GREGOIRE LAKE MONITORING PROGRAM:

SIX MONTH REPORT,

APRIL TO SEPTEMBER 1979

by

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for

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and

ALBERTA ENVIRONMENT

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SUMMARY

This report presents a summary of the meteorological data collected by the meteorological tower network in the Gregoire Lake region of northeast Alberta during the spring and summer of 1979. The network was established to help monitor the impact on the environment by the Amoco Canada Co. Ltd. pilot plant. A previous report, prepared by Athabasca Research Corporation (Ferguson 1979), presented an analysis of the winter 1978-79 data.

A discussion is presented of the theoretical meteorological background including synoptic and mesoscale influences on the dispersion of effluents emitted into the atmosphere. Field dispersion experiments in the oil sands area are reviewed briefly.

The statistics of the various weather elements are discussed. Wind velocity was measured at the 30 m tower level at Anzac, the Gregoire Lake Provincial Park, the Amoco pilot plant, and Stoney Mountain. Temperature, relative humidity, vertical velocity, precipitation, barometric pressure, and solar radiation were to be monitored at the pilot plant. The system for recording these data was not completely debugged by the end of the summer so data are not available yet.

The meteorological statistics and the case studies indicated that when the air is stable or neutral, the regional airflow is deflected to follow the contours of the ridge, which is south of Gregoire Lake, and parallel to the Athabasca and Clearwater rivers. Under convectively unstable conditions, air flow tended to be upslope at the plant site and on Stoney Mountain, but similar to the regional flow at the valley stations.

Wind speeds were generally light in agreement with long-term records in the oil sands area. Temperatures also followed the long-term trends.

Examination of local meteorological and upper air data from Edmonton and Fort Smith indicated that the high concentrations of nitric oxide recorded on 27 September 1979 may have been related to low mixing heights. The source was probably not the pilot plant because the wind had been from the northwest for several hours prior to the incident.

It is recommended that the reliability of data acquisition be improved. A study such as this one depends on valid, complete data. It is of little value to collect data which has uncertainties as to time, calibration, or scale zeroes.

1. INTRODUCTION

A meteorological tower network has been established in the Gregoire Lake region of northeastern Alberta to monitor the impact of the Amoco Canada Petroleum Company Ltd. pilot plant on the regional airshed. Promet Environmental Group Ltd. was retained to produce a summary report on the data gathered during the spring and summer of 1979.

The aims of this report were to:

1. Present a discussion of the theoretical meteorological background, including a description of large scale meteorology, discussion of topographic effects, and an outline of the relationship between the atmospheric controls and air quality;
2. Present a climatological interpretation and analysis of network wind and temperature data, and precipitation, solar radiation, and relative humidity data provided by the Alberta Oil Sands Environmental Research Program (AOSERP);
3. Present a mesometeorological interpretation and analysis including a comparison of wind speeds at four sites (Anzac, Gregoire Lake Provincial Park, Amoco pilot plant, and Stoney Mountain); and
4. Present a dispersion climatology analysis, including a discussion of specific concentration events, and an evaluation, if possible, of the occurrence of factors such as inversions which might limit dispersion.

2. BACKGROUND

The meteorology of the Gregoire Lake region can be discussed under three general headings: (1) synoptic meteorology (large scale); (2) mesometeorology (local influences such as terrain); and (3) dispersion climatology (factors which influence dispersion of emissions into the atmosphere).

2.1 SYNOPTIC METEOROLOGY

The meteorology of the Gregoire Lake region is affected by three air massess. In the summer, maritime Arctic air gives warm, dry weather. Occasionally, the maritime Pacific air mass intrudes to produce cloud and rain. On rare occasions, the maritime Tropical air mass may influence the area resulting in hot muggy weather and thunderstorms.

Continental Arctic air frequently covers the region in winter. Clear skies, very cold temperatures, and light winds are associated with this air mass. Now and then, the maritime Pacific air mass provides some relief with milder conditions, cloud, and snow. The winter atmosphere is generally very stable. Strong inversions occur frequently that may limit the dispersion of effluents emitted into the atmosphere.

For further information on the large scale weather in the region, the reader is referred to an excellent description of the climate of the oil sands area by Longley and Janz (1978).

2.2 MESOMETEOROLOGY

The two topographic features which may influence the wind flow pattern near the Amoco pilot plant are Gregoire Lake and Stoney Mountain.

Gregoire Lake is about 5 km northeast of the Amoco experimental plant. It has an area of about 27 km^2 and is about 9 km long; its greatest dimension being in the west-northwest to east-southeast direction. Temperature differences between the land and water surfaces can lead to the development of a lake breeze.

This is most likely to occur in the summer under light synoptic wind conditions. During the day, the land warms more than the water so that pressures are relatively low. This causes an onshore breeze to develop. An offshore wind may arise in the evening because the land surface cools more rapidly than the water.

The surface of the lake is much smoother than the surrounding land which is heavily forested with trees 20 to 25 m in height. This may result in local differences in wind speed due to the varying surface friction force.

Stoney Mountain (760 m ASL) rises about 270 m above the lake. It is about 4 km southwest of the pilot plant. Under stable atmospheric conditions, airflow is likely to be split by Stoney Mountain. That is, the air tends to flow around the terrain rather than over it. For thermally unstable conditions, the influence of terrain on the flow is suppressed (Egan 1975).

2.3 DISPERSION CLIMATOLOGY

The dispersion potential of the lower atmosphere is controlled by the vertical distribution of the wind and temperature. Both profiles play an important role in determining the rise and spread of smoke plumes. The wind speed affects height of plume rise, the time of travel of the pollutant between source and receptor, and the volume of air into which contaminants will be diluted. Turbulence generated by the wind shear enhances dilution of pollutants also.

The temperature profile determines whether the atmosphere is thermally stable, unstable, or neutral. Stability influences the vertical and horizontal spread of smoke plumes. Under stable conditions, a plume tends to spread as a thin, meandering ribbon. Under unstable conditions, the vertical spread tends to be relatively large.

In the unstable case (where the potential temperature gradient decreases with height), typical of a sunny, warm summer afternoon, turbulent cells are formed which feature thermally induced, overturning air currents. The net result is vertical mixing and a looping type of plume. When there is no significant amount of surface heating (e.g., at night or when there is snow cover on the ground), a stable type of temperature profile is typical. Because the temperature increases with height (inversion condition), vertical motion is suppressed and a fanning type of plume is common.

In general, the atmospheric boundary layer is layered with different stabilities, so that the dispersion of a smoke plume is determined by the characteristics of the layers surrounding it. For example, at night, as the ground cools due to radiative cooling, a ground-based inversion forms. Smoke plumes either fan if they are embedded in the inversion or loft if they are in near neutral air above the inversion. In the morning, the ground warms, causing an unstable layer to develop at the ground and a breakup of the inversion a few hours after sunrise. When the unstable layer reaches the plume height, the smoke is mixed to the ground and one of the critical conditions for dispersion takes place: inversion breakup fumigation. Ground level concentrations can be quite high many miles downwind from the source because only downward mixing takes place. Fumigations usually persist for only brief periods of a half-hour or so because the unstable layer continues to grow rapidly in depth.

Extensive modelling of the dispersion of emissions in the oil sands area has been carried out on behalf of both AOSERP (Walmsley and Bagg 1977), and industry (Murray and Kurtz 1976). These have been based upon many assumptions with regard to plume rise and dispersion coefficients. In the past few years, a number of experimental studies have been carried out in the area which have provided more realistic dispersion data. Aerial surveys of the plumes of the Suncor Inc. plant were conducted by the Mines Branch of the Fuels Research Centre of the Canadian Department of Energy, Mines and Resources in October 1971 and February 1973 (Whaley and Lee 1978). Further plume dispersion measurements were carried out by the Federal Atmospheric Environment Service in

March 1976 and February and June 1977 on behalf of AOSERP (Fanaki 1978). An aerial sampling program to study the dispersion characteristics of the Suncor plumes was carried out in 1977 by Envirodyne Ltd. on behalf of Syncrude Canada Ltd. (Slawson et al. 1979).

3. CLIMATOLOGICAL RESULTS

3.1 TEMPERATURE

Daily mean temperatures at the Stoney Mountain (AOSERP) station are shown in Figure 1. Longley and Janz (1978) have estimated the long-term means for this station based upon Fort MacMurray Airport data. The estimated long-term means are plotted in Figure 1 for comparison with study period data. April and June were colder than normal; July was warmer than normal. August was relatively cool, except for the week of the 14th to the 21st. September was cool until the 10th with the remainder of the month being relatively warm. May data were not available from AOSERP.

Temperature data were obtained at the plant site on only 25 days of the period due to data acquisition system failures. A comparison of the daily mean temperatures with simultaneous Stoney Mountain (AOSERP) readings is presented in Figure 2. The correlation is good in July (correlation coefficient 0.99 and standard error of estimate 0.3°C). Agreement is very poor in the other months, however. The standard errors are 2.0, 4.3, and 1.1°C for June, August, and September, respectively. Such large differences would not arise from topographic differences because the two stations are only 4 km apart and differ by only 245 m in elevation. The lack of agreement could arise from either calibration error, or errors in labeling the time of observation.

An example illustrates that the differences probably are not related to elevation differences. On August 9, the minimum temperature at the plant was reported to be 11°C warmer than at Stoney Mountain. A difference of only 2.5°C would be expected due to the elevation difference if the atmosphere lapse rate was adiabatic.

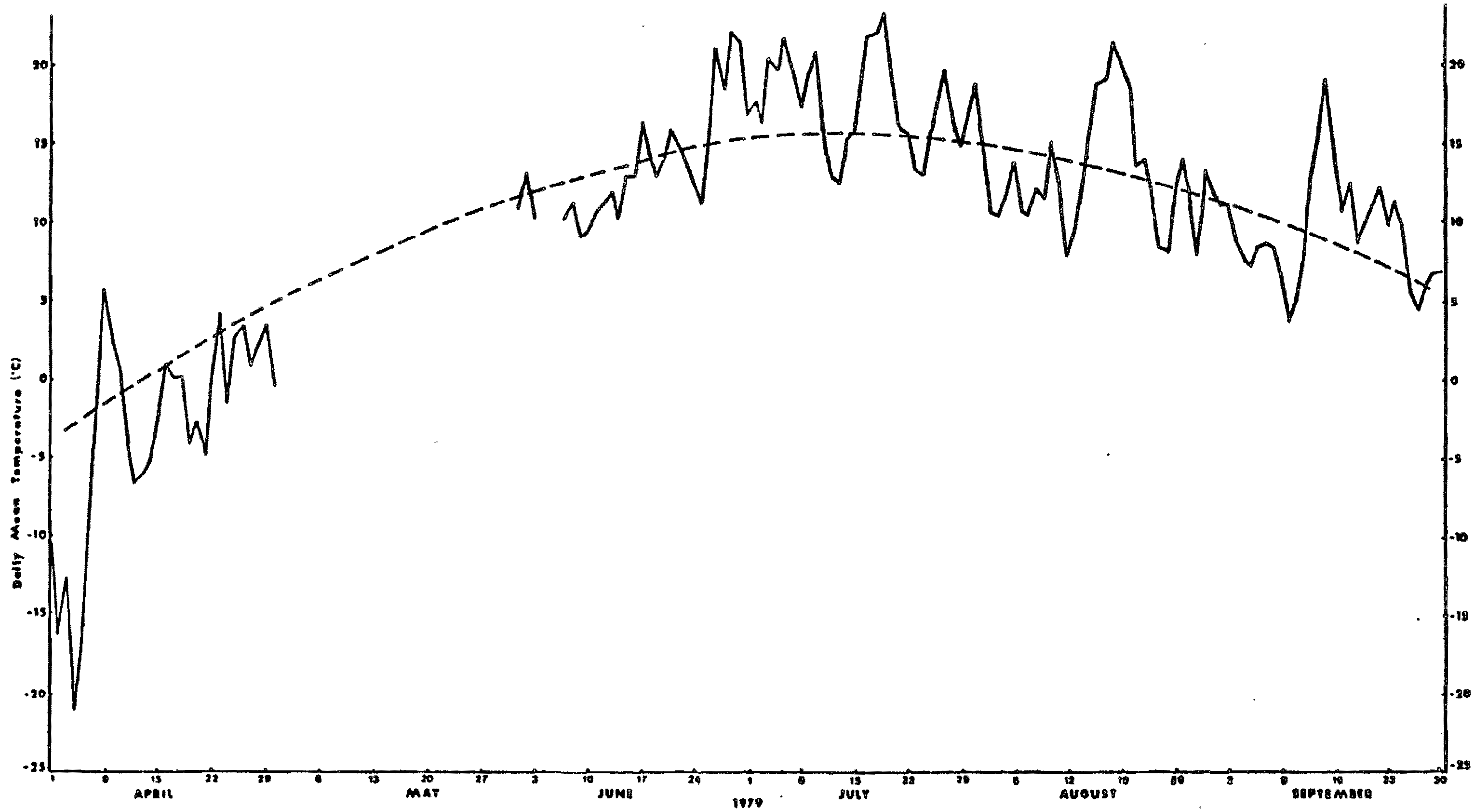


Figure 1. Mean daily temperatures at the Stoney Mountain (AOSERP) meteorological station for several months of 1979. For comparison, the dashed line indicates the adjusted long-term mean for Stoney Mountain (Longley and Janz 1978).

