AN INVESTIGATION OF ATMOSPHERIC DIFFUSION IN THE VICINITY OF THE ENRICO FERMI ATOMIC POWER PLANT

Report No. 2: Measurement and Analysis of Surface Characteristics of the Lake Breeze

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ABSTRACT

Measurements and analyses of surface lake breeze characteristics inland from the Enrico Fermi Atomic Power Plant are described. Battery-powered wind speed and direction recording systems designed and built for the study and conventional hygrothermographs at 6 locations up to 6 miles inland provide the basic wind, temperature and humidity data for the study and are described in detail. Results of the lake breeze analysis using three years of measurements show that lake breezes occur on about one-third of the days for the months between April and October, over half of which move inland at least 6 miles. Wind direction fluctuations in lake breeze situations are analyzed in relation to wind speed and Pasquill diffusion categories.

TABLE OF CONTENTS

		Page
ABSTRACT		ii
LIST OF FIGURES		iv
LIST OF TABLES		v
I	INTRODUCTION	1
II	MEASUREMENTS AT INLAND STATIONS	3
	Wind speed and direction system	3
	Temperature and relative humidity equipment	11
	Calibration of equipment	14
	Locations and installation	15
	Data processing	17
III	FIRST RESULTS OF LAKE BREEZE STUDY	20
	Meteorological changes caused by a lake breeze front	20
	Frequency of occurrence and penetration inland	31
IV	WIND DIRECTION FLUCTUATIONS	38
	Tests of the relationship of wind direction range to standard deviation	38
	Standard deviation of wind direction in lake breezes	43

LIST OF FIGURES

Figure		Page
1.	Gill propeller vane	5
2.	Wind system translator	7
3.	10-meter tower with propeller vane	10
4.	Shelter containing wind translator, recorders, and battery	12
5.	Belfort hygrothermograph in weather shelter	13
6.	Map showing locations of inland stations	16
7.	Wind direction recordings for 6 stations during a true lake breeze situation on 8 August 1971	23
8.	Temperature and relative humidity recordings for the week including the lake breeze situation on 8 August 1971	24
9.	Weather map for 8 August 1971	26
10.	Weather map for 10 June 1971	30
11.	Wind direction recordings for 6 stations during lake breeze enhancement on 10 June 1971	32
12.	Temperature and relative humidity recordings for the week including lake breeze enhancement on 10 June 1971.	33
13.	Percent occurrence of lake breezes at various distances inland.	36
14.	Response of Esterline-Angus Model 601C recorder for various chart speeds	40
15.	Ratio of wind direction range to standard deviation versus range for 6-ipm chart speed	42
16.	Ratio of wind direction range for 6-iph chart speed to standard deviation for 6-ipm chart speed versus range for 6-iph chart speed	42
17.	Standard deviation of wind direction at 10 meters versus wind speed for lake breeze situation at 0.8 miles inland	44

LIST OF TABLES

Table		Page
1	Lake breeze occurrences for all gradient wind directions	35
2	Lake breeze occurrences in opposition to a gradient wind	35

I INTRODUCTION

In 1970, work was begun on Contract No. C-071023 between the University of Michigan and the Detroit Edison Company to determine the nature of atmospheric diffusion in the vicinity of the Enrico Fermi Atomic Power Plant. The power plant is located about 6 miles northeast of Monroe on the western shore of Lake Erie. The specific goal is to determine the frequency of occurrence of different diffusion conditions in order to assess the potential hazard from both routine and accidental releases of radioactive materials. The approach to the goal is through the analysis of atmospheric transport and turbulent diffusion for various meteorological conditions. It emphasizes the acquisition of information on the nature of onshore flow and the resulting transitional diffusion regimes.

A type of onshore flow of special concern is the lake breeze. In a typical lake breeze, air which is thermally stable (inversion) up to several hundred feet because of a trajectory over a cold water surface moves over warm land. As the air moves inland, an unstable layer develops near the ground and grows vertically, with a stable layer above it (Bierly, 1968). At some distance inland, depending on stability and wind conditions over water as well as those over land, the entire layer becomes unstable and well-mixed. If effluent is discharged from a tall stack at the shoreline in a lake breeze situation, very little dispersion takes place downwind as long as it remains in the stable air. At some distance inland, however, where the vertically increasing unstable layer intersects the plume, material in the plume mixes rapidly downward and may cause unacceptably high concentrations at ground level. It is obviously important to know the frequency of occurrence of the lake breeze, the meteorological changes caused by it in relation to diffusion, and the distance of its penetration inland.

The work described below supplements that reported in the first progress report (Portman, Ryznar and Walter, 1970) which gives a general discussion of wind and temperature conditions near the shoreline, using information available up to that time. It also represents a step forward to oil fog diffusion experiments in onshore flow, accompanied by wind and temperature profile measurements up to 500 feet, scheduled for summer 1973.

II MEASUREMENTS AT INLAND STATIONS

Wind speed and direction system

Because of the importance of the lake breeze in determining diffusion conditions at the Fermi site particularly during spring, summer and early autumn, one of the main requirements for a wind system was that it measure speed and direction as accurately as possible in lake breeze conditions. This requirement meant that a wind speed recording range of 0-15 mph was desirable to provide adequate resolution for the wind speeds most commonly associated with a lake breeze and that the sensor itself should have good response characteristics within this range. Provisions also had to be made, however, for recording significantly higher speeds, such as those which may last for a few minutes during thunderstorms or for a day or two during the passage of intense migratory pressure systems. Associated with a deep low pressure system, for example, strong onshore winds may occur at Fermi which then shift to strong offshore as the system passes.

Another requirement was that the wind system be independent of electrical power from utility lines. With this feature, a wind station could be readily moved to a new location if an analysis of lake breeze situations showed that a different grouping of stations was necessary.

A wind system comprised of the following basic components fulfilled the above requirements:

1) An R. M. Young Co. Model 35001 Gill Propeller Vane (wind speed and direction sensors in one unit).

2) Translator for wind speed and direction.

3) Two Esterline-Angus 0-1 ma spring-wound chart recorders (one for wind speed and one for direction).

4) One 12-volt battery (regulated and rechargeable).

Sensor. The Gill Propeller Vane is shown in Figure 1 . By the use of (1) a fin and propeller molded of low density foamed polystyrene and (2) low torque, stainless steel ball bearings in the construction of a propeller vane, excellent response characteristics for both low and high wind speeds result. The vane and propeller have threshold sensitivities of 0.3 - 0.5 mph and 0.4 - 0.7 mph, respectively. The vane has a delay distance (50% recovery) of 2.9 feet and the propeller has a distance constant* of 2.4 feet.

The vane converts angular position to resistance through a set of gears linked to the shaft of a precision conductive plastic potentiometer. With a constant voltage applied to the potentiometer, the output signal is directly proportional to the vane direction.

Wind speed is sensed by a 2-bladed helicoid propeller. Its shaft is coupled to a d-c tachometer generator whose output voltage is directly proportional to rpm and is linear throughout its working range.

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*Distance constant is the length of air required to cause a 63.2 percent response to a square wave change in the variable measured.

Figure 1. Gill propeller vane

Translator. The purpose of a wind speed and direction translator is to adapt and condition the signals from the propeller vane to the requirements of two current-driven recorders, one for wind speed and one for direction. Commercially available translators were considered for use with the sensor described above, but their main disadvantage was that they lacked a low enough wind speed range to provide the resolution desired. In addition, electrical loading effects of the recorders on the sensor were not eliminated to the degree believed necessary for accurate wind recordings. A translator was designed and built in-house, therefore, with the following features:

1) It has wind speed ranges of 0 - 15, 0 - 30, and 0 - 60 mph and automatically switches from one range to the next,
2) It eliminates electrical loading effects of the recorders on the sensor by means of voltage-to-current amplifiers in both the wind speed and direction circuits, and
3) It is operable from a 12-volt battery with very little current drain.

A translator is shown in Figure 2 . Its general operating characteristics are briefly described below.

The automatic wind speed range selection and switching is accomplished by means of 2 voltage level detectors and a voltage-to-current amplifier. When the level detector for the 0 - 15 mph range senses a voltage corresponding to a wind speed equal to or greater than 15 mph, it causes a change in the gain of the voltage-to-current amplifier and a switch to the 30 mph range. If the

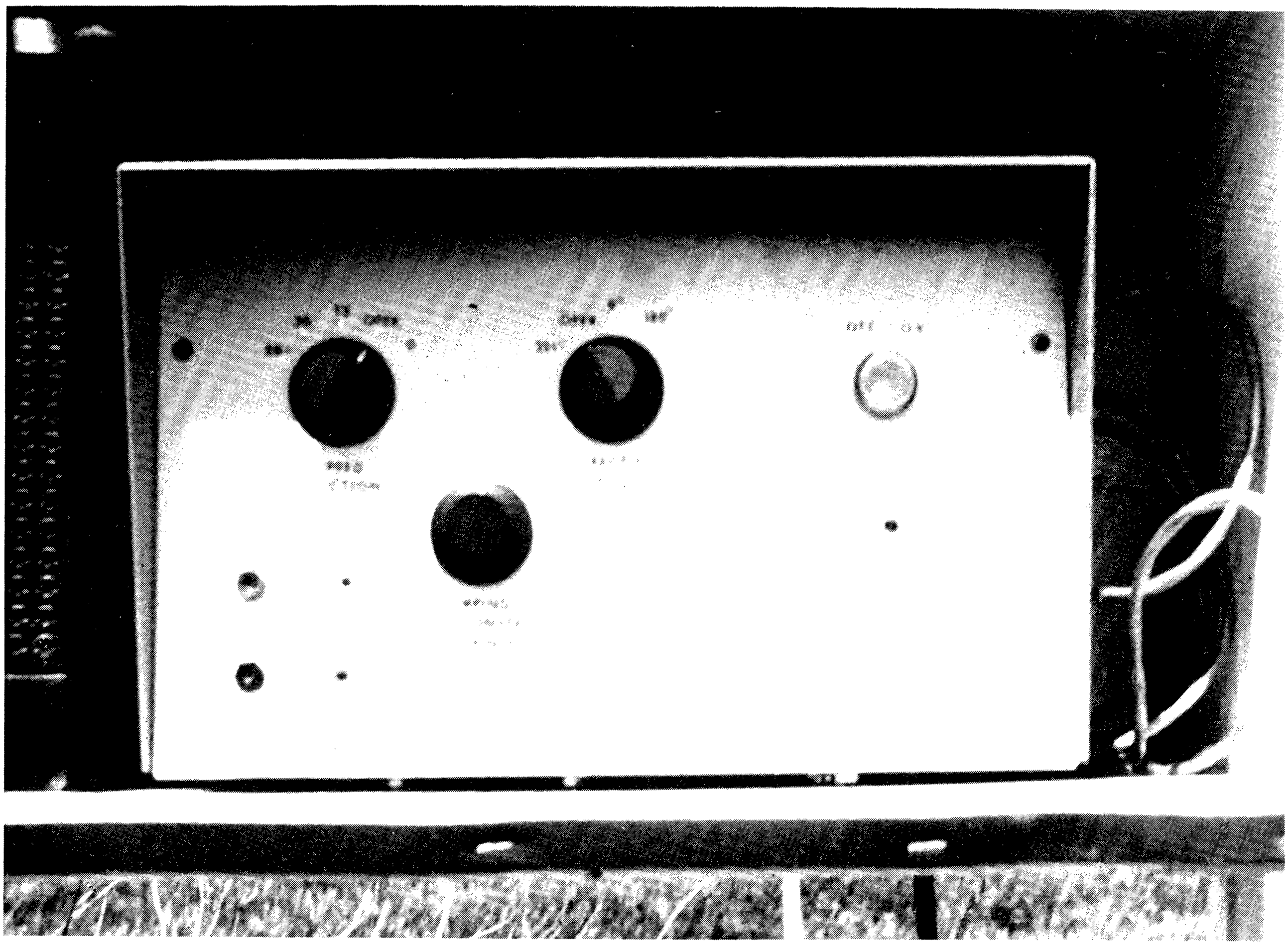

Figure 2. Wind system translator

wind speed decreases to less than 15 mph a switch back to the 15 mph range is prohibited until the level detector senses a voltage equivalent to a speed of about 5 mph. Without this feature, a wind speed fluctuating between 12 and 18 mph, for example, would cause intermittent range switching and a subsequent difficulty in determining the correct wind speed. If the wind speed exceeds 15 mph and continues to increase, the 30 mph range is maintained until the second level detector senses a voltage corresponding to a wind speed equal to or greater than 30 mph. It then causes a gain change in the voltage-to-current amplifier and a switch to the 60 mph range. A switch back to the 30 mph range is prohibited until the wind speed decreases to about 12 mph. The recording of wind speeds greater than 60 mph is not provided for because they occur so seldom.

