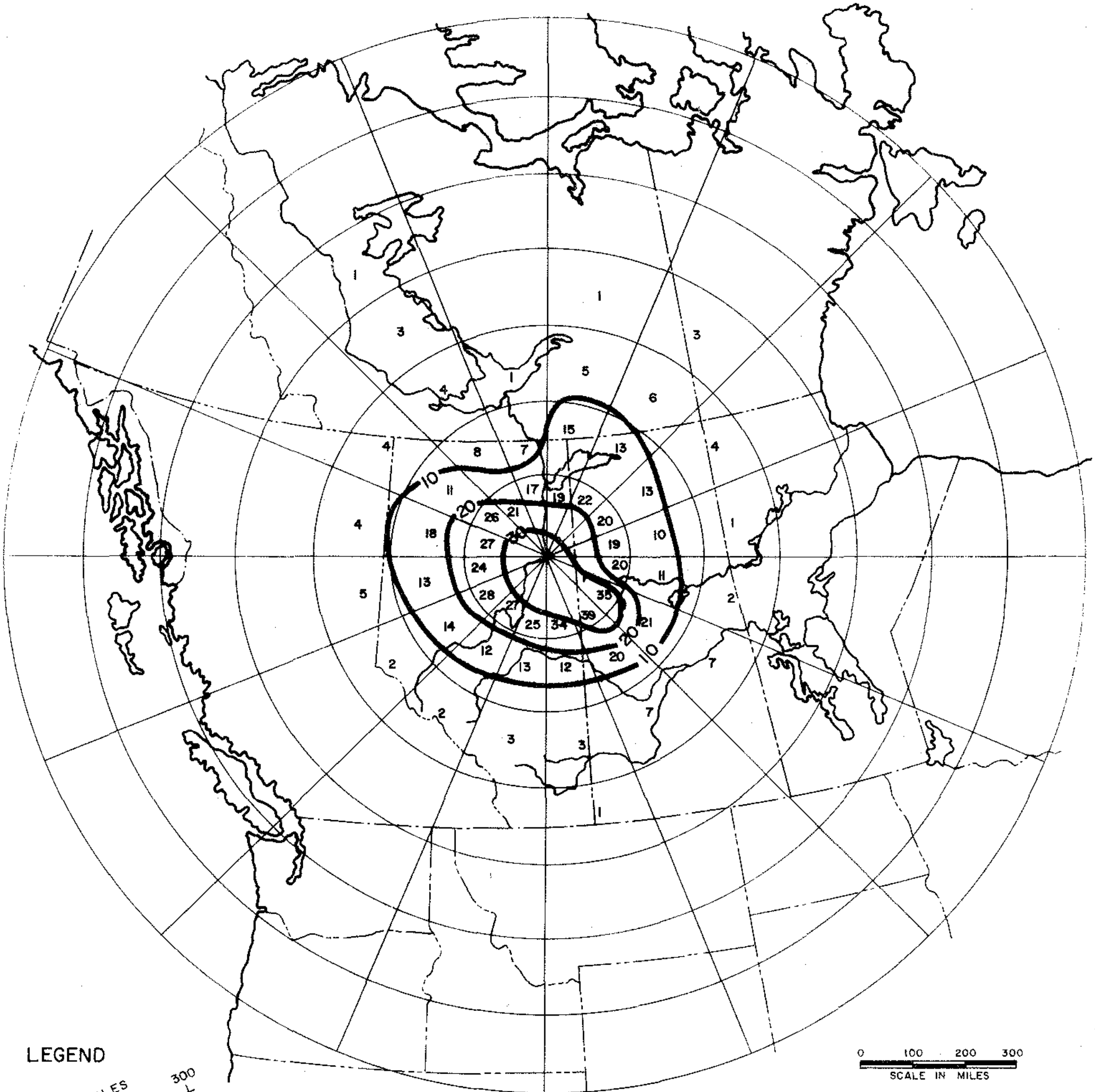
FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 37

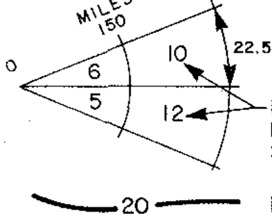
HEAVY PRECIPITATION

Surface - 925 mb - 830 mb Levels

In To and Out From Study Area



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

—20— ISOLINE OF FREQUENCY

LEVEL – SURFACE

72 HOUR PRECIPITATION – HEAVY

DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

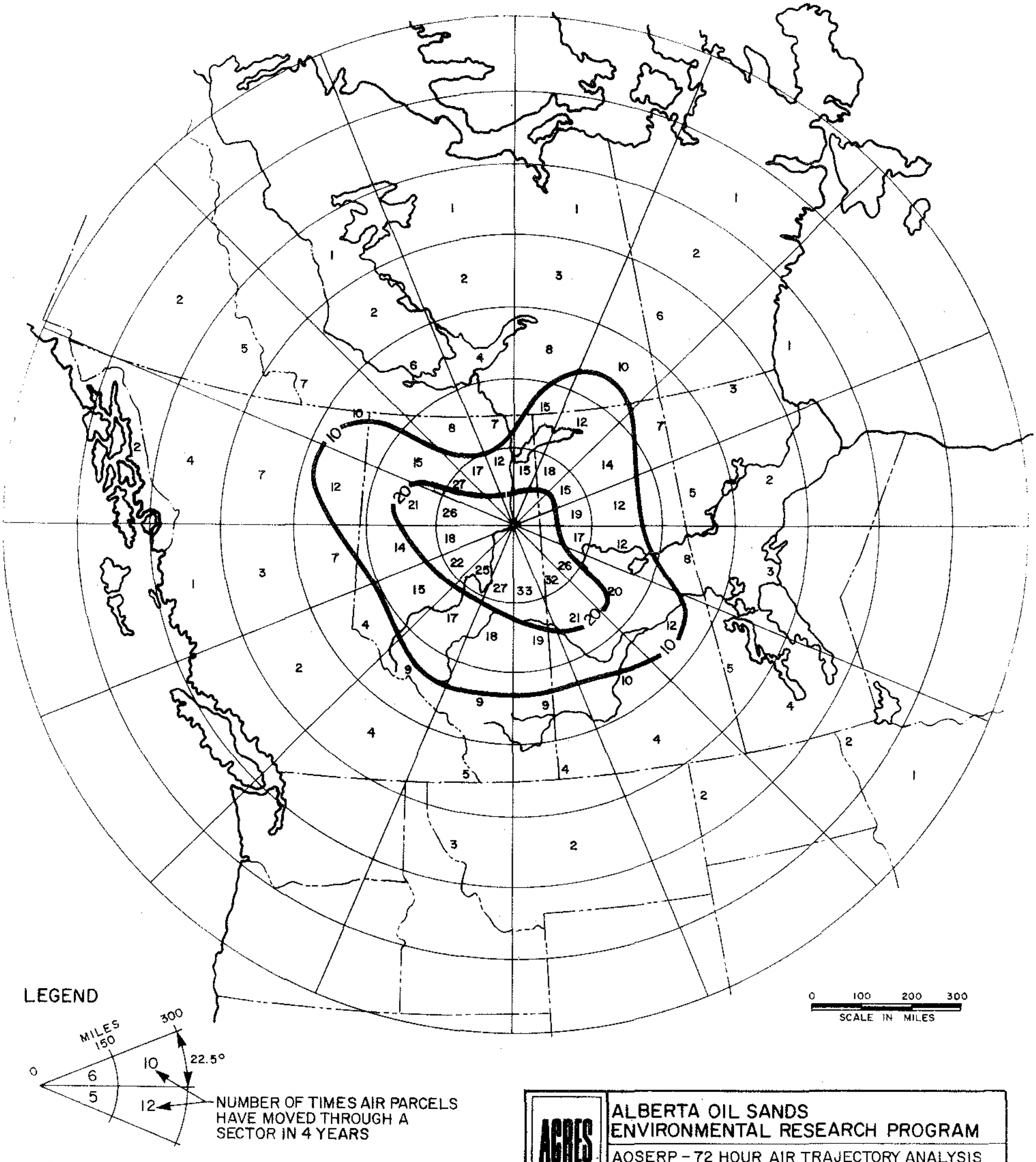
ACRES

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 38



LEVEL – 925 mb

72 HOUR PRECIPITATION – HEAVY

DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

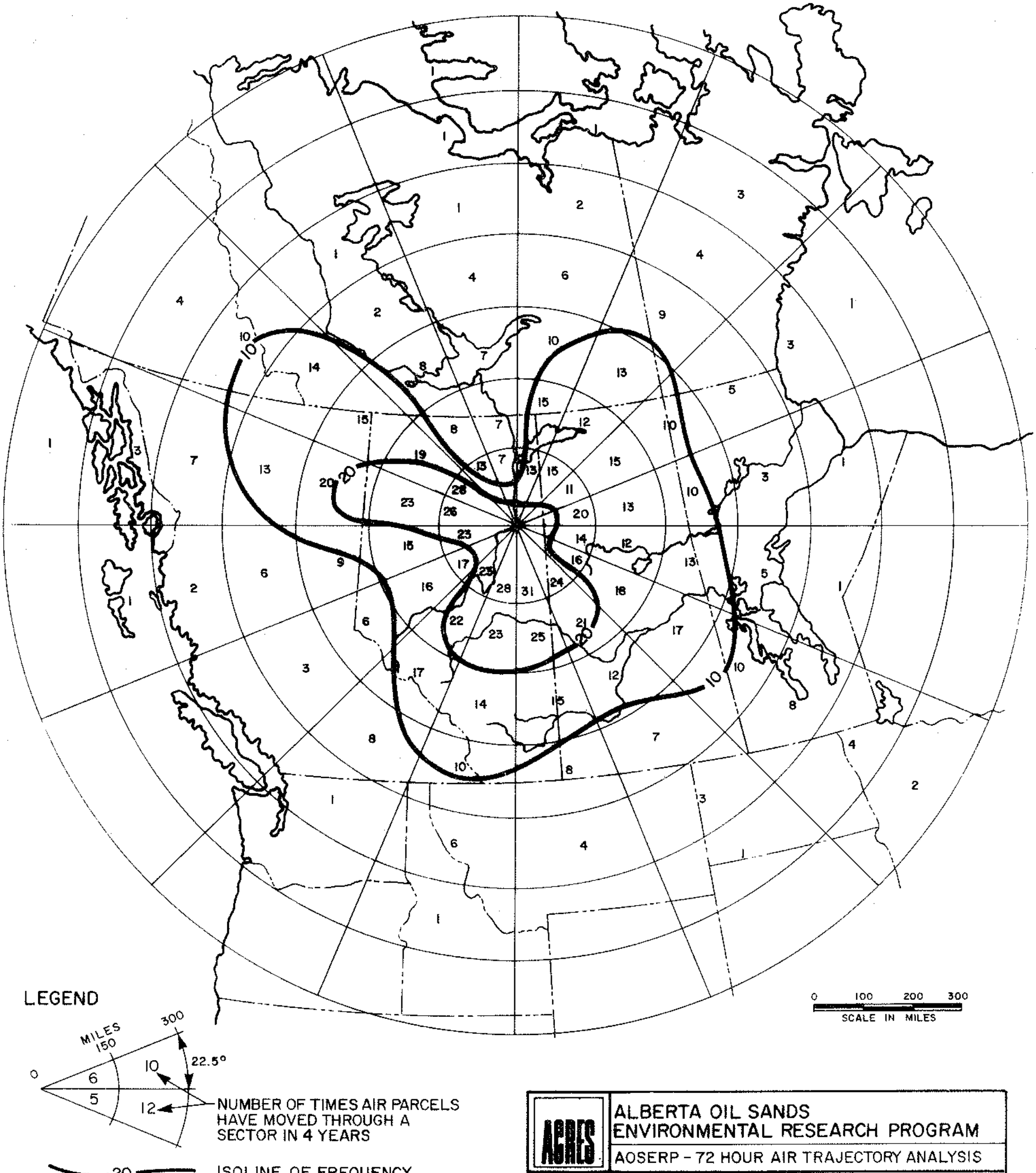
ACRES

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 39



LEVEL – 850 mb

72 HOUR PRECIPITATION – HEAVY

DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

ACRES

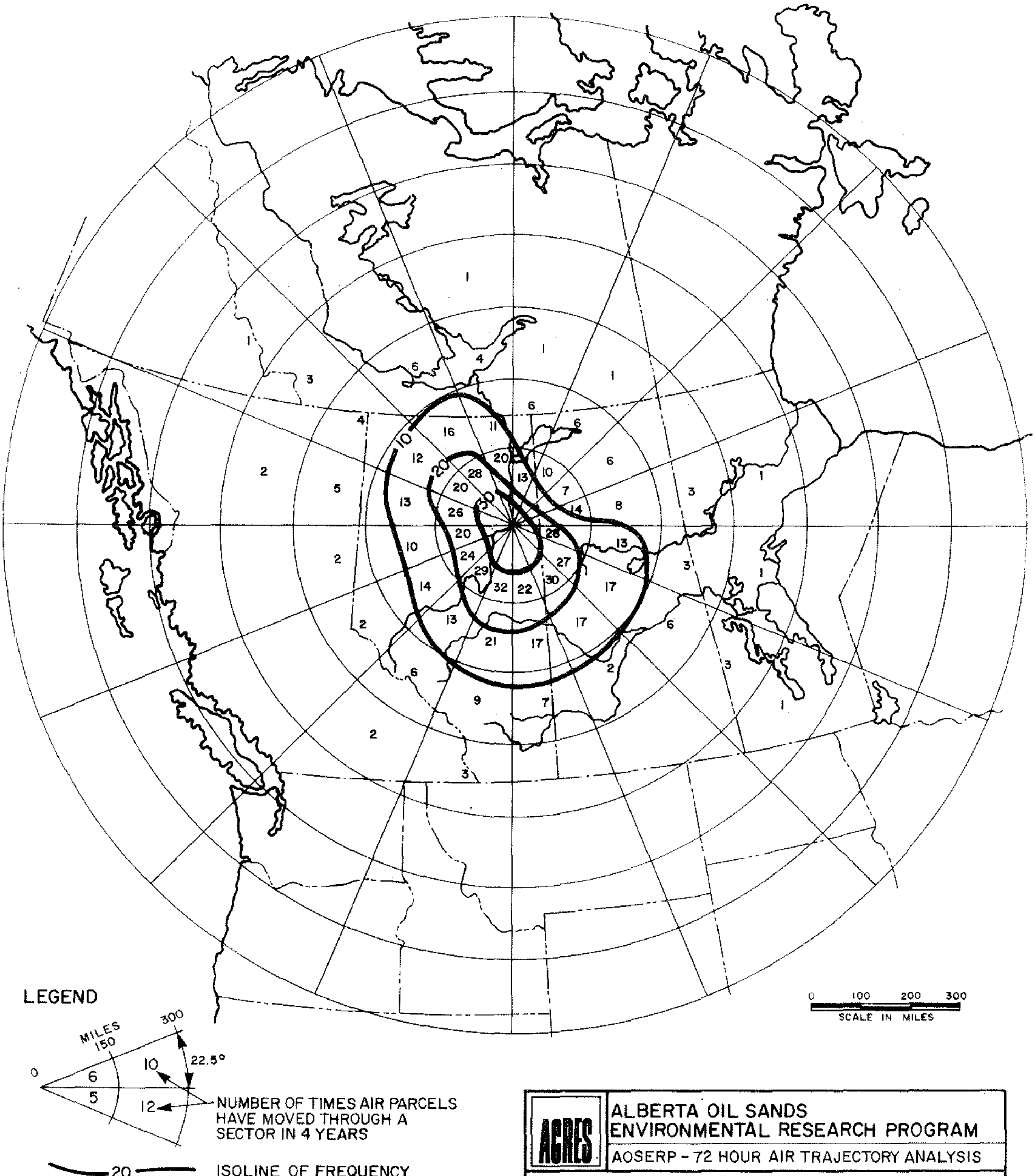
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976

FIGURE 40



LEVEL – SURFACE

72 HOUR PRECIPITATION – HEAVY

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

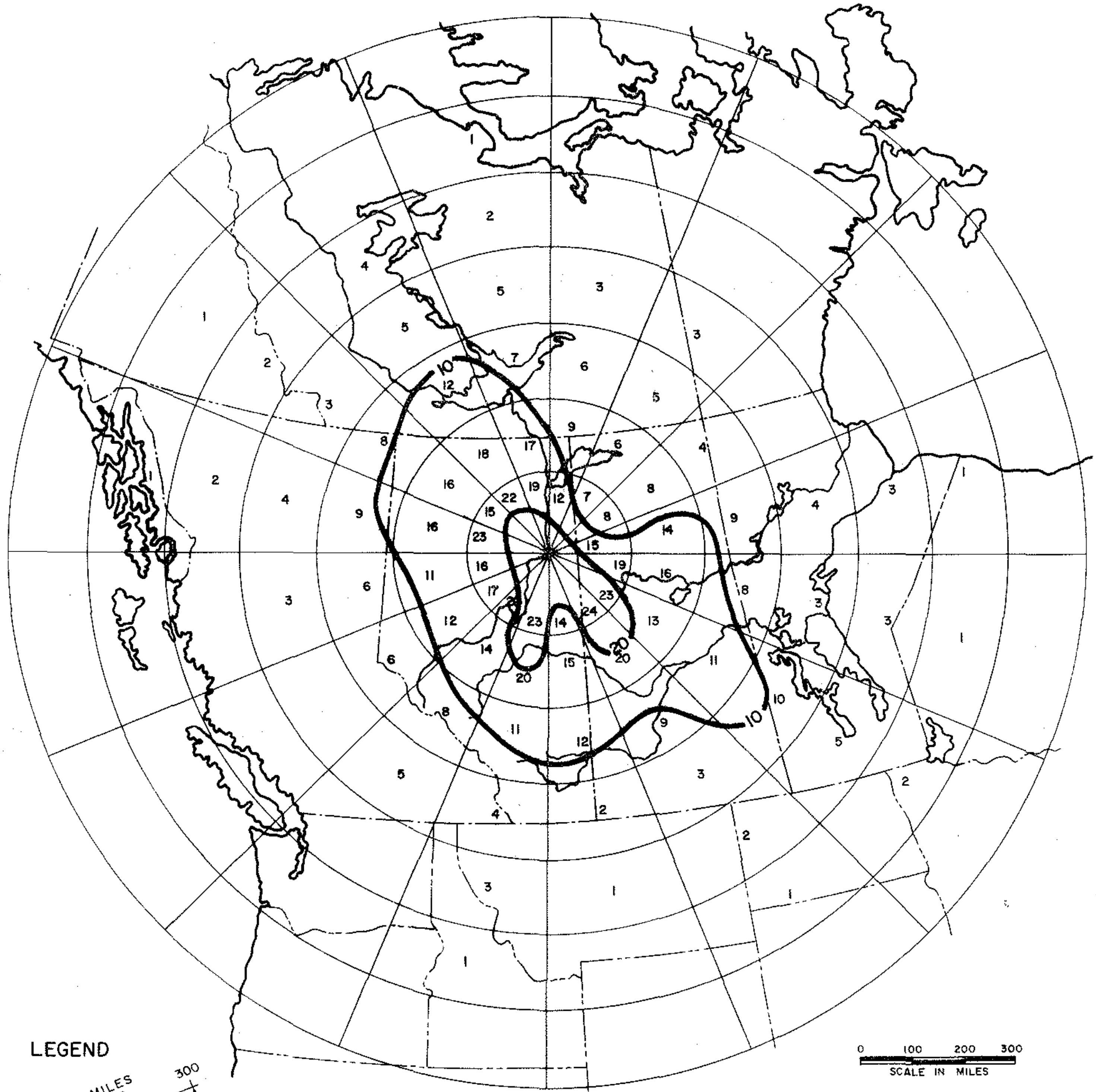
ACRES

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

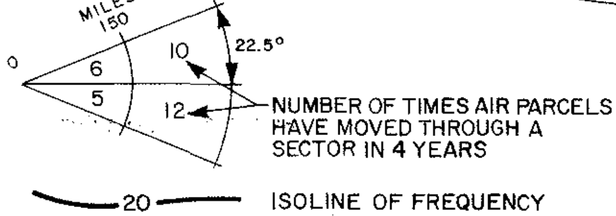
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 41



