A FEASIBILITY STUDY FOR THE ESTIMATION OF ATMOSPHERIC DISPERSION COEFFICIENTS FROM WIND FLUCTUATION STATISTICS IN THE AOSERP STUDY AREA

by

H.E. TURNER AND F.H. FANAKI
Atmospheric Environment Service

for

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

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TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

ABSTRACT

During the fall and winter of 1976-77 a project was undertaken to establish the feasibility of using a bivane anemometer to calculate dispersion coefficients from wind fluctuation statistics.

The measurements procedure and the experimental results are described in this report.

It was determined that the time allowed for the project was insufficient to collect samples of the weather conditions required.

The lack of agreement between the concurrent bivane measurements and the vertical dispersion of the plume indicates that care must be taken in applying the bivane results to determine the dispersion of the GCOS plume.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

Many mathematical models for pollutant transport and diffusion on short to medium distance scales require, as input, values for atmospheric dispersion coefficients (standard deviations of time averaged, crosswind, concentration distributions) as a function of downwind distance. These coefficients, however, are complex functions of height, atmospheric stability, and surface roughness. As a consequence, they have been parameterized only for some simple cases and attempts to apply these parameterizations for heights above the surface boundary layer or for unique terrain lead to highly questionable extrapolation.

Empirical techniques do exist for the direct estimation of dispersion parameters from measured turbulence statistics at the appropriate height and at the site in question. Such measurements, however, are too difficult, expensive, and time-consuming to carry out on a scale large enough to devise a "dispersion climatology" for a particular area. The problem, therefore, is to establish, for the AOSERP study area, significant relationships between dispersion parameters and more conventional meteorological parameters in order that the latter may be used to infer longer-term dispersion statistics and to serve as parameterizations for input to dispersion models. In order to attack this problem, however, it is necessary to first establish the feasibility of using this approach in the Oil Sands area.

The objectives for this project were:

1. To experimentally examine the feasibility of estimating, by means of turbulence measurements, the atmospheric dispersion coefficients relevant to pollutant plumes from the Great Canadian Oil Sands plant under weather conditions typical of the AOSERP study area;
2. To investigate the possibility of a significant relationship between the above dispersion coefficients and coincident wind and temperature profiles, surface wind speed, and net radiation; and
3. Where possible, to test the validity of results from (1) and (2) above with existing data on plume dimensions, turbulence statistics and meteorological profiles obtained from other experiments at the GCOS plant.

2. EXPERIMENTAL SITE AND SCOPE OF WORK

2.1 EXPERIMENTAL SITE

In general, the AOSERP study area comprises the new developed oil extraction area (Figure 1). It is located approximately 40 km north of Fort McMurray, Alberta, west of the Athabasca River.

The topography around the Athabasca River is variable, ranging from undulating to rolling land. The Athabasca River was frozen during most of the study period. The river valley has an elevation of about 230 m, MSL and a width of about 1 km at the site location. The valley slope rises gradually to an elevation of about 400 m at 25 km to the east and, for the same distance to the west, it rises to an elevation of 520 m.

The east bank of the river rises relatively rapidly to a height of about 60 m and is covered with trees, averaging 10 m in height. The west bank of the river rises gradually for a distance of 1.5 km and then sharply to 30 m in height. North and west of the site,at a distance of about 100 m,the land is covered with trees, mostly spruce and poplar, averaging 15 m in height. The area south of the site is relatively clear and the nearest buildings are 800 m due south of the site. The buildings'heights vary from a few meters to tens of meters.

2.2 SCOPE OF WORK

The work required the installation of a Gill type anemometer bivane on a rotatable base at the top of the 152 m meteorological tower at the Lower Syncrude site in the AOSERP study area (Figure 1). The bivane output was to be logged digitally after passing through a series of averaging circuits which would permit the simultaneous estimation of dispersion coefficients for a variety of sampling times and downwind distances. The system was to operate for selected periods.

