T H E   U N I V E R S I T Y   O F   M I C H I G A N

COLLEGE OF ENGINEEERING
Department of Civil Engineering

Third Progress Report

METEOROLOGICAL ANALYSIS

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PREFACE

The past two progress reports have discussed data through 31 May 1957. The present report will add data up to 30 November 1957. For the sake of continuity and ease of reference, it was decided to include a year of data in this report. Therefore the data are presented by seasons and also in the form of a yearly summary.

The past reports and the present one emphasize the special meteorological features resulting from the proximity of the plate site to Lake Erie. The lake-breeze circulation occurring at the plant site is discussed fully as is the effect of this circulation on the diffusion characteristics.

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ABSTRACT

Temperature-lapse-rate data are classified according to their importance in relation to air-pollution characteristics. The frequency of inversions, seasonal trends, diurnal variation, and persistence of inversions are discussed. Lapse rates and their association with wind speed and wind direction are examined. Wind directions and wind speeds at the Enrico Fermi plant site are analyzed so as to bring out the differences between them and those observed at Detroit City Airport and Toledo Express Airport. A definite lake breeze at Lagoona Beach is identified and characterized and its effects are shown. Seasonal variations in the frequency of precipitation and the association of wind speed and direction with precipitation are discussed. A method for eliminating the bias from wind-direction frequency statistics is presented in the Appendix along with a discussion of the force which generates land and lake breezes.

I. ANALYSIS OF TEMPERATURE-LAPSE-RATE DATA

1. CLASSIFICATION OF LAPSE-RATE DATA

Temperature-lapse rates at the plant site are obtained from the difference between the temperatures at heights of 25 and 100 ft on the meteorological tower. This represents a relatively thin slice of the layer that is important in studies of turbulence and diffusion. Moreover, the lapse rate in this 75-ft slice is likely to differ substantially in magnitude if not in characteristic from that of the lower few hundred feet, taken as a whole. For these reasons, the practice initiated in the second progress report of simply classifying lapse rates as strong, weak, or inversion has been continued. Strong lapse rates are those which exceed the dry adiabatic lapse rate; weak lapse rates are intermediate between dry adiabatic and isothermal lapse rates; all cases in which temperatures increase with height are inversions.

The implications of each lapse-rate classification in diffusion were outlined in the second progress report and are repeated here. Generally speaking, strong lapse rates, weak lapse rates, and inversions are associated with above average, average, and below average diffusion conditions, respectively.

In the present report the investigation of the inversion climatology at the plant site is extended through the summer and fall of 1957. Lapse-rate data for the WJBK-TV tower continue to be available, so that comparisons between the two installations are again included. Annual summaries are included with most of the tables and charts. The analysis continues to lay stress on any evidence that there are lake influences present at the plant site which result in a climatology different from that of inland locations.

2. FREQUENCY OF INVERSIONS AND SEASONAL TRENDS

From the hourly record of lapse rates at the plant site it is possible to compute the relative frequency of inversions, strong lapse, and weak lapse rates in the layer of from 25 to 100 ft. This has been done for each season of the first full year of operation at the plant site. The results are presented in Table I together with an annual summary.

Although lapse-rate data at the WJBK-TV tower are abstracted and summarized in a somewhat different manner, they still provide a seasonal breakdown of relative frequencies of inversion in the layer of from 20 to 300 ft. These are presented in Table II.

TABLE I

SUMMARY OF TEMPERATURE-LAPSE-RATE DATA 25 TO 100 FT AT THE ENRICO FERMI SITE BY SEASONS AND ANNUAL SUMMARY

1 December 1956 - 30 November 1957

	Winter	Spring	Summer	Fall	Annual
Total hours	2160	2208	2208	2184	8760
Number missing hours	404	70	715	681	1870
Number hourly observations	1756	2138	1493	1503	6890
Percent missing data	18.7%	3.2%	32.4%	31.2%	21.3%
Percent inversions	21.4	18.6	19.3	17.4	19.2
Percent strong lapse	46.3	71.3	68.9	76.1	65.5
Percent weak lapse	32.3	10.1	11.8	6.5	15.3
	100.0%	100.0%	100.0%	100.0%	100.0%

TABLE II

SUMMARY OF TEMPERATURE-LAPSE-RATE DATA 20 TO 300 FT AT THE WJBK-TV TOWER, DETROIT, MICHIGAN BY SEASONS AND ANNUAL SUMMARY

1 December 1956 - 30 November 1957

	Winter	Spring	Summer	Fall	Annual
Total hours	2160	2208	2208	2184	8760
Number missing hours	664	426	824	112	2026
Number hourly observations	1496	1782	1384	2072	6734
Percent missing data	30.7%	19.3%	37.3%	5.1%	23.1%
Number hours inversion	392	388	569	834	2096
Percent inversions	26.3%	21.8%	41.1%	38.1%	31.1%

The most striking difference between the two sites is the greater frequency of inversions at the WJBK-TV tower, a feature that is present in each season, but one which is particularly noticeable in the fall. The seasonal variation of inversion frequency provides another basis for differentiation. From winter through summer the seasonal variations at the two sites appear to be in phase; then in the fall the frequency at WJBK-TV remains high whereas that at the plant site falls to a minimum. Of the two records, that for WJBK-TV is more or less consistent with what is usually considered to be the frequency and the seasonal variation of inversion frequency in this area.

It will be well to await further data before attempting to account for or interpret the differences that have appeared in the first year. Insofar as the WJBK-TV tower is concerned, it is known that most of the inversion hours occur at night (see Section 3) as the result of the cooling of the ground. The situation at the plant site is quite different since the lapse rates are measured within a few feet of the lake surface which does not cool appreciably at night. Hence, whenever winds are off the water, there will be little tendency for nocturnal inversions to form. This could lead to a greater frequency of inversions at the WJBK-TV tower. The difference in the seasonal frequency of inversions is less easy to account for and no attempt will be made to do so until the apparent anomaly at the plant site is confirmed by additional data. However, the following section sheds some additional light on the infrequency of inversions at the plant site during the fall season.

3. DIURNAL VARIATION OF INVERSIONS

The diurnal variation of inversions at inland stations is well documented. Since inversions form readily at night, they are most frequent during the night and least frequent during the day. A study of radiosoundings taken at Mount Clemens, Michigan, and Toledo, Ohio,[1] showed that inversions were much more frequent at 10 p.m. than 10 a.m. Eastern Standard Time. Some of the results are presented in Table III.

TABLE III

PERCENTAGE FREQUENCY OF SURFACE BASED INVERSIONS AT MOUNT CLEMENS, MICHIGAN, FEBRUARY 1948 - DECEMBER 1950 AND AT TOLEDO, OHIO, JANUARY 1946 - DECEMBER 1950 AS OBSERVED AT 10 A.M. AND 10 P.M. EASTERN STANDARD TIME

Station	Time	Winter	Spring	Summer	Fall	Annual
Mt. Clemens	10 a.m.	8.1	7.0	2.8	7.2	6.2
	10 p.m.	25.5	45.7	61.5	56.3	47.2
Toledo	10 a.m.	13.8	3.7	0.5	4.6	5.6
	10 p.m.	38.6	49.1	72.6	67.3	56.9

The diurnal variation of inversions at the WJBK-TV tower during the 12 months ending November 30, 1957, is in good agreement with the accepted diurnal variation. The diurnal variation of inversions at WJBK-TV is shown in Table IV.

TABLE IV

DIURNAL VARIATION IN PERCENT OF INVERSION FREQUENCY AT WJBK-TV TOWER DURING THE PERIOD 1 DECEMBER 1956 - 30 NOVEMBER 1957

6 hours ending at	Winter	Spring	Summer	Fall	Annual
0600	41.2	46.1	77.5	59.5	55.6
1200	22.3	15.3	33.0	33.9	26.2
1800	4.6	2.7	6.5	9.3	5.9
2400	36.5	24.9	45.9	58.2	42.0

The diurnal variation of inversions at the plant site has now been examined for the first full year of operation. The results appear in Table V for each of the seasons and an annual summary. The same data plus those of Table IV are presented graphically in Figs. 1-5.

The difference between the two locations is quite striking. Instead of the nighttime maximum and daytime minimum which characterizes the WJBK-TV tower data, two maxima and two minima occur at the Enrico Fermi site. The nighttime maximum is still present, with a decreasing frequency in the early daylight hours. About mid-afternoon the frequency rises to a second maximum of the same order of magnitude as the first but of shorter duration. There is a second minimum which occurs about the last hour of daylight, and then the frequency starts to rise again as the effects of nighttime cooling begin to show up. The afternoon maximum is evidence of a process or mechanism at the Enrico Fermi site that is not present at the WJBK-TV tower.

In an attempt to identify the mechanism causing these frequent afternoon inversions, the data comprising Table V were examined month by month. On 13 afternoons in June and 10 in July, inversions occurred. Afternoon inversions occurred in all months except October. It is this complete absence of afternoon inversions in October that is chiefly responsible for the infrequency of inversions during the fall. The 23 summer occurrences of afternoon inversions were examined in more detail and proved to be the result of the well-known lake-breeze effect. With the identification of the lake breeze as a primary factor in the inversion climatology of the Enrico Fermi site, an extensive investigation of the characteristics of the lake breeze has been undertaken and is described separately in Part III of this report.

TABLE V

HOURLY PERCENTAGE FREQUENCY OF INVERSIONS AT THE ENRICO FERMI SITE
BY SEASONS AND ANNUAL SUMMARY

1 December 1956 - 30 November 1957

Hour Ending	Winter	Spring	Summer	Fall	Annual
0100	25.7	20.0	18.0	26.2	22.4
0200	24.3	20.0	19.7	31.3	23.4
0300	23.0	20.0	24.6	23.1	22.4
0400	23.3	25.8	21.7	17.2	22.4
0500	24.7	20.2	25.0	22.6	22.9
0600	25.0	20.5	28.9	21.0	23.5
0700	22.5	19.5	19.6	25.8	21.7
0800	21.4	17.2	9.1	19.4	17.2
0900	22.2	11.1	6.5	16.9	17.6
1000	11.1	13.5	13.4	10.6	12.2
1100	11.1	14.6	14.9	9.1	12.6
1200	15.3	19.1	24.6	9.0	17.1
1300	19.4	20.5	15.4	10.6	16.8
1400	21.9	23.6	21.5	12.3	20.2
1500	22.5	21.3	24.6	19.7	22.0
1600	19.2	20.5	35.9	16.7	22.7
1700	14.9	15.7	34.4	13.2	19.0
1800	13.3	16.7	25.0	14.7	17.2
1900	17.3	15.6	14.1	14.7	15.5
2000	24.0	16.7	9.7	20.6	18.0
2100	32.0	16.7	11.5	13.4	18.8
2200	29.3	16.7	16.1	14.9	19.4
2300	25.3	20.0	16.1	19.7	20.4
2400	24.3	20.2	11.5	18.2	19.0

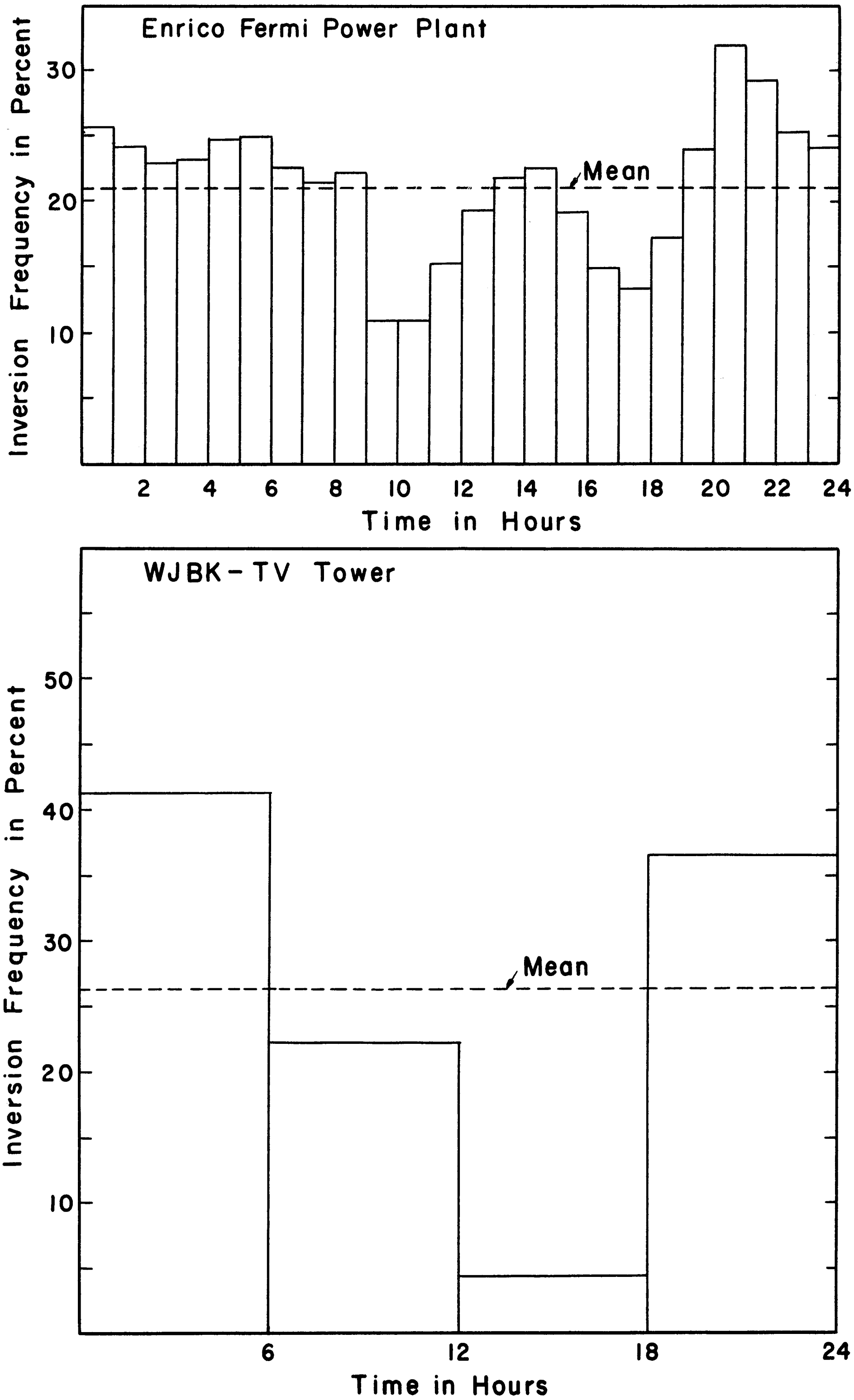


Fig. 1. Diurnal variation of inversions at the Enrico Fermi site and at WJBK-TV tower: Winter, 1956-1957.

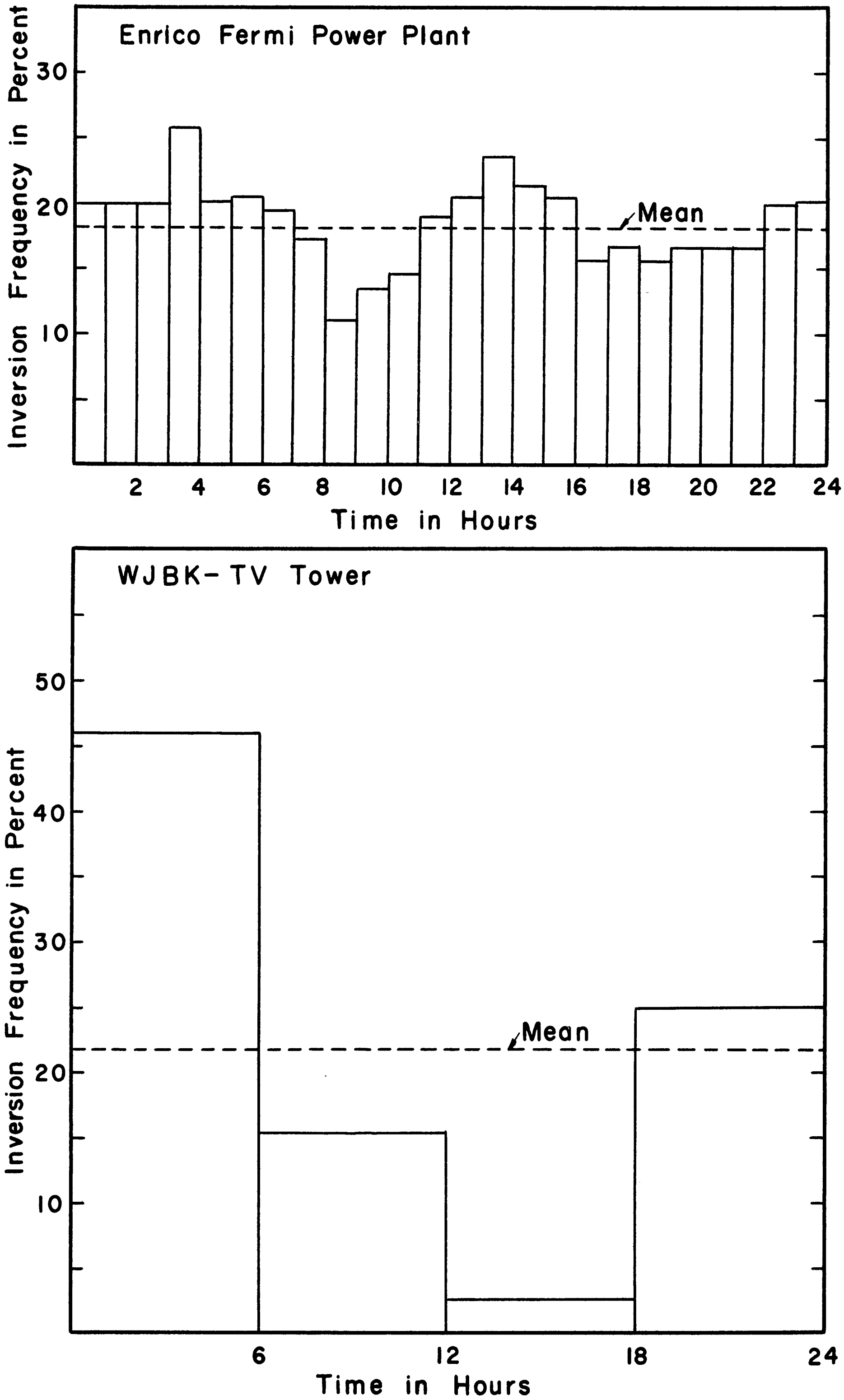


Fig. 2. Diurnal variation of inversions at the Enrico Fermi site and at WJBK-TV tower: Spring, 1957.

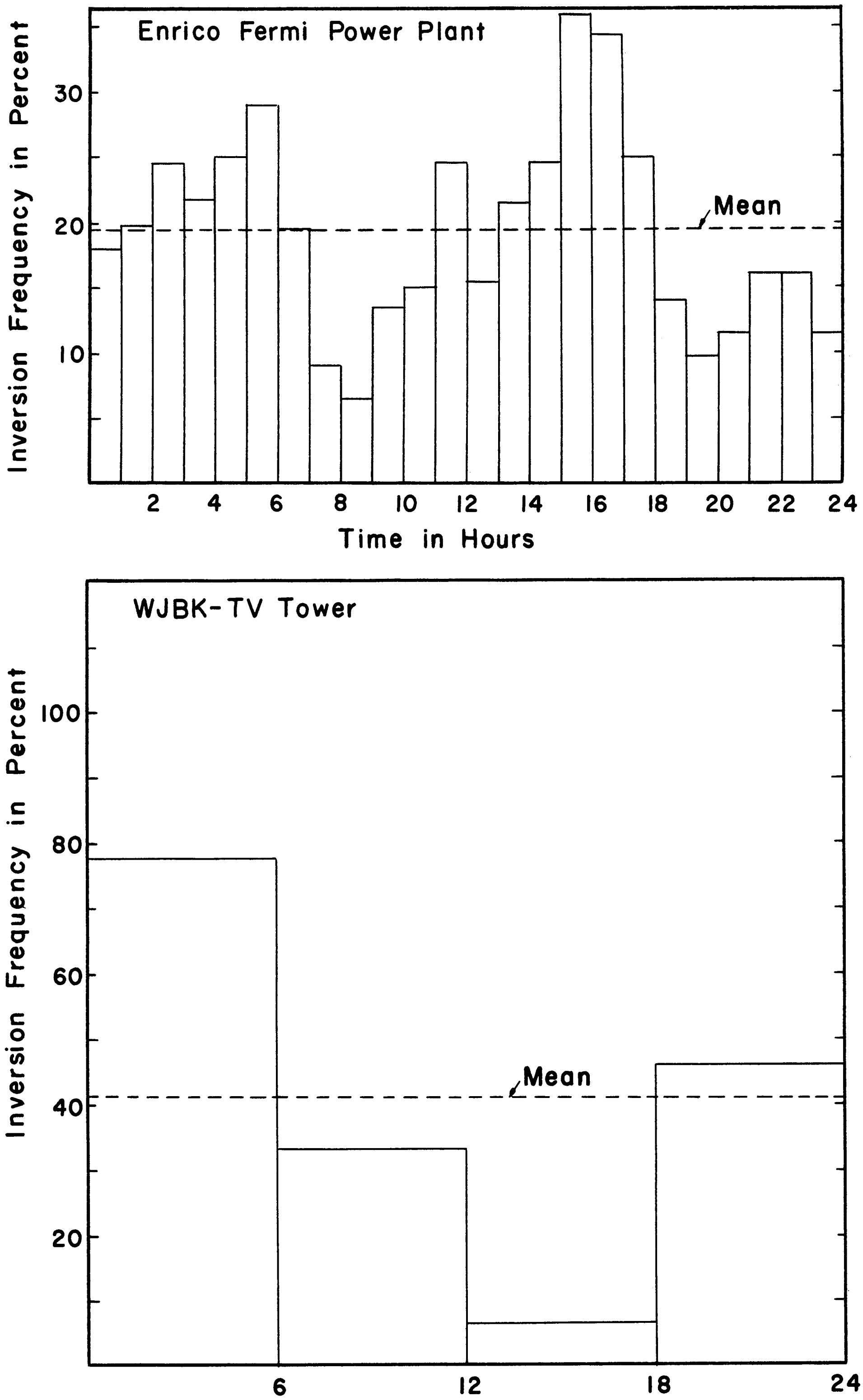


Fig. 3. Diurnal variation of inversions at the Enrico Fermi site and at WJBK-TV tower: Summer, 1957.

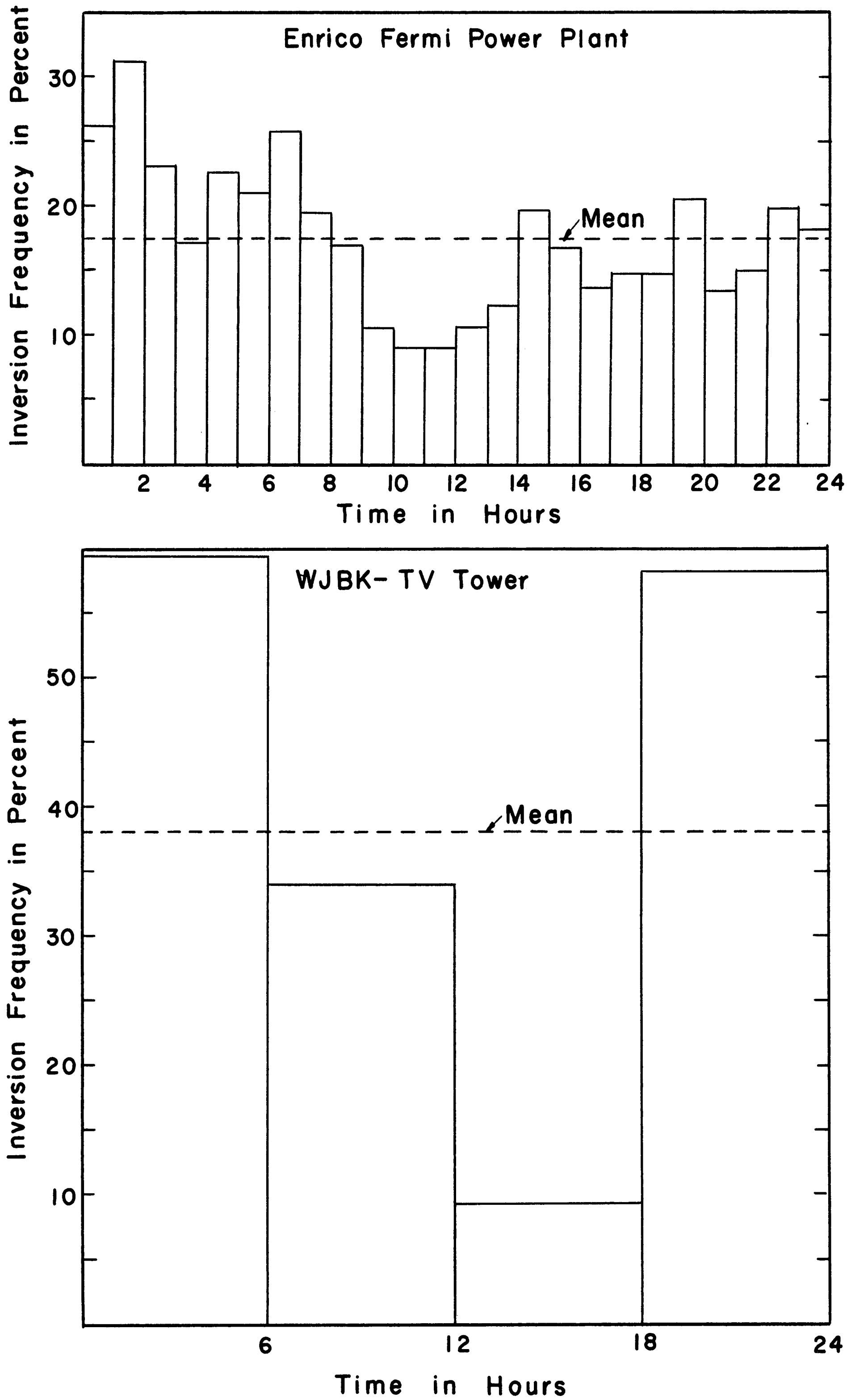


Fig. 4. Diurnal variation of inversions at the Enrico Fermi site and at WJBK-TV tower: Fall, 1957.

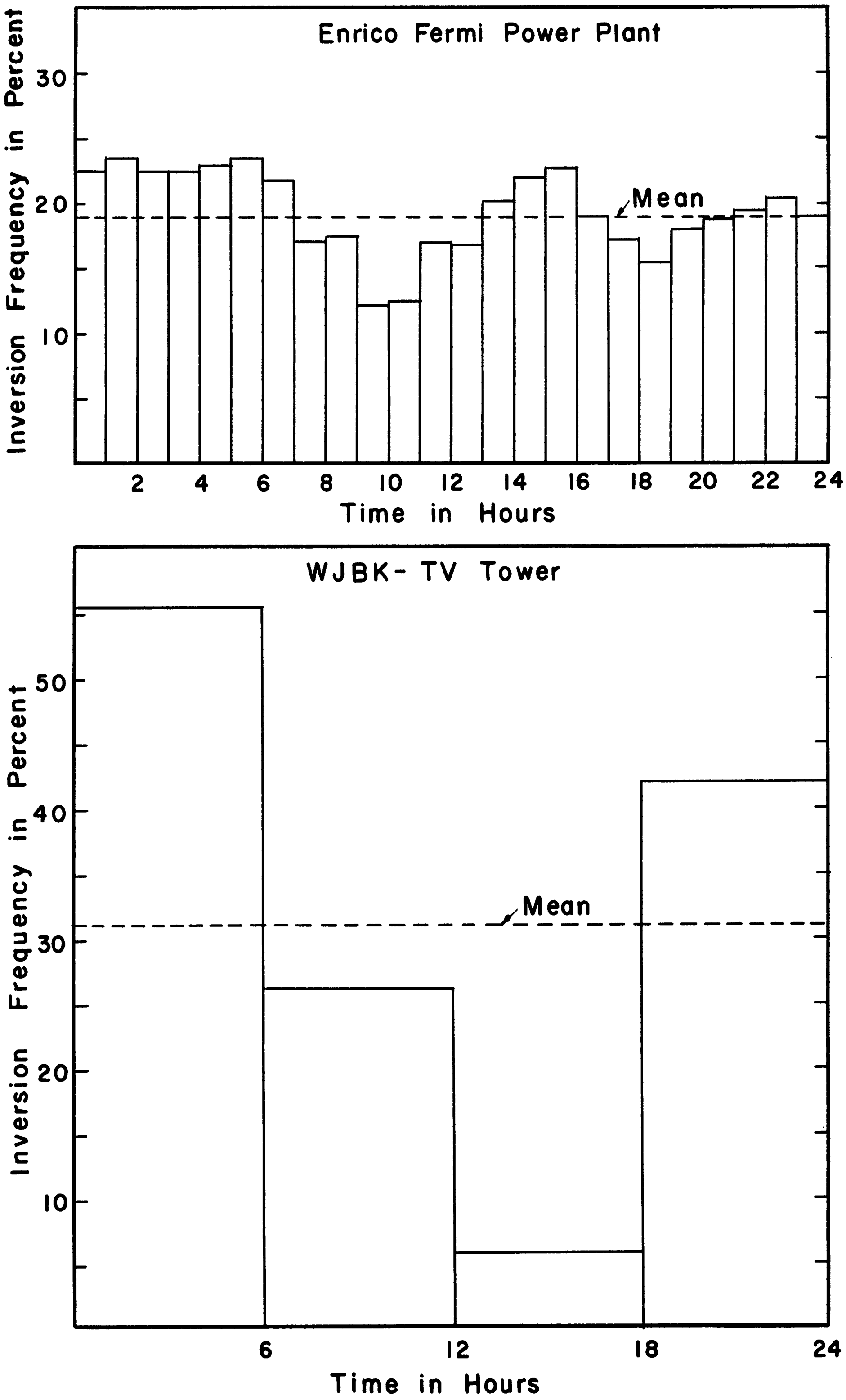


Fig. 5. Diurnal variation of inversions at the Enrico Fermi site and at WJBK-TV tower: Annual Summary, 1956-1957.

4. THE PERSISTENCE OF INVERSIONS

The inversion climatology of any site can be characterized usefully by the duration of inversions as was done in the first and second progress reports. Inversion duration is determined as follows. Each occurrence of inversion conditions which persists for a number of consecutive hours is considered to be a single inversion. Its duration is simply the number of consecutive hours of inversion, except that an occurrence of one hour of weak lapse rate within the sequence of inversion hours is not considered a break in the continuous inversion. For example, six consecutive hours of inversion followed by a one-hour weak lapse rate and then five more hours of inversions would be treated as an inversion of 12 hours duration.

Many inversions occur as isolated 1-, 2-, or 3-hour events both at the WJBK-TV tower and at the Enrico Fermi site. It is reported that at the WJBK-TV tower "the highest duration frequency is in the 1 to 3-hour period."[2] Inversions of short duration are quite frequent at the Enrico Fermi site also, since most of the afternoon inversions associated with the lake-breeze effect form after noon and disappear an hour or more before dark. However, in the present analysis, attention is focused on inversions of 6 hours or more duration since these have somewhat different implications than shorter inversions in problems of diffusion.

The substance of the difference between the Enrico Fermi and the WJBK-TV sites can be described more clearly in words than graphically. In Section 2 it was stated that inversions occur 31.1% of the time at the WJBK-TV tower and only 19.0% of the time at the Enrico Fermi site. Although there are gaps in the record at both stations due to equipment failure, the number of hours of lapse-rate data available at the two stations is practically identical, 6734 at WJBK-TV and 6748 at the Enrico Fermi site. Hence it is not necessary to present the comparison in terms of percentages. During the period of record from December 1, 1956, to November 30, 1957, there were 141 occurrences of inversions at the WJBK-TV tower which exceeded 5 hours in duration, but only 70 such occurrences at the Enrico Fermi site. Nevertheless, there were 5 inversions lasting longer than 24 hours at the Enrico Fermi site but none of this duration at the WJBK-TV tower. These 5 prolonged occurrences consisted of inversions of 43 and 50 hours in the winter, 26 and 34 hours in the spring, and 50 hours in the summer. The appearance of these very lengthy inversions at the Enrico Fermi site is related to yet a third important mechanism, which results from the adjacent lake surface.

Under certain meteorological conditions a broad southerly flow of air is established over the eastern portion of the United States. When this happens, unseasonably warm air from the Gulf of Mexico ranges far north of its normal limits, moving out across Lake Erie where it is cooled by the surface of the lake, thus forming an inversion. It is convenient to designate this type of inversion as circulation inversions because of their means of formation. This distinguishes them from nocturnal inversions formed by surface cooling, and the afternoon inversions caused by the lake-breeze effect. The essential ingredients of this circulation type of inversion are a southerly flow of air, and air temperatures that are several degrees above the temperature of the lake.

A number of these circulation inversions were observed in the first year of operation, and the question naturally arises of how often they are likely to occur. The frequency of inversion is related both to the temperature of the lake and the frequency and magnitude of positive departures from normal temperature. A very good estimate of lake temperatures near the Enrico Fermi site is provided by water intake temperatures at the Monroe waterworks. Five years of records from 1953 through 1957 of intake temperatures have been analyzed for this purpose. A comprehensive analysis of the frequency and magnitude of positive departures from normal temperatures could constitute an extensive investigation in its own right. A less elaborate analysis that still gives useful results is described in the following paragraphs.