The 12-volt battery used as a power supply for the translator is regulated by a pair of matched, aged, Zener diodes which provide the necessary $\pm$ 5 volts for the translator. Separate regulators are used for the wind speed and wind direction circuits, thus eliminating any possible interaction of one circuit with the other. The complete translator, including regulators, draws about 10 milliamperes from the 12-volt battery. Tests have shown that this voltage drain on a conventional car battery results in a decrease from 12.35 to 12.00 volts in about three months at normal summer-time temperatures and in 2 months at normal wintertime temperatures.

To minimize the effects of temperature extremes on the performance of the translator, its critical components have a very small drift with temperature. The voltage-to-current amplifiers are temperature compensated, for example, and the voltage regulators are encapsulated in an aluminum shell filled with a potting compound having a high thermal conductivity.

Recorders. The recorders chosen for the wind measurement system are Esterline-Angus single channel 0-1 ma recorders with spring-wound chart drives. The chart drive runs at a speed of 6 inches per hour. At this speed, 8 days of recordings are obtained on a single chart roll. The accuracy of the recorder is 1% of full scale reading. The time required for the recorder to respond to 99% of the final value of an input signal is 0.5 second.

A pair of recorders, one for speed and one for direction, is used at each inland station. Synchronization of the wind speed and wind direction recordings is accomplished by means of a chart drive coupling between the two recorders.

Tower and shelter. The supporting equipment for the wind measurement system includes a 10-meter triangular tower 12 inches on a side and an equipment shelter. A 1-inch pipe extends from the top of the tower and supports the propeller vane. The Fermi I pier tower with a propeller vane is shown in Figure 3 .

The shelter for the recorders, translator and battery is approximately 2-feet wide, 1-foot deep, and 2-feet high. It has screened

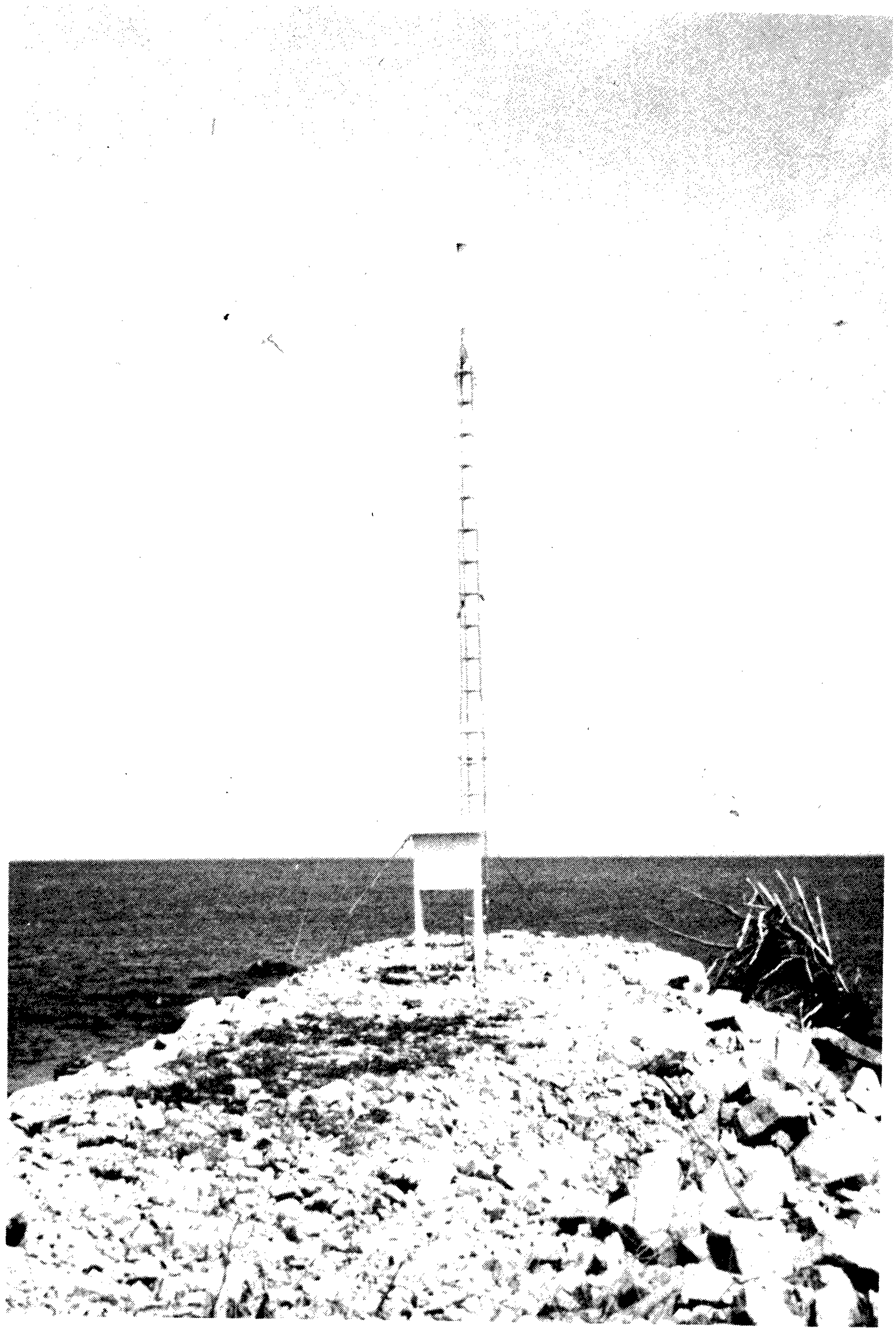

Figure 3. 10-meter tower with propeller vane

vent holes which provide adequate air circulation for the equipment, ventillation for the hydrogen emitted by the lead acid battery, and protection from insects and rodents. The entire shelter is painted white not only for protection from the weather, but also to minimize heating effects of solar radiation in summer. One of the shelters containing the translator, recorders, and battery is shown in Figure 4 .

Temperature and relative humidity equipment

For the continuous recording of temperature and relative humidity, Belfort hygrothermographs Model No. 5-594 were used. A unit is shown in Figure 5 as it was positioned in a standard weather shelter at one of the inland stations. Data are recorded on a single dual-channel chart which has a one-week record length. Air temperature is sensed by a Bourdon tube and relative humidity is sensed by a human hair assembly as described below.

The Bourdon tube is a liquid-in-metal thermometer which consists of a curved, chrome-plated phosphor bronze tube filled with an organic liquid. It expands with an increase in temperature and contracts with a decrease in temperature. The deformation moves a link and lever assembly, causing a pen to respond accordingly. According to the manufacturer's specifications, the accuracy between -20F and 100F is $\pm$ 1F.

The humidity sensing element is a banjo spread human hair element. The hair element lengthens as relative humidity increases and shortens as relative humidity decreases. An appropriate linkage

Figure 4. Shelter containing wind translator, recorders, and battery

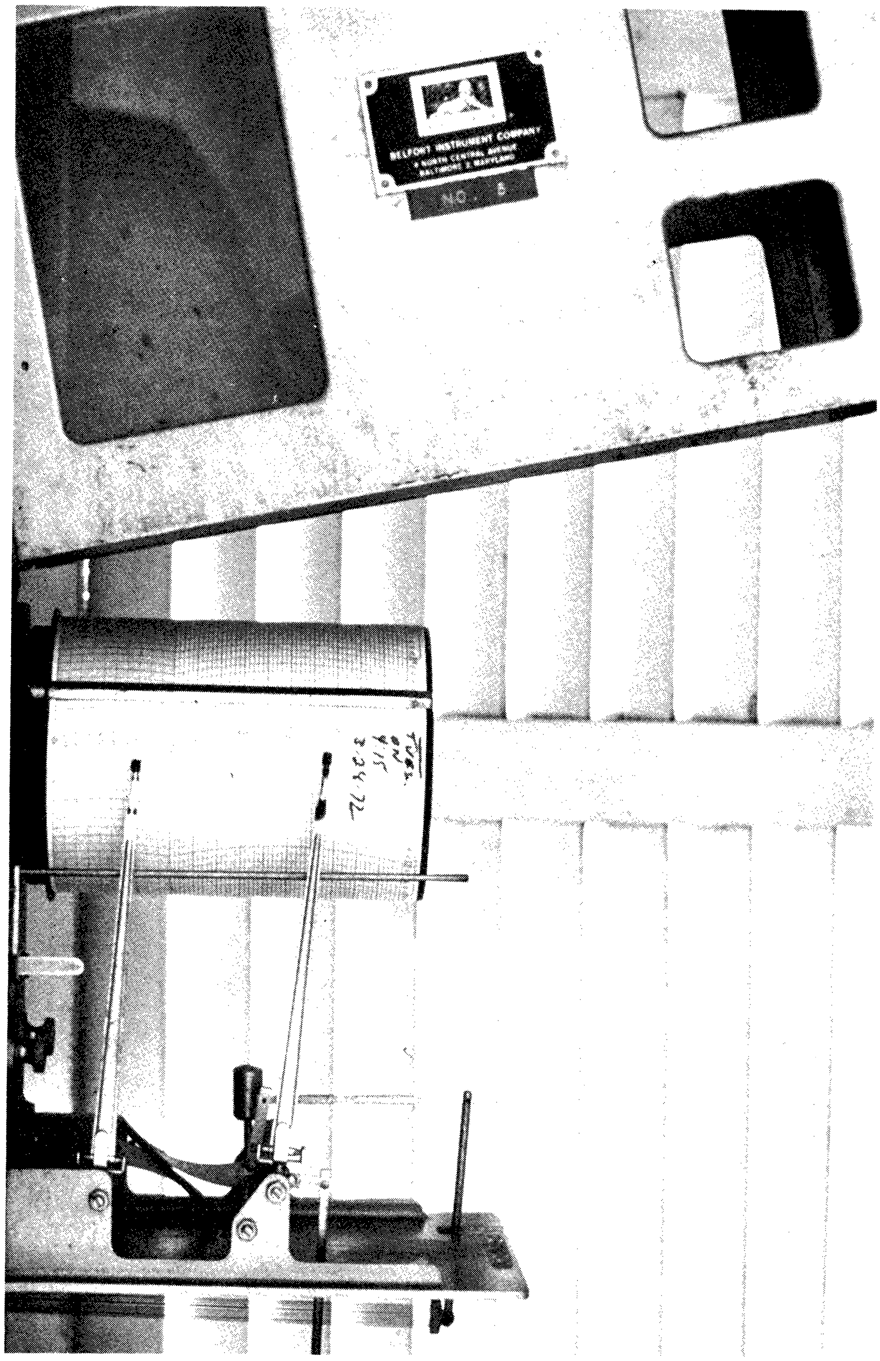

Figure 5. Belfort hygrothermograph in weather shelter at 1.5 mile station

between the element and a movable pen translates hair length into relative humidity. According to the manufacturer's specifications, the accuracy of the humidity element is ± 3% RH between 20% and 95% RH with a sensitivity of 1% RH at room temperature.

