ENVIRONMENTAL RESEARCH MONOGRAPH 1984-4
A Public Service of
Syncrude Canada Ltd.

A STATISTICALLY DERIVED FORECAST SCHEME FOR WINDS AND TEMPERATURES IN THE ATHABASCA TAR SANDS AREA

D.M. Leahey and M.C. Hansen
Western Research

FOREWORD

Upgrading facilities like Syncrude's are designed in such a way that they can operate within their respective emission guidelines and remain within the ambient air quality standards. However, under certain extreme meteorological conditions, or under plant upsets, ambient air quality standards are not always met. In this situation supplementary emission control might be appropriate because it is designed to maintain air quality standards. It is based on the concept that by reducing emissions shortly before the onset of and during unfavorable meteorological conditions, the ambient air quality standards can be maintained. This makes necessary a predictive scheme which is capable of reliably forecasting, several hours in advance of real time, any impending contraventions of the standards. The development of input parameters to such a scheme is the purpose of the work described in this report.

Syncrude's Environmental Research Monographs are published verbatim from final reports of professional environmental consultants. Only proprietary technical or budget-related information is withheld. Because Syncrude does not necessarily base decisions on just one consultant's opinion, recommendations found in the text should not be construed as commitments to action by Syncrude.

Syncrude Canada Ltd. welcomes public and scientific interest in its environmental activities. Please address any questions or comments to Environmental Affairs, Syncrude Canada Ltd., 10030 - 107 Street, EDMONTON, Alberta, T5J 3E5.

A STATISTICALLY DERIVED FORECAST SCHEME FOR WINDS AND TEMPERATURES IN THE ATHABASCA TAR SANDS AREA

Prepared for:

Syncrude Canada Ltd.

Environmental Affairs Department

Prepared by:

D.M. Leahey

M.C. Hansen

Western Research

Submitted

October 1, 1981

EXECUTIVE SUMMARY

Syncrude Canada Ltd. operates an oil sands extraction plant in the Athabasca Tar Sands region of northeastern Alberta. Although this facility is designed to maintain resulting ground level air quality within the objectives of Alberta Environment, exceedances of these objectives may occur in extreme meteorological conditions. If these conditions were to be predicted in advance, then plant emissions could be adjusted in order to maintain ground level air quality at a desirable level.

The purpose of this study is to develop a forecast scheme, based on analysis of historical, site specific data, which will allow prediction eight hours in advance of real time of those parameters which are required to predict ground level air quality. Specifically, these predictands are: wind speed and direction at stack and plume heights, vertical temperature gradient at stack height, mixing height and horizontal fluctuations of wind direction.

Development of the forecast scheme for predictands relating to wind and temperature employed multiple linear regression analyses. Historical data for these parameters were obtained from analysis of 2 399 pibal observations and 2 289 minisonde observations made near the Syncrude plant site over the years 1975 to 1979 inclusive.

Concurrent data for the predictors used in the regression equations were obtained from the following national, regional and local sources: the 850 mb pressure level wind field prepared by the Canadian Meteorological Centre (CMC), radiosonde temperature profiles obtained at Fort Smith and Stony Plain, upper air wind profiles and hourly surface records from the Fort McMurray airport, winds and the temperatures from the Tall Tower, and finally, surface winds from the towers at Stony Mountain and Mildred Lake.

In this study approximately half the observations of predictands were randomly selected for purposes of deriving forecast equations. They formed the derivation set of data. The remaining data formed the verification set. Regression analyses and evaluations were done using the Statistical Analysis System (SAS) computer program package available from the SAS Institute Inc., P.O. Box 10066, Raleigh, North Carolina 27605.

Regression equations were not derived for wind direction because of the circular nature of the variable. Equations were developed instead for the u component (east-west) and the v component (north-south) of wind velocity at stack and plume heights. The u and v components of velocity can be used to calculate wind direction. Forecasts of winds were evaluated at two plume heights determined by the methods of Briggs and of Djurfors - Netterville. The latter method takes into account windspeed shears with height.

Regression analyses for wind parameters have shown that the most important sources of meteorological data for the forecast scheme were the CMC 850 mb wind analysis, Fort McMurray airport surface data, Mildred Lake winds and time of day and day of year.

Regression equations were tested on the sets of data used for derivation and verification. Values calculated for the squares of the multiple correlation coefficient (R^2) using the derivation set ranged from 0.50 to 0.59. This means that 50 to 59 percent of the total variation of the predictands about their respective mean values was explained by variability in the predictors (i.e. 850 mb winds, Fort McMurray airport winds etc.). Values of R^2 using the verification set of data ranged from 0.33 to 0.55. Standard errors of estimate for wind speeds obtained using the verification data were about 40 percent of mean values. Errors in predicted wind directions were typically about 55 degrees. There appeared to be no difference in forecast ability for winds at the two plume heights.

The forecast scheme for temperature related parameters required derivation of forecast equations for vertical temperature gradient at stack top, conventional mixing height and kink mixing height. Conventional mixing height is the height at which a dry adiabat through the surface temperature intersects the temperature profile. Kink mixing height is the height at which the rate of change of temperature with height is maximum.

Regression analyses for vertical temperature gradient have shown that the most significant sources of data are the time of day, day of year and the Fort McMurray Airport surface record. Values of R^2 calculated using an equation based on these sources for the derivation and verification sets of data were 0.29 and 0.27 respectively. The standard error of estimate obtained using the verification data was about 300 percent of the mean observed vertical temperature gradient.

Regression analyses for mixing heights were performed using data for 1400, 1500 and 1600 hours only. These times were determined by the availability of the first daily radiosonde information and the 8 hour forecast time. The most important sources of meteorological data were the time of day, day of year, Fort McMurray airport surface observations and radiosonde temperature profiles from Fort Smith and Stony Plain. Temperature gradients between the 90 and 152 m levels of the Tall Tower were also important, but were not included in the final analysis because the Tall Tower is no longer in operation.

Values of R^2 calculated using the forecast equation for conventional mixing height based on the above sources for the derivation and verification data were 0.30 and 0.20 respectively. Values for the kink mixing height were 0.29 and -0.16 respectively. Standard errors of estimate obtained using the verification data were 63 and 72 percent of the mean observed conventional and kink mixing depths, respectively.

Development of the forecast scheme for horizontal fluctuations of wind direction was based on a less sophisticated approach than the one taken for wind and temperature parameters. Wind fluctuation data from the 152 m level of the Tall Tower for the months of January, April, July and October for the years 1977, 1978 and 1979 were analyzed according to atmospheric stability, windspeed and season of the year. Horizontal wind direction fluctuations were found to depend on season, windspeed class (greater than or less than 10 km hr^{-1}) and atmospheric stability (stable, neutral or unstable). Forecast information relating to atmospheric stability and windspeed can be used to give an indication of horizontal wind direction fluctuation.

TABLE OF CONTENTS

PAGE

TABLE OF CONTENTS.. viii

LIST OF TABLES... xi

LIST OF FIGURES.. xii

LIST OF APPENDICES....................................... xiii

INTRODUCTION... 1
OBJECTIVES... 1
BACKGROUND... 1

METHODS.. 5
FORECAST SCHEME.. 5
  Theory... 5
PREDICTANDS.. 6
  Wind at Plume Height................................... 7
  Vertical Potential Temperature Gradient at Stack Top..... 8
  Height of Mixing Layer................................. 11
  Standard Deviation of Horizontal Wind Fluctuations....... 12
  Summary.. 14
PREDICTORS FOR WIND AND TEMPERATURE...................... 15
  Local Meteorological Data.............................. 15
  Regional Wind and Temperature Data..................... 16
  Time Parameters.. 17
  Overview of Predictors Relating to Wind and Temperature.. 18
  Forecast Equations..................................... 18
  Forecast Scheme for Wind Predictands................... 24
  Forecast Scheme for Temperature Predictands............. 39
FORECAST SCHEME FOR HORIZONTAL WIND DIRECTION FLUCTUATIONS. 48

DISCUSSION... 55
WIND FORECAST SCHEME..................................... 55
TEMPERATURE FORECAST SCHEME.............................. 56
WIND DIRECTION FLUCTUATION FORECAST SCHEME................ 56
CONCLUDING REMARKS....................................... 57

REFERENCES CITED... 59

LIST OF TABLES

TABLE		PAGE
1	Data used in the forecast scheme as initial predictors of wind speed	21
2	Data used in the forecast scheme as initial predictors of wind direction components	22
3	Data used in the forecast scheme as initial predictors of temperature gradient and mixing depths	23
4	Sources of meteorological data used as initial predictors of wind parameters	25
5	Equation for estimating windspeed at stack height	28
6	Equation for estimating u-component of wind velocity at stack height	29
7	Equation for estimating v-component of wind velocity at stack height	30
8	Equation for estimating windspeed at plume height by the Briggs formulation	31
9	Equation for estimating u-component of wind velocity at plume height by the Briggs formulation	32
10	Equation for estimating v-component of wind velocity at plume height by the Briggs formulation	33
11	Equation for estimating windspeed at plume height by the Djurfors-Netterville formulation	34
12	Equation for estimating u-component of wind velocity at plume height by the Djurfors-Netterville formulation	35
13	Equation for estimating v-component of wind velocity at plume height by Djurfors-Netterville formulation	36
14	Squares of the multiple correlation coefficient (R^2) for wind predictands using both derivation and verification data	37

		PAGE
15	Comparison between predicted and observed wind speeds and direction..................................	38
16	Sources of meteorological data used as initial predictors of temperature parameters in each test case...	40
17	Summary statistics of regression analyses for predictands relating to temperature.................	41
18	Equation for estimating temperature gradient (in °C/m) at stack height...........................	43
19	Equation for estimating mixing depth by the conventional method................................	44
19	Equation for estimating mixing depth by the kink method..	45
20	Squares of multiple correlation coefficient (R^2) for temperature predictands using both dependent and independent data...............................	45
21	Seasonal median values of σ_θ (degrees) for wind speed and stability classes. The number of data (N) on which each median is based are shown................	46
22	Comparison between predicted and observed temperature predictands...	47
23	Median values of σ_θ (degrees) for specified season, wind speed and stability classes. The number of data (N) on which each median is based are shown.........	51
24	Estimated seasonal median values of σ_θ (degrees) for air flow in the Athabasca Oil Sands area............	52
25	Standard deviation of horizontal wind fluctuations, σ_θ, (degrees) associated with Pasquill stability categories..	53
26	Key to Pasquill stability categories................	53
27	Constants used in plume rise calculations...........	63
28	Components of the alphanumeric code for designation of predictands and predictors......................	76
29	Alphanumeric codes used for designating wind and temperature predictands............................	77
30	Alphanumeric codes used for designating wind and temperature predictors.............................	78

		PAGE
31	Key for statistics used in following tables..........	93
32	Statistics for windspeed at stack height.............	94
33	Statistics for u component of wind velocity at stack height..	94
34	Statistics for v-component of wind velocity at stack height..	95
35	Statistics for windspeed at plume height by Briggs...	95
36	Statistics for u-component of wind velocity at plume height by Briggs..............................	96
37	Statistics for v-component of wind velocity at plume height by Briggs..............................	96
38	Statistics for windspeed at plume height by Djurfors-Netterville..	97
39	Statistics for u-component of wind velocity at plume height by Djurfors-Netterville................	97
40	Statistics for v-component of wind velocity at plume height by Djurfors-Netterville................	98
41	Statistics for temperature gradient at stack height (183 to 283 m).....................................	103
42	Statistics for conventional mixing height............	104
43	Statistics for kink mixing height...................	104

LIST OF FIGURES

FIGURE		PAGE
1	Location of meteorological sites in the vicinity of the Syncrude oil sands plant, and the nearest radiosonde stations	2
2	Distribution according to time of year for pilot observations from which wind predictands were derived	9
3	Distribution according to hour of day for pilot balloon observations from which wind predictands were derived	10
4	Distribution according to time of year for minisonde observations from which mixing depth predictands were derived	13
5	Frequency of occurrence for predictands and predictors used in deriving forecast schemes for wind and temperature parameters	19
6	Cumulative frequency of occurrence of σ_θ in unstable atmospheres during summer as a function of windspeed classification	50
7	Data management system for regression analysis procedure	66
8	Product-moment correlation coefficients, r, between wind and temperature predictors	85
9	Product-moment correlation coefficients, r, between wind and temperature predictands and predictors	87
10	Predictors included in final regression equation for winds at stack height	99
11	Predictors included in final regression equation for winds at Briggs plume height	100
12	Predictors included in final regression equation for winds at Djurfors-Netterville plume height	101
13	Predictors included in a final regression equation for temperature predictands	105

LIST OF APPENDICES

APPENDIX		PAGE
I	Plume Rise Formulas Given by Briggs & Djurfors-Netterville..............................	61
II	Data Management for Wind and Temperature Predictands and Predictors.......................	65
III	Alphanumeric Code for Designating Predictors and Predictands.................................	75
IV	Tests for Linear Dependence Between Predictors and Predictands Relating to Wind and Temperature..	81
V	Evaluation of Goodness and Significance of Regression Equations..............................	89
VI	Forecast Development for Wind Predictands - Statistics and Selected Predictors for Test Cases.	93
VII	Forecast Scheme Development for Temperature Predictands - Statistics and Selected Predictors for Test Cases........................	103

ABSTRACT

A forecast scheme has been developed for predicting 8 hours in advance of real time the observed wind and temperature fields at the Syncrude Canada Ltd. Athabasca Tar Sands extraction plant in northeastern Alberta. Such a scheme could allow for the maintenance of ground level air quality within desirable limits by controlling plant operation and resulting stack emissions according to the forecasted dispersion potential of the local atmosphere.

Multiple linear regression techniques were used to derive forecast relations between site specific wind and temperature predictands obtained from 2 289 minisonde and 2 399 pibal observations over the years 1975 to 1979 inclusive, and concurrent predictors from national regional and local sources of meteorological data.

Approximately half of the 2 471 wind and temperature predictand observations were randomly selected to derive forecast equations. Values for the multiple correlation coefficients squared (R^2) for wind and temperature regression equations were about 0.55 and 0.29 respectively. Testing of the equations with the remaining portion of observations gave R^2 values for wind and temperature predictands of about 0.48 and 0.10 respectively.

Site specific data for horizontal fluctuations of wind direction from atop a 152 m meteorological tower over the years 1977 to 1979 inclusive, were analyzed according to season, windspeed and atmospheric stability. Horizontal wind direction fluctuations were found to be a function of season, windspeed class and atmospheric stability.

INTRODUCTION

OBJECTIVES

This report presents information on the development and evaluation of a planetary boundary layer modelling scheme for the Athabasca Tar Sands Area in northeastern Alberta. The project was undertaken by Western Research for Syncrude Canada Ltd. The objectives were to:

(1) Develop a forecast scheme, based on statistical evaluation of historical data, for predicting observed wind and temperature fields eight hours in advance of real time, using data from national, regional and local weather stations and monitoring networks.

(2) Develop a computer code for the above scheme, complete with appropriate documentation.

(3) Test the performance of the above scheme against observed independent data.

BACKGROUND

Syncrude Canada Ltd. operates an oil sands extraction plant located about 50 km north of Fort McMurray (Figure 1). It may emit up to 292 tonnes per day of sulphur dioxide from a 183 m high main stack.

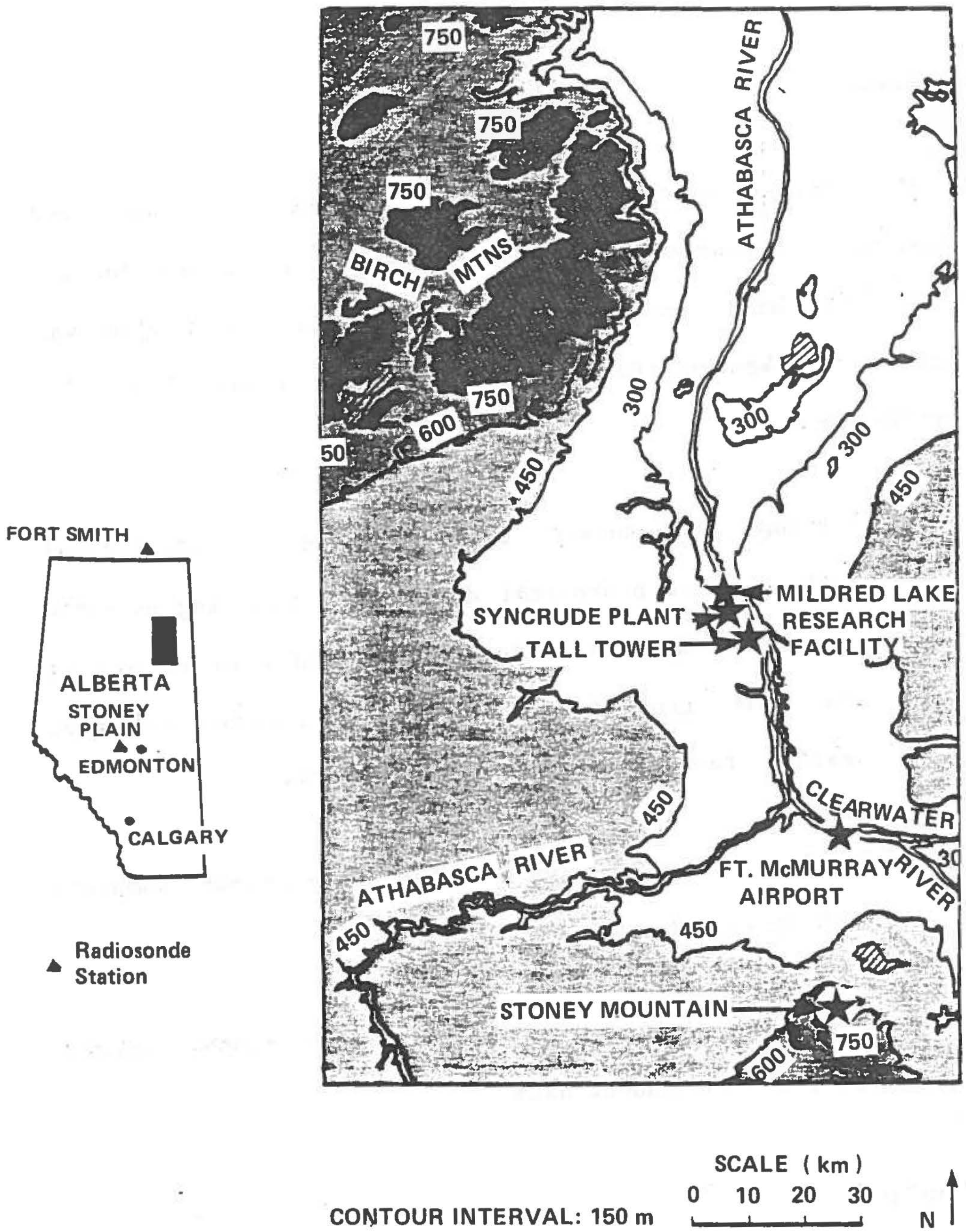


Figure 1. Locations of meteorological sites in the vicinity of the Syncrude oil sands plant, and the nearest radiosonde stations.

