THE UNIVERSITY OF MICHIGAN
College of Engineering
Department of Atmospheric and Oceanic Science

Second Annual Report

AN INVESTIGATION OF THE METEOROLOGICAL IMPACT OF A ONCE-THROUGH COOLING SYSTEM AT THE DONALD C. COOK NUCLEAR PLANT

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ABSTRACT

Meteorological activities conducted during the period 1 April 1973 through 31 March 1974 concentrated upon establishing a pre-operational data base for the locale of the Donald C. Cook Nuclear Plant and developing the processing system necessary for reduction and analysis of the data. Temperature, relative humidity, precipitation, longwave and shortwave radiation, wind speed and direction, and visibility were monitored for the whole year from a network of stations. Several improvements in network instrumentation were made. The data processing system converts the data analog to digital format, applies appropriate calibration corrections, creates a final data file, makes preliminary tabulations, and, if desired, Calcomp plots of the data. Analyses of existing National Weather Service data considered to be representative of the Nuclear Plant locale were made to obtain order of magnitude information on the natural spatial variability in temperature and precipitation.

ACKNOWLEDGMENTS

Our special appreciation is expressed to Dr. Harry Moses of Argonne National Laboratory for his ideas and suggestions pertaining to all aspects of the work in the last year.

Several people made important contributions to data processing and analysis and to portions of this report. They are Jeffrey Baron, William Snell, Robert Kessler, and Michael Weber, all of whom are or were graduate students; and Andrew Detwiler, Dennis Kahlbaum, and Dennis Dismachek, who are undergraduate students. Gary Goldman constructed the humidity calibration chambers.

Paul Titus was responsible for much of the calibration work and coordinated the field program with our man in the field, Donald Pearson, who maintained the network data collection.

Ms. Bonnie Beasley did her usual excellent job of typing the report.

For the second year, very little vandalism occurred in the network, which is a credit to the community in the area near the Palisades Nuclear Plant.

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I. INTRODUCTION

Background

This report covers the activities conducted during the second year of a five-year investigation to determine (1) if the once-through lake cooling system of the Donald C. Cook Nuclear Plant will significantly affect the natural temperature, moisture, precipitation and fog conditions inland from the plant, and (2) if so, how and to what extent these variables are affected. The Donald C. Cook Nuclear Plant is located on the Lake Michigan shoreline about 10 miles south of Benton Harbor, Michigan. This investigation is being conducted in conjunction with a similar investigation of mechanical draft cooling towers at the Palisades Nuclear Plant, located 20 miles further north along the Lake Michigan shoreline.

This project was undertaken because of the virtual absence of quantitative investigations of the meteorological effects of near-shore warm water plumes. Most information presently available is based upon reasonable speculations from order of magnitude calculations, such as given by Carson (1972). Verification of such conjectures is needed. Definitive information is particularly important in the vicinity of the Donald C. Cook Nuclear Plant because of the economic dependence of the local population on agricultural products, especially fruit. In addition, a comparison of the magnitude of the effects of the Donald C. Cook Nuclear Plant with that of the Palisades Nuclear Plant will also provide some necessary environmental input into decisions involving types of cooling methods to be used with future power plants in the region.

Because of the lack of adequate hourly meteorological and climatological data in the vicinity of the Power Plant, a network of 12 meteorological stations was established to measure the important meteorological variables. The effects of the once-through cooling system will be established through 1) a statistical analysis of data from the network, 2) case studies of particular weather situations thought to be associated with significant modification and 3) numerical models of airflow over thermal plumes in the lake. A data base of 4 years is planned: two years before operations begin and two years after operations begin. The period of 4 years represents a compromise between the substantial cost of maintaining such a network and the improvement in the validity of the statistical results from a long period of records.

The major achievement of the first year of the project was the establishment and instrumentation of the network. In the second year, the following advances, described in detail in this report, have been made:

1) the first full year of continuous data collection has been completed;

2) some preliminary analyses and tabulations of data have been made;

3) routine calibrations of the hair hygrothermographs using calibration chambers were begun;

4) an EG&G dew point hygrometer was installed at station CO3A (the main station nearest the Nuclear Plant):

5) computer programs for processing digitized data were virtually completed.

In the third year, the pre-operational phase of the data collection should end and the second phase begin. Tabulations of the network data will be published and a thorough analysis of the data carried out. Some numerical modeling of the pertinent physical processes will be made to estimate the magnitude of any modification in particular meteorological situations.

Description of network

A map showing network station locations is given in Figure 1. Precipitation is measured by Belfort recording precipitation gages at all stations except C10B (the prefix C indicates a Cook network station, while the prefix P indicates a Palisades network station). Temperature and relative humidity are recorded with hair hygrometers (Belfort Instrument Co. Model 5-594) at all stations except CO2A and CO2B. At the two main stations, CO3A and C10A, wind velocity (R. M. Young Co. Model 12101 3-cup anemometer; WeatherMeasure Corp. Model 104 wind vane), incident solar radiation (direct plus diffuse with a WeatherMeasure Model R411 pyranometer), and total incoming radiation (solar plus atmospheric with a Teledyne-Geotech Model TCH-188-D1 radiometer) are also measured. Dew Point (EG&G Model 880 dew point hygrometer) and visibility (MRI Model 1580 visiometer) are measured at station CO3A. Site CO3A is the nearest feasible site to the Nuclear Plant. Site C10A, near the outer edge of the network, serves as a control station, since any modification in the vicinity of the plant should be undetectable at this distance. A complete description of the network stations, equipment, and operations is given in the First Annual Progress Report (Baker and Ryznar, 1973).

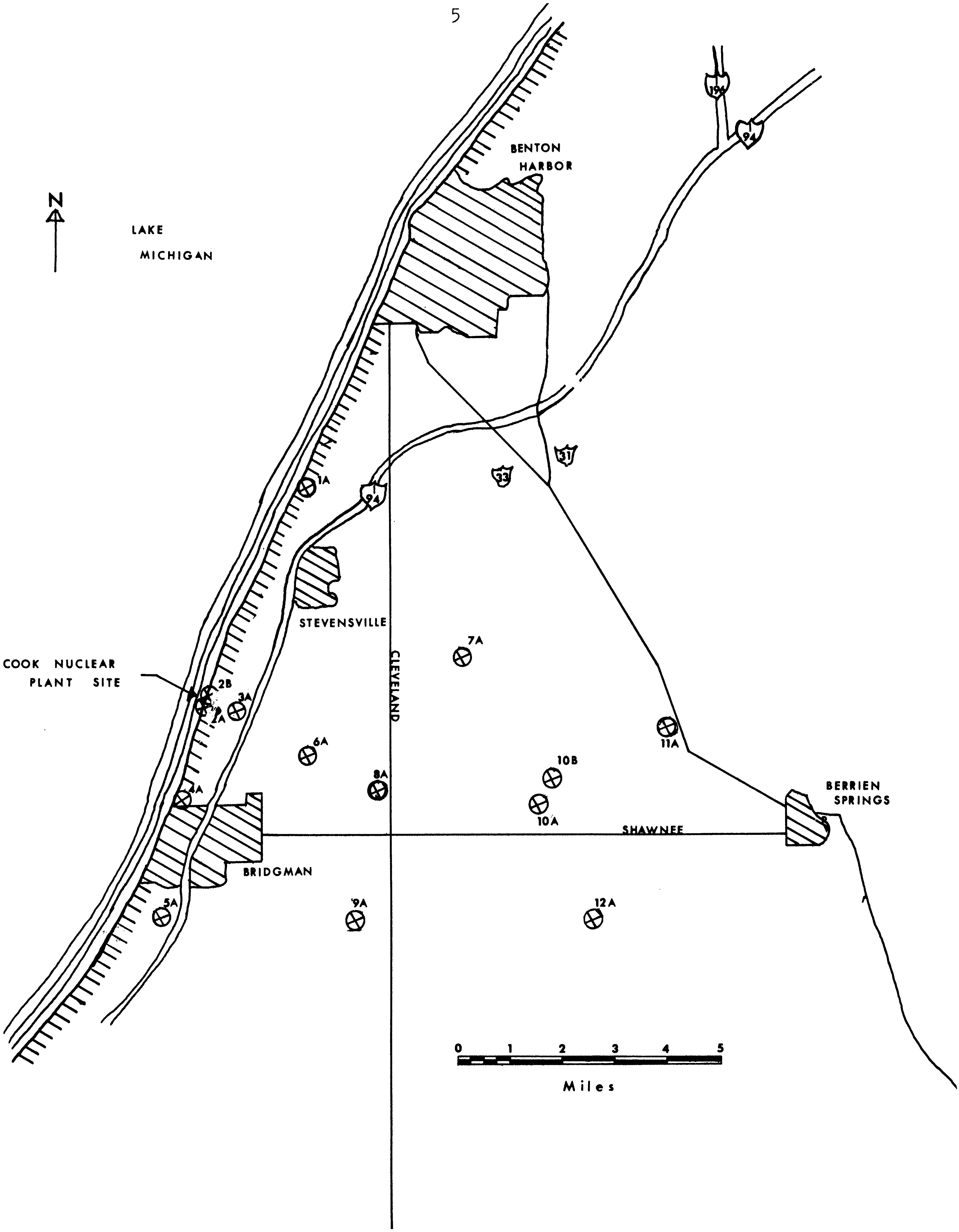

Figure 1. Locations of network stations

II. DATA COLLECTION

The recording of meteorological data by the network of 12 stations during the past year was maintained on a continuous basis as much as possible. The percent possible data recorded for each month for the period 1 April 1973 through 31 March 1974 are given in Table 1. Reasons for major periods of missing data are also given. The percentages given for precipitation, temperature, and relative humidity are averages for the 12 stations. Those for solar radiation (direct plus diffuse), total incoming (solar plus atmospheric) radiation, wind direction, wind speed, and visibility are for each of the two main stations as indicated. The dew point system was installed at station CO3A on 20 March, 1974.

Table 1. Percent possible data recorded for the Cook network

		1973									1974		
		Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Precip.		71	92	97	93	85	95	99	99	98	91	100	99
Temp.		73	96	95	86	80	89	96	96	89	83	95	94
Rel. Hum.		73	95	92	94	86	92	95	98	85	81	86	99
Solar Rad.	CO3A	100	100	99	100	99	100	99	100	80	3[1]	93	95
	C10A	100	100	91	100	85	72	99	51	0[1]	93	99	95
Total Rad.	CO3A	100	95	82	21[2]	0[2]	0[2]	22[2]	97	94	11	88	92
	C10A	100	79	42	95	95	100	100	51	63	93	91	100
Wind Dir.	CO3A	87	100	100	95	80	89	100	100	100	98	100	100
	C10A	100	100	100	99	82	0[3]	24[3]	86	89	64	100	66
Wind Speed	CO3A	69	100	100	100	98	93	100	100	100	98	100	86
	C10A	100	100	100	100	82	0[3]	24[3]	86	68	80	100	66
Visibility	CO3A	61	0[4]	0[4]	0[4]	0[4]	0[4]	24[4]	95	100	98	100	100
Dew Point	CO3A												37

1. Pyranometer malfunction.
2. Total radiometer malfunction.
3. Wind system decommissioned for wind tunnel calibration.
4. Recorder breakdown and high voltage power supply malfunction (delay in delivery of replacement components).

III. DATA TABULATION AND ANALYSIS

Examples of tabulations and summaries

In the past year, a substantial amount of network data were processed and tabulated. The tabulations, along with the other data, are being analyzed to determine meteorological conditions near the shoreline and their variations with distance inland which existed prior to the operation of the cooling system. This work is being carried on for the network data obtained to date. A separate report containing data tabulations and an analysis of conditions for this phase of the study is in preparation and will be submitted at a later date. This section of the progress report presents and describes some examples of the tabulations, summaries and analyses being prepared.

