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METEOROLOGICAL BRANCH

AN ANALYSIS OF LOCAL FOG IN
THE COPPERCLIFF AREA

BY

R.E. SMITH

U.D.C. 551.509.325
551.575.3

CIR. 4138
TEC. 543
2 NOV. 64

CIR-4138
TEC-543
2 Nov. 64.

ABSTRACT

A study of annual, seasonal, and diurnal variations in fog occurrence at Sudbury airport and at Highway 17 near Copper Cliff has been made and related to several meteorological variables. In addition traffic accidents which occurred during fog conditions were analyzed.

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1. INTRODUCTION

Dangerous fog conditions have periodically developed on Highway No. 17 in the vicinity of Copper Cliff, Ontario. Serious accidents resulting in bodily injury, and in one case fatality, have occurred in the past three years. The Ontario Department of Highways has asked the Meteorological Branch of the Department of Transport to determine the contributing causes of these fog conditions.

Data are discussed in this paper with respect to seasonal and diurnal variation, and dependence on the amount of smoke, wind direction, and wind speed. A brief analysis of traffic accidents is also made.

2. TOPOGRAPHY OF THE AREA

A map of the highway and vicinity is given in Fig. 1. The stream which crosses Highway No. 17 1000 ft. east of the railway overpass has its origin in Lady MacDonald Lake to the north, and discharges into Kelly Lake to the south. During its passage through Copper Cliff, water is contributed from the tailing ponds and smelter of International Nickel Company of Canada's Copper Cliff plant. Prior to passing under the railway embankment, an effluent from the Copper Cliff sewage plant is also discharged into this stream. The water temperature remains near 40°F throughout the winter. There is a decided dip in the highway with the low point just above the twin culvert carrying the stream under the highway; at this point the roadway elevation is 12 ft. lower than the pavement elevation at the railway overpass.

The Copper Cliff INCO plant is operated on a twenty-four hour basis, seven days a week. Every forty minutes, eighteen pots of slag of ten tons each are dumped on the slag heap at a temperature in the range of 1500°F. The temperature half way up the INCO stacks is maintained at 400°F to provide velocity. Discharge temperatures at the top of the stack are estimated between 120° and 150°F.

Four pictures of the site, taken on June 14, 1964 at 1400 EST are given in Figure 2 showing:

- 1) the railway embankment and twin culvert at the underpass
- 2) and 3) the slag dump with INCO stacks in the background
- 4) the stream.

The camera was set up as close as possible to the lowest point on the road.

3. SOURCES OF DATA

Observations on smoke and fog obstruction were made at Department of Transport weather stations at North Bay airport (for a general comparison of conditions with Sudbury) and Sudbury airport, situated fifteen miles northeast of the townsite. Measurements of air and water temperatures were taken from January 13 to March 15, 1964, by DHO patrolmen at approximately 0400, 0930, 1600, and 2100 EST at two locations:

- (1) the outlet of the twin culverts under the railway overpass embankment
- (2) the point at which the creek turns south near Kelly Lake Road, which is the closest point to the highway.

These locations are marked W and E respectively in Figure 1.

Accident records were supplied by the Ontario Provincial Police, the Copper Cliff police, and Co-operators Insurance Association.

4. SEASONAL VARIATIONS

Throughout this report the abbreviations F (dense fog), K (smoke), and H (haze) will be used. For purposes of this study, dense fog is defined as fog which limits visibility to $\frac{1}{4}$ mile or less. Whenever quarterly averages are taken, they are over the months December, January, February, March, April, May, June, July, August, September, October, November.

Comparisons of fog at Sudbury airport with some surrounding weather stations are given below, averaged over the years 1958, 1959, and 1960. It is noted that Sudbury has the largest number of hours of dense fog, and also of K and H of the five localities.

<u>Location</u>	<u>Hrs. F/yr.</u>	<u>Hrs K H/yr.</u>	<u>Mi. from Sudbury</u>
Sudbury airport	210	578	-
North Bay "	136	299	76
Earlton "	61	114	103
Timmins "	54	28	140
Rouyn "	23	87	156

Figure 3 shows a histogram of the monthly values of dense fog at Sudbury airport over the period 1955-1963, and the quarterly averages for Sudbury and North Bay. Data for North Bay were not available for 1962 and 1963. The correlation between the two sites is very close, with maxima in the spring and fall, minima in the summer and winter, although exceptions occurred at both stations in the springs of 1958 and 1961. The fall maximum is usually larger than the spring, but this is not always the case. Sudbury shows consistently higher fog values.

The quarterly means of hours and visibility obstruction by smoke and haze at Sudbury and North Bay airports for the period 1955 to 1963 are given in Figure 4. Unlike the fog cycles, there is no close correspondence between the two sites. An annual peak usually occurs in the summer months at North Bay, and a broader, less pronounced peak in the fall and winter at Sudbury, but several of its maxima are greater; it has been suggested that these summer peaks are due to forest fires in the area.

While the obstructions to vision at Sudbury were nearly all recorded as smoke, those at North Bay were recorded as haze.

The mean trends of smoke and dense fog at Sudbury are given in Figure 5 for the years 1955 to 1963. The straight lines were plotted by the least square method. Smoke obstruction has been increasing about 2 hrs./mo. and fog has been decreasing slightly.

5. DIURNAL VARIATIONS AT SUDBURY AIRPORT

Figures 6 and 7 show the hours of dense fog, hours of smoke and haze, hours of smoke with the relative humidity $\geq 80\%$, and hours of fog and smoke reported together (FK) plotted versus the time of day and totaled over June-July and November-December 1962-1963 respectively. It is seen that fog reaches a daily maximum approximately one hour after sunrise, suggesting that it is mainly radiation fog thickening with a weak turbulence created by initial heating from the sun, then burning off during the morning. In winter the peak is less pronounced than in summer, the maxima being about three and eight times their minima respectively.

The FK values correspond closely to the K ($RH \geq 80\%$), and occur when the combined values of F + K are at their maxima.

The smoke histogram is rather unusual since it shows a definite maximum during the daylight hours, although smoke emission from Sudbury is nearly constant (INCO operates 24 hours per day, seven days a week).

6. THE EFFECT OF INCO SMOKE

During the months September 1958 to January 1959 there was a strike at INCO which stopped the main source of smoke. However, as seen in Figure 4, the corresponding fog frequency was not significantly lower than average.

The following tables also show no lower values in 1958:

Number of Days with Fog at Sudbury Airport

	January	Sept.	Oct.	Nov.	Dec.
1947	-	2	5	2	5
48	0	3	9	2	2
49	1	1	5	2	5
1950	5	3	3	0	1
51	1	1	5	1	3
52	1	5	1	4	7
53	9	1	5	4	0
54	1	10	11	2	6
55	1	5	8	5	4
56	3	7	16	12	9
57	4	14	9	8	4
58	3	6	10	9	7
59	4	11	4	5	5
1960	4	12	4	9	3
Mean	2.8	5.8	6.8	4.6	4.4
Mean ('55-'60)	3.2	9.2	8.5	8.0	5.4

Number of Hours with Smoke and Haze at Sudbury Airport

	Sept.			Oct.			Nov.			Dec.		
	K	H	K+H	K	H	K+H	K	H	K+H	K	H	K+H
1947	3	54	57	0	44	44	2	2	4	1	8	9
48	11	35	46	6	34	40	0	13	13	1	54	55
49	1	1	2	0	1	1	0	0	0	4	3	7
1950	6	39	45	2	29	31	0	7	7	37	11	48
51	2	0	2	1	17	18	1	4	5	4	3	7
52	1	41	42	1	9	10	5	45	50	3	0	3
53	0	12	12	10	24	34	10	74	84	3	7	10
54	7	4	11	7	10	17	9	9	18	10	1	11
55	23	13	46	62	3	65	56	0	56	57	1	58
56	40	9	49	120	1	121	18	0	18	8	0	8
57	53	7	60	31	6	37	29	0	29	46	0	46
58	61	0	61	35	0	35	52	0	52	41	2	43
59	73	0	73	38	0	38	36	0	36	27	0	27
1960	83	3	86	28	0	28	46	2	48	82	1	83
61	122	2	124	80	0	80	93	0	93	68	2	70

In 1955 there was a large increase in the number of hours of smoke, but a decrease in the occurrence of haze. The 1958 values were not significantly low, as they should have been with the strike. The same is true for the values of fog, although there was again a large increase beginning in 1955. This remains unexplained.

7. DEPENDENCE ON WIND DIRECTION

Occurrences of dense fog at Sudbury airport, situated fifteen miles NE of the townsite, were most common for winds from S to SW and NNW to NNE; as shown in Figure 8. These are also the directions of the most prevalent winds.

