METEOROLOGICAL FACTORS AFFECTING AMBIENT SO_2 CONCENTRATIONS NEAR AN OIL SANDS EXTRACTION PLANT

by

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ABSTRACT

Occurrences of maximum 0.5 h hour ground level measurements of SO_2 near a point source are related to the meteorological processes at the time such that a cause analysis of the occurrences is established. Measurements, from a 10 station, continuous air quality monitoring network, range from 0.12 to 0.65 ppm and are taken over a 2 year period, from 1976 to 1978, in the Alberta Oil Sands Environmental Research Program (ASOERP) study area. Point source emissions during this period average 125 tonnes sulphur per day (125 MTS/day). Meteorological data used in the analysis consist of local minisonde temperature profiles, synoptic weather maps, wind and temperature data from a 152 m tower, data from a nine station climatology network, local measurements of incoming solar radiation, and airport weather office and regional radiosonde observation (RAOB) data.

Analysis of ambient monitoring measurements indicates that SO_2 concentrations can be grouped into case data sets that suggest an influence of specific synoptic weather systems. Results of the analysis show that the SO_2 concentrations are caused by arctic air mass inversions occurring in the spring, fall, or winter seasons. Frontal inversions with moderate winds, and convective mixing have also been identified as contributing factors for other cases, occurring in the spring.

Comparison of observed and calculated ground level concentrations is made using Alberta Environment's dispersion program. The two-layer model predicts within a factor of 2 for the trapping cases. The unlimited mixing cases only predict to within a factor of 10 to 100.

ACKNOWLEDGEMENTS

The examination of many current technical and scientific problems requires the expertise of several disciplines. The topic of this report is no exception, and the authors are extremely grateful and appreciative of the support, review and criticism offered by Randy Angle, Alberta Environment, and Joe Kotylak, Atmospheric Environment Service, in the areas of dispersion meteorology and synoptic meteorology respectively. The encouragement and review comments of Av Mann, Atmospheric Environment Service, and Jerry Lack, Alberta Environment, provided additional direction and scope to the work. Without the involvement of the noted individuals, topics in this report could not have been examined with any degree of depth or completeness.

Our gratitude is extended to the industrial operators in the Athabasca oil sands; Syncrude for their provision of air monitoring data, and Great Canadian Oil Sands Ltd. (now Suncor Inc.) for their ambient monitoring and in-stack emission data.

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1. INTRODUCTION

1.1 PROBLEM DEFINITION

The approach to air quality management used by Alberta Environment is one that combines best practicable technology and air resource management (Angle 1979). Dispersion models are used to establish the acceptable stack parameters that will mathematically satisfy ambient air quality objectives, once best practicable technology has been applied. The success of this widely accepted approach has been, in part, dependent on the choice of dispersion model used. Meteorological processes or synoptic features influencing dispersion in a given area can vary. Consequently, the kinds of questions posed by Angle (1976) reflect a desire to improve the understanding of these processes so they can be dealt with accordingly.

A partial list of the questions follows:

1. Which meteorological conditions result in the highest ground level (tree-top) concentrations?
2. What is the frequency and duration of these critical meteorological conditions?
3. What concentrations can be expected under these conditions and for how long will they last?
4. How will the construction of several more extraction plants affect the answers to the preceding questions?

Because of the nature of the questions as listed above, some rational decision making must be carried out in order to establish a standard site on which to base stack design. This indeed has been done in the Guidelines for Plume Dispersion Calculations (Alberta Environment

1978). The standard site (i.e., defines meteorology and location) for Alberta as described in this document assumes the plume is trapped between the ground and an elevated inversion whose height is equivalent to the effective stack height. Pasquill stability category D is used for this standard site with the revised curves for dispersion of F. B. Smith, and wind speeds up to 20 m/s.

Notwithstanding the establishment of a standard site, pollution events can be caused by a number of other meteorological factors; a knowledge of these factors and how often they occur could certainly be of benefit.

Trapping, as defined in the standard site, can be brought on by a number of meteorological conditions. Two of the more significant in this case are arctic air mass inversions and fronts. Characteristics of these meteorological conditions are described in the text. Nocturnal inversions and their subsequent transformation by solar radiation are also considered and described. Convective mixing, as defined by Venkatram (1979), is turbulence produced by upward heat flux originating from the ground by solar radiation. Convective mixing causes rapid vertical mixing in the planetary boundary layer and moderate winds do not affect the character of the PBL. Turner and Dicke (1973) describe the numerous effects of terrain on wind characteristics illustrating the significance of the mechanical mixing process. Related to this is the classical worst case of high wind coning. Inversion breakup fumigation occurs where a plume is initially emitted into a stable atmosphere. Convective mixing builds from the surface until it reaches the plume, mixing it to ground level. (U.S. Atomic Energy Commission 1968). High wind fumigation, as discussed by Gifford (1975), occurs when the atmosphere is well mixed by turbulence at all heights encountered by the plume.

These are a few possibilities for consideration as causes of pollution events. There are others. The work described in this report uses these standard definitions as the basis for relating the meteorological factors as causes of pollution events.

1.2 SCOPE OF WORK

The Alberta Oil Sands Environmental Research Program (AOSERP), through its Air System, has provided funds for air quality data acquisition for the past four years. During that time, a number of air quality monitoring stations were commissioned and data analysis has focused on the establishment of background levels by means of frequency distribution tables (Strosher 1978).

Observation of a number of high SO_2 concentration readings through frequency distribution tables prompted a more detailed case analysis. The oil sands extraction plant operating at the time had been designed to a 0.30 ppm ground level under neutral coning conditions but, as mentioned previously, it was possible that a number of SO_2 concentration events had been caused not only by that phenomenon but by other specific meteorological conditions under "normal" plant operation as well.

With this hypothesis in mind, the objectives for this study were laid out as follows:

1. To illustrate and discuss the occurrence, magnitude, and frequency of events of ambient SO_2 concentration;

2. To relate a number of these SO_2 events to the meteorological processes that occurred; and
3. To type and correlate qualitatively the various meteorological processes such that a cause/effect relationship might be established.

The successful accomplishment of these objectives depended in part on the existence of other meteorological data acquisition programs conducted, not continuously, but fortunately at appropriate time periods to provide support data to the high concentration occurrences. The remaining judgement of success for accomplishment of these objectives becomes qualitative. The degree to which the cause/effect relationship was established may therefore appear relative, arbitrary and inconclusive as there is no quantitative basis on which to assess a final conclusion. This scope was deliberate, not to escape the hard science of dispersion meteorology, but to illustrate the complexity of merging disciplines. The difficulties encountered also draw attention to and question the conceptual approaches which sometimes tend to oversimplify the realities of air pollution meteorology. The authors do not profess to resolve these realities, but encourage more respect to their very existence in future investigations.

This report presents the methodology and results of case studies of events of SO_2 concentration over the 2 year period 1976 to 1978 in light of the objectives stated above. The events are first described and discussed separately from the meteorological conditions. Subsets of events are then reviewed as case studies, in relation to the meteorological factors present at event times. Plume rise calculations are made, the Department's dispersion program is tested, and conclusions are drawn from the plume/atmosphere relationship.

2. EVENT ANALYSIS

2.1 METHODOLOGY USED IN THE ANALYSIS OF EVENTS

The following definition for an event was chosen. Each of the five highest 0.5 h SO_2 concentrations recorded at each monitoring station over a period of one year is designated as an event. This definition is further qualified by the following: the year commences 1 June (start of the summer season) and ends 31 May (end of the spring season); the SO_2 concentrations are only valid as events if the SO_2 emission sources are operating in a normal condition; and no two events from the same location can occur on the same day.

The definition of events isolated those five highest ground level concentrations from each station, each year. This approach treated each station with equal significance even though the concentration magnitudes could vary greatly depending on the distance from the emission source. Highest concentrations occurring on the same day at different stations could be illustrated using this method. Unfortunately, the limited data base does not provide a frequency of occurrence of the associated meteorological causes.

The SO_2 concentration events were taken from 13 continuous monitoring stations in the AOSERP study area (Strosher 1978) and cover a 2 year time period, 1 June 1976 to 31 May 1978. Because monitoring stations, operated by either industry or AOSERP, were commissioned at various times in that 2 year period, only five stations were available for data analysis in the first year, while 13 were available in the second year.

During the 2 year time period ending 31 May 1978, only one oil sands plant was in operation [Great Canadian Oil Sands[1] (GCOS)]. Although the emission data for the following year (1978/79) are available, the erratic operation of the Syncrude plant during start-up prohibited their use.

2.2 RESULTS OF EVENTS ANALYSIS

Data giving the time duration, location, magnitude and plant operating conditions at event times are tabulated in Appendix 7.1. In addition to the powerhouse and incinerator stacks, the hydrocarbon flare is emitting a continual 10 to 12 MTS/day (metric tonnes sulphur per day) from the process, and therefore is considered for this study as part of the normal operation. There is no emission from the acid gas flare during these events. Figures 1 and 2 map the locations of all continuous monitoring stations, the source (GCOS) and the sites at which meteorological data were measured.

Tables 1 to 3 show the diurnal and seasonal distribution of all events on a yearly cycle. Table 1 (1976-77) deals with five monitoring stations or 25 events and shows highest frequency of event occurrence in the 0900 to 1500 h time period and the fall and summer seasons. Table 2 (1977-78) illustrates results from 10 monitoring stations or 50 events which favor the 0900 to 1500 h time period and the spring season. Table 3 shows results from the three AOSERP monitoring stations located greater than 40 km from the emission source. Winter

1. GCOS became Suncor Inc. in August 1979.

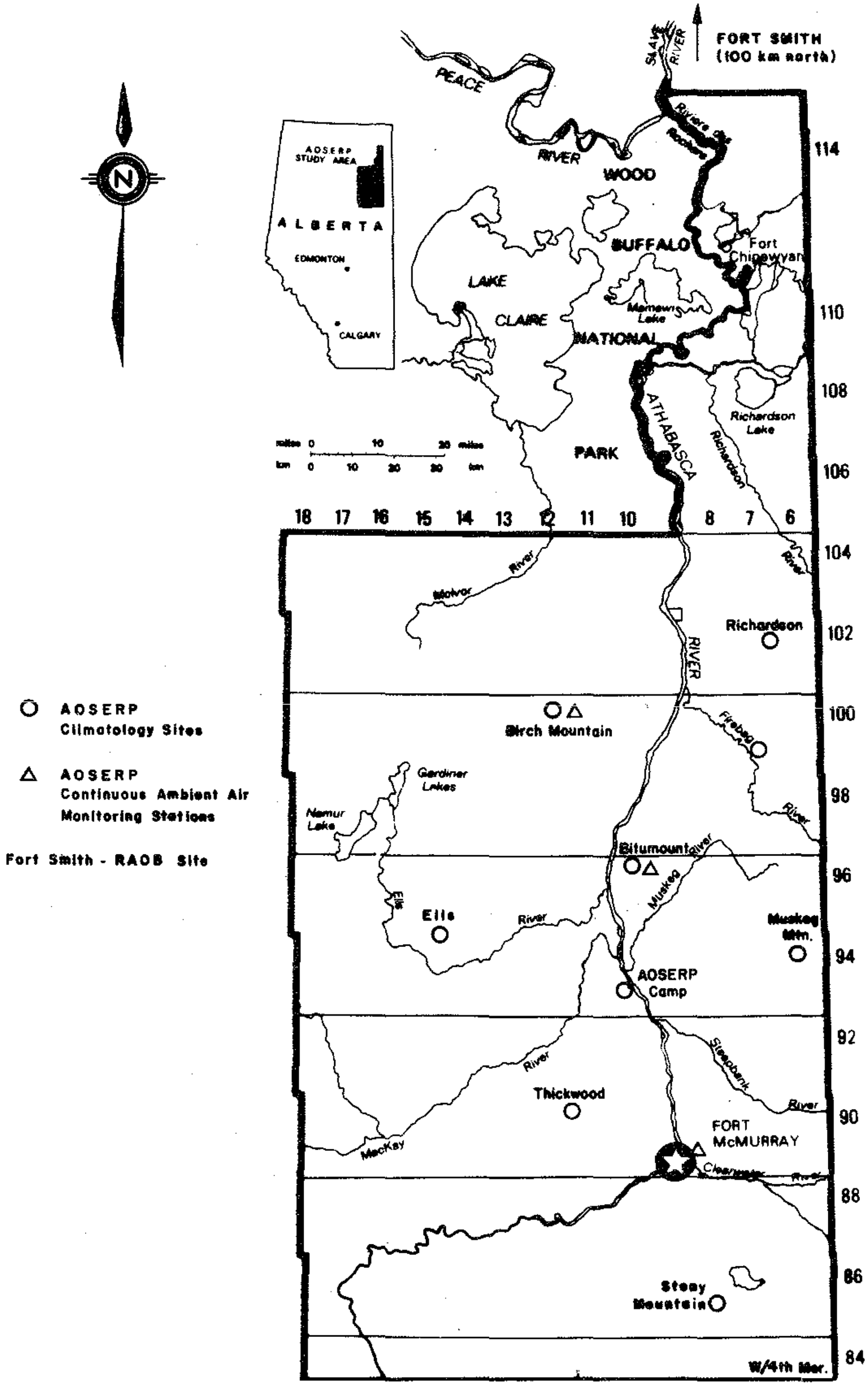


Figure 1. Map of AOSERP study area showing monitoring stations.

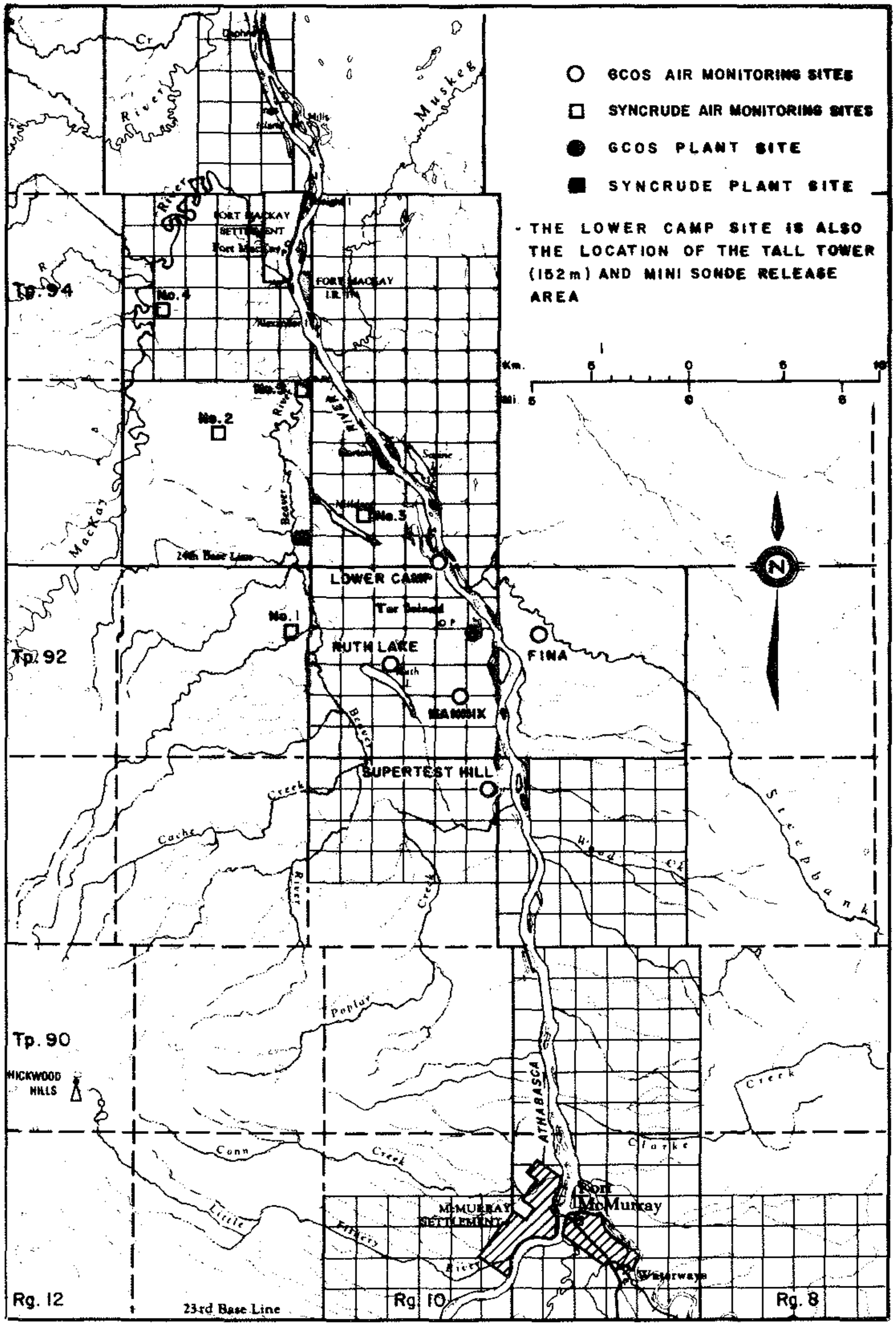


Figure 2. Map of continuous ambient air monitoring stations and meteorological data collection sites.

Table 1. Time distribution of 0.5 h average SO_2 concentrations (ppm), five Great Canadian Oil Sands stations, June 1976 to May 1977.

Time	0000 0300	0300 0600	0600 0900	0900 1200	1200 1500	1500 1800	1800 2100	2100 2400
Winter	0.26			0.22		0.23 0.15 0.19	0.16	
Spring				0.61		0.15		
Summer			0.16	0.17 0.19 0.12	0.23 0.33 0.21			
Fall		0.20 0.30	0.37	0.65 0.20 0.21	0.19 0.29 0.29		0.31	

Table 2. Time distribution of 0.5 h average SO_2 concentrations (ppm), five Great Canadian Oil Sands station, five Syncrude stations, June 1977 to May 1978.

Time	0000 0300	0300 0600	0600 0900	0900 1200			1200 1500			1500 1800		1800 2100	2100 2400
Winter	0.16									0.32			0.18
										0.14			
Spring		0.28		0.44	0.16	0.15	0.14	0.16	0.14	0.15		0.32	
		0.28		0.34	0.12	0.33	0.24	0.18	0.11	0.19	0.21		
				0.14	0.14	0.19	0.25	0.26	0.29	0.14	0.33		
				0.14	0.29	0.58	0.22	0.12	0.47	0.16	0.14		
							0.39	0.20		0.22	0.18		
Summer			0.09	0.16	0.28								
				0.16									
				0.21									
Fall				0.10			0.13						0.10

Table 3. Time distribution of 0.5 h average SO_2 concentrations (ppm), three AOSERP stations, June 1977 to May 1978.

Time	0000 0300	0300 0600	0600 0900	0900 1200	1200 1500	1500 1800	1800 2100	2100 2400
Winter	0.06	0.06	0.08		0.10 0.10	0.12		0.24
Spring		0.07		0.09	0.07	0.15 0.25		
Summer				0.13				
Fall				0.07		0.10		

and spring are the seasons with highest frequency of event occurrence. There is no strong diurnal pattern at these stations from the available data base.

