AIRSHED MANAGEMENT SYSTEM FOR THE ALBERTA OIL SANDS

VOLUME II

METEOROLOGICAL DATA

by

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for

Research Management Division
Alberta Environment

March 1981

C80-017

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ABSTRACT

A climatological air quality dispersion was developed which provides more powerful analyses capabilities than are available in traditional CDM-type models.

The model incorporates a time series approach to satisfy identified user needs. The three components of the model are: the time series file of meteorological variables, the program (GLCGEN) used to generate ground level concentrations, and the frequency analysis program (FRQDTN) which defines the analyses for a particular run.

The time series file contains the meteorological data necessary to define dispersion classes and also includes other meteorological parameters which can be used to further classify the ground level concentrations analyzed in the frequency distribution program.

Program GLCGEN incorporates the disperision formulations and computes ground level concentrations for each receptor source pair for each dispersion class utilizing user-defined source characteristics and an emission rate of unity. This array of ground level concentration values is stored on a random access file for access by FRQDTN. This precalculation of procedure permits considerable saving of computer costs when long time series of data are processed.

The model assumes a Gaussian plume framework with plume sigmas defined by a modification to statistical theory. Effective downwind distances are utilized to allow for source affects and to simplify the analytical downwind dependence of the plume sigmas. The standard deviation of the azimuth and elevation wind fluctuations are estimated from a planetary boundary layer parameterization involving similarity theory and empirical results.

The analysis program, FRQDTN, is designed for ease of user operation. Once GLCGEN has been used to generate the ground level concentration file, the user can proceed to consider various scenarios. Source emission rates are set in FRQDTN and so various sources can be turned off or on and various emission strengths can be assigned. Different chemical species can thus be readily examined. The ground level concentration values can also be weighted according to user-selected parameters from the meteorological time series. FRQDTN can be used to generate average ground level concentrations, frequency distributions of ground level concentrations, average dry and wet deposition, and time series of ground level concentration values.

ACKNOWLEDGEMENTS

INTERA Environmental Consultants Ltd. and Western Research and Development express appreciation to the Research Management Division of Alberta Environment who funded this project and especially to Mr. Bruce Thomson and Mr. Bill Hume who supervised. Additional thanks must go to Mr. Randy Angle of Alberta Environment, Dr. Keith Hage of the University of Alberta, Dr. John Reid of Environment Canada, and Mr. Sven Djurfors of Syncrude Canada Ltd. who served on the External Quality Assurance Team.

I. INTRODUCTION

The Research Management Division of Alberta Environment has instituted a multi-year program to develop and implement a series of air quality models. These models were designed to provide air quality assessments that can be used to ensure that development of the Athabasca Oil Sands can be accomplished without undue environmental degradation.

A Gaussian frequency distribution model has been developed to satisfy user needs identified with respect to air quality in the Athabasca Oil Sands area (Volume I). In order to test the model and obtain preliminary results, a time series of meteorological data is required by the frequency distribution program, FRQDTN. This report discusses the types and sources of meteorological data incorporated into the time series file.

Time series data concerning convective mixing heights and winds at plume level were derived from climatologies previously developed for the Athabasca Oil Sands region. These climatologies were obtained from a report prepared during the first year of the Gaussian frequency distribution development (Leahey and Hansen, in prep.).

Potential local sources of meteorological data that can be used to generate the time series data file include the Fort McMurray Airport, the Mildred Lake Research Facility, and a 152 m meteorological tower known as the "Tall Tower." The location of the first two sites relative to the surrounding topography is shown in Figure 1. The Tall Tower is located in the Athabasca River Valley about 10 km southeast of the Mildred Lake Research Facility. In addition to these local sources, surface and upper air synoptic charts are available from the Atmospheric Environment Service (AES).

As shown in Figure 1, the topography of the region is characterized by the Athabasca River Valley, the steeply rising Birch Mountains in the northwest, the more gently rising Muskeg Mountain in the east, and Stoney Mountain in the south. To the southwest the terrain is relatively flat.

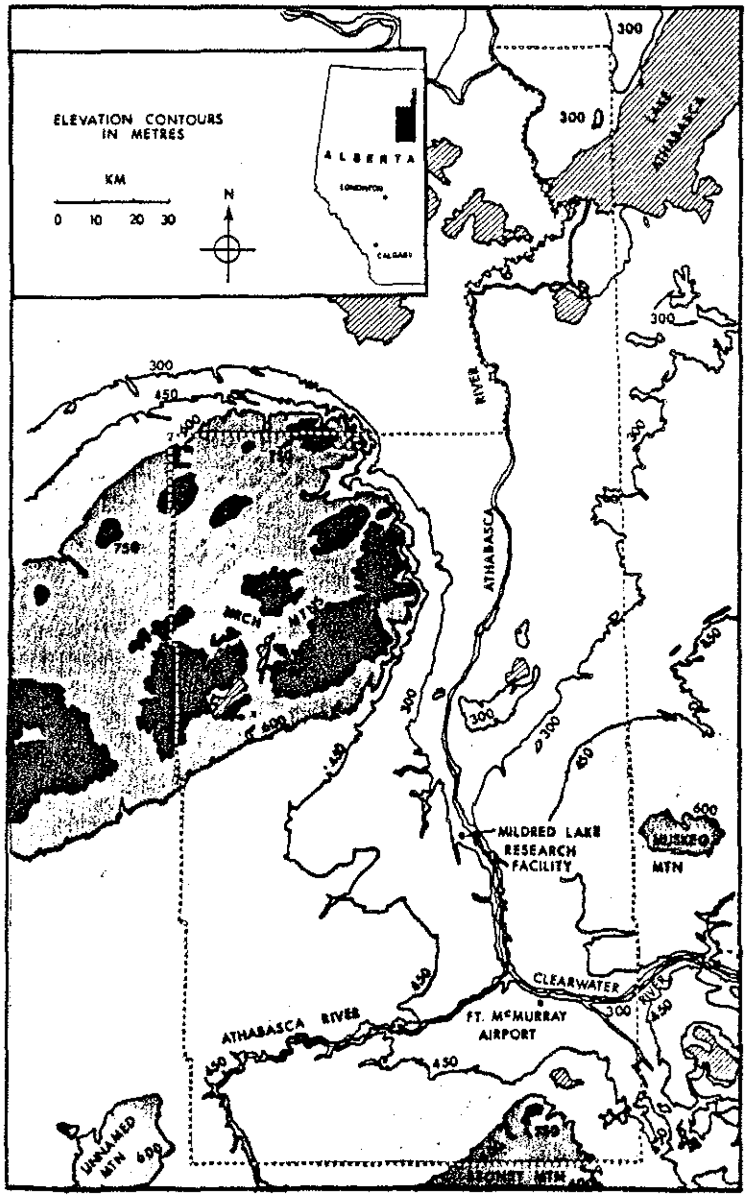

Figure 1. Topography in the vicinity of the Athabasca Oil Sands area.

2. THE TIME SERIES METEOROLOGICAL FILE

The meteorological time series file was developed to permit testing of the model, generation of initial results, and an evaluation of how a larger data base could be constructed. It was decided that these objectives could be met with a data base comprising four months: January, April, July, and October, for three years: 1976 to 1978. The following paragraphs give an overview of the contents of the meteorological time series file. Details of the derivation are presented in the following sections.

The data base was processed to form a time series of relevant meteorological parameters for use by the frequency distribution program FRQDTN. Specifically, the time series contains hourly values of:

1.	Surface weather code	(-6 to 6)
2.	Ambient temperature	(°C)
3.	Relative humidity	(fraction)
4.	Cloud cover	(fraction)
5.	Precipitation	(mm)
6.	Snow cover	(cm)
7.	Net radiation	(Wm^{-2})
8.	Wind direction at 400 m	(degrees)
9.	Wind speed at 400 m	(m/s)
10.	Convective mixing height	(m)

Some of these values were obtained directly from meteorological observations in the area and others were derived. Standard meteorological parameters were obtained from the Fort McMurray Airport surface weather records. Hourly data were extracted for temperature, relative humidity, surface weather activity, and opaque cloud cover. The precipitation values were available as 6 h totals. Daily snow depth was also abstracted from the records.

Net radiation, wind speed and direction, and mixing height were not available on surface weather records and were determined from other sources.

Net radiation was estimated from solar altitude, cloud cover, and season. Derivation of radiation values involved separate formulations for both solar and terrestrial radiation and used the Alberta Oil Sands Environmental Research Program (AOSERP) radiation data as processed by Kumar (1978) for evaluation of site-specific parameters.

Wind speed and direction data at typical plume heights were estimated from 850 mb synoptic charts using empirical power laws and turning angles. The wind data analysis demonstrated that local topographical effects may have been present even at plume heights. The minisonde data from both AOSERP- and Syncrude-sponsored studies were used to generate the empirical relationships needed to synthesize the data set. They were also used to confirm the limitations to the representativeness of the Tall Tower data and to assess the error levels in the generated wind data.

Convective mixing heights as a function of time of day and season were estimated from the minisonde data. The height of the layer was taken as the height above ground where the dry adiabat through the surface temperature intersected the temperature profile. The hourly mixing height values adopted in the time series file for a given season were taken as the median of all non-zero minisonde values for each particular hour observed within that season. Thus, seasonal climatological hourly values are contained in the time series file.

The dates and times of all the hourly observations were converted to Greenwich Mean Time (GMT) in creating the time series file. This required an additional 7 h of data at the beginning of each month.

3. STANDARD METEOROLOGICAL PARAMETERS

Data from the hourly surface weather records obtained from AES for the Fort McMurray Airport were digitized. Hourly values include surface weather condition, temperature, relative humidity, and opaque cloud cover. The surface weather condition refers to precipitation and is given as a code ranging from -6 to 6. The key to this code is given in Table 1. Temperatures are given to the nearest 0.1°C, relative humidities to the nearest percent, and cloud cover in tenths.

Precipitation from the AES records was in the form of a 6-h total. Hourly values of precipitation were estimated on the basis of the surface weather condition codes given in Table 1. Light, moderate, and heavy precipitation, regardless of type, were given relative weightings of 1, 2, and 6. There is obviously some arbitrariness in this weighting; however, it appears to be a better distribution of the precipitation amounts than a uniform distribution. It is recognized that rainfall, particularly for convective storms in the summer, is not spatially uniform. Thus, applications of weighting parameters which involve the generated pseudo-hourly precipitation values need to be done with a caution not to exceed the limits to the representativeness of the data.

Depth of snow cover is recorded on the surface weather record once for each day. In the time series file, snow cover was assumed to be a constant for each day. The values given are to the nearest centimetre.

Table I. Surface weather condition code and corresponding precipitation.

Symbol	Precipitation Type	Precipitation Intensity
-6	Snow shower	Heavy
-5	Snow shower	Moderate
-4	Snow shower	Light
-3	Snow	Heavy
-2	Snow	Moderate
-1	Snow	Light
0	No precipitation	
1	Rain, freezing rain, drizzle or freezing drizzle	Light
2	Rain or freezing rain	Moderate
3	Rain or freezing rain	Heavy
4	Rain shower	Light
5	Rain shower	Moderate
6	Rain shower	Heavy

4. NET RADIATION

The net solar and terrestrial radiation were estimated in order to provide a means of computing surface heat flux in FRQDTN for dispersion classification. Net radiation estimates also provided a potential weighting parameter for the ground level concentrations. The surface heat flux appears in the surface energy budget, therefore, its value can be estimated knowing the net radiation and approximating the remaining terms. The surface heat budget can be written as (Haltiner and Martin 1957: 130)

$$Q_s + Q_t + H + W + G = 0 \qquad (1)$$

where: Q_s = net solar radiation (direct and diffuse)
Q_t = the net terrestrial radiation
H = the sensible heat flux
W = the latent heat flux
G = the heat flux associated with the ground storage of heat

The sensible heat flux provides a surface boundary condition for the planetary boundary layer.

Most of the terms in Equation 1 can be roughly approximated to permit an estimate of the surface heat flux. The formulations adopted for the solar and terrestrial net radiations are based upon simple approaches discussed in many standard references. For the purposes of a climatological model, these approximations of average conditions are considered adequate unless further sensitivity testing shows a need for refinement. The adopted parameter values are recognized as being approximate; validation by further testing and analyses of the existing data taken in the region of the Athabasca Oil Sands is worthwhile.

A major assumption in the present approach or other similar approaches using a surface energy budget is that local conditions determine the local stability. This assumption is equivalent to assuming horizontal homogeneity. In a real atmosphere, advective effects are often very important. Allowance for advective effects can be made in a three-dimensional model. However, for the present time a local determination of the parameters governing the local planetary boundary layer will probably be adequate since systematic errors are probably small. A model designed for specific case simulations would need to include advective effects.

The formulation for the net radiation is a standard form following Sutton (1953):

$$Q = (1 - A)\ Q_s - Q_t \tag{2}$$

where A is albedo and the expression for Q_s is:

$$Q_s = (1 - K_1 C)\ (\sin \alpha)\ F\ q^m \tag{3}$$

where: $\sin \alpha \ \sin \phi \ \sin \delta + \cos \phi \ \cos \delta \ \cos h$ (4)

and where:

K_1 = a cloudiness constant

C = the fraction of opaque cloud cover

α = the solar altitude

F = the solar constant = 1353 (watts $\cdot$ m^{-2})

q = the average transmission of one optical air mass (>0.7)

m = the optical air mass

ϕ = the latitude

δ = the solar declination

h = the sun hour

A unit optical air mass is the air mass for a zenith angle. The optical air mass is the air mass traversed by direct radiation from the sun for a given latitude, declination, and sun hour and is given by:

$$m = (\sin \alpha)^{-1} \tag{5}$$

where α is the solar altitude defined above.

The expression used to evaluate Q_t is:

$$Q_t = K_2 \sigma T^4 (1 - K_3 C) \qquad (6)$$

where: σT^4 = black body radiation

$K_2 2$ = 0.3

K_3 = 0.9

In order to evaluate the net radiation at a given hour, several parameters needed to be specified. The solar declination is available in standard reference tables. However, the regression equation for the solar declination as a function of Julian date cited by Kumar (1978) was adopted as being sufficiently accurate.

The solar hour angle was calculated using the formulation:

$$h = (t_s - 12) RADPHR \qquad (7)$$

where t_s is the true solar time and RADPHR is the number of radians per hour of the earth's rotation. The true solar time is given by

$$t_s = (GMT - IDELTA) + CLONG + EQNT \qquad (8)$$

where: GMT = the GMT time

IDELTA = the difference of GMT and local standard time (7 hours)

CLONG = a longitudinal correction for the AOSERP study area compared to the standard meridian

EQNT = a small time correction to account for the asymmetry of the earth's orbit about the sun

The values of CLONG and EQNT were obtained from the Smithsonian Meteorological Tables (List 1951).

The values of the parameters q, K_2, and A were estimated based upon observations of net radiation as analyzed by Kumar (1978). The adopted estimates were guided by what was physically reasonable given the site characteristics and values recommended by a variety of authors (Sutton 1953; Haltiner and Martin 1957; Kondratiev 1969). Values were matched at noon on the equinoxes and the solistices to be compatible with Kumar's analysis. The estimated values are given in Table. 2. There was a marked difference between spring and autumn in the observed radiation data and this difference can probably be attributed to an albedo difference due to snow. The data analyzed showed that the transmission for a unit optical air mass (zenith angle) is less in the winter, an effect possibly due to the reduced water vapour pressure due to the cold temperatures.

The albedo difference, indicated in Table 2, between 21 March and 21 December at noon was attributed to solar angle differences. Over a mixed open snow and forest surface, the albedo due to hemispheric scattered radiation may be similar in winter and spring. However, for direct radiation, the lower solar angle at noon on 21 December would mean that the effective surface seen by the sun would be more forested and less open, snow-covered areas. If this interpretation is correct, then the effective albedo for the entire surface becomes a function of solar altitude. Note, however, that a direct measurement of albedo over any given surface element (i.e., forest, open area) would not show a dependence on solar altitude.

In the model, the albedo was made a function of solar altitude using an empirical expression consistent with the observed values:

$$A = 0.2 + K_A \ (\sin \alpha - \sin \alpha_o) \qquad (9)$$

Table 2. Estimated values of the radiation parameters based upon radiation data as analyzed by Kumar (1978).

Dates	Snow Cover	Approximate solar altitude at noon (day)	Assumed temperature (°C)	K_2	q	A
21 March	yes	33	5	0.25	0.7	0.5
21 June	no	56	20	0.25	0.7	0.2
21 Sept.	no	33	5	0.25	0.7	0.2
21 Dec.	yes	10	-20	0.20	0.8	0.2

where:

α = the solar altitude (must be larger than α_o)

α_o = the solar altitude at noon in late December (taken as 10°C)

K_A = a parameter evaluated from the late March noon data as 0.8.

The above formulation gives an albedo value of about 0.5 on noon 31 March and a value of 0.7 at noon on 21 June if there were snow. A check was made on the time series data that there was snow cover, as measured at Fort McMurray Airport, before the albedo was modified for solar altitude.

The values of K_2 and q in the program were made functions of the month. The December matching was assumed to be representative of the coldest months: December, January, February. The values for all other months were taken to be the same and equal to those of March, June, and September as shown in Table 2.

The two remaining constants are the constants for the reductions of solar and terrestrial radiation due to cloud cover. Reviews by Sutton (1953), Haltner and Martin (1957), and Kondratiev (1969) suggest values of about 0.77 and 0.9 for the solar and terrestrial cloud coefficients, respectively. The formulation for cloud cover effect is an approximation of an average effect which ignores many factors. Kondratiev (1969) summarizes the effects of many workers, and shows that the transmission efficiency of clouds varies markedly with cloud type, cloud thickness, and, to a somewhat lesser degree, solar altitude. More recent work has considered the problem of multiple cloud layers and explicit values of dust effects (e.g., Davies et al. 1975). However, for the initial version of the present model, simple averaged values as outlined above are considered to be adequate until a clear need for an improved expression is demonstrated by sensitivity studies of the climatological model output.

5. WIND SPEED AND DIRECTION

Various sources of wind data from the Athabasca Oil Sands area were evaluated to determine wind speeds and directions applicable to the anticipated height of industrial plumes. Plume heights were estimated using stack and emission parameters similar to those of the existing Syncrude plant. Winds were derived for the typical plume height and then incorporated into the time series file.