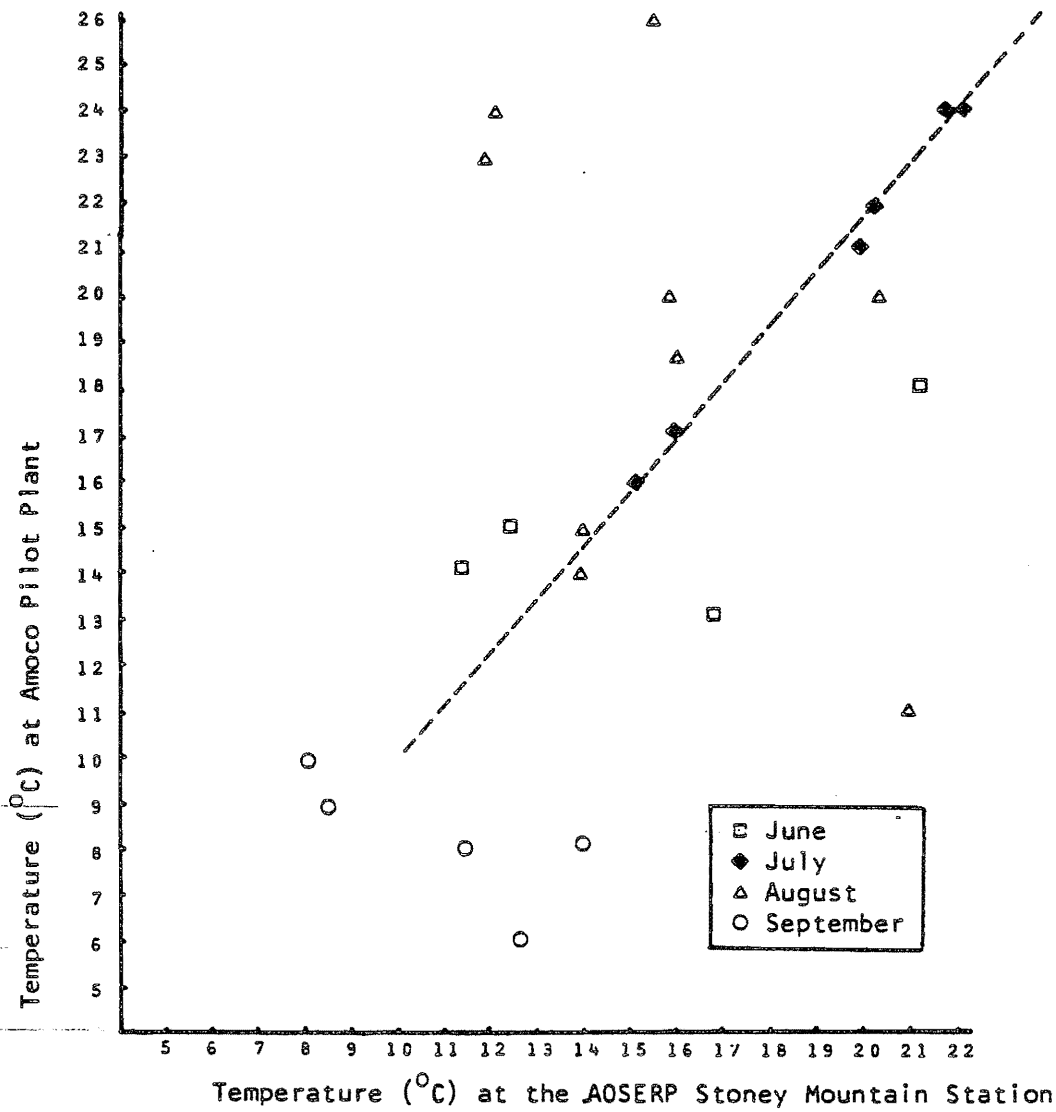


Figure 2. Comparison of plant site and Stoney Mountain temperatures (dashes-line of best fit for July data).

3.2 WIND SPEED

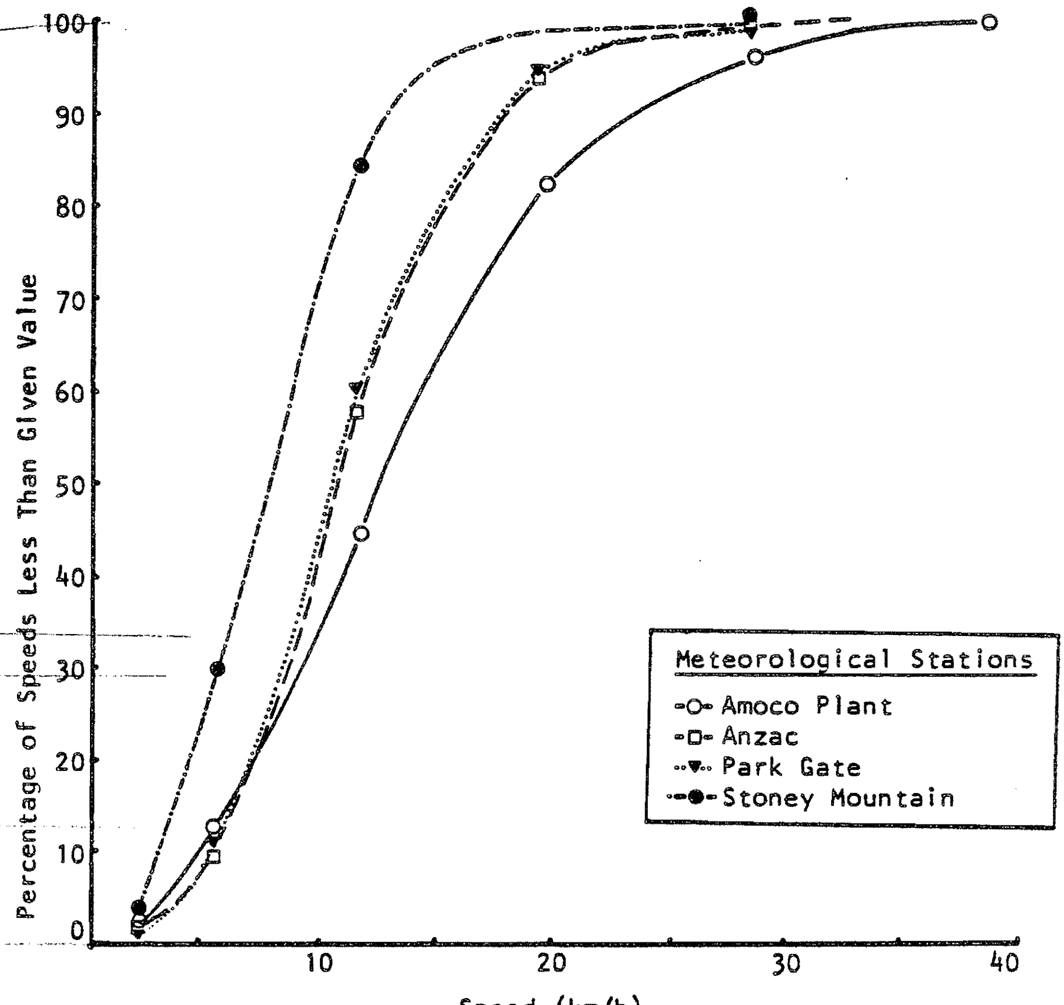
Wind speed distributions at the different weather stations in the Gregoire Lake network are illustrated in Figure 3. These distributions consist of counts of how often the wind speed was less than a given value.

The wind speed distributions at Anzac and the Gregoire Lake Provincial Park were very similar. At both sites, the winds were generally light. About 60% of the wind speeds were less than 12 km/h and about 2% were calm. Strong winds were infrequent, with only 6% of the speeds greater than 20 km/h.

Winds are apparently stronger at the plant site. About 17% of the speeds were greater than 20 km/h or higher. Light winds were common, with 45% of the speeds less than 12 km/h. About 2% of the observations were calm.

The Stoney Mountain (AOSERP) wind speed distribution cannot be compared directly with the others because the anemometer is 12 m above the ground rather than 30 m. If wind speed is assumed to vary as the 0.3 power of height above ground, the Stoney Mountain speeds would be 1.3 times higher at the 30 m level than the observed values at 12 m. If the curve for Stoney Mountain in Figure 3 was shifted to speeds 30% higher, it would be almost identical to the curves for Anzac and the park gate.

It should be noted that the Amoco anemometers are roughly 12 m above the tree canopy, that is, the same height as the AOSERP anemometer is above the bare Stoney Mountain site. Consequently, both anemometers are about the same height above the effective surface and the height differences may not explain the speed differences.



Meteorological Stations

Figure 3. Wind speed distributions at the Gregoire Lake meteorological network.

The variation of mean wind speed by month and direction is presented in Tables 1, 2, and 3. The overall mean speeds show little variation from month to month, averaging about 11 km/h at both Anzac and the park gate. The highest speeds were in September at all three stations. The calibration of the anemometer at the plant site appears to have been in error in August and September. Speeds were 35 to 45 percent higher in these months than at the other two sites. In the previous months, the mean speeds were within 1 km/h of the three station mean, suggesting that the calibration had drifted for the plant site instrument.

The lightest winds were from the northeast quadrant at all three weather stations. At the park site and Anzac, the strongest winds were from the southeast or west. At the plant site, the strongest winds were generally from the southeast.

The relatively low wind speeds observed at Gregoire Lake are in agreement with the long-term records in the oil sands area. For example, the mean monthly speeds at Fort McMurray Airport varied from 9.2 to 11.8 km/h in the months April through September, based upon the period 1955 to 1972.

Table 1. Mean speeds by month and direction at Anzac (units: tenths of km/h).

Direction	Month					
	April	May	June	July	August	September
N	122	61	104	117	131	90
NNE	113	57	156	100	108	96
NE	61	56	99	86	90	85
ENE	64	66	95	84	71	111
E	80	87	94	91	77	106
ESE	62	124	77	141	79	105
SE	87	132	168	162	92	122
SSE	133	118	140	139	121	101
S	97	88	121	139	121	98
SSW	80	98	98	94	106	100
SW	81	83	83	106	109	111
WSW	86	80	118	103	103	118
W	95	97	128	108	89	105
WNW	131	89	134	145	132	161
NW	113	87	127	123	132	160
NNW	123	68	115	113	124	136
ALL	105	94	125	123	116	125

Table 2. Mean speeds by month and direction at the park gate (units: tenths of km/h).

Direction	Month					
	April	May	June	July	August	September
N	118	70	113	87	65	100
NNE	66	65	85	75	64	70
NE	80	73	78	73	78	121
ENE	100	93	82	120	70	114
E	74	100	85	120	90	125
ESE	98	98	122	131	103	136
SE	84	154	108	143	93	75
SSE	73	123	91	130	112	80
S	80	163	87	111	122	58
SSW	77	160	94	130	115	117
SW	86	144	117	97	94	145
WSW	117	122	129	134	125	146
W	107	115	108	121	112	138
WNW	126	83	104	84	98	142
NW	101	95	118	91	99	83
NNW	119	63	130	95	112	66
ALL	102	104	109	115	101	126

Table 3. Mean speeds by month and direction at the Amoco pilot plant (units: tenths of km/h).

Direction	Month					
	April	May	June	July	August	September
N	104	75	ND[a]	60	117	131
NNE	80	86	50	45	55	140
NE	99	103	100	120	121	155
ENE	53	100	145	153	148	148
E	77	110	130	115	162	147
ESE	98	132	152	155	215	126
SE	122	33	146	163	177	169
SSE	105	50	133	139	160	162
S	192	99	111	107	148	219
SSW	118	26	123	90	135	205
SW	151	71	122	102	125	213
WSW	122	78	59	77	77	197
W	136	70	70	41	85	211
WNW	129	64	98	77	104	195
NW	133	17	72	86	105	208
NNW	123	36	65	ND	160	215
ALL	124	119	127	125	147	184

[a]ND = no data.

3.3 WIND DIRECTION

The percent frequencies of winds by direction and month are shown in Tables 4, 5, and 6. At Anzac, winds were predominately from the south-southeast for most of the study period. There was a secondary maximum from the west-northwest.

At the park gate, the prevailing directions were east-southeast, off the lake, and secondarily, west-southwest. April was an exception with a maximum frequency of occurrence of winds from the north-northwest.

