VARIABILITY IN WIND SPEED MEASUREMENT AND ITS EFFECT ON FIRE DANGER RATING

by
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Abstract

This paper analysizes wind speed and direction distributions obtained at nine forestry stations and nine airports across Canada. The effect of differences in the distributions on forest fire danger rating is discussed. The major finding is that forestry stations have a significantly lower average wind speed than airports and the difference between the two decreases as wind speed increases. This difference caused a considerably greater percentage of days to fall in the extreme fire danger class at the airports. The data did not permit the derivation of a function relating the wind speed ratio to the size of the clearing at the forestry station.

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INTRODUCTION

Every day thousands of meteorological observations are made across Canada and the United States for the purpose of calculating forest fire danger. The most common measurements are: wind speed, rainfall, temperature and relative humidity. These observations are combined through the use of a forest fire danger rating system to produce a numerical estimate of the local fire behaviour potential. The local fire danger is generally transmitted to a central agency which combines the individual values to produce an area fire danger. The area fire danger forms the basis of many presuppression and prevention decisions such as: the intensity of air patrols, the number of lookouts to man, the size of the initial attack crew, the disposition of stand-by forces, and occasionally the closure of certain areas to the public. In general the degree of preparedness of the fire control organization is highly dependent on the area fire danger.

As an organization increases the intensity of its preparedness activities, expenditures rise rapidly. This is particularly true where expensive equipment, such as aircraft are involved. On the other hand, the consequences of being insufficiently prepared for the occurrence of a major fire can be disastrous. Since the total budget for presuppression activities is normally fixed at the beginning of the fire season, it is imperative that funds be allocated in such a way as to minimize unnecessary expenditures. Furthermore, since the allocation of funds is generally determined on the basis of fire danger over an extensive area, it is also important that the area value accurately represents the average potential behaviour of a fire, should an outbreak occur.

The accuracy of local values of fire danger is dependent on the validity of the fire danger rating system which is used. However, even if completely reliable local values are obtained, a number of problems arise when they are combined to obtain an area value. One very important consideration is the uniformity of the meteorological measurements at all the stations which enter into the combination. For example, fire danger is dependent on wind speed. Therefore, if two stations measure different wind speeds, they will report different fire dangers. The question then arises as to whether the difference in wind speed measurement is due to an actual difference in velocity, or due to differences in anemometer exposure. Conversely, two different exposures can give identical readings when an actual wind speed difference exists. The occurrence of either of these two situations will cause one station to be in error relative to the other. Therefore an area fire danger computed by using the values obtained at the two stations in the foregoing example would have an error in proportion to the difference between the two stations

The main purpose of this paper is to examine the magnitude of the differences in wind speed distributions between forestry stations and airports, and discuss some of the causes for these differences. The effect of wind speed differences on the final fire danger rating is also discussed. Finally, an attempt to relate these differences to a simple measure of the distance to and height of surrounding obstructions is presented.

DISCUSSION

The most important factors affecting wind speed measurements can be classified in three general groups. All factors related to the topography of the general area surrounding the site are in the first group. The second group consists of factors related to the site on which the anemometer is exposed. The last group is related to the exposure of the anemometer within the site. Each will be discussed separately.

A. Topography

Only the briefest possible summary is presented here. More detailed discussions can be found in MacHattie (1968) and Geiger (1965). In the absence of obstructions, the nature of the topography surrounding the site on which the anemometer is located greatly affects wind speed and direction. For example; winds tend to be intensified and diverted in the vicinity of hills. Wind also has a tendency to be channelled along major valleys. In mountainous areas the effect of valley and slope winds have to be considered. Near oceans and large lakes, land and sea breezes play an important role. It can be seen therefore that a great deal of care is needed in selecting a site to ensure that wind observations are representative of a general area rather than simply measuring local phenomena.

B. Site

Generally, meteorological instruments are located in an open area adjacent to an adminstrative office. This office may be a ranger station, a sawmill, an airport, a fire tower; in fact it may be any permanently manned structure involved in the adminstration or use of a forested area. For the majority of meteorological observations such as temperature, rainfall and relative humidity, it is not difficult to find a clearing of sufficient size so that the instruments are relatively unaffected by adjacent obstructions. In the case of wind measurements, however, a reduction in wind speed due to obstructions such as buildings and trees, can be felt as much as twenty or more times the height of the obstruction on the downwind side, and five times the height of the obstruction on the upwind side (Caborn 1953, Stoeckeler 1962, and van Eimern 1964). The amount by which wind speed is reduced and the distance to which the reduction is felt, is also influenced by the profile of the obstruction. A house with a sloping roof or a shelter belt would have a considerably different effect from an abrupt change in the reference level (for example; an opening in a solid stand of trees). The reduction in wind speed in an open area adjacent to a solid stand of trees can be felt for a distance of about seven times the height of the trees from the edge of the forest (Munn 1966, and Anon 1959).

Caborn (1953) explains the increased distance of wind speed reduction for shelter belts in terms of their lifting action, whereby an upward momentum is induced in the wind by the windward slope of the shelterbelt. He states that the absence of lifting action at the leeward edge of a forest canopy allows the wind to drop to the ground more quickly. However, he also points out that a shelterbelt which allows some of the wind to pass through at a reduced speed causes a smaller reduction in speed behind the belt but that this effect extends over a considerably greater distance. More recently, van Eimern (1964) states that the main factor affecting the distributions of wind speed on the leeward edge of a shelterbelt is its permeability. If one considers a stand of trees as a very dense shelterbelt, it follows therefore that the reduction in wind speed on the lee edge of the stand would be great, but this reduction would not extend as far as it would behind a shelterbelt of moderate density. This is thought to be due to the fact that a great deal of turbulence is created at the leeward edge of a stand of trees which quickly transfers the winds' momentum downward. The turbulence arises in large measure as a result of the pressure reduction which occurs behind the lee edge of the stand in accordance with Bernoullis equation. The greater the difference between wind speeds above and behind the stand, the greater will be the pressure difference and therefore the turbulence will also be proportionately greater. If some of the wind is allowed to pass through (40% to 50% density appears to give the greatest distance of reduction according to van Eimern (1964), who conducted a thorough literature review), a more streamlined flow results and the air which has been lifted is carried to far greater distances.

In predominately forested areas there are few sites available other than airports which are completely open for considerable distances in all directions. While anemometers are generally exposed in the largest space available, no two open areas are identical. As the size of the clearing becomes smaller, wind speed in the clearing is reduced. Furthermore, clearings are rarely perfectly round so that the reduction in wind speed varies as the wind direction changes. In addition, buildings within the opening have an effect on wind speed measurements when they are near the anemometer.

C. Location of the Anemometer

As an economic measure, anemometers have often been mounted on a short (six to twelve foot) pole placed on the roof of a building. This practice makes interpretation of the observations very difficult. Some of the problems are:

1. Observations are affected by the slope of the roof (if peaked) when the winds blow towards the sloping face.

2. Unless the anemometer is centered on the roof, it will be on the lee side on some days and on the windward side on others, with corresponding changes in wind speed measurements.

3. A great deal of turbulence is generated by buildings which causes anemometer readings to be quite variable and unreliable.

4. The degree to which the building affects the anemometer is influenced by the height of the anemometer above the roof.

In summary, any wind measurements taken from an anemometer mounted above the roof of a building will be of dubious reliability. This practice should be avoided if at all possible.

The last factor to be considered is the height of the anemometer above ground. Wind velocity increases with increasing elevation above the zero reference level. The zero reference level may be the ground itself, the top of a cornfield, or the top of a forest canopy. Between the ground and the zero reference level wind patterns are extremely complex and difficult to analyze. Above this level a widely used empirical relationship for the increase of wind speed with height is given by Sellers (1965) as:

(1)
$$\frac{U_2}{U_1} = \left(\frac{Z_2}{Z_1}\right)^a$$

Where: U_2 = wind speed at height 2

U_1 = wind speed at height 1

Z_2 = height above zero reference level of U_2

Z_1 = height above zero reference level of U_1

a = stability parameter

Sellers states that the relationship fits observed wind profiles when a=0.14 for unstable (afternoon) conditions, a=0.18 for neutral (early morning and evening) conditions and a=0.33 for stable (night) conditions. Using these values the ratios of wind speed at various heights relative to the speed at 100 ft. were computed and are presented in Table 1.

Table 1. Ratio of wind speed at several heights relative to the speed at 100 ft. under stable, neutral, and unstable conditions.

Height (ft.)	Stable	Neutral	Unstable
100	1.000	1.000	1.000
80	.929	.961	.969
60	.845	.912	.931
40	.739	.848	.880
30	.672	.805	.845
20	.588	.748	.798
10	.468	.661	.724
5	.372	.583	.657

As can be seen, the rate of change is greatest under stable conditions, and at lower elevations. Since meteorological observations for fire danger rating purpose are generally taken during the day, the values for neutral or unstable conditicns would normally apply.