The wind direction during occurrences of smoke and haze in 1963 was most commonly from the S to SW, which would bring smoke from Sudbury. All obstruction with winds from the NW and NE quadrants were recorded as haze. (Figure 9).

The frequency of wind direction at Sudbury airport during dense fog lasting 3-4-5 and ≥ 6 hrs. is given in Figure 10. The percentages were found over the period January 1962 to March 1964. The normal wind pattern was found over a one-year period with readings at 0000, 0600, 1200, and 1800 EST daily being used. Of the occurrences of fog lasting more than 6 hrs, the longest were 17 hrs. on April 6, 1962 and 13 hrs. on Oct. 26, 1963; the rest were under 10 hrs. duration, out of a total nineteen cases. There were twenty-nine occurrences of dense fog in the 3-4-5 hr. group. It is seen that unlike the short duration fogs, (Figure 8) prolonged fogs did not occur with northerly winds.

Figure 11 shows the frequency of wind directions at Sudbury airport and the highway during occurrences of fog at the highway over the period Jan. 13 to Mar. 15, 1964. The high northerly frequency at the highway would bring smoke from the smelter; the south-west, smoke from the refinery (see Fig. 1). Concurrent winds at the airport show greater values in the S, SE, and W. Winds at the highway were measured only to eight points of the compass, and airport measurements were reduced to eight points by adding half the sixteenth point values to the eighth point value on either side. The highway fog follows the same pattern as the airport fog (Fig. 8), but it is not known whether this is due to prevalent winds or the position of the refinery and smelter.

There was no noticeable dependence on wind speed with winds varying from calm to 25 mph. The average speed was 10 mph.

8. FOG FORMATION AT THE HIGHWAY 17 SITE

The cooling of air in the lower levels of the atmosphere to its dew point results in the condensation of suspended water vapor, and hence the formation of fog. 'Radiation fog' is a result of the cooling of the ground at night being transferred to the air. The air must contain sufficient moisture to permit condensation, and since the cooling is not usually great, the relative humidity must be in the order of 80% when there is an abundance of condensation nuclei such as smoke particles to aid the fog formation. Radiation fog is very local, since the cooled air tends to drain into low areas; it generally burns off during the morning. Steam fog is formed by cool air moving over warmer water; water vapor escaping from the

water surface saturates the colder air. It is seen from the photographs in Figure 2 and the information in Section 2 that the site is a natural bowl for radiation and steam fog.

Air temperature, approximate creek temperature, and dew point are displayed over a one-year period in Figure 12. Steam fog is limited to the approximate period November to May, and radiation fog November to April (since the dew point curve is closest to the air temperature curve here, giving maximum probability of the dew point being equal to the air temperature).

No definite relationship between temperature and fog occurrence was found at the highway site, although for fogs classified as 'heavy' the mean temperature was -3°F ; for 'light' fog, $+3^{\circ}\text{F}$; and for no fog, $+15^{\circ}\text{F}$.

Of the fifteen cases of fog being reported simultaneously at the airport and highway from January 13 to March 22, 1964, eleven occurred in Maritime Polar warm sectors with a cold front approaching. There were no reports of local fog at the highway alone under the same circumstances.

9. TRAFFIC ACCIDENTS

All accidents are marked on the map in Figure 1.

On most occasions the fog causing the accidents was very local and was not being recorded at the airport. This is shown in detail in the following table:

<u>DATE</u>	<u>TIME</u>	<u>AIRPORT:</u>	<u>VIS</u>	<u>FOG</u>	<u>WIND</u>	<u>NO. OF VEH.</u>	<u>TYPE</u>
20-01-62	1855 EST		8 mi.	none	S 10	3	rear-end
20-01-62	2029		8	"	S 10	2	head-on
20-01-62	2115		12	"	SSW 8	2	rear-end
04-02-62	0230		15	"	WNW 12	2	"
03-03-62	0335		15	"	NE 17	3	"
03-03-62	0340		15	"	NE 17	4	"
20-10-62	2250		15	"	NNE 5	2	"
26-10-62	2225		8	"	WNW 12	6	"
26-10-62	2330		1/8	yes	NW 8	2	"
27-10-62	0030		1	"	NNW 5	2	"
12-02-63	2315		12	none	N 5	2	"
09-03-63	0745		15	"		3	"
14-09-63	0445		15	"	S 4	1	side-swipe
11-12-63	1910		15	"	E 7	2	head-on
11-12-63	1910		15	"	E 7	2	rear-end
11-12-63	1910		15	"	E 7	4	"
14-12-63	0140		15	"	W 6	2	"
27-12-63	2215		7	"	SW 4	2	"
28-12-63	1840		15	"	C	2	"
12-01-64	1855		15	"	SW 5	4	"
31-01-64	1950		1 1/2	yes	S 14	2	
09-02-64	2232		12	none	W 9	1	

Figure 13 shows the number of accidents associated with fog and the number of hours of fog at the highway and airport plotted versus the time of day. The airport fog curve shows a primary maximum about two hours after sunrise, a very small secondary maximum at 1900 EST, and minima at sunset and 2200 EST. The highway fog curve was smoothed from patrol accounts of fog at 0330, 0430, 0830, 0930, 1630, 2130, and 2230 EST. It shows a maximum at sunrise, a large secondary maximum about 2100 EST and minima at 1600 EST (one hour before sunset) and 0030 EST. The airport fog curve includes dense fog only; the highway fog curve includes all instances of fog since no qualitative measurements were made by the highway patrolmen. The histogram shows that the accidents all occur at times of maximum highway fog, and that the onset of daylight gives sufficient visibility to stop the accidents (with the exception of one at sunrise), assuming constant traffic density. It is possible that the accident distribution is caused by workers commuting from Sudbury to the Copper Cliff mines in shifts, but no data was available to confirm this.

The following points with regard to accidents involving fog should be noted:

- (a) all accidents except one occurred in darkness
- (b) nearly all were rear-end
- (c) they occurred in two distinct places - one near the under-pass and the other about three miles to the west (Figure 1), where the stream could not be a factor in fog formation.
- (d) all except one occurred in the period October to April, the only time of year when the creek could possibly be a factor.

10.

CONCLUSION

Annual, seasonal, and diurnal variations were found in occurrences of smoke and fog at Sudbury airport. Smoke obstruction is increasing approximately 2 hrs./mo. and fog is decreasing slightly. The fog reaches seasonal maxima in the spring and fall, and smoke minima occurs in the spring. A daily peak in fog occurs shortly after sunrise, while smoke obstruction was recorded as higher in the daylight hours than in darkness.

There was no significant change, either in smoke or fog levels, during the strike at INCO in 1958, although there was a sharp rise in both in 1955.

The wind direction was found to have an important bearing on reports of fog and smoke. At Sudbury airport, the highest incidence of fog was with winds from the SW to S and NNW to NNE; these were also the prevailing wind directions. Smoke occurred only with winds from the direction of Sudbury. Fog at the highway followed the same pattern as at the airport, but the effects of the refinery to the SW and the smelter to the N cannot be estimated since they both lie in the direction of the prevailing winds.

Dense fogs lasting several hours were found to occur mainly with S-SE winds, and occurrences of prolonged fogs with northerly winds were negligible, unlike those fogs only lasting an hour or two. Hence, it is possible that smoke from Sudbury is a more noticeable factor in prolonged fogs.

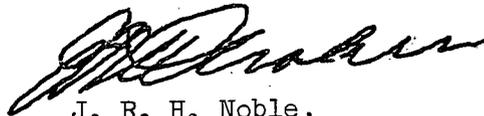
No relationship was found between fog and windspeed or temperature.

The diurnal variations of fog at the highway were found to be different than at the airport: the morning maximum occurs slightly before sunrise, and the secondary maximum in the evening is much larger.

While there was little relationship between the number of accidents and the frequency of fog reported at Sudbury airport, there was good correspondence with the diurnal variations at the highway. It would appear that the fog causing the accidents is local only.

The effect of daylight was found to be very significant in reducing the number of accidents, if the traffic density is assumed constant, although workers commuting in shifts to Copper Cliff may influence the results.

