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

COLLEGE OF ENGINEERING
Department of Civil Engineering
Meteorological Laboratories

ATMOSPHERIC DIFFUSION STUDY AT THE ENRICO FERMI NUCLEAR REACTOR SITE

Second Progress Report

A QUALITATIVE ANALYSIS OF FURTHER DIFFUSION EXPERIMENTS

E. Wendell Hewson
Professor of Meteorology

Gerald C. Gill
Associate Professor of Meteorology

Eugene W. Bierly
Assistant Research Meteorologist

UMRI Project 2728

under contract with:

POWER REACTOR DEVELOPMENT COMPANY
DETROIT, MICHIGAN

administered by:

THE UNIVERSITY OF MICHIGAN RESEARCH INSTITUTE   ANN ARBOR

July 1960

PREFACE

This second progress report presents a qualitative estimation of atmospheric diffusion at the Enrico Fermi plant site during the winter and spring seasons of 1960. The individual experiments are treated in a manner similar to those in the first report.

The authors wish to make the following acknowledgments: to Mr. Dwight Meeks for use of his tape recorder; to Lt. Michael J. Menadier, Weather Services Officer at the Grosse Ile Naval Air Station, for allowing the hourly weather observations to be copied and for doing the synoptic map analysis; to Colonel W. R. Schaal and Captain John Doty of the 127th Tactical Reconnaissance Wing of the Michigan Air National Guard based at Detroit Metropolitan-Wayne County Airport for photographing the smoke plume and developing the film; to Mrs. Anne C. Rivette, for typing the manuscript; and to supporting personnel of the Meteorological Laboratories for abstracting the data and putting it into usable form.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Concluded)

ABSTRACT

Experimental runs were made on February 4, April 3, May 8, and June 25, 1960. A general discussion of the synoptic situation for the day of each experiment is presented along with the Monroe area weather details, special characteristics at Lagoona Beach, plume characteristics, and results of the plane sampling. A qualitative estimation is then made of the atmospheric diffusion for each experiment. A summary of all the experiments concludes the report.

I. INTRODUCTION

Since this project was initiated to study atmospheric diffusion in transitional states at the reactor site near Lake Erie, it might be well to define such diffusion again. Diffusion in transitional states is the condition that exists when the field of atmospheric turbulence exhibits marked variation in time or space or both. At a shoreline there are marked horizontal variations in turbulence. Air flowing from land over a cool water surface, as in spring, becomes increasingly stable and experiences reduced mechanical turbulence over the relatively smooth water surface. In the autumn the water is relatively warm and the air leaving the land may develop instability and thermal turbulence over the water, leading to enhanced diffusion.

An effort was made to obtain data over Lake Erie during the spring when the water was cold. Unfortunately, no run was successful until 25 June 1960, because our trained crew of students was available only during school vacations or weekends. The probability of westerly winds of sufficient magnitude to overcome the lake-breeze effect on weekends was quite small. Once school was over, it was possible to devote all forces to make a run on a suitable day. Ironically, June 25 was a Saturday anyway.

Thus, four experiments have been carried out and are reported on qualitatively in this report, as were the first four experiments in progress report 2728-1-P. A summary of all eight experiments concludes the report with remarks about their value in computing diffusion parameters.

Quantitative estimates for all eight experimental runs will be contained in a separate technical report, 2728-3-T.

II. EXPERIMENTAL RUNS

1. EXPERIMENTAL RUN OF 4 FEBRUARY 1960

a. Synoptic Situation.—The surface weather map at 0700 EST on 4 February shows a large, cool, high-pressure area centered near Killaloe, Ontario, with one ridge extending southward beyond Cape Hatteras, North Carolina and another ridge extending westward to western Lake Superior (see Fig. 1).

A widespread, stagnant, low-pressure system was centered near the eastern Texas-Oklahoma border. Approximately 450 miles east of the low center an occluded front lay with the warm front skirting the northeastern Gulf of Mexico shore and then passing through the northern part of the Florida peninsula. The cold front ran southward through Pensicola, Florida, and then into the Gulf of Mexico.

The western U. S. was under the influence of a NE-SW-oriented high-pressure area centered in the southeastern corner of Idaho. An insignificant low center was located on the Saskatchewan-Montana border with a weak stationary front running eastward through southern Hudson Bay.

As a result of the circulation from both the Ontario high and the Texas low, the Great Lakes region was in an area of easterly winds. Due to surface friction effects, the winds actually observed were from the northeast and east-northeast.

The air mass represented by the high-pressure area over Killaloe was initially of a continental polar type; however, it was beginning to modify so that the temperature near the surface during the daylight hours was beginning to run well above the freezing point. It is important to note this fact, for there was quite a difference in diffusion when this air was passing over water and when if passed over land.

b. Monroe Area Weather.—Figure 2 shows the hourly surface observation as recorded at Grosse Ile Naval Air Station. Refer to Fig. 3 for the location of Grosse Ile relative to the plant site. The winds at Grosse Ile were from the east-northeast throughout the day. Figure 3 shows that an ENE wind is a land trajectory for Grosse Ile, but that it is a water trajectory at the reactor site.

Visibility at the air station was below three miles from 0740 EST until 0956. Such visibilities in fog and smoke are indicative of inversion conditions. This conclusion seems probable because it appeared to have been a clear night. See the 0557 EST observation of clear skies and 7 miles visibility.

Under such conditions, the earth's surface cools by radiative transfer, so it assumes the lowest temperature. Note that at 0759 EST the temperature was 23°F (-5.0°C). This reading was made at a height of 4 feet above the surface, so the temperature near the surface would be even colder. Any air above the earth's surface, even if it were from a cool air mass, would be relatively warmer than the surface under such a condition, so an inversion could form. Figure 4 illustrates this process during the evening and early morning hours.

Although no temperature-lapse-rate measurements were made at Grosse Ile, it is felt that such was the condition during the early morning of 4 February. From the observations, it appears that this nocturnal inversion dissipated between 1000 and 1100 EST. The ground fog and smoke lifted and the temperature rose 8F° (4.2C°) in one hour, indicating that mixing from aloft had taken place.

As the day progressed at Grosse Ile, the temperature continued to rise until 1357 EST when it reached a maximum of 42°F (5.6°C). In all probability, the lapse rate became strong after 1100 EST due to the solar heating and continued so until after sunset.

c. Special Characteristics at Lagoona Beach.—The data from the meteorological tower at the plant site are shown in Table I. It can be seen that the wind data at the plant agree with the Grosse Ile observations as to direction. The speed naturally is higher at the plant site due to the greater height of the aerovane there than at the air station.

The lapse-rate data at the plant site initially seem to be in error since they indicate a strong lapse condition, but a deeper analysis shows that they are not. The first fact to be kept clear is that the ENE winds at the plant site are an over-water trajectory for a distance of well over ten miles. At Grosse Ile such a trajectory is over land. The lake temperature on 4 February was about 34°F (1.1°C) with a good deal of open water between the ice flows. Assuming that the temperature 4 ft above the water was the same as Grosse Ile's at 0759 EST, that is, 23°F (-5.0°C), then the temperature profile would be as shown in Fig. 5, at least up to 4 ft. In other words, it would be a super adiabatic lapse-rate condition over the water.

In reality, it probably was not as strong a lapse rate as indicated because some heat from the water would be transferred upward, thus warming the air above the water's surface. However, we may postulate that the vertical temperature profile at the plant site was similar to that shown in Fig. 5.

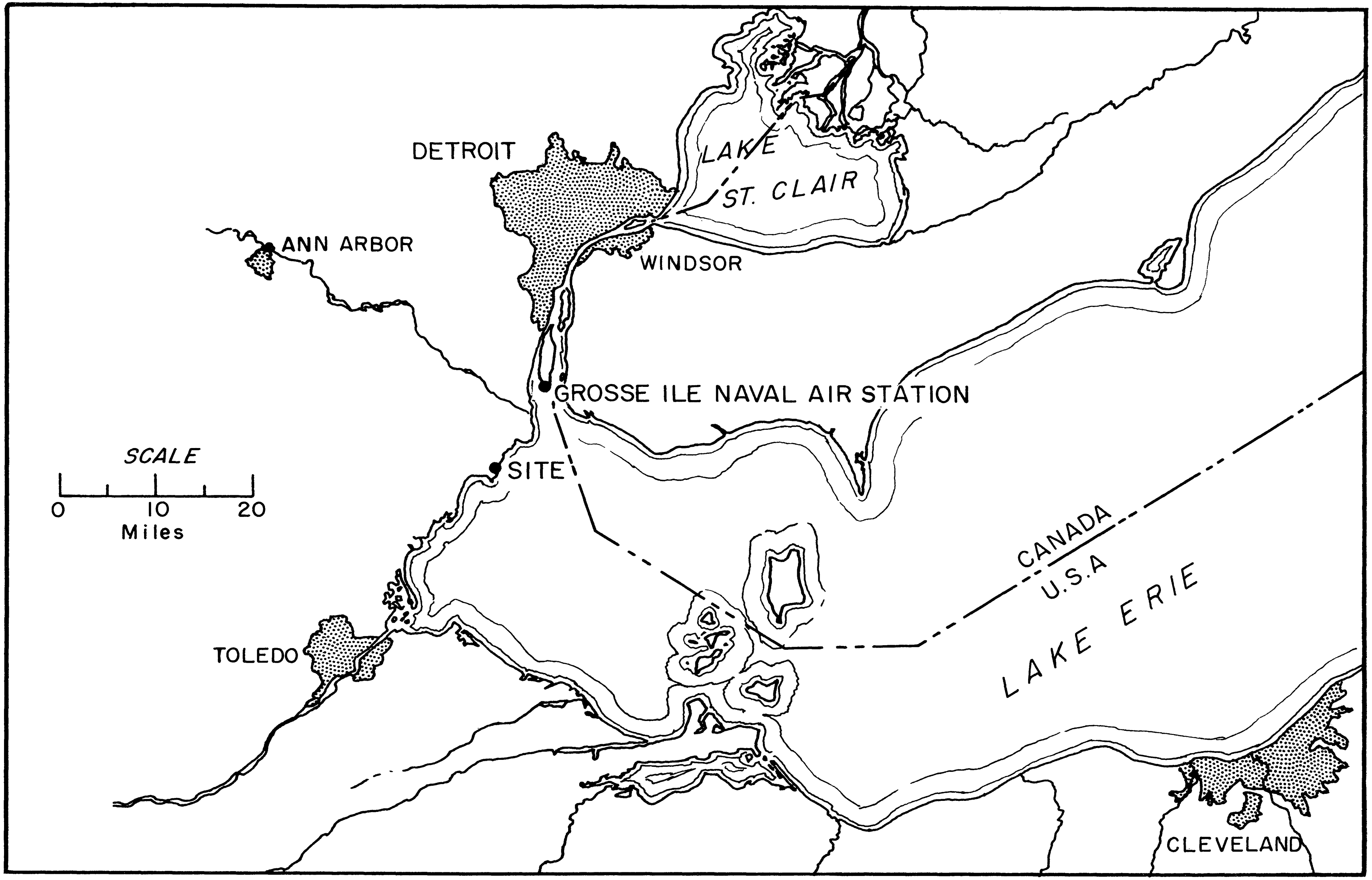
The observed lapse rates at the tower are indeed correct and shall be accepted as being accurate. It is important to note that by the time the Grosse Ile area was having a lapse-rate condition, about 1100 EST, the tower site's temperature lapse rate began to change from strong to weak and finally to an inversion. This situation may be analyzed as follows.