PROCEDURE

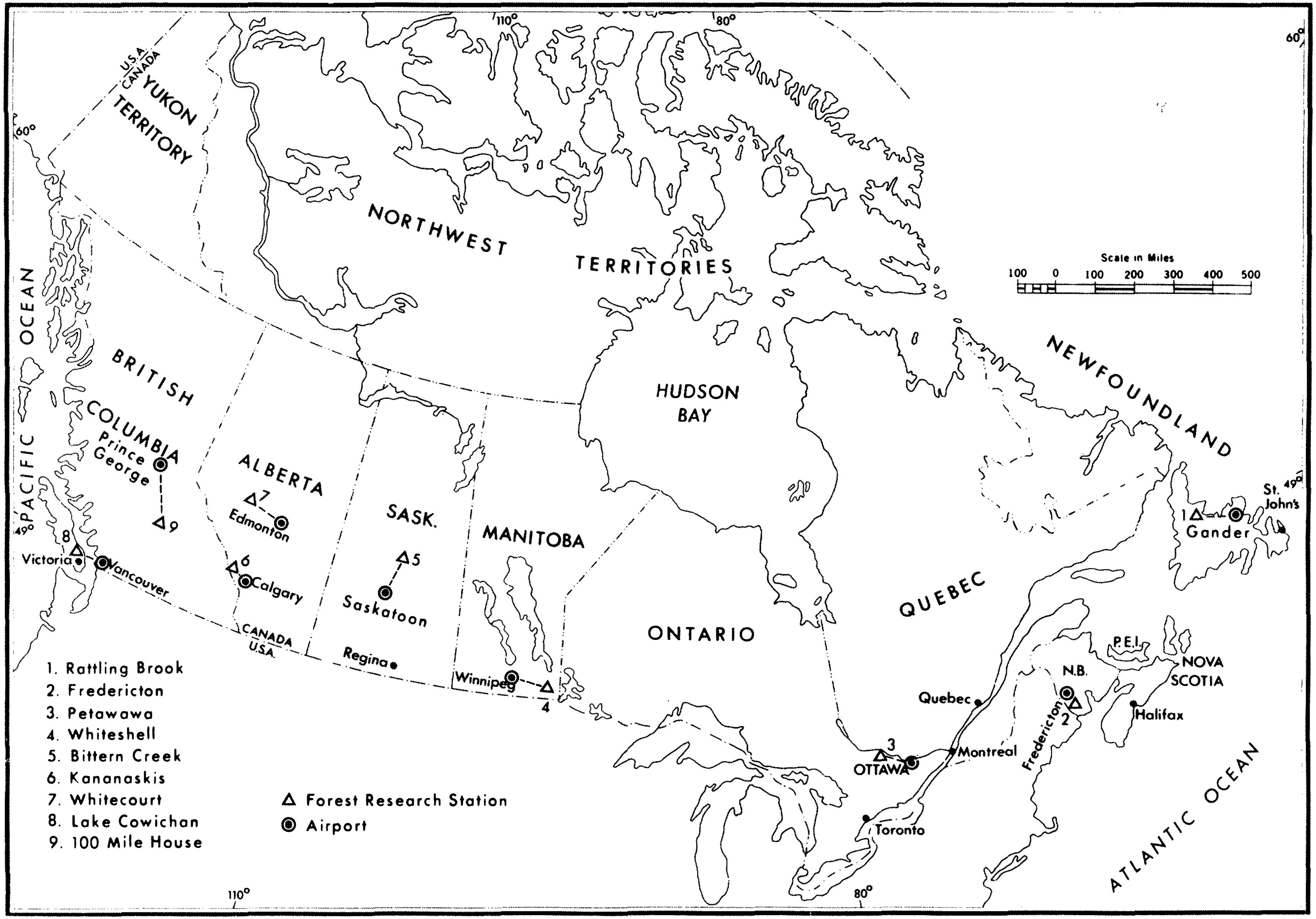
A. Wind Speed Analysis

Nine forestry stations across Canada were chosen for analysis. The names and locations of the stations are shown in Figure 1. All stations had been, and in some cases are still being used for forest fire research investigation. An effort was made to locate the anemometers in the largest open areas available, consistent with the necessity for accessibility. It was felt by those persons involved that the sites chosen were as good as could be found in the area.[1/] In addition, since the stations were used for research rather than operational activities, it can be assumed that the instruments used were of high quality and properly maintained. All anemometers were mounted on a pole or mast which was at least ten or more feet higher than the trees surrounding the clearing. Between 2 and 28 summers of wind observations have been recorded and placed on magnetic tape for each station.

Airports, for which ten-year climatic summaries are published (Anon. 1967), were chosen as close as possible to the forestry stations. The airport locations are also shown in Figure 1. Whenever possible, airports for which diurnal averages are also published (Cudbird, 1964) were chosen. This is so that adjustments

1/ *WILLIAMS, D.E. - Personal Communication, 1968*

Figure 1. Location of Forestry Stations and Airports



could be made to the wind speed distributions, as will be discussed subsequently.

Forestry station winds were divided into classes of 3 m.p.h. Calm winds and the 1-3 m.p.h. class, were grouped together. Since velocity measurements are rounded off to the nearest mile it was assumed that all calm winds were from observations of 0.5 m.p.h. or less. Therefore the range for the lowest class is 3.5 m.p.h. (0 to 3.5 m.p.h.) rather than 3 m.p.h. (0.5 to 3.5 m.p.h.). The percentage of observations falling into each class was determined. The percentage of observations at the mid-point of each class for a 1 m.p.h. range was then determined by dividing by the class interval. This may also be considered the probability of obtaining an observation at the center point of the class (assuming a constant rate of change within a class). Smooth curves joining the center points are plotted in Figures 2 through 10, and listed in Table 2. Mathematically, the equation for the above procedure is simply:

(2) $$P_i = \frac{n_i}{N \cdot C}$$

where: P_i = probability of obtaining observations at center point of class i

n_i = number of observations in a wind speed class

N = total number of observations, and

C = class interval.

For airport winds, n was the total number of hours (using monthly averages obtained over a 10 year period) during which the wind blew in a particular speed class during the months of May through October. N is the total number of hours of observation during the months of May through October. The data was obtained from the Meteorological Branch, Department of Transport (Anon 1967). It should be pointed out that the wind speed classes are not uniform for airport winds. The computed percentages are listed in Table 3.

The foregoing procedure results in normalized wind speed probability curves with an area under the curve of 1.0 for each airport and forestry station. It is not possible to compare the curves directly, however, due to differences in sampling techniques used at the two types of stations. First, an adjustment must be made for differences in anemometer heights. Airport anemometer heights were obtained from the Climatic Summaries (Anon 1959) and are listed in Table 3. Approximate forestry station anemometer heights were obtained by interpreting photographs of the weather sites, and are listed in Table 2. The ratios of wind speeds at the two heights (U_2/U_1) was computed using equation (1) where a=0.18 (neutral conditions). The actual adjustment was computed using:

TABLE NO. 2

PROBABILITY OF OBTAINING OBSERVATION AT CENTER POINT OF CLASS INTERVAL FOR FORESTRY STATIONS (IN PERCENT) *

STATION	CENTER POINT OF INTERVAL (MPH)									ANENOMETER HEIGHT (FT)	ER
	1.75	5.	8.	11.	14.	17.	20.	23.	26.		
Rattling Brook	11.54	10.60	6.89	1.77	0.61					33	2.5
Fredericton	9.91	10.42	7.45	2.81	0.97	0.12	0.01			30	
Petawawa	12.68	10.02	5.61	2.06	0.86	0.25	0.08	0.06		65	2.2
Whiteshell	8.63	11.73	8.09	2.53	0.74	0.10	0.07			60	2.2
Bittern Creek	7.60	11.86	8.12	3.54	0.72	0.18	0.04	0.02		45	2.0
Kananaskis	12.36	9.57	6.07	2.11	0.76	0.22	0.13	0.04	0.01	48	3.6
Whitecourt	18.38	8.71	2.87	0.31						30	4.4
Lake Cowichan	19.78	8.60	1.49	0.11	0.03	-	-	0.03		45	3.9
100 - Mile House	20.89	7.02	1.64	0.25	0.03					35	2.0

* Within ± 0.5 MPH of center point of class

TABLE NO. 3

PROBABILITY OF OBTAINING OBSERVATION AT CENTER POINT OF CLASS INTERVAL FOR AIRPORTS (IN PERCENT) *

AIRPORT	CENTER POINT OF INTERVAL (MPH) 1.75	5.5	10.0	15.5	21.5	28.0	35.0	42.5	ANENOMETER HEIGHT (FT)	MAXIMUM VELOCITY ** (MPH)
Gander	1.71	3.91	5.90	5.34	1.97	0.56	0.14	0.02	61	65
Fredericton	5.57	7.58	5.68	2.97	0.55	0.09	0.01		59	43
Ottawa	2.99	8.36	6.99	2.90	0.52	0.08	0.01		64	54
Winnipeg	1.65	5.02	6.33	4.43	1.89	0.54	0.10	0.01	77	54
Saskatoon	1.74	5.03	6.66	4.50	1.67	0.44	0.05		57	52
Calgary	3.25	5.83	6.33	3.41	1.51	0.47	0.10	0.02	60	56
Edmonton	1.59	3.54	6.12	5.51	1.84	0.62	0.16	0.02	60	50
Vancouver	5.88	9.30	6.02	1.62	0.30	0.07	0.01		64	55
Prince George	9.57	6.78	4.60	2.17	0.40	0.10	0.01		54	41

* Within ± 0.5 MPH of center of class

** Average Velocity for one hour.

Fig. 2 Percentage distributions of wind speed and direction for Rattling Brook and Gander Airport.

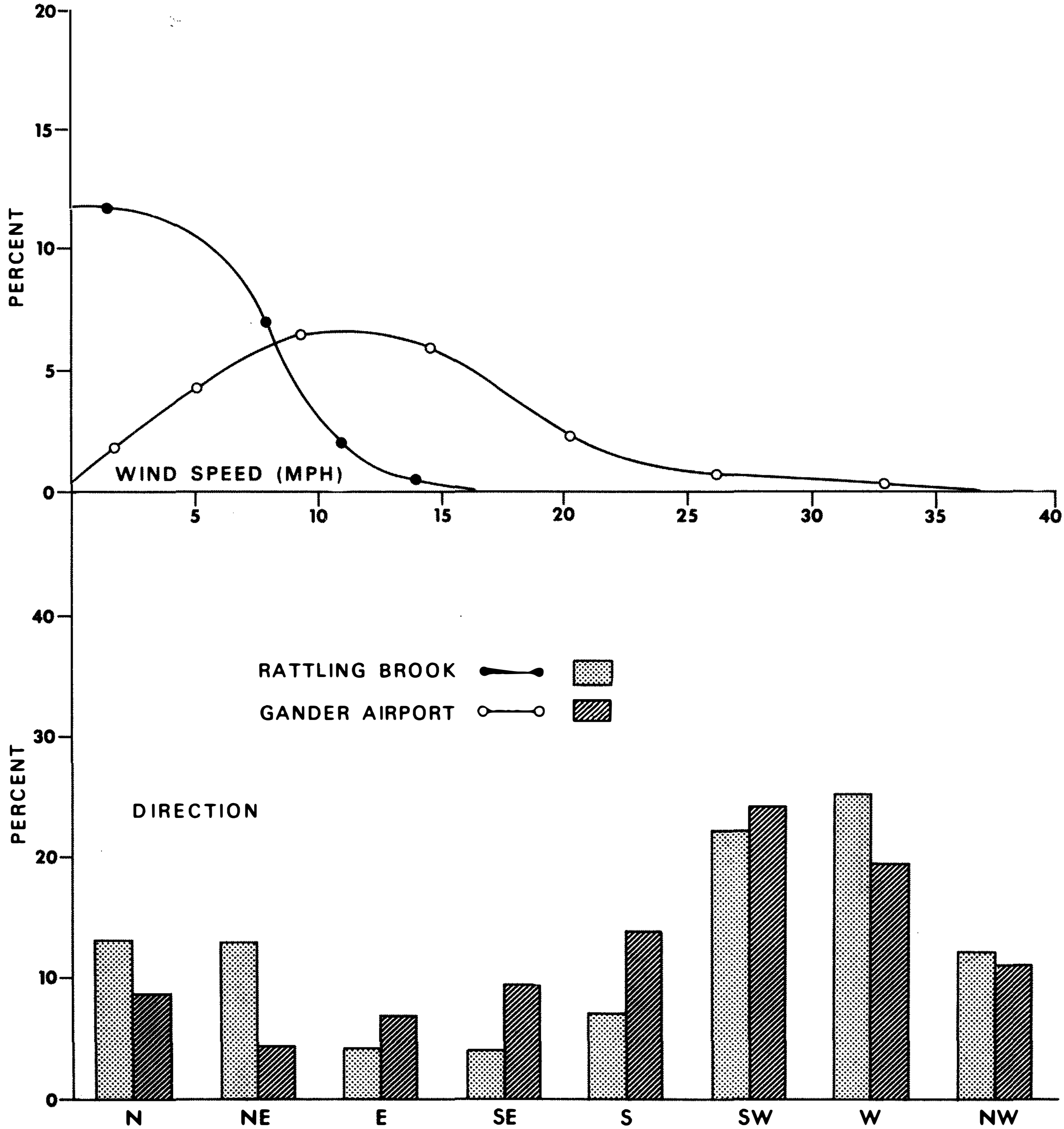


Fig. 3 Percentage distributions of wind speed and direction for Fredericton and Fredericton Airport.