5.1 ESTIMATED PLUME HEIGHTS

Theoretical plume heights were calculated in order to determine the altitude at which the wind climatology should pertain. Theoretical plume heights were calculated using the Briggs 2/3 law plume rise formula for unstable and neutral atmospheres, and the final rise as predicted by the Briggs stable plume rise formulation for stable atmospheres (Briggs 1975). A value for the entrainment constant of 0.74 as reported for the Athabasca Oil Sands area by Davison and Leavitt (1979) was used.

Stack height, diameter, exit velocity, and exit temperatures assumed for plume rise calculations were 138 m, 7.9 m, 23.3 m/s and 246°C, respectively. These parameters are similar to those of the existing Syncrude extraction plant stack.

A frequency distribution of theoretical plume heights was obtained using wind and temperature gradient data from the Tall Tower which is located on the floor of the Athabasca River Valley, 10 km southeast of the Mildred Lake Research Facility. Wind speeds from the 152 m level, and temperature gradients between the 10 and 152 m levels, for the period 27 October 1976 to 30 April 1979, were used. Stable atmospheres were identified with potential temperature gradients greater than 0.005°C m^{-1}, and were found to occur 61% of the time. The overall median plume height was calculated to be 420 m. About 65% of the predicted plume heights were between 300 and 500 m. A wind speed and direction, climatologically appropriate to a height of 400 m above ground level was then derived from existing wind data.

5.2 WIND DATA SOURCES

There were five main sources of data that might be relevant to the derivation of a wind climatology in the Athabasca Oil Sands area. Three of these are ground based, one relates to pibals, and the other involves 850 mb synoptic charts.

Ground-based wind information is available from instruments located at the 10 m level at the Fort McMuuray Airport, the Mildred Lake Research Facility, and the Tall Tower. Instrumentation for the Tall Tower consists of Bendix aerovanes at the 10, 90, and 152 m levels, and aspirated temperature bulbs at the 1.5, 10, 30, 90, and 152 m levels.

Data relating to wind velocity are also available from a total of 2344 pibal observations taken in the Mildred Lake area from 1975 to 1978. Some of the data are from continuous programs ranging over several months and involving two to four releases per day. Other data are from more intensive programs ranging over one or two weeks and involving up to 20 releases per day.

The Atmospheric Environment Service (AES) prepares 850 mb synoptic charts twice daily. The geostrophic wind assumption may be used to obtain wind speed and direction data from these charts. In the Athabasca Oil Sands area, the 850 mb pressure level corresponds a height of about 1200 m above the surface.

5.3 EVALUATION OF EXISTING WIND DATA

A wind rose was constructed for 400 m above the surface using 2344 pibal observations taken from February 1975 to November 1978. Wind data obtained from 850 mb synoptic maps, Fort McMurray Airport, Mildred Lake, and the Tall Tower then were examined to determine which source most closely represented the pibal winds at 400 m.

5.3.1 <u>Wind at the 400 m Level</u>

Figure 2 shows the distribution of the pibal observations used to determine winds at the 400 m level. There is

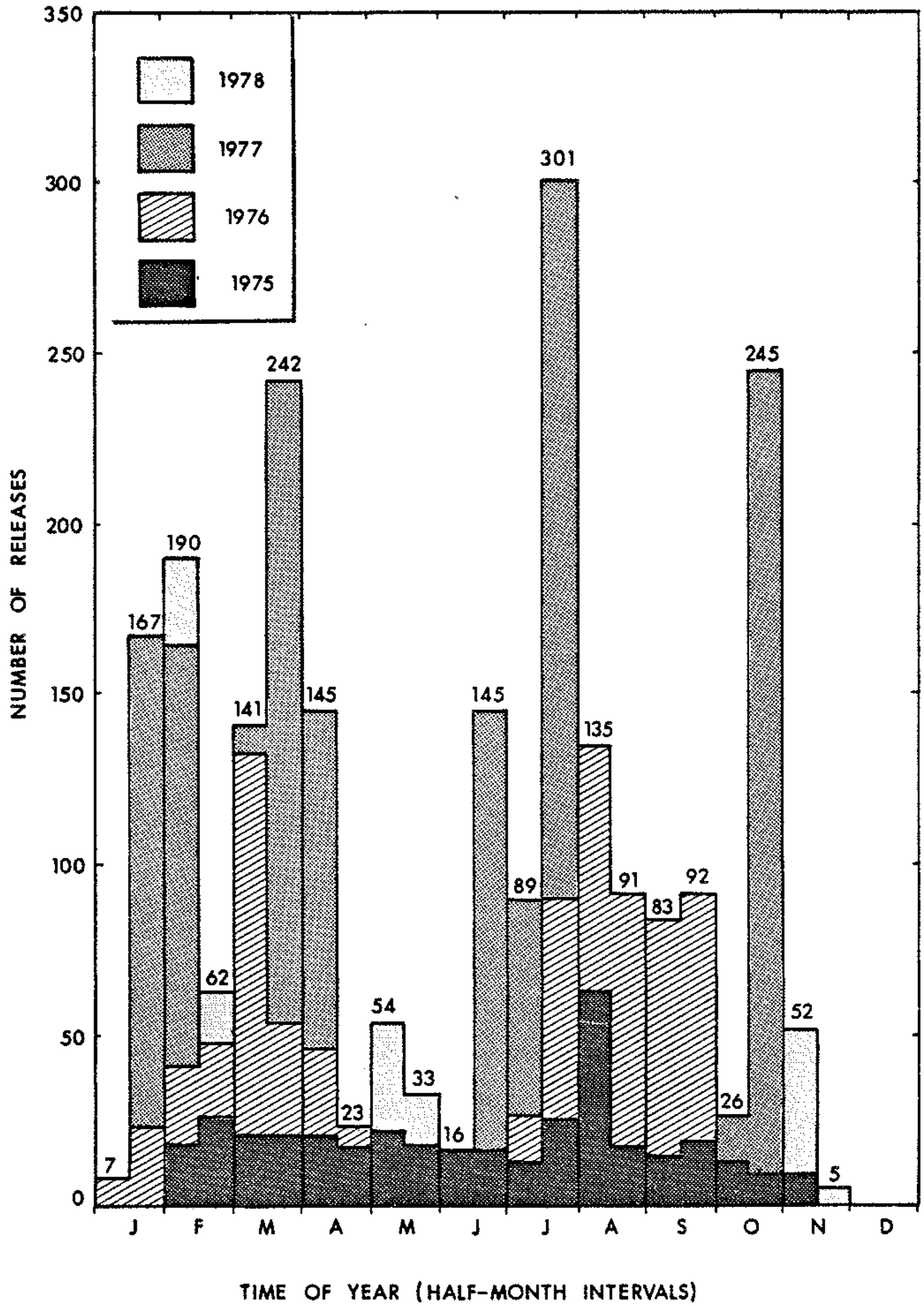

Figure 2. Monthly distribution of the 2344 pibal releases from which wind data at 400 m were obtained.

a relative paucity of data from mid-April to mid-June and from the first of November to mid-January.

Figure 3 is a wind rose for the 400 m level based upon all 2344 pibal releases. The wind rose shows that westerly and west-southwesterly winds predominate at the 400 m level. Northeasterly winds are not common. It is interesting to note that northwesterly and north-northwesterly winds are also relatively uncommon. This may reflect the channelling effects of the Birch Mountains which lie to the northwest of the observational area.

While the wind rose shown in Figure 3 is based on a limited number of data, it should nonetheless broadly represent the main features of the 400 m windflow regimes. It should be noted that pibal observations essentially represent instantaneous values. Pibal wind observations are the only available data set that can be used to obtain direct measurements of wind in the plume layer. However, these measurements are taken too infrequently to generate an hourly time series of winds for long periods. The pibal observations can be used to generate empirical parameters needed to relate winds at plume level (400 m) to winds measured more frequently at other heights. They can also serve as an indicator of uncertainties in the derived 400 m wind values.

5.3.2 Wind at the 850 mb Level

Geostrophic winds were extracted from 850 mb contour maps which are available twice daily (for 0000 and 1200 GMT) from AES. Data were linearly interpolated to approximate hourly average winds for the times at which pibal measurements were available.

Figure 4 presents the 850 mb wind rose for times which coincide with the 2344 pibal measurements. Wind directions are appreciably more northwesterly and speeds much greater than at the 400 m level. This might have been expected as winds in the troposphere tend to increase in speed and veer with height, due to thermal wind and surface frictional effects (e.g., Haltiner and

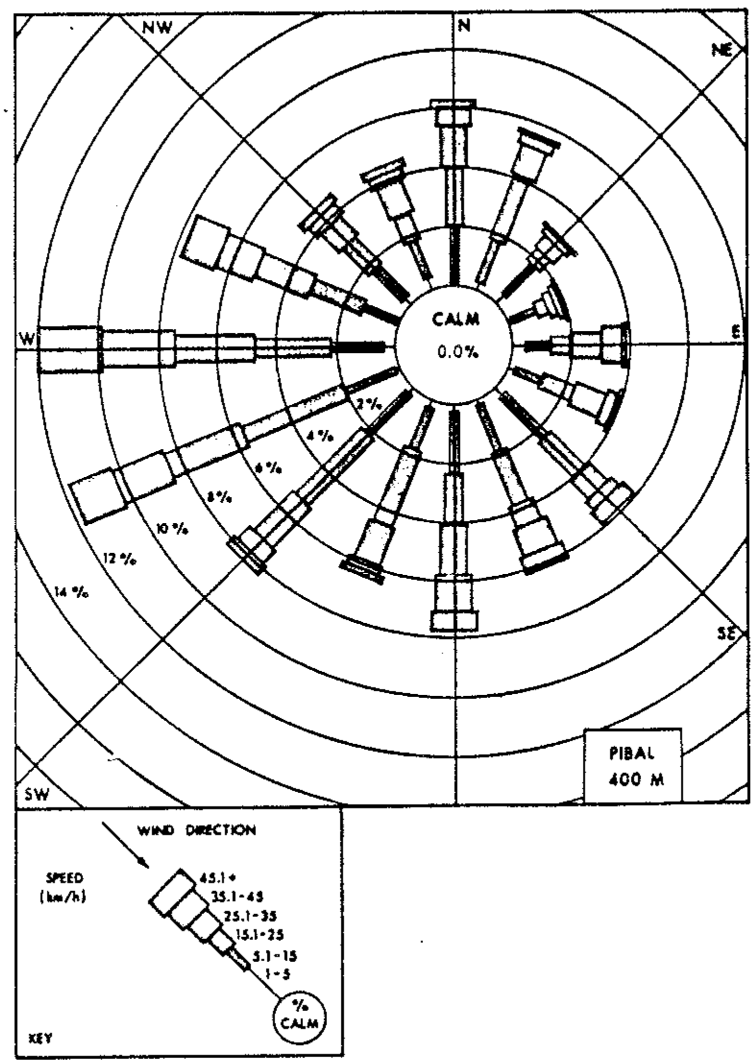

Figure 3. Winds at 400 m, based on 2344 pibal releases.

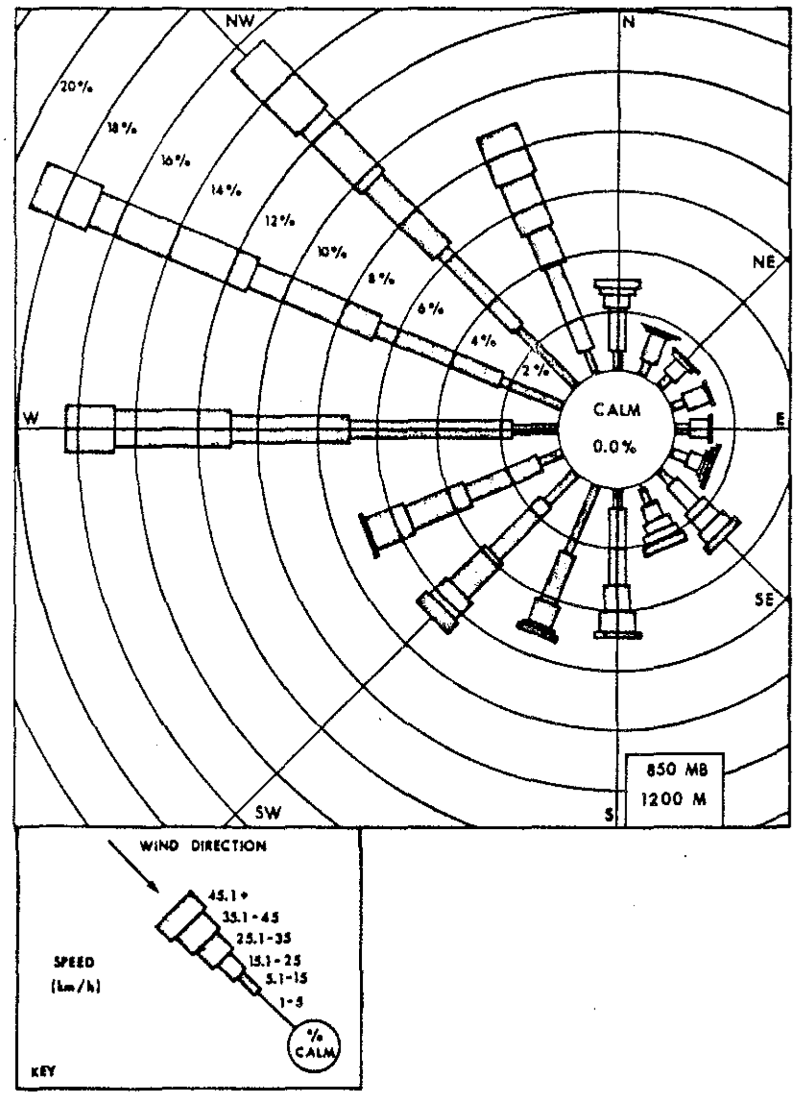

Figure 4. Winds at 1200 m, based on 850 mb data coinciding with the 2344 pibal releases.

5.3.3 Winds from the Fort McMurray Airport

Figure 5 presents the annual wind rose from the Fort McMurray Airport based on data collected from 1963 to 1975. It shows a large percentage of easterly winds. This is presumably due to the influence of the Clearwater River Valley which joins the Athabasca River Valley from the east in the near vicinity of the Airport (Figure 1). These wind rose data do not seem representative of conditions at the 400 m level as derived from the 2344 pibal observations.

5.3.4 Winds from the Tall Tower

Figure 6 shows the wind rose derived from data collected at the 152 m level of the Tall Tower during the years 1975 to 1979. The wind rose shows evidence of the atmospheric channelling effects of the Athabasca River Valley, whose axis in the vicinity of the tower generally has a north-south orientation. The walls of the valley rise in excess of 65 m above the tower base. The tower winds at 152 m bear little resemblance to winds at the 400 m level.

5.3.5 Winds from the Mildred Lake Research Facility

Figure 7 presents synthesized wind data based on observations made at the 10 m level at Mildred Lake for the years 1963 to 1975 (Walmsley and Bagg 1977). The most common winds are southeasterly. Both east and west winds are rare. These data also appear to reflect channelling effects of the nearby Athabasca River Valley. There seems to be little resemblance between Mildred Lake winds and those observed at the 400 m level.

5.3.6 Conclusion

Of the five main sources of atmospheric data in the Athabasca Oil Sands area, the 850 mb information appears to be the most reliable basis on which to derive a time series of 400 m wind.

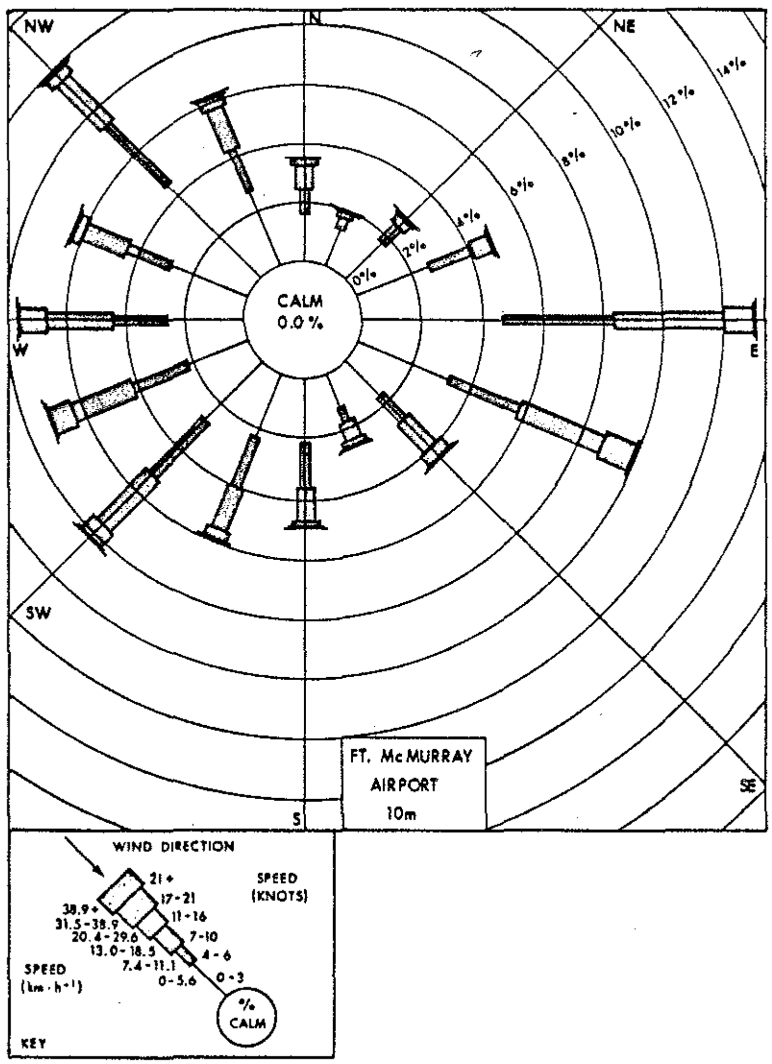

Figure 5. Winds for the Fort McMurray Airport, based on hourly-average data collected from 1963 to 1975.