STATION U.S. NAVAL AIR STATION, GROSSE ILE, MICH. DATE 4 Feb 1960

TYPE 1	TIME (LST) 2	SKY and CEILING (Hundreds of Feet) 3	VISIBILITY (Miles) 4	WEATHER and OBSTRUCTIONS TO VISION 5	SEA LEVEL PRESS. (mbs.) 6	TEMP. (°F) 7	DEW PT. (°F) 8	WIND DIRECTION 9	WIND SPEED (knots) 10	WIND CHARACTER & SHIFTS 11	ALTIMETER SET. (ins.) 12	REMARKS AND SUPPLEMENTAL CODED DATA 13	14A	14B	OBSERVERS Initials 15
*R	0557	0	7		281	21	17	←↙	7		030				
R	0656	12 ⦶	7		282	22	19	←↙	8		031	503 1600 20			
S1	0710	E 10 ⊕	4	FK				←↙	9						
S2	0740	E 10 ⊕	2	FK				←↙	7						
R	0759	E 10 ⦶	2	FK	280	23	21	←↙	7		030				
S3	0815	10 - ⦶	1½	FK				←↙	6						
R	0858	10 - ⦶	1½	FK	278	24	22	←↙	8		029				
RS4	0956	0	3	GFK	278	29	25	←↙	6		030	VSBY S1½ 603			
R	1059	1-⦶	4	HK	272	37	25	←↙	6		028				
R	1159	1-⦶	4	HK	263	38	29	←↙	7		026				
S5	1242	1-⦶	5	HK				←↙	7						
R	1258	1-⦶	6	HK	254	40	30	←	7		023	822 1001 20			
R	1357	1-⦶	6	HK	241	42	29	←↙	8		019				
R	1456	1-⦶	7		240	40	30	←↙	8		019				
R	1557	1-⦶	7		234	39	29	←	6		017	819 1008			
R	1655	100⦶/⊕	7		229	38	28	←↙	5		016				
R	1758	100⦶/⊕	5	HK	233	35	29	←↙	4		017				
R	1858	100⦶/⊕	5	HK	235	35	27	←↙	6		017	500 1077 42			
R	1955	100⦶/⊕	5	HK	233	34	28	←	4		017				
R	2056	100⦶/⊕	7		227	33	29	←↙	3		015				
RS6	2158	E 100⦶/⊕	7		221	34	29	←↙	3		014	814 1077			

*See USWB Circular N for definition of symbols and abbreviations.

Fig. 2. Surface weather observations taken at U. S. Naval Air Station, Grosse Ile, Michigan, on 4 February 1960.



Scale

Fig. 3. Map of the local area in the vicinity of the Enrico Fermi plant site.

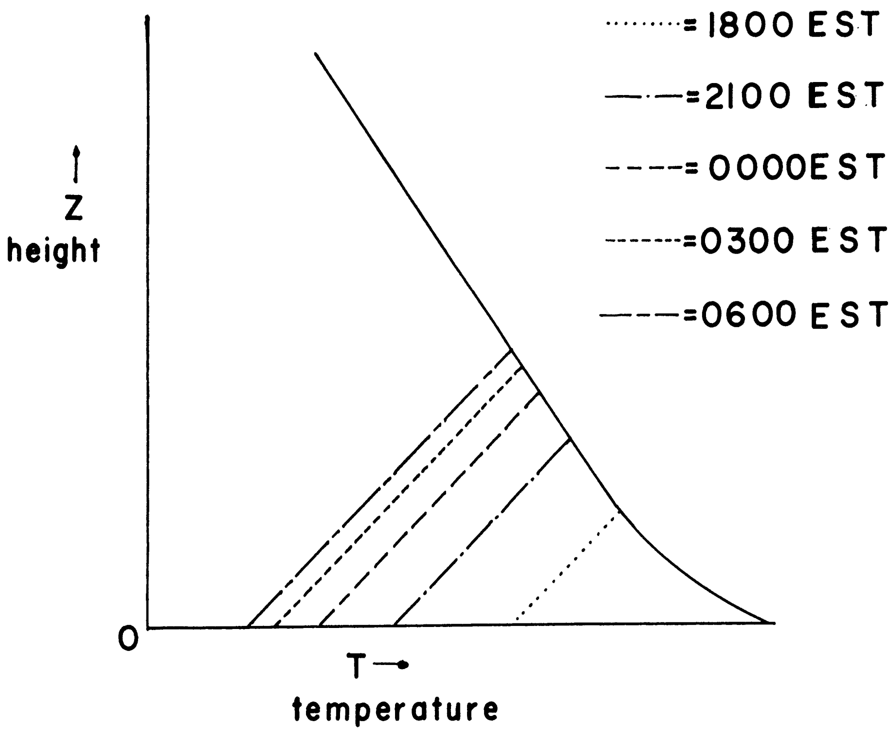


Fig. 4. Idealized time variation of vertical temperature distribution at Grosse Ile, Michigan, during the night of 3 February and early morning of 4 February 1960.

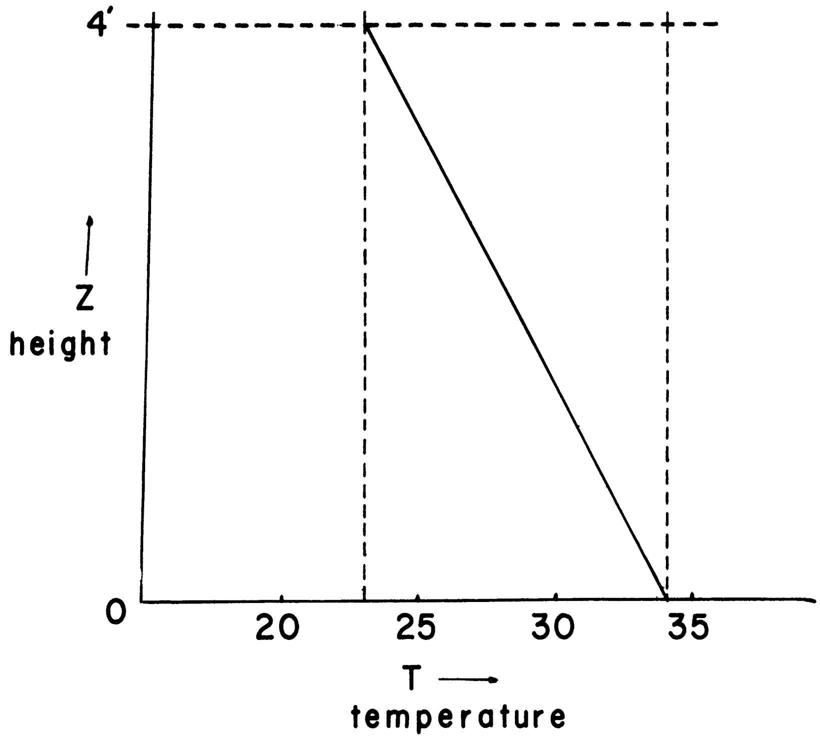


Fig. 5. Vertical temperature distribution to 4 ft over the water and at the plant site on the morning of 4 February 1960.

TABLE I

HOURLY AVERAGE VALUES OF WIND DIRECTION, WIND SPEED, AND TEMPERATURE-LAPSE-RATE DATA FROM THE METEOROLOGICAL TOWER AT THE ENRICO FERMI SITE ON 4 FEBRUARY 1960

Hour Ending	Wind Direction	Wind Speed (mph)	Lapse Rate
0100	ENE	15	S
0200	ENE	14	S
0300	ENE	15	S
0400	ENE	19	S
0500	NE	14	S
0600	NE	14	S
0700	NE	17	S
0800	NE	16	S
0900	NE	15	S
1000	NE	13	S
1100	ENE	16	W
1200	ENE	19	W
1300	E	17	W
1400	E	16	W
1500	E	12	I
1600	ENE	10	I
1700	ENE	15	I
1800	ENE	12	I
1900	ENE	12	I
2000	NE	9	I
2100	ENE	8	I
2200	ENE	6	I
2300	E	7	I
2400	ENE	6	I

As the day progressed, the air temperature rose, reaching a maximum temperature at Grosse Ile of 42°F (5.6°C) at 1357 EST. This warm air from the Canadian shore passing over the then relatively colder water would cause an inversion to form. (See Fig. 6 which shows the soundings taken by the airplane during the afternoon.) The sounding taken by the plane at 1435 over the water indicates that an inversion did exist at that time. The land sounding taken at the same time indicates a lapse condition to about 1500 ft above ground and then an inversion above that. By the time the later soundings were taken near 1630 EST, the land temperature had begun to drop. This is seen in the sounding. The over-water sounding at 1616 showed that a great deal of warming had taken place in the lower several hundred feet yet the lake surface was still near 32°F (0.0°C) indicating that the temperature difference between 4 ft and 100 ft at the tower would still read as an inversion. This is confirmed in Table I where hourly average values of wind direction, speed, and temperature lapse rate as measured at the meteorological tower on the plant site are shown.

This section can be summed up by saying that great differences are caused by the proximity to the lake especially if the prevailing wind flow is from off the water.

d. Plume Characteristics.—Aerial photographs and ground photographs were taken of the smoke plume that was released from the tower. Because of mechanical difficulty, the airplane was not able to sample until midafternoon, whereas the jet reconnaissance plane was available about noontime. Since it was felt that the aerial photography would add materially to this diffusion experiment, it was decided to release a continuous oil-fog smoke plume from the 56-ft level of the tower during midday.

The plume left the tower in more or less of a straight line as seen in Figs. 7 and 8. By the time this smoke had reached the western end of the parking lot at the plant site, it was down on the ground. (See Fig. 9.) Since the lapse rate at the tower between 4 ft and 100 ft was weak, it seems strange that the smoke should intersect the ground within such a short distance. Such a condition would be expected with a strong lapse rate when there is a great deal of mixing. The following explanation is offered. The easterly wind from off the lake passing over the shoreline was deflected upward due to a rock embankment which was placed between the lake and the tower during construction of the plant. (See Fig. 6 of 2728-1-P.) A further proof of this deflection is that the 56-ft bivane recorded a continuous updraft throughout this period of the day. It is postulated, then, that the wind flow deflected by the embankment caught the plume as it left the tower and lifted it. This cold air from off the water would be cooler than the environment surrounding it and hence would tend to sink at some distance from the lake shore. This sinking brought the lower edge of the plume to the ground at a distance of about 600 ft from the tower. This explanation is sketched in Fig. 10.

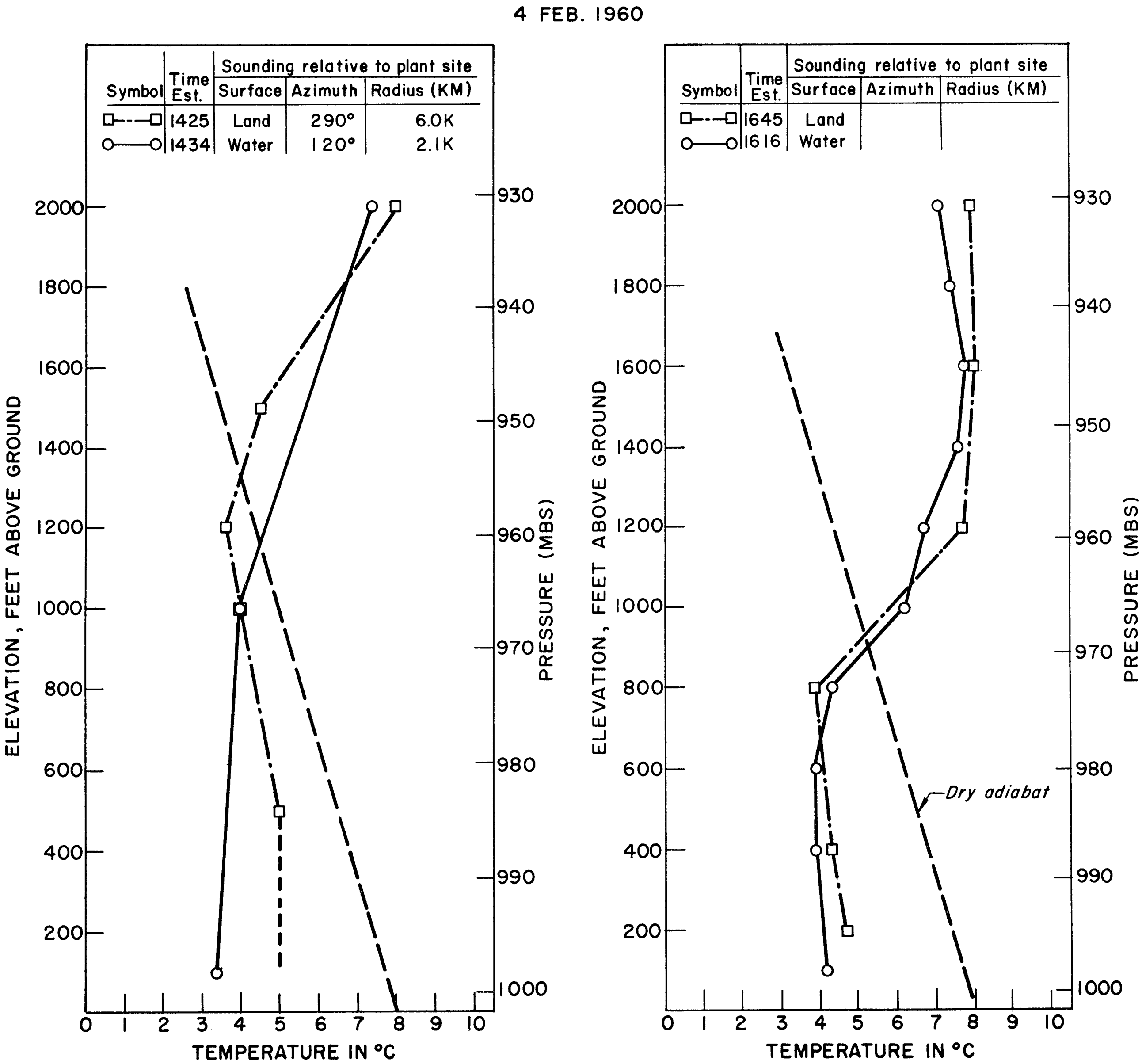


Fig. 6. Plots of the vertical temperature distribution as recorded by the aerometeorograph during the afternoon of 4 February 1960.