Visibility. The visiometer data for April 1973 for station CO3A for visibilities less than 3 km are given in Table 2. The criterion used here to define an episode of low visibility is a visibility less than 3 km. As discussed below, this value represents the greatest visibility for which the visiometer data are reliable. The onset time of an episode shown in the table means that the visibility has remained greater than 3 km for at least 1/2 hour prior to decreasing to less than 3 km. The ending time means that the visibility has remained greater than 3 km for at least 1/2 hour. "Total hours" is the total accumulated time within the episodes when the visibility is actually less than the specified visibility.

Table 2. Visiometer data for station COSA for visibilities less than 3 km

Dates of Recording: 1-19 April 1973
Total Hours of Data: 441

Date	<3 km Onset (EST)	<3 km End (EST)	Total Hours	<1 km Onset (EST)	<1 km End (EST)	Total Hours	<0.5 km Onset (EST)	<0.5 km End (EST)	Total Hours	Min. vis. (km)	Obstruction to Vis.
2 Apr	1926	1943	0.27	None			None			2.6	Fog/drizzle
3 Apr	0859	1034	0.67	None			None			1.1	Fog
	1401	1404		None			None				
	1440	1441		None			None				
4 Apr	0110	0259	1.80	None			None			1.3	Fog/drizzle
10 Apr	0734	0812	1.27	None		0.02	None			0.6	Snow
	1228	1424		1328	1329		None				
	1615	1617		None			None				
	1730	1750		None			None				
	1822	1847		None			None				
12 Apr	0010	0015	.51	None			None			2.4	Snow
	0208	0234		None			None				
18 Apr	0046	0808	7.38	0212	0510	2.96	0250	0441	1.06	0.4	Fog

Summary: Percent of recorded data

	Fog	Snow
<3 km	2.29	0.40
<1 km	0.67	0
<0.5 km	0.24	0

For each episode of low visibility the percentages of each hour that the visibility is (1) less than 3 km, (2) less than 1 km, and (3) less than 0.5 km are shown. If the obstruction to visibility is fog, a visibility less than about 0.5 km is classified by National Weather Service as heavy fog. The percentages are not computed if data are missing for all or part of a given hour. The number of hours with complete data for a given month are given at the top of the table and the percent of complete data in each visibility category is summarized at the bottom.

For each episode shown, the minimum visibility and the obstruction to visibility are also given. Information on the type of obstruction is necessary because (1) it is likely that the cooling system will exert a different effect on fog than on precipitation and (2) the visiometer does not give as accurate a measure of visibility in precipitation as it does in obstructions comprised of smaller-sized particles.

A preliminary analysis of visibility data obtained during snow, for example, has shown occasional significant reductions in visibility but no measured precipitation associated with them. The reasons for this behavior, which occurs mainly during gusty winds, appear to be that (1) the visibility may indeed be reduced but sufficient snow has not entered the gage because of the gusty wind and/or the water equivalent of the snow did not exceed the 0.01 inch sensitivity of the gage or (2) the actual visibility is greater than that indicated by the visiometer, which may over-respond to snow. Either reason or a combination of both could be valid, and both are being studied.

The type of obstruction to visibility is determined on the basis of (1) hourly weather observations made at Benton Harbor Airport between 0630 and 2030 each day and at Muskegon and South Bend on a 24-hour basis and (2) measurements of precipitation and other variables within the meteorological network.

Wind speed and direction. For tabulation, digitized wind data are reduced to hourly averages of wind speed and direction. A finite-difference scheme is used which involves making linear interpolations between digitized values for every 3 minutes. These values are then averaged for each hour and tabulated.

From the hourly averages, joint occurrences of wind direction and wind speed in assigned catagories are counted. The categories for wind speed in miles per hour are: calm (less than 1 mph), 1-3, 4-7, 8-12, 13-18, 19+, and missing. Wind direction is defined by the direction from which the air is moving. For comparison with other published wind data it is tabulated in two ways: (1) by every 10 degrees, in keeping with standard National Weather Service tabulations and (2) by 16 standard compass points (N, NNE, NE, etc.), plus categories for calm and missing data. In addition, a category for a variable wind direction is included. A wind direction is classified "variable" if the range of wind directions during an hour exceeds 180 degrees.

Joint percentage frequencies for each month are determined by dividing the number of joint occurrences in each pair of categories by the total number of hours of data. From the joint frequency data, two wind roses for each main station are plotted, one using 10-degree increments and one using compass points.

Wind roses with 10 degree divisions for station C03A and C10A for February 1973 are given in Figures 2 and 3. North is toward the top of the figure. The length of each line is proportional to the percent of time that the wind was from that direction. One inch equals 2% of the time. The number at the end of each line is the average wind speed in miles per hour for that direction. The percent of time that the wind was calm, as well as the percent of time the wind direction was variable, are also indicated. The sum of the percentages for (1) the 36 directions, (2) the percentage of calms, and (3) the percentage of variable winds equals 100%.

Precipitation. Daily and monthly totals of precipitation for all stations are given in Tables 3 and 4 for January and February, 1973. For these two months, seventeen days, or 29%, had measurable precipitation. Variations in precipitation among the stations are evident both on a daily and monthly basis, but an isopleth analysis did not reveal a significant trend with distance in land. A number in parenthesis gives the total of the amounts for the preceeding days marked with asterisks.

Temperature. Daily maximum and minimum temperatures for February, 1973, are given in Table 5. The reason for the missing data early in February is that initial delivery of the hygrothermographs was on 2 February and they were compared and adjusted prior to installation.

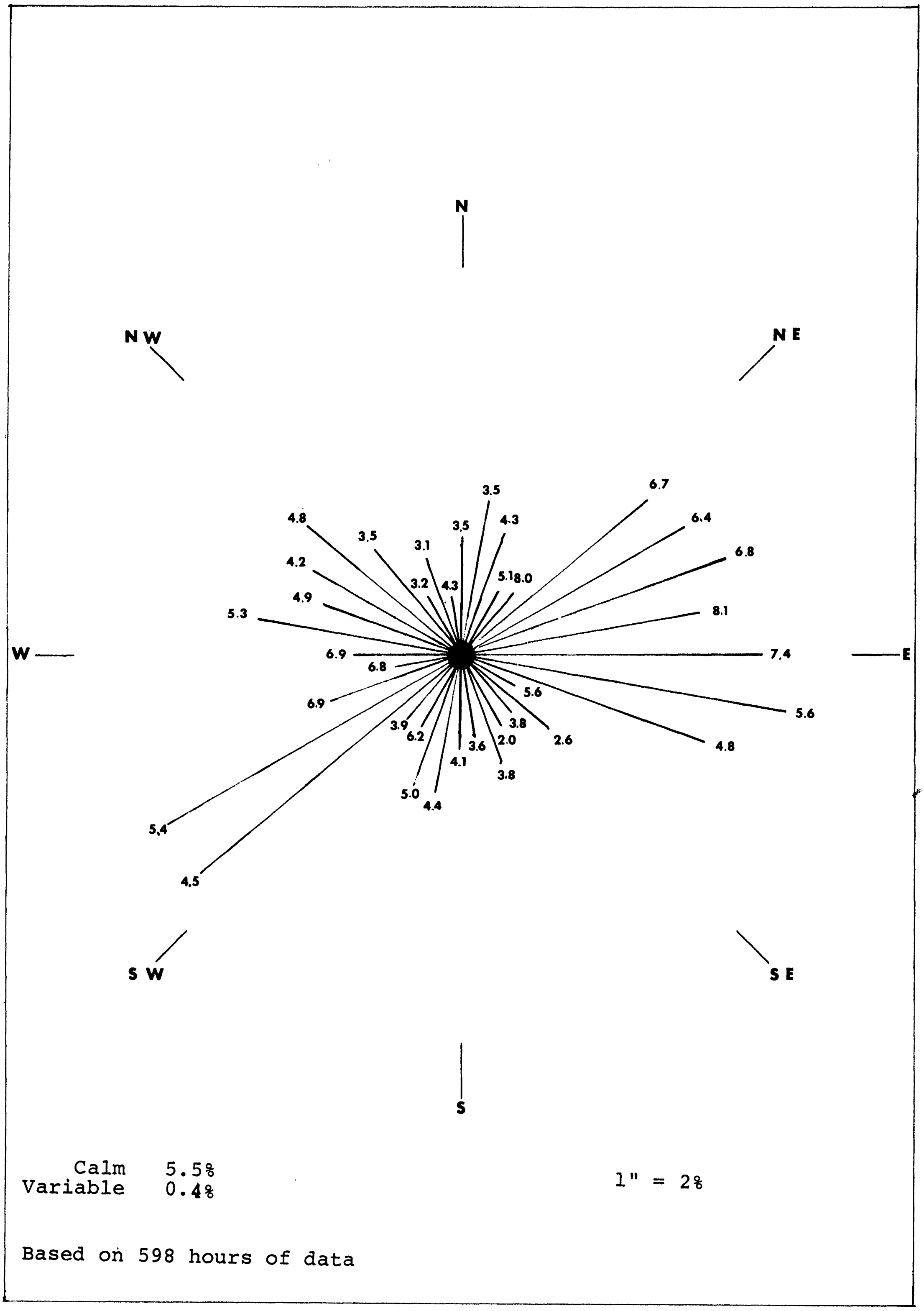

Figure 2. Wind rose for station CO3A for February, 1973. The numbers are wind speed in miles per hour.

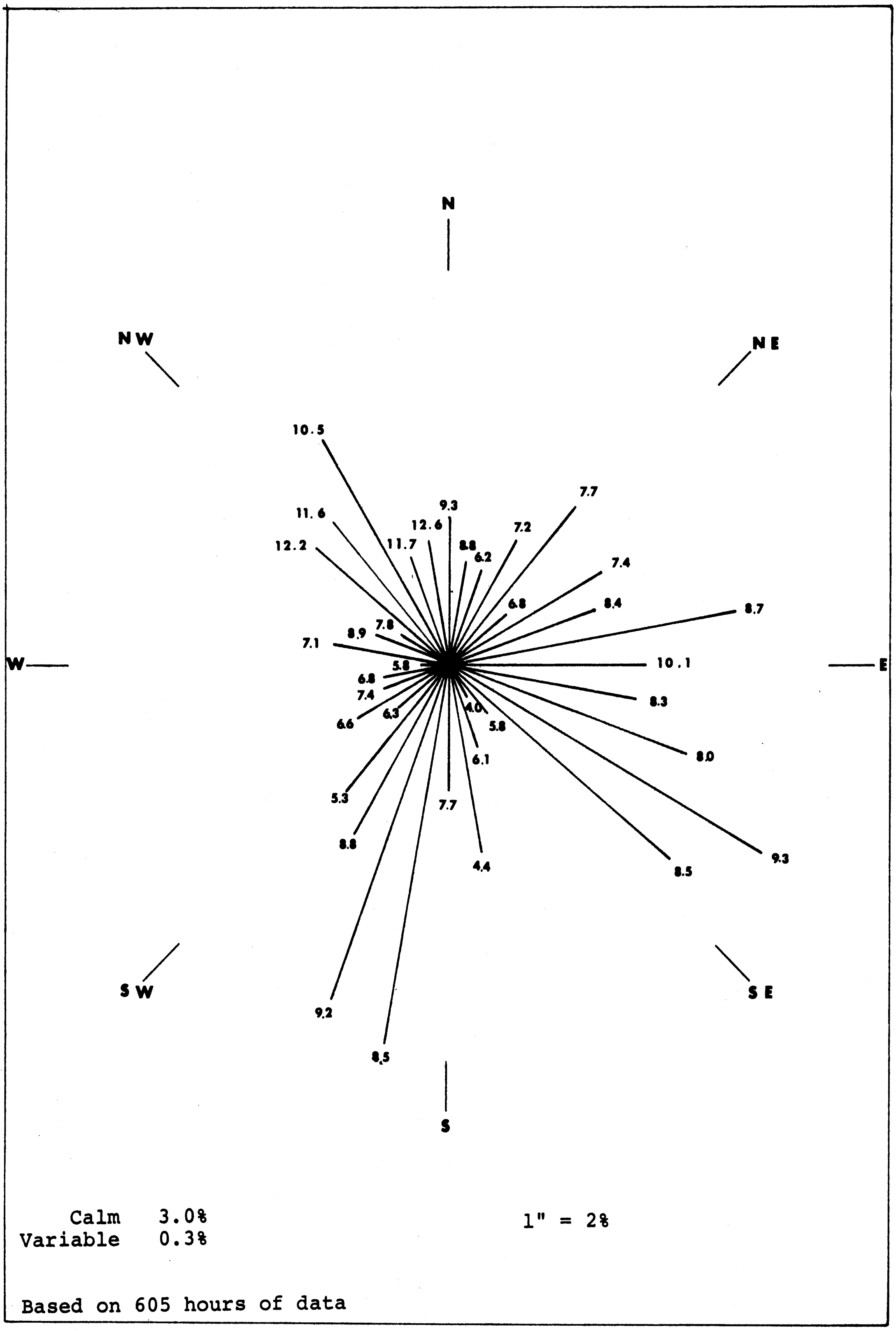

Figure 3. Wind rose for station C10A for February, 1973. The numbers are wind speed in miles per hour.