This stack is designed such that ground-level air quality will remain within the ambient objectives under most meteorological conditions. During some situations, for example those relating to fumigation, plume trapping, or high winds, concentrations of ground-level sulphur dioxide may exceed the air quality objectives.

To attain a zero exceedance policy, an air quality prediction scheme must be used. Such a scheme would require accurate forecasts of meteorological variables some eight hours in advance of real time in order that required changes in plant procedures be implemented. Specific meteorological parameters needed for an air quality modelling scheme are: wind speed and direction at plume height, vertical temperature gradient at stack height, mixing layer height and turbulence levels. Information specific to the oil sands area for these parameters is available from minisonde and pilot balloon data obtained from 1975 to 1979, and from meteorological tower data.

The Canadian Atmospheric Environment Service (AES) issues forecasts of wind and temperature that tend to be regional rather than site specific due to the relative coarse grid spacing associated with their forecast model. For this reason, AES forecasts cannot usually be accurately applied to a specific site.

This is true of the Athabasca Oil Sands area near Fort McMurray where terrain effects appreciably influence the wind field. AES forecasts may be adjusted by statistical means to make them more specific to the oil sands area. This may be done by establishing a statistical relationship between forecast model outputs and meteorological parameters measured within the area of Fort McMurray.

Two methods can be used to develop and test statistical relationships between a desired predictand and a number of predictor variables from a numerical model. The difference between the two methods lies in the nature of predictor data used in the development phase. One method, called model output statistics (MOS), uses as predictors values from a numerical model applicable at a required time. The other method, called the perfect prog method, uses actual observed values at the required time. Both methods utilize predicted numerical model parameters during the forecast phase.

Ideally, the MOS method could be used in developing a forecast scheme between the desired predictand and a number of predictor variables. Unfortunately, predicted meteorological parameters are not available from AES for the period over which minisonde and pibal data from the oil sands region are available. Therefore, the perfect prog method has been adopted for the forecast scheme.

METHODS

FORECAST SCHEME

Theory

Multiple linear regression was used to relate one variable, Y, called the dependent variable or predictand, to k other variables, X_i, called the independent variables or predictors. The result is an equation which can be used for estimating the predictand as a linear combination of the predictors:

$$\hat{Y} = A_o + A_1 X_1 + A_2 X_2 + \ldots\ldots + A_k X_k \qquad (1)$$

The carat indicates an estimate and the A_i's are the regression constant and coefficients. They are determined such that the sum of the squares of the estimation errors, Q, is a minimum on the developmental samples of size n. That is:

$$Q = \sum_{j=1}^{n} (y_j - \hat{y}_j)^2 = \text{minimum} \qquad (2)$$

There are several methods for screening predictors to include in a regression equation. The one adopted for development of the forecast scheme is called the forward stepwise method.

The first step in the procedure is to select the variable which correlates most highly (in either a positive or negative sense) with the predictand. This is the variable which explains a greater fraction of the predictand variance than any other of those available. The next step is to select the variable which, together with the first, reduces the residual variance the most. Selection can continue in this way until some special cutoff criterion is met. Usually, the cutoff criterion is some function of the reduction of residual variance afforded by the next best predictor. A discussion of the screening technique and the necessary matrix operations is given by Efroymson (1960).

PREDICTANDS

Some meteorological parameters required for an air quality prediction scheme, specifically the mathematical and physical components, are:

(1) wind speeds at stack and plume heights
(2) wind directions at stack and plume heights
(3) vertical temperature gradients at stack height
(4) height of mixing layer
(5) standard deviation of horizontal wind fluctuations

Forecast schemes for the first four predictands were developed using the perfect prog statistical approach. A forecast procedure for the standard deviations of horizontal wind fluctuations was developed using a less sophisticated approach.

Wind at Plume Height

Wind speed and direction may be used to estimate plume rise, determine plume position, indicate turbulence levels of the atmosphere and hence estimate ground level pollutant concentrations.

In order to derive predictands relating to wind speed and direction at plume height, it is first necessary to know the plume height. Plume height is the sum of the physical stack height and the plume rise. Plume rise was determined with formulations developed by Briggs (1971, 1975), and by Djurfors-Netterville (1978). They are similar except the Djurfors-Netterville formulations take into account wind speed shears. Details of the plume rise equations are given in Appendix I.

Regression of wind direction posed a problem because of the circular nature of the variable. It was decided to examine separately the east-west (u-component) and the north-south component (v-component) of wind velocity. Since the mean square of each component is minimized by the regressions, the mean square vector error is also minimized.

Thus, three parameters were used for estimating wind velocity. These are wind speed and the u and v components of velocity. The u and v components can be used to calculate wind direction. Since predictands relating to wind speed and direction are required at three levels (stack height and plume heights according to Briggs and Djurfors-Netterville), there were a total of nine equations for wind parameters.

Predictands related to wind were obtained from 2 352 pilot balloon observations made in the vicinity of the Syncrude oil sands extraction plant during the years 1975 to 1978 inclusive. The annual distribution of these observations is shown in Figure 2. There were relatively few observations in December and from mid April to mid June. The distribution of pibal observations according to hour of the day is shown in Figure 3. All data were collected during day light hours. Most of the observations were made from 4 to 17 hours.

Vertical Potential Temperature Gradient at Stack Top

Vertical temperature gradients are required to determine atmospheric stability for plume rise considerations and to calculate the Brunt-Vaisalla frequency in stable conditions. They may also be used to estimate mixing heights.

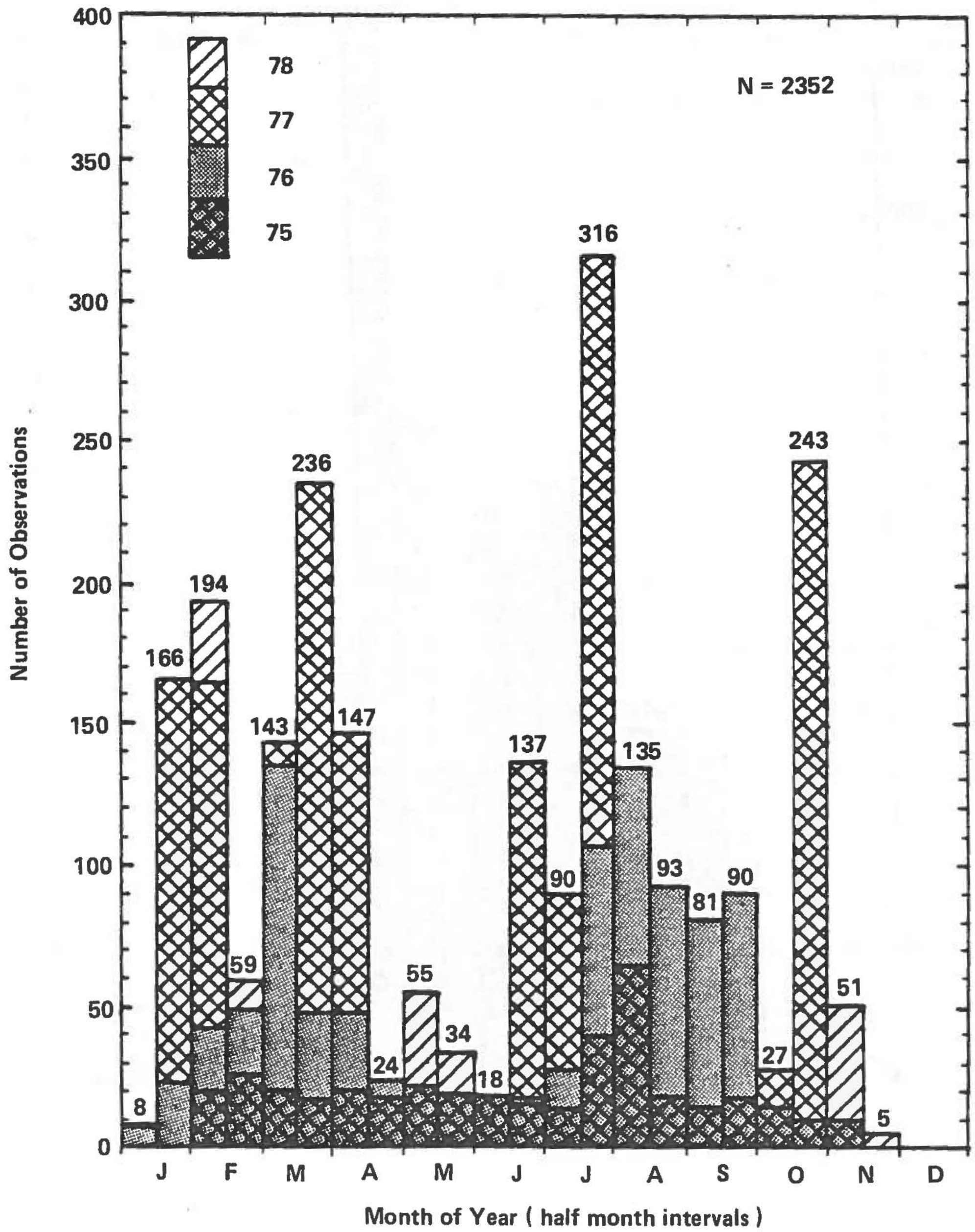


Figure 2. Distribution according to time of year for pilot balloon observations from which wind predictands were derived.

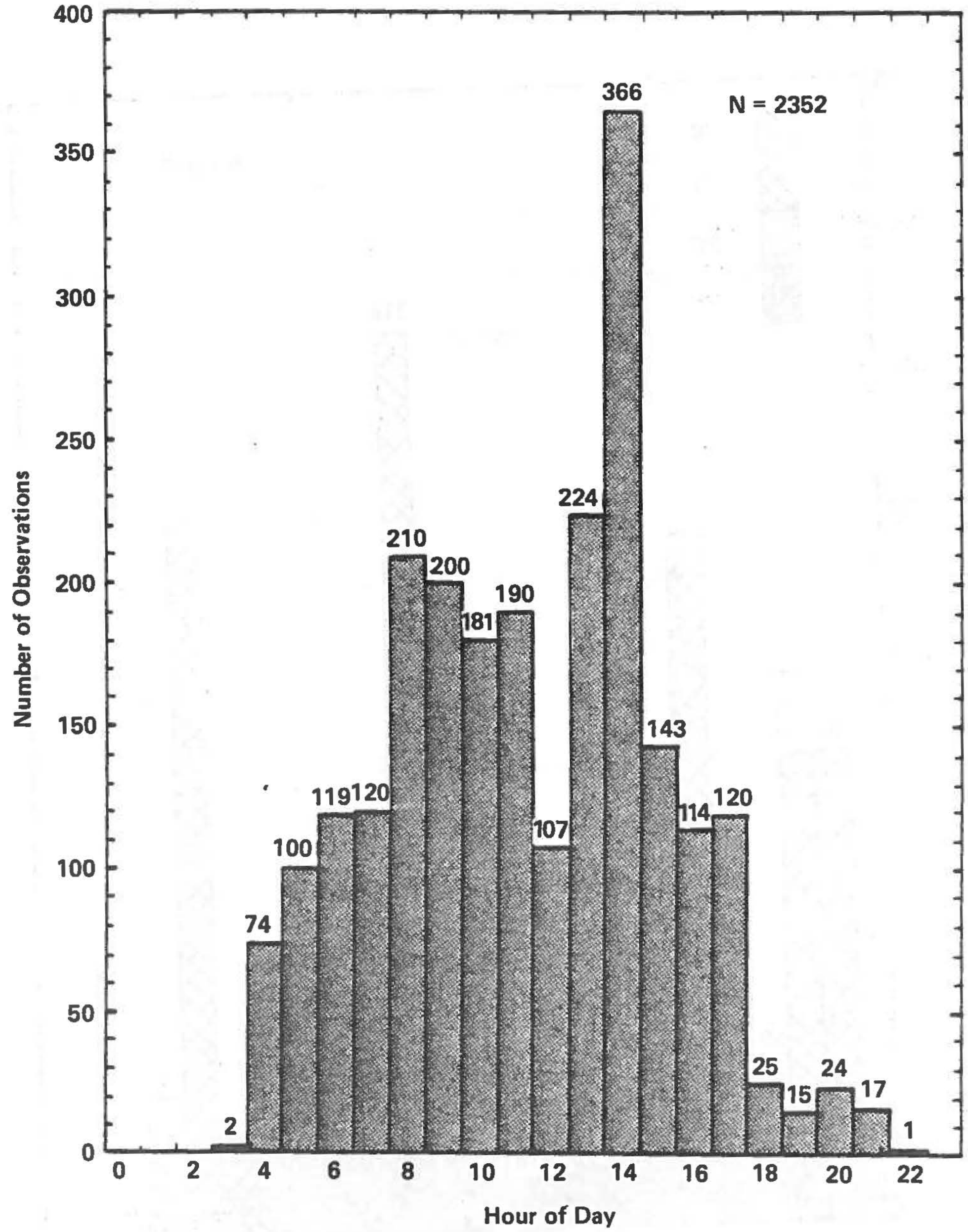


Figure 3. Distribution according to hour of day for pilot balloon observations from which wind predictands were derived.

Temperature gradients for use in developing a forecast scheme were obtained as the average temperature difference over the hundred meters extending from stack top to 283 m. The necessary information was available from 2 289 minisonde observations which were generally made at the same time as the pibal measurements. Occasionally minisonde data were missing but temperatures were available from the 90 and 152 m levels of the Tall Tower. Under these circumstances the Tall Tower data were used to estimate temperature gradients.

Height of Mixing Layer

The height and variability of the mixing layer is important in the assessment of fumigation and plume trapping situations. There are two different methods for estimating the mixing height: the conventional method and the kink method.

In the conventional method, the mixing height is the height above ground at which the dry adiabat through the surface temperature intersects the temperature profile. In the kink method, the mixing height is the first point at which the rate of change of potential temperature with height is maximum (Kumar 1979).

Data for mixing depths evaluated by both the conventional and the kink methods were obtained from the 2 289 minisonde observations made near the Syncrude oil sands extraction plant.

The forecast scheme will provide estimated values of mixing depths eight hours in advance of real time. Predictor variables will be derived from radiosonde data. The first radiosonde information for the day is obtained at 0500 MST (1200 GMT) and is generally not available until 0600. Therefore, the earliest time for which an eight-hour forecast can be made is 1400. In consequence, mixing depths were evaluated from the minisonde observations only for the hours 1400, 1500 and 1600. During non winter seasons when the conventional mixing depth may exceed 800 m, its value was taken as the average seasonal maximum value given by Portelli (1977). These values are 1 240, 1 730 and 870 m for spring, summer and autumn, respectively.

Of the 2 289 minisonde observations, 471 were analyzed for mixing depths. A distribution of these observations as a function of time of year is shown in Figure 4. Most of the observations were made during the winter and early spring.

Standard Deviation of Horizontal Wind Fluctuations

Horizontal plume dispersion is related to horizontal fluctuations in wind direction. Greater fluctuations are associated with greater plume dispersion. As horizontal plume dispersion increases, ground-level concentrations of plume constituents decrease.