LEGEND



LEVEL – 925 mb

72 HOUR PRECIPITATION – HEAVY

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

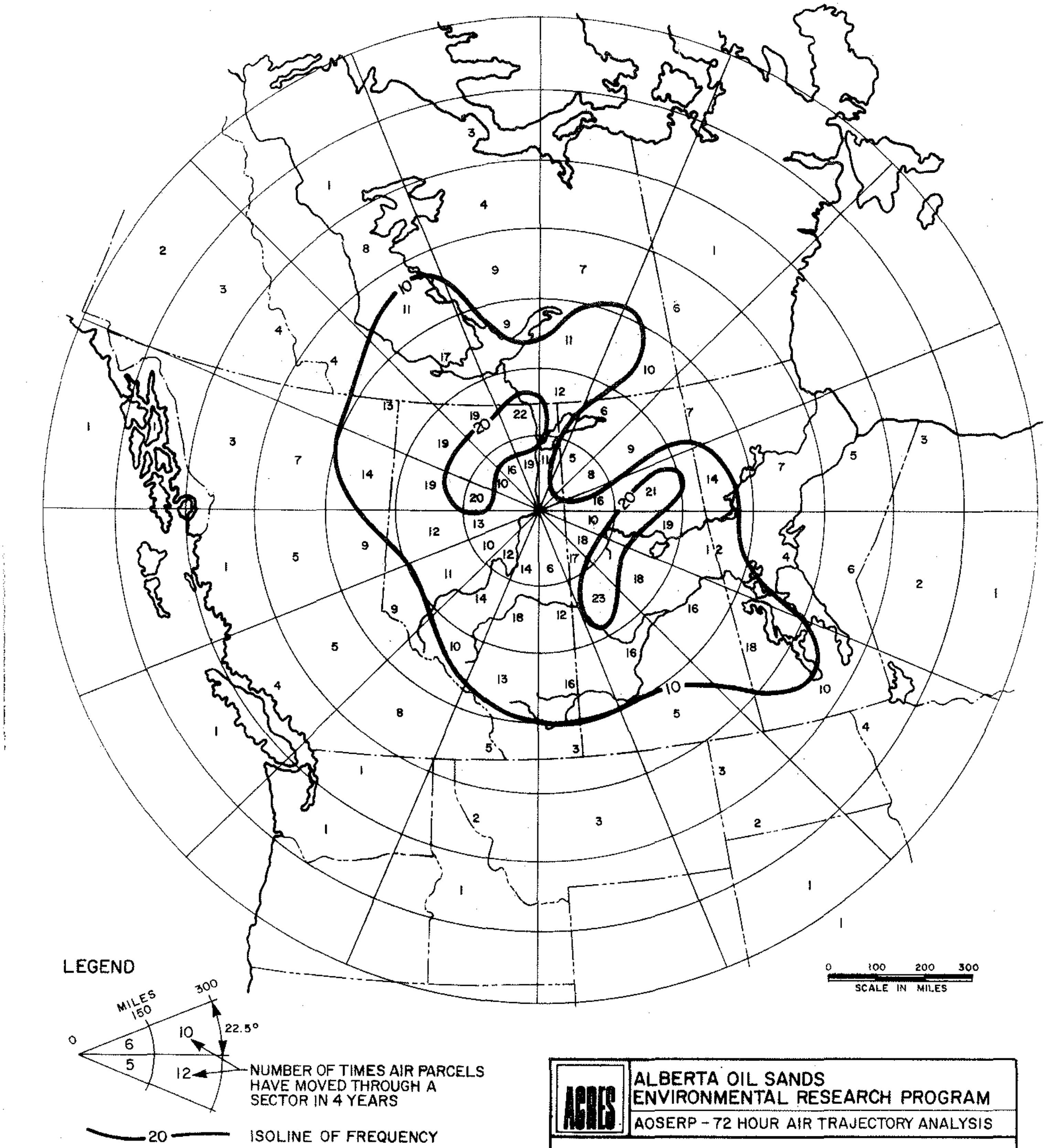
ACRES

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976 | FIGURE 42



LEVEL – 850 mb

72 HOUR PRECIPITATION – HEAVY

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 AND 75 ANNUAL TOTALS

ACRES

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976 | FIGURE 43

5.4 - Four-Year Total Seasonal Frequencies

Because of the relatively limited number of occurrences of moderate and heavy precipitation conditions, seasonal frequencies were analyzed only for nil and light precipitation at the surface and 850-mb levels. These analyses are shown on Figures 44 to 75. Seasons were defined as December-January-February (winter), March-April-May (spring), June-July-August (summer) and September-October-November (fall).

In the case of nil precipitation, for air parcels moving in to the study area, the dominant surface level frequencies are from the west-southwest in winter and fall, the west in spring and the west-northwest in summer. A secondary bias from the south-southeast shows in the spring. At the 850-mb level dominant frequencies are from the northwest in winter, west in spring, northwest in summer and west-northwest in fall.

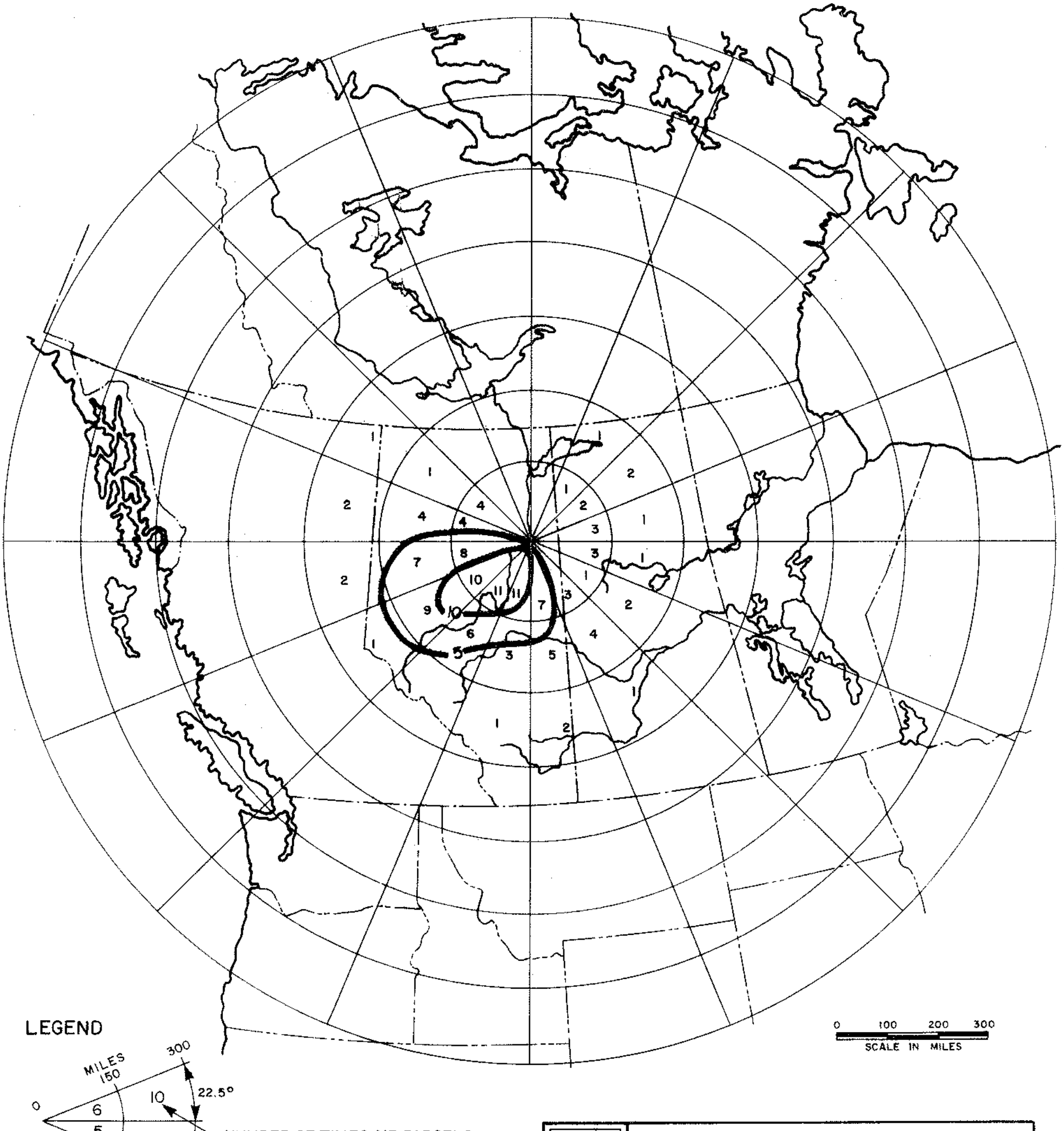
For air parcels moving out from the study area, under nil precipitation conditions, the dominant surface level frequencies are to the northeast in winter and spring and east-northeast in summer and fall. A secondary bias to the north-northwest shows in the spring. At 850 mb the dominant frequencies are to the east-southeast in winter and fall and east-northeast in spring and summer.

In the case of light precipitation and air parcels moving in to the study area at the surface level, winter frequencies slightly favor the westerly directions, are dominant from the east-southeast in the spring, the northwest in the summer and the southwest in the fall. At 850 mb the dominant frequencies are from the northwest in winter, west in the spring, northwest in the summer and west in the fall.

In the case of light precipitation and air parcels moving out from the study area, dominant frequencies at the surface level are to the east in winter and the northwest in spring; frequencies are dominant to the east again in summer and fall. At the 850-mb level for these same conditions, dominant frequencies are to the east in all four seasons.

TOTAL SEASONAL FREQUENCIES

NIL PRECIPITATION
Surface - 850-mb Levels
In To Study Area



LEVEL – SURFACE

72 HOUR PRECIPITATION – NIL

DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 & 75, DEC., JAN., FEB., TOTALS

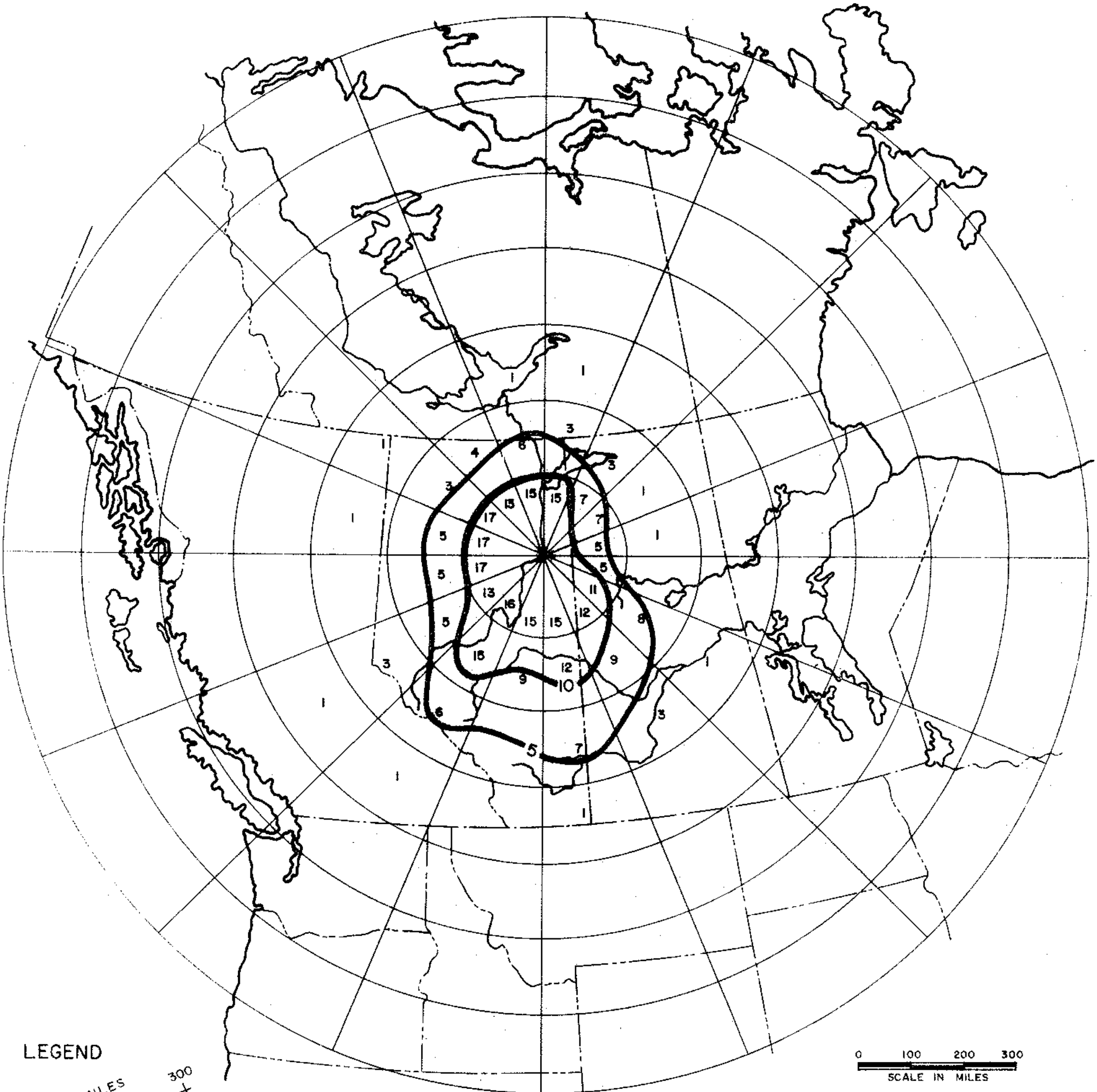
ACRES

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

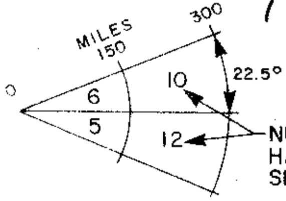
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976 | FIGURE 44



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

—— 20 —— ISOLINE OF FREQUENCY

LEVEL - SURFACE

72 HOUR PRECIPITATION - NIL

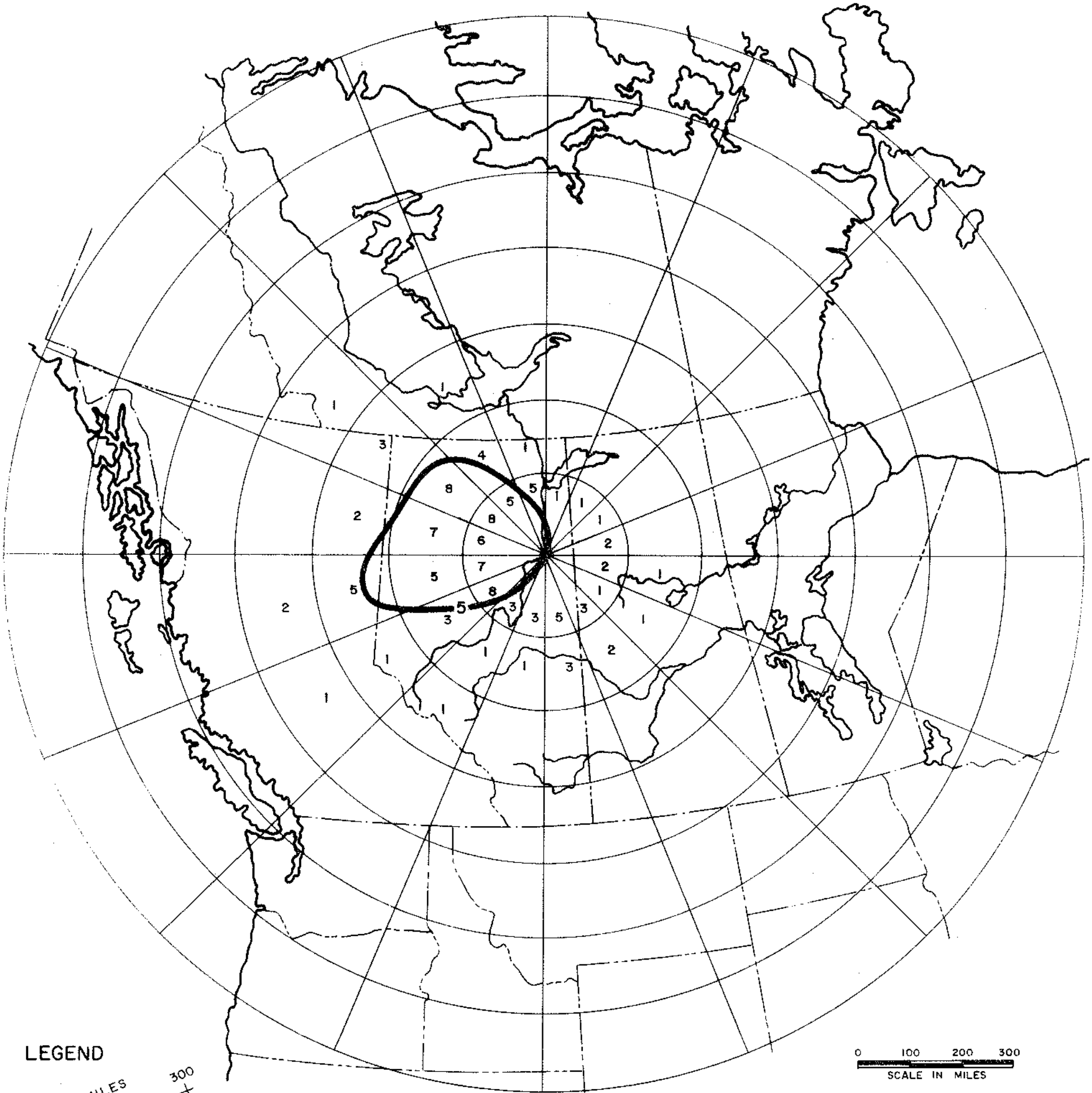
DIRECTION - IN TO STUDY AREA

PERIOD - 1968, 73, 74 & 75, MAR., APR., MAY TOTALS

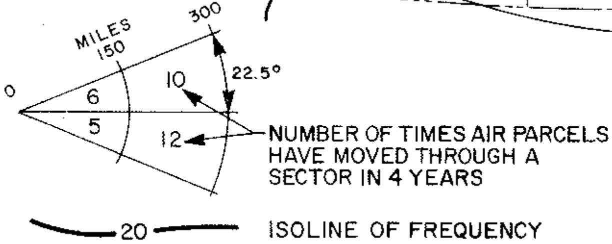
ACRES	ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
	AOSERP - 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 45



LEGEND



LEVEL – SURFACE

72 HOUR PRECIPITATION – NIL

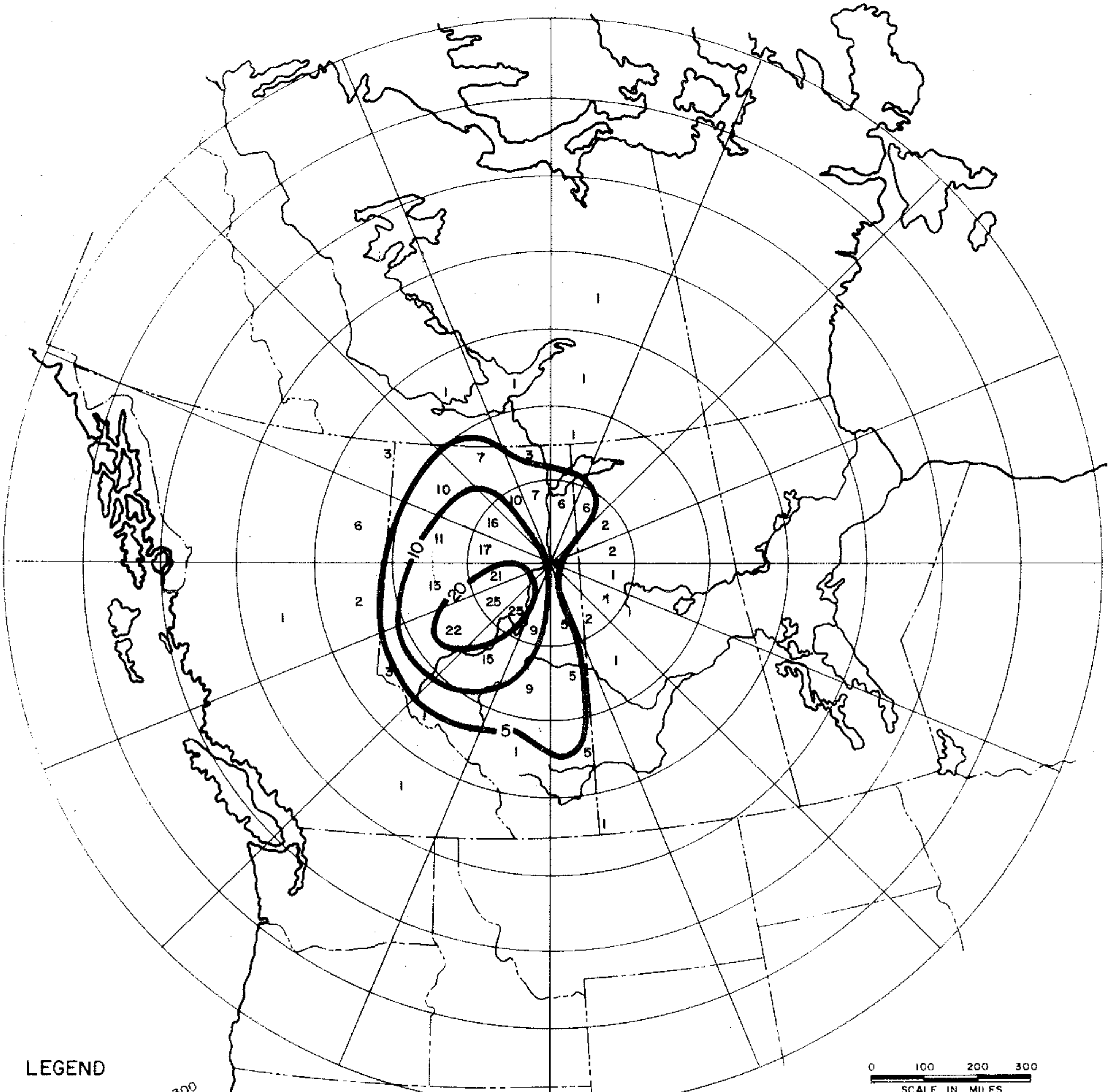
DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 & 75, JUN., JUL., AUG. TOTALS