A study of positive temperature anomalies (i.e., departures from normal) at Toledo was undertaken to learn something about the frequency and magnitude of warm spells. Seven years of records were examined for occurrences of positive anomalies greater than or equal to 10°F. The results of this study are presented in Table VI.

TABLE VI

FREQUENCY AND MAGNITUDE OF POSITIVE TEMPERATURE ANOMALIES BY MONTHS AT TOLEDO, OHIO, DURING A PERIOD OF 7 YEARS

Number of Occurrences by Months

Anomaly, °F	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
10	63	52	42	41	29	37	21	19	24	50	42	45
15	32	20	16	24	3	6	1	2	5	24	17	23
20	15	6	7	7	0	0	0	0	0	4	5	9
25	6	1	0	0	0	0	0	0	0	0	1	3

It turns out that the magnitude of positive temperature anomalies is much greater in the winter than the summer. However, insofar as the formation of the inversions is concerned, greater temperature anomalies are needed in the winter since the lake temperature is several degrees above the average air temperature.

The variables have been brought together in the following way. During the two winter inversion occurrences, temperatures of 25°F and 27°F above normal were recorded at Toledo Express Airport which corresponded to temperatures 16°F and 19°F above the lake temperature at Monroe. During one of the spring occurrences, the temperature was 22°F above normal and above the lake temperature. In addition, on one occasion in the summer, when except for two consecutive hours of weak lapse rate an inversion persisted for 33 hours, the temperature was 15°F above normal and 20°F above the lake temperature. Based on these occurrences, a favorable thermal regime for the formation of prolonged inversions has been set tentatively as an air temperature 15°F above the lake temperature. Now considering the month of January, in which the average lake temperature is 35°F, an average air temperature of 50°F at Toledo provides a favorable regime for inversion formation. Since 26°F is the normal January temperature at Toledo, 50°F corresponds to a temperature anomaly of 24°F. In the Toledo records of 7 years, 8 occurrences in January of anomalies greater than or equal to 24°F, or a little better than 1 per year, were recorded. Similar computations have been made for each month of the year and are presented in Table VII.

Certain inferences may be drawn from Table VII. Clearly, thermal regimes favorable for the formation of prolonged inversions occur most frequently in the spring and through June, after which their frequency falls off abruptly. On a seasonal basis a favorable regime occurs about 2 times per winter, 11 times per spring, 6 times per summer (5 of these in June), and about once every 2 years in the fall. Since this analysis does not take wind direction into account, or the fact that some occurrences of the required temperature anomaly were on consecutive days and would therefore initiate only one prolonged inversion, the numbers obtained should not be taken literally. In addition, it is by no means certain that prolonged inversions will not form when air temperatures at Toledo are only 10°F above lake temperatures, However, it is completely warranted to assert that prolonged inversions at the Enrico Fermi site are least probable in the fall and most probable in April, May, and June. No doubt the absence of any lengthy inversions in the first fall of record, at the Enrico Fermi site, and the infrequency of inversion conditions in the fall as noted earlier in this report, reflect these findings.

5. THE ASSOCIATION OF LAPSE RATES WITH WIND SPEED

Inasmuch as an inversion is often a manifestation of stagnant air conditions, it is usual to find that winds are lighter during inversions than at other times. It is not simply an association of the two conditions; it is a cause and effect relationship. Under steep lapse rates, vigorous mixing transports momentum from aloft to the surface layers, and wind speeds are high. When inversions develop, vertical mixing is inhibited, the transport of momentum from aloft diminishes, and surface winds decrease. To some extent this pattern appears at the Enrico Fermi site. Once again, however, the presence of the lake influences the association of wind speed and lapse rate.

For purposes of this analysis, two classes of lapse rates, inversion and noninversion, have been used. The percentage occurrence of inversion and noninversion and the average wind speed for each class have been computed for each wind direction. The results of this analysis are presented in Tables VIII through XII for each of the seasons and for the entire year from 1 December 1956 to 30 November 1957. Figures 6-10 provide a graphical display of the same information.

TABLE VII

THE FREQUENCY OF THERMAL REGIMES FAVORABLE FOR THE FORMATION OF PROLONGED INVERSIONS AT THE ENRICO FERMI SITE SHOWN AS A FUNCTION OF MEAN LAKE TEMPERATURES AT MONROE AND NORMAL AIR TEMPERATURES AT TOLEDO

(All temperatures in °F)

Variables	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mean lake temperature	35	35	36	43	53	64	71	72	68	59	47	38
Required air temperature for inversion (add 15°F to lake temperature)	50	50	51	58	68	79	86	87	83	74	62	53
Normal Toledo temperature	26	27	36	46	58	69	73	71	64	53	40	29
Required temperature anomaly at Toledo for inversion (line 2 minus line 1)	24	23	15	12	10	10	13	16	19	21	22	24
Number of occurrences of required anomaly at Toledo in 7 years of record	8	2	13	33	29	37	6	1	0	2	1	3
Number of occurrences of required anomaly by seasons	Winter - 13			Spring - 75			Summer - 44				Fall - 3	

TABLE VIII

MEAN WIND SPEEDS ASSOCIATED WITH INVERSIONS AND NONINVERSIONS
AT THE ENRICO FERMI SITE

1 December 1956 - 28 February 1957
(Winter)

Wind Direction	Inversion		Noninversion	
	Occurrence, %	Mean Speed, mph	Occurrence, %	Mean Speed, mph
N	0.7	6.7	2.6	16.6
NNE	0.7	7.0	3.0	17.3
NE	0.5	10.9	5.2	17.0
ENE	0.9	12.8	2.3	10.5
E	1.0	11.8	1.8	11.2
ESE	1.1	11.8	2.6	11.0
SE	1.9	10.0	1.7	11.2
SSE	1.1	10.7	1.2	9.9
S	1.1	11.6	3.1	12.8
SSW	3.0	14.2	6.9	16.3
SW	2.8	15.5	8.3	14.0
WSW	2.2	12.3	13.4	13.1
W	1.5	10.7	7.4	12.1
WNW	0.9	8.1	7.4	11.6
NW	1.3	6.5	6.4	11.6
NNW	0.5	6.2	4.8	12.1
Calm	0.1	0.0	0.6	0.0
Totals	21.3		78.7	
Average		11.4		13.2

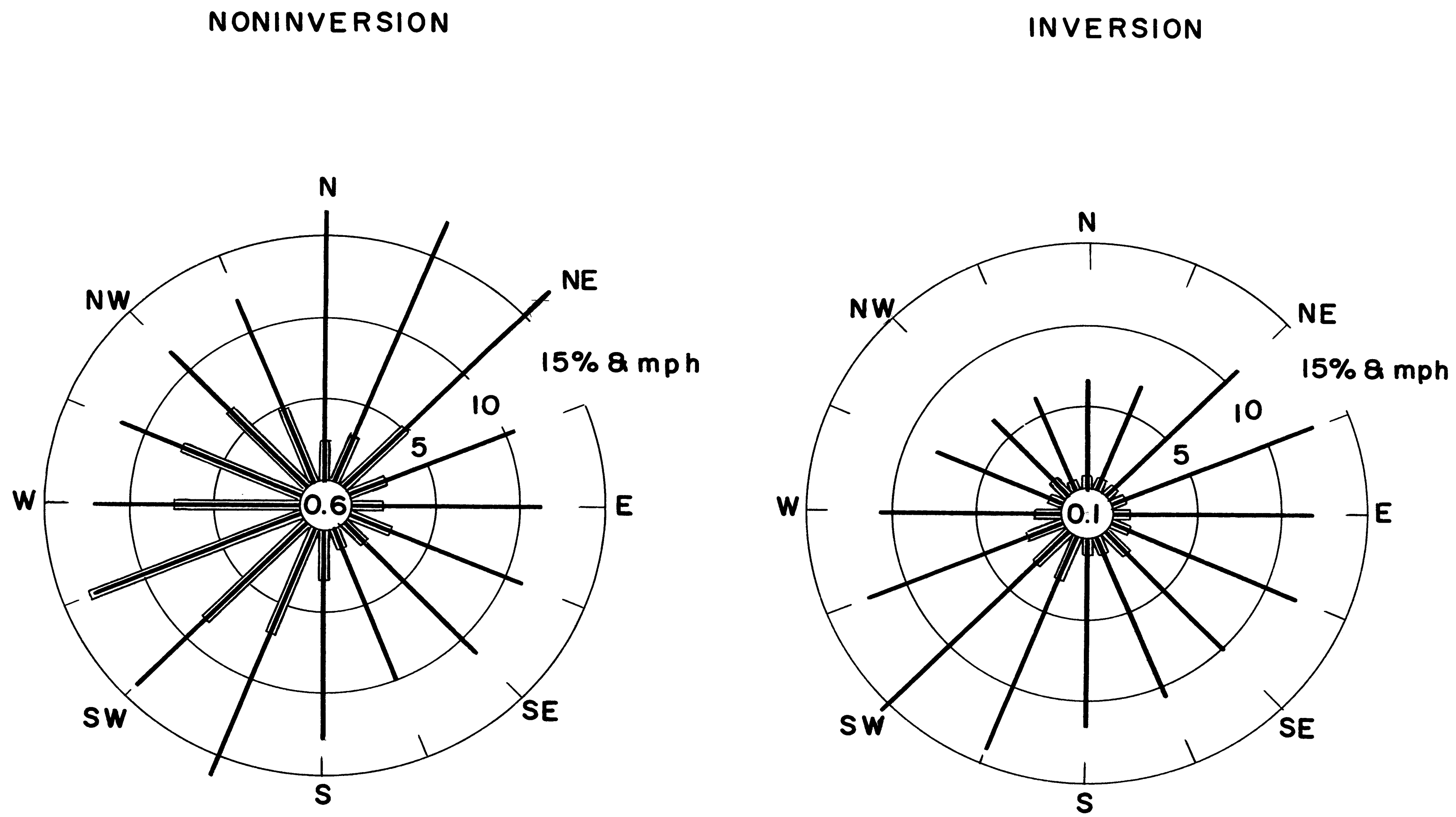


Fig. 6. Percentage frequency of inversions and noninversions associated with winds for 16 directions and corresponding wind speed in mph at the Enrico Fermi site: Winter, 1956-1957.

TABLE IX

MEAN WIND SPEEDS ASSOCIATED WITH INVERSIONS AND NONINVERSIONS AT THE ENRICO FERMI SITE

1 March 1957 - 31 May 1957
(Spring)

Wind Direction	Inversion		Noninversion	
	Occurrence, %	Mean Speed, mph	Occurrence, %	Mean Speed, mph
N	0.3	6.9	2.7	13.1
NNE	0.7	7.7	6.2	14.0
NE	0.5	8.1	6.8	16.0
ENE	0.4	8.9	9.5	15.6
E	0.8	12.6	6.8	18.5
ESE	1.5	14.9	5.2	12.8
SE	2.0	14.6	2.6	12.6
SSE	2.9	12.3	2.4	8.5
S	2.6	10.9	2.0	9.8
SSW	2.2	10.7	3.1	11.8
SW	1.2	12.3	6.2	14.0
WSW	1.0	9.0	8.4	17.1
W	0.6	10.0	5.8	14.3
WNW	0.8	10.8	7.9	14.7
NW	0.3	7.0	4.1	13.8
NNW	0.6	8.8	1.7	11.6
Calm	0.1	0.0	0.1	0.0
Totals	18.5		81.5	
Average		11.3		14.7

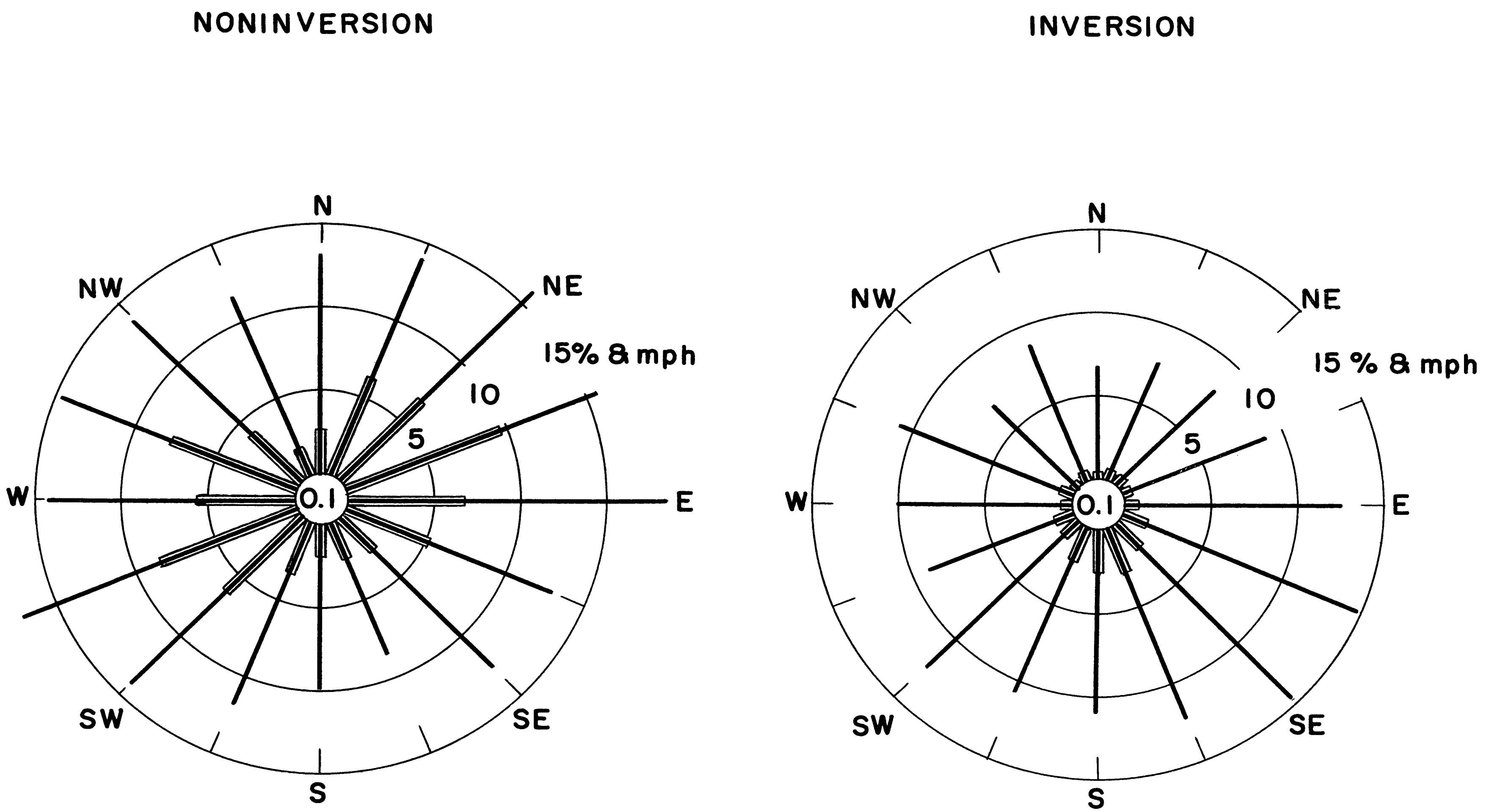


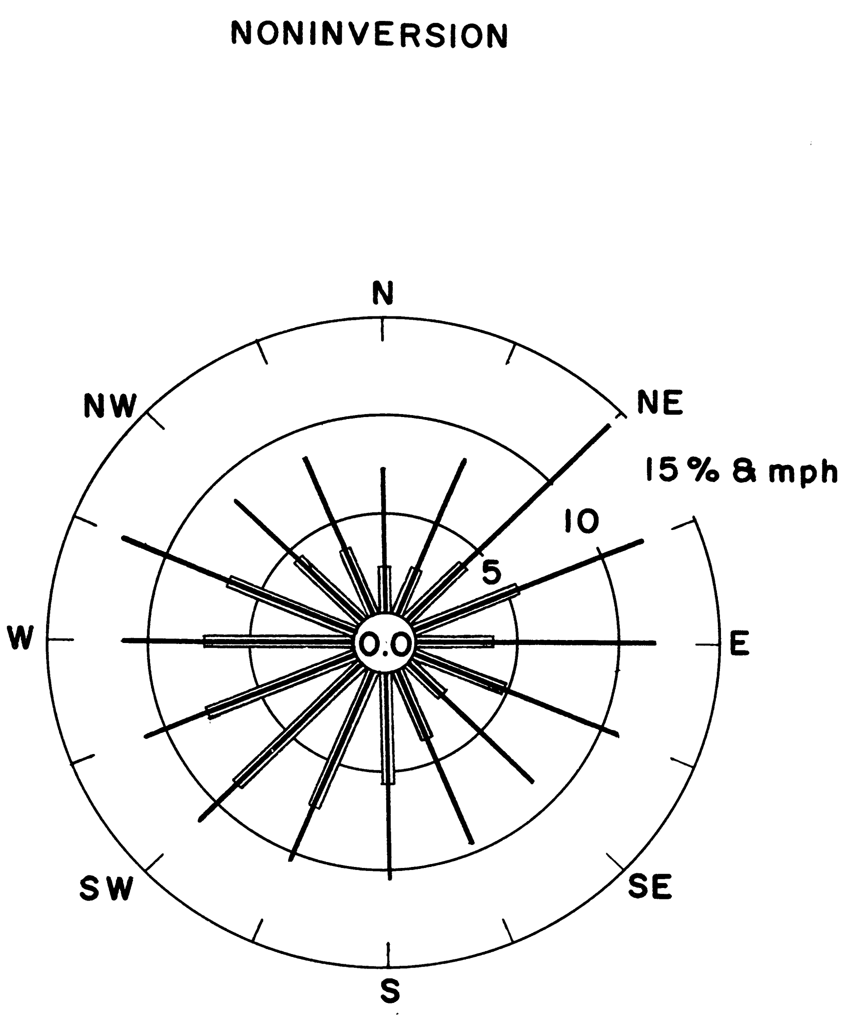
Fig. 7. Percentage frequency of inversions and noninversions associated with winds for 16 directions and corresponding wind speed in mph at the Enrico Fermi site: Spring, 1957.

TABLE X

MEAN WIND SPEEDS ASSOCIATED WITH INVERSIONS AND NONINVERSIONS AT THE ENRICO FERMI SITE

1 June 1957 - 31 August 1957
(Summer)

Wind Direction	Inversion		Noninversion	
	Occurrence, %	Mean Speed, mph	Occurrence, %	Mean Speed, mph
N	0.9	7.0	2.5	7.4
NNE	2.1	10.7	2.5	8.5
NE	1.7	13.7	4.0	14.0
ENE	0.5	8.4	5.4	12.0
E	0.4	2.3	3.8	11.6
ESE	0.7	12.5	4.8	10.9
SE	2.4	10.5	2.4	8.5
SSE	2.9	9.8	3.8	9.4
S	2.4	8.2	5.6	10.5
SSW	0.7	7.6	7.5	10.5
SW	0.7	5.4	8.6	11.2
WSW	0.7	6.9	7.8	11.1
W	0.9	6.7	7.2	11.3
WNW	1.2	6.1	6.7	12.3
NW	0.6	6.8	4.5	8.7
NNW	0.4	7.0	3.7	8.6
Calm	0.1	0.0	___	0.0
Totals	19.3		80.8	
Average		9.0		10.7



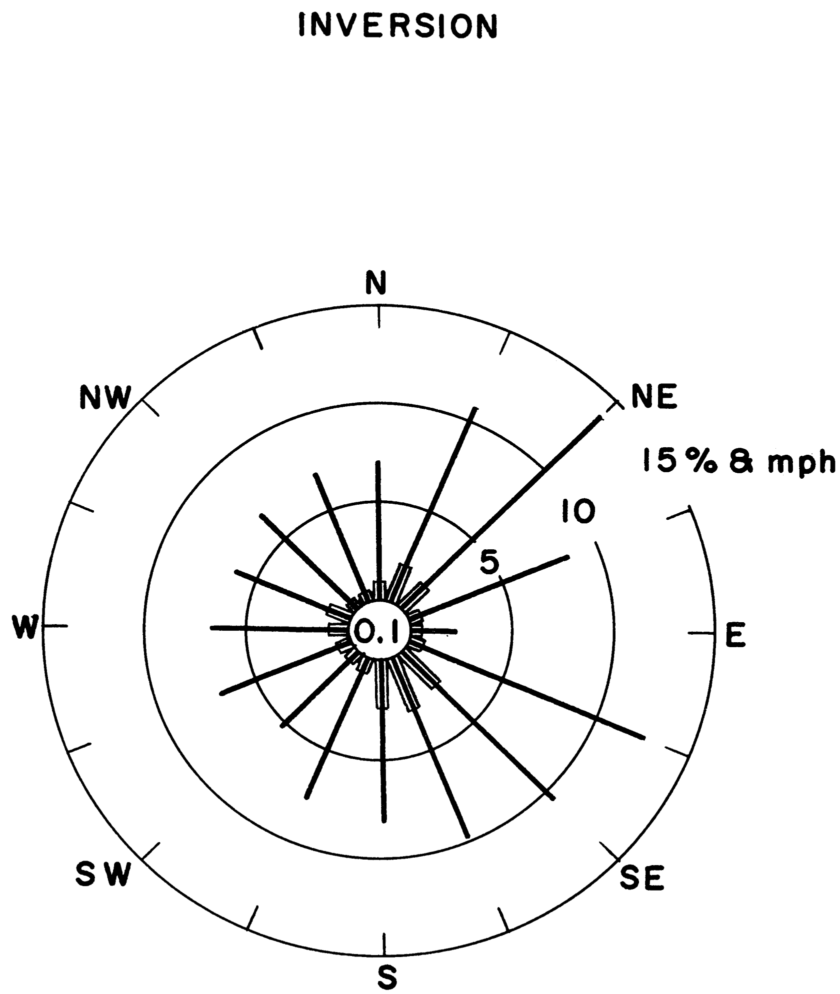


Fig. 8. Percentage frequency of inversions and noninversions associated with winds for 16 directions and corresponding wind speed in mph at the Enrico Fermi site: Summer, 1957.

TABLE XI

MEAN WIND SPEEDS ASSOCIATED WITH INVERSIONS AND NONINVERSIONS AT THE ENRICO FERMI SITE

1 September 1957 - 30 November 1957
(Fall)

Wind Direction	Inversion		Noninversion	
	Occurrence, %	Mean Speed, mph	Occurrence, %	Mean Speed, mph
N	0.5	8.4	6.0	10.0
NNE	0.9	8.9	2.1	9.4
NE	0.8	8.6	6.3	15.3
ENE	0.8	8.1	3.9	13.3
E	0.6	9.0	1.4	9.9
ESE	1.1	8.7	4.2	9.3
SE	0.8	17.8	2.4	9.9
SSE	1.6	13.6	4.5	10.5
S	0.8	9.6	4.9	10.9
SSW	1.7	11.7	8.6	12.3
SW	1.7	9.0	6.0	12.3
WSW	0.9	6.9	9.4	14.7
W	1.9	9.7	2.7	11.7
WNW	1.7	9.0	5.3	10.8
NW	0.6	7.3	6.4	10.9
NNW	1.1	7.7	8.2	11.1
Calm	0.0	0.0	0.4	0.0
Totals	17.5		82.7	
Average		10.3		11.8

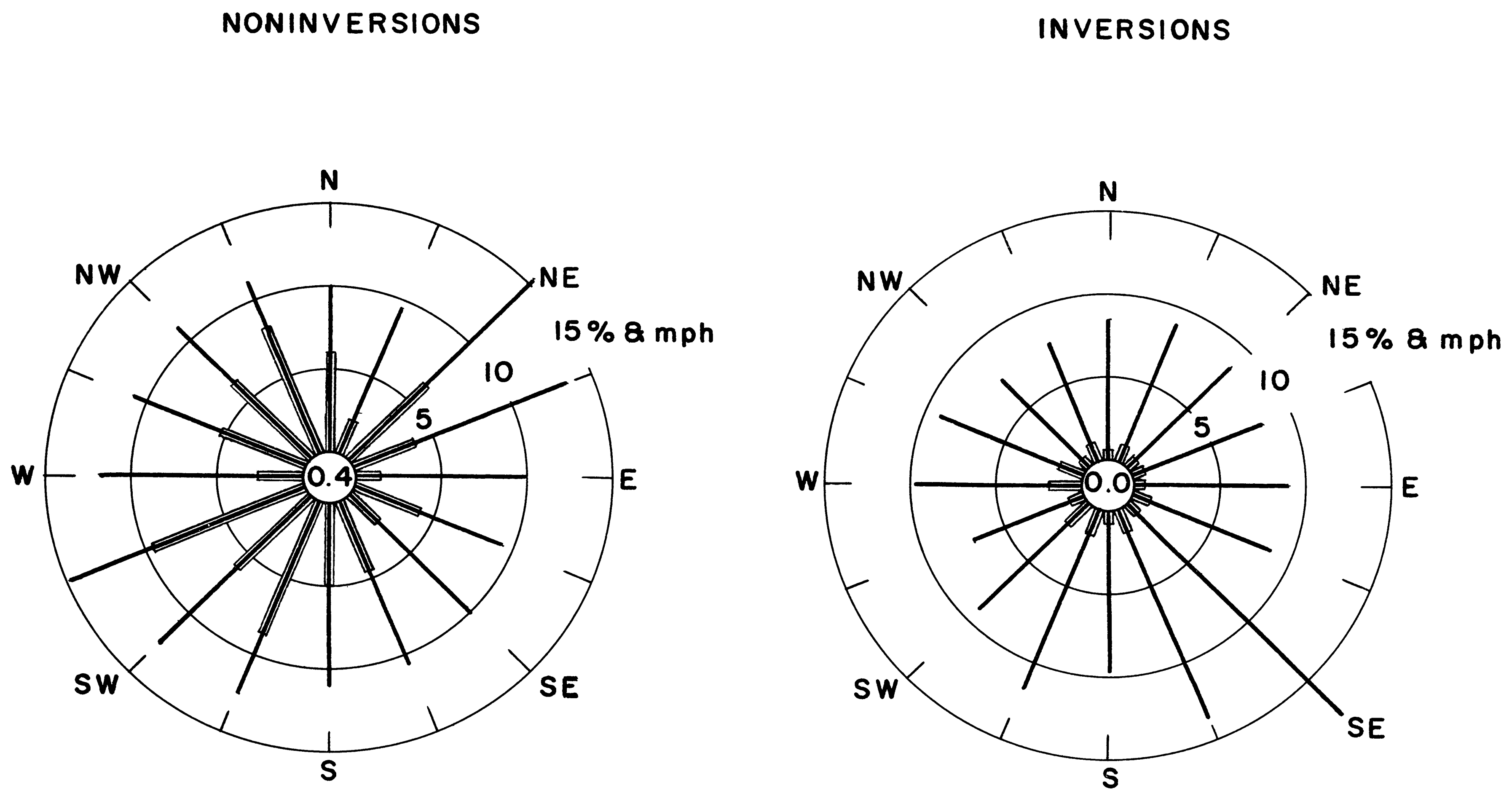


Fig. 9. Percentage frequency of inversions and noninversions associated with winds for 16 directions and corresponding wind speed in mph at the Enrico Fermi site: Fall, 1957.

TABLE XII

MEAN WIND SPEEDS ASSOCIATED WITH INVERSIONS AND NONINVERSIONS AT THE ENRICO FERMI SITE

1 December 1956 - 30 November 1957
(Annual Summary)

Wind Direction	Inversion		Noninversion	
	Occurrence, %	Mean Speed, mph	Occurrence, %	Mean Speed, mph
N	0.6	6.8	3.3	11.6
NNE	1.1	9.1	3.7	13.3
NE	0.8	11.1	5.7	15.8
ENE	0.6	9.9	5.6	14.5
E	0.7	10.4	3.7	15.4
ESE	1.1	12.5	4.2	11.3
SE	1.9	12.4	2.3	10.8
SSE	2.1	11.7	2.8	9.6
S	1.8	10.1	3.7	11.0
SSW	2.0	12.0	6.2	12.9
SW	1.6	12.3	7.2	13.0
WSW	1.2	9.9	9.8	14.2
W	1.2	9.6	5.8	12.5
WNW	1.1	8.6	6.9	12.7
NW	0.7	6.8	5.3	11.4
NNW	0.6	7.7	4.3	11.0
Calm	0.1	0.0	0.2	0.0
Totals	19.2		80.7	
Average		10.5		12.8

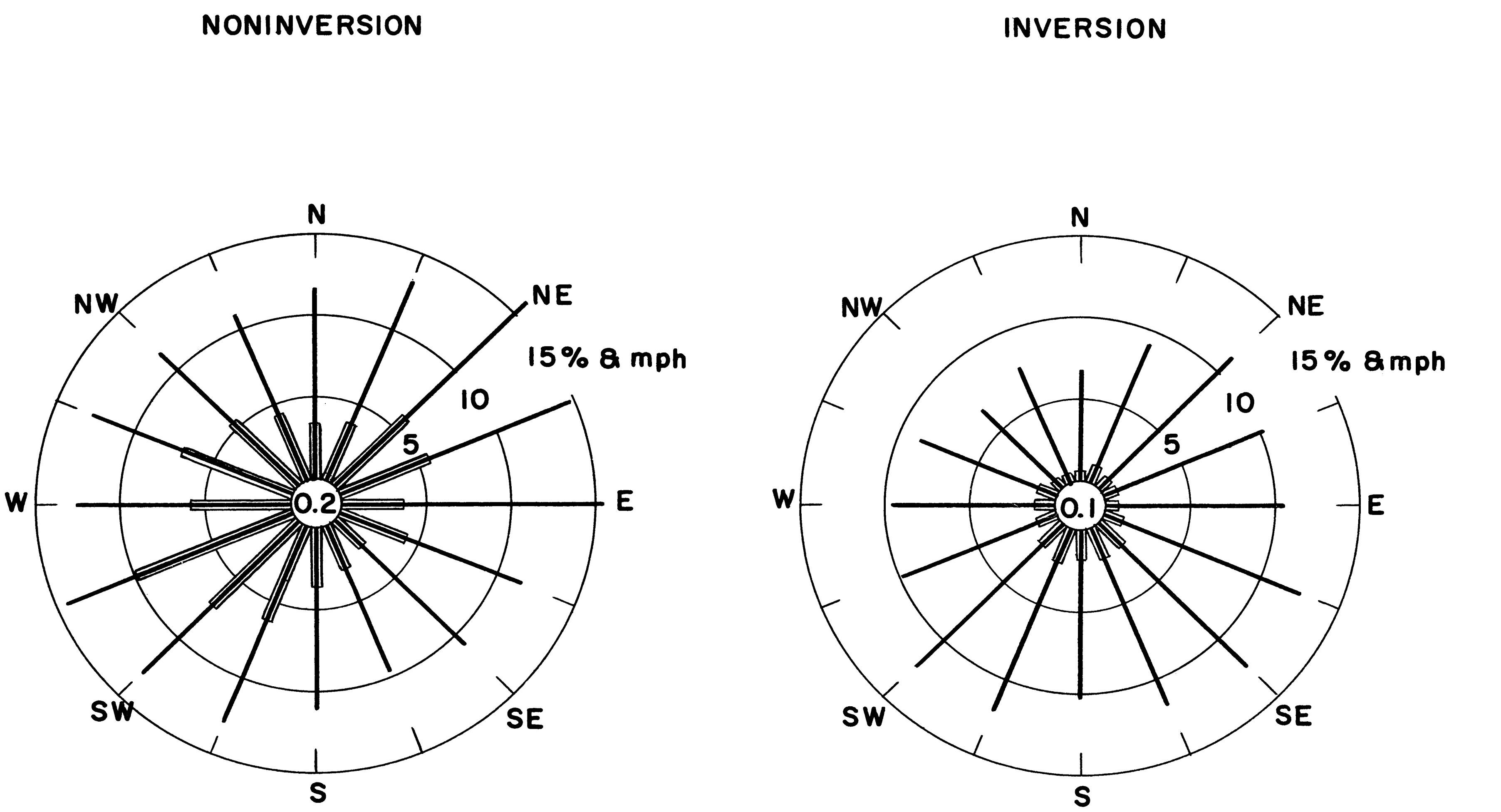


Fig. 10. Percentage frequency of inversions and noninversions associated with winds for 16 directions and corresponding wind speed in mph at the Enrico Fermi site: Annual Summary, 1956-1957

For each of the seasons, combining all wind directions, the average wind speed is less for the inversion than for the noninversion class. However, for winds from the ESE, SE, and SSE, the directions associated with the circulation type of inversion discussed in the previous section, wind speeds are actually somewhat higher for the inversion than for the noninversion class. Another relevant aspect is displayed quite strikingly in the inversion windrose of Figs. 6-10, where it can be noticed that winds from the sector WNW clockwise through NNE are quite light compared to the diametrically opposed sector ESE through S. The contrast in wind speeds noted here is magnified by the fact that winds from the WNW through N are over the land with its relatively high frictional effects, whereas winds from the ESE through S cross the lake where frictional effects are small. This does not account for the fact that winds from the ESE, SE, and SSE are stronger during inversions than noninversions. One possible explanation for this may be that the pressure gradient is usually stronger during the warm outbreaks of air which feature circulation inversions than it is with other winds from the same direction. Another curious feature of the data is that, given calm conditions, inversions are less frequent than noninversions.

