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M.E.P. Company

THE VERTICAL WIND PROFILE AT MILDRED LAKE, ALBERTA

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SUMMARY

A study of the winds of the Alberta Tar Sands region was performed by the MEP Company from 1974 to 1976. The objectives of this study were to establish the wind climatology of the region in order to predict the dispersion of emissions from the Syncrude plant. Detailed studies of the vertical, horizontal and diurnal variation of the wind velocity were performed.

The raw data consisted of pibal and minisonde soundings taken at least twice daily during the period of the field experiment. In addition, three periods of intensive studies, one during the winter and two during the summer, were performed. The field results were transformed into vertical profiles of the temperature, potential temperature, and wind velocity.

Two models of the vertical profile of the wind, a power law model and a geostrophic model, were evaluated. The power law model was generally the better model in that it produced smaller RMS errors more often than the geostrophic model. The geostrophic model was more successful during winter limited mixing.

Several levels were tested as a reference height for the power law. The best height was found to be 183 metres. The exponent of the power law varied considerably with the stability, while the actual reference height used made relatively little difference, considering the entire data set.

The diurnal variation of the wind was found to have typical characteristics. Surface winds had maximum values at the time of maximum heating and minimum values during mid-morning.

Plume layer winds had maximum values in early morning and late afternoon, with minimum values at the time of maximum heating.

The wind profile during limited mixing could be approximated by an unstable ground based layer capped by a stable layer. The wind speed was approximately constant up to the mixing height.

Low level jets were found, most commonly from 200 to 500m, where they could have a significant effect on the plume. The height of the jets did not correlate well with the mixing height or the inversion height, although the jets occur most often near those heights.

The simultaneous winds at the C-13 (Shell) and C-17 (Syncrude) leases were qualitatively compared. Little correlation was found between the wind speeds at the two locations, but the directions generally agreed to within ninety degrees.

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LIST OF SYMBOLS

x	- horizontal space coordinate
y	- horizontal space coordinate
z	- vertical space coordinate
Z_0	- roughness length
Z_r	- reference height
u	- velocity component in x direction
v	- velocity component in y direction
V	- mean wind speed
V_r	- wind speed at reference height
$V(z)$	- mean wind speed at height z
G	- geostrophic wind speed
u_*	- friction velocity
p	- pressure
ρ	- air density
f	- coriolis parameter
k	- von Karman's constant
h	- height of Ekman layer
β	- exponent of power law
A	- arbitrary constant
B	- constant of integration
r	- correlation coefficient
Δ	- absolute (RMS) error
δ	- relative error
α	- wind deviation angle
L	- mixing height
H	- height of top of inversion layer

INTRODUCTION

An atmospheric sounding program was conducted by the MEP Company in the Athabasca Tar Sands, from September 1974 to September 1976, for the purpose of establishing a climatology of the area. The climatological statistics resulting from this study would be applied to the prediction of air quality effects due to emissions from the Syncrude plant.

The vertical variation of wind velocity is an important factor in atmospheric dispersion due to its effects on the horizontal trajectory and surface concentration of effluents. For modeling the ground concentrations of pollutants, a predictive model of the vertical structure of the wind allows savings of time and computer storage over the use of discrete wind values. To the objective of developing a predictive model of the vertical wind profile, the following points are examined in this study:

1. to test physical and empirical models.
2. to determine a reference height and the relation to roughness length
3. to investigate the variation of surface and upper winds during the day
4. to determine the effects of non-homogeneous temperature stratification and limited mixing
5. to investigate the existence of low level jets
6. to compare wind data from leases C-13 and C-17

This report concerns the results of the data obtained from two minisonde stations; the C-13 (Shell) station, which began operation in late September 1974, and the C-17 (Syncrude) station, which commenced in February, 1975. Vertical profiles of temperature and wind speed and direction were obtained at least twice daily at each station.

At the C-17 station, three periods of intensive releases were carried out during the winter of 1975 and during the summers of 1975 and 1976. These periods were 6 February 1975 to 21 February 1975, 28 July 1975 to 09 August 1975, and 14 July 1976 to 30 September 1976. During these periods, from four to seven soundings were performed daily.

This report will be concerned chiefly with data from the C-17 releases. A total of 1238 soundings were obtained during the experimental period. The raw data consisted of theodolite measurements of balloon azimuth and elevation, as well as minisonde temperature readings. The balloons were assumed to rise at a constant rate, from 128 m s^{-1} to 170 m s^{-1}, determined by the weight of the balloon and minisonde. The accuracy of this assumption was tested during the intensive study periods by double theodolite tracking, and is discussed in the report "A Predictive Study of the Dispersion of Emissions from the Syncrude Mildred Lake Plant" 1976. The conclusions of the testing were that a single theodolite technique which assumed a constant balloon ascent rate gave results that agreed with double theodolite tracking measurements. The data of this report is derived entirely from single theodolite balloon tracking. Coordinates were usually obtained every 30 seconds. On 13 August, 1976 the sampling interval was reduced to 15 seconds. Tracking the balloon continued for 15 minutes, or until the balloon was lost. Due to staff requirements, the minisonde and pibal were occasionally released separately. The times of the two ascents may differ by up to one hour in these situations.

The raw data were then computer processed into vertical profiles of wind speed, wind direction, temperature, and potential temperature. The soundings were classified into cases of limited mixing, zero mixing and unlimited mixing depending on the structure of the temperature profile. The mixing height and top of the inversion were determined by a conventional method for the appropriate cases. The mixing height is taken as the height at which a dry adiabat through the surface temperature intersects the temperature profile. A direction for each sounding was determined by averaging the wind direction from 200 m to 600 m. This direction does not necessarily correspond to the surface wind direction, the geostrophic wind direction, or the mean wind direction in the boundary layer. However, it may be a representative value of the wind direction in the plume layer. The change in wind direction in this layer was generally less than 45 degrees.

These resulting data were then studied with the previously mentioned objectives in mind. Sources of error to this point arise from errors in reading the theodolite angles. These errors will cause uncertainties in the calculated balloon position which will increase with height. Some errors originate from the computer processing due to coding mistakes, but these tend to be extreme values and can be corrected.

PREVIOUS WIND STUDIES IN THE TAR SANDS

The results of an atmospheric sounding project in the Tar Sands region were the subject of a previous report (Environmental Research Monograph 1976-1 A Predictive Study of the Dispersion of Emissions from the Syncrude Mildred Lake Plant). That report discussed soundings taken at the C-13 and C-17 leases in 1974 and 1975 for the purpose of establishing the climatology of the region. Some of the results are applicable to this report.

Comparing the winds at leases C-13 and C-17, it was found that the wind directions in the layer 200 - 400 metres were the same at both sites. The mean wind speeds also were comparable with morning and afternoon speeds of 6.7 and 5.9 m s^{-1} at C-17 compared to 5.8 and 5.8 m s^{-1} at C-13. Local low-level variations were interpreted to reflect circulation patterns induced by the valley. A down-slope wind dominated in winter as opposed to an upslope wind in summer.

Mean wind speeds in the plume layer were about 6 m s^{-1} and did not vary seasonally. Wind speeds were slightly higher at C-17 in the spring and summer.

Wind directions varied seasonally. In the spring, the flow was generally up or down the valley, that is, northerly or southerly. In summer, the winds were from the southwest quadrant. Fall winds were westerly or southwesterly. Winter winds were from every direction but east.

THE WIND BELOW THE GRADIENT LEVEL

Very near the surface of the earth, the wind speed is zero, due to the frictional effects of the surface. At upper levels, generally above about 1 kilometre, the wind is geostrophic and is described by the balance of the pressure gradient force and the coriolis force. Between these two levels, known as the boundary layer, the behaviour of the wind is more complex and is influenced by several factors, such as surface roughness and air stability.

The stability of the air in the boundary layer is largely determined by radiant energy to and from the ground. At night, the surface radiates heat more rapidly than the air and cools to a lower temperature than the lowest layer of the atmosphere. This lowest layer cools by conduction of heat to the ground. The potential temperature tends to increase with height and an inversion, or layer of stable air, forms. When the sun rises, the ground heats up rapidly and warms the lowest layer of the atmosphere. The potential temperature profile is modified so that a warmer lower layer lies below a cooler layer. The profile is then unstable and vertical motion and turbulent flow results. Since snow is a poor absorber and radiator of heat, compared to the ground, inversion breakups are less extreme in the winter than in the summer.

The wind speed in the boundary layer varies with height and stability. It generally increases, due to decreasing influence of friction, to about one kilometre, where it becomes geostrophic. The rate of change of the wind with height varies with the stability of the air. For stable air, the wind speed increases rapidly with height. In unstable air, turbulence distributes the momentum of the air more evenly across all layers and the wind speed tends to be constant with height. Figure 1 shows examples of wind speed profiles for various air stabilities.

The direction of the wind may also be variable in the boundary layer. Factors influencing the wind direction include the pressure gradient force, coriolis force, and eddy-viscosity forces. Near the surface, the wind vector points towards the low pressure. The vector rotates with increasing altitude until it is parallel to the geostrophic wind at the gradient level. Figure 2 shows an example of the variation of the wind direction with altitude.

Figure 1 . Wind speed profiles for various atmospheric stabilities.

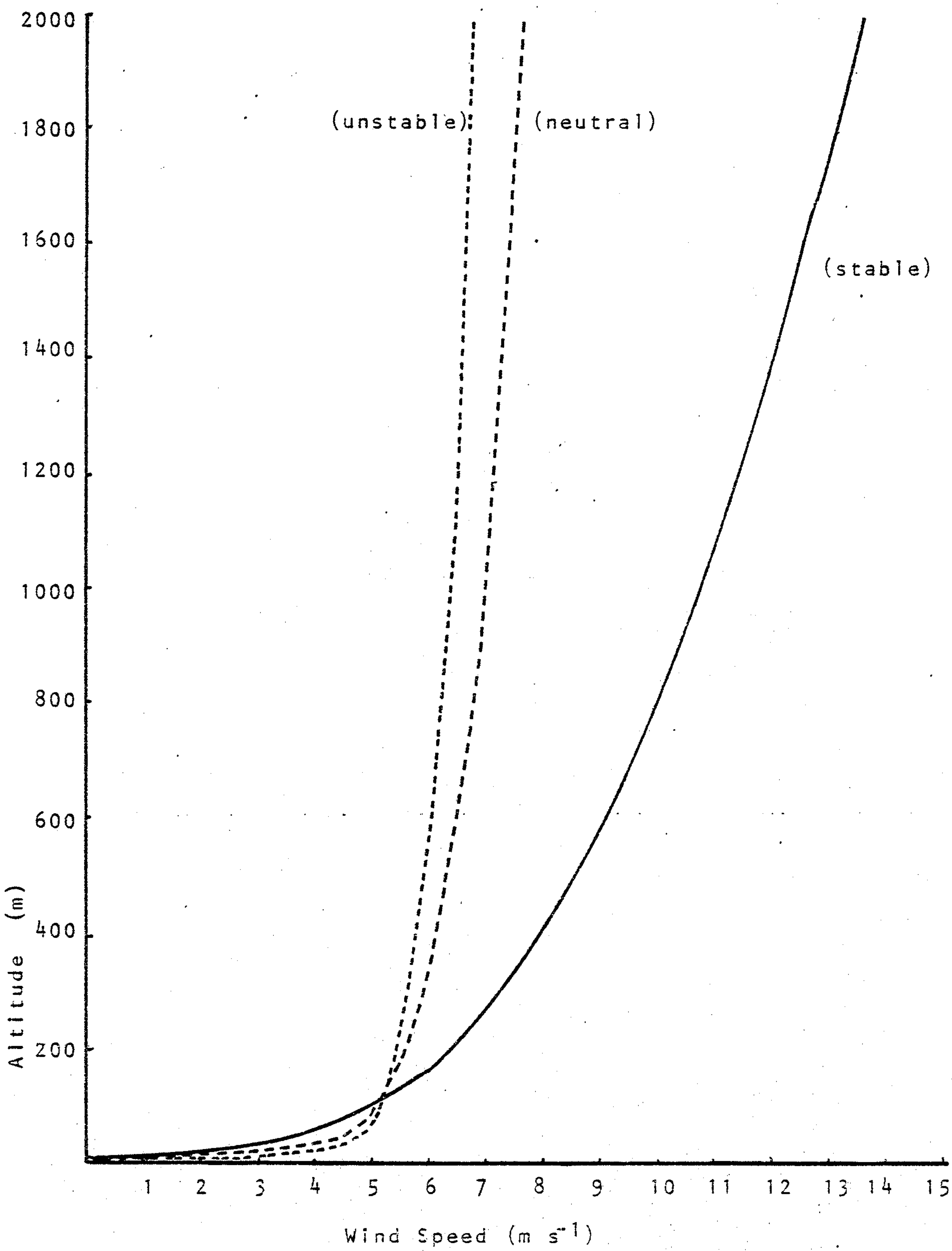
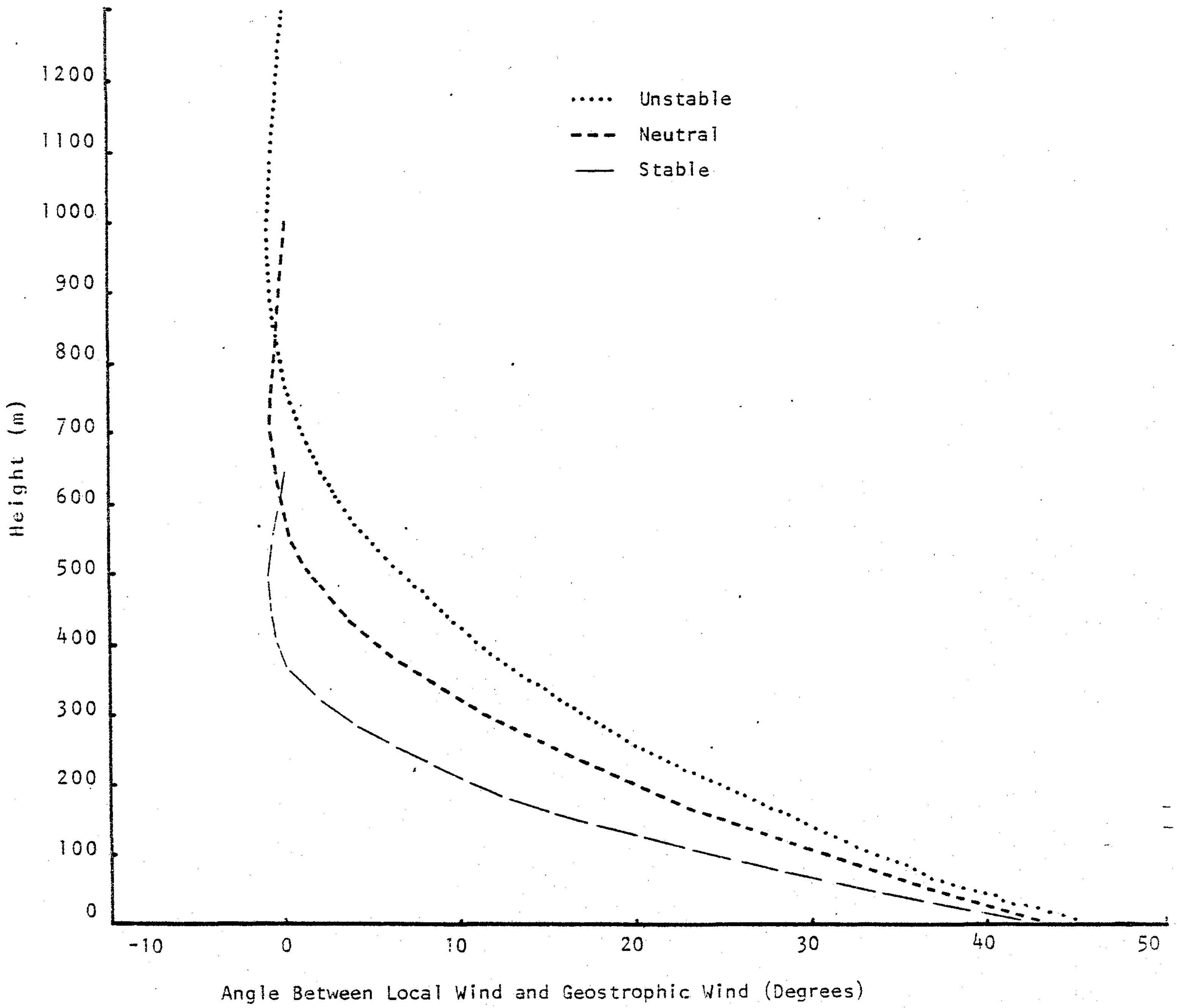