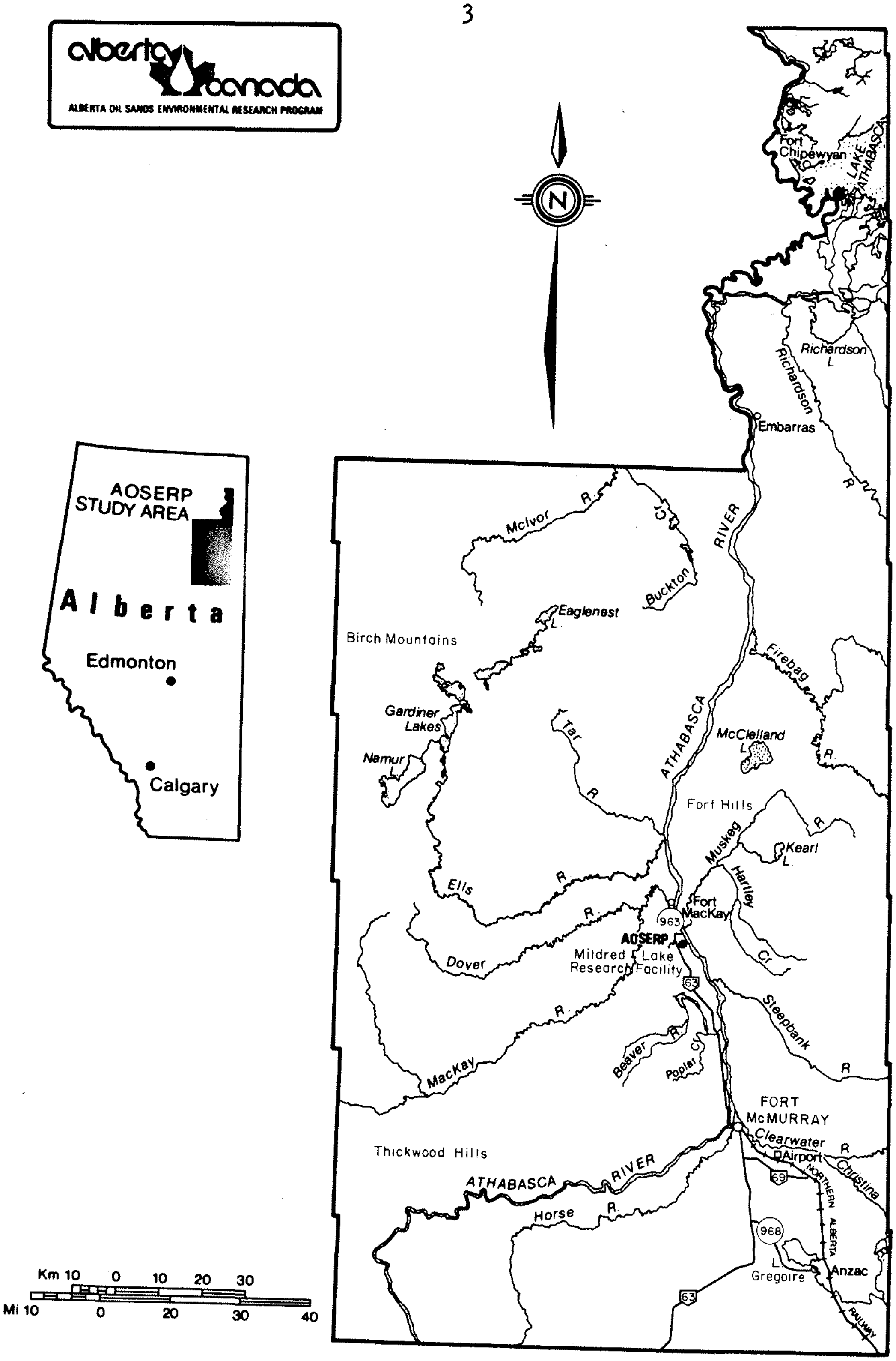

Figure 1. Map of the AOSERP study area.

The collected data on dispersion coefficients were to be related to simultaneous temperature and wind measurements from the tower, to net radiation measurements from the AOSERP Mildred Lake Research Facility and, if possible, to the results of previous aircraft turbulence measurements carried out by INTERA Environmental Consultants Ltd. (Davison et al. 1977) and by the Department of Energy, Mines and Resources (Whaley and Lee 1972). Conclusions were then to be drawn with respect to the feasibility and usefulness of a longer term bivane measurement program.

2.3 RESEARCH SCHEDULE

The development schedule proposed for this project was as follows:

<u>July-August 1976</u>
- Construct rotor system averaging circuit
- Assemble, lab. test, and calibrate equipment
- Install and field test equipment (to coincide with instrumentation of 152 m tower).

<u>September-December 1976</u>
- Operation of equipment at selected times
- data (including tower and radiometer) forwarded weekly to AES Headquarters.

<u>September 1976-January 1977</u>
- Analysis of preliminary results at AES Headquarters and adjustment of experimental methods as required.

<u>February 1977</u>
- Inclusion of AES field bivane study at the AOSERP study area.
- Submission of report on analysis of preliminary data and recommendations on a contract for implementation during 1977.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Purchase of components and fabrication of the system began in August 1976. By late September it was evident that some critical components for the data logger would not be available in time and it was accordingly decided to record data on strip charts. These would be subsequently analysed at AES Headquaters by curve follower.

The equipment was installed in November 1976 and field technical staff instructed in its operation. This operating schedule specified two, one-hour recordings under each of 16 separate meteorological conditions. These conditions are listed in Appendix 6.1.

By the end of January, 12 one-hour records had been acquired. Staff holidays in December and extreme cold, calm weather in January prevented more samples from being collected.

Since the data samples collected in 1976 and subsequent short periods in 1977 were insufficient for valid analysis the project was terminated in June 1977.

During the winter February 1977 field study, bivane data were recorded on a 3 channel chart recorder which was installed in the tower shelter. A continuous record of wind speed and direction fluctuations were recorded.

Due to a malfunction of the bivane equipment, only the last few days of the data were obtained. The first few days were spent in adjusting the bivane. While it is desirable to obtain observations for a longer period, it is felt that the data obtained are sufficient to draw the conclusions described below.

The data collected represents 20 h of observations. A sample of the recorded data is shown in Figure 2. The data were divided into 30 min segments. Non-overlapping 4 s smoothed values of elevation (θ) and azimuth (ϕ) angle were scaled by hand. The travel time of the plume, during this study, usually exceeded 20 s; the standard deviations of azimuth σ_ϕ and elevation σ_θ were obtained by using 5 s mean values.