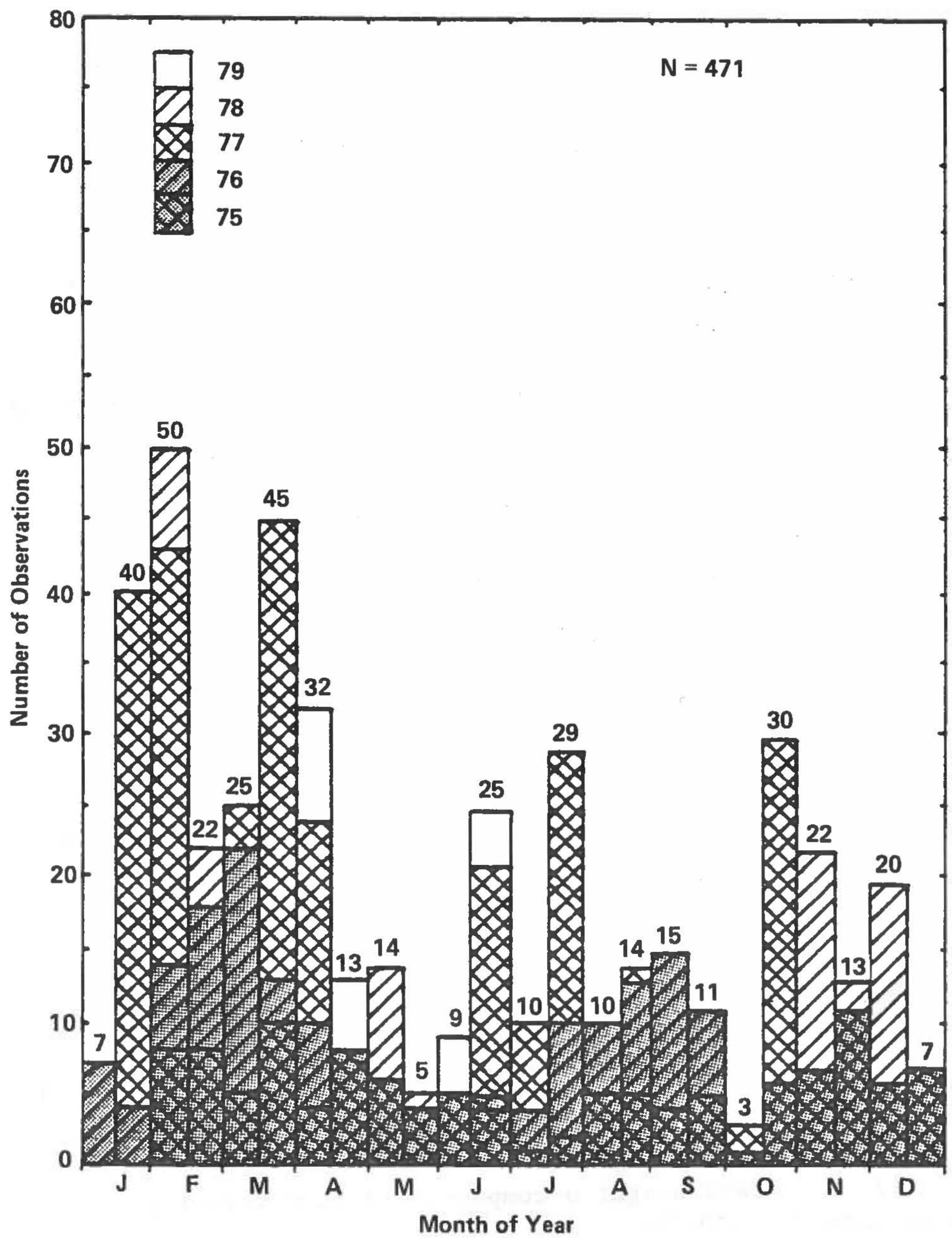


Figure 4. Distribution according to time of year for minisonde observations from which mixing depth predictands were derived.

Wind fluctuation data were obtained from the Tall Tower, a 152 m high meteorological tower located in the Athabasca River valley, near the Syncrude oil sands extraction plant. Hourly information relating to wind direction ranges was abstracted for representative seasonal months (January, April, July, October) for the years 1977, 1978 and 1979. These ranges were divided by six to approximate standard deviations of the horizontal wind fluctuations, σ_θ. This approximation has been tested for horizontal standard deviations by Markee (1963). It is based upon the assumption that the distribution of wind directions within the observed range is normal. If such is the case, then 6 σ_θ should represent about 99 percent of the observations within the range.

Summary

A list of the predictands for which forecast techniques were developed is given below:

(1) stack height wind speed

(2) plume height (Briggs) wind speed

(3) plume height (Djurfors-Netterville) wind speed

(4) stack height u-component of wind velocity

(5) stack height v-component of wind velocity

(6) plume height (Briggs) u-component of wind velocity

(7) plume height (Briggs) v-component of wind velocity

(8) plume height (Djurfors-Netterville) u-component of wind velocity

(9) plume height (Djurfors-Netterville) v-component of wind velocity

(10) temperature gradient in the vicinty of stack top (183 to 283 m)

(11) conventional mixing depth

(12) kink mixing depth

(13) standard deviation of horizontal wind fluctuations

PREDICTORS FOR WIND AND TEMPERATURE

There are a wide variety of possible predictors which might be employed in a forecast scheme. These include both observed and forecast local and regional data as well as time of day and day of year. Locations from which data may be obtained have been shown in Figure 1.

Local Meteorological Data

Meteorological information related to wind, temperature, and precipitation is collected on an hourly basis at a number of locations in the Fort McMurray area. These include the Fort McMurray airport, the Tall Tower and a network of monitoring stations (MAPS) operated by Alberta Environment. Only four of these stations have been in operation since April 1980.

Data related to cloud cover is available from the Fort McMurray airport.

Upper air winds at the Fort McMurray airport are observed by pibals released up to three times per day.

Regional Wind and Temperature Data

Wind and temperature data at 850 mb (about 1200 m above surface in the Syncrude plant area) can be obtained twice daily for the oil sands area from pressure-height charts, which are based on information provided by the AES radiosonde network.

Forecast winds at 850 mb can be obtained from forecast pressure-height charts which are prepared by the AES.

Vertical profiles of temperature are available twice daily, at 0000 and 1200 GMT, from AES radiosonde stations at Fort Smith and Stony Plain. These stations lie about 350 km north and 400 km southwest of Fort McMurray, respectively. Their locations are shown in Figure 1.

These profiles were used to estimate hourly mixing depths by modifying the lower portion of the morning sounding (0500 MST) according to two parameters: hourly surface temperatures at a nearby surface station, and temperature change at 700 mb between consecutive soundings. The estimation procedure is described in a paper by Benkley-Schulman (1979).

Time Parameters

Following a suggestion of Glahn and Lowry (1972), time of day and day of year were incorporated in the forecast scheme to reflect diurnal and annual cycles.

The time of day parameters, T_{day}, were calculated according to the relation:

$$T_{day} = \sin\left[(HR-2)\ \frac{\pi}{24}\right] \tag{3}$$

where HR is hour of the day, from 0 to 23.

The time of year parameter, T_{year}, was calculated according to the relations:

$$T_{year} = \sin\left[(DAY-13.5)\ \frac{\pi}{365}\right] \text{ (non-leap years)} \tag{4}$$

$$T_{year} = \sin\left[(DAY-14.0)\ \frac{\pi}{366}\right] \text{ (leap year)} \tag{5}$$

where DAY represents the cumulative day of the year (from 1 to 365 or 366).

Overview of Predictors Relating to Wind and Temperature

The total number of observations for predictands relating to wind and/or temperature is 2 471. The number of simultaneous observations of predictands and predictors from each source of meteorological data are shown in Figure 5. Predictors which occur most frequently are those relating to time of day, day of year and to the Fort McMurray Airport surface data, with the full 2 471 observations. Mixing depths from Syncrude area minisondes occurred least frequently with only 290 observations. These mixing depths were determined for only 3 hours in the afternoon. Parameters from Alberta Environment monitoring stations (Mildred Lake, Tall Tower and Stony Mountain) are available less often because the network did not begin operation until late 1976. Note that Stony Mountain data is present for only about 400 observations.

Forecast Equations

The reduction of meteorological data from various locations and the calculations of predictands and predictors relating to wind and temperature were done by computer. The steps involved are described in detail in Appendix II. All regression analyses and data correlations were performed using the Statistical Analysis System (SAS) computer program package available from the SAS Institute Inc., P.O. Box 10066, Raleigh, North Carolina 27605.

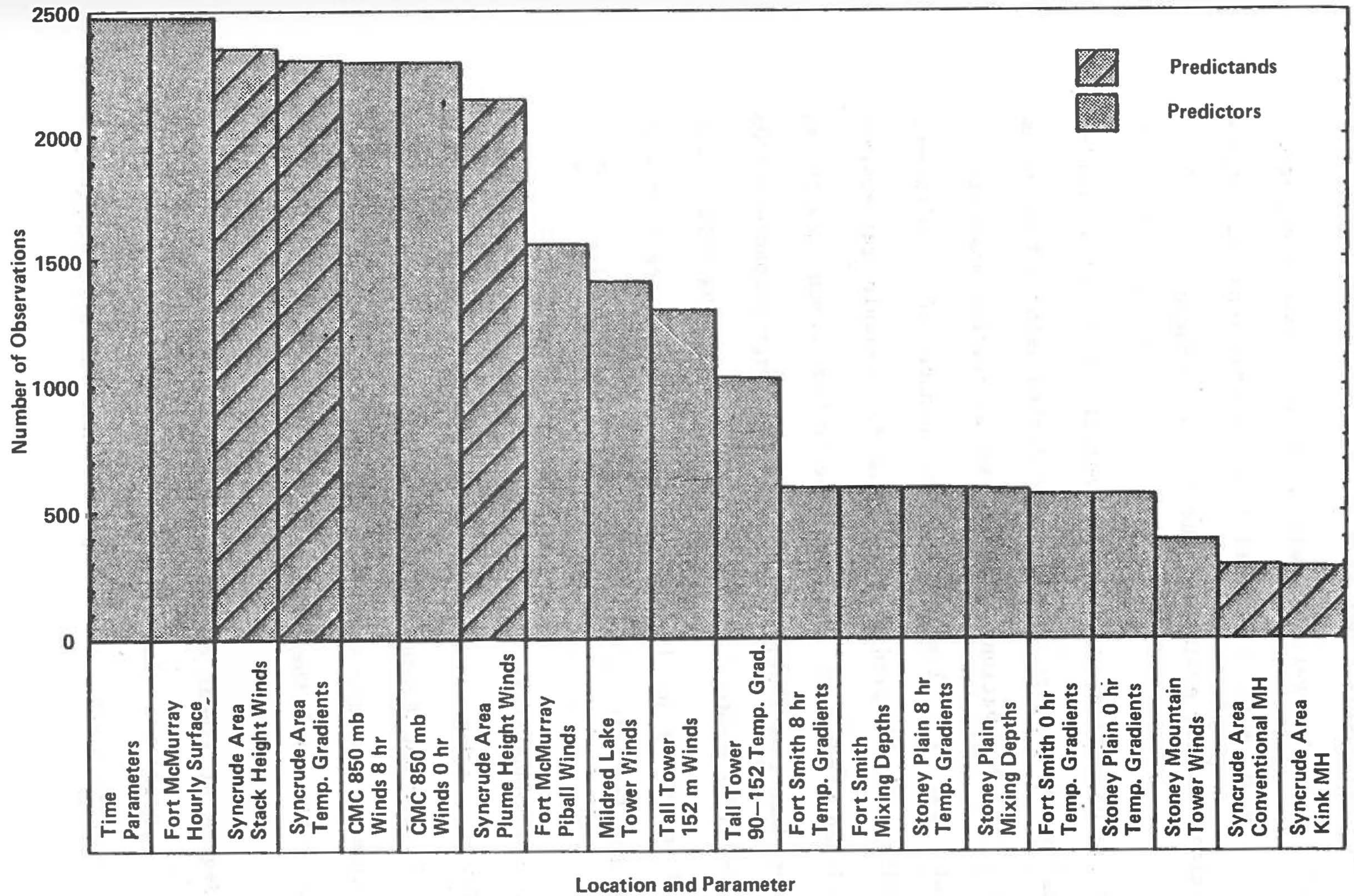


Figure 5. Frequency of occurrence for predictands and predictors used in deriving forecast schemes for wind and temperature parameters.

Observations for predictands were divided in a pseudo-random fashion into two nearly equal size groups. Group A, which contained 1 303 observations, was used to develop the forecast scheme. Group B, which contained 1 168 observations, was used as verification data for evaluating the forecast scheme.

The contribution of meteorological data from various locations to the forecast scheme was evaluated using 4 test cases. The number of observations used in the regression analysis for each test case was limited by the number of simultaneous observations of all predictors. Thus for example regressions which included predictors from the Alberta Environment monitoring network were based on fewer observations than regressions which do not include these predictors. Regressions for mixing depths were also based on only a small number of observations since they were evaluated only for a three hour period in the afternoon.

Wind and temperature data initially selected as predictors for the forecast scheme are presented in tables 1, 2 and 3. The notations 0-hour and 8-hour referred to in the tables indicate relative times of predictor data. The forecast scheme will be applied at 0-hour and the prediction will be valid at 8-hour.

The degree of linear dependence between pairs of parameters to be used as potential wind or temperature predictors (tables 1, 2, 3) and between predictors and predictands was also examined.

Table 1. Data used in the forecast scheme as initial predictors of wind speed.

PARAMETERS	LOCATION	LEVEL	TIME
Time of day parameter	+[e]	+	0-hour[a]
Time of day parameter	+	+	8-hour[b]
Time of year parameter	+	+	+
Windspeed,	Fort McMurray	surface	0-hour
u-component of velocity,	Fort McMurray	surface	8-hour
and	Fort McMurray	plume B[c]	0-hour
v-component of velocity	Fort McMurray	plume D[d]	0-hour
	Stony Mountain	surface	0-hour
	Mildred Lake	surface	0-hour
	Tall Tower	surface	0-hour
	+	850 mb	0-hour
	+	850 mb	8-hour
Temperature	Fort McMurray	surface	0-hour
	Fort McMurray	surface	8-hour

[a] 0-hour is the hour at which a forecast is made
[b] 8-hour is the hour at which a forecast will be valid
[c] plume height by the Briggs formulation
[d] plume height by the Djurfors-Netterville formulation
[e] entry not applicable for this parameter

Table 2. Data used in the forecast scheme as initial predictors of wind direction components.

PARAMETERS	LOCATION	LEVEL	TIME
Time of day parameter	+[e]	+	0-hour[a]
Time of day parameter	+	+	8-hour[b]
Time of year parameter	+	+	0-hour
Windspeed,	Fort McMurray	surface	0-hour
u-component of velocity,	Fort McMurray	surface	8-hour
and	Fort McMurray	plume B[c]	0-hour
v-component of velocity	Fort McMurray	plume D[d]	0-hour
	Stony Mountain	surface	0-hour
	Mildred Lake	surface	0-hour
	Tall Tower	surface	0-hour
	+	850 mb	0-hour
	+	850 mb	8-hour

[a] 0-hour is the hour at which a forecast is made
[b] 8-hour is the hour at which a forecast will be valid
[c] plume height by the Briggs formulation
[d] plume height by the Djurfors-Netterville formulation
[e] entry not applicable for this parameter

Table 3. Data used in the forecast scheme as initial predictors of temperature gradient and mixing depths.

PARAMETERS	LOCATION	LEVEL	TIME
Time of day parameter	+[f]	+	0-hour[a]
Time of day parameter	+	+	8-hour[b]
Time of year parameter	+	+	+
Wind speed	Fort McMurray	surface	0-hour
	Fort McMurray	surface	8-hour
u-component of velocity	Fort McMurray	surface	0-hour
	Fort McMurray	surface	8-hour
v-component of velocity	Fort McMurray	surface	0-hour
	Fort McMurray	surface	8-hour
Cloud amount	Fort McMurray	surface	0-hour
Temperature gradient	Tall Tower	90-152 m	0-hour
Temperature gradient[e]	Fort Smith	stack top[c]	0500[d]
	Fort Smith	stack top	0-hour
	Fort Smith	stack top	8-hour
	Stony Plain	stack top	0500[d]
	Stony Plain	stack top	0-hour
	Stony Plain	stack top	8-hour
Convective mixing height[e]	Fort Smith	stack top	0-hour
	Stony Plain	stack top	0-hour

[a] 0-hour is the hour at which a forecast is made
[b] 8-hour is the hour at which a forecast is valid
[c] mean temperature gradient between 183 and 283 m
[d] morning radiosonde profile
[e] parameter obtained from radiosonde profile modified for the indicated hour according to the Benkley-Schulman scheme
[f] entry not applicable for this parameter

This was done for general information and had no direct bearing on the development of the forecast scheme. Results of these examinations are presented for the interested reader in Appendix IV.

Regression equations were limited to a maximum of 10 predictors. Predictors were selected from tables 1, 2 and 3 such that they met three criteria.

(1) Inclusion of the predictor must result in a reduction of residual variance by at least 0.5 percent.

(2) The significance of the predictor included in the equation must be at least 15 percent as determined by the F statistic (see Appendix V).

(3) After the addition of the predictor to the equation the significance level of each predictor already in the equation must remain at 15 percent or less.

Forecast Scheme for Wind Predictands

Data from four different groups of sources were examined as test cases in order to determine the best predictors. Sources of information for each test case are shown in Table 4. As may be seen test case 1 involved the maximum amount of sources but the minimum amount of data.