Figure 2 . Change in wind direction with height for different stabilities



MODELS AND EQUATIONS

Two models of the wind speed vertical profile are examined in this report. One is an empirically derived power law of the form

$$V(Z) = V_r(Z/Z_r)^{\beta} \tag{1}$$

where V_r is the wind speed at a reference height Z_r. The value of β increases with increasing stability and is about 1/7 for neutral conditions. This model has the advantage that the effects of stability and to some extent, mechanical turbulence, are included. A disadvantage is that V(Z) increases indefinitely with Z, rather than approaching the geostrophic value at the gradient level.

A model which used different physical arguments is described by Brown (1974). An outer, viscous-coriolis force balance is matched to an inner logarithmic layer in this model. In the matching layer, it is basically a logarithmic wind profile given by

$$V(Z) = U_*(\ln(Z/Z_b)\ /k \tag{2}$$

with the side conditions:

$$U_G/U_* = (\ln(U_*/fZ_b)-A)/k \tag{3}$$

$$V_G/U_* = -B/k \tag{4}$$

where V(Z) is the wind speed at a height Z. U_* is the friction velocity, k is von Karman's constant, Z_b is a characteristic length for the matched layer. U_G is the component of the geostrophic wind parallel to the surface wind, V_G is the perpendicular component, f is the coriolis parameter and A and B are empirical constants. The geostrophic wind is assumed to be constant with height. In the matched layer where equation 2 applies, Z is small compared to U_*/f and large compared to Z_b.

Equations 3 and 4 can be combined to give

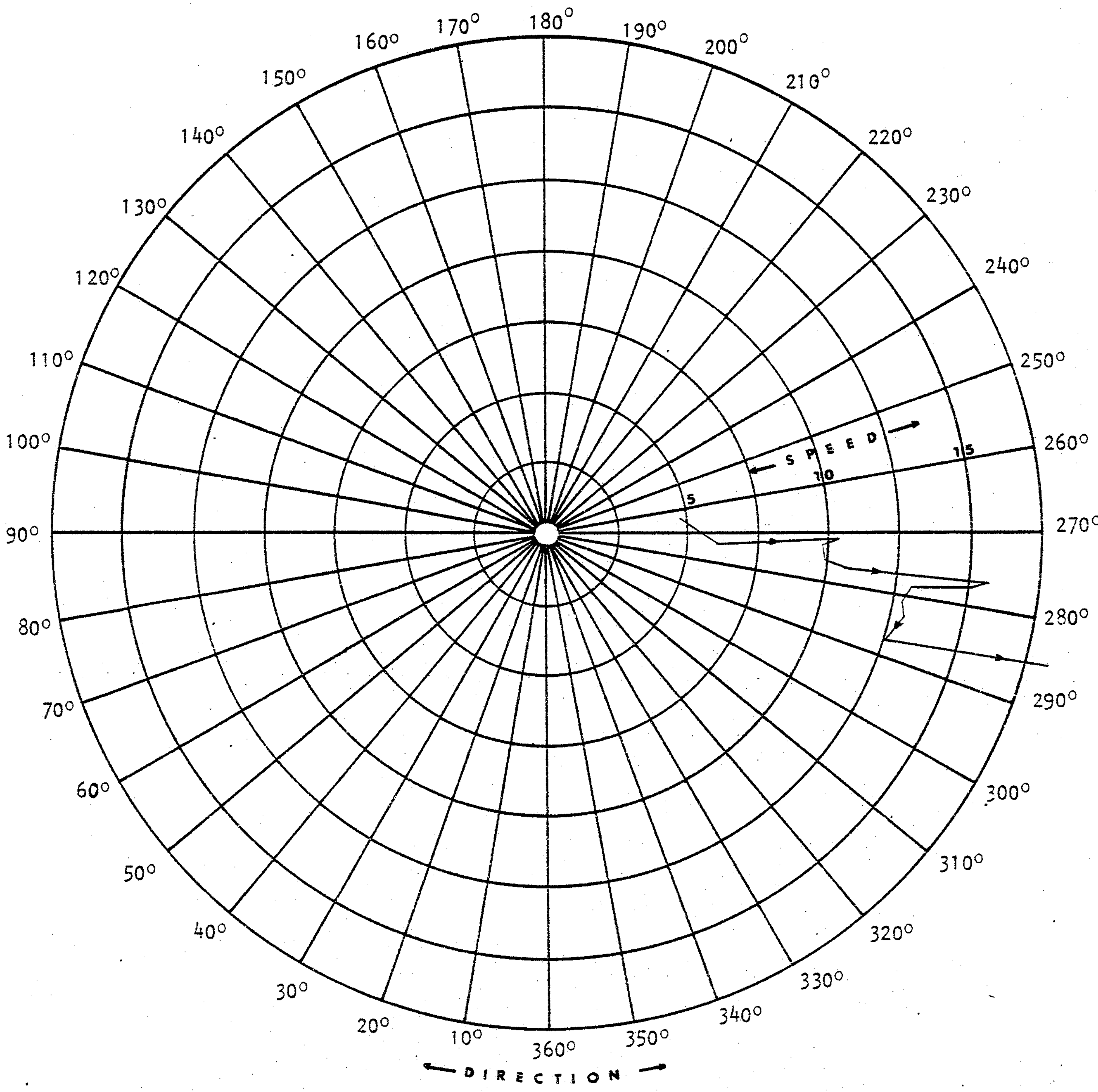
$$\ln(U_*/G) = A - \ln(G/fZ_b) + (kG/U_*)\ (1-\sin^2\alpha)^{\frac{1}{2}} \quad (5)$$

where G is the magnitude of the geostrophic wind and α is the angle between the geostrophic and surface winds.

To apply the model, values of the constants A, B and Z_b must be determined. Given these values, equation (5) can be solved for U_*. This value then enables calculation of the wind profile from (2). Appendix 1 contains a listing of the computer program written to solve the geostrophic model.

The approximate values of G and α can be obtained from hodographs of the wind profile. Figure 3 is an example of such a hodograph. The geostrophic wind direction is estimated from the direction to which the upper winds appear to converge, while its magnitude is estimated from the point where the wind first crosses the geostrophic direction.

Figure 3 . Profile of wind speed and direction for 1751 MDT September 2, 1976 drawn on a hodograph.



RESULTS

Model Evaluation

The relative abilities of the two models described previously to fit the actual vertical profile of the wind were tested on data samples selected from the intensive release soundings. The criteria used for evaluation were the average RMS error and the relative performance of the two models on one profile.

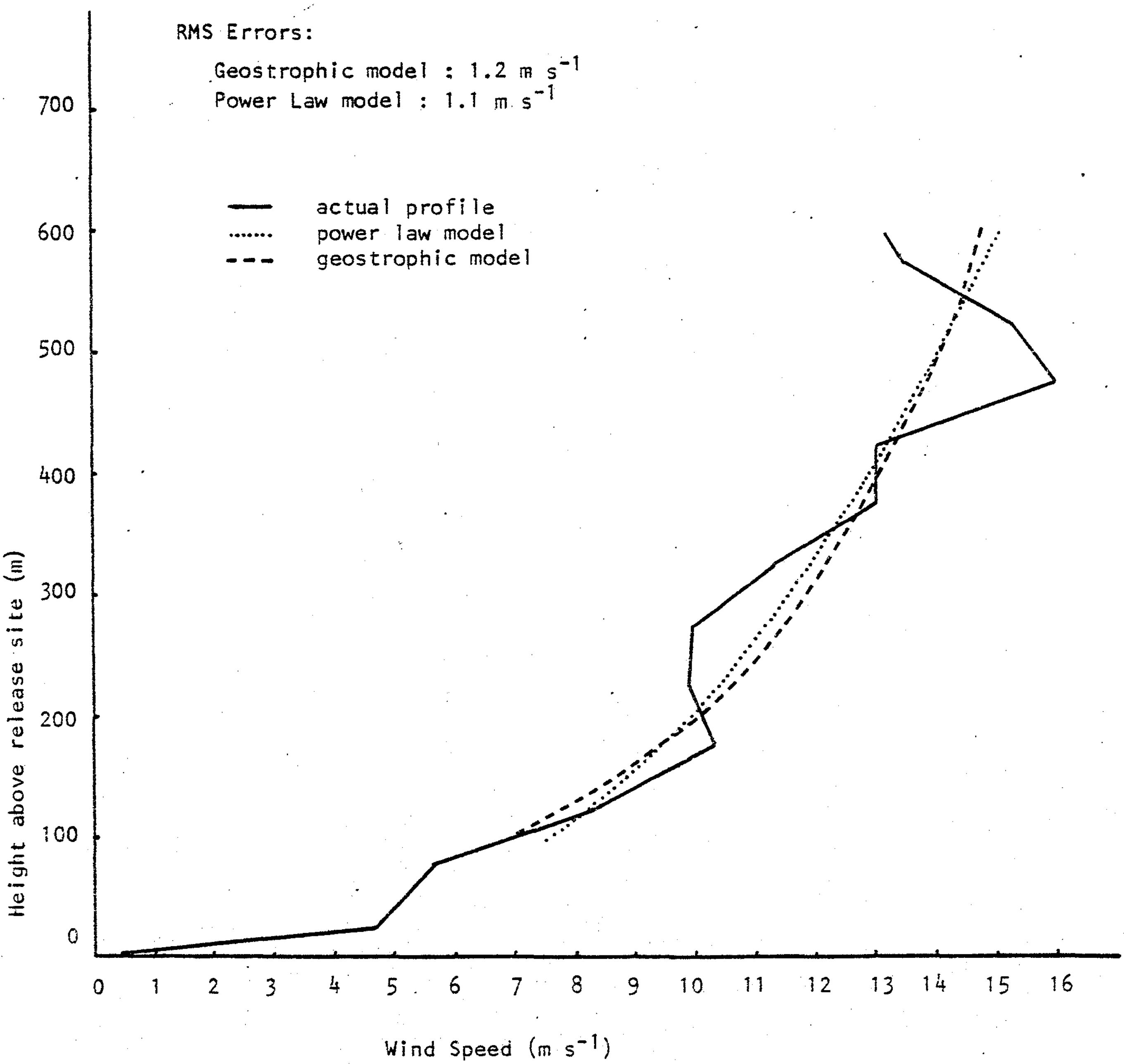
The actual wind profile, and the best fit logarithmic (geostrophic) model and power law profiles for a summer day are shown in Figure 4. The wind profile is that shown in the hodograph of Figure 3. This figure illustrates that as empirical models, there is little difference between the two.

Table 1 shows the results of model comparison considering the layer from 100 to 600 metres, the estimated plume layer. Forty one winter and sixty summer profiles were examined. The power law produces smaller errors than the logarithmic model for most of the cases examined. During winter limited mixing, the power law was better for more cases than the geostrophic model, but the geostrophic model produced a smaller average RMS error. This may indicate that when the models fail, the power law model will "blow up" more than the geostrophic model. Pronounced stratification sometimes occurs in the layer 100 to 600 metres, so that lower RMS errors may result if the layer is split into limited mixing and stable regimes.

This evaluation shows that for the layer in which the Syncrude plume will diffuse, the power law model provides a more accurate

Figure 4. Wind Profile for 1751 MDT September 2, 1976.

$G = 15.5\ m\ s^{-1}$ (from weather map)
$\alpha = 25^{o}$
$u_{*} = 1.66\ m\ s^{-1}$
$h = 1580\ m$



description of the wind than does the geostrophic model. A reference height and velocity must be determined in order to apply either of the models. The geostrophic model has the advantage of a theory which will supply these parameters. However, there are difficulties in practice because the model assumptions are often invalid in the Tar Sands area. The arctic weather front is often aligned Northwest-Southeast over the area resulting in a geostrophic wind which varies in both height and direction.

	Total			Winter			Summer		
	F	E_G (ms^{-1})	E_p (ms^{-1})	F	E_G (ms^{-1})	E_p (ms^{-1})	F	E_G (ms^{-1})	E_p (ms^{-1})
Limited Mixing	0.69	0.45	0.41	0.71	0.58	0.80	0.69	0.42	0.33
Zero Mixing	0.80	0.62	0.33	0.83	0.72	0.36	0.74	0.45	0.28
Unlimited Mixing	0.75	0.51	0.25	---	---	---	0.75	0.51	0.25

Table 1: Evaluation of geostrophic and power law models in the layer from 100 m to 600 m. F is the fraction of cases when the power law model produced a smaller RMS error. E_G is the average RMS error produced by the geostrophic model and E_p is the average RMS error produced by the power law model.

Determination of a Reference Height

The derived wind profiles were used to determine a suitable reference height for the power law model. The method employed was to fit lines to the equation

$$\ln\left(\frac{V(z)}{V_r}\right) = \beta \ln\left(\frac{Z}{Z_r}\right) \qquad (6)$$

by the method of least squares. The wind profiles were separated into various categories according to mixing class (limited mixing, zero mixing height, or unlimited mixing), time of day, season and wind direction. The data values employed were limited to those obtained during the periods of intensive study in February 1975 and the summers of 1975 and 1976. In cases of limited mixing, wind speeds below the mixing level only were evaluated.