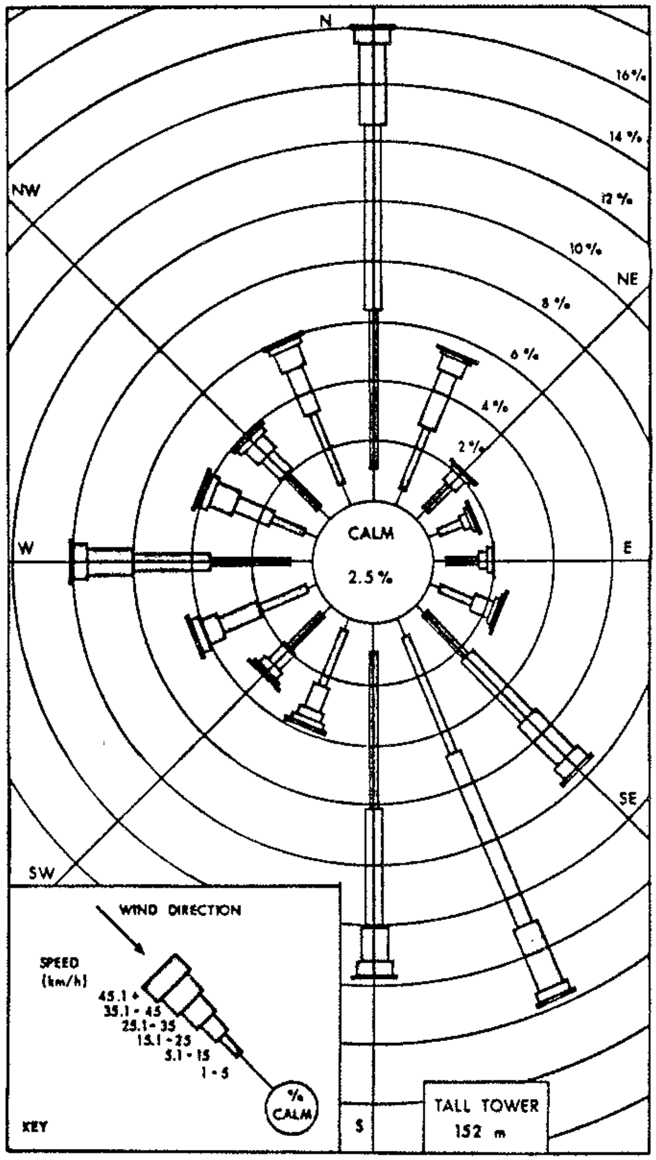

Figure 6. Winds at 152 m, based on hourly-average Tall Tower data from 27 October 1976 to 30 April 1979.

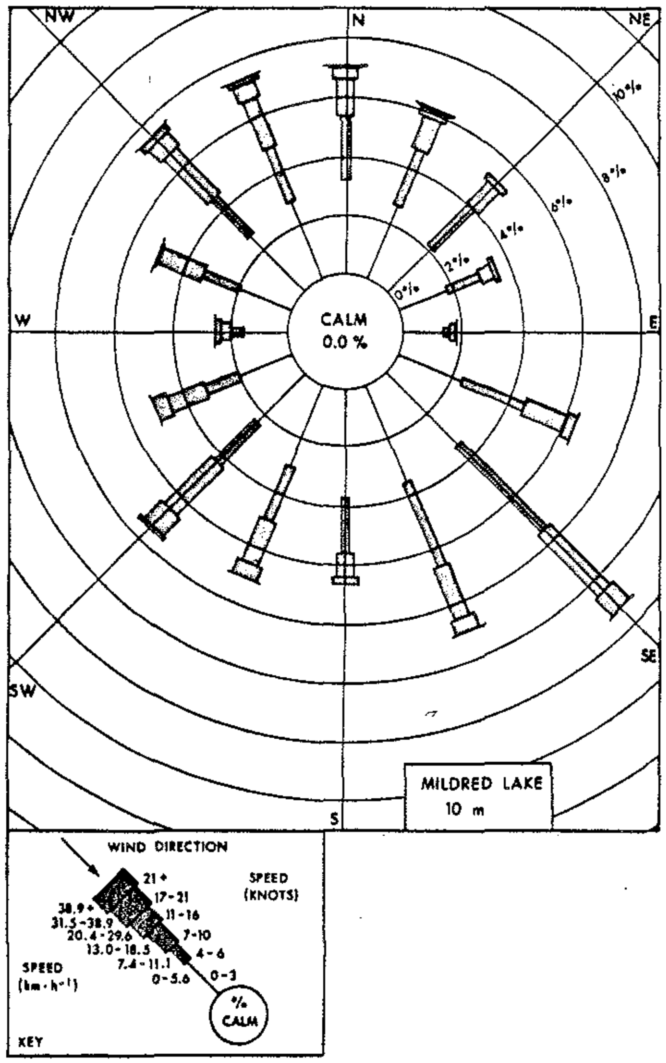

Figure 7. Winds for Mildred Lake, based on hourly-average data collected from 1963 to 1975, as synthesized by Walmsley and Bagg (1977).

5.4 COMPARISON OF THE 850 mb and 400 m WINDS

On the basis of the previous section, it was decided to derive the 400 m wind climatology from the 850 mb information. Concurrent 400 m and 850 mb wind data were used to establish relationships between the speeds and directions at the two levels. The method used to establish these relationships is presented in this section.

5.4.1 Wind Speed Variation with Height

One of the most widely employed methods of expressing the variation of wind speed with height is the power law formulation:

$$U_1 = U_2 \ (Z_1/Z_2)^P \qquad (10)$$

where: U_1 = wind speed of height Z_1
U_2 = wind speed at height Z_2
P = exponential parameter

The exponent P is not constant and can be influenced by factors such as surface roughness and thermal stability (Haltiner and Martin 1957; Munn 1966). Equation 10 can be rearranged and used to estimate values of P from:

$$P = \text{LOG} \ (U_1/U_2)/\text{LOG} \ (Z_1/Z_2) \qquad (11)$$

Normally, wind speeds averaged over a period of 1 h are used to calculate P.

Values of P usually have been derived from meteorological tower data collected at a lower height of 10 m and an upper height not exceeding 100 m. Data concerning P at several different sites have been recently presented by Touma (1977). Overall average values for unstable, neutral, and stable atmospheric conditions were found to be 0.15, 0.21, and 0.41, respectively. If the wind data had been obtained from higher altitudes in the atmosphere, such as 400 and 1200 m, values for P would have been smaller or even negative. (Negative values of P are associated with a decrease of wind speed with height). Two possible explanations for a negative values of P include:

1. Anticyclonic flow aloft tends to die down above cold anticyclones; and
2. Some flows such as drainage winds (katabatic winds) are driven by local density gradients which originate at the surface due to topographical configurations. As these flows are of limited vertical extent, wind speeds may decrease above a certain level.

Values of P relating the 850 mb and 400 m wind speeds as a function of season and wind direction were determined from Equation II using empirically derived values of P as discussed below.

5.4.2 Wind Direction Variation With Height

Frictional forces usually cause a clockwise change of wind direction (veering) with height above the ground. On the average, this veering amounts to about 20° between the 10 and 1000 m levels (ASME 1973). Direction changes with height normally decrease as the atmosphere becomes more turbulent. Higher atmospheric turbulence levels are associated with greater instability and rougher terrain.

For complex topography, changes in direction with height may be either much greater than 20° or much less, and may even become anti-clockwise (backing). This is especially true when the low-level pattern is decoupled from the pattern aloft, as may occur during stable atmospheric conditions.

Values of the wind direction difference, Q, between the 850 mb and 400 m level wind direction as a function of wind direction and season were evaluated using the pibal data and the simultaneous 850 mb winds. A positive value of Q indicates a veering wind and a negative value indicates a backing wind.

5.4.3 Comparison Considerations

Before proceeding with the comparison, it is perhaps worthwhile to discuss potential limitations in the data and analysis techniques. These limitations can lead to uncertainties that are difficult to quantify. Basically, the following points should be stressed:

1. The derived wind climatology will be assumed to represent hourly average values;
2. The 850 mb winds derived from the analyzed pressure height gradients on 850 mb synoptic charts were interpolated between the 12 h maps and these interpolated winds were assumed to approximate hourly average values;
3. The 400 m level winds obtained from the pibal releases represent instantaneous values that can result in a scatter of the P's and Q's;
4. During convective and stable conditions, the range in values of Q attributable to the instantaneous nature of the pibals may be as large as ±45 and ±20°, respectively. These values are based on horizontal wind direction standard deviations of 15 and 6.7° associated with typical convective and stable conditions, respectively.
5. The statistical sampling uncertainties of the pibal observations can lead to uncertainties in the estimation of appropriate values of P. During convective conditions, a range of ±45° in the wind directions corresponds to a range of ±0.78 U in the wind speed (where U is the mean wind speed). This type of range implies that the uncertainty in the calculated P values could range from Pm -0.5 to +1.4, where Pm is the value that would be calculated from hourly rather than instantaneous data. During stable conditions, a range of ±20° in wind direction corresponds to a range of ±0.35U in the wind speed.

Thus, the estimated P value could range from -0.3 to +0.4;

6. Uncertainties in determining the 850 mb chart analysis, measurement limitations, and the validity of the geostrophic assumption will generate increased uncertainties in the values of P and Q;
7. The 400 m winds may be influenced by local terrain more than the abstracted 850 mb winds; and
8. Most of the pibal data were collected during the daylight hours. The data may be biased against the identification of diurnal wind patterns.

The above points can lead to appreciable scatter and systematic errors in the derived values of P and Q. The use of median values will tend to reduce the effects of random scatter at the expense of removing extreme events.

5.4.4 Comparison Results

Figure 8 presents a comparison between concurrent winds at the 400 m and 850 mb levels for the seasons of winter (January, February, March) and spring (April, May, June). It is based on 809 and 416 wind data for winter and spring, respectively. There is little resemblance between the two winter wind roses. The spring wind roses, however, are more similar.

Figure 9 shows a comparison between the wind roses for the seasons of summer (July, August, September) and autumn (October, November, December). It is based on 791 and 328 wind data for summer and autumn, respectively. In both summer and autumn, the 1200 m winds appear to be mostly explainable if one assumes that the 400 m winds veer by about 20°.

5.4.4.1 Winter season. Figures 10 and 11 show median values of Q and P for the winter season as a function of wind direction. The number of observations upon which the medians are based is shown. A veering or backing wind is indicated by a positive or negative median value of Q respectively.

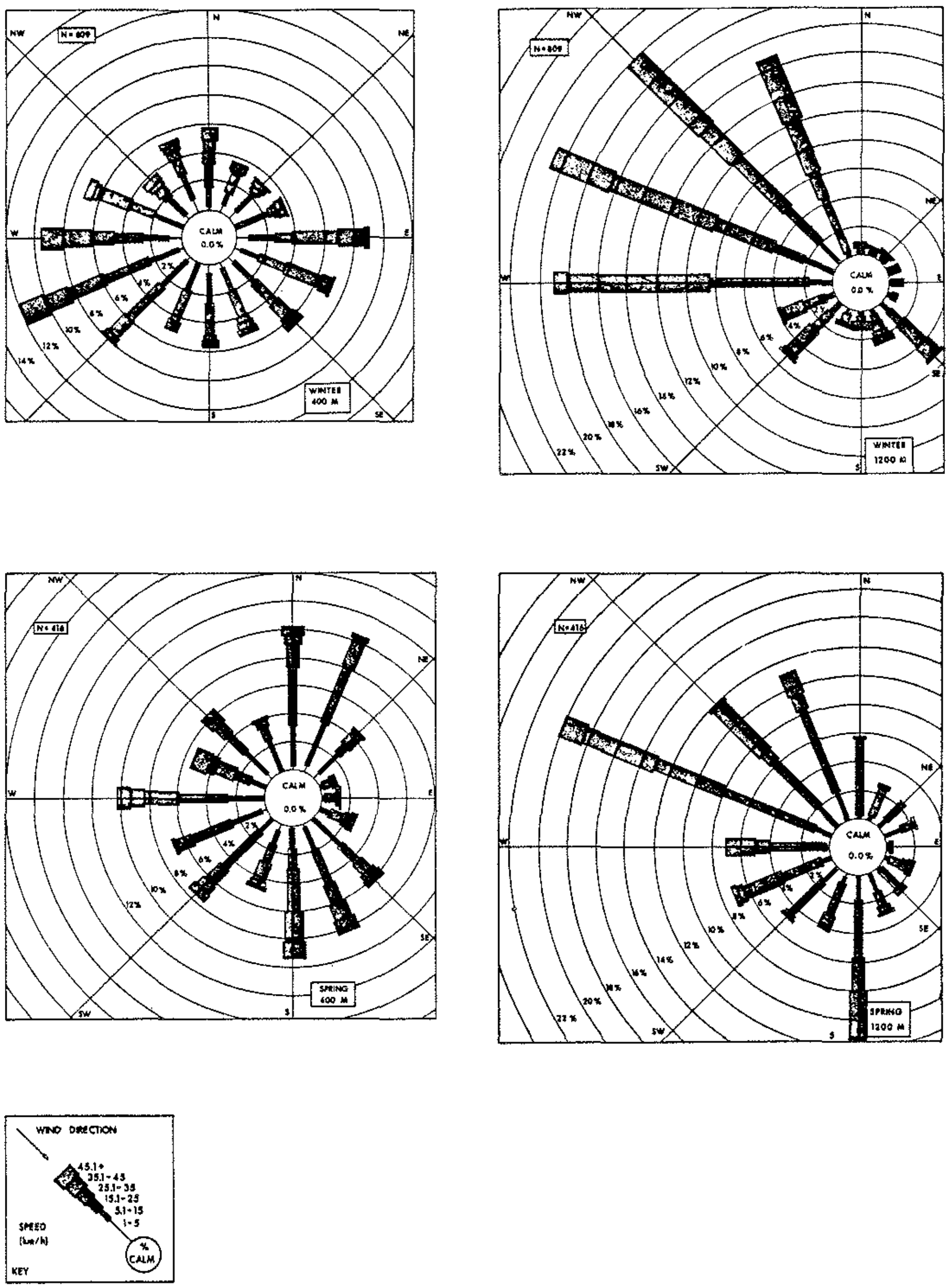

Figure 8. Comparison between 400 m and 850 mb winds for winter and spring.

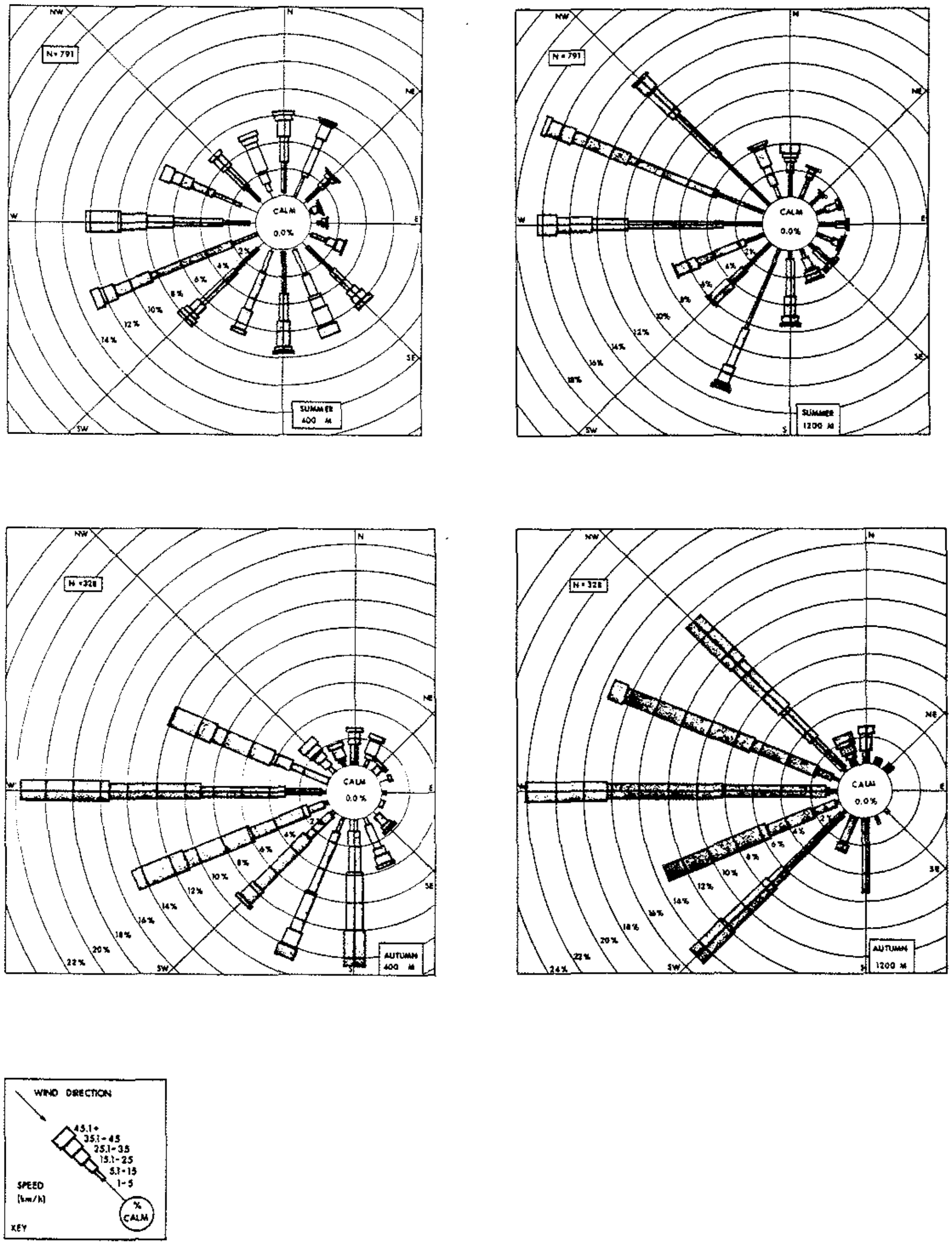

Figure 9. Comparison between the 400 m and 850 mb winds for summer and autumn.