APPROVED,



J. R. H. Noble,
Director.

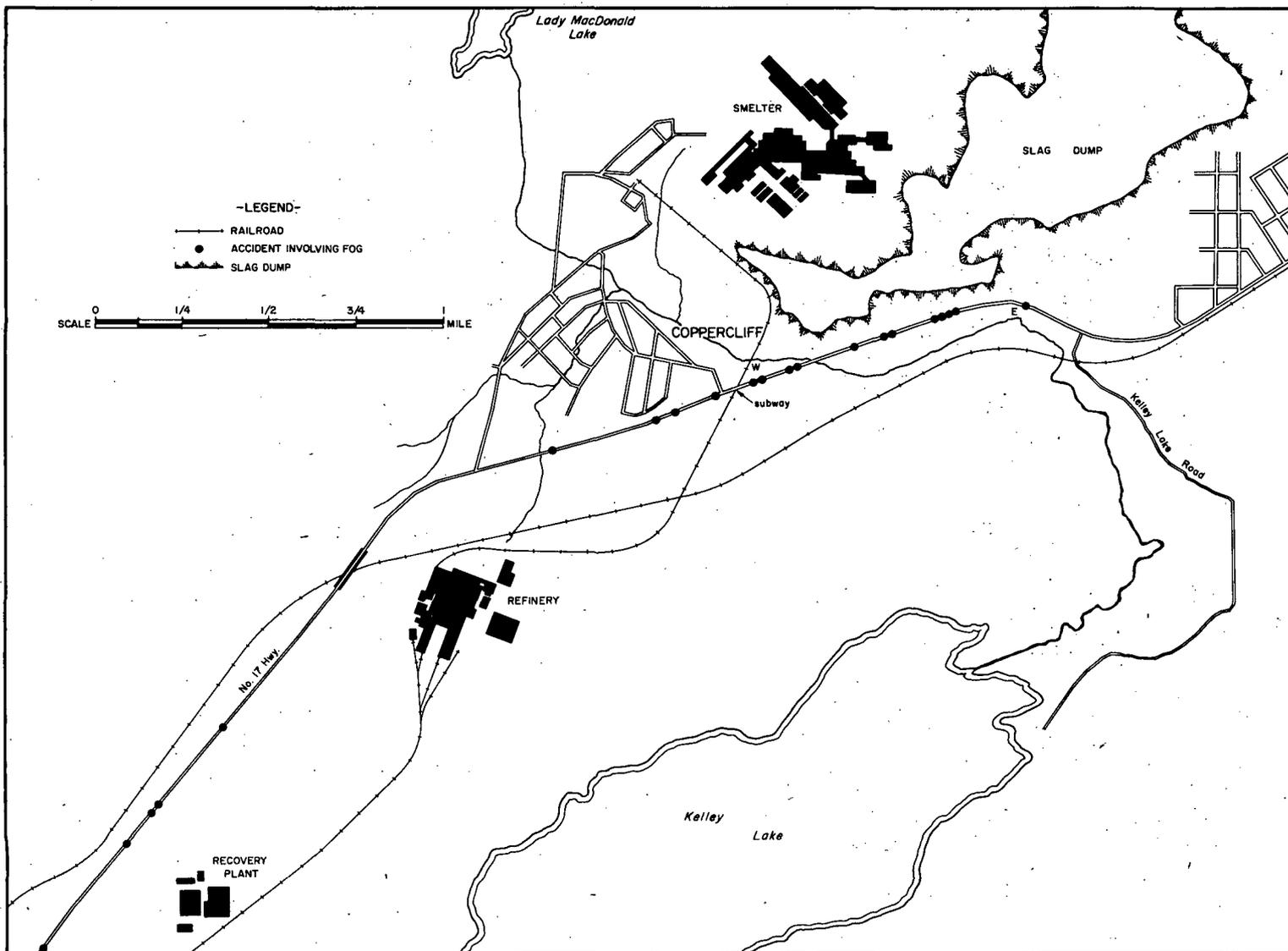
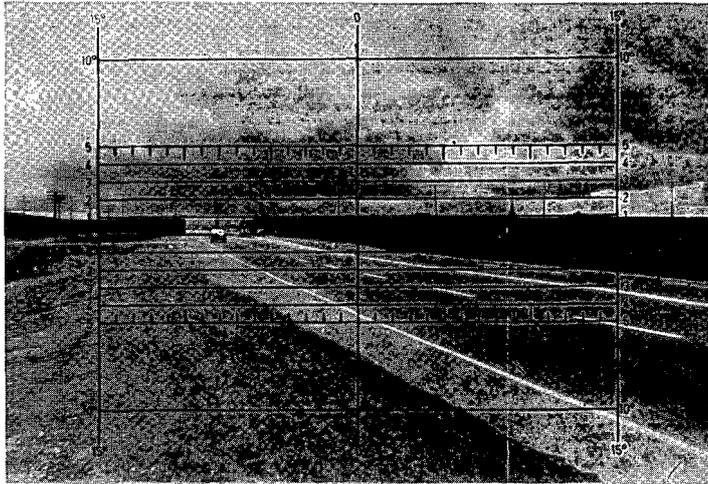
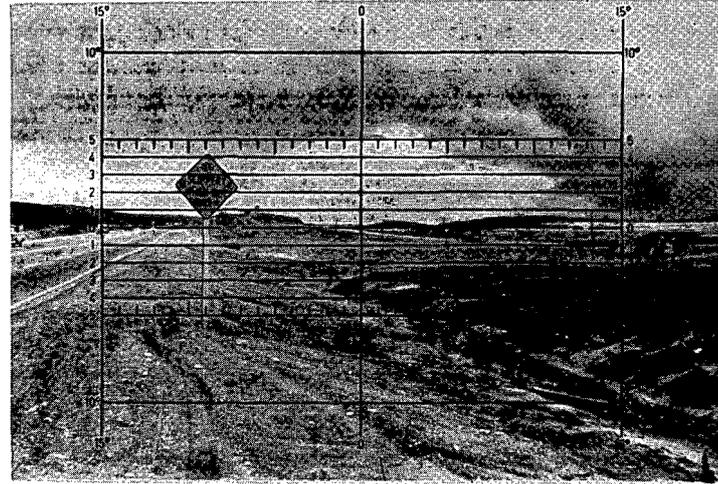