Figure 5 illustrates an ascent with the best-fitting power law profile. The error of the line is expressed as an RMS error in ms^{-1} and as a percent of the average speed of the winds over the profile.

The reference heights to be tested were selected to provide examples over the entire range of heights measured during the field experiments. No heights below 100 m were used since the speed of the ascending baloon precluded many measurements below that height. 183 m was included to correspond with the height of the Syncrude stack. Several heights were selected to be in the expected plume layer.

Table 2 summarizes the results obtained from this phase of the

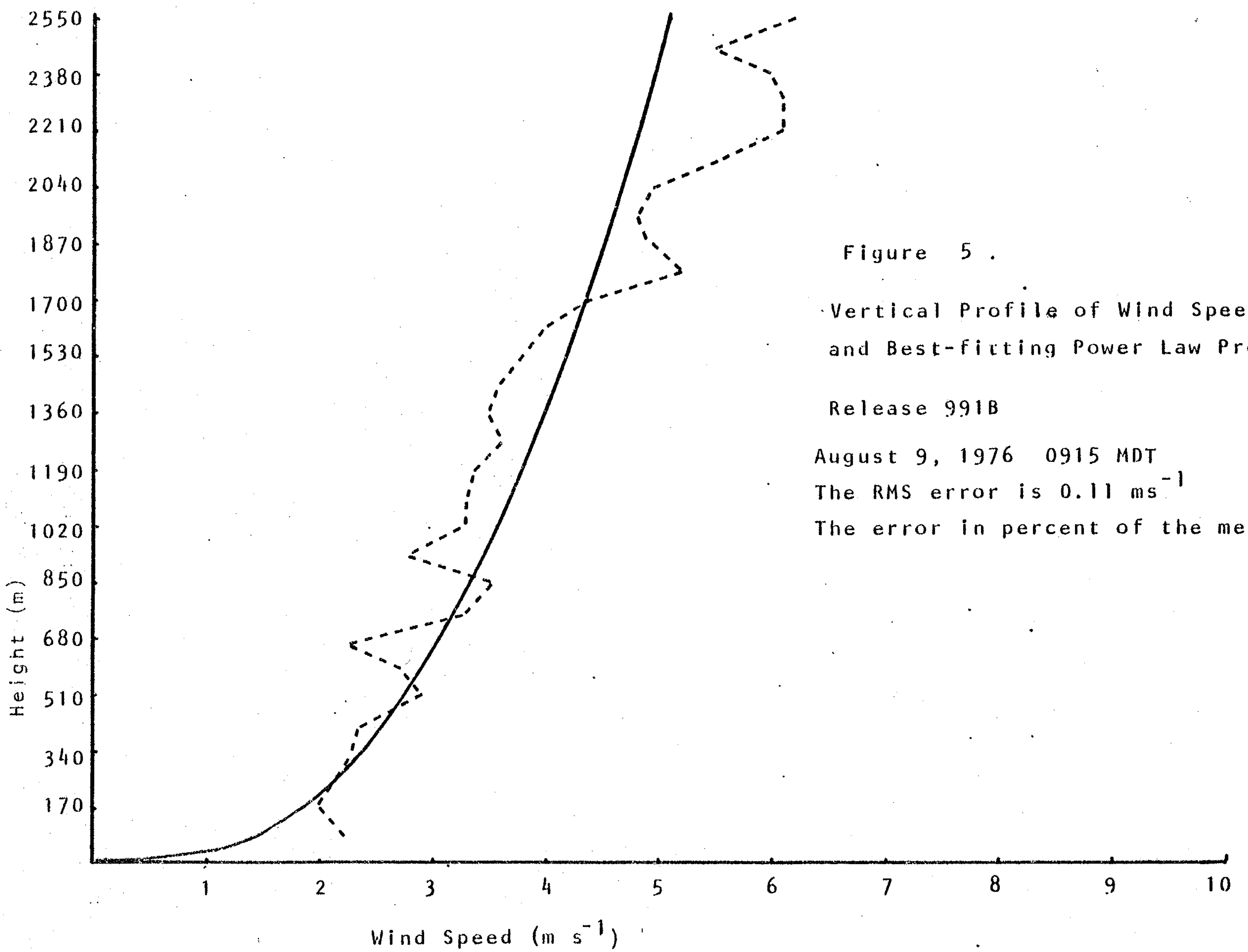


Figure 5.

Vertical Profile of Wind Speed and Best-fitting Power Law Profile

Release 991B

August 9, 1976 0915 MDT

The RMS error is 0.11 ms^{-1}

The error in percent of the mean wind is 2.8

REFERENCE HEIGHT (m)		LIMITED MIXING	STABLE	UNLIMITED MIXING
100	β	0.16	0.27	0.17
	Δ	2.0	2.1	2.0
	δ	28	23	22
183	β	0.11	0.18	0.19
	Δ	2.0	2.0	2.0
	δ	28	22	21
400	β	0.26	0.19	0.26
	Δ	1.6	1.9	1.8
	δ	31	25	24
800	β	0.25	0.19	0.24
	Δ	1.7	1.6	2.2
	δ	32	22	29
2000	β	0.25	0.19	0.30
	Δ	1.8	1.7	1.5
	δ	34	19	19

TABLE 2 Power law exponents and errors for different reference heights. β is the power law exponent, Δ is the RMS error (ms^{-1}), δ is the relative error in percent of the mean wind. Data are from the 1975 and 1976 intensive study periods.

analysis. A blank in the following tables indicates that no values were found in the sample set to fit a line to. The absence of results for unstable cases during the morning and winter reflects the stability of the atmosphere during these times.

The variation of β with reference height is small for the cases of unlimited mixing (unstable air) and zero mixing (stable air). In the case of limited mixing, the values of β are close to 0.1 for reference height up to about 400 m, then they become about 0.22 to 0.28. This change in β may be a result of the reference height being in the stable air mass above the inversion, where characteristic values of β are 0.25. At the lower levels, the reference height is usually in unstable air.

The variation of β with the stability of the air was examined at levels up to 2000 m. The value of β is near 0.1 for cases of limited mixing, about 0.18 for unstable air (mixing height above the vertical range of the sounding), and about 0.25 for stable air. These values compare with the typical value of 1/7 for neutral air. The low values of β in the case of limited mixing means that the wind speed will be essentially constant up to the mixing height. Increasing values of β imply that the wind speed increases faster with height.

Figures 6 and 7 show the average diurnal variation of β for winter and summer. The raw curve has been smoothed by adding a few of the Fourier components to get the dashed lines. The idealized variations for both seasons show a maximum in the early morning, when the air is most stable, and a minimum at about 1500 local time during the time of maximum heating and instability. The idealized curves fit the summer raw data better than for the winter case. This may be a consequence of lower inversion heights during the winter, thus allowing two different wind regimes to be closer together.

Discussions of the variation of β by season of the year is limited to cases of limited mixing and stable air. The results shown in Table 3 show that β tends to be greater during the winter than during the summer, indicating the increased average stability of the air near the ground in winter. Figures 6 and 7 and Table 3 show that a change in season generally has a small effect on β.

Table 4 shows the variation of β and the RMS errors for winds from different directions. The wind direction in these cases was defined to be the average wind direction for winds in the 200 m to 600 m layer. The error for each direction will not change with height, so the reference height was standardized to 183 m. Generally, β does not change much with direction. The only anomalous result is an east wind during unlimited mixing. The large errors in this case indicate that the situation is not well handled by a power law model. The results of Table 4 indicate that differences in wind profiles due to direction may be less significant than differences due to seasonal or diurnal variations.

Figure 6. Average diurnal variation of β. The solid horizontal line indicates the mean value of β and the broken horizontal lines indicate one standard deviation from the mean. The dashed curved line was derived by summing the first two Fourier components of the raw data.

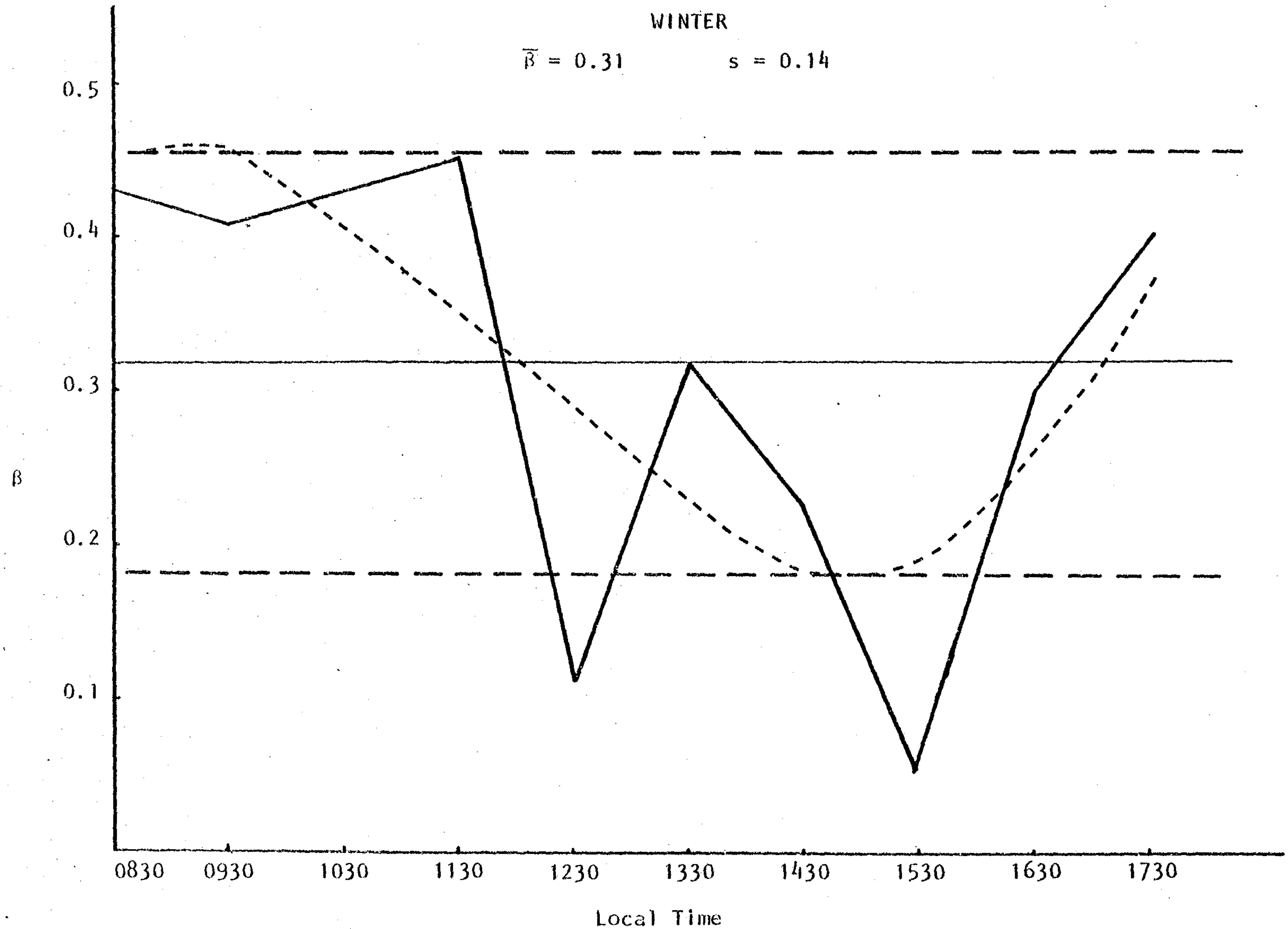
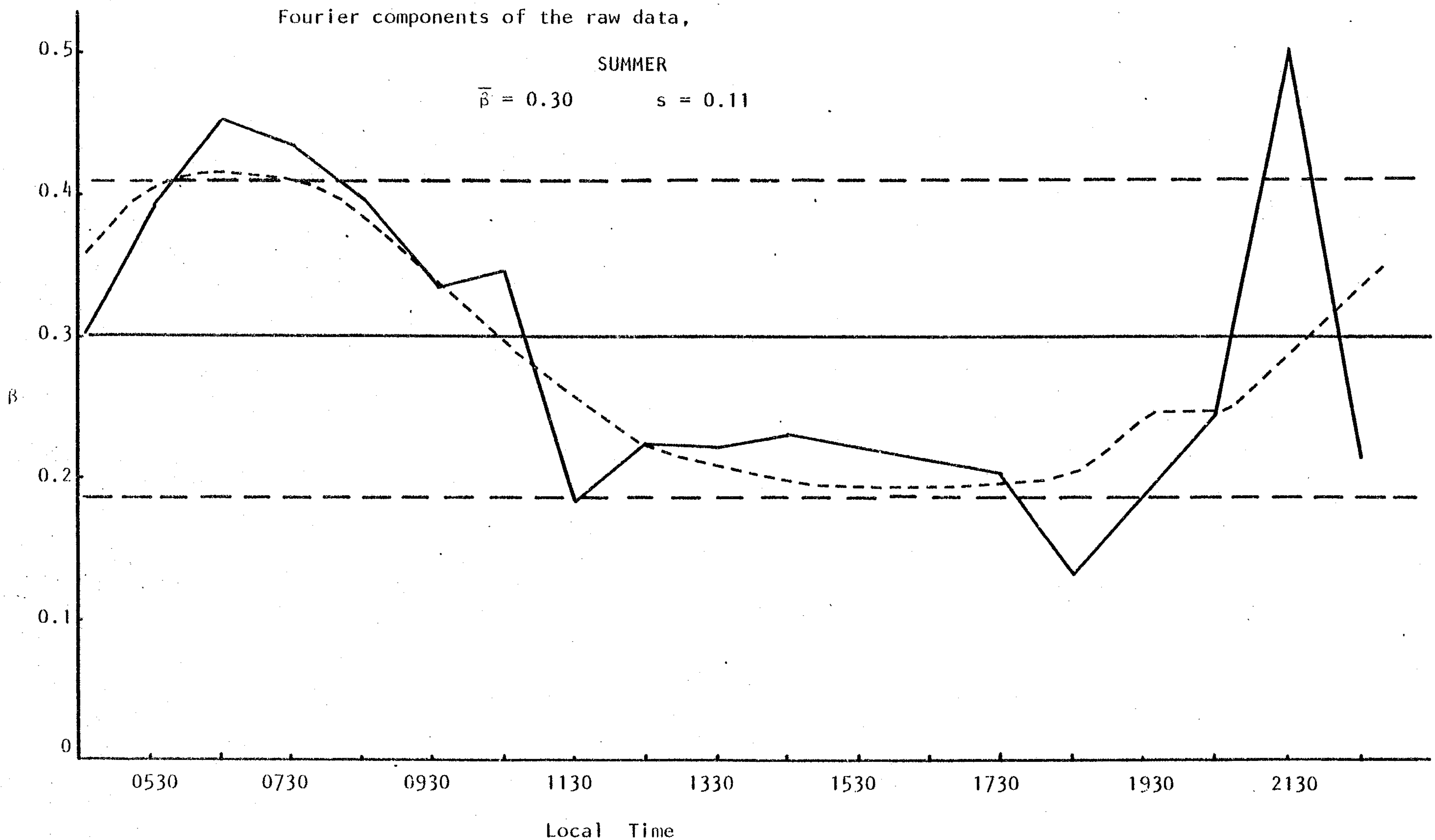


Figure 7. Average diurnal variation of β. The solid horizontal line indicates the mean value of β and the broken horizontal lines indicate one standard deviation from the mean. The dashed curved line was derived by summing the first two Fourier components of the raw data.