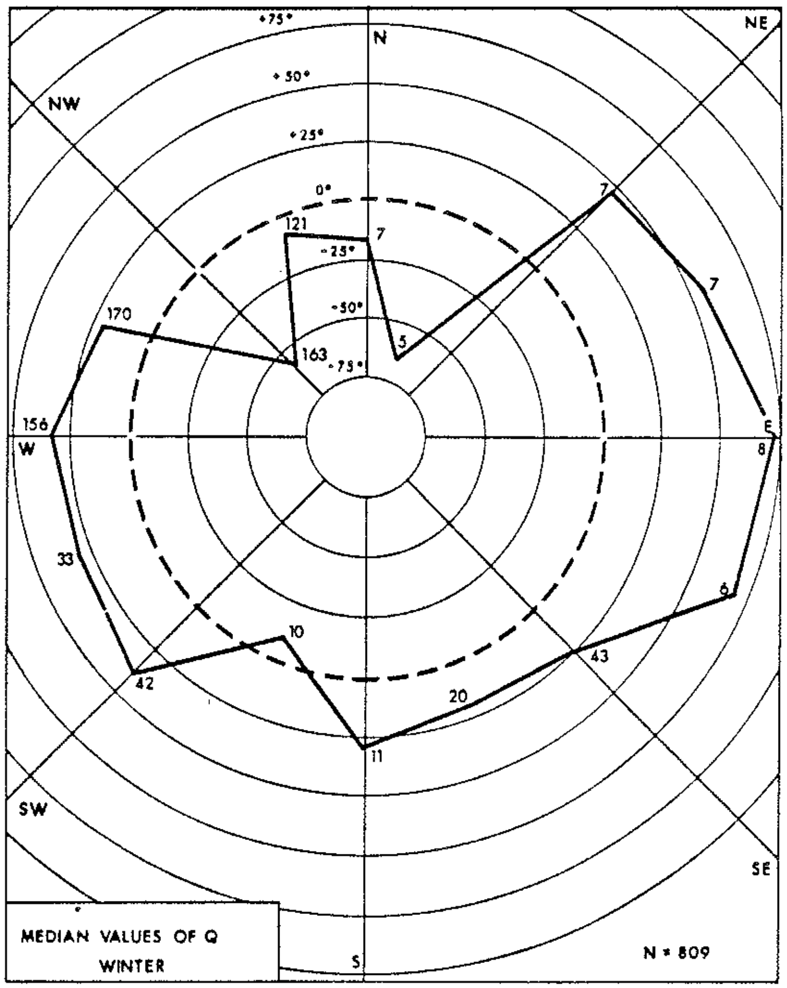

Figure 10. Median values of Q for winter months as a function of wind direction, showing the number of observations for each direction.

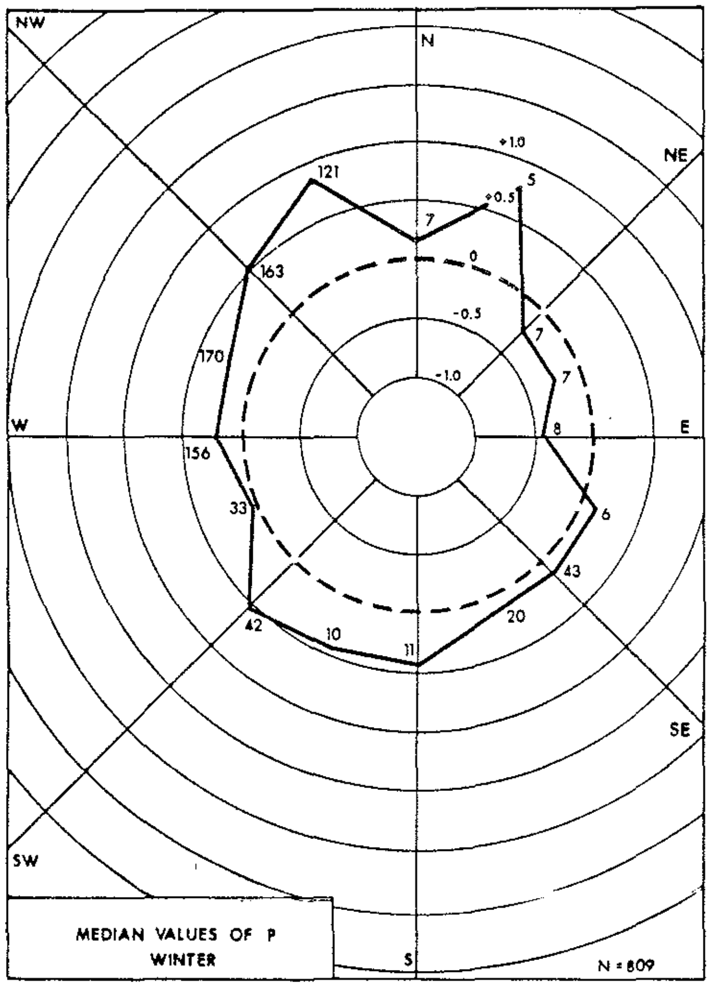

Figure 11. Median values of P for winter months as a function of wind direction, showing the number of observations for each direction.

During the winter season, there seem to be three main flow regimes which depend on wind direction sectors;

1. Sector I (NW-NNE). Much of this sector lies between Birch Mountain and Muskeg Mountain. Wind backs with height with median values of Q less than -60°. Median values of P tend to be large;
2. Sector II (NE-ESE). Muskeg Mountain is situated in this sector. Median values of Q are as large as 70° indicating a strong veering with height. Median values of P are negative indicating a decrease of wind speed with height; and
3. Sector III (SE-WNW). Stoney Mountain and an "unnamed mountain" lie in this sector. Most of the sector however is relatively flat. The wind generally tends to veer by about 25°, except when wind directions are south-southwesterly and it backs about 10°. That direction is along the valley axis between Stoney Mountain and the unnamed mountain. Median values of P tend to be close to 0.25.

Figure 12 shows the cumulative frequency distribution of Q's for each of the sectors. The median Q for Sectors I, II and III are -30, 60 and 25° respectively. About 15 and 30% of all Q values in Sector I lie within a ±20 and ±45° range centered on the median value. This suggests that only a small part of the variance in Q values might be explaned as being due to the nature of the pibal observations. Of all Q values in Sectors II and III, 75 and 50%, respectively, lie within ±45 and ±20° range centered on the median value.

Figure 12 also shows the cumulative frequency distribution of P's for each of the sectors. The median P for Sectors I, II and III are 0.60, -0.35, and 0.25, respectively. It is noteworthy that all three distributions are separate. This could mean that the wind flow regimes reflect the influence of three separate physical phenomena.

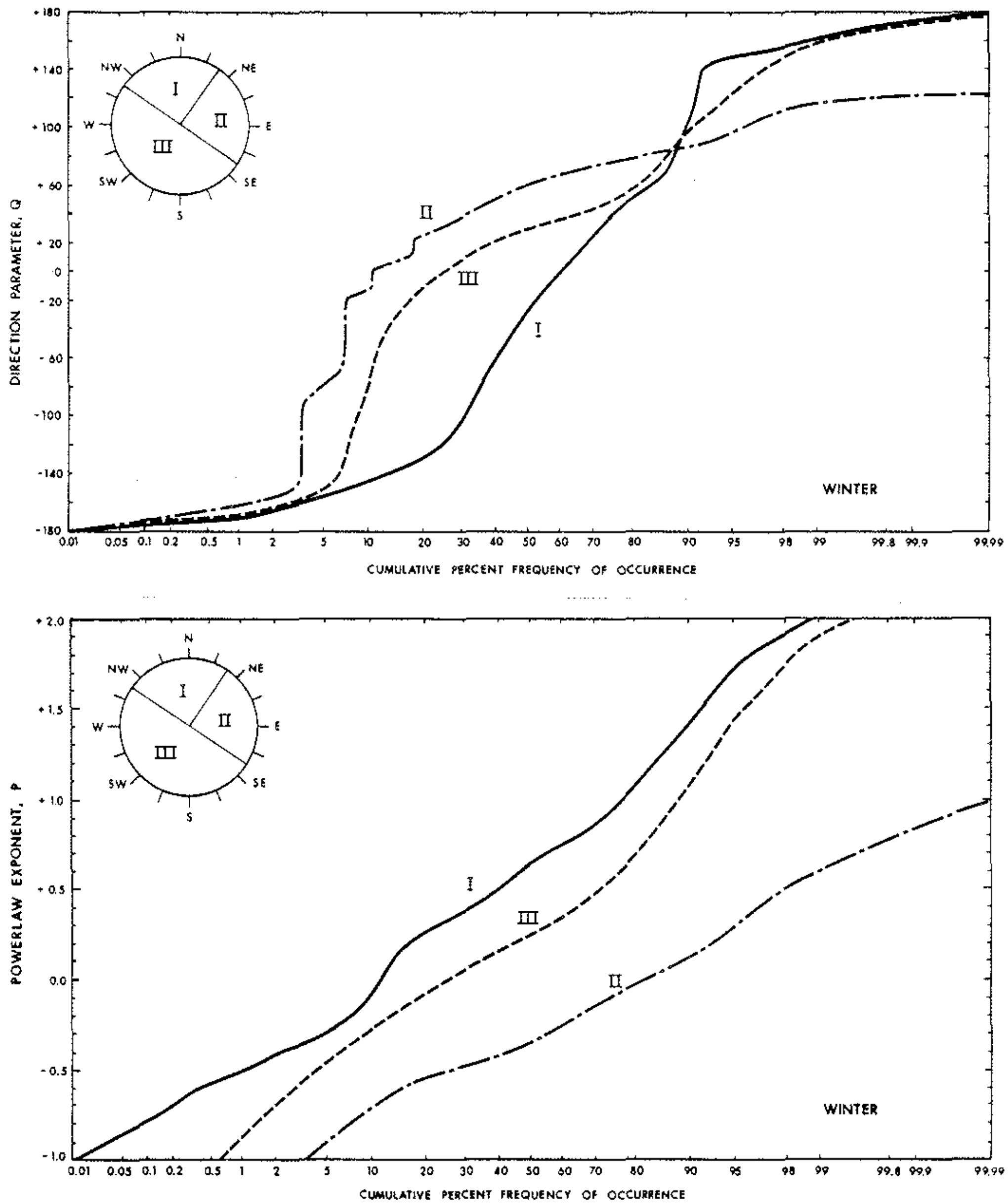

Figure 12. Cumulative frequency of Q and P in each of the indicated sectors for the winter months.

About 90% of the median P values in all sectors range from -0.5 to 1.47. About 55% of the P values for Sectors I and III, and 75% of the P values for Sector II, occur between -0.3 and +0.4. The tendency for low-level winds to back with height when the 1200 m winds are from Sector I suggests either a channelling or a combination of channelling and katabatic flow between the Birch Mountains and Muskeg Mountain. The fact that wind speeds associated with this flow increase markedly with height does not favour an explanation based upon a purely katabatic phenomenon.

The tendency for 400 m winds to veer sharply with increasing height, while decreasing in speed when 1200 m winds are in Sector II, suggests a katabatic flow between the Birch Mountains and Muskeg Mountain.

Winds from Sector III usually behave in a manner typical of air flows over relatively flat terrain. An exception to this statement occurs for south-southwesterly winds, which seem to be affected by Stoney Mountain and the unnamed mountain.

5.4.4.2 Spring season. Figures 13 and 14 show the median values of Q and P for the spring season. The variations of P and Q are not as striking as in winter. There seems to be perhaps only two wind direction sectors in which the flow regimes are distinct:

1. Sector I (NW-NNE). Much of this sector lies between the Birch Mountains and Muskeg Mountain. Wind backs with height with median Q values of about -20°. Median values of P range from about 0.5 to -0.3. Terrain effects appear to be less evident than during the winter months; and
2. Sector II (NE-WNW). This sector contains both Muskeg and Stoney Mountains. Winds tend to veer with height. Overall median values of Q and P are about 20° and 0 respectively. Effects of Muskeg Mountain on the flow regime are not very noticeable. South-southwesterly winds show a tendency to back.

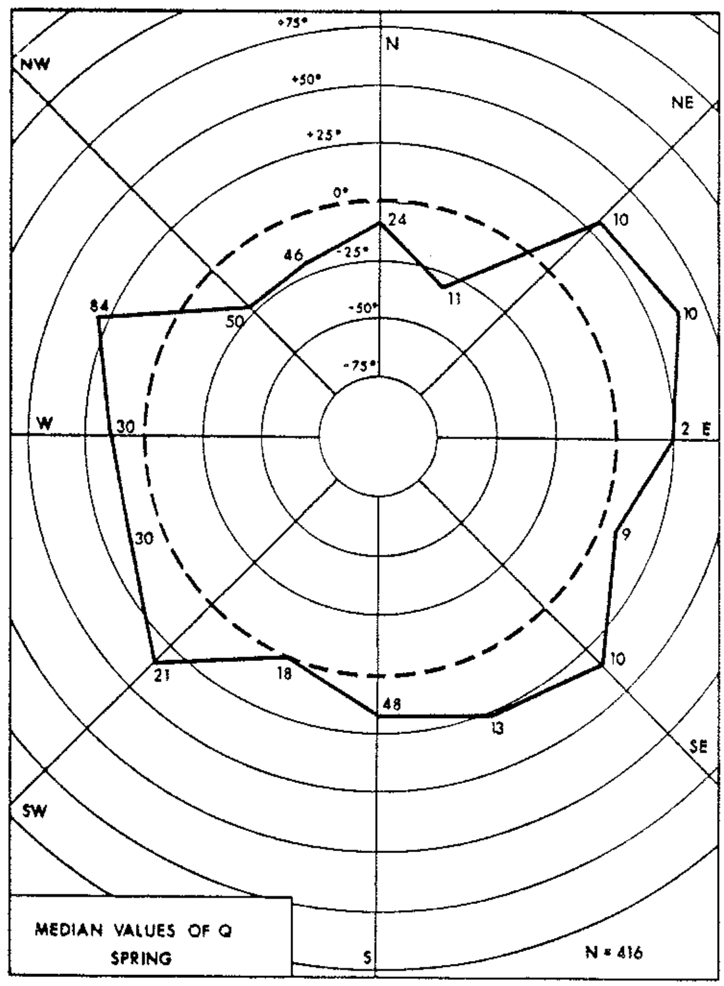

Figure 13. Median values of Q for spring months as a function of wind direction, showing the number of observations for each direction.

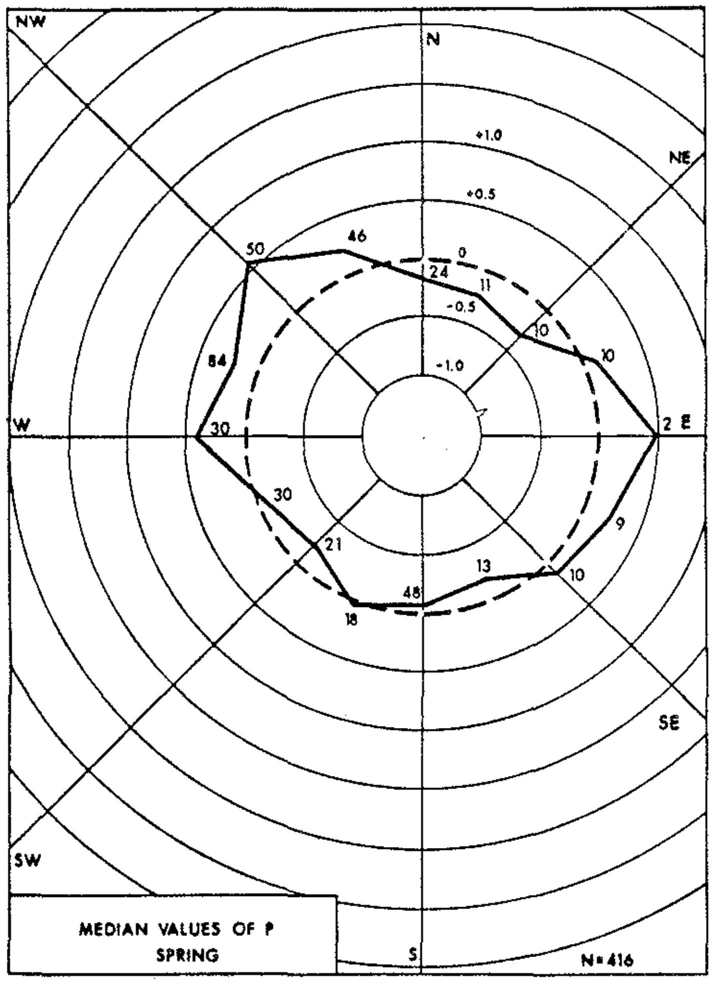

Figure 14. Median values of P for spring months as a function of wind direction, showing the number of observations for each direction.

the influence of Stoney Mountain and the unnamed mountain.

Figure 15 shows the cumulative frequency distribution for Q's in each of the above sectors. The median values for Q in Sectors I and II are -20 and 20°, respectively. Of all Q values in both sectors, 70 and 40% lie within ±45 and ±20° range, respectively, centred on the median.

Figure 15 also shows the cumulative frequency distributions of P's for each of the sectors. The distributions do not appear to be appreciably distinct. It is of interest, however, to note that the median P value for Sector I of 0.15 is larger than corresponding value of 0.10 for Sector II. About 80% of the P values occur within the limits of (P_m -0.5) and (P_m + 1.47). About 30 and 50% of the P values for Sector I and II, respectively, occur between -0.3 and +0.4.