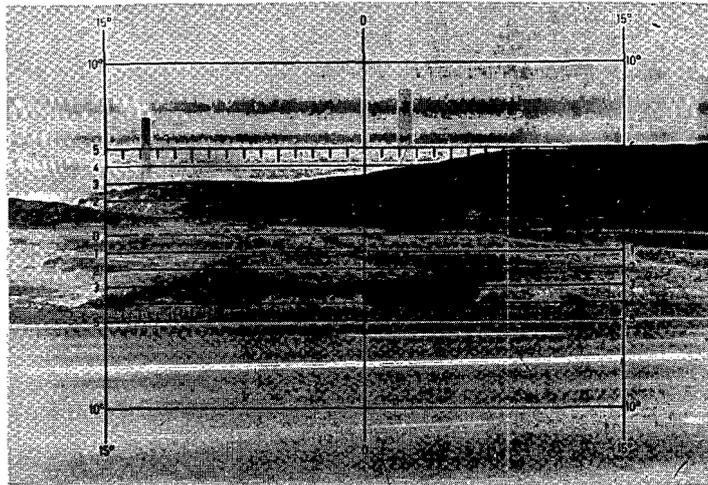
Figure 1
Map of the Copper Cliff Area



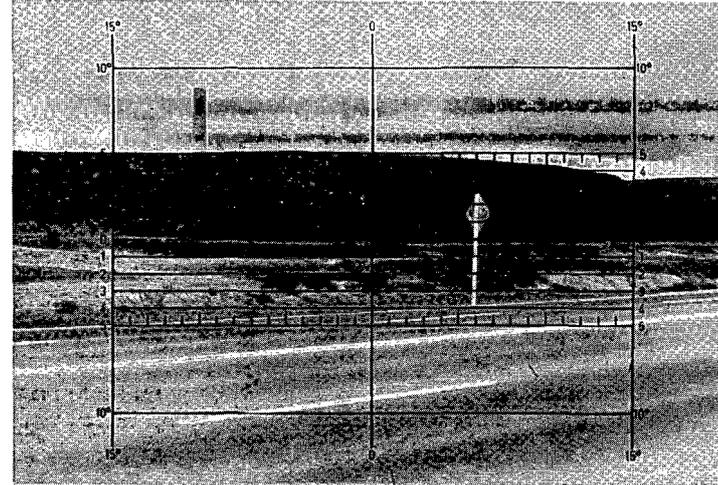
RAILWAY EMBANKMENT



STREAM



SLAG DUMP



SLAG DUMP

Figure 2
Photographs of the Railway Embankment, Slag Dump, and Stream

FIG. 3-DENSE FOG AT SUDBURY AND NORTH BAY AIRPORTS 1955-1963

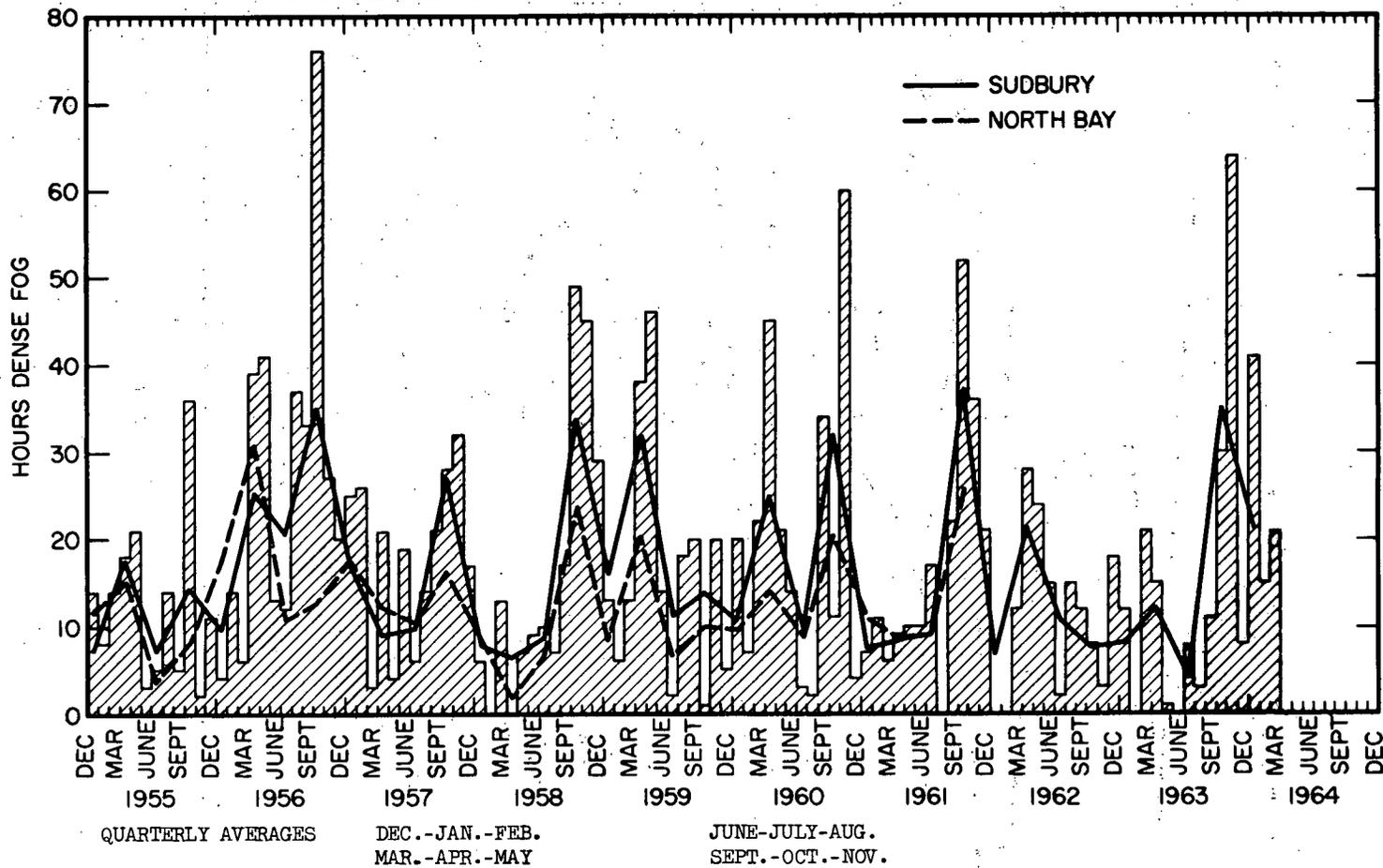


Figure 3
 Monthly and Quarterly Values of Fog for Sudbury and North Bay Airports
 1955-1963

FIG. 4-OBSTRUCTION TO VISION BY SMOKE AND HAZE
 SUDBURY AND NORTH BAY AIRPORTS-1955-1963

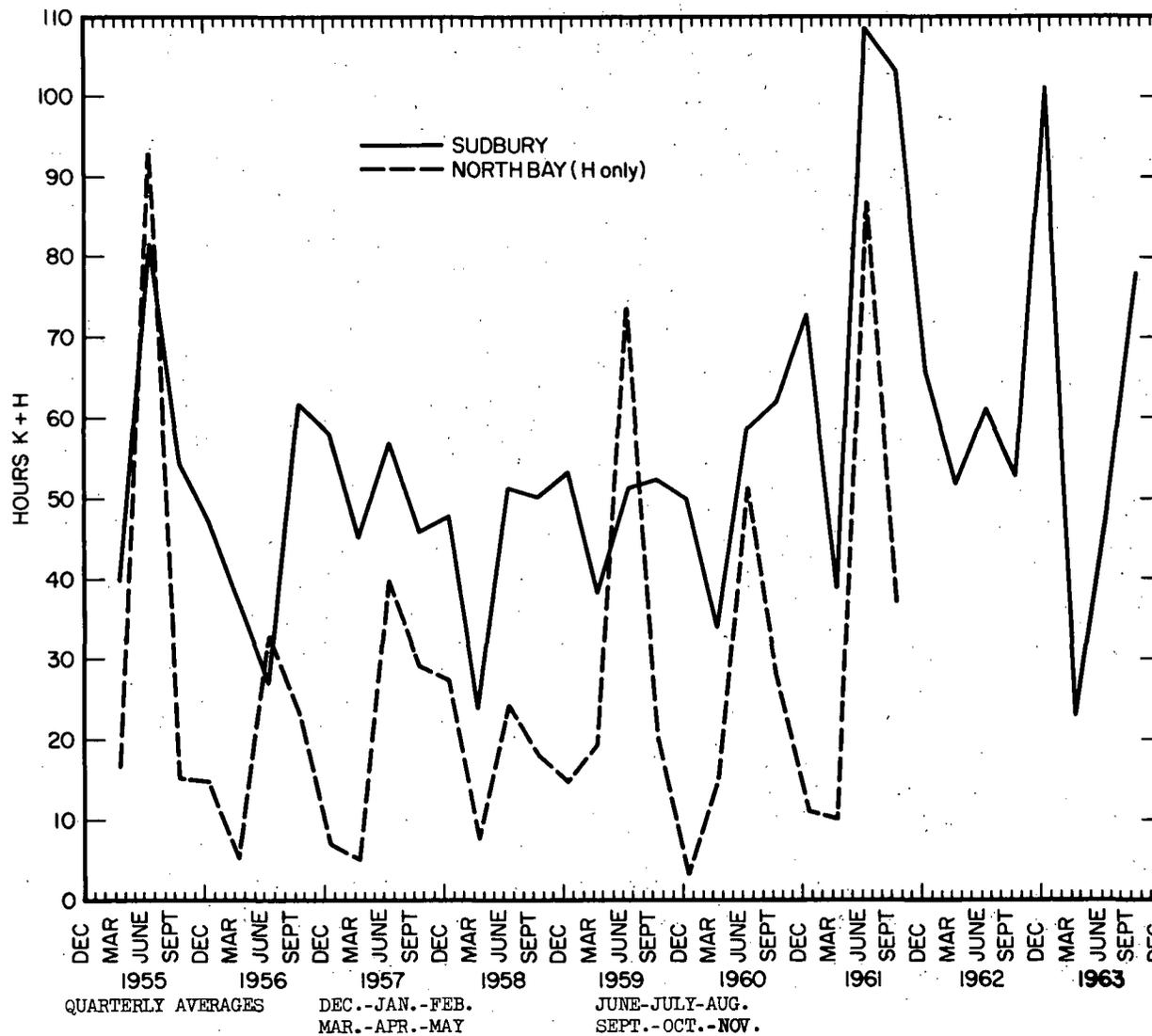


Figure 4

Quarterly Means of Obstruction to Vision by Smoke and Haze at Sudbury and North Bay Airports
 1955-1963