Table 3 Daily totals of precipitation for January 1973 for the Cook network

DAY	CO1A	CO2A	CO2B	CO3A	CO4A	CO5A	CO6A	CO7A	CO8A	CO9A	C10A	C11A	C12A
1	0	0	0	9	0	0	0	0	0	0	0	0	0
2	0	0	0	9	0	0	0	0	0	0	0	0	0
3	0.59	0.65	0.65	0.57	0.67	0.71	0.65	0.74	0.65	0.63	0.72	0.67	0.75
4	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0.02	0	0	0	0	0	0	0.02	0.02	0.02	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0
14	*	0	0	0.02	0.02	0	0	0.01	0	0	0	0	0
15	(0.04)	0.05	0.04	0.03	0.03	0	0.03	0.01	0.04	0.03	0	0	0.03
16	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0.30	0.33	0.34	0.34	0.37	0.45	0.38	0.30	0.28	0.20	0.20	0.28	0.24
19	0.08	0.04	*	0.05	0.03	0.04	0.04	0.09	0.02	0.02	0.05	0.08	0.10
20	0	0	*	0	0	0	0	0	0	0	0	0	0
21	0.11	0.15	(0.20)	0.10	0.12	0.10	0.13	0.18	0.15	0.17	0.24	0.18	0.18
22	0.11	0.09	0.11	0.10	0.13	0.17	0.13	0.08	0.13	0.15	0.08	0.10	0.10
23	0.03	0.03	0.04	0.04	0.02	0.06	0.05	0.05	0.08	0.06	0.05	0.08	0.07
24	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0
	1.28	1.34	1.38	1.25	1.39	1.53	1.41	1.48	1.37	1.28	1.34	1.39	1.47

* ( ) The number in parenthesis is the total of the amounts for the preceding days marked with asterisks.

Table 4 . Daily totals of precipitation for February 1973 for the Cook network

DAY	CO1A	CO2A	CO2B	CO3A	CO4A	CO5A	CO6A	CO7A	CO8A	CO9A	C10A	C11A	C12A
1	0.28	0.31	0.29	0.26	0.31	0.42	0.25	0.26	0.26	0.27	0.31	0.27	0.36
2	0.25	0.24	0.26	0.26	0.26	0.30	0.27	0.33	0.31	0.30	0.37	0.32	0.43
3	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0.14	0.14	0.13	0.16	0.13	0.17	0.09	0.05	0.08	0.11	0.05	0.08	0.10
8	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0.04	0.03	0.02	0.02	0.04	0.05	0.05	0.07	0.09	0.10	0.06	0.09	0.11
15	0.18	0.12	0.13	0.14	0.06	0.11	0.05	0.04	0.03	0.10	0.03	0.06	0.08
16	0.	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	*	0.01	0.01	0.01	0	0.01	0	0.02	0	0	0	0
20	0.08	*	0.07	0.06	0.05	0.08	0.08	0.05	0.07	0.10	0.06	0.08	0.09
21	0.08	*	0.06	0.05	0.07	0.06	0.07	0.05	0.07	0.06	0.04	0.03	0.05
22	0	*	0	0	0	0	0	0	0	0	0	0	0
23	0	*	0	0	0	0	0	0	0	0	0	0	0
24	0	*	0	0	0	0	0	0	0	0	0	0	0
25	0.04	*	0	0.02	0.02	0.03	0.02	0.04	0.03	0.04	0.03	0.03	0.04
26	0	(0.26)	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0
	1.09	1.10	0.97	0.98	0.95	1.22	0.89	0.89	0.96	1.08	0.95	0.96	1.26

*
( ) The number in parenthesis is the total of the amounts for the preceding days marked with asterisks.

Table 5 Daily maximum temperatures (0000-2400 EST) for February 1973

Day	CO1A	CO3A	CO6A	CO7A	C10A	C11A	C12A
1	M	M	M	M	M	M	M
2	M	M	M	M	M	M	M
3	M	M	M	M	M	M	M
4	M	M	M	M	M	M	M
5	M	M	M	M	M	M	M
6	M	M	M	M	M	M	M
7	M	M	M	M	M	M	M
8	26	26	23	25	25	24	M
9	24	24	22	23	22	22	M
10	29	29	26	27	27	27	M
11	28	29	26	27	27	26	M
12	35	37	36	35	34	34	M
13	43	44	42	42	41	40	40
14	37	38	37	36	37	36	36
15	34	34	34	33	33	33	33
16	M	18	15	14	13	14	14
17	M	23	22	20	19	M	20
18	32	32	31	31	31	31	31
19	36	36	36	36	36	36	36
20	37	37	37	36	36	36	36
21	35	35	34	33	33	33	33
22	34	34	33	32	32	31	31
23	37	38	36	36	34	35	35
24	37	38	37	36	36	36	36
25	37	38	37	34	36	36	36
26	31	32	31	30	30	29	30
27	34	36	36	38	37	37	38
28	47	47	47	45	45	44	45
Ave.	36.5	37.1	36.2	35.6	35.5	35.2	35.4

M Missing data
Ave. Average for days with data for all stations

Table 5. (cont) Daily minimum temperature (0000-2400 EST) for February 1973

Day	C01A	C03A	C06A	C07A	C10A	C11A	C12A
1	M	M	M	M	M	M	M
2	M	M	M	M	M	M	M
3	M	M	M	M	M	M	M
4	M	M	M	M	M	M	M
5	M	M	M	M	M	M	M
6	M	M	M	M	M	M	M
7	M	M	M	M	M	M	M
8	19	19	17	18	18	17	M
9	20	20	16	14	14	14	M
10	17	17	14	16	15	15	M
11	13	13	10	11	11	10	M
12	16	15	13	14	14	14	M
13	22	22	22	22	21	20	20
14	34	34	34	33	33	33	33
15	14	13	13	12	12	11	12
16	M	3	2	4	2	3	1
17	M	-1	-2	-3	-2	-2	-4
18	18	18	16	17	16	17	17
19	32	32	31	31	31	31	31
20	33	33	32	31	30	30	30
21	24	24	22	22	21	21	21
22	21	21	20	19	19	19	18
23	26	26	25	23	24	24	23
24	27	26	25	25	25	26	24
25	27	27	25	25	24	25	25
26	25	25	24	23	25	22	23
27	15	16	15	15	16	15	17
28	22	23	23	25	24	24	24
Ave.	24.3	24.3	23.4	23.5	22.6	22.7	22.7

M Missing data
Ave. Average for days with data for all stations

The average temperatures given in these summaries are obtained only for those days where data were available for all stations. Such an average allows comparisons among stations without the averages being biased by different sampling periods. In February 1973, there was an average decrease of about 1.5° F from near the Nuclear Plant to about 10 miles inland in both the maximum and minimum temperatures.

Natural variability

Fog. Table 6 shows the average percent of time natural fog may be expected to occur each month near the Cook Nuclear Plant.

Table 6. Average percent of total hours with natural fog by month expected for the Cook area

J	F	M	A	M	J	J	A	S	O	N	D
15	10	8	8	9	7	7	9	5	9	7	15

The percentages are from an analysis of the number of hours with fog observed at the National Weather Service station at Muskegon County Airport (Koss and Altomare, 1971) located about 90 miles north of the Cook Nuclear Plant and about 3.5 miles inland. It is the nearest station with hourly observations on a 24-hour basis whose long-term visibility data are complete and considered to be representative of average conditions near Lake Michigan.

It is evident that fog occurs most often in January and February, each of which has fog about 15% of the time, and least often in September, which has fog about 5% of the time. If the data are further divided into winter months of December, January, and February; spring months of March, April, and May; summer months of June, July, and August; and fall months of September, October, and November; fog occurs about 14% of the time in winter, 8% in spring, 8% in summer, and 7% in the fall. Except for summer, these frequencies compare well with those observed for Midway Airport in Chicago in spite of differences in location, distance with respect to Lake Michigan and other factors expected to cause differences in fog frequencies. Chicago has fog 14% of the total hours in winter, 8% in spring, 4% in summer, and 7% in fall (Huff and Vogel, 1973). It is likely that an urban heat island effect is primarily responsible for the lower frequencies of fog in summer for Chicago.

Temperature and precipitation. Information on the natural variability of temperature and precipitation across the inland extent of the network was obtained from climatological records for Benton Harbor, located near Lake Michigan, and Eau Claire, located 14 miles inland and about 7 miles northeast of station C10A. Climatological summaries for the period 1940-1969 were used (Michigan Weather Service, 1971). Monthly means of temperature and precipitation for two stations are shown in Table 7 . Differences in temperature and precipitation between the stations are also shown.

Table 7. Monthly means of temperature and precipitation for Benton Harbor and Eau Claire, Michigan

Temp. °F	J	F	M	A	M	J	J	A	S	O	N	D
(1) Benton Harbor	25.9	27.7	35.6	47.7	57.3	67.7	71.4	70.1	64.0	53.9	40.9	30.0
(2) Eau Claire	24.7	26.9	35.7	48.7	58.7	69.1	73.1	71.8	64.6	54.3	40.2	28.9
diff. (1)-(2)	+1.2	+0.8	-0.1	-1.0	-1.4	-1.4	-1.7	-1.7	-0.6	-0.4	+0.7	+1.1
Precip. (in.)												
(1) Benton Harbor	2.67	2.02	2.47	3.49	3.83	3.55	3.11	2.99	2.97	3.04	2.83	2.72
(2) Eau Claire	2.29	1.75	2.32	3.70	3.68	3.89	3.25	2.94	3.13	3.21	2.80	2.10
diff. (1)-(2)	+0.38	+0.27	+0.15	-0.21	+0.15	-0.34	-0.14	+0.05	-0.16	-0.17	+0.03	+0.62

The average temperature decreases with distance inland for the months between September and March and increases inland between March and October. The maximum decrease (near 1° F) occurs from November through February and the maximum increase (near 2° F) occurs in July and August. Both results can be explained by the fact that the surface water temperature of Lake Michigan lags in cooling in late fall and early winter and thereby is warmer than the land, on the average, and then lags in heating in late spring and early summer and thereby is colder than the land.

A seasonal variation in precipitation is also evident. Except for May and August, average precipitation is greater at Benton Harbor from November through March and less from April through October. The summertime results are in keeping with what would be expected, since as air moves from over a cold (lake) to a warm (land) surface convective activity generally increases with distance downwind. At this location, downwind is inland, on the average. The wintertime results imply that for onshore winds, vertical motions are enhanced by (1) thermal instability (cold air over warm water) and (2) greater surface roughness along the shoreline and act in concert with air near saturation to produce more snowfall near the shoreline.

Variations of precipitation with season and wind direction. One of the statistical analyses to be made in studying meteorological effects of the cooling system involves a comparison of effects with onshore and offshore winds. To determine if differences in precipitation occur in onshore and offshore flow, a study was made using data for Muskegon. Hourly precipitation totals and wind observations were obtained for the 4-year period from 1960 through 1963. The limited extent of this period was determined by the availability of a homogeneous data set on magnetic tapes from the National Climatic Center. A total of 35,064 hourly observations were used, a preliminary analysis and interpretation of which are given below.