Standard U.S. Weather Bureau instrument shelters were used to house the hygrothermographs at the inland stations. In accordance with standard procedure, each shelter was oriented with the door facing north to prohibit solar radiation from striking the instrument when the door was opened.

Calibration of equipment

Hygrothermograph. For several days before their installation in the field, the hygrothermographs were allowed to record in individual instrument shelters outdoors. During steady temperature and humidity conditions, their readings were compared periodically with measurements made with standard dry-bulb and wet-bulb mercury thermometers. After a series of measurements, temperatures and relative humidities measured by the hygrothermographs were adjusted to conform as closely as possible to the standard measurements.

Wind system. The wind speed portion of the wind system was calibrated in a wind tunnel by measuring the output voltage of the propeller-driven d-c tachometer generator at several wind tunnel speeds up to about 25 mph. The resulting calibration curve allowed the translator scale to be set and gave a check of the linearity of the d-c tachometer generator for the above range of wind speeds.

The wind direction portion of the system was calibrated by rotating the propeller vane from 0-360° in ten degree increments and adjusting the translator so that the reading on the recorder chart corresponded to the vane's direction.

Locations and installation

Hygrothermographs and wind systems were installed at 6 locations up to 6 miles inland from Fermi in a general northwesterly direction. This direction is approximately perpendicular to the orientation of the shoreline. The locations of the other stations were based on there being (1) as few obstructions to the wind field in as many directions as possible (2) no standing water nearby, and (3) accessibility to the station from a nearby road. The locations of the stations are shown on the map in Figure 6 . Station numbers and distances inland are given below.

Station Number	Distance Inland (miles)
1. (Fermi I South Pier)	0
2.	0.8
3.	1.5
4.	3
5.	4.5
6.	6

In 1970, recordings of temperature and relative humidity began on 9 June at the Fermi and 0.8 mile stations and on 11 June at the remaining ones. Wind speed and direction recordings began on 13 July at the 1.5 mile station. All equipment was removed from the

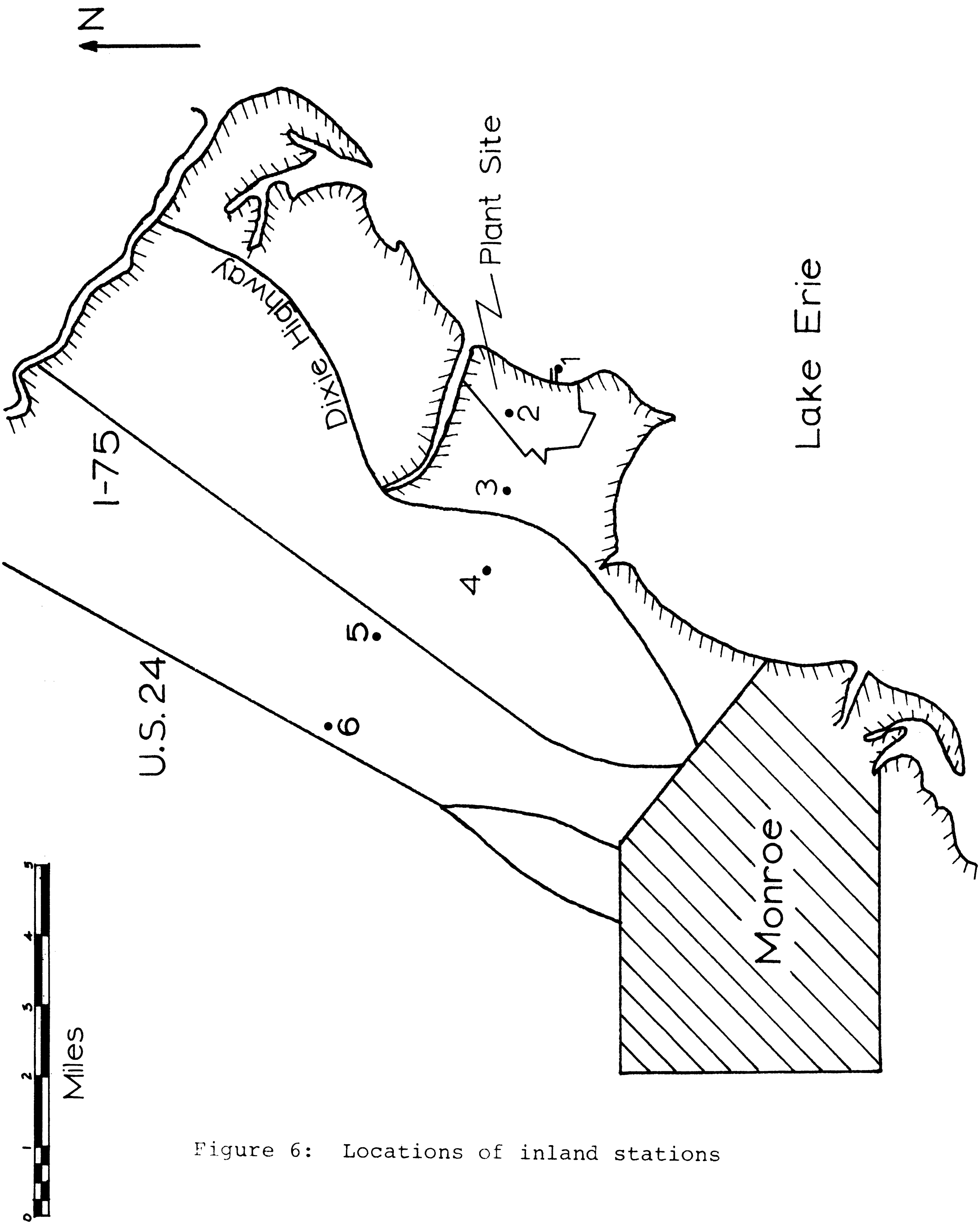

Figure 6: Locations of inland stations

field in the first week of November.

In 1971, temperature and humidity recordings began at all stations on 2 April. Wind systems were installed at a height of 10 meters at the end of the Fermi pier on 22 April and at a height of about 3.5 meters at the other 5 stations shortly thereafter. Recordings continued until the second week in November, when the equipment was removed except for that at Fermi and at the 0.8 and 1.5 mile stations. Wind, temperature and humidity recordings continued throughout the winter of 1971-72 at Fermi and at the 1.5 mile station. Only temperature and humidity were recorded at the 0.9 mile station. Except for missing data caused by the recorders stopping for several days during extremely cold weather, the wintertime records were quite complete.

By 17 April, 1972, all equipment had been reinstalled at the remaining stations with the exception of that at 4.5 miles, which was eliminated because of repeated incidents of vandalism. All wind measurements were made at a height of 10 meters.

Data processing

All wind, temperature, and relative humidity data from the inland stations were screened to determine lake breeze occurrences and the magnitudes of changes in these variables accompanying lake breeze frontal passages. For the screening process and data interpretation, it was necessary to have information available from weather maps as well as more detailed information on cloudiness and wind conditions far enough inland to be out of the influence of the lake breeze. Observations of wind and cloudiness made on an hourly basis at the National Weather Service Station at Detroit Metropolitan Airport provided the detailed control station weather information, since the station is located about 19 miles northwest of Fermi. Daily weather maps provided other necessary information such as types and positions of fronts and sea level pressure distributions. With the above information, it was possible to distinguish changes in the variables measured at the inland stations which may have been caused by a large scale weather system from those which were caused by a lake breeze.

Prior to a screening of the data, each day was evaluated in terms of the likelihood of formation of a lake breeze, based on the above weather information. For reasons given below, there is a greater likelihood that a lake breeze will occur on a clear day with light winds than on an overcast day or on one with strong offshore winds. Because a shift in wind direction is the most reliable indicator of the passage of a lake breeze front, recordings of this variable were given special attention. The screening process consisted of monitoring and periodically noting average wind direction throughout each day as well as noting the times and magnitudes of significant wind shifts for each of the six stations. Recordings of temperature and relative humidity were then inspected for changes accompanying the wind shifts. In this way it was possible to determine both lake breeze occurrences and their penetrations inland.

Once the preliminary screening was completed, days with lake breezes were selected for more detailed data processing. It consisted of abstracting hourly averages of temperature, relative humidity, wind speed and direction for all stations as well as recording changes in these variables with each lake breeze frontal passage. For most lake breeze days, data were processed for the hours between 0600 and 1900 EST. Data for a total of 99 days between 30 April and 12 December 1971 were processed in this way.

In addition, hourly averages of all wind speed and direction data obtained at a height of 10 meters at the end of the Fermi I south pier were abstracted and tabulated, beginning with its date of installation, 22 April 1971 through December, 1971.

III FIRST RESULTS OF LAKE BREEZE STUDY

Meteorological changes caused by a lake breeze front

A lake breeze front moving inland along the western shore of Lake Erie causes the following simultaneous changes in the variables measured at each inland station:

(1) a decrease or leveling off of temperature

(2) an increase in relative humidity

*(3) a shift in wind direction to the southeast quadrant

(4) an increase in wind speed

Because the lake air is cooler than the land air, it displaces the land air as it moves inland. Vigorous mixing takes place in a transition zone along its leading edge. As a result of the mixing, changes in temperature and relative humidity in the transition zone usually decrease with increasing distance inland. At stations within about 3 miles of the shoreline, temperature decreases as much as 4F and relative humidity increases as much as 12 to 15% within a few minutes after the passage of a lake breeze front. At stations farther inland, however, temperature usually only levels off and humidity increases slightly.

If only temperature and relative humidity are measured, in fact, determining the passage of a lake breeze front at an inland station with any degree of certainty would be possible only if the sky were cloudless or if there were nearly uniform high cloudiness. The reason is that for the months when the frequency of occurrence of the lake breeze is greatest, shading of the sun by a large enough

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*a southeast wind is air moving from the southeast cumulus cloud passing over a station, for example, causes changes in temperature and humidity which are very similar to those caused by a lake breeze front. Of the variables measured at the inland stations, the most certain indicator of a lake breeze frontal passage is a wind shift. A well-defined lake breeze front moving inland along the western shore of Lake Erie causes a wind shift from a direction usually determined by the atmospheric pressure pattern on a synoptic scale to a direction between east and south.

In the discussion below, the wind speed and direction observed at stations outside the influence of the lake breeze, such as at Detroit Metropolitan Airport are called a gradient wind velocity, since they are determined, for the most part, by the horizontal gradient in pressure. Because the orientation of the shoreline in the vicinity of Fermi is approximately north-northeast to south-southwest, a gradient wind from any direction between southwest clockwise to north was considered to be in opposition to the onshore movement of the lake air and a wind from any direction between northeast clockwise to south in support of it.

In a typical lake breeze situation wherein lake air forces its way inland against a gradient wind, the wind shift first occurs at the Fermi station, usually between 0800 and 0900 EST and gradually moves inland. It was found that those lake breeze fronts which moved inland against a gradient wind as far as 6 miles moved with an average speed between 1 and 2 miles per hour.