SEASON		LIMITED MIXING	STABLE	UNLIMITED MIXING
Winter	β	0.14	0.28	---
	Δ	1.6	2.0	---
	δ	39	21	---
Summer	β	0.10	0.17	0.19
	Δ	2.0	2.0	2.0
	δ	28	22	21

TABLE 3 Comparison of the power law for different seasons. β is the power law exponent, Δ is the RMS error (ms^{-1}) and δ is the relative error expressed in percent of the mean wind. Data are for the 1975 and 1976 intensive study periods. A reference height of 183 m is used.

WIND DIRECTION		LIMITED MIXING	STABLE	UNLIMITED MIXING
North	β	0.08	0.22	---
	Δ	1.92	1.97	---
	δ	37	23	---
East	β	0.06	0.18	0.38
	Δ	2.04	2.09	2.34
	δ	37	25	65
South	β	0.07	0.12	0.09
	Δ	2.09	1.83	2.06
	δ	34	24	24
West	β	0.14	0.21	0.14
	Δ	1.97	2.07	1.67
	δ	23	20	14

TABLE 4 Comparison of the power law model for different wind directions. β is the power law exponent, Δ is the RMS (ms^{-1}) and δ is the relative error expressed as percent of the mean wind. Data are for the 1975 and 1976 intensive study periods. A reference height of 183 m is used.

These results, if employed for the purposes of selecting a suitable reference height for a power law model, indicate that the actual height used for a reference level is relatively unimportant. Much greater effects are introduced by different seasons, times of day, and air stabilities. Other factors influencing a decision are the height of the mixing level and errors from the theodolite measurements. The theodolites measure elevation and azimuth angles which are transformed into height and horizontal displacements. Errors in these values will increase with height. For the rest of this study, a reference height of 183 m will be employed.

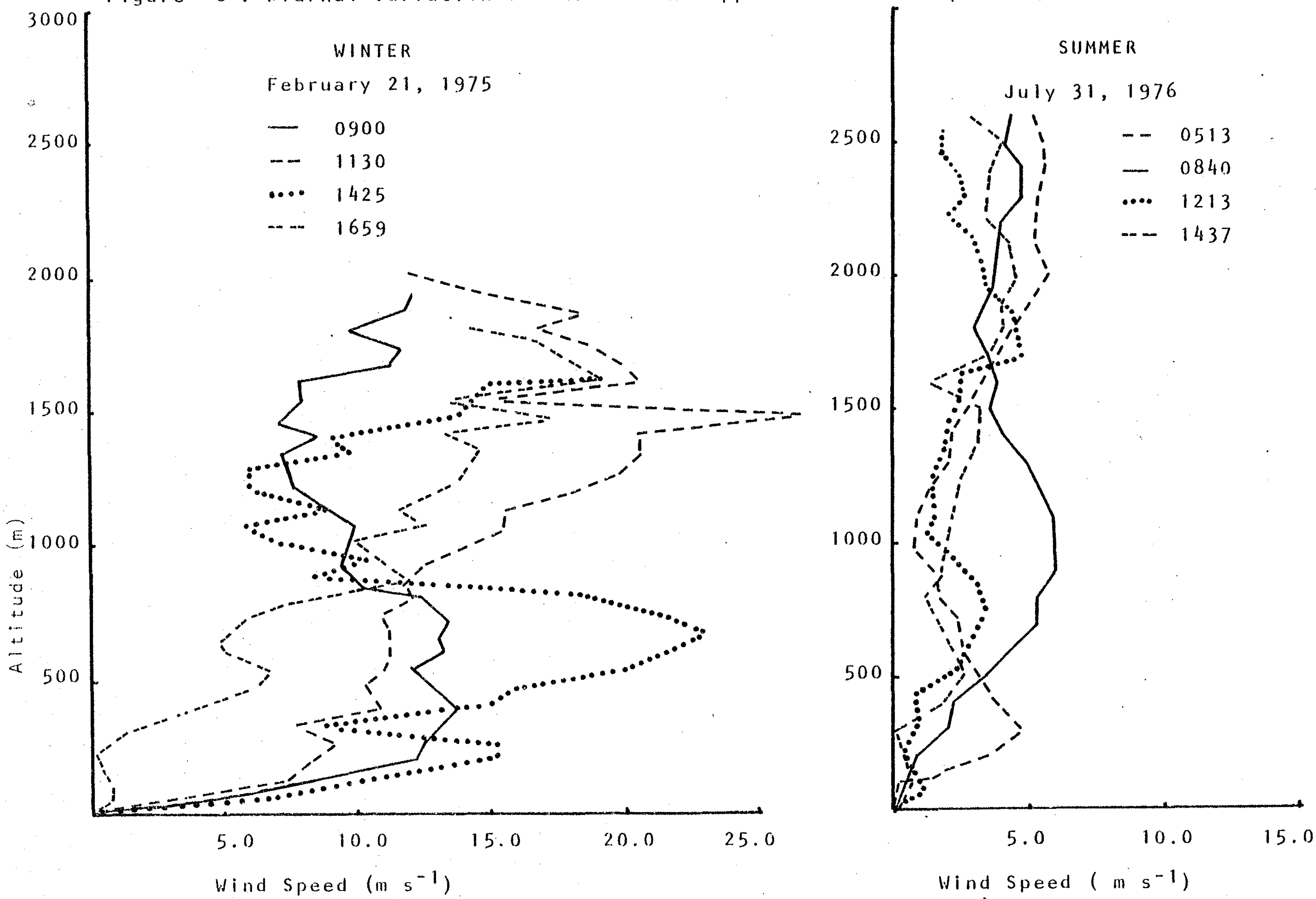
DIURNAL VARIATION OF SURFACE AND UPPER WINDS

Since the wind varies during the day, part of this report was devoted to the study of the variation of the surface and upper winds at lease C-17. The days studied were limited to those of the intensive study periods, since only those days had more than two vertical profiles per day. The timing of the soundings was not at fixed times of the day. The first one was performed at sunrise. The others were spaced to occur at about mid-morning, mid-afternoon during the time of greatest heating, and in the late afternoon.

Figure 8 shows an example of the diurnal variation of the vertical wind profile for a winter and a summer day. The examples are not meant to be typical. For the surface winds, the lowest layers show characteristics of small values in the morning, with a maximum during the early afternoon and then decreasing again. In the plume layer, at 500 m for example, the winter variation shows a maximum in the morning and again in the afternoon. The summer wind at 500 m has a maximum in the mid-morning and tends to decrease during the afternoon. Levels of relatively constant wind speed during the day appear to exist at about 850 m in the winter and 500 m in the summer.

The method followed for this analysis was to average the winds for each hour. During the winter the hours of the day with available data were from 0800 to 1800 local time, while during the summer, data was available from 0300 to 2100. No soundings were performed during the winter between 0900 and 1000, and during the summer between 1500 and 1700 or between 1900 and 2000, so the behavior of the winds during these hours is unknown. The surface wind was approximated by the mean wind for the layer from the surface to 100 m of the vertical profile. For the plume layer,

Figure 8. Diurnal Variation of Surface and Upper Level Wind Speeds (local time)



the wind speeds from 200 m to 600 m were averaged.

Figure 9 shows the average diurnal variation of the surface and plume layer winds during the winter. Forty differents runs were used for the winter data. The average surface wind during the day is 4.13 m s^{-1}, and the standard deviation is 0.68 m s^{-1}. The surface wind begins in the morning at about the average value, then decreases to a minimum during the mid-morning. The wind speed then increases to the maximum at about the time of maximum heating, then decreases again, presumably to another minimum during the night. The plume layer wind has an average speed of 7.77 m s^{-1} and a standard deviation of 1.67 m s^{-1}. It decreases to a minimum late in the morning, then increases to the maximum early in the afternoon, then decreases to the minimum at the time of maximum heating, then increases to another maximum. At the time of maximum heating, the average plume layer wind is comparable to the average surface wind speed. The correlation coefficient of the winter surface wind and the plume layer wind is -0.15, indicating that the two winds are not closely related. This poor correlation may be the result of two different wind regimes, one near the surface, and one in the plume layer.

Figure 10 shows the average diurnal variation of the surface and plume layer winds during the summer. The average surface wind is 3.45 m s^{-1} and the standard deviation is 0.45 m s^{-1}. Like the winter case, there is a minimum at mid-morning, and a maximum during the afternoon, but the magnitudes of these features are not as great. The plume layer has an average wind speed of 6.47 m s^{-1} and standard deviation of 1.60 m s^{-1}. It decreases to a minimum in the late afternoon and then increases to a maximum during the night. The improved relation-

Figure 9. Average Diurnal Wind Variation WINTER

The curved lines are derived by summing the first two Fourier components of the raw data. The horizontal solid lines are the mean wind speeds and the horizontal broken lines indicate one standard deviation.

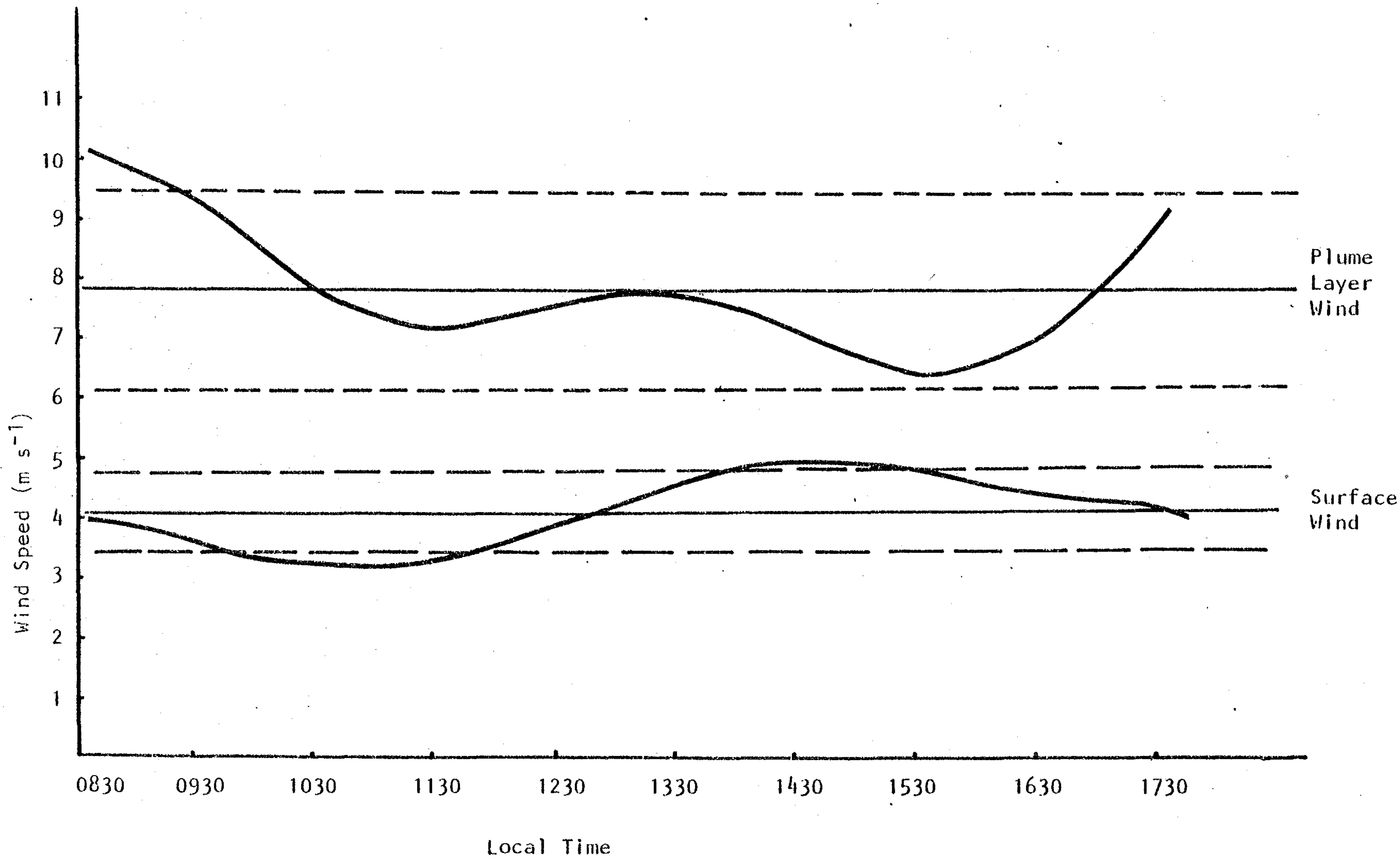
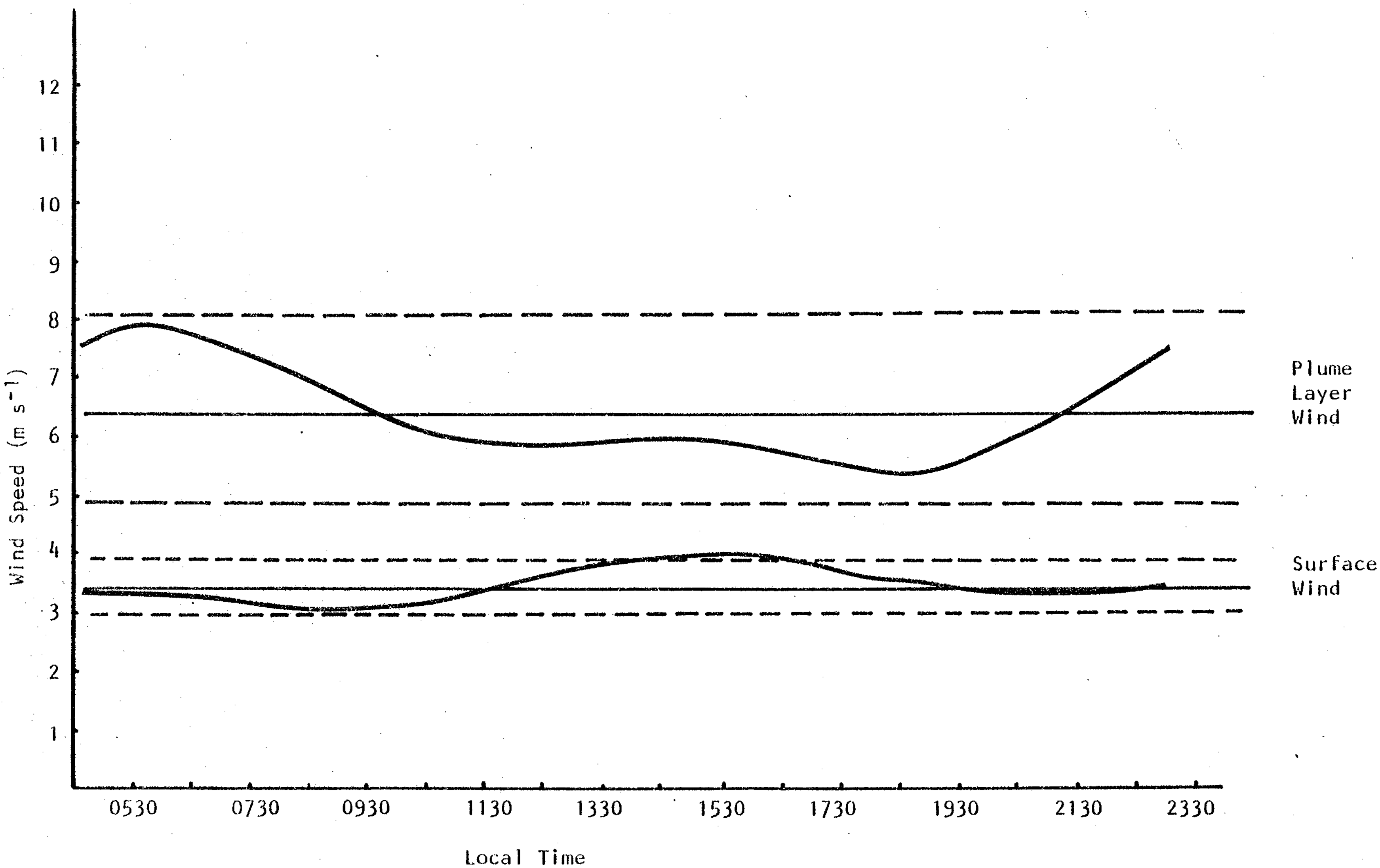