The graphical output of the analysis is shown in Figure 4. Wind roses are given in the first row. The number at the end of each direction is the frequency, not the mean speed as given in other wind roses shown in this report. In the upper left box, directions for onshore, offshore, and along shore winds are shown for reference. The data were further categorized in terms of the four seasons as shown, with winter on the left and fall on the right.

The wind roses show that for all seasons, onshore winds occur more frequently than offshore winds. Changes in frequencies are evident from one season to the next. For example, the prevailing wind direction in winter is WNW, while in the other seasons it is SSW. Winds from NNE and SSE occur least frequently in all seasons.

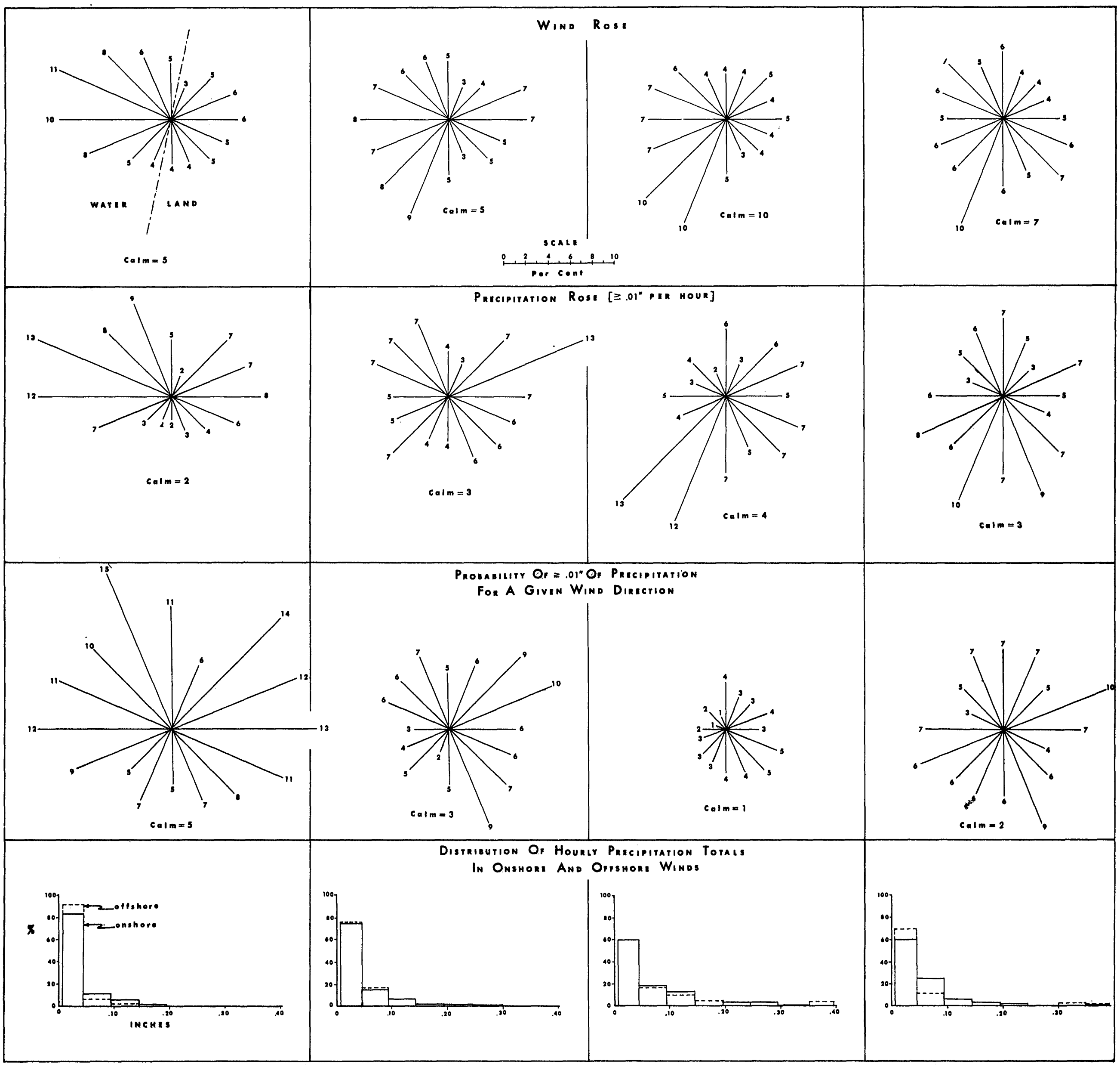

Figure 4. Wind roses and precipitation wind roses for Muskegon by season. The number at the end of each direction is frequency of occurrence in percent.

The second row in Figure 4 gives precipitation roses, which are wind roses for a subset of the above data consisting of the number of hours, converted to frequency in percent, when 0.01 inch or more of precipitation was recorded. If precipitation and wind direction were completely uncorrelated, the precipitation and wind roses would be quite similar. Distinct differences are apparent in the patterns shown, however, indicating that precipitation is correlated with the wind direction. In winter there are maxima for the W and WNW directions which are probably associated with frequent polar outbreaks accompanied by snow to the lee of Lake Michigan. The high frequency for east winds could be due to precipitation with low pressure systems passing to the south of Muskegon. Like the wind rose, in winter a frequency minimum is generally apparent for the NNE and SSE directions. In spring, the maximum associated with a west wind in winter disappears and is replaced by a maximum with an ENE wind. In summer, SW and SSW are preferred directions for precipitation.

The precipitation roses discussed above are useful for studying the natural frequency of precipitation for winds from various directions. They are inadequate, however, for determining changes from the natural frequency of precipitation. For instance, a wind direction which has a low frequency of occurrence in the wind rose usually has a low frequency in the precipitation rose also. One technique for examining the changes is to calculate the probability that precipitation will occur, given a particular wind direction.

Probabilities of precipitation for various wind directions are given in the third row in Figure 4 . They show a marked change with season, with winter having the higher probability for all directions than the other seasons. There is a distinct mimimum for the south quadrant, probably resulting from the fact that low pressure systems which move to the west of Muskegon generally do not produce much precipitation at Muskegon in winter. It is usually not until a cold frontal passage associated with the systems occurs that snow begins, which could account for the maximum in the NW quadrant. In summer the probability of precipitation is about one-half to one-third that of winter for a particular direction, reflecting the brief convective nature of summertime rains. In spring, the probability of precipitation for an onshore wind is much lower than that for an offshore wind. The difference results from the stabilizing effect of Lake Michigan in spring - an effect that was not evident from the precipitation roses. In summer, the probabilities are more evenly distributed. In fall there is a distinct variation in probability with direction, although this variation is apparently not related to whether or not the wind is onshore or offshore.

To determine if the onshore or offshore winds have a pronounced effect on the intensity of precipitation, hourly precipitation data were divided into precipitation categories of 0.05 inch (except .04 in the first box) and are shown in the fourth row. They are further divided into onshore and offshore winds. The totals per hour in winter are much smaller than in summer, for which there is a distinct skewness of the distribution to the right. Significantly, there does not appear to be a difference for onshore and offshore directions.

IV. DATA PROCESSING

The University of Michigan 360/67 digital computer is used extensively to process the 96 items recorded by both meteorological networks. The conversion from analog format on strip charts to digital format on magnetic tapes is accomplished with a Graf/pen digitizer and a complementary set of computer programs.

Figure 5 gives a flow diagram showing how the data from both meteorological networks are handled. The blocks at the top of the diagram show the 9 variables recorded on analog strip charts. The number of stations per data type varies from 2 for dew point to 26 for temperature, relative humidity and precipitation. The variable recorded, the number of stations for both the Palisades and Cook networks, and the interval between chart changes are given in each block.

As indicated in Figure 5 , when the strip chart records are received from the field, (1) they are screened for any obvious errors due to instrument malfunction, (2) dates and times are entered, (3) the analog recordings are digitized, and (4) the digitized data are read into disk files of the University of Michigan Computer Facility. Frequent checks of these data are made by reproducing the original data on a cathode-ray tube display scope. The processed data are then merged onto a magnetic tape. Steps in this procedure are discussed below and examples of processed data are presented.

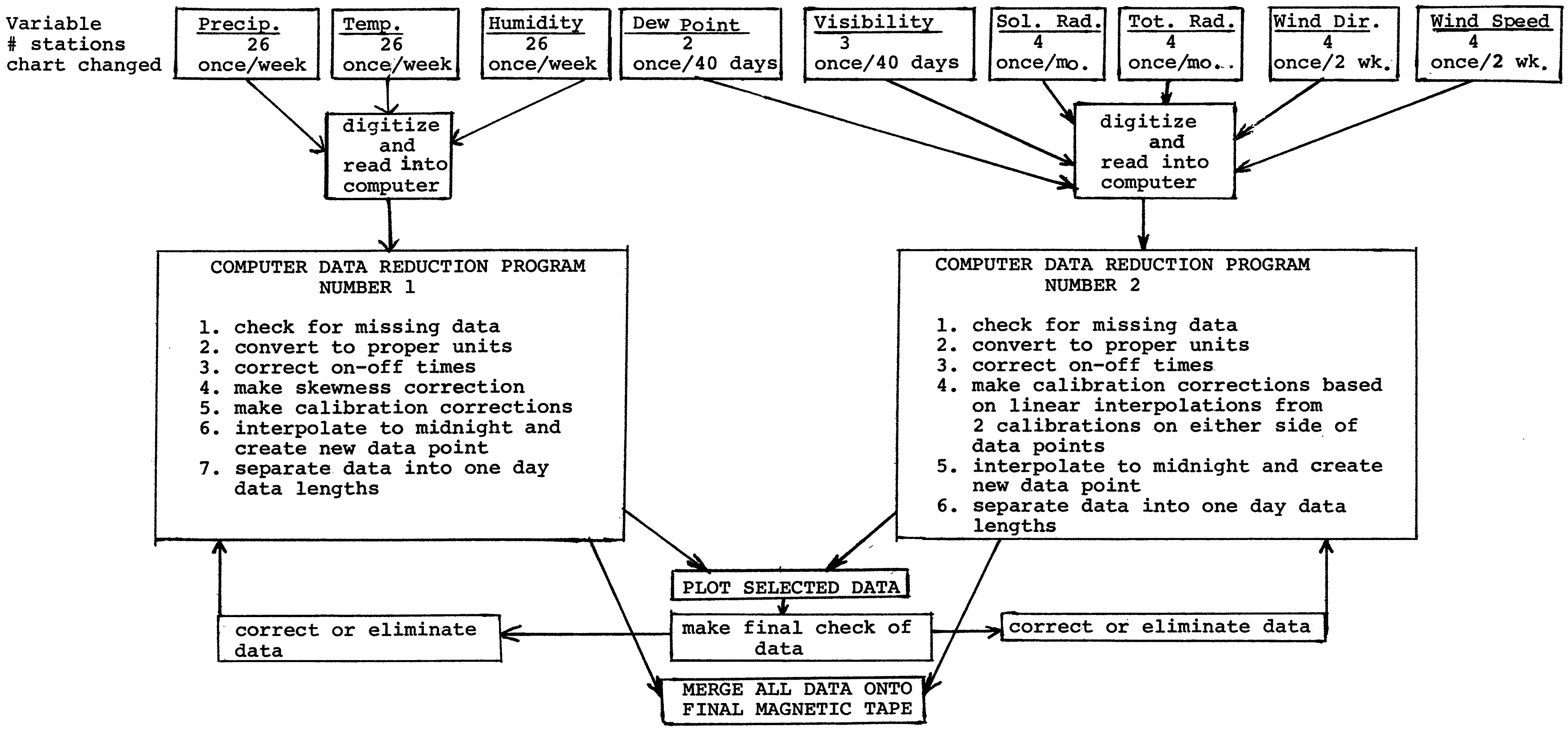

Figure 5. Flow diagram for meteorological data handling.