A significant feature extracted from these results is that 61% of events occurred between 0900 and 1500 h from monitoring stations within 20 km of the emission source. Seasonally the data base is small and, although the spring of the first year was dominant for event occurrence, the fall and summer respectively showed dominance the second year.

Examination of event dates shows the events from different stations are occurring on the same day. The spatial distribution indicates a strong occurrence in spring with fall and winter being the secondary seasons of occurrence. The spatial continuity of event occurrence suggests the influence of a large-scale meteorological condition.

3. CASE STUDY ANALYSIS

3.1 METHODOLOGY USED IN THE ANALYSIS OF CASES

3.1.1 Definition of Cases

Cases were developed by grouping events by time on the general hypothesis that events occurring close together could better be related to meteorology.

Specifically, three types of cases were obtained using the following criteria:

1. Events that occur at more than one monitoring station on the same day and are also part of a group of events that occurred at any station, plus or minus three days from a central event;
2. Not more than one event on the same day but part of a group of event that occurred at any station, plus or minus three days from a central event; and
3. Any one single event with no apparent relation to the others.

The above criteria were applied to the event data from Tables 7, 8, and 9 (see Appendix 7.1), all from monitoring stations within 20 km of the emission source.

Criteria in (1) provided the basis for Cases 1 to 8, while criteria in (2) provided the basis for Cases 9 to 12, and criteria in (3) provided the basis for Cases 13 to 16. Table 4 shows relevant data for each case.

Table 4. Case data.

Case No.	Date	Time	Station	SO_2 Concentration (0.5 h ppm)
1	20 Sep 76	1230	Supertest Hill	0.19
	21 Sep 76	1130	Ruth Lake	0.65
		1130	Mildred Lake[a]	0.20
		1200	Mannix	0.29
		1300	Fina	0.29
	22 Sep 76	1100	Mildred Lake	0.21
2	26 Jan 77	1630	Ruth Lake	0.15
		1730	Mannix	0.19
	27 Jan 77	1530	Ruth Lake	0.19
		1600	Mannix	0.23
3	04 Mar 77	1530	Mannix	0.33
		1630	Supertest Hill	0.22
		1730	Ruth Lake	0.14
	07 Mar 78	1330	Syncrude #2	0.16
	10 Mar 78	1300	Supertest Hill	0.24
4	21 Mar 78	1430	Ruth Lake	0.14
	22 Mar 78	1200	Supertest Hill	0.25
	23 Mar 78	1300	Syncrude #4	0.12
		1300	Syncrude #5	0.14
		1300	Syncrude #3	0.26
		1400	Syncrude #2	0.18
		1530	Syncrude #1	0.19
5	03 Apr 78	1200	Mannix	0.22
		1330	Syncrude #2	0.14
	05 Apr 78	1130	Fina	0.33
6	22 Apr 78	1300	Fina	0.29
		1930	Mannix	0.32
	23 Apr 78	0430	Mannix	0.28
7	28 Apr 78	1100	Syncrude #4	0.14
		1100	Lower Camp	0.19
		1100	Syncrude #3	0.29
	01 May 78	1000	Syncrude #2	0.14
	03 May 78	0530	Fina	0.28
8	24 May 78	1000	Syncrude #1	0.12
		1030	Ruth Lake	0.15
		1030	Lower Camp	0.58
		1200	Fina	0.47
		1700	Supertest Hill	0.21
	27 May 78	1030	Mildred Lake	0.34
		1200	Fina	0.39
	28 May 78	1130	Mildred Lake	0.44

continued...

Table 4. Concluded.

Case No.	Date	Time	Station	SO_2 Concentration (0.5 h ppm)
9	31 Jul 76	1200	Mildred Lake	0.33
	02 Aug 76	1300	Mildred Lake	0.21
	04 Aug 76	1030	Ruth Lake	0.12
10	30 Aug 76	1230	Mannix	0.23
	02 Sep 76	1830	Fina	0.31
11	10 Apr 78	1530	Syncrude #5	0.16
	14 Apr 78	1530	Lower Camp	0.18
	15 Apr 78	0900	Syncrude #5	0.14
12	12 May 78	1700	Supertest Hill	0.15
	14 May 78	1130	Syncrude #1	0.16
	17 May 78	1230	Lower Camp	0.20
13	10 Sep 76	0330	Fina	0.30
14	14 Sep 76	0400	Mildred Lake	0.20
15	11 Feb 78	1530	Syncrude #4	0.14
16	03 May 78	0530	Fina	0.28

[a] Mildred Lake and Syncrude #3 are the same station. Operator changed from GCOS to Syncrude in June 1977.

3.1.2 Procedures of Relating Meteorology to Case Studies

Events in Cases 1 to 8 have the strongest association one to another with their multiple occurrence on a single day. For this reason it was hypothesized that an association with synoptic weather patterns could be made. To test this hypothesis, the following steps were carried out:

1. For each case, a central event day was chosen on which to focus the meteorology analysis;
2. Temperature profiles were examined to determine mixing heights and lapse rates, and analyzed for conditions reflecting specific synoptic patterns;
3. In the absence of measured plume rise data, emission data from the GCOS plant were obtained for selected event days for Cases 1 to 8 and plume rise calculations were made using plume rise formulas of Briggs (1975);
4. Synoptic weather maps were obtained from Alberta Weather Centre, Atmospheric Environment Service for selected event days primarily to determine if the profile structure could be directly related to a general weather system; and
5. Where applicable, tall tower data, AOSERP climatology station data, Fort McMurray airport weather office data and RAOB's from Fort Smith and Edmonton were also used.

All 16 cases described in Table 4 were analyzed using the procedures described above. Plume rise and dispersion calculations were made only for Cases 1 to 8.

3.2 RESULTS OF METEOROLOGY CORRELATION TO CASE STUDIES

Whether one deals with conceptual or mathematical models, assumptions cannot be avoided. The authors' list of assumptions will follow the traditional list of definitions that describe the meteorological processes and synoptic features that, as outlined in the Introduction, historically have been applied to understanding air quality models. The objective will remain to determine which of them are of significance and how interactive they are for the AOSERP area.

The detailed case by case analysis is presented in Appendix 7.2. Summaries for Cases 1 to 16 are given in this section and include relevant temperature profiles and synoptic maps. Table 5 summarizes the first eight cases, by stating the synoptic features associated with each case. The following subsections will deal with each of those main features or processes and relate, where necessary, back to the case data.

3.2.1 Arctic Air Mass Inversions

The arctic air mass inversion is the main feature associated with the cause of events for Cases 2 and 3. Light and variable winds or calms occurred during these time periods. The deep arctic inversion develops in northern latitudes of cold continents as the air mass strives to achieve radiation equilibrium with the snow- and ice-covered surfaces. Characteristics of this air mass are very cold temperatures, and temperature profiles with a very deep surface inversion and stable air aloft. These extremely cold surfaces are the result of a low net gain in energy. They occur in winter and in a modified form in fall and spring due to the low angle of the sun and high albedo of snow,

Table 5. Case data.

Case No.	Date & Times	No. of Events	SO Conc. Range (ppm) 0.5 h avg.	Case (No. of Events)
1	21 Sep 76 1130 to 1300	4	0.20 - 0.65	frontal inversion weak pressure gradient (4)
2	27 Jan 77 1530 to 1600	2	0.19 - 0.23	arctic air mass inversion (2)
3	04 Mar 78 1530 to 1730	3	0.14 - 0.33	arctic air mass inversion (3)
4	23 Mar 78 1300 to 1530	5	0.12 - 0.26	frontal inversion (5) tight pressure gradient (5)
5	03 Apr 78 1200 to 1300	2	0.14 - 0.22	strong solar radiation (2)
6	22 Apr 78 1300 to 1930	2	0.29 - 0.32	strong solar radiation (1) tight pressure gradient (1)
7	28 Apr 78 1100	3	0.14 - 0.29	frontal inversion (3) tight pressure gradient (3)
8	24 May 78 1000 to 1700	5	0.12 - 0.58	strong solar radiation (4)

combining to minimize energy absorption and heating of the surface. Long wave energy losses are particularly effective because of the longer nights and lower humidity in these colder seasons. The intensity and depth of the surface inversion is typified in the summary profile of Case 3 while Case 2, winter, indicates a loss of intensity, but greater depth.

It is the combination of intensity and depth of the surface inversions that slows the development of the mixing height by the incoming solar radiation. Thus the potential for causing pollution events by trapping is created from a circumstance somewhat unique to Canada's northwest, and labelled here as arctic air mass inversions.

The air mass described above had the tendency to be associated with a high pressure circulation pattern, although this weakened to a col in Case 3. Because of its uniqueness, it is worth contrasting this system to the more well known and publicized subsidence inversion associated with warm anticyclones. The end result of pollution trapping is the same but the origin of each system is unique.

Warm anticyclones originate from the Pacific High and move through the United States (Williamson 1973) rarely affecting Alberta. Characteristics typical to warm anticyclones are slow movement, warm temperatures, intense nocturnal inversions, and light winds through a deep layer (Holzworth 1969). A ridge of high pressure is maintained above the warm anticyclone, causing compressional heating of air aloft, sustaining subsidence or a subsidence inversion. It is the elevated subsidence inversion, persisting after early morning break-up of the nocturnal inversion, that slows the development of the mixing height, creating a great potential for causing pollution events (Holzworth 1969). These characteristics were not found in any of our investigations.

3.2.2 Frontal Inversions

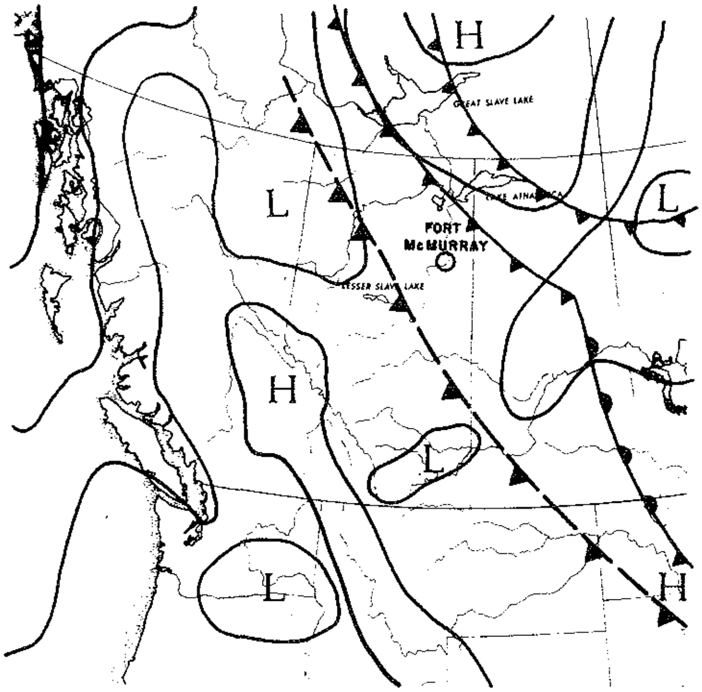
Frontal inversions can arise at the interface of two air masses of quite different temperature, and absolute humidity. Events of Case 1 are attributed to frontal inversion and light winds. Events of Cases 4 and 7 are similar in that they are attributed to a combination of a frontal inversion and a pressure gradient across the system strong enough to produce moderate winds. The mixing depth was limited to 400 to 500 m for these two cases, at event times. These conditions have been documentated by Nudelman and Frizzola (1974) and relate to an air pollution episode in New York City over a three-day period. Winds in their documented epidsode could be classifed as moderate as well. The events in northeastern Alberta again appear to be complicated by the noctural inversion.

3.2.3 Mechanical and Thermal Turbulence

Mechanical and thermal turbulence can be described in terms of pressure gradient and solar radiation, respectively.

Events of Cases 5, 6, and 8 appear to occur in the presence of strong mechanical or thermal turbulence. Light, moderate, or strong winds and insolation were the only parameters available for determining the significance of these processes. (See Appendix 7.2.1 for ranges used.) The strong winds are brought about by the tight pressure gradient during one event of Case 6 and the convective mixing is brought

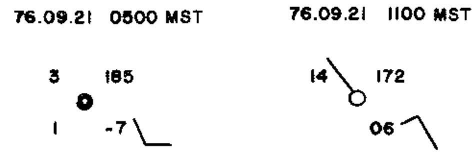
SYNOPTIC MAP



DATE : 21 September 1976 1100 MST

FOR TIME PERIOD : 20, 21 & 22 September 1976

METEOROLOGICAL DATA



TIME RANGE OF EVENT 1130-1300 MST

DATA DURING EVENTS

RANGE OF $[SO_2]$ = STRONG

WINDS (152 m) = 0.5 m/s

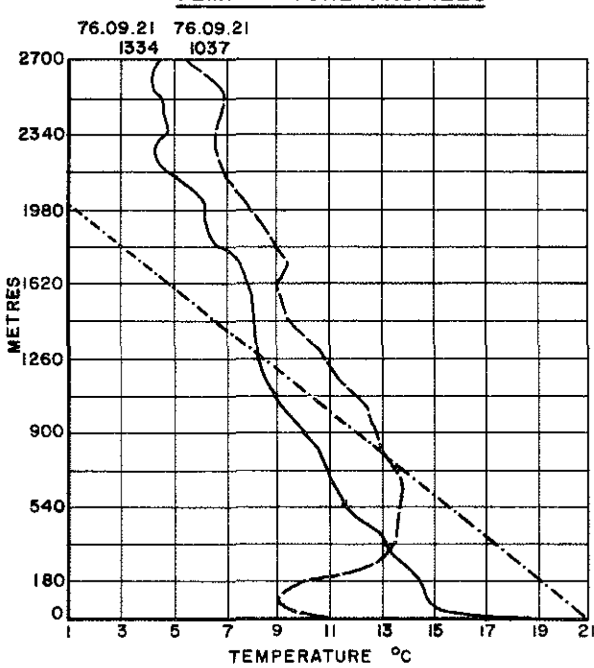
RADIATION = MODERATE

SYNOPTIC PICTURE

20TH - HIGH ALONG THE ROCKIES WEAKENS AND MOVES TO THE SOUTHEAST

21ST & 22ND - ARCTIC HIGH AFFECTS NORTHERN ALBERTA

TEMPERATURE PROFILES



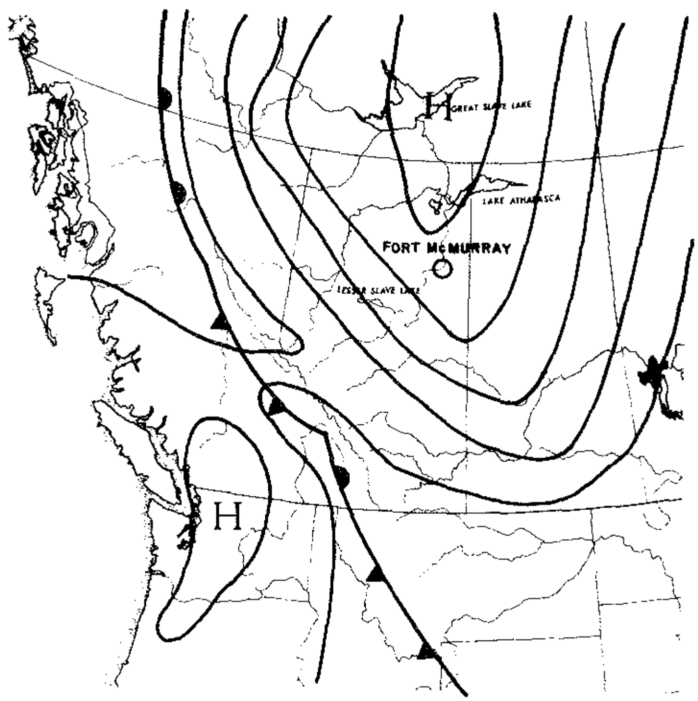
-·-·- DRY ADIABATIC LAPSE RATE

INTERPRETATION OF $[SO_2]$ EVENT(S)

Profile information from both Lower Camp and Fort Smith indicate the pressure of the washout front overlapping the entire area. The presence of this layer is reconfirmed by local surface information and weather maps.

Information listed leads us to conclude that cold frontal trapping and light variable winds produced events at ground level.

SYNOPTIC MAP

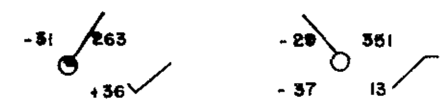


DATE : 27 JANUARY 1977 1400 MST

FOR TIME PERIOD : 26, 27, & 28 JANUARY 1977

METEOROLOGICAL DATA

77.01.27 0500 MST 77.01.27 1400 MST



TIME RANGE OF EVENTS 1530-1600 MST

DATA DURING EVENTS

RANGE OF $[SO_2]$ = MODERATE

WINDS (152 m) = 0.5 m/s

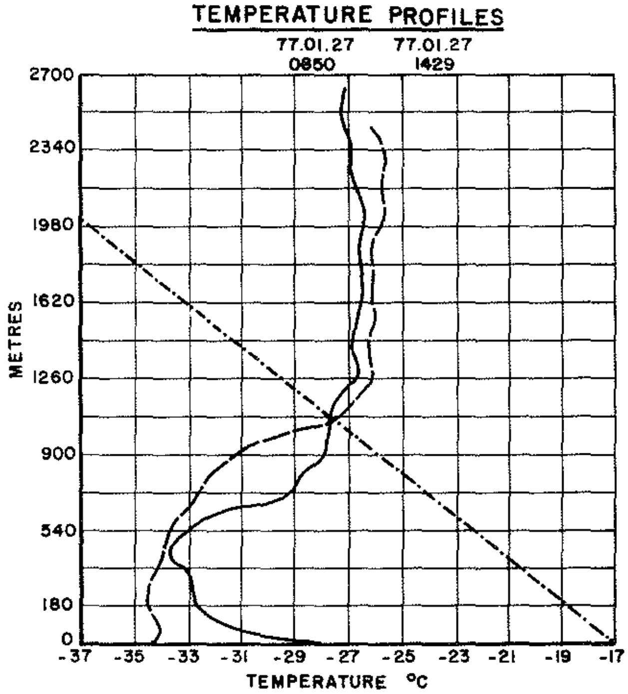
RADIATION = SLIGHT

SYNOPTIC PICTURE

26TH - ARCTIC HIGH MOVES IN OVER ALBERTA

27TH & 28TH - MAINTAINS RELATIVE POSITION OVER ALBERTA AND ELONGATES SOUTHWARD

TEMPERATURE PROFILES

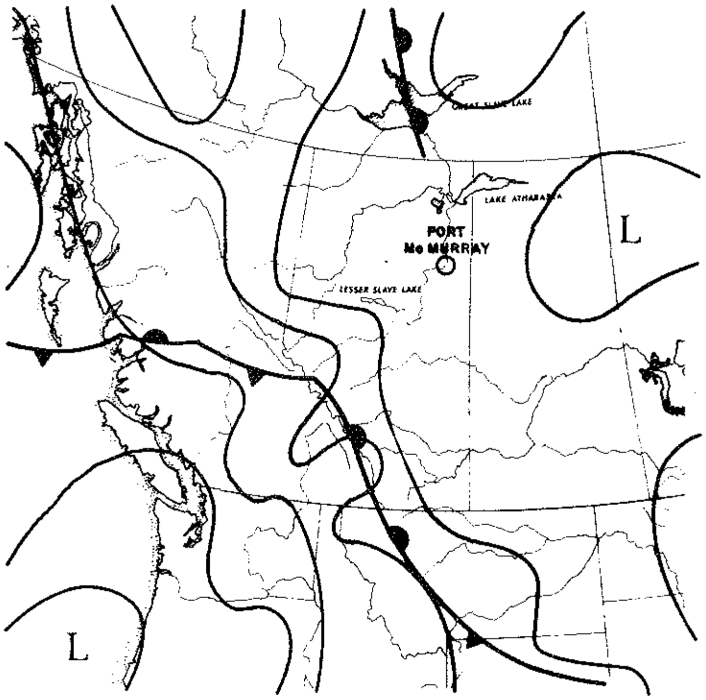


-·-·- DRY ADIABATIC LAPSE RATE

INTERPRETATION OF $[SO_2]$ EVENT(S)

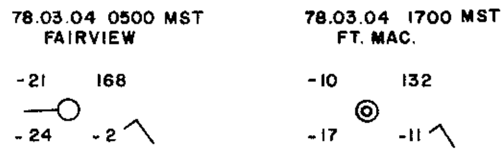
The deep inversion due to radiative cooling and the stable layer aloft is characteristic of the cold continental arctic high pressure system situated over Alberta. Daytime heating does not destroy the inversion but creates a shallow mixing layer at the surface. Trapping of emissions by the inversion due to the cold arctic air has resulted in the events at ground level.