Figure 10. Average Diurnal Wind Variation SUMMER

The curved lines are derived by summing the first two Fourier components of the raw data. The horizontal solid lines are the mean wind speeds and the horizontal broken lines indicate one standard deviation.



ship of the summer surface wind to the plume layer wind is reflected in the correlation coefficient of 0.26.

This method of averaging the winds may mask some features of the diurnal wind speed variation. For example, an extreme value of the wind speed in the morning may have consequences later in the day, but averaging out the extreme values will hide such effects. However, some facts are apparent. The surface winds have relatively small values in the mid-morning and maximum values at the time of maximum heating. The plume layer winds have maximum values in the early morning and late afternoon, with minimum values at maximum heating. The surface and upper winds correlate better in summer than in winter, probably due to greater momentum transfer by turbulence.

THE WIND PROFILE IN LIMITED MIXING

A limited mixing condition occurs when a unstable surface layer is capped by a stable inversion. This condition is important in the dispersion of pollutants, since the turbulent layer allows the pollutants to reach the ground. The capping inversion prevents the pollutant from dispersing upward and tends to increase the possible ground concentrations. According to the report on the dispersion of emissions from the Syncrude plant, (ERM 1976-1) the predicted ground concentration of pollutants exceeded the Clean Air Regulations (Alberta) only under conditions of limited mixing.

Table 4 shows the distribution of limited mixing profiles during the periods of intensive study. It shows that cases of limited mixing are more prevalent in summer than in winter.

	Total	Winter	Summer	Sunrise	Daytime
Number of Profiles	499	40	459	96	403
Number of Limited Mixing Profiles	316	7	309	14	302
Fraction of Profiles that are Limited Mixing	0.63	0.18	0.67	0.15	0.75

TABLE 4 Distribution of limited mixing profiles

Figure 11 shows a wind profile during a limited mixing condition. Two possible characteristics of the wind speed may be seen in this example. The wind speed is approximately constant up to about the mixing height. Above the mixing height, the wind speed increases rapidly. These two wind speed profiles are characteristic of the wind in unstable air and stable air respectively.

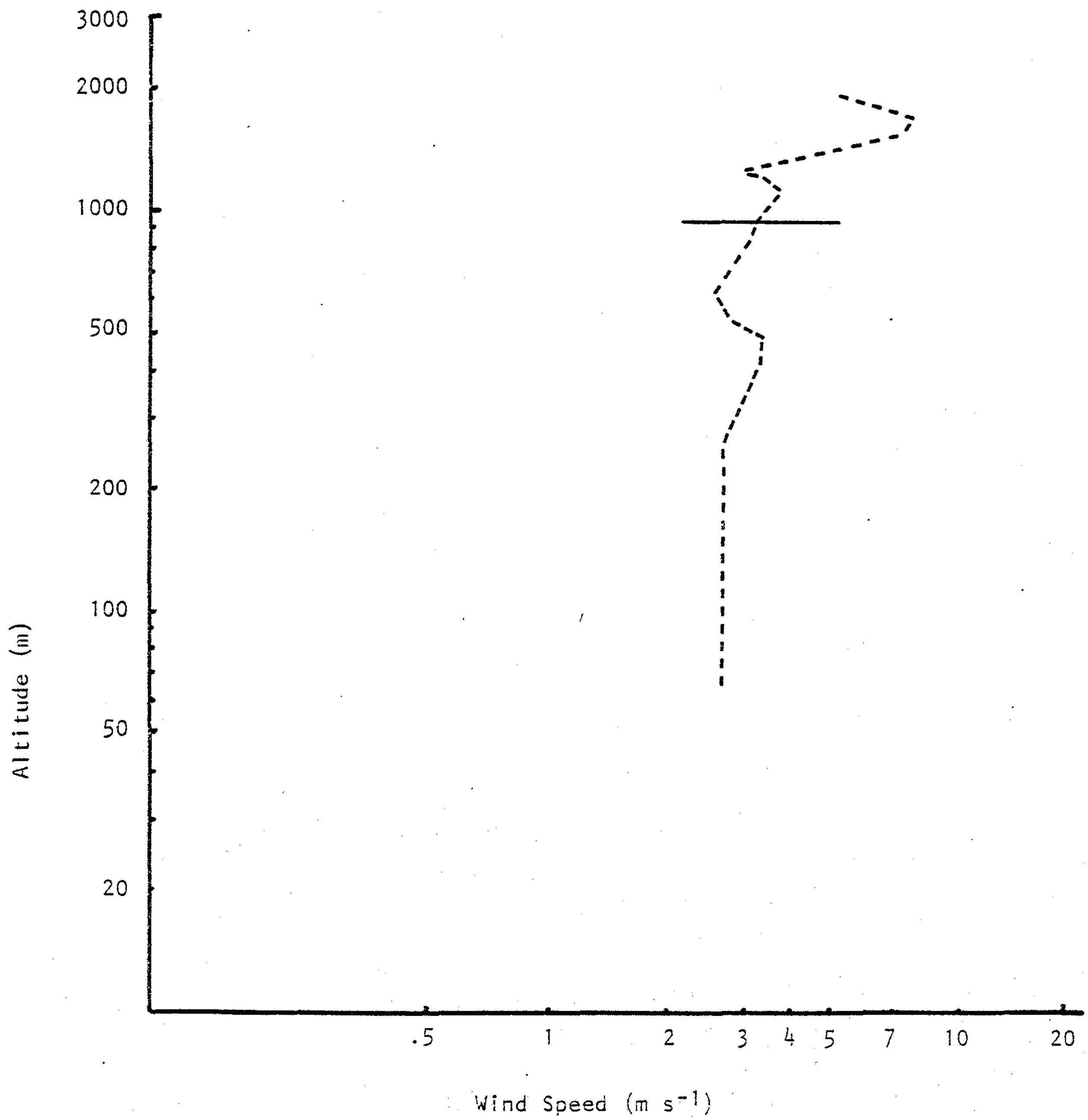
The vertical profiles of the wind speed were plotted for several days of the intensive study period. Although the two characteristic variations with height occurred occasionally, they were not typical. They also occurred in cases that were not limited mixing. Another possible feature seen on the graphs was oscillation of the wind speed above the mixing height. This oscillation may be due to errors associated with the balloon ascent speed and the theodolite measurements.

To test if the air in limited mixing could be described as a stable layer capping an unstable layer, power law profiles were fitted separately to the air layers below and above the mixing height. Table 6 shows the results of this calculation. In this analysis, a stable layer is characterized by a larger value of β than for an unstable layer. Table 6 indicates that the upper layer is more stable than the lower layer. The only exception is in the sunrise cases. The values of β in the upper layers compare with the values for stable air to the surface. A major variation occurs for the winter cases, where the upper level appears to be extremely stable. The lower layer has values of β about one half of that for a completely stable profile.

Figure 11.

Wind Speed Profile in Limited Mixing - August 4, 1975 1418 MDT

Mixing Height = 959 m



		TOTAL	WINTER	SUMMER	SUNRISE	DAYTIME
Stable Profile	β	0.18	0.28	0.17	0.12	0.28
	Δ	2.0	2.0	2.0	1.9	2.1
	δ	22	21	22	20	84
Below Mixing Height	β	0.11	0.13	0.11	0.17	0.11
	Δ	2.0	1.6	2.0	1.9	2.0
	δ	28	39	28	26	28
Above Mixing Height	β	0.29	1.33	0.28	0.13	0.30
	Δ	2.1	2.3	2.0	1.5	2.1
	δ	22	25	23	11	24

TABLE 6 Comparison of limited mixing power law profiles with stable power law profiles above and below the mixing height. β is the power law exponent, Δ is the RMS error (ms^{-1}), δ is the relative error in percent of the mean wind. Reference height = 183 m.

LOW LEVEL JETS

The existence of low level jets, or regions of relative wind speed maxima in the vertical profiles, was investigated. The presence of such jets may have considerable effect on the transportation and dispersion of pollutants.

Several vertical wind profiles from August 1975 were plotted on graphs. One profile that illustrates a possible jet is shown in Figure 12. In this figure, the wind speed reaches a relative maximum of 3.5 m s^{-1} at 500 m and decreases to a relative minimum of 0.5 m s^{-1} at 1100 m. The wind speed then increases almost continuously to the top of the ascent.

After examining several similar cases, the following rather arbitrary algorithm for defining a low level jet was developed. Beginning at the surface, the wind speed was examined until a relative maximum was found at some level. The levels above were then examined. If a wind speed was found at a higher level that was less than one half the relative maximum speed, then the relative maximum wind speed was considered to be a jet. The profile shown in Figure 12 thus defines a low level jet.

All 1238 wind profiles were examined by this definition, and low level jets were found in 575 cases or about 46 percent of the time. Table 7 shows the numbers of jets found in the sample obtained during the intensive field experiments. The results show that jets occur slightly more often in summer than in winter. This conclusion indicates that jet activity may be in some way related to the stability of the air, since it was shown earlier the air tends to be more stable in the winter than in the summer.

Figure 12. August 1, 1976 1130 Release

Windspeed Profile

Low Level Jet

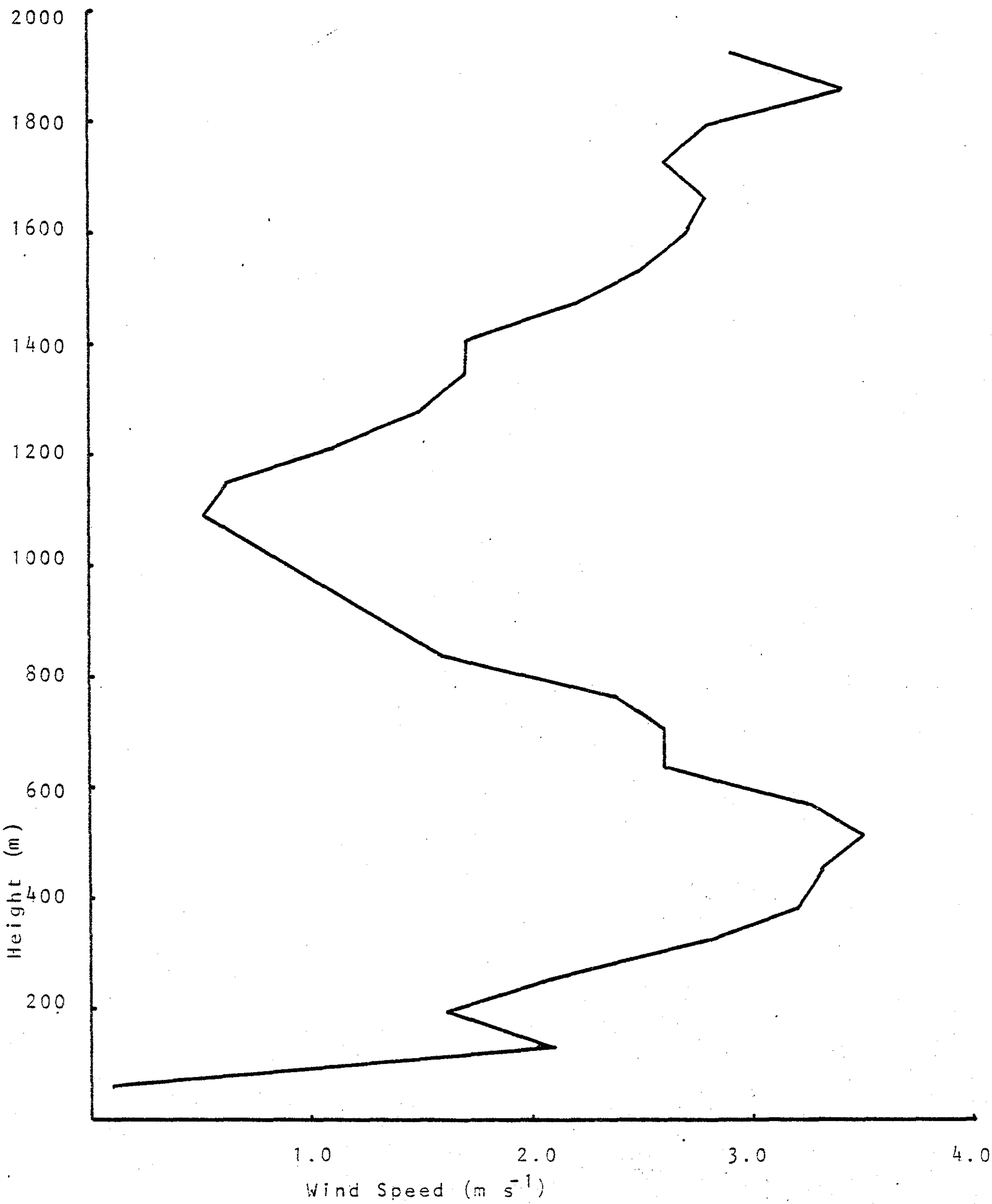


TABLE 7. Number of vertical wind profiles found to have jets during the intensive experimental periods. Total number of ascents = 499.