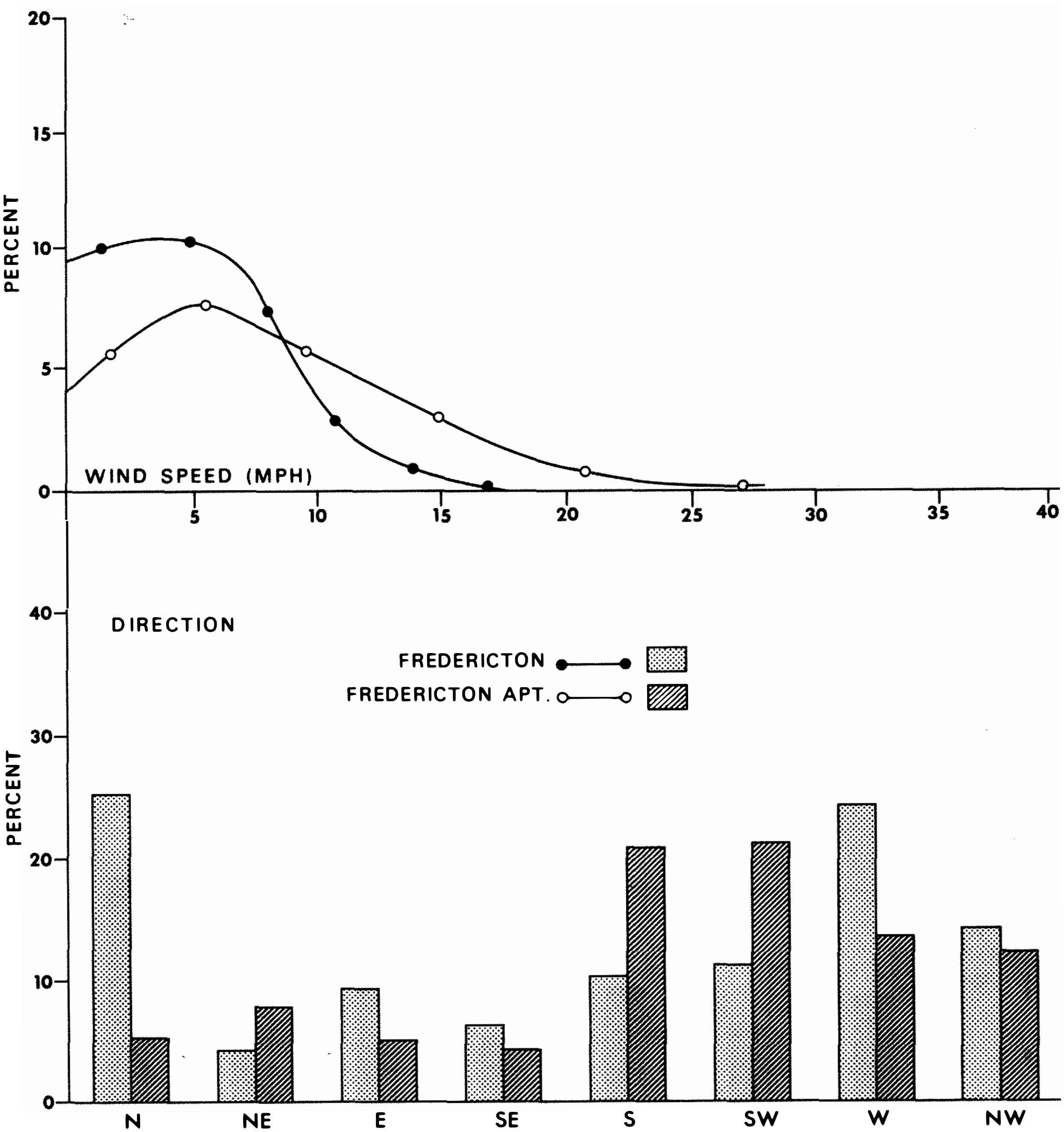


Fig. 4 *Percentage distributions of wind speed and direction for Petawawa and Ottawa Airport.*

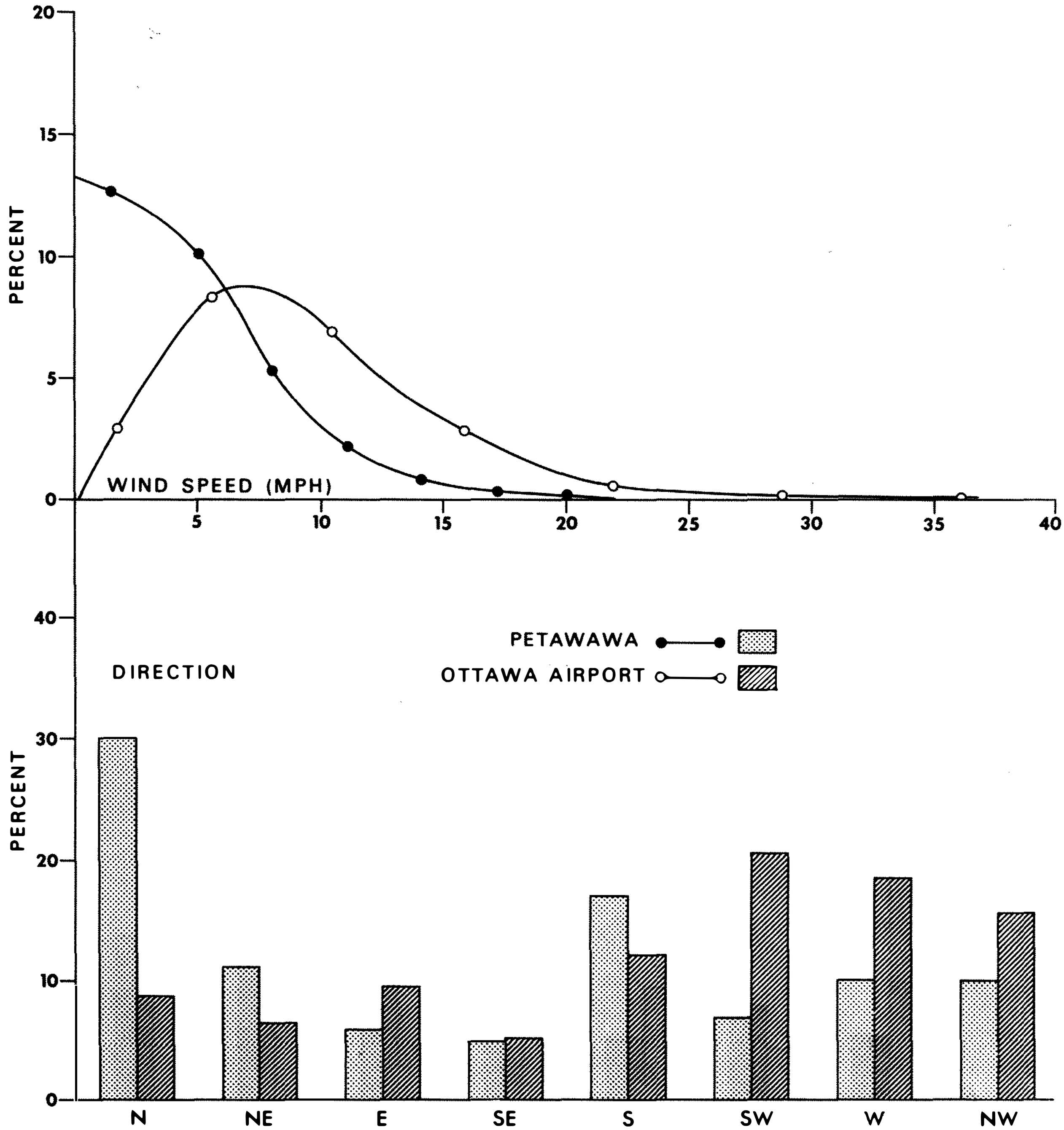


Fig. 5 Percentage distributions of wind speed and direction for Whiteshell and Winnipeg Airport.

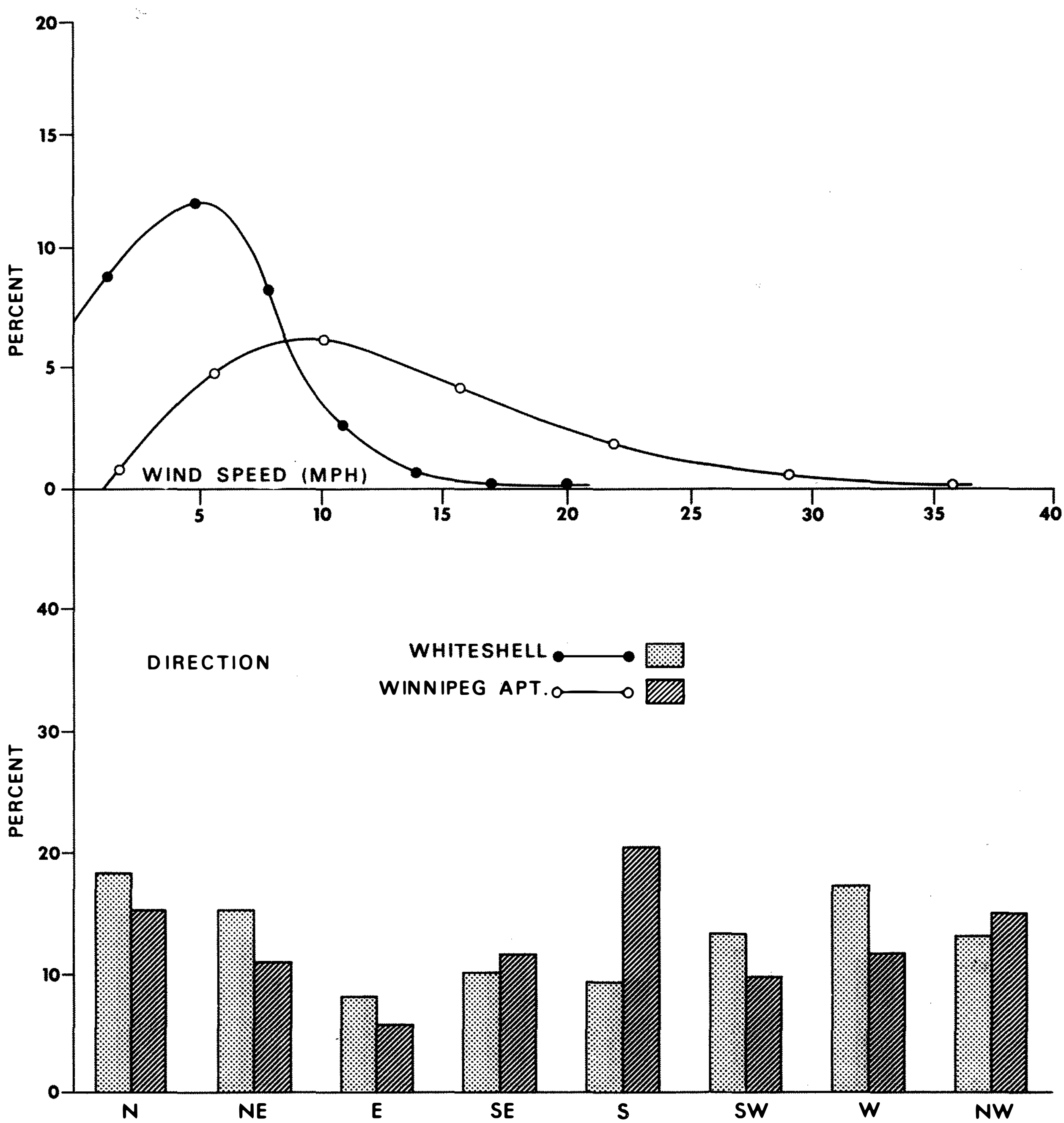


Fig. 6 Percentage distributions of wind speed and direction for Bittern Creek and Saskatoon Airport.