SYNOPTIC MAP



DATE : 4 MARCH 1978 1700 MST
FOR TIME PERIOD : 3, 4 & 5 MARCH 1978

METEOROLOGICAL DATA



TIME RANGE OF EVENTS 1530-1730 MST

DATA DURING EVENTS

RANGE OF [SO_2] = MODERATE TO STRONG

WINDS (152 m) = 0.5 m/s

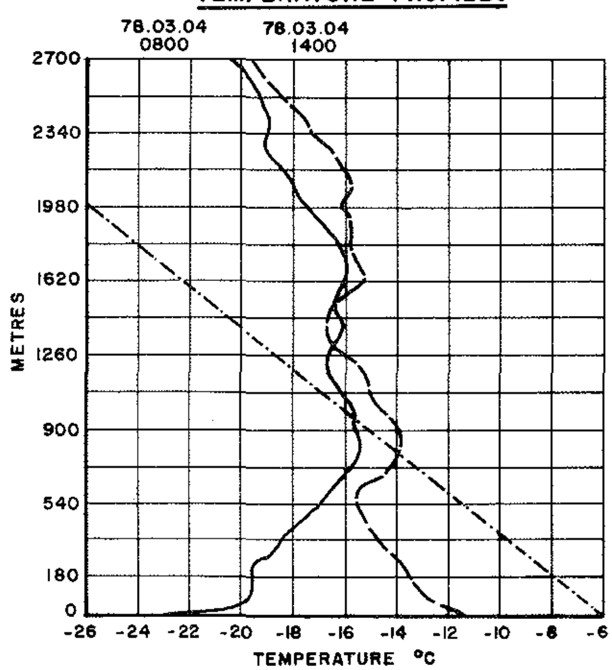
RADIATION = SLIGHT

SYNOPTIC PICTURE

3RD & 4TH - HIGH MOVES SOUTHEASTWARD, LOW MOVES IN OVER LOWER BRITISH COLUMBIA INTERIOR

5TH - RELATIVE POSITIONS OF SYSTEMS ARE MAINTAINED

TEMPERATURE PROFILES

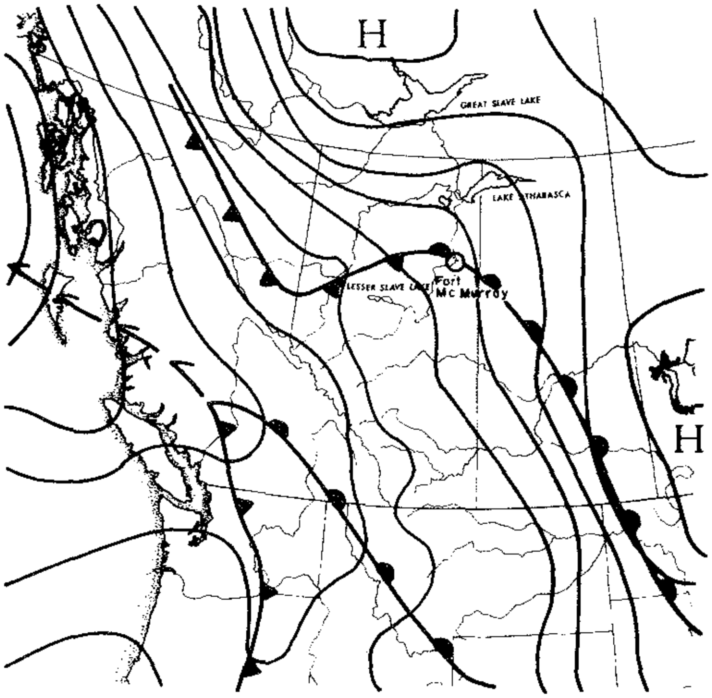


-·-·- DRY ADIABATIC LAPSE RATE

INTERPRETATION OF [SO_2] EVENT(S)

Profiles show a deep inversion and stable air above which are characteristi of cold continental arctic air that surrounds the Fort McMurray region. Daytime heating has reduced the nocturna inversion due to the cold arctic air to an elevated inversion which traps emissions and causes the events at ground level.

SYNOPTIC MAP



DATE : 23 MARCH 1978 1400 MST
FOR TIME PERIOD : 22, 23 & 24 MARCH 1978

METEOROLOGICAL DATA

TIME RANGE OF EVENTS 1300-1530 MST

DATA DURING EVENTS

RANGE OF $[SO_2]$ = MODERATE

WINDS (152 m) = 3.1 - 1.8 m/s

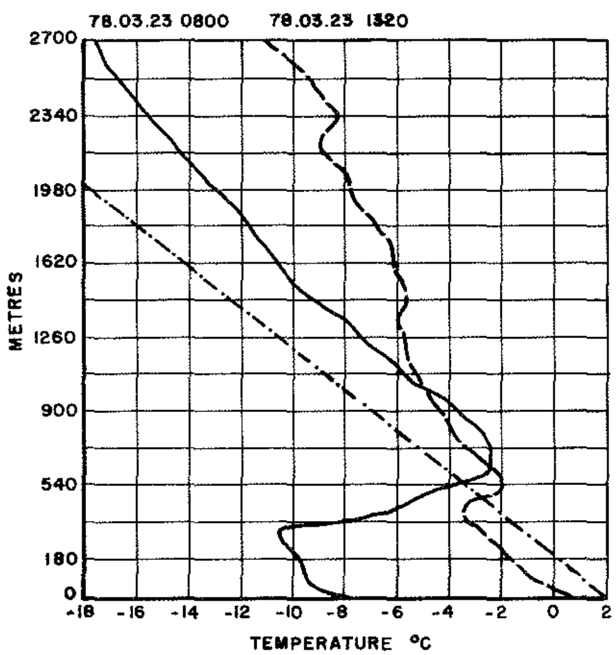
RADIATION = MODERATE

SYNOPTIC PICTURE

21ST & 22ND - ARCTIC HIGH MOVES DOWN INTO NORTHERN ALBERTA

23RD & 24TH - RETREAT OF THE ARCTIC HIGH

TEMPERATURE PROFILES



-·-·- DRY ADIABATIC LAPSE RATE

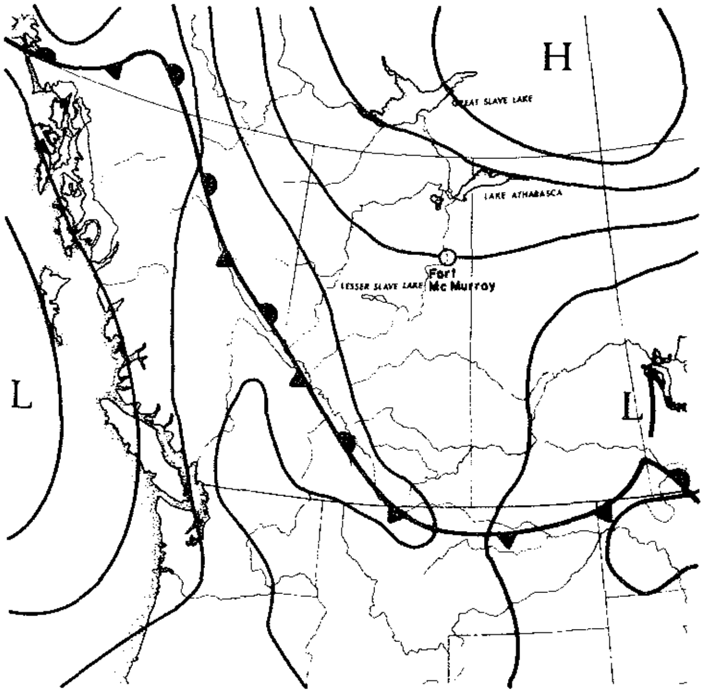
INTERPRETATION OF $[SO_2]$ EVENT(S)

Profiles at Lower Camp show an elevated inversion in the morning that is modified and elevated to a greater height by the afternoon.

Surface maps and analysis reveals the warm front to exist through the immediate AOSERP area.

Warm frontal trapping and moderate winds lead to the occurrences of events at ground level.

SYNOPTIC MAP



DATE : 3 APRIL 1978 1100 MST
FOR TIME PERIOD 2 & 3 APRIL 1978

METEOROLOGICAL DATA

78.04.03 0500 MST

78.04.03 1200 MST

TIME RANGE OF EVENTS 1200-1300 MST

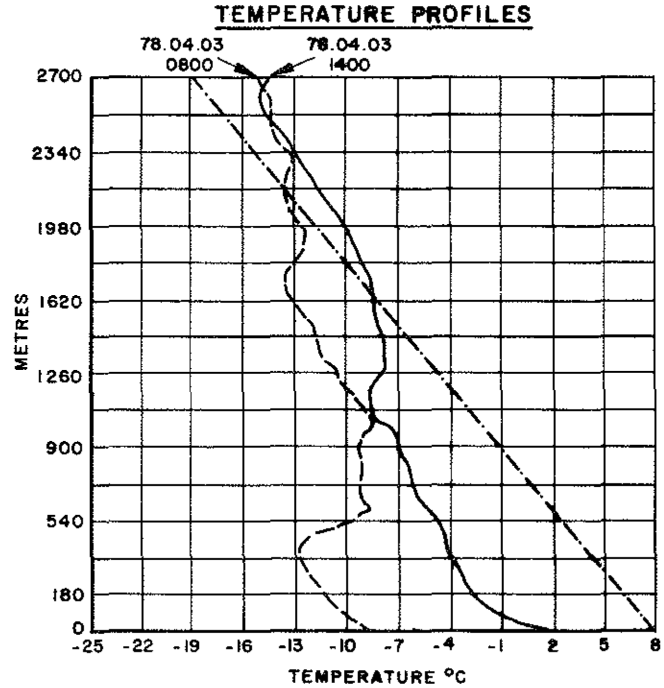
DATA DURING EVENTS

RANGE OF $[SO_2]$ = MODERATE
WINDS (152 m) = 0.5 m/s
RADIATION = STRONG

SYNOPTIC PICTURE

2ND & 3RD - LOW MOVES THROUGH ON THE 2ND AND ARCTIC HIGH ELONGATES SOUTHWARD OVER ALBERTA

TEMPERATURE PROFILES



--- DRY ADIABATIC LAPSE RATE

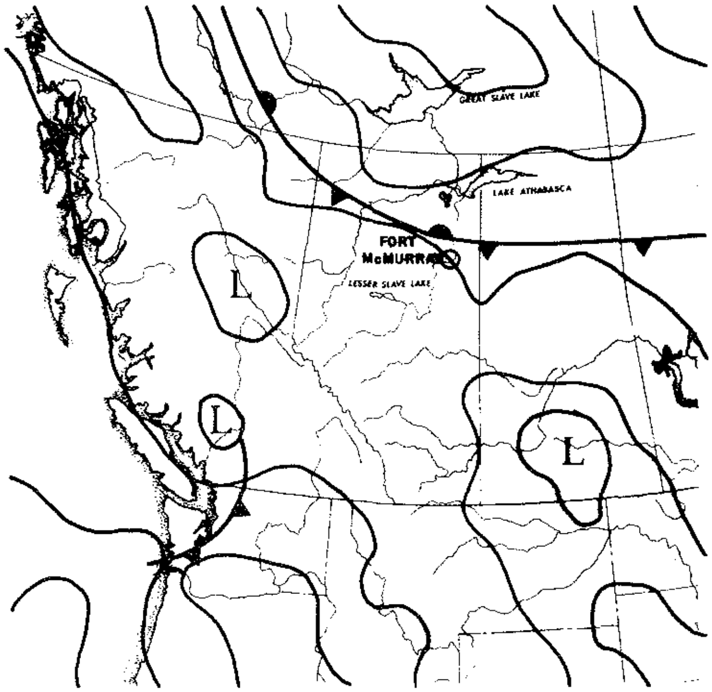
INTERPRETATION OF $[SO_2]$ EVENT(S)

Profiles from Lower Camp and Fort Smit show two elevated inversions in the mornin which are modified to superadiabatic lapse rates at ground level and near isothermal lapse rate above.

Surface maps indicate a modified continental arctic air mass over the Fort McMurray region.

Trapping of emissions by the elevated inversions was not the most significant process by early afternoon but strong thermal turbulence or convective mixing caused the ground level events.

SYNOPTIC MAP



DATE : 22 APRIL 1978 1700 MST
FOR TIME PERIOD : 22 & 23 APRIL 1978

METEOROLOGICAL DATA

78.04.22 0500 MST

78.04.22 1400 MST

TIME RANGE OF EVENTS 1300 & 1930 MST

DATA DURING EVENTS

RANGE OF [SO_2] = STRONG

WINDS (152 m) = 0.9 m/s 1300 MST
8.5 m/s 2000 MST

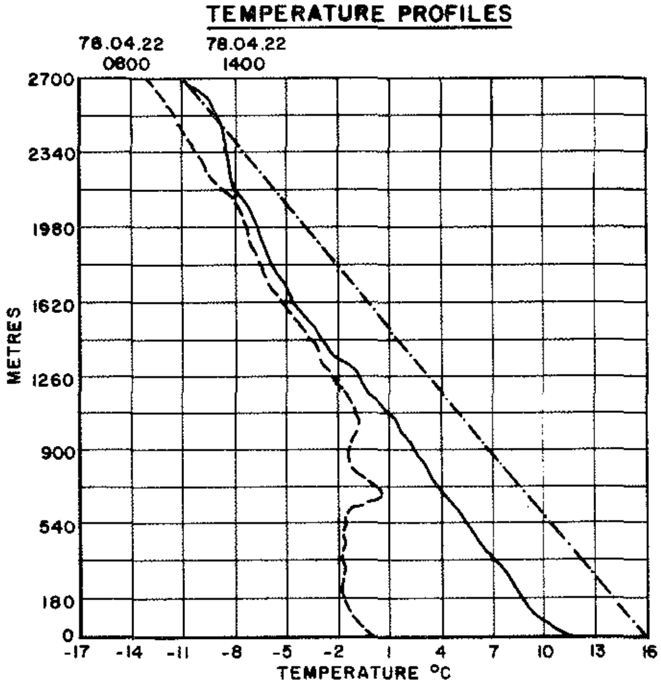
RADIATION = STRONG 1300 MST

SYNOPTIC PICTURE

22ND - ARCTIC HIGH AND FRONT JUST NORTH OF FORT McMURRAY ARE STATIONARY

23RD - HIGH INTENSIFIES MOVING FRONT SOUTHWARD

TEMPERATURE PROFILES



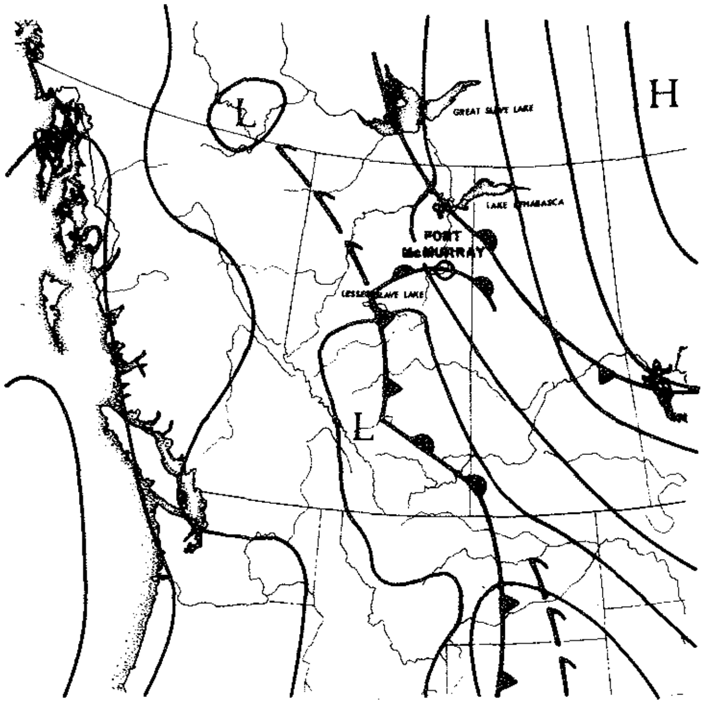
—·—·— DRY ADIABATIC LAPSE RATE

INTERPRETATION OF [SO_2] EVENT(S)

Profiles, surface maps and surface analysis reveal a front over the AOSERP region. The frontal inversion is broken down by the time of the early afternoon event. Strong thermal turbulence is credited with being the primary cause of the early afternoon event.

Late afternoon saw strong winds mix the plume to ground level causing the event.