Digitization

Figure 6 shows the digitizer and peripheral equipment. The main component is a Graf/Pen GP-2 Sonic digitizer manufactured by Science Accessories Corporation. The digitizer measures the interval of time it takes sound to travel from a spark on the pen shown in Figure 6 to two microphone sensors separated by 90 degrees. The time interval is then converted electronically to X and Y distances with an accuracy of 0.01" and punched onto paper tape using a FACIT 4070 Tape Punch. The sensor portion of the tablet has what is called a menu at the top. This is a portion of the sensing area which is reserved for special instructions. By placing the pen on a particular pre-assigned point, the person digitizing is able to (1) identify the station, (2) indicate the variable, (3) give on-off times, (4) indicate end of data, (5) indicate mispunched data, and (6) indicate missing data.

Rules have been established for digitizing the various types of data. For most data the greater the variability of the parameter recorded, the more the number of values digitized. A greater number of values of solar radiation, for example, are obtained on a partly cloudy day than on a clear or uniformly overcast day. In addition, if there are sudden excursions in the trace of a recorded variable, a decision must be made to determine if they are real or if they are caused by equipment problems. An example is those which occur occasionally in the visiometer data during precipitation, in which case they would be expected, and those which occur in the absence of precipitation, in which case they

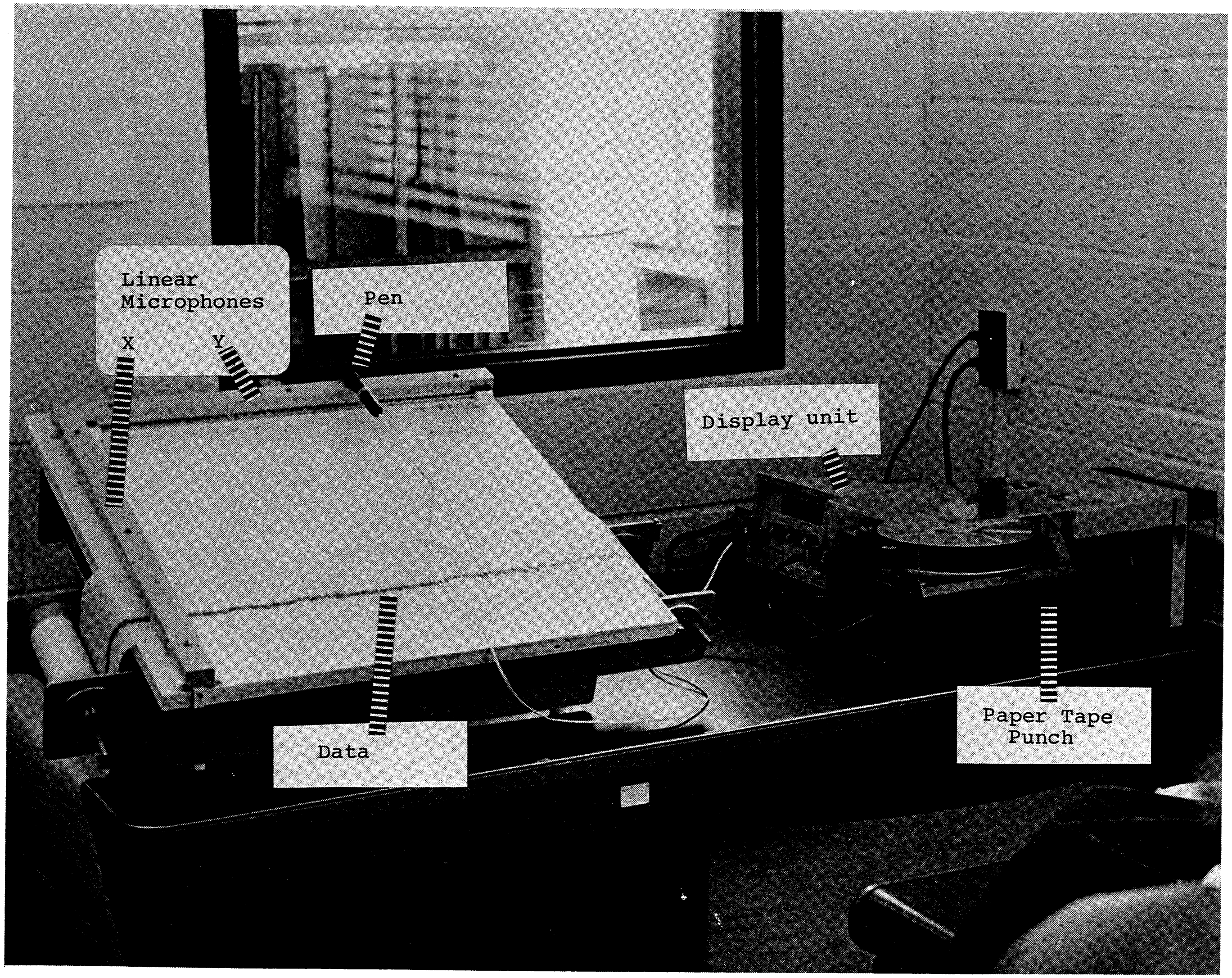

Figure 6. Graf/pen Model GP-2 Sonic Digitizing System.

are due to electrical noise and are not digitized.

In addition to these and other rules which are applied in the digitizing process, the fact that the meteorological variables are recorded on a different type of strip charts requires different ways of handling the data. For example, precipitation is recorded on a curvilinear chart with arcs for the time scale concave to the right. Temperature and relative humidity are recorded together on a double curvilinear chart, also with the time arcs concave to the right. Wind speed and direction charts are curvilinear with the time arcs concave to the left. Radiation and visibility charts are rectilinear, with the radiation chart 6 inches wide and the visibility chart 12 inches wide.

Data package

Because the strip charts which contain a week of recordings of precipitation, temperature, and relative humidity are less than 12 inches long, and those which contain recordings of radiation, wind and visibility for longer time periods are 100 feet long, two different computer programs are needed for data reduction. In Figure 5 they are shown as "Program #1" for the former charts and "Program #2" for the latter. Both programs accomplish similar tasks; only the details are different.

Digitized data are read into the computer in a sequence called here a data package. A package is defined as a body of digitized data which is handled throughout the computerized operation as a single compact data file. Each data package is initialized by a prologue which identifies it uniquely. The prologue provides the station name and data type, the starting date and time and other information which establishes a proper coordinate system.

The computer programs are designed to be as general as possible. For example, a package can begin on any date and at any time of day and, in most cases, can end on any later date and time of day. Diagnostic routines have been implemented to correct for chart interruptions caused by power failures, clock stoppages, time adjustments, chart changes, and calibrations. The computer programs are designed, furthermore, so that for unique or unusual events which cannot be anticipated, human intervention and manual correction of the data are possible. In addition, comparisons of the computer output with data processed manually are made occasionally.

Final storage format

The processed data are stored on magnetic tape in a series of files, each of which contains one month of data. Within each file, the data are ordered by day in a pre-assigned sequence. All digitized data points for one item, one station and one day (e.g., precipitation on January 3, 1973, at C10A) are stored on one record. Since there are nearly 100 items of data, a file consists of about 3000 records. A record can be variable in length. The organization of the first 15 4-byte words of the record establishes its identity and is given below:

Word No.	Item
1	year
2	month
3	day
4	data type

Word No.	Item
5-8	station call letters
9	priority number
10	creation date
11-14	storage of special data
15	data accuracy

From the 16th word on, the data are stored in 4-byte word pairs. The first word gives the time and the second gives the value of the variable. Where necessary, the value for the time 2400 EST are interpolated from the given data and treated like other data points.

Example of input data

In an example given below, visibility data are used to illustrate the data reduction process. Data are followed from the recording stage to their final presentation.

Visibility is recorded at stations P03A and P07A of the Palisades network, and station number C03A of the Cook network. The visibility measuring system is a MRI visiometer and recorder. The voltage output from the visiometer is recorded on a MRI 0-5 volt strip chart recorder at a chart speed of one inch per hour. A decreasing visibility produces an increasing voltage.

A visibility data package must be accompanied by a calibration file before it can be completely processed. The file consists of (1) a calibration voltage for the visiometer as input to the recorder and (2) a recorder calibration. Recorder calibration factors are determined by the number of inches the recorder pen moves up scale in response to voltages up to 5 volts applied in 1-volt increments. Linearity is assumed only for the 1-volt increments and, as a result, each digitized value is calibrated for pen movements upscale corresponding to 0, 1, 2, 3, 4 and 5 volts, respectively.

There is a system calibration for the beginning and end of the package as well as any which is made between the beginning and ending dates of the package. The computer program applies the calibration data and converts the digitized data to visibility values. It accomplishes this by taking the data from the calibration file and setting and adjusting the recorder and sensor calibration parameters one day at a time by interpolating between the calibrations nearest to that day. Voltage is converted to visibility by the equation:

$$\text{Vis(km)} = 0.39/\text{voltage}$$

The data are questionable for voltages less than about 0.1 volt, which corresponds to a visibility of at least 4 km. Any calculated visibility greater than 5 kilometers, therefore, is set equal to 5 kilometers.

Final data plot

An example showing data for station PO3A for the period 28 June - 2 July 1973 which have been plotted by the CALCOMP 780/763 digital plotter is given in Figure 7 . Time is listed across the bottom and increases from left to right. Vertical lines are given for every 6 hours. Plots of the variables are arranged vertically.

From top to bottom, the variables are visibility, in kilometers; total incoming radiation (solar plus atmospheric), in

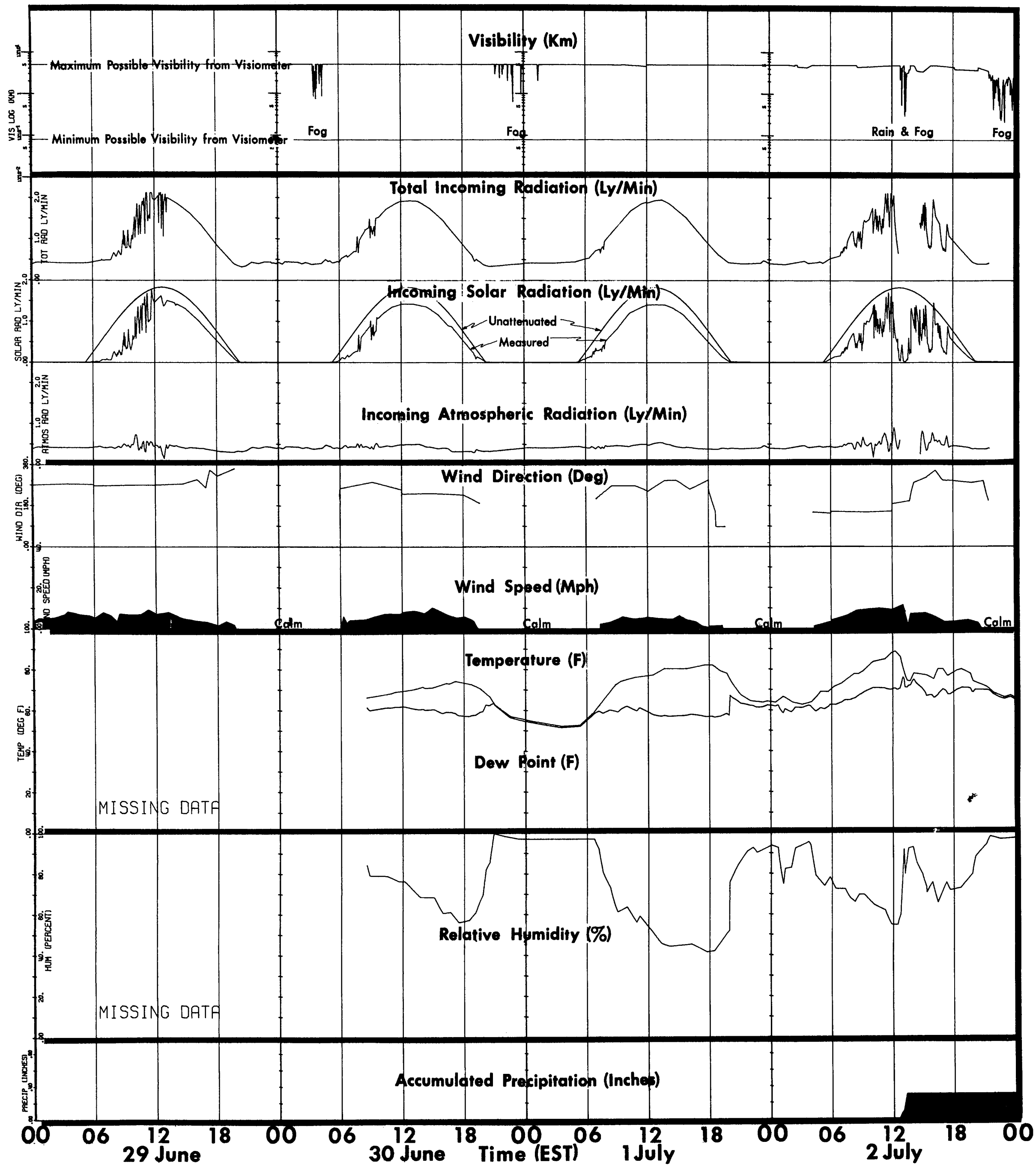

Figure 7. CalComp plot of variables for station CO3A.

langley*/min; solar radiation (direct and diffuse), in langleys/min; atmospheric radiation (total incoming minus solar), in langleys/min; wind direction, in degrees clockwise from north; wind speed, in miles/hour; temperature and dew point, in degrees F; relative humidity, in percent; and precipitation, in inches. In the plot of solar radiation, the upper curve is the computed solar radiation arriving at the top of the earth's atmosphere and the lower curve is the measured values. The values of dew point shown are calculated from temperature and humidity data.