At the plant site, southerly or east-southeasterly winds dominated during May through August, inclusive. In April, the maximum frequency was from the northwest, while southwesterly winds prevailed in September.

Northeasterly winds occurred rarely at all three stations. Southwesterly winds were infrequent at both Anzac and the park gate.

Calms decreased in frequency during the spring and seldom occurred in the summer.

A similar frequency table for Stoney Mountain (AOSERP) is shown in Table 7. There were difficulties in comparing the Stoney Mountain data with the Amoco stations because the anemometer at Stoney Mountain is at a different height. Particularily at night, there may be significant differences of wind direction with height above ground. It should also be noted that the 116 consecutive hours of calm winds reported at the end of September at Stoney Mountain were discarded.

Wind directions at Stoney Mountain were quite variable during the spring and summer. Northerly winds dominated in April, but these shifted to southerly in May through August. Westerly winds were most frequent in September. Calm winds were reported much more frequently than at the Amoco stations. This was probably due to the difference in height of the anemometers.

Table 4. Percent frequencies of occurrence of winds by direction and month at Anzac. Shading indicates directions with relatively high frequency.

Direction	Month					
	April	May	June	July	August	Sept.
N	18.5	4.7	7.4	8.5	10.3	3.0
NNE	3.4	1.8	2.9	3.9	6.0	0.5
NE	1.1	5.9	3.2	4.2	3.6	1.3
ENE	1.7	7.0	1.0	3.0	3.4	1.2
E	7.0	16.5	1.7	1.6	3.4	2.2
ESE	0.6	9.8	1.2	3.1	2.3	5.2
SE	3.1	14.7	7.4	5.2	3.0	10.9
SSE	8.4	11.1	11.0	6.7	9.8	8.0
S	6.9	5.2	12.7	6.3	15.8	5.2
SSW	2.3	1.8	5.4	3.3	2.8	1.5
SW	4.1	1.6	2.0	3.1	2.8	6.2
WSW	2.9	0.2	3.9	6.4	2.1	7.8
W	2.1	2.6	5.1	7.0	4.4	7.5
WNW	11.0	5.7	17.4	20.2	10.7	19.9
NW	6.6	4.1	12.3	12.4	13.3	13.5
NNW	12.4	2.8	5.4	4.8	6.2	6.0
CALM	8.0	4.4	0.0	0.0	0.0	0.2

Table 5. Percent frequencies of occurrence of winds by direction and month at the park gate. Shading indicates directions with relatively high frequency.

Direction	Month					
	April	May	June	July	August	Sept.
N	6.0	4.3	6.0	3.3	3.0	0.5
NNE	1.2	4.6	3.4	3.3	3.7	1.4
NE	2.0	3.3	1.5	3.6	2.5	3.6
ENE	2.8	6.9	1.8	0.7	3.0	2.4
E	5.6	24.4	9.7	11.2	7.2	12.2
ESE	7.1	10.9	16.2	14.2	13.7	20.5
SE	2.8	17.0	8.1	5.6	6.8	4.1
SSE	1.2	3.3	4.3	3.3	5.0	1.0
S	2.4	1.5	2.4	5.6	1.6	1.7
SSW	1.6	0.8	2.1	3.3	3.5	1.9
SW	6.0	1.3	3.4	4.3	5.6	8.0
WSW	5.6	1.8	11.3	11.9	12.8	16.1
W	11.5	2.8	9.2	11.9	10.3	13.7
WNW	8.7	4.6	7.1	5.0	8.8	7.0
NW	13.9	3.6	7.4	6.3	7.7	3.6
NNW	16.3	2.0	6.0	6.6	4.7	2.2
CALM	5.6	7.1	0.0	0.0	0.2	0.0

Table 6. Percent frequencies of occurrence of winds by direction and month at the Amoco pilot plant. Shading indicates directions with relatively high frequency.

Direction	Month					
	April	May	June	July	August	Sept.
N	5.8	8.8	0.0	0.1	0.8	3.5
NNE	1.2	2.5	0.2	0.3	0.3	2.2
NE	2.6	2.6	1.9	3.5	2.3	1.8
ENE	1.8	8.6	9.2	5.4	3.8	5.2
E	3.6	11.9	9.3	7.0	8.0	7.9
ESE	4.1	5.6	13.4	10.2	14.2	2.8
SE	3.8	3.3	11.6	16.9	9.3	2.0
SSE	2.4	5.1	10.5	16.3	13.2	7.4
S	12.1	10.0	11.6	14.3	15.7	11.2
SSW	3.6	2.6	11.0	10.1	11.9	10.0
SW	3.6	7.2	11.6	6.9	6.2	6.5
WSW	3.2	7.9	3.1	5.2	4.2	12.0
W	7.7	7.0	2.5	1.3	3.3	12.2
WNW	15.3	6.5	1.9	1.3	3.8	7.5
NW	18.5	1.8	1.6	1.0	2.2	5.0
NNW	4.7	3.7	0.3	0.0	0.3	2.7
CALM	5.8	5.0	0.3	0.1	0.3	0.0

Table 7. Percent frequencies of occurrence of winds by direction and month at Stoney Mountain (AOSERP). Shading indicates directions with relatively high frequency.

Direction	Month					
	April	May	June	July	August	September
N	18.7	ND	5.9	5.3	13.0	4.4
NNE	1.9		4.9	7.7	7.5	1.7
NE	2.5		4.5	6.6	4.3	3.9
ENE	3.9		8.0	2.6	1.2	3.4
E	2.6		9.3	4.7	3.4	5.8
ESE	1.8		6.2	7.0	3.6	5.6
SE	2.8		11.2	7.6	3.4	8.2
SSE	4.9		8.6	7.8	4.6	6.1
S	9.7		8.0	5.5	9.7	3.6
SSW	6.7		5.1	3.5	8.1	6.8
SW	5.4		4.8	5.8	5.6	9.2
WSW	3.6		5.8	4.6	6.3	8.0
W	4.5		5.1	7.4	6.7	9.8
WNW	6.8		3.2	3.5	5.4	7.8
NW	11.3		3.4	5.3	8.1	8.5
NNW	12.0		2.4	5.4	6.9	5.7
CALM	0.8		3.5	9.5	2.2	1.2

Table 8 shows the standard deviation of the frequency of wind directions. The smaller the standard deviation, the more uniform the frequency distribution is (all directions equally likely). The distributions tend to become more uniform in the summer, particularly at Stoney Mountain (AOSERP). The plant site tends to have a very non-uniform distribution for the entire period.

Table 8. Standard deviations of wind direction frequency (percent) by month for weather stations in the Gregoire Lake region.

Station	Month					
	April	May	June	July	August	Sept.
Anzac	4.9	4.8	4.8	2.8	4.3	5.2
Park Gate	4.6	6.5	4.0	3.8	3.6	6.2
Plant Site	5.1	3.0	5.1	5.6	5.2	4.6
Stoney Mtn.	4.6	ND	2.4	1.6	2.9	2.3

4. MESOMETEOROLOGICAL ANALYSIS

The topography of the Gregoire Lake region is illustrated in Figure 4. The major feature is a horseshoe-shaped ridge with its apex about 5 km west of Gregoire Lake. Under stable atmospheric conditions and a northerly flow of air, the surface winds would tend to split around this ridge. Surface winds would tend to be northeasterly to the west, and northwesterly to the east of the apex. Westerly winds would tend to be channelled southwesterly to the west and northwesterly to the east of the apex.

Stoney Mountain is really a minor feature on this ridge which parallels the Athabasca and Clearwater rivers. The ridge, not Stoney Mountain, is the major feature in channelling the regional winds.

The following sections will attempt to illustrate the channelling effects of this ridge and the effects of Gregoire Lake. Data from the Gregoire Lake stations will be compared statistically and several specific events will be examined.

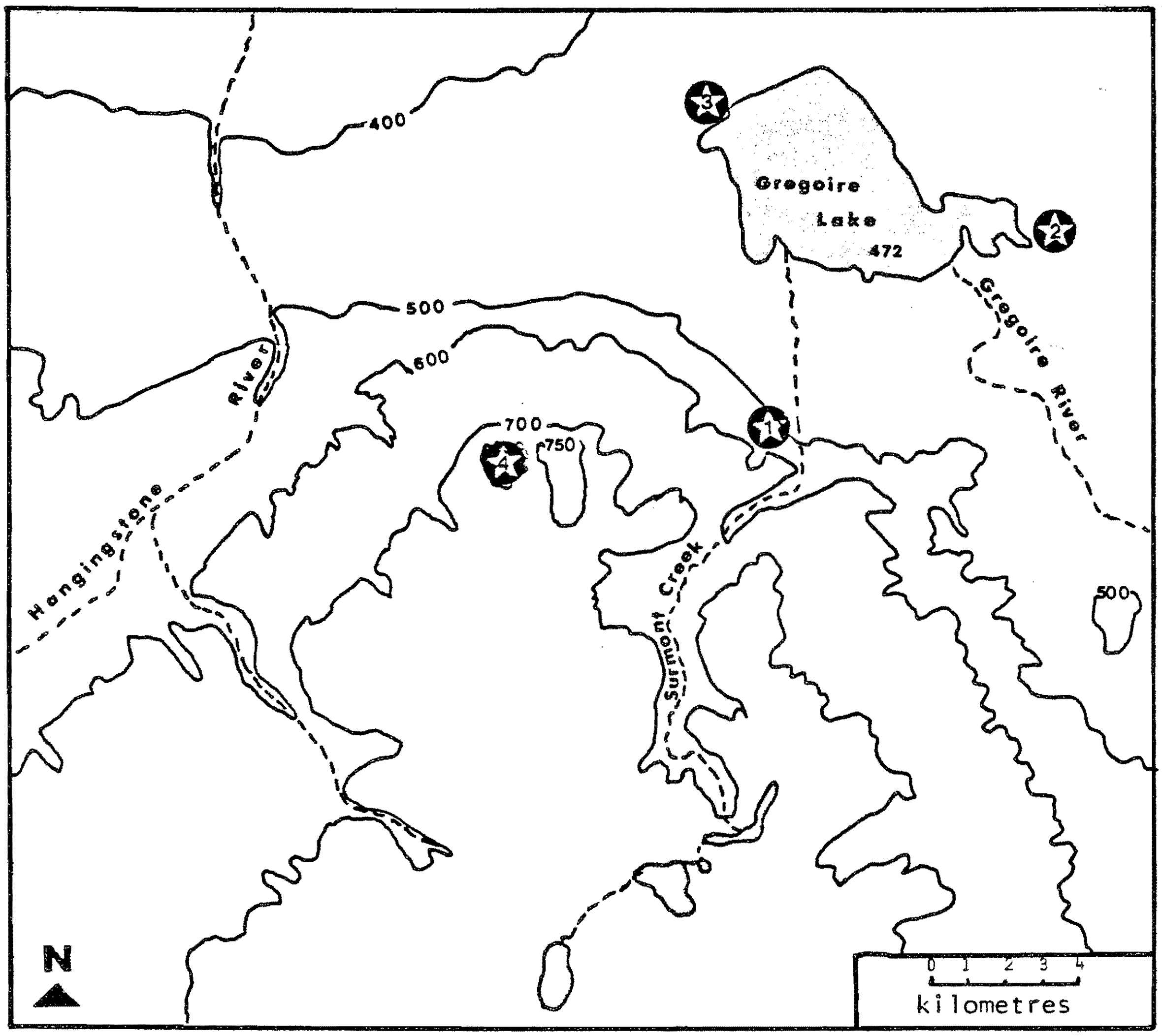


Figure 4. Topography of the Gregoire Lake region. Contours are at 100 m intervals. Meteorological tower sites are:

1. Amoco Plant tower site
2. Anzac tower site
3. Park tower site
4. Stoney Mountain (AOSERP) tower site

4.1 STATISTICAL COMPARISON OF WINDS

Comparison of wind roses for different times of day shows marked differences between the four stations (Figures 5 to 8).

The Stoney Mountain data, Figure 5, show a downslope drainage wind at 0500 MST. By 1700 MST, northerly, upslope winds were evident. At the pilot plant, Figure 6, the drainage winds were also evident at 0500 MST, but the northerly, upslope winds did not show up in the daytime.

The park gate wind roses, Figure 7, show a preponderance of easterly and westerly winds. From 0500 MST to 1100 MST, there was a decrease in the frequency of offshore winds, and a slight increase of occurrence of winds off the lake, possibly indicating the development of a lake breeze.

Anzac, Figure 8, shows little variation of the wind roses with time of day. Winds trended along a west-northwest to east-southeast orientation, parallel to the terrain contours.

At all the stations, calm winds tended to be most frequent at night. The highest frequency of calms was at Stoney Mountain. This is probably due to differences in the height and type of anemometer, rather than topographical influences.