FIG. 5-AVERAGE HRS/MO/YR DENSE FOG AND SMOKE AT SUDBURY AIRPORT

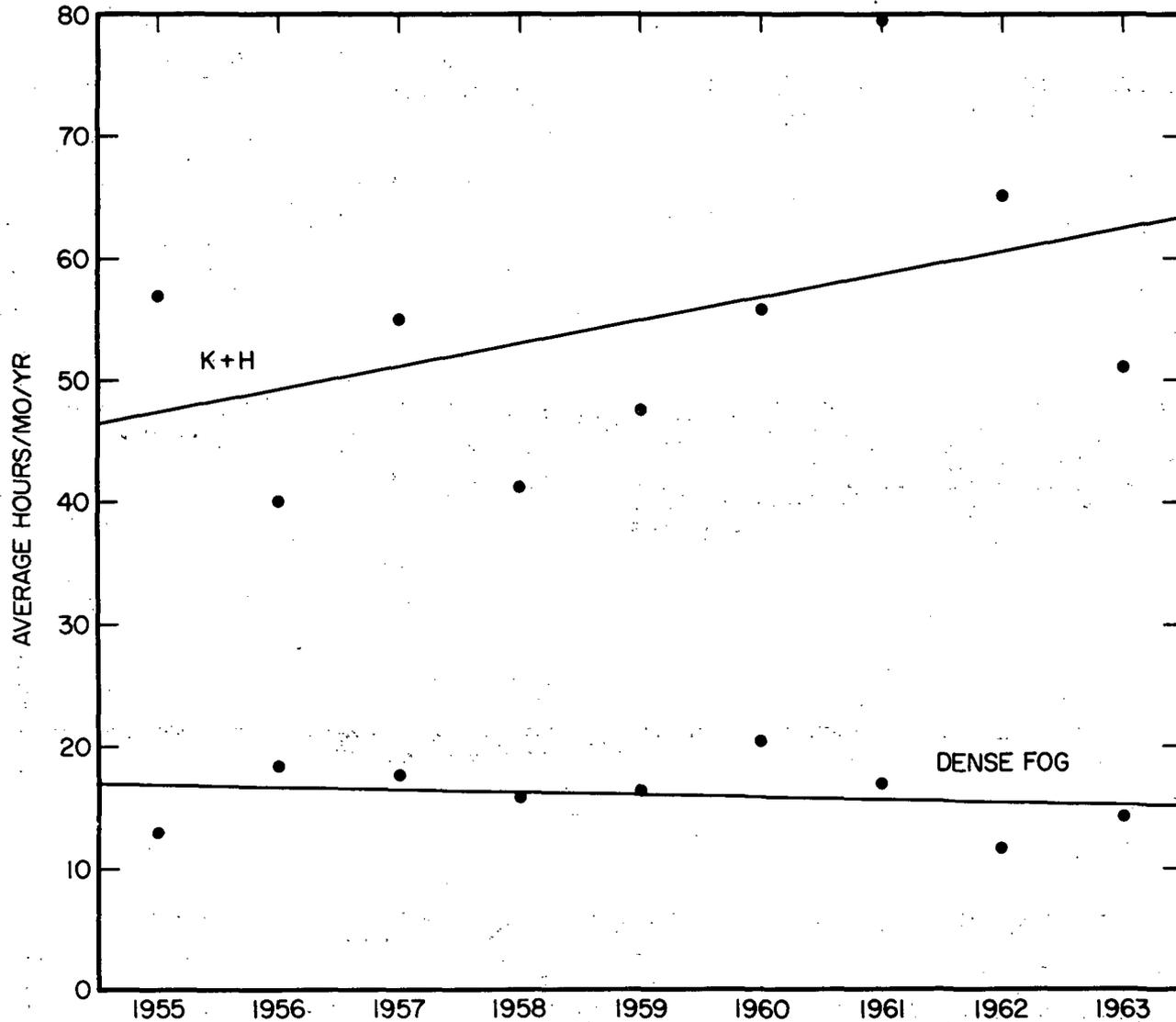


Figure 5
Average Hrs./Mo./Yr. Dense Fog and Smoke at Sudbury Airport
1955-1963

FIG. 6-TOTAL HOURS F, K+H, K(RH \geq 80%) AND FK JUNE AND JULY 1962, 1963 vs TIME OF DAY

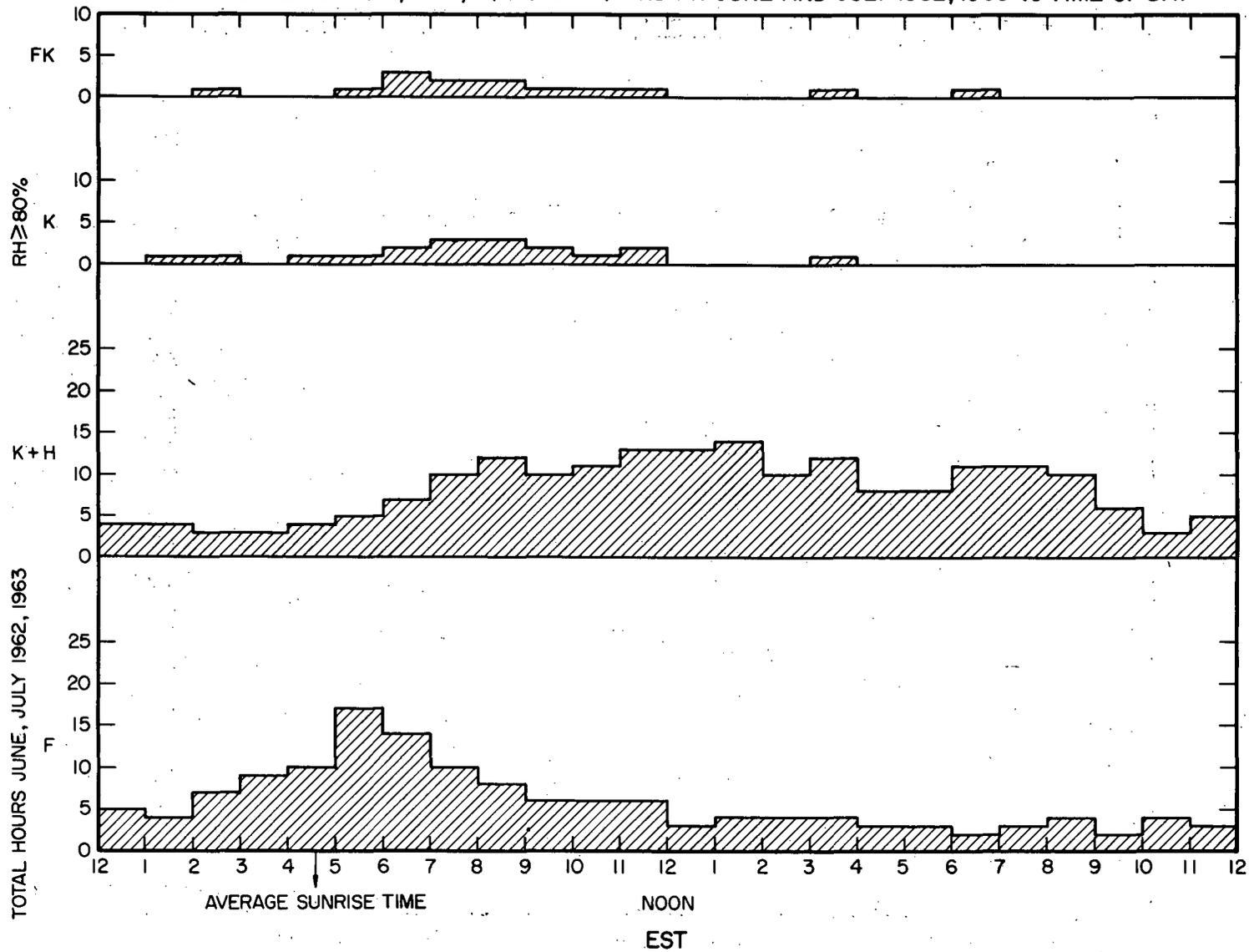


Figure 6
Histograms of F, K H, K (RH = 80%) and FK for Summer
1962-1963

FIG. 7 - TOTAL HOURS F, K+H, K(RH≥80%) AND FK NOV. AND DEC. 1962, 1963 vs TIME OF DAY