6. THE ASSOCIATION OF LAPSE RATES WITH WIND DIRECTION

Because winds from different directions occur with varying frequencies, a simple table displaying the number of hours of inversion for each wind direction fails to show the association of lapse rate with wind direction. What is needed is a summary of the data which indicates, for any given wind direction, the relative frequency of inversion conditions and strong lapse-rate conditions. For example, if there were 200 occurrences of SW winds during a season, and if there were an inversion on 20 of those occurrences, one would compute the relative frequency of inversions to be 10% for SW winds. If during the same season there were 30 occurrences of SE winds, and if there were an inversion on 20 of those occurrences, one would compute the relative frequency of inversions to be 67% for SE winds. A reasonable conclusion would be that there was a marked association or correlation between SE winds and inversions and little correlation between SW winds and inversions. The data for the first year have been analyzed in this way on a seasonal basis and on an annual basis so that the association of lapse rate with wind direction is clearly revealed. The last 3 columns of Tables XIII-XVII give frequencies for the three lapse-rate categories, strong, weak, and inversion. These would be referred to by the statistician as conditional frequencies, i.e., the frequency conditional on the wind being from the given direction. Figure 11 displays the association of inversions with wind direction by plotting from Tables XIII-XVII the frequency of inversions as ordinate against wind direction as abscissa.

Interpretation of the data is aided by referring to the mean lake temperatures and normal Toledo temperatures in Table VII, which show that the lake is cold in comparison to air temperatures during the spring and early summer and warm in comparison to air temperatures during the fall and winter. Recall also that, as pointed out in the discussion of circulation-type inversions, positive temperature departures large enough to cause inversions in S to SE winds are un-

TABLE XIII

THE ASSOCIATION OF TEMPERATURE LAPSE RATES WITH WIND DIRECTION AT THE ENRICO FERMI SITE

1 December 1956 - 28 February 1957
(Winter)

Wind Direction	Hourly Lapse Rates			Compass Totals	Frequency of Lapse Rates as a Percent of Compass Totals for a Given Wind Direction		
	S	W	I		S	W	I
N	44	1	13	58	75.9	1.7	22.4
NNE	36	17	12	65	55.4	26.2	18.5
NE	73	19	9	101	72.3	18.8	8.9
ENE	22	19	15	56	39.3	33.9	26.8
E	14	17	18	49	28.6	34.7	36.7
ESE	24	21	19	64	37.5	32.8	29.7
SE	23	7	33	63	36.5	11.1	52.4
SSE	14	7	20	41	34.1	17.1	48.8
S	23	32	19	74	31.1	43.2	25.7
SSW	65	56	53	174	37.4	32.2	30.5
SW	55	91	50	196	28.1	46.4	25.5
WSW	111	123	39	273	40.7	45.1	14.3
W	72	58	27	157	45.9	36.9	17.2
WNW	85	45	16	146	58.2	30.8	11.0
NW	84	28	22	134	62.7	20.9	16.4
NNW	64	20	9	93	68.8	21.5	9.7
Calm	4	6	2	12	33.3	50.0	16.7
Totals	813	567	376	1756			

Code:

S = A lapse rate in excess of the dry adiabatic lapse rate.
W = A positive lapse rate that is less than the dry adiabatic lapse rate.
I = A temperature increase with height.

TABLE XIV

THE ASSOCIATION OF TEMPERATURE-LAPSE RATES WITH WIND DIRECTION AT THE ENRICO FERMI SITE

1 March 1957 - 31 May 1957
(Spring)

Wind Direction	Hourly Lapse Rates			Compass Totals	Frequency of Lapse Rates as a Percent of Compass Totals for a Given Wind Direction		
	S	W	I		S	W	I
N	52	5	7	64	81.3	7.8	10.9
NNE	128	5	15	148	86.5	3.4	10.1
NE	141	5	11	157	89.8	3.2	7.0
ENE	196	8	9	213	92.8	3.8	4.2
E	136	9	17	162	84.0	5.6	10.5
ESE	101	11	32	144	70.1	7.6	22.2
SE	46	10	43	99	46.5	10.1	43.4
SSE	40	11	61	112	35.7	9.8	54.5
S	24	18	56	98	24.5	18.4	57.1
SSW	52	14	47	113	46.0	12.3	42.6
SW	95	37	26	158	60.1	23.4	16.5
WSW	156	24	22	202	77.2	11.9	10.9
W	101	22	13	136	74.3	16.2	9.6
WNW	156	13	18	187	83.4	7.0	9.6
NW	75	12	6	93	80.6	12.9	6.5
NNW	26	11	12	49	53.1	22.4	24.5
Calm	0	1	2	3	0.0	33.3	66.7
Totals	1525	216	397	2138			

Code:
S = A lapse rate in excess of the dry adiabatic lapse rate.
W = A positive lapse rate that is less than the dry adiabatic lapse rate.
I = A temperature increase with height.

TABLE XV

THE ASSOCIATION OF TEMPERATURE-LAPSE RATES WITH WIND DIRECTION AT THE ENRICO FERMI SITE

1 June 1957 - 31 August 1957
(Summer)

Wind Direction	Hourly Lapse Rates			Compass Totals	Frequency of Lapse Rates as a Percent of Compass Totals for a Given Wind Direction		
	S	W	I		S	W	I
N	31	7	13	51	60.8	13.7	25.5
NNE	34	5	32	71	47.9	7.0	45.1
NE	58	1	25	84	69.0	1.2	29.8
ENE	78	2	8	88	88.6	2.3	9.1
E	51	5	6	62	82.2	8.1	9.7
ESE	50	21	10	81	61.7	25.9	12.4
SE	22	14	37	73	30.2	19.2	50.6
SSE	35	21	42	98	35.7	21.4	42.9
S	56	28	36	120	46.7	23.3	30.0
SSW	91	22	11	124	73.4	17.7	8.9
SW	102	25	11	138	73.9	18.1	8.0
WSW	108	6	10	124	87.1	4.8	8.1
W	100	9	14	123	81.3	7.3	11.4
WNW	96	4	18	118	81.3	3.4	15.3
NW	62	5	9	76	81.6	6.6	11.8
NNW	54	1	6	61	88.5	1.6	9.9
Calm	0	0	1	1	0.0	0.0	100.0
Totals	1028	176	289	1493			

Code:

S = A lapse rate in excess of the dry adiabatic lapse rate.
W = A positive lapse rate that is less than the dry adiabatic lapse rate.
I = A temperature increase with height.

TABLE XVI

THE ASSOCIATION OF TEMPERATURE-LAPSE RATES WITH WIND DIRECTION AT THE ENRICO FERMI SITE

1 September 1957 - 30 November 1957
(Fall)

Wind Direction	Hourly Lapse Rates			Compass Totals	Frequency of Lapse Rates as a Percent of Compass Totals for a Given Wind Direction		
	S	W	I		S	W	I
N	82	8	7	97	84.5	8.3	7.2
NNE	30	2	14	46	65.3	4.4	30.3
NE	94	1	12	107	87.9	0.9	11.2
ENE	54	4	12	70	77.1	5.7	17.2
E	19	2	9	30	63.3	6.7	30.0
ESE	59	4	16	79	74.6	5.1	20.3
SE	33	3	12	48	68.7	6.3	25.0
SSE	56	11	24	91	61.5	12.1	26.4
S	68	6	12	86	79.0	7.0	14.0
SSW	118	12	25	155	76.2	7.7	16.1
SW	77	13	25	115	66.9	11.3	21.8
WSW	125	17	14	156	80.1	10.9	9.0
W	37	3	28	68	54.4	4.4	41.2
WNW	74	5	25	104	71.2	4.8	24.0
NW	90	6	9	105	85.7	5.7	8.6
NNW	122	1	17	140	87.2	0.7	12.1
Calm	6	0	0	6	100.0	0.0	0.0
Totals	1144	98	261	1503			

Code:
- S = A lapse rate in excess of the dry adiabatic lapse rate.
- W = A positive lapse rate that is less than the dry adiabatic lapse rate.
- I = A temperature increase with height.

TABLE XVII

THE ASSOCIATION OF TEMPERATURE-LAPSE RATES WITH WIND DIRECTION AT THE ENRICO FERMI SITE

1 December 1956 - 30 November 1957
(Annual Summary)

Wind Direction	Hourly Lapse Rates			Compass Totals	Frequency of Lapse Rates as a Percent of Compass Totals for a Given Wind Direction		
	S	W	I		S	W	I
N	209	21	40	270	77.4	7.8	14.8
NNE	228	29	73	330	69.1	8.8	22.1
NE	366	26	57	449	81.5	5.8	12.7
ENE	350	33	44	427	82.0	7.7	10.3
E	220	33	50	303	72.6	10.9	16.5
ESE	234	57	77	368	63.6	15.5	20.9
SE	124	34	125	283	43.8	12.0	44.2
SSE	145	50	147	342	42.4	14.6	43.0
S	171	84	123	378	45.2	22.2	32.5
SSW	326	104	136	566	57.6	18.4	24.0
SW	329	166	112	607	54.2	27.3	18.5
WSW	500	170	85	755	66.2	22.5	11.3
W	310	92	82	484	64.0	19.0	16.9
WNW	411	67	77	555	74.1	12.1	13.9
NW	311	51	46	408	76.2	12.5	11.3
NNW	266	33	44	343	77.6	9.6	12.8
Calm	10	7	5	22	45.5	31.8	22.7
Totals	4510	1057	1323	6890			

Code:
- S = A lapse rate in excess of the dry adiabatic lapse rate.
- W = A positive lapse rate that is less than the dry adiabatic lapse rate.
- I = A temperature increase with height.

likely to occur in the fall.

The following features are evident from Fig. 11 and the five associated tables. During the winter, inversions were relatively more frequent with SE and SSE winds than with any other wind direction. This effect is present, despite the relative warmth of the lake at this time, mainly because there were two prolonged inversions due to warm spells 25°F and 27°F above normal temperatures. During the spring the influence of the comparatively cold lake is very pronounced with a high relative frequency of inversions when winds are from the SE through SW. This effect is less pronounced in summer since only in June is the lake relatively cold, but the association of inversions with SE and SSE winds is still present. During the fall, scarcely any pattern emerges, presumably because the comparatively warm lake temperature does not promote the formation of inversions. The association of strong lapse rates with wind direction is essentially a complementary picture to that of inversions. Strong lapse rates occur least frequently with winds from the SE through S and most frequently with winds from the W through N to NE. However, as in the case of the association of inversions with wind direction, the pattern is not very evident during the fall.

7. SUMMARY

The inversion climatology of the Enrico Fermi site apparently differs from that of inland stations such as the WJBK-TV tower in a number of ways. The salient features of these differences are enumerated below.

a. Inversion conditions are more frequent at the WJBK-TV tower than at the Enrico Fermi site. Although this difference appears at all seasons, it is most noticeable in the fall when inversions are about twice as frequent at the TV tower as at the plant site.

b. Most of the inversions that occur at the TV tower are of the nocturnal type which is associated with light winds and poor diffusion conditions. On the other hand, three distinct types of inversions occur at the Enrico Fermi site, namely, nocturnal, circulation, and lake breeze. The latter two types of inversions which represent more than half of all the inversions are associated with wind speeds greater than or equal to 10 mph, i.e., they do not necessarily imply the poorest type of diffusion conditions.

c. Circulation inversions at the plant site may persist for over two days or as long as extremely warm air crosses Lake Erie from the south. Circulation inversions are most probable in the months of April, May, and June, and least probable in the fall.

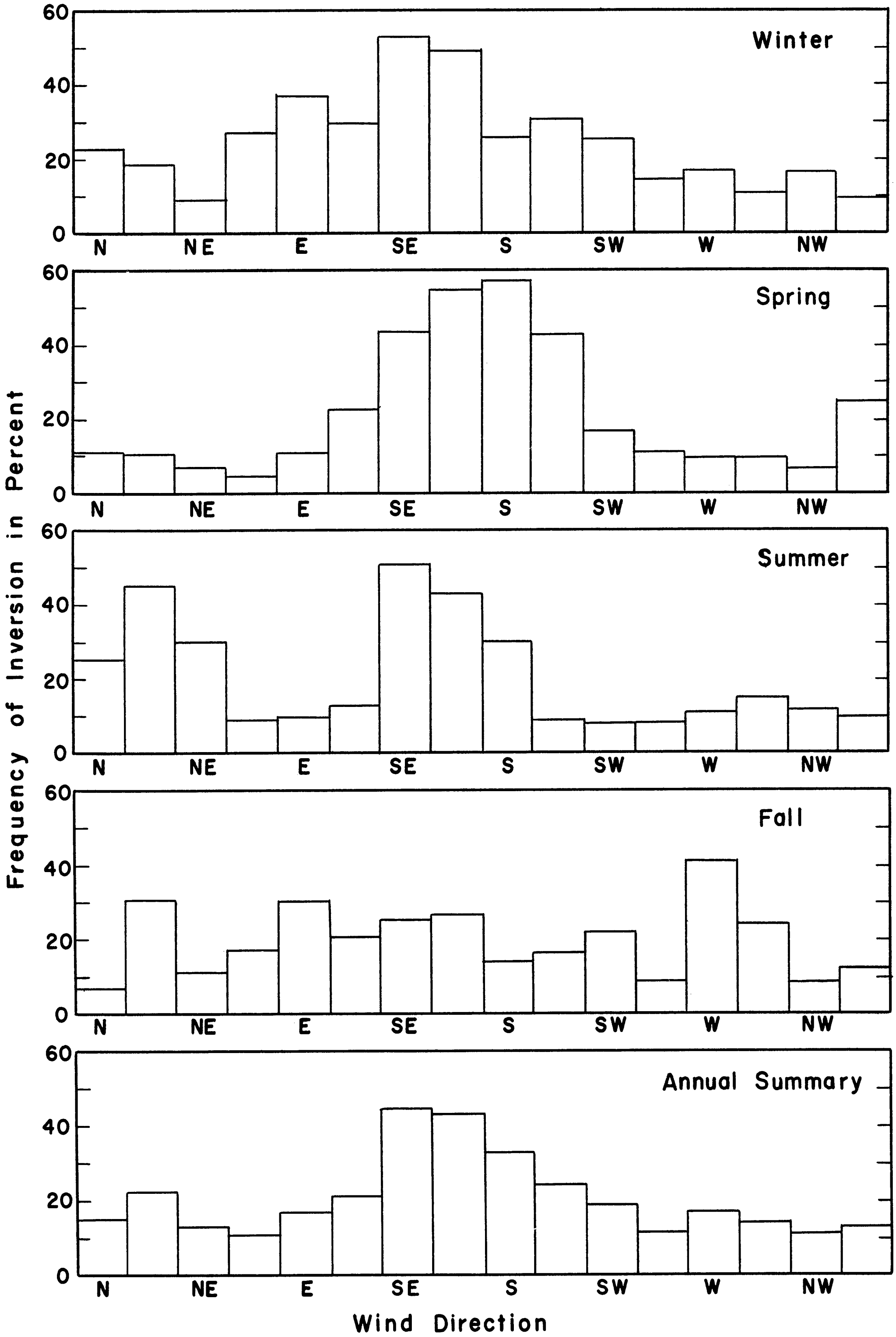


Fig. 11. Frequency of inversions associated with wind direction for the Enrico Fermi site for all seasons and annual summary, 1956-1957.

II. ANALYSIS OF WIND DATA

1. INTRODUCTION

The second progress report included a discussion of the winds observed at the Enrico Fermi site during the winter and spring of 1956-57. The present report extends this analysis through the summer and fall of 1957 with some remarks about annual wind statistics and some inter-seasonal comparisons. The wind records for the plant site are compared with current observations at Toledo and Detroit, and to a 5-year record at Toledo Municipal Airport.

In earlier progress reports reference has been made to the unfortunate bias which persists in the wind records for Detroit City Airport. This bias takes the form of an apparently greater frequency of the winds from the 8 cardinal compass points than from the intermediate points. Although a bias of this type does not generally appear in the record at Toledo,* it is all too common in wind observations across the country. In the course of other research at the Meteorological Laboratory, a method has been developed for taking a biased wind record, such as that at Detroit, and converting it into a good approximation of what the unbiased record should be. This method is described in detail in Appendix A. By means of this method, the reported wind occurrences at Detroit City Airport which appear in Tables XX, XXV, XXX, XXXV, and XL for the period 1 December 1956 to 30 November 1957 have been converted into an unbiased record. The unbiased record is presented in Tables XXI, XXVI, XXXI, XXXVI, and XLI. Although the evidence of bias was not great for the winter season, it was very strong for the other three seasons and for the annual summary. <u>In the discussion which follows, the Detroit City Airport wind-direction frequencies referred to will be the computed unbiased record of Tables XXI, XXVI, XXXI, XXXVI, and XLI.</u>

2. WIND DIRECTIONS AT THE ENRICO FERMI SITE

The discussion of wind-direction statistics will be carried on in relation to the population centers of interest in the manner of earlier progress reports. For convenience in interpretation, a topographic map of the site and surroundings is reproduced in Fig. 12. The actual records of winds at the Enrico Fermi site, Toledo Express Airport, Detroit City Airport, and the 5-year reference record at Toledo Municipal Airport followed by a windrose presentation of the same data appear on successive pages grouped according to seasons. These are Tables XVIII - XLII, and Figs. 13-17. Although the records for winter and spring are repeated in this report to provide a complete record for a year, the

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*The Toledo record for the fall of 1957 appears to be biased.

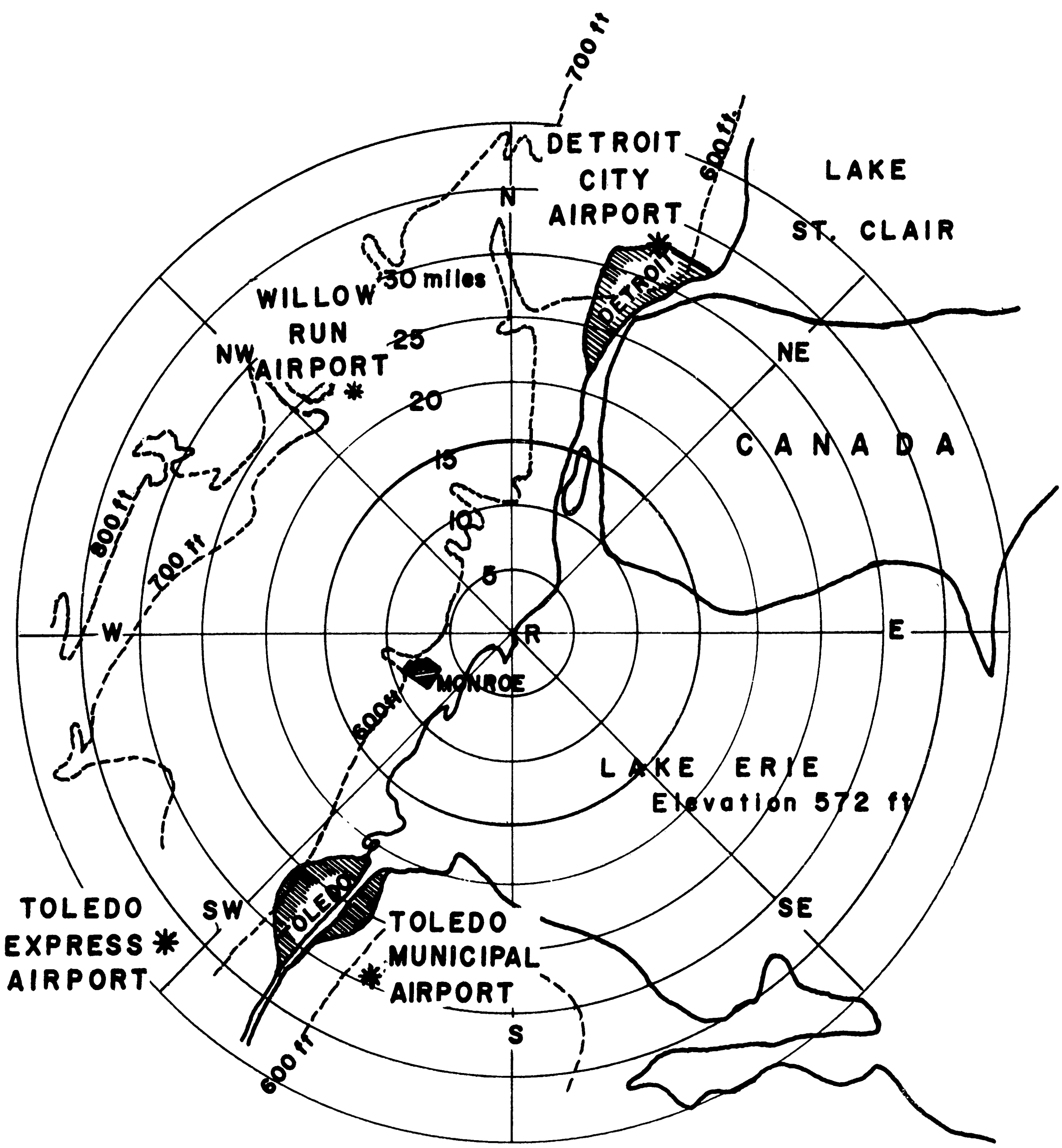


Fig. 12. Topographic map of site and surroundings.

TABLE XVIII

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS GROUPED ACCORDING TO WIND SPEEDS

Enrico Fermi Site
(Aerovane at height of 102 ft)
1 December 1956 - 28 February 1957
(Winter)

Wind Direction	Speed, mph					Total Observations		Mean Speed	
	0-3	4-12	13-24	25 and Over	Total 4 and Over	%	No.	mph	% of Over-all Mean
N	0.1	1.7	1.2	0.6	3.5	3.6	78	14.5	111
NNE	0.2	1.2	1.7	0.5	3.4	3.6	76	15.4	118
NE	0.3	1.0	3.9	0.5	5.4	5.6	120	16.8	128
ENE	0.2	1.3	1.2		2.5	2.7	60	12.2	93
E	0.3	1.0	1.2		2.2	2.5	54	12.0	92
ESE	0.1	1.9	1.0		2.9	3.0	64	11.5	88
SE	0.3	1.6	1.0		2.6	2.9	63	10.8	82
SSE	0.1	1.1	0.9		2.0	2.1	46	12.1	92
S	0.2	1.8	2.1	0.1	4.0	4.2	89	13.2	101
SSW	0.2	2.7	5.7	0.3	8.7	8.9	193	15.3	117
SW	0.3	3.7	7.0	0.1	10.8	11.1	240	12.9	98
WSW	0.2	7.5	6.9		14.4	14.6	315	14.6	111
W	0.5	5.4	4.3	0.1	9.8	10.3	223	12.4	95
WNW	0.5	5.1	4.1	0.1	9.3	9.8	213	12.3	94
NW	0.7	5.1	2.6	0.1	7.8	8.5	183	10.9	83
NNW	0.1	3.6	2.4		6.0	6.1	131	12.0	93
Calm	0.6	—	—	—	—	0.6	12	0.0	—
Totals	4.8	45.7	47.2	2.4	95.3	100.1	2160		
Mean								13.1	100

TABLE XIX

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS GROUPED ACCORDING TO WIND SPEEDS

Toledo Express Airport
(Wind instruments at height of 72 ft)
1 December 1956 - 28 February 1957
(Winter)

Wind Direction	Speed, mph					Total Observations		Mean Speed	
	0-3	4-12	13-24	25 and Over	Total 4 and Over	%	No.	mph	% of Over-all Mean
N	0.3	3.1	2.0		5.2	5.5	118	10.8	104
NNE	0.1	2.1	1.4		3.6	3.7	80	11.0	106
NE	0.2	2.6	1.1		3.7	3.9	85	10.0	96
ENE	0.4	2.0	0.7		2.7	3.1	68	9.0	86
E	0.4	2.4	0.8		3.2	3.6	77	9.1	87
ESE	0.5	2.1	0.3		2.4	2.8	61	7.5	58
SE	0.4	1.9			1.9	2.3	50	6.0	58
SSE	0.6	2.5	0.2		2.7	3.3	71	7.4	71
S	0.4	4.3	1.9		6.2	6.6	142	10.0	96
SSW	0.3	2.9	3.5	0.2	6.6	6.9	148	12.6	121
SW	0.2	5.5	6.1	0.1	11.8	11.9	258	12.9	124
WSW	0.2	8.8	7.4	0.1	16.3	16.5	357	11.9	114
W	0.1	5.3	2.7		8.0	8.1	175	10.8	104
WNW		4.4	2.0		6.5	6.5	141	10.4	100
NW	0.3	4.8	1.7		6.5	6.9	148	9.9	95
NNW	0.5	3.8	1.4		5.2	5.7	123	9.5	91
Calm	2.7	—	—	—	—	2.7	58	0.0	—
Totals	7.6	58.5	33.2	0.4	92.5	100.0	2160		
Mean								10.4	100

TABLE XX

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS GROUPED ACCORDING TO WIND SPEEDS

Detroit City Airport
(Wind instruments at height of 81 ft)
1 December 1956 - 28 February 1957
(Winter)

Wind Direction	Speed, mph					Total Observations		Mean Speed	
	0-3	4-12	13-24	25 and Over	Total 4 and Over	%	No.	mph	% of Over-all Mean
N	0.7	6.7	3.8		10.5	11.2	243	10.4	94
NNE	0.3	2.5	1.2		3.8	4.1	88	10.2	92
NE	0.6	1.3	0.4		1.7	2.3	49	7.7	69
ENE	0.1	2.7	0.4		3.1	3.2	69	8.9	80
E	0.7	3.3	0.3		3.6	4.3	93	7.0	63
ESE	0.3	1.4	0.0		1.4	1.7	37	6.9	62
SE	0.1	2.4	0.1		2.5	2.7	58	6.6	59
SSE	0.1	3.5	0.3		3.8	3.9	85	8.0	72
S	0.5	5.1	2.1		7.3	7.8	168	10.1	91
SSW	0.0	2.0	2.8		4.9	4.9	105	12.6	113
SW	0.1	4.7	6.9	0.2	11.8	11.9	257	13.3	120
WSW	0.0	3.3	3.7		7.0	7.0	151	12.5	113
W	0.1	5.8	5.8	0.3	11.6	11.7	253	12.1	109
WNW	0.2	2.5	5.8	0.1	8.7	8.8	191	14.0	126
NW	0.5	4.4	3.6		8.1	8.6	186	11.6	104
NNW	0.2	2.2	2.8		5.0	5.2	112	12.6	113
Calm	0.7	___	___	___	___	0.7	15	0.0	___
Totals	5.2	53.9	40.0	0.6	94.8	100.0	2160		
Mean								11.1	100

TABLE XXI

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS, BIASED AND UNBIASED

Detroit City Airport
1 December 1956 - 28 February 1957
(Winter)

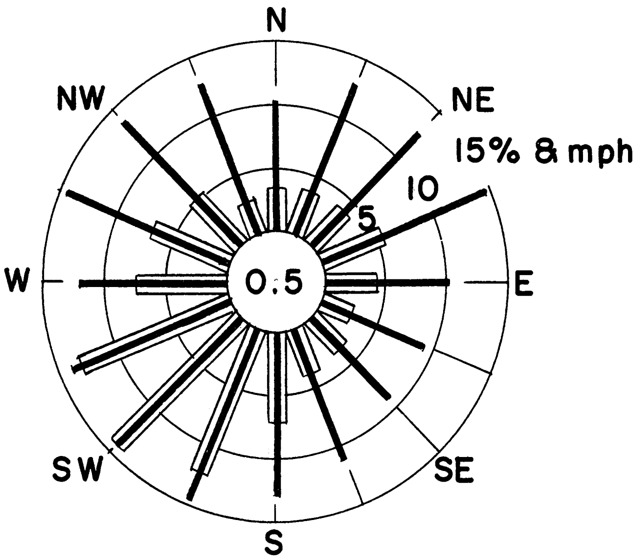
Wind Direction	Total Observations			
	Biased Record		Unbiased Record	
	No.	%	No.	%
N	243	11.2	190	8.8
NNE	88	4.1	108	5.0
NE	49	2.3	44	2.0
ENE	69	3.2	71	3.3
E	93	4.3	81	3.8
ESE	37	1.7	42	1.9
SE	58	2.7	47	2.2
SSE	85	3.9	94	4.4
S	168	7.8	136	6.3
SSW	105	4.9	156	7.2
SW	257	11.9	199	9.2
WSW	151	7.0	214	9.9
W	253	11.7	219	10.1
WNW	191	8.8	222	10.3
NW	186	8.6	158	7.3
NNW	112	5.2	164	7.6
Calm	15	0.7	15	0.7
Totals	2160	100.0	2160	100.0

TABLE XXII

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS GROUPED ACCORDING TO WIND SPEEDS

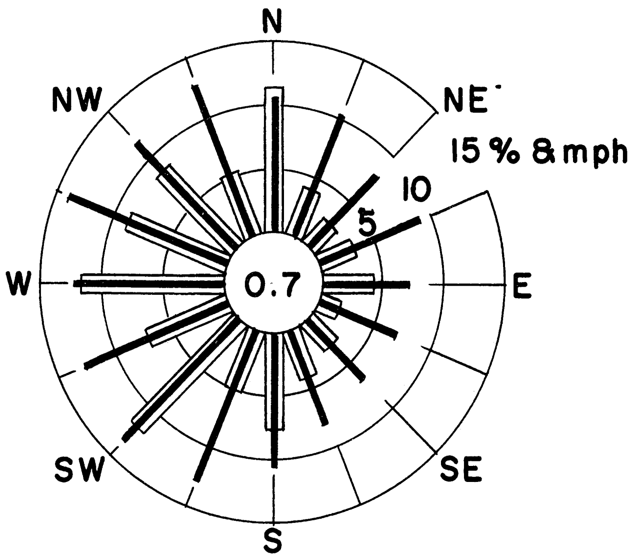
Toledo Municipal Airport
(Wind instruments at height of 47 ft)
1 January 1950 - 31 December 1954
(Winter Seasons)

Wind Direction	Speed, mph					Total Observations		Mean Speed	
	0-3	4-12	13-24	25 and Over	Total 4 and Over	%	No.	mph	% of Over-all Mean
N	0.3	2.3	1.0		3.4	3.6	395	10.1	78
NNE	0.1	1.8	1.6	0.1	3.4	3.6	385	12.4	96
NE	0.2	1.9	1.8	0.1	3.8	4.0	432	12.3	95
ENE	0.2	2.1	2.8	0.4	5.3	5.5	591	14.3	111
E	0.3	2.6	1.4		4.0	4.3	467	10.1	78
ESE	0.2	2.0	0.6		2.5	2.8	301	9.1	71
SE	0.3	2.3	0.7		3.0	3.3	352	8.9	69
SSE	0.2	2.2	1.3		3.6	3.8	411	11.1	86
S	0.4	3.2	3.4	0.2	6.8	7.2	777	12.9	100
SSW	0.2	4.8	6.5	0.8	12.1	12.3	1330	14.5	112
SW	0.3	5.7	7.1	1.0	13.8	14.1	1524	14.1	109
WSW	0.3	5.4	6.6	1.0	12.9	13.2	1429	14.0	109
W	0.3	3.6	2.9	0.2	6.8	7.2	774	12.1	94
WNW	0.1	2.6	3.5	0.5	6.7	6.8	732	14.3	111
NW	0.2	2.1	2.7	0.2	5.0	5.3	570	13.5	105
NNW	0.1	1.2	2.2	0.1	2.6	2.7	295	12.5	97
Calm	0.5	___	___	___	___	0.5	59	0.0	___
Totals	3.9	45.8	45.1	4.7	95.6	100.0	10824		
Mean								12.9	100



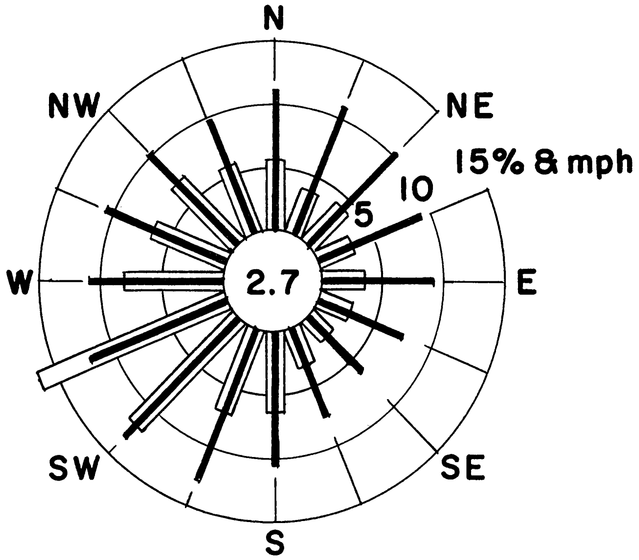
TOLEDO MUNICIPAL AIRPORT
TOLEDO, OHIO

Wind Instrument at Height of 47 ft.
Winter (Dec., Jan., Feb.) 1950-1954



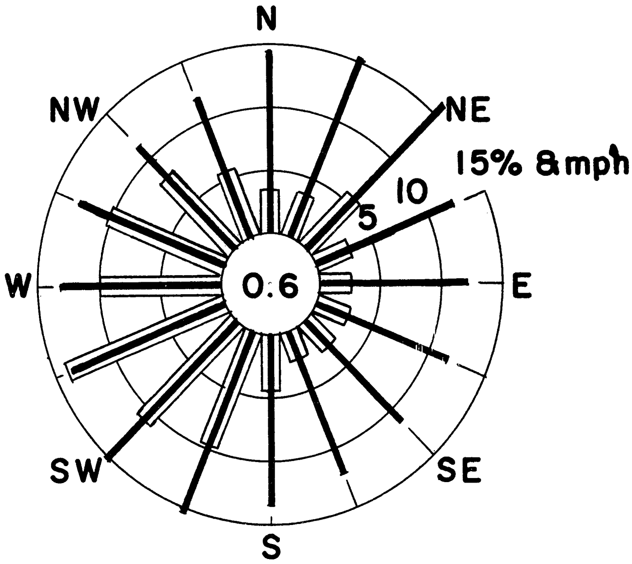
DETROIT CITY AIRPORT
DETROIT, MICHIGAN

Wind Instrument at Height of 81 ft.
Winter (Dec., Jan., Feb) 1957



TOLEDO EXPRESS AIRPORT
TOLEDO, OHIO

Wind Instrument at Height of 72 ft.
Winter (Dec., Jan., Feb.) 1957



ENRICO FERMI POWER PLANT SITE
LAGOONA BEACH, MICHIGAN

Aerovane at Height of 102 ft.
Winter (Dec., Jan., Feb.) 1957

Fig. 13. Percentage frequency of occurrence of winds from 16 directions and corresponding wind speed in mph at Toledo Municipal Airport, Winter Seasons, 1950-1954; Detroit City Airport, Toledo Express Airport, and Enrico Fermi site, Winter, 1956-1957.