SYNOPTIC MAP



DATE : 28 APRIL 1978 1100 MST

FOR TIME PERIOD : 28 APRIL, 1 & 3 MAT 1978

METEOROLOGICAL DATA

78.04.28 0500 MST | 78.04.28 1100 MST

TIME RANGE OF EVENTS 1100 MST

DATA DURING EVENTS

RANGE OF $[SO_2]$ = MODERATE

WINDS (152 m) = 5.0 m/s

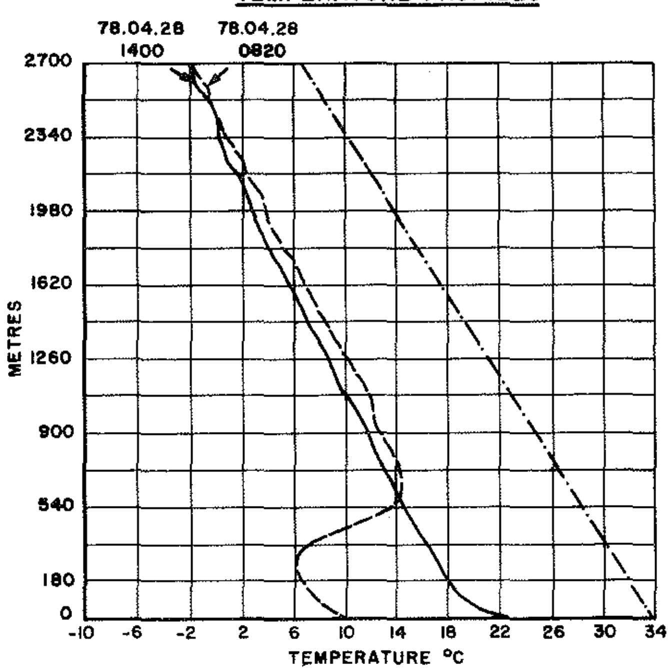
RADIATION = STRONG

SYNOPTIC PICTURE

28TH - HIGH MOVES INTO AND THEN RETREATS FROM NORTHEASTERN ALBERTA BY NOON

29TH - HIGH MOVES EASTWARD AS LOW MOVES IN FROM THE COAST

TEMPERATURE PROFILES



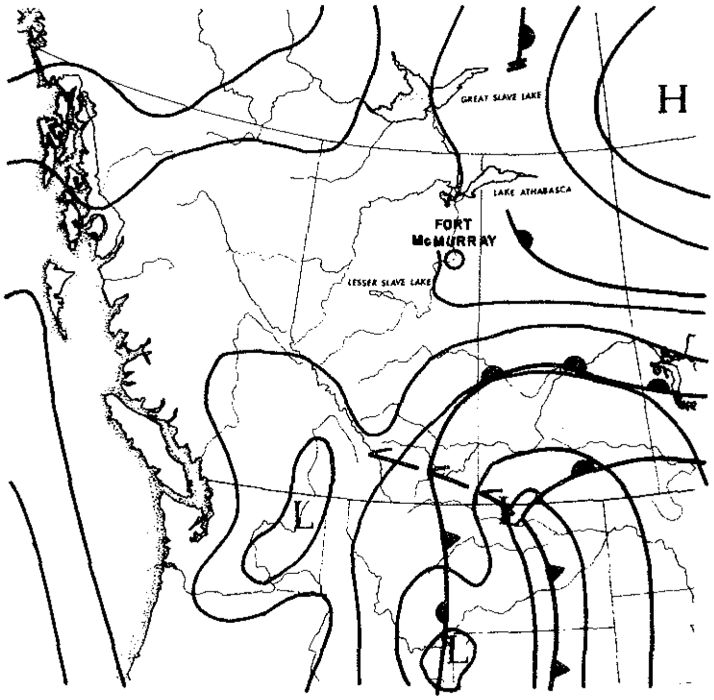
—·—·— DRY ADIABATIC LAPSE RATE

INTERPRETATION OF $[SO_2]$ EVENT(S)

Profiles indicate an elevated inversion which is found to be a cold front from an intense high pressure system moving in from the northeast. Surface maps and analysis confirm the presence of the front and moderate winds over the area.

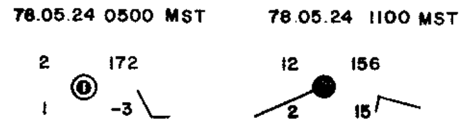
A combination of an elevated frontal inversion and moderate winds brought emissions down to ground level.

SYNOPTIC MAP



DATE : 24 MAY 1978 1100 MST
FOR TIME PERIOD : 24 MAY 1978

METEOROLOGICAL DATA



TIME RANGE OF EVENTS 1000-1700 MST

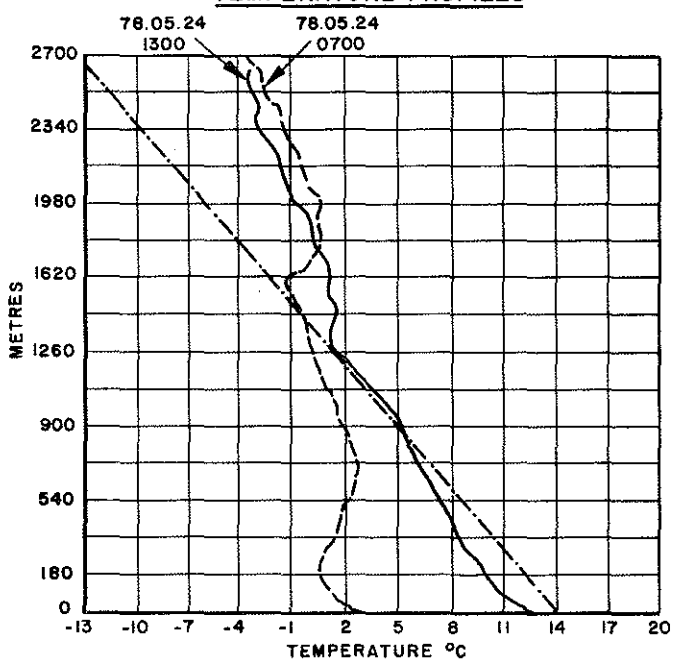
DATA DURING EVENTS

RANGE OF $[SO_2]$ = MODERATE - STRONG
WINDS (152 m) = 0.9 m/s
RADIATION = MODERATE - STRONG
1000 - 1200 MST

SYNOPTIC PICTURE

24TH - LOWS MOVE ACROSS SOUTHERN ALBERTA, HIGH MAINTAINS SAME RELATIVE POSITION

TEMPERATURE PROFILES



—·—·— DRY ADIABATIC LAPSE RATE

INTERPRETATION OF $[SO_2]$ EVENT(S)

Profiles indicate two elevated inversions which are created by radiative cooling and a warm front from a system to the south.

Detailed information leads us to conclude that we cannot disassociate the cause of the events from either the nocturnal inversion or the thermal turbulen However, the interpretation of the data suggests the primary cause of the events was thermal turbulence.

about by the strong incoming solar radiation during the other event of Case 6 and events of Cases 5 and 8. As the summary case data indicate, elevated inversions exist just prior to event times for all three cases.

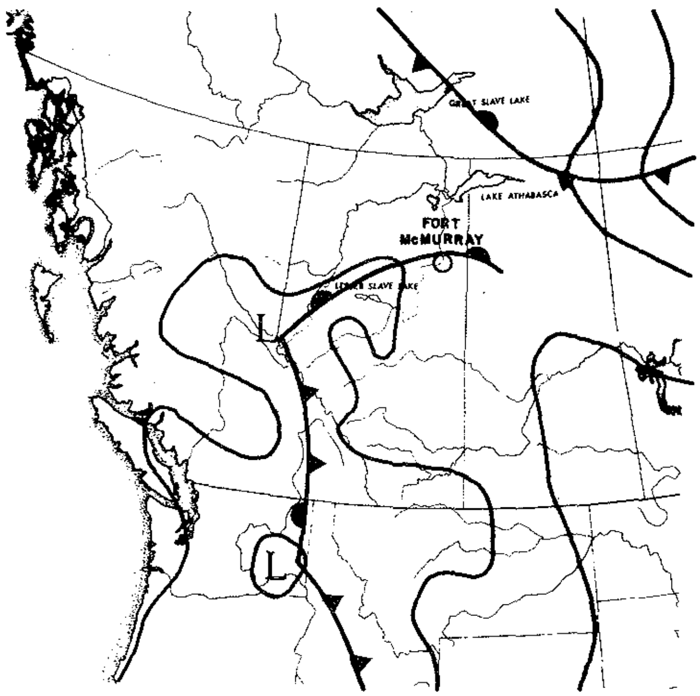
The sequential occurrence or slight overlap of these processes complicates the understanding of the meteorological factors involved and illustrates how complex the plume/atmosphere relationship can be.

3.2.4 Case Summaries--Cases 9 to 16

Events of Cases 9 to 12 do not have the spatial continuity (i.e., events from stations on the same day) but they do occur within three days of one another. The meteorological data coincident with these events as well as Cases 13 to 16 show similarities to events of Cases 1 to 8 in that the same factors are present at one time or another. One or more of the factors may be intense enough to cause an isolated event but the combination of factors is neither simultaneous nor persistent enough to cause the spatial coverage of events as in Cases 1 to 8, at least, not with the existing monitoring network.

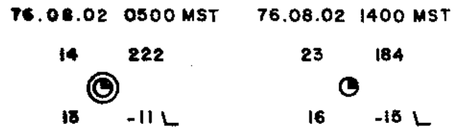
Relating causes of events to air masses and fronts became more difficult for Cases 9 to 16 (see case summary data). It was still possible, however, to relate two cases (13 and 14) to frontal inversions combined with moderate winds and one case (15) to arctic air mass inversion, combined with moderate winds illustrating the persistence of these two features. The moderate winds in this case is the probable factor reducing the number of events, since arctic air mass inversions with light winds or calms produced multiple events in Cases 2 and 3. For the remainder of the cases, only pressure gradients and solar radiation remain as primary factors. Understanding the wind

SYNOPTIC MAP



DATE: 2 AUGUST 1976 1400 MST
FOR TIME PERIOD: 2 AUGUST 1976

METEOROLOGICAL DATA



TIME OF EVENT 1300 MST

DATA DURING EVENT

RANGE OF [SO_2] = MODERATE

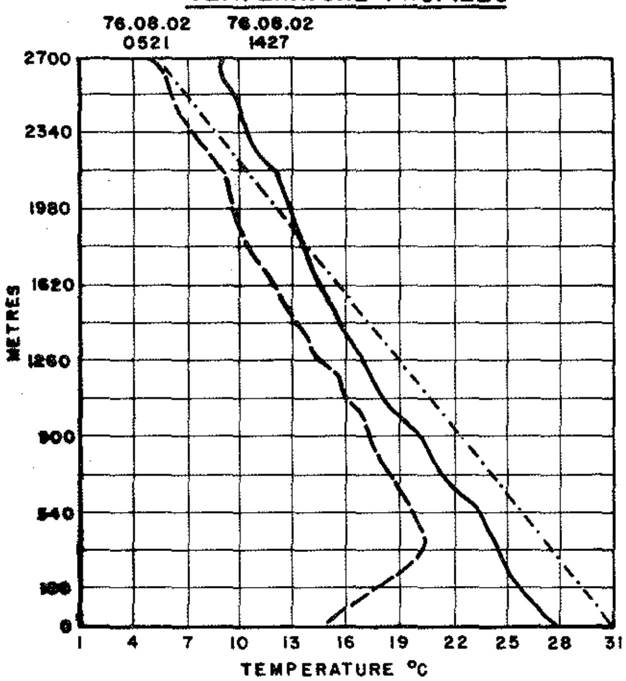
WINDS (10 m) = CALM

RADIATION = STRONG

SYNOPTIC PICTURE

2ND - LOW MOVES INTO CENTRAL ALBERTA, HIGH TO THE NORTH MOVES INTO NORTHERN ALBERTA

TEMPERATURE PROFILES



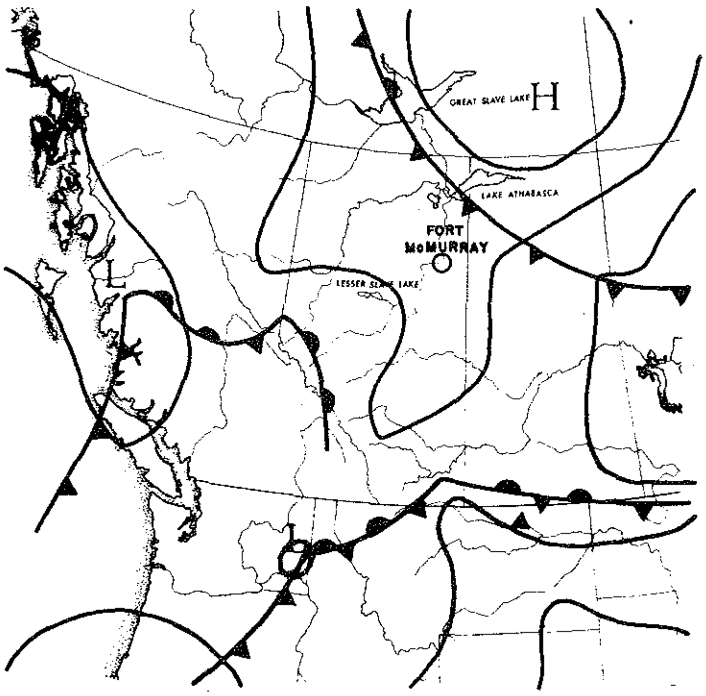
-·-·- DRY ADIABATIC LAPSE RATE

INTERPRETATION OF [SO_2] EVENT(S)

Profiles indicate no prominent synoptic feature, in respect to the cause of the event. Profiles and surface information suggest strong thermal turbulence is occurring at the time of the event. Surface information also indicates light winds in the direction of the event site at event time.

Information leads us to conclude that a combination of thermal turbulence and light winds in the direction of the event site lead to the occurrence of the event.

SYNOPTIC MAP



DATE : 30 AUGUST 1976 1100 MST
FOR TIME PERIOD : 30 AUGUST 1976

METEOROLOGICAL DATA

76.08.30 1100 MST 76.08.30 1400 MST

TIME OF EVENT 1230 MST

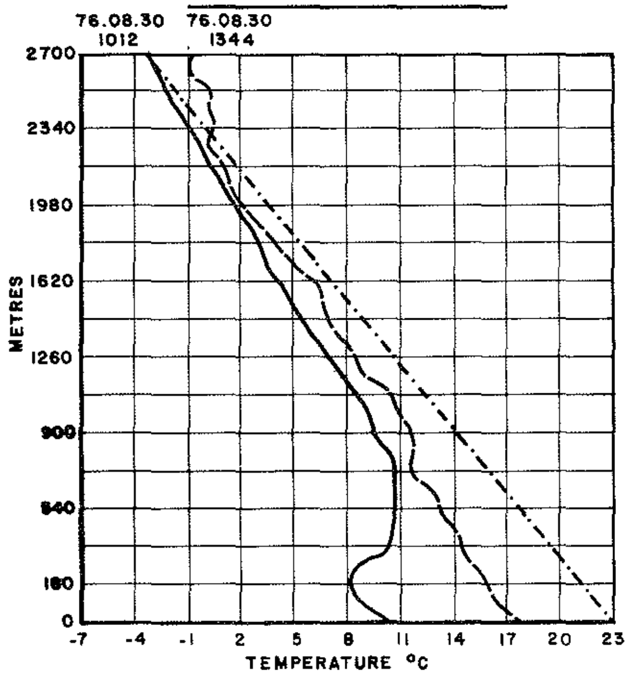
DATA DURING EVENT

RANGE OF [SO_2] = MODERATE
WINDS (10 m) = CALM
RADIATION = STRONG

SYNOPTIC PICTURE

30TH - COLD FRONT NORTH OF FORT McMURRAY MOVES SOUTH OF FORT McMURRAY IN THE NEXT 3 HOURS

TEMPERATURE PROFILES



-·-·- DRY ADIABATIC LAPSE RATE

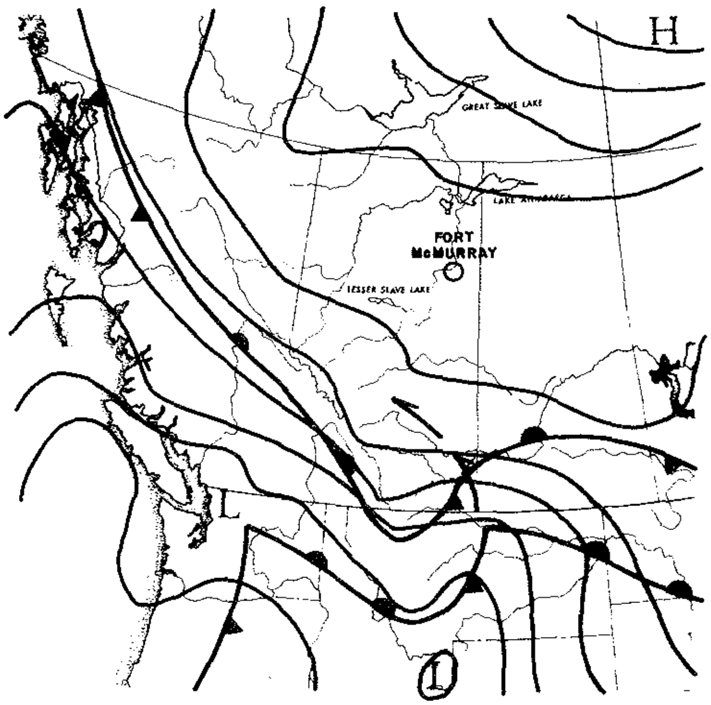
INTERPRETATION OF [SO_2] EVENT(S)

Profiles show evidence that an elevated inversion resulting from a nocturnal inversion (ground based) occurred at the time of event. Profiles and surface information give evidence of thermal turbulence occurring.

Surface maps indicate the event region to be under modified continental arctic air.

Information leads us to conclude the nocturnal inversion trapped emissions.

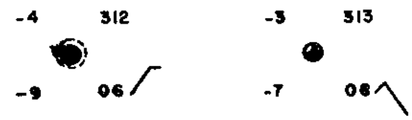
SYNOPTIC MAP



DATE: 14 APRIL 1978 1700 MST
FOR TIME PERIOD: 14 APRIL 1978

METEOROLOGICAL DATA

78.04.14 1400 MST — 78.04.14 1700 MST



TIME OF EVENT 1530 MST

DATA DURING EVENT

RANGE OF $[SO_2]$ = MODERATE

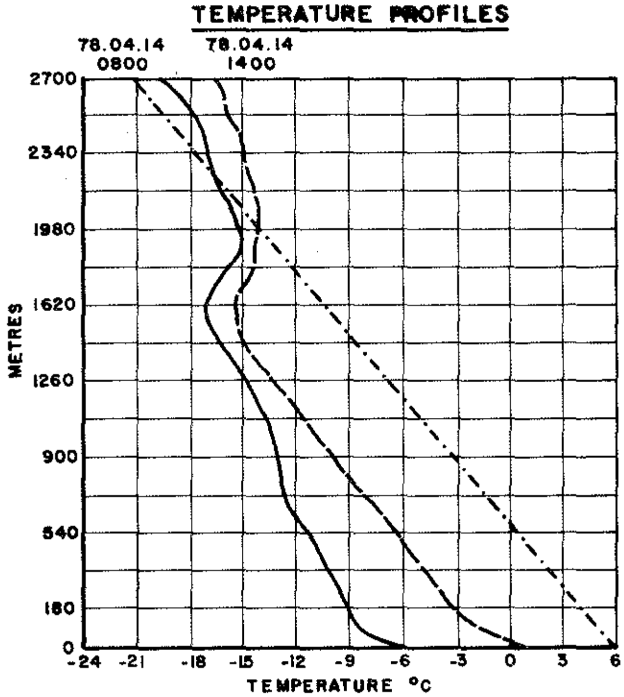
WINDS (152 m) = 0.5 m/s

RADIATION = MODERATE

SYNOPTIC PICTURE

14TH - SYNOPTIC PICTURE STAYS THE SAME FOR NEXT 6 HOURS

TEMPERATURE PROFILES



.-.-.- DRY ADIABATIC LAPSE RATE

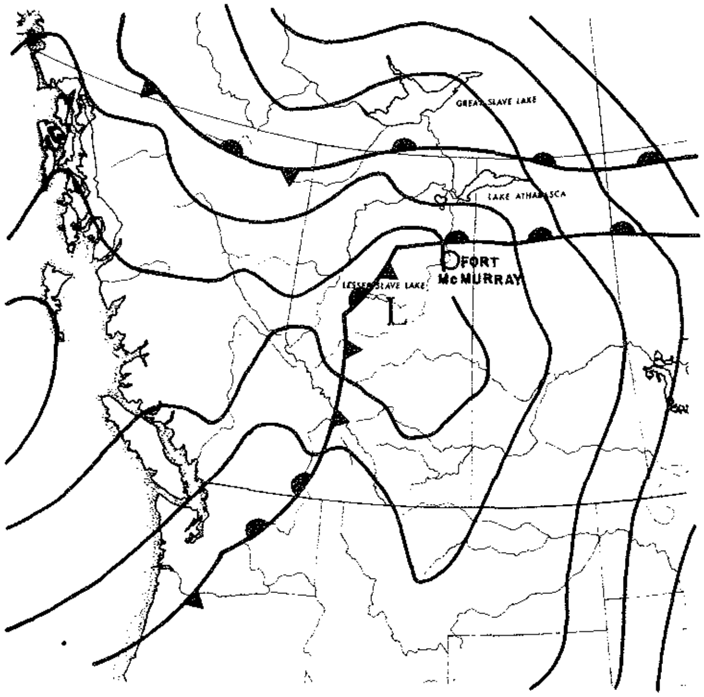
INTERPRETATION OF $[SO_2]$ EVENT(S)

Profiles indicate no prominent synoptic feature, in respect to the cause of the event. Profiles and surface information indicate thermal turbulence and moderate to strong winds in the direction of the event site at event time.