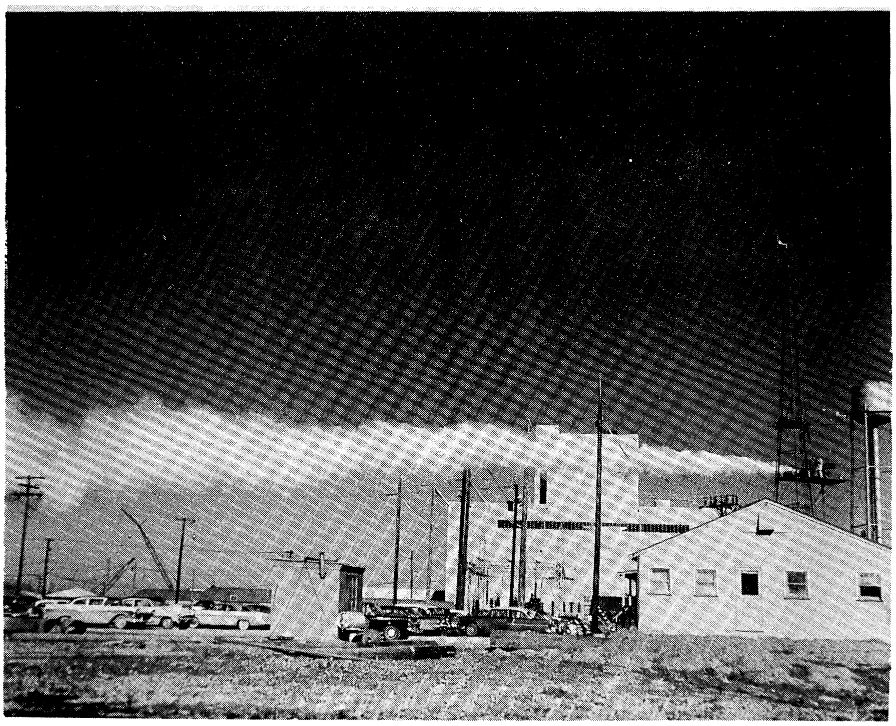


Fig. 7. View looking northward as smoke leaves the 40-ft level of the meteorological tower on 4 February 1960.

Fig. 8. View looking westward as smoke plume intersects with the ground west of the parking lot.

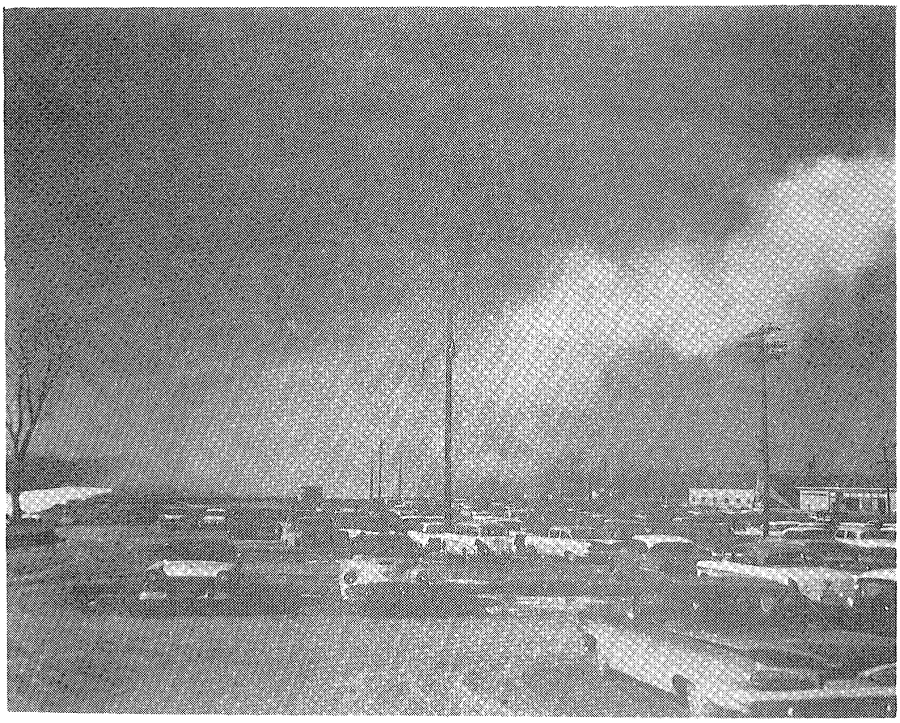


Fig. 9. View looking westward from top of meteorological tower as smoke leaves the tower and flows westward.

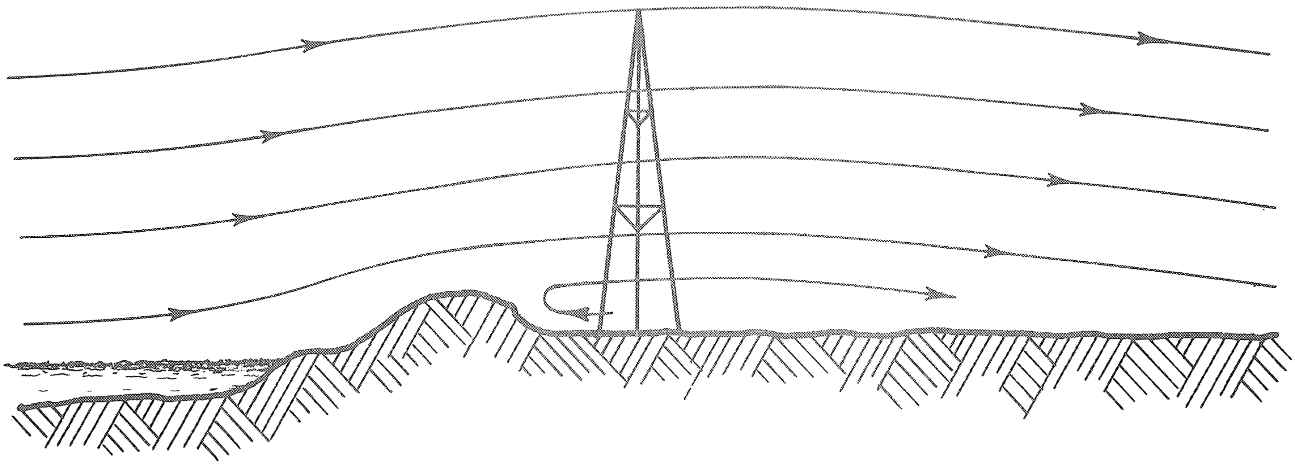


Fig. 10. Sketch of streamlines of wind flow from the lake deflected by rock embankment.

The smoke plume traveled for at least five km along or near the ground with little vertical diffusion. Figures 11, 12, and 13 give an idea of the length of the smoke plume. Note that the smoke can still be seen in the right of Fig. 13, indicating that perhaps it could be traced even further downstream. All the pictures show a relatively flat bottom to the smoke, which would indicate that it was on the surface of the ground. The top edges get more and more diffuse, showing that some vertical diffusion was taking place. Note the evidence of wind shear near the 2-km marker in Fig. 11.

The further inland the plume progressed, the better were its chances for diffusion, since only in the vicinity of the lake would the temperature lapse rate have been weak. Over the land away from the lake breeze inversion effect, there would likely be a strong lapse rate due to solar heating. This effect is shown in Fig. 13 where the plume is relatively narrow at the 3-km marker and considerably wider at the 5-km marker.

The FP plume was released when the lapse rate at the plant site was recorded as an inversion condition. The smoke puffs released at the same time indicated that the plume width was about 12°. This figure is probably too high since the observations were taken within 100 ft of the point of release. It is believed that the FP plume behaved quite similarly to the smoke plume.

e. Results of Plane Sampling.—Figure 14 shows the results of the FP counts as collected on the drum sampler. There are several important facts to be pointed out. First, the plume is well defined at all radii and all levels. On the 2-km arc the plume is quite narrow but by the time 4 km were reached, the plume had begun to spread out more evenly, indicating that surface roughness and change of lapse rate had begun to aid in a more rapid diffusion of the material. Secondly, notice that no samples were collected above 300 ft, although by 4 km it can be seen that there was some diffusion upward. It is quite unfortunate that sampling was not carried out on the 8-km arc.

f. Comments on the Diffusion Patterns.—This experiment is certainly of diffusion in transitional states. Obviously diffusion was not good in the immediate vicinity of the plant site, but this condition began to change as the plume was carried inland. Here is a case of a strong off-lake wind changing the entire diffusion characteristics of the plant area. The effect of the lake is dominant.

2. EXPERIMENT OF 3 APRIL 1960

a. Synoptic Situation.—At 0700 EST the surface weather map, Fig. 15, shows a long occluded front running from near North Bay, Ontario, southward through central Lake Erie and then south-southwestward to Montgomery, Alabama.