Table 4. Sources of meteorological data used as initial predictors of wind parameters.

TEST CASE	SOURCES OF INITIAL PREDICTORS	NUMBER OF DATA
1	Time of day, Day of year Fort McMurray surface records CMC 850 mb analyses Fort McMurray upper air records Mildred Lake Tall Tower Stony Mountain	150
2	Time of day, Day of year Fort McMurray surface records CMC 850 mb analyses Fort McMurray upper air records Mildred Lake Tall Tower	481
3	Time of day, Day of year Fort McMurray surface records CMC 850 mb analyses Mildred Lake	544
4	Time of day, Day of year Fort McMurray surface records CMC 850 mb analyses	1 108

Each successive test case included less sources but more data. The square of the multiple correlation coefficient (R^2) was used to evaluate the goodness of the equation for estimating the $\hat{Y}$ of equation (1). The F statistics were used to indicate the significance of the relation. Both of these statistics are defined and discussed in Appendix V.

Results of the regression analyses demonstrated that:

(1) The highest correlations were obtained from the limited data of test case 1. These correlations however were achieved without predictors from Stony Mountain. This means that in the final analysis, sources from test cases 1 and 2 were identical.

(2) Correlation coefficients for test cases 2 and 3 were similar.

(3) The poorest correlations were achieved for test case 4.

Details of the correlation coefficients, significant predictors and associated F values are given in Appendix VI.

Based upon the above results it was decided to employ regression equations developed from test case 3 as the basis for forecasts. Equations from test case 2 were rejected because they contained predictors from the Tall Tower which is no longer in operation.

Equations derived for the recommended forecast scheme are shown in tables 5 to 13. These equations were tested using the verification set of data previously referred to as group B. Squares of the multiple correlation coefficient calculated using the recommended forecast scheme are shown in Table 14. Correlation coefficients obtained using the derivation data are shown for comparison.

Values of R^2 in Table 14 calculated using the derivation data range from 0.50 to 0.59. The means that 50 to 59 percent of the total variation of wind speeds and direction components about their mean values are explained by the regression. Values of R^2 are slightly less for wind speeds than for wind direction components. Values of R^2 shown in Table 14 for tests on the verification data range from 0.33 to 0.55. For wind direction components, these values are generally consistent with those calculated using derivation data. However, for wind speeds, R^2 values were slightly lower. Similarities in R^2 obtained using both derivation and verification data indicate some degree of stability in the entire data set.

Comparison between predicted and observed wind speeds and directions using the derivation data are given in Table 15. The RMS error in wind speeds was about 40 percent of the mean values. Wind direction RMS errors were about 53 degrees.

Table 5. Equation for estimating windspeed at stack height.

PREDICTOR					CUMULATIVE
Parameter	Location	Level	Time	COEFFICIENT	INCREASE OF R^2
Constant	+[a]	+	+	1.1588	+
Windspeed	Fort McMurray	surface	8-hour[b]	0.5004	.273
Windspeed	+	850 mb	8-hour	0.2266	.369
Temperature	Fort McMurray	surface	0-hour[c]	0.1036	.420
v-component of velocity	Fort McMurray	plume B[d]	0-hour	-0.0364	.449
Temperature	Fort McMurray	surface	8-hour	-0.0716	.461
v-component of velocity	Mildred Lake	surface	0-hour	-0.3346	.476
Time of day	+	+	0-hour	1.1583	.484
v-component of velocity	Fort McMurray	surface	8-hour	-0.1350	.490
u-component of velocity	+	850 mb	8-hour	-0.0908	.493
u-component of velocity	Fort McMurray	surface	8-hour	0.0976	.496

[a] entry not appropriate for this parameter
[b] 8-hour is the hour at which a forecast will be valid
[c] 0-hour is the hour at which a forecast is made
[d] plume height according to Briggs

Table 6. Equation for estimating u-component of wind velocity at stack height.

PREDICTOR					CUMULATIVE
Parameter	Location	Level	Time	COEFFICIENT	INCREASE OF R^2
Constant	+[a]	+	+	4.2001	+
u-component of velocity	Fort McMurray	surface	8-hour[b]	0.5906	.443
u-component of velocity	+	850 mb	0-hour[c]	0.2322	.486
Time of year	+	+	+	-4.4162	.511
v-component of velocity	Fort McMurray	surface	8-hour	-0.2062	.521
u-component of velocity	Fort McMurray	plume B[d]	0-hour	0.1090	.526
Temperature	Fort McMurray	surface	8-hour	0.0604	.531
Time of day	+	+	0-hour	-1.2042	.538
v-component of velocity	Fort McMurray	plume B[d]	0-hour	0.1020	.543
v-component of velocity	+	850 mb	0-hour	-0.1017	.547

[a] entry not appropriate for this parameter
[b] 8-hour is the hour at which a forecast will be valid
[c] 0-hour is the hour at which a forecast is made
[d] plume height according to Briggs

Table 7. Equation for estimating v-component of wind velocity at stack height.

PREDICTOR					
Parameter	Location	Level	Time	COEFFICIENT	CUMULATIVE INCREASE OF R^2
Constant	+[a]	+	+	-2.1760	+
v-component of velocity	+	850 mb	8-hour[b]	0.3466	.268
u-component of velocity	+	850 mb	8-hour	0.3087	.404
v-component of velocity	Fort McMurray	surface	8-hour	0.4954	.462
Time of day	+	+	0-hour[c]	1.6027	.479
v-component of velocity	Mildred Lake	surface	0-hour	0.4948	.493
u-component of velocity	Mildred Lake	surface	0-hour	-0.3526	.505
Time of day	+	+	8-hour	2.0362	.513
v-component of velocity	Fort McMurray	plume D[d]	0-hour	-0.2421	.522
v-component of velocity	Fort McMurray	plume B[e]	0-hour	0.1619	.526
v-component of velocity	Fort McMurray	surface	0-hour	0.2363	.531

[a] entry not appropriate for this parameter
[b] 8-hour is the hour at which a forecast will be valid
[c] 0-hour is the hour at which a forecast is made
[d] plume height according to the Djurfors-Netterville formulation
[e] plume height according to the Briggs formulation

Table 8. Equation for estimating windspeed at plume height by the Briggs formulation.

PREDICTOR				COEFFICIENT	CUMULATIVE INCREASE OF R^2
Parameter	Location	Level	Time		
Constant	+[a]	+	+	7.3419	+
Windspeed	+	850 mb	8-hour[b]	0.6109	.415
v-component of velocity	+	850 mb	8-hour	-0.2017	.475
Windspeed	Fort McMurray	surface	8-hour	0.3980	.491
Time of day	+	+	8-hour	-2.5928	.506
Time of year	+	+	+	-4.6687	.516
Temperature	Fort McMurray	surface	0-hour[c]	0.0846	.534
v-component of velocity	Fort McMurray	surface	8-hour	-0.1470	.536

[a] entry not appropriate for this parameter
[b] 8-hour is the hour at which a forecast will be valid
[c] 0-hour is the hour at which a forecast is made
[d] plume height according to the Briggs formulation
[e] plume height according to the Djurfors-Netterville formulation

Table 9. Equation for estimating u-component of wind velocity at plume height by the Briggs formulation.

PREDICTOR					CUMULATIVE
Parameter	Location	Level	Time	COEFFICIENT	INCREASE OF R^2
Constant	+[a]	+	+	2.5862	+
u-component of velocity	+	850 mb	8-hour[b]	0.9582	.437
Time of year	+	+	+	-4.4388	.497
v-component of velocity	+	850 mb	0-hour[c]	0.2680	.516
u-component of velocity	Fort McMurray	surface	8-hour	0.4520	.536
Windspeed	+	850 mb	0-hour	0.4535	.545
Windspeed	Fort McMurray	surface	0-hour	-0.4442	.556
Windspeed	Fort McMurray	plume B[d]	0-hour	-0.1757	.562
Temperature	Fort McMurray	surface	8-hour	0.0635	.569
v-component of velocity	Fort McMurray	surface	8-hour	-0.3391	.576
Time of day	+	+	0-hour	1.6270	.580

[a] entry not appropriate for this parameter
[b] 8-hour is the hour at which a forecast will be valid
[c] 0-hour is the hour at which a forecast is made
[d] plume height according to Briggs

Table 10. Equation for estimating v-component of wind velocity at plume height by the Briggs formulation.

PREDICTOR Parameter	Location	Level	Time	COEFFICIENT	CUMULATIVE INCREASE OF R^2
Constant	+[a]	+	+	-4.7790	+
v-component of velocity	+	850 mb	8-hour[b]	0.6357	.304
Time of year	+	+	+	6.8156	.421
v-component of velocity	Fort McMurray	surface	8-hour	0.7011	.467
Windspeed	+	850 mb	0-hour[c]	-0.3896	.501
v-component of velocity	Fort McMurray	plume B[d]	0-hour	-0.1526	.514
v-component of velocity	Mildred Lake	surface	0-hour	0.5235	.528
Temperature	Fort McMurray	surface	8-hour	-0.0989	.535
u-component of velocity	Fort McMurray	surface	8-hour	-0.2528	.544
Windspeed	Fort McMurray	plume B[d]	0-hour	0.1560	.555
Time of day	+	+	0-hour	1.6275	.561

[a] entry not appropriate for this parameter
[b] 8-hour is the hour at which a forecast will be valid
[c] 0-hour is the hour at which a forecast is made
[d] plume height according to Briggs

Table 11. Equation for estimating windspeed at plume height by the Djurfors and Netterville formulation.

PREDICTOR Parameter	Location	Level	Time	COEFFICIENT	CUMULATIVE INCREASE OF R^2
Constant	+[a]	+	+	4.9311	+
Windspeed	+	850 mb	8-hour[b]	0.4241	.363
v-component of velocity	Fort McMurray	plume D[d]	0-hour[c]	-0.1138	.431
Temperature	Fort McMurray	surface	0-hour	0.1581	.454
Windspeed	Fort McMurray	surface	8-hour	0.3596	.469
Temperature	Fort McMurray	surface	8-hour	-0.0973	.492
v-component of velocity	+	850 mb	8-hour	-0.2379	.502
Time of year	+	+	+	-2.5801	.511
u-component of velocity	+	850 mb	8-hour	-0.0742	.515
v-component of velocity	+	850 mb	0-hour	0.1284	.518

[a] entry not appropriate for this parameter
[b] 8-hour is the hour at which a forecast will be valid
[c] 0-hour is the hour at which a forecast is made
[d] plume height according to Djurfors-Netterville

Table 12. Equation for estimating u-component of wind velocity at plume height by the Djurfors and Netterville formulation.

PREDICTOR Parameter	Location	Level	Time	COEFFICIENT	CUMULATIVE INCREASE OF R^2
Constant	+[a]	+	+	6.4633	+
u-component of velocity	+	850 mb	8-hour[b]	0.9332	.434
Time of year	+	+	+	-4.1604	.499
u-component of velocity	Fort McMurray	surface	8-hour[c]	0.5966	.514
v-component of velocity	+	850 mb	8-hour	0.2090	.528
Windspeed	+	850 mb	0-hour	0.5597	.541
Windspeed	Fort McMurray	plume D[d]	0-hour	-0.1650	.554
Windspeed	Mildred Lake	surface	0-hour	-0.2795	.564
Temperature	Fort McMurray	surface	8-hour	0.2807	.572
Temperature	Fort McMurray	surface	0-hour	-0.2307	.578
Time of day	+	+	8-hour	-6.3046	.588

[a] entry not appropriate for this parameter
[b] 8-hour is the hour at which a forecast will be valid
[c] 0-hour is the hour at which a forecast is made
[d] plume height according to Djurfors-Netterville

Table 13. Equation for estimating v-component of wind velocity at plume height by Djurfors and Netterville formulation.

PREDICTOR					
Parameter	Location	Level	Time	COEFFICIENT	CUMULATIVE INCREASE OF R^2
Constant	+[a]	+	+	-5.0628	+
v-component of velocity	+	850 mb	8-hour[b]	0.5693	.311
Time of year	+	+	+	6.9514	.412
v-component of velocity	Fort McMurray	surface	8-hour	0.5991	.455
v-component of velocity	Mildred Lake	surface	0-hour[c]	0.6293	.481
Temperature	Fort McMurray	surface	8-hour	-0.1091	.494
v-component of velocity	Fort McMurray	plume D[d]	0-hour	-0.1466	.509
Time of day	+	+	0-hour	1.6155	.517
Windspeed	+	850 mb	8-hour	-0.2670	.523
u-component of velocity	Fort McMurray	surface	8-hour	-0.2388	.535
Windspeed	Fort McMurray	plume D[d]	0-hour	0.0923	.540

[a] entry not appropriate for this parameter
[b] 8-hour is the hour at which a forecast will be valid
[c] 0-hour is the hour at which a forecast is made
[d] plume height according to Djurfors-Netterville

Table 14. Squares of the multiple correlation coefficient (R^2) for wind predictands using both derivation and verification data.

LEVEL	WIND PREDICTAND	R^2 Derivation Data	R^2 Verification Data
Stack height	Windspeed	0.50	0.47
	u-component of velocity	0.55	0.54
	v-component of velocity	0.53	0.50
Plume height B[a]	Windspeed	0.54	0.33
	u-component of velocity	0.58	0.49
	v-component of velocity	0.56	0.50
Plume height D[b]	Windspeed	0.52	0.43
	u-component of velocity	0.59	0.50
	v-component of velocity	0.54	0.55

[a] plume height according to Briggs
[b] plume height according to Djurfors-Netterville

Table 15. Comparison between predicted and observed wind speeds and direction

ELEVATION	PREDICTAND	NO. OF PREDICTIONS	MEAN VALUE		STANDARD DEVIATION		RMS ERROR
			OBSERVED	PREDICTED	OBSERVED	PREDICTED	
Stack Height	Speed (ms^{-1})	530	5.2	5.3	2.8	2.0	2.0
	u (ms^{-1})	736	-1.5	-1.4	4.3	2.9	2.9
	v (ms^{-1})	529	-1.4	-1.6	3.5	2.7	2.5
	Direction (°)	529	194	208	85	73	56
Briggs Plume Height	Speed (ms^{-1})	1012	7.7	7.6	4.0	2.9	3.3
	u (ms^{-1})	736	-3.5	-3.5	6.0	4.6	4.3
	v (ms^{-1})	530	-1.5	-1.4	5.2	3.9	3.7
	Direction (°)	530	218	234	81	69	52
Djurfors-Netterville Plume Height	Speed (ms^{-1})	734	7.5	7.4	3.8	2.4	2.9
	u (ms^{-1})	529	-3.4	-3.6	6.1	4.5	4.3
	v (ms^{-1})	529	-1.5	-1.3	5.0	3.6	3.3
	Direction (°)	529	216	232	81	71	51

Forecast Scheme for Temperature Predictands

Data from the five different groups of sources shown in Table 16 were examined in test cases to determine the best predictors for temperature gradients at stack height, conventional mixing depths and kink mixing depths. Test cases 1 and 3 included information from the Tall Tower which is no longer in operation. Table 17 presents the results of regression analyses. It shows that:

(1) Values of R^2 for the temperature gradient regressions were about 0.29 for test cases 1 to 4. The value of R^2 derived from test case 5 was appreciably lower at 0.20.

(2) The significance of the results as indicated by large F values is greater for test case 4 than for other tests.

(3) The largest values of R^2 for mixing depth regressions were obtained from test cases 1 and 3 which contain information from the Tall Tower which is no longer in operation.

(4) Neglecting test cases 1 and 3 the best correlation for mixing height was achieved with test case 2.

Details of the derived correlation coefficients and significant predictors are contained in Appendix VII.

Table 16. Sources of meteorological data used as initial predictors of temperature parameters in each test case.

TEST CASE	SOURCES OF INITIAL PREDICTORS	NUMBER OF DATA: Temperature Gradient	NUMBER OF DATA: Conventional Mixing Depth	NUMBER OF DATA: Kink Mixing Depth
1	Time of day, Day of year Fort McMurray surface records Tall Tower Fort Smith Stony Plain	115	55	60
2	Time of day, Day of year Fort McMurray surface records Fort Smith Stony Plain	314	150	143
3	Time of day, Day of year Fort McMurray surface records Tall Tower	530	59	62
4	Time of day, Day of year Fort McMurray surface records	1210	158	151
5	Time of day, Day of year	1210	158	151

Table 17. Summary statistics of regression analyses for predictands relating to temperature.

PREDICTAND	STATISTIC	CASE 1	2	3	4	5
Temperature Gradient	Number of Observations	115	314	530	1210	1210
	R^2	0.31	0.28	0.27	0.29	0.20
	F	16.4	20.2	27.3	71.0	97.8
Conventional Mixing Height	Number of Observations	55	150	59	158	158
	R^2	0.46	0.30	0.43	0.26	0.23
	F	8.4	12.2	13.7	26.5	46.7
Kink Mixing Height	Number of Observations	60	143	62	151	151
	R^2	0.57	0.29	0.36	0.18	0.06
	F	10.0	7.8	10.6	8.3	9.9[a]

[a] associated with a significant level of 0.20 percent

It was decided as a consequence of the above results to employ equations from test case 4 to forecast temperature gradients and equations from test case 2 to forecast mixing heights. Recommended equations are shown in tables 18, 19 and 20.