Surface maps show a continental arctic high covers Alberta.

Information leads us to conclude that emissions were dispersed by thermal and strong mechanical turbulent within a deep mixing layer.

SYNOPTIC MAP



DATE: 14 MAY 1978 1100 MST

FOR TIME PERIOD: 14 MAY 1978

METEOROLOGICAL DATA

78.05.14 0500 MST   78.05.14 1100 MST

TIME OF EVENT 1130 MST

DATA DURING EVENT

RANGE OF $[SO_2]$ = MODERATE

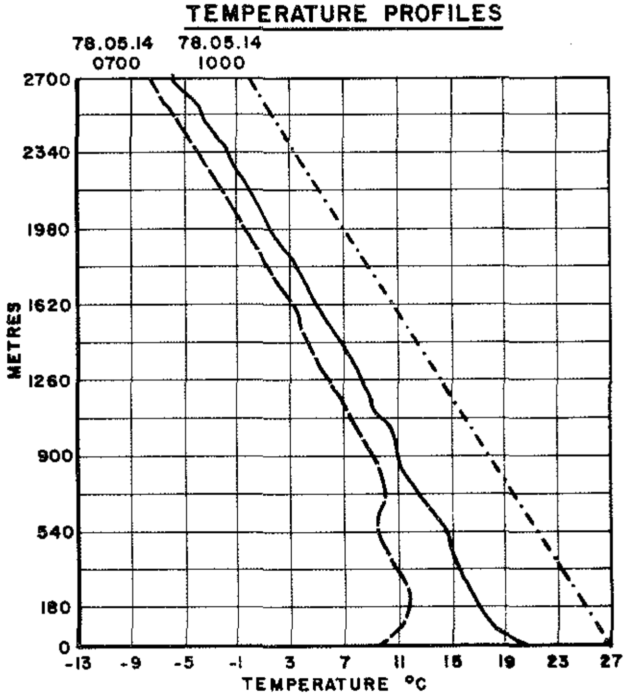
WINDS (152 m) = 3.6 m/s

RADIATION = STRONG

SYNOPTIC PICTURE

14TH - LOW SWINGS UP INTO CENTRAL ALBERTA EARLY ON THE 14TH, THEN SHIFTS SOUTHWARD TO SOUTHERN ALBERTA

TEMPERATURE PROFILES



·—·—·— DRY ADIABATIC LAPSE RATE

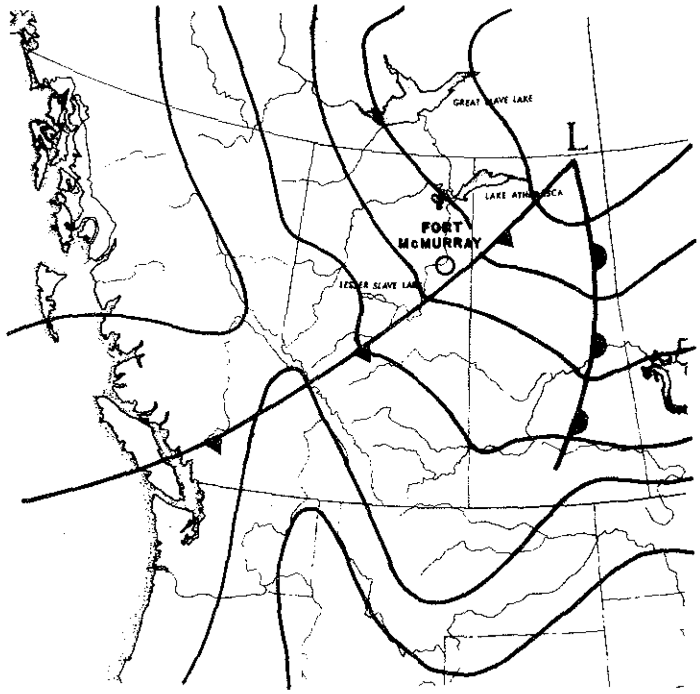
INTERPRETATION OF $[SO_2]$ EVENT(S)

Profiles indicate no prominent synoptic feature, in respect to the cause of the event. Profiles and surface information indicate thermal turbulence and moderate winds in the direction of the event site at event time.

Surface maps show a warm front in the area at the time of the event.

Information leads us to conclude that mechanical and thermal turbulence lead to the occurrence of events at ground level.

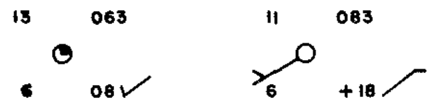
SYNOPTIC MAP



DATE : 10 SEPTEMBER 1976 0200 MST
FOR TIME PERIOD : 10 SEPTEMBER 1976

METEOROLOGICAL DATA

76.09.10 0200 MST   76.09.10 0500 MST



TIME OF EVENT 0330 MST

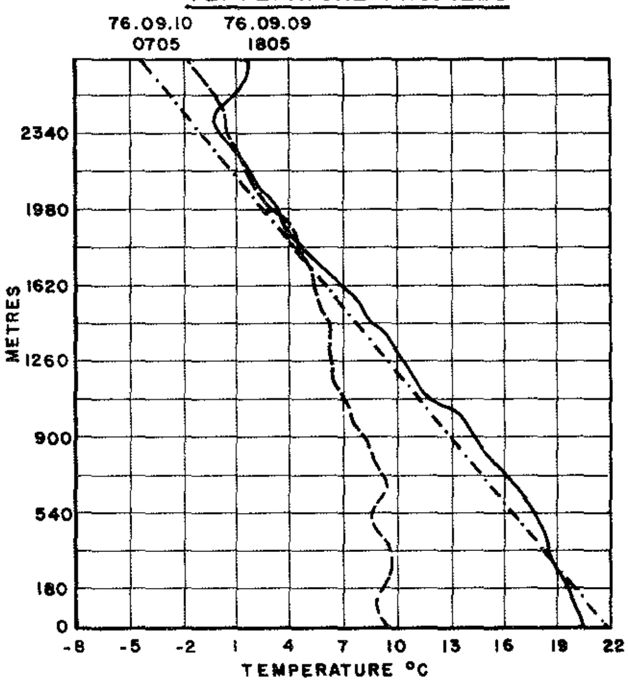
DATA DURING EVENT

RANGE OF $[SO_2]$ = STRONG
WINDS (10 m) = 2.0 m/s
RADIATION = NIL

SYNOPTIC PICTURE

10TH - LOW MOVES EASTWARD, COLD FRONT MAINTAINS SAME RELATIVE POSITION JUST SOUTH OF FORT McMURRAY

TEMPERATURE PROFILES



-·-·- DRY ADIABATIC LAPSE RATE

INTERPRETATION OF $[SO_2]$ EVENT(S)

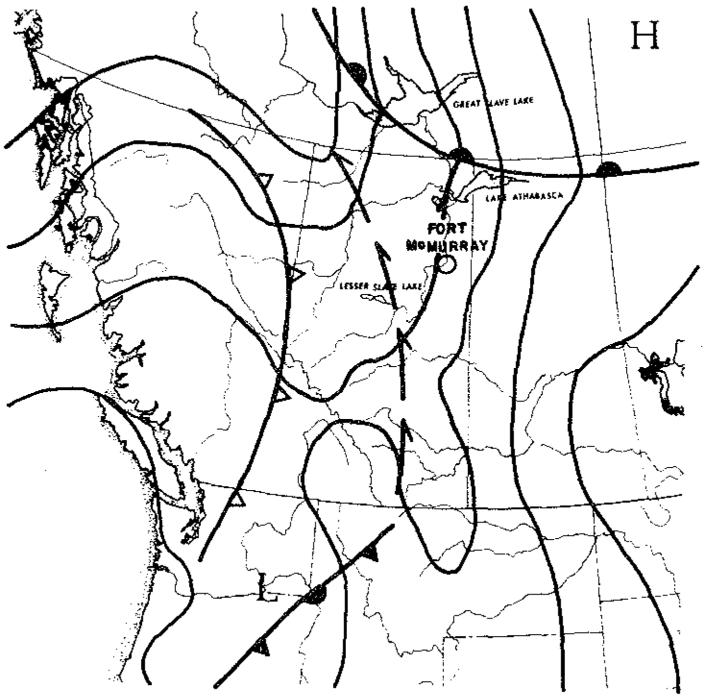
Profiles indicate an elevated inversion present at the time of the event.

Surface information indicate strong wind in the direction of the event site at event time.

Surface maps show a cold front in the area at the time of the event.

Information leads us to conclude that a cold front trapped emissions and strong winds at plume height produced coning of the plume to ground level.

SYNOPTIC MAP



DATE: 14 SEPTEMBER 1976 0500 MST
FOR TIME PERIOD: 14 SEPTEMBER 1976

METEOROLOGICAL DATA

76.09.14 0200 MST **76.09.14 0500 MST**

TIME OF EVENT 0400 MST

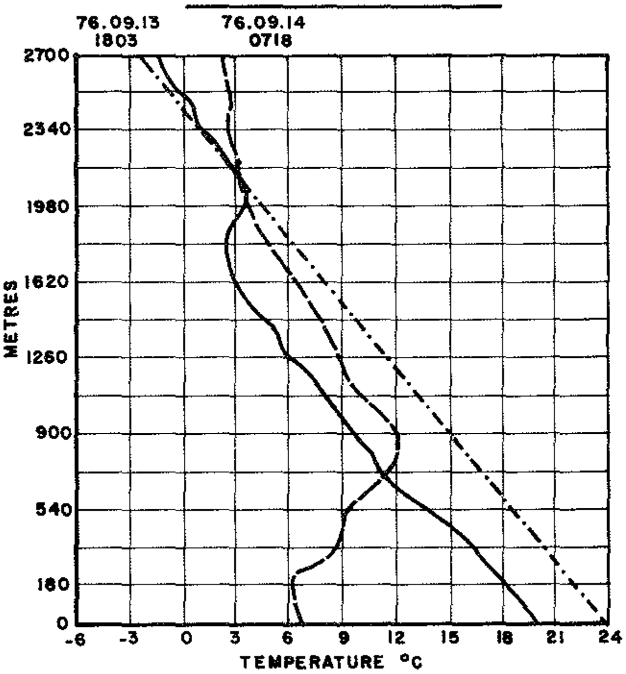
DATA DURING EVENT

RANGE OF $[SO_2]$ = MODERATE
WINDS (152 m) = 3 m/s
RADIATION = NIL

SYNOPTIC PICTURE

14TH - HIGH MAINTAINS SAME RELATIVE POSITION, LOW MOVES INTO WESTERN MONTANA

TEMPERATURE PROFILES



-·-·-·- DRY ADIABATIC LAPSE RATE

INTERPRETATION OF $[SO_2]$ EVENT(S)

Profiles indicate an elevated inversion is present at the time of the event.

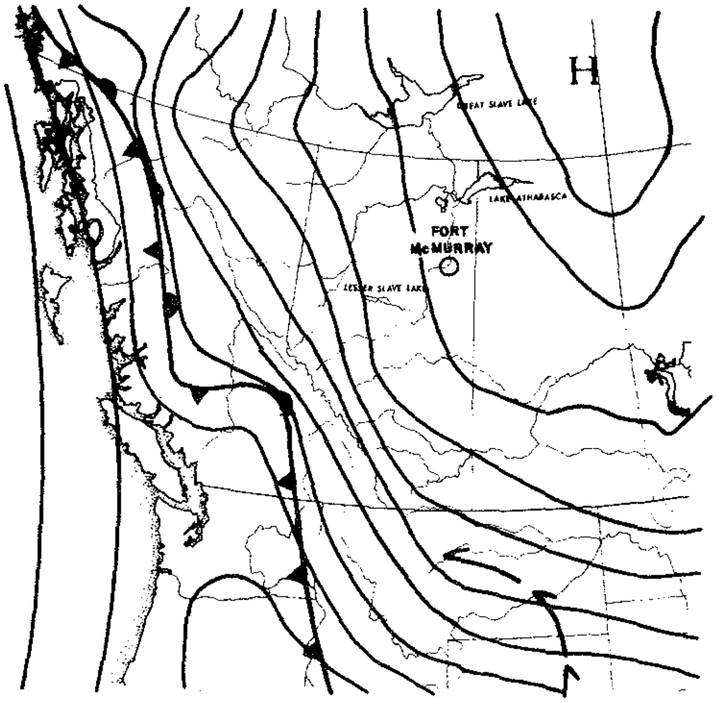
Surface information indicate moderate winds in the direction of the event site at event time.

Surface maps show an occluded front in the area at the time of the event.

Information leads us to conclude that an occluded front trapped emissions and moderate winds produced coning of the plume to ground level.

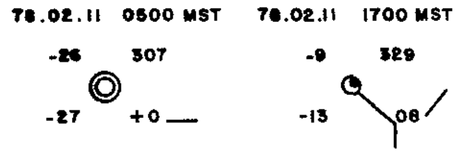
CASE No. 14

SYNOPTIC MAP



DATE: 11 FEBRUARY 1978 1700 MST
FOR TIME PERIOD: 11 FEBRUARY 1978

METEOROLOGICAL DATA



TIME OF EVENT 1530 MST

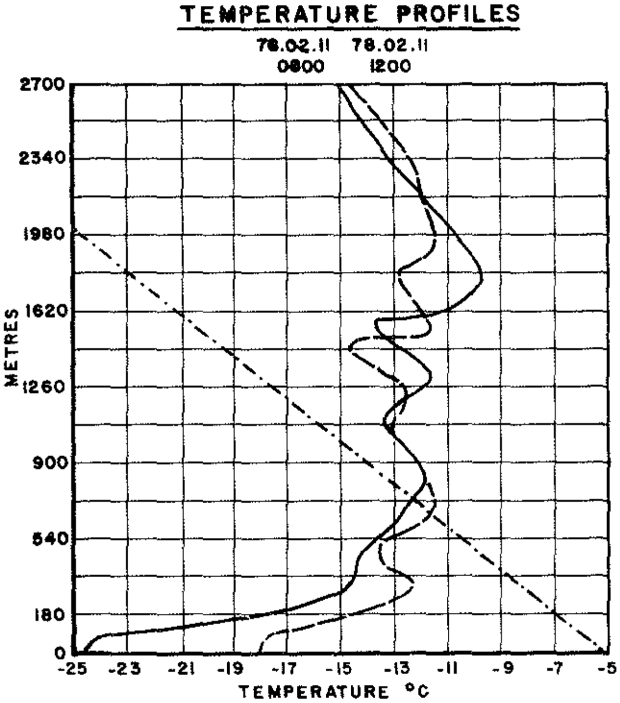
DATA DURING EVENT

RANGE OF [SO_2] = MODERATE
WINDS (152 m) = 3.1 m/s
RADIATION = NIL

SYNOPTIC PICTURE

11TH - HIGH MAINTAINS POSITION

TEMPERATURE PROFILES



-·-·- DRY ADIABATIC LAPSE RATE

INTERPRETATION OF [SO_2] EVENT(S)

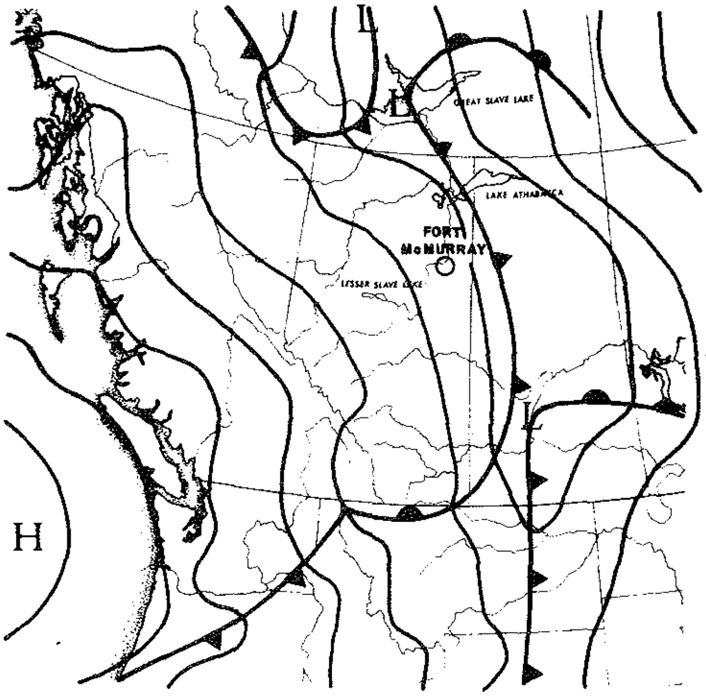
Profiles indicate several inversions were present at event time.

Surface information indicate moderate winds in the direction of the event site.

Surface maps show an intense continental arctic air mass covers most of Alberta.

Information leads us to conclude cold continental arctic air produced a deep inversion under which emissions were trapped and moderate winds produced coning of the plume to ground level.