The value of such a plot is that it gives a visual display of all the variables measured and thereby allows their interdependence to be examined. The data from a main station are not plotted in this way on a continuous basis, but occasionally for monitoring the output data and for case studies, such as those involving fog episodes.

* A langley is equivalent to one gram-calorie per square centimeter.

Accuracy of the analog to digital conversion

Since all analog data collected in the field are converted to digital data, it is important that the accuracy of this conversion be established. The accuracy depends upon the precision of the Graf/pen digitizer, where the precision is the repeatability of a measurement. The computer programs are designed so that they depend not upon the absolute distance measurement of the apparatus but upon the distance measured relative to a reference distance determined by placing the pen on preassigned points on the chart being digitized. A statistical routine was developed to establish the inherent precision of the Graf/pen digitizer in relation to the x, y position on the tablet, the age of the digitizer and the person digitizing.

A test pattern of 36 points on the 14" by 14" grid on the digitizing tablet is digitized ten times. A computer program was written to calculate the average location of each of the 36 points, the mean distance between adjacent points, the standard deviation S of each distance, and the standard deviation S_n of each mean distance computed from the repeated digitization of the grid points. Figures 8 and 9 show the grids with a reduced scale.

The standard deviation S is the best statistical estimate of the inherent precision of the digitizing process. It is defined by Equation 1.

$$S = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}} \qquad 1)$$

a. x-direction

	Col 1	Col 3	Col 5
	3.984	3.977	3.984
	3.980	3.972	3.979
	3.980	3.975	3.984
	3.983	3.978	3.982
	3.981	3.975	3.984
	3.979	3.972	3.982
Ave.	3.981	3.975	3.983

b. y-direction

							Ave.
Row 1	3.977	3.975	3.980	3.975	3.984	3.983	3.979
Row 3	3.978	3.972	3.974	3.975	3.975	3.981	3.976
Row 5	3.987	3.983	3.984	3.992	3.990	3.987	3.987

Average for grid is 3.980

Scale

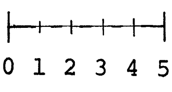

Figure 8. Spatial distribution of time-averaged distances for 7 runs with digitizer.

a. x-direction

	Col 1	Col 3	Col 5
	.0166	.0190	.0187
	.0185	.0152	.0161
	.0177	.0157	.0172
	.0165	.0158	.0168
	.0194	.0184	.0160
	.0195	.0175	.0154
Ave.	.0180	.0169	.0167

b. y-direction

					Ave
Row 1	.0196	.0210 .0212	.0176 .0247	.0186	.0204
Row 3	.0201	.0222 .0230	.0184 .0257	.0192	.0214
Row 5	.0275	.0213 .0234	.0189 .0252	.0187	.0225

Average for grid = .0193

Scale

0 1 2 3 4 5

Figure 10. Humidity calibration chamber

where n = sample size

x_i = elements of sample

$\bar{x}$ = sample mean = $\frac{1}{n} \Sigma x_i$

The accuracy of a sample mean increases with sample size and with the inherent accuracy of a process. In this case, the standard deviation S_n of the mean distance between any two points, based on the given sample, is referred to as the adjusted standard error. It is defined by Equation 2.

$$S_n = \frac{S}{\sqrt{n}} \qquad 2)$$

The dates when the 36-point test grid was digitized are shown in Table 8. Run #5 revealed that left-handed individuals could not use the digitizer in its present arrangement, since the position of the left hand holding the pen changed the travel time of the sound from the pen to the transducers (labelled "linear microphones" in Figure 6). For accurate, reproducible results, all digitizing is now done with the pen held in the right hand.

Results of the use of the test grid are also given in Table 8 which gives the spatial average of all independent distances shown in Figure 8 and S during each use of the test pattern. Although the distances in the x and y directions were measured by a ruler to be 4.00 inches, the distance measured by the digitizer was 3.98 inches. Since data processing programs are designed to be independent of actual distance measurements, the difference between a ruler measurement and a digitizer measurement is unimportant.

TABLE 8

Average distance and standard deviation, S, of the data points in inches

			X				Y		
Run #	Date	Col 1	Col 3	Col 5	S	Row 1	Row 3	Row 5	S
1	5/2/73	3.972	3.971	3.973	.0167	3.962	3.967	3.977	.0182
2A	4/17/73	3.977	3.977	3.976	.0130	3.978	3.974	3.977	.0141
2B	5/17/73	3.977	3.975	3.976	.0116	3.973	3.976	3.979	.0109
3	11/1/73	3.988	3.976	3.983	.0276	3.981	3.946	3.983	.0291
4	3/2/74	3.989	3.981	3.991	.0112	3.982	3.986	3.989	.0121
6	4/29/74	3.977	3.978	3.994	.0186	3.987	3.985	4.012	.0190
7	4/30/74	3.989	3.967	3.986	.0219	3.990	3.991	3.992	.0361
Average					.0172				.0199

The standard deviation S of the various distance measurements is slightly different for each separate use of the test grid, with the values in Table 8 ranging from 0.011 inches to 0.036 inches. The variations observed appear to depend more on the person using the digitizer than the apparatus itself. The average S for the x direction (corresponding to time on meteorological charts) is 0.0172 inches, with the average S in the y direction (corresponding to the magnitude of a variable) of 0.0199 inches. Thus, assuming a normal distribution, 67% of all data digitized are within these limits.

Table 9 gives the equivalent accuracy of a 0.02-inch variation in the digitized data in terms of meteorological units. Except for precipitation, the accuracy of the analog to digital data conversion is better than the accuracy of the meteorological instruments as given by the manufacturers. For precipitation, the accuracy of the digitization process is less than the measurement accuracy claimed by the manufacturer. However, considering the overall accuracy of the precipitation gage and its shortcomings in measuring precipitation during snow and/or strong winds, the digitization is sufficiently accurate.

The time average of the digitized distance between each pair of points separated by 4.00 inches (ruler distance) is performed to ascertain whether variations in distance occur across the tablet. The variations in distances measured by the digitizer are generally less than the adjusted error (approximately 0.007 inches) and are not significant. However, a trend across

Table 9

Equivalent accuracy in meteorological units
to ± .02" in strip chart reading

Variable	Time (hours)	Accuracy[1]
Temperature	± .30	± .64 F
Relative Humidity	± .30	± 1.28% R.H.
Precipitation	± .30	± .02 inch
Visiblity	± .02	see note 2
Wind Direction	± .006	± 2.4 degrees
Wind Speed	± .006	± .12 miles/hour
Short-wave Radiation	± .02	± .06 ly/min
Long-wave Radiation	± .02	± .06 ly/min
Dew point	± .02	see note 3

Notes

1. This is the accuracy before any smoothing by the man digitizing
2. The accuracy is ± .01 volts which corresponds to ± .64 km at 5 km and ± .01 km at 0.1 km
3. The accuracy is ± .01 which corresponds to around ± 0.4 F at -20 F dew point to ± .24 F at 20F dew point.

the grid may be indicated by a smaller measured distance across column number 3 in comparison with distance measured across the other two columns, and a larger measured distance across row number 5 than across the other two rows. This trend is too slight to be important in the data processing.

A spatial display of standard deviation is shown in Figure 9 . Figure 9a shows a steady increase in the variability of measurements from the top to the bottom of the test grid, and Figure 9b shows an increase from right to left. The magnitude of the standard deviation in the x direction is about 24% greater on the lower left side of the grid than on the lower right side. For the y direction, the standard deviation shows a 35% increase from lower right to lower left. In digitizing meteorological charts, this increase is unimportant except, possibly, for precipitation charts. It was found that since the variation of standard deviation across row number 3 is much less than across row number 5, the digitization of precipitation charts could be improved by placing the charts on the upper two-thirds of the digitizer tablet.

In conclusion, it has been found that use of a digitizer test grid has been of value in ascertaining the accuracy of the digitization procedure. The use of the right hand in holding the pen and the placement of the precipitation chart on the upper two thirds of the tablet have contributed to better analog to digitial data conversion. The test grid indicates that the digitization accuracy is slightly less than $\pm$ .02 inches.

V. NETWORK INSTRUMENTATION

Calibration of hair hygrothermographs

In the planning stages of the study when equipment for continuous measurements of temperature and relative humidity was being considered, it was realized that the main shortcoming of the hygrothermograph was the uncertain accuracy of the hair hygrometer for measuring relative humidity. Although Belfort Instrument Company claimed an accuracy of indicated relative humidity within ± 4% of true, other researchers, as well as our own experience, suggested that to achieve such an accuracy, the hygrothermographs had to be routinely calibrated using a standard humidity measuring device. For the first several months, therefore, a psychrometer, consisting of matched mercury thermometers was used to obtain field measurements of relative humidity which were then compared with those indicated by the hygrothermographs. For windy and overcast conditions, during which the humidity did not change significantly, the method gave reliable results. The method was unreliable, however, for conditions in which the humidity was varying significantly because the hair element had a slower response to changes in humidity than did the psychrometer.

To obtain a controlled range of steady relative humidities, a humidity calibration chamber was built, following the principles and design discussed by Haegele and Matthews (1964). This section describes the humidity chamber, summaries the calibration procedure, and presents results of basic tests made on the hygrothermographs.

Principle of operation. Many saturated salt solutions, when placed in a closed container, cause the relative humidity within that container to reach a value which depends upon the particular salt solution and its temperature. Some salt solutions produce relative humidities which are nearly independent of their temperature, and most produce humidities which show a minor temperature dependence (Wexler and Hasegawa, 1954). If various salt solutions are placed one at a time in a chamber containing (1) the hygrothermograph to be calibrated and (2) a standard instrument for determining the true relative humidity, therefore, it is possible to determine the difference between the true relative humidity as measured with a psychrometer and that indicated by the hygrothermograph for a large range of relative humidities.

Physical description of the chamber. A photograph of the chamber is shown in Figure 10. It is 16" high by 16" long by 12" wide, and weighs about 35 pounds. It is made of 1/2" thick transparent plexiglass and has two hinged access doors. A large door is for passage of the hygrothermograph and a small one is for the salt solution container.

The permanent seals of the chamber (those edges not containing a door) are made using an acrylic solvent and are air-tight. The access doors are rimmed with a soft rubber gasket material and the ports have either gasket material or rubber stoppers. Although a completely air-tight chamber was not achieved, for a given salt solution the chamber did maintain a fixed relative humidity over many hours of operation.