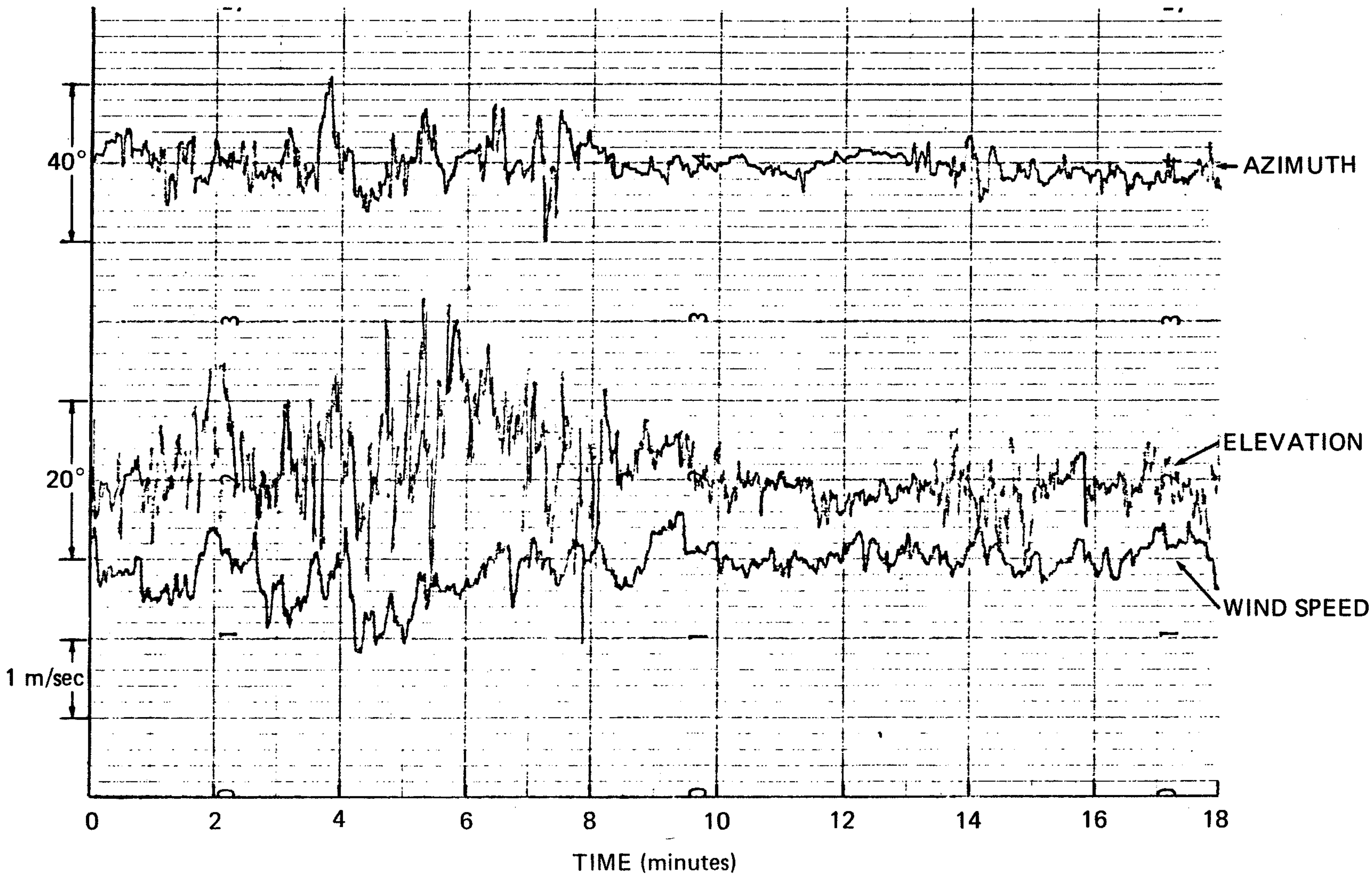

Figure 2. Sample of the bivane record for 18 min periods on 3 February 1977 at the Lower Syncrude Site.

Gifford (1960) and Munn (1964) have indicated that wind direction variances should be computed from running rather than end-to-end means. The bivane readings were then grouped by overlapping pairs, fives, tens, and twenties to yield standard deviations for presmoothing times of 10, 25, 50, and 100 s. Table 1 shows the calculated standard deviations for both the azimuth and elevation angles.

The daily pattern of σ_θ and σ_ϕ was examined and the result is shown in Figures 3 to 6 for 6 and 10 February 1977. In general, σ_θ and σ_ϕ increase with the time of the day. They are at a maximum in the afternoon and fall to a minimum both in the early morning and in the evening.

On 10 February, σ_θ at 1600 (Figure 5) increased to a value greater than 6. A strong destabilization of the atmospheric conditions occurred in the afternoon. A frontal inversion returned during that time as the accluded front passed.

The wind was calm. Measurements by the minisonde indicated that the wind speed was less than 2 $m.s^{-1}$ at the bivane level. One suspects then that the increase in the value of σ_θ at that time was due to the increase in turbulent intensity along the vertical, induced by the local changes in the topography.

In order to examine the effect of changes of wind speed on the magnitude of both σ_θ and σ_ϕ , median values of σ were grouped according to wind speed (Table 2). Although the number of observations is too small to draw firm conclusions, it appears that both σ_θ and σ_ϕ decrease with increasing wind speed for all smoothing times. The increase is more evident with σ_θ than with σ_ϕ. One concludes that an increase in wind speed, which in turn supresses thermal turbulence during the day, decreases wind standard deviation along the vertical.

The bivane data described above were used to determine the dispersion parameters σ_y and σ_z. The basic working theories with regards to determining σ_y and σ_z were discussed by Pasquill

Table 1. Standard deviations of bivane data and running means of 5, 10, 25, 50 and 100 s.

Date	Time	Data	Smoothing Time (Sec)				
			5	10	25	50	100
05/02/77	1030	AZIMUTH	3.59	3.29	2.75	2.25	1.81
05/02/77	1030	ELEVATION	4.66	4.11	3.08	2.38	1.66
05/02/77	1140	AZIMUTH	2.14	2.04	1.79	1.52	1.36
05/02/77	1140	ELEVATION	2.17	1.96	1.58	1.18	0.83
05/02/77	1240	AZIMUTH	2.27	2.17	1.96	1.72	1.44
05/02/77	1240	ELEVATION	2.33	2.02	1.66	1.37	1.02
05/02/77	1615	AZIMUTH	1.76	1.63	1.39	1.19	0.99
05/02/77	1615	ELEVATION	2.53	2.22	1.68	1.30	0.96
06/02/77	0800	AZIMUTH	2.91	2.82	2.63	2.38	1.95
06/02/77	0800	ELEVATION	1.58	1.45	1.25	1.06	0.88
06/02/77	0900	AZIMUTH	2.30	2.24	2.03	1.89	1.61
06/02/77	0900	ELEVATION	1.53	1.49	1.41	1.25	1.16
06/02/77	1000	AZIMUTH	5.81	5.74	5.60	5.48	5.32
06/02/77	1100	AZIMUTH	2.57	2.55	2.47	2.37	2.23
06/02/77	1100	ELEVATION	1.65	1.58	1.49	1.38	1.19
06/02/77	1136	AZIMUTH	8.25	8.11	7.89	7.69	7.38
06/02/77	1300	AZIMUTH	7.91	7.45	6.90	6.36	5.34
06/02/77	1300	ELEVATION	3.19	2.67	2.00	1.53	1.10
06/02/77	1400	AZIMUTH	6.68	6.36	5.76	5.17	4.51
06/02/77	1400	ELEVATION	5.44	4.79	3.75	3.03	2.32
06/02/77	1500	AZIMUTH	4.28	3.97	3.43	2.99	2.34
06/02/77	1500	ELEVATION	4.01	3.28	2.56	1.82	1.34
06/02/77	1600	AZIMUTH	4.63	4.32	3.76	3.27	2.54
06/02/77	1600	ELEVATION	2.78	2.29	1.68	1.29	1.06

continued ...

Table 1. Continued.