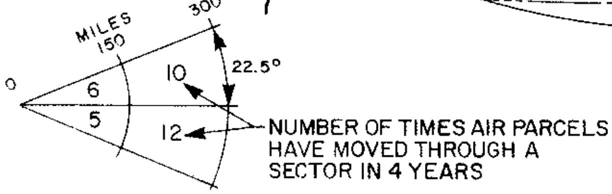
ACRES	ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 46



LEGEND



—— 20 —— ISOLINE OF FREQUENCY

LEVEL - SURFACE

72 HOUR PRECIPITATION - NIL

DIRECTION - IN TO STUDY AREA

PERIOD - 1968, 73, 74 & 75, SEPT., OCT., NOV., TOTALS

AGRES

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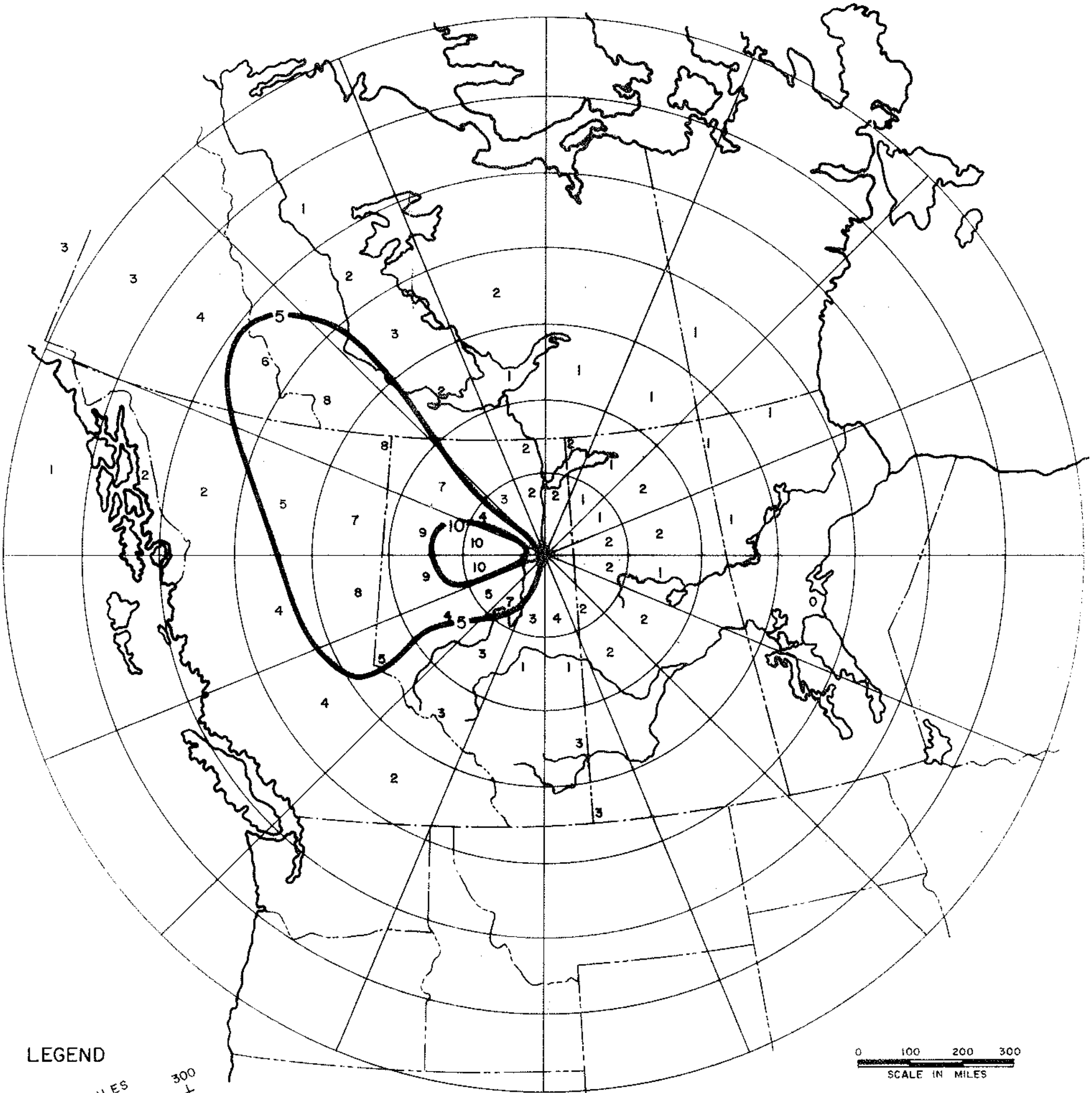
ENVIRONMENTAL RESEARCH PROGRAM

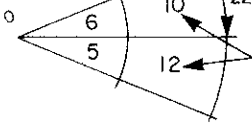
AOSERP - 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 47



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

20 ISOLINE OF FREQUENCY

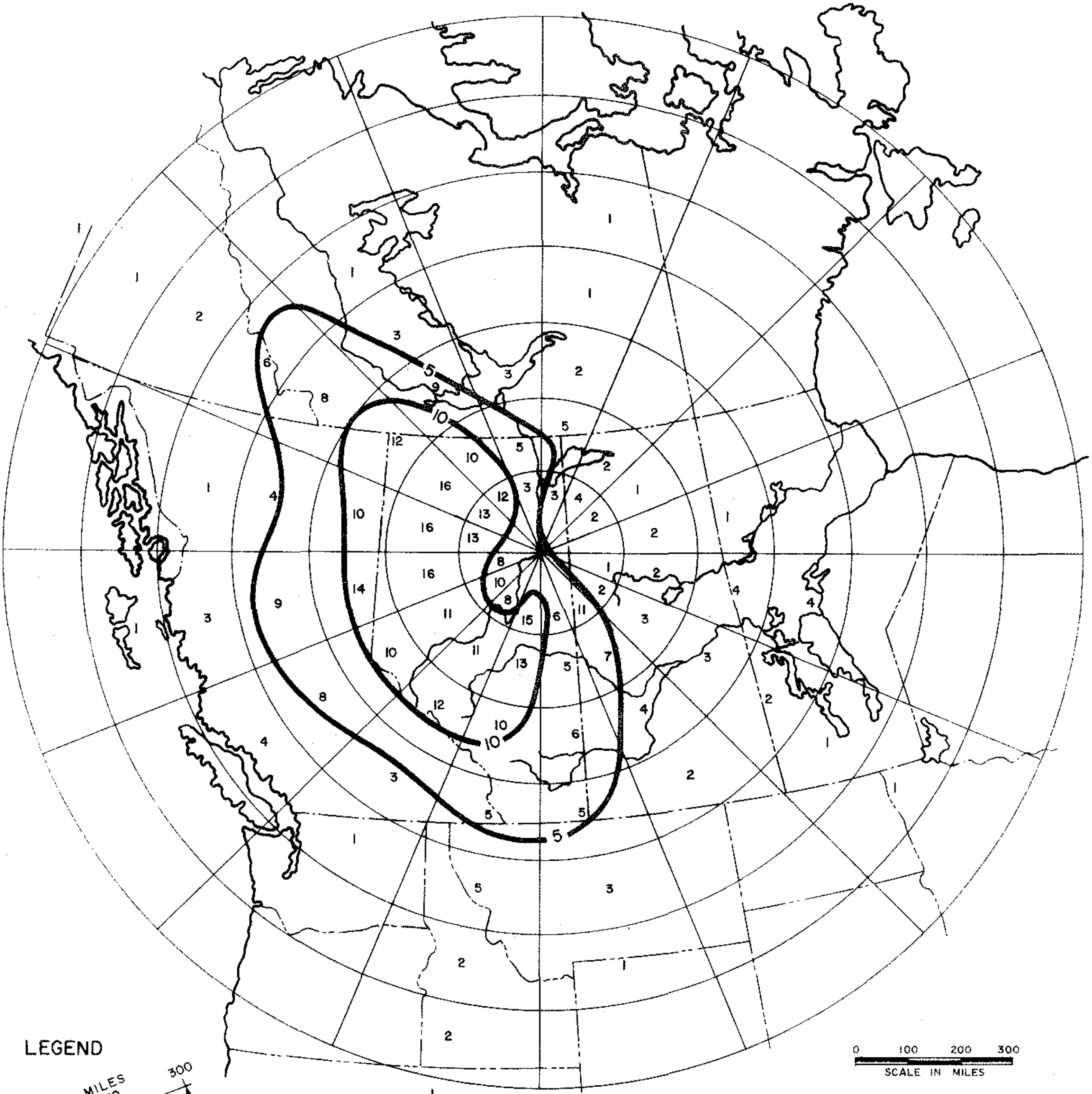
LEVEL – 850 mb

72 HOUR PRECIPITATION – NIL

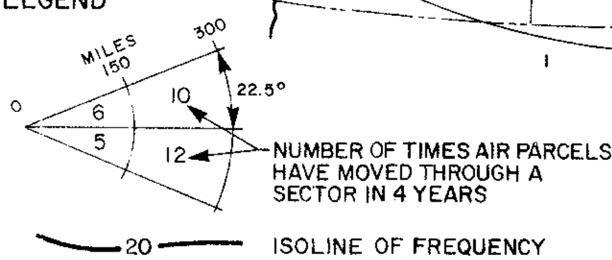
DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 & 75, DEC., JAN., FEB. TOTALS

ACRES	ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS
	FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA
NOVEMBER 1976	FIGURE 48



LEGEND



LEVEL – 850 mb

72 HOUR PRECIPITATION – NIL

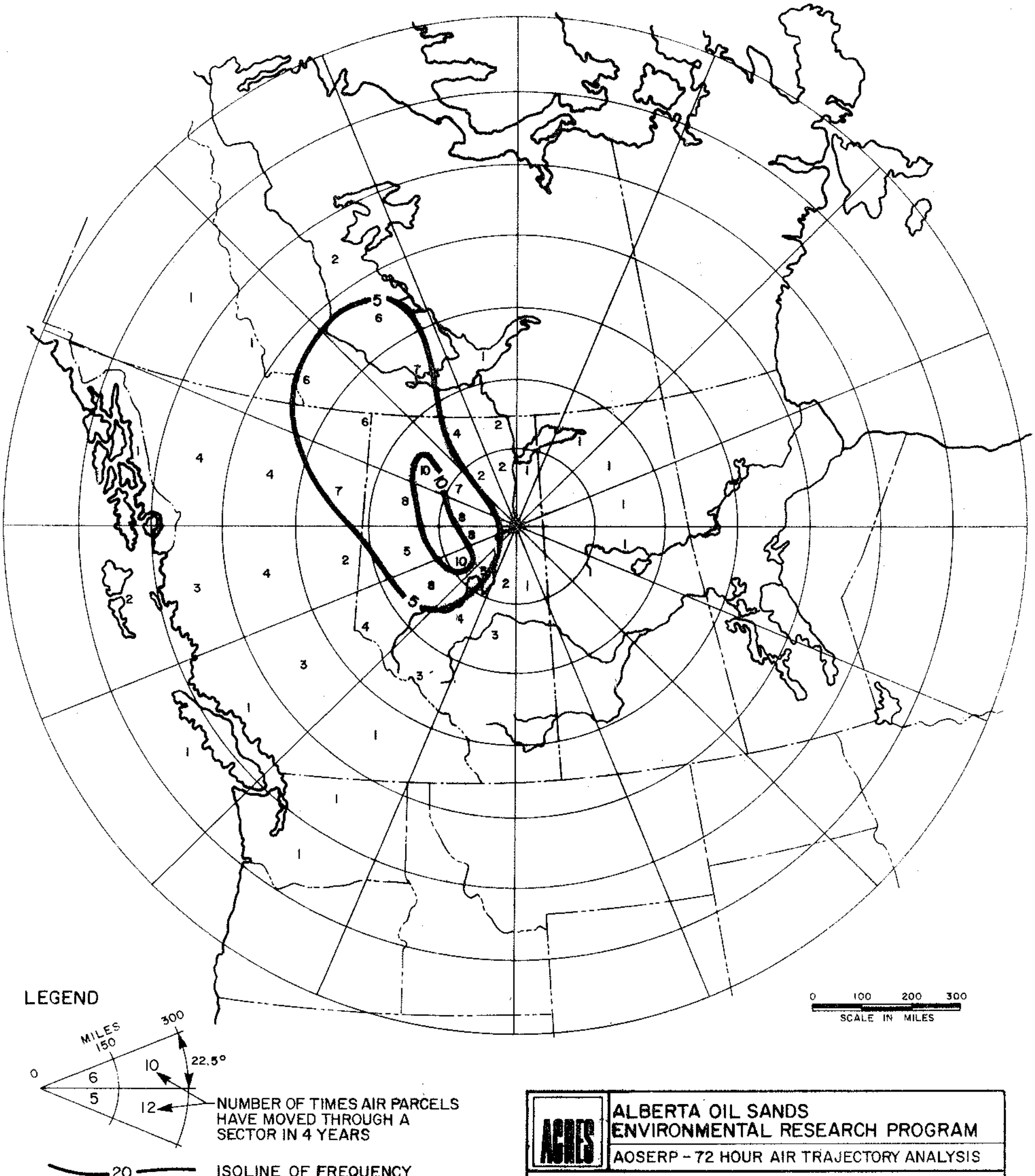
DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 & 75, MAR., APR., MAY TOTALS

ACRES	ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
	AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 49



LEVEL – 850 mb

72 HOUR PRECIPITATION – NIL

DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 & 75, JUN., JUL., AUG. TOTALS

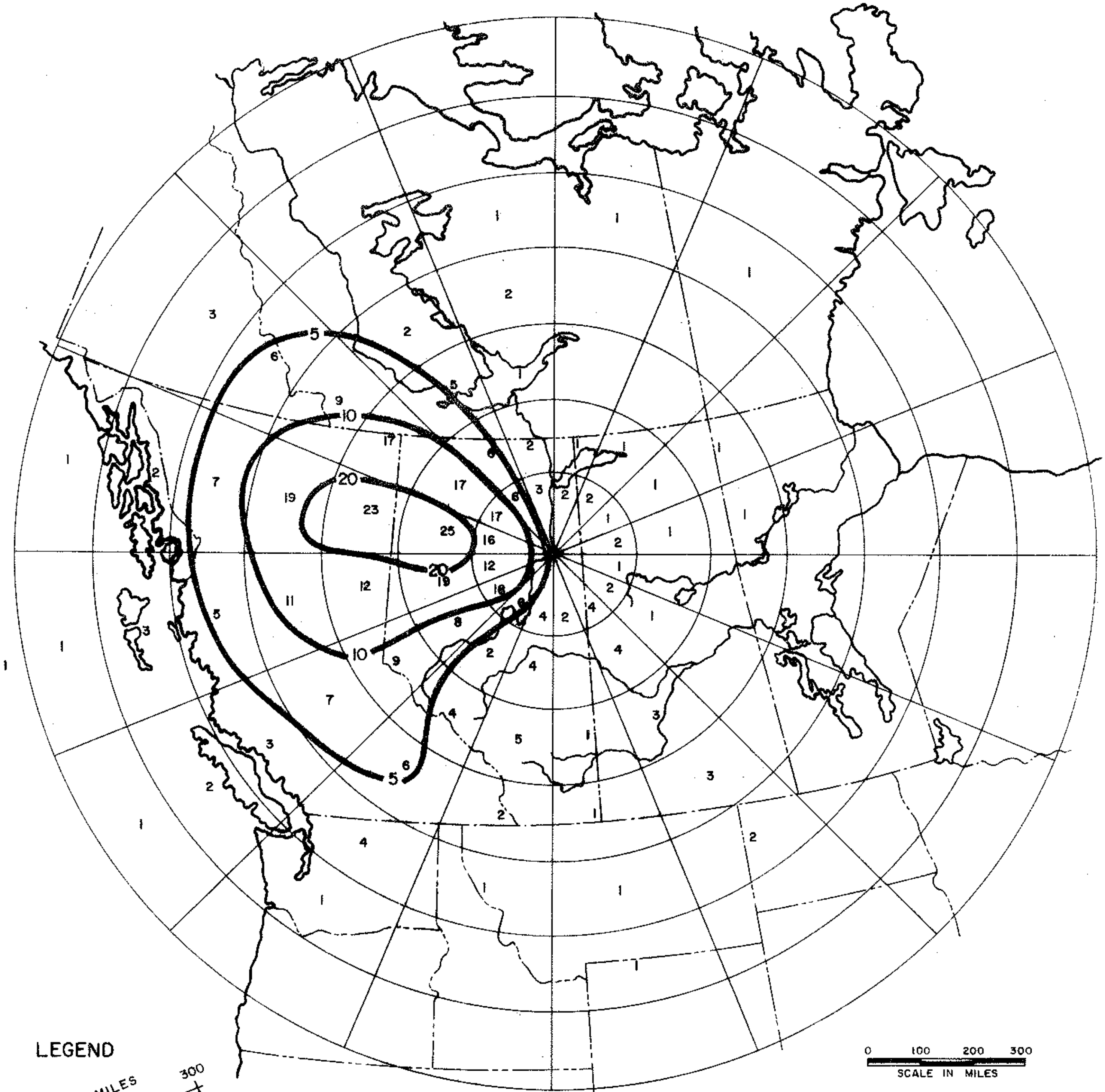
ACRES

ALBERTA OIL SANDS
ENVIRONMENTAL RESEARCH PROGRAM

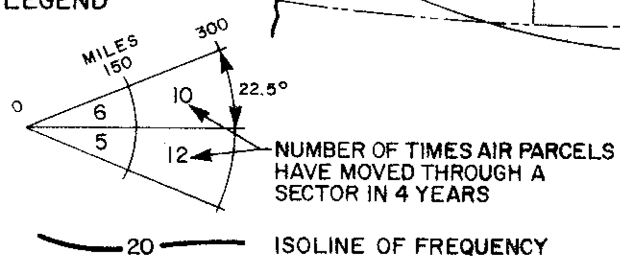
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 50



LEGEND



LEVEL — 850 mb

72 HOUR PRECIPITATION — NIL

DIRECTION — IN TO STUDY AREA

PERIOD — 1968, 73, 74 & 75, SEPT., OCT., NOV. TOTALS

ACRES

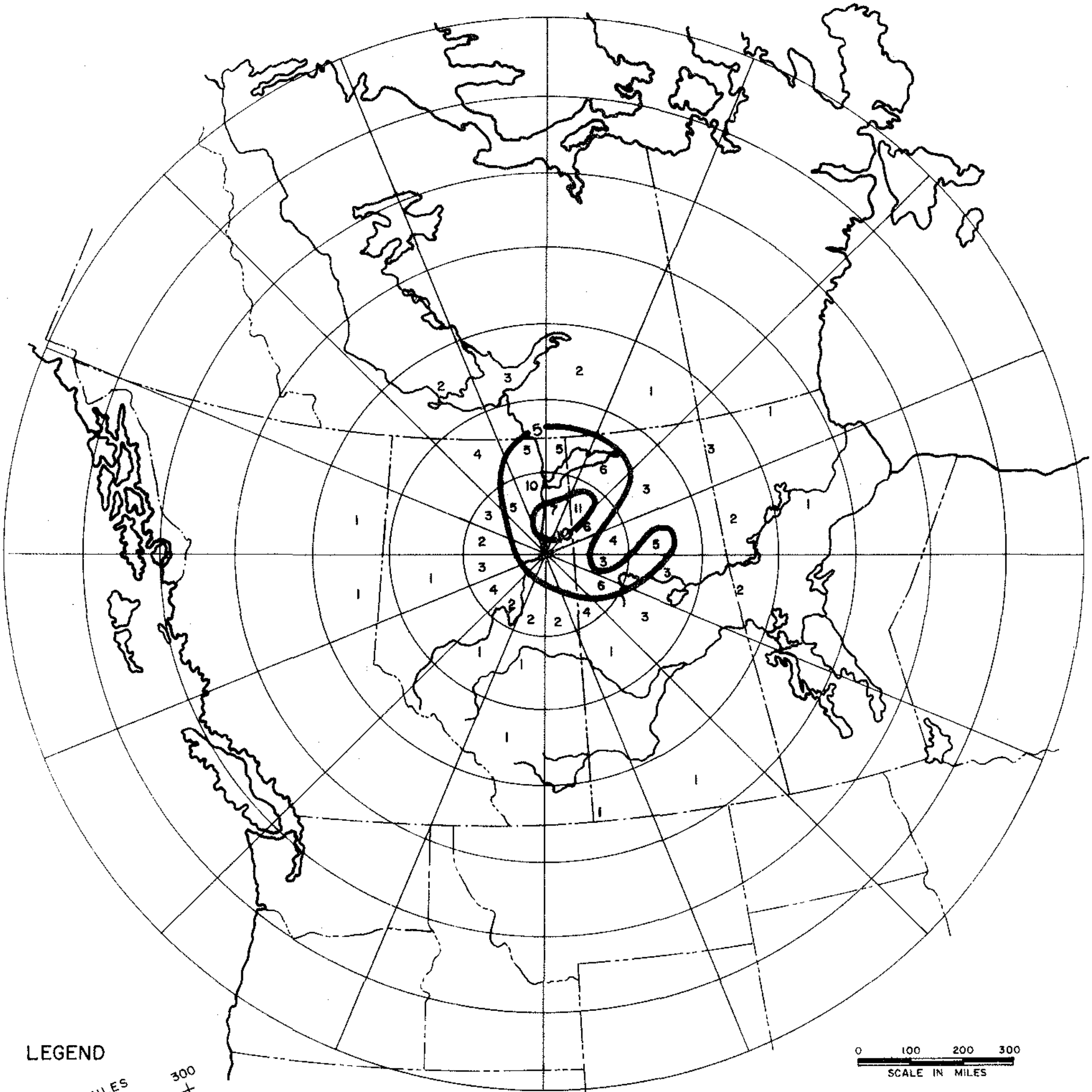
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