TABLE XXIII

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS GROUPED ACCORDING TO WIND SPEEDS

Enrico Fermi Site
(Aerovane at height of 102 ft)
1 March 1957 - 31 May 1957
(Spring)

Wind Direction	Speed, mph					Total Observations		Mean Speed	
	0-3	4-12	13-24	25 and Over	Total 4 and Over	%	No.	mph	% of Over-all Mean
N	0.1	1.4	1.5		2.9	3.0	67	13.2	92
NNE	0.1	2.7	3.8	0.1	6.6	6.7	149	14.3	99
NE	0.1	2.1	4.8	0.3	7.2	7.3	161	15.6	108
ENE	0.1	2.6	6.2	1.0	9.8	9.9	220	16.6	115
E	0.2	2.0	3.7	1.5	7.2	7.4	162	18.6	129
ESE	0.1	2.8	3.5	0.1	6.4	6.5	144	13.9	97
SE	0.1	2.3	2.2	0.2	4.7	4.8	105	13.7	95
SSE	0.2	4.0	1.2	0.1	5.3	5.5	120	10.3	72
S	0.3	2.8	1.4		4.2	4.5	99	11.0	76
SSW	0.2	2.8	2.2	0.1	5.1	5.3	114	12.4	87
SW	0.1	2.6	4.5		7.1	7.2	159	14.5	101
WSW	0.3	3.0	4.9	1.5	9.4	9.7	214	16.3	113
W	0.1	3.7	2.5	0.5	6.7	6.8	151	13.4	93
WNW	0.1	3.1	5.6		8.7	8.8	193	14.6	101
NW	0.2	1.6	2.4	0.1	4.1	4.3	94	14.0	97
NNW	0.1	1.7	0.5		2.2	2.3	50	10.1	70
Calm	0.2	___	___	___	___	0.2	5	0.0	___
Totals	2.6	41.2	50.9	5.5	97.6	100.2	2207		
Mean								14.4	100

TABLE XXIV

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS GROUPED ACCORDING TO WIND SPEEDS

Toledo Express Airport
(Wind instruments at height of 72 ft)
1 March 1957 - 31 May 1957
(Spring)

Wind Direction	Speed, mph					Total Observations		Mean Speed	
	0-3	4-12	13-24	25 and Over	Total 4 and Over	%	No.	mph	% of Over-all Mean
N	0.1	3.4	1.5		4.8	4.9	109	9.9	82
NNE	0.2	3.3	2.3		5.6	5.8	129	11.2	92
NE	0.3	4.0	1.7		5.7	5.9	131	10.0	83
ENE	0.1	4.6	4.3	0.1	9.0	9.1	202	12.2	101
E	0.3	5.0	4.3	0.4	9.8	10.1	222	12.5	103
ESE	0.4	3.2	0.6		3.8	4.2	92	8.6	71
SE	0.2	1.6	0.4		1.9	2.1	47	9.0	74
SSE	0.1	2.6	1.6		4.3	4.4	97	11.5	95
S		3.8	2.2		6.0	6.0	133	10.9	90
SSW		2.2	2.0	0.1	4.3	4.3	94	12.9	107
SW		2.5	5.4	0.6	8.5	8.6	189	15.4	127
WSW	0.2	3.8	4.8	1.6	10.1	10.4	229	16.3	135
W	0.1	4.9	2.8	0.2	8.0	8.1	178	11.9	98
WNW	0.2	4.3	3.2		7.6	7.7	171	11.4	94
NW	0.2	2.7	1.9		4.6	4.8	106	11.0	91
NNW	0.2	1.9	1.0		2.9	3.1	69	9.7	80
Calm	0.5	___	___	___	___	0.5	10	0.0	___
Totals	3.1	53.8	40.0	3.0	96.9	100.0	2208		
Mean								12.1	100

TABLE XXV

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS GROUPED ACCORDING TO WIND SPEEDS

Detroit City Airport
(Wind instruments at height of 81 ft)
1 March 1957 - 31 May 1957
(Spring)

Wind Direction	Speed, mph					Total Observations		Mean Speed	
	0-3	4-12	13-24	25 and Over	Total 4 and Over	%	No.	mph	% of Over-all Mean
N	0.6	6.2	3.5		9.7	10.4	228	10.3	93
NNE	0.2	4.3	1.5		5.8	6.0	132	10.2	92
NE	0.8	3.3	1.9		5.2	6.0	133	9.6	86
ENE	0.2	4.6	2.0		6.6	6.8	151	10.2	92
E	0.5	7.7	1.8		9.6	10.2	224	9.5	86
ESE	0.2	2.9	0.9		3.8	4.0	88	9.9	89
SE	0.6	3.8	0.5		4.3	4.9	109	7.4	67
SSE	0.1	2.4	0.9		3.4	3.4	76	9.3	84
S	0.2	7.1	1.5		8.6	8.9	195	9.0	81
SSW		1.7	1.6		3.3	3.4	74	10.3	93
SW		1.4	3.8	1.0	6.2	6.2	137	15.0	135
WSW		1.3	2.7	0.3	4.3	4.3	96	15.6	141
W	0.4	3.8	4.0	0.4	8.3	8.6	192	13.0	117
WNW	0.1	2.1	4.7	0.3	7.1	7.2	158	14.8	133
NW	0.2	3.2	3.4		6.7	6.9	152	12.2	110
NNW		1.2	1.0		2.1	2.1	47	12.1	109
Calm	0.7	—	—	—	—	0.7	16	0.0	—
Totals	4.8	57.1	35.7	2.1	95.0	100.0	2208		
Mean								11.1	100

TABLE XXVI

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS, BIASED AND UNBIASED

Detroit City Airport
1 March 1957 - 31 May 1957
(Spring)

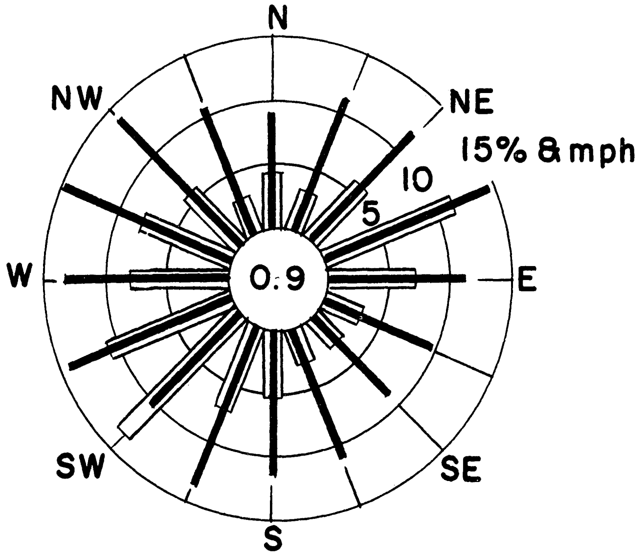
Wind Direction	Total Observations			
	Biased Record		Unbiased Record	
	No.	%	No.	%
N	228	10.4	170	7.7
NNE	132	6.0	180	8.2
NE	133	6.0	119	5.4
ENE	151	6.8	179	8.1
E	224	10.2	189	8.6
ESE	88	4.0	118	5.3
SE	109	4.9	83	3.8
SSE	76	3.4	111	5.0
S	195	8.9	144	6.5
SSW	74	3.4	115	5.2
SW	137	6.2	104	4.7
WSW	96	4.3	123	5.6
W	192	8.6	168	7.6
WNW	158	7.2	196	8.9
NW	152	6.9	121	5.5
NNW	47	2.1	72	3.3
Calm	16	0.7	16	0.7
Totals	2208	100.0	2208	100.1

TABLE XXVII

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS GROUPED ACCORDING TO WIND SPEEDS

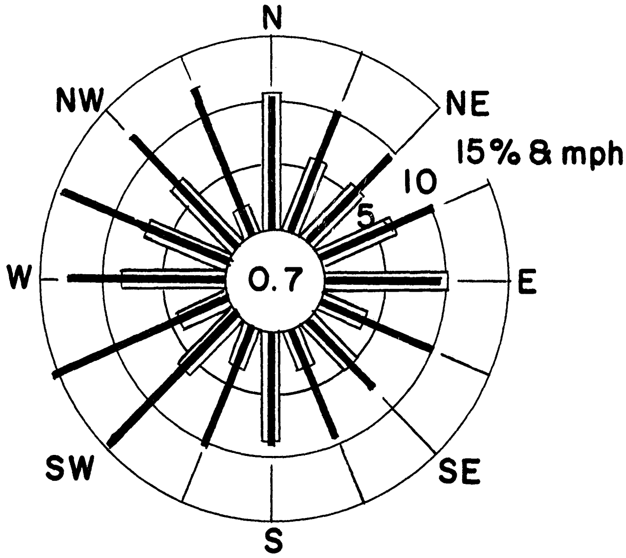
Toledo Municipal Airport
(Wind instruments at height of 47 ft)
1 January 1950 - 31 December 1954
(Spring Seasons)

Wind Direction	Speed, mph					Total Observations		Mean Speed	
	0-3	4-12	13-24	25 and Over	Total 4 and Over	%	No.	mph	% of Over-all Mean
N	0.3	2.9	1.0		3.9	4.2	468	9.1	72
NNE	0.1	1.9	1.2		3.1	3.2	351	11.1	87
NE	0.2	3.0	2.7		5.8	6.0	667	11.8	93
ENE	0.2	4.1	6.5	0.7	11.2	11.4	1258	14.6	115
E	0.4	3.8	3.0	0.1	6.9	7.3	811	11.4	90
ESE	0.2	2.2	0.7		3.0	3.2	350	9.4	74
SE	0.3	2.3	0.5		2.7	3.0	332	8.4	66
SSE	0.2	1.8	0.9	0.1	2.7	2.9	323	11.0	87
S	0.3	2.9	1.8	0.2	4.9	5.3	582	11.7	92
SSW	0.2	3.1	3.5	0.4	7.0	7.2	796	13.7	108
SW	0.4	4.8	4.4	0.7	9.8	10.2	1127	13.3	105
WSW	0.3	4.2	5.4	0.9	10.4	10.8	1189	14.3	113
W	0.2	3.6	3.7	0.4	7.7	8.0	881	13.4	106
WNW	0.3	2.4	4.7	0.4	7.6	7.8	865	14.9	117
NW	0.1	2.2	3.1	0.3	5.6	5.8	636	14.0	110
NNW	0.2	1.7	0.8	0.1	2.6	2.8	307	10.6	83
Calm	0.9	___	___	___	___	0.9	97	0.0	___
Totals	3.9	46.9	43.9	4.3	95.2	100.0	11040		
Mean								12.7	100



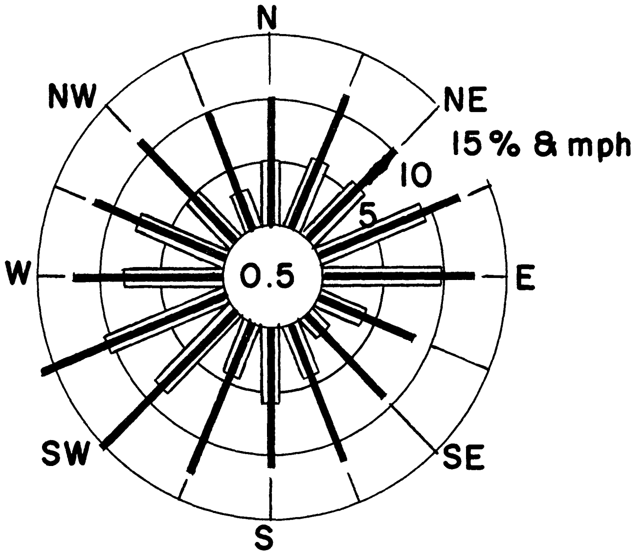
TOLEDO MUNICIPAL AIRPORT
TOLEDO, OHIO

Wind Instrument at Height of 47 ft.
Spring (Mar., Apr., May) 1950-1954



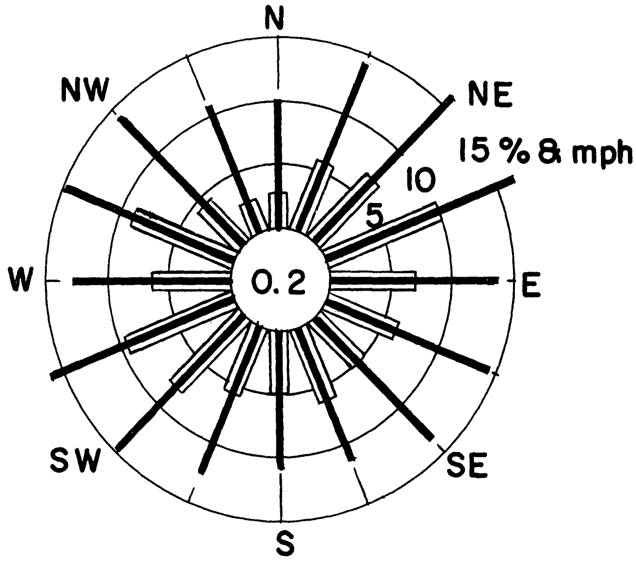
DETROIT CITY AIRPORT
DETROIT, MICHIGAN

Wind Instrument at Height of 81 ft.
Spring (Mar., Apr., May) 1957



TOLEDO EXPRESS AIRPORT
TOLEDO, OHIO

Wind Instrument at Height of 72 ft.
Spring (Mar., Apr., May) 1957



ENRICO FERMI POWER PLANT SITE
LAGOONA BEACH, MICHIGAN

Aerovane at Height of 102 ft.
Spring (Mar., Apr., May) 1957

Fig. 14. Percentage frequency of occurrence of winds from 16 directions and corresponding wind speed in mph at Toledo Municipal Airport, Spring Seasons, 1950-1954; Detroit City Airport, Toledo Express Airport, and Enrico Fermi site, Spring, 1957.

TABLE XXVIII

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS GROUPED ACCORDING TO WIND SPEEDS

Enrico Fermi Site
(Aerovane at height of 102 ft)
1 June 1957 - 31 August 1957
(Summer)

Wind Direction	Speed, mph					Total Observations		Mean Speed	
	0-3	4-12	13-24	25 and Over	Total 4 and Over	%	No.	mph	% of Over-all Mean
N	0.3	4.0	0.3		4.3	4.6	101	8.2	79
NNE	0.6	3.1	1.1		4.2	4.8	106	9.6	92
NE	0.1	1.8	2.8		4.6	4.7	105	14.0	135
ENE	0.2	3.2	3.4		6.6	6.8	150	13.0	125
E	0.5	3.6	1.7		5.3	5.8	129	10.5	101
ESE	0.5	2.9	2.0		4.9	5.4	120	11.4	110
SE	0.3	3.5	1.4		4.9	5.2	114	10.5	101
SSE	0.1	6.7	1.2		7.9	8.0	177	9.4	90
S	0.2	5.6	1.4		7.0	7.2	159	9.8	94
SSW	0.3	4.9	1.7		6.6	6.9	152	10.3	99
SW	0.4	5.2	2.0		7.2	7.6	167	10.4	100
WSW	0.3	5.1	1.9		7.0	7.3	163	10.5	101
W	0.5	5.4	2.0	0.1	7.5	8.0	177	10.4	100
WNW	0.3	5.1	1.6	0.2	6.9	7.2	159	10.7	103
NW	0.1	4.2	0.7		4.9	5.0	111	9.3	89
NNW	0.3	4.4	0.5		4.9	5.2	116	8.6	83
Calm	0.1	___	___	___	___	0.1	2	0.0	___
Totals	5.1	68.7	25.7	0.3	94.7	99.8	2208		
Mean								10.4	100

TABLE XXIX

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS GROUPED ACCORDING TO WIND SPEEDS

Toledo Express Airport
(Wind instruments at height of 72 ft)
1 June 1957 - 31 August 1957
(Summer)

Wind Direction	Speed, mph					Total Observations		Mean Speed	
	0-3	4-12	13-24	25 and Over	Total 4 and Over	%	No.	mph	% of Over-all Mean
N	0.6	5.8	1.2		7.0	7.6	167	9.1	94
NNE	0.6	4.7	0.8		5.5	6.1	136	8.7	90
NE	0.5	3.9	1.0		4.9	5.4	121	9.3	96
ENE	0.6	4.8	1.5		6.3	6.9	152	9.7	100
E	0.6	4.7	1.1		5.8	6.4	142	9.2	95
ESE	0.4	3.8	0.2		4.0	4.4	97	7.9	81
SE	0.5	2.4	0.1		2.5	3.0	67	7.1	73
SSE	0.2	2.3	0.2		2.5	2.7	61	8.3	86
S	0.3	4.9	1.1		6.0	6.3	140	9.6	99
SSW	0.4	4.2	2.0		6.2	6.6	145	10.8	111
SW	0.3	5.7	3.1	0.1	8.9	9.2	203	11.5	119
WSW	0.6	6.6	3.8	0.1	10.5	11.1	246	11.5	119
W	0.2	4.2	2.4		6.6	6.8	150	11.4	118
WNW	0.4	5.1	1.8		6.9	7.3	161	10.3	106
NW	0.7	2.7	0.6		3.3	4.0	90	8.5	88
NNW	0.4	3.7	0.5		4.2	4.6	102	8.7	90
Calm	1.3	—	—	—	—	1.3	28	0.0	—
Totals	8.6	69.5	21.4	0.2	91.1	99.7	2208		
Mean								9.7	100

TABLE XXX

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS GROUPED ACCORDING TO WIND SPEEDS

Detroit City Airport
(Wind instruments at height of 81 ft)
1 June 1957 - 31 August 1957
(Summer)

Wind Direction	Speed, mph					Total Observations		Mean Speed	
	0-3	4-12	13-24	25 and Over	Total 4 and Over	%	No.	mph	% of Overall Mean
N	1.6	6.6	1.6		8.2	9.8	216	8.6	84
NNE	0.6	4.3	1.4		5.7	6.3	142	9.7	95
NE	1.0	3.3	0.7		4.0	5.0	109	8.3	81
ENE	0.2	3.5	1.3		4.8	5.0	110	10.5	103
E	0.8	5.5	1.1		6.6	7.4	164	8.8	86
ESE	0.1	3.7	0.5		4.2	4.3	94	9.2	90
SE	0.9	3.8	0.3		4.1	5.0	110	7.5	74
SSE	0.2	1.4	0.5		1.9	2.1	46	9.6	94
S	0.6	8.8	2.3		11.1	11.7	259	9.7	95
SSW		2.4	1.6		4.0	4.0	88	12.3	121
SW	0.5	3.6	2.6		6.2	6.7	149	11.6	114
WSW	0.1	1.7	2.2		3.9	4.0	86	13.8	135
W	0.6	4.7	4.2	0.2	9.1	9.7	212	12.4	122
WNW	0.1	2.8	2.2	0.7	5.7	5.8	126	14.6	143
NW	0.6	4.5	2.2		6.7	7.3	162	10.5	103
NNW	0.4	2.6	1.1		3.7	4.1	91	10.1	99
Calm	2.0	___	___	___	___	2.0	44	0.0	___
Totals	10.3	63.2	25.8	0.9	89.9	100.2	2208		
Mean								10.2	100

TABLE XXXI

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS, BIASED AND UNBIASED

Detroit City Airport
1 June 1957 - 31 August 1957
(Summer)

Wind Direction	Total Observations			
	Biased Record		Unbiased Record	
	No.	%	No.	%
N	216	9.8	181	8.2
NNE	142	6.3	166	7.5
NE	109	5.0	101	4.6
ENE	110	5.0	121	5.5
E	164	7.4	143	6.5
ESE	94	4.3	120	5.4
SE	110	5.0	81	3.7
SSE	46	2.1	86	3.9
S	259	11.7	174	7.9
SSW	88	4.0	169	7.7
SW	149	6.7	109	4.9
WSW	86	4.0	120	5.4
W	212	9.7	167	7.6
WNW	126	5.8	173	7.8
NW	162	7.3	128	5.8
NNW	91	4.1	125	5.7
Calm	44	2.0	44	2.0
Totals	2208	100.2	2208	100.1

TABLE XXXII

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS GROUPED ACCORDING TO WIND SPEEDS

Toledo Municipal Airport
(Wind instruments at height of 47 ft)
1 January 1950 - 31 December 1954
(Summer Seasons)

Wind Direction	Speed, mph					Total Observations		Mean Speed	
	0-3	4-12	13-24	25 and Over	Total 4 and Over	%	No.	mph	% of Overall Mean
N	0.7	3.3	0.6		3.9	4.6	509	7.[illegible]	91
NNE	0.3	2.4	0.8		3.2	3.5	391	9.1	106
NE	0.6	3.7	1.3		5.0	5.6	619	9.1	106
ENE	0.6	4.9	2.2		7.1	7.7	849	9.9	115
E	0.7	4.1	0.6		4.7	5.4	604	7.7	90
ESE	0.4	2.5	0.1		2.6	3.0	330	6.4	74
SE	0.7	3.3	0.1		3.4	4.1	456	6.0	70
SSE	0.6	2.9	0.3		3.2	3.8	416	6.7	78
S	0.7	5.2	0.7		5.9	6.6	727	7.6	88
SSW	0.7	6.6	2.4	0.1	9.1	9.8	1086	9.7	113
SW	1.1	9.0	3.1	0.1	12.2	13.3	1463	9.1	106
WSW	0.7	5.5	2.6	0.1	8.2	8.9	973	9.7	113
W	0.8	4.1	1.4		5.5	6.3	705	8.8	102
WNW	0.5	3.8	2.1		5.9	6.4	721	10.5	122
NW	0.7	2.9	1.3		4.2	4.9	545	9.3	108
NNW	0.5	2.2	0.8		3.0	3.5	394	8.8	102
Calm	2.3	___	___	___	___	2.3	252	0.0	___
Totals	12.6	66.4	20.4	0.3	87.1	99.7	11040		
Mean								8.6	100

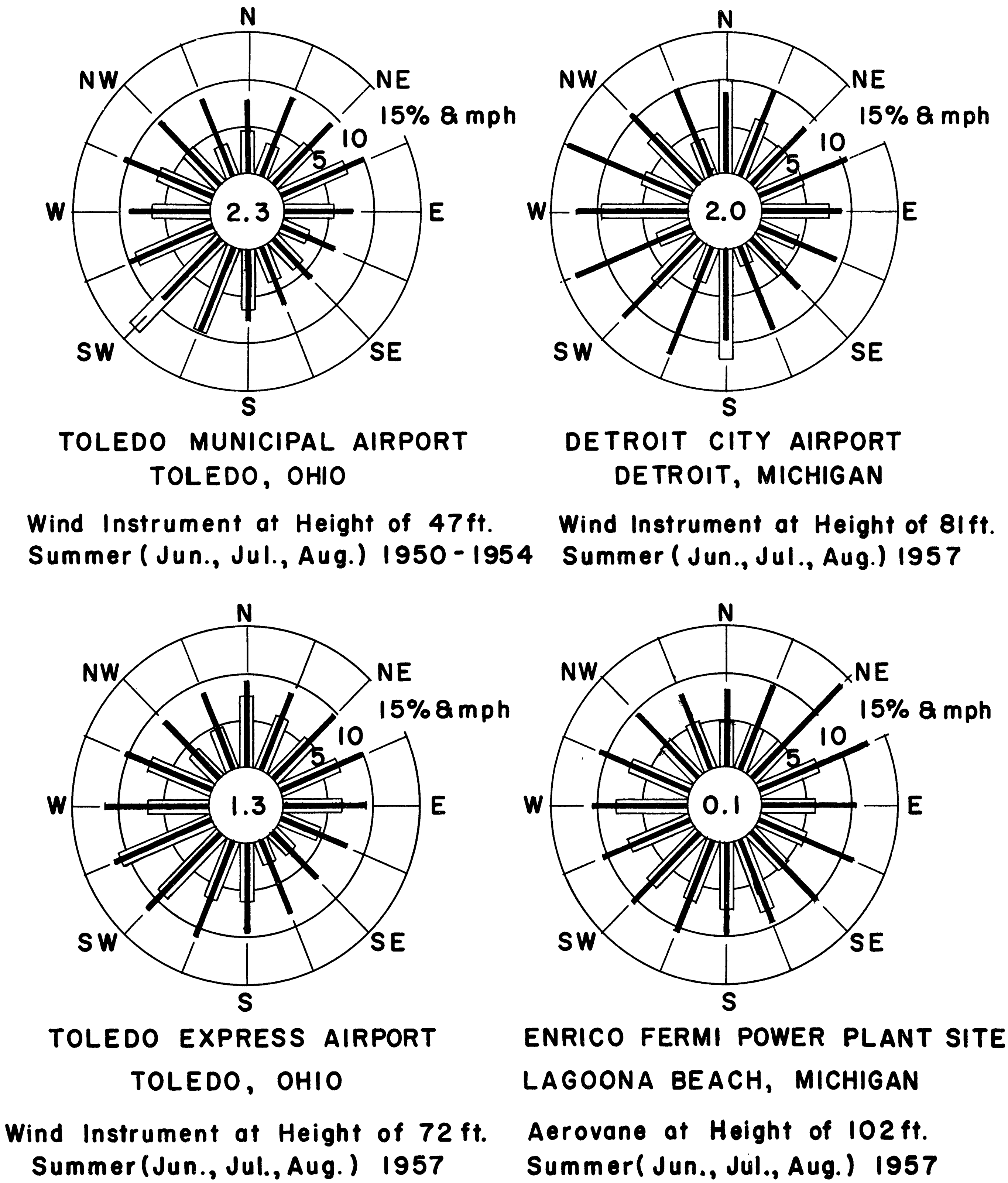


Fig. 15. Percentage frequency of occurrence of winds from 16 directions and corresponding wind speed in mph at Toledo Municipal Airport, Summer Seasons, 1950-1954; Detroit City Airport, Toledo Express Airport, and Enrico Fermi site, Summer, 1957.

TABLE XXXIII

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS GROUPED ACCORDING TO WIND SPEEDS

Enrico Fermi Site
(Aerovane at height of 102 ft)
1 September 1957 - 30 November 1957
(Fall)

Wind Direction	Speed, mph					Total Observations		Mean Speed	
	0-3	4-12	13-24	25 and Over	Total 4 and Over	%	No.	mph	% of Over-all Mean
N	0.1	3.8	1.0		4.8	4.9	103	9.8	81
NNE	0.1	2.1	0.3		2.4	2.5	52	8.8	73
NE	0.0	2.1	3.6		5.7	5.7	121	14.5	120
ENE	0.1	2.6	3.1		5.7	5.8	121	13.5	112
E	0.0	2.0	0.9	0.1	3.0	3.0	64	11.6	96
ESE	0.2	3.8	1.0		4.8	5.0	105	9.7	80
SE	0.1	1.7	0.8	0.3	2.8	2.9	60	12.5	103
SSE	0.1	3.6	1.7	0.4	5.7	5.8	122	12.2	101
S	0.1	3.4	1.6		5.0	5.1	108	11.1	92
SSW	0.3	5.2	3.2	0.0	8.4	8.7	186	13.5	112
SW	0.3	4.8	3.8	0.2	8.8	9.1	193	12.7	105
WSW	0.4	4.7	5.4	2.3	12.4	12.8	267	16.0	132
W	0.2	3.1	2.0		5.1	5.3	112	11.6	96
WNW	0.1	5.1	1.5		6.6	6.7	140	10.2	84
NW	0.2	4.8	1.9		6.7	6.9	147	10.6	88
NNW	0.1	7.3	1.9		9.2	9.3	196	10.0	83
Calm	0.3					0.3	7	0.0	
Totals	2.7	60.1	33.7	3.3	97.0	99.8	2104		
Mean								12.1	100

TABLE XXXIV

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS GROUPED ACCORDING TO WIND SPEEDS

Toledo Express Airport
(Wind instruments at height of 72 ft)
1 September 1957 - 30 November 1957
(Fall)

Wind Direction	Speed, mph					Total Observations		Mean Speed	
	0-3	4-12	13-24	25 and Over	Total 4 and Over	%	No.	mph	% of Over-all Mean
N	0.8	8.2	0.5		8.7	9.5	208	8.0	81
NNE	0.3	3.8	0.4		4.2	4.5	98	8.5	86
NE	0.4	4.5	0.5		5.0	5.4	118	8.4	85
ENE	0.3	3.1	0.8		3.9	4.2	91	9.5	96
E	0.3	4.3	0.8		5.1	5.4	117	9.2	93
ESE	0.4	1.6			1.6	2.0	45	6.7	68
SE	0.2	2.4	0.0		2.4	2.6	57	7.7	78
SSE	0.0	3.0	0.9		3.9	3.9	86	10.4	105
S	0.7	5.8	1.6		7.4	8.1	177	9.6	97
SSW	0.3	4.5	1.5	0.1	6.1	6.4	139	10.5	106
SW	0.1	6.5	4.4	0.3	11.2	11.3	247	12.6	127
WSW	0.1	6.0	3.7	0.6	10.3	10.4	229	12.8	129
W	0.4	4.3	2.5	0.3	7.1	7.5	164	12.0	121
WNW	0.3	4.0	0.9		4.9	5.2	114	9.5	96
NW	0.6	6.3	0.6		6.9	7.5	164	8.3	84
NNW	0.2	4.6	0.6		5.2	5.4	118	8.9	90
Calm	0.5	—	—	—	—	0.5	12	0.0	—
Totals	5.9	72.9	19.7	1.3	93.9	99.8	2184		
Mean								9.9	100

TABLE XXXV

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS GROUPED ACCORDING TO WIND SPEEDS

Detroit City Airport
(Wind instruments at height of 81 ft)
1 September 1957 - 30 November 1957
(Fall)

Wind Direction	Speed, mph					Total Observations		Mean Speed	
	0-3	4-12	13-24	25 and Over	Total 4 and Over	%	No.	mph	% of Over-all Mean
N	1.7	7.7	2.7		10.4	12.1	264	9.4	81
NNE	0.5	2.2	0.3		2.5	3.0	66	7.8	67
NE	1.0	2.9	0.8		3.7	4.7	103	8.5	73
ENE	0.2	2.1	0.7		2.8	3.0	67	10.0	86
E	1.4	2.8	0.5		3.3	4.7	102	7.1	61
ESE	0.3	1.5	0.1		1.6	1.9	41	7.6	66
SE	0.4	3.2	0.6		3.8	4.2	91	9.0	78
SSE	0.2	3.2	0.7	0.1	4.0	4.2	90	9.8	85
S	0.3	6.0	2.4	0.1	8.5	8.8	191	10.8	93
SSW	0.2	1.6	2.5		4.1	4.3	96	13.7	118
SW	0.3	4.6	6.9	1.5	13.0	13.3	287	15.7	135
WSW	0.1	2.7	4.2	0.3	7.2	7.3	159	14.8	128
W	0.2	3.2	3.1	0.1	6.4	6.6	143	12.9	111
WNW	0.2	2.1	2.9	0.3	5.3	5.5	120	14.3	123
NW	0.5	4.9	3.6	0.2	8.7	9.2	200	12.1	104
NNW	0.5	2.6	3.1	0.1	5.8	6.3	137	12.7	110
Calm	1.2	—	—	—	—	1.2	27	0.0	—
Totals	9.2	53.3	35.1	2.7	91.1	100.3	2184		
Mean								11.6	100

TABLE XXXVI

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS, BIASED AND UNBIASED

Detroit City Airport
1 September 1957 - 30 November 1957
(Fall)

Wind Direction	Total Observations			
	Biased Record		Unbiased Record	
	No.	%	No.	%
N	264	12.1	195	8.9
NNE	66	3.0	102	4.7
NE	103	4.7	78	3.6
ENE	67	3.0	87	4.0
E	102	4.7	79	3.7
ESE	41	1.9	77	3.5
SE	91	4.2	70	3.2
SSE	90	4.2	92	4.2
S	191	8.8	145	6.6
SSW	96	4.3	160	7.3
SW	287	13.3	226	10.3
WSW	159	7.3	210	9.6
W	143	6.6	123	5.6
WNW	120	5.5	130	6.0
NW	200	9.2	165	7.6
NNW	137	6.3	218	10.0
Calm	27	1.2	27	1.2
Totals	2184	100.3	2184	100.0

TABLE XXXVII

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS GROUPED ACCORDING TO WIND SPEEDS

Toledo Municipal Airport
(Wind instruments at height of 47 ft)
1 January 1950 - 31 December 1954
(Fall Seasons)