Fans are installed at both ends of the chamber to facilitate airflow at the salt solution - air interface and to circulate the air throughout the chamber, thus preventing stratification. The

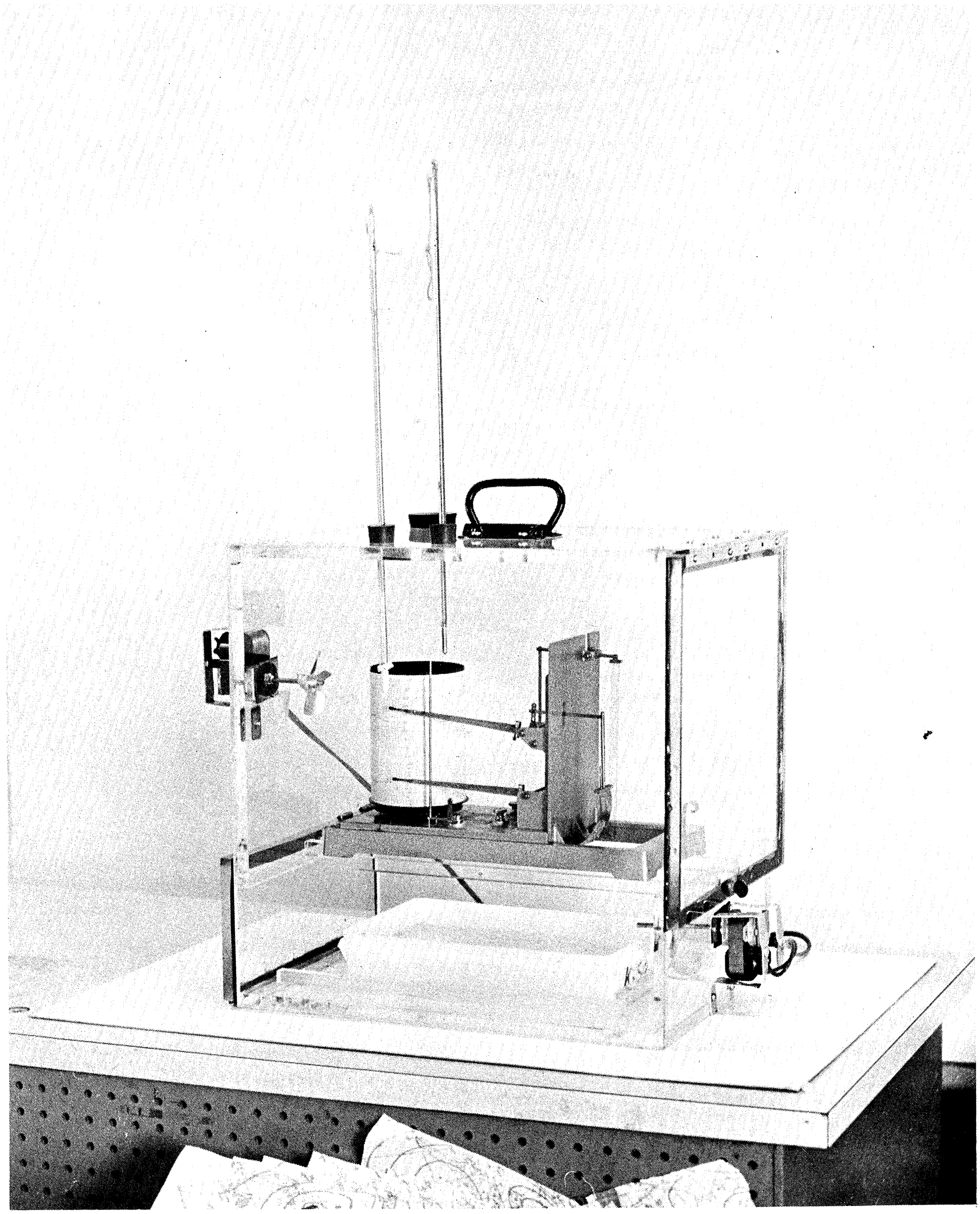

Figure 9. Spatial distribution of time-averaged standard deviation for 7 runs with digitizer.

driving motors for the fans are placed outside the chamber walls to minimize internal heating.

The hygrothermograph shelf is placed above the salt solution container so that the solution can be changed with the hygrothermograph in place. The hygrothermograph shelf consists of a track of two 1/2" thick rails that run the length of the chamber about 1/3 the way from the bottom to the top. The use of two rails instead of a solid platform permits additional circulation within the chamber. Because the relative humidity produced by each salt solution is approximate, the true relative humidity, which is compared to that indicated by the hygrothermograph, is measured with a psychrometer. The psychrometer consists of matched wet- and dry-bulb thermometers with 0.1°C graduations.

In the chamber, the wet-bulb thermometer is placed with its wick about 2" downstream from the upper fan. The dry-bulb is placed about 2" downstream from the wet-bulb and 2" higher. Each thermometer is held in place by a one-hole rubber stopper that is set into the top of the chamber.

Auxiliary and preoperational tests. The use of a psychrometer for humidity measurements requires matched thermometers, since even a small difference in the two thermometers can produce significant errors in relative humidity, especially for low temperatures.

In order to find matched pairs of thermometers, 10 thermometers (mercury-in-glass) graduated to 0.1°C with a range of -1°C to 51°C were compared. The 10 thermometers were suspended in a large vessel containing water and, initially, ice. The water was constantly stirred by a magnetic stirrer spinning at the bottom of the vessel (about 6" below the thermometers' bulbs.) The temperature of the water was changed by applying heat to the bottom of the vessel. The heat was turned off and the entire contents of the vessel were allowed to come to equilibrium while the stirring continued. After 5 minutes with no change in temperature of any of the thermometers, they were read to the nearest 0.05°C.

Thermometer readings were compared at four temperatures: 8.5, 15, 17.5 and 20°C. The pairs which matched the best and their temperatures are given in Table 12. It is evident that Pair I had the best match, with a maximum difference of only 0.05°C occurring at only one point. Pairs II and III had a maximum difference of 0.05°C at two and three points, respectively. The results for Pairs IV and V were not as good, varying from a minimum difference of 0.05°C to a maximum difference of 0.20°C. Because of these large differences, pairs IV and V were not used.

The maximum error introduced into the psychrometric measurements of relative humidity is around $\pm$ 0.5%, using Pairs I, II and III. This error is considerably less than other sources of error in the calibration procedure.

Relative humidity: psychrometric vs. dew point. In the initial testing, two nearly independent methods were used to determine the relative humidity within the chamber. Relative humidities obtained from the wet- and dry-bulb thermometers were compared with those obtained with an EG&G Model 880 Dew Point Hygrometer.

Table 10. Thermometer Matching Results

Pair #	Thermometer (serial #)	Temp. 1 (°C)	Temp. 2 (°C)	Temp. 3 (°C)	Temp. 4 (°C)
I	48243	8.40	15.30	17.50	19.90
	6194093	8.45	15.30	17.50	19.90
	Difference	0.05	0.00	0.00	0.00
II	6194095	8.45	15.35	17.50	19.85
	6194097	8.40	15.35	17.50	19.90
	Difference	0.05	0.00	0.00	0.05
III	48138	8.40	15.35	17.55	20.00
	6194052	8.45	15.30	17.50	20.00
	Difference	0.05	0.05	0.05	0.00
IV	6194125	8.40	15.20	17.35	19.80
	6194200	8.45	15.30	17.45	19.85
	Difference	0.05	0.10	0.10	0.05
V	6194141	8.30	15.20	17.45	19.90
	6194185	8.55	15.40	17.55	20.00
	Difference	0.15	0.20	0.10	0.10

Table 11 presents twenty-five sets of readings taken over a range of relative humidities between 20 and 94%. The rms difference between the relative humidities determined from the psychrometer and from the dew point hygrometer was ± 1.4%, with an average difference of ± 0.1%. 88% of these readings differed by 1% relative humidity or less. Of the three readings that were larger than 1%, 2 were taken under ambient conditions of about 20% relative humidity. For these low humidities, the discrepancies may have been caused by evaporation from the wet bulb which affected the dew point sensor.

These results indicate that the relative humidity within the chamber was determined with wet- and dry-bulb thermometers to an accuracy of ± 1%.

Calibration procedures. A calibration begins with measurements at the highest humidity and proceeds in a stepwise fashion to the lowest. Once the lowest humidity is reached, measurements at progressively higher humidities are again obtained. Consequently, measurements at every humidity but the lowest are obtained twice per calibration.

Table 12 shows the results of calibrations obtained for 4 hygrothermographs. The arrow to the right of the solution type gives the direction of progression of the calibration. It is evident that differences occur, depending on whether the relative humidity is increasing or decreasing.

Repeatability of laboratory calibration. The repeatability of a calibration was studied by subjecting one instrument to three cycles of humidities in rapid succession. Tables 13 and 14 give the results.

Table 11. Difference between the psychrometric and dew point hygrometer methods of determining relative humidity in the humidity calibration chamber. All values are relative humidity in percent.

Psychrometric Method	Dew Point Method	Difference
21.5	19	2.5*
23	18	5 *
25	24	1
54.5	55	-0.5
55	58	-3
56	57	-1
78.5	78	0.5
79	79	0
81	81.5	-0.5
81	81.5	-0.5
81.5	82	-0.5
82	81	1
82	83	-1
82.5	82	0.5
82.5	82.5	0
84	85	-1
85	85	0
85.5	84.5	1
86	86	0
86.5	86.5	0
90.5	91.5	-1
91	92	-1
93	92.5	0.5
93.5	93	0.5
94	93.5	0.5

average difference is 0.1%
rms difference is 1.4%

*exceeds the rms difference

Table 12. Results of chamber calibration of four hygrothermographs

Serial #	Chamber Conditions	Hygrothermograph Relative Humidity (%)	Psychrometric Relative Humidity (%)	Difference (Hygro-Psychro)
6599	Ambient	22	21.5	+0.5
	K_2SO_4 (↓)	88	91	-3
	(↑)	90	90.5	-0.5
	$ZnSO_4$ (↓)	82	84	-2
	(↑)	82	82	0
	NaCl (↓)	79.5	81.5	-2
	(↑)	80	82	-2
	$Na_2Cr_2O_7$	52	54.5	-2.5
4985	Ambient	28	19	+9
	K_2SO_4 (↓)	90	91	-1
	(↑)	92	92.5	-0.5
	$ZnSO_4$ (↓)	80	83	-3
	(↑)	84	85	-1
	NaCl (↓)	76	80	-4
	(↑)	80	82	-2
	$Na_2Cr_2O_7$	53.5	55	-1.5
7478	Ambient	26	24.5	+1.5
	K_2SO_4 (↓)	89	92	-3
	(↑)	88.5	93	-4.5
	$ZnSO_4$ (↓)	82	85	-3
	(↑)	81	83	-2
	NaCl (↓)	76.5	81	-4.5
	(↑)	77	79	-2
	$Na_2Cr_2O_7$	51	54.5	-3.5
	Ambient	18	15	+3
	K_2SO_4 (↓)	90.5	90	+0.5
	(↑)	92.5	91	+1.5

Table 12. (cont.)

Serial #	Chamber Conditions	Hygrothermograph Relative Humidity (%)	Psychrometric Relative Humidity (%)	Difference (Hygro-Psychro)
7064	$ZnSO_4$ (↓)	82.5	84	-1.5
	(↑)	86.5	85.5	+1
	NaCl (↓)	79.5	80	-0.5
	(↑)	79.5	80	-0.5
	$Na_2Cr_2O_7$	49.5	55.5	-6

Table 13. Repeatability test on hygrothermograph #4985

Solution	Hygrothermograph Rel. Humidity (%)	Psychrometric Rel. Humidity (%)	Difference (Hygro-Psychro) (%)
Ambient	28	25	+3
K_2SO_4	90	93	-3
$ZnSO_4$	81.5	85	-3.5
$(NH_4)_2SO_4$	74	78.5	-4.5
NaCl	78	81	-3
$Na_2Cr_2O_7$	54	55	-1
NaCl	80	81	-1
$(NH_4)_2SO_4$	77	79	-2
$ZnSO_4$	84	86	-2
K_2SO_4	92.5	93.5	-1
$ZnSO_4$	84	86.5	-2.5
NaCl	80	82.5	-2.5
$Na_2Cr_2O_7$	55	56	-1
NaCl	80	82.5	-2.5
$ZnSO_4$	84	85.5	-1.5
K_2SO_4	92.5	94	-1.5
Ambient	24	23	+1
K_2SO_4	90	91	-1
$ZnSO_4$	80	83	-3
NaCl	76	80	-4
$Na_2Cr_2O_7$	53.5	55	-1.5
NaCl	80	82	-2
$ZnSO_4$	84	85	-1
K_2SO_4	92	92.5	-0.5
Ambient	28	19	+9

Table 14. Difference between psychrometric measurements of relative humidity and hygrothermograph #4985 readings for increasing relative humidity; decreasing relative humidity, and overall.