AOSERP - 72 HOUR AIR TRAJECTORY ANALYSIS

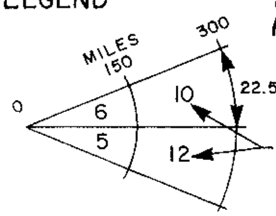
FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976 | FIGURE 51

NIL PRECIPITATION
Surface - 850-mb Levels
Out From Study Area



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

20 — ISOLINE OF FREQUENCY

LEVEL – SURFACE

72 HOUR PRECIPITATION – NIL

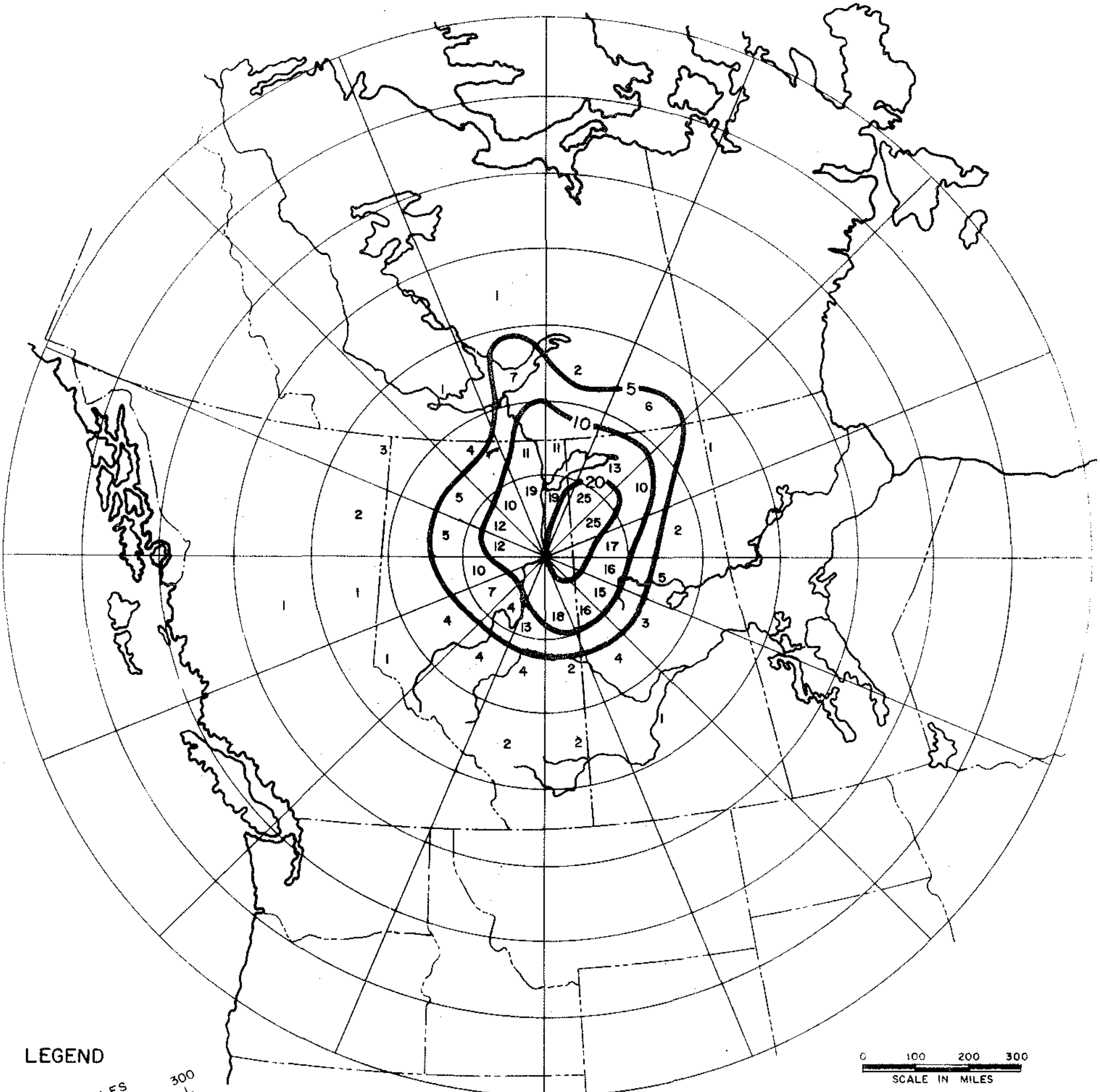
DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 & 75, DEC., JAN., FEB., TOTALS

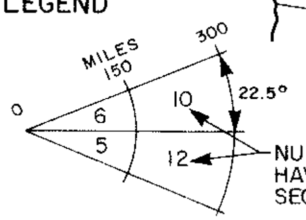
AGRES	ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
	AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 52



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

20 ISOLINE OF FREQUENCY

LEVEL – SURFACE

72 HOUR PRECIPITATION – NIL

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 & 75, MAR., APR., MAY TOTALS

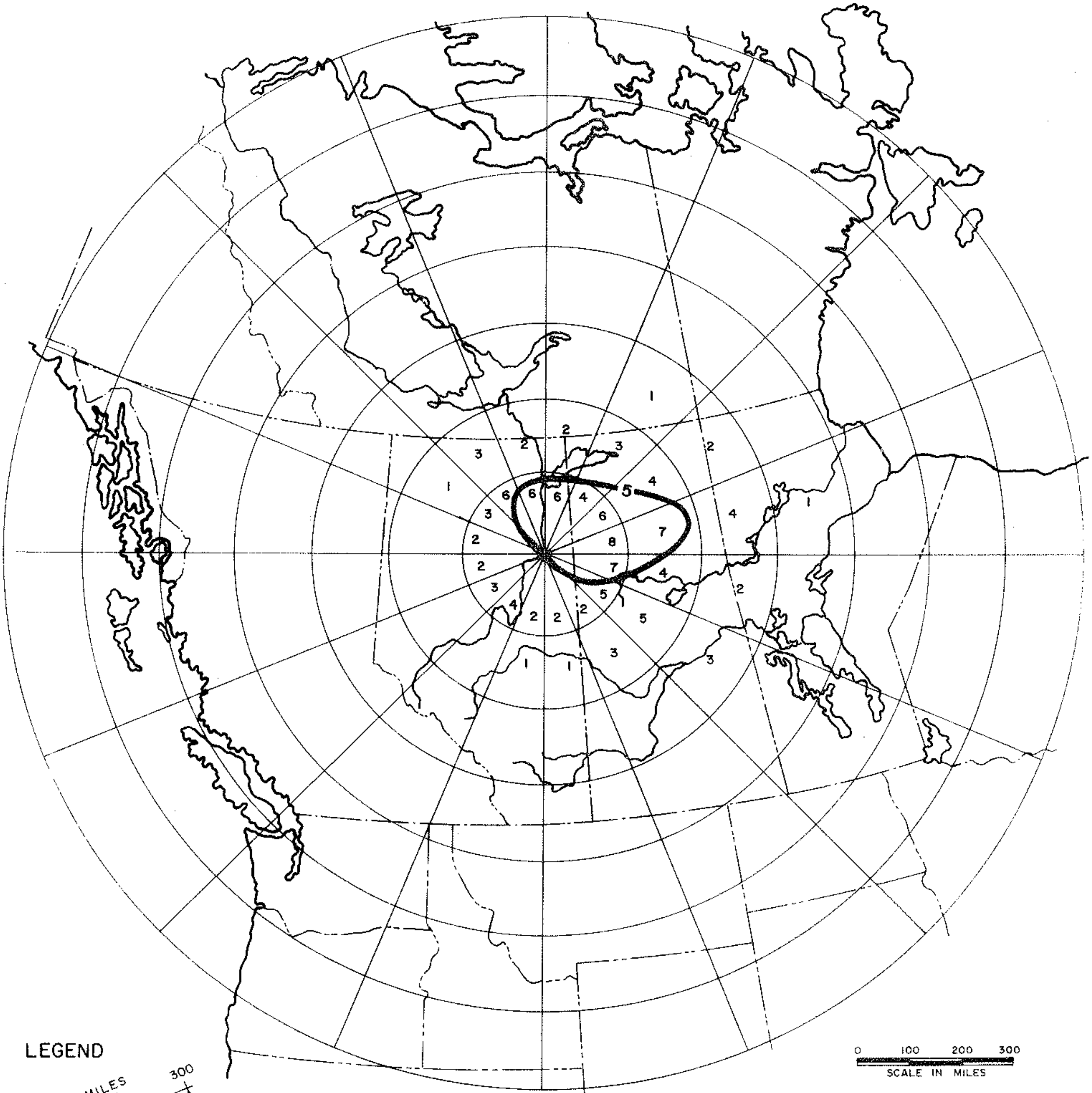
ACRES

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

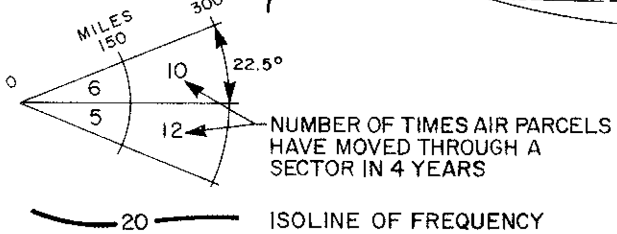
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 53



LEGEND



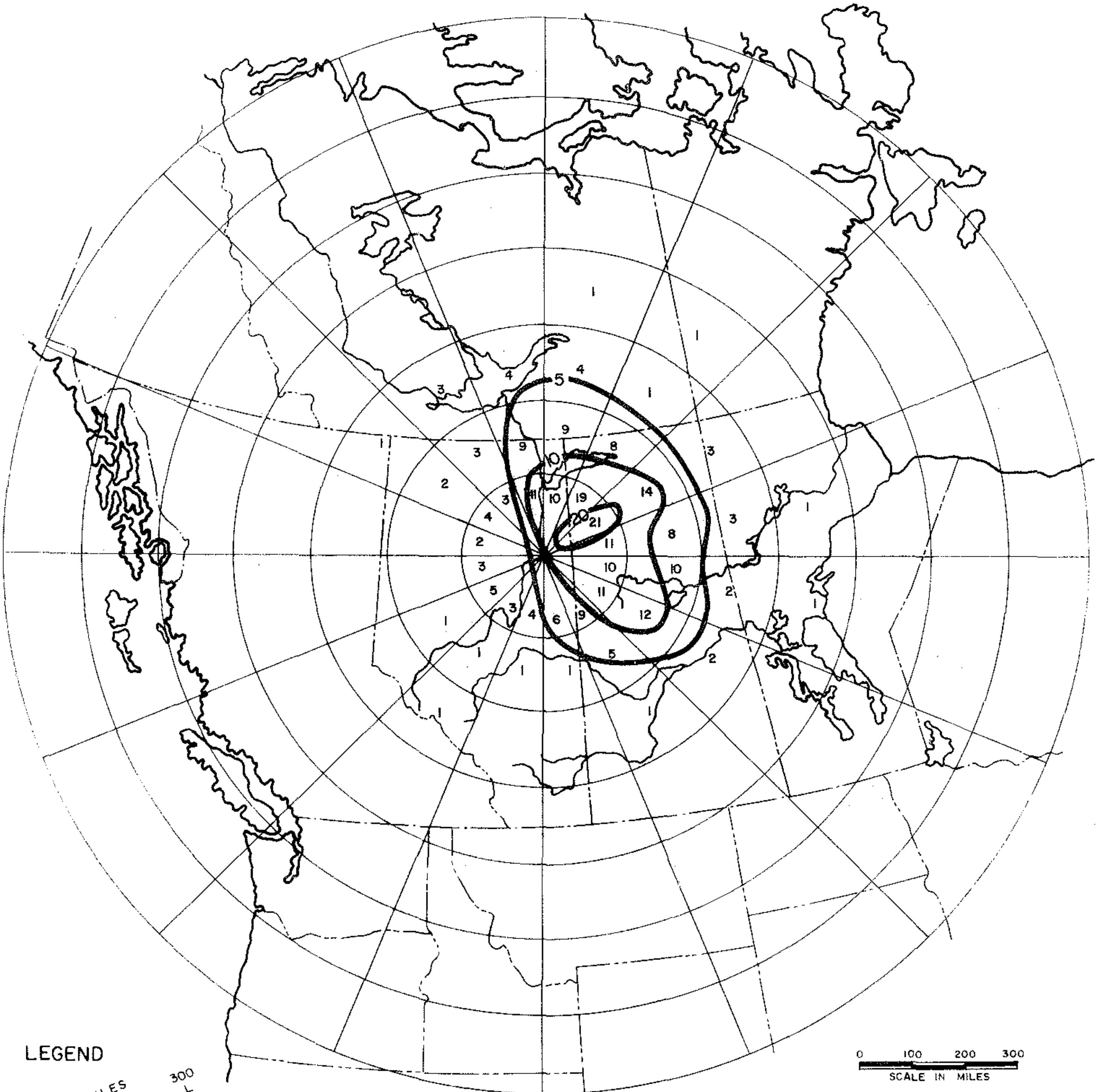
LEVEL – SURFACE

72 HOUR PRECIPITATION – NIL

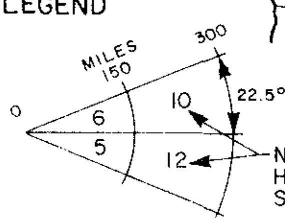
DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 & 75, JUN., JUL., AUG. TOTALS

ACRES	ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS
	FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA
NOVEMBER 1976	FIGURE 54



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

20 ISOLINE OF FREQUENCY

LEVEL – SURFACE

72 HOUR PRECIPITATION – NIL

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 & 75, SEPT., OCT., NOV. TOTALS

0 100 200 300
SCALE IN MILES

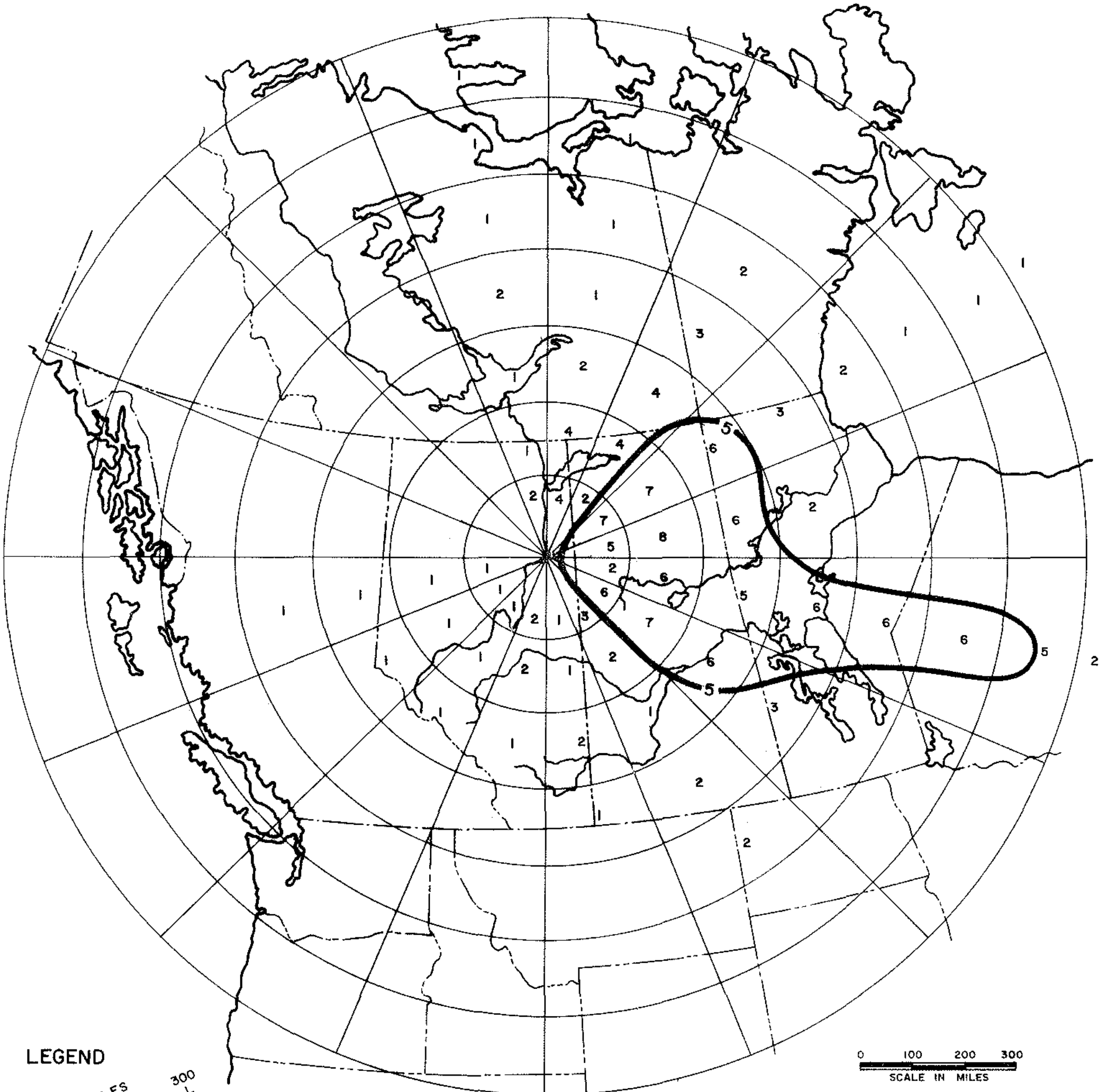
ACRES

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

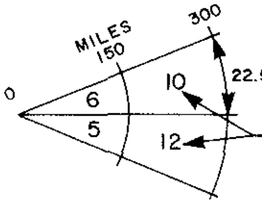
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976 | FIGURE 55