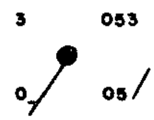
SYNOPTIC MAP



DATE: 3 MAY 1978 0500 MST
FOR TIME PERIOD: 3 MAY 1978

METEOROLOGICAL DATA

78.05.03 0500 MST



TIME OF EVENT 0530 MST

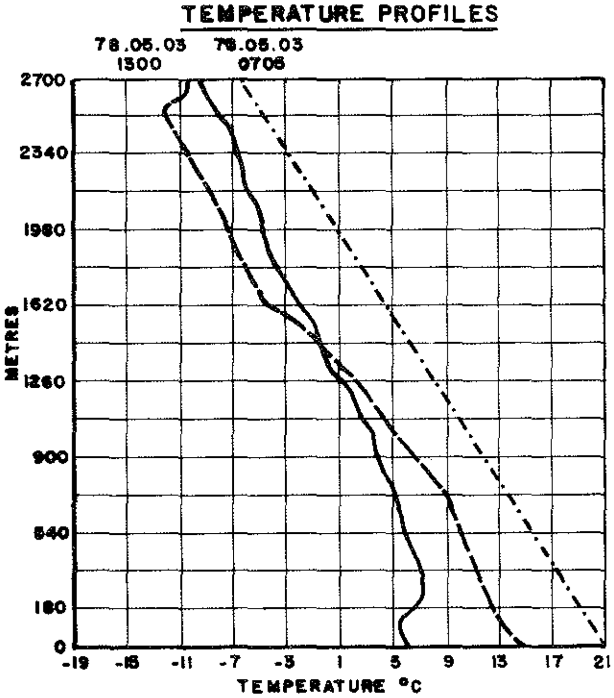
DATA DURING EVENT

RANGE OF $[SO_2]$ = STRONG
WINDS (152 m) = 6.7 m/s
RADIATION = SLIGHT

SYNOPTIC PICTURE

3RD - COLD FRONT PASSED THROUGH FORT McMURRAY LESS THAN 6 HOURS PREVIOUSLY, CONTINUES EASTWARD FOR NEXT 6 HOURS

TEMPERATURE PROFILES



-·-·- DRY ADIABATIC LAPSE RATE

INTERPRETATION OF $[SO_2]$ EVENT(S)

Profiles indicate an elevated inversion is present at event time.

Surface information indicate moderate winds in the direction of the event site at event time.

Surface maps show cold maritime arctic air covers most of Alberta at event time.

Information leads us to conclude emissions were trapped by a nocturnal inversion and moderate winds produced coning of the plume to ground level.

fluctuations and turbulence characteristics during these occurrences would improve the predictability of these more isolated events.

In summary, it is not only the presence of the various synoptic features and meteorological processes described herein that have caused the pollution episodes at ground level, but also their occurrence in a particular pattern. This pattern may depend on long nights in winter, changes in incoming radiation, diurnal cycle, and relative temperature differences of air masses with respect to surface temperature. As the factors become more simultaneous and persistent in their pattern, the occurrence of events becomes more frequent and intense. As the factors become more disjointed in their pattern, the events become more widespread in time and/or less detectable by the existing monitoring network.

Understanding these patterns, on the one hand, leads to a better understanding of why and when these events occur. On the other (because of the complex nature of the causes) the application of analytical or numerical type models becomes more difficult.

3.3 RESULTS OF MATHEMATICAL MODELLING CALCULATIONS

Briggs' formulas (Briggs 1969, 1970, 1975) for plume rise are used in Alberta Environment's dispersion program (Alberta Environment 1978). Fanaki (1978) and Davison et al. (1976) showed that Briggs' formulas best described plume rise in the AOSERP area, even though correlation to actual measurements was not completely satisfactory and usually under predicted the actual plume rise by 15 to 30% according to Fanaki.

A programmed system developed for Alberta Environment and described by Choukalos (1978) was used to interpret minisonde data for input into the model. This system provided temperature and potential temperature vertical gradients as well as mixing height determinations by the base of elevated inversions and by the Holzworth technique (Holzworth 1964). The latter technique determines the mixing height at the intersection of the temperature profile and the dry adiabatic lapse rate extrapolated upward from ground level temperature.

Table 6 shows calculated and measured ground level concentrations of SO_2 for the first eight case studies. The calculated ground level concentrations shown in the table were done with only the powerhouse stack and incinerator stack emissions included. However, when flare emissions were superimposed, the calculated ground level concentrations only increased by 10%. Conversely, when the incincerator stack emissions were removed, the calculated ground level concentrations decreased by 10%. Consequently, by calculation, and using the assumptions stated in Table 6, the powerhouse is by far the most significant contributor to the ground level concentrations.

Case 5 and 6 calculations are the only ones modelled in an unlimited mixing layer, with Case 6 being related to mechanical turbulence from the high winds. These two cases also had the poorest correlation to a measured ground level concentration using the gaussian dispersion program of Alberta Environment (Alberta Environment 1978). For Cases 5 and 6, the predictions were low by a factor of 100 and 10, respectively. Changing the stability category to class "C" only improved the predictions to a factor of 50 and 6, respectively.

Table 6. A comparison of calculated plume rise and ground level concentrations to measured mixing heights and ground level concentrations for cases 1 through 8.

Case No.	Calculated Plume Rise[a]		Measured[b] Mixing Height (m)	Calculated[c] Maximum Ground Level Conc. (ppm)	Measured[d] Ground Level Conc. (ppm)
	Powerhouse Stack (m)	Incinerator Stack (m)			
1	327	206	220	0.137	0.20 - 0.65
2	399	249	414	0.406	0.19 - 0.23
3	376	256	612	0.096	0.14 - 0.33
4	308	327	414	0.182	0.12 - 0.26
5	2394	744	unlimited	0.001	0.14 - 0.22
6[e]	391	188	unlimited	0.041	0.29 - 0.32
7	243	244	500	0.069	0.14 - 0.29
8	414	250	600	0.084	0.12 - 0.58

[a] Plume rise calculated using Briggs' formulas (Briggs 1969, 1970, 1975) and department's procedure (Alberta Environment 1978); stack data provided for Cases 3, 4, 5, and 8 by Great Canadian Oil Sands; stack data averaged from Cases 3, 4, 5, and 8 for Cases 1, 2, 6, and 7.

[b] Taken at base of elevated inversion layer or isothermal layer, by Holzworth technique at event time or by criteria established in Choukalos (1978), at profile time.

[c] Using the gaussian model with Pasquill stability class D, neutral (Alberta Environment 1978).

[d] Shows lowest and highest concentration on event day, respectively (i.e., 0.xx - 0.xx).

[e] Event at 1930 h at 9 m/s was modelled.

The other six cases were assumed to be in a well defined mixed layer and in all instances the plume was calculated to be trapped within the mixing layer. For these cases, Table 6 shows the calculated ground level concentration to be within a factor of two of the corresponding measured values.

It is important to note that a number of assumptions were made in carrying out the plume rise calculations and in establishing the gaussian model predictions. Although listed in Table 6, they are worth listing again here:

1. It was assumed that the Briggs plume rise formulas would provide an accurate indication of where the plume was with respect to the measured mixing height;
2. Stack data for Cases 1, 2, 6, and 7 were averaged from the actual stack data for Cases 3, 4, 5, and 8;
3. If the actual temperature profile was not provided at event times, then the mixing height was determined using the Holzworth technique;
4. A single and two-layer gaussian model and Pasquill's revised sigma curves was used;
5. The two layer cases (1, 2, 3, 4, 7, and 8) were modelled using class D, neutral stability category;
6. The single layer cases (5 and 6) were modelled using class C and D stability categories.

Case 8 is an example where the physical processes prevalent at event time are very complex. The modelled conditions for Case 8 assume the presence of a mixing layer 600 m deep during event times (see

Table 6). Under these conditions, the two layer gaussian model predicted well. However, as event time approaches, available data suggest that the thermal turbulence brought on by strong solar radiation could have eroded the elevated inversion completely and produced strong convective mixing. This changing condition produces a case that is not steady state.

Rapid changes in atmospheric conditions do not readily allow for the application of steady state models. In this case, the conditions were not steady state, making the use of any one given model very difficult. It is probably only fortuitous that Alberta Environment's two-layer model accurately predicts the ground level concentrations in such a complex time dependent set of circumstances.

4. SUMMARY CONCLUSIONS

1. Events over a 2-year period show no seasonal preference for spring, summer or fall, but show a lower occurrence in winter, from those stations located within 20 km of the plant site.

2. Events over a 2 year period show that 61% of events occurred between 0900 and 1500 h, from those stations located within 20 km of the plant site.

3. Synoptic features could be related as causes of events that occurred at more than one station on the same day (Cases 1 to 8), but could not be related as readily or as often to events occurring on different days (Cases 9 to 16).

4. Events occurring at more than one station on the same day (Cases 1 to 8) have the highest frequency in spring with secondary maximum into fall and winter.

5. The arctic air mass inversion with calm or light winds has been identified as the main synoptic feature causing events in two of the first eight cases and in one of the last eight cases. The moderate winds of Case 15 were probably sufficient to reduce the number of detectable events to one in this case.

6. The frontal inversion combined with moderate winds has been identified as the main synoptic feature in two of the first eight cases, and in two of the last eight

cases. A fifth frontal case was found to be associated with light winds.

7. Long nights in winter with extremely cold surfaces and air masses as opposed to shorter nights in spring and fall with greater temperature differentials of land to air mass appear to alter the role played by the nocturnal cooling process on inversion formation in a cold anticyclone.

8. Conditions of strong mechanical turbulence (high winds) dominated only one event of the first eight cases. The condition of strong thermal turbulence (convective mixing) was identified as the main process in two of the first eight cases and in one event of a third case.

9. For Cases 9 to 16, the factors of variable wind fields, strong solar insolation, arctic air masses, and frontal inversions were present. However, because of their lack of association, their effects as event causes were not as severe with respect to number of event occurrences.

10. Estimated ground level concentrations are dominated by the powerhouse stack emission and only increase by 10% when considering emission from the incinerator stack or the hydrocarbon flare stack.

11. Plume rise using Briggs' formula show the plume to be trapped in six of the first eight cases. Alberta Environment's gaussian dispersion program using Pasquill "D" stability shows calculated ground level

concentrations within a factor of two of the measured concentrations for trapped cases. Unlimited cases correlate only within a factor of 10 to 100. If one assumes the plume rise calculations to be accurate, the effective stack height becomes an important criterion for stack design in order to eliminate events caused by trapping.

12. Rapid changes in meteorological factors within a given case study or from case to case have been illustrated. This condition does not readily allow for the application of steady state models, no matter how complex. It is probably only fortuitous that Alberta Environment's two-layer model accurately predicts the ground level concentrations in these cases.

5. RECOMMENDATIONS

Data from a 10 station air monitoring network have shown 0.5 h concentrations of SO_2 to be as high as 0.65 ppm. Relating events to meteorological causes has shown that specific synoptic and meso-meteorological factors have reproduced themselves as contributing factors to event occurrence. It is not known how often these meteorological conditions develop. The existing monitoring network cannot be relied upon to detect all events. It is therefore recommended that work progress on identifying the frequency distribution of the meteorological conditions found to be contributing to event occurrence. Based on the above statements, it is further recommended that support be given to the existing attempts at continuous meteorological data collection for the purpose of resolving boundary layer conditons in the Mildred Lake area through such instrumentation as acoustic radar. Only by continuous collection of specific meteorological data will one be able to correlate these data quantitatively as factors contributing to the occurrence of events detected at the existing continuous ambient air monitoring network.

A brief rationale has been stated in support of continuous meteorological data collection in the Mildred Lake area. The relatively flat terrain in this area, with the exception of tha Athabasca River valley, should allow for widespread application of these data. However, the Stony Mountain area has unique terrain irregularities and also a potential for oil sand plant development. It is therefore recommended that similar data collection be supported for this area as well.

The application of air quality models for plant design is a valid and necessary approach to air quality management. However, the variety of meteorological factors, shown to be contributing to event occurrence, illustrates the complex and non-steady state nature of the atmosphere. By nature of their design and use, models can easily become "black boxes" of the computing age. Concern for the appropriate application of a model to the atmosphere must be foremost before levels of accuracy and performance are assessed. The fundamental concept of practical application should not be overlooked, and it is this general statement the authors leave as a strong recommendation.

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7. APPENDIX

7.1 DETAILED EVENT DATA

The event data provided in Tables 7 to 10 provide information on the duration, location, magnitude, and plant operating conditions at event times.

Table 7. SO_2 events monitored at Great Canadian Oil Sands stations, June 1976 to May 1977.

				0.5 h Reading			
Station	Date	Max. 0.5 h Reading (ppm)	Time of Max. 0.5 h Reading	Before Max. (ppm)	After Max. (ppm)	Incinerator Stack Emissions (MTS/d)	Powerhouse Stack Emissions (MTS/d)
Supertest Hill	06 Jun 76	0.17	1030	0.11	0.13	12	122
	16 Jun 76	0.16	0830	0.12	0.06	15	120
	20 Sep 76	0.19	1230	0.10	0.13	15	110
	10 Dec 76	0.16	2030	0.07	0.04	19	124
	06 Apr 77	0.15	1630	0.13	0.10	10	91
Mannix	14 Jul 76	0.21	0300	0.05	0.19	11	106
	30 Aug 76	0.23	1230	0.09	0.11	9	101
	21 Sep 76	0.29	1200	0.02	0.26	12	114
	26 Jan 77	0.19	1730	0.14	0.09	14	116
	27 Jan 77	0.23	1600	0.11	0.09	12	117
Ruth Lake	06 Jul 76	0.19	1030	0.06	0.13	12	105
	04 Aug 76	0.12	1030	0.01	0.08	11	122
	21 Sep 76	0.65	1130	0.07	0.22	12	114
	26 Jan 77	0.15	1630	0.10	0.15	14	116
	27 Jan 77	0.19	1530	0.12	0.02	12	117
Mildred Lake	31 Jul 76	0.33	1200	0.09	0.20	13	112
	02 Aug 76	0.21	1300	0.15	0.12	12	105
	14 Sep 76	0.20	0400	0.15	0.07	13	100
	21 Sep 76	0.20	1130	0.07	0.09	12	114
	22 Sep 76	0.21	1100	0.10	0.05	8	104
Fina Airstrip	02 Sep 76	0.31	1830	0.02	0.19	14	74
	10 Sep 76	0.30	0330	0.01	0.06	13	104
	21 Sep 76	0.29	1300	0.25	0.18	12	114
	08 Nov 76	0.37	0830	0.18	0.07	13	132
	01 Apr 77	0.61	1030	0.39	0.12	12	117

Table 8. SO_2 events monitored at Great Canadian Oil Sands stations, June 1977 to May 1978.

Station	Date	Max. 0.5 h Reading (ppm)	Time of Max. 0.5 h Reading	0.5 h Reading Before Max. (ppm)	0.5 h Reading After Max. (ppm)	Incinerator Stack Emissions (MTS/d)	Powerhouse Stack Emissions (MTS/d)
Supertest Hill	04 Mar 78	0.22	1630	0.12	0.21	11	105
	10 Mar 78	0.24	1300	0.03	0.10	7	115
	22 Mar 78	0.25	1200	0.14	0.14	8	118
	12 May 78	0.15	1700	0.10	0.15	13	91
	24 May 78	0.21	1700	0.12	0.18	7	105
Mannix	09 Jul 77	0.21	1030	0.05	0.07	17	103
	04 Mar 78	0.33	1530	0.05	0.25	11	105
	03 Apr 78	0.22	1200	0.12	0.18	-	110
	22 Apr 78	0.32	1930	0.13	0.07	6	97
	23 Apr 78	0.28	0430	0.10	0.15	7	87
Ruth Lake	09 Jul 77	0.16	1130	0.05	0.15	17	103
	04 Mar 78	0.14	1730	0.13	0.05	11	105
	21 Mar 78	0.14	1430	0.05	0.04	7	108
	03 Apr 78	0.11	1330	0.07	0.10	-	110
	24 May 78	0.15	1030	0.11	0.08	7	105
Fina Airstrip	05 Apr 78	0.33	1130	0.27	0.06	-	109
	22 Apr 78	0.29	1300	0.22	0.19	6	97
	03 May 78	0.28	0530	0.25	0.17	12	92
	24 May 78	0.47	1200	0.12	0.23	7	105
	27 May 78	0.39	1200	0.07	0.33	9	107
Lower Camp (Start-up Jul 77)	06 Feb 78	0.18	2130	0.12	0.15	8	131
	14 Apr 78	0.18	1530	0.16	0.16	7	108
	28 Apr 78	0.19	1100	0.11	0.11	12	91
	17 May 78	0.20	1230	0.04	0.03	10	89
	24 May 78	0.58	1030	0.35	0.36	7	105

Table 9. SO_2 events monitored at Syncrude stations, June 1977 to May 1978.

Station	Date	Max. 0.5 h Reading (ppm)	Time of Max. 0.5 h Reading	0.5 h Reading: Before Max. (ppm)	0.5 h Reading: After Max. (ppm)	Incinerator Stack Emissions (MTS/d)	Powerhouse Stack Emissions (MTS/d)
#1 (Mine Site)	03 Sep 77	0.10	1100	0.08	0.09	11	85
	10 Sep 77	0.10	2100	0.10	0.09	11	82
	23 Mar 78	0.19	1530	0.08	0.04	11	125
	14 May 78	0.16	1130	0.08	0.06	13	87
	24 May 78	0.12	1000	0.00	0.10	7	105
#2 (Tailings)	11 Jun 77	0.09	0630	0.09	0.09	13	104
	07 Mar 78	0.16	1330	0.02	0.09	10	116
	23 Mar 78	0.18	1400	0.14	0.18	11	125
	03 Apr 78	0.14	1530	0.12	0.09	0	110
	01 May 78	0.14	1000	0.06	0.02	11	93
#3 (Mildred Lake)	13 Dec 77	0.32	1600	0.13	0.04	-	98
	23 Mar 78	0.26	1330	0.22	0.06	11	125
	28 Apr 78	0.29	1100	0.22	0.19	12	91
	28 May 78	0.44	1130	0.18	0.22	0	105
	27 May 78	0.34	1030	0.04	0.22	9	107
#4 (MacKay River)	01 Jul 77	0.28	0900	0.10	0.14	13	107
	24 Sep 77	0.13	1300	0.08	0.11	8	96
	11 Feb 78	0.14	1530	0.10	0.04	5	131
	23 Mar 78	0.12	1300	0.10	0.10	11	125
	28 Apr 78	0.14	1100	0.10	0.13	12	91
#5 (Beaver River)	19 Jun 77	0.16	1000	0.10	0.14	15	110
	06 Feb 78	0.16	0130	0.16	0.06	8	131
	23 Mar 78	0.14	1300	0.12	0.12	11	125
	10 Apr 78	0.16	1530	-	0.11	11	106
	15 Apr 78	0.14	0900	-	0.03	5	109

Table 10. SO_2 events monitored at AOSERP stations, June 1977 to May 1978.