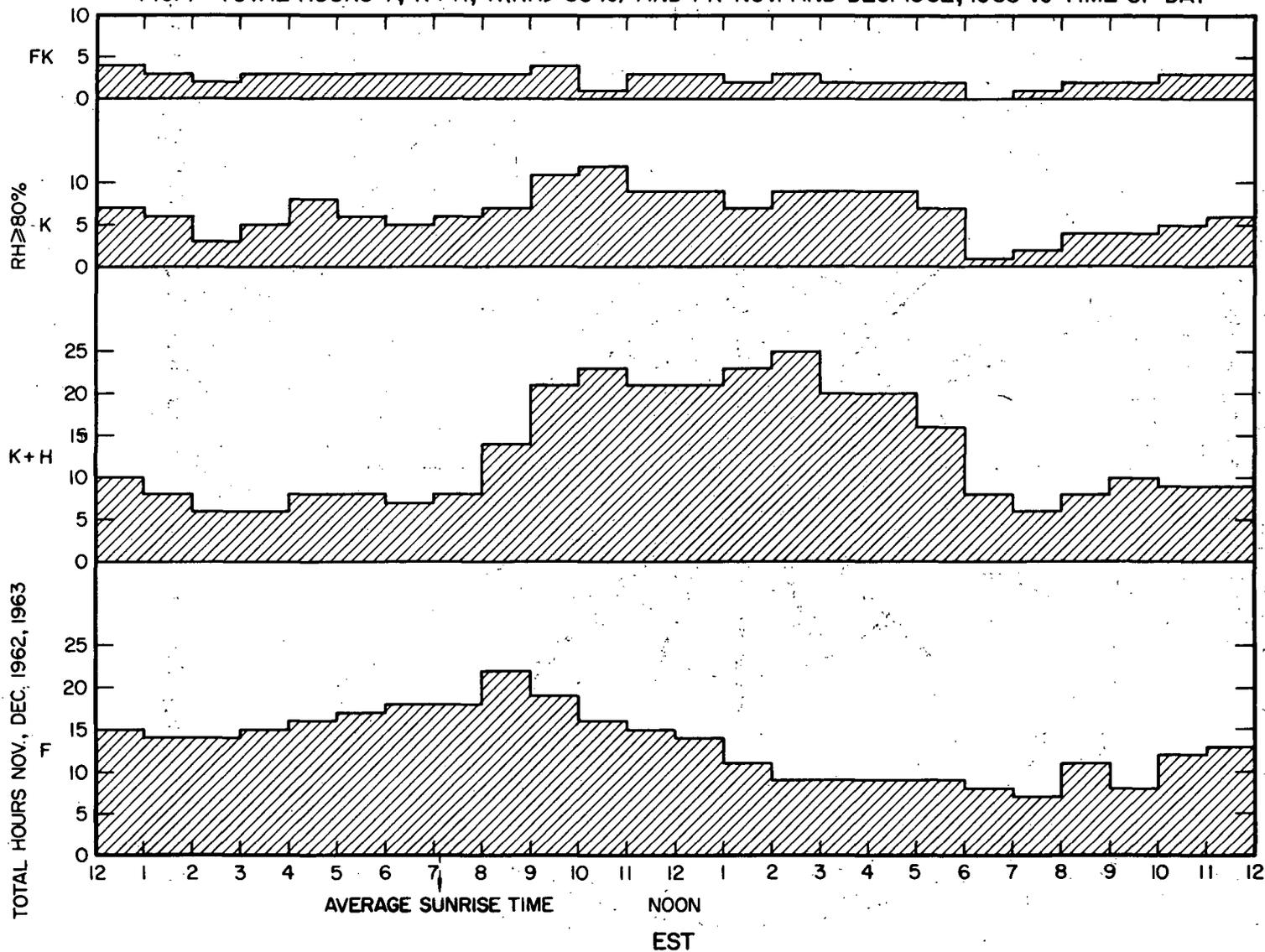


Figure 7
Histograms of F, K H, K (RH = 80%) and FK for Winter
1962-1963

FIG. 8-WIND DIRECTION DURING DENSE FOG
AT SUDBURY AIRPORT 1963

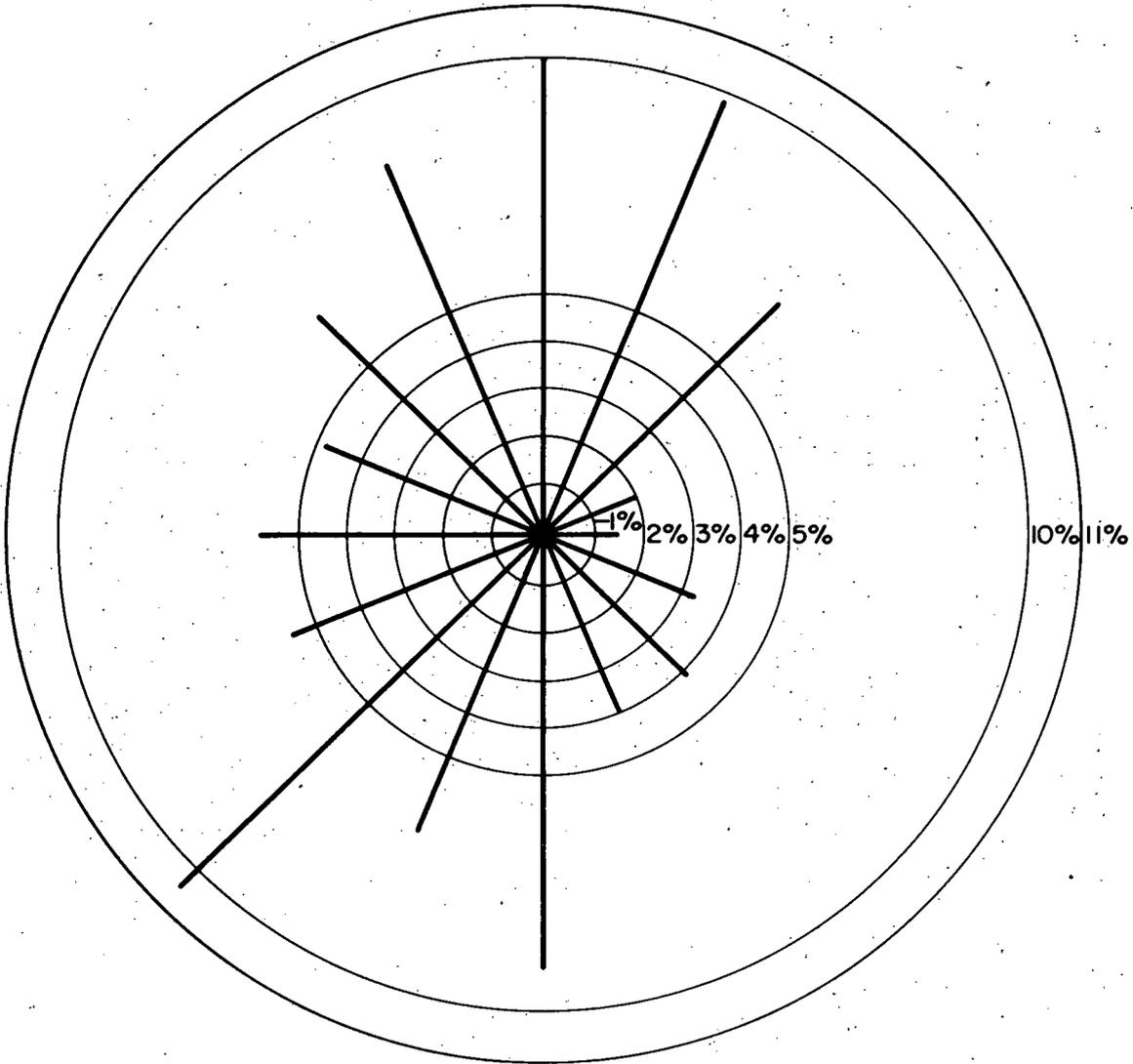


Figure 8
Wind Rose Showing Wind Direction During Dense Fog at Sudbury Airport

FIG. 9-WIND DIRECTION DURING OCCURRENCES OF SMOKE AND HAZE AT SUDBURY AIRPORT 1963

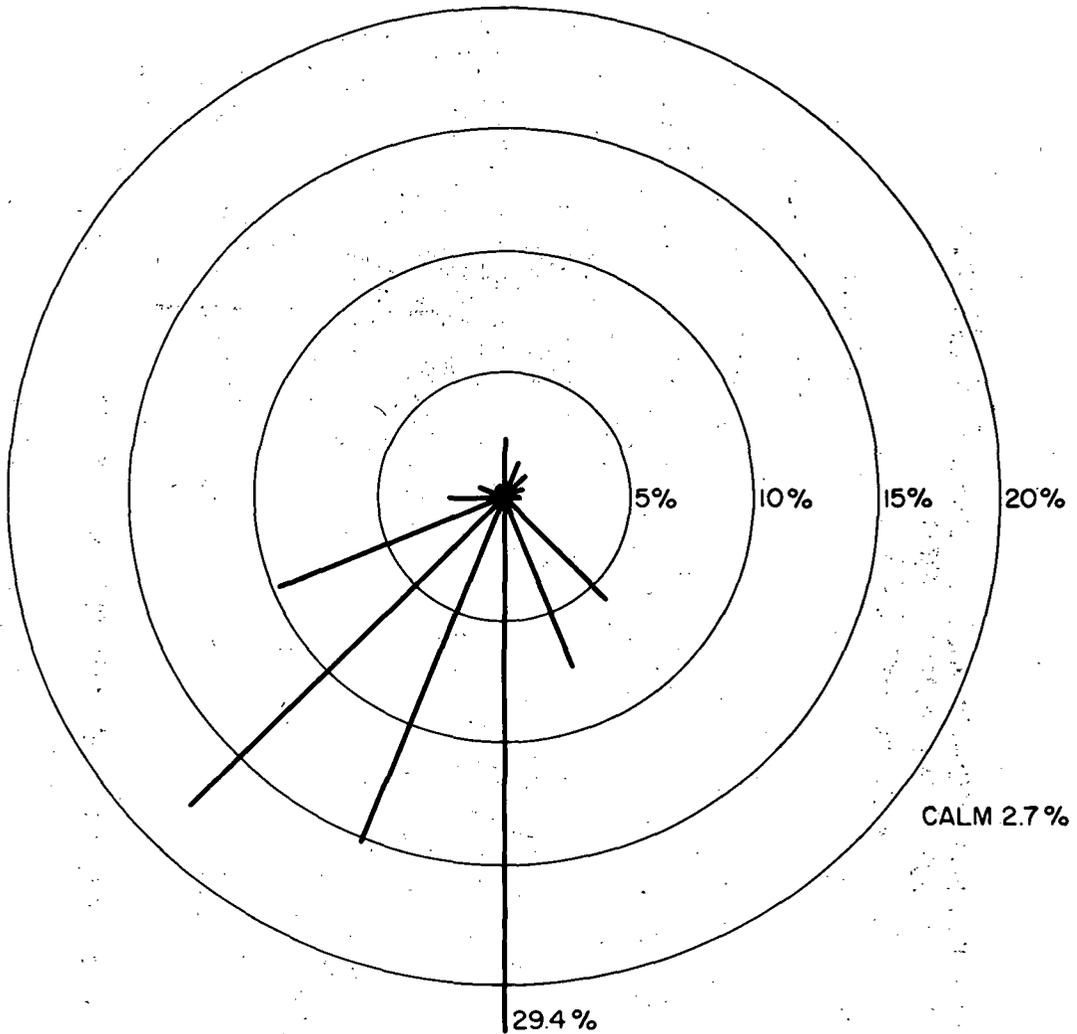


Figure 9

Wind Rose Showing Wind Direction During Occurrences of Smoke and Haze at Sudbury Airport