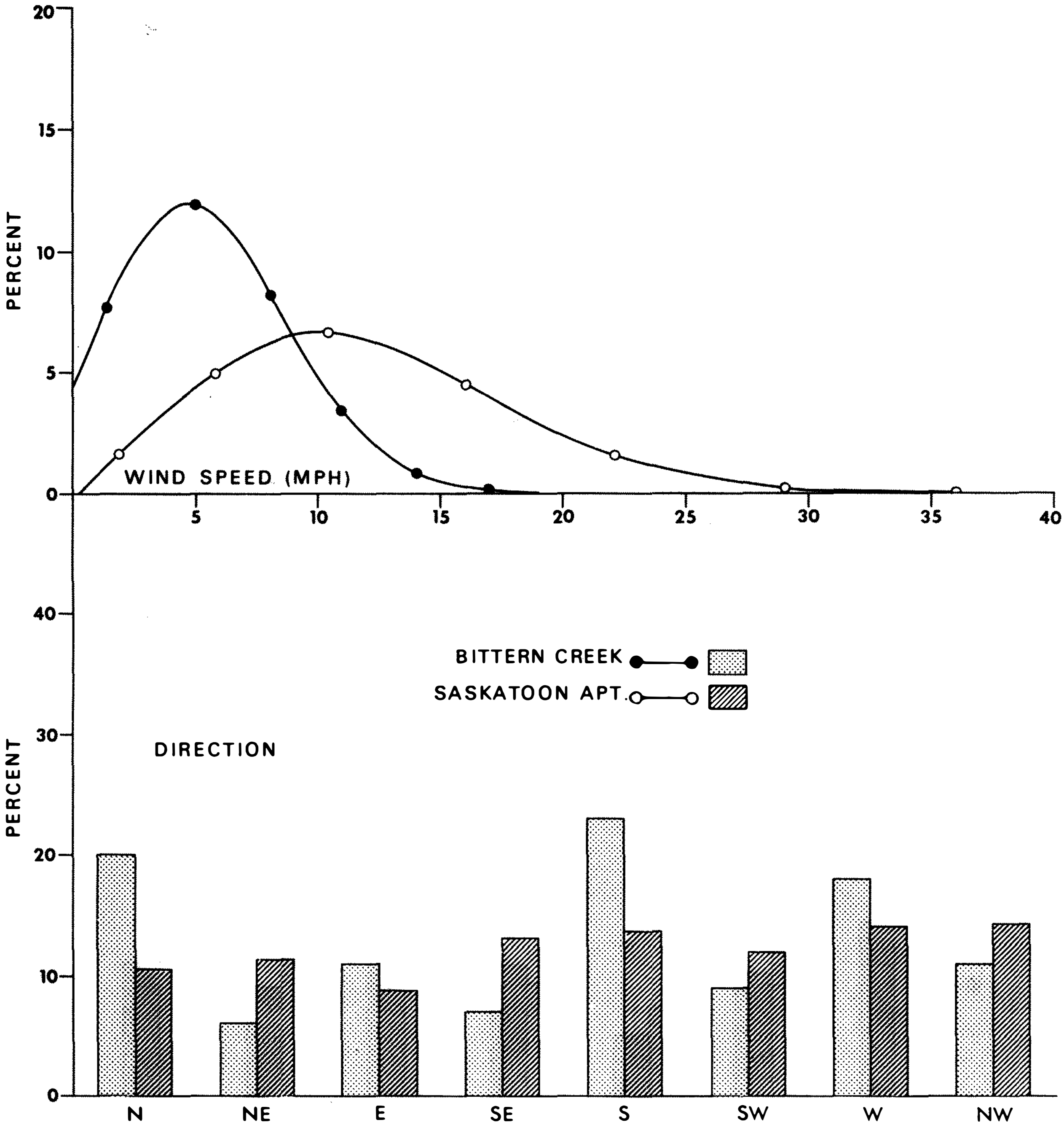


Fig. 7 Percentage distributions of wind speed and direction for Kananaskis and Calgary Airport.

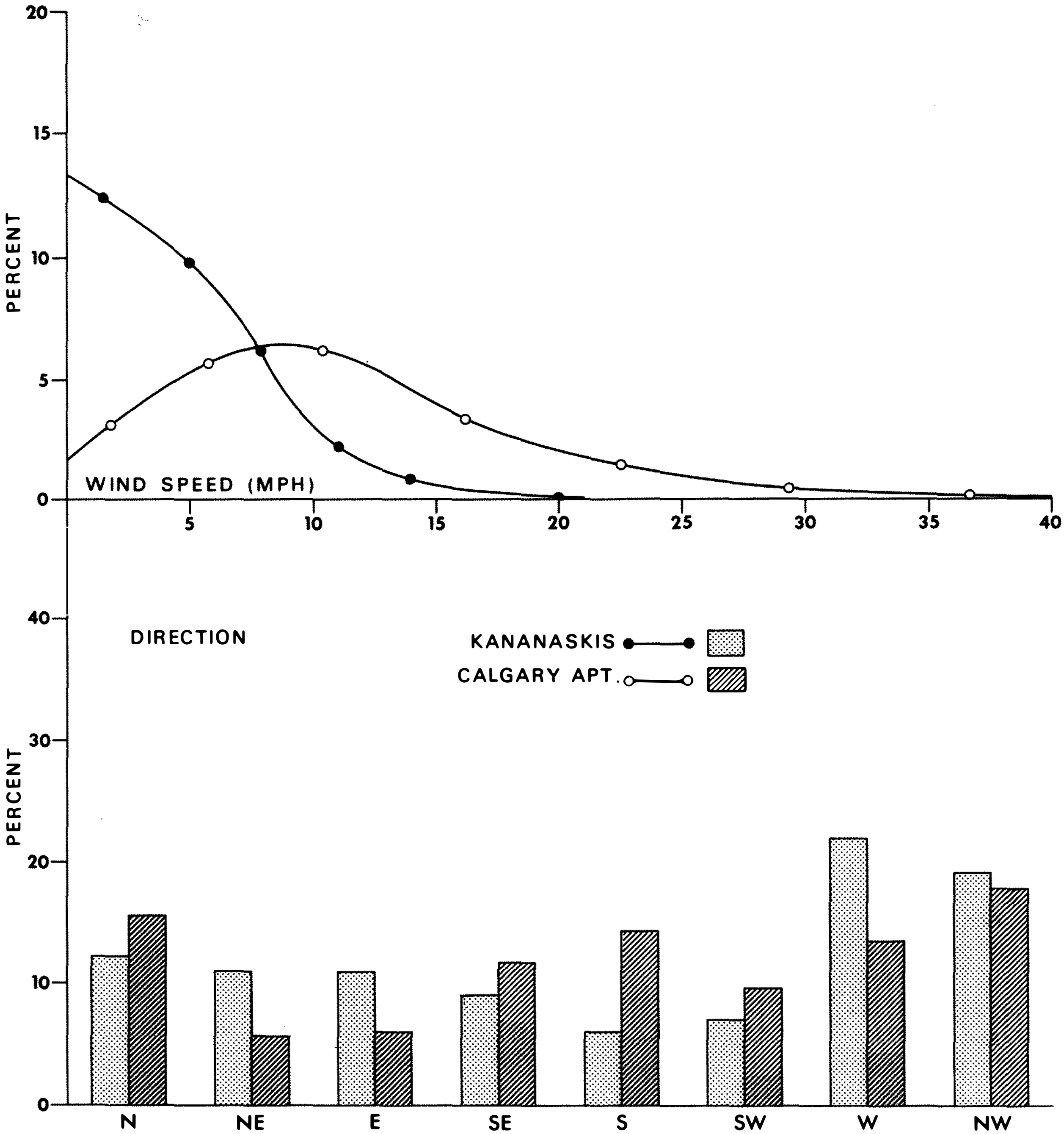


Fig. 8 *Percentage distributions of wind speed and direction for Whitecourt and Edmonton Airport.*

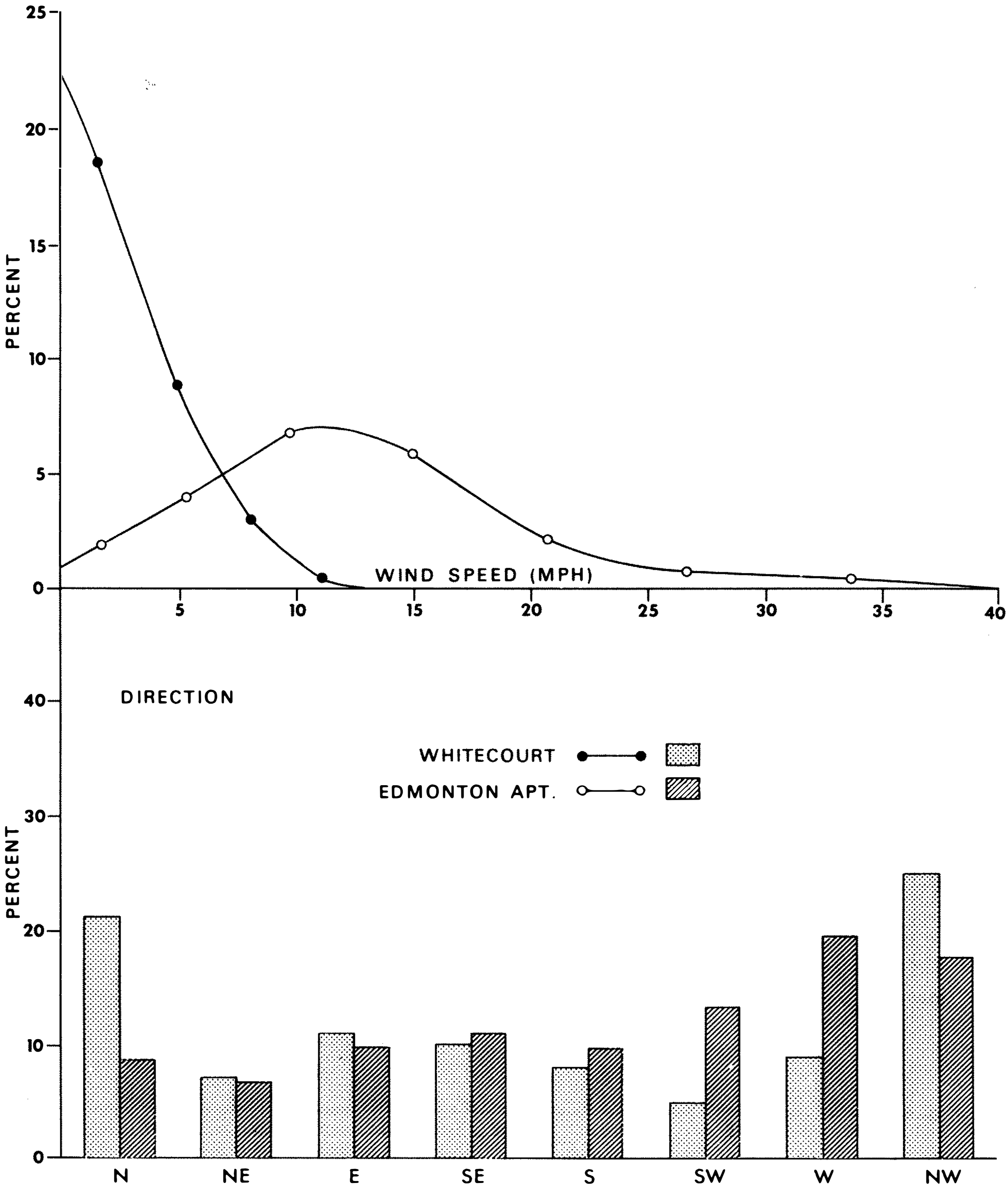


Fig. 9 Percentage distributions of wind speed and direction for Lake Cowichan and Vancouver Airport.