Station	Date	Max. 0.5 h Reading (ppm)	Time of Max. 0.5 h Reading	0.5 h Reading Before Max. (ppm)	0.5 h Reading After Max. (ppm)	Incinerator Stack Emissions (MTS/d)	Powerhouse Stack Emissions (MTS/d)
Bitumount Tower	12 Jun 77	0.13	0900	0.01	0.07	12	106
	16 Jan 78	0.10	1300	0.08	0.06	4	125
	18 Jan 78	0.10	1230	0.07	0.07	2	119
	16 Mar 78	0.15	1730	0.15	0.15	6	116
	17 May 78	0.09	1030	0.06	0.06	10	89
Fort McMurray	16 Nov 77	0.10	1730	0.06	0.09	13	102
	14 Jan 78	0.24	2330	0.12	0.20	2	91
	24 Feb 78	0.12	1530	0.08	0.09	-	140
	10 Mar 78	0.25	1600	0.01	0.03	7	115
	14 Mar 78	0.07	1430	0.07	0.06	6	108
Birch Mountain	08 Oct 77	0.07	0900	0.05	0.03	13	113
	10 Feb 78	0.08	0630	0.06	0.08	5	145
	13 Feb 78	0.06	0230	0.03	0.03	5	123
	14 Feb 78	0.06	2400	0.04	0.05	5	108
	23 Mar 78	0.07	0430	0.05	0.06	11	125

7.2 DETAILED CASE DATA, CASES 1 TO 16

7.2.1 Introduction to Detailed Case Data

Unless otherwise stated, "region" or "area" will refer to the AOSERP area.

Automatic stations are a network of climatology stations. For locations, see Figure 1.

Tall tower - 152 m tower located as per Figure 2 collecting wind and temperature data.

Location of Fort Smith - 300 km north of emission source (see Figure 1).

Holzworth technique - refer to Section 3.3 (Holzworth 1964).

Single theodolite data are used unless otherwise stated from Lower Camp located as per Figure 2.

Heights indicated from the Fort Smith temperature profile were taken from plotted tephigrams from AES Western Region Headquarters.

Surface and 500 mb maps were predominantly taken from the local AES office in Edmonton but some were used from the nationally produced U.S. daily weather map, Weather Bureau, Washington, D.C.

Wind scale:

light	<2 m/s
moderate	3 to 7 m/s
strong	>8 m/s

Insolation scale:

slight	<25 langley/h
moderate	25 to 50 langley/h
strong	>50 langley/h

Weather information from Fort McMurray unless otherwise noted.

CASE 1, 21 SEPTEMBER 1976

Synoptic Picture

The 500 mb maps show a strong ridge of high pressure over Alberta and British Columbia which has existed there for several days. The Fort McMurray region is at the edge of a strong pressure gradient to the northeast on the 21st.

Surface maps show a cold maritime arctic high pressure system affecting northeastern Alberta. Two cold fronts lie to the northeast while a washed out front lies to the southwest of the Fort McMurray region.

Description of Data

Lower Camp Profiles

The 1037 MST profile shows a superadiabatic lapse rate to 108 m, an inversion from 108 to 620 m and two isothermal layers, the first from 1540 to 1720 m and the second from 2160 to 2520 m.

The 1334 MST profile shows a superadiabatic lapse rate to 108 m.

The 1037 to 1334 MST profiles shows a cooling of 2°C above 200 m.

Fort Smith Profile

The 0500 MST profile shows a ground based inversion to 300 m, and an isothermal layer from 1950 to 2150 m. Profile indicates air is dry below 700 mb.

Other Data

Automatic station data show one station at 600 m MSL to be higher in temperature at 0500 MST by 7 to 9°C than all other stations between 200 to 300 m MSL.

The Holzworth estimation technique indicates portions of the inversion are still present at the times of the events.

Light variable winds and incoming solar radiation boardering strong insolation occur at event times.

Event times were 1130, 1130, 1200 and 1300 MST.

Interpretation of Data

Lower Camp profiles indicate a shallow layer of modified cold arctic air overlaying the AOSERP area. Automatic station data also give evidence of this layer of cold air and the presence of light variable winds. Surface maps show that the washed out front has disappeared and the secondary cold front is just north and east of Fort McMurray. The position of this front is debatable since profiles indicate a 2°C drop overall and the Fort Smith profile is very similar indicating the secondary front is south and west of Fort McMurray.

Radiation and superadiabatic lapse rates indicate convective mixing at ground level.

Conclusion

Information listed leads us to conclude that cold frontal trapping and light variable winds produced events at ground level.

CASE 2, 27 JANUARY 1977

Synoptic Picture

The 500 mb maps show a intense closed low over most of North America. A steep pressure gradient and strong winds out of the northwest are shown over Alberta.

Surface maps show an intense cold continental arctic high pressure system over most of the western provinces.

Description of Data

Lower Camp Profiles

The 0850 MST profile shows a ground based inversion to 108 m, an elevated inversion from 216 to 1250 m, and an isothermal layer from 1250 m to the top of the profile at 2700 m.

The 1429 MST profile shows a superadiabatic layer to 108 m, an inversion from 216 to 310 m, an inversion from 410 to 1250 m and an isothermal layer from 1250 m to the top of the profile at 2700 m.

Fort Smith Profile

The 1700 MST profile shows a ground based inversion to 100 m and an elevated inversion from 200 to 1400 m.

Other Data

Scattered cloud at 0500 MST to clear at 1400 MST.

Light variable winds are reported from the tall tower and automatic station network.

Slight incoming solar radiation occurred at the time of the events.

Event times were 1530 and 1600 MST.

Interpretation of Data

The deep inversions and the stable air aloft are characteristic of cold anticyclones. The 1429 MST Lower Camp profile shows that daytime heating does not destroy the inversions but creates a shallow mixing layer. Trapping of emissions occur below the main inversion from 410 to 1250 m.

Conclusion

Information listed leads to the conclusion that trapping of emissions by the inversion due to the cold arctic air resulted in the ground level events.

CASE 3, 4 MARCH 1978

Synoptic Picture

The 500 mb weather maps show the general circulation has been weak over the Fort McMurray area for several days. A deep arctic low is situated above Hudson Bay and a shallow low at the northeast corner of British Columbia.

Surface maps show a high pressure system moving out on the 3rd and the 4th sees the Fort McMurray region between two lows east and west, repectively, and a high to the south. The lack of movement over Fort McMurray has caused the continental arctic air over the area to become modified.

Description of Data

Lower Camp Profiles

The 0800 MST profile shows a ground based inversion to 801 m and an elevated inversion from 1260 to 1710 m.

The 1400 MST profile shows a superadiabatic lapse rate to 108 m, two elevated inversions, the first from 612 to 801 m and the second from 1350 to 1620 m, and a near isothermal layer from 1620 to 2160 m.

Fort Smith Profile

The 0500 MST profile shows a ground based inversion to 500 m and a near isothermal layer from 1000 to 2000 m.

Other Data

Clear skies, light variable winds and slight incoming radiation occurred during the events.

Event times were 1530, 1630 and 1730 MST.

Interpretation of Data

The Fort McMurray region is located within what is known as a col, since the primary weather systems are far removed. Radiative cooling and the cool arctic air has produced a strong surface based inversion. Daytime heating has reduced the surface based inversion and produced a mixing layer to 612 m.

Conclusion

Information listed leads to the conclusion that modified continental arctic air in a col and radiative cooling has produced an inversion which trapped emissions and caused events at ground level.

CASE 4, 23 MARCH 1978

Synoptic Picture

The 500 mb maps show a building ridge of high pressure along the Alberta-British Columbia border from the 22nd to the 23rd. A strong flow out of the northwest and a strong gradient exist over the northern half of Alberta.

Surface maps show a maritime arctic high pressure system moving down into northern Alberta. The Fort McMurray area is affected by a warm frontal system south of the high.

On a sub-synoptic scale, there is a weak depression moving southeastward along the warm front with a trough to the northeast.

Description of Data

Lower Camp Profiles

The 0800 MST profile shows a superadiabatic layer to 108 m and an elevated inversion from 315 to 620 m.

The 1320 MST profile shows a superadiabatic layer to 108 m and an elevated inversion from 414 to 500 m.

Fort Smith Profile

The 1700 MST profile shows two elevated inversions, the first from 1400 to 2400 m and the second from 4000 to 4200 m.

Other Data

Automatic station data show southern stations to be significantly warmer than northern stations. Precipitation occurred at two northern stations during event times.

The tall tower station indicated moderate winds in the direction of the event sites.

Winds at the tall tower change from a southerly to northeasterly direction near the end of event times, indicating the passage of the warm front.

Event times were 1300, 1300, 1330, 1400 and 1530 MST.

Interpretion of Data

Surface maps, profiles and surface data indicate a warm frontal inversion over the region. The elevated inversions in both of the Lower Camp profiles and the second of the two inversions in the Fort Smith profiles are the relative indicators of the positions of the front.

Mechanical mixing of the plume beneath the inversion occurs due to moderate winds.

Conclusion

Information listed leads to the conclusion that warm frontal trapping and moderate winds combined to produce the events at downwind sites of the emission source.

CASE 5, 3 APRIL 1978

Synoptic Picture

The 500 mb maps show a trough building along the British Columbia coast. A flattening ridge over the interior produces a west by northwest flow and moderate gradient over Alberta.

Surface maps show a modified continental arctic high pressure system over Alberta in a light easterly flow.

Description of Data

Lower Camp Profiles

The 0800 MST profile shows a superadiabatic layer to 108 m and two elevated inversions, one from 414 to 620 m and the second from 1720 to 1900 m.

The 1400 MST profile shows a superadiabatic layer to 216 m and an elevated inversion from 1170 to 1260 m.

Fort Smith Profile

The 0500 MST profile shows two elevated inversions, the first from 100 to 900 m and the second from 1300 to 1550 m.

Other Data

Tall tower and automatic station data indicate that winds are light and range from southwest to northwest in direction.

Clear skies and strong insolation occur for event times.

Event times were 1200 and 1330 MST.

Interpretation of Data

Radiative cooling and the modified arctic air has produced the lowest inversion. The inversion above this shows the top of the cold air mass indicating the shallowness of the arctic air in the region. Thermal turbulence has reduced the strength of the first inversion and elevated it. Strong thermal turbulence is apparent due to superadiabatic lapse rate to 216 m by 1400 MST.

Conclusion

Information listed leads to the conclusion that trapping of emissions by the elevated inversions was not the most significant process by early afternoon but strong thermal turbulence or convective mixing caused the ground level events.

CASE 6, 22 APRIL 1978

Synoptic Picture

The 500 mb maps show a weak disorganized flow over Alberta due to an intense low in the arctic and weak flattening ridge over Saskatchewan and Manitoba. Surface maps show a maritime arctic high pressure system just north of Fort McMurray. Due to the weak flow, the frontal positions across Alberta are ill defined and show little well defined motion. A low is located northwest with a quasi-stationary front over the Fort McMurray area.

Description of Data

Lower Camp Profiles

The 0800 MST profile shows a superadiabatic layer to 108 m, a near isothermal layer from 216 to 620 m, and an inversion from 620 to 700 m.

The 1400 MST profile shows a superadiabatic layer to 108 m.

Fort Smith Profile

The 1700 MST profile shows two near isothermal layers, the first from 110 to 2350 m, and the second from 3400 to 4000 m.

Other Data

Early afternoon sees a combination of light surface winds in the direction of the event sites and strong insolation.

Strong winds are indicated in the direction of the event site from tall tower and automatic station data for the late afternoon.

Holzworth technique estimates the inversion to be already gone by the early afternoon event time.

Event times were 1300 and 1930 MST.

Interpretation of Data

Lower Camp profile indicates that at 0800 MST the AOSERP area is under a frontal inversion. Veering winds from the direction of the event site at event time in the low levels indicate warm air advection and a northeastward motion of the warm front.

By early afternoon the frontal inversion is broken down by thermal turbulence.

Strong winds in the late afternoon lead to strong mechanical mixing of the plume.

Conclusion

Information listed leads to the conclusion that the frontal inversion found over the AOSERP region is broken down by the time of the early afternoon event. Strong thermal turbulence is credited with being the primary cause of the early afternoon event.

Strong winds in the late afternoon mix the plume to ground level, causing the event.

CASE 7, 28 APRIL 1978

Synoptic Picture

The 500 mb maps show Alberta to be under a ridge of high pressure.

Surface maps show a cold continental arctic high moving through eastern Northwest Territories into the eastern prairies and northeastern Alberta. A cold front across northeastern Alberta is shown in the region of Fort McMurray. Ahead of the cold front a series of lows extends down and through Alberta associated with a maritime arctic frontal system.

Description of Data

Lower Camp Profiles

The 0800 MST profile shows an elevated inversion from 315 to 620 m.

The 1400 MST profile shows a superadiabatic layer to 108 m.

Fort Smith Profile

The 0500 MST profile shows two elevated inversions, the first from 1000 to 1200 m and second from 3200 to 3500 m.

Other Data

Tall tower and automatic station data indicate moderate to strong winds in the directin of the event sites.

Strong insolation is indicated during the times of the events.

Event times were 1100, 1100 and 1100 MST.

Interpretation of Data

Arctic air pushed into northeastern Alberta in a moderate to strong southeasterly flow early in the morning. The 0820 MST profile shows a cold frontal inversion and adiabatic lapse rate in the lowest 300 m caused by strong turbulent mixing.

The inversions' total disappearance as shown on the 1400 MST profile is a result of mechanical and thermal turbulence combined with the northward movement of the warm sector associated with the maritime arctic front.

Conclusion

The information above leads to the conclusion that a combination of an elevated cold frontal inversion and moderate winds mixed emissions down to ground level.

CASE 8, 24 MAY 1978

Synoptic Picture

The 500 mb maps show that,from May 23rd to the 25th a cold low was situated over southwestern British Columbia giving Alberta a moderate south to southwesterly flow.

Surface maps indicate an arctic front lay in a northwest to southeast line to the north of the Fort McMurray area and a frontal system from a low in Montana drifted slowly east to northeastward across southern Saskatchewan. The Fort McMurray region is in a modified maritime arctic air mass.

Description of Data

Lower Camp Profiles

The 0700 MST profile shows a superadiabatic layer to 108 m, two elevated inversions, the first from 216 to 620 m and the second from 1620 to 1800 m.

The 1300 MST profile shows a superadiabatic lapse rate to 108 m and an isothermal layer from 1170 to 1530 m.

Fort Smith Profile

The 1700 MST profile indicates an inversion from 2400 to 2600 m with an isothermal layer above to 3000 m.

Other Data

The Holzworth technique estimates the inversions' possible disappearance by initial event time.

Variable cloudiness occurred during the day.

Light variable winds and strong insolation occurred at the time of the late morning events.

Tall tower lapse rates indicate extensive radiative cooling. Also, superadiabatic lapse rates are found during the event day.

Event times were 1000, 1030, 1030, 1200 and 1700 MST.

Interpretation of Data

The Fort McMurray region is regarded to be in a weak col position.

The 0800 MST Lower Camp profile, tall tower data, and surface map analysis suggest that lowest elevated inversion is nocturnal. The higher of the two inversions is felt to be a result of the warm front from the intense low to the south-southeast.

Fort Smith also indicates this warm front at 2400 m.

Conclusion

Information above leads to the conclusion that we cannot disassociate the cause of the events from either the nocturnal inversion or the thermal turbulence. However, the interpretation of the data suggests the primary cause of the events was thermal turbulence.

CASE 9, 2 AUGUST 1976

Synoptic Picture

The 500 mb maps show Alberta dominated by a warm continental ridge. A weak flow pattern has existed over Alberta for several days.

Surface maps show a weak flow of modified maritime polar air over the area.

Description of Data

Lower Camp Profiles

The 0521 MST profile shows a ground based nocturnal inversion to 400 m. The 0852 MST profile shows an elevated nocturnal inversion from 200 to 400 m. The 1225 MST profile shows a superadiabatic layer to 216 m and light winds from the south by southeast at stack height. The 1427 MST profile shows a superadiabatic layer to 108 m and light winds out of the south at stack height.

Fort Smith Profile

The 0500 MST profile shows a ground based nocturnal inversion to 400 m and a weak inversion from 2500 to 2600 m.

Other Data

AOSERP Camp station at which the event occurred reports light winds and strong insolation surrounding the time of the event.

Automatic and tower stations were not in operation.

Event time was 1300 MST.

Interpretation of Data

Lower Camp profiles show that the nocturnal inversion has disappeared before event time. Superadiabatic lapse rates, strong insolation and light winds suggest strong thermal turbulence at the time of the event.

Fort Smith profiles confirm the nocturnal inversion and give possible indications of the warm front at 2500 m.

Conclusions

The information above leads to the conclusion that a combination of thermal turbulence and light winds in the direction of the event station lead to the occurrence of the event.

CASE 10, 30 AUGUST 1976

Synoptic Picture

The 500 mb maps show a ridge of high pressure over most of Alberta. An intense closed low in the northeastern arctic affects the very northeastern corner of Alberta. A relatively strong gradient exists over Alberta.

Surface maps indicate maritime arctic air over Alberta except for the extreme northeastern part of the province which is under modified continental arctic air. A weak quasi-stationary front exists southwest of Fort McMurray at the time of the event.

Description of Data

Lower Camp Profiles

The 1012 MST profile shows a superadiabatic lapse rate to 108 m and an elevated inversion from 216 to 540 m. The 1344 MST profile show a superadiabatic lapse rate to 108 m and an isothermal layer from 710 to 900 m.

Fort Smith Profile

The 0500 MST profile shows a nocturnal inversion to approximately 300 m and near isothermal layers from 2100 to 2700 m and from 3300 to 3500 m.

Other Data

AOSERP Camp station reports calm winds and strong insolation surrounding the time of the event.

Event time was 1230 MST.

Interpretation of Data

Fort Smith 0500 MST profile indicates a nocturnal inversion to 300 m that probably occurred at Lower Camp at the same time.

The Lower Camp 1012 MST profile shows the remains of the nocturnal inversion from 216 to 540 m. The 1344 MST profile shows the remains of the morning nocturnal inversion from 710 to 900 m.

Superadiabatic lapse rates, low winds, and strong insolation produced strong convective mixing.

Conclusion

The information above leads to the conclusion that the nocturnal inversion trapped emissions which were then brought to ground level by intense convection.

CASE 11, 14 APRIL 1978

Synoptic Picture

The 500 mb maps show Alberta between two low pressure troughs. One is located over southwestern British Columbia and the other over Quebec. A flat ridge exists over the southern tip of Alberta and is beginning to build northward. No significant flow pattern exists over northeastern Alberta.

Surface maps show a continental arctic high pressure system covers most of Alberta.

Description of Data

Lower Camp Profiles

The 0800 MST profile shows a superadiabatic layer to 108 m, an isothermal layer from 800 to 900 m, and an elevated inversion from 1620 to 1900 m. The 1400 MST profile shows a superadiabatic layer to 108 m and an elevated inversion from 1620 to 2100 m.

Fort Smith Profile

The 0500 MST profile shows a near isothermal layer from 300 to 1110 m, an inversion from 1110 to 1460 m, and an isothermal layer from 1460 to 2000 m.

Other Data

Moderate insolation, broken cloud cover and light to moderate winds in the direction of the event station occurred at event time.

Convective precipitation occurred during the day but before event time.

Event time was 1530 MST.

Interpretation of Data

The Lower Camp and Fort Smith profiles show characteristics of a cold continental arctic air mass which has been highly modified in the lowest 1500 m. The elevated inversions in both profiles show the depth of the arctic air over the region.

Comparison of profiles and data indicates strong mixing by both thermal and mechanical processes.