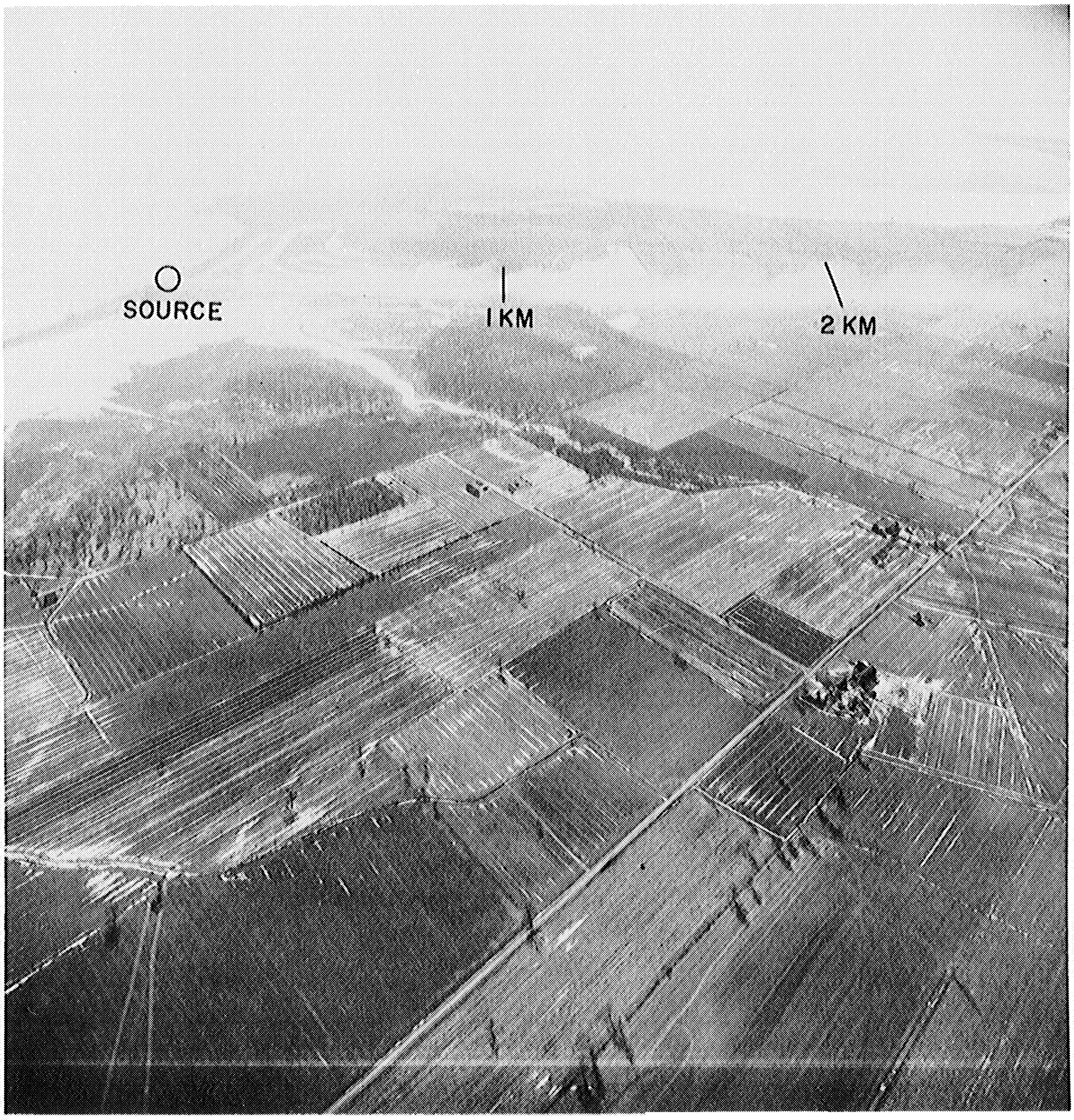


Fig. 11. Aerial view looking south as smoke leaves tower and flows westward over the land.

Fig. 12. Aerial view looking south of smoke diffusing inland.

Fig. 13. Aerial view looking south, showing the greater diffusion of the smoke after an overland trajectory.

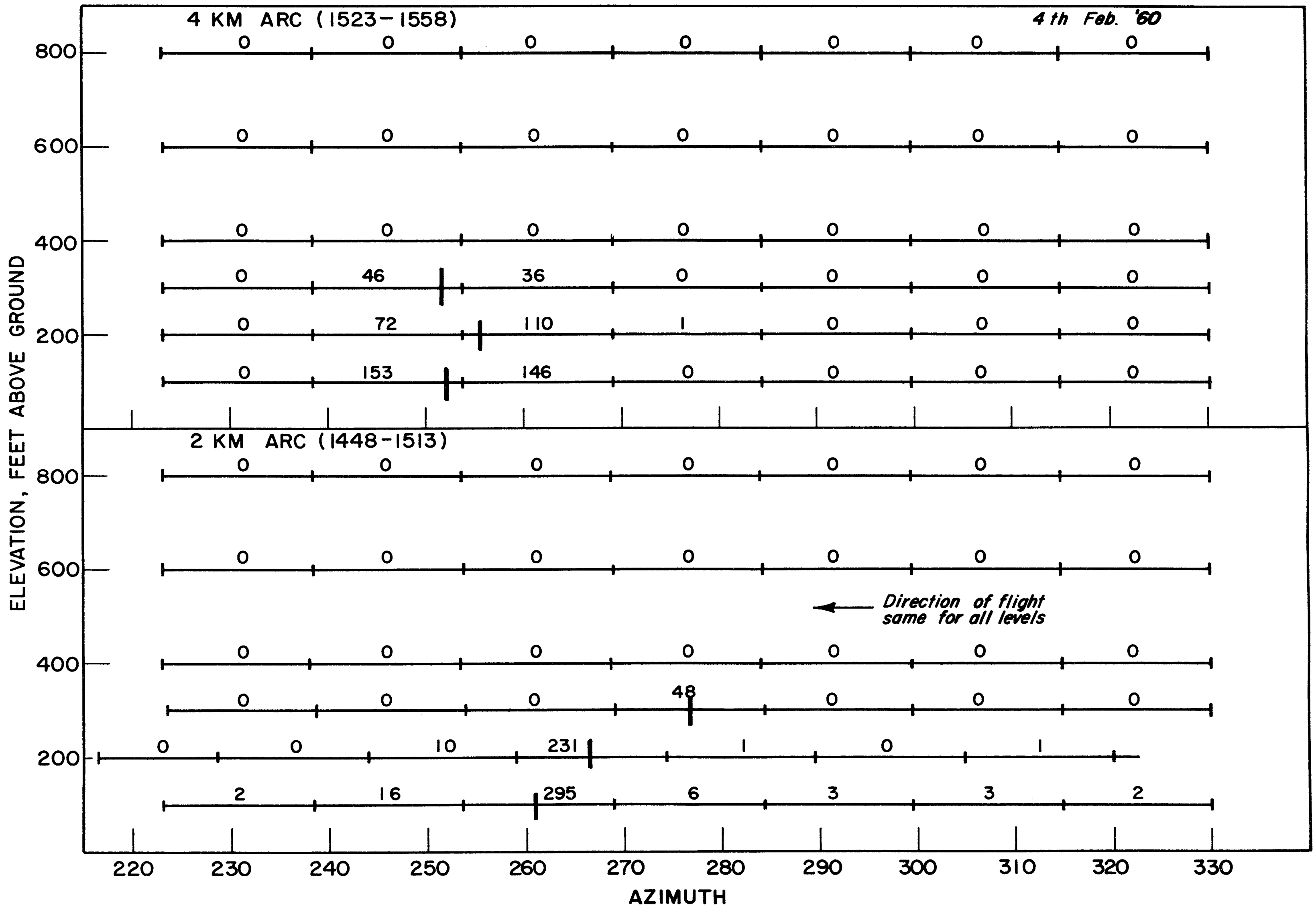


Fig. 14. Raw counts of FP material from 4 February 1960 plotted according to azimuth and height above the lake surface.

A low was centered about 50 miles southeast of Meridian, Mississippi, with the warm front extending northeastward to meet the occlusion near Montgomery. The cold front from the Mississippi low ran southward into the Gulf of Mexico.

Another low-pressure area was centered some 300 miles west of southern Hudson Bay. An occluded frontal system ran from Le Pas, Manitoba, southward through central North Dakota and thence southwestward through central Wyoming.

A large high-pressure center was located south of Halifax, Nova Scotia, causing a strong southerly gradient ahead of the eastern U. S. occluded front.

Thus the synoptic pattern caused the area at and adjacent to the plant site to have a westerly wind that became less and less strong as the day progressed. In such a situation, the lake-breeze effect could become a significant factor.

b. Monroe Area Weather.—The Monroe area was in an area of weak pressure gradient which allowed the wind direction to be light and variable. Figure 16, which is a copy of the hourly surface weather observations from the U. S. Naval Air Station at Grosse Ile, Michigan, shows that the wind was light, never reaching more than 4 knots all day, and also quite variable in direction, although there seems to have been a definite southerly dominance throughout the daylight hours. This S and SSE wind is the lake breeze as evidenced by the decrease in rapidity of temperature rise after 0900 and the increase in the temperature of the dew point after 0800. Both observations lend evidence to the notion that a lake breeze had developed at Grosse Ile even though the gradient wind was westerly.

Visibility remained excellent throughout the day even during several late afternoon rainshowers. These showers were caused by a trough which passed in the afternoon. As the day progressed, a high deck of cirrus clouds began to appear, eventually becoming an overcast. A middle layer also began to appear at 1055, and by 1657 was a solid overcast. Low clouds appeared first at 1758 and thickened as long as observations were taken.

Since the lake was still quite cold during this period, it is probably safe to assume that an inversion was formed over the area surrounding the lake shore soon after the lake breeze set in. Confirmation of this assumption is given in Table II, which indicates that an inversion was observed at the plant site continuously on the meteorological tower. Figure 17 indicates that the aerometeorograph measured an inversion over the lake and the surrounding swampy area north of the plant site proper. This, too, supports the assumption of an inversion formation following the lake breeze.

c. Special Characteristics at Lagoona Beach.—Table II shows the hourly average wind speed, wind direction, and lapse rate as measured on the 100-ft meteorological tower at the plant site. The first conclusion is that the wind

STATION U.S. NAVAL AIR STATION, GROSSE ILE, MICH. DATE 3 April 1960

TYPE 1	TIME (LST) 2	SKY and CEILING (Hundreds of Feet) 3	VISIBILITY (Miles) 4	WEATHER and OBSTRUCTIONS TO VISION 5	SEA LEVEL PRESS. (mbs.) 6	TEMP. (°F) 7	DEW PT. (°F) 8	WIND DIRECTION 9	WIND SPEED (knots) 10	WIND CHARACTER & SHIFTS 11	ALTIMETER SET. (ins.) 12	REMARKS AND SUPPLEMENTAL CODED DATA 13	14A	14B	OBSERVERS Initials 15
R	0557	100⊘/-⊘	10		168	41	36	→↘	1		000				
R	0657	1⊘	10		170	40	35		C		001	114 1002 40			
R	0756	1⊘	10		170	42	39	↑	4		001				
R	0859	1⊘	8		167	48	39	↑↗	1		000				
R	0955	1-Ⓘ	15+		164	49	40	↑	3		000	805 1001			
R	1055	100⊘/⊕	15		158	49	41	↑	4		998				
R	1156	100⊘/⊕	15		149	50	41	↑	4		995				
S1	1246	E90Ⓘ/⊕	10					↑	3						
R	1256	90⊘/⊕	10		142	50	39	↑	4		992	722 1077 40			
RS2	1355	E90Ⓘ/⊕	15		140	46	40	↑↖	4		992				
R	1456	E90Ⓘ/⊕	15		127	48	38		C		988				
R	1555	E80Ⓘ/⊕	15		121	51	42	↑↖	3		986	720 1077			
R	1657	E80⊕	10	RW-	103	47	40	↑↖	4		980	RB20			
R	1758	50⊘E80⊕	10	RW--	107	42	38	→	3		981				
R	1856	50⊘E80⊕	10	RW-	110	45	41	→↗	2		982	RE02 B50 51403 157X	53		
R	1958	E90Ⓘ	15		106	46	42	↗	1		981	RE42			
R	2057	30Ⓘ E90⊕	10		105	45	43		C		981				
S3	2135	E30Ⓘ 90⊕	8					↗	1						
R	2159	E30Ⓘ 90⊕	8		100	46	44		C		980	807 157X			

Fig. 16. Surface weather observations taken at the U. S. Naval Air Station, Grosse Ile, Michigan, on 3 April 1960.