Approximate Chamber Relative Humidity (%)	Difference Hygro-Psychro Relative Humidity (%)	Average Difference Relative Humidity (%)
	Increasing Relative Humidity	
95	-1, -1.5, -2.5, -3	-2.0
90	-0.5, -1	-0.8
85	-1, -1, -1.5, -2	-1.4
80	-2, -2.5, -3	-2.5
	Average	-1.7
	Decreasing Relative Humidity	
85	-2.5, -3, -3.5	-3
80	-2, -2.5, -4, -4.5	-3.2
55	-1, -1, -1.5	-1.2
	Average	-2.5
	Overall	
95	-1, -1.5, -2.5, -3	-2
90	-0.5, -1	-0.8
85	-1, -1, -1.5, -2, -2.5 -3, -3.5	-2.1
80	-2, -2, -2.5, -2.5, -3 -4, -4.5	-2.9
55	-1, -1, -1.5	-1.2
Less than 30	+3 , +9	+6
	Average	-2.0

As can be seen in Table 14, the hygrothermograph is about 1% lower, on the average, for decreasing humidity than for increasing humidity. Overall, it averages about 2% low throughout the entire range, regardless of the direction.

The data further indicate about a 2% difference in relative humidity from one calibration to another. This is equivalent to one chart division and exceeds the accuracy claimed by the manufacturer.

Effects of transportation. It was originally thought that the chamber could be used to calibrate the hygrothermographs in the field. Tests with the chamber, however, indicated that using it for on-site calibrations would be impractical and it was concluded that the most convenient location for the calibrations would be at the meteorological laboratory in Ann Arbor. This meant, however, that the hygrothermographs would have to be transported about 150 miles, with the risk of a possible calibration change in transit. A study was made to determine the effects of transportation by calibrating four hygrothermographs in Ann Arbor and transporting them by car to Benton Harbor, where two of them (hygrothermographs 4985 and 7478) were recalibrated. Although the trip itself took about 4 hours, for practical reasons the calibrations occurred 4 days apart.

The results of the calibrations are shown in Table 15. For hygrothermograph 4985, the calibration in Ann Arbor differed from that in Benton Harbor by 2% or less. The comparison of the calibrations for hygrothermograph 7478 is almost as good, with only the ambient reading differing by more than 2%.

Table 15. Calibration data for two hygrothermographs calibrated in Ann Arbor and Benton Harbor

Hygrothermograph Serial Number	Approximate Chamber Relative Humidity (%)	Location	Difference (Hygro-Psychro) Relative Humidity (%)
4985	Ambient (25)	Ann Arbor	+6 (ave)
		Benton Harbor	+4
	93	Ann Arbor	-1.7 (ave)
		Benton Harbor	-1
	93	Ann Arbor	-1 (ave)
		Benton Harbor	+1
	80	Ann Arbor	-3.1 (ave)
		Benton Harbor	-2
	80	Ann Arbor	-1.8 (ave)
		Benton Harbor	-0
	55	Ann Arbor	-1.5 (ave)
		Benton Harbor	-0
7478	Ambient (25)	Ann Arbor	+1.5
		Benton Harbor	-2
	93	Ann Arbor	-3
		Benton Harbor	-3
	93	Ann Arbor	-4.5
		Benton Harbor	-2.5
	85	Ann Arbor	-3
		Benton Harbor	-4
	85	Ann Arbor	-2
		Benton Harbor	-3
	80	Ann Arbor	-4.5
		Benton Harbor	-6
	80	Ann Arbor	-2
		Benton Harbor	-2
	55	Ann Arbor	-4
		Benton Harbor	-4

Hygrothermographs 6599 and 7064 were transported to Benton Harbor and returned to Ann Arbor about 1 1/2 weeks later where they were again calibrated. The results of the calibrations are given in Table 16. Hygrothermograph 6599 exceeded the 2% difference for only two humidities, one of which was the ambient reading. Hygrothermograph 7064 also exceeded the 2% difference for only two humidities, and again, one of these was the ambient reading.

In all cases, the greatest difference occurred for comparatively low ambient humidity conditions. As mentioned above, this is most likely due to the change in humidity within the chamber when the wet-bulb thermometer is added, and not to transportation.

These results indicate that accuracy is not lost by transporting the instruments from the field to Ann Arbor for calibration and back to the field. Consequently, all calibrations are currently being performed in Ann Arbor.

Calibration and maintenance of field units. The procedure for using the chamber to calibrate a hygrothermograph which has been returned from the field is given below:

1. The unit is subjected to the humidities listed. A set of data is obtained for both decreasing and increasing humidity. This procedure takes about 3 days, since about one hour is required for humidity conditions in the chamber to come to equilibrium with a salt solution.
2. The unit is then removed, cleaned and all moving parts are lubricated. It is reinstalled in the chamber and subjected to the extreme humidities of 35% and 90%.

Table 16 . Calibration data for two hygrothermographs before and after transportation from Ann Arbor to Benton Harbor and return

Hygrothermograph Serial Number	Approximate Chamber Relative Humidity (%)	Date Nov. 1972	Difference (Hygro-Psychro) Relative Humidity (%)
6599	Ambient	9	+0.5
		19,20	-3
	93	9	-3
		19,20	-4
	93	9	-0.5
		19,20	-4
	85	9	-2
		19,20	--
	85	9	-0
		19,20	-1
	80	9	-2
		19,20	-3
	80	9	-2
		19,20	-2
	55	9	-2.5
		19,20	-3.5
7064	Ambient	9	+3
		19	-0.5
	93	9	+0.5
		19	-1
	93	9	+1.5
		19	+1
	85	9	-1.5
		19	--
	85	9	+1
		19	0
	80	9	-0.5
		19	-5.5
	80	9	-0.5
		19	-2
	55	9	-5
		19	-7

3. Any adjustments on the link and lever assembly necessary to make the unit conform as closely as possible to the psychrometric measurements at these humidities are made.
4. Step (1) is repeated so that data showing true versus indicated humidity are obtained for the unit as it received from the field and again after reconditioning.
5. The unit is returned to the field.

The construction of four chambers was completed in December. They allow four hygrothermographs to be calibrated simultaneously. The time required for 4 units to be returned to Ann Arbor for calibration and returned to the network is about one month. Since there are 26 units altogether in the Palisades and Cook networks, each unit is reconditioned and calibrated at least once every 6 months. Enough spare units are on hand so that recordings at a station are not interrupted when a unit is removed for calibration.

Dew point system

An EG&G Cambridge Systems Model 880 Dew Point Hygrometer together with a sampling and recording system were procured, tested, and installed at Station CO3A in March 1974. The dew point hygrometer measures the dew point of an air sample by (1) cooling a small polished gold surface exposed to the air sample until the temperature of the surface is below the temperature of the air sample and condensation occurs on it, (2) optically detecting the water film, and (3) thermoelectrically maintaining a condition in which the amount of water on the surface does not change. The dew point is the state of dynamic equilibrium in which the rate at which water molecules leaving the water surface is equal to the rate at which water molecules enter the surface. The accuracy of the sensor is given by the manufacturer as ± 1.5°F. Its response to changes in moisture is orders of magnitude faster than the hair hygrometer.

For use in the field, the complete dew point system consists of the sensing unit and electronics, a pump and tubing for continuously drawing air past the sensor, and a recorder for the voltage signal from a thermistor in the sensing unit. The termmistor measures the temperature of the metal surface. Its output signal therefore, is proportional to the dew point. The recorder is a Leeds and Northrup Speedomax W strip chart recorder with a range of 0-40 millivolts on a 10-inch chart. In working with the complete system and comparing recorded values of dew point with those measured with a psychrometer, we have found that the agreement is better than the claimed accuracy of ± 1.5°F.

The dew point system supplements the hygrothermograph measurements of relative humidity at main station CO3A. The faster response and greater sensitivity of the dew point system will prove important in studying any occurrences of steam fog which may form in the vicinity of the thermal plume and move inland.

Precipitation gages

Complete calibrations of the precipitation gages by a National Weather Service technician were made in June 1973, and December 1973. In addition, weekly checks are made by the field observer by subjecting each gage to a weight equivalent of 2 inches of water.

Visiometers

Missing data were caused by a recorder breakdown and line voltage surges which caused a defective high voltage power supply in the visiometer. Following a prolonged period waiting for replacement components the recorder and visiometer were repaired and placed back into operation in October.

Wind systems

Wind tunnel calibrations of the wind speed systems for both main stations were made at the University of Michigan micrometeorology wind tunnel in August and December, 1973. Linearity checks of the wind direction sensors and translators were made in the field in February 1974 and were found to be the same as when installed. Spare wind speed sensors were recently obtained so that recordings will not have to be interrupted in the future while wind tunnel calibrations are made.

VI. WORK SCHEDULED FOR NEXT YEAR

The following five tasks will be undertaken in the next year:

1. Data analysis. The study of the long-term means and variability of precipitation, temperature, and moisture using data from nearby National Weather Service observations will be completed.

Network data collected during the pre-operational phase will be analyzed. (Since the cooling system is not expected to be operating until early 1975, substantial analysis of data for the operational phase cannot be made in this contract year.) Data for individual network stations and groups of stations will be compared by means of the Tabulation Prediction Technique (Moses et al., 1972) where multivariant contingency tables in tabular format are used for testing the effects of a single dependent variable when the others are held constant. For instance, comparisons can be made between stations near the coast and those far inland.

Some additional information concerning the effects of once-through cooling may be obtainable from an analysis of the Palisades network data. During the last two years, the Palisades Plant has occasionally ceased operation for prolonged periods. Since the Palisades Plant used a once-through cooling system during these years, an opportunity is provided to investigate conditions with and without the thermal plume. The Tabulation Prediction Technique will be employed on the Palisades network data to determine if any effects of the once-through system are discernible.

2. Modeling of Physical Processes

Some numerical modeling of pertinent physical processes will be made to estimate the magnitude of any modification caused by heating from the heated lake plume, in particular meteorological situation, especially onshore flows. The models will be two-dimensional and predict the difference of temperature and moisture between plume and non-plume situations. Until the operation of the cooling system begins, theoretical plume calculations such as given on pages III-16 to III-20 of the First Environmental Statement of the Donald C. Cook Nuclear Plant (U.S. Atomic Energy Commission, 1973) will be used as input data. Account will be taken of the change in surface roughness from the lake to land, stability of the atmosphere, air-water temperature difference, mean wind velocity, and dew point depression.

3. Continued operation and maintenance of the 12 meteorological stations.

The measurements presently being made will continue, along with the schedule of calibration and maintenance of equipment. Plans are being made to install a time lapse camera in the direction of the thermal plume. The photographs may occasionally be supplemented by observations made by personnel employed at the Nuclear Plant.

4. Processing, tabulation and reporting of meteorological data.

Data processing will continue. A report consisting of data tabulations and summaries will be prepared. It will include computer printouts of data using a format similar to that shown in Quarterly Progress Report 320157-5-L.

5. Fog studies. It is expected that a paper will be prepared and submitted to the Indiana & Michigan Power Company which describes results of a preliminary fog climatology for western Michigan along with an assessment of the present knowledge of fog formation.

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