Conclusion

The information above leads to the conclusion that emissions were dispersed by strong thermal and mechanical turbulence within a deep mixing layer.

CASE 12, 14 MAY 1978

Synoptic Picture

The 500 mb maps show a closed low off the southwest coast of British Columbia giving Alberta a southwesterly flow. The northern portion of the province is under a weak southwesterly flow.

Surface maps show a deep low pressure system centred in Alberta. The warm front from this low is depicted just north of Fort

McMurray at event time. Modified maritime polar overlies maritime arctic air north of the warm front.

Description of Data

Lower Camp Profiles

The 0700 MST profile shows a nocturnal inversion to 216 m and an elevated inversion from 513 to 720 m. The 1000 MST profile show a superadiabatic lapse rate to 108 m and a near isothermal layer from 800 to 1000 m.

Fort Smith Profile

The 0500 MST profile shows an inversion to 850 m.

Other Data

Moderate winds in the direction of the event station and strong insolation occur at event time.

Automatic station data show that stations on the north side of a diagonal line running from the southwest to the northeast through the centre of the stations have winds out of the northeast and stations on the south side of this diagonal line have winds out of the southeast. No such differences existed with temperatures at these stations.

Event time was 1130 MST.

Interpretation of Data

The profiles indicate that prior to event time, a warm frontal inversion enhanced by radiative cooling at the surface affected the area. By event time, the warm front and the nocturnal inversion had disappeared. The position of the surface warm front is taken from the automatic station wind data at the time of the event.

Conclusion

The information above leads to the conclusion that mechanical and convective mixing of emissions lead to the occurrence of events at ground level.

CASE 13, 10 SEPTEMBER 1976

Synoptic Picture

The 500 mb maps show a strong westerly flow over Alberta with an intense low in the arctic contributing a northwesterly flow to the northern portions of the province.

Surface maps show a deep low pressure system centred in northern Saskatchewan with its cold front depicted just south of Fort McMurray at event time. Modified maritime arctic air lies behind this cold front.

Description of Data

Lower Camp Profiles

The 1805 MST profile on September 9, 1976, shows an elevated inversion from 2430 to 2620 m. The 0705 MST profile on the 10th shows two elevated inversions, one from 108 to 320 m and the second from 520 to 620 m. Also, a near isothermal layer exists from 1360 to 1440 m.

Fort Smith Profile

The 0500 MST profile on the 10th shows the whole of the lowest layers follow a saturated adiabatic lapse rate.

Other Data

Dual theodolite readings on Lower Camp profiles provided wind measurements at elevated levels. The data on the 9th show light winds of 3 to 4 m/s and on the 10th show strong winds of 10 to 11 m/s, both directly out of the west and in the direction of the event stations at event time.

Event time was 0330 MST.

Interpretation of Data

The elevated inversions in the 1805 MST Lower Camp profile on the 9th is probably a warm front in the area. The 0705 MST Lower Camp profile on the 10th shows two inversions, the lowest being nocturnal and the upper due to the cold front. The near isothermal layer is indicative of the depth of the colder air mass.

The Fort Smith profiles gives no indications of a front.

Strong winds beneath the inversions produce a coning plume.

Conclusion

The information above leads to the conclusion that the cold front has trapped emissions and strong winds produced coning of the plume to ground level.

CASE 14, 14 SEPTEMBER 1976

Synoptic Picture

The 500 mb maps show a short wave ridge over western Canada gradually moving eastward as a short wave trough moves inland from the British Columbia coast. A moderately strong westerly gradient exists over most of Alberta.

Surface maps show a surface trough associated with the trough aloft moving from the west. Along with this trough is a complex frontal and trowal structure. The trowal exists through central Alberta at event time. Maritime arctic air exists over the Fort McMurray area.

Description of Data

Lower Camp Profiles

The 1803 MST profile on the 13th shows a weak inversion from 1750 to 2000 m. The 0718 MST profile on the 14th shows a strong inversion from 108 to 900 m and an isothermal layer at 2340 to 2520 m.

Fort Smith Profile

The 0500 MST profile on the 14th shows a nocturnal inversion to 250 m, a near isothermal layer above to 1200 m, and an isothermal layer from 1500 to 1650 m. The profile indicates that, between 700 and 950 mb, the air has dried significantly.

Other Data

Clear skies were present at the time of the event.

Dual theodolite profiles at Lower Camp yield moderate winds of 5.5 m/s at stack height from the south on the 13th and the southwest on the 14th of September. Wind direction correlates to event station site and time.

Event time was 0400 MST.

Interpretation of Data

The profile for Lower Camp at 1803 on the 13th shows the frontal structure of the trowal from 1700 to 2000 m. Below that, the lapse rate is basically dry adiabatic due to daytime surface heating. By 0718 on the 14th the inversion due to the trowal is topped at 900 m and together with radiative cooling has produced a pronounced surface based inversion. At Fort Smith the identification of the front aloft is more difficult, possibly camoflaged by possible low level subsidence.

Conclusions

The information above leads to the conclusion that the occluded front trapped emissions and moderate winds produced coning of the plume to ground level.

CASE 15, 11 FEBRUARY 1978

Synoptic Picture

The 500 mb maps show a high pressure system building from the arctic down into the western provinces for the last several days until the 11th. The 11th sees an intense massive low centred in the Atlantic provinces elongate into the western provinces weakening the flow pattern above the Fort McMurray area.

Surface maps show an intense continental arctic high over north-central Canada extending into the eastern United States. The high encompasses most of Alberta in a cold southeasterly flow.

Description of Data

Lower Camp Profiles

The 0800 MST profile shows a strong ground based inversion to 801 m and two elevated inversions, the first from 1080 to 1260 m and the second from 1540 to 1720 m. The 1200 MST profile shows a strong ground based inversion to 315 m and four elevated inversions.

Fort Smith Profile

The 0500 MST profile shows a ground based inversion to 2000 m.

Other Data

Tall tower and automatic station data show moderate winds out of the southeast and in the direction of the event station site at event time.

Event time was 1530 MST.

Interpretation of Data

Lower Camp and Fort Smith depict the characteristic profiles of cold continental arctic air. Radiative cooling has enhanced the strength and depth of the ground based inversion.

Conclusion

The information above leads to the conclusion that cold continental arctic air produced a deep inversion under which emissions were trapped.

CASE 16, 3 MAY 1978

Synoptic Picture

The 500 mb maps show a ridge moving slowly through Manitoba. A moderate southwesterly flow over Alberta gradually changes to a southerly flow as a trough elongates in a northwest-southeast line through western Alberta.

Surface maps show a north-south trough through central Alberta on May 2nd which moves into Saskatchewan on the 3rd. A cold maritime arctic cold front lies in the trough.

Description of Data

Lower Camp Profiles

The 0705 MST profile shows an elevated inversion from 108 to 220 m. The 1300 MST profile shows a superadiabatic lapse rate to 108 m and an elevated inversion from 2520 to 2620 m.

Fort Smith Profile

The 0500 MST profile shows no inversion below 3000 m and the curve follows the saturated adiabatic in this region.

Other Data

Tall tower and automatic station data indicate moderate winds out of the west and in the direction of the event station site at event time.

Event time was 0530 MST.

Interpretion of Data

The 0705 MST Lower Camp profile indicate a low level inversion probably produced by radiative cooling overnight. By the time of the afternoon profile, the nocturnal inversion has disappeared but an elevated inversion appears which is probably the cold front to the east.

Stable conditions with light winds the previous day change to moderate westerly winds and unstable conditions by mid-morning.

Conclusion

The information above leads to the conclusion that emissions were trapped by a nocturnal inversion and moderate winds produced coning of the plume to ground level.

8. LIST OF AOSERP RESEARCH REPORTS

1.		AOSERP First Annual Report, 1975
2.	AF 4.1.1	Walleye and Goldeye Fisheries Investigations in the Peace-Athabasca Delta--1975
3.	HE 1.1.1	Structure of a Traditional Baseline Data System
4.	VE 2.2	A Preliminary Vegetation Survey of the Alberta Oil Sands Environmental Research Program Study Area
5.	HY 3.1	The Evaluation of Wastewaters from an Oil Sand Extraction Plant
6.		Housing for the North--The Stackwall System
7.	AF 3.1.1	A Synopsis of the Physical and Biological Limnology and Fisheries Programs within the Alberta Oil Sands Area
8.	AF 1.2.1	The Impact of Saline Waters upon Freshwater Biota (A Literature Review and Bibliography)
9.	ME 3.3	Preliminary Investigations into the Magnitude of Fog Occurrence and Associated Problems in the Oil Sands Area
10.	HE 2.1	Development of a Research Design Related to Archaeological Studies in the Athabasca Oil Sands Area
11.	AF 2.2.1	Life Cycles of Some Common Aquatic Insects of the Athabasca River, Alberta
12.	ME 1.7	Very High Resolution Meteorological Satellite Study of Oil Sands Weather: "A Feasibility Study"
13.	ME 2.3.1	Plume Dispersion Measurements from an Oil Sands Extraction Plant, March 1976
14.		
15.	ME 3.4	A Climatology of Low Level Air Trajectories in the Alberta Oil Sands Area
16.	ME 1.6	The Feasibility of a Weather Radar near Fort McMurray, Alberta
17.	AF 2.1.1	A Survey of Baseline Levels of Contaminants in Aquatic Biota of the AOSERP Study Area
18.	HY 1.1	Interim Compilation of Stream Gauging Data to December 1976 for the Alberta Oil Sands Environmental Research Program
19.	ME 4.1	Calculations of Annual Averaged Sulphur Dioxide Concentrations at Ground Level in the AOSERP Study Area
20.	HY 3.1.1	Characterization of Organic Constituents in Waters and Wastewaters of the Athabasca Oil Sands Mining Area
21.		AOSERP Second Annual Report, 1976-77
22.		Alberta Oil Sands Environmental Research Program Interim Report to 1978 covering the period April 1975 to November 1978
23.	AF 1.1.2	Acute Lethality of Mine Depressurization Water on Trout Perch and Rainbow Trout
24.	ME 1.5.2	Air System Winter Field Study in the AOSERP Study Area, February 1977.
25.	ME 3.5.1	Review of Pollutant Transformation Processes Relevant to the Alberta Oil Sands Area

26.	AF 4.5.1	Interim Report on an Intensive Study of the Fish Fauna of the Muskeg River Watershed of Northeastern Alberta
27.	ME 1.5.1	Meteorology and Air Quality Winter Field Study in the AOSERP Study Area, March 1976
28.	VE 2.1	Interim Report on a Soils Inventory in the Athabasca Oil Sands Area
29.	ME 2.2	An Inventory System for Atmospheric Emissions in the AOSERP Study Area
30.	ME 2.1	Ambient Air Quality in the AOSERP Study Area, 1977
31.	VE 2.3	Ecological Habitat Mapping of the AOSERP Study Area: Phase I
32.		AOSERP Third Annual Report, 1977-78
33.	TF 1.2	Relationships Between Habitats, Forages, and Carrying Capacity of Moose Range in northern Alberta. Part I: Moose Preferences for Habitat Strata and Forages.
34.	HY 2.4	Heavy Metals in Bottom Sediments of the Mainstem Athabasca River System in the AOSERP Study Area
35.	AF 4.9.1	The Effects of Sedimentation on the Aquatic Biota
36.	AF 4.8.1	Fall Fisheries Investigations in the Athabasca and Clearwater Rivers Upstream of Fort McMurray: Volume I
37.	HE 2.2.2	Community Studies: Fort McMurray, Anzac, Fort MacKay
38.	VE 7.1.1	Techniques for the Control of Small Mammals: A Review
39.	ME 1.0	The Climatology of the Alberta Oil Sands Environmental Research Program Study Area
40.	WS 3.3	Mixing Characteristics of the Athabasca River below Fort McMurray - Winter Conditions
41.	AF 3.5.1	Acute and Chronic Toxicity of Vanadium to Fish
42.	TF 1.1.4	Analysis of Fur Production Records for Registered Traplines in the AOSERP Study Area, 1970-75
43.	TF 6.1	A Socioeconomic Evaluation of the Recreational Fish and Wildlife Resources in Alberta, with Particular Reference to the AOSERP Study Area. Volume I: Summary and Conclusions
44.	VE 3.1	Interim Report on Symptomology and Threshold Levels of Air Pollutant Injury to Vegetation, 1975 to 1978
45.	VE 3.3	Interim Report on Physiology and Mechanisms of Air-Borne Pollutant Injury to Vegetation, 1975 to 1978
46.	VE 3.4	Interim Report on Ecological Benchmarking and Biomonitoring for Detection of Air-Borne Pollutant Effects on Vegetation and Soils, 1975 to 1978.
47.	TF 1.1.1	A Visibility Bias Model for Aerial Surveys for Moose on the AOSERP Study Area
48.	HG 1.1	Interim Report on a Hydrogeological Investigation of the Muskeg River Basin, Alberta
49.	WS 1.3.3	The Ecology of Macrobenthic Invertebrate Communities in Hartley Creek, Northeastern Alberta
50.	ME 3.6	Literature Review on Pollution Deposition Processes
51.	HY 1.3	Interim Compilation of 1976 Suspended Sediment Date in the AOSERP Study Area
52.	ME 2.3.2	Plume Dispersion Measurements from an Oil Sands Extraction Plan, June 1977

53.	HY 3.1.2	Baseline States of Organic Constituents in the Athabasca River System Upstream of Fort McMurray
54.	WS 2.3	A Preliminary Study of Chemical and Microbial Characteristics of the Athabasca River in the Athabasca Oil Sands Area of Northeastern Alberta
55.	HY 2.6	Microbial Populations in the Athabasca River
56.	AF 3.2.1	The Acute Toxicity of Saline Groundwater and of Vanadium to Fish and Aquatic Invertebrates
57.	LS 2.3.1	Ecological Habitat Mapping of the AOSERP Study Area (Supplement): Phase I
58.	AF 2.0.2	Interim Report on Ecological Studies on the Lower Trophic Levels of Muskeg Rivers Within the Alberta Oil Sands Environmental Research Program Study Area
59.	TF 3.1	Semi-Aquatic Mammals: Annotated Bibliography
60.	WS 1.1.1	Synthesis of Surface Water Hydrology
61.	AF 4.5.2	An Intensive Study of the Fish Fauna of the Steepbank River Watershed of Northeastern Alberta
62.	TF 5.1	Amphibians and Reptiles in the AOSERP Study Area
63.	ME 3.8.3	Analysis of AOSERP Plume Sigma Data
64.	LS 21.6.1	A Review and Assessment of the Baseline Data Relevant to the Impacts of Oil Sands Development on Large Mammals in the AOSERP Study Area
65.	LS 21.6.2	A Review and Assessment of the Baseline Data Relevant to the Impacts of Oil Sands Development on Black Bears in the AOSERP Study Area
66.	AS 4.3.2	An Assessment of the Models LIRAQ and ADPIC for Application to the Athabasca Oil Sands Area
67.	WS 1.3.2	Aquatic Biological Investigations of the Muskeg River Watershed
68.	AS 1.5.3 AS 3.5.2	Air System Summer Field Study in the AOSERP Study Area, June 1977
69.	HS 40.1	Native Employment Patterns in Alberta's Athabasca Oil Sands Region
70.	LS 28.1.2	An Interim Report on the Insectivorous Animals in the AOSERP Study Area
71.	HY 2.2	Lake Acidification Potential in the Alberta Oil Sands Environmental Research Program Study Area
72.	LS 7.1.2	The Ecology of Five Major Species of Small Mammals in the AOSERP Study Area: A Review
73.	LS 23.2	Distribution, Abundance and Habitat Associations of Beavers, Muskrats, Mink and River Otters in the AOSERP Study Area, Northeastern Alberta
74.	AS 4.5	Air Quality Modelling and User Needs
75.	WS 1.3.4	Interim Report on a Comparative Study of Benthic Algal Primary Productivity in the AOSERP Study Area
76.	AF 4.5.1	An Intensive Study of the Fish Fauna of the Muskeg River Watershed of Northeastern Alberta
77.	HS 20.1	Overview of Local Economic Development in the Athabasca Oil Sands Region Since 1961.
78.	LS 22.1.1	Habitat Relationships and Management of Terrestrial Birds in Northeastern Alberta

79. AF 3.6.1 The Multiple Toxicity of Vanadium, Nickel, and Phenol to Fish.
80. HS 10.2 & HS 10.1 History of the Athabasca Oil Sands Region, 1980 to 1960's. Volumes I and II.
81. LS 22.1.2 Species Distribution and Habitat Relationships of Waterfowl in Northeastern Alberta.
82. LS 22.2 Breeding Distribution and Behaviour of the White Pelican in the Athabasca Oil Sands Area.
83. LS 22.2 The Distribution, Foraging Behaviour, and Allied Activities of the White Pelican in the Athabasca Oil Sands Area.
84. WS 1.6.1 Investigations of the Spring Spawning Fish Populations in the Athabasca and Clearwater Rivers Upstream from Fort McMurray; Volume I.
85. HY 2.5 An intensive Surface Water Quality Study of the Muskeg River Watershed. Volume I: Water Chemistry.
86. AS 3.7 An Observational Study of Fog in the AOSERP Study Area.
87. WS 2.2 Hydrogeological Investigation of Muskeg River Basin, Alberta
88. AF 2.0.1 Ecological Studies of the Aquatic Invertebrates of the Alberta Oil Sands Environmental Research Program Study Area of Northeastern Alberta
89. AF 4.3.2 Fishery Resources of the Athabasca River Downstream of Fort McMurray, Alberta. Volume 1
90. AS 3.2 A Wintertime Investigation of the Deposition of Pollutants around an Isolated Power Plant in Northern Alberta
91. LS 5.2 Characterization of Stored Peat in the Alberta Oil Sands Area
92. WS 1.6.2 Fisheries and Habitat Investigations of Tributary Streams in the Southern Portion of the AOSERP Study Area. Volume I: Summary and Conclusions
93. WS 1.3.1 Fisheries and Aquatic Habitat Investigations in the MacKay River Watershed of Northeastern Alberta
94. WS 1.4.1 A Fisheries and Water Quality Survey of Ten Lakes in the Richardson Tower Area, Northeastern Alberta. Volume I: Methodology, Summary, and Discussion.
95. AS 4.2.6 Evaluation of the Effects of Convection on Plume Behaviour in the AOSERP Study Area
96. HS 20.3 Service Delivery in the Athabasca Oil Sands Region Since 1961
97. LS 3.4.1 Differences in the Composition of Soils Under Open and Canopy Conditions at Two Sites Close-in to the Great Canadian Oil Sands Operation, Fort McMurray, Alberta
98. LS 3.4.2 Baseline Condition of Jack Pine Biomonitoring Plots in the Athabasca Oil Sands Area; 1976 and 1977
99. LS 10.1 Synecology and Autecology of Boreal Forest Vegetation in the AOSERP Study Area
100. LS 10.2 Baseline Inventory of Aquatic Macrophyte Species Distribution in the AOSERP Study Area
101. LS 21.1.3 Woodland Caribou Population Dynamics in Northeastern Alberta
102. LS 21.1.4 Wolf Population Dynamics and Prey Relationships in Northeastern Alberta