The equations were tested using the verification data. Table 21 shows that values of R^2 for temperature gradient data calculated from derivation and verification data are comparable. Success in forecasting mixing heights from the verification data was poor. This is especially true for the kink mixing height for which the negative value R^2 indicates no correlation between predicted and observed values.

Comparisons between predicted and observed values for temperature related predictands as obtained from the verification data set are given in Table 22. The RMS error for temperature gradients was 1.2°C/100 m. Mixing heights were forecasted with RMS errors which were about 68 percent of their mean values.

Table 18. Equation for estimating temperature gradient (in °C/m) at stack height[a].

PREDICTOR				COEFFICIENT	CUMULATIVE INCREASE OF R^2
Parameter	Location	Level	Time		
Constant	+[b]	+	+	0.0391	+
Windspeed	Fort McMurray	surface	8-hour[c]	-0.0009	0.104
Time of day	+	+	8-hour	-0.0228	0.154
Time of year	+	+	+	-0.0227	0.241
Cloud amount	Fort McMurray	surface	0-hour[d]	-0.0006	0.265
Windspeed	Fort McMurray	surface	0-hour	-0.0011	0.276
u-component of velocity	Fort McMurray	surface	8-hour	0.0006	0.284
Temperature	Fort McMurray	surface	0-hour	0.0002	0.292

[a] average temperature gradient between 183 and 283 m
[b] entry is appropriate for this parameter
[c] 8-hour is the hour at which a forecast will be valid
[d] 0-hour is the hour at which a forecast is made

Table 19. Equation for estimating mixing depth by the conventional method.

PREDICTOR				COEFFICIENT	CUMULATIVE INCREASE OF R^2
Parameter	Location	Level	Time		
Constant	+[a]	+	+	-39.2983	+
Time of year	+	+	+	737.1585	0.220
u-component of velocity	Fort McMurray	surface	8-hour[b]	43.7379	0.252
Mixing depth	Stony Plain	+	8-hour[c]	0.1409	0.276
Cloud amount	Fort McMurray	surface	0-hour	17.6309	0.287
Temperature gradient	Fort Smith	stack top[d]	8-hour	-12638.5228	0.298

[a] entry not appropriate for this parameter
[b] 8-hour is the hour at which a forecast will be valid
[c] 0-hour is the hour at which a forecast will be made
[d] stack top level is between 183 and 283 m

Table 20. Equation for estimating mixing depth by the kink method.

PREDICTOR					
Parameter	Location	Level	Time	COEFFICIENT	CUMULATIVE INCREASE OF R^2
Constant	+[a]	+	+	529.2503	+
Temperature	Fort McMurray	surface	8-hour[b]	-10.2266	0.069
Time of year	+	+	+	333.3227	0.151
Temperature Gradient	Fort Smith	stack top[d]	0-hour[c]	-4147.0597	0.196
Time of day	+	+	0-hour	-594.7246	0.231
u-component of velocity	Fort McMurray	surface	0-hour	17.0450	0.256
Temperature Gradient	Stony Plain	stack top[d]	8-hour	-2574.6970	0.277
Mixing height	Stony Plain	+	8-hour	-0.0737	0.288

[a] entry not appropriate for this parameter
[b] 8-hour is the hour at which a forecast will be valid
[c] 0-hour is the hour at which a forecast will be made
[d] stack top level is between 183 and 283 m

Table 21. Squares of multiple correlation coefficient (R^2) for temperature predictands using both dependent and independent data.

TEMPERATURE PREDICTAND	R^2	
	Derivation Data	Verification Data
Temperature Gradient at stack height[a]	0.29	0.27
Conventional Mixing Depth	0.30	0.20
Kink Mixing Depth	0.29	-0.16

Table 22. Comparison between predicted and observed temperature predictands

PREDICTAND	NUMBER OF PREDICTIONS	MEAN VALUE		STANDARD DEVIATION		RMS ERROR
		OBSERVED	PREDICTED	OBSERVED	PREDICTED	
Temperature Gradient at Stack Height (°C/100 m)	1080	0.4	0.4	1.5	0.8	1.2
Conventional Mixing Height (m)	132	802	805	568	311	505
Kink Mixing Height (m)	122	374	302	252	138	270

FORECAST SCHEME FOR HORIZONTAL WIND DIRECTION FLUCTUATIONS

Horizontal plume dispersion can be related to σ_θ, the standard deviation of wind direction fluctuations about the mean (Irwin 1979). A simpler prediction scheme for σ_θ was devised than the one developed for other predictands.

Seasonal data from the Tall Tower relating to the standard deviation, σ_θ, were categorized according to the vertical temperature gradient.

Vertical temperature differences, indicative of stability, were obtained from temperatures measured at the 1.5 and 10 m levels. The use of these near surface temperatures to characterize stability has been recommended by the American Meteorological Society (Hanna et al. 1977). The lapse rate, γ (°C/100 m), associated with each stability were:

stable :	$\gamma < 0.5$
neutral :	$0.5 \leq \gamma \leq 1.5$
unstable:	$\gamma > 1.5$

Data within each stability class were analyzed according to whether the wind speed was low (0-10 km hr^{-1}), moderate (11-20 km hr^{-1}), strong (21-30 km hr^{-1}) or very strong (> 30 km hr^{-1}).

An example of the cumulative frequency distribution of σ_θ during unstable atmospheric situations in summer for the four wind speed classes is given in Figure 6. Median values of σ_θ for low, moderate, strong and very strong winds were 20, 12, 11 and 9 degrees, respectively. These data together with information from other seasons and stability conditions are presented in Table 23 which shows that:

(1) Stable atmospheres occur much more frequently than unstable or neutral atmospheres. This is especially true for the winter season.

(2) Neutral stability conditions rarely occur.

(3) Values of σ_θ tend to be insensitive to windspeed for speeds greater than 10 km hr^{-1}.

(4) Values of σ_θ are insensitive to stability during autumn and winter seasons.

Information for σ_θ in Table 23 for wind speeds less than or greater than 10 km hr^{-1} are summarized in Table 24. These σ_θ values can be compared to those usually assumed for flat terrain as given in Table 25 by Gifford (1968) for Pasquill stability categories ranging from extremely unstable (A) through neutral (D) to moderately stable (F). The key to these categories is shown in Table 26.

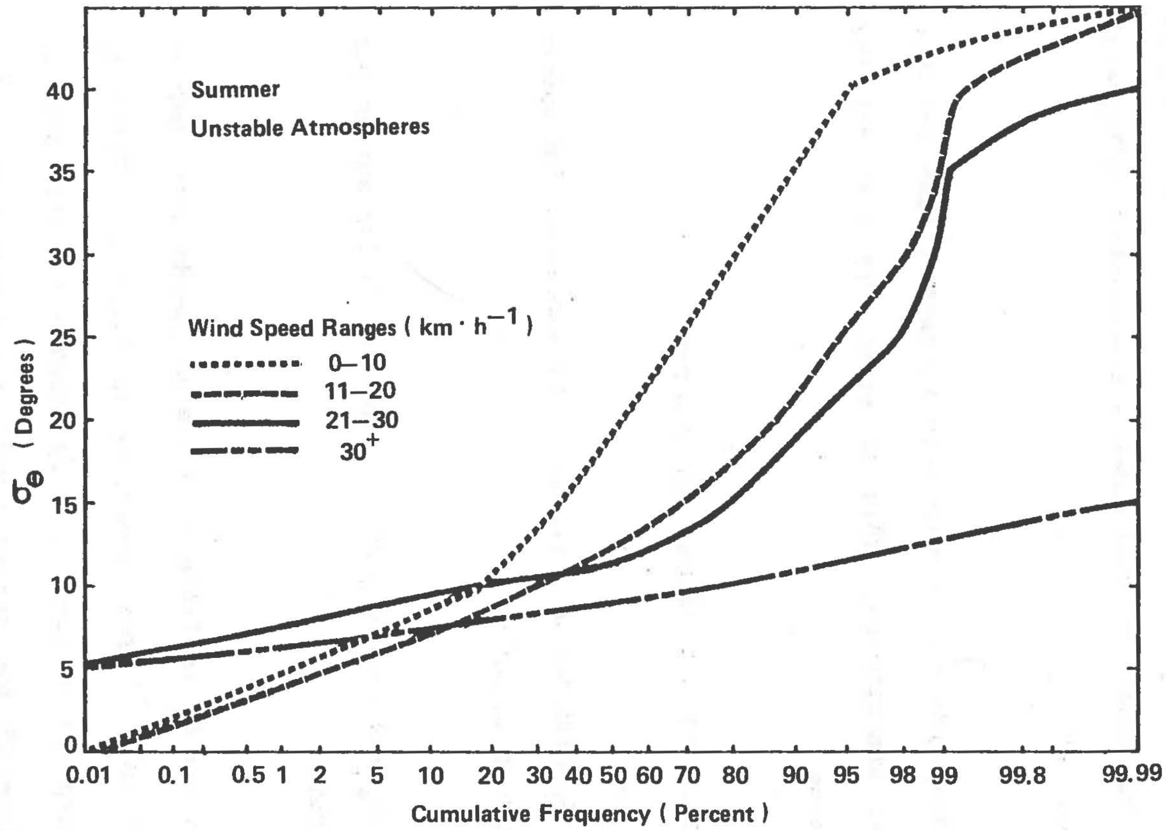


Figure 6. Cumulative frequency of occurrence of σ_θ in unstable atmospheres during summer as a function of windspeed classification.

Table 23. Median values of σ_θ (degrees) for specified season, wind speed and stability classes. The number of data (N) on which each median is based are shown.

STABILITY	WIND SPEED CLASS ($km\ h^{-1}$)	WINTER σ_θ	WINTER N	SPRING σ_θ	SPRING N	SUMMER σ_θ	SUMMER N	AUTUMN σ_θ	AUTUMN N
Stable	0-10	6	547	12	250	12	284	10	201
	11-20	5	728	8	354	8	375	8	449
	21-30	5	397	7	317	8	202	6	379
	>30	5	79	6	108	8	35	7	264
Neutral	0-10	5	8	12	2	18	16	11	22
	11-20	4	10	10	5	10	7	6	55
	21-30	+[a]	0	8	11	10	7	8	36
	>30	+	0	10	8	10	3	8	28
Unstable	0-10	7	11	20	51	20	110	11	135
	11-20	5	9	15	78	12	109	9	282
	21-30	3	4	12	39	11	93	7	140
	>30	3	1	10	16	9	20	8	86
Stable	all	5	1751	8	1029	9	896	7	1293
Neutral	all	6	18	9	26	11	33	8	141
Unstable	all	5	25	14	184	13	332	9	643

[a] no values due to lack of data

Table 24. Estimated seasonal median values of σ_θ (degrees) for air flow in the Athabasca Oil Sands area.

Windspeed Range (km/hr)	Stability	Winter	Spring	Summer	Autumn
<10	Stable	6	12	12	10
	Neutral	6	12	18	11
	Unstable	+[a]	20	20	11
>10	Stable	5	7	8	9
	Neutral	5	9	10	7
	Unstable	+[a]	13	11	8

[a] lack of sufficient data

Table 25. Standard deviation of horizontal wind fluctuations, σ_θ, (degrees) associated with Pasquill stability categories.

STABILITY CATEGORY		STANDARD DEVIATION
Extremely Unstable	A	25
Moderately Unstable	B	20
Slightly Unstable	C	15
Neutral	D	10
Slightly Stable	E	5
Moderately Stable	F	2.5

Table 26. Key to Pasquill stability categories.

SURFACE WIND SPEED	DAYTIME INSOLATION			NIGHTTIME CONDITIONS[a]	
($km\ hr^{-1}$)	strong	moderate	slight	thinly overcast $\geq$ 4/8 low cloud	$\leq$ 3/8 cloud
< 5	A	A-B	B		
5-7	A-B	B	C	E	F
8-10	B	B-C	C	D	E
11-13	C	C-D	D	D	D
> 13	C	D	D	D	D

[a] The neutral class D should be assumed for overcast conditions during day or night

Information presented in Table 24 can be used together with forecasts of wind and stability classes as a prediction scheme for standard deviation of horizontal wind fluctuations. Forecasts of whether the wind speed will be greater or less than 10 km h^{-1} can be obtained directly from the Atmospheric Environment Service. Forecasts of stability can be made according to a knowledge of incoming radiation and historical performance. For example, Table 23 shows that unstable and neutral atmospheres rarely occur in winter and therefore should not be forecast. Forecasts of unstable conditions would be appropriate during summer days when there is a clear sky and low winds.

DISCUSSION

WIND FORECAST SCHEME

Forecast schemes for winds at stack height and at plume heights developed by regression analyses are presented in tables 5 to 13. Values for the multiple correlation coefficient squared, R^2, of around 0.5 were obtained by testing these equations on both derivation and verification data sets.

Regression analyses for wind related parameters were based on predictands obtained from pibal observations. There are some uncertainties inherent in their measurement as discussed by Netterville-Djurfors (1979). In addition, pibal winds are instantaneous winds which may contain scatter about a mean value. These winds were used in the regression analyses with predictors which for the most part represent winds averaged over a larger time interval. It seems reasonable that the use of site specific, time-averaged winds (from an acoustic sounder) as predictands in the regression analyses could result in higher R^2 values.

Winds from the 850 mb level were found to be the most significant predictors in the regression analyses for wind. Winds from 850 mb levels appear closely related with the surface winds at Stony Mountain. This relationship could be explored further.

TEMPERATURE FORECAST SCHEME

Forecast schemes derived by regression analysis for temperature gradient at stack height and mixing heights have been presented in tables 18, 19 and 20. Values for the multiple correlation squared, R^2, of about 0.3 were obtained from the derivation data. Lower values R^2 were obtained from verification analyses.

Correlation coefficients for temperature parameters are lower than those obtained for wind parameters. Use of predictors other than those considered in this report may improve the results. These may be either observed meteorological parameters from the region, or predicted parameters from boundary layer models.

WIND DIRECTION FLUCTUATION FORECAST SCHEME

A forecast scheme for horizontal fluctuations of wind direction was developed through an analysis of Tall Tower data. It was shown that horizontal fluctuations were related to season, windspeed class and stability. Forecasts relating to these parameters can be used to give an indication of expected horizontal fluctuation of wind direction and hence plume dispersion.

CONCLUDING REMARKS

This study has demonstrated the value of regression analysis as a tool for meteorological evaluations and forecasting in the Oil Sands area. Other uses include further investigation of relationships between meteorological parameters, and the generation of a climatology for mixing heights and plume height winds.

REFERENCES CITED

Benkley, C.W. and L.L. Schulman. 1979. Estimating hourly mixing depths and historical meteorological data. Journal of Applied Meteorology 18:772-780.

Briggs, G.A. 1971. Some recent analysis of plume rise observations. Pages 1029-1032 in H.M. England and W.T. Beery, eds. Proceedings of the Second International Clean Air Congress. Academic Press, New York and London, 1354 pp.

Briggs, G.A. 1975. Plume rise predictions. Pages 59-111 in Lectures on air pollution and environmental impact analyses, American Meteorological Society, 45 Beacon Street, Boston, Mass., 02108, U.S.A. 296 pp.

Djurfors S. and D. Netterville. 1978. Buoyant plume rise in nonuniform wind conditions. Journal of the air pollution control association 28 (8):780-784.

Efroymson, M.A. 1960. Multiple Regression Analysis. Pages 191-203 in A. Raltson and H.S. Wilft, eds. Mathematical methods for digital computers, New York, Wiley.

Gifford, Franklin A. 1968. "An Outline of Theories of Diffusion in the Tower Layers of the Atmosphere", Chapter 3 in Meteorology and Atomic Energy edited by David H. Slade TlD-24190. Clearing House for Federal Scientific and Technical Information National Bureau of Standards, U.S. Department of Commerce Springfield Virginia 22151.

Glahn, Harry R. and Dale A. Lowry 1972. "The Use of Model Output Statistics (MOS) in Objective Weather Forecasting" J. Appl. Meteor. 11 (12) 1203-1211.

Hanna, S.R., G.A. Briggs, J. Deardroff, B.A. Egan, F.A. Gifford and F. Pasquill. 1977. AMS workshop on stability classification schemes and sigma curves - summary of recommendations. Bulletin of the American Meteorological Society, 58 pp:1 305-1 309.

Irwin, John S. 1979. "Estimating Plume Dispersion - A Recommended Generalized Scheme" Fourth Symposium on Turbulence, Diffusion and Air Pollution Reno, Nevada January 15-18, 1979. American Meteorological Society, 45 Beacon Street, Boston, Massachesetts 02108 U.S.A.

Kumar, Ashok 1979. "Numerical Modeling of the Thermal Boundary Layer Near a Synthetic Crude Oil Plant" J. Air Poll. Contr. Assoc. 29 (8) 827-832.

Markee, E.H., Jr. 1963. On the relationship of range to standard deviation of wind fluctuations. Monthly Weather Review. 91:83-87.

References Cited (cont'd)

Netterville, D.D.J. and S.G. Djurfors. 1979. Controlling inherent uncertainties in double theodolite measurements. Journal of Applied Meteorology. 18(10): 1371-1375.