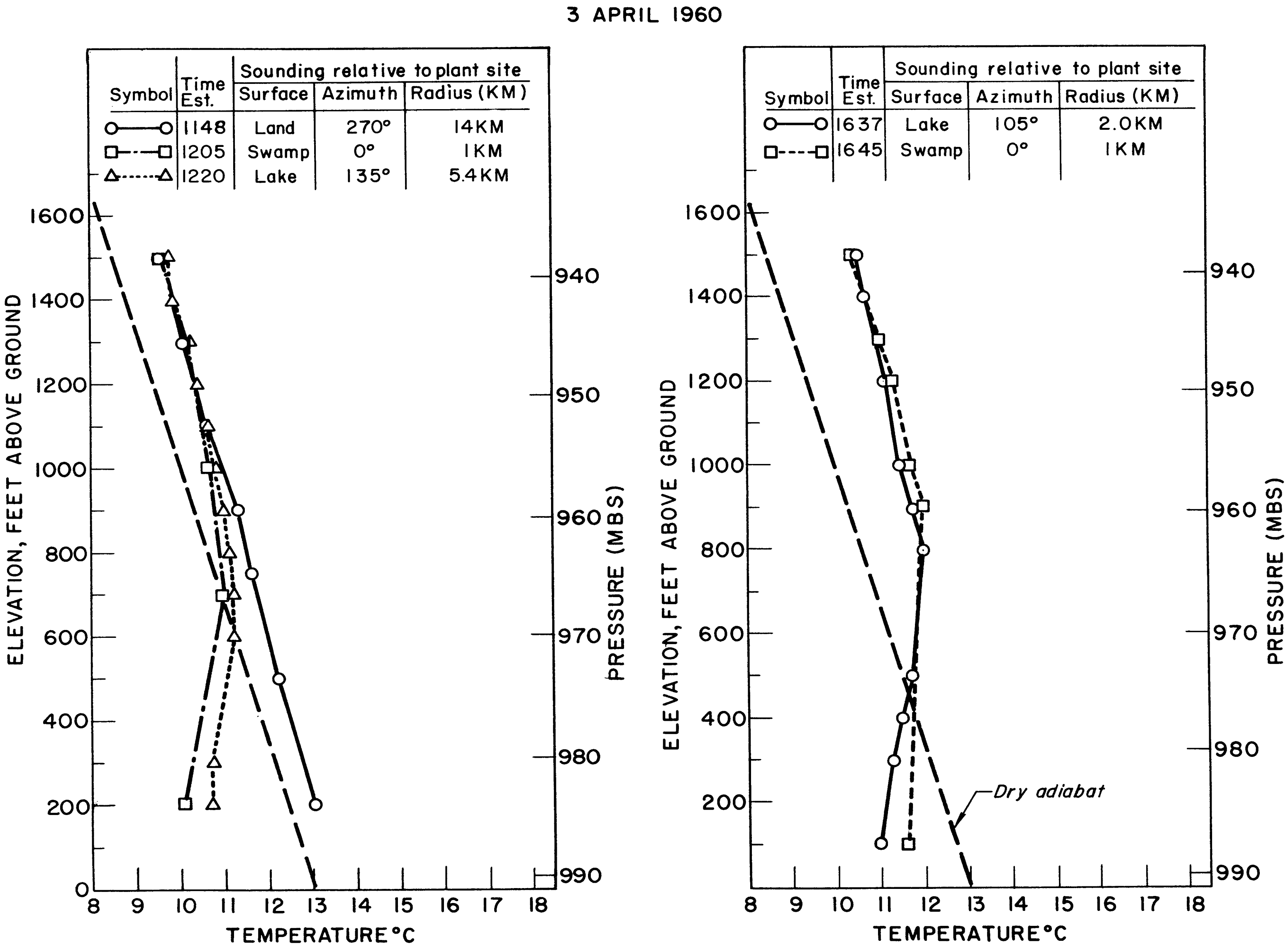


Fig. 17. Plots of the vertical temperature distribution as recorded by the aerometeorograph on 3 April 1960.

TABLE II

HOURLY AVERAGE VALUES OF WIND DIRECTION, WIND SPEED, AND TEMPERATURE-LAPSE-RATE DATA FROM THE METEOROLOGICAL TOWER AT THE ENRICO FERMI SITE ON 3 APRIL 1960

Hour Ending	Wind Direction	Wind Speed (mph)	Lapse Rate
0100	SSW	14	I
0200	W	11	I
0300	NW	13	I
0400	NW	11	I
0500	NW	8	I
0600	NW	9	I
0700	W	7	I
0800	SW	7	I
0900	SSW	6	I
1000	S	7	I
1100	SSE	7	I
1200	SSE	9	I
1300	SSE	9	I
1400	SE	8	I
1500	SSE	7	I
1600	SSW	5	I
1700	msg	msg	I
1800	msg	msg	I
1900	msg	msg	I
2000	msg	msg	I
2100	msg	msg	I
2200	msg	msg	I
2300	msg	msg	I
2400	msg	msg	I

regime at the site was similar to that at Grosse Ile. The lake breeze began to be felt between 1000 and 1100 EST as evidenced by the S to SSE wind. The wind speeds are higher at the site but this can be accounted for by the different exposures of the wind instrument at Grosse Ile and the site. It seems, then, that the normal nocturnal inversion was replaced by a lake-breeze-induced inversion, causing inversion conditions throughout the day. It should be noted from Fig. 17 that over land, at any point far enough away from the influence of the lake breeze, a weak lapse-rate condition existed.

The data of Fig. 17 are interesting from another standpoint. A sounding was taken over the swamp at 1205 EST and again at 1645 EST. At 1205 EST there was an inversion from the surface to 700 ft. At 1645 the inversion still existed but was weaker and extended from the surface to 900 ft. It seems safe to assume that the horizontal extent of the lake-breeze-induced inversion probably had increased inland during this period, too.

Thus the area immediately adjacent to the lake and the lake itself was in an area of poor diffusion, while at inland stations moderate diffusion is likely to have occurred.

d. Plume Characteristics.—Aerial photographs were not taken during this experiment due to the short notice of performing the experiment. The smoke generator was not working properly, so no comments can be made concerning the visual characteristics of the plume.

e. Results of Plane Sampling.—The plots of the FP counts are shown in Fig. 18. Unfortunately, the aerosol generator was not operating at its usual capacity; hence the emission rate was reduced to almost 1/10 of its prior output. Even so, the counts do indicate that the plume was low and quite small in width. In fact, at 2 km the plume was only 20° or less in width and there were no particles collected above 200 ft. At 4 km, only scattered particles were collected above 300 ft, but the plume had spread out horizontally to as much as 30° in width.

f. Comments on the Diffusion Patterns.—April 3 was actually quite a common type of day at the plant site—a weak pressure gradient, warming over the land during the day, a cold lake, and hence a lake breeze which induces an inversion in the areas immediately adjacent to the lake. Diffusion in this region would not be expected to be good. As one gets further from the lake, the vertical temperature structure changes from an inversion to a lapse condition, so diffusion should get progressively better. The occurrence of rain showers superimposed upon such conditions may be considered as either favorable or unfavorable depending on where the washout would occur. In an uninhabited area, of which there are many around the lake, it could be considered good.

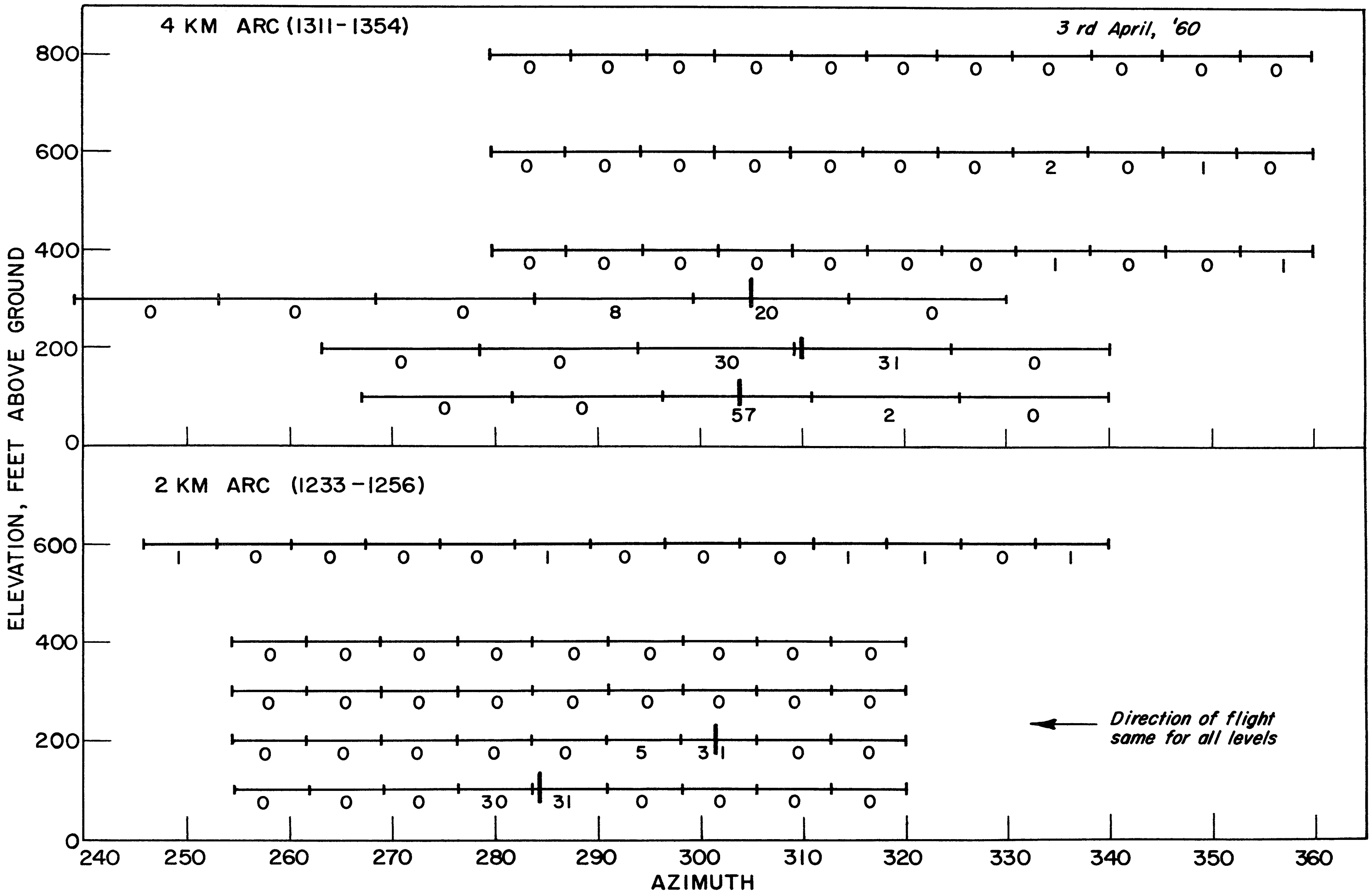


Fig. 18. Raw counts of FP material from 3 April 1960 plotted according to azimuth and height above the lake surface.

3. EXPERIMENT OF 8 MAY 1960

a. Synoptic Situation.—The surface map at 0700 EST showed several low-pressure centers in the eastern United States (see Fig. 19). The northernmost center was located just east of Erie, Pennsylvania, while the second was over Sumpter, South Carolina. A cold front ran from the northern low southward to the southern one, becoming a warm front just before entering the Carolina low. Another cold front ran southward from Sumpter, South Carolina, through the southeastern tip of Florida.

A third low-pressure area was centered over Sheridan, Wyoming, with an associated cold front going southward through central Colorado and then through the northwest corner of New Mexico.

Two high-pressure areas dominated the central U. S. The southern one was located over Houston, Texas, with a ridge pushing as far northward as central Kansas. Another ridge of high-pressure from a center located near Hudson Bay pushed down into northern Nebraska.

The net effect at the plant site was that the winds were westerly, but the gradient was quite weak, thus causing the winds to be variable in direction.

b. Monroe Area Weather.—Figure 20, the hourly surface observations from Grosse Ile, indicates that the winds were generally from the northwest at speeds of 3-4 knots until 1058 EST. From 1058 to 1556 EST the winds were very light and variable in direction, but usually with an easterly component.

Visibility was good all day. Throughout most of the day there was a high overcast of cirrostratus clouds. From 0900 until 1500 EST, there was also an overcast of altocumulus type clouds. Beneath the middle layer were some low stratocumulus which came and then disappeared and then returned again before the afternoon was over.