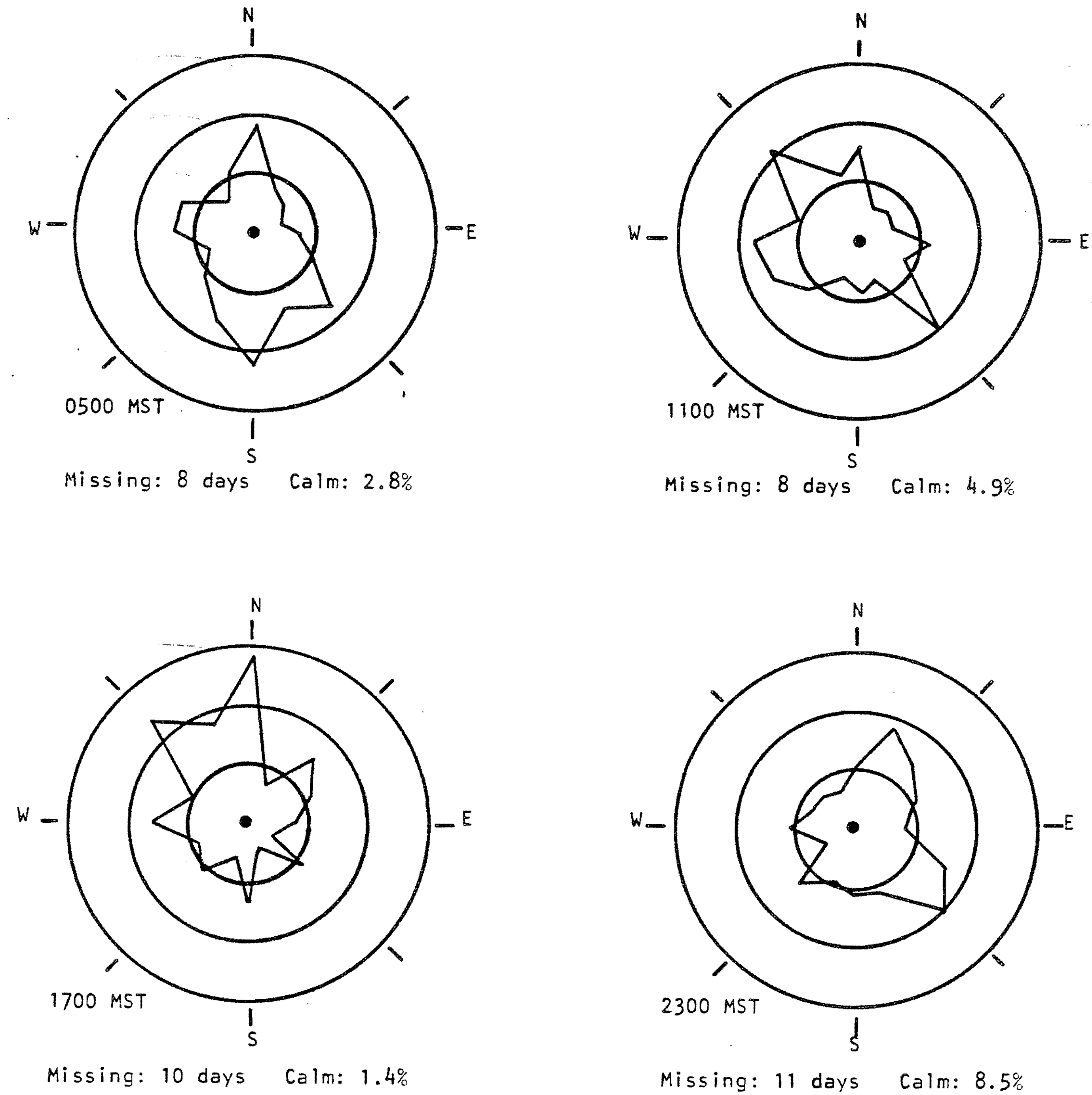


Figure 5. Diurnal wind roses at Stoney Mountain (AOSERP). Distance from the center of the rose represents the percentage frequency of the 16 compass points. Based upon data for April through September 1979, inclusive.

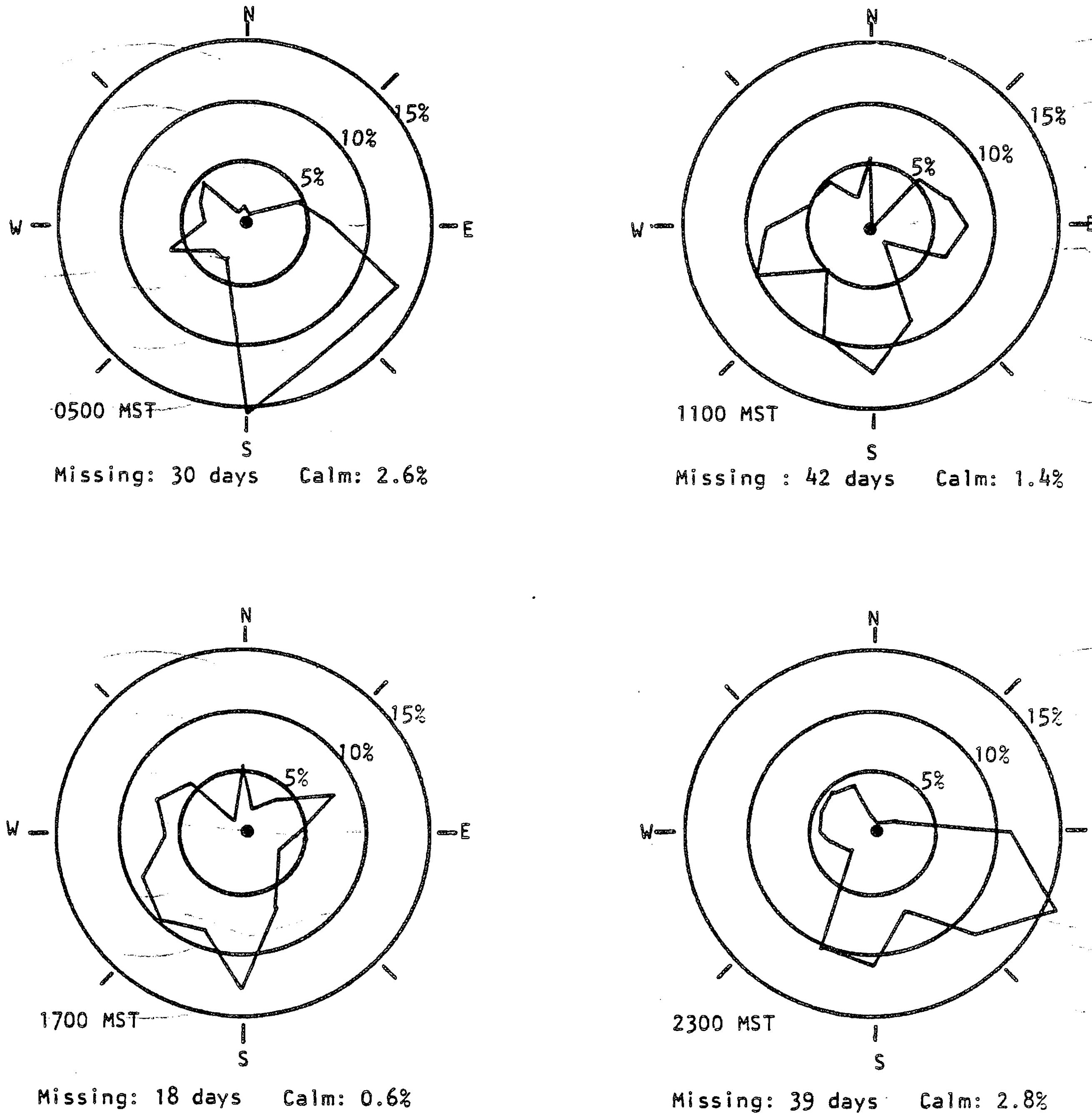


Figure 6. Diurnal wind roses at the Amoco pilot plant. Distance from the center of the rose represents the percentage frequency of the 16 compass points. Based upon data for April through September 1979, inclusive.

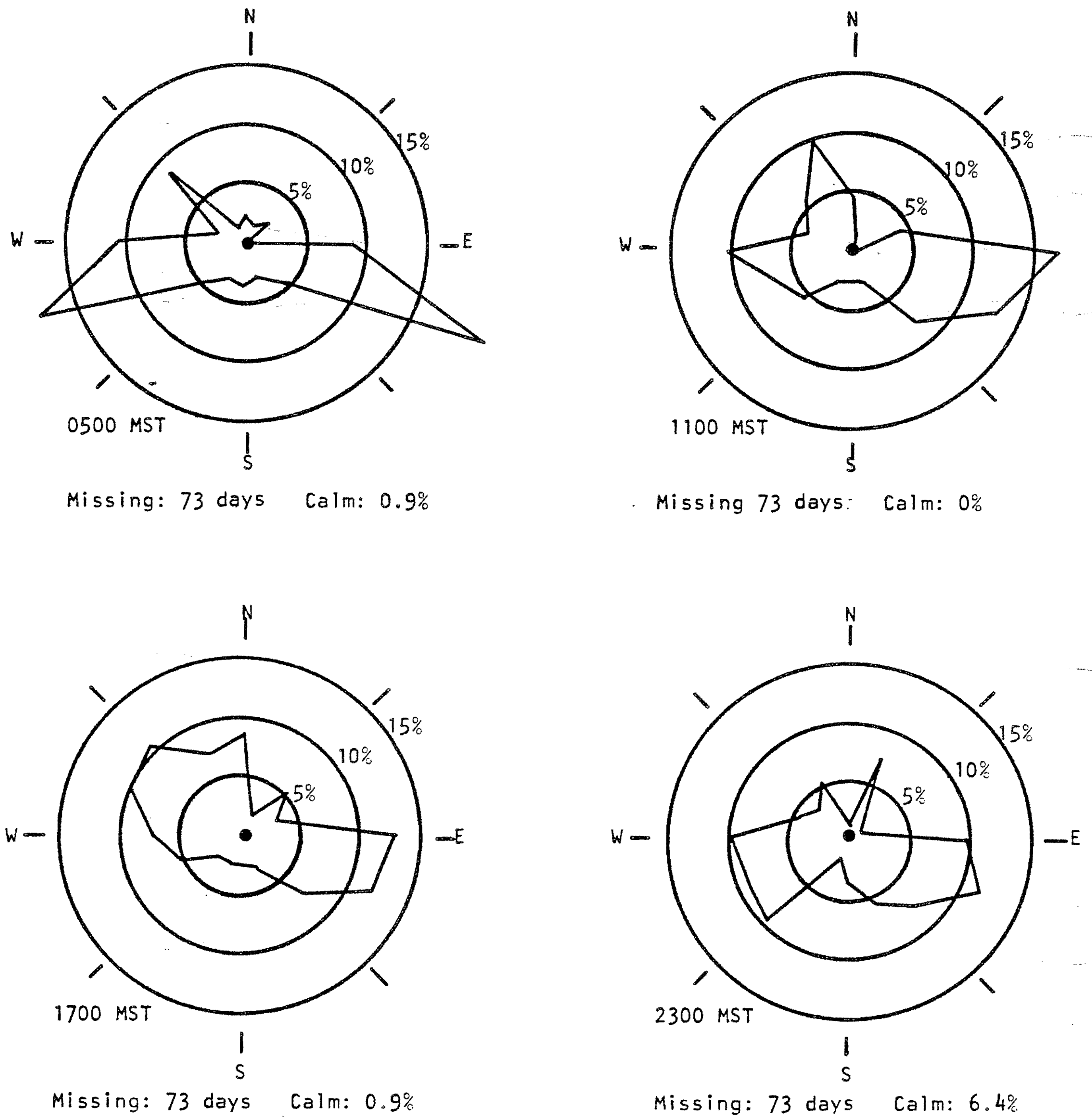


Figure 7. Diurnal wind roses at the park gate. Distance from the center of the rose represents the percentage frequency of the 16 compass points. Based upon data for April through September 1979, inclusive.