	TOTAL	WINTER	SUMMMER	MORNING	DAY
Limited Mixing	181	3	178	4	177
Zero Mixing	83	11	72	43	40
Unlimited Mixing	12	0	12	0	12

Figure 13 shows the number distribution of jets with height. This figure indicates a relatively common occurence of jets at the levels of 200 - 300 m and 400 - 500 m. No explanation is obvious for the relative minimum number from 300 m to 400 m. The number of jets drops off suddenly above 600 m. Thus it can be seen that jet activity may be significant in the plume layer of the Syncrude stack. Two factors will influence the numbers found at higher levels. First, at higher levels, fewer levels will be above a relative maximum in which to find a relative minimum, and hence define a jet. Secondly, there are fewer measurements at higher levels due to obscuration by clouds and loss of balloon tracking. Both of these factors bias the distribution of numbers towards lower levels.

A scheme similar to that of Figure 14 illustrates the possible relationship of jet activity to changes in the vertical temperature gradient. In Figure 14 the number of jets is plotted as a function of a non-dimensional height parameter, either ln(Z/H) or ln(Z/L) where H is the height of the top of the inversion and L is the mixing height. This figure indicates that jet activity is associated with the mixing level, since the largest number of jets occurs when the mixing height is equal to the jet height. The maximum number of jets for inversions is displaced below the inversion level. This fact is probably a consequence of the top of the inversion generally being above the mixing height, and reinforces the hypothesis that the jet height is related to the mixing height. The local maxima at ln(Z/H) = 3.0 and ln(Z/L) = 1.0 may be real, since similar maxima show up for each summer, although not at exactly the same points. The sharpness of the graph is deceptive, due to the logarithmic nature of the x - axis.

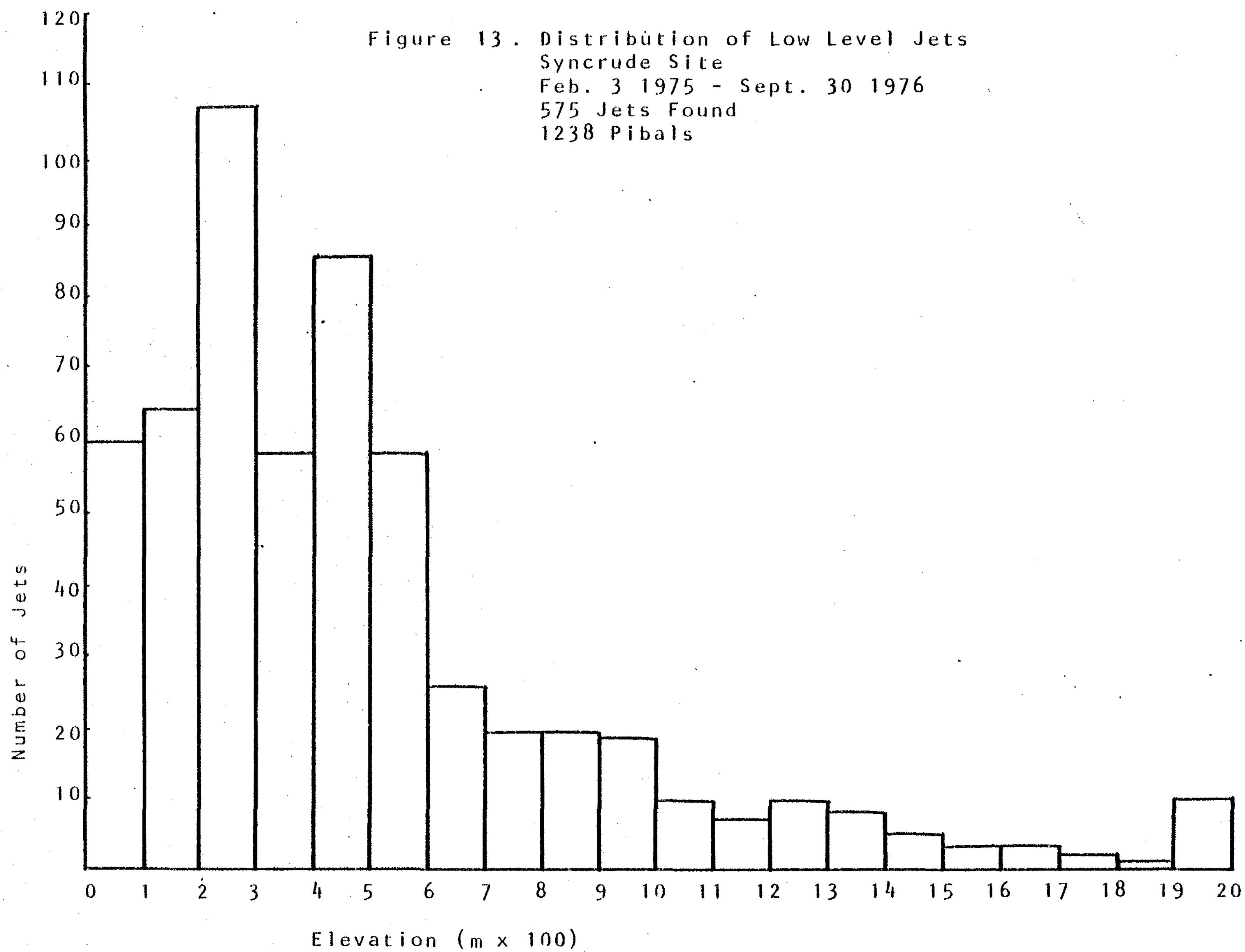
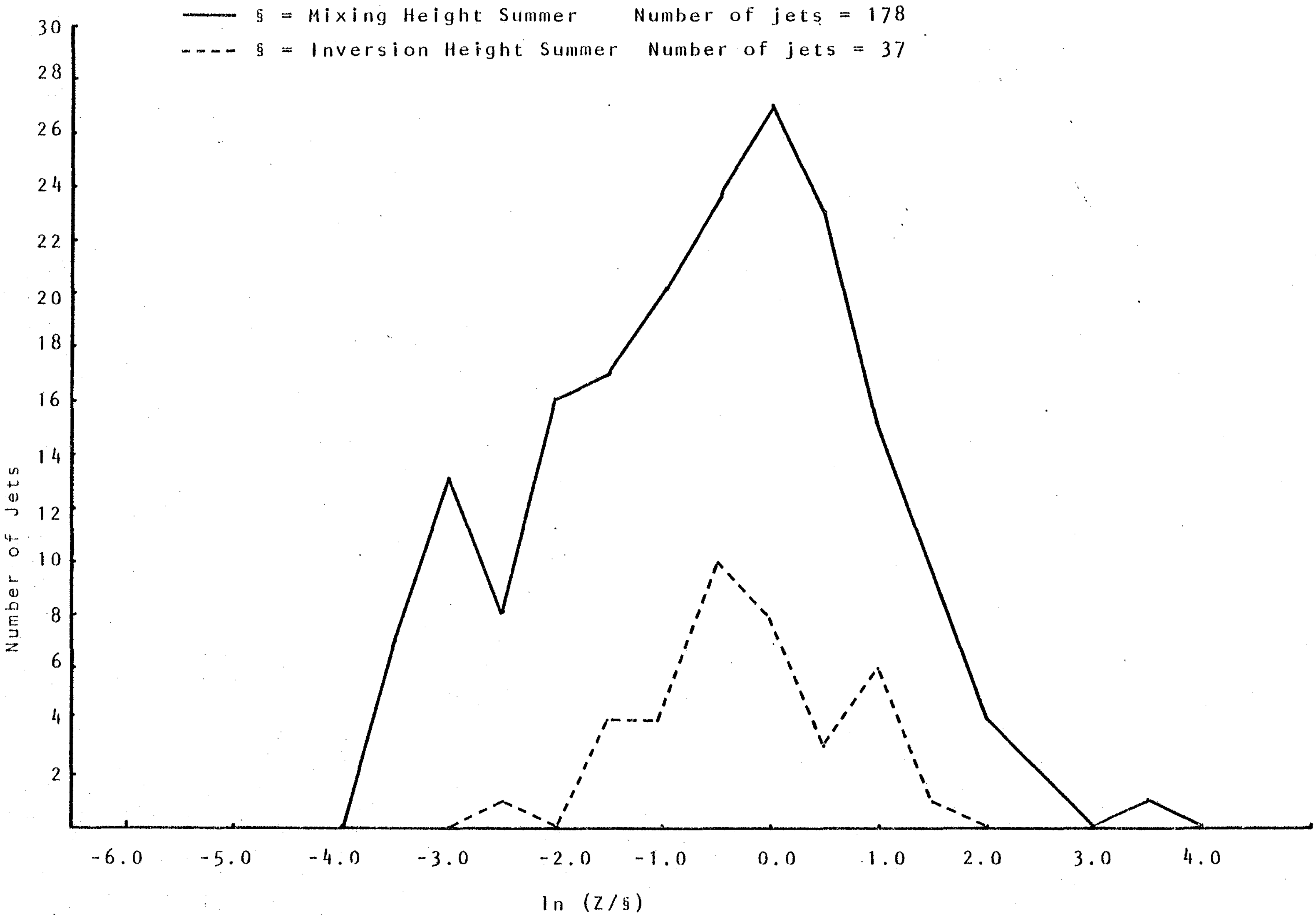


Figure 13. Distribution of Low Level Jets
Syncrude Site
Feb. 3 1975 - Sept. 30 1976
575 Jets Found
1238 Pibals
Number of Jets
120
110
100
90
80
70
60
50
40
30
20
10
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Elevation (m x 100)

Figure 14.

Distribution of Low Level Jets with Non-dimensional Height



The previous results indicate that jet activity may be related to changes in the stability of the air. Two likely levels for jet activity occur in cases of limited mixing at the top of the inversion, where the wind regime changes from thermally unstable air to stable air, and at the mixing level, where low level turbulence ceases. Accordingly, the heights of the jets were correlated with the inversion heights and mixing heights. Table 8 shows the results for the cases of the intensive study periods. All the correlation coefficients are small and negative. The results of the correlations are not favorable to the hypothesis. These results are severely handicapped by the small number of points for some correlations, but the results are close to zero in all cases. The fact that all the correlations are negative does not seem to be significant, due to the large scatter of the values.

Table 9 shows the correlation of jet speed with jet height. The positive correlations indicate that jet speeds increase with height. This is not a surprising result, as that is the general behavior of winds.

The results of this study indicate that low level jets do exist, but do not suggest a cause. One problem might be the definition of a jet. The algorithm described located only the lowest jet in a profile, while rejecting any possible higher ones. The requirement of a relative minimum above the jet may also have rejected some reasonable jets.

TABLE 8 . Correlation coefficients of jet height with atmospheric levels. The numbers are the number of profiles with jets and the correlation coefficients.

	WINTER		SUMMER	
	MORNING	DAY	MORNING	DAY
Mixing Height	--	3 -0.058	4 -0.348	177 -0.163
Top of Inversion	--	--	41 -0.148	--

TABLE 9 . Correlation of jet speed with height.

	MORNING	DAY	FRACTION OF PROFILES WITH JETS
WINTER	.631	.676	.35
SUMMER	.436	.340	.58

COMPARISON OF THE WINDS AT LEASES C-13 AND C-17

The wind speeds and directions were compared for lease C-13 (Shell) and C-17 (Syncrude). The C-13 lease is approximately northeast of C-17 at a distance of about 16 kilometres. C-13 is about 300 m ASL and C-17 270 m ASL. A river valley with a floor elevation of about 230 m runs north-south between the two leases.

For purposes of this study, the wind speeds between 200 m and 400 m were averaged and plotted on graphs composed of the total intensive sample and morning and day wind speeds. To study wind directions polar graphs of C-13 wind direction deviation from the C-17 wind direction versus the C-17 wind direction were plotted for various values of the potential temperature gradient.

Figure 15 and 16 show the C-17 wind speed versus C-13 wind speed for the sample period. This figure shows little correlation of the wind speeds measured at the two sites. The morning winds at C-17 tend to be higher than those at C-13, since most points are above the line r = 1. No such trend is evident for the daytime winds.

Table 10 lists properties of the wind speeds of the two locations as derived from the monthly graphs. In general, there is no strong relation in wind speeds at the two locations. The wind speed is generally higher at C-17 than at C-13. The wind speeds seem to correlate better in the morning than during the day, and better in the winter than during the summer.

Figure 15. Comparison of wind speeds in the plume layer (200 - 400 metres above ground) at Lease C-13 and Lease C - 17.
SUNRISE

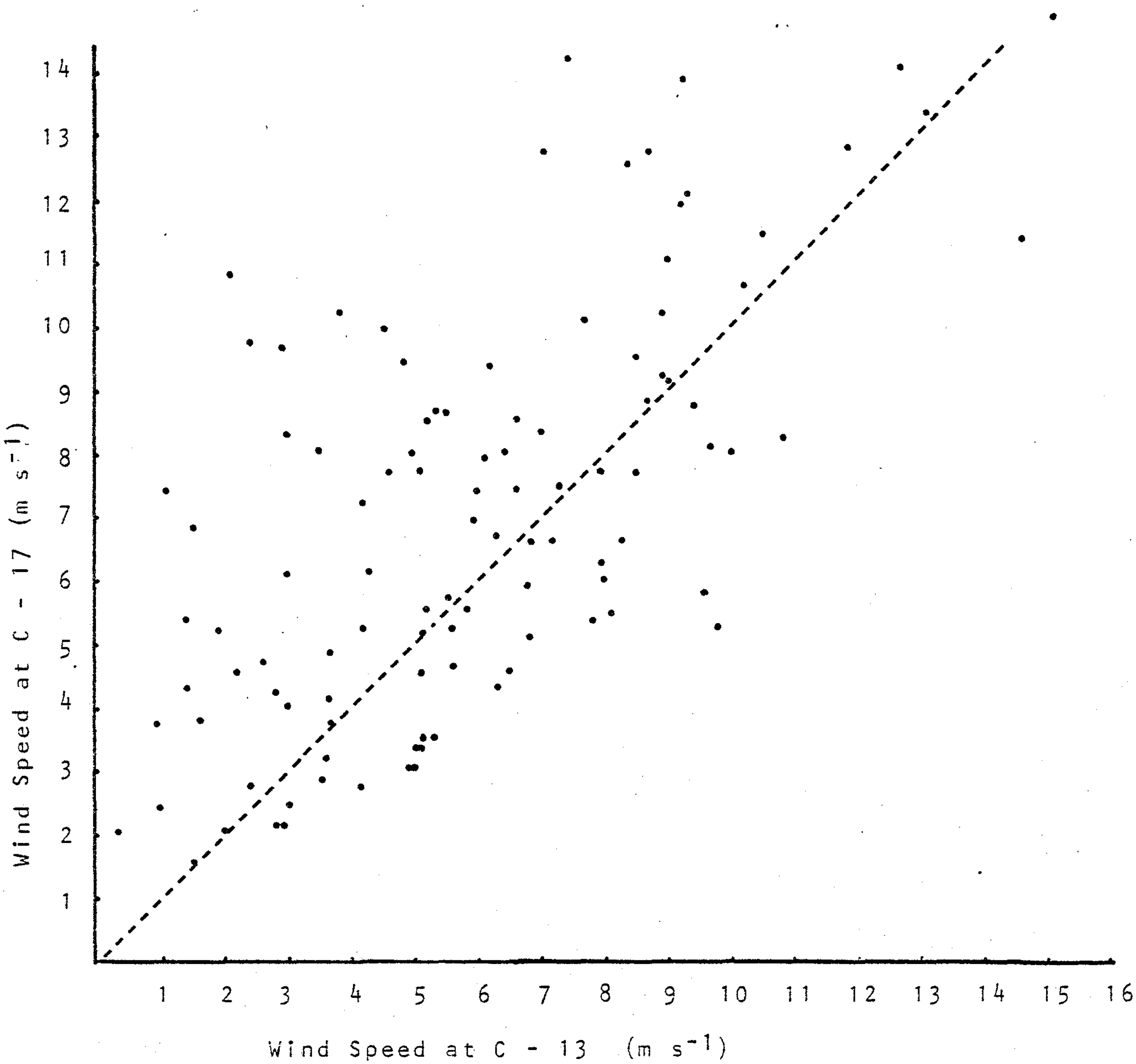


Figure 16 . Comparison of wind speeds in the plume layer (200 - 400 metres above ground) at Lease C-13 and Lease C-17.
AFTERNOON (1330 MST)