Wind Direction	Speed, mph					Total Observations		Mean Speed	
	0-3	4-12	13-24	25 and Over	Total 4 and Over	%	No.	mph	% of Over-all Mean
N	0.6	3.0	0.9		3.9	4.5	493	8.7	85
NNE	0.2	1.7	1.3		3.0	3.2	347	11.3	110
NE	0.4	2.4	1.5		3.9	4.3	478	10.4	100
ENE	0.4	2.1	1.2		3.3	3.7	403	10.0	97
E	0.6	2.6	0.5		3.1	3.7	405	7.5	73
ESE	0.2	1.6	0.1		1.7	1.9	221	7.1	69
SE	0.6	2.5	0.1		2.6	3.3	355	6.3	61
SSE	0.5	2.5	0.5	0.1	3.1	3.6	395	8.6	84
S	0.7	5.8	2.0	0.1	7.9	8.6	940	9.8	95
SSW	0.6	7.9	5.4	0.2	13.5	14.1	1556	11.4	111
SW	0.9	9.4	5.2	0.6	15.2	16.1	1745	11.3	110
WSW	0.8	5.5	3.7	0.3	9.5	10.3	1122	11.2	109
W	0.5	3.6	1.6	0.1	5.3	5.8	630	10.0	97
WNW	0.3	3.2	2.8	0.1	6.1	6.4	703	12.1	118
NW	0.6	2.3	2.6	0.1	5.0	5.5	606	12.1	118
NNW	0.2	1.7	1.3		3.0	3.2	362	11.2	109
Calm	1.5	—	—	—	—	1.5	159	0.0	—
Totals	9.6	57.8	30.7	1.6	90.1	99.7	10920		
Mean								10.3	100

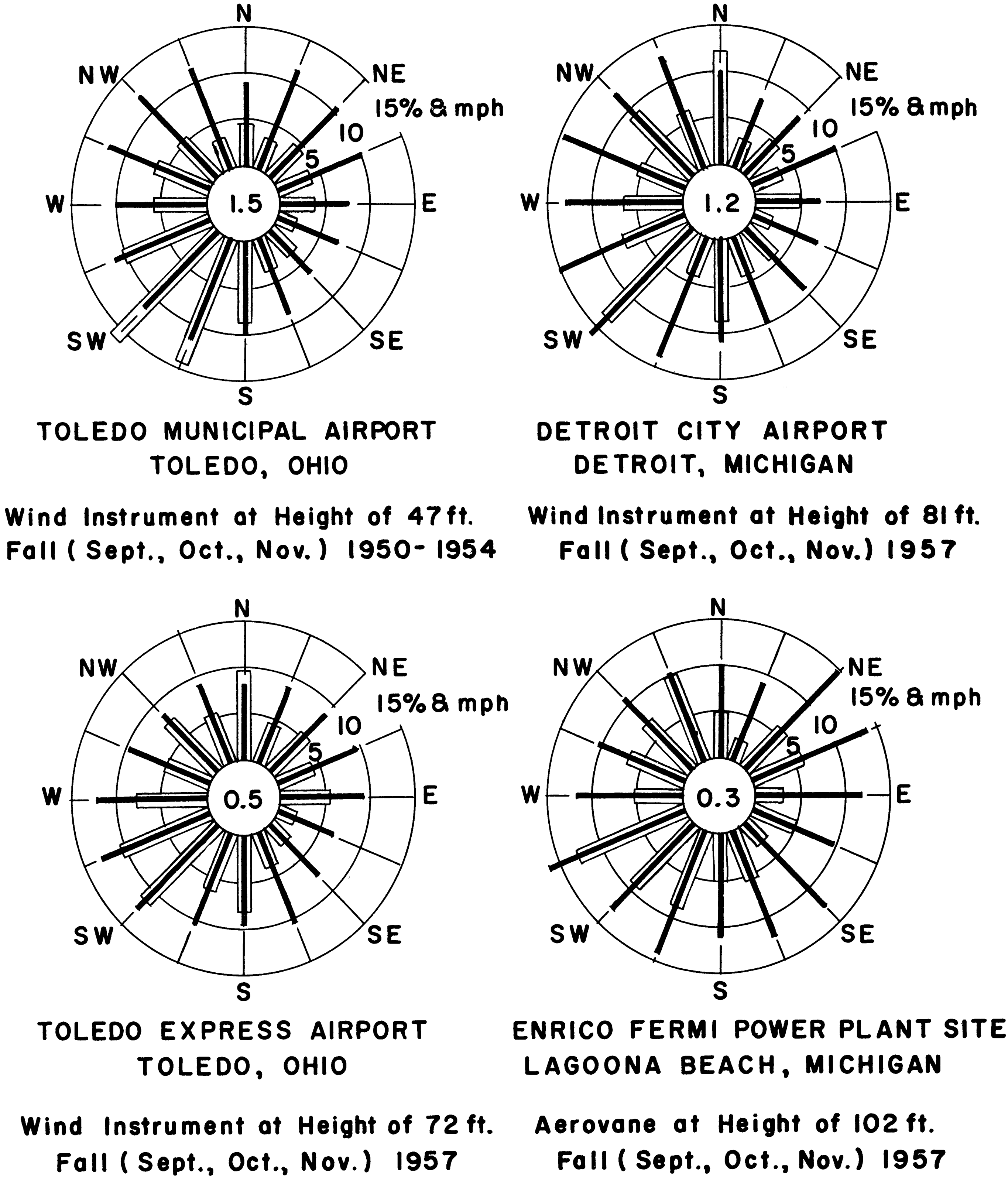


Fig. 16. Percentage frequency of occurrence of winds from 16 directions and corresponding wind speed in mph at Toledo Municipal Airport, Fall Seasons, 1950-1954; Detroit City Airport, Toledo Express Airport, and Enrico Fermi site, Fall, 1957.

TABLE XXXVIII

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS GROUPED ACCORDING TO WIND SPEEDS

Enrico Fermi Site
(Aerovane at height of 102 ft)
1 December 1956 - 30 November 1957
(Annual Summary)

Wind Direction	Speed, mph					Total Observations		Mean Speed	
	0-3	4-12	13-24	25 and Over	Total 4 and Over	%	No.	mph	% of Over-all Mean
N	0.1	2.7	1.0	0.1	3.8	3.9	349	11.1	89
NNE	0.2	2.3	1.8	0.1	4.2	4.4	383	12.5	100
NE	0.1	1.8	3.8	0.3	5.9	6.0	507	15.3	122
ENE	0.2	2.4	3.5	0.3	6.2	6.4	551	14.5	116
E	0.3	2.2	1.9	0.4	4.5	4.8	409	14.1	113
ESE	0.2	2.9	1.9	0.1	4.9	5.1	433	11.8	94
SE	0.2	2.3	1.3	0.1	3.7	3.9	342	11.9	95
SSE	0.1	3.9	1.2	0.1	5.2	5.3	465	10.6	85
S	0.2	3.4	1.6	0.1	5.1	5.3	455	11.0	88
SSW	0.2	3.9	3.2	0.2	7.3	7.5	645	12.6	101
SW	0.3	4.1	4.3	0.2	8.6	8.9	759	13.2	106
WSW	0.3	5.1	4.8	0.9	10.8	11.1	959	14.1	113
W	0.3	4.4	2.7	0.2	7.3	7.6	663	11.9	95
WNW	0.2	4.6	3.2	0.1	7.9	8.1	705	12.2	98
NW	0.3	3.9	1.0	0.1	5.9	6.2	535	11.0	88
NNW	0.2	4.2	1.3		5.5	5.7	493	10.2	82
Calm	0.3	___	___	___	___	0.3	26	0.0	___
Totals	3.7	54.1	39.4	3.3	96.8	100.5	8679		
Mean								12.5	100

TABLE XXXIX

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS GROUPED ACCORDING TO WIND SPEEDS

Toledo Express Airport
(Wind instruments at height of 72 ft)
1 December 1956 - 30 November 1957
(Annual Summary)

Wind Direction	Speed, mph					Total Observations		Mean Speed	
	0-3	4-12	13-24	25 and Over	Total 4 and Over	%	No.	mph	% of Over-all Mean
N	0.5	5.1	1.3	0.0	6.4	6.9	602	9.6	88
NNE	0.3	3.5	1.2	0.0	4.7	5.0	443	10.2	94
NE	0.4	3.8	1.1		4.9	5.3	455	9.7	89
ENE	0.4	3.6	1.8	0.0	5.4	5.8	513	11.0	101
E	0.4	4.1	1.8	0.1	6.0	6.4	558	10.9	100
ESE	0.4	2.7	0.3		3.0	3.4	295	8.1	74
SE	0.3	2.1	0.1		2.2	2.5	222	7.7	71
SSE	0.2	2.6	0.7	0.0	3.3	3.5	315	9.9	91
S	0.3	4.7	1.7	0.0	6.4	6.7	592	10.3	95
SSW	0.2	3.4	2.2	0.1	5.7	5.9	526	12.0	110
SW	0.2	5.0	4.8	0.3	10.1	10.3	897	13.3	122
WSW	0.3	6.3	4.9	0.6	11.8	12.1	1060	13.1	120
W	0.2	4.7	2.6	0.1	7.4	7.6	667	11.8	108
WNW	0.2	4.5	2.0		6.5	6.7	587	10.9	100
NW	0.5	4.1	1.2	0.0	5.3	5.8	508	9.7	89
NNW	0.3	3.5	0.9		4.4	4.7	412	9.5	87
Calm	1.2	—	—	—	—	1.2	108	0.0	—
Totals	6.3	63.7	28.6	1.2	93.5	98.8	8760		
Mean								10.9	100

TABLE XL

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS
GROUPED ACCORDING TO WIND SPEEDS

Detroit City Airport
(Wind instruments at height of 81 ft)
1 December 1956 - 30 November 1957
(Annual Summary)

Wind Direction	Speed, mph					Total Observations		Mean Speed	
	0-3	4-12	13-24	25 and Over	Total 4 and Over	%	No.	mph	% of Over-all Mean
N	1.2	6.8	2.9		9.7	10.9	951	10.1	89
NNE	0.4	3.3	1.1		4.4	4.8	428	9.9	87
NE	0.8	2.7	1.0		3.7	4.5	394	9.1	80
ENE	0.2	3.2	1.1		4.3	4.5	397	10.3	90
E	0.9	4.9	0.9		5.8	6.7	583	8.7	76
ESE	0.2	2.4	0.4		2.8	3.0	260	8.9	78
SE	0.5	3.3	0.4		3.7	4.2	368	8.2	72
SSE	0.2	2.6	0.6		3.2	3.4	297	9.6	84
S	0.4	6.8	2.1		8.9	9.3	813	10.1	89
SSW	0.1	2.1	2.0		4.1	4.2	363	12.9	113
SW	0.2	3.7	5.1	0.5	9.3	9.5	830	14.5	127
WSW	0.1	2.2	3.2	0.2	5.6	5.7	492	14.5	127
W	0.3	4.4	4.3	0.1	8.8	9.1	800	13.0	114
WNW	0.1	2.4	3.9	0.4	6.7	6.8	595	15.1	133
NW	0.5	4.2	3.2	0.1	7.5	8.0	700	12.0	105
NNW	0.3	2.1	2.0		4.1	4.4	387	12.3	108
Calm	1.2	—	—	—	—	1.2	102	0.0	—
Totals	7.6	57.1	34.2	1.3	92.6	100.2	8760		
Mean								11.4	100

TABLE XLI

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS, BIASED AND UNBIASED

Detroit City Airport
1 December 1956 - 30 November 1957
(Annual Summary)

Wind Direction	Total Observations			
	Biased Record		Unbiased Record	
	No.	%	No.	%
N	951	10.9	739	8.4
NNE	428	4.8	563	6.4
NE	394	4.5	340	3.9
ENE	397	4.5	458	5.2
E	583	6.7	490	5.6
ESE	260	3.0	325	3.7
SE	368	4.2	281	3.2
SSE	297	3.4	419	4.8
S	813	9.3	599	6.8
SSW	363	4.2	597	6.8
SW	830	9.5	632	7.2
WSW	492	5.7	671	7.7
W	800	9.1	680	7.8
WNW	595	6.8	717	8.2
NW	700	8.0	571	6.5
NNW	387	4.4	576	6.6
Calm	102	1.2	102	1.2
Totals	8760	100.2	8760	100.0

TABLE XLII

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS IN VARIOUS DIRECTIONS GROUPED ACCORDING TO WIND SPEEDS

Toledo Municipal Airport
(Wind instruments at height of 47 ft)
1 January 1950 - 31 December 1954
(Five-Year Summary)

Wind Direction	Speed, mph					Total Observations		Mean Speed	
	0-3	4-12	13-24	25 and Over	Total 4 and Over	%	No.	mph	% of Over-all Mean
N	0.5	2.9	0.9		3.8	4.3	1865	8.8	79
NNE	0.2	2.0	1.2		3.2	3.4	1474	10.9	98
NE	0.4	2.8	1.8		4.6	5.0	2196	10.8	97
ENE	0.3	3.3	3.2	0.2	6.7	7.0	3101	12.6	113
E	0.5	3.3	1.4		4.7	5.2	2287	9.5	86
ESE	0.3	2.1	0.4		2.5	2.8	1202	8.1	73
SE	0.5	2.6	0.3		2.9	3.4	1495	7.3	66
SSE	0.3	2.4	0.7	0.1	3.2	3.5	1545	9.2	83
S	0.5	4.2	2.0	0.1	6.3	6.8	3026	10.4	94
SSW	0.4	5.6	4.5	0.4	10.5	10.9	4768	12.3	111
SW	0.7	7.2	4.9	0.5	12.6	13.3	5859	11.9	107
WSW	0.5	5.1	4.6	0.5	10.2	10.7	4713	12.5	113
W	0.5	3.7	2.4	0.2	6.3	6.8	2990	11.3	102
WNW	0.3	3.0	3.3	0.2	6.5	6.8	3021	13.1	118
NW	0.4	2.4	2.4	0.1	4.9	5.3	2357	12.3	111
NNW	0.3	1.7	1.1		2.8	3.1	1358	10.6	95
Calm	1.3	___	___	___	___	1.3	567	0.0	___
Totals	7.9	54.3	35.1	2.3	91.7	99.6	43824		
Mean								11.1	100

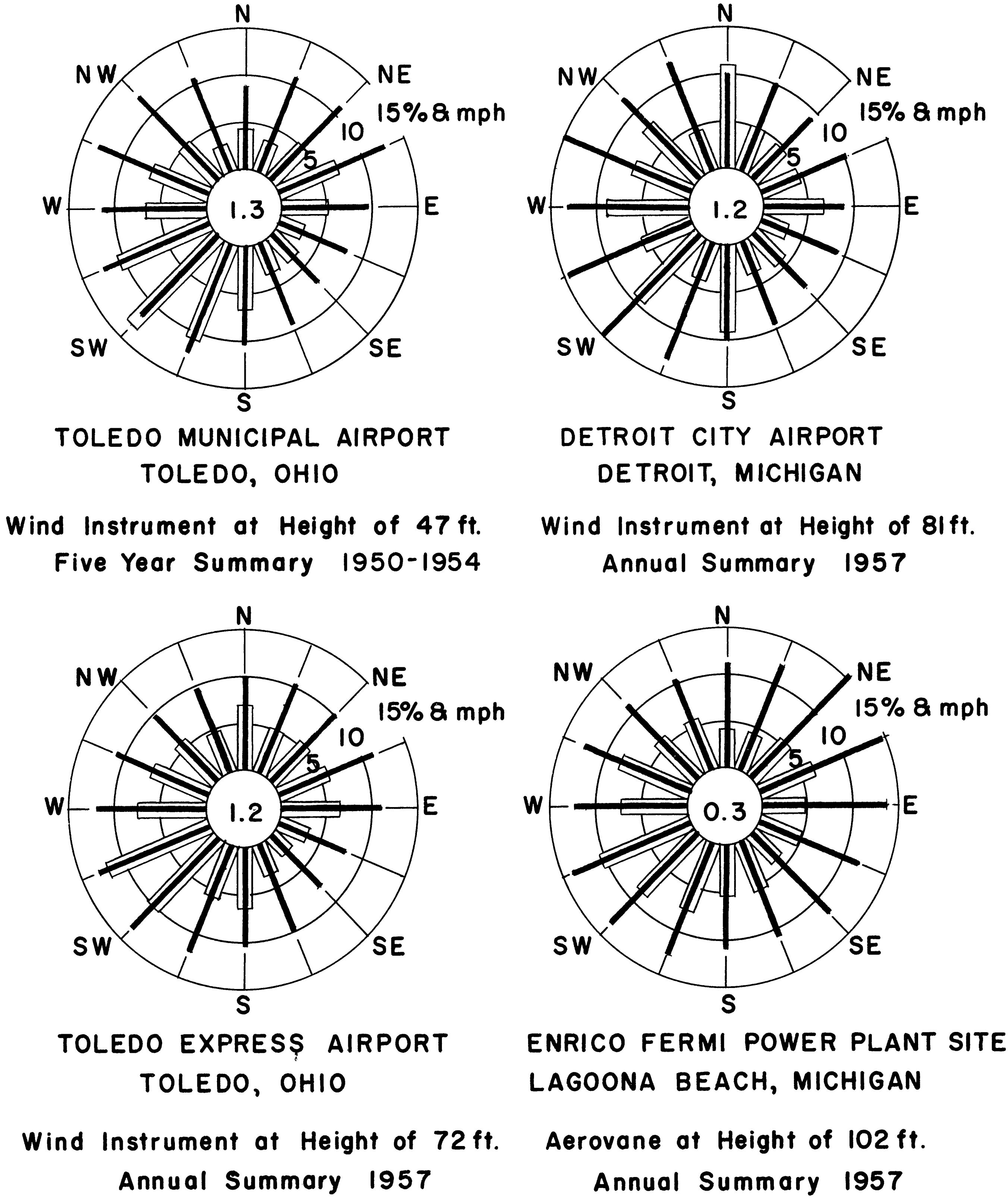


Fig. 17. Percentage frequency of occurrence of winds from 16 directions and corresponding wind speed in mph at Toledo Municipal Airport, Five-Year Summary, 1950-1954; Detroit City Airport, Toledo Express Airport, and Enrico Fermi site, Annual Summary, 1956-1957.

discussion of these records in the second progress report is considered adequate. It should be noted that the Detroit City Airport record which appears in the windroses of Figs. 13-17 is the record as it was reported and as it appears in Tables XX, XXV, XXX, XXXV, and XL.

E, ESE, SE, SSE, and S combined—In Table XLIII the percentage frequency of these winds at the site from 1 December 1956 to 30 November 1957 is compared to those for the same period at Toledo Express Airport, Detroit City Airport, and to the 5-year period 1950-1954 at Toledo Municipal Airport. With the exception of summer when the influence of the lake breeze is strong (see Part III) the plant site is not unlike Toledo and Detroit. Judging from the annual summary in the last line of Table XLIII, it was a fairly typical year.

TABLE XLIII

COMBINED PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS FROM THE E, ESE, SE, SSE, AND S, 1 DECEMBER 1956 - 30 NOVEMBER 1957, AT THE ENRICO FERMI SITE, TOLEDO EXPRESS AIRPORT, AND DETROIT CITY AIRPORT, AND 5-YEAR AVERAGE AT TOLEDO MUNICIPAL AIRPORT.

	Enrico Fermi Site	Toledo Express Airport	Detroit City Airport (approximation)	Toledo Municipal Airport (5-yr. Avg.)
Winter	15.5	18.6	18.6	21.4
Spring	29.3	26.8	29.2	21.7
Summer	31.6	22.8	27.4	22.9
Fall	21.8	22.0	21.2	21.1
Annual	24.4	22.5	24.1	21.7

W, WNW, NW, NNW, N, and NNE combined—Winds from these directions are summarized in the same manner in Table XLIV. Here it appears as if Toledo is more representative of the plant site than Detroit. Winds from this sector were more frequent during this year than during the 5-year average and one may interpret the departure from the 5-year means as a crude measure of the amount of variation one may expect above and below the mean.

ENE—Monroe—Winds from this direction are summarized in Table XLV. Again it appears as if Toledo is more representative of the plant site than Detroit. It was a typical year even to the spring maximum.

SSW—Detroit River communities—Winds from the SSW are summarized in Table XLVI. For this wind direction, Detroit appears to be more representative of the plant site than Toledo. Frequencies at Toledo Express Airport are less than the 5-year average in each season which may indicate either an abnormal year or some minor difference in winds at the two airports. Another year of data may help to throw light on this feature.

TABLE XLIV

COMBINED PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS FROM THE W, WNW, NW, NNW, N, AND NNE, 1 DECEMBER 1956 - 30 NOVEMBER 1957, AT ENRICO FERMI SITE, TOLEDO EXPRESS AIRPORT, AND DETROIT CITY AIRPORT, AND 5-YEAR AVERAGE AT TOLEDO MUNICIPAL AIRPORT.

	Enrico Fermi Site	Toledo Express Airport	Detroit City Airport (approximation)	Toledo Municipal Airport (5-yr. Avg.)
Winter	40.8	36.4	49.1	29.2
Spring	30.7	34.4	41.2	31.8
Summer	34.8	36.4	42.2	29.2
Fall	35.6	39.6	42.8	28.6
Annual	35.9	36.7	43.9	29.7

TABLE XLV

PERCENTAGE FREQUENCY OF OCCURRENCE OF ENE WINDS, 1 DECEMBER 1956 - 30 NOVEMBER 1957, AT ENRICO FERMI SITE, TOLEDO EXPRESS AIRPORT, AND DETROIT CITY AIRPORT, AND 5-YEAR AVERAGE AT TOLEDO MUNICIPAL AIRPORT.

	Enrico Fermi Site	Toledo Express Airport	Detroit City Airport (approximation)	Toledo Municipal Airport (5-yr. Avg.)
Winter	3.0	3.1	3.3	5.3
Spring	10.1	9.1	8.1	11.4
Summer	6.8	6.9	5.5	7.1
Fall	5.8	4.2	4.0	3.7
Annual	6.4	5.8	5.2	7.0

TABLE XLVI

PERCENTAGE FREQUENCY OF OCCURRENCE OF SSW WINDS, 1 DECEMBER 1956 - 30 NOVEMBER 1957, AT ENRICO FERMI SITE, TOLEDO EXPRESS AIRPORT, AND DETROIT CITY AIRPORT, AND 5-YEAR AVERAGE AT TOLEDO MUNICIPAL AIRPORT.

	Enrico Fermi Site	Toledo Express Airport	Detroit City Airport (approximation)	Toledo Municipal Airport (5-yr. Avg.)
Winter	9.7	6.9	7.2	12.1
Spring	5.6	4.3	5.2	7.2
Summer	6.9	6.6	7.7	9.1
Fall	8.7	6.4	7.3	14.1
Annual	7.5	5.9	6.8	10.9

SW and WSW—Ontario shores—Winds from the SW and WSW are summarized in Table XLVII. Toledo appears to be very representative of the plant site except in summer when the lake-breeze effect apparently diverts some of the SW and WSW winds to the quadrant E through S.

TABLE XLVII

PERCENTAGE FREQUENCY OF OCCURRENCE OF WINDS FROM THE SW AND WSW, 1 DECEMBER 1956 - 30 NOVEMBER 1957, AT THE ENRICO FERMI SITE, TOLEDO EXPRESS AIRPORT, AND 5-YEAR AVERAGE AT TOLEDO MUNICIPAL AIRPORT.

	Enrico Fermi Site	Toledo Express Airport	Detroit City Airport (approximation)	Toledo Municipal Airport (5-yr. Avg.)
Winter	24.8	28.4	19.1	26.7
Spring	17.2	19.0	10.3	21.0
Summer	14.9	20.3	10.3	20.4
Fall	21.9	21.7	19.9	26.4
Annual	20.0	22.4	14.9	24.0

3. WIND SPEED AT THE ENRICO FERMI SITE

The analysis of wind speeds has centered on obtaining evidence of special effects due to the lake. These effects are related to the relative smoothness of the lake which reduces friction and to the temperature of the lake which results sometimes in inversions and other times in strong lapse rates over the lake. The following description of the analytical technique is taken directly from the second progress report.

"Figure 12 indicates that winds from the sector bounded by NE through SSE have a water trajectory prior to reaching the aerovane at the plant site, whereas, for all other directions at the plant site, and without exception at Detroit and Toledo, the winds experience a land trajectory. Direct comparisons between wind speeds for corresponding directions at three stations are meaningless because of different heights of anemometer exposure and differences in instrumentation. However, if mean wind speeds for each direction are first expressed as a percentage of the overall mean wind speeds for all directions, comparisons may then be made. For example, during the spring of 1957 the mean wind speed at the plant site was 14.4 mph. The mean wind speed for WNW winds was 14.6 mph or 101 percent of 14.4. Computations of this sort have been made for all wind directions for the three stations." These appear as the last column of Tables XVIII - XLII except Tables XXI, XXVI, XXXI, XXXVI, and XLI.

The analysis is brought to a focus in Figs. 18-22. In these figures the wind speed in percent at the Enrico Fermi site is compared to a combined wind speed in percent for Detroit and Toledo, for each of the seasons and for the year as a whole. The directions which represent a water trajectory are shown

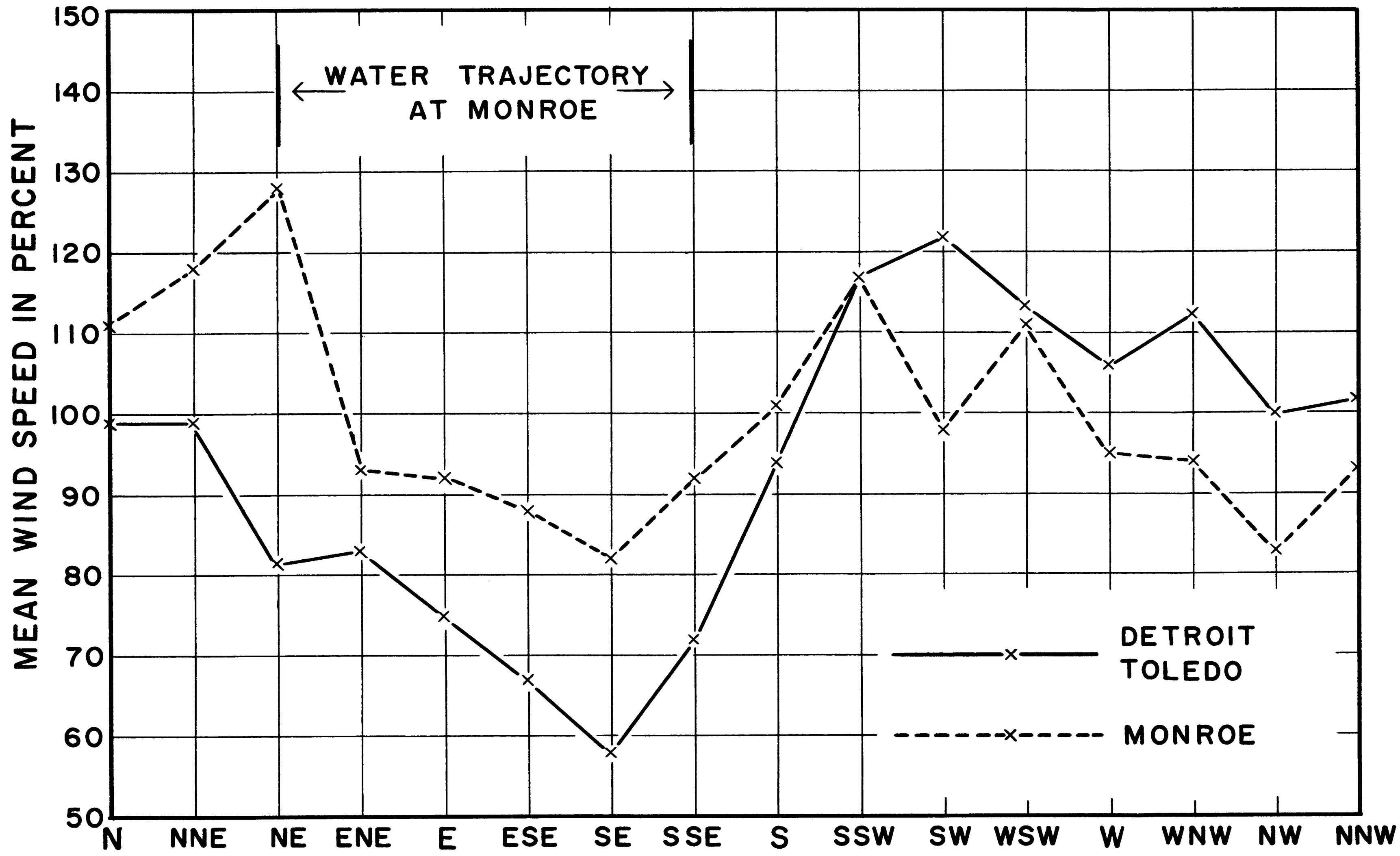


Fig. 18. Mean wind speed at the Enrico Fermi site and Detroit-Toledo combined, for 16 directions, expressed as a percentage of the overall mean winter wind speed, 1956-1957.

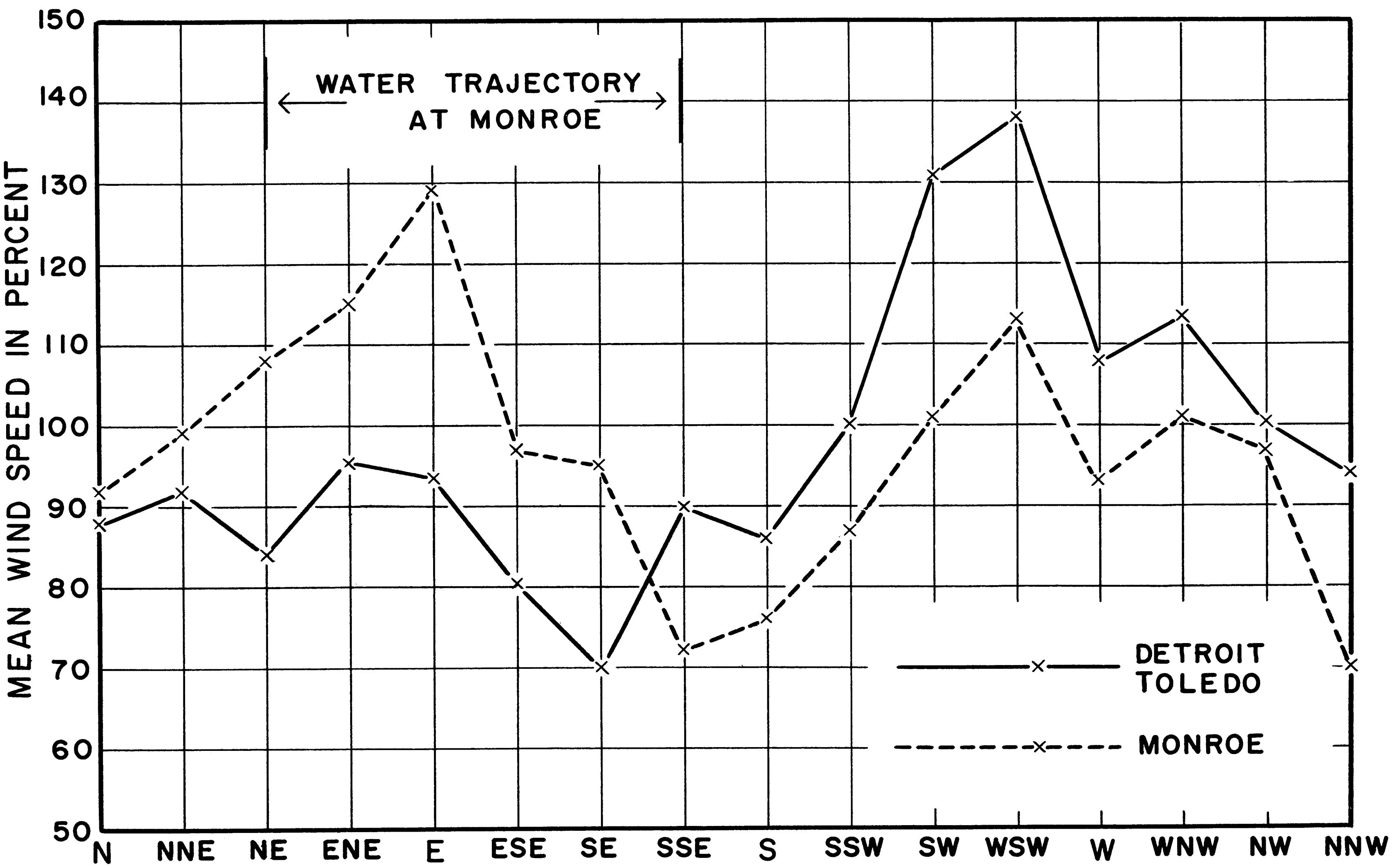


Fig. 19. Mean wind speed at the Enrico Fermi site and Detroit-Toledo combined, for 16 directions, expressed as a percentage of the overall mean spring wind speed, 1957.