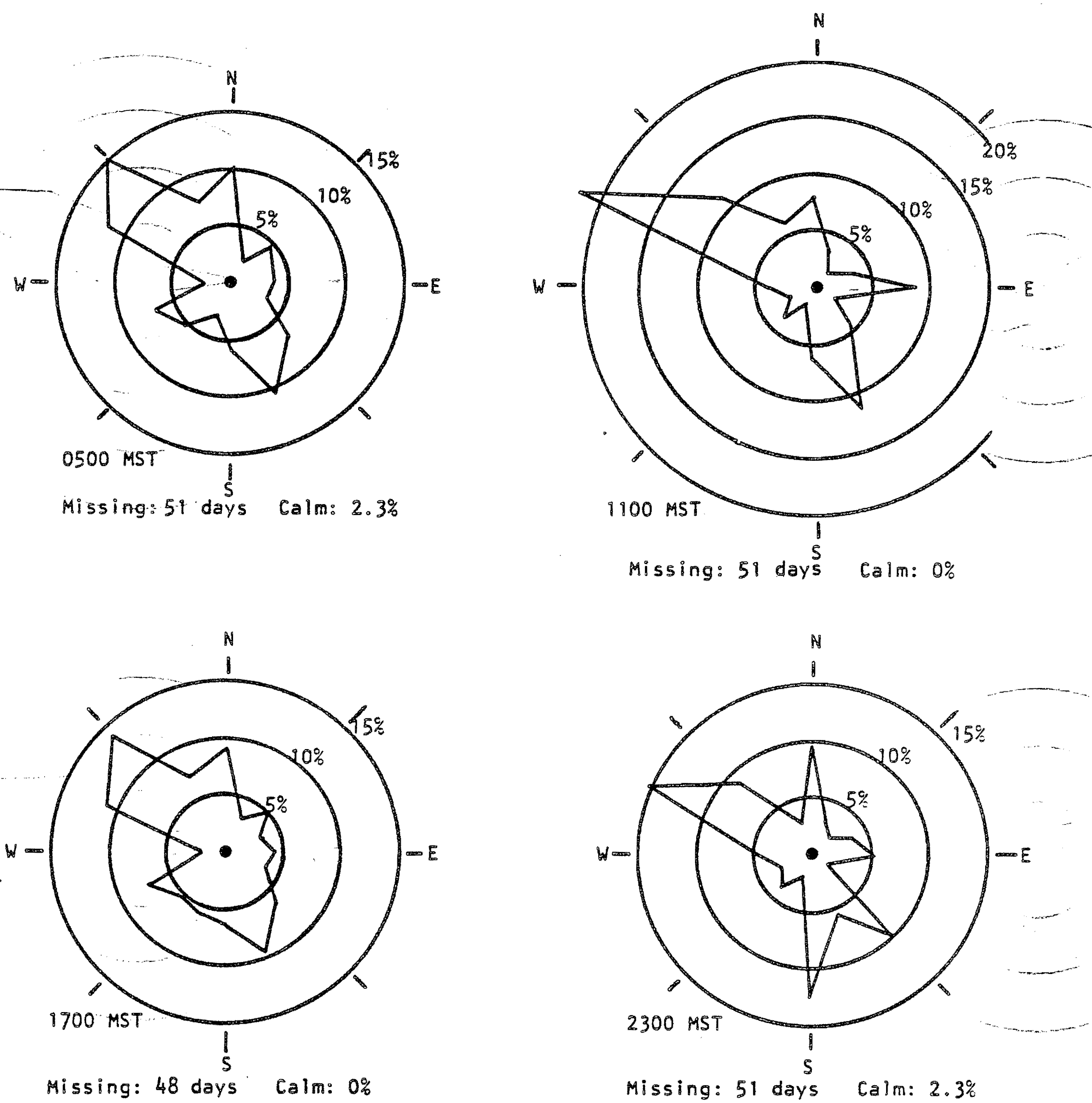


Figure 8. Diurnal wind roses at Anzac. Distance from the center of the rose represents the percentage frequency of the 16 compass points. Based upon data for April through September 1979, inclusive.

4.2 CASE STUDIES

4.2.1 4 April 1979

The surface weather map for 4 April 1979 is shown in Figure 9. The continental Arctic air mass extended over Alberta from a center of high pressure over the Northwest Territories. Over the oil sands area, light northerly or northeasterly winds would be expected from this pattern of air pressure. The actual winds, shown in Figure 9, were northerly at 3 to 15 km/h at Anzac. Light, generally northwesterly winds were observed at Stoney Mountain (AOSERP) and at the Amoco pilot plant. The northerly winds were deflected to follow the northwest-southeast orientation of the terrain, as would be expected under these very stable atmospheric conditions.

4.2.2 6 April 1979

The very cold air present on 4 and 5 April was displaced on 6 April as milder Pacific air pushed in from the west as illustrated in Figure 10. Southeasterly winds with a speed of about 25 km/h would be expected from the weather map. Southeasterly winds up to 26 km/h were observed at Anzac as shown in Figure 10. At Stoney Mountain (AOSERP), the winds were also southeasterly, but considerably lighter. The atmospheric stability was probably neutral because skies were overcast and winds moderately strong.

4.2.3 29 June 1979

A warm, unstable air mass covered northern Alberta on 19 June, as shown in Figure 11. Surface winds from the south at 20 to 30 km/h would be expected over the oil sands area. Observed winds were southerly at about 20 km/h at Anzac. The park gate winds were about the same strength, but east-southeasterly shifting to southerly in the evening. Both the Stoney Mountain (AOSERP) and pilot plant winds were generally easterly (upslope).

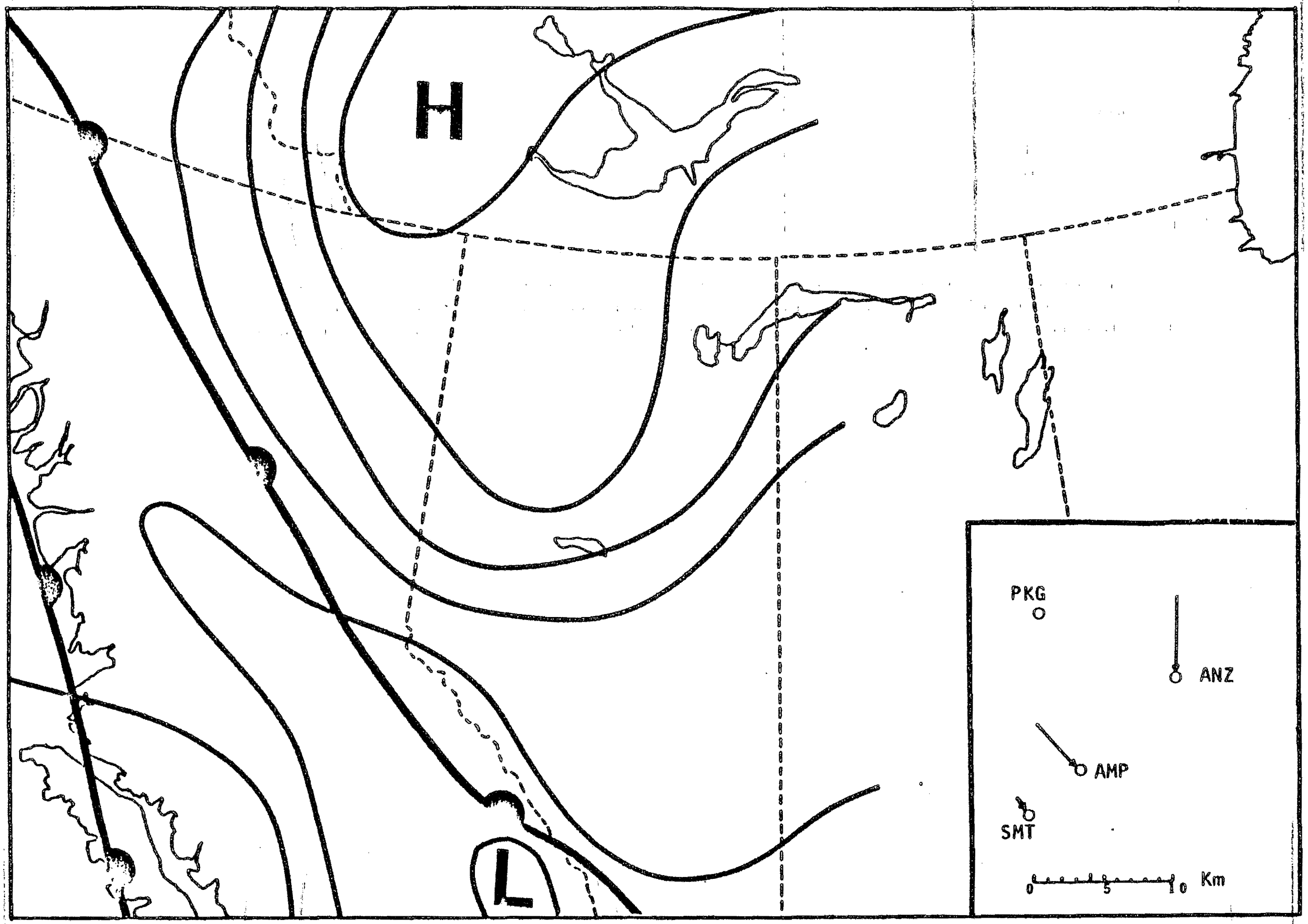


Figure 9. Surface weather map for 4 April 1979 (0500 MST). Contours represent atmospheric pressure. The insert shows wind vectors at Gregoire Lake stations (1 mm: 1 km/h). Stations are: Stoney Mountain (AOSERP) - SMT, Amoco Pilot Plant - AMP, Anzac - ANZ, and Park Gate - PKG.

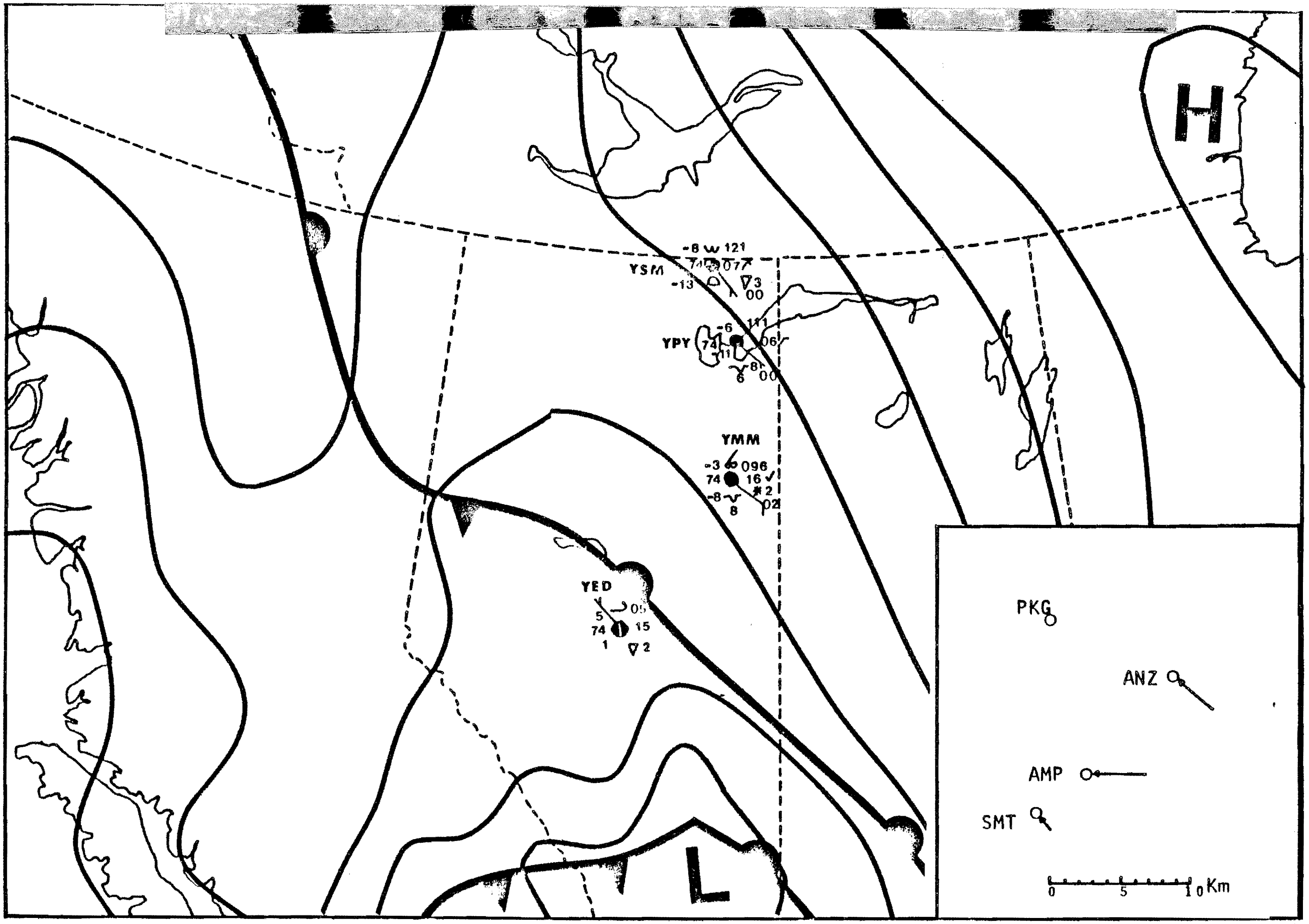


Figure 10. Surface weather map for 6 April 1979 (1700 MST). Contours represent atmospheric pressure. The insert shows wind vectors at Gregoire Lake stations (1 mm: 1 km/h).