Date	Time	Data	Smoothing Time (Sec)				
			5	10	25	50	100
07/02/77	0920	AZIMUTH	3.89	3.77	3.59	3.49	3.41
07/02/77	0920	ELEVATION	1.16	0.95	0.73	0.57	0.46
07/02/77	1020	AZIMUTH	1.46	1.44	1.41	1.38	1.29
07/02/77	1020	ELEVATION	0.48	0.46	0.42	0.38	0.33
07/02/77	1100	AZIMUTH	3.72	3.66	3.57	3.46	3.27
07/02/77	1100	ELEVATION	1.28	1.14	0.95	0.80	0.61
07/02/77	1140	AZIMUTH	3.04	2.94	2.72	2.45	2.10
07/02/77	1140	ELEVATION	1.95	1.85	1.64	1.48	1.20
07/02/77	1300	AZIMUTH	7.52	6.90	5.34	4.24	3.36
07/02/77	1300	ELEVATION	5.32	4.39	2.97	2.31	1.73
07/02/77	1400	AZIMUTH	9.42	8.71	7.20	5.69	4.57
07/02/77	1400	ELEVATION	6.03	5.16	3.67	2.55	1.97
07/02/77	1435	AZIMUTH	7.71	6.87	5.27	3.86	2.62
07/02/77	1435	ELEVATION	5.84	5.06	3.70	2.75	2.19
08/02/77	0800	AZIMUTH	4.37	4.14	3.74	3.46	3.18
08/02/77	0800	ELEVATION	2.88	2.39	1.64	1.29	0.98
08/02/77	1000	AZIMUTH	8.32	8.17	7.88	7.55	7.12
08/02/77	1000	ELEVATION	2.40	1.96	1.44	1.09	0.76
08/02/77	1100	AZIMUTH	12.35	11.95	10.97	10.00	8.97
08/02/77	1100	ELEVATION	6.57	5.85	4.76	3.81	2.75
08/02/77	1200	AZIMUTH	4.82	4.77	4.64	4.35	3.80
08/02/77	1200	ELEVATION	1.29	1.14	0.94	0.80	0.66
08/02/77	1300	AZIMUTH	3.39	3.15	2.84	2.64	2.25
08/02/77	1300	ELEVATION	2.11	1.76	1.35	1.10	0.85
10/02/77	0720	AZIMUTH	5.68	5.31	4.66	4.28	4.04
10/02/77	0720	ELEVATION	3.06	2.59	1.87	1.57	1.38
10/02/77	0800	AZIMUTH	4.79	4.58	4.34	4.17	3.86
10/02/77	0800	ELEVATION	2.38	2.00	1.58	1.33	1.15
10/02/77	0900	AZIMUTH	2.95	2.81	2.56	2.24	1.84
10/02/77	0900	ELEVATION	2.05	1.74	1.36	1.10	0.81

continued ...

Table 1. Concluded.

Date	Time	Data	Smoothing Time (Sec)				
			5	10	25	50	100
10/02/77	1000	AZIMUTH	2.00	1.91	1.74	1.49	1.19
10/02/77	1000	ELEVATION	1.50	1.36	1.21	1.07	0.92
10/02/77	1100	AZIMUTH	5.44	5.34	5.08	4.64	3.87
10/02/77	1100	ELEVATION	4.12	3.96	3.67	3.37	2.98
10/02/77	1200	AZIMUTH	6.52	6.25	5.63	4.66	3.13
10/02/77	1200	ELEVATION	5.57	5.25	4.48	3.73	3.14
10/02/77	1300	AZIMUTH	2.80	2.71	2.52	2.31	1.98
10/02/77	1300	ELEVATION	2.31	2.03	1.57	1.19	0.92
10/02/77	1400	AZIMUTH	4.52	4.36	3.92	3.27	2.53
10/02/77	1400	ELEVATION	4.46	4.11	3.40	2.86	2.30
10/02/77	1500	AZIMUTH	2.27	2.26	2.22	2.15	2.01
10/02/77	1500	ELEVATION	2.78	2.74	2.65	2.55	2.38
10/02/77	1600	AZIMUTH	7.93	7.91	7.84	7.71	7.48
10/02/77	1600	ELEVATION	2.43	2.34	2.13	1.86	1.71
12/02/77	0745	AZIMUTH	4.27	4.20	4.06	3.89	3.68
12/02/77	0745	ELEVATION	3.14	2.88	2.41	2.11	1.86
12/02/77	0810	AZIMUTH	7.38	7.25	6.94	6.63	6.16
12/02/77	0810	ELEVATION	5.21	4.16	3.62	3.29	2.80
12/02/77	0910	AZIMUTH	8.41	8.41	8.39	8.37	8.36
12/02/77	0910	ELEVATION	1.60	1.53	1.40	1.24	1.08

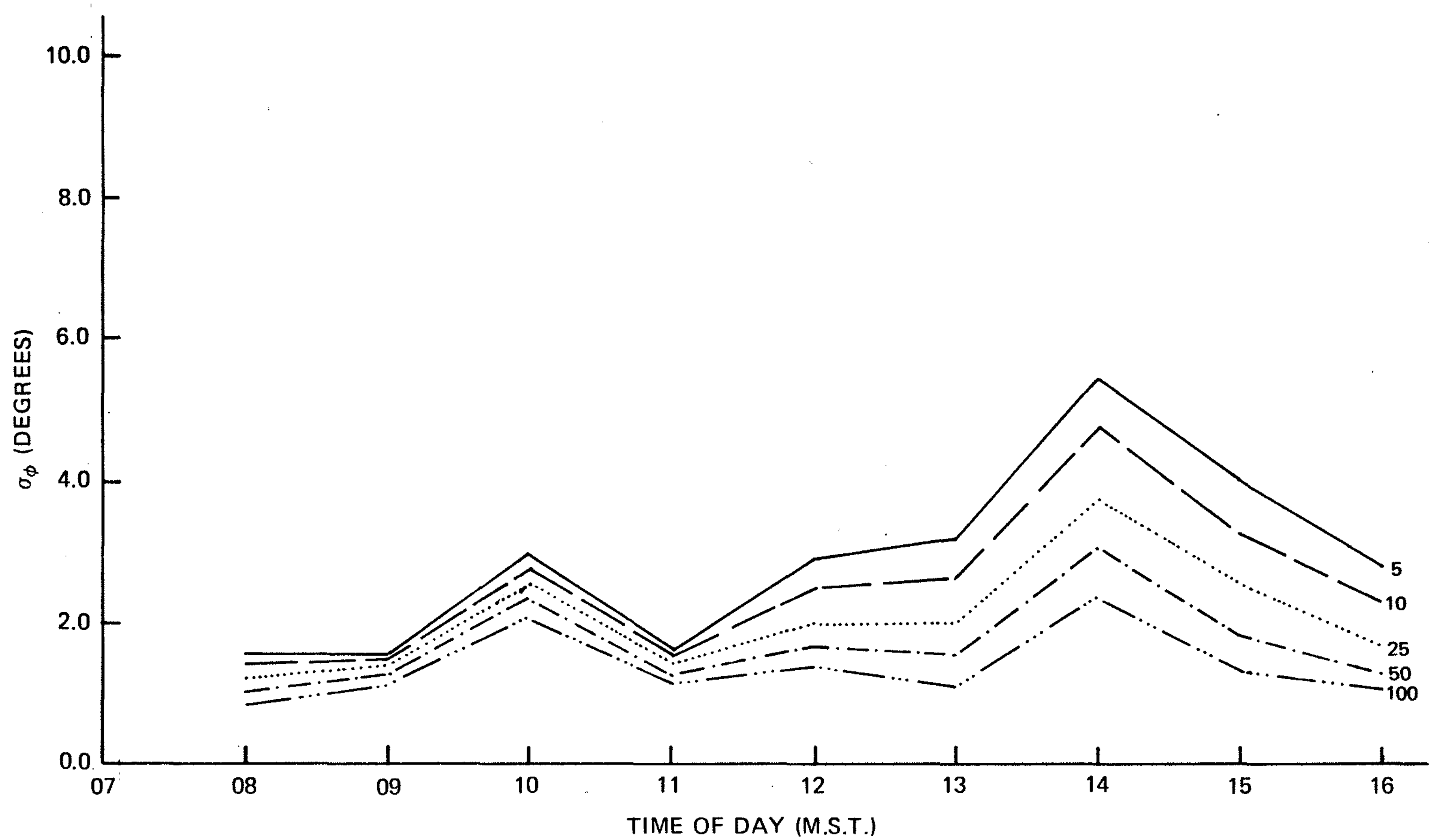

Figure 3. Variations of standard deviation of azimuth angle with the time of day for 6 February 1977.