The lake temperature during this period of the year usually runs about 50°F (10.0°C). It is of interest to note that the maximum temperature for the day was only 50°F (10.0°C). Thus it seems plausible that there was no inversion around the lake shore throughout the day. This is fairly well substantiated by Table III and Fig. 21, which show the observed lapse rates at the plant site and in the sampling area.

c. Special Characteristics at Lagoona Beach.—Table III presents the hourly average values of wind direction, wind speed, and temperature lapse rate as observed on the meteorological tower at the plant site. It is unfortunate that the wind direction is missing during the early morning hours, but it can be assumed that it was a northwesterly wind since the wind at Grosse Ile was from that direction. Again the wind speed is higher but this has been explained in earlier experiments. Between 0900 and 1000 EST, the wind began

STATION U.S. NAVAL AIR STATION, GROSSE ILE, MICH. DATE 8 May 1960

TYPE 1	TIME (LST) 2	SKY and CEILING (Hundreds of Feet) 3	VISIBILITY (Miles) 4	WEATHER and OBSTRUCTIONS TO VISION 5	SEA LEVEL PRESS. (mbs.) 6	TEMP. (°F) 7	DEW PT. (°F) 8	WIND DIRECTION 9	WIND SPEED (knots) 10	WIND CHARACTER & SHIFTS 11	ALTIMETER SET. (ins.) 12	REMARKS AND SUPPLEMENTAL CODED DATA 13	14A	14B	OBSERVERS Initials 15
R	0557	30⦶/⦶	10		078	41	34	↘	4		973				
RS1	0658	E100⦶/⊕	10		081	41	32	↓↘	4		974	108 1077 41			
R	0758	E120⦶/⊕	10		075	42	34	↓↘	3		972				
R	0858	35⦶E120⊕	10		075	44	34	↓↘	3		972				
R	0957	35⦶E120⊕	10		069	46	35	→↘	2		971	708 157X			
R	1058	30⦶E120⊕	10		069	47	32	↓↙	3		971				
R	1157	E120⊕	10		069	47	34	↙	1		971				
R	1256	E120⊕	10		069	47	34		C		971	400 107X 41			
S2	1320	E30⦶100⊕	10						C						
R	1358	E30⦶100⊕	10		068	48	34	↑↖	5		971				
R	1457	E30⦶100⊕	10		063	50	38		C		969				
S3	1525	30⦶/⊕	10					←↖	2						
R	1556	30⦶/⊕	10		059	50	35	←	3		968	812 1506			

Fig. 20. Surface weather observations taken at the U. S. Naval Air Station, Grosse Ile, Michigan, on 8 May 1960.

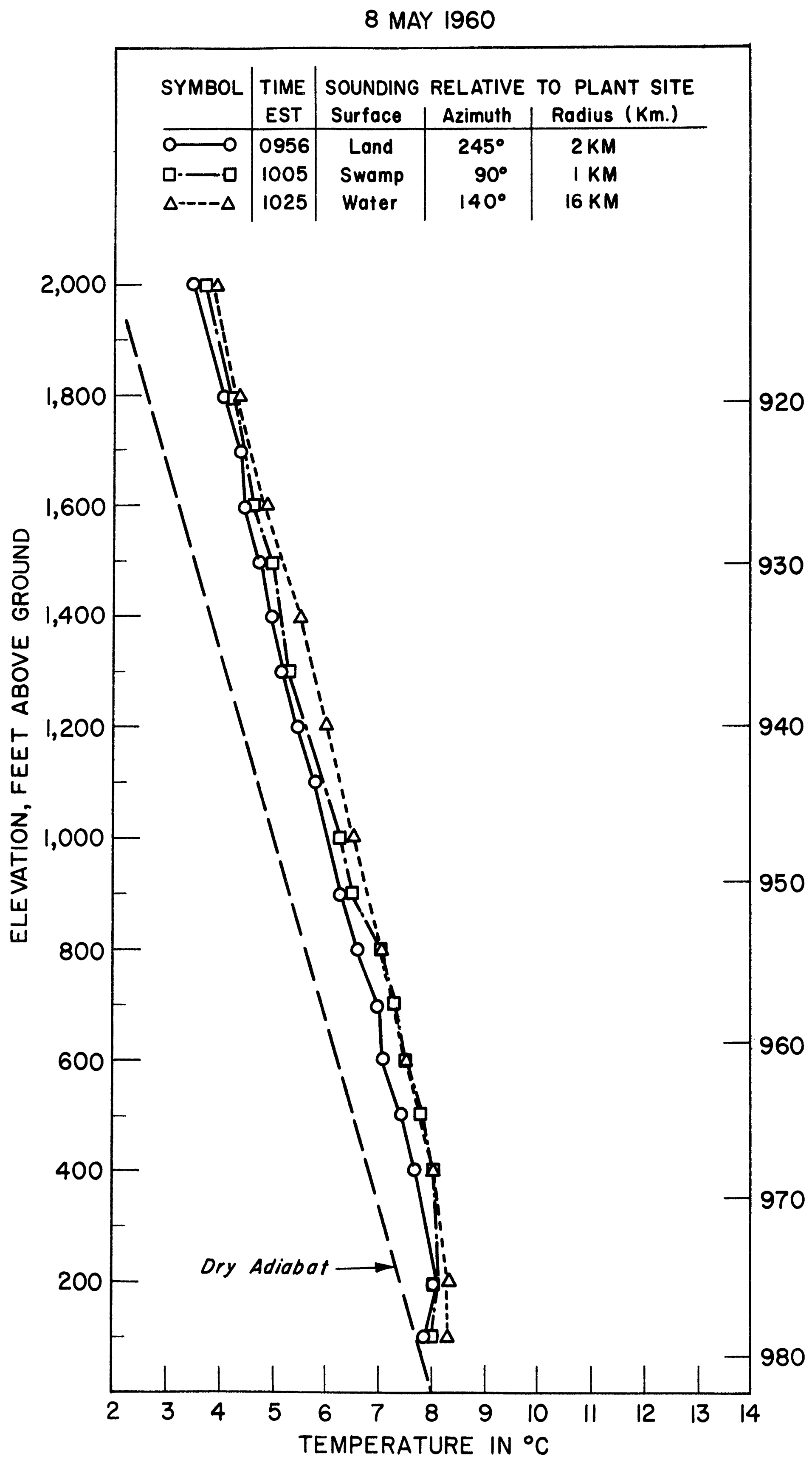


Fig. 21. Plots of the vertical temperature distribution as recorded by the aerometeorograph on 8 May 1960.

TABLE III

HOURLY AVERAGE VALUES OF WIND DIRECTION, WIND SPEED, AND TEMPERATURE-LAPSE-RATE DATA FROM THE METEOROLOGICAL TOWER AT THE ENRICO FERMI SITE ON 8 MAY 1960

Hour Ending	Wind Direction	Wind Speed (mph)	Lapse Rate
0100	msg	7	S
0200	msg	7	S
0300	msg	8	S
0400	msg	7	S
0500	msg	7	S
0600	msg	7	S
0700	msg	8	S
0800	msg	7	S
0900	NE	6	S
1000	N	4	S
1100	NNE	3	S
1200	SE	1	S
1300	W	3	S
1400	S	3	S
1500	S (SE)*	4	S
1600	S (ESE)	4	I
1700	S (E)	3	W
1800	S (E)	2	S
1900	S (SE)	8	S
2000	S (ESE)	10	S
2100	S (ESE)	9	S
2200	S (ESE)	9	S
2300	S (ESE)	8	S
2400	S (ESE)	9	S

*Directions in parentheses are from the 56-foot level aerovane.

to change direction. Whether this change was due to a true sea breeze has not been ascertained. Because the analysis is not clearcut, the wind direction at the 56-ft level on the meteorological tower was added to Table III. At this lower level, the wind seems to be that of a lake breeze and in fact the 1600 EST hourly lapse rate average is an inversion followed by weak at 1700. It certainly would be possible to have a low-level inversion extending to just over 100 ft.

The vertical temperature structure as indicated by the aerometeorograph record on the plane shows that a weak inversion did exist over the land at 1000 EST, but there was a very weak lapse rate over the water (see Fig. 21). Since there was a NE to a N wind at the plant site at that time, the lapse rate recorded at the site was strong. It is quite possible to have a superadiabatic lapse rate in the lower 100 ft with a weak lapse or near isothermal layer above.

Thus the plant area's diffusion was probably fair in the lower 100 ft but was somewhat restricted in the next 200 to 300 ft.

d. Plume Characteristics.—Again aerial photographs were not taken. Definite characteristics of the plume from the smoke generator are not available because the smoke generator was not operating correctly. But the winds were so light that one burst of smoke went up straight and enveloped the entire meteorological tower, which indicates that diffusion was good in the lowest 100 ft.

e. Results of Plane Sampling.—Figure 22 indicates what has already been made evident in the earlier discussion. Diffusion was good in the lower 100 ft but poor at higher levels. The counts at 4 km are sparse due to a change in the wind direction and the fact that again the aerosol generator was only putting out about 1/10 of its normal output.

f. Comments on the Diffusion Pattern.—May 8 represents a day when there is a lake effect but which seems to act as a damper effect above a level of good diffusion. This is a case when there is no inversion formed immediately over the lake after a cold frontal passage because the lake surface is already warmer than the air above it. In this regard, it is more like a fall day than a spring day. It is a case of plume trapping and a case of transition in time of the lake surface temperature relative to the air above it. Fortunately, the damped diffusion condition was alleviated by changing wind directions to mix the air, and also, the upper inversion probably dissipated due to the heating effect of the sun.

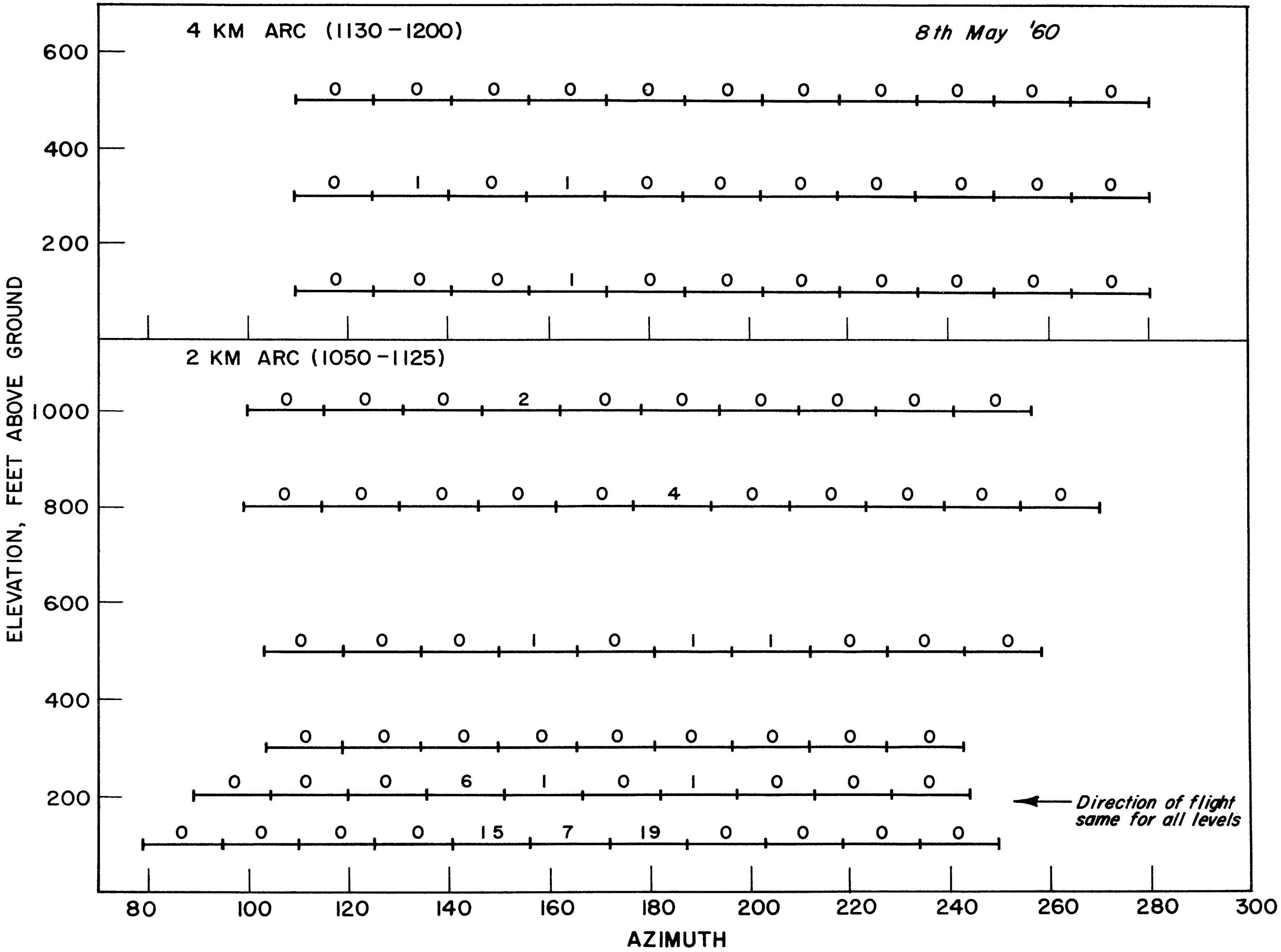


Fig. 22. Raw counts of FP material from 8 May 1960 plotted according to azimuth and height above the lake surface.