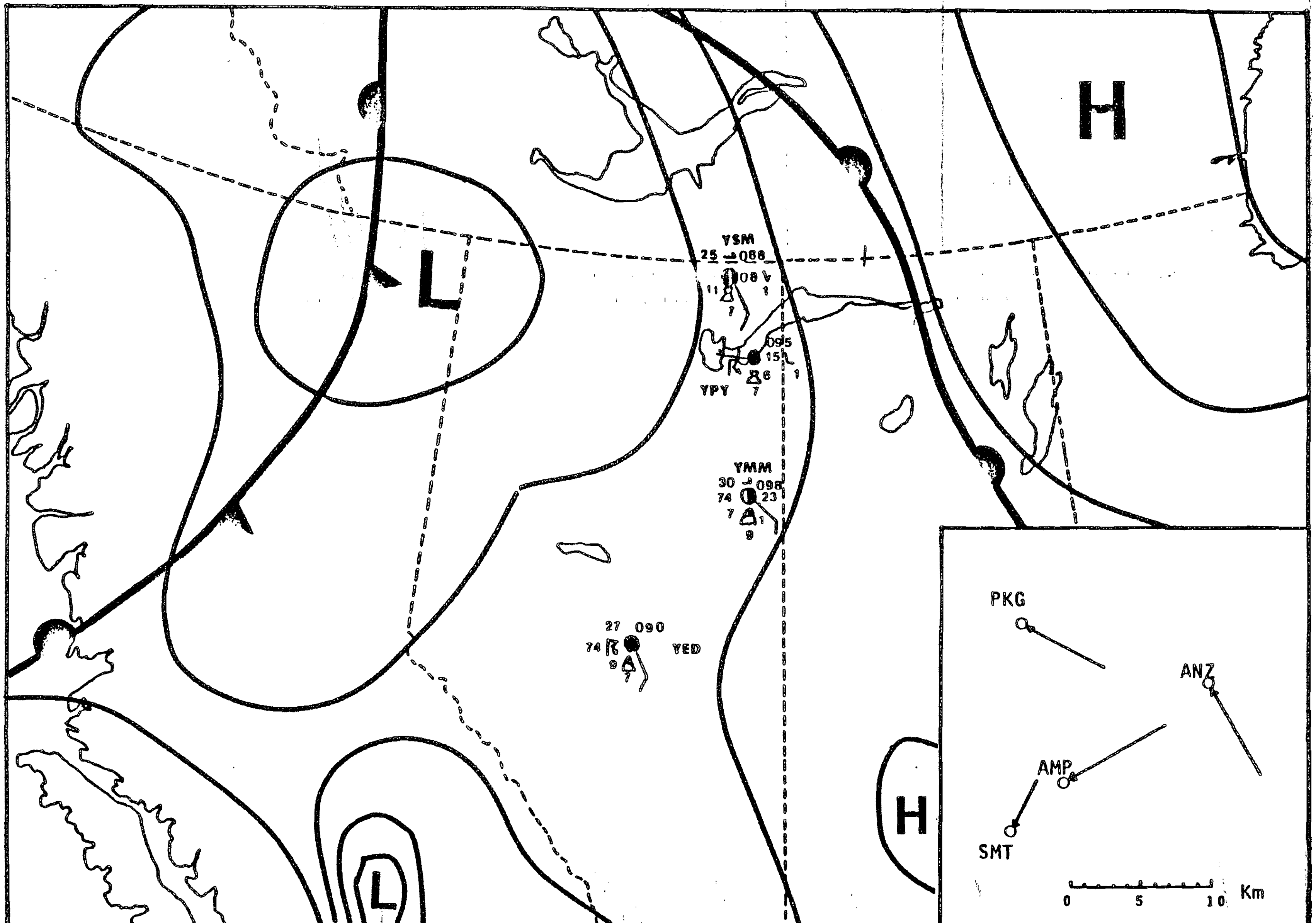


Figure 11. Surface weather map for 29 June 1979 (1700 MST). Contours represent atmospheric pressure. The insert shows wind vectors at Gregoire Lake stations (1 mm: 1 km/h).

4.2.4 19 July 1979

A northwesterly circulation around a low pressure areas over the Northwest Territories prevailed on 19 July. The air mass was of maritime origin and was convectively unstable. Cumulonimbus clouds were noted at a number of stations in northern Alberta (see weather map, Figure 12). Westerly winds at 15 km/h, which would be expected from the surface pressure pattern, were observed at Anzac. Winds were calm or very light northwesterly at Stoney Mountain (AOSERP). The pilot plant winds were recorded as southerly. The variation of winds from site to site was likely associated with convective cells typical of this type of air mass.

4.2.5 18 August 1979

Quite a common surface pattern over northern Alberta in summer is shown in Figure 13. A trough of low pressure is oriented northwest to southeast over the oil sands area. Winds were easterly to the north of the trough, and westerly to the south. The horizontal pressure gradients were weak, so very light winds would be expected. Winds were light at the Gregoire Lake stations. The direction was somewhat variable: east at Stoney Mountain (AOSERP), southeasterly at the park gate, northeast at Anzac, and north-northeast at the pilot plant.

4.2.6 18 September 1979

The weather map for 1700 MST 18 September 1979 (Figure 14) shows the Gregoire Lake region to be in the warm sector of a weather disturbance. Light westerly winds would be expected and were observed at Anzac and Stoney mountain. About 5 hours later, the wind direction shifted to northwesterly at Anzac and Stoney Mountain as the cold front shown in Figure 14 passed through the area. The wind at the pilot plant did not shift until 0700 MST the next morning. As this site is not sheltered from northwest winds, it is suspected that this delay was due to an error in recording the time.

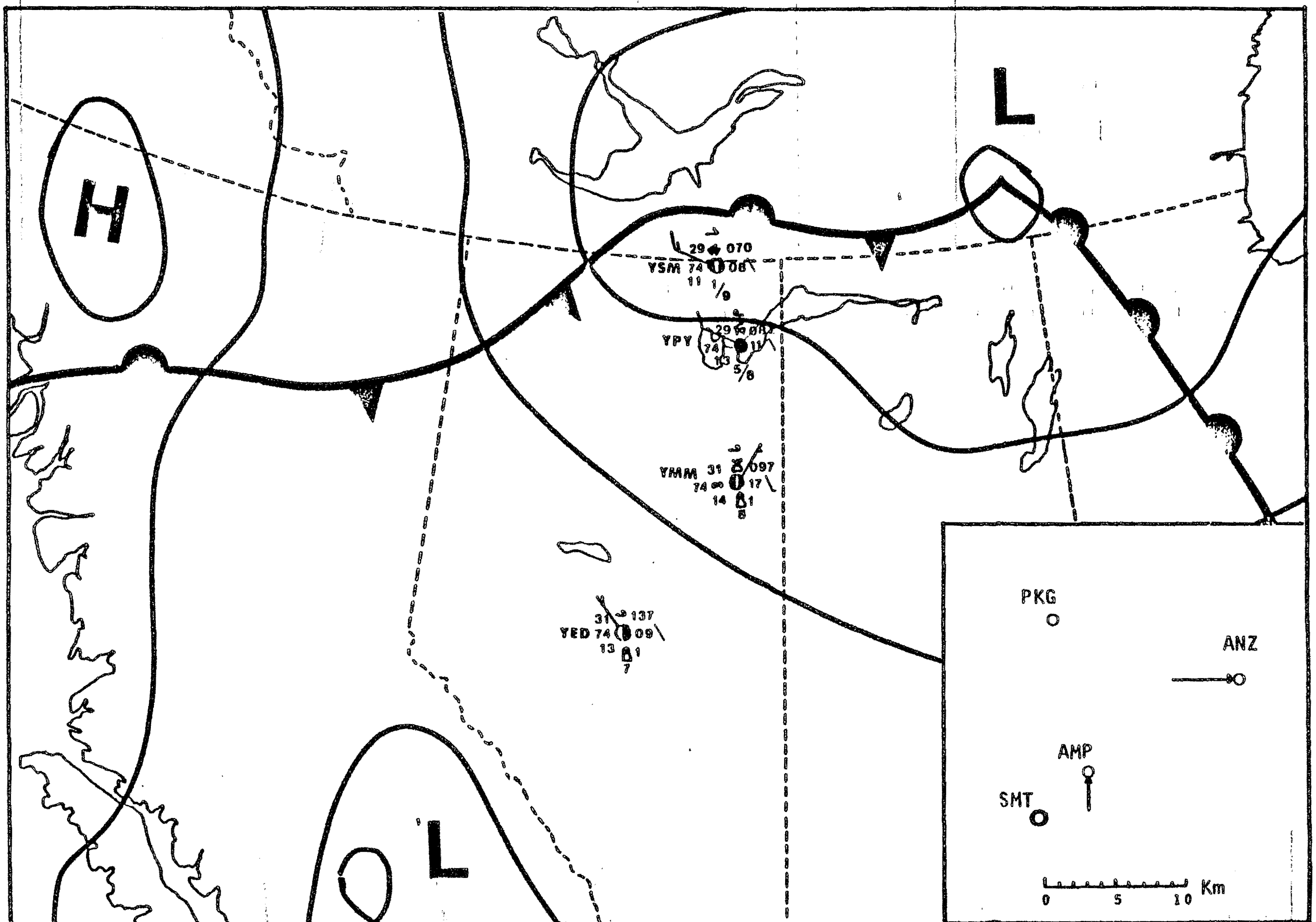


Figure 12. Surface weather map for 19 July 1979 (1700 MST). Contours represent atmospheric pressure. The insert shows wind vectors at Gregoire Lake stations (1 mm: 1 km/h). The circle at SMT represents calm winds.

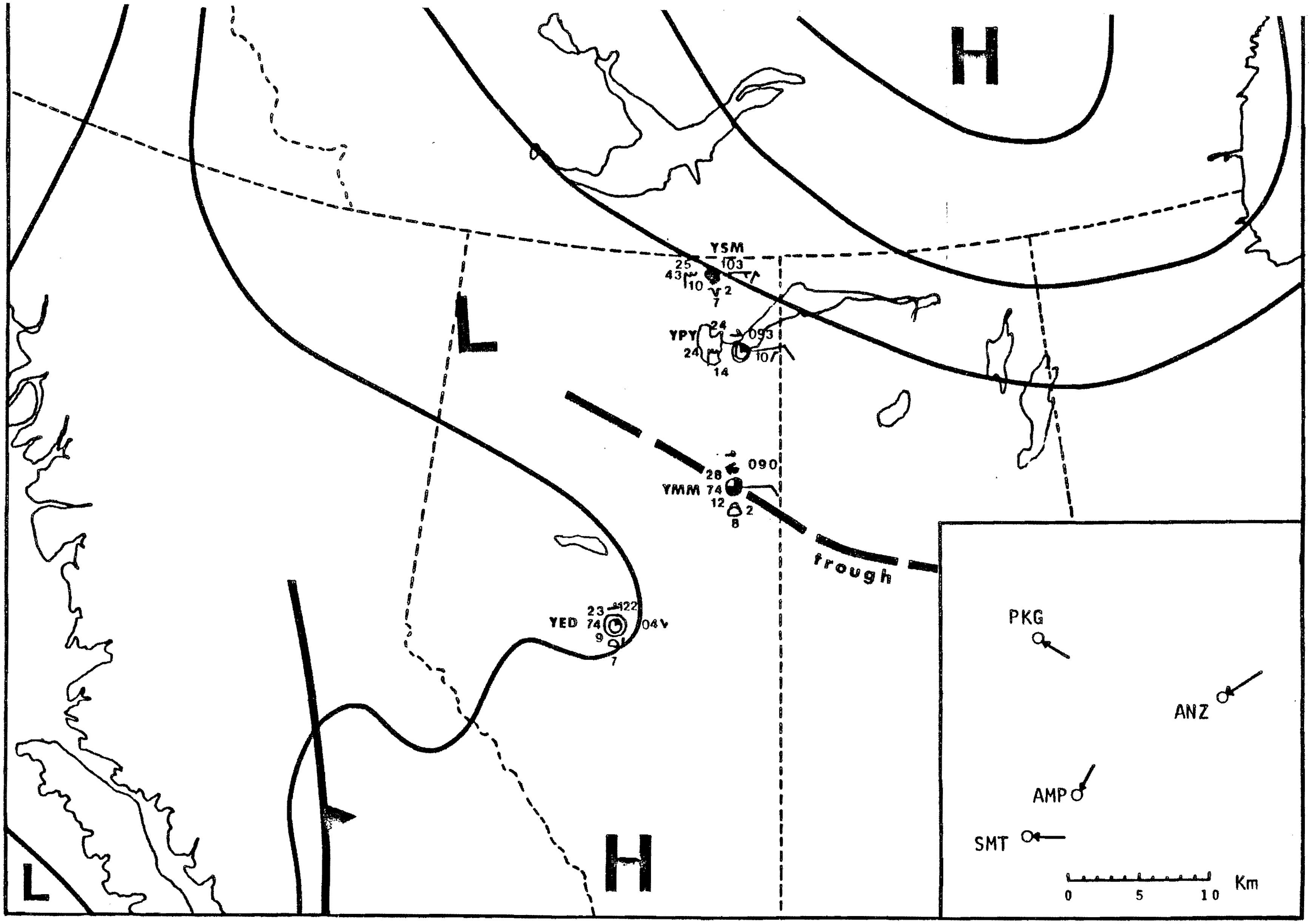


Figure 13. Surface weather map for 17 August 1979 (1700 MST). Contours represent atmospheric pressure. The insert shows wind vectors at the Gregoire Lake stations (1 mm: 1 km/h).