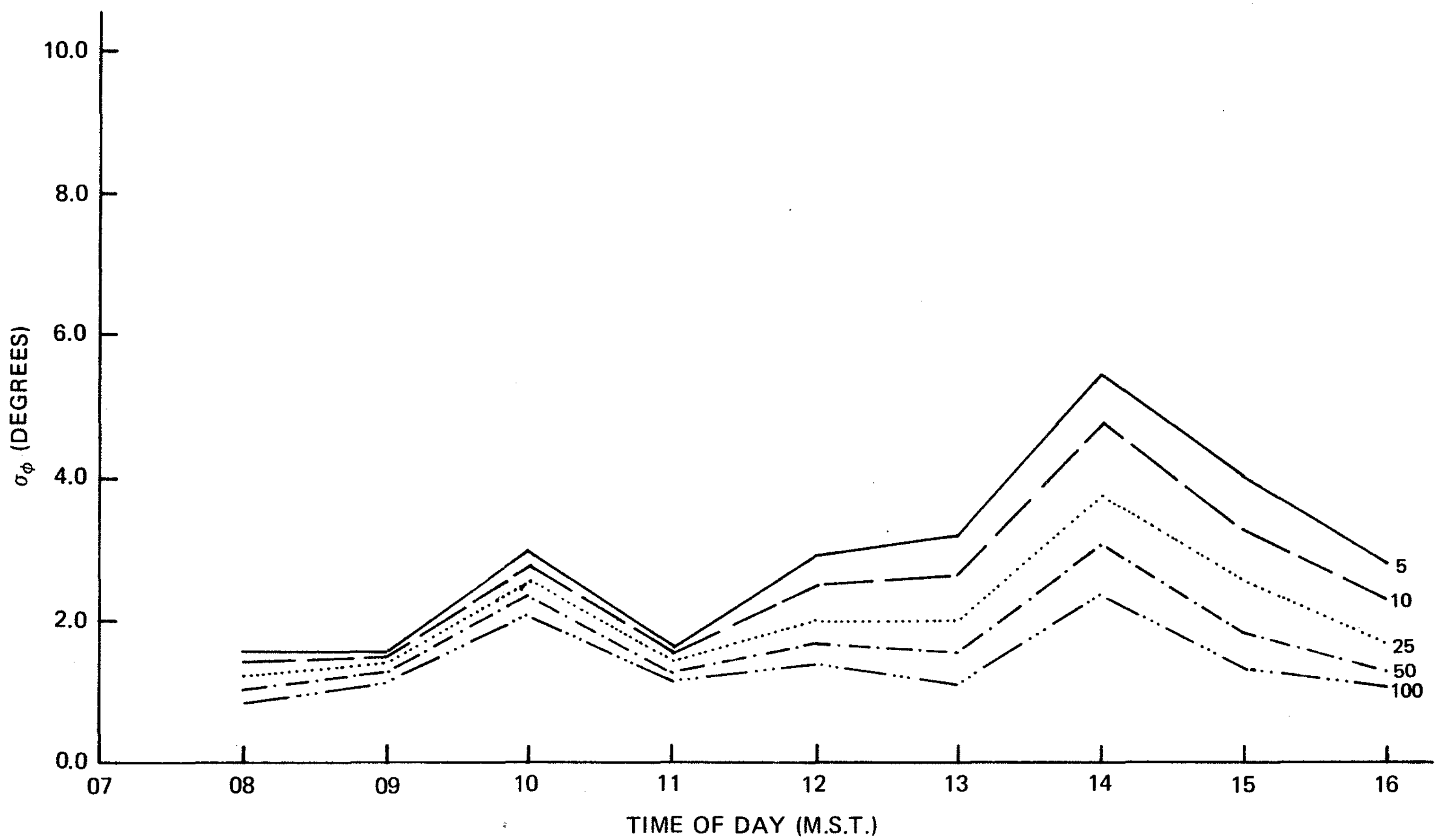

Figure 4. Variations of standard deviation of azimuth angle with the time of day for 6 February 1977.