5.4.4.3 Summer season. Figures 16 and 17 present median values of Q and P for the summer season. It is difficult to isolate wind direction sectors in which the flow regimes might be distinct. Nonetheless, three sectors were examined:

1. Sector I (NNW-NE). Much of this sector lies between Birch Mountains and Muskeg Mountain. Wind directions tend to remain constant with height while wind speeds tend to decrease;
2. Sector II (ENE-SE). Muskeg Mountain is situated in this sector. In general, winds tend to veer with height while wind speed decreases;
3. Sector III (SSE-NW). Stoney Mountain and the unnamed mountain lie within this sector. Wind has a tendency to veer with height while speed remains essentially constant; and

Figure 18 shows the cumulative frequency of Q for each of the three sectors. All median values of Q are small. The difference in Q values between the three sectors is probably not statistically significant. Of all Q values in Sectors I, II and

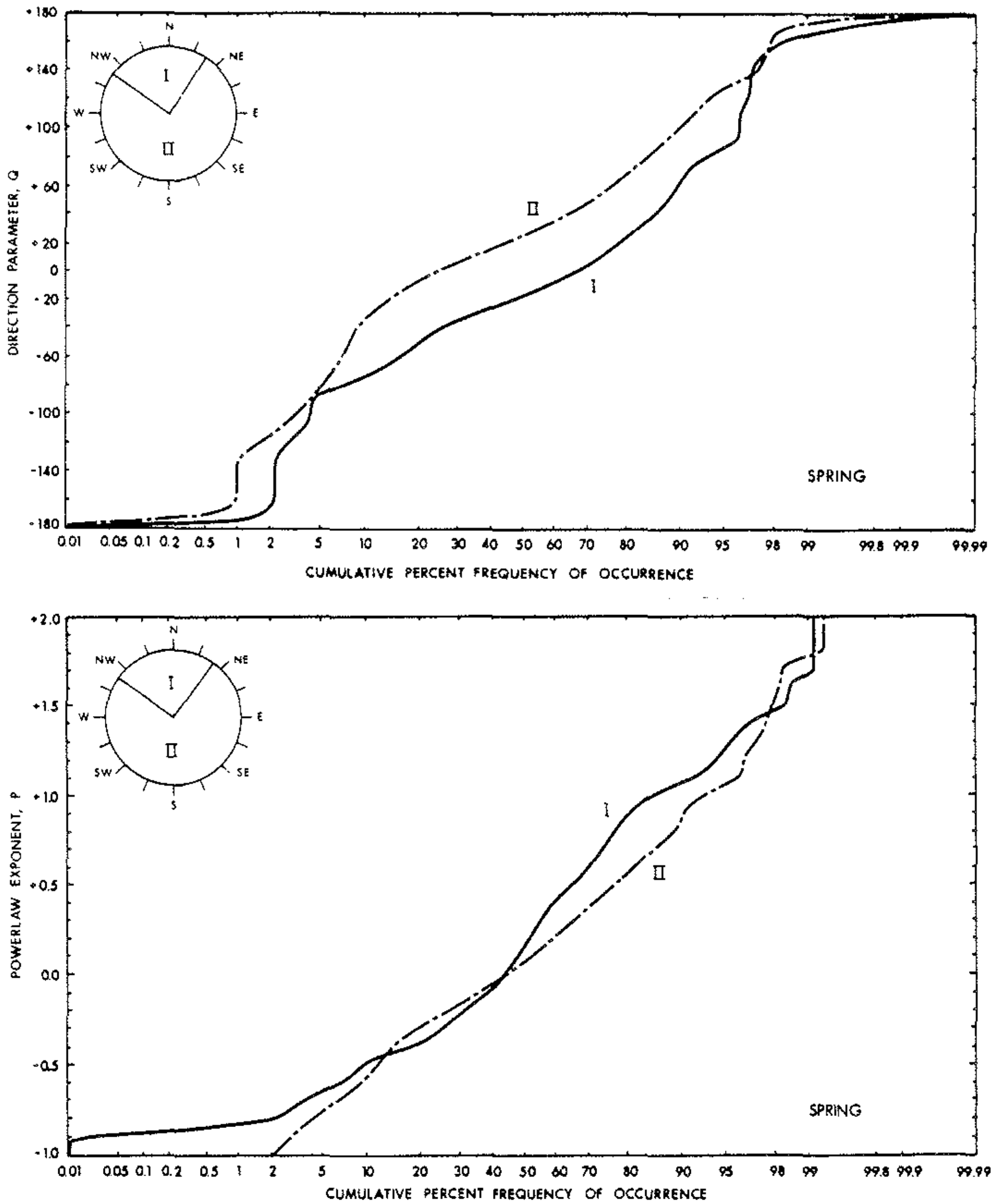

Figure 15. Cumulative frequency distribution of Q and P in each of the indicated sectors for spring months.

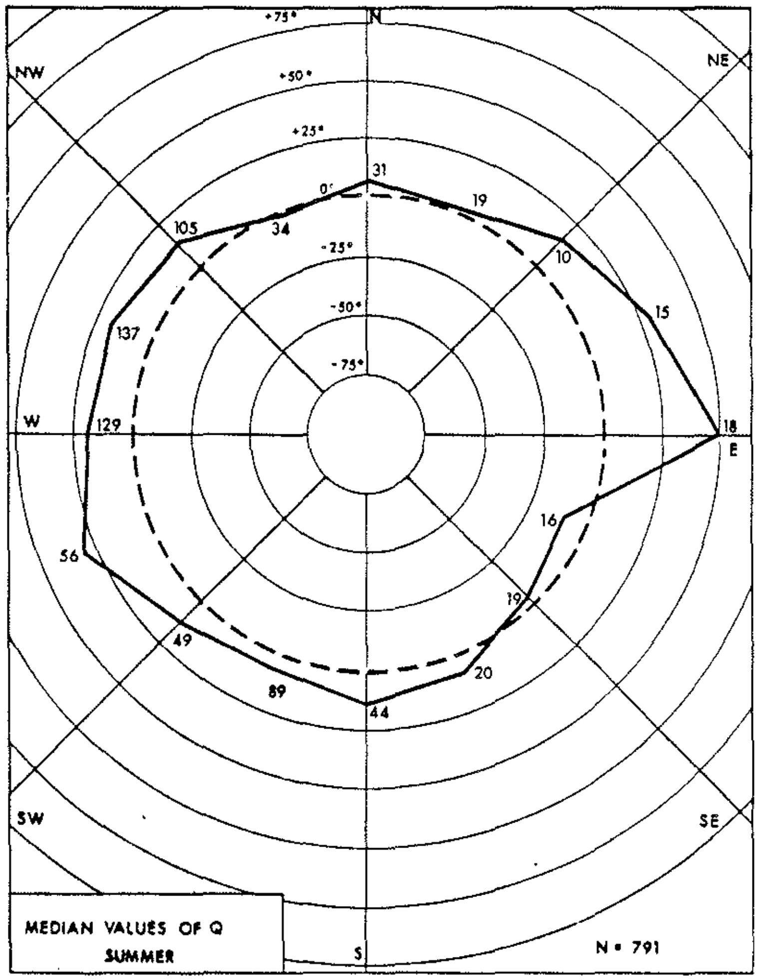

Figure 16. Median values of Q for summer months as a function of wind direction, showing the number of observations for each direction.

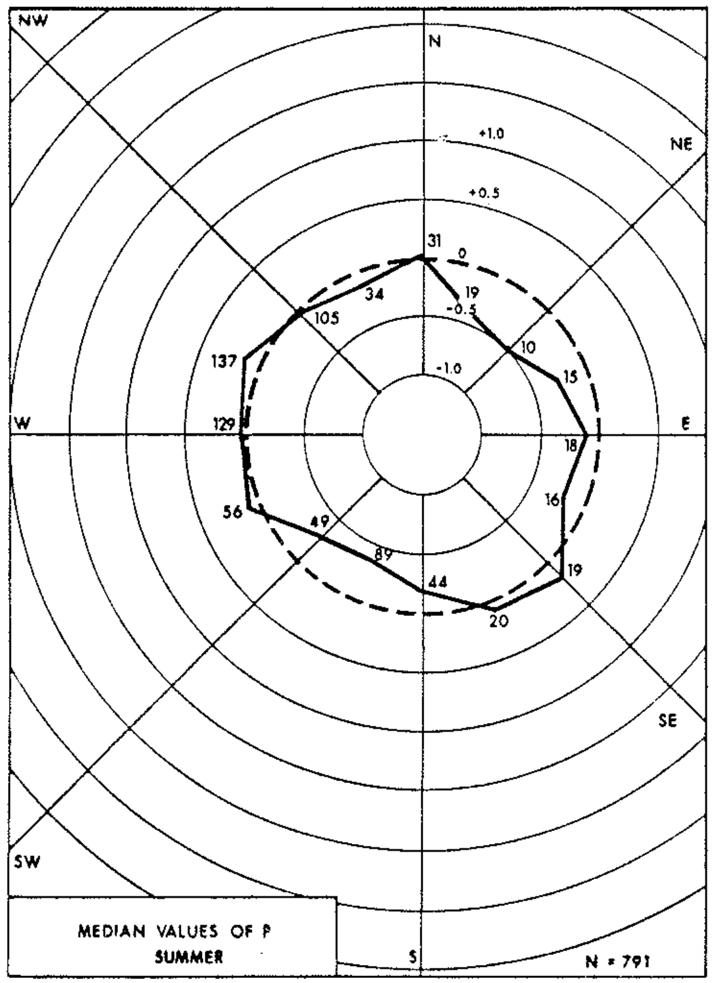

Figure 17. Median values of P for summer months as a function of wind direction, showing the number of observations for each direction.

III, respectively, lie within ±20° range centred on the median.

Figure 18 also shows cumulative frequency distributions of P for each of the three sectors. Median values for Sectors I, II, and III are -0.2, -0.1, and 0.0, respectively. These differences are probably not statistically significant. About 80% of the P values occur within the limits of P_m - 0.5 and P_m + 1.47 and about 50% of the P values occur within the limits of P_m - 0.3 and P_m + 0.4.

In conclusion, it appears as though topographically induced air flows are not very significant at the 400 m level during summer months. This statement, however, must be qualified with the reminder that most of the pibal observations were made during daylight hours when terrain influences are minimal.

5.4.4.4 Autumn season. Figures 19 and 20 present median values of Q and P for the autumn season. The data may be discussed in terms of three sectors.

1. Sector (NNW-NE). Much of this sector lies between the Birch Mountains and Muskeg Mountain. Median values of both P and Q tend to be small.
2. Sector II (ENE-ESE). There are no data from this sector; and
3. Sector III (SE-NNW). Stoney Mountain and the unnamed mountain lie in this sector. The wind usually veers with height with a change of 25° between the 400 and 1200 m levels. Wind speeds tend to remain constant with height.

Figure 21 presents the cumulative frequency of Q for each of the sectors. The median values of Q for Sectors I and III are 5 and 25°, respectively. Of all Q values in Sectors I and III, 75 and 90%, respectively, lie within ±45° of the median value. For both sectors, 65% of all Q values lie within ±20° range of the median value.

Figure 21 also shows the cumulative frequency distributions of P for each of the two sectors. The median value

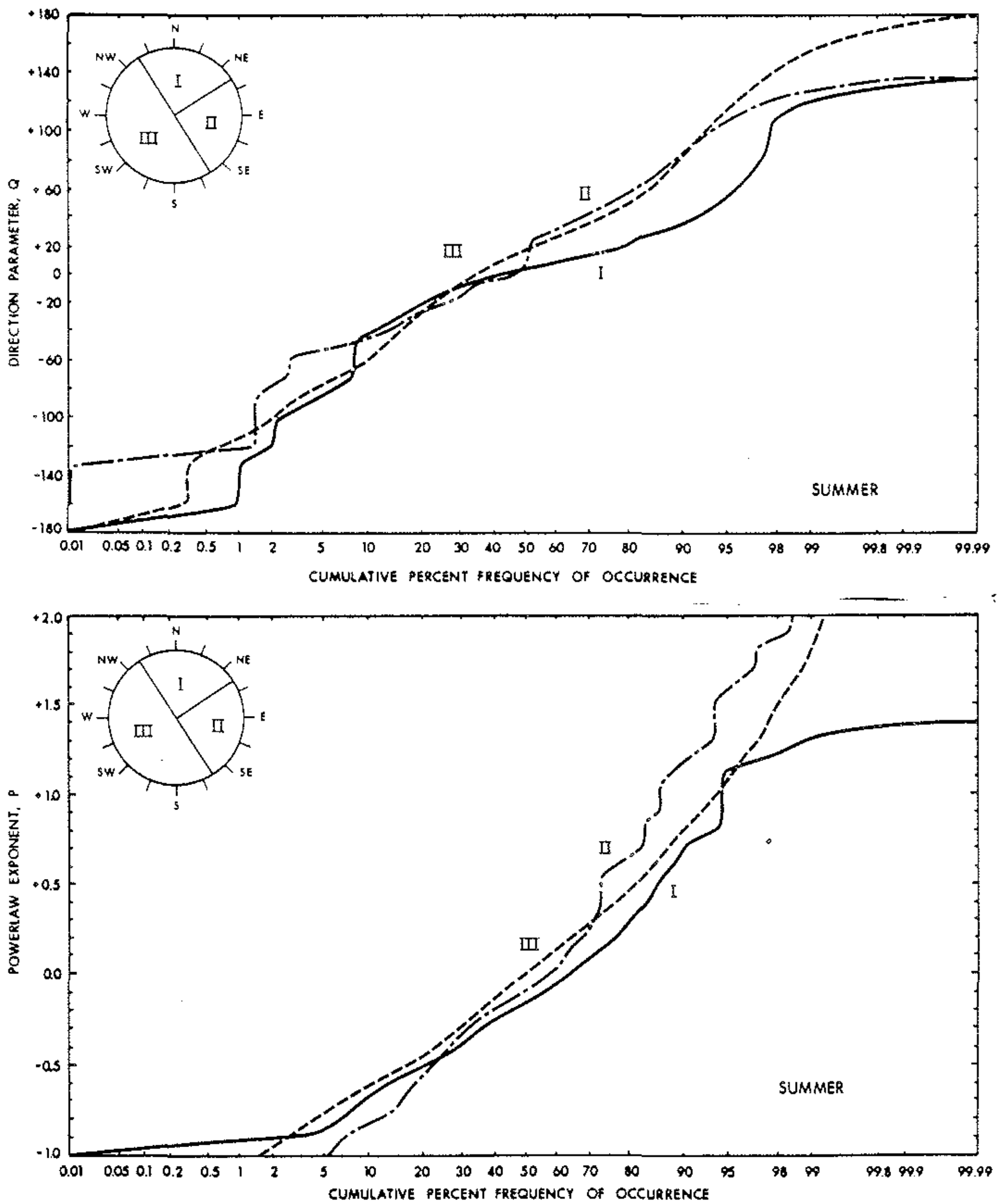

Figure 18. Cumulative frequency distribution of Q and P in each of the indicated sectors for the summer months.

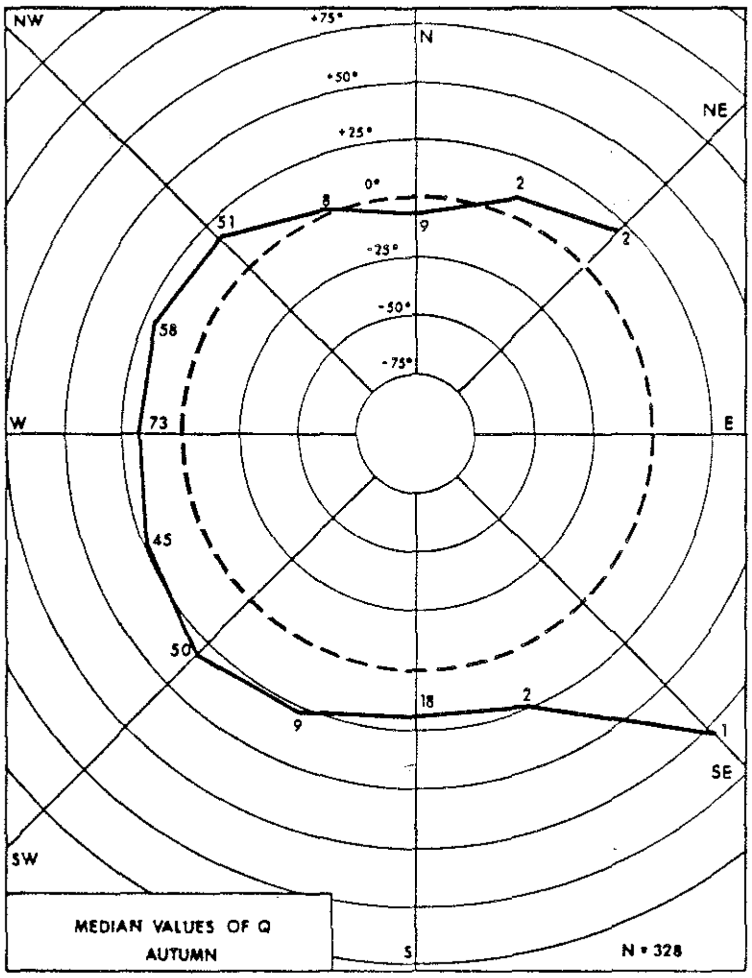

Figure 19. Median values of Q for autumn months as a function of wind direction, showing the number of observations for each direction.

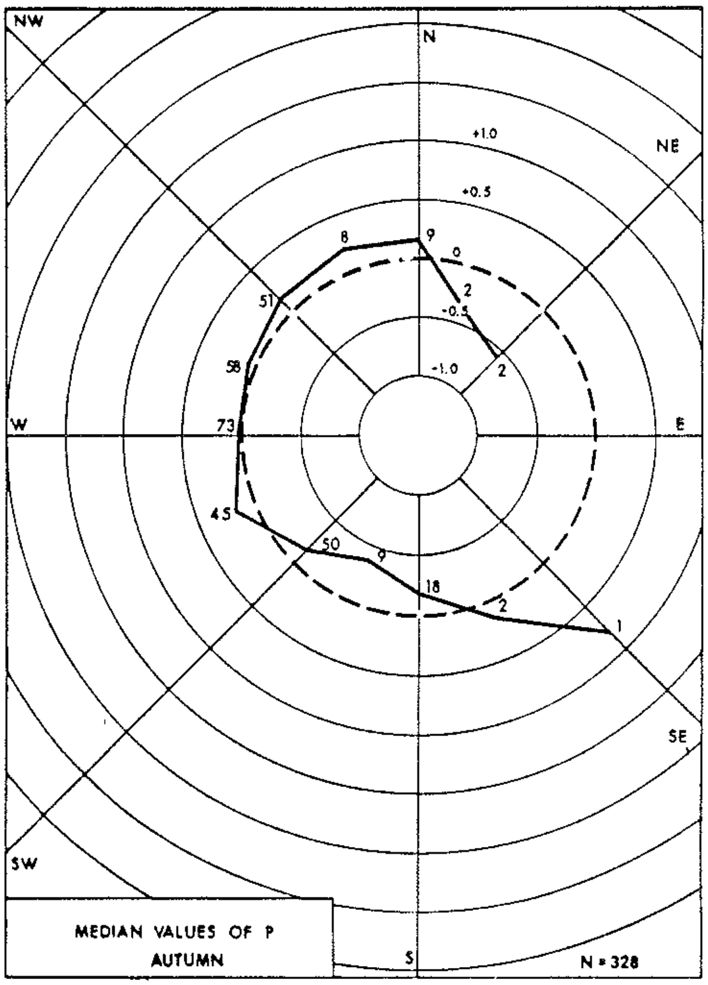

Figure 20. Median values of P for autumn months as a function of wind direction, showing the number of observations for each direction.

for both sectors is near zero. There is no appreciable difference in the distributions. About 90% of the P values occur within the limits P_m - 0.5 and P m + 1.4. About 70% of the P values occur within the limits P_m - 0.3 and P_m + 0.4.