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

20 ISOLINE OF FREQUENCY

LEVEL – 850 mb

72 HOUR PRECIPITATION – NIL

DIRECTION – OUT FROM STUDY AREA

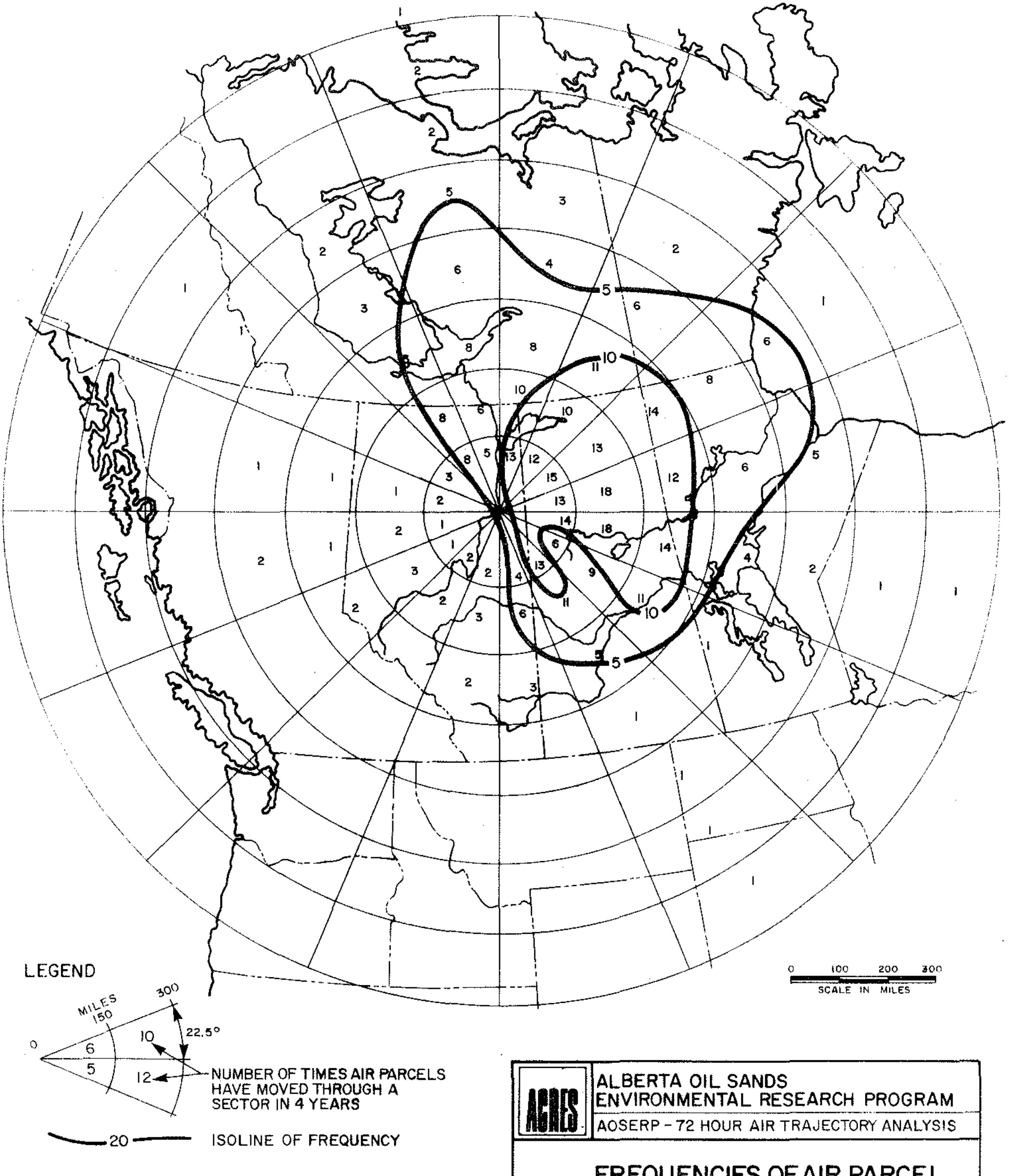
PERIOD – 1968, 73, 74 & 75, DEC., JAN., FEB. TOTALS

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 56



LEVEL – 850 mb

72 HOUR PRECIPITATION – NIL

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74, 75, MAR., APR., MAY TOTALS

ACRES

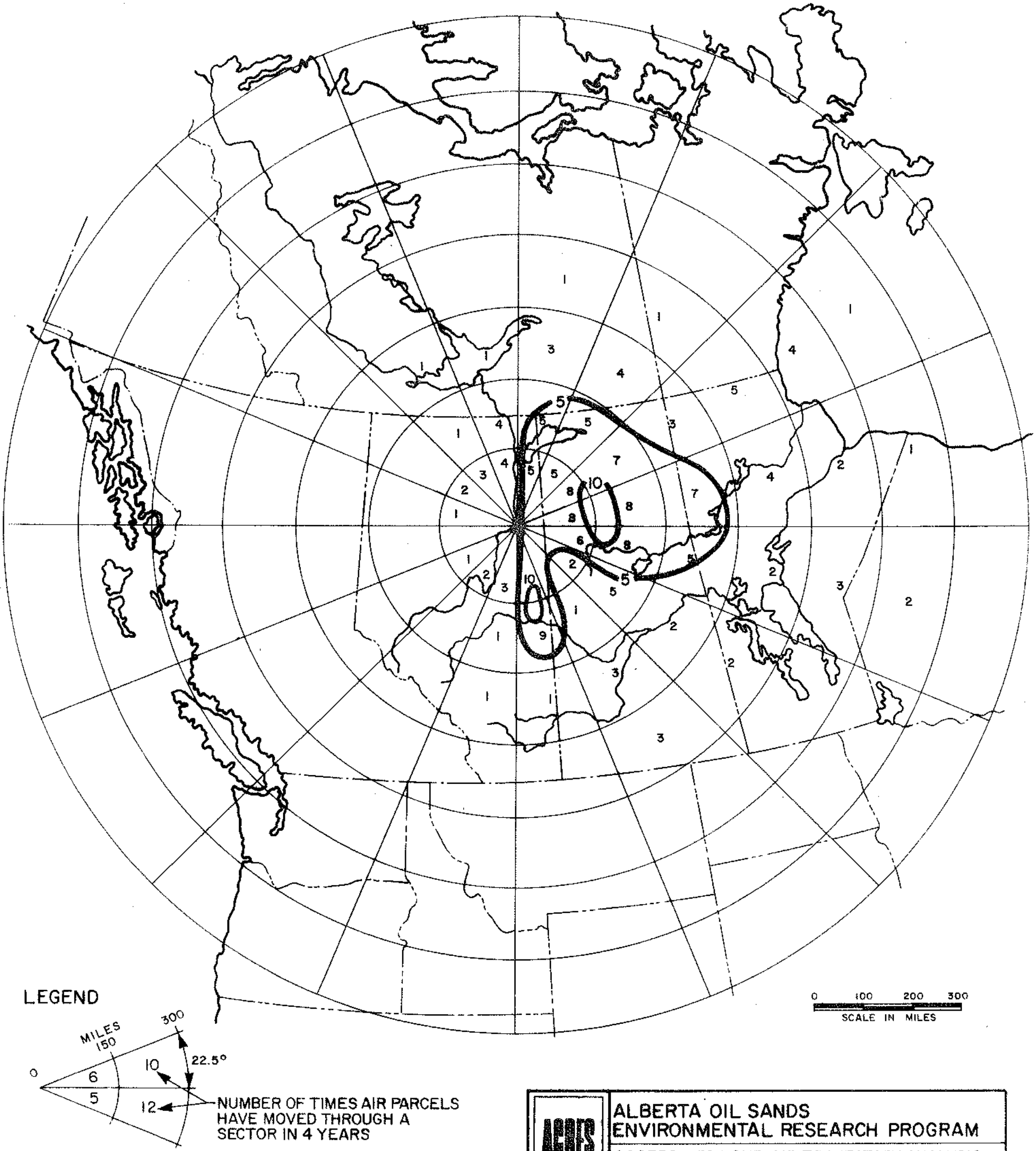
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976

FIGURE 57



LEVEL – 850 mb

72 HOUR PRECIPITATION – NIL

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 & 75, JUN., JUL., AUG. TOTALS

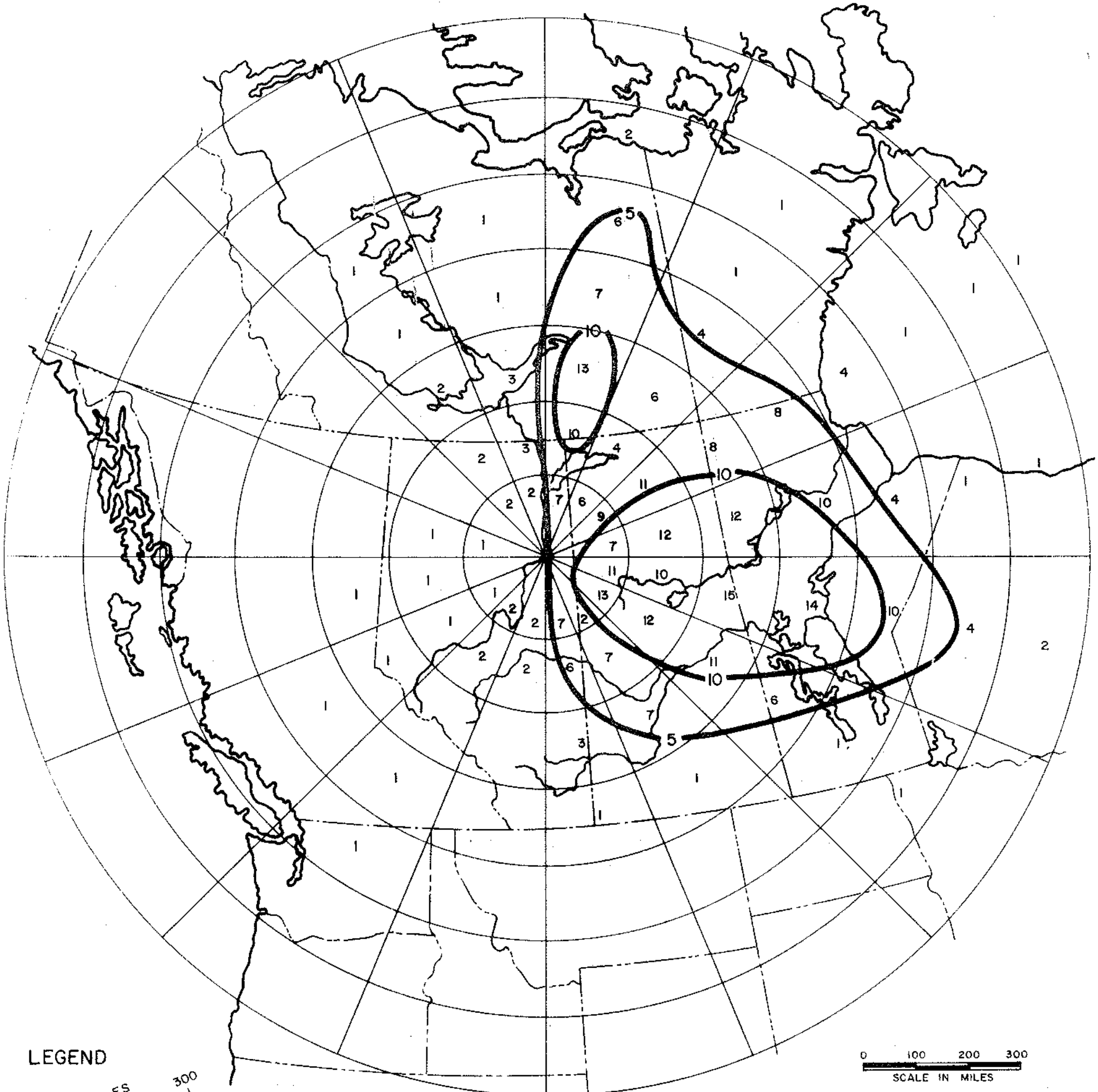
AOSERP

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

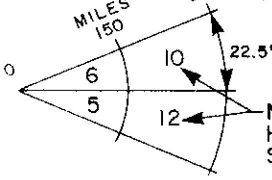
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976 | FIGURE 58



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

20 ISOLINE OF FREQUENCY

LEVEL – 850 mb

72 HOUR PRECIPITATION – NIL

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74, 75, SEPT., OCT., NOV. TOTALS

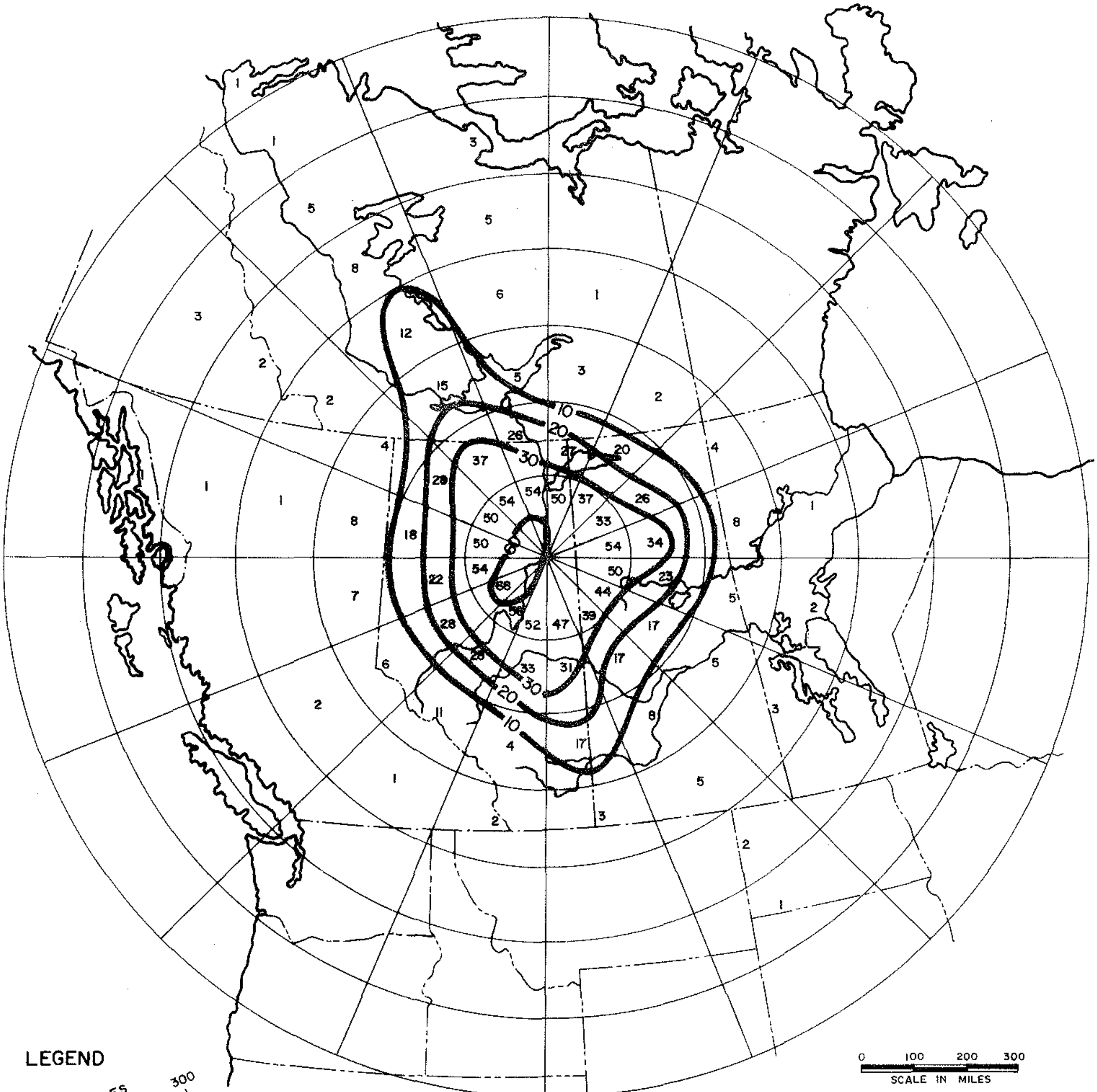
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

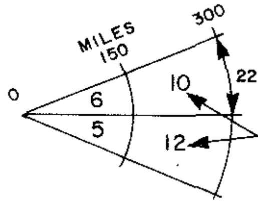
FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976 | FIGURE 59

LIGHT PRECIPITATION
Surface - 850-mb Levels
In To Study Area



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

—— 20 —— ISOLINE OF FREQUENCY

LEVEL – SURFACE

72 HOUR PRECIPITATION – LIGHT

DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 & 75, DEC., JAN., FEB. TOTALS

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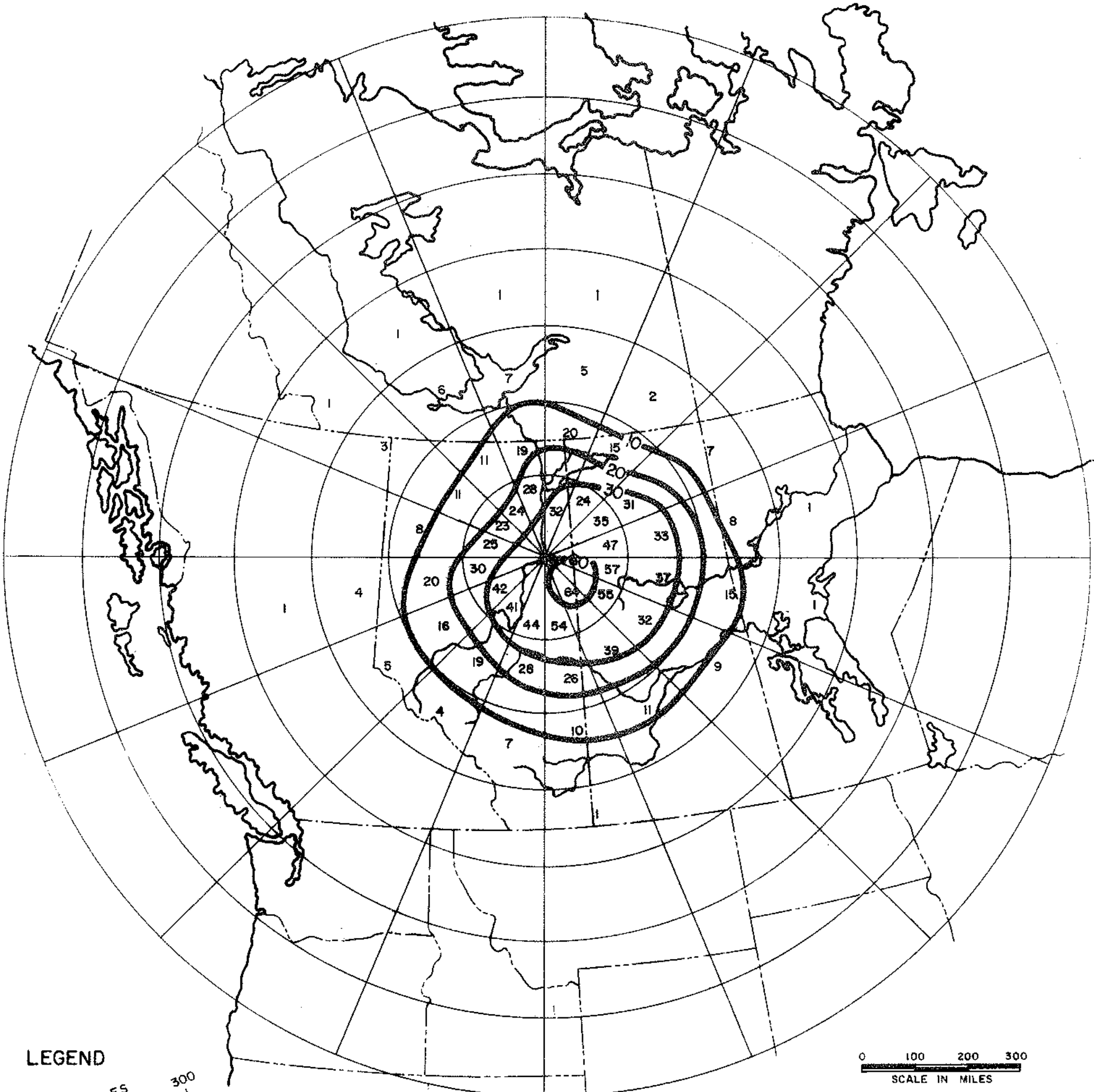
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

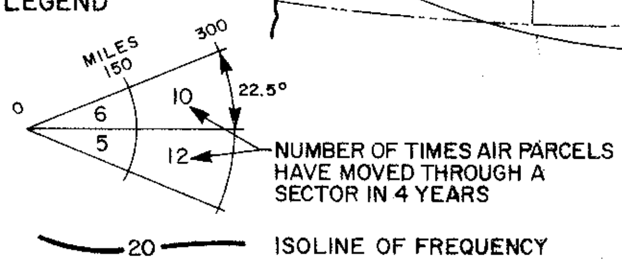
FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976