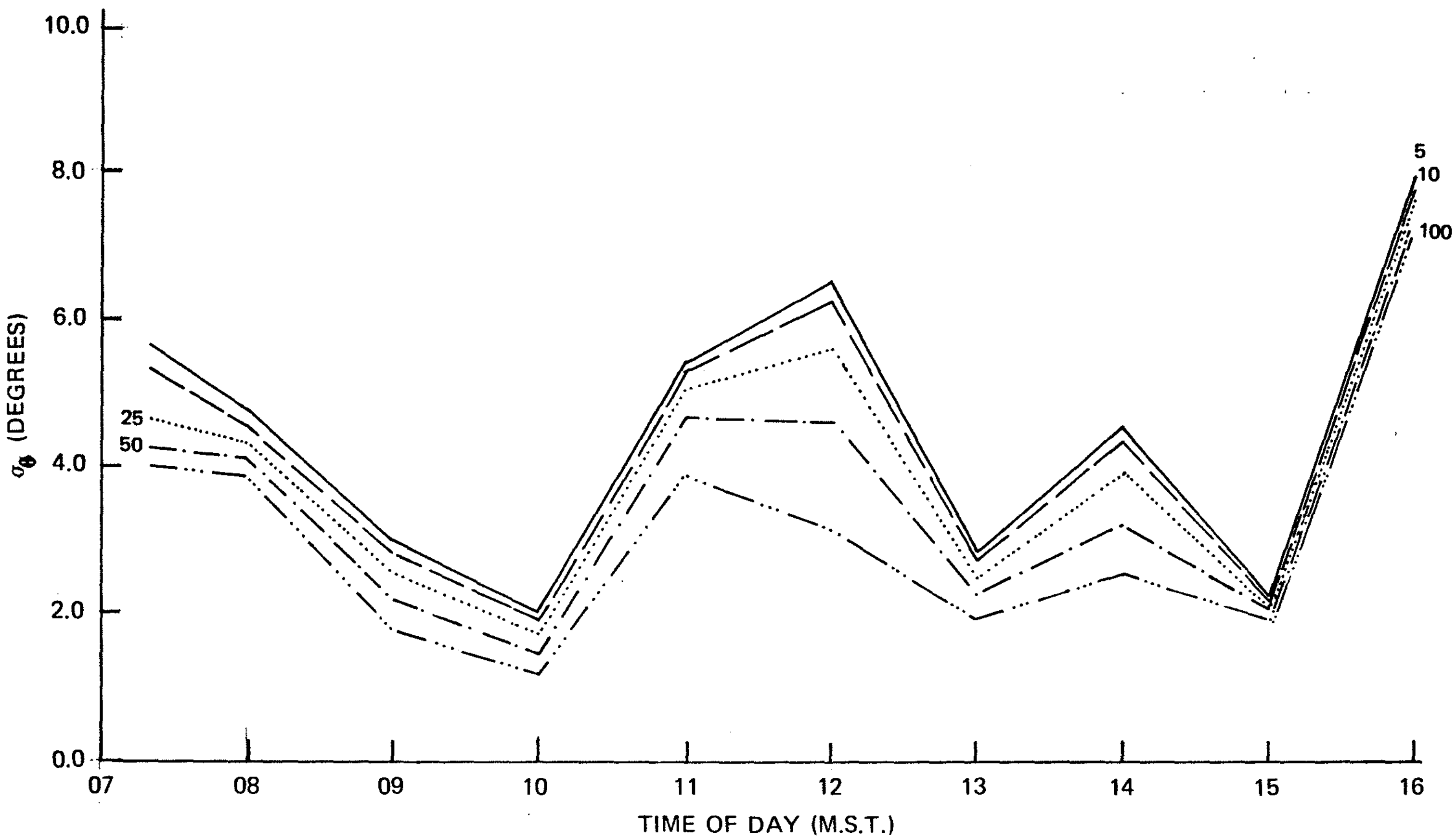

Figure 5. Variation of standard deviation of the elevation angle with the time of day for 10 February 1977.

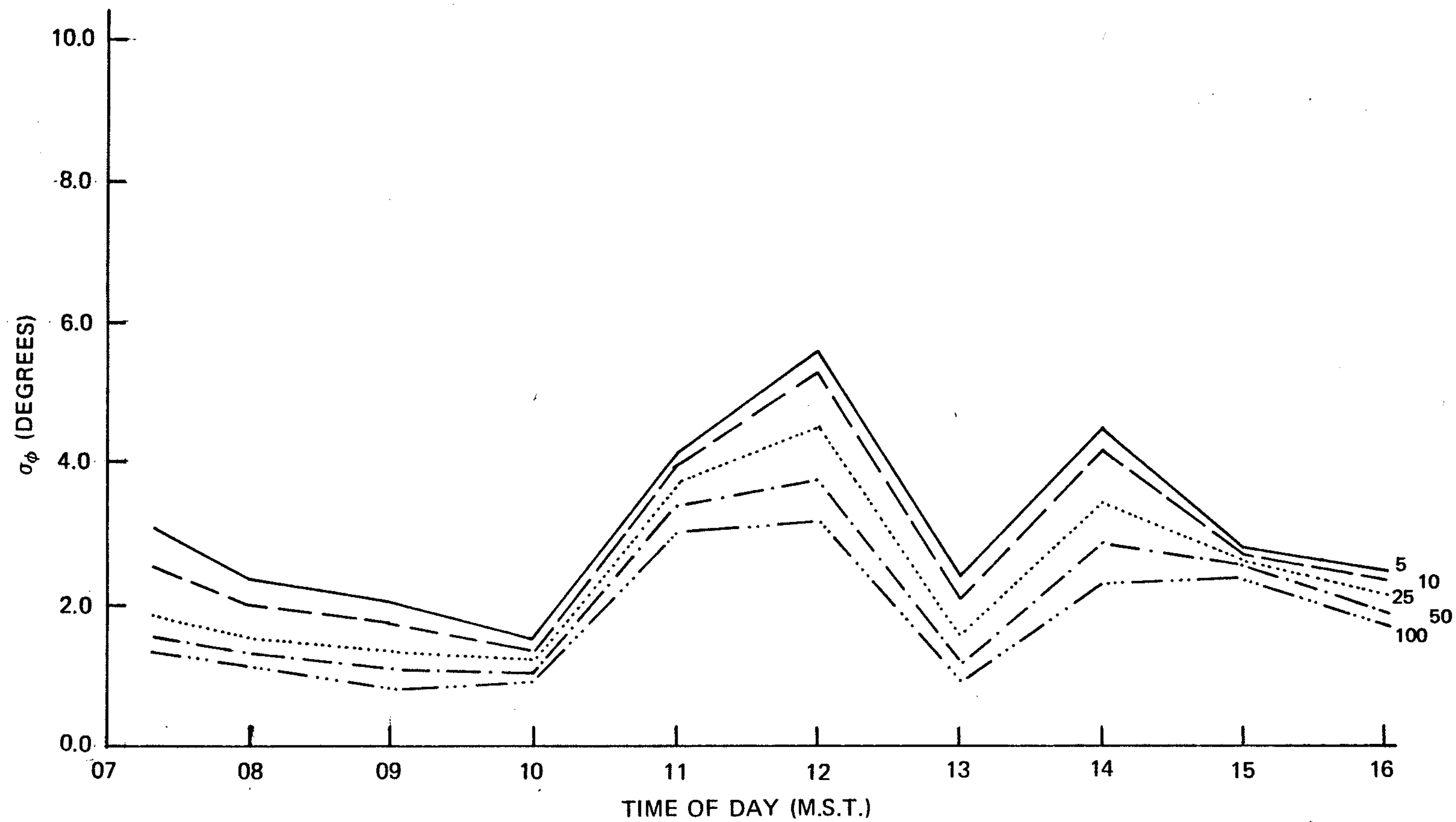

Figure 6. Variation of standard deviation of the azimuth angle with the time of day for 10 February 1977.

Table 2. Median Values of $\sigma\theta$ and $\sigma\phi$ for different wind classes and different smoothing times.

Wind Speed Class ($m\ sec^{-1}$)	Number of Observations	σ_ϕ (Elevation) Smoothing Time (Seconds)					σ_θ (Azimuth) Smoothing Times (Seconds)				
		5	10	25	50	100	5	10	25	50	100
$o \leq u < 2.5$	6	3.62	3.42	3.02	2.70	2.34	7.22	7.08	6.73	6.18	5.30
$2.5 \leq u < 5$	16	2.87	2.42	1.75	1.45	1.17	4.80	4.68	4.49	4.22	3.83
$5 \leq u < 7.5$	15	2.17	1.96	1.64	1.29	1.02	3.39	3.15	2.75	2.45	2.10

(1974, 1975). The parameters σ_y and σ_z have been derived by applying one of the following theories:

1. gradient transfer theory;
2. similarity theory; and
3. statistical theory.