FIG. 10-WINDS DURING OCCURRENCES OF DENSE FOG LASTING
1962-1963-MARCH, 1964
(SUDBURY AIRPORT)

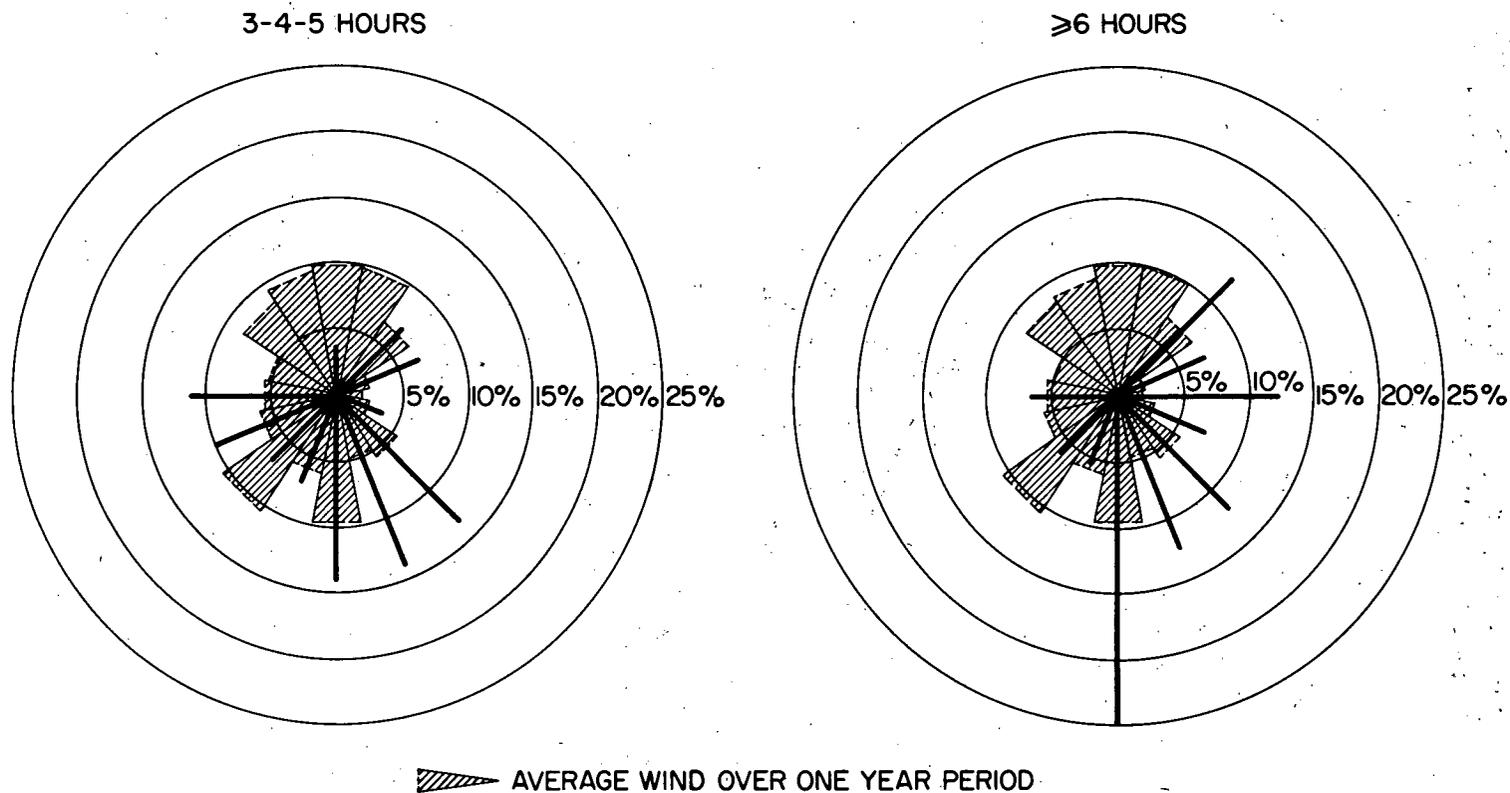


Figure 10
Wind Roses Showing Wind Direction During Prolonged Dense Fog at Sudbury Airport

FIG. 11-WIND DIRECTION DURING HIGHWAY FOG
(JAN. 13-MAR. 15, 1964)

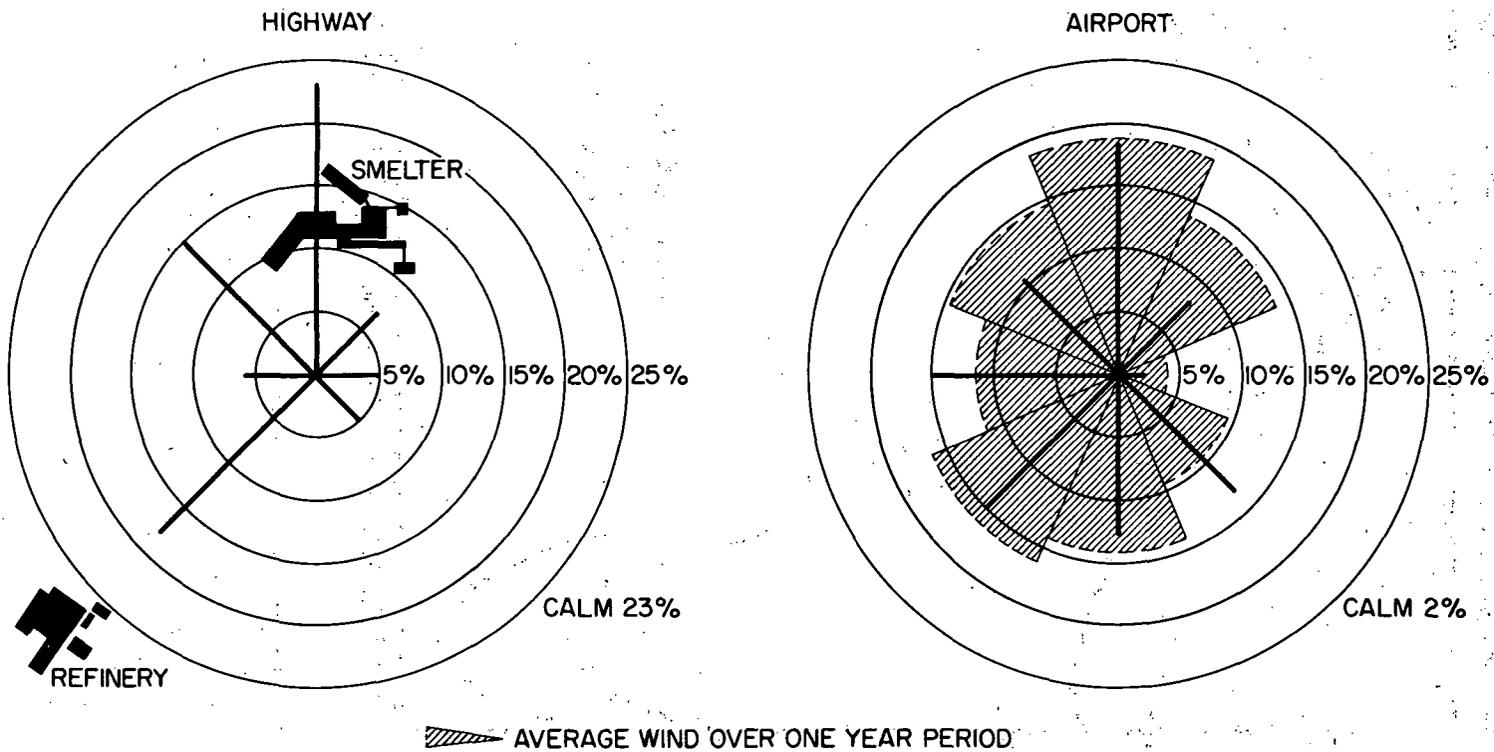


Figure 11
Wind Roses Showing Simultaneous Wind Direction at the Airport and Highway During Highway Fog