An example of wind directions recorded at each of the 6 stations during a lake breeze situation on 8 August, 1971, is shown in Figure 7. The top record is for the Fermi site, and progressing downward, the records are for stations at distances of 0.8, 1.5, 3.0, 4.5, and 6.0 miles inland. Time increases from right to left and covers an interval from 0800 to 1600 EST. The numbers 0, 45, 90, 135, 180 . . . 360 printed on each chart are azimuth degrees (proceeding clockwise from north) from which the air is moving. Zero on the chart is the same as 360, or north. The occasional large swings of the wind direction trace across the entire width of a chart are caused by the wind direction fluctuations causing the wind vane contacts to swing back and forth across an electrical gap inherent in the construction of the vane's potentiometer. The gap was oriented to the north, so a variable north wind produces the trace described above.

The corresponding daily recordings of temperature and relative humidity for that week are shown in Figure 8. Temperature (^{o}F) is at the top and relative humidity (percent) is at the bottom of each record. Each scale division represents 2^{o}F in temperature and 2 percent in relative humidity. Time increases from left to right, with each vertical curved line on the chart representing 2 hours. The record for the Fermi station is at the top and that for the 4.5-mile station is at the bottom. The 6-mile station record is missing due to instrument malfunction.

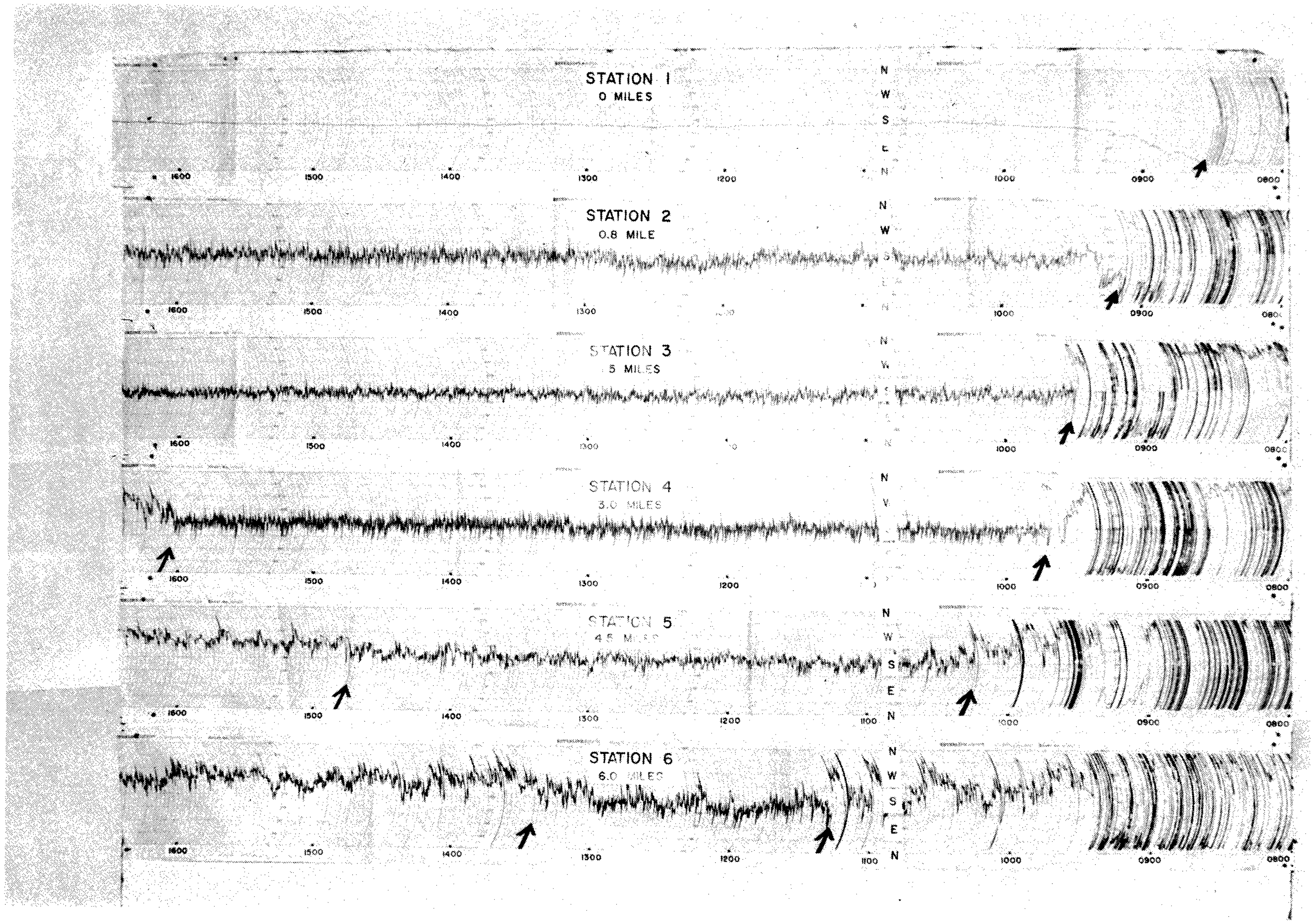

Figure 7. Wind direction recordings for 6 stations during a true lake breeze situation on 8 August 1971

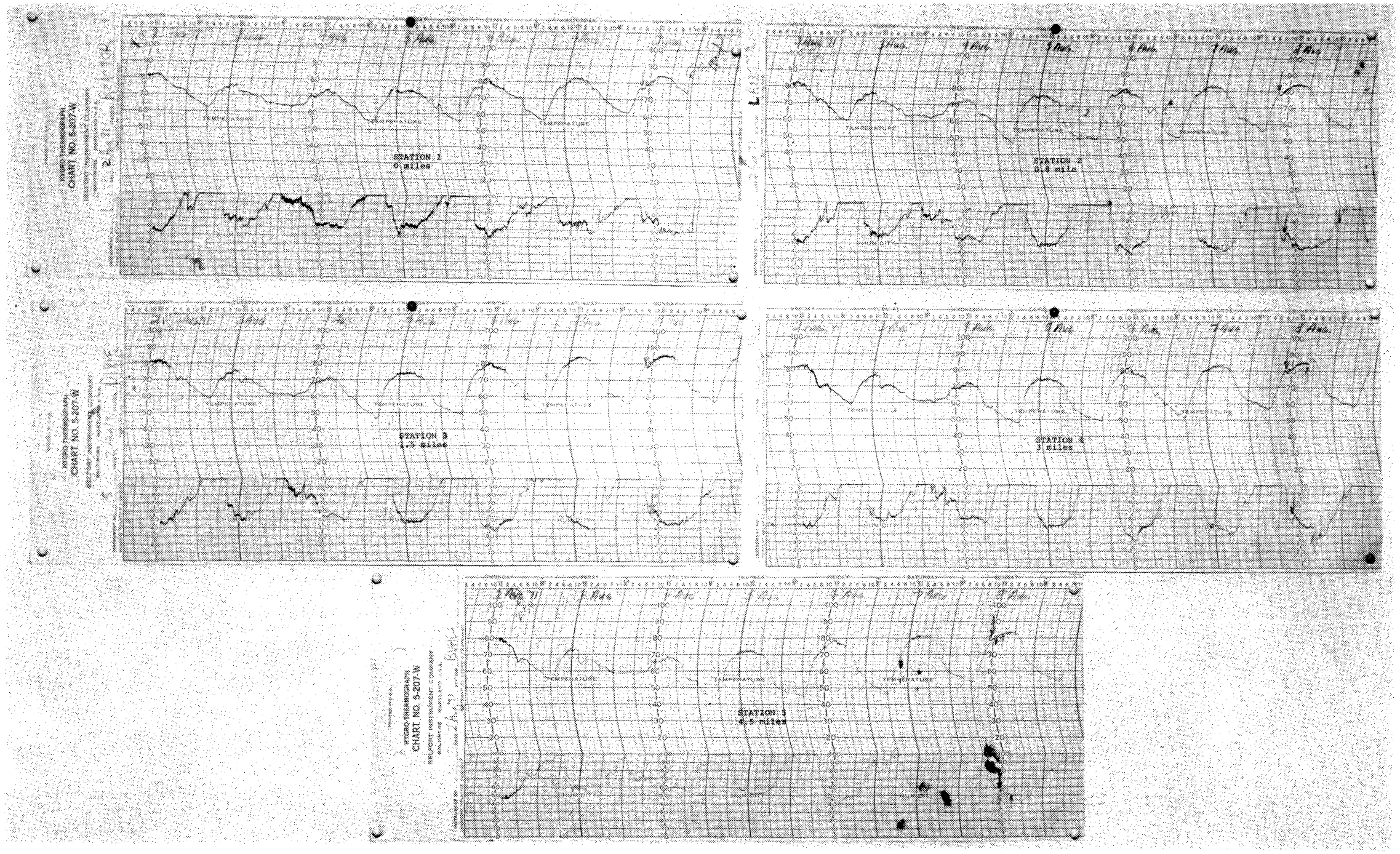

Figure 8. Temperature and relative humidity recordings for the week including the lake breeze situation on 8 August 1971

The weather map for 0700 EST on 8 August, 1971, is shown in Figure 9 . The pressure pattern is given by the solid lines and shows an area of high pressure centered over Ohio and West Virginia. A clockwise circulation around it is occurring, with wind speeds generally less than 5 mph. Based on the location of the high pressure area and a clockwise circulation around it, wind directions from a general southwesterly direction could be expected in southeast lower Michigan. By 1000 EST, average wind velocities at Detroit Metropolitan Airport and at Toledo Express Airport were west-southwest at 7 to 12 mph. They remained from that direction with speeds up to 14 mph throughout the day. The sky was cloudless, and the maximum temperature inland reached 90F at Detroit and 85F at Toledo. The average of 4 water temperatures measured on 8 August at the Fermi water intake was 70F.