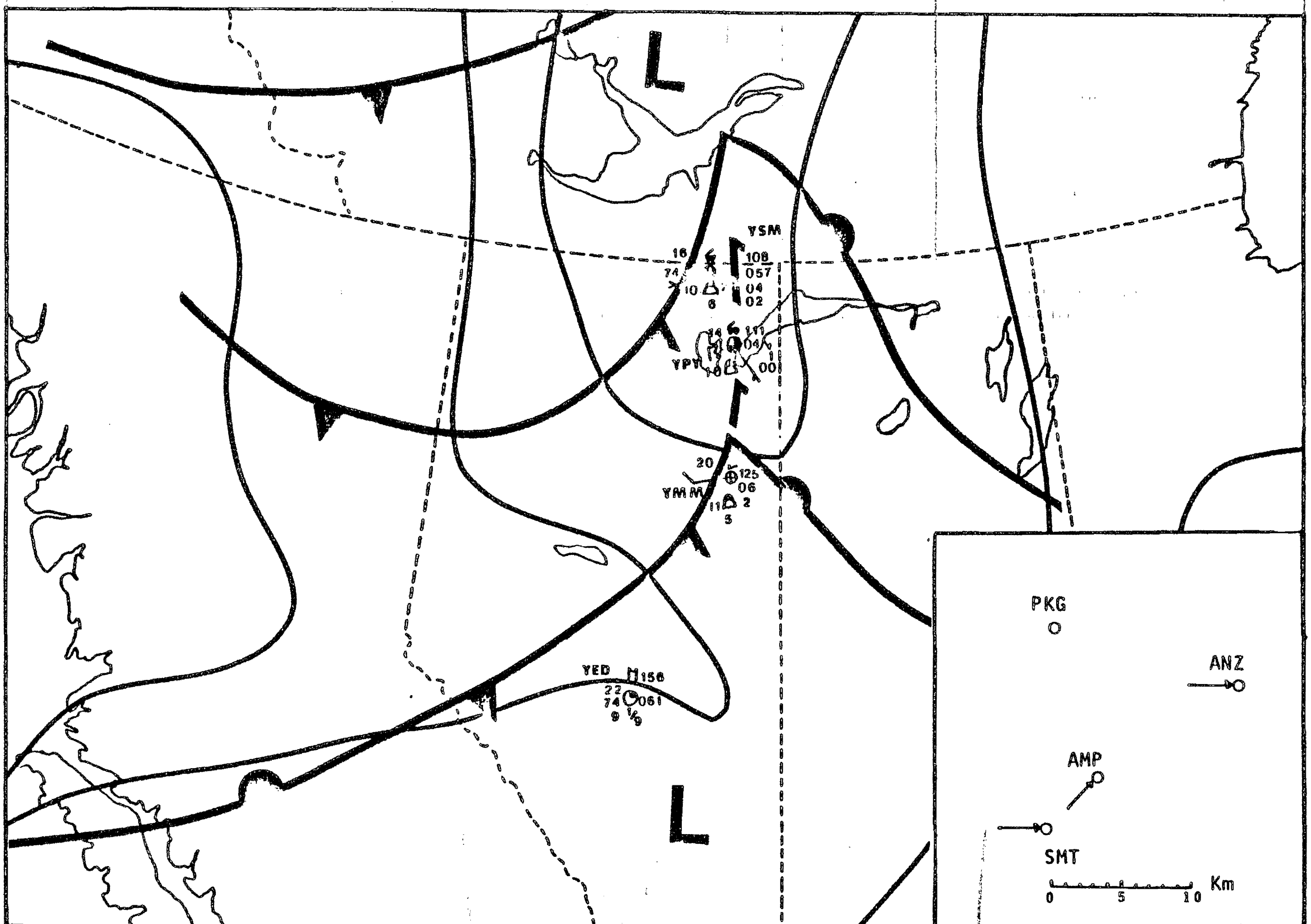


Figure 14. Surface weather map for 18 September 1979 (1700 MST). Contours represent atmospheric pressure. The insert shows wind vectors at the Gregoire Lake stations (1 mm: 1 km/h).

5. DISPERSION CLIMATOLOGY

Dispersion climatology is really the statistics of the dispersion parameters such as mixing height, inversions, lapse rates, and wind velocities. In this report, statistics are not presented other than for winds because of the limitations of the monitoring data. However, comments follow as to how the above parameters might be inferred from the local data. In addition, the duration of low wind speeds at Gregoire Lake is discussed and a specific concentration event is examined in detail.

The parameters derived from the temperature profile can be estimated by interpolation of a local profile as in Figure 15. The interpolation was performed subjectively using the weather maps in addition to the Edmonton and Fort Smith upper air observations. Local verification would lend confidence to this procedure. Longley and Janz (1978) estimated the occurrence of inversions in the oil sands area by comparing temperatures from stations at different altitudes. This assumes that the temperature variation along a slope on the ground is the same as the variation vertically in the free air. There can be differences of 2°C or so between the free air and slope temperatures in valleys according to Dean and Swan (1944), so the method described above for finding inversions isn't infallible. At Gregoire Lake, temperatures at the pilot plant could be compared with those at Stoney Mountain. Unfortunately, there were few reliable data available for the study period, so it was not possible to try the above method.

5.1 DURATION OF LOW WIND SPEEDS

The duration of low wind speeds (12 km/h or less) is a factor in air pollution potential according to Shaw et al. (1972). If a high air pollution potential occurs in an area where there are large emissions of contaminants into the atmosphere, then high concentrations of the contaminants are likely to occur at ground level.

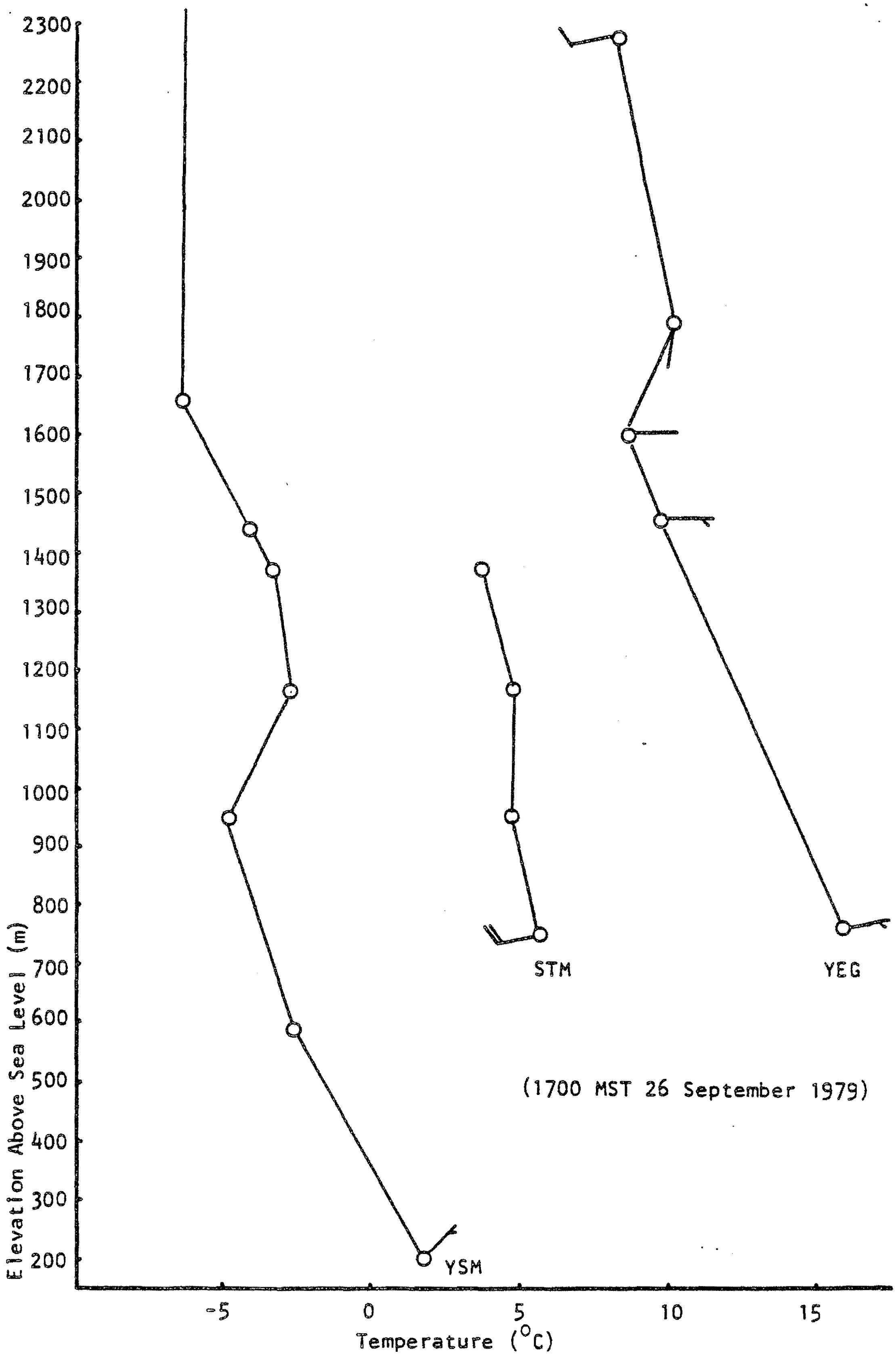


Figure 15. Temperature and wind profiles at Edmonton (YEG), Fort Smith (YSM), and interpolated profile at Stoney Mountain (STM). Wind speeds are indicated by barbs on the direction arrows: small barb - 3 km/h, large barb - 6 km/h.

The Amoco plant site anemometer data were analyzed for the persistence of winds less than or equal to 6 and 12 km/h as shown in Tables 9 and 10, respectively.

Persistent winds less than 6 km/h were not common. There were only three cases of duration more than 12 h. The longest duration was 16 h on the night of 16/17 April. The longest duration of speeds less than 12 km/h was 71 h on 5 to 7 August 1979.

There were eight cases of winds less than 12 km/h which persisted for more than 24 h. These are considerable fewer occurrences than would be expected in spring and summer from the figures of Shaw et al (1972). The number of occurences may have been underestimated due to missing data at the plant site.

Table 9. Frequency of the duration of wind speeds of 6 km/h or less at the Amoco pilot plant.

Duration (Hours)	Month						
	April	May	June	July	August	Sept.	All
1 to 4	17	25	41	41	44	7	175
5 to 8	4	5	6	8	2	1	26
9 to 12	2	1	2	3	2	0	10
13 to 16	2	0	0	0	1	0	3
17+	0	0	0	0	0	0	0

Table 10. Frequency of the duration of wind speeds of 12 km/h or less at the Amoco pilot plant.

Duration (Hours)	Month						
	April	May	June	July	August	Sept.	All
1 to 4	14	7	38	42	35	20	156
5 to 8	13	10	10	28	6	5	72
9 to 12	1	6	6	6	3	2	24
13 to 16	3	3	2	2	2	1	13
17 to 20	1	1	1	0	0	0	3
21 to 24	4	1	1	0	1	1	8
24 to 48	1	3	1	0	1	0	6
48+	0	1	0	0	1	0	2

5.2 CONCENTRATION EVENTS

A significant concentration event on 26/27 September was selected for detailed examination. The weather map for this incident is shown in Figure 16. A series of pacific disturbances passed through the oil sands area in the period surrounding the incident. A weak ridge of high pressure was to the west at map time. It passed through the Gregoire Lake region around 0600 MST as can be seen from the atmospheric pressure and wind records in Figure 16.

Temperature profiles at Edmonton and Fort Smith are shown in Figure 15. The interpolated profile at Stoney Mountain indicates that mixing heights in the Gregoire Lake region were relatively low, about 200 m during the incident. With cloudy skies and fairly strong winds, a mixed layer probably was present overnight.