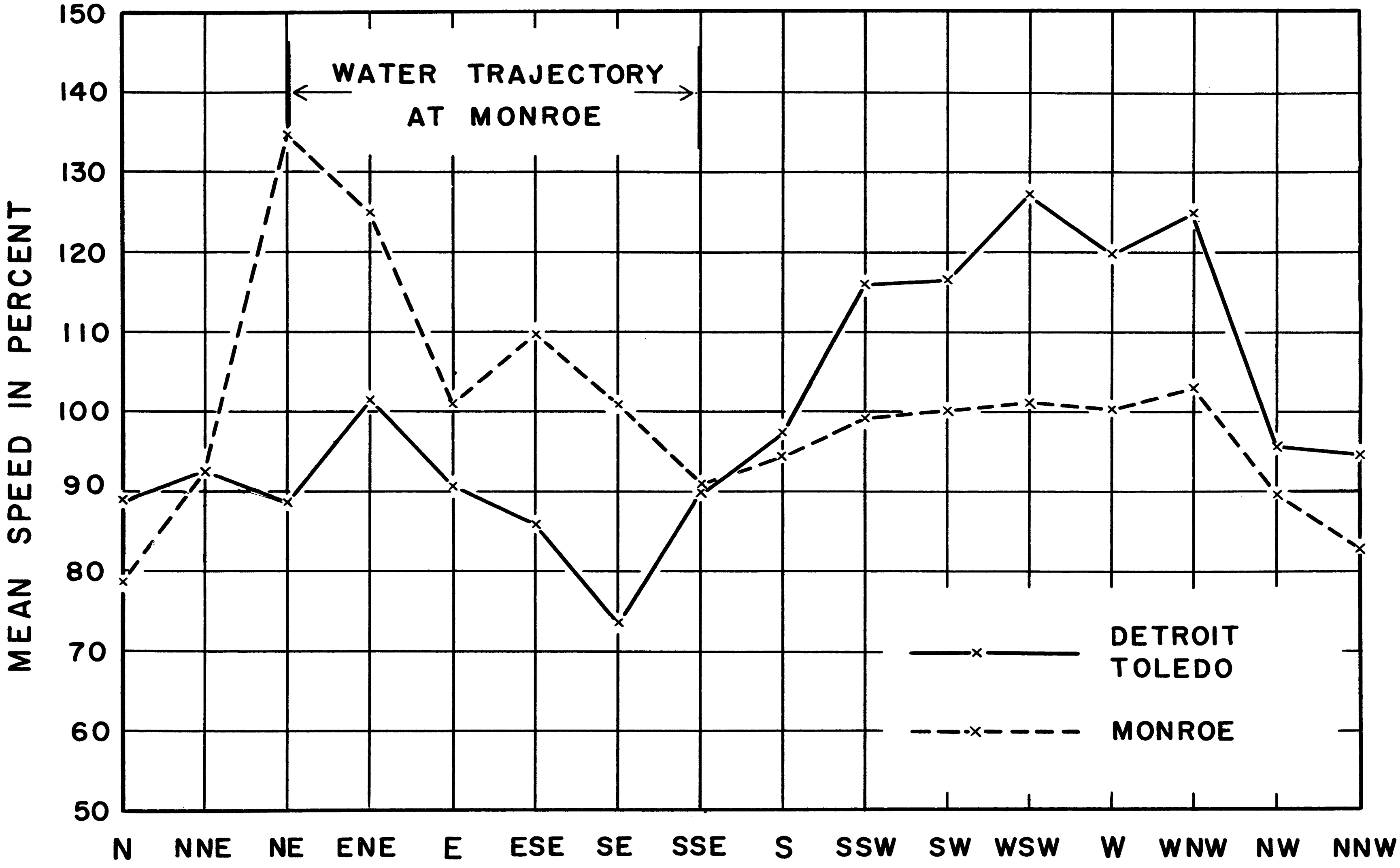


Fig. 20. Mean wind speed at the Enrico Fermi site and Detroit-Toledo combined, for 16 directions, expressed as a percentage of the overall mean summer wind speed, 1957.

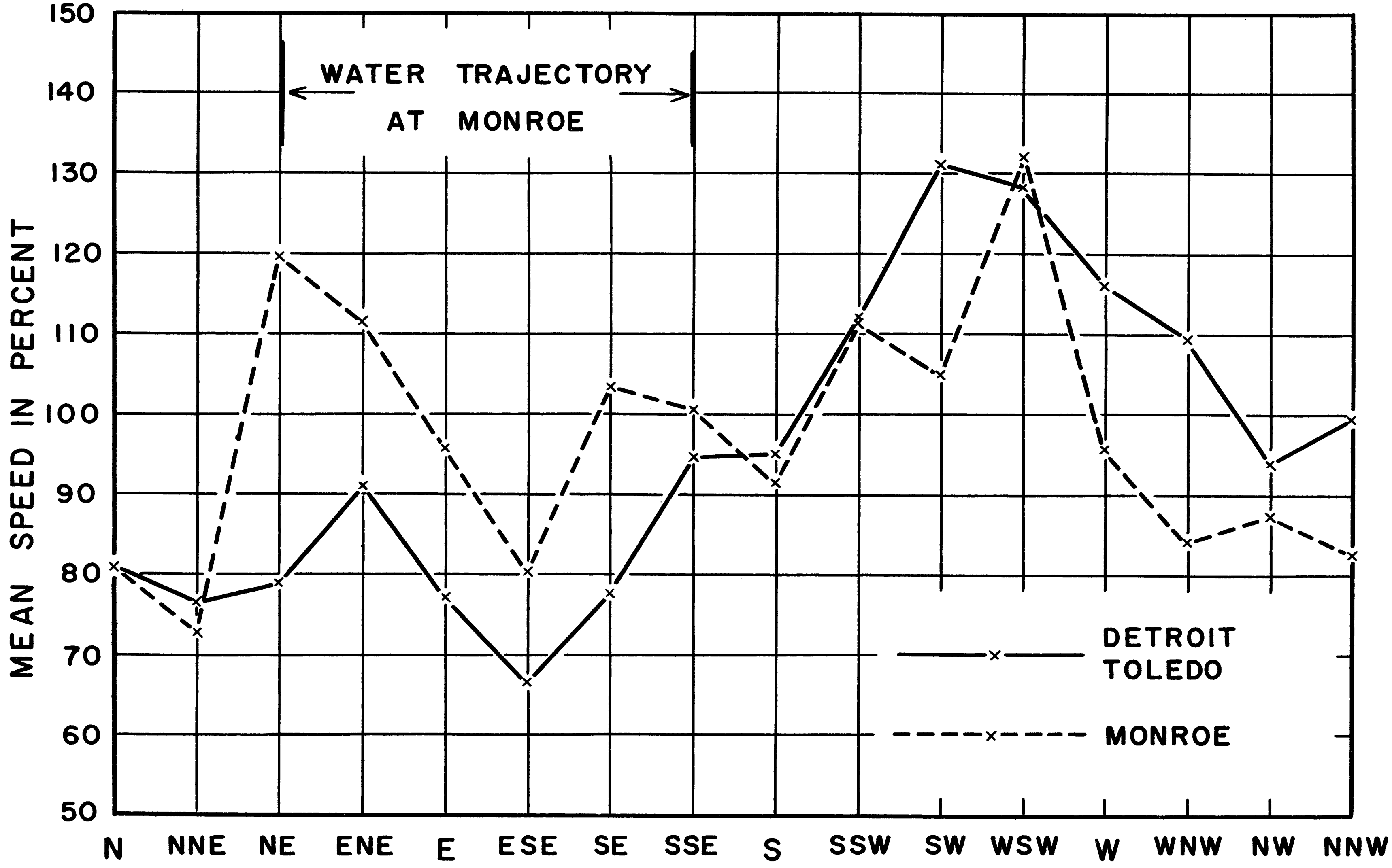


Fig. 21. Mean wind speed at the Enrico Fermi site and Detroit-Toledo combined, for 16 directions, expressed as a percentage of the overall mean fall wind speed, 1957.

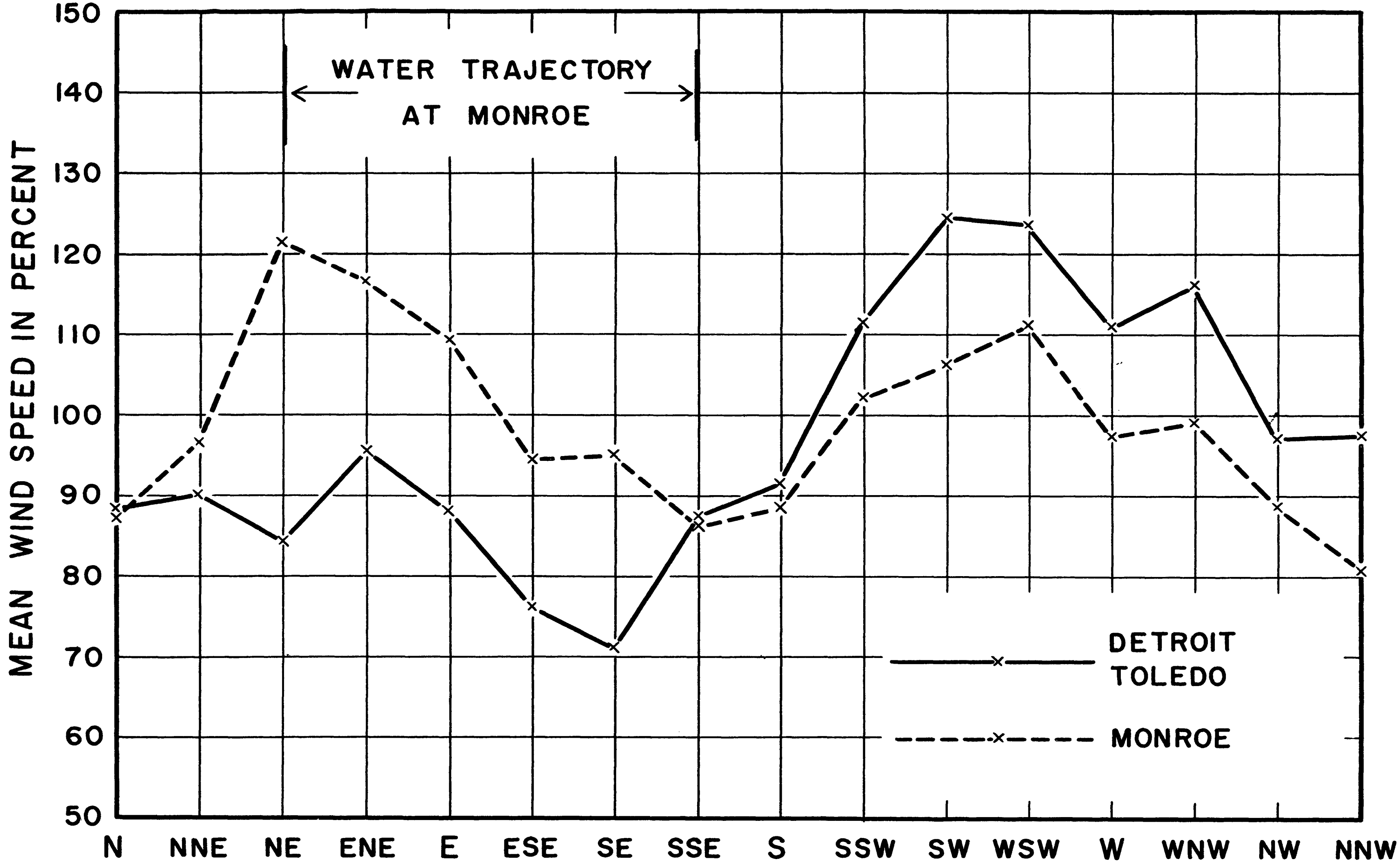


Fig. 22. Mean wind spedd at the Enrico Fermi site and Detroit-Toledo combined, for 16 directions, expressed as a percentage of the overall mean annual wind speed, 1956-1957.

on the figures. It is evident that winds which are off the lake are relatively stronger at the plant site than the same winds at Detroit and Toledo. This effect had been noted in winter and spring in the second progress report but there was speculation as to whether the same effect would be noted in all seasons. In general this appears to be the case except for SSE winds in spring and summer.

The factors underlying the effect have been referred to in the first paragraph of this section. The reduced frictional drag on the air crossing the lake will tend to make winds stronger. However, if the lake temperature is cold enough relative to the air temperature to produce an inversion, the resultant decreased downward transport of momentum will tend to make the winds weaker. This will be recognized as the circulation inversion, discussed earlier in Section 4 of Part I which, it was pointed out, is most likely to occur with SSE winds and in the spring and early summer. It thus appears that the tendency of inversions to decrease wind speeds will dominate the tendency of reduced frictional drag to increase winds when both factors operate as they frequently do in spring and early summer.

A reasonable extrapolation of these results would be the expectation that winds from land to water at the plant site will tend to accelerate as they move across the lake except when one can predict the development of an inversion over the lake.

III. LAND- AND LAKE-BREEZE EFFECTS AT LAGOONA BEACH

1. INTRODUCTION

Lagoona Beach is situated at the western end of Lake Erie. The general terrain, which is very flat in all directions, is overgrown by a mixture of tall grass, low bushes, and occasional clumps of trees about 40 ft high. Figure 12 illustrates the general topography of the area. The general bearing of the shoreline at this end of the lake is NE-SW but in the immediate vicinity of the site southerly winds will cross a point of land. As a result only those winds which blow from the sector NE through SSE are considered to reach the site directly from the lake.

Following a preliminary investigation into the air-pollution climatology of the region,[3] an investigation based on data from two first-order Weather Bureau stations some 25 to 30 miles from the site, it was decided to conduct an on-the-spot study of the local climatology. The possibility of finding special lake effects not present at the abovementioned Weather Bureau stations was one of the principal reasons for undertaking the local study.

Since hourly records of lapse rate between 25 and 100 ft are available for the Lagoona Beach site, it was possible to compute the relative frequency of inversions for each hour of the day and then consider the diurnal variation of inversion frequency. A somewhat similar analysis, but for 6-hour intervals, was undertaken of the lapse-rate data obtained on the WJBK-TV tower in Detroit. The diurnal variation of inversion frequency at both sites was computed for each season and for the year as a whole, as shown in Tables IV and V, and displayed graphically in Figs. 1-5. The results at WJBK-TV were altogether typical of a continental station with a pronounced nocturnal maximum. An interesting feature at the Lagoona Beach site was a secondary maximum during the afternoon, a maximum as large as the nocturnal one but somewhat shorter in duration. The feature was most pronounced in the summer and least pronounced in the fall, but it was discernible at all seasons.

A more detailed analysis of the data showed that there were 13 instances of afternoon inversions in June and 10 in July, 1957. A preliminary scanning of the 100-ft wind records at Lagoona Beach for these 23 days revealed a systematic backing of the wind around to the southeasterly quadrant, i.e., off the lake during the daytime, followed by a gradual veering again during the evening and night. Clearly a lake breeze bringing cool air off the lake was responsible for the inversions. Later sections of this report will present a detailed analysis of the land- and lake-breeze effect at Lagoona Beach as revealed by the meteorological conditions on those 23 summer days in 1957.

2. IDENTIFYING THE PHENOMENON

Land and lake breezes are localized shoreline wind circulations, the essential features of which are onshore winds during the daytime and offshore winds at night. The onshore wind, designated the lake breeze, is usually better defined than the offshore wind, in turn designated the land breeze, but this difference might be less well marked if it were the custom to compare the lake breeze measured at a shore installation with the land breeze measured some distance off shore. The lake breeze is commonly associated with relief from summer heat because it is accompanied by local cooling along a narrow coastal strip of land. As stated before, it is a local circulation, most evident right at the shoreline where the full effect of wind speed and temperature contrast is felt which fades out rather rapidly a few miles inland. The lake breeze has been studied more than the land breeze because it is simpler to provide a close network of observing stations over land than over water. Further details about the mechanics of land and lake breezes appear in Appendix B.

3. CHARACTERISTICS OF LAND AND LAKE BREEZES

The bulk of observational data on local winds of this type applies to shores of bodies of water larger than Lake Erie, so it would be a mistake to expect an exact replica at the Lagoona Beach site. Nevertheless, the body of observational data permits a few generalizations which are summarized below.

(1) The phenomenon is most likely to be observed if the general pressure gradient is very weak.

(2) The phenomenon requires the presence of strong sunlight; hence in northern latitudes it is most likely to occur in the summer.

(3) The lake breeze usually starts 2 or 3 hours before noon, is most pronounced about mid-afternoon, and subsides by sunset.

(4) In the absence of strong pressure gradients, onset is gradual. Nothing striking occurs at the coast although the temperature usually becomes steady. A pronounced gradient often leads to a delayed onset which occurs as a sort of cold frontal passage, complete with squally winds and temperature drop.

(5) The Coriolis effect, although measurable, is not great and is not usually evident until some 5 or 6 hours after the onset of the lake breeze.

4. LAKE BREEZE EFFECTS AT LAGOONA BEACH

Pressure Gradient During Lake Breeze.—Although the use of mean pressure maps is a somewhat unrefined technique, in this case such maps help to throw some light on the situation. Mean sea level pressures were obtained from the U. S. Weather Bureau Daily Weather Map for each of the 23 lake-breeze days for 22 weather stations around the Great Lakes and in neighboring areas. Thus it was possible to construct a mean map representing the average synoptic situation at Lagoona Beach for lake-breeze situations. This mean map is shown in Fig. 23.

The first feature that is evident is the weakness of the gradient which is, of course, favorable to the development of the lake-breeze effect. Secondly, it may be noted that the mean gradient is almost perpendicular to the shoreline at Lagoona Beach causing little if any trans-shoreline flow with a gradient wind. Therefore, any occurrences of onshore or offshore winds must be attributed to the land- and lake-breeze effect. Finally, it may be observed that the synoptic situation is one which characteristically leads to high temperatures in the region of the Great Lakes. Thus we may expect not only that the temperature difference over land and lake may become extreme during the afternoon, but also that a temperature inversion may be a semipermanent feature of the meteorological situation over the lake.

Windrose Analysis.—Separate windroses were prepared for eight 3-hour periods to display the diurnal shifting of the wind. These are presented in Fig. 24. In the light of the available observational data on penetration of lake breezes, it seems likely that Stoney Point to the south of Lagoona Beach will have relatively little influence on the lake breeze and that for present purposes, the predominant SW-NE shoreline will determine the local circulation. This would require us to include S, SSE, SE, and ESE winds as lake breezes.

It is indicated from Fig. 24 that the onset of the lake breeze is rather gradual. Since the windroses represent the integrated effect of 23 days, their interpretation indicates that the onset occasionally takes place before noon, that the lake breeze is most generally realized during the 3 hours ending at 1500 EST, and that on many days it has disappeared by 2100 EST. The characteristic direction appears to be between SE and SSE or nearly at right angles to the general shoreline. Since a backing of the wind precedes the full realization of the lake breeze, it is difficult to detect any Coriolis effect.

Synoptic Study of Winds and Temperatures.—One of the aspects of the lake-breeze effect at Lagoona Beach which was evident from the beginning of the investigation was the association of the phenomenon with unusually warm weather. This directed attention to the temperatures at Toledo Express Airport as a sort of control station where the modifying effect of the lake breeze would not be felt. Mean hourly temperatures for the 23 days were computed for Toledo from the monthly climatological summaries and for Lagoona Beach from the thermograph records.

Taking a somewhat more conservative view of the direction of lake breezes, the frequencies of ESE, SE, and SSE winds were combined into a single class to represent the lake breeze. The frequencies of winds from the opposite sector

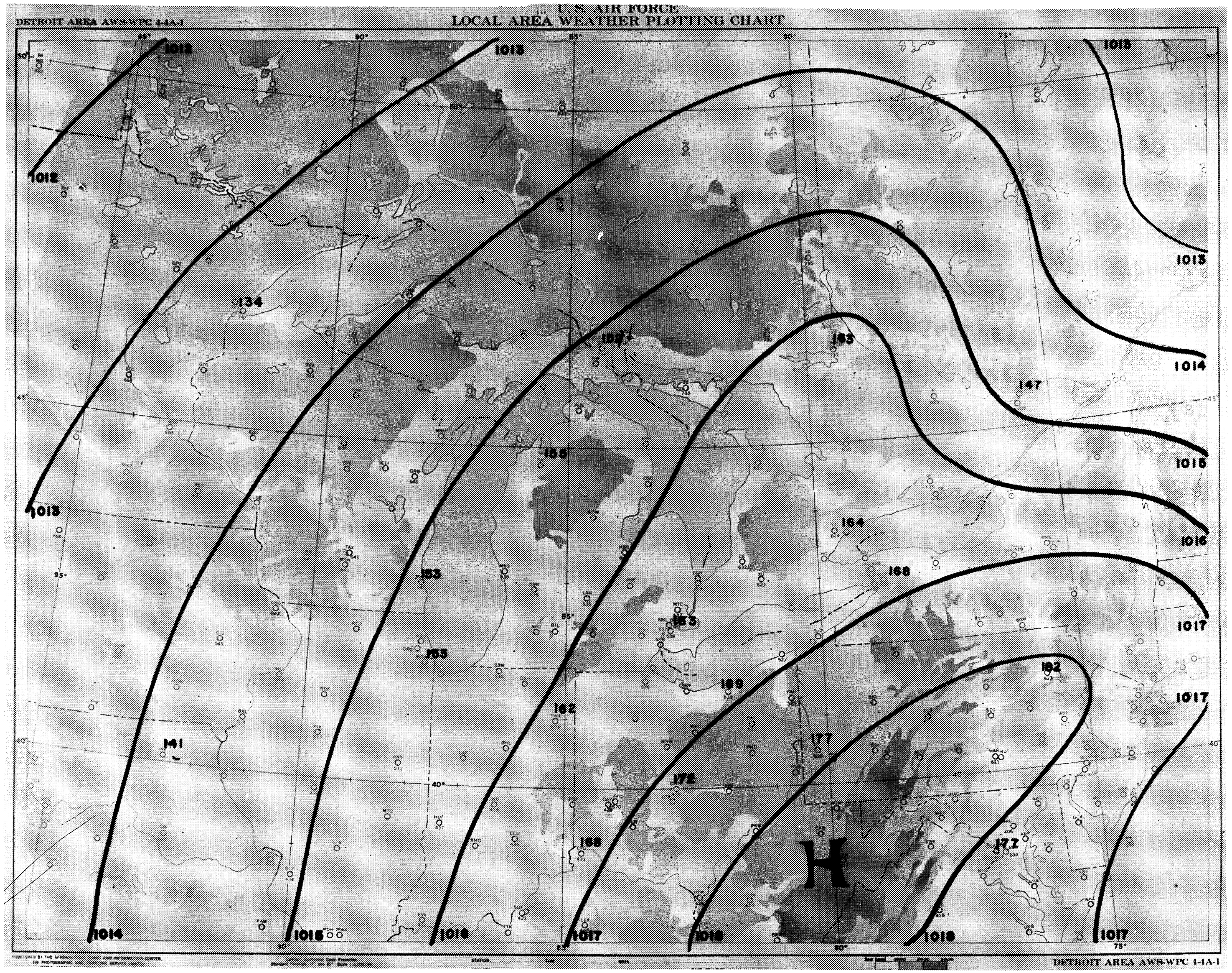


Fig. 23. Mean pressure map of Great Lakes area for 23 selected lake-breeze days.

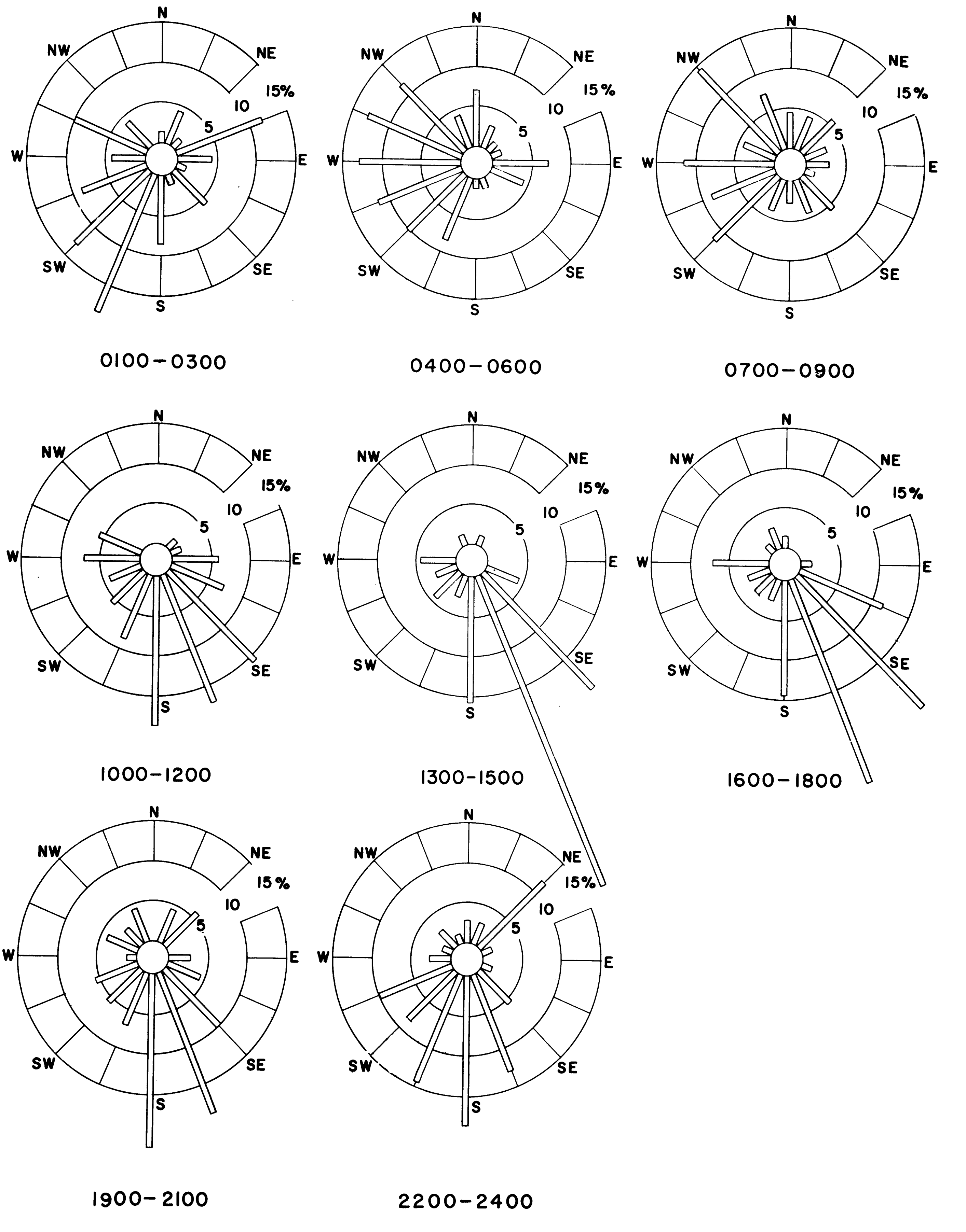


Fig. 24. Three hourly windroses for 23 selected lake-breeze days at the Enrico Fermi site.

WNW, NW, and NNW were combined for evidence of the nocturnal land breeze. These data and the temperature records discussed above have been plotted in Fig. 25 to permit comparisons.

The interval 1200 to 1800 EST is strikingly displayed as the characteristic lake-breeze period. By referring to the bottom block of the figure, it may be seen that during this 6-hour interval the temperature at Monroe remains essentially constant at a temperature of 80°F, as we would expect it to do, while that at Toledo rises to a maximum of 86°F. However, the interval within which the temperature at Monroe is depressed in relation to that at Toledo is somewhat longer, extending from about 1000 EST to 2000 EST. Combining the two pieces of evidence, one may infer that the average time of development of the lake breeze is about 1000 EST and that virtually 100% of all lake breezes have formed by 1200 EST. We also may infer that the lake-breeze regime, in some instances, terminates as early as 1800 EST and that half of it has terminated by 2000 EST.

Turning our attention to the land breeze from the middle chart of Fig. 25, the evidence is clear that a land breeze regime is occasionally realized. The frequency of winds from the W, WNW, and NW reaches a maximum during the last hours of darkness. Further, reference to the second windrose of Fig. 24 indicates that these are the prevailing winds for the hours ending 0400, 0500, and 0600. Returning to the mean map of Fig. 23 we see that these winds, blowing from low to high pressure, are in no sense characteristic of the circulation pattern. We may conclude that some form of local circulation from land to water has developed on many of the 23 days studied, and tentatively identify this as the nocturnal land breeze.

There remain some weaknesses in the evidence. For example, the average lake temperature at the Monroe Waterworks intake for the 23 days was 67.1°F. We observe that this is cooler, not warmer, than the average minimum observed at Lagoona Beach. On the other hand, the elevation of the temperature at Lagoona Beach that occurs at night in comparison to Toledo may result from the presence of a light circulation. Clearly the land breeze is less in evidence than the lake breeze, which is consistent with theory and with observation elsewhere.

5. CONCLUSIONS

a. A lake breeze develops at Lagoona Beach on warm summer days when the pressure gradient is light.

b. About half of the lake breezes occurred from 1000 EST to 2000 EST and virtually all of them persist from noon to 1800 EST.

c. The lake breeze is associated with a temperature inversion but wind speeds are generally 10 mph throughout.

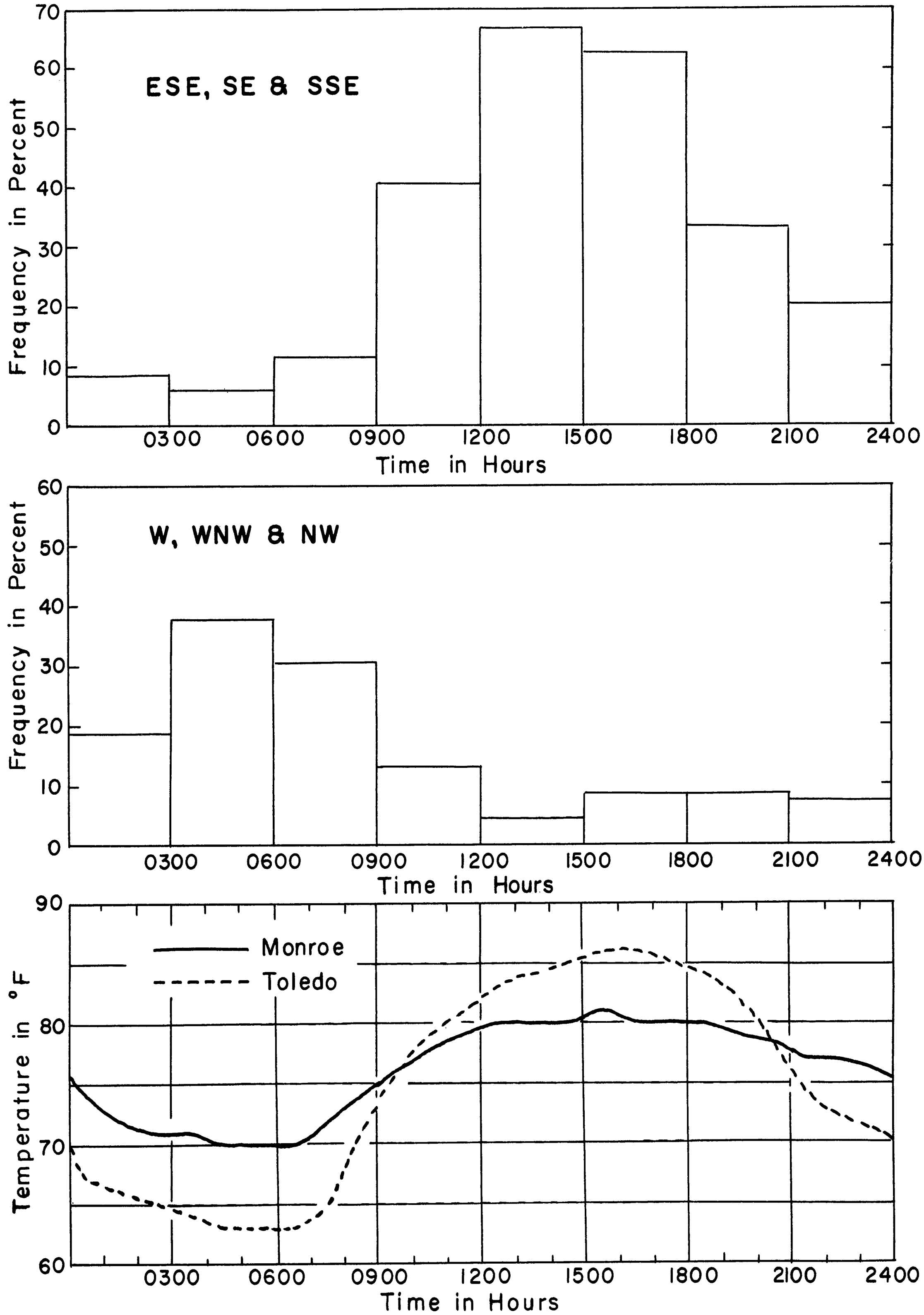


Fig. 25. Percentage frequency of diurnal lake breeze, ESE, SE, and SSE and diurnal land breeze, W, WNW, and NW and diurnal temperatures in °F at Monroe and Toledo for 23 selected lake-breeze days.

d. The significance of this association of inversion and lake breeze in relation to diffusion patterns at Lagoona Beach is not entirely obvious since the trajectories of air after crossing the beach are unknown. However, it is clear that inversions associated with moderate winds and a meso-scale mixing process, as these are, offer a better diffusion regime than is customary to associate with inversions.

e. Under the same meteorological situation, it appears that a nocturnal land breeze often develops. The land breeze is evidently weaker and/or less likely to occur than the lake breeze.

IV. ANALYSIS OF PRECIPITATION DATA

1. INTRODUCTION

Precipitation is one of the weather elements requiring consideration because of its scavenging effect upon particulates and gases suspended in air. From the standpoint of air pollution, the occurrence of rain may be either desirable or undesirable depending upon whether the scavenging takes place over an unpopulated area or a populated center. We observe that in the vicinity of Lagoona Beach the heavily populated areas are less extensive than the thinly populated areas. If we assume that the areas of rainfall occurrence are randomly distributed, we must concede that rainfall will be desirable more often than undesirable.

With these considerations in mind, we observe the frequency of rainfall at Lagoona Beach, comparing its frequency to that at Toledo Express Airport for the same period, and to the frequencies at Toledo Municipal Airport established over a 5-year period for the same season. As a further refinement, the analysis is undertaken separately for each wind direction. Thus we are able to tell at a glance if there is an association of precipitation with wind direction. The manner in which this is done is described in Section 4 of this part.