4. EXPERIMENT OF 25 JUNE 1960

a. Synoptic Situation.—The 0700 EST map of the surface weather, Fig. 23, showed a relatively deep low-pressure area near Bagotville, Quebec. The frontal system associated with this low had already begun to occlude, so that the apex of the occlusion was located about 100 miles southeast of Caribou, Maine. The warm front ran from the apex eastward and then southeastward through Ecumseecum, Nova Scotia, and into the Atlantic Ocean. The associated cold front ran near St. John, New Brunswick, and then southwestward paralleling the U. S. east coast until it reached Cape Hatteras. From Cape Hatteras the cold front began a more westerly course through Myrtle Beach, South Carolina, and Birmingham, Alabama, finally becoming weak and diffuse north of Fort Worth, Texas.

A small low was located in southern Texas causing widespread rain through the south central states.

A large, cool, high-pressure center was located just south of Lake Michigan. This high-pressure area spread out across most of the central U. S. A weak cold front ran from North Battleford, Saskatchewan, southward through eastern Montana and then into northwestern Wyoming.

The Detroit area was under a fairly strong northwesterly gradient which lasted throughout most of the daylight hours.

b. Monroe Area Weather.—The hourly observations from Grosse Ile Naval Air Station, Fig. 24, indicated that the winds were from the northwest or west until the 1455 EST observation, after which time the winds became southerly or from the south-southwest. Wind speeds were between 3 and 7 knots during the daylight hours.

Visibility was unlimited all day and there were no clouds reported at any time. The temperature reached a maximum of 77°F (25.0°C). The fact that the air was relatively dry is attested to by dew point temperature readings in the high 40's. As soon as the wind shifted to the SSW, the dew point rose due to the air trajectory over the lake.

The temperature of Lake Erie was 63°F (17.2°C). Thus the temperature of the air over the lake was warmer than the lake and an inversion should be present in the lower layers. Over the land, the lapse rate was probably strong at least after the nocturnal inversion dissipated.

c. Special Characteristics at Lagoona Beach.—Table IV shows the hourly average values of wind direction, wind speed, and temperature lapse rate from the meteorological tower at the plant site. The wind direction and wind speed are basically the same as at Grosse Ile. This was to be expected with the gradient as strong as it was behind the cold front.

STATION U.S. NAVAL AIR STATION, GROSSE ILE, MICH. DATE 25 June 1960

TYPE 1	TIME (LST) 2	SKY and CEILING (Hundreds of Feet) 3	VISIBILITY (Miles) 4	WEATHER and OBSTRUCTIONS TO VISION 5	SEA LEVEL PRESS. (mbs.) 6	TEMP (°F) 7	DEW PT. (°F) 8	WIND DIRECTION 9	WIND SPEED (knots) 10	WIND CHARACTER & SHIFTS 11	ALTIMETER SET. (ins.) 12	REMARKS AND SUPPLEMENTAL CODED DATA 13	14A	14B	OBSERVERS Initials 15
R	0558	0	15+		199	53	46	→ ↘	3		011				
R	0658	0	15+		202	56	46	→ ↘	5		012	127 51			
R	0755	0	15+		205	62	47	→ ↘	5		013				
R	0855	0	15+		208	66	48	→	7		014				
R	0955	0	15+		211	68	51	↘	6		015	210 1000			
R	1055	0	15+		211	70	46	→ ↘	6		015				
R	1155	0	15+		213	73	47	→	5		016				
R	1255	0	15+		212	74	49	→ ↗	5		015	202 1000 51			
R	1355	0	15+		206	75	47	→	4		014				
R	1455	0	15+		207	77	49	→	4		013				
R	1558	0	15+		203	75	58	↑	6		013	710 1000			
R	1658	0	15+		203	75	54	↑ ↗	7		013				
R	1758	0	15+		199	74	52	↑ ↗	6		012				
R	1857	0	15+		199	73	53	↑ ↗	5		012	603 1800 77			
R	1958	0	15+		199	68	56	↑ ↗	3		012				
R	2057	0	15+		199	67	58	↑ ↗	2		012				
R	2158	0	15+		205	66	57	↗	2		013	305			

Fig. 24. Surface weather observations taken at the U. S. Naval Air Station, Grosse Ile, Michigan, on 25 June 1960.

TABLE IV

HOURLY AVERAGE VALUES OF WIND DIRECTION, WIND SPEED, AND TEMPERATURE-LAPSE-RATE DATA FROM THE METEOROLOGICAL TOWER AT THE ENRICO FERMI SITE ON 25 JUNE 1960

Hour Ending	Wind Direction	Wind Speed (mph)	Lapse Rate
0100	WNW	14	I
0200	WNW	14	I
0300	WNW	15	I
0400	WNW	14	I
0500	WNW	15	I
0600	WNW	15	I
0700	WNW	15	I
0800	NW	15	I
0900	NW	16	W
1000	NW	16	W
1100	NW	15	W
1200	WNW	13	S
1300	W	12	S
1400	WSW	11	W
1500	SSW	10	W
1600	S	11	I
1700	S	9	I
1800	SSW	7	I
1900	S	6	I
2000	S	9	I
2100	S	9	I
2200	SSW	9	I
2300	SSW	9	I
2400	SSW	8	I

As suspected above, an inversion did exist at the plant site until sometime between 0800 and 0900 EST. Then as heating took place, the lapse rate began to change slowly, until, at 1200, the lapse rate was recorded as being strong. At 1400, the wind changed slightly so as to be from the WSW. The lapse rate then became weak, probably because warmer air was being advected aloft. By 1600 the lapse rate was recorded as an inversion. The wind had shifted so as to be from the S. One of the authors was at the Grosse Ile Naval Air Station during the day. It was noticed that, at 1530 EST, the wind shifted to the south and the temperature stopped rising while the dew point continued to rise. All these facts point to the presence of a lake-breeze-induced inversion. By 1530 the pressure gradient force must have become light enough so that a lake breeze could develop. This inversion then continued until night, when it was replaced by a nocturnal inversion.

The aerometeorograph records are interesting to observe (see Fig. 25). The morning sounding over the land shows the nocturnal inversion while the overwater trajectories show the effect of the warm lake surface. At 0.5 km the inversion base is at 200 ft, whereas at 5 km the base is at 500 ft. The afternoon soundings all show a weak low level inversion up to about 200 ft. This is natural for the overwater soundings since the air passing over the water has been warmed by previous passage over the warm land several hours before. The land sounding taken at 1639 is an effect of the lake breeze. The cool air in the low levels has been blown in over the land from the water. The result is that the land and water soundings are quite similar in their appearance and characteristics.

d. Plume Characteristics.—No aerial photographs were taken during this experiment but there were comments from the observers on the scene. During the morning, the smoke left the smoke generator and rose slightly before sinking and hitting the water. At the same time the plume seemed to bifurcate in the vertical—half of the plume hitting the water and half rising. The net result seemed to be two plumes, one on the water and one aloft. Once the smoke came close to the water, it began to diffuse rapidly. This verifies the weak lapse rate condition over the water at 0.5 km from the morning sounding. By afternoon the plume was mixing well with the surroundings air mass. After the wind shifted, no smoke was put out by the smoke generator due to a mechanical failure.

e. Results of the Plane Sampling.—Figures 26 and 27 show the raw counts of FP material as collected by the airplane sampler. This was the first experiment where data were collected at 16 km. Although the wind began to shift at the plant site, the plane observer reported that the surface wind at 16 km was still westerly. This observation was based upon the direction of the smoke plume from lake freighters below the plane. Although the aerosol generator had been repaired since earlier experiments, the output of the generator was still only about 40% of its rated output. However, all radii of the sampling pattern look good. Counts were made from 60-1000 ft above the water on the 2- and 4-km

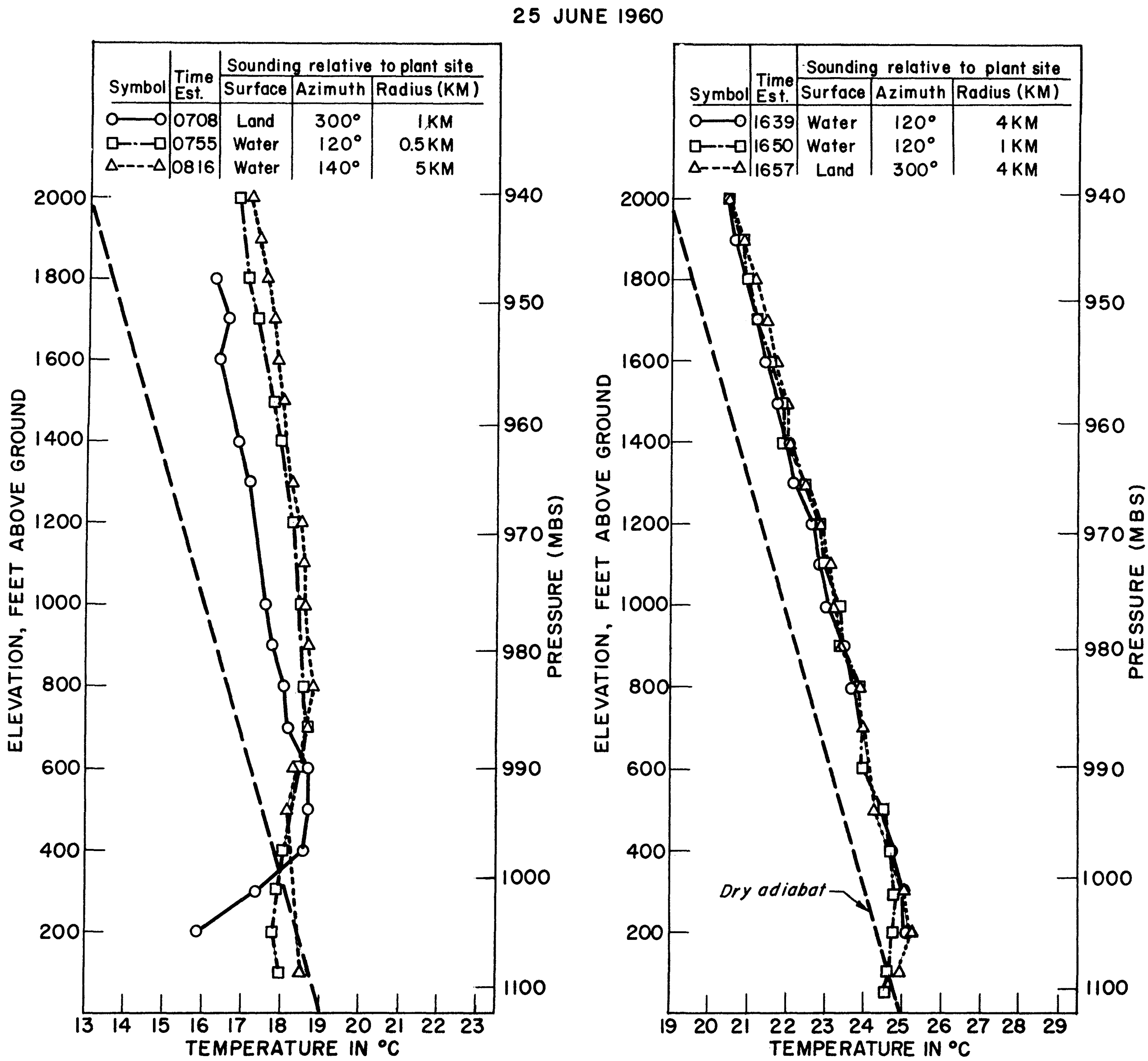


Fig. 25. Plots of the vertical temperature distribution as recorded by the aerometeorograph on 25 June 1960.