Pollutant concentrations and simultaneous meteorological readings during and after the incident are shown in Figure 17. Peak concentrations of 0.18 ppm and 20 ppb of nitric oxide (NO) and nitrogen dioxide (NO_2), respectively, were observed from 0000 to 0100 MST on 26 September. Wind direction at the pilot plant was north-northwesterly for several hours prior to midnight. The pilot plant is to the west of the monitor, so it is likely that the pollutants were from other sources to the north of the Gregoire Lake region. It should be kept in mind though that pollutant trajectories are not likely to be straight lines in a synoptic situation like this, in which a series of disturbances move through the area. Hence, the wind direction alone is not necessarily an indicator of the source of pollutants.

The concentrations of NO and NO_2 followed a very similar trend over the night of the incident, showing that the same source was likely involved. Ozone was also relatively high on this night but followed a different trend--fairly steady concentrations in the 0.02 to 0.03 ppm range. Sulphur dioxide (SO_2) and hydrogen sulphide (H_2S) data were missing for September, unfortunately. Like ozone, carbon dioxide (CO_2) followed a steady trend with concentrations around 4.3% by volume.

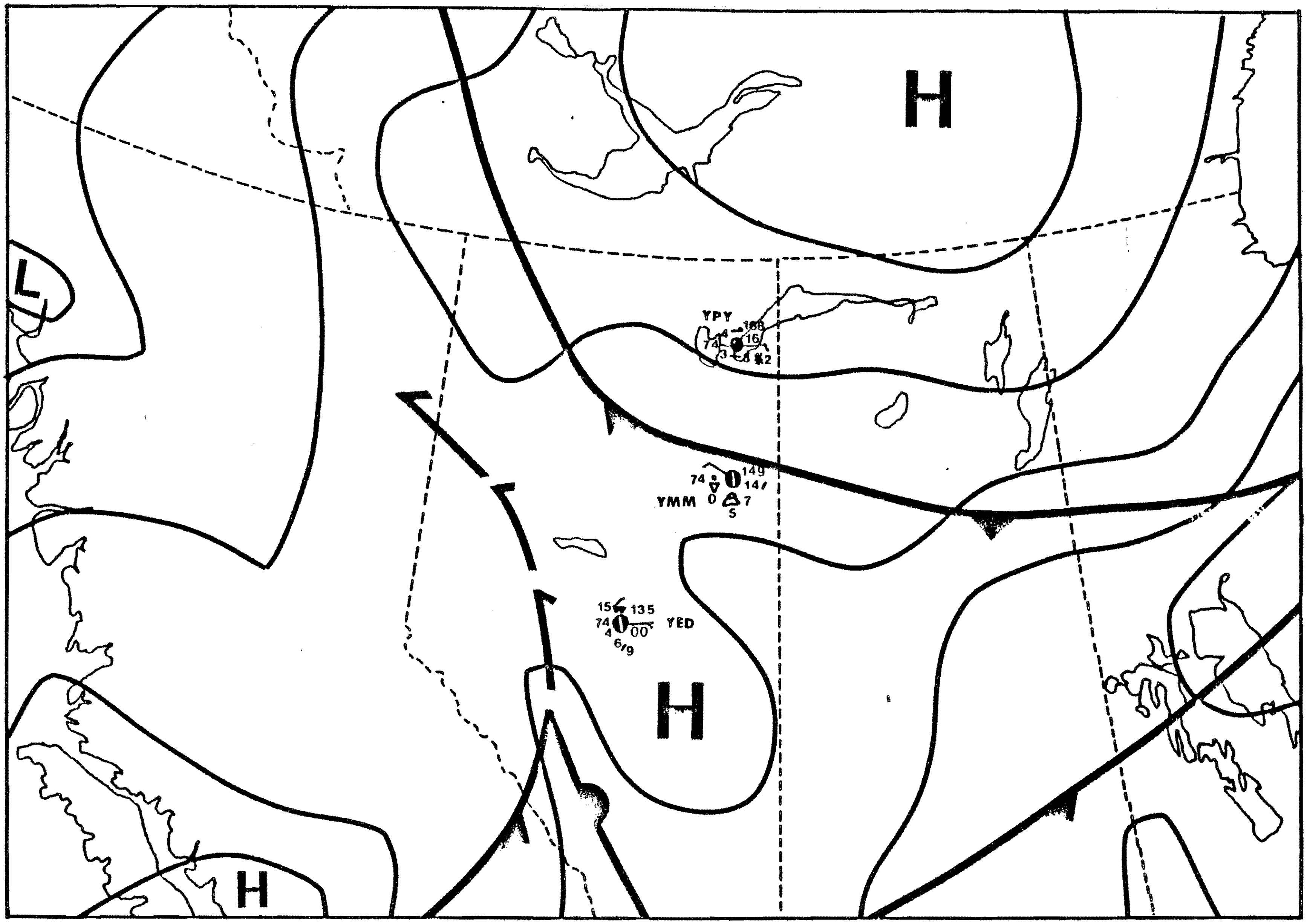


Figure 16. Surface weather map for 26 September (1700 MST). Contours represent atmospheric pressure.

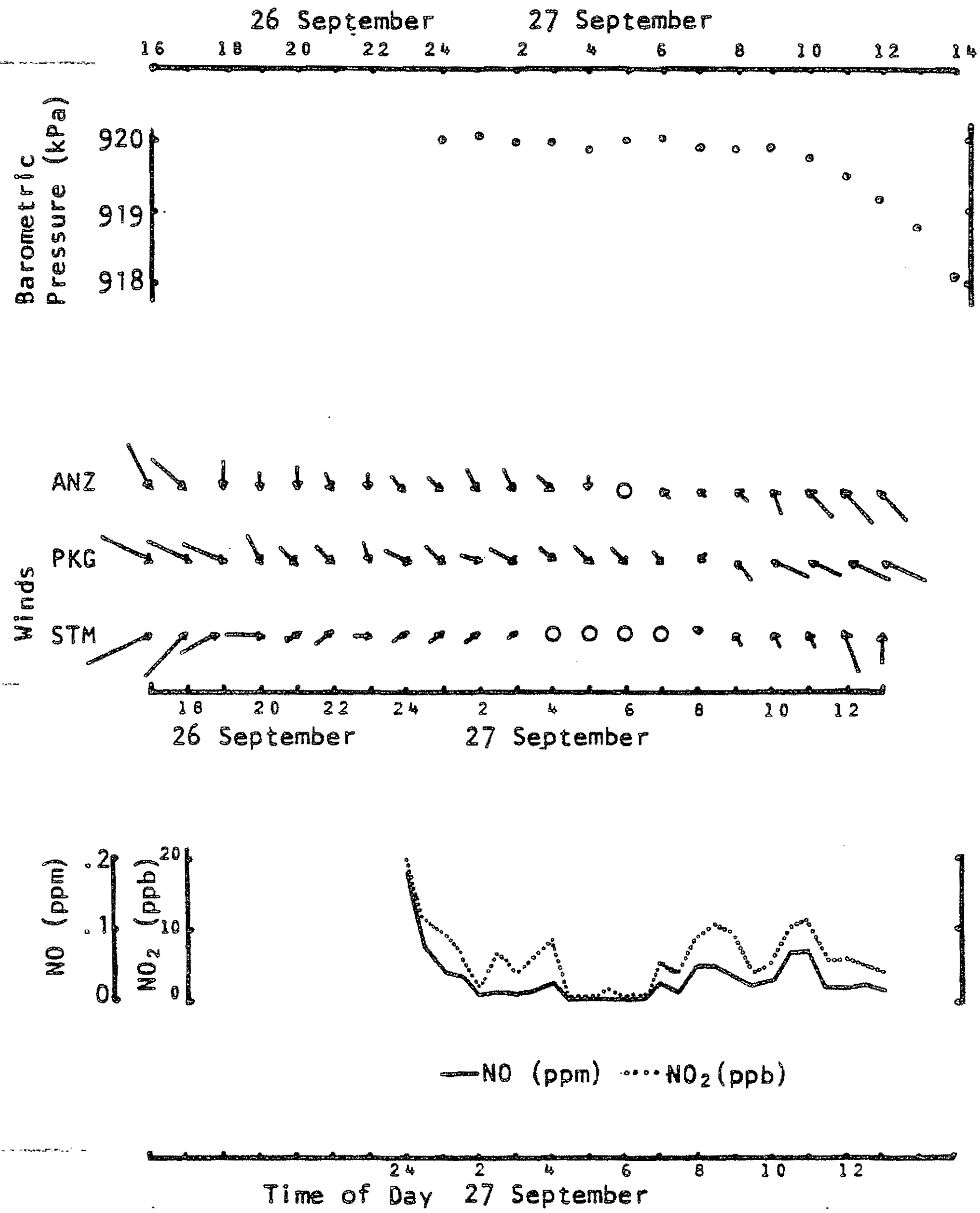


Figure 17. Pollutant concentrations and associated meteorological parameters as a function of time on 26/27 September 1979. Length of wind vectors represents speed (1 mm: 2 km/h).

6. CONCLUSIONS AND RECOMMENDATIONS

Air temperatures at Stoney Mountain (AOSERP) followed the trend of the long-term mean as estimated by Longley and Janz (1978). Air temperatures at the pilot plant are poorly correlated with the Stoney Mountain data. It is suspected that this is due to timing and calibration problems with the pilot plant temperatures.

Wind speeds at the Gregoire Lake stations were generally very light. The wind speed was less than 12 km/h, 60% of the time at Anzac and the park gate. Speeds were apparently stronger at the plant, but this may have been due to calibration problems. Speeds were lower than in the winter months. There was little variation on the average from month to month in the summer. The relatively low speeds were in agreement with long-term records in the oil sands area.

The predominant wind directions at Anzac and the park gate are parallel to the orientation of the terrain contours of the ridge to the south of these stations. Southwest and northeast winds, which are perpendicular to the contours, are rare at Anzac and the park gate. Cross-contour flow is more common at the plant and Stoney Mountain. This may be due to drainage winds and the tendency for cloud cells to form over the ridge. Inflow into the convective cells tends to be upslope across the terrain contours.

The case study of 4 April 1979 demonstrated how a stable northerly regional airflow tended to be deflected to follow the topography. The neutral, southeasterly airflow of 6 April followed the topographic contours. Under moist, unstable conditions (29 June, 19 July), there tended to be upslope flow at the stations near Stoney Mountain while the valley stations at the park gate and Anzac tended to parallel the regional wind directions. The typical summer pattern (17 August) of a trough of low pressure over Alberta resulted in light variable winds.

Although light winds are common, persistent light winds were not a frequent occurrence. There were only three cases of winds less than 6 km/h of duration more than 12 h at the pilot plant.

High concentrations of nitric oxide were recorded at the monitor on 27 September 1979. Examination of the local meteorological data and the upper air data from Edmonton and Fort Smith indicated that low mixing heights may have been an important factor in the incident. Wind directions were north-northwesterly for several hours before the event, indicating some pollutant source other than the plant which is to the west of the monitor. The source is not necessarily one to the north-northwest though because a sequence of shifting wind directions was occurring.

The only recommendation is that the data acquisition system be improved. There is far too much missing data and there are indications of problems with time marks, calibration, and instrument zero scale readings.

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8. APPENDIX

8.1 GLOSSARY OF METEOROLOGICAL TERMS

Dispersion climatology	- statistics of the parameters which control the spreading of gases or small particles in the atmosphere.
Dry adiabatic lapse rate	- the cooling rate of a parcel of air (unsaturated) as it is lifted without addition of external heat (0.98°C/100 m)
Fumigation	- a high ground level concentration of effluents due to the destruction of an inversion layer by thermal or mechanical turbulence.
Inversion	- an atmospheric layer in which air temperature increases with height.
Lapse rate	- the rate of decrease of temperature with height.
Limited mixing condition	- mixing of effluents in a turbulent atmospheric layer capped by a stably stratified layer.
Mesoscale	- medium scale, tens to hundreds of kilometres.
Mixing height	- the height of the surface based layer in which vertical mixing can occur.
Neutral layer	- an atmospheric layer in which the lapse rate is equal to the dry adiabatic value.
Pollution potential	- capability of the atmosphere to dilute and disperse effluents.
Stable layer	- an atmospheric layer in which the lapse rate is less than the dry adiabatic value.
Synoptic scale	- large scale, thousands of kilometres.

Unstable layer - an atmospheric layer in which the lapse rate is greater than the dry adiabatic value.

Wind shear - the change of wind velocity with height.

9. LIST OF AOSERP RESEARCH REPORTS

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.
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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.
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6	PM	Patterson, R., and A.M. Lansdown. 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.
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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, Freshwater Institute. 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 Fisheries and Environment Canada, 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. 70 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. Edmonton, Alberta. AOSERP Report 22.

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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.
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