FIGURE 60



LEGEND



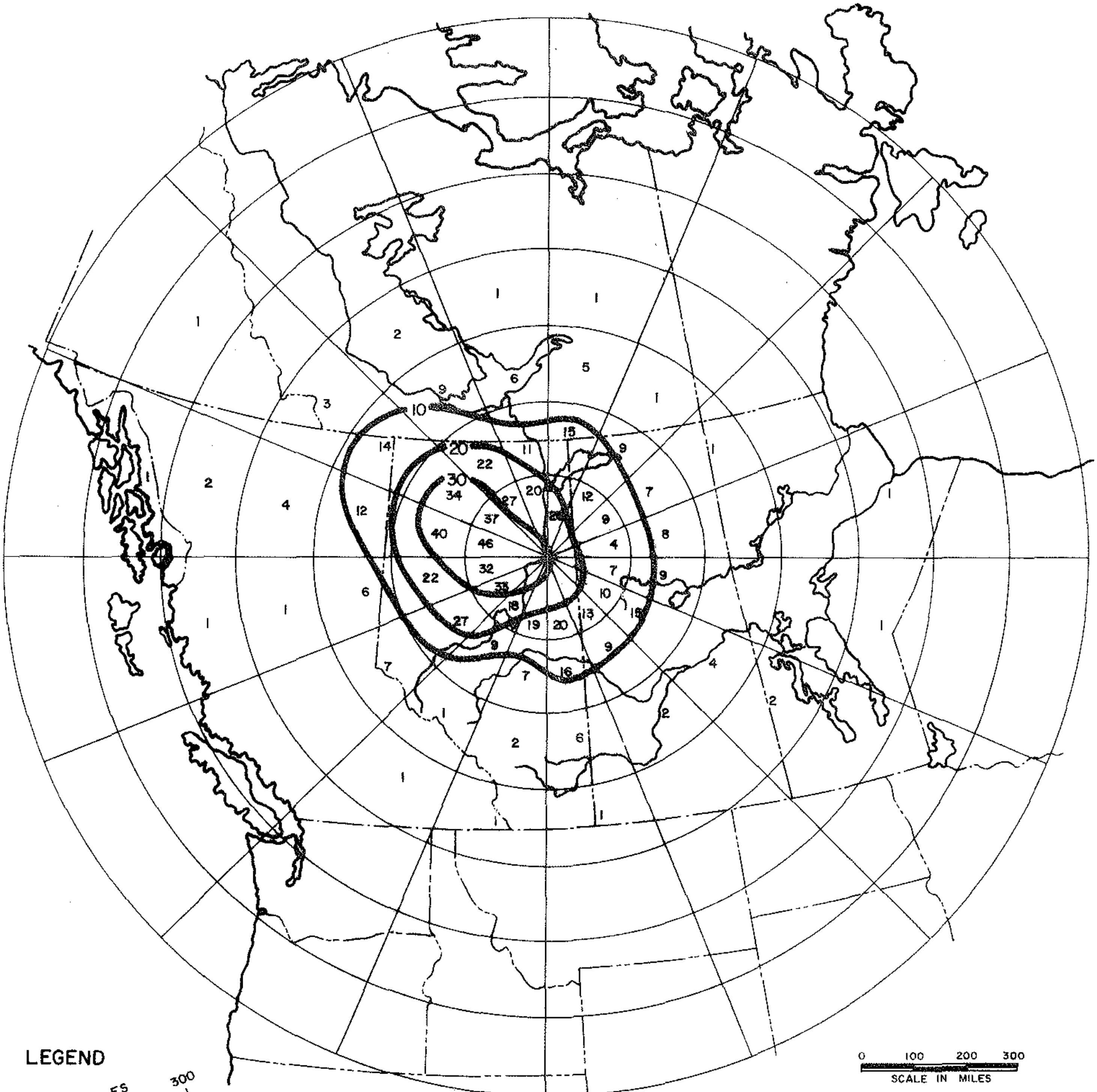
LEVEL – SURFACE

72 HOUR PRECIPITATION – LIGHT

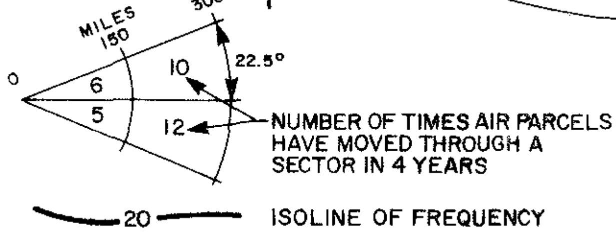
DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 & 75, MAR., APR., MAY TOTAL

ACRES	ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
	AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS
FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA	
NOVEMBER 1976	FIGURE 61



LEGEND



LEVEL – SURFACE

72 HOUR PRECIPITATION – LIGHT

DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 & 75, JUN., JUL., AUG. TOTALS

ACRES

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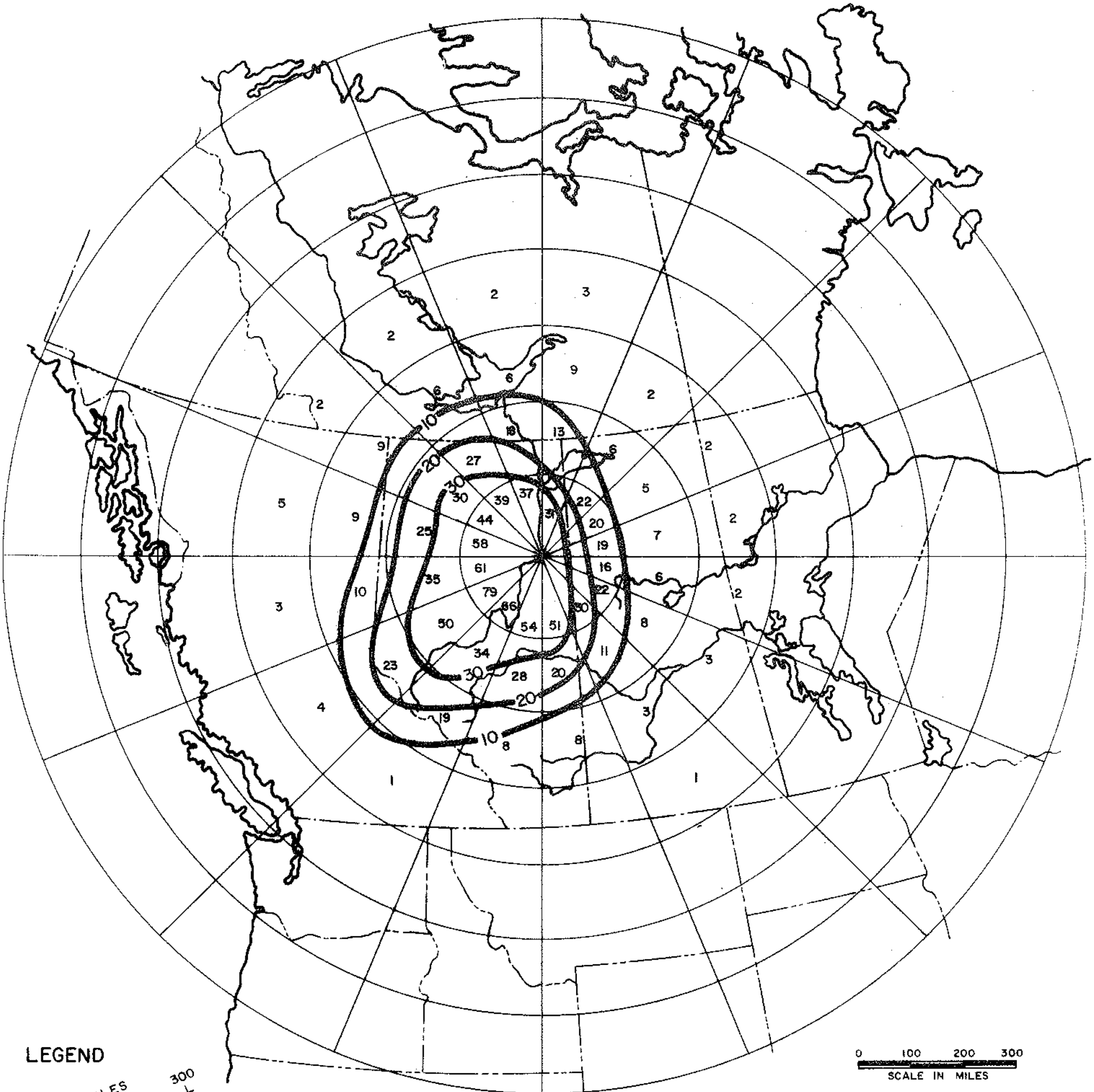
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

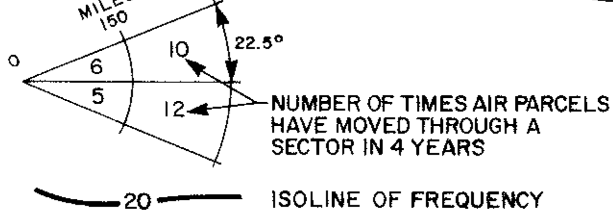
FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976

FIGURE 62



LEGEND



LEVEL – SURFACE

72 HOUR PRECIPITATION – LIGHT

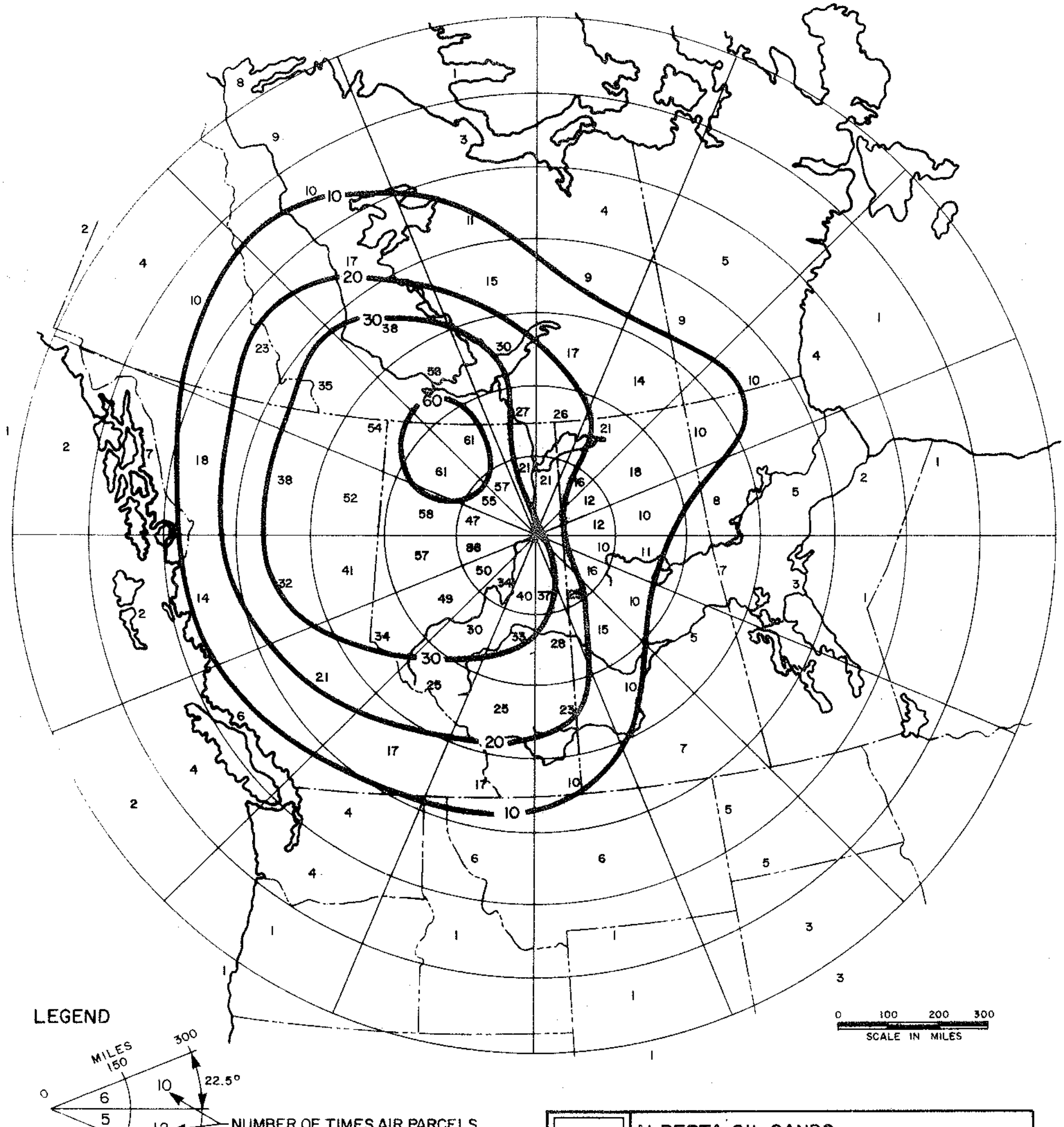
DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 & 75, SEPT., OCT., NOV. TOTALS

AGRES	ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
	AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 63



LEGEND

NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

ISOLINE OF FREQUENCY

LEVEL – 850 mb

72 HOUR PRECIPITATION – LIGHT

DIRECTION – IN TO STUDY AREA

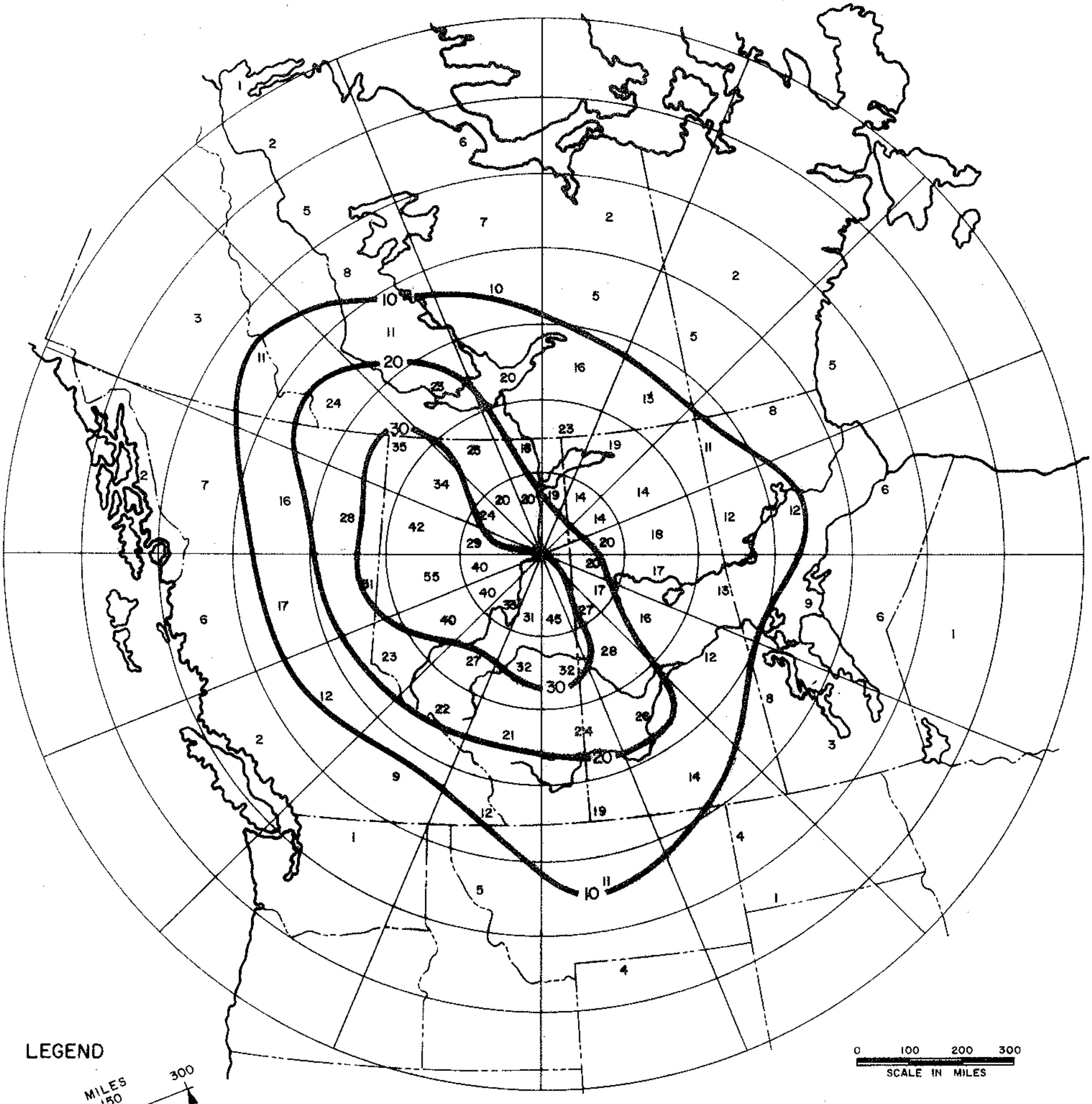
PERIOD – 1968, 73, 74 & 75, DEC., JAN., FEB. TOTALS

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

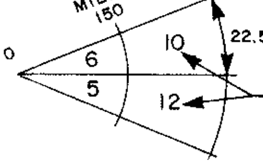
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976 | FIGURE 64



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

—20— ISOLINE OF FREQUENCY

LEVEL – 850 mb

72 HOUR PRECIPITATION – LIGHT

DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 & 75, MAR., APR., MAY TOTALS

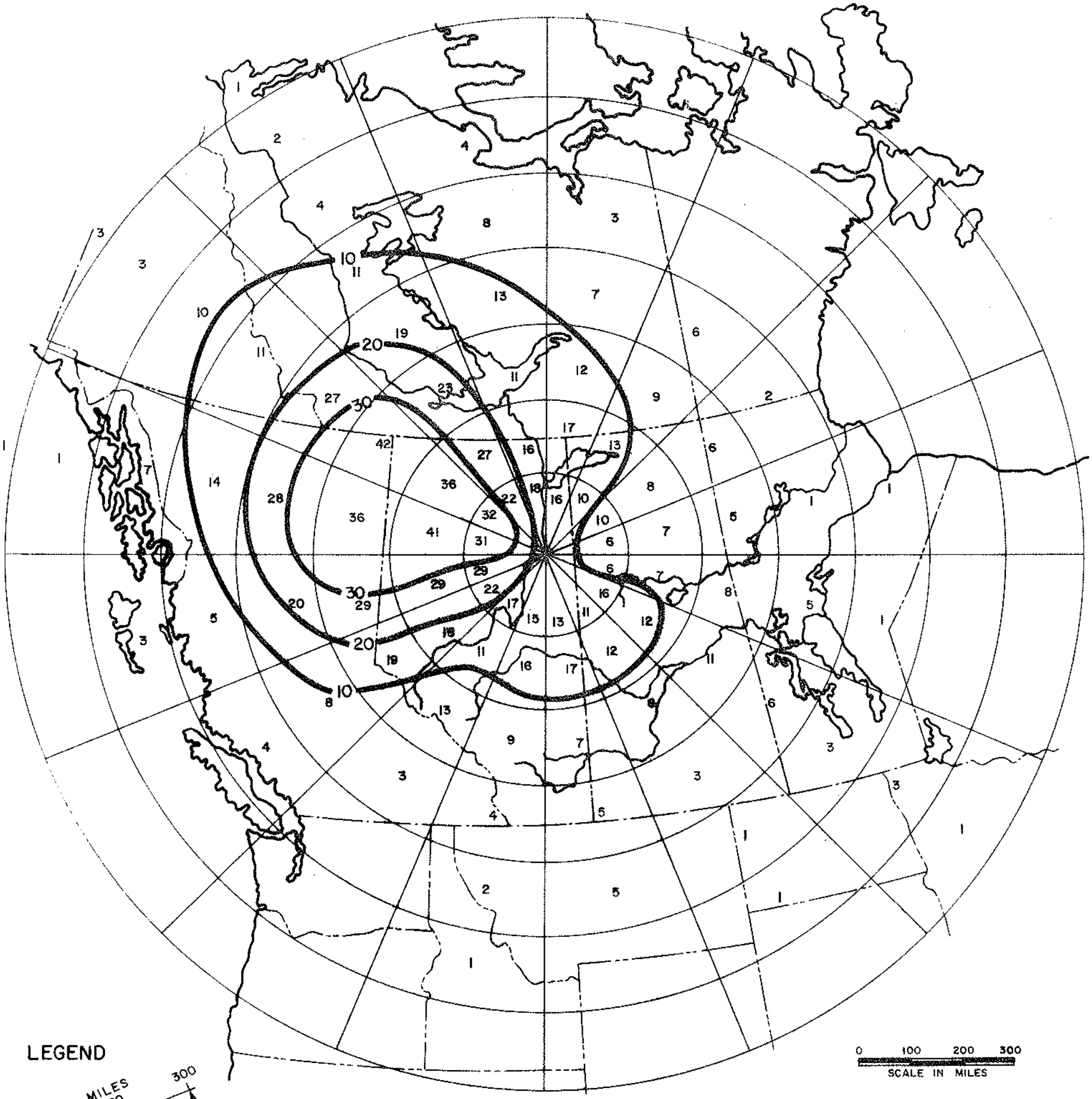
ACRES

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

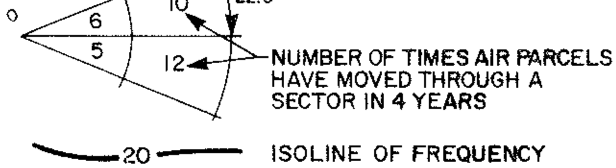
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 65



LEGEND



LEVEL – 850 mb

72 HOUR PRECIPITATION – LIGHT

DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 & 75, JUN., JUL., AUG. TOTALS