5.4.5 Summary

The results of the comparisons between the predicted and observed 400 m level winds are presented in Table 3. This table provides an indication of the amount of scatter that can be attributed to the nature of the pibal observations. For example, during the spring, about 70% of the scatter in the median value of Q is within the range ±45°. For neutral atmospheres, this is within the range expected (± three sigma) due to the instantaneous nature of the pibal observations. However, only 40% of the data are within ±20°, and so a significant portion of the discrepancies cannot be attributed to the statistics of the pibal data. The worst case for wind direction is for northerly winds in the winter, where the scatter of Q indicates significant correlation limitations.

Terrain features such as the Birch Mountains and Muskeg Mountain appear to have a noticeable influence on wind velocity at the 400 m level. This is especially true during the winter months. More detailed comparisons between observed and derived 400 m level winds and the impact of their uncertainty on model predictions are presented in Volume 3 of this report.

5.5 DERIVED TIME SERIES WIND DATA FILE

Estimated hourly average geostrophic wind data for the Athabasca Oil Sands area were obtained through use of the 850 mb charts available from the AES for 0000 and 1200 GMT for the months of January, April, July, and October from 1976 to 1978, inclusive. These data were then adjusted using the directional median values of P and Q shown in Figures 10, 11, 13, 14, 16, 17, 19, and 20. Details of the mechanics involved to obtain 400 m winds from the 850 mb charts are presented as an appendix.

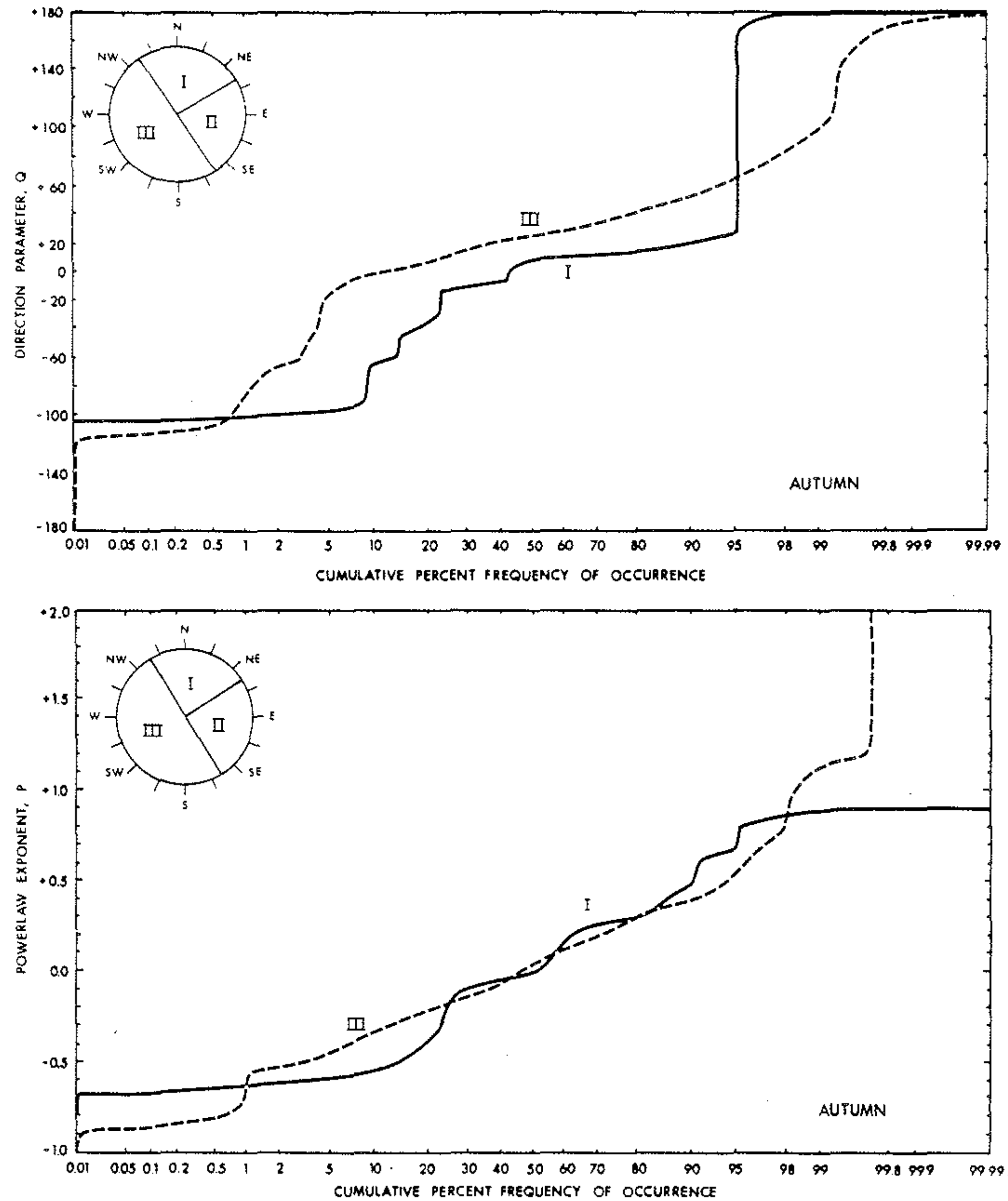

Figure 21. Cumulative frequency distribution of Q and P in each of the indicated sectors for the autumn months.

Figure 22 presents the preliminary wind climatology derived from the above procedure for winter, spring, summer, and autumn months. Northerly and southwesterly winds are predicted to predominate in winter. In spring, the wind flow is predicted to be mainly southwesterly. Winds are predicted to be generally westerly during the summer and strongly westerly during the autumn months.

Table 3. Percent of observations within selected P and Q ranges for different sectors and seasons.

		P		Q	
Season	Sector	(-0.5,+1.4)	(+0.4,-0.3)	±45°	±20°
Winter	1 NW-NNE	90	55	30	15
	2 NE-ESE	90	75	75	50
	3 SE-WNW	90	55	75	50
Spring	1 NW-NNE	80	30	70	40
	2 NE-WNW	80	50	70	40
Summer	1 NNW-NE	80	50	85	60
	2 ENE-SE	80	50	70	35
	3 SSE-NW	80	50	65	40
Autumn	1 NNE-NE	90	70	75	65
	2 ENE-ESE	-	-	-	-
	3 SE-NNW	90	70	90	65

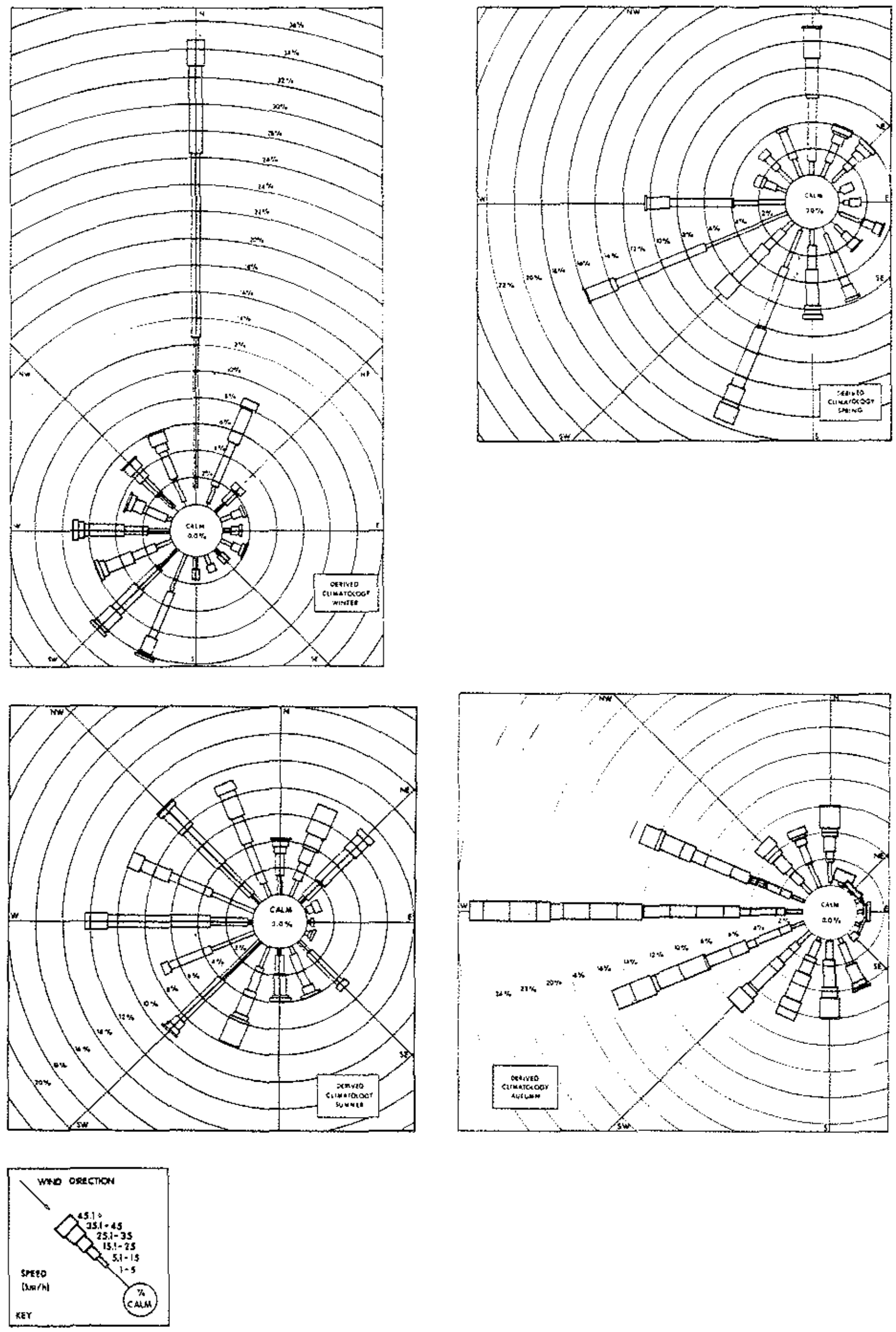

Figure 22. Derived wind climatologies for each season based on 850 mb data from 1976 to 1978 and seasonal directional median P and Q.

6. CONVECTIVE MIXING HEIGHTS

The thermal structure of the atmosphere will have a significant influence on plume dispersion and hence ground level air quality. This is especially true in cases where the plume may be trapped within a convective mixing layer. It is therefore important to know how this parameter might vary with time.

There were a total of 2222 vertical temperature profiles obtained by minisonde in the Mildred Lake area during the years 1975 to 1978, inclusive. Figure 23 shows the distribution of the data according to time of year. Most of the data were collected towards the beginning of February and during March and July. There are relatively few data for the months of May and December.

All the minisonde temperature data were analyzed to determine the convective mixing depth, which was taken as the height above ground at which the dry adiabat through the surface temperature intersects the temperature profile. When no surface mixing layers were observed, the height was taken as zero. These mixing depths were then analyzed to determine the variation according to time of day and season. The results for the winter season were based on data from December, January, and February; for spring, March, April, and May; for summer, June, July, and August; and for autumn, September, October, and November.

Figure 24 shows the diurnal variation in the median calculated mixing depths based on non-zero mixing height values. The smooth lines through the median values were subjectively drawn. Median values in excess of 400 m indicate that plumes from a Syncrude-type source will be trapped within a limited mixing layer during the spring, summer, and autumn months. During the winter season, plumes from these sources will not normally be trapped.

The convective mixing heights for the time series file were obtained from smooth curves given in Figure 24 and are presented in Table 4. Slightly larger median mixing depths were observed during the spring than in the summer for 7 h of the day. For these hours, the larger spring values were also used for the summer. These values are indicated in the table.

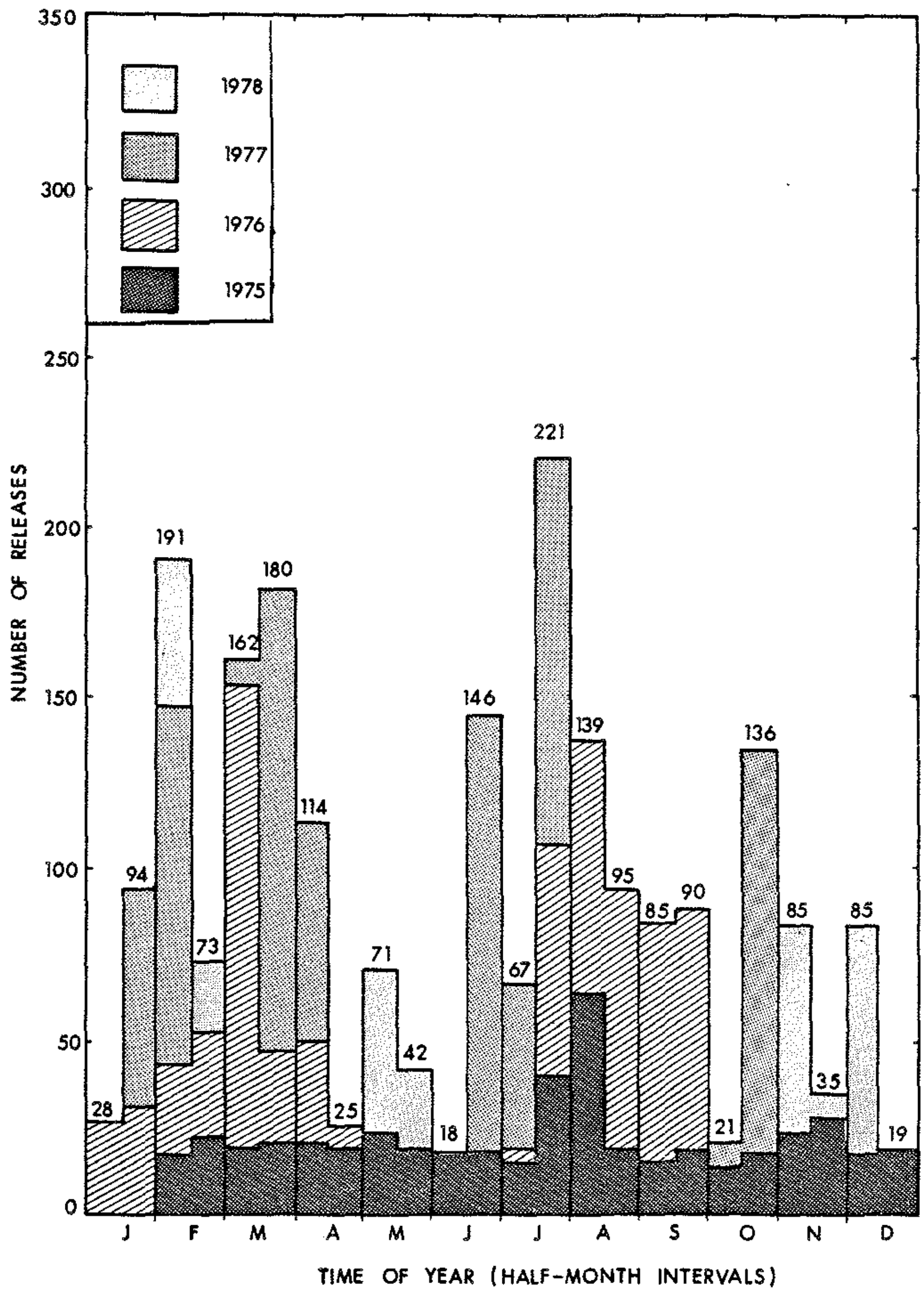

Figure 23. Monthly distribution of the 2222 minisonde releases from which conventional convective mixing heights were obtained.

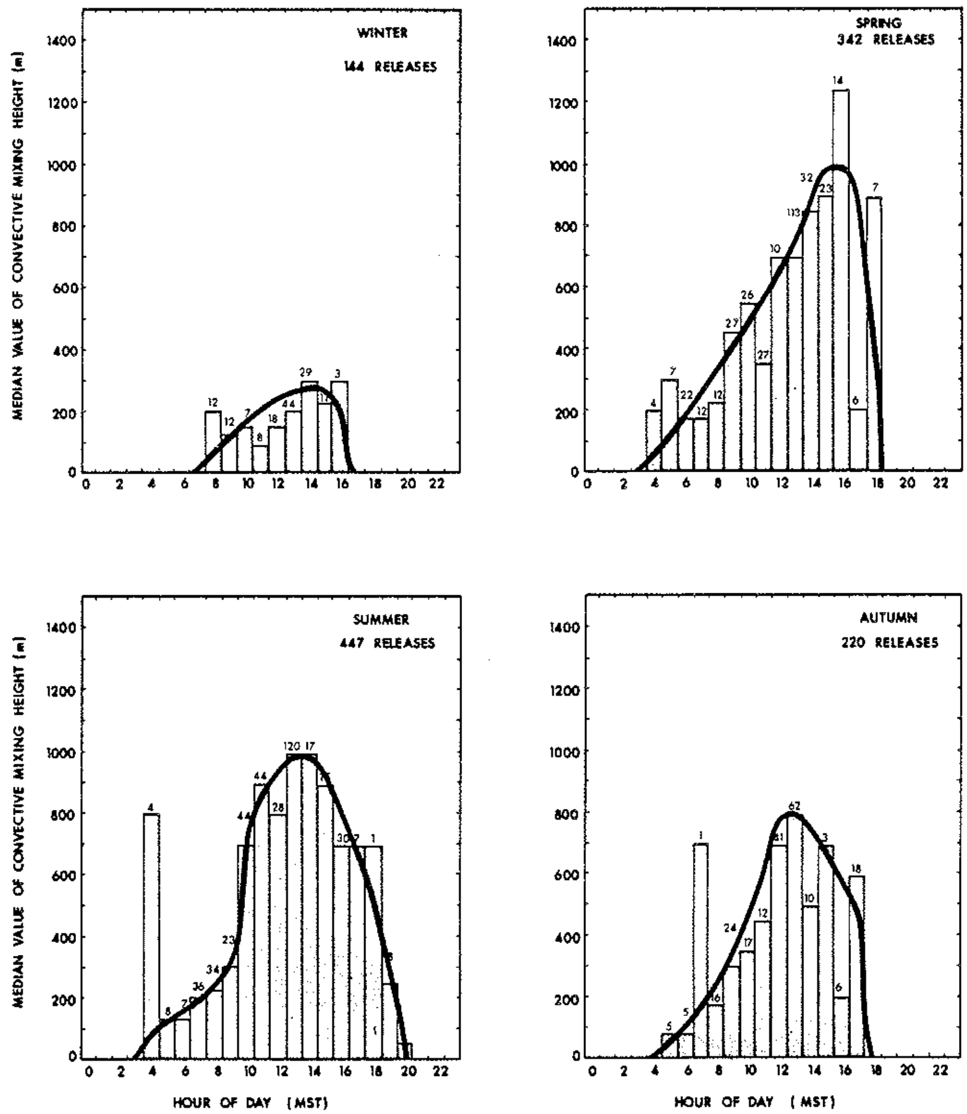

Figure 24. Hourly median values of convective height for each season based on minisonde data. The number of data for each hour is shown.