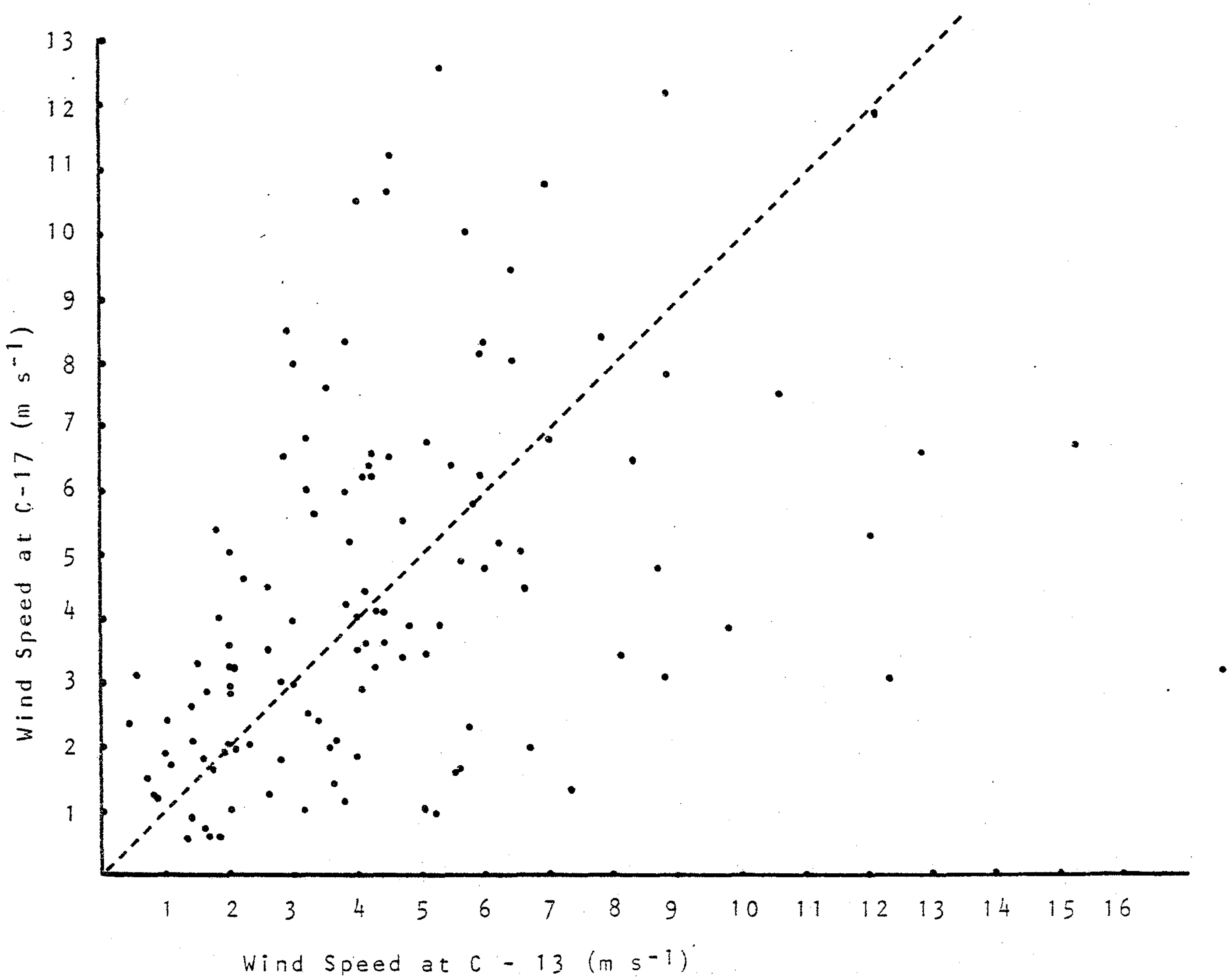


TABLE 10 . Comparison of wind speeds at C-13 and C-17.

MONTH		SUNRISE	DAYTIME
SEPTEMBER	1975	Good correlation	Weak correlation -winds occur at one site but not the other
OCTOBER	1975	Wind fairly constant at about 4 m s^{-1} at C-17 - winds variable at C-13	Wind near zero at C-17 - variable at C-13
NOVEMBER	1975		No winds at C-17 variable at C-13
DECEMBER	1975		Usually no wind at C-17
JANUARY	1976	A few relatively strong winds up to 10 m s^{-1} - weak correlation	
FEBRUARY	1976	Correlation- tendency to stronger winds at C-17	Correlation- tendency to stronger winds at C-17
MARCH	1976	Correlation- Stronger winds at C-17	No correlation - a few zero winds at C-17 with winds at C-13
APRIL	1976	Slight correlation	Slight correlation - stronger winds at C-17
MAY	1976	Correlation - stronger winds at C-17	Cases of zero wind at C-13
JUNE	1976	Slight Correlation - stronger winds at C-17	No correlation -many cases of zero wind at C-13
JULY	1976	Few but strong winds - stronger at C-17	No correlation
AUGUST	1976	No correlation - stronger winds at C-17	

Figure 17 is a polar graph of the deviation of the wind direction at C-13 from the direction at C-17 versus the wind direction at C-17 for a potential temperature gradient less than or equal to $-0.15^{\circ}C$ 100m^{-1} (unstable). Similar graphs were drawn for three different levels of stability. Analysis of the graphs gives the following results. The results can be summarized as follows:

1. For PTG <-0.15C 100m^{-1} the maximum deviations are from -90 degrees to +50 degrees. The deviations are approximately evenly distributed positively and negatively.

2. For -0.15 <PTG <PTG <1.10C 100m^{-1} the maximum deviations are from -180 degrees to +160 degrees. For west-southwest winds, the deviations tend to be negative, while for northerly winds, the deviations tend to be positive.

3. For PTG >1.10C 100m^{-1} the maximum deviations are from -150 degrees to 90 degrees.

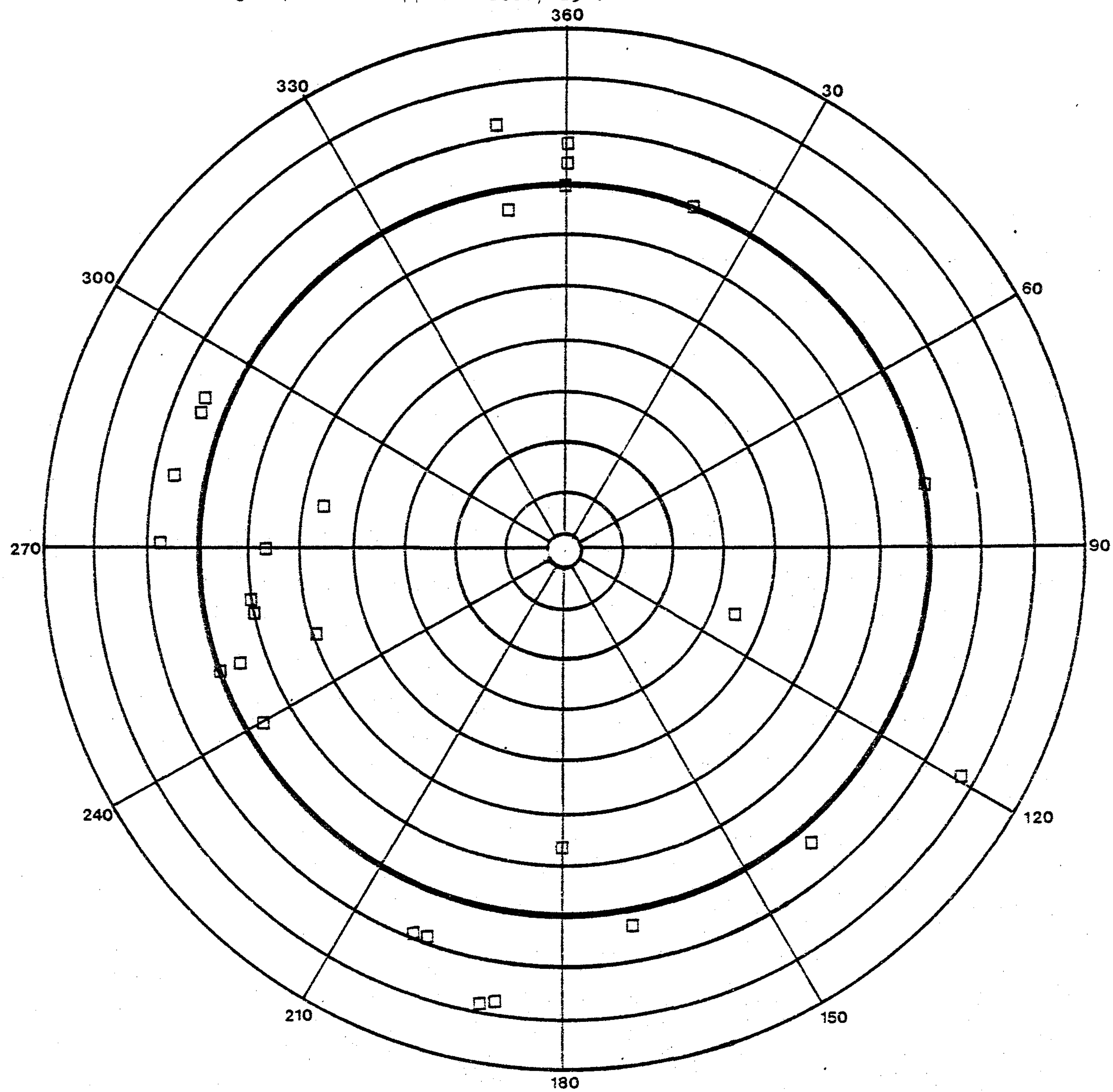
4. The deviations do not have a strong relationship to the wind direction.

5. Deviations greater than 90 degrees occur less than 10 percent of the time.

This comparison was done in a qualitative manner and hence suffers from subjective error. A point of further investigation may be the correlation of the winds with a time lag. Also the correlation of the wind speeds for different directions has not been studied.

Figure 17.

Deviation of wind direction in the layer 200 - 400 metres above the ground from Lease C-17 to Lease C-13 September 1975 to August 1976, when plume layer potential temperature gradient was less than, or equal to, $-0.15^{\circ}C/100m$ at Lease C-17. Radials indicate wind direction at Lease C-17. The heavy ring represents 0° deviation with negative deviation toward the centre, positive deviation toward the outside. Each ring represents approximately 25°.



CONCLUSIONS

The analysis performed for this report was generally limited to the rather small data sample obtained during the intensive study periods. The winter sample of February 1975 was small compared to the length of the winter season, and no intensive studies were available during the spring and late fall. Additionally, the winter of 1975 may have been atypically warm, further distorting the winter results. The following paragraphs summarize the results of this report, subject to the above limitations.

A geostrophic model and a power law model were evaluated for their ability to describe the vertical profile of the wind. The winds considered were restricted to those from 100 m to 600 m. The power law model was clearly superior. Winter limited mixing was the only category for which the geostrophic model gave smaller RMS errors. Even in this category, the power law model gave smaller errors for the majority of profiles.

To determine a reference height for the power law model, various heights from 100 m to 2000 m were tested. A height of 183 m gave the smallest relative error. The value of the exponent of the power law varied most with the atmospheric stability and time of day, while variations due to season, wind direction and reference height were relatively unimportant. Typical values of the exponent were 0.11 for limited mixing, 0.18 for unstable air, and 0.28 for stable air. Over the entire profile, the power law model produced an error of about 25 percent of the mean wind, while the geostrophic model produced an error of about 10 percent. In the plume layer, the corresponding errors were 10 percent and 20 percent.

During the cases of limited mixing, the value of β is small for the layer below the mixing height. For dispersion calculations, an appropriate model of the wind speed in this layer might be a constant speed model.

The surface and plume layer winds had typical diurnal variations. The surface winds had minimum values during mid-morning and maximum values at the time of maximum heating. Plume layer winds had maximum values in the early morning and late afternoon, with minimum values at the time of maximum heating.

The wind profile in limited mixing did not exhibit any clear characteristics. It could be characterized as an unstable ground based layer capped by a stable layer. The wind speed was approximately constant up to the mixing height. If a power law was fitted to the winds above and below the mixing height, typical summer values of β are 0.11 in the mixed layer and 0.28 above. The corresponding figures in winter were 0.14 and 1.34.

Low level jets were shown to exist, most often from 200 m to 500 m. The height of the jets did not correlate well with the mixing height, although the jets seemed to occur most often near those levels.

In the comparison of the winds at leases C-13 and C-17, little correlation was seen in the wind speeds. The wind speed was generally higher at C-17 than at C-13. The wind directions were generally within ninety degrees of each other at the two sites.

REFERENCES

Brown, R.A., 1974: Analytical methods in planetary boundary-layer modelling. John Wiley and Sons, Inc., Toronto, pp 68-77.

Murray,W. and J. Kurtz, 1976: A predictive study of the dispersion of emissions from the Syncrude Mildred Lake Plant, Environmental Research Monograph 1976-1. Syncrude Canada Ltd., Syncrude Environmental Affairs, Box 5790, Edmonton, Alberta, T6C 4G3.