Portelli, R.V. 1977. Mixing heights, wind speeds and ventilation coefficients for Canada, Climatological studies number 31. Atmospheric Environment Service, Downsview.

APPENDIX I

PLUME RISE FORMULAS GIVEN BY BRIGGS AND DJURFORS-NETTERVILLE

Plume rises were determined from equations developed by Briggs (1971, 1975) and by Djurfors-Netterville (1978).

Briggs Formulation

In neutral or unstable atmospheres, final plume rise is given by:

$$h_r = 24.2 \left[\frac{3}{2\beta^2}\right]^{1/3} \left[\frac{F}{u_s}\right]^{3/5} \tag{6}$$

In stable atmospheres, final plume rise is given by (Briggs 1975):

$$h_r = \left[\frac{6F}{u_s\ \beta^2\ N^2}\right]^{1/3} \tag{7}$$

where h_r = final plume rise

β = plume entrainment constant

u_s = wind speed at stack top level

$$N^2 = \frac{g}{\theta}\ \frac{d\theta}{dz} \quad \text{(Brunt Vaisalla frequency squared)} \tag{8}$$

g = acceleration due to gravity

θ = ambient potential temperature

z = vertical rise distance coordinate above stack top

$$F = v R_s^2 g \left(\frac{T_g - T_a}{T_g} \right) \text{(plume buoyancy flux)} \tag{9}$$

where v = stack exit velocity

R_s = inner stack radius

T_g = stack effluent exit temperature (°K)

T_a = ambient stack top temperature (°K)

Djurfors-Netterville Formulation

This is similar to the formulation of Briggs, but it also takes into account wind speed shears. This necessitates the substitution of u_B for u_S in equations (3) and (4) where:

$$u_B = u_s \left[\frac{A\beta F}{U_s R_s^3 (1 + \gamma/3)^{3/\gamma} (1 + \gamma/2)^{(3/\gamma)} (2 + \gamma)} \right]^{\gamma/(3 + \gamma)} \tag{10}$$

where $A = 6/N^2$ for stable atmospheres

$A = 21241.5\ F^{4/5}/U_s^2$ for neutral or unstable atmospheres

γ = index for wind power law

The windspeed power law is expressed as:

$$u = u_s \left[1 + \frac{z}{z_o} \right]^{\gamma} \tag{11}$$

where z_o = required displacement of plume origin below stack top (virtual source origin)

$$z_o = R_s (1 + \gamma/s) / \beta \tag{12}$$

Plume Rise Parameters

Plume heights were estimated using the parameters given in Table 27. The value of β is that given by Slawson et al (1980).

Table 27. Constants used in plume rise calculations.

PARAMETER	SYMBOL	VALUE
plume entrainment constant	β	0.68
acceleration due to gravity	g	9.81 m sec^{-2}
stack effluent exit velocity	v	27.0 m sec^{-1}
inner stack radius	R_s	3.96 m
stack effluent exit temperature	T_g	176.0 C
stack height	h_s	183.0 m
virtual source origin	z_o	5.0 m

REFERENCES CITED

Briggs, G.A. 1971. Some recent analysis of plume rise observations. Pages 1029-1032 in H.M. England and W.T. Beery, eds. Proceedings of the Second International Clean Air Congress. Academic Press, New York and London, 1354 pp.

Briggs, G.A. 1975. Plume rise predictions. Pages 59-111 in Lectures on air pollution and environmental impact analyses. American Meteorological Society, 45 Beacon Street, Boston, Mass., 02108, U.S.A. 296 pp.

Djurfors S. and D. Netterville. 1978. Buoyant plume rise in nonuniform wind conditions. Journal of the air pollution control association 28 (8):780-784.

Slawson P.R., G.A. Davidson and C.S. Maddukuri (1980). "Dispersion Modeling of a Plume in the Tar Sands Area" Environmental Research Report 1980-1, Syncrude Canada Ltd.

APPENDIX II: DATA MANAGEMENT FOR WIND AND TEMPERATURE PREDICTANDS AND PREDICTORS

In order to undertake regression analysis using meteorological information spanning five years in time, a system is required for data organization and reduction to a usable form. This Appendix discusses preparation of data for predictands and predictors, and gives an overview of the method used in the forecast scheme development and evaluation. A flow diagram outlining the system in terms of data files and computer programs is shown in Figure 7. All mention of programs and data files in the following description refers to Figure 7. Programs names used in this discussion are descriptive; the actual system uses different names in some cases.

The final step of the system involves use of a computer program package called Statistical Analysis Systems (SAS), which is available from SAS Institute Inc., P.O. Box 10066, Raleigh, North Carolina 27605. One program in this package, STEPWISE, will determine regression equation information employing the method described by Efroymson (1960).

Development of the forecast scheme can be described in six steps:

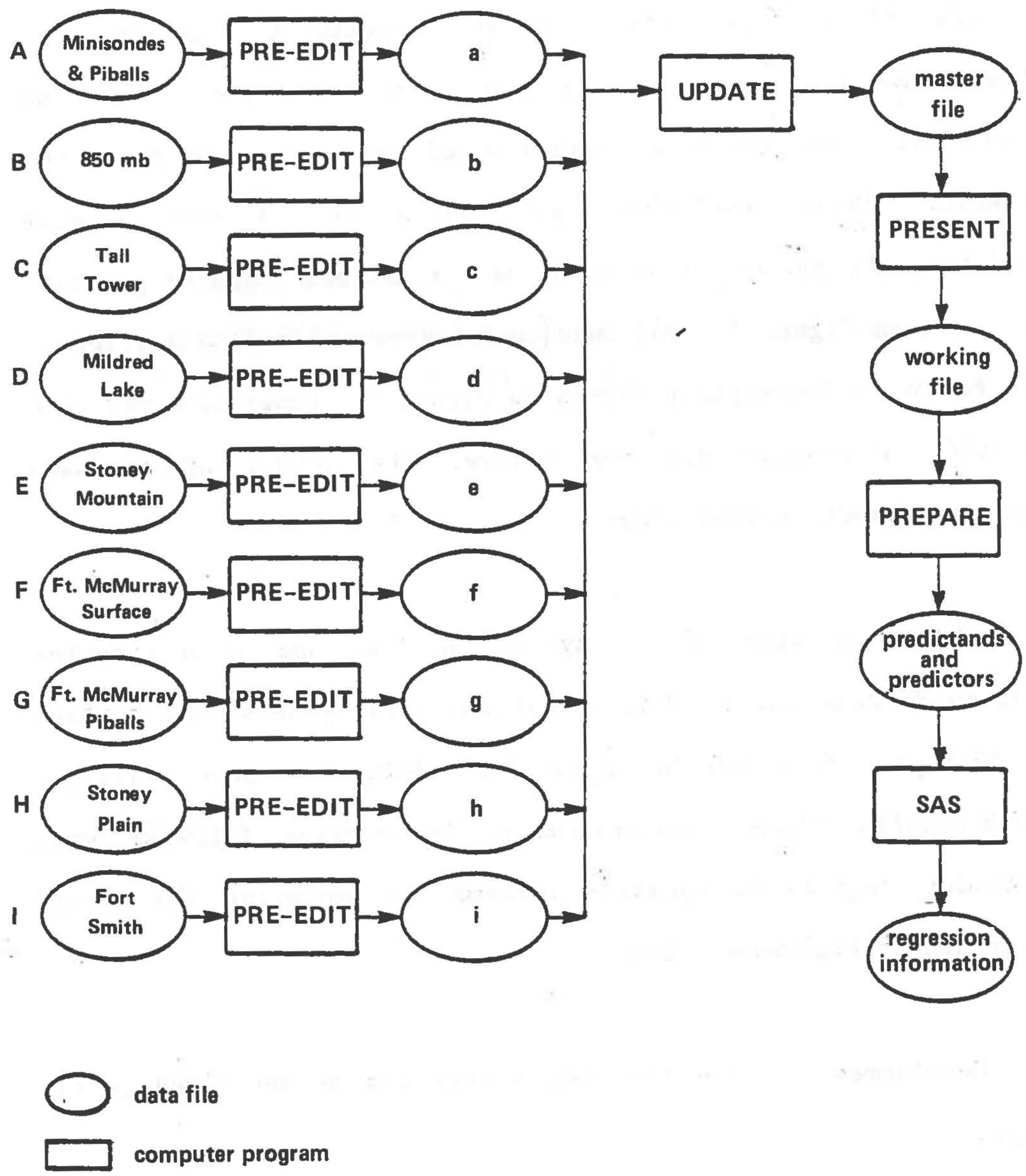


Figure 7. Data management system for regression analysis procedure. Each component is described in the text.

(1) Obtain raw data.

Information relating to the predictands and potential predictors discussed previously was available from nine locations. Meteorological records from each location were obtained and stored on computer. Files 'A' to 'I' in Figure 7 represent the records of raw meteorological data from each location.

(2) Edit raw data

Information for the predictand and potential predictors was abstracted from the raw data files. Data for each meteorological parameter from all sources had to be converted to consistent units and stored in a uniform format. These tasks and preliminary quality control checks were performed by FORTRAN PRE-EDIT programs indicated in Figure 7.

The abstracted, converted and reformatted information generated by the PRE-EDIT programs for each location are represented by files 'a' to 'i' in Figure 7. In these files, each individual data value is stored on one record, with a coding scheme to denote the time, location, height and type of data which the record contains. A data flag is also included to note any special characteristics of the data.

The total number of individual records from all PRE-EDIT programs was about 611 000.

(3) Merge data and sort according to time

In order to work simulataneously with information for the same time periods from each source, data in files 'a' to 'i' were merged and stored in the master file according to time. All data for a given time has been grouped according to location, and data for a given location, has been grouped according to height above surface.

Data is added to the master file by the program UPDATE. This program also performs additional quality control editing to ensure data flags and codes for time, location and data type are valid. All heights and data values are checked to ensure they are within valid limits.

The program UPDATE is written in COBOL, a language more suited to reading and writing large amounts of data. The tasks in this step can be performed using computer time an order of magnitude less than taken by a FORTRAN program to process the same amount of data.

(4) Select and reformat data for analysis

The grouping of data within the master file may be appropriate for some uses of the data, but not for others. The COBOL program, PRESENT, was written to select and reformat specific data from the master file for future analysis.

In relation to this study, the program PRESENT was designed to operate as follows. The times of release were tabulated for all minisonde and/or pibal observations. For each time of release, all data required to calculate predictands and potential predictors were assembled. This includes seven parts as outlined below:

(a) the wind and/or temperature profiles.

(b) all hourly data at the time of release, for determining the 8-hour predictors.

(c) all hourly data at eight hours prior to the time of release, for determining the 0-hour predictors.

(d) all hourly data at 0500 or 1700 (0000 or 1200 GMT) following the time of release. This information was used to determine predictors for parameters which are measured only twice daily (CMC 850 mb analysis or radiosonde releases).

(e) all hourly data at 0500 or 1700 prior to the times of release, for linear interpolation with the data of Step (d).

(f) all hourly data at 12 hours prior to the 0500 or 1700 of step (e). Information for this hour was required if 0-hour occurred in the 12 hour GMT interval prior to the interval in which 8-hour occurred.

(g) hourly values of surface wind speed and temperature at a selected surface station for the entire day of the observation. This data is required to estimate temperature profiles for 0-hour and 8-hour from radiosonde data using the Benkley and Schulman (1979) scheme.

All data from parts a to g above for each minisonde and/or piball observation were assembled into a standard format record of 18 120 characters in length. Some comments regarding the selection of data are outlined below:

(a) hourly values of missing data were replaced by linearly interpolated values if data for the preceeding and following hours were present. Otherwise they remained as missing.

(b) Fort McMurray piball data were available from one to three times per day at times close to 0500, 1100, 1700 and 2300 MST. The piball data which appears in each hourly segment above was obtained by searching the three hours preceeding and following the segment hour. If data were not found in this search, then piball data was coded as missing. Thus, piball data used in the analysis are not necessarily data observed in the hour with which they are associated.

(c) In the application of the Benkley and Schulman (1979) scheme, surface winds and temperatures were taken from the Fort McMurray airport.

(5) Calculate predictands and potential predictors

All steps to this point have, with a few exceptions, involved organization of data from which predictands and potential predictors can be obtained.

The data records generated in the previous step by PRESENT are analysed by the FORTRAN/COBOL combination program PREPARE, which calculates all predictands and potential predictors, and then stores them in a standard record format on an output file. Each of these output records contains all wind and/or temperature predictands available and the corresponding potential predictors. There may be up to 12 predictands and up to 54 predictors per record. Each of these records has been marked in a pseudo-random fashion by the program PREPARE so that the file can be divided into two parts in Step 6. There are a total of 2 471 records in this file.

(6) Perform regression analysis

Having obtained the predictands and potential predictors, the remaining tasks in the forecast scheme development were carried out using the program package, SAS.

Preliminary statistics (number of occurrences, mean, maximum value and minimum value) were obtained for each predictand and predictor using the program PROC MEANS. Cross correlations between predictors and between predictors and predictands were generated using the program PROC CORR.

The regression constants, coefficients and statistics were developed using half of the randomly segmented data file with the program STEPWISE. The equations were coded and correlation coefficients calculated using the other, independent half of the data file with the program PROC MEANS.

REFERENCES

Benkley, C.W. and L.L. Schulman. 1979. Estimating hourly mixing depths and historical meteorological data. Journal of Applied Meteorology 18:772-780.

Efroyman, M.A. 1960. Multiple Regression Analysis. Pages 191-203 in A. Raltson and H.S. Wilft, eds. Mathematical methods for digital computers, New York, Wiley.

APPENDIX III: ALPHANUMERIC CODE FOR DESIGNATING PREDICTORS AND PREDICTANDS

A coding scheme for predictands and predictors has been devised to simplify tables in which they appear. Each parameter is represented by a 4 component, 6 character alphanumeric code. The first character specifies the meteorological parameter, the second and third specify location, the fourth and fifth specify the height or level, and the last character specifies relative time of the data. A key for each of the four components is presented in Table 28. Codes which are used throughout tables in the following appendices are defined explicitly in Tables 29 and 30.

Table 28. Components of the alphanumeric code for designation of predictands and predictors.

COMPONENT	CHARACTERS	MEANING
1	A	cloud amount
	C	conventional mixing depth
	G	temperature gradient
	K	kink mixing depth
	S	wind speed
	T	temperature
	U	u-component of wind velocity
	V	v-component of wind velocity
2	CM	Canadian Meteorological Centre
	FM	Fort McMurray airport
	FS	Fort Smith radiosonde station
	ML	Mildred Lake tower
	MP	Syncrude area minisonde and piballs
	SM	Stony Mountain tower
	SP	Stony Plain radiosonde station
	TT	Tall Tower
3	HB	plume height according to Briggs
	HD	plume height according to Djurfors and Netterville
	HS	stack height
	85	850 mb pressure level
	15	152 m above surface
	SF	surface
4	0	0-hour[a]
	8	8-hour[b]

[a] 0-hour is the hour at which a forecast is made
[b] 8-hour is the hour at which a forecast will be valid

Table 29. Alphanumeric codes used for designating wind and temperature predictands.

CODE	PARAMETER	LOCATION	LEVEL	TIME
SMPHS8	Windspeed	Syncrude area	stack top	8-hour[a]
UMPHS8	u-component of velocity	minisondes and piballs	stack top	8-hour
VMPHS8	v-component of velocity		stack top	8-hour
SMPHB8	Windspeed	Syncrude area	plume B[b]	8-hour
UMPHB8	u-component of velocity	minisondes and piballs	plume B	8-hour
VMPHB8	v-component of velocity		plume B	8-hour
SMPHD8	Windspeed	Syncrude area	plume D[c]	8-hour
UMPHD8	u-component of velocity	minisondes and piballs	plume D	8-hour
VMPHD8	v-component of velocity		plume D	8-hour
GMPHS8	Temperature gradient	Syncrude area minisondes	stack top[d]	8-hour
CMP	Conventional mixing depth	and piballs	+[e]	8-hour
KMP	Kink mixing depth		+	8-hour

[a] 8-hour is the hour at which a forecast will be valid
[b] plume height by the Briggs formulation
[c] plume height by the Djurfors-Netterville formulation
[d] stack top means the interval from 183 to 283 m
[e] entry not applicable for this parameter

Table 30. Alphanumeric codes used for designating wind and temperature predictors.

CODE	PARAMETER	LOCATION	LEVEL	TIME
HOUR	hour of day	+[a]	+	+
TIME0	time of day	+	+	0-hour[b]
TIME8	time of day	+	+	8-hour[c]
DAY	day of year	+	+	+
TIMEYR	time of year	+	+	+
SFMSF0	Windspeed	Fort McMurray	surface	0-hour
UFMSF0	u-component of velocity	Fort McMurray	surface	0-hour
VFMSF0	v-component of velocity	Fort McMurray	surface	0-hour
SFMSF8	Windspeed	Fort McMurray	surface	8-hour
UFMSF8	u-component of velocity	Fort McMurray	surface	8-hour
VFMSF8	v-component of velocity	Fort McMurray	surface	8-hour
TFMSF0	Temperature	Fort McMurray	surface	0-hour
TFMSF8	Temperature	Fort McMurray	surface	8-hour
SSMSF0	Windspeed	Stony Mountain	surface	0-hour
USMSF0	u-component of velocity	Stony Mountain	surface	0-hour
VSMSF0	v-component of velocity	Stony Mountain	surface	0-hour
SMLSF0	Windspeed	Mildred Lake	surface	0-hour
UMLSF0	u-component of velocity	Mildred Lake	surface	0-hour
VMLSF0	v-component of velocity	Mildred Lake	surface	0-hour
STT150	Windspeed	Tall Tower	152 m	0-hour
UTT150	u-component of velocity	Tall Tower	152 m	0-hour
VTT150	v-component of velocity	Tall Tower	152 m	0-hour
SCM850	Windspeed	+	850 mb	0-hour
UCM850	u-component of velocity	+	850 mb	0-hour
VCM850	v-component of velocity	+	850 mb	0-hour

continued..