The frequency of measurable precipitation—i.e., .02 inch at Lagoona Beach and .01 inch at Toledo—and the pertinent wind data are presented season by season along with an annual summary for the above 3 stations in Tables XLVIII-LXII.

Figures 26 to 30 serve to illustrate graphically the association of winds with precipitation.

2. SEASONAL VARIATIONS IN FREQUENCY OF PRECIPITATION

Referring to Tables XLVIII - LXII, the entry at the bottom of the last column indicates the relative frequency of measurable precipitation for the station and season given. All these entries are summarized into Table LXIII for convenience. Precipitation is, of course, more frequent in winter and spring than in the other seasons. The 12 months under study are typical in this regard. The indicated deficiency at the Enrico Fermi site can be attributed to the different sensitivities of the two types of rain gages in use.

TABLE XLVIII

THE ASSOCIATION OF PRECIPITATION WITH WIND AT THE ENRICO FERMI SITE

1 December 1956 - 28 February 1957
(Winter)

Wind Direction	Average Wind Speed, mph	Average Wind Speed During Precipitation, mph	No. of Observations During Precipitation	Hours of Precipitation as Percentage of	
				Total Hours of Precipitation	Total Hours
N	14.2	20.6	9	7.6	0.4
NNE	14.9	17.8	14	11.9	0.6
NE	16.0	22.4	17	14.4	0.8
ENE	12.2	9.1	8	6.8	0.4
E	12.0	7.1	7	5.9	0.3
ESE	11.7	10.8	4	3.4	0.2
SE	11.1	11.0	5	4.2	0.2
SSE	12.0	14.0	1	0.8	0.1
S	13.3	14.4	5	4.2	0.2
SSW	15.2	15.9	14	11.9	0.6
SW	15.0	8.0	3	2.5	0.1
WSW	13.5	11.1	15	12.7	0.7
W	13.1	6.8	6	5.1	0.3
WNW	12.7	7.3	3	2.5	0.1
NW	11.2	12.7	3	2.5	0.1
NNW	11.6	18.5	4	3.4	0.2
Calm	0.0	0.0	0	0.0	0.0
Totals			118	100.0	5.3
Average	13.3	14.5			

TABLE XLIX

THE ASSOCIATION OF PRECIPITATION WITH WIND AT THE TOLEDO EXPRESS AIRPORT

1 December 1956 - 28 February 1957
(Winter)

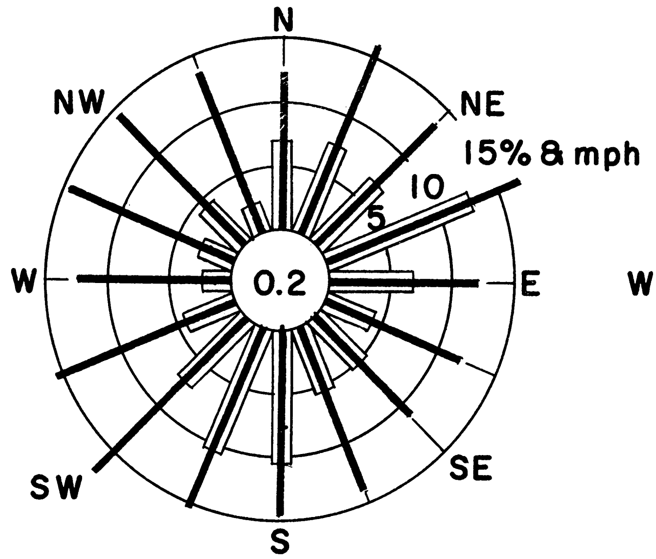
Wind Direction	Average Wind Speed, mph	Average Wind Speed During Precipitation, mph	No. of Observations During Precipitation	Hours of Precipitation as Percentage of	
				Total Hours of Precipitation	Total Hours
N	10.8	13.3	22	12.5	1.0
NNE	11.0	12.2	20	11.4	0.9
NE	10.0	13.1	14	8.0	0.6
ENE	9.0	11.0	9	5.1	0.4
E	9.1	7.6	8	4.5	0.4
ESE	7.5	4.8	3	1.7	0.1
SE	6.0	5.7	3	1.7	0.1
SSE	7.4	6.2	5	2.8	0.2
S	10.0	11.3	11	6.3	0.5
SSW	12.6	12.8	21	11.9	1.0
SW	12.9	12.4	18	10.2	0.8
WSW	11.9	9.7	16	9.1	0.7
W	10.8	9.2	5	2.8	0.2
WNW	10.4	8.5	8	4.5	0.4
NW	9.9	6.8	6	3.4	0.3
NNW	9.5	10.5	5	2.8	0.2
Calm	0.0	0.0	2	1.1	0.1
Totals			176	100.0	7.9
Average	10.4	10.9			

TABLE L

THE ASSOCIATION OF PRECIPITATION WITH WIND
AT THE TOLEDO MUNICIPAL AIRPORT

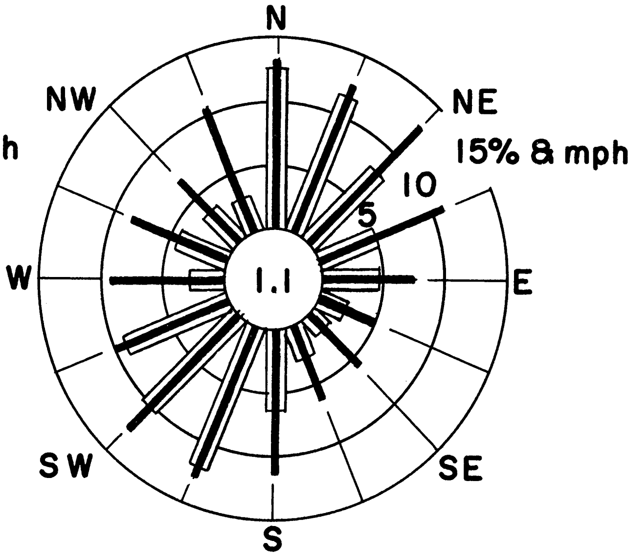
1 January 1950 - 31 December 1954
(Winter Seasons)

Wind Direction	Average Wind Speed, mph	No. of Observations During Precipitation	Hours of Precipitation as Percentage of	
			Total Hours of Precipitation	Total Hours
N	12.1	78	7.1	0.7
NNE	15.9	81	7.4	0.7
NE	13.6	75	6.8	0.7
ENE	16.7	136	12.4	1.3
E	12.0	73	6.7	0.7
ESE	11.9	46	4.2	0.4
SE	11.1	57	5.2	0.5
SSE	13.9	60	5.5	0.6
S	14.6	116	10.6	1.1
SSW	15.2	114	10.4	1.1
SW	16.9	77	7.0	0.7
WSW	15.7	47	4.3	0.4
W	12.4	26	2.4	0.2
WNW	14.5	32	2.9	0.3
NW	14.3	47	4.3	0.4
NNW	13.5	29	2.6	0.3
Calm	0.0	2	0.2	0.0
Totals		1096	100.0	10.1
Average	14.3			



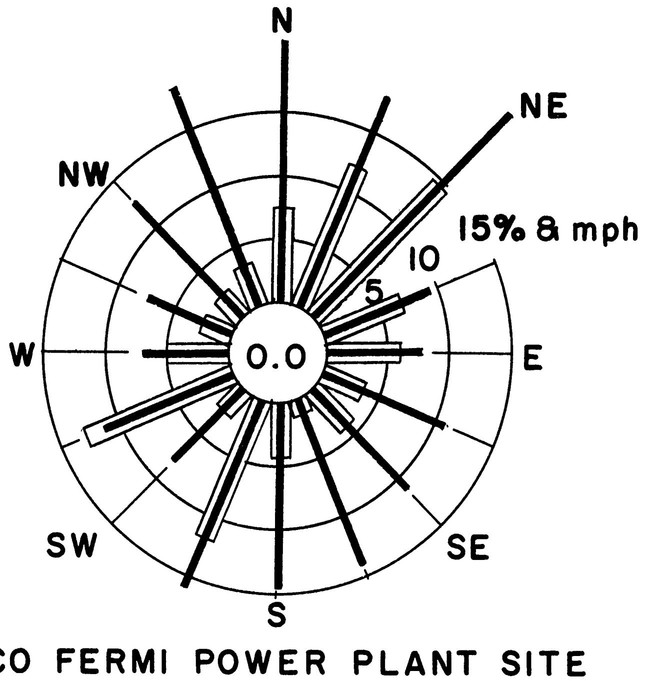
TOLEDO MUNICIPAL AIRPORT
TOLEDO, OHIO

Winter (Dec., Jan., Feb.) 1950-1954



TOLEDO EXPRESS AIRPORT
TOLEDO, OHIO

Winter (Dec., Jan., Feb.) 1957



ENRICO FERMI POWER PLANT SITE
LAGOONA BEACH, MICHIGAN

Winter (Dec., Jan., Feb.) 1957

Fig. 26. Percentage frequency of occurrence of winds from 16 directions and corresponding wind speed with precipitation at Toledo Municipal Airport, Winter Seasons, 1950-1954, and at Toledo Express Airport and the Enrico Fermi site, Winter, 1956-1957.

TABLE LI

THE ASSOCIATION OF PRECIPITATION WITH WIND AT THE ENRICO FERMI SITE

1 March 1957 - 31 May 1957
(Spring)

Wind Direction	Average Wind Speed, mph	Average Wind Speed During Precipitation, mph	No. of Observations During Precipitation	Hours of Precipitation as Percentage of Total Hours of Precipitation	Hours of Precipitation as Percentage of Total Hours
N	10.2	5.3	3	1.6	0.1
NNE	14.4	14.3	9	4.7	0.4
NE	15.9	15.3	9	4.7	0.4
ENE	16.5	18.9	36	18.7	1.6
E	13.6	25.5	38	19.7	1.7
ESE	14.2	15.7	8	4.1	0.4
SE	13.6	17.1	20	10.4	0.9
SSE	11.1	13.5	12	6.2	0.5
S	10.9	9.7	6	3.1	0.3
SSW	12.4	12.4	8	4.1	0.4
SW	14.7	14.5	10	5.2	0.5
WSW	16.1	14.8	9	4.7	0.4
W	12.8	15.5	2	1.0	0.1
WNW	15.0	17.2	20	10.4	0.9
NW	13.9	12.0	3	1.6	0.1
NNW	10.6	0.0	0	0.0	0.0
Calm	0.0	0.0	0	0.0	0.0
Totals			193	100.0	8.7
Average	14.0	17.7			

TABLE LII

THE ASSOCIATION OF PRECIPITATION WITH WIND AT THE TOLEDO EXPRESS AIRPORT

1 March 1957 - 31 May 1957
(Spring)

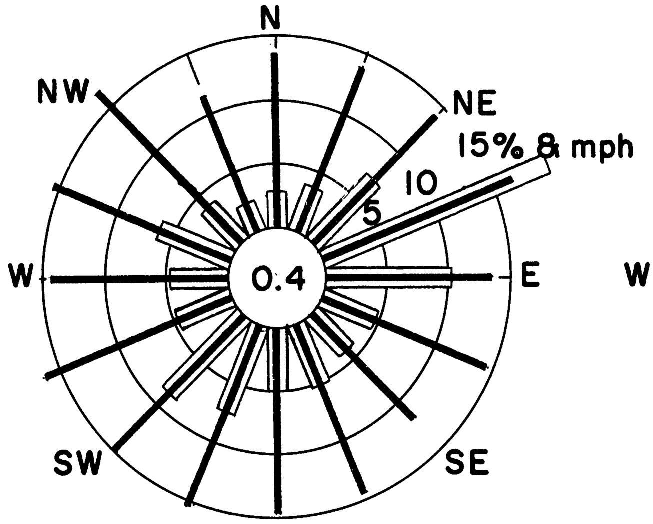
Wind Direction	Average Wind Speed, mph	Average Wind Speed During Precipitation, mph	No. of Observations During Precipitation	Hours of Precipitation as Percentage of	
				Total Hours of Precipitation	Total Hours
N	9.9	12.0	1	0.5	0.1
NNE	11.2	9.0	16	7.9	0.7
NE	10.0	9.5	16	7.9	0.7
ENE	12.2	11.4	30	14.9	1.4
E	12.5	14.2	54	26.7	2.4
ESE	8.6	8.6	6	3.0	0.3
SE	9.0	9.3	4	2.0	0.2
SSE	11.5	12.4	14	6.9	0.6
S	10.9	10.1	14	6.9	0.6
SSW	12.9	14.3	12	5.9	0.5
SW	15.4	12.3	10	5.0	0.5
WSW	16.3	11.5	4	2.0	0.2
W	11.9	10.0	3	1.5	0.1
WNW	11.4	10.6	10	5.0	0.5
NW	11.0	11.5	8	4.0	0.4
NNW	9.7	0.0	0	0.0	0.0
Calm	0.0	0.0	0	0.0	0.0
Totals			202	100.0	9.2
Average	12.1	13.1			

TABLE LIII

THE ASSOCIATION OF PRECIPITATION WITH WIND
AT THE TOLEDO MUNICIPAL AIRPORT

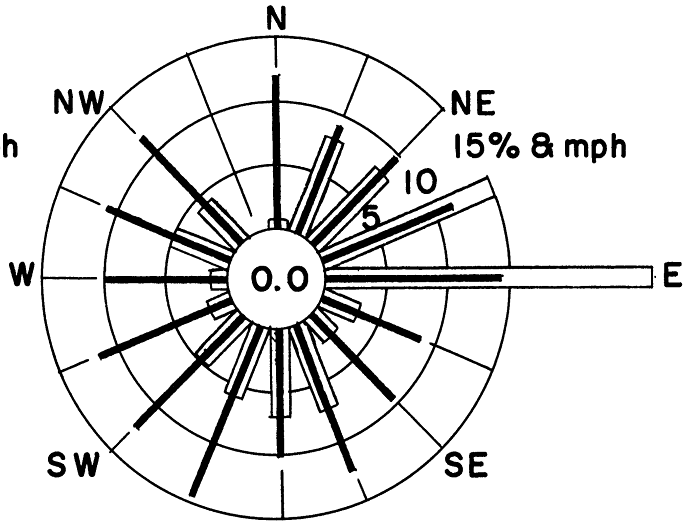
1 January 1950 - 31 December 1954
(Spring Seasons)

Wind Direction	Average Wind Speed, mph	No. of Observations During Precipitation	Hours of Precipitation as Percentage of	
			Total Hours of Precipitation	Total Hours
N	13.3	26	2.7	0.2
NNE	14.0	34	3.5	0.3
NE	13.9	69	7.1	0.6
ENE	16.3	193	19.8	1.7
E	13.4	98	10.1	0.9
ESE	14.5	44	4.5	0.4
SE	11.6	40	4.1	0.4
SSE	14.0	49	5.0	0.4
S	14.6	49	5.0	0.4
SSW	15.4	73	7.5	0.7
SW	14.8	84	8.6	0.8
WSW	16.4	46	4.7	0.4
W	14.3	45	4.6	0.4
WNW	15.5	57	5.9	0.5
NW	16.6	40	4.1	0.4
NNW	11.5	23	2.4	0.2
Calm	0.0	4	0.4	0.0
Totals		974	100.0	8.8
Average	14.7			



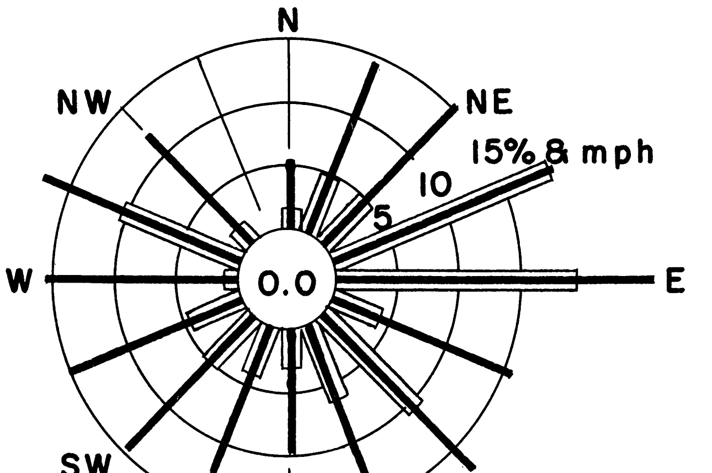
TOLEDO MUNICIPAL AIRPORT
TOLEDO, OHIO

Spring (Mar., Apr., May) 1950-1954



TOLEDO EXPRESS AIRPORT
TOLEDO, OHIO

Spring (Mar., Apr., May) 1957



ENRICO FERMI POWER PLANT SITE
LAGOONA BEACH, MICHIGAN

Spring (Mar., Apr., May) 1957

Fig. 27. Percentage frequency of occurrence of winds from 16 directions and corresponding wind speed with precipitation at Toledo Municipal Airport, Spring Seasons, 1950-1954, and at Toledo Express Airport and the Enrico Fermi site, Spring, 1957.

TABLE LIV

THE ASSOCIATION OF PRECIPITATION WITH WIND AT THE ENRICO FERMI SITE

1 June 1957 - 31 August 1957
(Summer)

Wind Direction	Average Wind Speed, mph	Average Wind Speed During Precipitation, mph	No. of Observations During Precipitation	Hours of Precipitation as Percentage of Total Hours of Precipitation	Hours of Precipitation as Percentage of Total Hours
N	8.2	7.0	1	2.2	0.1
NNE	9.6	6.7	3	6.7	0.1
NE	14.0	1.0	1	2.2	0.1
ENE	13.0	10.0	1	2.2	0.1
E	10.5	6.0	3	6.7	0.1
ESE	11.4	5.5	2	4.4	0.1
SE	10.5	0.0	0	0.0	0.0
SSE	9.4	5.5	2	4.4	0.1
S	9.8	11.8	8	17.8	0.4
SSW	10.3	13.5	4	8.9	0.2
SW	10.4	12.0	6	13.3	0.3
WSW	10.5	10.5	6	13.3	0.3
W	10.4	7.0	2	4.4	0.1
WNW	10.7	12.0	1	2.2	0.1
NW	9.3	12.0	1	2.2	0.1
NNW	8.6	11.5	4	8.9	0.2
Calm	0.0	0.0	0	0.0	0.0
Totals			45	99.8	2.4
Average	10.4	9.9			

TABLE LV

THE ASSOCIATION OF PRECIPITATION WITH WIND AT THE TOLEDO EXPRESS AIRPORT

1 June 1957 - 31 August 1957
(Summer)

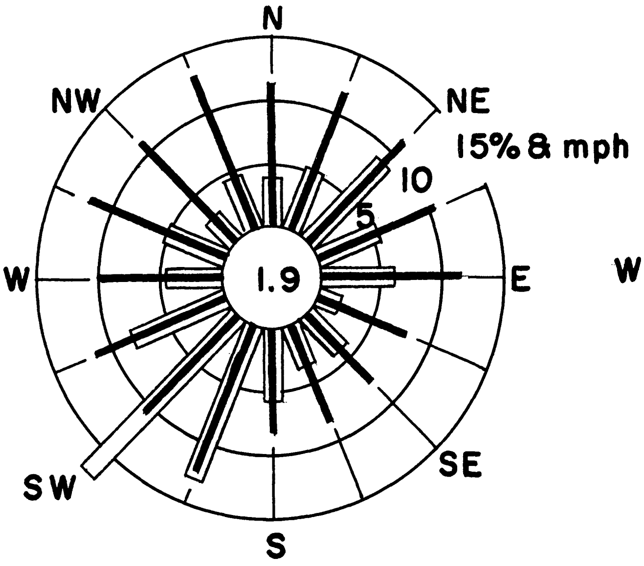
Wind Direction	Average Wind Speed, mph	Average Wind Speed During Precipitation, mph	No. of Observations During Precipitation	Hours of Precipitation as Percentage of	
				Total Hours of Precipitation	Total Hours
N	7.8	7.8	10	9.2	0.5
NNE	9.1	7.6	5	4.6	0.2
NE	9.1	10.8	4	1.8	0.1
ENE	9.9	5.0	2	1.8	0.1
E	7.7	7.0	2	1.8	0.1
ESE	6.4	5.0	2	1.8	0.1
SE	6.0	8.0	4	3.7	0.2
SSE	6.7	8.2	10	11.0	0.5
S	7.6	8.6	21	19.3	1.0
SSW	9.7	10.3	12	11.9	0.6
SW	9.1	12.3	16	13.8	0.7
WSW	9.7	12.3	9	8.3	0.4
W	8.8	10.3	4	3.7	0.2
WNW	10.5	7.4	5	4.6	0.2
NW	9.3	0.0	0	0.0	0.0
NNW	8.8	10.3	3	2.8	0.1
Calm	0.0	0.0	0	0.0	0.0
Totals			109	100.1	5.0
Average	8.6	9.4			

TABLE LVI

THE ASSOCIATION OF PRECIPITATION WITH WIND
AT THE TOLEDO MUNICIPAL AIRPORT

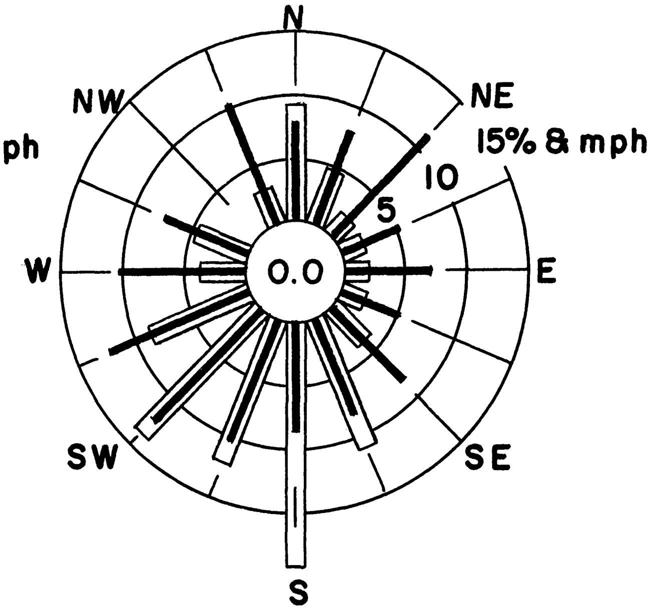
1 January 1950 - 31 December 1954
(Summer Seasons)

Wind Direction	Average Wind Speed, mph	No. of Observations During Precipitation	Hours of Precipitation as Percentage of Total Hours of Precipitation	Hours of Precipitation as Percentage of Total Hours
N	11.2	18	3.8	0.2
NNE	11.5	24	5.0	0.2
NE	11.0	42	8.8	0.4
ENE	10.2	25	5.2	0.2
E	11.3	28	5.9	0.3
ESE	7.6	8	1.7	0.1
SE	7.3	18	3.8	0.2
SSE	8.2	17	3.6	0.2
S	8.2	27	5.7	0.2
SSW	12.4	62	13.0	0.6
SW	10.8	82	17.2	0.7
WSW	11.4	38	8.0	0.3
W	9.8	21	4.4	0.2
WNW	12.0	24	5.0	0.2
NW	10.9	13	2.7	0.1
NNW	13.0	21	4.4	0.2
Calm	0.0	9	1.9	0.1
Totals		477	100.0	4.3
Average	10.6			



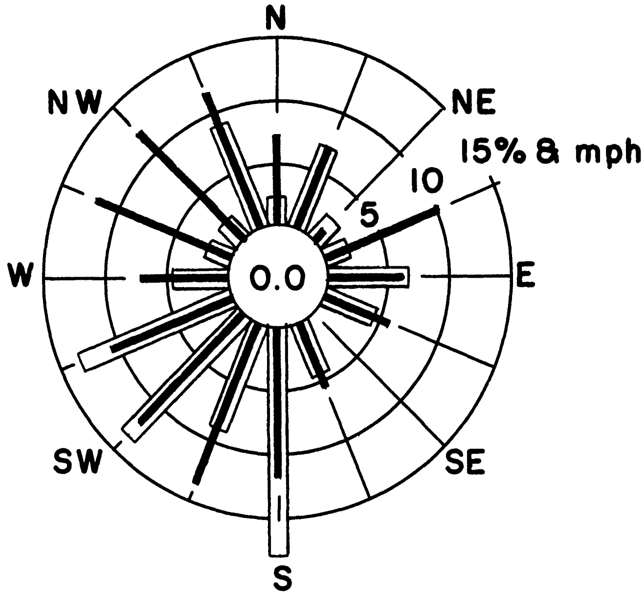
TOLEDO MUNICIPAL AIRPORT
TOLEDO, OHIO

Summer (Jun., Jul., Aug.) 1950-1954



TOLEDO EXPRESS AIRPORT
TOLEDO, OHIO

Summer (Jun., Jul., Aug.) 1957



ENRICO FERMI POWER PLANT SITE
LAGOONA BEACH, MICHIGAN

Summer (Jun., Jul., Aug.) 1957

Fig. 28. Percentage frequency of occurrence of winds from 16 directions and corresponding wind speed with precipitation at Toledo Municipal Airport, Summer Seasons, 1950-1954, and at Toledo Express Airport and the Enrico Fermi site, Summer, 1957.

TABLE LVII

THE ASSOCIATION OF PRECIPITATION WITH WIND AT THE ENRICO FERMI SITE

1 September 1957 - 30 November 1957
(Fall)

Wind Direction	Average Wind Speed, mph	Average Wind Speed During Precipitation, mph	No. of Observations During Precipitation	Hours of Precipitation as Percentage of	
				Total Hours of Precipitation	Total Hours
N	9.8	0.0	0	0.0	0.0
NNE	8.8	0.0	0	0.0	0.0
NE	14.5	1.0	1	1.2	0.1
ENE	13.5	9.5	2	2.4	0.1
E	11.6	13.0	2	2.4	0.1
ESE	9.7	9.0	1	1.2	0.1
SE	12.5	19.7	7	8.4	0.3
SSE	12.2	14.8	18	21.7	0.9
S	11.1	13.5	11	13.3	0.5
SSW	13.5	14.2	16	19.3	0.8
SW	12.7	11.3	8	9.6	0.4
WSW	16.0	12.8	5	6.0	0.2
W	11.6	8.7	3	3.6	0.1
WNW	10.2	12.3	3	3.6	0.1
NW	10.6	7.0	2	2.4	0.1
NNW	10.0	18.5	4	4.8	0.2
Calm	0.0	0.0	0	0.0	0.0
Totals			83	99.9	4.0
Average	12.1	11.8			

TABLE LVIII

THE ASSOCIATION OF PRECIPITATION WITH WIND AT THE TOLEDO EXPRESS AIRPORT

1 September 1957 - 30 November 1957
(Fall)

Wind Direction	Average Wind Speed, mph	Average Wind Speed During Precipitation, mph	No. of Observations During Precipitation	Hours of Precipitation as Percentage of	
				Total Hours of Precipitation	Total Hours
N	8.0	17.0	1	0.7	0.0
NNE	8.5	0.0	0	0.0	0.0
NE	8.4	7.7	3	2.1	0.1
ENE	9.5	10.0	2	1.4	0.1
E	9.2	8.9	10	7.1	0.5
ESE	6.7	5.0	1	0.7	0.0
SE	7.7	10.5	6	4.3	0.3
SSE	10.4	15.0	21	15.0	1.0
S	9.6	12.7	36	25.7	1.6
SSW	10.5	14.3	10	7.1	0.5
SW	12.6	11.8	12	8.6	0.5
WSW	12.8	8.9	14	10.0	0.6
W	12.0	13.5	6	4.3	0.3
WNW	9.5	7.5	6	4.3	0.3
NW	8.3	7.6	5	3.6	0.2
NNW	8.9	12.1	7	5.0	0.3
Calm	0.0	0.0	0	0.0	0.0
Totals			140	99.9	6.3
Average	9.9	11.8			

TABLE LIX

THE ASSOCIATION OF PRECIPITATION WITH WIND AT THE TOLEDO MUNICIPAL AIRPORT

1 January 1950 - 31 December 1954
(Fall Seasons)

Wind Direction	Average Wind Speed, mph	No. of Observations During Precipitation	Hours of Precipitation as Percentage of Total Hours of Precipitation	Hours of Precipitation as Percentage of Total Hours
N	14.6	36	5.7	0.3
NNE	15.2	40	6.3	0.4
NE	11.5	27	4.3	0.2
ENE	14.3	35	5.5	0.3
E	10.8	53	8.4	0.5
ESE	10.0	15	2.4	0.1
SE	9.4	14	2.2	0.1
SSE	13.6	35	5.5	0.3
S	14.3	69	10.9	0.6
SSW	13.6	77	12.1	0.7
SW	12.4	79	12.5	0.7
WSW	12.2	48	7.6	0.4
W	9.7	23	3.6	0.2
WNW	12.9	27	4.3	0.2
NW	17.1	33	5.2	0.3
NNW	19.2	18	2.8	0.2
Calm	0.0	5	0.8	0.0
Totals		634	100.0	5.8
Average	13.2			

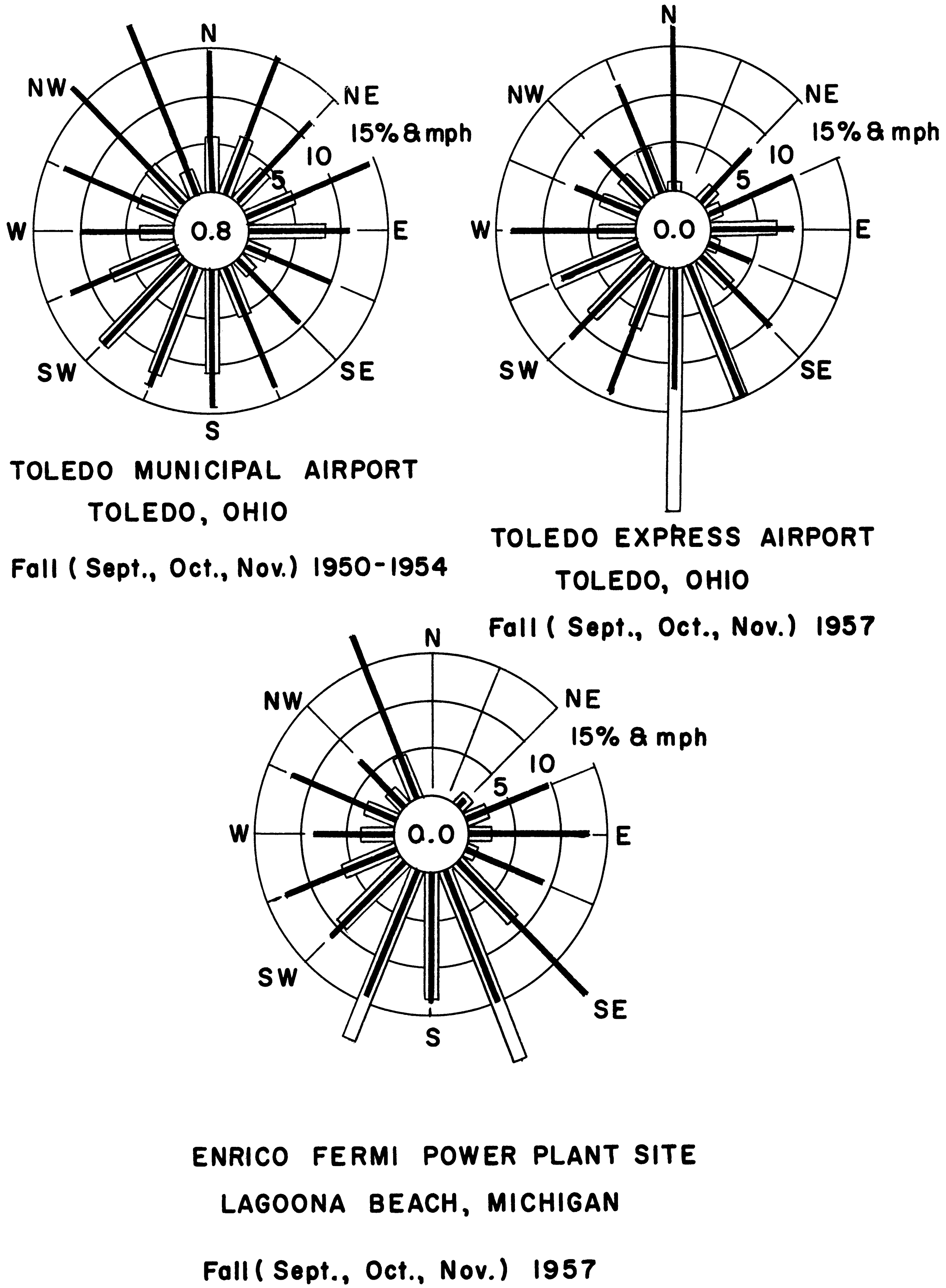


Fig. 29. Percentage frequency of occurrence of winds from 16 directions and corresponding wind speed with precipitation at Toledo Municipal Airport, Fall Seasons, 1950-1954, and at Toledo Express Airport and the Enrico Fermi site, Fall, 1957.