A lake breeze front passed Fermi at 0836 EST as indicated by an abrupt wind shift from about 340 degrees to 045 degrees, then gradually to 165 degrees or south southeast by 1000 EST. A 2F temperature drop and a 10% increase in relative humidity accompanied its passage. It passed the 0.8 mile inland station at 0910, the 1.5 mile station at 0936, and the 3 mile station at 0950 with similar wind shifts and changes in temperature and humidity. It passed the 4.5 mile station at 1020 EST, where a wind shift provided the only certain indication of its passage. The fact that temperature only leveled off for a short time before continuing to increase slowly, and humidity increased only about 3% was an indication of the modification taking place in the lake breeze frontal

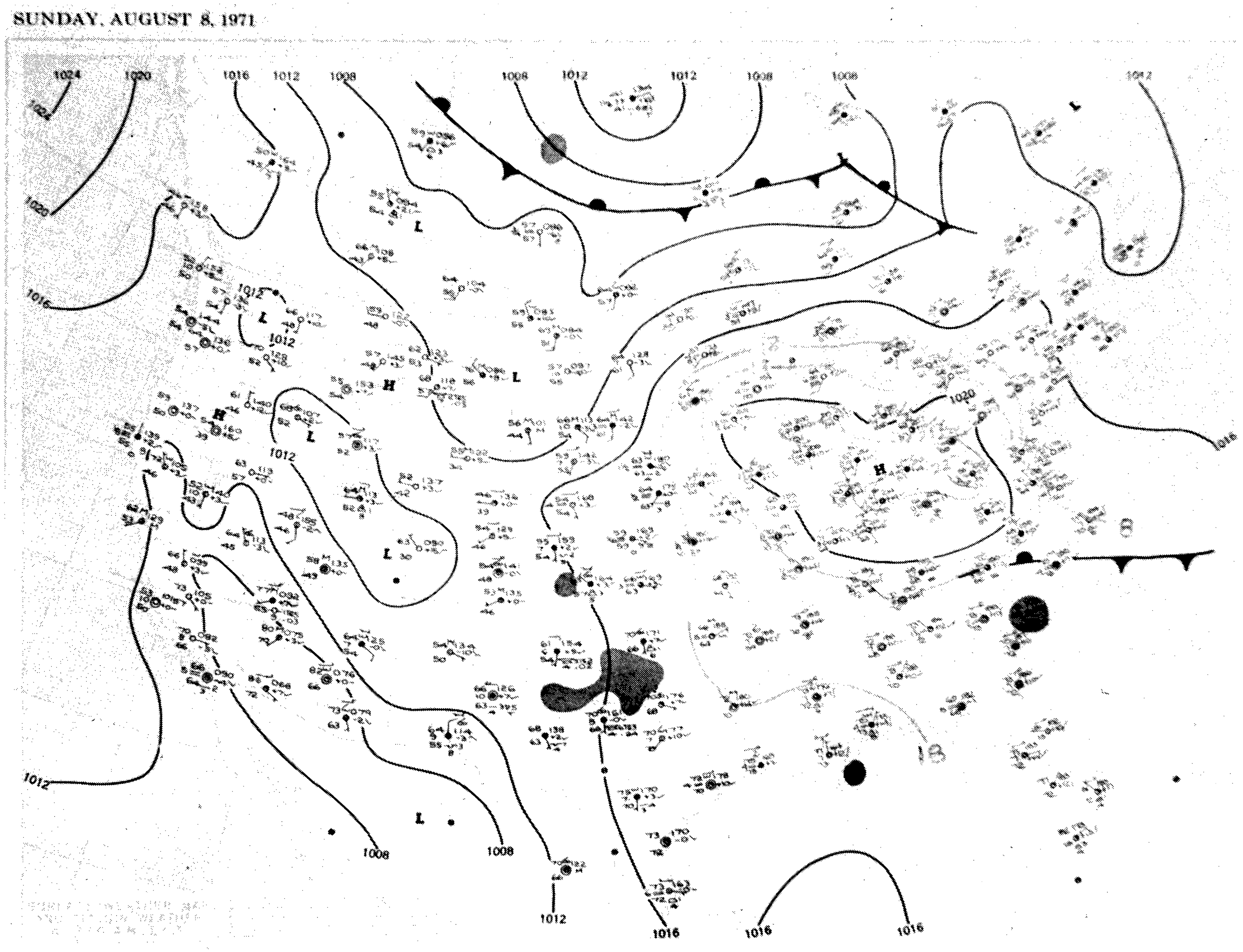

Figure 9. Weather map for 8 August 1971

zone. At 1122 EST, it passed the 6-mile station, but as discussed below, it is evident from the characteristics of the wind direction trace that this distance was near the maximum inland penetration of the lake air.

Between about 1300 and 1330 EST at the 6-mile station a wind shift from 180 degrees back to about 250 degrees occurred, indicating that the southwesterly gradient wind mentioned above was forcing the lake air to retreat lakeward. Accompanying the wind shift was a slight increase in temperature and a decrease in humidity as the warmer and drier land air again moved back over the station. The land air continued to force its way lakeward and moved past the 4.5 mile station at about 1500 EST, causing a wind shift from 180 to about 240 degrees and temperature and humidity changes similar to those observed at the 6-mile station. It passed the 3-mile station at 1620 and produced marked changes in temperature and humidity as well as in wind velocity. Within half an hour after the land air displaced the lake air at this station, the temperature rose from 84 to 88F and relative humidity dropped from 52 to 36%. There is some indication that it passed the 1.5 mile station at about 1800, but by this time of day, the ground was cooling rapidly and the discontinuity in temperature and moisture between land and lake air was rapidly losing its identity.

Of the 65 days in 1971 that had a lake breeze which moved inland when the average gradient wind was between southwest and north, 16 days were similar to the example given above in that lake air was forced to retreat after having moved some distance inland. Of the 16, 11 were forced back to the lake itself. Of the remaining 5, lake air retreated to between 1 and 1.5 miles from the lake and lost its identity as cooling of the land took place late in the day. Of the 33 occurrences in 1972, 5 were forced back to the lake.

The example described above was a true lake breeze in that the air over land became warm enough in contrast to the colder air over water to set up the pressure distribution needed for the lake air to move inland in opposition to the gradient wind. On some days, however, the synoptic scale pressure pattern in itself produces an onshore gradient wind. In these situations, significant enhancement of the onshore flow occurs if the sky condition is similar to that which in itself leads to the formation of a true lake breeze. As might be expected, a complete absence of cloudiness is the most effective sky condition for this to occur because it results in maximum heating of the land, but a significant enhancement can also occur with scattered to broken cloudiness. There is no discernible enhancement if the sky is completely overcast.

By enhancement is meant that changes in temperature, humidity and wind speed similar to those discussed in the above example move inland with approximately the speed of the onshore wind, but unlike the example, any wind shift is usually small. Because of the breakdown of the wind shift criterion, determining the front's movement inland for any sky condition other than for a cloudless one or one with uniform high cloudiness is difficult, since, as mentioned above, certain types of variable low cloudiness can produce temperature and humidity changes similar to those caused by a passage of a lake breeze front.

A typical sequence of events with lake breeze enhancement is

(1) light and variable winds early in the morning.

(2) a wind shift to a direction between northeast and south which, unlike a true lake breeze, is nearly simultaneous at all stations and is accompanied by a slight increase in wind speed, usually between 0700 and 0800 EST.

(3) a subsequent drop in temperature and an increase in relative humidity which moves inland.

Unlike the true lake breeze which forces its way inland against a gradient wind and whose inland penetration is limited as a result, it is a rule rather than an exception for the discontinuity in temperature and moisture to move inland at least 6 miles, diminishing in magnitude as it does so.

An example of an enhancement of an onshore gradient wind occurred on 10 June 1971. The onshore gradient wind itself was caused by the synoptic pressure pattern shown on the 0700 EST weather map in Figure 10 . A prominent feature of the map is a large area of high pressure centered in Canada northeast of Georgian Bay. A clockwise wind circulation around it is causing onshore winds along the western shore of Lake Erie. Wind speeds as given on the map are light, but they increased with time of day and by 1000 EST they were easterly at 12 mph at Detroit Metropolitan Airport and east northeast at 12 mph at Toledo Express Airport. The sky was cloudless throughout the day and maximum temperatures reached 73F at Detroit

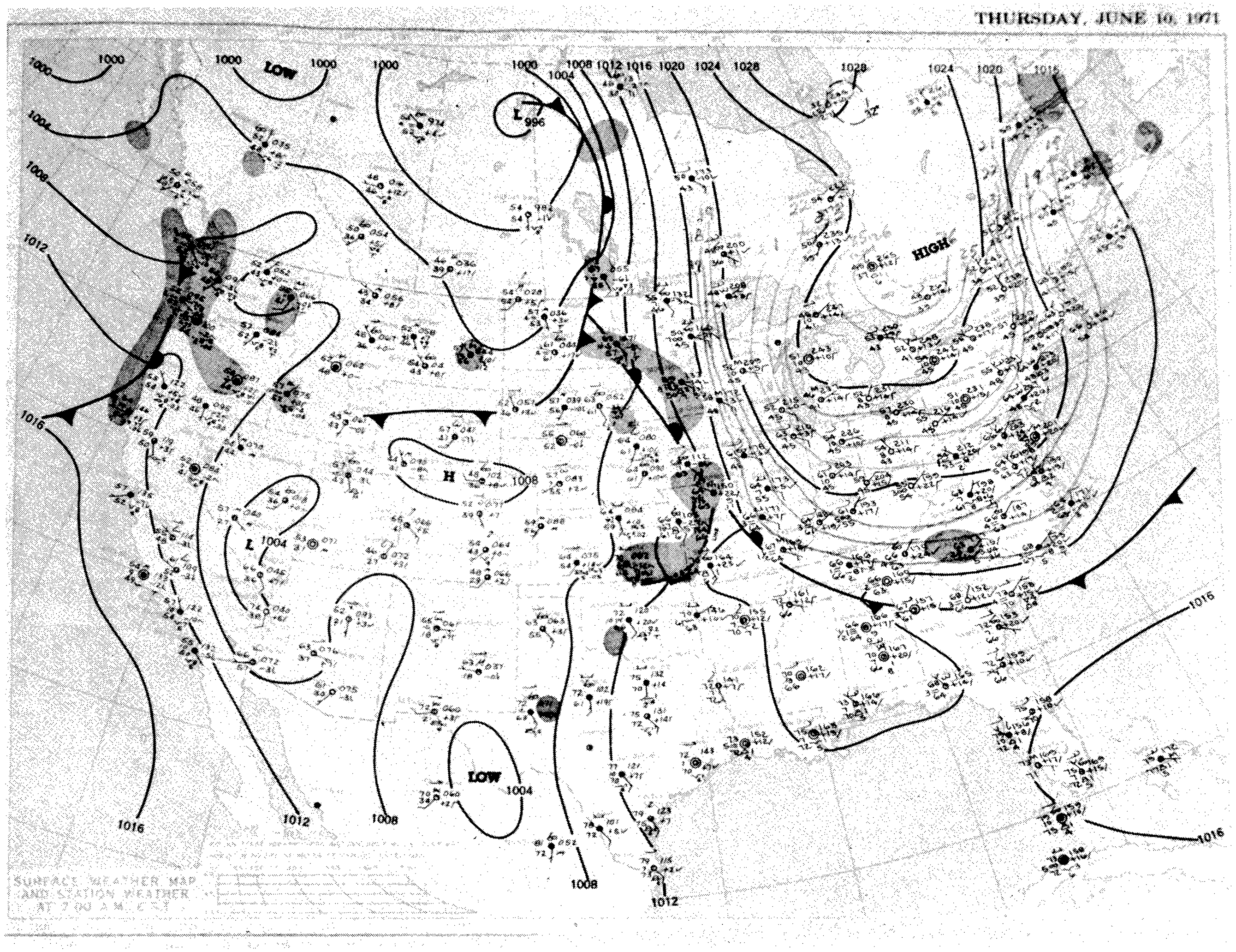

Figure 10. Weather map for 10 June 1971

and 74F at Toledo. The average water temperature at the Fermi intake was 63F.

The wind direction recordings for the inland stations are shown in Figure 11 . They are arranged similarly to those in Figure 10 , with the Fermi record at the top and the 6-mile station record at the bottom. The corresponding recordings of temperature and relative humidity are shown in Figure 12 .

At all stations except Fermi, average wind directions were northerly through the night. The Fermi wind direction remained east northeast. Wind directions at all stations shifted to east northeast between 0700 and 0800 EST and gradually to east southeast by 1300 EST. Average speeds increased from about 3 to 6 mph between 0700 and 0800 EST and gradually to 10-15 mph by 1000 EST.

Accompanying the initial wind shift at each station was a leveling off of temperature and an increase in relative humidity. The most pronounced increase in humidity occurred within 4 miles of the shoreline. A second major increase in humidity occurred between about 1200 and 1300 EST at all stations. It was likely due to a gradual shift in wind direction to east-southeast, since air moving from this direction has a longer fetch over water than an east wind and therefore contains more moisture when it moves inland in the vicinity of Fermi.