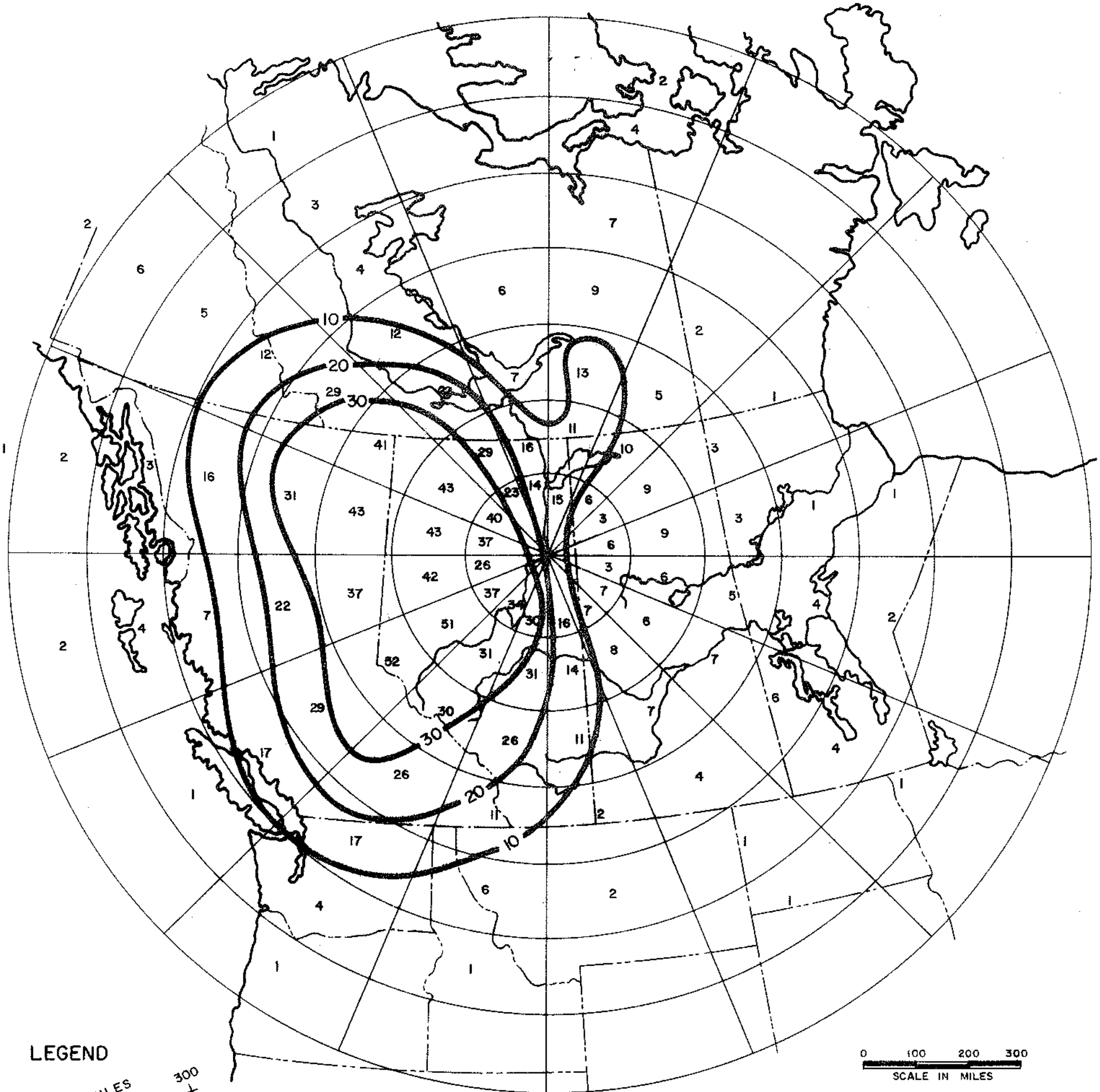
ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

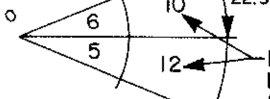
FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976

FIGURE 66



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

20 — ISOLINE OF FREQUENCY

LEVEL – 850 mb

72 HOUR PRECIPITATION – LIGHT

DIRECTION – IN TO STUDY AREA

PERIOD – 1968, 73, 74 & 75, SEPT., OCT., NOV. TOTALS

AOSERP	ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM
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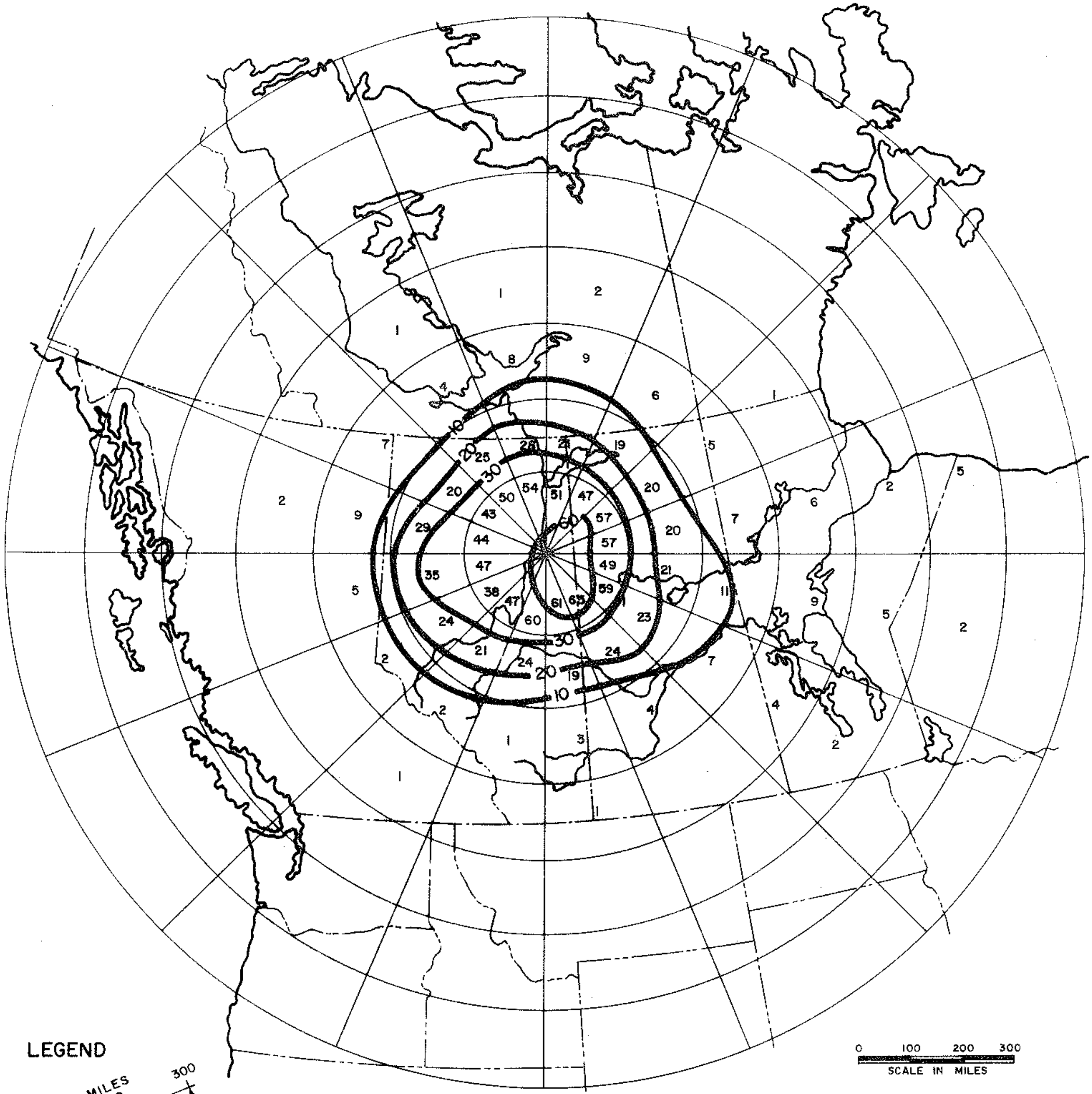
FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 67

LIGHT PRECIPITATION
Surface - 850-mb Levels
Out From Study Area



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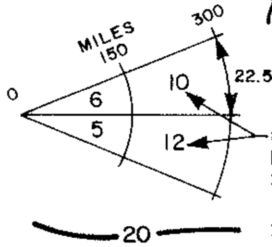

NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

—20— ISOLINE OF FREQUENCY

LEVEL – SURFACE

72 HOUR PRECIPITATION – LIGHT

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 & 75, DEC., JAN., FEB. TOTALS

ACRES

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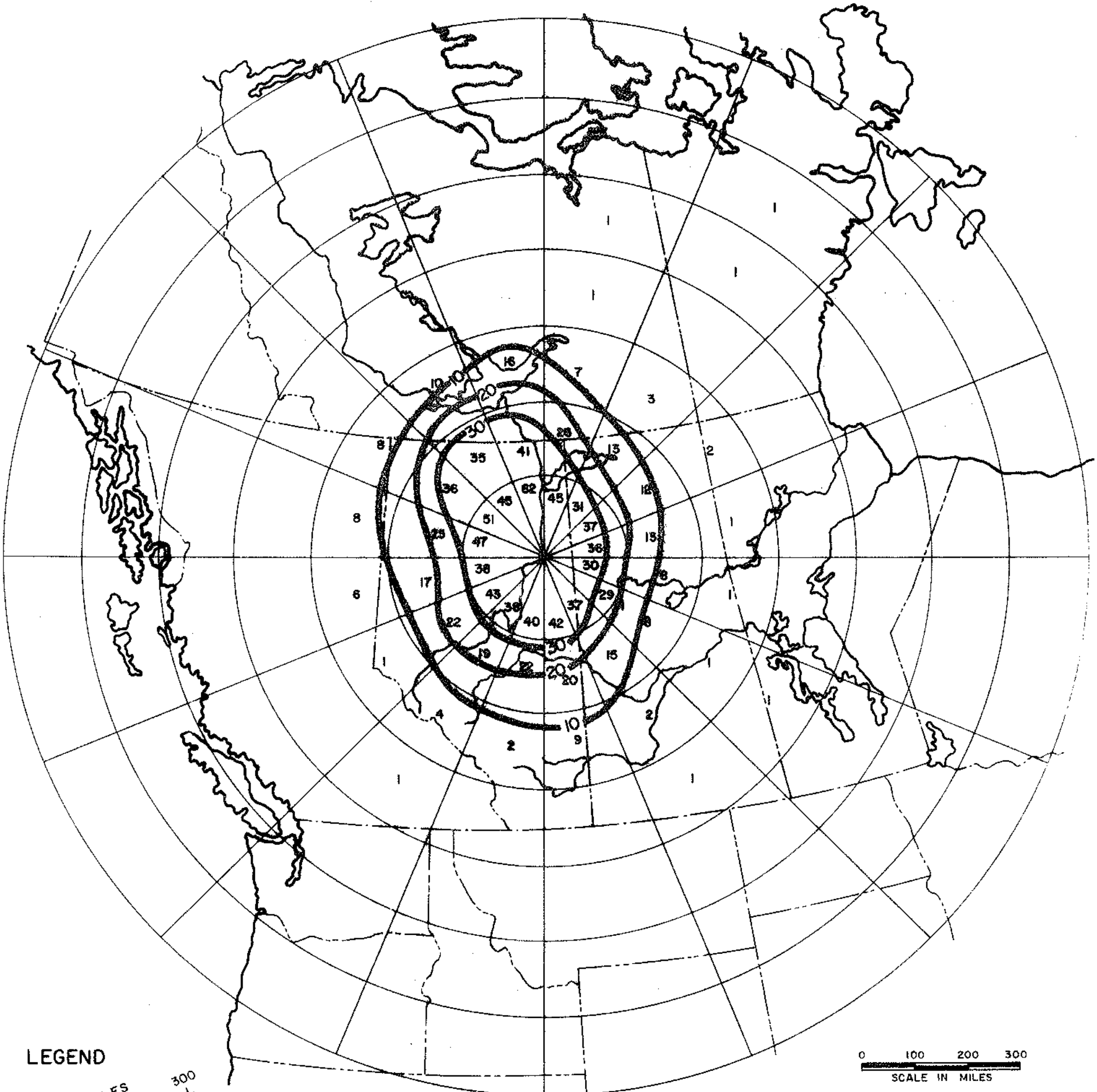
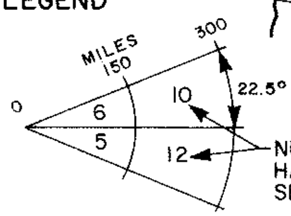
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 68



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

20 ISOLINE OF FREQUENCY

LEVEL – SURFACE

72 HOUR PRECIPITATION – LIGHT

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 & 75, MAR., APR., MAY TOTALS

0 100 200 300
SCALE IN MILES

ACRES

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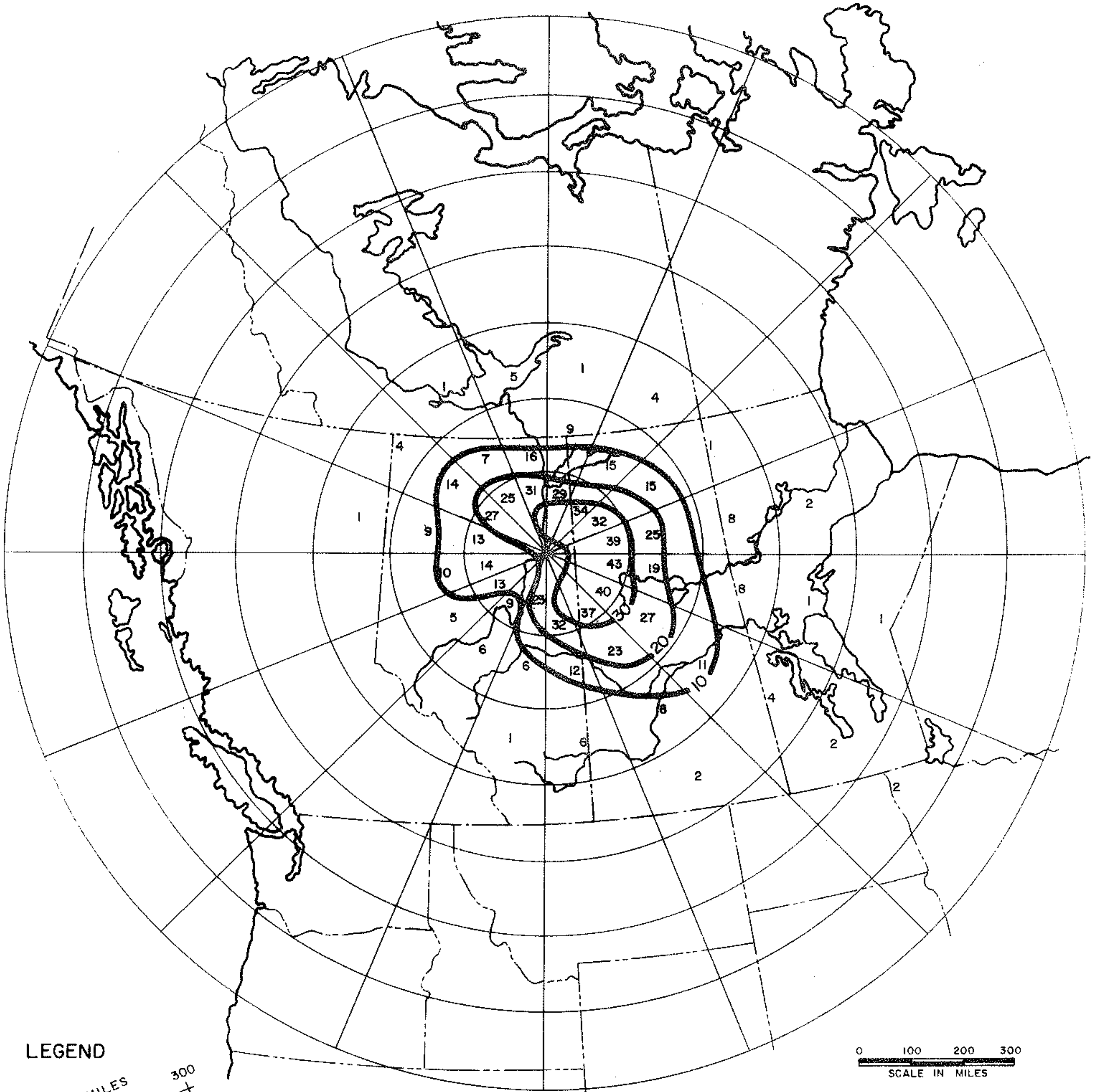
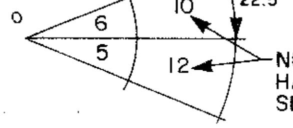
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976 | FIGURE 69



LEGEND



NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

—— 20 —— ISOLINE OF FREQUENCY

LEVEL – SURFACE

72 HOUR PRECIPITATION – LIGHT

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 & 75, JUN., JUL., AUG. TOTALS

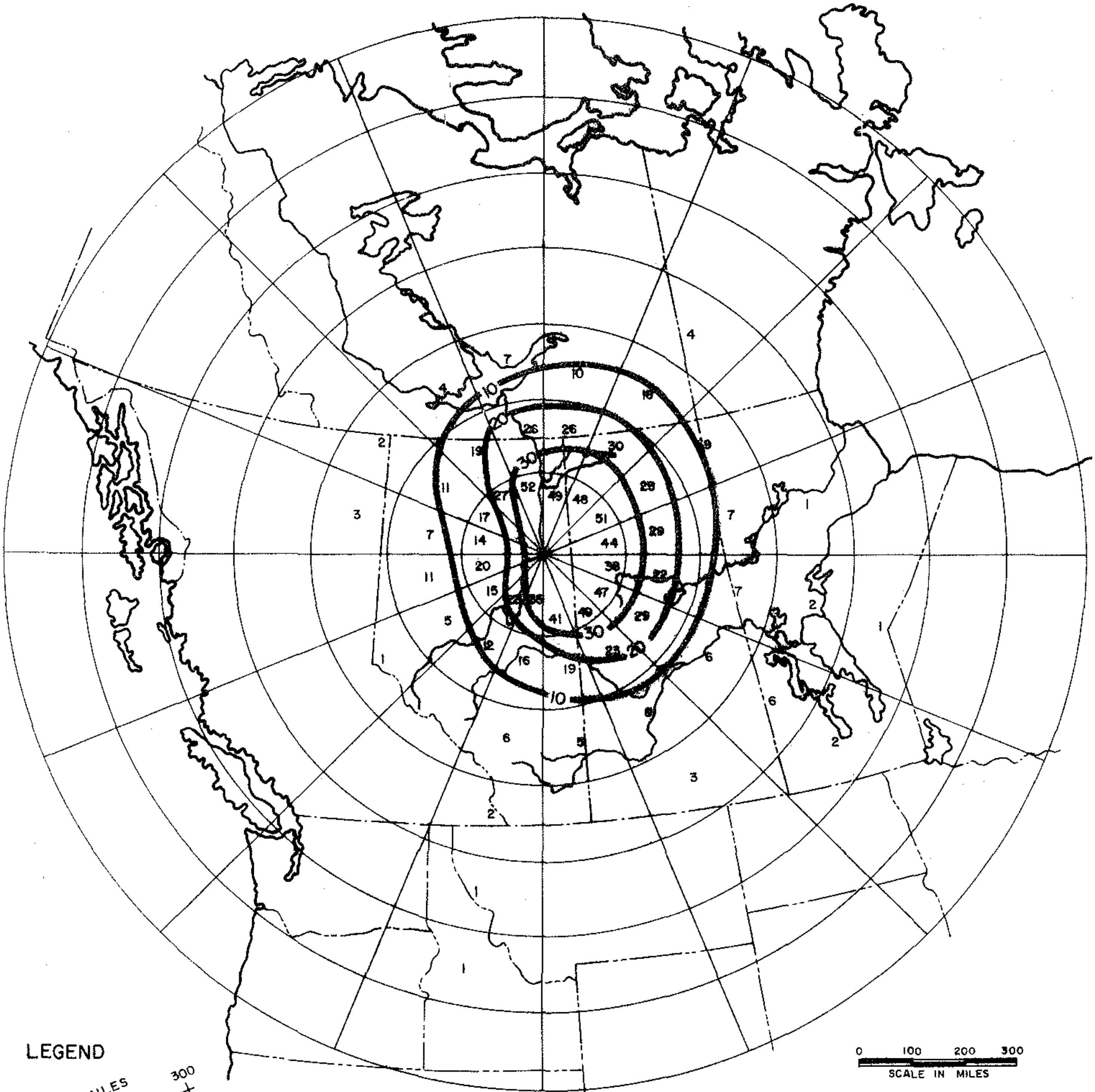
ACRES

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

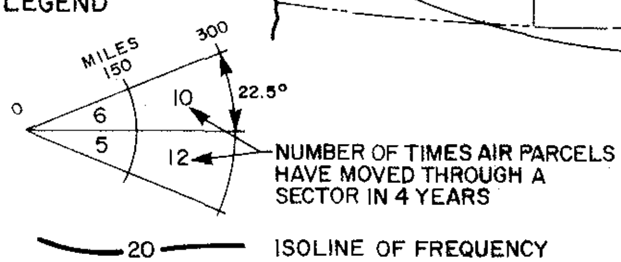
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 70



LEGEND



LEVEL – SURFACE

72 HOUR PRECIPITATION – LIGHT

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 & 75, SEPT., OCT., NOV. TOTALS