Table 30. Alphanumeric codes used for designating wind and temperature predictors (continued).

Code	Parameter	Location	Level	Time
SCM858	Windspeed	+	850 mb	8-hour
UCM858	u-component of velocity	+	850 mb	8-hour
VCM858	v-component of velocity	+	850 mb	8-hour
SFMHB0	Windspeed	Fort McMurray	plume B[d]	0-hour
UFMHB0	u-component of velocity	Fort McMurray	plume B	0-hour
VFMHB0	v-component of velocity	Fort McMurray	plume B	0-hour
SFMHD0	Windspeed	Fort McMurray	plume D[e]	0-hour
UFMHD0	u-component of velocity	Fort McMurray	plume D	0-hour
VFMHD0	v-component of velocity	Fort McMurray	plume D	0-hour
AFMSF0	Cloud Amount	Fort McMurray	surface	0-hour
GTT150	Temperature Gradient	Tall Tower	90-152 m	0-hour
GFSHS	Temperature Gradient	Fort Smith	stack top	0500[f]
GFSHS0	Temperature Gradient[g]	Fort Smith	stack top	0-hour
GFSHS8	Temperature Gradient[g]	Fort Smith	stack top	8-hour
CFS8	Conventional mixing depth	Fort Smith	+	8-hour

continued..

Table 30. Alphanumeric codes used for designating wind and temperature predictors (continued).

Code	Parameter	Location	Level	Time
GSPHS	Temperature Gradient	Stony Plain	stack top	0500[f]
GSPHS0	Temperature Gradient[g]	Stony Plain	stack top	0-hour
GSPHS8	Temperature Gradient[g]	Stony Plain	stack top	8-hour
CSP8	Conventional mixing depth	Stony Plain	+	8-hour

[a] entry not applicable for this parameter
[b] 0-hour is the hour at which a forecast is made
[c] 8-hour is the hour at which a forecast will be valid
[d] plume height is the Briggs formulation
[e] plume height by the Djurfors-Netterville formulation
[f] morning radiosonde sounding
[g] temperature gradient derived using the scheme of Benkley and Schulman

APPENDIX IV: TESTS FOR LINEAR DEPENDENCE BETWEEN PREDICTORS AND PREDICTANDS RELATING TO WIND AND TEMPERATURE

Tests were made for linear dependence between all pairs of predictors, and between all predictors and each predictand. These tests are defined below. Results are presented in the figures which follow. The coding scheme for these tables has been explained in the tables of Appendix III.

Goodness of the Relation

A measure of the degree of linear dependence between two variables, X and Y, is given by the product-moment correlation, r, where:

$$r = \frac{\sum_{j=1}^{n} (x_j - x)\,(y_j - y)}{\left[\sum_{j=1}^{n} (x_j - x)^2 \sum_{j=1}^{n} (y_j - y)^2\right]^{1/2}} \qquad (13)$$

Values of r range from +1 to -1, where the sign indicates whether or not the relationship is direct or indirect. The square of the product moment coefficient gives the proportion of variance in Y that can be attributed to its relation with X. It should be noted that a high value of r does not necessarily indicate a causal relationship between X and Y.

Significance of the Relationship

The significance level associated with a relationship having a product-moment correlation coefficient of r can be obtained using the t-statistic where:

$$t = \frac{r\ (n-2)^{1/2}}{(1-r^2)^{1/2}} \qquad (14)$$

The number of (x,y) pairs considered in the calculation of r is given by n.

The t-statistic is used to test how representative the sample from which r has been calculated is of the entire population. For samples with a given number of degrees of freedom, (n-2), the probability of that sample being representative of the entire population increases for larger values of t.

Results

Product-moment correlation coefficients, r, were calculated between all pairs of predictors and between predictands and predictors using 2 471 observations which were prepared for development and testing of the forecast scheme.

Absolute values of r calculated among predictors are tabulated in Figure 8. The highest values appear for predictors correlated with themselves, which is to be expected. Large r values appear between winds at the two plume heights, and between plume height winds and winds at 850 mb. Relatively larger values also appear between winds at Stony Mountain and at Mildred Lake, Tall Tower 850 mb and plume heights.

Absolute values of r calculated between predictands and predictors are tabulated in Figure 9. Large values of r occur most frequently between wind predictands and winds at 850 mb and Stony Mountain. The values of r between temperature predictands and predictors are not very high.

Significance levels were calculated by the t-test for each product-moment correlation coefficient. A significance level of 0.01 percent, as determined by the t-test, was associated with all absolute values of r greater than 0.27 (for many variables, significance levels of 0.01 percent were associated with absolute values of r lower than 0.10). This means that in figures 9 and 10, all pairs of parameters with a non blank entry have a significance level of 0.01 percent associated with the product-moment correlation coefficient.

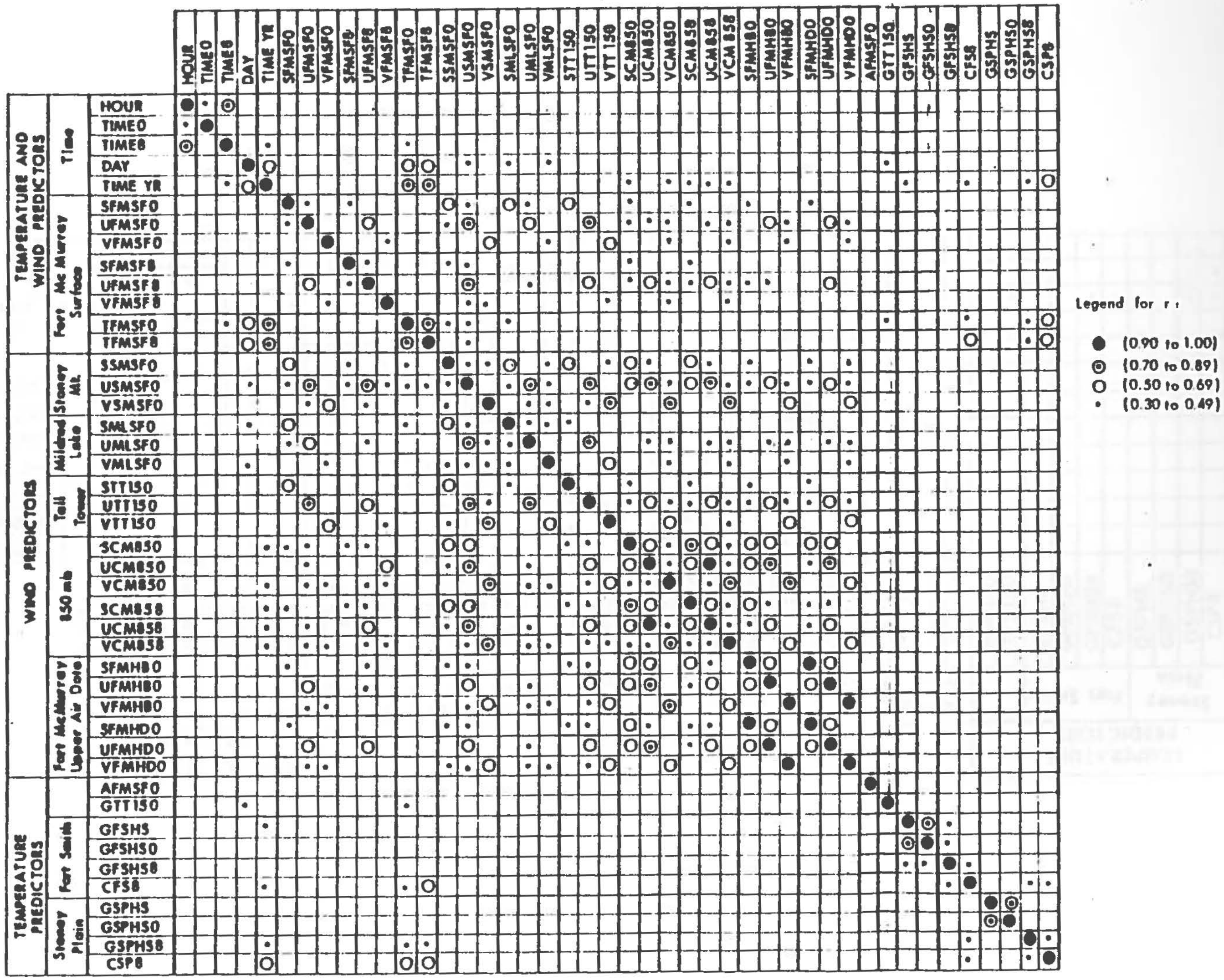


Figure 8. Product-moment correlation coefficients, r, between wind and temperature predictors.

			SMPHS8	UMPHS8	VMPHS8	SMPHB8	UMPHB8	VMPHB8	SMPHD8	UMPHD8	VMPHD8	GMPHS8GHS	CMP	KMP
TEMPERATURE AND WIND PREDICTORS	Time	HOUR												
		TIMEO												
		TIME8												
		DAY												
		TIME YR											•	
	Fort Mc Murray Surface	SFMSFO												
		UFMSFO		•			•			•				
		VFMSFO			•			•			•			
		SFMSF8	•			•			•			•		
		UFMSF8		○			○			○				
		VFMSF8			○			•			•			
		TFMSFO											•	
		TFMSF8											•	
WIND PREDICTORS	Stoney Mt.	SSMSFO	•			•			•					
		USMSFO		○			○			⊙				
		VSMSFO		•	○			○			○			
	Mildred Lake	SMLSFO												
		UMLSFO		•						•				
		VMLSFO			•						•			
	Tall Tower	STT150	•						•					
		UTT150		○			•			•				
		VTT150			○			•			•			
	850 mb	SCM850	•						•					
		UCM850		○			○		•	○				
		VCM850						•			•			
		SCM858	•			○	•		○					
		UCM858		○		•	○		•	○				
		VCM858		•	•			○			○			
	Fort McMurray Upper Air Data	SFMHBO				•			•					
		UFMHBO		•			•			•				
		VFMHBO			•			•			•			
		SFMHDO				•			•					
		UFMHDO		•			•			•				
		VFMHDO			•			•			•			
TEMPERATURE PREDICTORS		AFMSFO												
		GTT150										•		
	Fort Smith	GFSHS												
		GFSHSO												
		GFSHS8										•		
		CFS8										•		
	Stoney Plain	GSPHS												
		GSPHSO												
		GSPHS8										•	•	
		CSP8										•	•	

Legend for r :

● (0.90 to 1.00)
⊙ (0.70 to 0.89)
○ (0.50 to 0.69)
• (0.30 to 0.49)

Figure 9. Product-moment correlation coefficients, r, between wind and temperature predictands and predictors.

APPENDIX V: EVALUATION OF GOODNESS AND SIGNIFICANCE OF REGRESSION EQUATIONS

GOODNESS OF THE EQUATION

A measure of the goodness of the equation for estimating $\hat{Y}$ is the multiple correlation coefficient R, where:

$$R^2 = 1 - \frac{SE^2}{\sigma^2} \tag{15}$$

SE = standard error of estimate

σ = standard deviation of predictand

The square of the correlation coefficient as given by equation (14) is the fractional part of the variation of Y about its mean value, Y that is "explained" by the regression equation.

SIGNIFICANCE OF THE RELATIONSHIP

A measure of the significance of a relationship for estimating $\hat{Y}$ from several predictors is given by the F statistic.

$$F = \frac{SS_R/DF_R}{SS_E/DF_E} \tag{16}$$

where SS_R = sum of squares of deviations of predicted values from the mean observed value (sum of squares due to regression)

DF_R = degrees of freedom associated with SS_R (DF_R = number of independent variables)

SS_E = sum of squares of deviations of predicted values from corresponding observed values (sum of squares about regression, residual sum of squares)

DF_E = degrees of freedom assocated with SS_E (DF_E = n-2)

mathematically:

$$SS_R = \sum_{j=1}^{n} (\hat{y}_j - \bar{y})^2 \tag{17}$$

$$SS_E = \sum_{j=1}^{n} (y_j - \hat{y}_j)^2 \tag{18}$$

The F statistic represents a ratio of the portion of variance explained by regression to the portion of unexplained variance. It can be used as a test of dependence between a predictand and several predictors. The magnitude of F, in conjunction with a probability of occurrence distribution of F values, represents a measure of random variation within a sample of data. The probability of obtaining a calculated F value by chance becomes small as F becomes larger. Thus the probability is a measure of confidence associated with $\hat{Y}$ and the regression coefficients A_i. Complete discussions and statistical theory concerning the F distribution are presented by McNeil et al (1975) and by Draper and Smith (1978).

A measure of the significance of one predictor, X_i, in the relationship for predicting $\hat{Y}$ is given by the partial F statistic, F_p:

$$F_p = \frac{(SS_R\ (X_i) - SS_R\ (X_{i-1}))/DF_R}{SS_E/DF_E} \tag{18}$$

where $SS_R(X_i)$ = sum of squares due to regression when X_i is included

$SS_R(X_{i-1})$ = sum of squares due to regression when X_i is not included

The partial F statistic can be used to determine the relative significance of each variable within the regression equation. It is useful as a criterion for adding or removing variables from the equation during the development phase of the forecast scheme.

REFERENCES

Draper, N.R. and H. Smith. 1968. Applied regression analysis, John Wiley & Sons Inc., New York, First Corrected Printing.

McNeil, K.A., F.J. Kelly and J.T. McNeil. 1975. Testing research hypotheses using multiple linear regression, Southern Illinois University Press, Carbondale and Edwardsville.

APPENDIX VI: FORECAST DEVELOPMENT FOR WIND PREDICTANDS - STATISTICS AND SELECTED PREDICTORS FOR TEST CASES

Table 31. Key for statistics used in following tables.

STATISTIC	DEFINITION
Case	Test case number as defined in body of report
N	number of data on which regression analysis is based
R^2	square of multiple correlation coefficient as defined in Appendix I (equation 14)
DF_R	degrees of freedom associated with sum of squares due to regression
DF_E	degrees of freedom associated with residual sum of squares
F	F-statistic as defined in Appendix I (equation 15)
α_F	significance level associated with F
α_{FP}	the largest significance level associated with the partial F (equation 18) values calculated for each predictor included in the regression equation

Table 32. Statistics for windspeed at stack height.

STATISTIC	CASE 1	2	3	4
N	150	481	544	1202
R^2	0.54	0.50	0.50	0.43
DF_R	6	10	10	9
DF_E	143	470	533	1192
F	27.8	47.8	52.6	99.6
α_F	0.0001	0.0001	0.0001	0.0001
α_{FP}	0.0861	0.1425	0.0466	0.0239

Table 33. Statistics for u component of wind velocity at stack height.

STATISTIC	CASE 1	2	3	4
N	150	481	544	1202
R^2	0.80	0.56	0.55	0.52
DF_R	9	10	9	9
DF_E	140	470	534	1192
F	61.7	59.1	71.8	141.2
α_F	0.0001	0.0001	0.0001	0.0001
α_{FP}	0.1377	0.0448	0.0224	0.0117

Table 34. Statistics for v-component of wind velocity at stack height.

STATISTIC	CASE 1	2	3	4
N	150	481	544	1202
R^2	0.64	0.54	0.53	0.47
DF_R	10	10	10	8
DF_E	139	470	533	1193
F	25.1	55.8	60.5	132.5
α_F	0.0001	0.0001	0.0001	0.0001
α_{FP}	0.1125	0.0025	0.0142	0.0217

Table 35. Statistics for windspeed at plume height by Briggs.

STATISTIC	CASE 1	2	3	4
N	150	481	546	1112
R^2	0.65	0.56	0.54	0.38
DF_R	10	10	7	7
DF_E	139	470	538	1104
F	25.4	60.3	89.0	96.4
α_F	0.0001	0.0001	0.0001	0.0001
α_{FF}	0.0654	0.0452	0.0796	0.0007

Table 36. Statistics for u-component of wind velocity at plume height by Briggs.

STATISTIC	CASE 1	CASE 2	CASE 3	CASE 4
N	150	481	546	1112
R^2	0.85	0.58	0.58	0.51
DF_R	10	10	10	7
DF_E	139	470	535	1104
F	76.6	65.8	73.8	167.0
α_F	0.0001	0.0001	0.0001	0.0001
α_{FP}	0.0188	0.0827	0.0148	0.0028

Table 37. Statistics for v-component of wind velocity at plume height by Briggs.