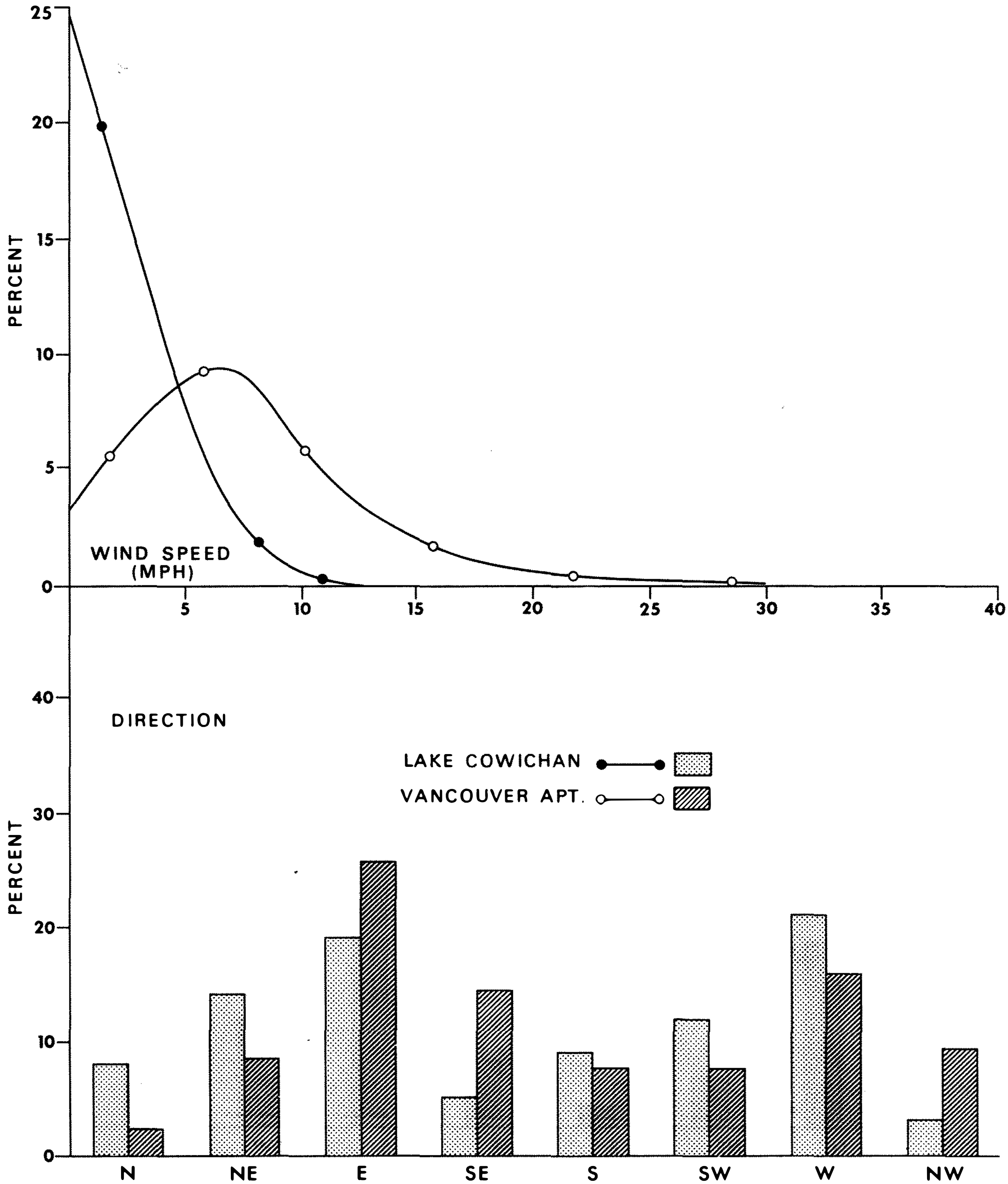
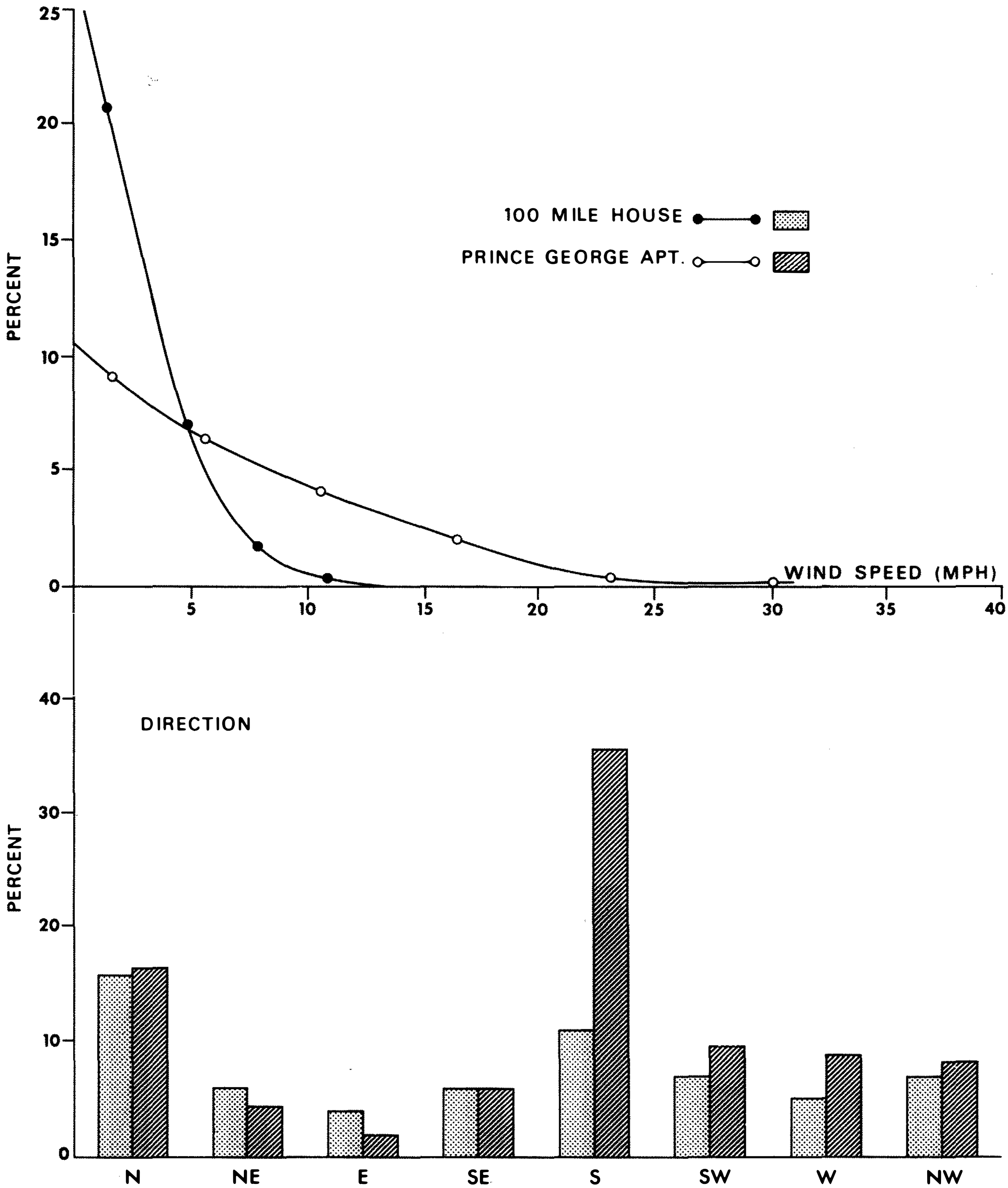


Fig. 10 Percentage distributions of wind speed and direction for 100 Mile House and Prince George Airport.



(3) $$a_h = -U_i \left[1 - \left(\frac{U_f}{U_a} \right) \right] .$$

where: a_h = adjustment due to height difference (m.p.h.)

u_i = wind speed at center point of class i (m.p.h.)

It is possible that the use of a = 0.18 for neutral conditions rather than a = 0.14 for unstable conditions might result in an error in the foregoing procedure, since the latter would be more applicable on a hot, clear summer afternoon. The fact that the vast majority of forestry station observations were taken during the day tends to argue in favor of the latter value. However, the airport winds to which the adjustment was applied, were measured 24 hours per day. In addition there are many days during the summer on which average or even stable conditions prevail. Furthermore, the greatest difference in adjustment which results by the use of a = 0.14 is less than 2% of the wind speed, or less than 0.2 m.p.h. at the average speed. As the amount of adjustment decreases the magnitude of this possible error also decreases. Therefore, this possible error is considered sufficiently small so that it will have a negligible effect on the final values.

The adjustment of airport winds was an arbitrary decision. It could have been applied to the forestry stations equally as well by computing the adjustment as a percentage of the value at the height of the forestry anemometer and changing the sign. However, it should be pointed out that it is very likely that the equation used is more applicable to an open airport situation than an opening in a forest canopy. This lends some support to making the adjustments to the airport winds.

The second difference in sampling technique is the fact that the airport averages are for 24 hours every day. The forestry station wind speeds were spot observations taken at various times during the day. Therefore the airport averages may be considered an unbiassed sample of the total population of winds. On the other hand, the forestry station sample is biassed in favour of daytime winds, when the speeds tend to be higher.

To adjust the probability distributions for the difference in sampling technique, a separate sample was taken from published diurnal averages (Cudbird, 1964) for the period 1953 to 1962. For Ottawa Airport diurnal averages were computed from the Monthly Meteorological Summary (Anon. 1963-68) for the period 1963 to 1968. Diurnal averages for Federicton and Saskatoon airports were not immediately available. The sampling differences for these two airports were therefore adjusted by the average adjustment for all other airports. The amount of adjustment was computed as:

(4) $$B = \sum_{t=1}^{12} (\bar{A}_t \cdot P_t)$$

where: B = amount of bias due to sampling procedure (m.p.h.)

A_t = average wind speed for 2 hour time interval t (m.p.h.), and

(5) $$P_t = \frac{n_t}{N}$$

where: P_t = probability of an observation falling within time interval t

n_t = number of observations at the forestry station in time interval t

N = total number of observations at the forestry station.

The final adjustment is the sum of the adjustments for anemometer height and sampling differences. Generally the adjustments tended to be self-cancelling - that is all the adjustments for anemometer height were zero or negative, whereas all of the adjustments for sampling differences were positive. The final range of adjustments to airport winds at the mid point of the speed range was -0.7 m.p.h. to +0.5 m.p.h. All of the percentage adjustments and the final values in m.p.h. at the mid point of the speed ranges are listed in Table 4.

The adjustment was applied by multiplying the net adjustment shown in Table 4 times the wind speed at the mid point of each speed class as follows:

(6) $$A_i = U_i(1+a_n)$$

where: A_i = final adjusted wind speed in class i (m.p.h.)

a_n = net adjustment (%)

The areas under the curves resulting from the above procedure are no longer equal to 1.0 because the amount of adjustment is not constant. The adjustment ranges from zero at a wind speed of zero to maximums of -2.1 mph and +1.8 mph at a wind speed of 35 mph for Gander and Calgary airports respectively. The respective areas under these two curves are approximately .92 and 1.04. To make the airport and forestry station curves directly comparable, the airport curves were readjusted to an area of 1.0 by dividing the percentage of

TABLE NO. 4

ADJUSTMENT FOR AIRPORT WIND SPEED DISTRIBUTIONS

AIRPORT	ANANOMETER HEIGHT (%)	SAMPLING DISTRIBUTION (%)	NET ADJUSTMENT (%)	NET ADJUSTMENT (MPH) *
Gander	-.11	+.05	-.06	-.73
Ottawa	.00	+.03	+.03	+.28
Winnipeg	-.04	+.07	+.03	+.36
Calgary	-.04	+.09	+.05	+.51
Edmonton	-.12	+.08	-.04	-.38
Vancouver	-.06	+.08	+.02	+.15
Prince George	-.08	+.15	+.07	+.48
Average		+.08		
Fredericton	-.11	+.08	-.03	-.26
Saskatoon	-.04	+.08	+.04	+.47

* At the weighted average wind speed

observations falling within each class by the new area. The adjusted percentages of observations in each class for the airports are plotted as a function of the adjusted wind speed at the mid point of each class in Figures 2 through 10. Since both curves have an area of 1.0 they are now directly comparable.