TABLE LX

THE ASSOCIATION OF PRECIPITATION WITH WIND AT THE ENRICO FERMI SITE

1 December 1956 - 30 November 1957
(Annual Summary)

Wind Direction	Average Wind Speed, mph	Average Wind Speed During Precipitation, mph	No. of Observations During Precipitation	Hours of Precipitation as Percentage of Total Hours of Precipitation	Hours of Precipitation as Percentage of Total Hours
N	10.9	16.2	13	3.0	0.2
NNE	12.1	15.3	26	5.9	0.3
NE	15.2	18.6	28	6.4	0.3
ENE	14.6	16.7	47	10.8	0.6
E	13.7	21.6	49	11.2	0.6
ESE	11.8	12.3	16	3.7	0.2
SE	11.9	16.7	32	7.3	0.4
SSE	10.8	13.9	32	7.3	0.4
S	11.1	12.4	30	6.9	0.4
SSW	12.8	14.4	42	9.6	0.5
SW	13.3	12.3	27	6.2	0.3
WSW	13.9	12.5	32	7.3	0.4
W	12.2	8.0	14	3.2	0.2
WNW	12.4	14.1	28	6.4	0.3
NW	11.1	11.1	9	2.1	0.1
NNW	10.1	16.2	12	2.7	0.1
Calm	0.0	0.0	0	0.0	0.0
Total			437	100.0	5.3
Average	12.5	14.5			

TABLE LXI

THE ASSOCIATION OF PRECIPITATION WITH WIND AT THE TOLEDO EXPRESS AIRPORT

1 December 1956 - 30 November 1957
(Annual Summary)

Wind Direction	Average Wind Speed, mph	Average Wind Speed During Precipitation, mph	No. of Observations During Precipitation	Hours of Precipitation as Percentage of	
				Total Hours of Precipitation	Total Hours
N	9.6	11.8	35	5.6	0.4
NNE	10.2	10.5	41	6.6	0.5
NE	9.7	10.7	35	5.6	0.4
ENE	11.0	11.0	45	7.2	0.5
E	10.9	12.4	72	11.5	0.8
ESE	8.1	6.4	12	1.9	0.1
SE	7.7	8.8	17	2.7	0.2
SSE	9.9	12.0	50	8.0	0.6
S	10.3	11.0	84	13.4	1.0
SSW	12.0	12.9	55	8.8	0.6
SW	13.3	12.2	55	8.8	0.6
WSW	13.1	10.2	40	6.4	0.5
W	11.8	11.0	18	2.9	0.2
WNW	10.9	8.8	29	4.6	0.3
NW	9.7	8.5	19	3.0	0.2
NNW	9.5	11.4	16	2.6	0.2
Calm	0.0	0.0	2	0.3	0.0
Totals			625	99.9	7.1
Average	10.9	11.1			

TABLE LXII

THE ASSOCIATION OF PRECIPITATION WITH WIND
AT THE TOLEDO MUNICIPAL AIRPORT

1 January 1950 - 31 December 1954
(Annual Summary)

Wind Direction	Average Wind Speed, mph	No. of Observations During Precipitation	Hours of Precipitation as Percentage of	
			Total Hours of Precipitation	Total Hours
N	12.7	158	5.0	0.4
NNE	14.8	179	5.6	0.4
NE	13.0	213	6.7	0.5
ENE	15.9	389	12.2	0.9
E	12.2	252	7.9	0.6
ESE	12.3	113	3.6	0.3
SE	10.6	129	4.1	0.3
SSE	13.2	161	5.1	0.4
S	13.8	261	8.2	0.6
SSW	14.3	326	10.2	0.7
SW	13.7	322	10.1	0.7
WSW	14.0	179	5.6	0.4
W	12.1	115	3.6	0.3
WNW	14.1	140	4.4	0.3
NW	15.4	133	4.2	0.3
NNW	14.0	91	2.9	0.2
Calm	0.0	20	0.6	0.0
Total		3181	100.0	7.3
Average	13.7			

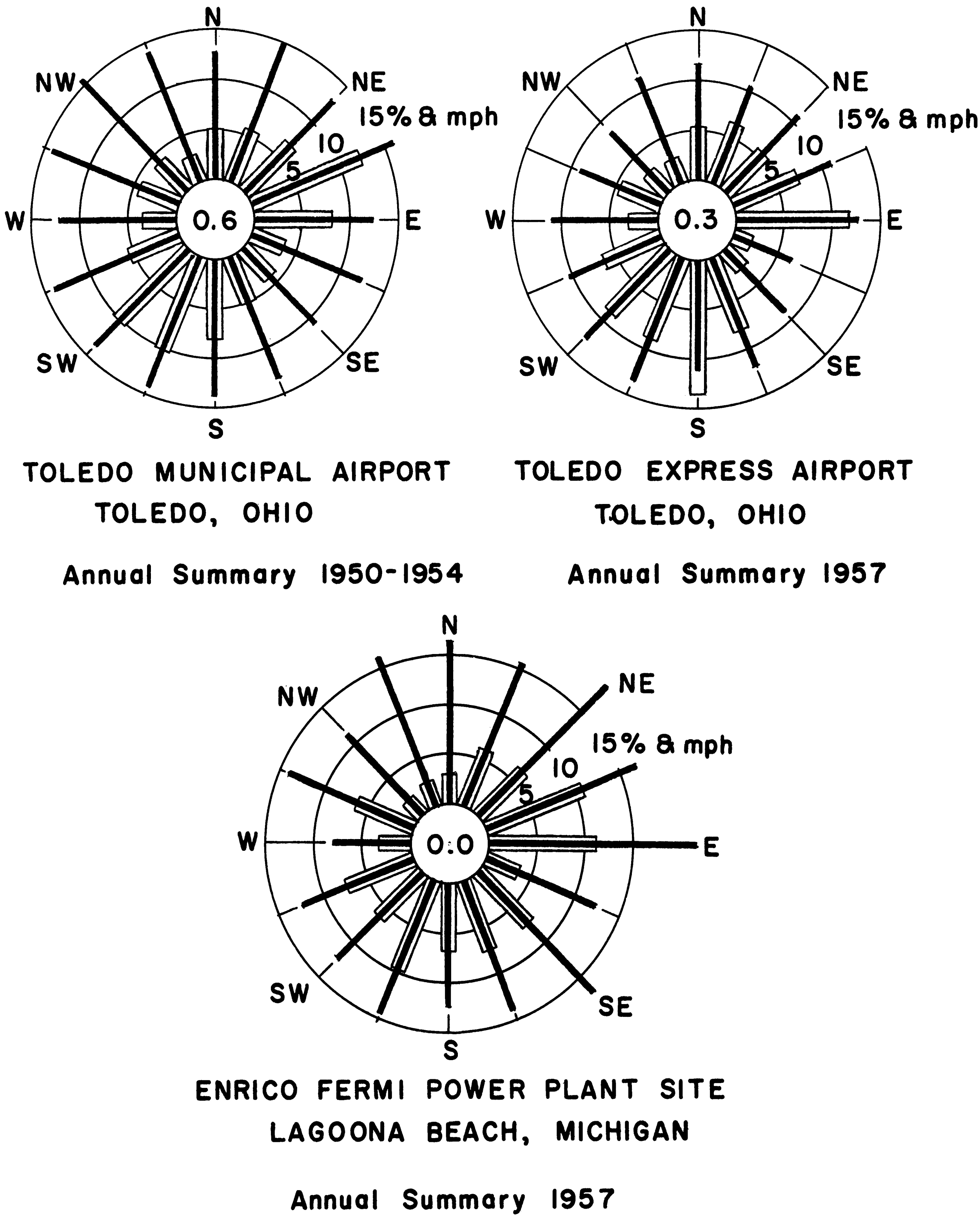


Fig. 30. Percentage frequency of occurrence of winds from 16 directions and corresponding wind speed with precipitation at Toledo Municipal Airport, Five-Year Summary, 1950-1954, and at Toledo Express Airport and the Enrico Fermi site, Annual Summary, 1956-1957.

TABLE LXIII

A COMPARISON OF RELATIVE FREQUENCY OF MEASURABLE PRECIPITATION AT THE ENRICO FERMI SITE, TOLEDO EXPRESS AIRPORT, 1 DECEMBER 1956 - 30 NOVEMBER 1957, AND TOLEDO MUNICIPAL AIRPORT, 1 JANUARY 1950 - 31 DECEMBER 1954 (.02 IN. MEASURABLE AT PLANT SITE, .01 IN. MEASURABLE AT TOLEDO)

	Enrico Fermi Site, %	Toledo Express Airport, %	Toledo Municipal Airport, %
Winter	5.3	7.9	10.1
Spring	8.7	9.2	8.8
Summer	2.4	5.0	4.3
Fall	4.0	6.3	5.8
Annual	5.3	7.1	7.3

3. THE ASSOCIATION OF WIND SPEED WITH PRECIPITATION

In general, precipitation is associated with above average wind speeds. This is shown by the overall average wind speed, and the average during precipitation, which appear as the entries at the bottom of columns 1 and 2 of Tables XLVIII - LXII. However, during the summer and fall, when precipitation is rather infrequent, there is essentially no difference between the overall average wind speed and the average for periods of precipitation only.

4. THE ASSOCIATION OF WIND DIRECTION WITH PRECIPITATION

The notion of conditional frequency is helpful in discussing the association of wind direction with precipitation. For example, we may consider the frequency of the event, Heads, in tossing a coin. Let us indicate this by $F(H)$. Let us also consider the conditional frequency of the event, Heads, given that it is raining outside. The notation is $F(H|R)$. For an unbiased coin

$$F(H) = F(H|R) = 0.5 \text{ (approximately)}$$

because the occurrence of heads when flipping a coin is in no way influenced by rain.

Now we may consider the analogous situation of conditional frequencies of the event, winds from direction D, given that it is raining [the notation is $F(D|R)$] and the simple frequency of the event, wind from direction D[notation $F(D)$]. If the occurrence of winds from direction D is independent of the condition of rain, we should observe that

$$F(D|R) = F(D).$$

Further, if the occurrence of precipitation and the wind direction are completely independent, then this relationship must hold for all wind directions. The entries of Tables XLVIII-LXII provide us with the values of $F(D|R)$, i.e., the conditional frequencies, which may be compared to the simple frequencies $F(D)$ from Tables XVIII-XLII. We conclude that in each season the occurrence of precipitation is in fact dependent upon wind direction since the quantities are generally not approximately equal.

Certain other features about the nature of precipitation are also revealed. During the winter, it may be noted that precipitation is associated about equally with northeasterly and southwesterly winds. These may be characterized as pre-warm-frontal and pre-cold-frontal, respectively. The emphasis definitely shifts to the warm-frontal or pre-warm-frontal type of precipitation associated with the easterly winds during the spring. This is seen most easily in the windroses of Fig. 27. During the summer, pre-cold-frontal rain is the dominant type as witnessed by the association of rain with southwesterly winds. Once again this is well illustrated by the windroses in Fig. 28. The picture in the fall does not differ significantly from that in summer.

V. CONCLUSIONS

Throughout this report, conclusions have been inserted after each part. The following list summarizes the facts presented in the report.

1. Inversion conditions are more frequent at thw WJBK-TV tower than at the Enrico Fermi site.

2. Three distinct types of inversions occur at the Enrico Fermi site, namely, nocturnal, circulation, and lake-breeze types.

3. The circulation and lake-breeze type of inversions which represent more than half of all the inversions are associated with wind speeds greater than or equal to 10 mph.

4. Inversions associated with moderate winds and a meso-mixing process offer a better diffusion regime than is customary to associate with inversions.

5. Circulation inversions at the plant site may persist for over two days or as long as air which is relatively much warmer than the underlying water crosses Lake Erie from the south. Such inversions are most probable in the late spring and least probable in the fall.

6. The year 1957 appears to be a typical year as concerns wind frequency distributions except for the summer season.

7. The frequency distributions of the wind indicate that Toledo Express Airport gives a closer approximation to the actual distribution at the Enrico Fermi site than does Detroit City Airport.

8. Winds which are off the lake are relatively stronger at the plant site than the same winds at Detroit and Toledo.

9. A lake breeze develops at Lagoona Beach on warm summer days when the pressure gradient is light. Under the same meteorological situation a nocturnal land breeze often develops which is weaker than the lake breeze.

10. Precipitation is generally associated with above average wind speeds at the Enrico Fermi site except during the summer and fall when precipitation is infrequent, and there is no difference between the overall average wind speed and the average wind speed during precipitation.

11. The frequency distribution of precipitation is dependent upon wind direction in all seasons of the year.

APPENDIX A

A METHOD FOR ELIMINATING THE BIAS FROM WIND-DIRECTION FREQUENCY STATISTICS

1. INTRODUCTION

Although it is now standard procedure at first-order weather stations to report wind directions to 16 points of the compass, it is not uncommon to discover evidence of a bias in the records. This bias takes the form of an apparently greater frequency of winds from the eight primary points (N, NE, E, SE, S, SW, W, and NW) than of winds from the eight intermediate points (NNE, ENE, ESE, SSE, SSW, WSW, WNW, and NNW). For example, the record may indicate that N winds are more frequent than NNW or NNE, NE winds are more frequent than NNE or ENE, E winds are more frequent than ENE or ESE, and so on around the compass. Since nature clearly has no preference for the cardinal points unless there is an unusual arrangement of valleys intersecting precisely at the weather station, this improbable result must be attributed to observer bias, specifically a preference for reporting the wind direction as one of the eight primary points.

2. TESTING FOR PRESENCE OF BIAS

In the case of the City A records, there is scarcely any need for a rigorous check for bias since a casual observation shows that a bias exists. However, such a check can easily be made by measuring the compatibility of the observed and expected frequencies. This test, known as the Chi-Square Test, is usually designated by χ^2.

$$\chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i} ,$$

where

O_i = observed frequencies,
E_i = expected frequencies, and
K = number of pairs of frequencies to be compared.

This test should be made when the evidence of bias is not so strikingly evident.

Consider the eight cardinal compass directions. The reported frequency of each of these directions may be assigned to one of three categories as follows:

Category	Identification	Probability of Occurrence	Expected Occurrences
I	Reported frequency exceeds that of both adjacent intermediate compass points.	.25	2
II	Reported frequency exceeds that of one adjacent intermediate compass point.	.50	4
III	Reported frequency exceeds neither adjacent intermediate compass point.	.25	2

The right-hand column indicates the expected frequency of occurrence of this event among eight cardinal compass points. These occurrences are assumed to stem from a population of unbiased records.

The quantity

$$\sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i}$$

that we are interested in has a χ^2 distribution with 2 degrees of freedom. This means that a number may be placed in either category I, II, or III but if a value is assigned to any two of these categories, then the value of the third one is fixed since the total of categories I, II, and III must equal 8. The number of degrees of freedom is defined as k-1 where k is again the number of pairs of frequencies to be compared. In the case at hand there are three categories so k = 3. Then k-1 = 2.

Wind-frequency statistics for City A were subjected to a χ^2 analysis. The results are shown in Table LXIV.

TABLE LXIV

COMPUTATIONS OF χ^2 FROM CITY A RECORDS

Season	Number of Occurrences			χ^2
	Category I	Category II	Category III	
Fall '56	7	0	1	17.00
Winter '56-'57	8	0	0	24.00
Spring '57	6	1	1	10.75
Fall '51-'55	8	0	0	24.00
Winter '51-'55	7	1	0	16.75
Spring '51-'55	7	1	0	16.75

From tables of X^2 a value greater than 10.60 can be expected to occur with a frequency of less than one in two hundred where there is no bias. The large values of X^2 in the above table indicate that it is highly probable that the record has a bias.

3. REMOVING THE BIAS FROM THE RECORD

A satisfactory method of removing the bias from the wind record must itself be free of bias, and must involve the minimum amount of smoothing. In the light of these criteria, two tests may be applied to determine the best method of eliminating the bias. First, when a method for removing the bias is applied to a record that is believed to be biased, the resulting table of wind frequencies must indicate no bias when subjected to the X^2 test. If two or more methods of removing the bias meet the test of being free of bias, the best method is that which effects the least smoothing to a nonbiased record. Two simple methods of removing the bias will be described, and the best method will be selected on the basis of the two tests stated above.

First Method.[4]—The method will be demonstrated with the reported wind occurrences at City A for October and November, 1956. The logic behind the method is as follows. Reported occurrences for each of the cardinal points are considered to be too high (positive bias), whereas for each adjacent intermediate point, occurrences are too low (negative bias). If the average frequency of each compass point and the adjacent clockwise point is computed, an unbiased 16-point wind record is obtained. However, the computed frequencies will refer to 16 points which are rotated 12.25° clockwise from the desired point. If frequencies are computed for 16 points which are rotated 12.25° counterclockwise from the desired directions, by the same procedure, then the average of the two sets of frequencies will be an unbiased record for the desired 16 compass points.

As an illustration, consider the case of NE winds (Table LXV). The reported frequencies of NNE, NE, and ENE winds are 57, 115, and 44, respectively. The average frequency of the NE with the ENE wind is (115+44)/2; the average frequency of the NE with the NNE wind is (115+57)/2. This gives the clockwise and counterclockwise displacement of 12.25°. To get the frequency of the NE winds with the bias removed, we average these two displacements. Therefore the average frequency of NE winds is

$$\frac{(115+44)/2 + (115+57)/2}{2} \quad \text{or simply} \quad \frac{115 + 44/2 + 57/2}{2} = \frac{165}{2} = 82 .$$

This then gives us a general equation to compute the frequencies with the bias eliminated:

$$f_n = \frac{f_o + f_c/2 + f_{cc}/2}{2} ,$$

TABLE LXV

REPORTED WIND OCCURRENCES AND COMPUTED OCCURRENCES WITH BIAS REMOVED (METHOD 1)

City A
1 October 1956 - 30 November 1956

Wind Direction	Column 1: Reported Occurrences	Column 2: $\frac{f_{cc}}{2}$	Column 3: $\frac{f_c}{2}$	1+2+3	Frequency with Bias Removed $\frac{1+2+3}{2}$
N	136	16	28	180	90
NNE	57	68	58	183	92
NE	115	28	22	165	82
ENE	44	58	27	129	64
E	54	22	10	86	43
ESE	19	27	96	142	71
SE	191	10	57	258	129
SSE	114	96	66	276	138
S	133	57	33	223	112
SSW	66	66	50	182	91
SW	101	33	34	168	84
WSW	69	50	30	149	74
W	60	34	42	136	68
WNW	83	30	72	185	92
NW	143	42	16	201	100
NNW	32	72	68	172	86
Calm	47	→	→	→	47

where

f_n = new computed frequency with the bias eliminated,
f_o = old frequency at the point under consideration,
f_c = old frequency next to the point under consideration in the clockwise direction, and
f_{cc} = old frequency next to the point under consideration in a counterclockwise direction.

The computed frequencies with bias eliminated appear as the last column of Table LXV. In Table LXIV it was pointed out that the original record yielded a value of χ^2 of 17.00. The new record gives $\chi^2 = 0.75$, indicating the effect of the smoothing process. In this case we assume, therefore, that most of the bias has been eliminated.

Second Method.—The second method assumes that the positive bias of the cardinal points is constant and that valid comparisons between cardinal points are offered by the reported frequencies. Similarly, it assumes that the negative bias of the intermediate points is constant and that valid comparisons may be made between intermediate points. That is to say, if the reported frequency of NE winds is twice that of E winds, this may be accepted as their true relationship although both are actually less frequent than reported.

The computations, which are illustrated in Table LXVI, first effect a transformation into an unbiased 8-point record by apportioning the occurrences of the intermediate points to the adjacent cardinal points on the basis of the comparative frequencies of the two cardinal points. Having done this, half of the computed 8-point occurrences are attributed to the central 22.5° of the whole 45° sector. The remaining half of the 8-point occurrences are apportioned between the adjacent intermediate points on the basis of their comparative occurrences. The occurrences of the cardinal points with the bias removed are obtained by halving the 8-point occurrences. As an illustration, consider the reported frequencies of N, NNE, NE, ENE, and E winds which are 136, 57, 115, 44, and 54, respectively (Table LXV). Computing the occurrence of NE winds with the bias removed for an 8-point compass we get

$$115 + \left(\frac{115}{115+136}\right)57 + \left(\frac{115}{115+54}\right)44 = 115 + 26 + 30 = 171 \quad .$$

By halving this number, the occurrence of NE winds with bias eliminated is obtained (171/2 = 86). The remaining 85 occurrences (171-86) are assigned to NNE and ENE as follows: to NNE, [57/(57+44)]85 = 48, and to ENE, (85-48 = 37). Thus each of the newly computed frequencies for the intermediate direction will have two components. The right-hand column in Table LXVI gives $\chi^2 = 2.00$, which falls within our assumed criterion for the elimination of the bias.

TABLE LXVI

REPORTED WIND OCCURRENCES AND COMPUTED OCCURRENCES WITH BIAS REMOVED (METHOD 2)

City A
1 October 1956 - 30 November 1956

Wind Direction	Reported Occurrences	Add to Cardinal Points	8-Point Bias Removed	Components of Intermediate Points	16-Point Occurrences: Bias Removed
N	136	15+31	182		91
NNE	57			58+48	106
NE	115	26+30	171		86
ENE	44			37+25	62
E	54	14+4	72		36
ESE	19			11+20	31
SE	191	15+67	273		136
SSE	114			117+69	186
S	133	47+38	218		109
SSW	66			40+42	82
SW	101	28+43	172		86
WSW	69			44+25	69
W	60	26+25	111		56
WNW	83			30+79	109
NW	143	58+17	218		109
NNW	32			33+30	63
Calm	47	→	→	→	47

4. COMPARISON OF METHOD 1 AND METHOD 2

The two methods may be compared by applying each of them to the reported occurrences at City B for the period 12 October - 30 November 1956. Table LXVII contains reported occurrences at City B, and computed occurrences with the bias eliminated by use of both methods. Since the reported occurrences gives $X^2 = 2.75$, the record appears to be unbiased. Accordingly, the better method will be that which effects the least smoothing to the frequencies as reported. Figure 31 presents graphically this comparison between reported relative frequencies and relative frequencies computed by the two methods for removal of bias. Method 1 has a standard deviation of 2.4% from the reported relative frequencies, compared to 1.6% for method 2. Method 2 is therefore selected as the better of the two.

5. CONCLUSION

By means of a simple Chi-square test, bias may be detected in records of occurrences of winds by directions. Biased records may have the bias removed with a minimum of smoothing by the second of the two methods described in the foregoing. In the present report, all tables of wind occurrences for City A have had the bias removed in this way. Records with the bias eliminated are better than biased records, but can never be more than an approach to the true, unbiased record. Observers should be trained to observe winds without making the observations subject to personal preferences.

TABLE LXVII

FREQUENCY OF OCCURRENCE OF WINDS FROM VARIOUS DIRECTIONS
AS REPORTED AND AS COMPUTED BY TWO METHODS FOR REMOVING THE BIAS

City B
12 October 1956 - 30 November 1956

Wind Direction	Occurrences			Relative Frequencies		
	Reported	Method 1	Method 2	Reported	Method 1	Method 2
N	103	106	130	8.7	8.9	11.0
NNE	195	132	162	16.5	11.1	13.7
NE	37	70	48	3.1	5.9	4.1
ENE	9	15	6	0.8	1.3	0.5
E	6	9	4	0.5	0.8	0.3
ESE	17	19	16	1.4	1.6	1.3
SE	35	32	30	3.0	2.7	2.5
SSE	40	55	41	3.4	4.6	3.5
S	105	113	136	8.8	9.5	11.5
SSW	202	139	164	17.0	11.7	13.8
SW	49	92	75	4.1	7.8	6.3
WSW	67	54	48	5.7	4.6	4.1
W	37	54	49	3.1	4.6	4.1
WNW	77	60	68	6.5	5.1	5.7
NW	52	51	52	4.4	4.3	4.4
NNW	23	50	22	1.9	4.2	1.9
Calm	131	131	131	11.1	11.1	11.1

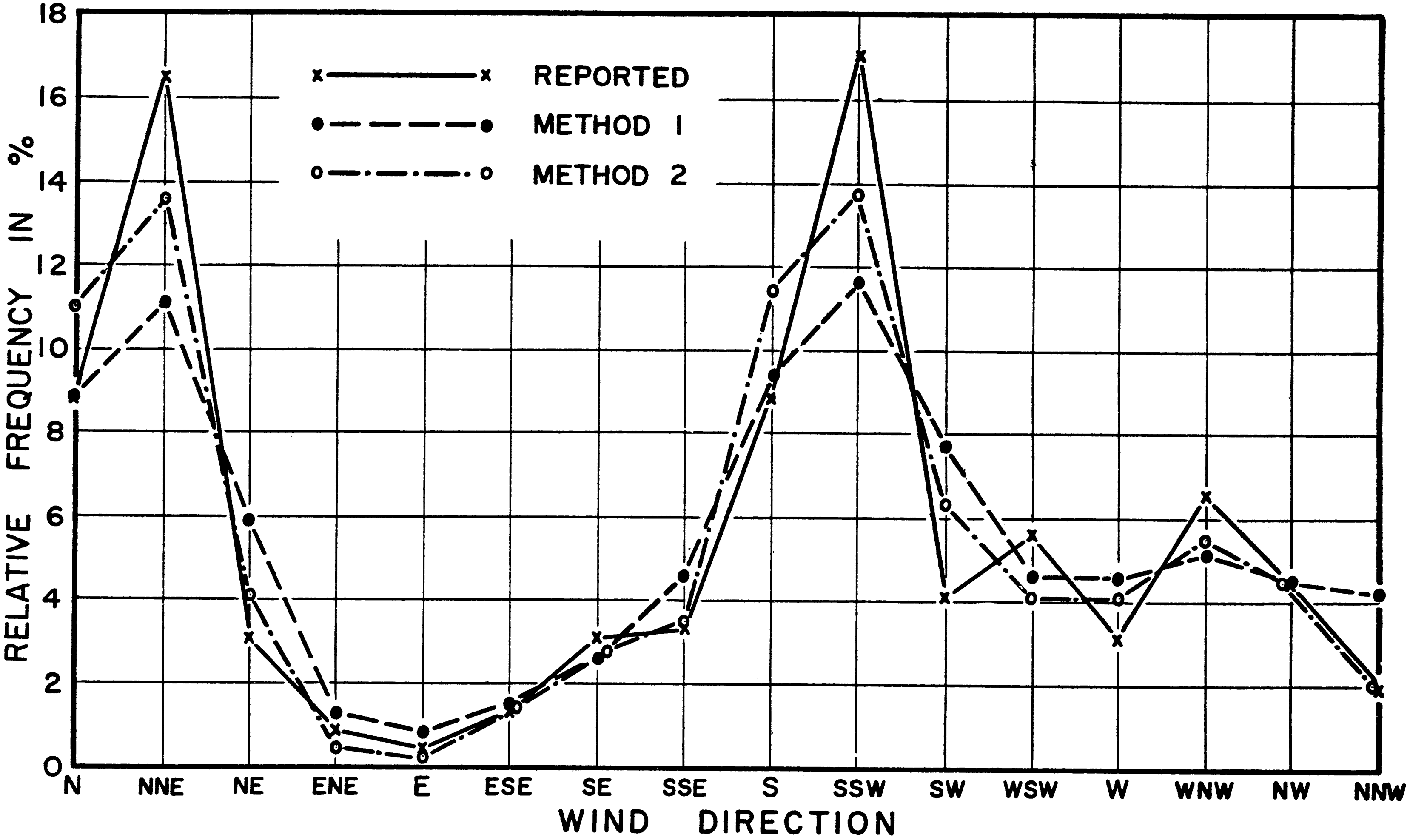


Fig. 31. Comparison of relative frequencies of wind at City B, USA, as reported and as computed by the two methods for removing bias, 12 October - 30 November 1956.

APPENDIX B

THE FORCE WHICH GENERATES LAND AND LAKE BREEZES

It is known that the force which sets the lake breeze in motion is the more rapid heating of the air over land than over the adjacent lake surface during the daytime. Conversely, the force which sets the land breeze in motion is the greater cooling of the air over land than over the lake surface at night.

Many reasons for the more rapid heating of the land surface than the adjacent water surface have been given. Although the ratio of the specific heats of sand, rock, and typical soil to that of water is about 1 to 5.5, the ratio of their specific gravities is about 3.7 to 1. The net result is that the ratio of the thermal capacities per unit volume of sand and soil to that of water is about 1 to 1.5. However, the much greater thermal conductivity of the soil and sand compared to the water neutralizes the residual difference from the first two factors and, as pointed out by Defant, "measurements reveal that the surfaces of water and sandy or rocky ground have temperature variations of comparable order."[5] Clearly, then, we must look elsewhere for an explanation of the differential heating that is observed.

Wexler[6] lists a number of factors that have been suggested at various times as accounting for the phenomenon, showing that each of these must be insignificant. For example it has been suggested that the greater penetration of the sun's rays into the water can account for the differential heating, but it is known that the infrared radiation is absorbed in the uppermost layer of the water. The greater amount of reflected radiation from the water surface has been cited, but Wexler points out that "with the sun at an altitude of 40 degrees the reflection from the water surface is slight (about 4 per cent) as compared to sand." Cooling of the water surface due to evaporation has also been mentioned in this connection, but Wexler reminds us that, with light wind speeds, which is the most favorable situation for sea breeze development, this factor is small.

The true explanation for the greater heating of the land surface is found in the turbulent mixing of the water which is set in motion by the waves. This results in a continuous downward flux of the heat which has been introduced at the surface by the sun's rays. Naturally, the temperature variation that takes place at the surface of the water is relatively small. In contrast to this behavior is the complete absorption of the incoming radiant energy on the surface of the sand, rock, or soil. The evidence of this is provided by the extremely high temperatures assumed by such surfaces in the direct summer sun.

The manner in which this differential heating generates the lake breeze is described by Brunt.[7] Starting with uniform pressure and temperature along the shoreline, the sun warms the air over the land more rapidly than that over the water. Through a layer of a few hundred feet the air becomes less dense over land than over water. Therefore pressure decreases less rapidly with height over land than over water, and at the top of the affected layer, pressure is high over land and low over the water. At this stage in the development of the lake breeze, the orientation of isobaric surfaces and isosteric (equal density) surfaces is as shown in the cross-sectional view of Fig. 32. Brunt shows mathematically that, whenever the isobaric and isosteric surfaces intersect as in Fig. 32, a circulation will be set up tending to bring the surfaces into phase again. Intuitively, it can be seen from Fig. 32 that air aloft will begin to move out over the water toward the region of lower pressure, inducing pressure changes at the surfaces. As a result of the surface-pressure changes, i.e., decreased over the land and increased over the lake, the surface lake breeze begins to blow. The circulation is closed by broad regions of ascending air over land and descending air over water.

The explanation of the land breeze proceeds in quite similar fashion. During the night the cooling of the water surface takes place much less rapidly than the land surface, again because of the turbulent mixing of the water. A local pressure gradient is established, this time in the reverse direction. In fact, the principal difference between the two circulations is introduced by stability factors. In many cases the daytime lake breeze receives an additional acceleration from gravitational forces realized by the establishment of superadiabatic lapse rates over the land. In general, there is no nocturnal counterpart, which accounts to some extent for the greater strength of the lake breeze than the land breeze.

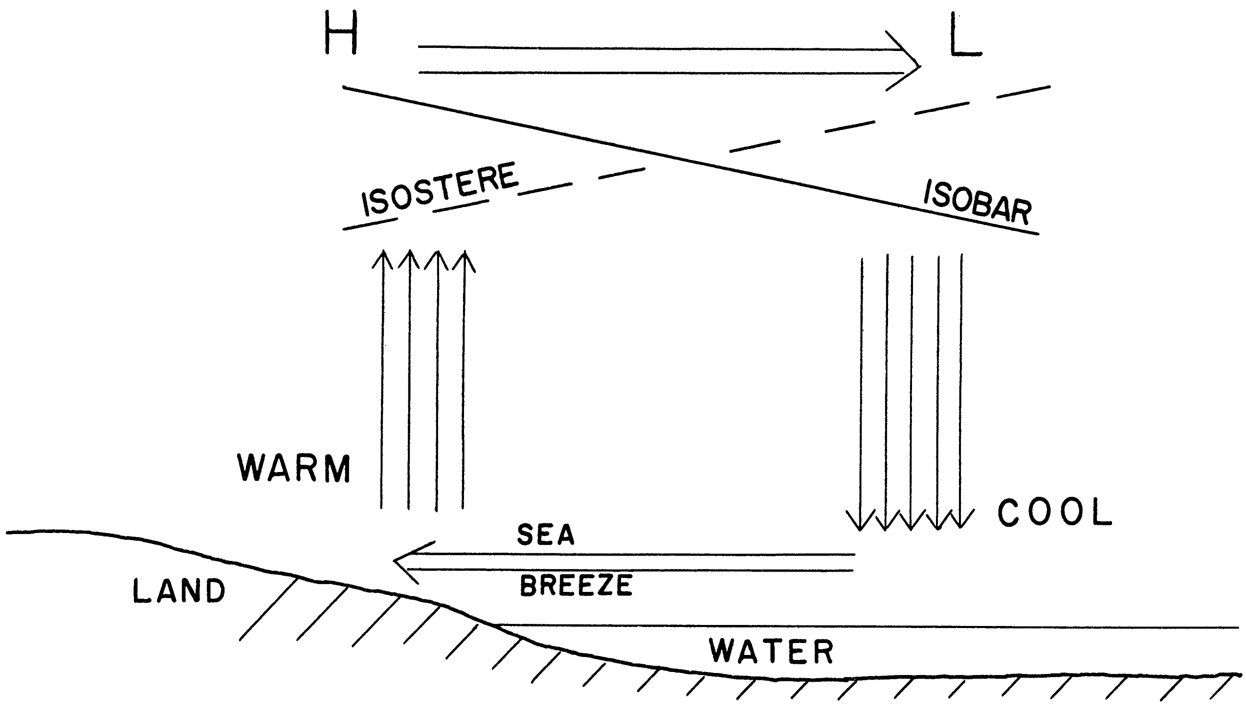


Fig. 32. Schematic diagram of lake-breeze circulation.

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