Frequency of occurrence and penetration inland

A study was made of the number of occurrences of the lake breeze for June through October, 1970, for April through December, 1971, and for January through September, 1972. As mentioned above, before

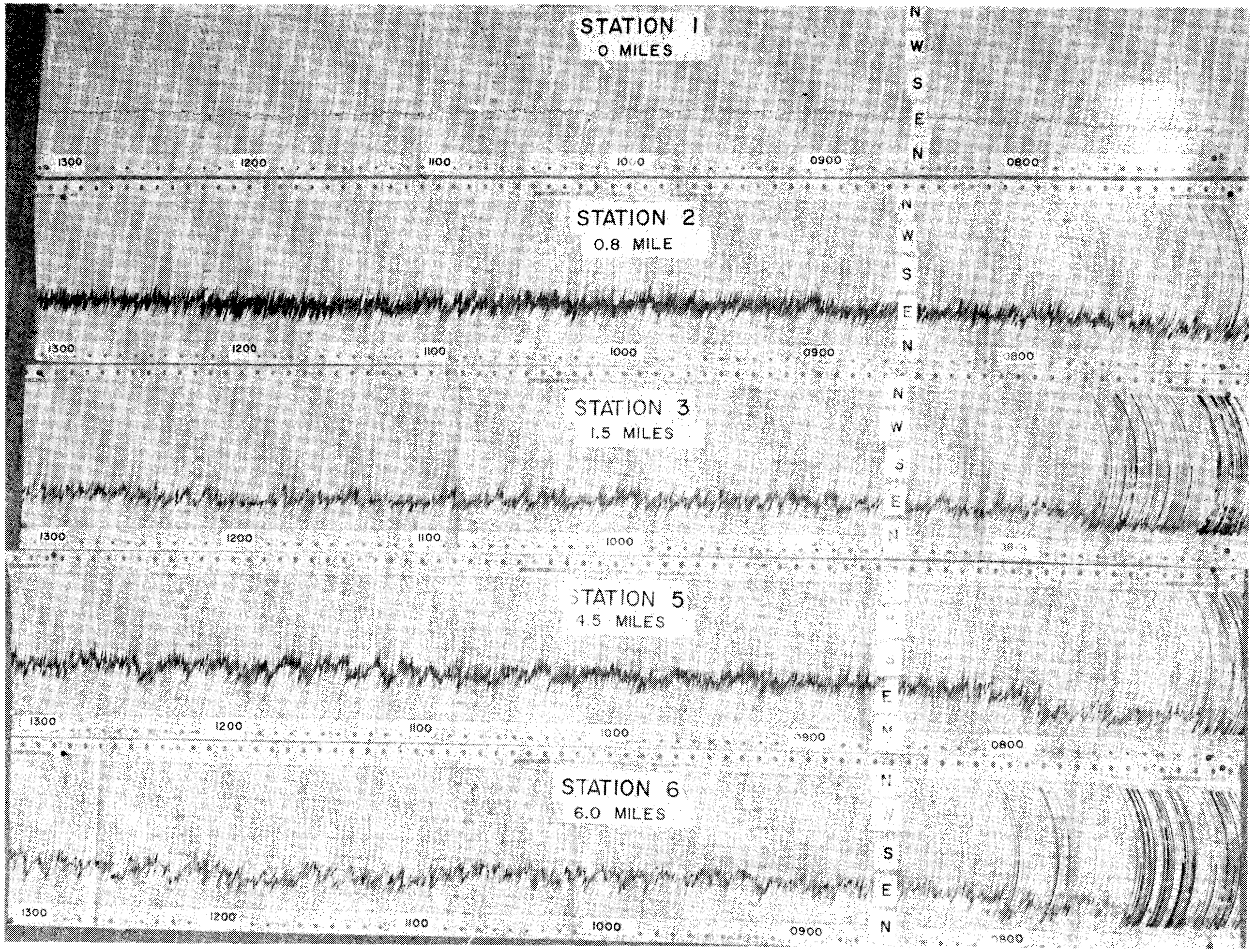

Figure 11. Wind direction recordings for 6 stations during lake breeze enhancement on 10 June 1971

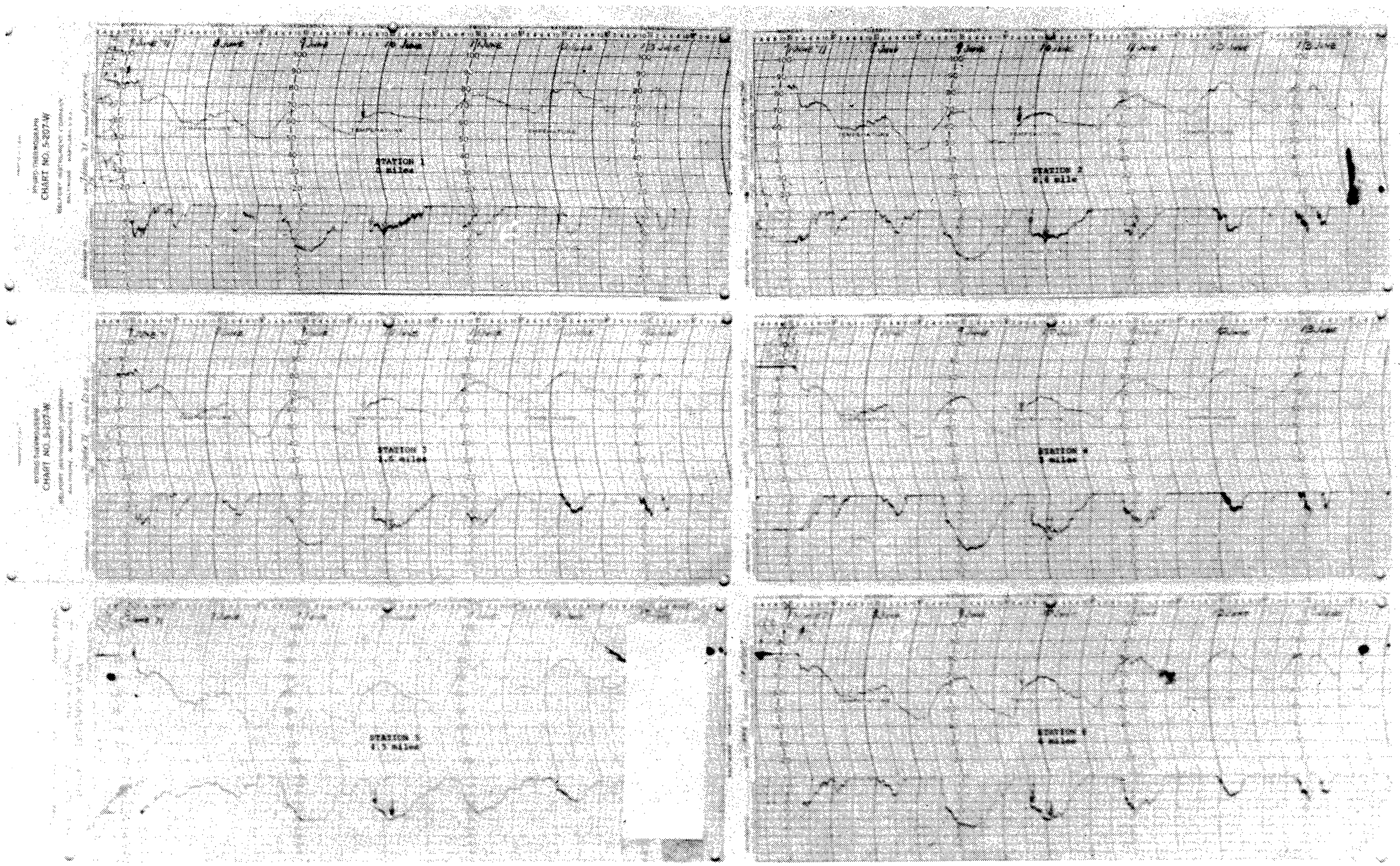

Figure 12. Temperature and relative humidity recordings for the week including lake breeze enhancement on 10 June 1971.

13 July 1970, lake breeze occurrences and their movements inland were determined only on the basis of recordings of temperature and humidity evaluated with respect to information from daily weather maps and hourly observations of cloudiness and wind velocities at Detroit Metropolitan Airport. After 13 July they were based, in addition, on recordings of wind velocity at the 1.5-mile station.

In 1971, temperature and humidity recordings began at all stations on 2 April. Wind systems were installed at the end of the Fermi I south pier on 22 April and at the other stations shortly thereafter. The 1971 study of lake breeze characteristics, then, was based on measurements of wind, temperature, and humidity at 6 stations through November and at 3 stations (0, 0.8 and 1.5 miles) thereafter. The 1972 study was based on measurements at 5 stations, beginning in April. A sixth station, that at 4.5 miles inland, had to be decommissioned because of repeated incidents of vandalism.

Results of the study are summarized in Table 1 and Table 2. Table 1 lists occurrences by month for 1970, 1971, and 1972 for all gradient wind directions. It includes occurrences of the type of lake breeze whose movement inland was enhanced by an onshore gradient wind as well as the true lake breeze which moved inland in opposition to a gradient wind or a component of it.

Table 2 lists only occurrences of the latter. Listed also is a breakdown of occurrences reaching various distances inland. The percent of occurrences at these distances is shown graphically in Figure 13 .

To generalize from these results, of the occurrences of a true lake breeze, (1) over half move at least 6 miles inland, (2) about

Table 1

Lake breeze occurrences for all gradient wind directions

Month	Occurrences 1970	1971	1972
Jan.	no data	no data	1
Feb.	no data	no data	1
Mar.	no data	no data	7
Apr.	no data	11	11
May	no data	18	15
Jun.	16	20	5
Jul.	13	14	11
Aug.	17	20	12
Sep.	8	11	9
Oct.	5	7	6
Nov.	no data	4	1
Dec.	no data	1	0
TOTAL	59	106	79

Table 2

Lake breeze occurrences in opposition to a gradient wind

Month	Occurrences			Total	Distances moved inland (miles)				
	1970	1971	1972		<0.8	0.8-1.5	1.5-3	3-6	>6
Jan.	no data	no data	1	1		1			
Feb.	no data	no data	1	1		1			
Mar.	no data	no data	4	4			4		
Apr.	no data	7	4	11				4	7
May	no data	8	4	12				4	8
Jun.	12	13	2	27			4	9	14
Jul.	13	10	6	29	1	2		10	16
Aug.	15	18	6	39	1	2	1	13	22
Sep.	2	7	5	14		1	1	2	10
Oct.	1	2	2	5		1			4
Nov.	no data	3	0	3			2		1
Dec.	no data	1	0	1			1		
Total	43	69	33	147	2	8	13	42	82
Percent					1.4	5.4	8.8	28.6	55.8