B. Effect of Wind Speed Differences on Fire Danger

Before expending a great deal of effort to standardize wind measurements at a number of sites, it would be worthwhile knowing the effect that the differences in measurements have on the final fire danger rating. The "Canadian Forest Fire Weather Index"1/ was used for comparitive purposes rather than one of the presently employed systems such as the British Columbia Coast Tables, (Mactavish, 1965) because it is felt that the new system shows a more realistic response to wind speed changes. A full discussion of the method of determining the index value would be far too involved for inclusion in this paper. Briefly, values which could be expected on a typical summer day were assigned to all functions other than wind. A fine fuel moisture content of 10%, and a numerical value for duff moisture equivalent to approximately 16 days without rain were chosen. Choice of the particular fuel moisture values was purely artificial. It is thought that any set of values would produce the same relative differences as will be discussed subsequently.

Using these, the value of the index was computed for the wind speed at the mid point of each wind speed class. Since interpretation of the numerical values of the new "Canadian Forest Fire Weather Index" will not be possible until after it has been tested in the field, the values were converted to equivalent ratings on the presently widely employed 0 to 16 scale, such as is found in the B.C. Coast tables. The present scale had to be extended beyond 16, however, as the new index incorporates a somewhat greater range of weather extremes. It should be mentioned that since the relationships in the two systems are not identical this conversion is semi-artificial in terms of absolute values. Since this study is only considering relative differences and the magnitude of such differences, this difficulty is not thought to reduce the validity of the conslusion which are drawn.

The computed index values obtained by using the above mentioned fuel moisture values, and the wind speeds at the center point of each wind speed class (listed across the top of Tables 2 and 3) were multiplied by the percentage of winds observed at the centre point of each speed class for each station (listed in the main body of Tables 2 and 3). Plotting the results and connecting the points with a smooth curve yields the normalized distributions of fire danger indices which would be expected if a large number of days with the above mentioned fuel moisture conditions occurred. The distributions are plotted in Figures 11 through 19. In addition, the average index value (weighted by the percentage of observations in each wind speed class) was computed. Finally, the area under each curve to the right

1/ *Recently developed by the Forestry Branch of the Dept. of Fisheries and Forestry; to be published on a trial basis in 1969.*

Fig. 11 - 16 Distribution of fire weather indices of Forestry Stations and nearby Airports.

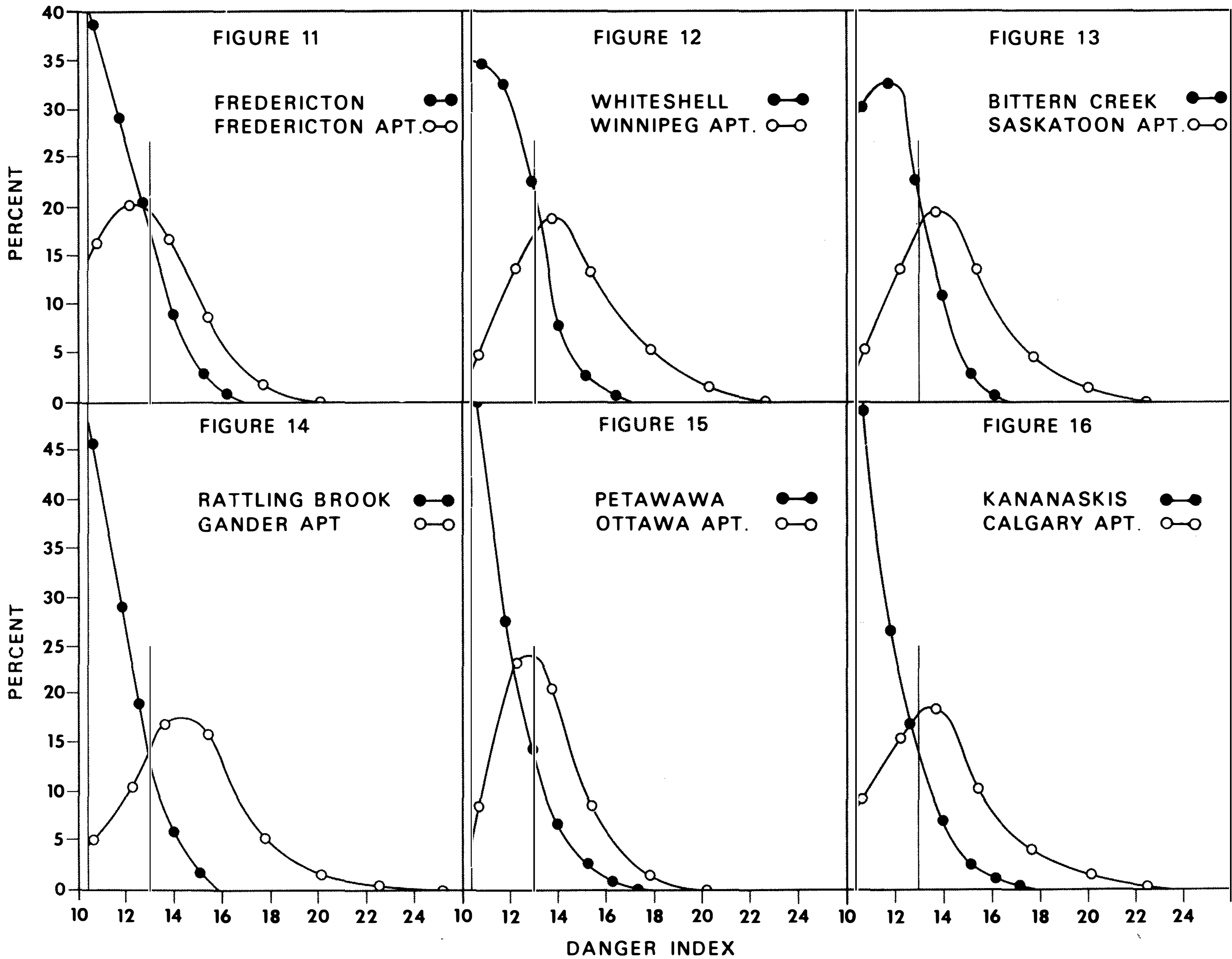
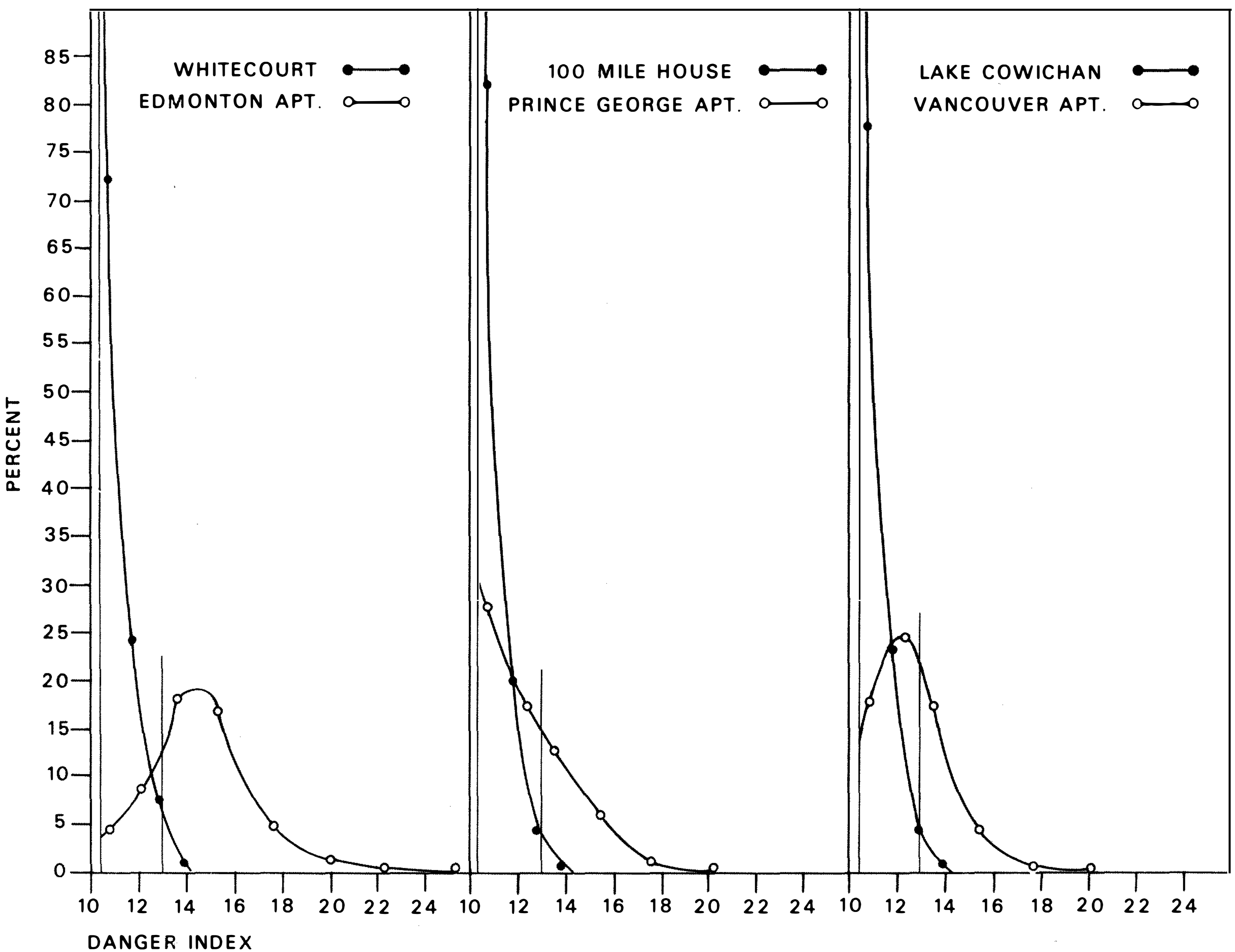


Fig. 17 - 19 Distribution of fire weather indices at Forestry Stations and nearby Airports.



of index value 13 was determined. This area is equivalent to the percentage of days which would fall in the extreme class under the given fuel moisture conditions. The average index values and the percent of days in the extreme class are listed in Table 5.