Table 4. Seasonal hourly values of convective mixing height (m).

Hour	Winter	Spring	Summer	Autumn
0	0	0	0	0
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	70	70	0
5	0	120	120	50
6	0	200	200a	100
7	0	250	250a	170
8	60	350	350a	220
9	120	420	420a	350
10	170	500	700	450
11	200	570	850	600
12	220	650	920	770
13	260	750	1000	800
14	270	900	1000	750
15	260	1000	1000a	670
16	200	1000	1000a	600
17	0	900	900a	500
18	0	400	500	0
19	0	0	300	0
20	0	0	50	0
21	0	0	0	0
22	0	0	0	0
23	0	0	0	0

[a] modified values--refer to text.

7. CONCLUSIONS

In order to obtain preliminary results and validate the Gaussian frequency distribution model, an hourly meteorological time series was developed for January, April, July, and October for the years 1976 through 1978. Major components of the time series are selected meteorological parameters from a standard surface weather record, as well as net radiation, 400 m wind speed and direction, and the convective mixing heights.

Hourly net radiation estimates were calculated from parameterizations of net solar and terrestrial radiation. Wind speed and direction estimates for heights of 400 m were generated by empirical direction dependent algorithms operating on estimated 850 mb winds. The empirical algorithms were based on the analysis of 2344 pibal ascents. Minisonde data were used to generate seasonal estimates of the convective mixing height as a function of time of day.

During the development of the time series files, several specific findings were made. These findings refer to the parameterization of the net radiation, derivation of wind climatology, and the derivation of the mixing height climatology.

7.1 NET RADIATION

The parameters in the net radiation formulation were evaluated using results of analyses of the AOSERP data base as presented by Kumar (1978). The data provided constraints on possible values for the parameters which were consistent with values in the literature. Of specific interest was the necessary allowance for the effect of snow cover on the albedo and the change of the effective surface for direct solar radiation. At lower solar altitudes, the albedo was low (0.2 at noon on 12 December) even in the presence of snow cover. However, at higher solar altitudes, the increased visibility of the snow for direct solar radiation apparently generated a significantly larger albedo (0.5 at noon on 21 March). At the autumn equimax, in the absence of snow, the albedo was similar to the summer and winter values.

There were marked seasonal differences in the net radiation estimates at noon on cloudless days (a factor of 30 between early January and early July). The differences were much greater than the ratio of solar altitudes because net radiation was a residual of solar and terrestrial radiation. The plume sigma formulations in the present model used estimates of the heat flux derived from the net radiation and so these major solar altitude effects were incorporated into the model. The sensitivity of net radiation to solar altitude, and particularly to the seasonal changes, should be a major consideration for any sigma typing scheme used in the mid- and higher latitudes. In particular, the simple criteria of daytime insolation in the stability formulation by Pasquill (1961) are clearly inappropriate for use in the winter months in the Athabasca Oil Sands region.

7.2 WIND

Theoretical calculations indicated that plume heights from Syncrude type sources would usually be near the 400 m level. Wind data obtained from pibal information showed that air flows at this level were poorly correlated to wind observed near ground level at either the Fort McMurray Airport or the Mildred Lake Research Facility. The 400 m winds were also poorly correlated to wind data obtained from the Tall Tower located in the Athabasca River Valley. This was attributed to valley flow effects.

During spring, summer, and autumn, the 400 m wind data were closely related to winds at 1200 m (i.e., geostrophic winds) as derived from 850 mb charts. There is some evidence of terrain effects caused by channelling of air between the Birch Mountains and Muskeg Mountain. During winter months, the correlation between 400 m winds and the 1200 m geostrophic winds is very poor. The explanation appears to lie in much enhanced influences of terrain induced phenomena such as channelling and katabatic effects.

A seasonal wind climatology was generated for the 400 m level from three years of 1200 m geostrophic wind data collected during the months of January, April, July, and October. Derived winds during spring, summer, and autumn are usually southwesterly, westerly, and strongly westerly, respectively. During winter months, the winds were predicted to be northerly.

7.3 MIXING HEIGHT

A climatology for the diurnal variation of median mixing depths has been derived from results of 2222 minisonde observations made in the Athabasca Oil Sands area from 1975 to 1978. Mixing depths were defined as the heights above ground at which a dry adiabat through the surface temperature intersects the temperature profile.

Results of the analysis showed that median mixing depths during winter are usually less than 300 m. They are much greater in the spring, summer, and autumn months where values during the early afternoon may routinely exceed 700 m.

8. RECOMMENDATIONS

The hourly meteorological time series file obtained for the study should be viewed as preliminary. Many tasks remain with respect to the further development of a more complete understanding of the meteorological characteristics in the Athabasca Oil Sands area. These include:

1. The derivation of heat flux from the net radiation estimates should be reviewed more thoroughly, particularly in light of the need for improvements in the representation of the other terms in the surface energy budget;
2. Evaluation of the wind data collected near the ground at sites within the AOSERP area other than Fort McMurray, the Tall Tower, and the Mildred Lake Research Facility;
3. Determination of the long-term climatological representativeness of the years 1976 through 1978 and the selection of additional years as necessary;
4. Determination and implementation of an optimized procedure for the expansion of the hourly time series of winds and other meteorological parameters;
5. A more detailed analysis of wind and atmospheric pressure data collected during winter seasons. The purpose of such an analysis would be to explain large departures of wind from the pattern expected on the basis of 1200 m pressure gradients;
6. A detailed analysis of wind and atmospheric pressure data to define the vertical, horizontal, and temporal extents of wind flow in the Athabasca River Valley.
7. The convective mixing height values need to be estimated according to a formulation which allows for day-to-day variations, rather than the present monthly climatology. The mixing height formulation

could involve the development of a statistical relationship with minisonde data, including the net radiation data which are now available. Alternatively, relationships could be established between the available minisonde data and the temperature profiles obtained by radiosonde from Stoney Plain and/or Fort Smith which lie 400 km south-southwest and 350 km north of Fort McMurray, respectively. Mixing height models with validation by the minisonde data might also be useful;

8. A comparison should be made of mixing depths defined by the conventional method with those defined by the kink method. In the kink method, the convective mixing height is the first point at which the rate of change of temperature and height is maximum. The mixing height definition utilized must suit the formulations in the boundary layer parameterizations used in the model; and

9. The frequency distribution of the ratio of plume height to mixing height should be calculated to optimize the mixing height discretizations in the model. This optimization would need to consider the magnitude of the ground level concentrations and the rate of change of those concentrations with changes in mixing height.

The above recommendations highlight the major areas to evaluate in order to obtain a more comprehensive and representative hourly average time series file. The amount of effort required depends to a large extent upon model sensitivity analyses presented in Volume 3 of this report and feedback by typical users after familization with the frequency distribution model.

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10. APPENDIX

10.1 DERIVATION OF THE TIME SERIES WIND DATA

The meteorological time series file contains derived wind speeds and directions for the 400 m level. The 400 m winds were derived from the 850 mb analysis charts provided twice daily by the Atmospheric Environment Service (AES). This section provides details of the procedure used to obtain time series wind data.

10.1.1 Calculation of 850 mb Winds

Upper atmospheric wind, pressure, temperature, and relative humidity are measured twice daily (0000 and 1200 GMT) by simultaneous release of radiosondes across the country. This information is used by AES to produce charts at standard pressure levels of which the 850 mb level is the lowest. In the Athabasca Oil Sands area, the 850 mb pressure level corresponds to an average height of about 1200 m above ground level.

Each 850 mb chart contains data for all radiosonde stations and contours of pressure level height based on all the stations. The 850 mb winds in the Athabasca Oil Sands area can be estimated from these pressure height contours using the geostropic approximation. Specifically, the wind speed was estimated from:

$$V = g\,\Delta Z/(fd) \qquad (12)$$

where:
V = wind speed (m/s)
g = acceleration due to gravity (9.81 m/s)
$f = 2\,\Omega \sin\phi$ (Coriolis parameter)
Ω = angular velocity of earth's rotation (7.29×10^{-5} radian$\cdot$ s^{-1})
ϕ = latitude (57°)
d = perpendicular distance between height contours (m)
ΔZ = height difference over distance d (normally 60 m).

This relationship can be reduce to

$$V = 4.8 \times 10^{6} \; (FC/d) \qquad (13)$$

where: F = the map scaling factor

C = height difference correction factor

d = perpendicular distance measured on 850 mb chart (cm).

The map scale factor converts the map distances to actual distances. This factor was obtained as the ratio of the Alberta-Saskatchewan border between 60 and 49° determined from the 850 mb charts, divided by the actual distance of 1220 km. Charts were supplied on microfilm with two different sizes of reduction. Care had to be taken to apply the proper scaling factor to each chart.

If a constant value for ΔZ of 60 m is assumed, then a correction factor(C) must be used for the cases where ΔZ is not 60 m ($C = \Delta Z/60$). Wind directions were determined from the 850 mb contour analysis. The direction was assumed to be parallel to the contours, clockwise around a contour high, and counter-clockwise around a contour low.

For each chart the following information is required:

1. Year, month, day, hour (0000 or 1200 GMT);
2. Map scaling factor;
3. Perpendicular distance, d(cm), between height contours;
4. Difference between height contours, if different from 60 m; and
5. Wind direction in degrees.

The analysis involves determining the correction factor (C) to convert the perpendicular distance (d) to wind speeds at 0000 and 1200 GMT using Equation 13. Linear interpolation was used to obtain hourly values of wind speed and direction from the 0000 and 1200 GMT values. It was assumed that the wind direction never shifted by more than 180° in a 12 h time period. The computer program WINDGEN was used to obtain the hourly values of the 850 mb winds using information abstracted from the 850 mb analysis charts.

10.1.1.1 Estimating wind direction. To aid in determining wind direction, templates were prepared with directional axes radiating from a reference location representing the Athabasca Oil Sands area. The axes ranged through 360° in increments of 20°. An outline of the Province of Alberta was traced on each template to provide a geographical reference and ensure proper orientation of the direction axes. The 850 mb charts were projected onto the appropriately sized template.

Wind directions were determined by comparing the orientation of the pressure height contours with respect to the direction axes. The wind direction was recorded to the nearest 10°. It could be determined quite readily most of the time by using this method. In some cases, more subjective judgement was required to estimate the wind direction. These cases included:

1. The presence of a high or low pressure centre near the reference location. In this case, the direction was assumed to be tangent to an intermediate contour; and
2. Poorly defined contour pattern. The direction was determined using the Fort Smith and Stoney Plain values as a guide.

It should be noted that Case 2 situations were infrequent.

All the abstracted wind directions were recorded by one observer, and verified by a second observer. The pressure height contour pattern was found to affect the reproductability of the abstracted data. For most well-defined contour patterns, there was good agreement between the observed and verified results. Occasionally, differences of 10° were encountered. For less well-defined contour patterns, differences of up to 30° could be found.

10.1.1.2 Estimating separation distances. The separation distances between two pressure heights were used to estimate wind speeds. These distances were estimated to the nearest 0.05 cm. For typical separations, ranging between 1.0 and 3.0 cm, this represents uncertainties in the estimated wind speed ranging from 5 to 2%.

As in the estimation of wind direction, there were cases where more subjective judgement was required to estimate separation distances. Again, these cases included:

1. The presence of a high or low pressure centre near the reference location. The separation distance was estimated by drawing in an intermediate contour. Here the contour spacing would be less than 60 m and the correction factor, C, was calculated; and
2. Poorly defined contour pattern. The wind speed was determined using the Fort Smith and Stoney Plain values as a guide.

As in the estimation of wind directions, the estimation of the separation distances involved two observers. For well-defined contour patterns, there was good agreement between the recorded and verified results. Occasionally, differences of 0.1 cm were encountered. For less well-defined contour patterns, differences of approximately 10% were found.

10.1.2 Calculation of the 400 m Winds

Empirical relationships between wind speed and direction at 850 mb and 400 m were derived using 400 m pibal wind information from the Athabasca Oil Sands area, and concurrent 850 mb wind information obtained by the methods described in Section 5. Equation 10 expresses the relationship between the wind speed at the two levels. The relationship between directions at the two levels is simply a difference. The parameters which characterize the change of speed and direction are P and Q. These values are three levels of P and Q data which result from this analysis: median values for each wind direction, median values for each sector, and best fit median values for each sector.

Hourly values of wind data at 850 mb were converted to hourly values of wind at 400 m using the computer program WINDCON. The program incorporates the median values of P and Q for each wind direction and season.

10.1.3 Uncertainties in the Generation of the 850 mb Wind Data

The derived time series wind data are treated by the Gaussian frequency model as hourly average values at the height of the plume. In deriving these winds, certain assumptions were made that could lead to uncertainties that are difficult to quantify.

Uncertainties in the estimation of hourly average winds at the 850 mb level include:

1. The validity of the geostrophic assumption at the 850 mb level.
2. Dependence of abstracted winds upon the pressure height contour analysis;
3. Measurement limitations in obtaining the 850 mb wind values; and
4. Linear interpolation of the 0000 and 1200 GMT values to obtain hourly average wind data.

The third point was discussed in the previous section and is relatively easy to quantify. The other three points are difficult to quantify since real data referring to hourly average 850 mb winds are not available for comparison purposes.

10.2 DERIVATION OF THE TIME SERIES OF THE CONVECTIVE MIXING HEIGHT DATA

The meteorological time series file contains hourly convective mixing heights for each season of the year. The data were obtained from 2222 minisonde releases in the Athabasca Oil Sands area from 1975 to 1978. This section provides details of the procedure used to obtain the time series convective mixing height data.

10.2.1 Calculation of Convective Height

Several minisonde programs took place in the Athabasca Oil Sands area in the period from February 1975 to December 1978, inclusive. Some of the data are from continuous programs ranging over several months and involving 2 to 4 releases per day. Other data are from more intensive programs ranging over 1 or 2 wks and involving up to about 10 releases daily. The more intensive programs were distributed in time so that for the entire observing period, one occurred in nearly every month of the year.

The conventional convective mixing height is defined as the height at which a dry adiabat through the surface temperature intersects the temperature profile. The procedure for calculating convective mixing heights for the time series of meteorological data is:

1. Conventional convective mixing heights (in metres) were obtained for each release;
2. The data were keypunched and sorted into seasons of the year using the computer program TISORT;
3. All release times were converted to Mountain Standard Time (MST). Next, a frequency distribution of mixing height was determined for each hour. These tasks were performed using the computer program MIXHFREQ;
4. Hourly median values of mixing height for each season were determined from the non-zero data in each frequency distribution. The summer values were modified such that the median values were not less than the spring values; and
5. The median hourly mixing heights for each season were used to prepare monthly data for the meteorological time series. This task was performed using the computer program MIXHGEN.

10.2.2 Reading Conventional Convective Mixing Heights from Minisonde Data

Conventional convective mixing heights were obtained from each minisonde release. The procedure for obtaining the information was very straight forward.

For about one-half of the minisonde data, calculation of the conventional convective mixing height was included in the procedure which evaluated observed field data to give wind and temperature profiles. Mixing heights as given in the evaluation for each release were used in the analysis for time series mixing heights.

In about three-quarters of the remaining minisonde data, the calculated mixing heights were made available only occasionally but listing of potential temperature with height was available. To make the analysis consistent for this data set, all mixing heights were taken from the profile of potential temperature. The level where potential temperature in the profile equalled the surface potential temperature was taken as the mixing height and used in the analysis for time series mixing heights.

The remaining minisonde data did not present any information on calculated mixing heights, but did include plots of temperature verses height for each release. An overlay containing a single plotted dry adiabat was used to read off the mixing height from these graphs.

10.3 COMPUTER PROGRAM DESCRIPTIONS

10.3.1 Overview of the Analysis Programs

A number of computer programs were used to generate the time series data file. Some of the programs were simply format changing programs to allow for the conversion of data tapes produced by Western Research and Development into data files that could be readily utilized on INTERA's computer system. These formatting programs should be of no interest to future users of the model. The other programs were used to synthesize data files from the three major sources of data. A summary of the programs and their purposes is presented in Table 5. Detailed descriptions of the programs and of each of the component subroutines are presented in the following sections.

Table 5. An overview of the computer programs used in the development of the meteorological time series data file.

Program	Purpose
SFCFIL	Reads the digitized daily surface weather record and produces two output files, one for the hourly data and one for the accumulated precipitation and snow cover data.
WINDGEN	Generates hourly wind data at 850 mb from data obtained from the twice daily 850 mb charts.
POWERLAW4	Determines frequency distributions for parameters relating windspeed and direction at two levels as a function of wind speed and direction at one of the levels.
WINDCON	Reads output file of WINDGEN and calculates hourly wind data for the 400 m level.
MIXHGEN	Generates a file of hourly mixing height data for 1 mo. periods from hourly values on particular days.
MIXHFREQ	Produces a frequency distribution of convective mixing height as a function of hours of the day.
TIMSER	Synthesizes output data files from the above programs to generate the meteorological time series data file used by the model. Radiation estimates are generated from the time and cloudiness data.