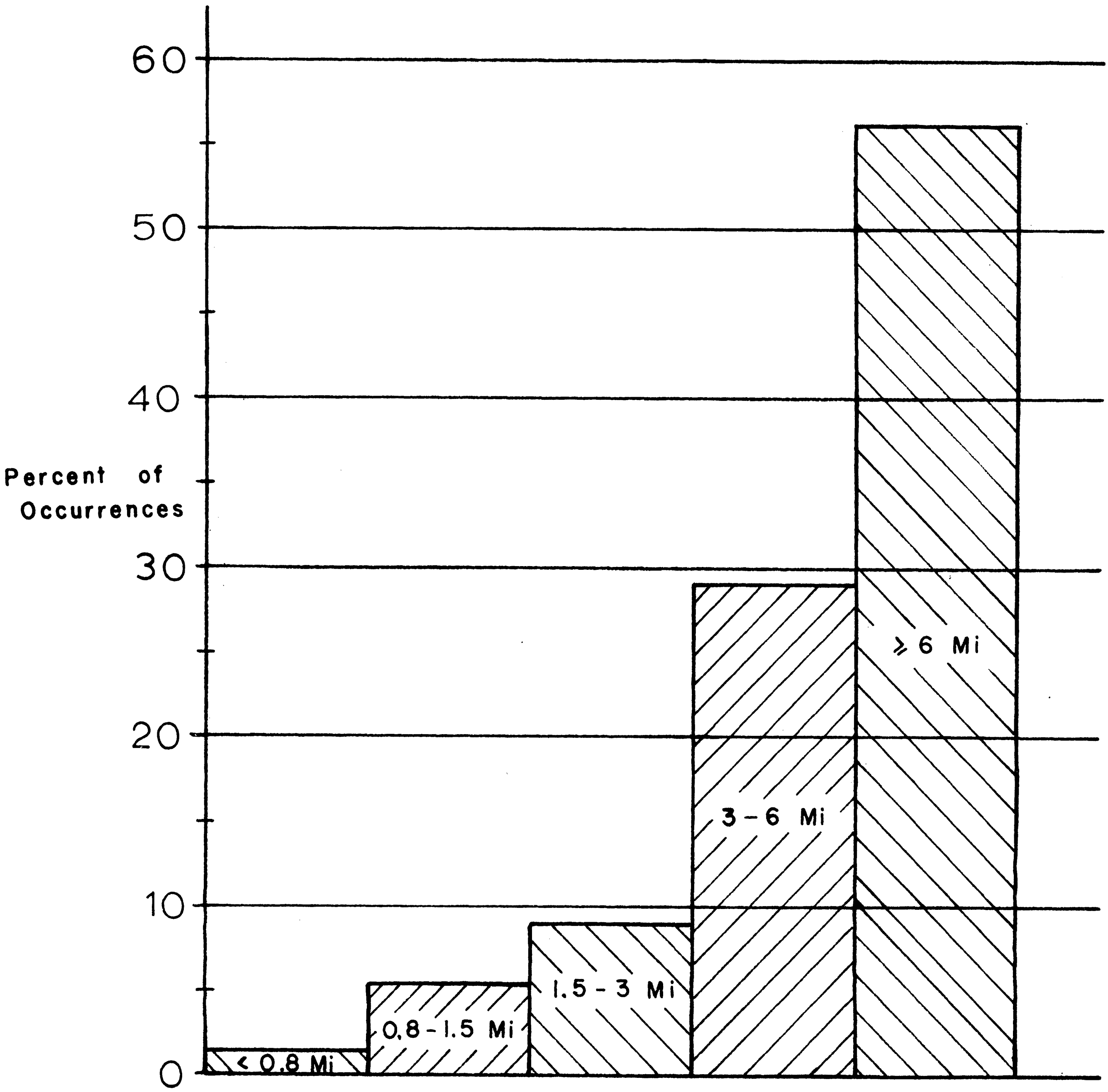

Figure 13. Percent of occurrences of lake breezes at various distances inland.

one out of three move past 3 miles but not as far as 6 miles, (3) about one out of ten more past 1.5 miles but not as far as 3 miles, (4) about one out of twenty move past 0.8 miles but not as far as 1.5 miles, and (5) about one out of one hundred do not move inland more than 0.8 mile.

IV WIND DIRECTION FLUCTUATIONS

Tests of the relationship of standard deviation to range

The standard deviation of fluctuations in horizontal wind direction has been shown to be a reliable index of dispersion (Hay and Pasquill, 1959 and Cramer Record, and Vaughn 1959). Only recently, however, has electronic equipment been developed to measure this parameter directly and accurately on a continuous basis. Standard deviation circuits were recently designed and built for the Fermi study. Because past recordings of wind direction exist for the Langton station, for which it was desirable to obtain standard deviations, a study was made of a method described by Markee (1963) of obtaining estimates of standard deviation from the range of wind direction fluctuations. The range is readily obtainable from the total width of a direction trace over some given time interval. According to his method, dividing the range by 6 gives a good approximation of the standard deviation.

The purpose of the tests was to determine if the factor 6 was valid for the sensor-translator-recorder systems in use at the inland stations described above. In particular, wind direction standard deviation data for the Langton station, located 0.8 mile inland within the plant site boundary were of special interest. The tests were designed to determine how wind direction standard deviations, computed from ranges obtained at a chart speed of 6 inches per minute (ipm), compared with those obtained from recordings made at 6 inches per hour (the normal recording speed at the station).

Prior to the field tests, laboratory tests were conducted with the Esterline-Angus Model 601C recorder used for wind direction recording to determine its response to a fluctuating signal. A sinusoidal input signal of ± 0.4 volts was fed into the recorder at frequencies of 0.05, 0.1, 0.25, 0.5, 0.75, 1.0, and 2.0 Hertz for chart speeds of 1.5, 3, 6, and 12 ipm. Ranges were computed for each frequency and chart speed. The results are shown in Figure 14 . Range in degrees is the ordinate and frequency in Hertz is the abscissa. It is evident from the figure that

(1) at frequencies up to 1 Hertz, the faster the chart speed, the larger the range indicated, and

(2) at frequencies greater than about 1 Hertz, the ranges are the same for all chart speeds.

The field tests were conducted by connecting the above recorder running at a chart speed of 6-ipm in series with a permanent one running at the normal year-round speed of 6-iph. Both recorders were connected to the same sensor-translator system at the Langton station, where wind speed and direction recordings at a height of 10 meters were begun in 1971.

Tests were conducted between the hours of 1200 and 1500 EST on 23 and 31 May, 1972. On 23 May, the site was under the influence of onshore flow associated with a lake breeze. The sky was clear, the temperature was about 82F, and the average wind speed was about 5 mph. On 31 May, there were offshore winds averaging 9 mph, there was a 1200-foot overcast, and the temperature was about 48F.

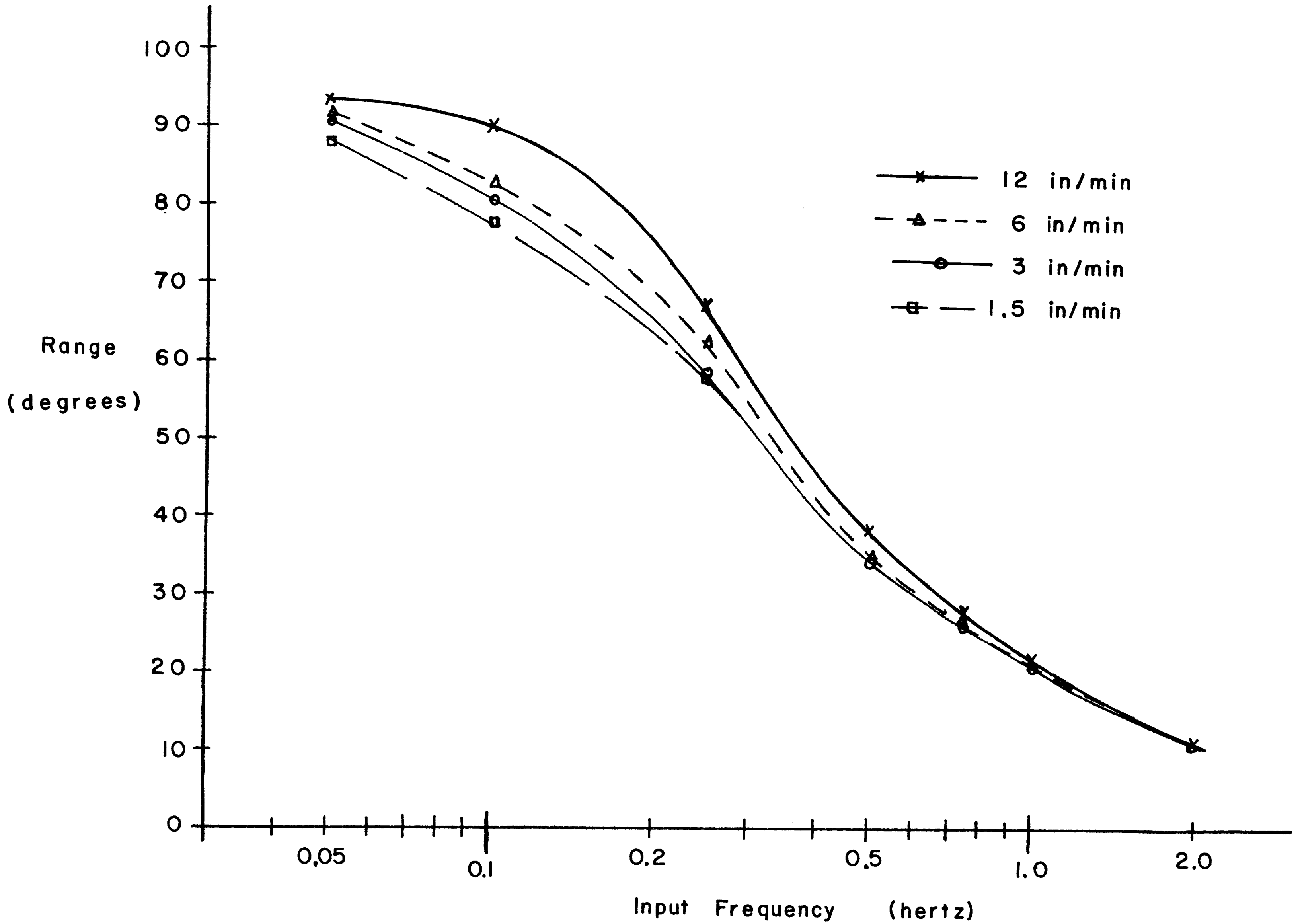

Figure 14. Response of Esterline-Angus Model 601C recorder for various chart speeds.

Values of wind direction for the 6-ipm chart speed were abstracted for every second for one hour of each test and were punched on computer cards for processing. Means, extremes, and standard deviations were computed for consecutive 10-minute intervals. Values of the range divided by their respective standard deviations were also computed for each 10-minute period. For the 6-iph record, values of the range were abstracted for the same consecutive 10-minute periods. Because of the greater resolution of the 6-ipm recordings and consequently more nearly accurate results, they became the standards to which the 6-iph results were compared.

A graph of the ratio of range to standard deviation versus range for the 6-ipm chart speed is shown in Figure 15 . Values of the range vary from 44 to 78 degrees and values of the ratio vary from 4.6 to 7.2. The mean of all ratios is 5.8. To test the applicability of this result to the 6-iph data, each range obtained for the 6-iph data was divided by the corresponding 6-ipm standard deviation and plotted against the 6-iph range values. The results are shown in Figure 16 . Values of range vary from 50 to 74 and values of the ratio vary from 4.8 to 7.4. The mean of all ratios is 5.9.

In each figure there is some indication that the ratio increases with increasing range, but the scatter of points around 6 is evident for the ranges covered by the tests. It was concluded that dividing the range of the fluctuations by 6 would give reliable estimates of standard deviation for the wind systems used.