FIG. 12- AIR, DEW POINT AND CREEK TEMPERATURES

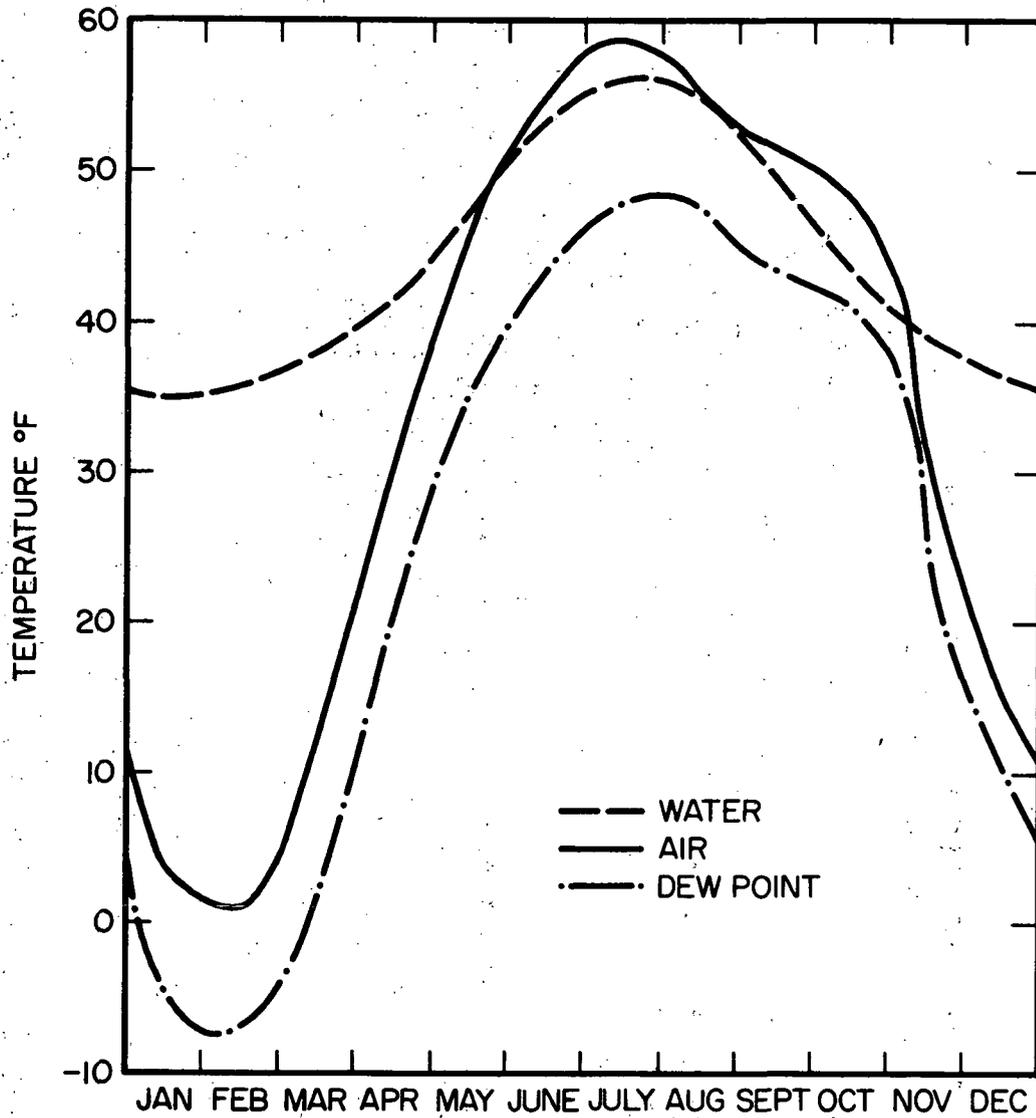


Figure 12
Air, Dew Point, and Creek Temperatures Over a One-Year Period

FIG. 13-HIGHWAY AND AIRPORT FOG vs TIME OF DAY AND NO. OF ACCIDENTS

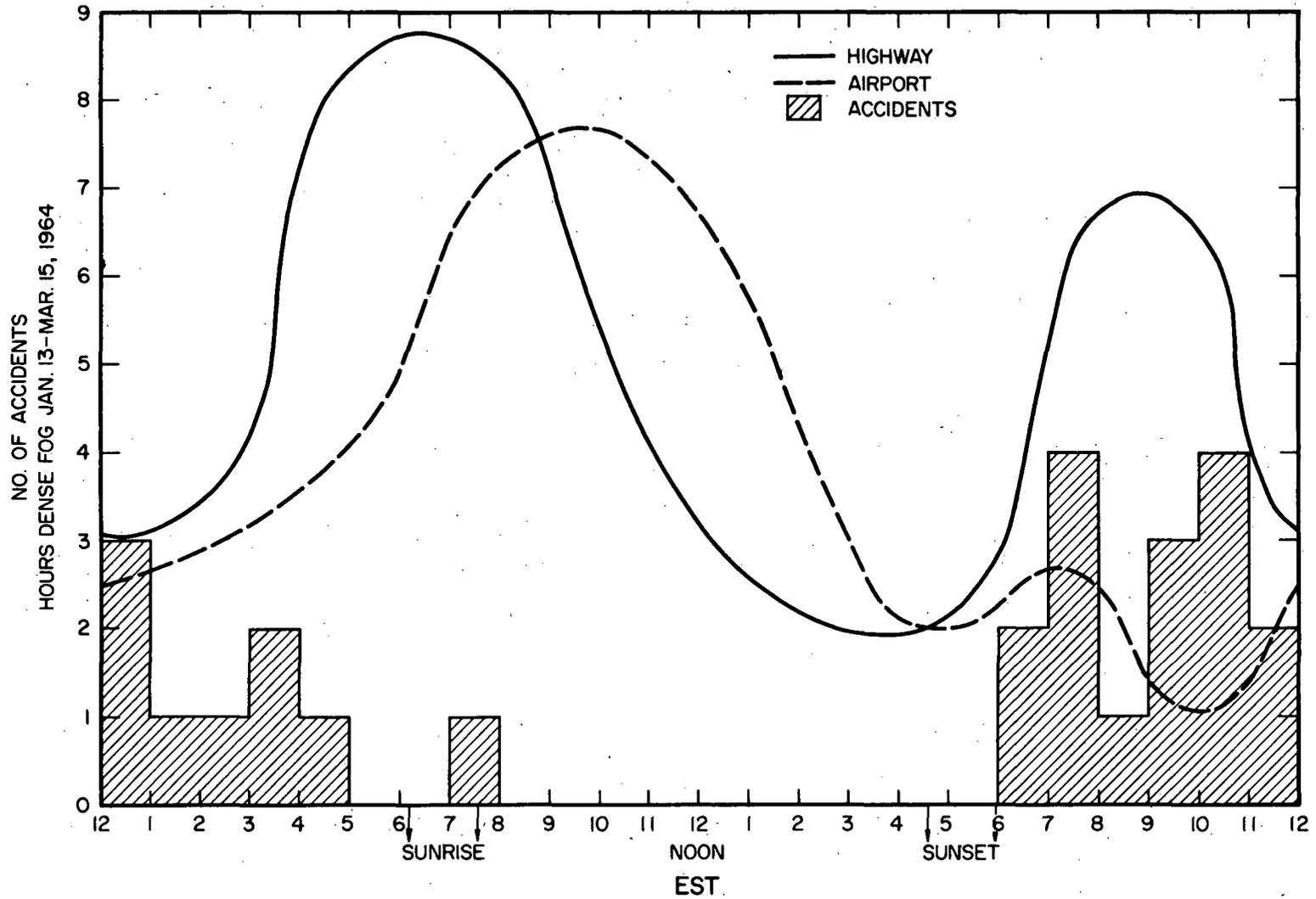


Figure 13
Highway and Airport Fog vs. Time of Day and No. of Accidents

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