10.3.2 SFCFIL

PURPOSE: This program creates the time series of surface meteorological data from AES surface weather records.

INPUT: COMMON/DAYTIM/ITIME,IDAY,IMONTH,IYEAR,IRH,ICLDCV,ITEMP ISFCWX

OUTPUT: COMMON/DAYTIM/ITIME,IDAY,IMONTH,IYEAR,IRH,ICLDCV, ITEMP,ISFCWX

PROCEDURE: The program checks whether hours of data have been lost in the conversion of times to GMT. If so, additional records are read from the input file. If the data are pre-1977, subroutine CHNGES is called which signals SFCFIL to restructure each hour's record and convert to metric units. Precipitation data are read from a second file and converted to metric if necessary. Data lost in GMT conversion are read if necessary. Precipitation data and the remainder of the surface weather data are written to two separate files, undifferentiated by month.

SUBROUTINE CHNGES

PURPOSE: This routine flags pre-1977 hourly records so that the program SFCFIL can re-order the values on the records and convert them to metric units. It is called by SFCFIL.

INPUT: None

OUTPUT: COMMON/DAYTIM/ITIME,IDAY,IMONTH,IYEAR,IRH,ICLDCV,
ITEMP,ISFCWX

10.3.3 WINDGEN

PURPOSE: This program generates hourly wind data at 850 mb from data obtained from the twice daily 850 mb charts

INPUT: NTIMES,VERIFY,DSKFIL,FSCALE
YR,MO,ISCALE
GMTDA,GMTHR,DIR,SPD,H1,H2

OUTPUT: YR,MO,DA,OUTHR,OUTDIR,OUTSPD

PROCEDURE: Control data are input with read statements. The scaling factors (FSCALE)for converting input 850 mb contour spacing (cm) to wind speed (m/s) are input with a data statement. The variable ISCALE determines which scaling factor will be used. The input 850 mb chart data for 1 mo. are read and stored. Contour spacing is converted to wind speed by applying the appropriate scaling and calculated correction factors. Hourly wind data are generated by linear interpolation between twice daily values. Hourly data for a month are written to an output file. Run parameters and verification information is written to the printer. The program can analyze data for several months in one run.

10.3.4 POWERLAW4

PURPOSE: This program determines frequency distributions for parameters relating windspeed and direction at two levels as a function of wind speed and direction at one of the levels.

INPUT: TITLE, NDATA, NCLASP, NCLASB, PCLASS, BCLASS
NLENEM,ERRORM,JFLAG,ITYPE,QTYPE
TITLE1,SUNIT,DIRF,Z,COR
DIRAS,TIME,DIR,SPD,
TITLE2,CSUNIT,CDIRF,CZ,CCOR
CDIRAS,CTIME,CDIR,CSPD

OUTPUT: TITLE,TITLE1,TITLE2,IA,IB,IC,ID,Z,CZ
JJJ,TYPE,ITYPE,QTYPE,NND,VCLASS
NCLASV,NV,CLASS,NCLASM,MMP,MP,RMED,
COMMON/LTLMAT/FREQ,CMFREQ

PROCEDURE: Run control parameters are input by the subroutine INPAR. Input control parameters for each wind data file are read by the subroutine READ1. Wind data at one level are read and stored by the subroutine READ2. Wind data at the second level are read line-by-line as the analysis proceeds. Each set of wind data is checked to ensure that correspondence exists between time and units. If any data is missing, the set is omitted from the analysis. The parameters relating speed and direction at the two levels are calculated and the appropriate frequency counters are incremented. After obtaining the frequency arrays, the subroutine SPETAB is called to combine frequency arrays for designated wind directions if analysis by sector has been specified. The subroutine

CUMMED is called to calculate for each speed and direction class a cumulative percent frequency and median value of the parameters relating direction and speed. The subroutine OUTPUT is called to write a table giving the frequency information.

II. LIST OF AOSERP WIDE DISTRIBUTION RESEARCH REPORTS

Report	Project	Reference
1	PM	Alberta Oil Sands Environmental Research Program. 1976. First annual report, 1975. Alberta Oil Sands Environmental Research Program. AOSERP Report 1. 58 pp.
2	AF 4.1.1	Kristensen, J., B.S. Ott, and A.D. Sekerak. 1976. Walleye and goldeye fisheries investigations in the Peace-Athabasca Delta--1975. Prep. for the Alberta Oil Sands Environmental Research Program by LGL Ltd., Environmental Research Associates. AOSERP Report 2. 103 pp.
3	HE 1.1.1	McVey, W.W. 1976. Structure of a traditional baseline data system. Prep. for the Alberta Oil Sands Environmental Research Program by the University of Alberta, Population Research Laboratory. AOSERP Report 3. 26 & 266 pp.
4	VE 2.2	Stringer, P.W. 1976. A preliminary vegetation survey of the Alberta Oil Sands Environmental Research Program study area. Prep. for the Alberta Oil Sands Environmental Research Program by Intraverda Plant Systems Ltd. AOSERP Report 4. 108 pp.
5	HY 3.1	Strosher, M.T. and E. Peake. 1976. The evaluation of wastewaters from an oil sand extraction plant. Prep. for the Alberta Oil Sands Environmental Research Program by the University of Calgary, Environmental Sciences Centre (Kananaskis). AOSERP Report 5. 103 pp.
6	PM	Patterson, R. and A.M. Landsdown. 1976. Housing for the north--the stackwall system; construction report--Mildred Lake tank and pump house. Prep. for the Alberta Oil Sands Environmental Research Program by the University of Manitoba, Faculty of Engineering, Northern Housing Committee. AOSERP Report 6. 36 pp.
7	AF 3.1.1	Jantzie, T.D. 1977. A synopsis of the physical and biological limnology and fishery programs within the Alberta oil sands area. Prep. for the Alberta Oil Sands Environmental Research Program by Renewable Resources Consulting Services Ltd. AOSERP Report 7. 73 pp.

8	AF 1.2.1	Machniak, K. 1977. The impact of saline waters upon freshwater biota (a literature review and bibliography). Prep. for the Alberta Oil Sands Environmental Research Program by Aquatic Environments Ltd. AOSERP Report 8. 258 pp.
9	ME 3.3	Croft, B.R., A. Lamb, and R.N. Dawson. 1977. A preliminary investigation into the magnitude of fog occurrence and associated problems in the oil sands area. Prep. for the Alberta Oil Sands Environmental Research Program by Stanley Associates Engineering Ltd. AOSERP Report 9. 87 pp.
10	HE 2.1	Millar, J.F.V. 1977. Development of a research design related to archaeological studies in the Athabasca Oil Sands area. Prep. for the Alberta Oil Sands Environmental Research Program by the University of Saskatchewan. AOSERP Report 10. 69 pp.
11	AF 2.2.1	Flannagan, J.F. 1977. Life cycles of some common aquatic insects of the Athabasca River, Alberta. Prep. for the Alberta Oil Sands Environmental Research Program by Fisheries and Environment Canada, Freshwater Institute. AOSERP Report 11. 20 pp.
12	ME 1.7	Mercer, J.M. and R.B. Charlton. 1977. Very high resolution meteorological satellite study of oil sands weather: "a feasibility study". Prep. for the Alberta Oil Sands Environmental Research Program by the University of Alberta, Department of Geography. AOSERP Report 12. 44 pp.
13	ME 2.3.1	Davison, D.S., C.J. Fortems, and K.L. Grandia. 1977. Plume dispersion measurements from an oil sands extraction plant, March 1976. Prep. for the Alberta Oil Sands Environmental Research Program by Intera Environmental Consultants Ltd. AOSERP Report 13. 195 pp.
14		none
15	ME 3.4	Denison, P.J. 1977. A climatology of low-level air trajectories in the Alberta oil sands area. Prep. for the Alberta Oil Sands Environmental Research Program by Acres Consulting Services. AOSERP Report 15. 118 pp.

16	ME 1.6	Barge, B.L., R.G. Humphries, and S.L. Olson. 1977. The feasibility of a weather radar near Fort McMurray, Alberta. Prep. for the Alberta Oil Sands Environmental Research Program by Alberta Research Council, Atmospheric Sciences Division. AOSERP Report 16. 72 pp.
17	AF 2.1.1	Lutz, A. and M. Hendzel. 1977. A survey of baseline levels of contaminants in aquatic biota of the AOSERP study area. Prep. for the Alberta Oil Sands Environmental Research Program by Fisheries and Environment Canada, Freshwater Institute. AOSERP Report 17. 51 pp.
18	HY 1.1	Loeppky, K.D. and M.O. Spitzer. 1977. Interim compilation of stream gauging data to December 1976 for the Alberta Oil Sands Environmental Research Program. Prep. for the Alberta Oil Sands Environmental Research Program by Fisheries and Environment Canada, Water Survey Branch. AOSERP Report 18. 257 pp.
19	ME 4.1	Walmsley, J.L. and D.L. Bagg. 1977. Calculations of annual averaged sulphur dioxide concentrations at ground level in the AOSERP study area. Prep. for the Alberta Oil Sands Environmental Research Program by Atmospheric Environment Service. AOSERP Report 19. 40 pp.
20	HY 3.1.1	Strosher, M.T. and E. Peake. 1978. Characterization of organic constituents in waters and wastewaters of the Athabasca Oil Sands mining area. Prep. for the Alberta Oil Sands Environmental Research Program by the University of Calgary, Environmental Sciences Centre (Kananaskis). AOSERP Report 20. 71 pp.
21	PM	Alberta Oil Sands Environmental Research Program. 1977. Second Annual Report, 1976-77. Alberta Oil Sands Environmental Research Program. AOSERP Report 21. 62 pp.
22	PM	Smith, S.B., ed. 1979. Alberta Oil Sands Environmental Research Program Interim Report covering the period April 1975 to November 1978. Prep. by A.S. Mann, R.A. Hursey, R.T. Seidner, and B. Kasinska-Banas. AOSERP Report 22.

23 AF 1.1.2 Lake, W. and W. Rogers. 1979. Acute lethality of mine depressurization water to trout-perch and rainbow trout: Volume I. Prep. for the Alberta Oil Sands Environmental Research Program by Alberta Environment, Water Control Branch. AOSERP Report 23. 44 pp.

24 ME 1.5.2, ME 3.5.1 Fanaki, F., R. Mickle, M. Lusis, J. Kovalick, J. Markes, F. Froude, J. Arnold, A. Gallant, S. Melnichuk, D. Brymer, A. Gaudenzi, A. Moser, and D. Bagg. 1979. Air system winter field study in the AOSERP study area, February 1977. Prep. for the Alberta Oil Sands Environmental Research Program by Fisheries and Environment Canada, Atmospheric Environment Service. AOSERP Report 24. 182 pp.

25 ME 3.5.1 Bottenheim, J.W. and O.P. Strausz. 1977. Review of pollutant transformation processes relevant to the Alberta oil sands area. Prep. for the Alberta Oil Sands Environmental Research Program by the University of Alberta, Hydrocarbon Research Centre. AOSERP Report 25. 166 pp.

26 AF 4.5.1 Bond, W.A. and K. Machniak. 1977. Interim report on an intensive study of the fish fauna of the Muskeg River watershed of northeastern Alberta. Prep. for the Alberta Oil Sands Environmental Research Program by Fisheries and Environment Canada, Department of Fisheries. AOSERP Report 26. 137 pp.

27 ME 1.5.1 Fanaki, F., compiler. 1978. Meteorology and air quality winter field study in the AOSERP study area, March 1976. Prep. for the Alberta Oil Sands Environmental Research Program by Fisheries and Environment Canada, Atmospheric Environment Service. AOSERP Report 27. 249 pp.

28 VE 2.1 Turchenek, L.W. and J.D. Lindsay. 1978. Interim report on a soils inventory in the Athabasca Oil Sands area. Prep. for the Alberta Oil Sands Environmental Research Program by Alberta Research Council, Soils Division. AOSERP Report 28. 100 pp.

29 ME 2.2 Shelfentook, W. 1978. An inventory system for atmospheric emissions in the AOSERP study area. Prep. for the Alberta Oil Sands Environmental Research Program by SNC Tottrup Services Ltd. AOSERP Report 29. 58 pp.

30	ME 2.1	Strosher, M.M. 1978. Ambient air quality in the AOSERP study area, 1977. Prep. for the Alberta Oil Sands Environmental Research Program by Alberta Environment, Pollution Control Division. AOSERP Report 30. 74 pp.
31	VE 2.3	Thompson, M.D., M.C. Wride, and M.E. Kirby. 1978. Ecological habitat mapping of the AOSERP study area: Phase I. Prep. for the Alberta Oil Sands Environmental Research Program by Intera Environmental Consultants Ltd. AOSERP Report 31. 176 pp.
32	PM	Alberta Oil Sands Environmental Research Program. 1979. Third Annual Report, 1977-78. Alberta Oil Sands Environmental Research Program. AOSERP Report 32. 114 pp.
33	TF 1.2	Nowlin, R.A. 1978. Relationships between habitats, forages, and carrying capacity of moose range in northern Alberta. Part I: moose preferences for habitat strata and forages. Prep. for the Alberta Oil Sands Environmental Research Program by Alberta Recreation, Parks and Wildlife, Fish and Wildlife Division. AOSERP Report 33. 63 pp.
34	HY 2.4	Allan, R. and T. Jackson. 1978. Heavy metals in bottom sediments of the mainstem Athabasca River system in the AOSERP study area. Prep. for the Alberta Oil Sands Environmental Research Program by Fisheries and Environment Canada, Freshwater Institute. AOSERP Report 34. 72 pp.
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36	AF 4.8.1	Jones, M.L., G.J. Mann, and P.J. McCart. 1978. Fall fisheries investigations in the Athabasca and Clearwater rivers upstream of Fort McMurray: Volume I. Prep. for the Alberta Oil Sands Environmental Research Program by Aquatic Environments Ltd. AOSERP Report 36. 71 pp.
37	HE 2.2.2	Van Dyke, E.W. and C. Loberg. 1978. Community studies: Fort McMurray, Anzac, Fort MacKay. Prep. for the Alberta Oil Sands Environmental Research Program by Applied Research Associates Ltd. AOSERP Report 37. 195 pp.

38 VE 7.1.1 Green, J.E. 1979. Techniques for the control of small mammal damage to plants: a review. Prep. for the Alberta Oil Sands Environmental Research Program by LGL Ltd., Environmental Research Associates. AOSERP Report 38. 111 pp.

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40 WS 3.3 Beltaos, S. 1979. Mixing characteristics of the Athabasca River below Fort McMurray--winter conditions. Prep. for the Alberta Oil Sands Environmental Research Program by Alberta Research Council, Transportation and Surface Water Engineering Division. AOSERP Report 40. 110 pp.

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44 VE 3.1 Malhotra, S.S. and P.A. Addison. 1979. Interim report on symptomology and threshold levels of air pollutant injury to vegetation, 1975 to 1978. Prep. for the Alberta Oil Sands Environmental Research Program by Canadian Forestry Service, Northern Forest Research Centre. AOSERP Report 44. 13 pp.

45 VE 3.3 Malhotra, S.S. 1979. Interim report on physiology and mechanisms of air-borne pollutant injury to vegetation, 1975 to 1978. Prep. for the Alberta Oil Sands Environmental Research Program by Canadian Forestry Service, Northern Forest Research Centre. AOSERP Report 45. 38 pp.

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48 HG 1.1 Schwartz, F.W. 1979. Interim report on a hydrogeological investigation of the Muskeg River basin, Alberta. Prep. for the Alberta Oil Sands Environmental Research Program by the University of Alberta, Department of Geology. AOSERP Report 48. 104 pp.

49 WS 1.3.3 Hartland-Rowe, R.C.B., R.W. Davies, M. McElhone, and R. Crowther. 1979. The ecology of macrobenthic invertebrate communities in Hartley Creek, northeastern Alberta. Prep. for the Alberta Oil Sands Environmental Research Program by the University of Calgary, Department of Biology. AOSERP Report 49. 144 pp.

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52 ME 2.3.2 Davison, D.S. and K.L. Grandia. 1979. Plume dispersion measurements from an oil sands extraction plant, June 1977. Prep. for the Alberta Oil Sands Environmental Research Program by Intera Environmental Consultants Ltd. AOSERP Report 52. 209 pp.

53 HY 3.1.2 Strosher, M.T. and E. Peake. 1979. Baseline states of organic constituents in the Athabasca River System upstream of Fort McMurray. Prep. for the Alberta Oil Sands Environmental Research Program by the University of Calgary, Environmental Sciences Centre (Kananaskis). AOSERP Report 53. 71 pp.

54 WS 2.3 Nix, P.G., J.W. Costerton, R. Ventullo, and R.T. Coutts. 1979. A preliminary study of chemical and microbial characteristics of the Athabasca River in the Athabasca Oil Sands area of northeastern Alberta. Prep. for the Alberta Oil Sands Environmental Research Program by Chemical and Geological Laboratories Ltd., Microbios Ltd., and Xenotox Services Ltd. AOSERP Report 54. 135 pp.

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57 LS 2.3.1 Thompson, M.D. 1979. Ecological habitat mapping of the AOSERP study area (supplement): Phase I. Prep. for the Alberta Oil Sands Environmental Research Program by Intera Environmental Consultants Ltd. AOSERP Report 57. 45 pp.

58 AF 2.0.2 Lock, M.A. and R.R. Wallace. 1979. Interim report on ecological studies on the lower trophic levels of Muskeg rivers within the Alberta Oil Sands Environmental Research Program study area. Prep. for the Alberta Oil Sands Environmental Research Program by Fisheries and Environment Canada. AOSERP Report 58. 105 pp.

59	TF 3.1	Gilbert, F.F., S.A. Brown, and M.E. Stoll. 1979. Semi-aquatic mammals: annotated bibliography. Prep. for the Alberta Oil Sands Environmental Research Program by the University of Guelph, Department of Zoology. AOSERP Report 59. 167 pp.
60	WS 1.1.1	Neill, C.R. and B.J. Evans. 1979. Synthesis of surface water hydrology. Prep. for the Alberta Oil Sands Environmental Research Program by Northwest Hydraulic Consultants Ltd. AOSERP Report 60. 84 pp.
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