Table 5 - Average Index Value and Percent of Days in Extreme Class

Forestry Station			Airports		
Station	Average Index	% Days In Extreme Class	Airport	Average Index	% Days In Extreme Class
Rattling Brook	12.0	14	Gander	14.7	74
Fredericton	12.6	22	Fredericton	13.2	46
Petawawa	12.4	17	Ottawa	13.6	52
Whiteshell	12.7	22	Winnipeg	14.5	72
Bittern Creek	12.9	28	Saskatoon	14.3	70
Kananaskis	12.9	18	Calgary	14.0	62
Whitecourt	11.4	5	Edmonton	14.9	52
Lake Cowichan	11.5	3	Price George	14.0	35
100 Mile House	11.5	3	Vancouver	12.8	33

C. Relationship Between Reduction in Wind Speed and Effective D/H Ratio

The distribution of wind speeds shown in Figures 2 through 10 are the averages for all directions. Since none of the forestry stations have symmetrically uniform exposures, the change in wind speed should vary for each direction where the D/H (distance to an obstruction divided by it's height) ratio varies. Therefore, the distribution of wind directions at the forestry stations was computed. They are listed in Table 6 and portrayed graphically in Figures 2 through 10. With this distribution it is possible to determine the average effective D/H (ER) ratio for each forestry station. Effective D/H ratio is defined as:

(7) $$ER = \sum_{i=1}^{n} \left[P_i \, (D/H)_i\right]$$

where: ER = Effective D/H ratio

$(D/H)_i$ = D/H ratio in direction i, and

(8) $$P_i = \frac{n_i}{N-C}$$

where: P_i = probability that winds will blow from direction i

TABLE NO. 6

PERCENT OF OBSERVATIONS BY DIRECTION
(FORESTRY STATIONS)

STATION	UC *	N	NE	E	SE	S	SW	W	NW
Rattling Brook	5	13	13	4	4	7	22	25	12
Fredericton	3	25	4	9	6	10	11	24	14
Petawawa	7	30	11	6	5	17	7	10	10
Whiteshell	1	18	15	8	10	9	13	17	13
Bittern Creek	1	20	6	11	7	23	9	18	11
Kananaskis	8	12	11	11	9	6	7	22	19
Whitecourt	8	21	7	11	10	8	5	9	25
Lake Cowichan	15	8	14	19	5	9	12	21	3
100-Mile House	41	16	6	4	6	11	7	5	7

* Unclassified (Calm)

TABLE NO. 7

PERCENT OF OBSERVATIONS BY DIRECTION

(AIRPORTS)

AIRPORT	UC*	N	NE	E	SE	S	SW	W	NW
	D I R E C T I O N								
Gander	2.6	9.0	4.2	6.8	9.4	13.9	24.0	19.2	11.0
Fredericton	11.7	5.0	7.6	4.9	4.1	20.6	20.8	13.3	12.1
Ottawa	3.3	8.8	6.5	9.6	5.1	12.1	20.6	18.4	15.6
Winnipeg	1.4	15.0	10.6	5.5	11.3	20.2	9.6	11.6	14.9
Saskatoon	2.4	10.5	11.3	8.6	13.2	13.8	11.9	14.0	14.2
Calgary	5.6	15.8	5.6	6.0	11.7	14.3	9.6	13.6	17.7
Edmonton	3.6	8.8	6.7	9.8	11.1	9.6	13.2	19.5	17.8
Vancouver	8.5	2.2	8.2	25.8	14.5	7.8	7.7	16.0	9.2
Prince George	8.2	16.7	4.5	1.9	6.0	35.7	9.7	9.0	8.2

* Unclassified (Calm)

n_i = number of observations in direction i

N = total number of observations

C = number of calm observations

Note that ER is not simply the average ratio for the clearing, but rather an average which has been weighted by the distribution of wind directions. N-C is used in equation (8) because calm winds have no corresponding direction; therefore the percentage of calm winds must be subtracted from the total.

Sketch maps for each of the stations were drawn from photographs. The distance to obstructions and obstruction heights were estimated in eight directions from the photographs. The ER for each station was then computed using equation (7).

As an aid in determining whether or not there are any wind shifts at the forestry stations caused by obstructions or local topography, the distribution of directions at each of the airports was also determined. Data were obtained from the Hourly Data Summary (Anon. 1967-1968) published by the Department of Transport for each airport. The distributions are listed in Table 7 and are plotted in Figures 2 through 10.

Using the ratios for each speed class, the average wind ratio between the two stations was determined. Knowing the area under the curve for each range of forestry winds, the wind speed range on the airport wind curve which had the same area as the forestry wind curve was determined. By dividing the mid-point of each forestry station range by the mid-point of the airport range, a ratio was determined for each range of forestry station winds. These values are listed in Table 8. Finally, by multiplying the ratio in each range by the percentage of winds which fall in the range, an average wind speed ratio for the stations was obtained. These ratios are listed in Table 8.

RESULTS

A. Wind Speed and Direction Analysis

Visual examination of the wind speed curves in Figures 2 through 10 indicate that in all cases the forestry station wind speed distributions peak at a considerably lower speed than the airports. Three of the forestry stations have a peak distribution at between 4 and 5 m.p.h. All other forestry stations have the greatest percent of observations in the calm class. (0-3.5 m.p.h.) In contrast, all airports but Prince George have peak distributions at between approximately 5 and 12 m.p.h. The peak for Prince George is in the Calm Class. In addition to all forestry stations having a peak in the distribution at a lower wind speed (or both occuring in the calm class in the case of Prince George and 100 Mile House), the forestry stations all have a considerable higher percentage of winds in the lower speed classes. In other words, the bulk of the observations at the forestry stations are at speeds lower than 10 m.p.h. In contrast, the majority of observations at the airports generally lie between 5 and 15-20 m.p.h. Finally, the range in wind speeds is considerably less at the forestry stations. The upper limit of wind speeds at the forestry stations ranges from 12 to 22 m.p.h., while the upper limit at the airports range from 28 to 40+ m.p.h.[1/]

Visual examination of the distributions of wind directions indicates that there are shifts in direction at all forestry stations relative to the adjacent airports. The amount of shifting varies between stations. In the case of some stations, such as Rattling Brook, the shift would probably not be sufficient to greatly affect normal day-to-day operations in which wind directions were required. On the other hand, the direction differences at Petawawa indicate a fairly strong channelling in the north-south direction. In the case of 100-Mile House, either there is a blockage of wind from the south (which appears likely due to the very high percentage (41%) of calm winds), or strong channelling at Prince George airport. In both of the latter examples, and in many other stations in the study, anomalies such as these should be considered prior to using the wind direction observations.

The wind speed ratios (W_f/W_a) listed in Table 8 have a range of .26 to .66. Furthermore, at seven of the nine stations, the ratio increases with increasing wind speed throughout the entire range. For these stations the increases range from .05 to .20. With respect to the other two stations, the ratio at Fredericton remains fairly uniform throughout the range, and the ratio at Bittern Creek increases up to the 7-9 mph class, and then remains fairly constant.

The average ratio for all stations in each wind speed class was computed up to the 10-12 mph class. In addition, the average for four stations which had values up to the 16-18 mph class were also computed. These average ratios are listed in Table 7 and plotted in Figure 20. In Figure 20, it can be seen that both averages increase as a linear function of wind speed. The slope of both lines is .175. For comparison, values obtained by Bates (1911)[2/] working with a dense White pine belt, are also plotted in Figure 20. For decidious shelter belts, and belts which are narrow and/or fairly permeable, the evidence is highly variable. It ranges from an increasing ratio with increasing wind speed (van Eimern, 1956, 1957) through little or no change (Loerch, 1959 and Woodruff, 1954) to a reduction in the ratio with increasing wind speed (Bates, 1911).

As a result of this variability van Eimern (1964) concludes that the major effect of wind speed on the effectiveness of a shelterbelt is through its influence on the degree of permeability of the belt rather than an immediate effect on the percentage of reduction in wind speed. In other words a thin open belt acts more like a

1/ *Wind speeds considerably higher than these values have been observed in many instances. They form an insignificant percentage of the total distribution however.*
2/ *See Kitteredge (1948)*

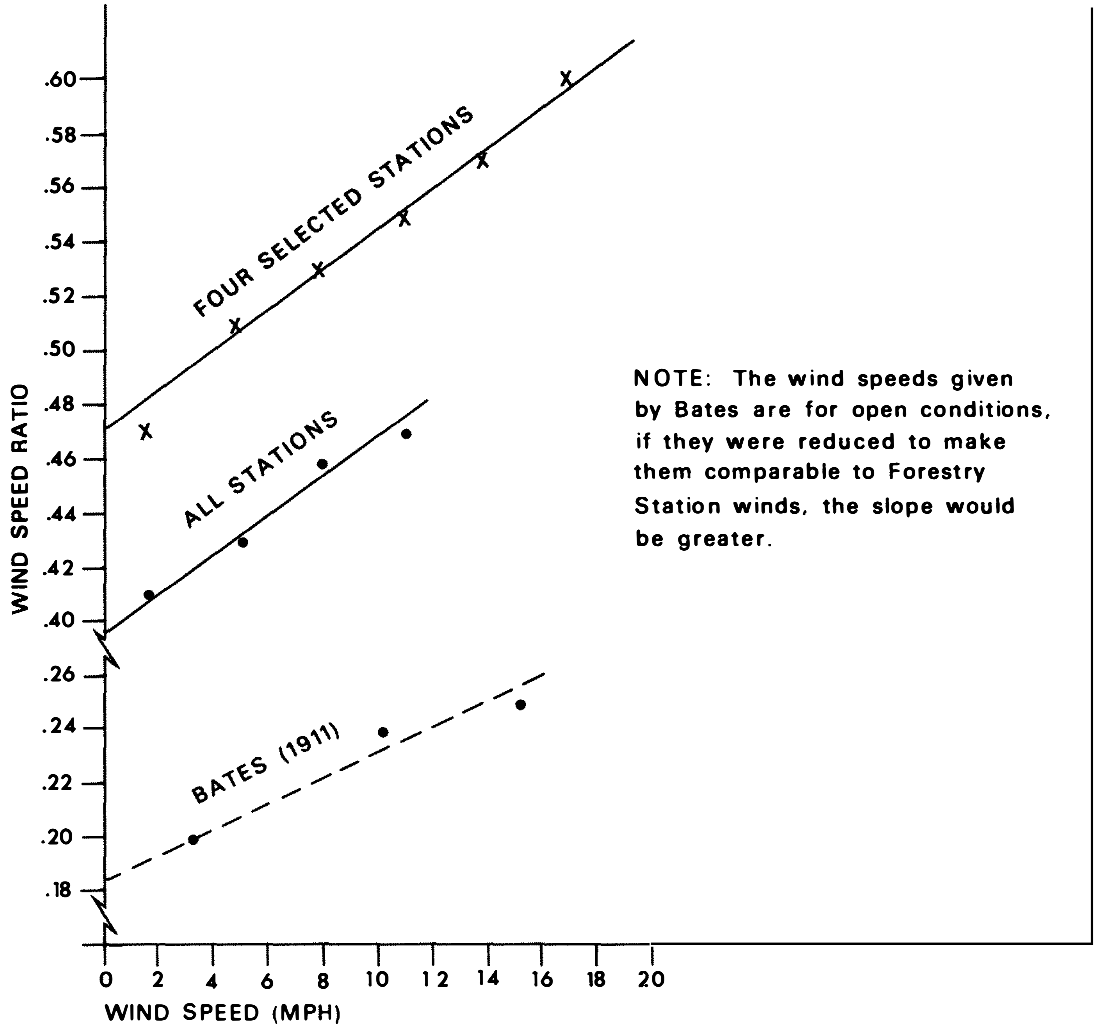
TABLE NO. 8

RATIO OF FORESTRY STATION WINDS

TO AIRPORT WINDS

STATION	RANGE (FORESTRY STATION)						
	0-3	4-6	7-9	10-12	13-15	16-18	W_f/W_a
Rattling Brook	.33	.38	.42	.44	.44	-	.37
Fredericton *	.66	.67	.66	.66	.68	.70	.66
Petawawa *	.45	.51	.58	.62	.64	.65	.51
Whiteshell *	.40	.42	.43	.44	.46	.49	.42
Bittern Creek	.45	.47	.49	.48	.48	-	.47
Kananaskis *	.39	.43	.46	.48	.51	.56	.43
Whitecourt	.25	.28	.29	.30	-	-	.26
Lake Cowichan	.36	.39	.41	.42	-	-	.37
100-Mile House	.37	.38	.41	.43	-	-	.38
Average (all)	.41	.43	.46	.47			
Average (*)	.47	.51	.53	.55	.57	.60	

Fig. 20 Ratio of wind speed in a forest opeining to open wind speed as a function of wind speed in the opening.



permeable one in a strong wind, and like a dense one in a light wind.