APPENDIX 1

COMPUTER SOLUTION OF THE GEOSTROPHIC MODEL

The subroutine PHYCAL calculates wind speeds for 60 different levels. The heights of the levels are stored in array Z(60) and and the speeds are returned in array U(N). Array S(60) contains the measured wind speeds at the levels. HMIX is the height selected to represent the gradient level, in this report 700m.

Subroutine SOLVE solves the geostrophic drag law for the value G/U_*. This parameter is named VRAT. The input parameter VG is the geostrophic wind speed. The method is Newton's iteration.

```
      SUBROUTINE PHYCAL (N,MIX,HMIX,U,IBAD,VG)
      DIMENSION U(N),Z(60),S(60)
      COMMON/DATA/Z,S
      DATA F/0.0001/,AK/0.38/
      DATA ASQ/1./
      DATA Z0/0.5/
      HMIX = 700.
      ILEV = 0
110   ILEV = ILEV + 1
      IF (ILEV .EQ. N) GO TO 120
      IF (Z(ILEV) .LT. HMIX) GO TO 110
120   IB = ILEV-2
      IF(IB .LT. 1) IB = 1
      IT = ILEV + 2
      IF (IT .GT. N) IT = N
      K = 0
      SPBAR = 0.0
      DO 200 KZ = IB,IT
      SPE = S(KZ)
      IF (SPE .LT. 0.01) GO TO 200
      K = K + 1
      SPBAR = SPBAR + SPE
200   CONTINUE
      VG = SPBAR/FLOAT(K)
130   IBAD = 0
      IF (VG .LT. 0.01) GO TO 150
      CALL SOLVE (VG,VRAT)
      IF (VRAT .LE. 0.) WRITE (6,201) VG,USTAR,VRAT
201   FORMAT (1X,3F10.5)
      USTAR = VG/VRAT
      AVRAT = ALOG(VRAT)
      ALRO = ALOG(VG/(F*Z0))
      C = ALRO/AK - (AVRAT/AK + VRAT + 3.44)
      HMIX = 0.3*USTAR/F
      DO 100 I = 1,N
      IF (Z(I) .LT. 0.001) GO TO 140
      U(I) = VG + USTAR*(ALOG(Z(I)/HMIX) + C)
      GO TO 100
140   U(I) = 0.0
100   CONTINUE
101   FORMAT (1X,5F10.5)
      RETURN
150   IBAD = 1
      RETURN
      END
```

```
      SUBROUTINE SOLVE (VG,VRAT)
      DATA AK,F,Z0,TOL/0.38,0.0001,0.5,0.01/
      VRAT = 20.
      K = 0
100   FX = 2. + ALOG(VRAT) + AK*VRAT - ALOG(VG/(F*Z0))
      DFX = 1./VRAT + AK
      VRAT1 = VRAT - FX/DFX
      DIF = VRAT - VRAT1
      VRAT = VRAT1
      K = K + 1
      IF (K .GT. 100) GO TO 200
      IF (ABS(DIF) .GT. TOL) GO TO 100
      RETURN
200   WRITE (6,201) VRAT,VRAT1,FX,DFX
201   FORMAT (1X, F10.5)
      RETURN
      END
```

APPENDIX II

COMPUTER ANALYSIS OF LOW LEVEL JETS

Program JETCOR is used for statistical analysis of low level jets. This particular version correlates jet height and mixing height.

The DO loop 200 beginning at line 48 is executed once for each profile desired. Statements 52 to 69 search the profile for a low-level jet. The jet speed is WSP and the height of the jet is Z(MAXLEV)

Statements 89 to 120 solve for the covariance and variances of the desired variables.

```
      PROGRAM JETCOR (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTP
     + TAPE11,TAPE12)
      DIMENSION INDEX(1501),JNDEX(1501),IHL(20),Z(60),SP(
     + ZM(60),T(60),PT(60),SX(3,3),SY(3,3),SXX(3,3),SYY(3
     + N(3,3),X(2),RHO(3,3)
      DIMENSION AHDEX(24)
      DIMENSION IST(3),IFN(3),IMF(3)
      DIMENSION NT(3),NW(3),NS(3),NF(3),ND(3)
      DIMENSION JETVEL(24),NJET(24)
      REAL JETVEL
      COMMON/NDX/JNDEX
      COMMON/DATA/Z,SP,DIR,ZM,T,PT
      EQUIVALENCE (ZINV,IHL(17)),(MIX,IHL(10)),(HMIX,IHL(
     + (IPTIME,IHL(6))
      EQUIVALENCE (IHL(6),ITIME)
      EQUIVALENCE (IHL(18),TINV)
      DATA IFILE,JFILE/11,12/,LINX/1501/,IRD/0/,NRECS/  3
      DATA IST/243,867,4/,IFN/328,1239,43/,IMF/800,800,10
      CALL OPENMS (IFILE,INDEX,LINX,0)
      CALL OPENMS (JFILE,JNDEX,LINX,0)
      NOJET = 0
      NINV = 0
      DO 100 I = 1,3
      DO 100 J = 1,3
      N(I,J) = 0
      SX(I,J) = 0.0
      SY(I,J) = 0.0
      SXX(I,J) = 0.0
      SYY(I,J) = 0.0
      SXY(I,J) = 0.0
      RHO(I,J) =10.0
  100 CONTINUE
      DO 2100 I = 1,24
      JETVEL(I) = 0.0
      NJET(I) = 0
 2100  CONTINUE
      DO 400 I = 1,3
      NT(I) = 0
      NW(I) = 0
      NS(I) = 0
      NF(I) = 0
      ND(I) = 0
  400 CONTINUE
      IPASS = 1
      IBEG = IST(IPASS)
      IEND = IFN(IPASS)
      IMORN = IMF(IPASS)
      DO 200 IREC = IBEG,IEND
      CALL READMS (IFILE,IHL,20,IREC)
      IF (MIX .EQ. 3) GO TO 200
      CALL READR (IRD,IREC,NP,NM,IBFLG)
      ALMAX = 0.0
      ALMIN = 999.
      DO 300 ILEV = 1,NP
      IF (Z(ILEV) .LT. 10.) GO TO 300
```

```
      WSP = SP(ILEV)
      IF (ALMIN .LT. 999.) GO TO 310
      IF (WSP .LE. ALMAX) GO TO 310
      ALMAX = WSP
      MAXLEV = ILEV
      CUT = 0.5*ALMAX
  310 CONTINUE
      IF (WSP .LT. 0.00001) GO TO 300
      IF (ILEV .LE. MAXLEV) GO TO 300
      IF (WSP .GT. CUT) GO TO 300
      IF (WSP .GE. ALMIN) GO TO 300
      ALMIN = WSP
      MINLEV = ILEV
  300 CONTINUE
      IF (ALMIN .EQ. 999.) NOJET = NOJET + 1
      IF (ALMIN .EQ. 999.) GO TO 200
      G = Z(MAXLEV)
      H = HMIX
      DO 600 IH = 1,2
      IF (IH .EQ. 2) H = TINV
      IF (IH .EQ. 2 .AND. ITIME .GT. IMORN) GO TO 600
      IF (IH .EQ. 2 .AND. TINV .LT. 10.) GO TO 600
      IF (IH .EQ. 1 .AND. MIX .NE. 1) GO TO 600
      IT = 1
      IF (ITIME .LT. IMORN) IT = 2
      N(IH,IT) = N(IH,IT) + 1
      SX(IH,IT) = SX(IH,IT) + H
      SY(IH,IT) = SY(IH,IT) + G
      SXX(IH,IT) = SXX(IH,IT) + H*H
      SYY(IH,IT) = SYY(IH,IT) + G*G
      SXY(IH,IT) = SXY(IH,IT) + G*H
  600 CONTINUE
  200 CONTINUE
      DO 700 I = 1,2
      DO 700 J = 1,2
      N(I,3) = N(I,3) + N(I,J)
      N(3,I) = N(3,I) + N(J,I)
      SX(I,3) = SX(I,3) + SX(I,J)
      SX(3,I) = SX(3,I) + SX(J,I)
      SY(I,3) = SY(I,3) + SY(I,J)
      SY(3,I) = SY(3,I) + SY(J,I)
      SXX(I,3) = SXX(I,3) + SXX(I,J)
      SXX(3,I) = SXX(3,I) + SXX(J,I)
      SYY(I,3) = SYY(I,3) + SYY(I,J)
      SYY(3,I) = SYY(3,I) + SYY(J,I)
      SXY(I,3) = SXY(I,3) + SXY(I,J)
      SXY(3,I) = SXY(3,I) + SXY(J,I)
  700 CONTINUE
      DO 750 I = 1,2
      N(3,3) = N(3,3) + N(I,3)
      SX(3,3) = SX(3,3) + SX(I,3)
      SY(3,3) = SY(3,3) + SY(I,3)
      SXX(3,3) = SXX(3,3) + SXX(I,3)
      SYY(3,3) = SYY(3,3) + SYY(I,3)
      SXY(3,3) = SXY(3,3) + SXY (I,3)
```

```
  750   CONTINUE
        DO 800 I = 1,3
        DO 800 J = 1,3
        IF (N(I,J) .LT. 2) GO TO 800
        AN = FLOAT(N(I,J))
        COV = SXY(I,J)-SX(I,J)*SY(I,J)/AN
        SDX = SXX(I,J)-SX(I,J)**2/AN
        SDY = SYY(I,J) - SY(I,J)**2/AN
        RHO(I,J) = COV/SQRT(SDX*SDY)
  800   CONTINUE
        WRITE (6,801) ((N(I,J),J=1,3),(RHO(I,J),J=1,3),I=1,3
        FORMAT (1X,3I10,/,3F10.5)
        STOP
        END
```

APPENDIX III

DATA BASE SAMPLES

STABLE

Height (m)	Speed (ms^{-1})	Direction (Degree)	T(^oC)	Potential Temperature (^oC)
		06 FEB 1975 1355		
64	5.1	335.8	-17.6	-17.0
128	6.1	339.6	-18.2	-17.0
192	6.2	342.9	-18.9	-17.0
256	6.4	348.7	-19.3	-16.8
320	7.4	351.4	-20.0	-16.9
384	8.8	354.3	-20.0	-16.2
448	8.9	350.3	-20.5	-16.1
512	10.6	345.0	-21.0	-15.9
516	11.6	238.9	-21.0	-15.3
640	12.0	335.1	-21.0	-14.6
704	10.5	330.6	-21.5	-14.5
768	11.0	329.2	-22.0	-14.4
832	9.7	327.0		
896			-22.5	-13.6
		11 FEB 1975 1705		
64	2.9	351.8	-34.6	-33.8
128	4.3	358.5	-34.9	-33.7
192	4.9	359.3	-35.5	-33.6
256	5.2	0.9	-36.1	-33.6
320	5.6	356.7	-36.7	-33.6
384	7.0	350.7	-36.7	-32.9
448	10.2	351.9	-34.4	-31.7
512	11.4	351.9	-34.4	-29.3
576			-34.4	-28.7
640	5.6	6.2	-33.9	-27.5

Height (m)	Speed (ms^{-1})	Direction (Degree)	T(^{o}C)	Potential Temperature (^{o}C)
		18 FEB 1975 833		
64	4.7	230.5	-7.7	-7.1
128	15.1	226.6	-7.2	-5.9
192	5.8	237.2	-5.4	-3.5
256	16.7	242.6	-5.6	-3.1
320	18.2	247.0	-5.9	-2.7
384	14.7	255.3	-6.3	-2.6
448	18.5	254.9	-6.1	-1.7
512	17.2	257.8	-5.9	-0.8
576	10.3	270.1	-6.1	-0.4
640	13.4	260.4	-6.5	-0.1

STABLE

Z(m)	V(ms^{-1})	O(Deg)	T(Deg C)	PT(Deg C)
		02 MARCH 1976 722		
85	2.4	351.0		
170	3.6	10.3	-30.3	-28.6
255	5.7	32.5	-28.1	-25.5
340	4.6	48.7	-27.6	-24.3
425	2.7	53.2	-27.2	-23.1
510	1.4	66.7	-25.4	-20.3
595	3.8	61.2	-23.7	-17.8
680	5.0	59.7	-24.0	-17.3
		25 JULY 1976		
85	4.0	270.1	10.8	11.6
170	8.5	268.6	12.0	13.7
255	12.0	285.6	11.6	14.1
340	12.0	294.5	13.0	16.3
425	13.5	300.5	12.8	17.0
510	13.5	306.7	12.3	17.3
595	12.5	303.1	11.8	17.7
680	12.5	302.7	11.2	18.0

THERMALLY UNSTABLE

01 AUG 1975

Height (m)	V (ms^{-1})	θ (Deg)	T (^oC)	PT (^oC)
64	2.0	170.5		
128	4.0	177.8	22.2	23.5
192	1.6	198.3		
256	2.4	194.0	19.3	21.8
320	1.8	180.8		
384	0.3	165.0	18.2	22.0
448	0.7	146.0		
512	1.0	196.0	16.5	21.5
576	0.9	185.0		
640	0.9	347.1	14.4	20.7

06 MAY 1445

Height (m)	V (ms^{-1})	θ (Deg)	T (^oC)	PT (^oC)
85	4.4	217.9		
170	4.6	209.7	14.8	16.5
255	4.3	209.1	12.8	15.3
340	4.8	212.2	10.7	14.1
425	5.1	206.3		
510	5.4	214.1	7.3	12.3
595	8.3	215.5		
680	8.8	215.5	5.1	11.8

12 MAY 1426

Height (m)	V (ms^{-1})	θ (Deg)	T (^oC)	PT (^oC)
85	8.5	230.5	14.8	15.6
170	6.1	251.4	13.6	15.3
255	3.8	271.9		
340	5.2	268.1	9.4	12.7
425	3.7	265.9		
510	5.2	266.8	5.3	10.3
595	4.4	293.3		
680	3.0	267.3	0.9	7.6

Height (m)	V (ms^{-1})	θ (Deg)	T (^oC)	PT (^oC)
		27 MAY 1976 1422		
85	4.4	185.1	25.0	25.8
170	5.0	188.3	23.5	25.2
255	5.4	188.7	22.0	24.5
340	5.2	189.0	20.6	23.9
425	4.8	185.8	19.5	23.7
510	4.9	182.6	18.0	23.0
595	5.0	166.1	16.4	22.3
680	4.3	161.6	15.2	21.9
		9 JUNE 1976 1415		
85	3.0	275.0	21.4	22.2
170	3.8	260.9	20.6	22.3
255	4.6	253.8	19.6	22.1
340	4.5	269.3	18.7	22.0
425	5.0	255.8	17.9	22.1
510	5.3	253.5	17.0	22.0
595	5.5	249.7	16.0	21.9
680	4.6	246.4	15.1	21.8

Conditions of Use

M.E.P. Company, 1977. The vertical wind profile at Mildred Lake, Alberta. Syncrude Canada Ltd., Edmonton, Alberta. Professional Paper 1977-1. 62 pp.