STATISTIC	CASE 1	CASE 2	CASE 3	CASE 4
N	150	481	546	1112
R^2	0.83	0.58	0.56	0.41
DF_R	8	10	10	6
DF_E	141	470	535	1105
F	88.8	64.1	68.4	127.0
α_F	0.0001	0.0001	0.0001	0.0001
α_{FP}	0.0505	0.0298	0.0057	0.0013

Table 38. Statistics for windspeed at plume height by Djurfors-Netterville.

STATISTIC	CASE 1	2	3	4
N	150	481	544	1108
R^2	0.55	0.53	0.52	0.42
DF_R	6	10	9	7
DF_E	143	470	534	1100
F	29.2	52.1	63.8	112.3
α_F	0.0001	0.0001	0.0001	0.0001
α_{FP}	0.1480	0.1476	0.0769	0.0001

Table 39. Statistics for u-component of wind velocity at plume height by Djurfors-Netterville.

STATISTIC	CASE 1	2	3	4
N	150	481	544	1108
R^2	0.83	0.59	0.59	0.52
DF_R	8	10	10	8
DF_E	141	470	533	1099
F	86.2	66.3	75.1	148.6
α_F	.0001	.0001	.0001	.0001
α_{FP}	.0118	.0939	.0184	.0009

Table 40. Statistics for v-component of wind velocity at plume height by Djurfors-Netterville.

STATISTIC	CASE			
	1	2	3	4
N	150	481	544	1108
R^2	0.78	0.55	0.54	0.45
DF_R	7	10	10	6
DF_E	142	470	533	1101
F	72.4	57.7	62.7	151.5
α_F	0.0001	0.0001	0.0001	0.0001
α_{FP}	0.1240	0.0161	0.0169	0.0062

			Wind Speed Case 1	Wind Speed Case 2	Wind Speed Case 3	Wind Speed Case 4	U-Component of Velocity Case 1	U-Component of Velocity Case 2	U-Component of Velocity Case 3	U-Component of Velocity Case 4	V-Component of Velocity Case 1	V-Component of Velocity Case 2	V-Component of Velocity Case 3	V-Component of Velocity Case 4
TEMPERATURE AND WIND PREDICTORS	Time	HOUR	///	///	///	///	///	///	///	///	///	///	///	///
		TIME0		●	●	●	●	●	●	●	●	●	●	●
		TIME8				●					●	●	●	●
		DAY	///	///	///	///	///	///	///	///	///	///	///	///
		TIME YR				●	●	●	●	●	●			
	Fort Mc Murray Surface	SFMSF0					●	●						
		UFMSF0												
		VFMSF0				●				●			●	●
		SFMSF8	●	●	●	●								
		UFMSF8		●	●		●	●	●	●				●
		VFMSF8		●	●			●	●	●	●	●	●	●
		TFMSF0	●	●	●	●								
		TFMSF8		●	●	●			●					
WIND PREDICTORS	Stoney Mt.	SSMSF0		///	///	///		///	///	///		///	///	///
		USMSF0		///	///	///		///	///	///		///	///	///
		VSMSF0		///	///	///		///	///	///		///	///	///
	Mildred Lake	SMLSF0	●	●		///		●		///				///
		UMLSF0				///				///		●	●	///
		VMLSF0	●	●	●	///				///	●	●	●	///
	Tall Tower	STT150			///	///			///	///			///	///
		UTT150			///	///		●	///	///	●		///	///
		VTT150			///	///	●		///	///		●	///	///
	850 mb	SCM850												
		UCM850		●		●	●	●	●	●				
		VCM850				●			●					
		SCM858	●	●	●	●				●				●
		UCM858			●					●	●	●	●	●
		VCM858					●	●		●	●	●	●	●
	Fort McMurray Upper Air Data	SFMHB0				///				///				///
		UFMHB0				///	●		●	///	●			///
		VFMHB0		●	●	///		●	●	///		●	●	///
		SFMHD0	●			///				///				///
		UFMHD0				///				///				///
		VFMHD0				///	●			///	●	●	●	///

● Predictor selected for inclusion in a regression equation

/// Predictor not included in regression analysis

Figure 10. Predictors included in final regression equation for winds at stack height.

			Wind Speed Case 1	2	3	4	U-Component of Velocity Case 1	2	3	4	V-Component of Velocity Case 1	2	3	4
TEMPERATURE AND WIND PREDICTORS	Time	HOUR	///	///	///	///	///	///	///	///	///	///	///	///
		TIME0											●	
		TIME8		●		●			●	●	●	●		●
		DAY	///	///	///	///	///	///	///	///	///	///	///	///
		TIME YR		●	●	●			●	●		●	●	●
	Fort Mc Murray Surface	SFMSF0		●			●					●		
		UFMSF0												
		VFMSF0	●							●				
		SFMSF8	●	●	●	●	●							
		UFMSF8					●	●	●	●		●	●	●
		VFMSF8						●		●	●	●	●	●
		TFMSF0		●	●	●			●					
		TFMSF8			●				●				●	
WIND PREDICTORS	Stoney Mt.	SSMSF0		///	///	///		///	///	///		///	///	///
		USMSF0		///	///	///		///	///	///		///	///	///
		VSMSF0		///	///	///		///	///	///	●	///	///	///
	Mildred Lake	SMLSF0		●		///		●	●	///				///
		UMLSF0				///		●		///				///
		VMLSF0				///				///		●	●	///
	Tall Tower	STT150	●		///	///		●	///	///			///	///
		UTT150		●	///	///	●	●	///	///			///	///
		VTT150			///	///	●		///	///		●	///	///
	850 mb	SCM850	●					●	●			●		
		UCM850				●	●				●			
		VCM850			●	●	●	●						
		SCM858	●	●	●	●				●			●	
		UCM858			●		●	●	●	●	●			●
		VCM858	●	●	●				●	●	●	●	●	●
	Fort McMurray Upper Air Data	SFMHB0			///	///			///	///			///	///
		UFMHB0			///	///			///	///			///	///
		VFMHB0			///	///			///	///			///	///
		SFMHD0				///		●	●	///	●		●	///
		UFMHD0				///				///				///
		VFMHD0		●	●	///				///		●	●	///

● Predictor selected for inclusion in a regression equation

/// Predictor not included in regression analysis

Figure 11. Predictors included in final regression equation for winds at Briggs plume height.

			Wind Speed Case 1	Wind Speed Case 2	Wind Speed Case 3	Wind Speed Case 4	U-Component of Velocity Case 1	U-Component of Velocity Case 2	U-Component of Velocity Case 3	U-Component of Velocity Case 4	V-Component of Velocity Case 1	V-Component of Velocity Case 2	V-Component of Velocity Case 3	V-Component of Velocity Case 4
TEMPERATURE AND WIND PREDICTORS	Time	HOUR	///	///	///	///	///	///	///	///	///	///	///	///
		TIME0	●				●	●	●				●	
		TIME8		●	●	●				●	●			●
		DAY	///	///	///	///	///	///	///	///	///	///	///	///
		TIME YR		●	●	●	●	●	●	●	●	●	●	●
	Fort Mc Murray Surface	SFMSF0					●		●			●		
		UFMSF0										●		
		VFMSF0	●							●				
		SFMSF8	●	●	●	●	●							
		UFMSF8					●	●	●	●			●	●
		VFMSF8			●			●	●	●	●	●	●	●
		TFMSF0		●	●	●								
		TFMSF8							●				●	
WIND PREDICTORS	Stoney Mt.	SSMSF0		///	///	///		///	///	///		///	///	///
		USMSF0		///	///	///		///	///	///		///	///	///
		VSMSF0		///	///	///		///	///	///		///	///	///
	Mildred Lake	SMLSF0	●			///				///				///
		UMLSF0	●			///				///				///
		VMLSF0				///				///		●	●	///
	Tall Tower	STT150			///	///		●	///	///			///	///
		UTT150	●		///	///	●	●	///	///			///	///
		VTT150			///	///			///	///		●	///	///
	850 mb	SCM850	●					●	●			●	●	
		UCM850	●			●	●					●		
		VCM850				●		●	●					
		SCM858	●	●	●	●					●			
		UCM858					●	●	●	●				●
		VCM858	●	●	●					●	●	●	●	●
	Fort McMurray Upper Air Data	SFMHB0		●		///			●	///			●	///
		UFMHB0				///				///				///
		VFMHB0		●		///				///	●		●	///
		SFMHD0		●	///	///		●	///	///	●		///	///
		UFMHD0			///	///	●		///	///			///	///
		VFMHD0		●	///	///			///	///	●	●	///	///

● Predictor selected for inclusion in a regression equation

/// Predictor not included in regression analysis

Figure 12. Predictors included in final regression equation for winds at Djurfors-Netterville plume height.

APPENDIX VII: FORECAST SCHEME DEVELOPMENT FOR TEMPERATURE PREDICTANDS - STATISTICS AND SELECTED PREDICTORS FOR TEST CASES

The parameters used in the following tables are defined in Table 31 of Appendix VI.

Table 41. Statistics for temperature gradient at stack height (183 to 283 m).

STATISTIC	CASE				
	1	2	3	4	5
N	115	314	530	1210	1210
R^2	0.31	0.28	0.27	0.29	0.20
DF_R	3	6	7	7	3
DF_E	111	307	522	1202	1206
F	16.4	20.2	27.3	71.0	97.8
α_F	0.0001	0.0001	0.0001	0.0001	0.0001
α_{FP}	0.0530	0.0850	0.0171	0.0001	0.1081

Table 42. Statistics for conventional mixing height.

STATISTIC	CASE 1	2	3	4	5
N	55	150	59	158	158
R^2	0.46	0.30	0.43	0.26	0.23
DF_R	5	5	3	2	1
DF_E	49	144	55	155	156
F	8.4	12.2	13.7	26.5	46.7
α_F	0.0001	0.0001	0.0001	0.0001	0.0001
α_{FP}	0.1110	0.1270	0.0907	0.0260	0.0001

Table 43. Statistics for kink mixing height.

STATISTIC	CASE 1	2	3	4	5
N	60	143	62	151	151
R^2	0.57	0.29	0.36	0.18	0.06
DF_R	7	7	3	4	1
DF_E	52	135	58	146	149
F	10.0	7.8	10.6	8.3	9.9
α_F	0.0001	0.0001	0.0001	0.0001	0.0020
α_{FP}	0.0834	0.1389	0.1109	0.1199	0.0020

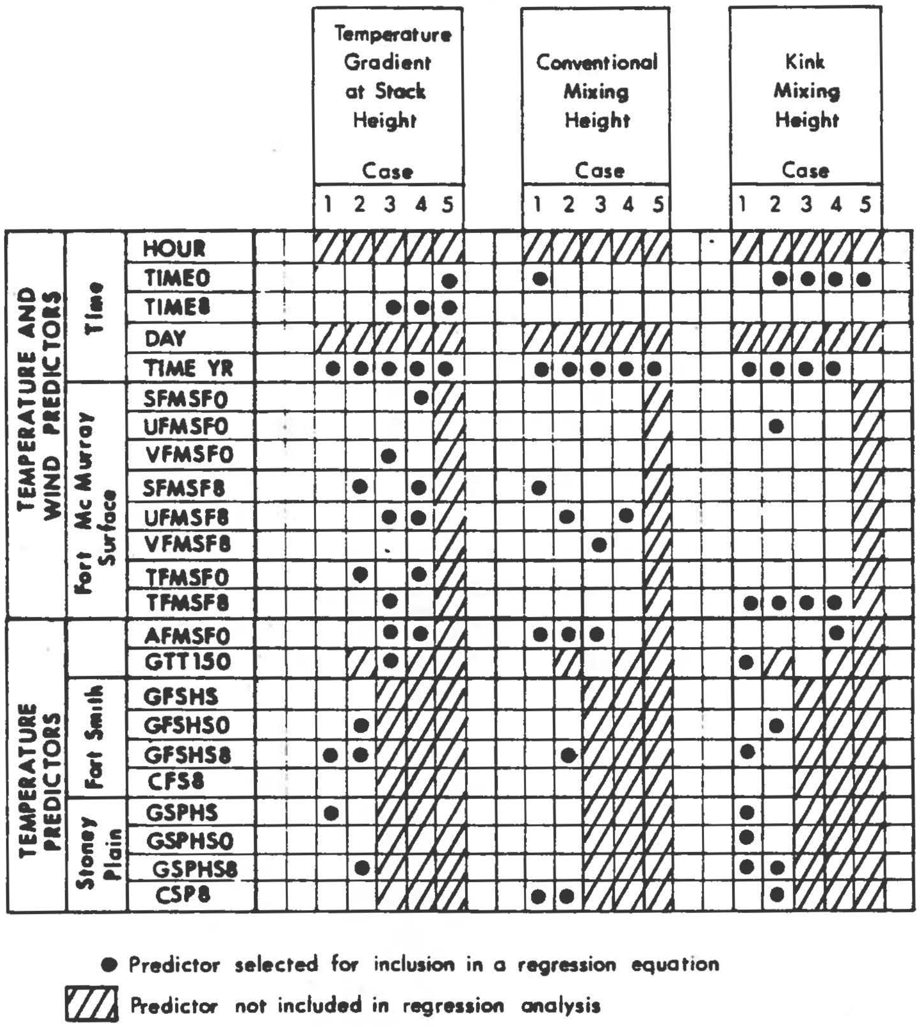
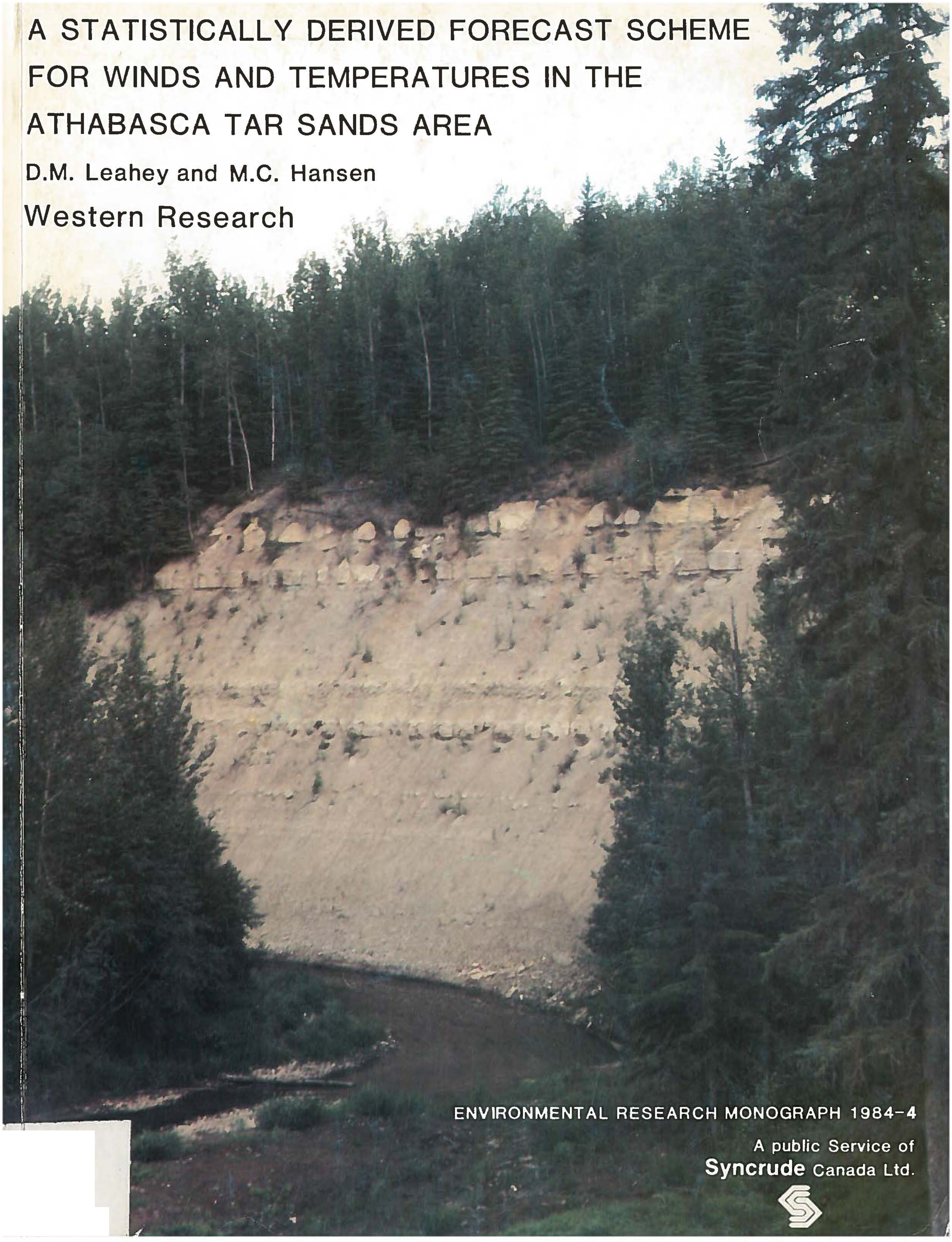


Figure 13. Predictors included in a final regression equation for temperature predictands.

A STATISTICALLY DERIVED FORECAST SCHEME FOR WINDS AND TEMPERATURES IN THE ATHABASCA TAR SANDS AREA

D.M. Leahey and M.C. Hansen

Western Research



ENVIRONMENTAL RESEARCH MONOGRAPH 1984-4

A public Service of
Syncrude Canada Ltd.