On the other hand a stand of trees would have to be considered as a dense belt regardless of the open wind speed. It follows therefore from the discussion of the difference in wind speed reduction between a stand of trees and a shelter belt that as wind speed increases, the pressure difference between the top edge and lower portions of the lee side of a stand will be greater. Therefore, the turbulence will also increase, and the momentum of the upper wind will be transferred to the ground more quickly.

The above discussion is supported by the data used in the present study and by that of Bates (1911). It is therefore concluded that the reduction in wind speed at the lee edge of a dense stand is partially influenced by the absolute value of the wind speed. As wind speed increases the percent reduction becomes less, or in other words the ratio of the wind speed at the forestry station relative to that at the airport becomes greater. The total extent of the influence does not appear to exceed 25 percent of the percentage of the reduction. It should be pointed out however that since this study is a comparison of wind speed distributions rather than simultaneous pairs of observations, the above conclusion should be considered tentative pending a more thorough investigation.

B. Effect of Wind Speed Differences on Fire Danger

It is readily apparent from a visual examination of the curves in Figures 11 through 19 that the distribution of fire dangers obtained at the forestry stations are all significantly different from those obtained at the corresponding airports. In fact there are only two cases (Bittern Creek and 100-Mile House) where the pair of curves are of a somewhat similar shape. Curves for the forestry stations all have a relatively narrow range of indices (from a minimum of 4 index units to a maximum of 7.5 units). The distributions all have a very pronounced peak at an index value of 10.4,[1/] with the exception of Bittern Creek, where it is about one and a half units to the right. On the other hand curves for the airports have a much broader range of indices (from a minimum of 10 units to a maximum of 15 units), and generally have a more gradual trail-off in the upper end of the range. While the peak of the distributions is also fairly pronounced for the airport curves, it is at 10.4 in only one case (100-Mile House). In all other cases it ranges from a minimum of 2 to a maximum of 4 units to the right of 10.4.

The relative contrasts discussed above are more important than the actual values mentioned. If other values of fuel moisture had been chosen, the fire danger at zero wind speed would have shifted to the right or left of 10.4, depending on whether the fuel moisture was respectively lower or higher that the values used. The curves would have shifted a corresponding amount. For higher moisture contents, the ranges would be reduced because the effects of both wind speed

1/ *10.4 is the index value at a wind speed of Zero m.p.h. for the given fuel moisture conditions.*

and fuel moisture are exponential. Since the areas under the curves are equal to 1.0, the percentage of observation of each index number would increase proportionally to the reduction in range. It should be pointed out however that the percentage change would be the same for both curves and that the relative differences between them would be unaffected. Similarly for lower, moisture contents, the ranges would be increase, the percent of observation at the various index values would decrease, but the relative differences would not be affected.

The level of presuppression activities normally increases in discrete steps as fire danger rises from one class to another (for example; from moderate to high). For this reason a difference in index value is normally considered significant only if the two values concerned lie within different fire danger classes. Therefore, for the purpose of this paper any difference in fire danger due to wind speeds which does not cause the two index values to fall within different classes, will not be considered sufficient to warrant the additional complication of adjustment of wind speed measurements.

As discussed previously, relative differences in index class are more important than actual values. This is important because the class boundaries for the new system will probably not be the same as for present systems. The present system has a total range of 16 units, with four classes, each with a width of 4 units. Since the new system incorporates greater extremes of weather the total equivalent range is approximately 28 units. If four classes are defined in the new system, the average class width will be seven units. Note that this is the average class width - it is entirely possible that the actual class widths will not be uniform. Since the maximum range of index units for the forestry stations is 7.5 units, it is possible that the majority of the indicies will lie entirely within a single class, if certain values of fuel moisture were chosen. This is further supported by the fact that the range of index values would be less at higher moisture contents. The airport distributions, on the other hand, with ranges of from 10 to 15 units will almost certainly have to fall within at least 2 classes, regardless of the class boundaries, or the fuel moisture values chosen. Therefore, although specific values are compared in the following discussion, it should be remembered that the relative differences would be the same, regardless of what class boundaries of fuel moisture values are compared.

Looking at the average index values presented in Table 8, and using the present lower boundary of 13 for the extreme class, it can be seen that all of the forestry stations lie in the high class, whereas all but one of the airports are in the extreme class (before the values are rounded off to the nearest whole number). It can also be seen however that the difference between the averages is quite small (from 0.6 to 3.5 units), and if the lower boundary of the extreme class were shifted one or two units in either direction, most of the average values would then fall within the same class. Therefore, the class within which the average values lie is highly dependant on the specific location of the lower boundary for the extreme class. This might easily lead to the argument that the difference in final index values does not appear to be significant. A more detailed examination of the distributions, however, positively demonstrates the significance of the difference.

Due to the greater range of index values for airports, all of the airports have a considerably higher percentage of observations in the extreme class than the forestry stations.1/ From the values presented in Table 5, it can be seen that the airports have from 2 to 10 times as many days in the extreme class as the forestry stations, despite the fact that both stations are theoretically attempting to measure the same fire danger.

The difference in expenditures for the same preparedness plan applied to both stations would therefore be from 2 to 10 times the difference between daily presuppression expenditures in the extreme class and the high class times the number of days on which the particular fuel moisture conditions occurred.

Furthermore, looking at the forestry stations only, it can be seen that Bittern Creek has nearly 10 times as many days in the extreme class as Lake Cowichan or 100 Mile House. Similarly, examination of the airport data shows that Gander and Winnipeg have more than twice as many days in the extreme class than Prince George or Vancouver. Therefore not only is there a considerable difference between forestry stations and airports; there is also a considerable difference between individual stations within the two types.

Therefore, based on the magnitude of the difference of fire danger indices between forestry stations and airports, it is concluded that it will be necessary to standardize wind speed measurements at all stations which will be used to record meteorological observations for fire danger rating purposes. Without standard measurements the potential errors in the index value will seriously impair the reliability of the system.

C. Relationship Between Wind Speed Reduction and Effective D/H Ratio.

An attempt to relate the wind speed ratio to the ER proved to be unsuccessful. Theory suggests that as ER increases the ratio should also increase. The data were highly scattered, and exhibited no significant tendency to either increase or decrease. An attempt was made to adjust the ER for proximity to obstacles on the downwind side of the anemometer, based on observations made by Naegeli (1953). There appears to be slight improvement but the scatter remains too great to enable any conclusions to be drawn from the data.

In retrospect, it is not surprising that such difficulties should occur. Only two of the many factors mentioned in the discussion were considered in the present study. In addition, there

1/ *The percent of observations in the extreme classes is given by the area under the respective curves to the right of index value, 13.*

are a number of additional possible sources of error related to the method by which the study was carried out, which are listed below:

1. As the D/H ratio becomes small (2 or less) the relationship between the height of the anemometer and the height of the obstruction undoubtly becomes important. For example; when the anemometer is adjacent to an obstruction, the effective anemometer height may be the height above the obstruction, rather than the height above the ground.

2. The distance between the airports and forestry stations was as great as 100 miles in certain cases. It is probable that some changes in velocity and direction occurred over such a great distance.

3. The airports themselves have a considerable difference in wind speed distributions. Although they generally have good exposures, a preliminary investigation of airports within an area 300 x 400 miles1/ showed that neighboring airports can have variations in velocity distributions of 10 to 20 percent, and in some cases even more.

4. Experimental error in the form of:

   a) Incorrect measurements of one of the following taken from the photographs:

      1. Anemomter height

      2. Height of obstructions

      3. Distance to obstructions

      4. Orientation of the obstructions with respect to the anemometer.

   b) Changes in anemometer locations, or the location of adjacent obstruction during the period when measurements were being taken are known to have occured at certain airports and forestry stations.

   c) Changes in instrumentation are known to have taken place during the period of observation at certain airports and forestry stations.

   d) The inclusion of wind observations from other than the forestry station in the data. One station was rejected for this reason. The possibility remains that during periods when the anemometer was inoperative, this might have occurred elsewhere.

1/ *Wind analysis of Maritime Stations being conducted by the Forest Fire Research Institute.*

CONCLUSIONS

From the previous discussion it can be seen that there are a great number of factors which affect wind speed measurements at forestry stations. The influence of these factors causes considerable differences in wind speeds and directions observed at forestry stations and airports. The difference in wind speed distributions, in turn, cause a considerable difference in the distribution of danger indices, which would be calculated at various stations. The differences are of sufficient magnitude to necessitate a procedure for the standardization of wind measurements taken for the purpose of forest fire danger rating.

Due to the conclusions mentioned above, the initial version of the new index has been designed for a forestry station which has a maximum absolute wind speed of 25 m.p.h. It is thought that this value will apply to a large number of forestry stations. Further research is currently in progress to determine a simple yet reliable method of standardizing wind speed measurements at stations which have a total range which is either greater or less than 25 m.p.h. by a significant amount. A brief discussion of possible alternate approaches would be in order at this time.

The results of the analysis presented in this paper suggest that it will be very difficult to determine a general theory for the behaviour of wind in the vicinity of an irregular forest opening, especially if buildings are located within the opening. The results further suggest that such a general theory would be very complex. Indeed, a theoretical approach may not be practical in that application of such a complex procedure on a operational basis would be very difficult.

Perhaps a more appropriate method would be to continue locating anemometers wherever practical considerations warrant. Then, after a year or two of data have been accumulated, the forestry station might be compared with a nearby airport, and a seperate wind speed ratio determined for each direction. This would, in effect, be a method of "calibrating" each station individually. For day-to-day operations this simple "calibration" procedure would, in all probability, prove to be far more convenient than a theoretical approach. Once it is complete, one would only have to check an observation against a simple table to determine the adjusted value. The "calibration" approach was undertaken concurrently with the present study. The results indicate that it may be promising. It is discussed in detail in a separate paper.

SUMMARY

This paper presents a comparison of wind speed and direction distributions as measured at forestry stations and airports across Canada. The distribution of wind speeds and directions were determined for each station and airport. Both curves were normalized to an area of 1.0. The airport curves were then adjusted for differences in anemometer height and sampling procedure. Using the area under the curve for each range of forestry wind speeds, the ranges of airport wind speeds which had the same area were determined. The ratio between the two was then computed. The average forestry station to airport wind speed ratio varied between .26 and .66. The ratio increased as wind speed increased in seven of the nine stations considered. There was a significant shift in wind direction at several of the forestry stations relative to the airports. The effect of differences in wind speed distributions on fire danger was investigated. It was shown that the differences are sufficient to place the index at an airport in the extreme class on from 2 to 10 times as many occasions as at the forestry station. Further, it was shown that there would be a significant relative difference between the two types of sites regardless of the particular class boundaries or fuel moisture values chosen. It was concluded that some procedure for standardizing wind speed measurements will have to be developed to compensate for the considerable differences which occur between various types of exposures. Presently, the system is designed for an exposure with a maximum wind speed range of 25 m.p.h., in the hope that this will applicable to a large majority of stations.

With respect to exposures which have a significantly greater or smaller range than 25 m.p.h., it was not possible to correlate the wind speed ratios with the effective D/H ratio. This is probably due to the fact that several factors which affect wind speed were not included in the present study. It is concluded therefore that a theoretical relationship which considers all of the factors involved would be of dubious practical value because of the difficulty of application to an operational system, due to its complexity. A simple calibration procedure for each station appears to have greater merit.

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