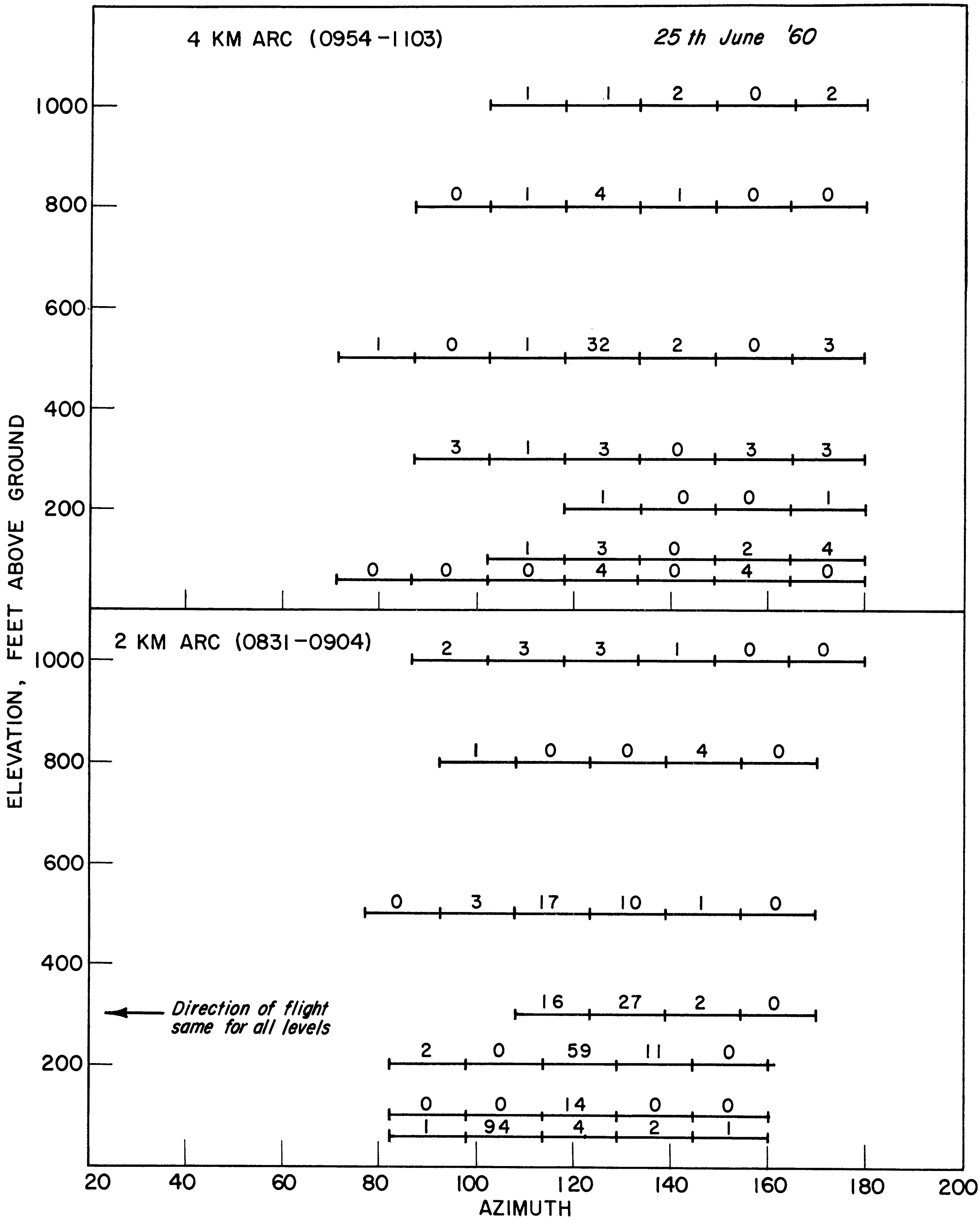


Fig. 26. Raw counts of FP material from 25 June 1960 at 2 and 4 km plotted according to azimuth and height above the lake surface.

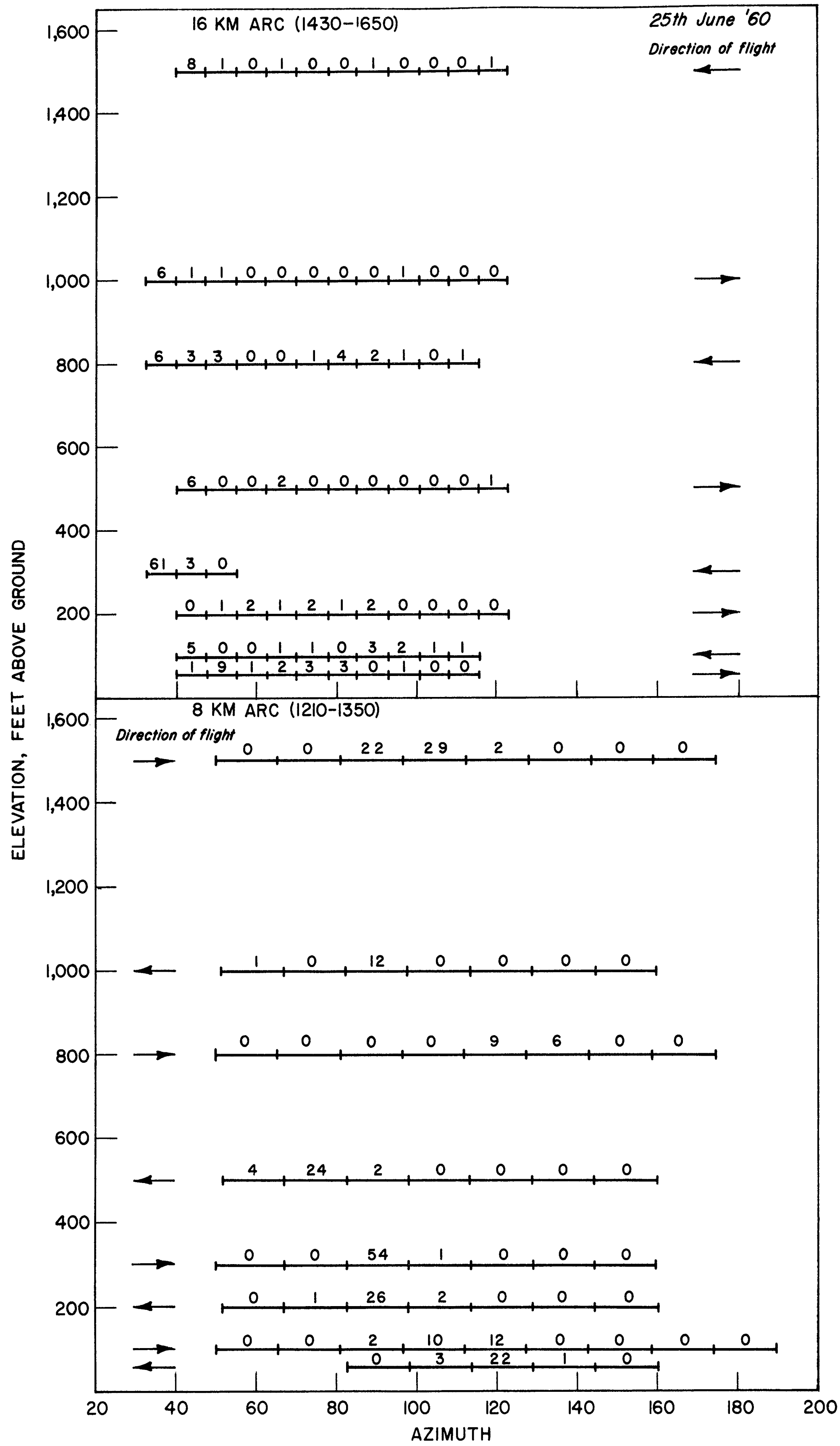


Fig. 27. Raw counts of FP materials from 25 June 1960 at 8 and 16 km plotted according to azimuth and height above the lake surface.

arcs and from 60-1500 ft on the 8- and 16-km arcs. Indications are that the plume had shifted when the 16-km arc was sampled and that only one side of the plume was really sampled.

f. Comments on the Diffusion Patterns.—It was hoped that this run would show a definite inversion over the lake for a long distance in which vertical diffusion would be markedly damped and in which horizontal diffusion would take place at normal rates. This was not the case, and in fact diffusion appears to be good all day. However, a low-level inversion did exist over the water late in the afternoon.

III. SUMMARY OF EXPERIMENTS

It is appropriate at this time to review the past experiments to assess their value not only in computing diffusion parameters but also in determining the many minor features which together make up the diffusion meteorology of an area. As in all research, every experiment was not a complete success in all respects. During one experiment, the aerosol generator might not work as efficiently as it should. During another, there may have been airplane difficulties. Then when all equipment was operating properly, the wind would shift. However, there is some information that can be gotten from each experiment.

Table V summarizes the eight successful experiments that have been reported on in the first two progress reports. The initial planning called for experiments to be conducted during each of the four seasons of the year. This has been accomplished. Sampling has taken place from right after sunrise until just before sunset under various meteorological conditions. When considering the enormity of such a program and the restrictive manpower conditions, the experiments turned out to be quite well balanced.

If one major fact could be picked from all the experimental evidence, it would be that the effect of Lake Erie on the air-pollution potential of the land areas immediately adjacent to the lake is major. This is not a new idea, but the diffusion experiments have made this fact more evident and better understood. During days when diffusion is normally good at land stations (that is, a strong lapse rate due to solar heating), the lake shore may be affected by a lake breeze which causes an inversion to form. Such inversions naturally inhibit diffusion in the area. On other days, when the air is cooler than the lake temperature, diffusion is enhanced over the lake. The situation of warm air over a relatively cool lake still remains to be fully investigated.

In conclusion, then, it may be said that this series of eight experiments when fully analyzed will not only have been useful for the contracting agency, but also educational for the field of meteorology as a whole. This experimental work in an area of land and lake interplay has helped to cast some light on the problem of diffusion in transitional states.

TABLE V

SUMMARY OF EXPERIMENTS AT THE ENRICO FERMI NUCLEAR POWER PLANT
LAGOONA BEACH, MICHIGAN

Date of Experiment	Season of Year	Time of Sampling	Lapse Rate at Meteor. Tower	Equipment Remarks	Comments Relative to Sutton's Equations	Value of Experiment
5 August 1959	Summer	0756-1051	W becoming S	None Aerial photographs	Missed plume	Not usable
6 August 1959	Summer	Run No. 1 0754-0936 Run No. 2 1115-1228	W W	None None	Missed plume at one level. Some meander	Good
27 November 1959	Fall	1206 1352	S becoming W	None	Some meander	Good
28 November 1959	Fall	1317-1646	S becoming W	None	Missed plume at some levels, sampled 8 km	Not usable
4 February 1960	Winter	1420-1606	W becoming I	None Aerial photographs	None	Good
3 April 1960	Spring	1130-1537	I	Smoke generator and aerosol generator not working properly	None	Good
8 May 1960	Spring	0956-1207	S	Smoke generator and aerosol generator not working properly	Appears to be a trapping situation	Good
25 June 1960	Summer	0744-1645	S becoming I	Aerosol generator not up to capacity output	Sampled out to 16 km. Wind shift caused only 1/2 plume to be sampled at 16 km	Good