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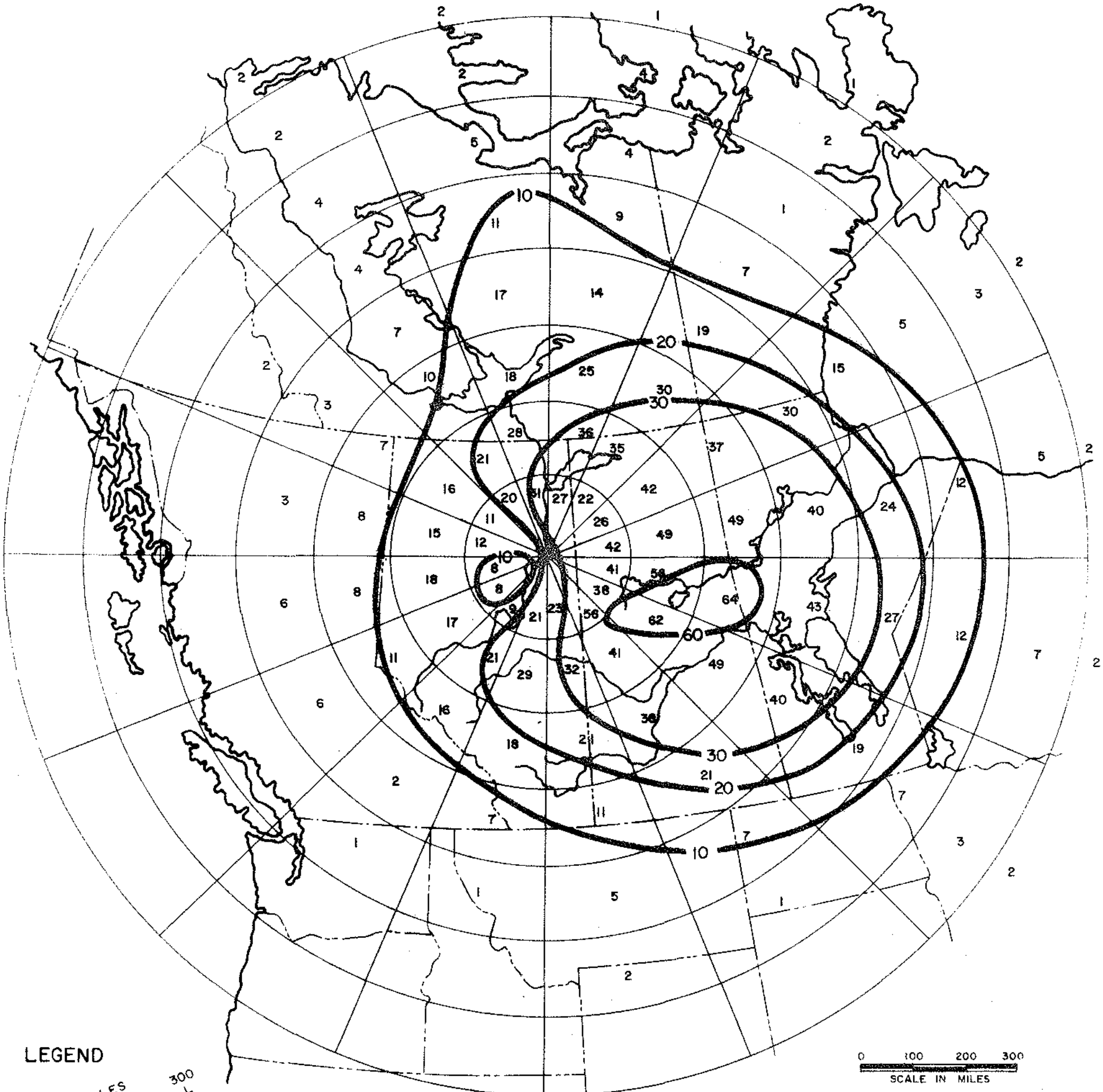
AOSERP – 72 HOUR AIR TRAJECTORY ANALYSIS

FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976

FIGURE 71



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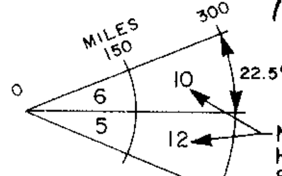

NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

20 ISOLINE OF FREQUENCY

LEVEL – 850 mb

72 HOUR PRECIPITATION – LIGHT

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 & 75, DEC., JAN., FEB. TOTALS

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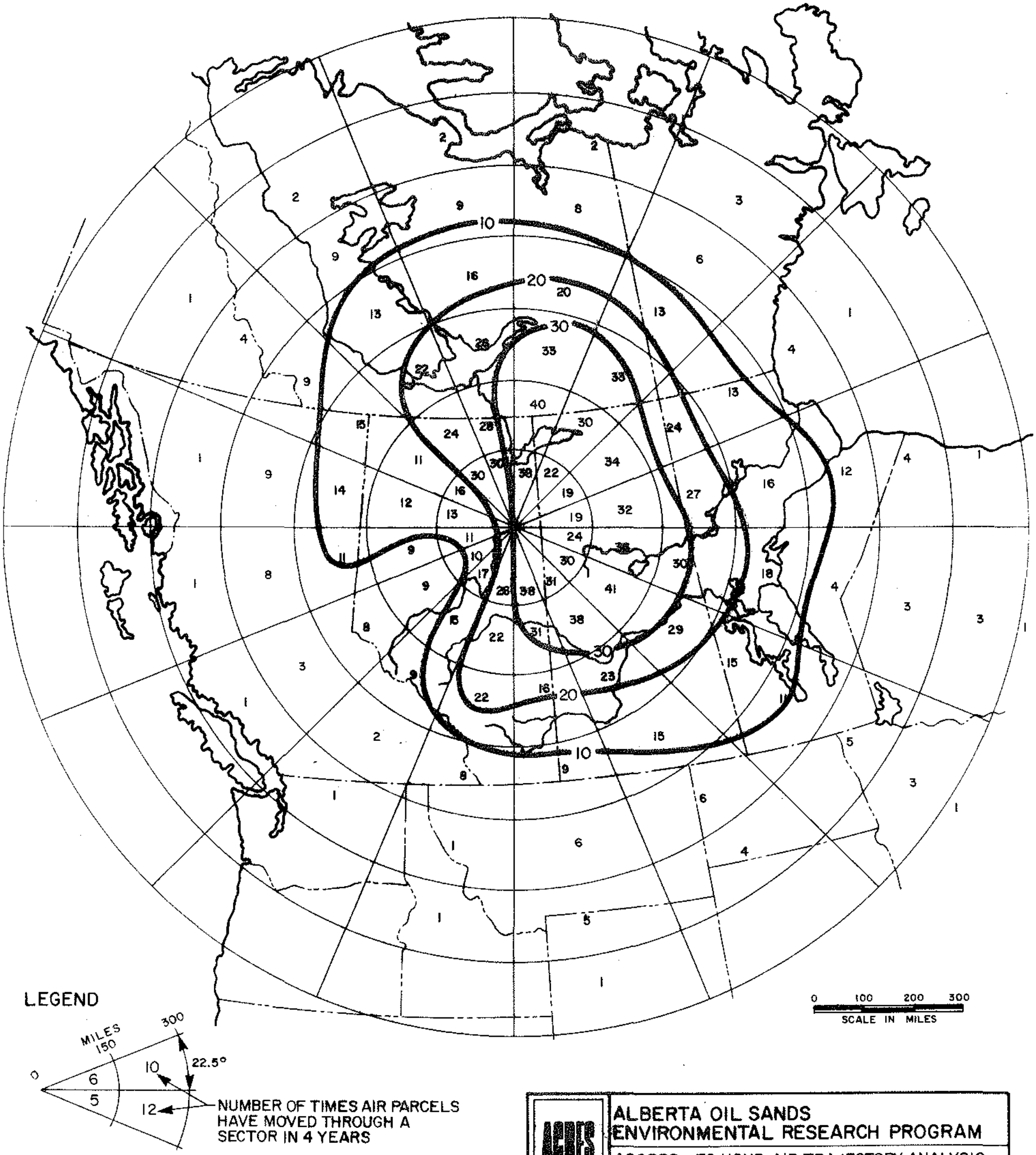
FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 72



LEGEND

NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

ISOLINE OF FREQUENCY

LEVEL – 850 mb

72 HOUR PRECIPITATION – LIGHT

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 & 75, MAR., APR., MAY TOTALS

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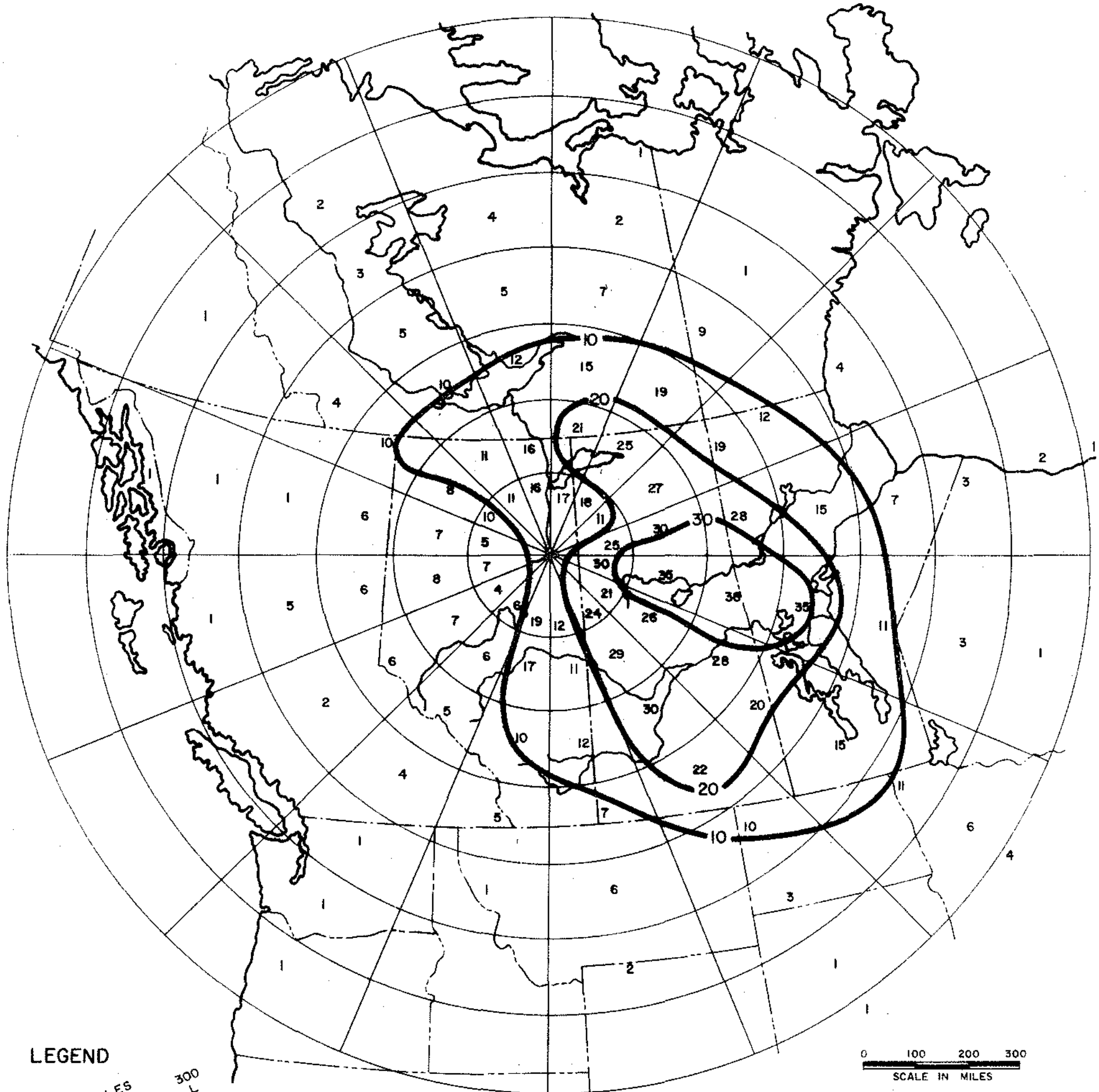
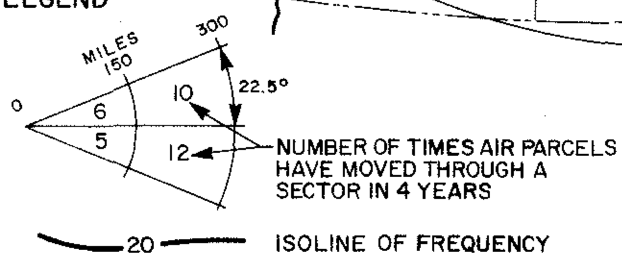
	FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA
NOVEMBER 1976	FIGURE 73



LEGEND



LEVEL – 850 mb

72 HOUR PRECIPITATION – LIGHT

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 & 75, JUN., JUL., AUG. TOTALS

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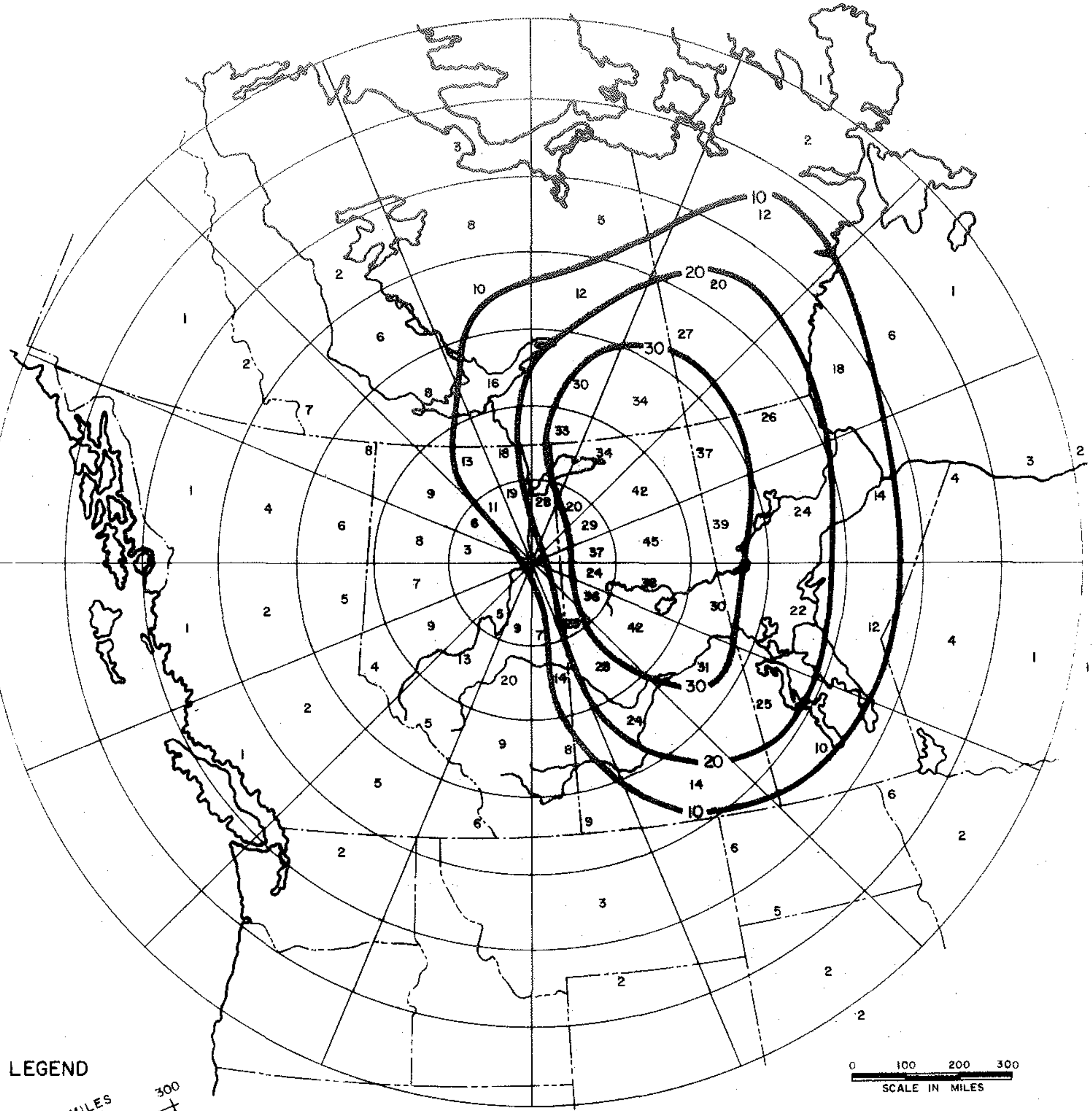
FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 74



LEGEND

MILES 150 300

0 6 5 10 12 22.5°

NUMBER OF TIMES AIR PARCELS HAVE MOVED THROUGH A SECTOR IN 4 YEARS

20 ISOLINE OF FREQUENCY

LEVEL – 850 mb

72 HOUR PRECIPITATION – LIGHT

DIRECTION – OUT FROM STUDY AREA

PERIOD – 1968, 73, 74 & 75, SEPT., OCT., NOV. TOTALS

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FREQUENCIES OF AIR PARCEL MOTIONS BY DIRECTION AND DISTANCE FROM STUDY AREA

NOVEMBER 1976	FIGURE 75

6 - SUMMARY

(a) There are major advantages for handling and speed of viewing to using microfilmed weather maps where analyses are required over several years of record.

(b) Horizontal trajectories can be analyzed with acceptable reproducibility by use of pressure or height contours and plotted wind data at the surface and 850-mb levels.

(c) Comparing air parcel frequency distributions for three consecutive years, 1973-1974-1975, with those for 1968, shows comparable patterns at both the surface and 850-mb levels, with no more than a 45-degree difference in the directions of dominant frequencies. It is concluded that frequency distributions for the entire 4 years closely approach a stable climatological regime.

(d) Consistent patterns of frequency distribution at surface, 925-mb and 850-mb levels show in analyses of 4 year annual totals for precipitation conditions of nil, light, moderate and heavy, although the patterns are less distinct at the surface level in the latter two conditions.

(e) Seasonal patterns of frequency distribution at surface and 850-mb levels are consistent from the west for air parcels moving in to the study area and to the east for air parcels moving out from the study area, except that in spring at the surface the southeasterly directions are somewhat more frequent for air moving in to the study area and the northwesterly directions more frequent for air moving out from the study area.

(f) The analyzed frequencies should satisfy the first objective of the project; viz.,to "contribute to the best design for air and precipitation sampling networks and in the selection of the best locations for sampling soils and lakes to monitor long-term trends in emission deposition".

(g) The large number of trajectory analyses, approximately 8,800, obtained under a full range of synoptic meteorological conditions over the four year period can provide necessary basic input data to meet the second objective of the project; viz., to "serve as the basis for a statistical regional dispersion and deposition model".

LIST OF REFERENCES

Bolin B., and C. Persson. "Regional Dispersion and Deposition of Atmospheric Pollutants with Particular Application to Sulfur Pollution over Western Europe". *Tellus XXVII (1975), 3. pp 284 - 310.*

Godske C. L., T. Bergeron, J. Bjerknes, R. C. Bundgaard. *Dynamic Meteorology and Weather Forecasting.* American Meteorological Society and Carnegie Institution of Washington, 1957.

Smith F. B., and F. G. Jeffrey. "Airborne Transport of Sulphur Dioxide from the U.K." *Atmospheric Environment June/July 1975.*

Wendell, L., Model of Northeastern U.S.A. Sulfur Trajectories. *Symposium on Atmospheric Turbulence and Diffusion, Raleigh, N.C., October 1976.*

Rao, K. S., J. S. Legue and B. A. Egan. Air Trajectory Model for Regional Transport of Atmospheric Sulphates. *Symposium on Atmospheric Turbulence and Diffusion, Raleigh, N.C., October 1976.*

LIST OF PUBLICATIONS

1. AOSERP First Annual Report, 1975
2. AF 4.1.1 Walleye and Goldeye Fisheries Investigations in the Peace-Athabasca Delta--1975
3. HE 1.1.1 Structure of a Traditional Baseline Data System
4. VE 2.2 Preliminary Vegetation Survey of the AOSERP Study Area
5. HY 3.1 Evaluation of Wastewaters from an Oil Sands Extraction Plant
6. Housing for the North--Stackwall System Construction Report
7. AF 3.1.1 Synopsis of the Physical and Biological Limnology and Fishery Programs within the Alberta Oil Sands Area
8. AF 1.2.1 Impact of Saline Waters upon Freshwater Biota (A Literature Review and Bibliography
9. ME 3.3 Preliminary Investigation into the Magnitude of Fog Occurrence and Associated Problems in the Oil Sands Area
10. HE 2.1 Development of a Research Design Related to Archaeological Studies in the Athabasca Oil Sands Area (at print)
11. AF 2.2.1 Life Cycles of Some Common Aquatic Insects of the Athabasca River, Alberta
12. ME 1.7 Very High Resolution Meteorological Satellite Study of Oil Sands Weather, "A Feasibility Study"
13. ME 2.3.1 Plume Dispersion Measurements from an Oil Sands Extraction Plant
14. HE 2.4 Athabasca Oil Sands Historical Research Project (3 volumes) (at print)
15. ME 3.4 Climatology of Low Level Air Trajectories in the Alberta Oil Sands Area

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For information regarding any of these publications or the Alberta Oil Sands Environmental Research Program, please contact the Program office

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