No one of these theories has yet been conclusively demonstrated to be universally applicable. The latter, however, has been applied extensively and offers the most promising solution to determine σ_y and σ_z. This type of analysis is adopted in this report.

It has been suggested that the diffusive spread of a plume from a continuous elevated point source, in a homogeneous field of turbulence, can be predicted by the following relation (Hay and Pasquill 1959):

$$\sigma_y, \sigma_z = \left\{\sigma_{\phi,\theta}\right\}_{\tau, S} x \qquad (1)$$

where x is the downwind distance, τ denotes the sampling time, and S is a running average time over which the data were sampled to obtain Eulerian time wind statistics equivalent to Langrangian statistics. S is given as:

$$S = \frac{x}{\beta \bar{U}} \qquad (2)$$

where $\bar{U}$ is the average wind speed and β is the Lagrangian-Eulerian time scale. Hay and Pasquill (1959) indicated that the value of β ranged from 1.1 to 8.5. Recently, however, Pasquill (1974) suggested that β is related to the turbulent intensity (i) by the following relation:

$$\beta i = \text{Constant} = 0.44 \qquad (3)$$

There is a limit for the averaging time of S that can be applied and this, in turn, depends on the length of the record. In order to examine this relationship, variations of the wind direction variance σ^2_ϕ with S are plotted and are shown in Figure 7. It will

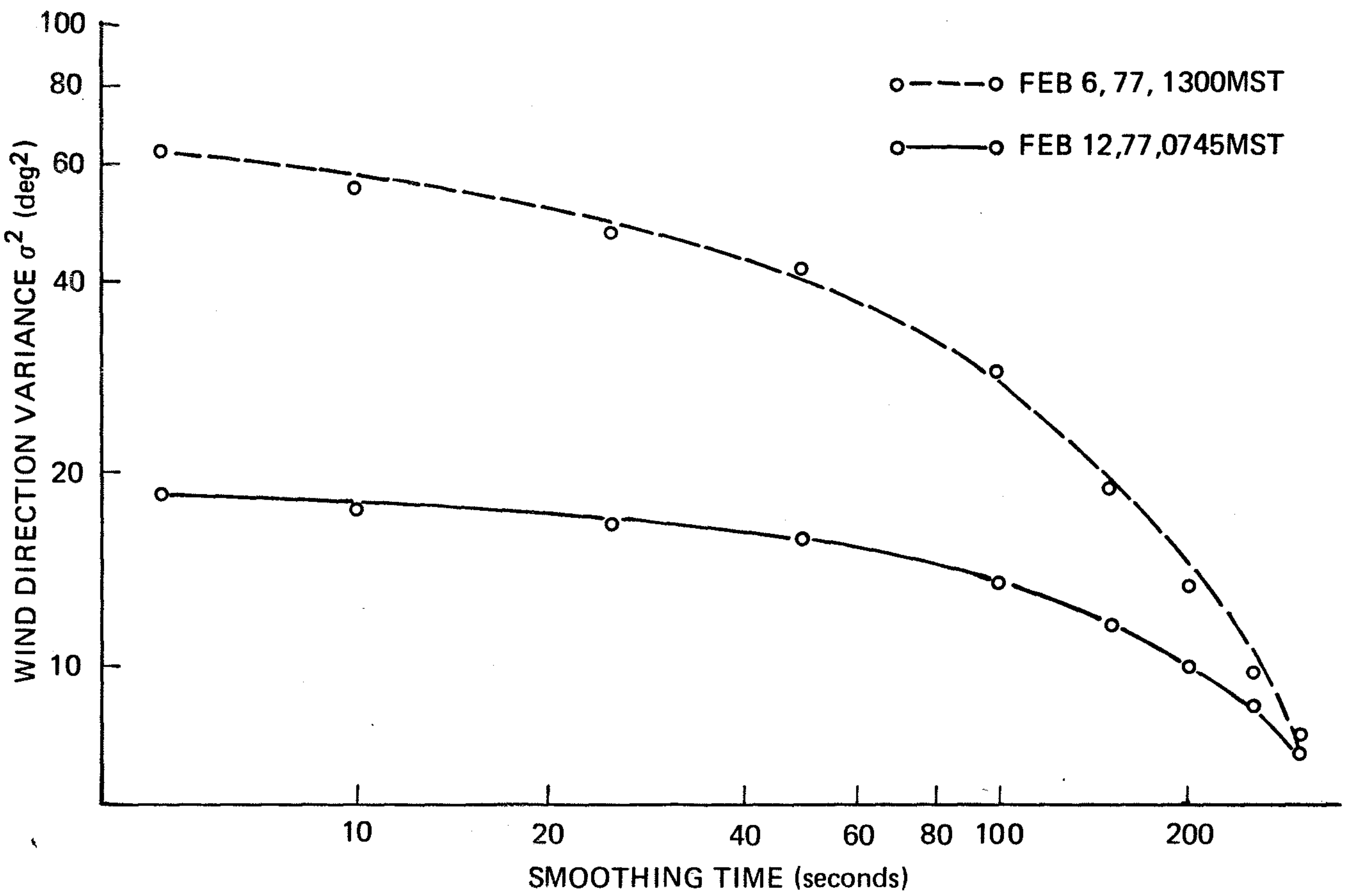

Figure 7. Variation of the wind direction variance with smoothing time for two days.