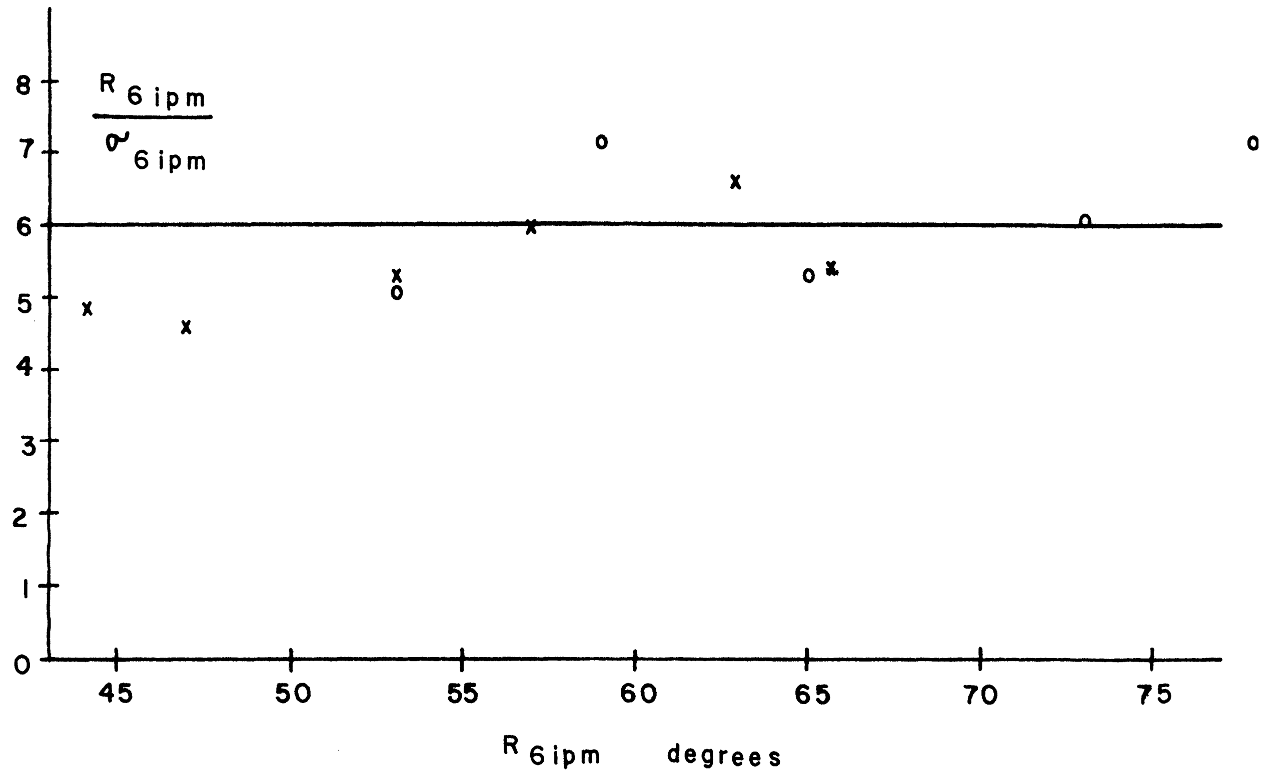

Figure 15. Ratio of wind direction range to standard deviation versus range for 6-ipm chart speed

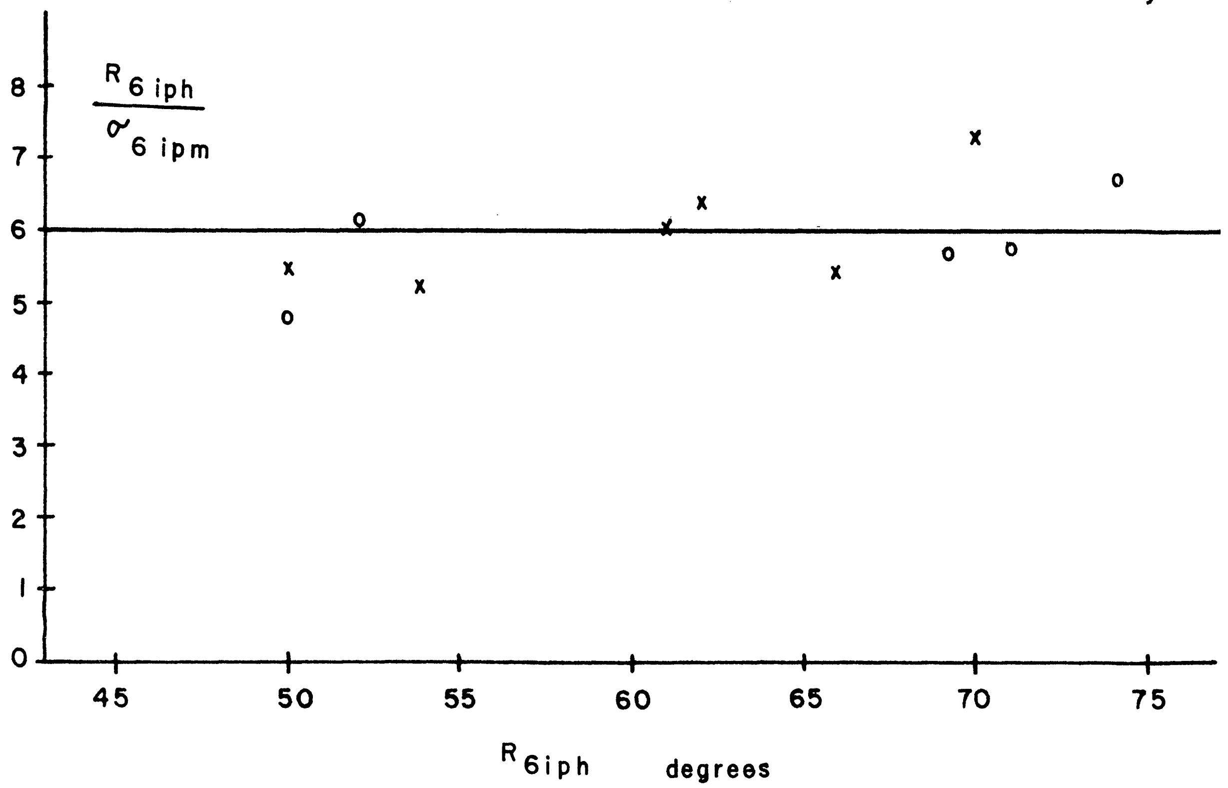

Figure 16. Ratio of wind direction range for 6-iph chart speed to standard deviation for 6-ipm chart speed versus range for 6-iph chart speed

Standard deviation of wind direction in lake breezes

For the period between 26 April and 30 October 1972, 51 days for which either a true lake breeze of lake breeze enhancement was observed were selected for a study of wind direction fluctuations in relation to wind speed. Daytime data from the Langton station were used. Each of the lake breeze days had either a small amount of cloudiness or none at all, so there was a strong likelihood that unstable lapse rates variable in magnitude prevailed in the first few meters.

Wind direction recordings were processed in terms of 10-minute values of range for hourly averages of wind speed and direction. Computations of standard deviation were made by dividing the range by 6. Hourly values of standard deviation were obtained by averaging each set of six 10-minute values. A graph of σ_{10} versus the 10-meter wind speed is shown in Figure 17. The points are about 460 hourly averages of both variables. Pasquill categories in terms of ranges of σ_{10} are labeled and shown by vertical line segments on the abscissa.

It is evident from the scatter of points that an expected decrease of σ_{10} with an increase in wind speed, such as the observed by Singer and Smith (1966) is not indicated. Their data, however, were obtained at a height of 108 m, where surface roughness effects on σ are significantly less than at 10 m. The scatter of values of σ_{10} decreases markedly at wind speeds greater than about 7.5 mph. Above this speed, values are confined to a range between 8 and 13 degrees, which is in the Pasquill C and D categories. About 75% of the values of σ_{10} for all wind speeds in lake breeze situations, in fact, were within this range.

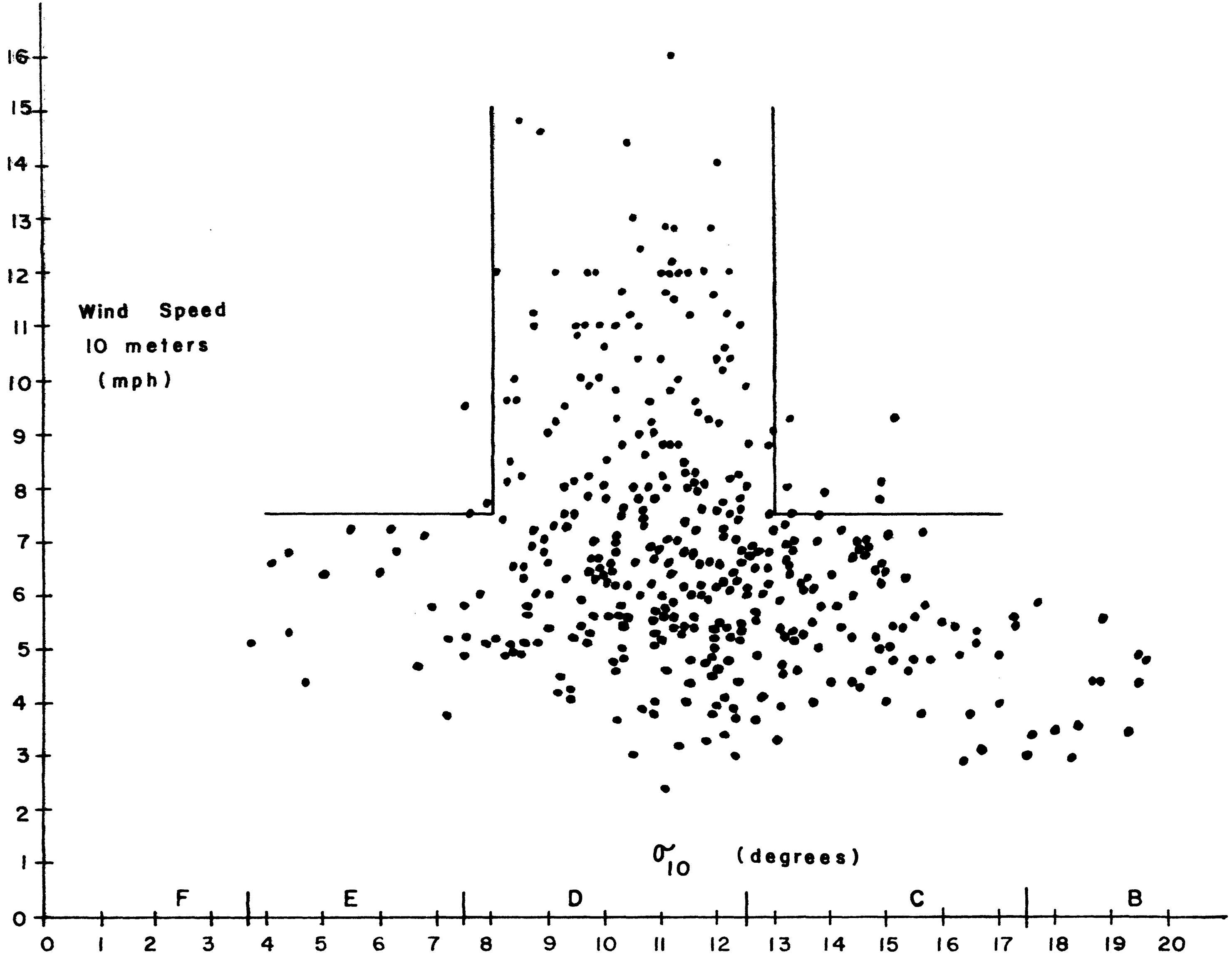

Figure 17. Standard deviation of wind direction at 10 meters versus wind speed for lake breeze situation at 0.8 miles inland. (Capital letters are Pasquill categories).

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