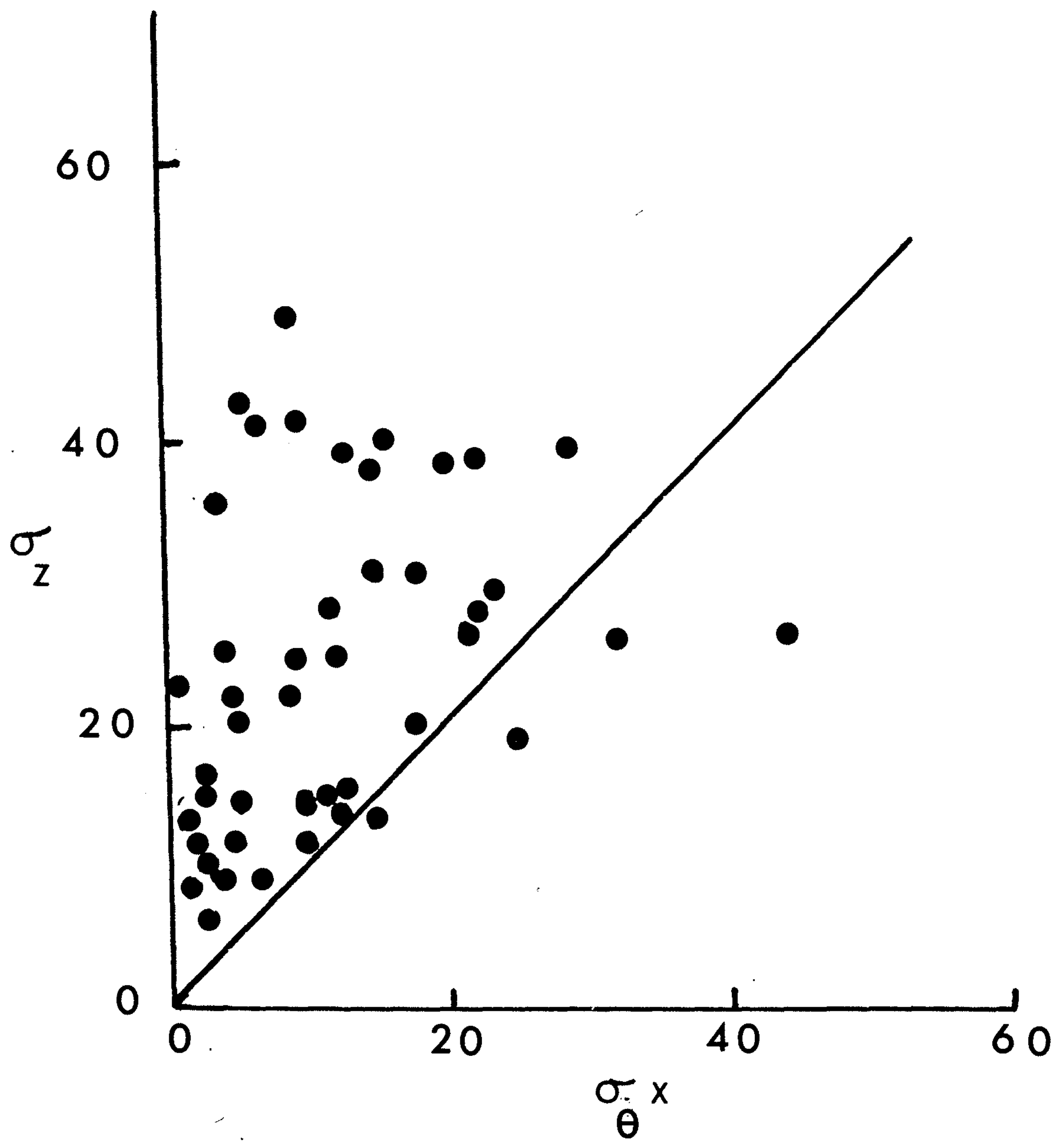

Figure 8. Comparison of predicted versus observed vertical dispersion coefficient using Eq (1). Solid line represents perfect agreement.

be noted that there is a slow decrease of variance from S = 5 to 100 s. For S > 100 the variance decreases rapidly to near zero. This is probably due to the end-of-record effect.

For this study, the averaging time S = 5 s was short enough to allow 20 min record of bivane data to be used.

To examine the applicability of Eq (1) to the AOSERP study area, the standard deviations of wind direction, using a running means as indicated previously, was compared with the observed σ of the plume along the vertical. σ values of σ_z were obtained from plume rise measurements (Section 4). No attempt was made to compare σ_y to this model due to the limited number of observations of σ_y. The result of the comparison is shown in Figure 8. It can be seen by the scatter of the points that Eq (1) underestimates the spread of the plume at various downwind distances.

The disagreement of the observed data with the theoretical model described by Eq (1) could be due to buoyancy induced intial growth of the plume. This in turns indicates that extrapolation of these theoretical models to the AOSERP study area must be done cautiously.

σ_θ is approximately equal to $\sigma_w/\bar{U}$ where σ_w is the standard deviation of the vertical wind. σ_w, in turn, is proportional to the friction velocity. Consequently, σ_θ is strongly dependent on the topography surrounding the bivane tower. It is expected then that sites with different topography will give different values of σ_z. Futhermore, the spectrum of turbulence may differ from one location to another and since the diffusion of the plume depends on this parameter one expects that the bivane data may not describe the plume's σ when the plume is at a different location and level.

4. CONCLUDING REMARKS

It is quite apparent that the objectives of ME 3.8.1 were not attained. This may be due to the absence of a trained field support staff to run an experimental work of this nature. The bivane proved to be too fragile for continuous exposure in that environment. Also because of the possibility of erroneous readings it is desirable to have an instrument technician available during sampling periods.

The chart recorder record proved to be time consuming to abstract. An electronic data logger to be used with the chart recorder would shorten the analysis time.

The results for the February 1977 field study support the feasibility of the bivane approach.

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6. APPENDIX

6.1 AOSERP BIVANE MEASUREMENT PROGRAM

One hour continuous recordings required under each of the following conditions:

(a) Night-time (basically ½ h after sunrise, but in no case to go beyond 1 h after sunrise)

Condition	Cloud Cover	Ceiling (ft.)	Surface Wing Speed (mph)
1	≤ 4/10	-	≤ 3
2	≤ 4/10	-	4-7
3	≤ 4/10	-	> 7
4	> 4/10	>7000	≤ 3
5	> 4/10	>7000	4-7
6	> 4/10	>7000	> 7
7	10/10	<7000	any speed

(b) Day-time (basically 1200 - 1300 MST)

Condition	Cloud Cover	Ceiling (ft.)	Surface Wing Speed (mph)
8	≤ 5/10	-	≤ 3
9	≤ 5/10	-	4-9
10	≤ 5/10	-	> 9
11	> 5/10	<7000	any speed
12	> 5/10	7000 -16000	≤ 3
13	> 5/10	7000 -16000	> 3
14	> 5/10	> 16000	≤ 3
15	> 5/10	> 16000	4-9
16	> 5/10	> 16000	> 9

7. 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"
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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.	HE 2.3	Maximization of Technical Training and Involvement of Area Manpower
23.	AF 1.1.2	Acute Lethality of Mine Depressurization Water on Trout Perch and Rainbow Trout
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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
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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.
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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
47.	TF 1.1.1	A Visibility Bias Model for Aerial Surveys of 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 Data in the AOSERP Study Area
52.	ME 2.3.2	Plume Dispersion Measurements from an Oil Sands Extraction Plant, 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

These reports are not available upon request. For further information about availability and location of depositories, please contact:

Alberta Oil Sands Environmental Research Program
15th Floor, Oxbridge Place
9820 - 106 Street
Edmonton, Alberta T5K 2J6