



OPERATION CENIZA-ARENA:
TECHNIQUES FOR THE MEASUREMENT
OF DEPOSITION AND REDISTRIBUTION
OF FALLOUT AROUND STRUCTURES

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**OPERATION CENIZA-ARENA:
TECHNIQUES FOR THE MEASUREMENT
OF DEPOSITION AND REDISTRIBUTION
OF FALLOUT AROUND STRUCTURES**

By:

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INTRODUCTION

Background

With the concurrence of the Research Directorate of the Office of Civil Defense, three Stanford Research Institute scientists made a field trip to Costa Rica in February of 1964 to investigate the feasibility of making technical measurements of the fallout-like material that was reportedly ejected during eruptions of Volcán Irazú. As a result of the preliminary findings, a combined Stanford Research Institute-U.S. Naval Radiological Defense Laboratory effort, during the period from March 20 to May 18, 1964, was undertaken to determine the physical and chemical characteristics of the ceniza-arena* fallout, the retention of ceniza-arena by available plants, and the extent of ceniza-arena ingress into a residential structure.

The Stanford Research Institute project was subsequently extended to include foliar retention measurements on a variety of vegetables and cereal grains throughout their growing periods. These studies have been published separately.^{1,2} In addition, a small amount of effort has gone into documentation of the ceniza-arena removal operations in the city of San José.³

Areas of research that have received very little attention include (1) fallout deposition and redistribution around city buildings; (2) ingress of particles into large structures through window openings; and (3) retention of particles by people, clothing, and automobiles.

These areas of research were discussed in a joint Stanford Research Institute-U.S. Naval Radiological Defense Laboratory conference on November 23, 1964, in which the responsibility for Area 1 was assigned to Stanford Research Institute and for Areas 2 and 3 to U.S. Naval Radiological Defense Laboratory. To conduct the research on Area 1, the authors made three field studies in San José, Costa Rica. The first trip, during the period December 1-15, 1964, enabled Stanford Research Institute to select suitable experimental sites, obtain preliminary data, and test experimental procedures. Data were collected at two of the selected

* Ash-sand, coined native descriptive terminology, also commonly referred to as ceniza.

experimental sites during the second and third trips (January 5-18, 1965, and February 7-24, 1965). Additional trips were planned but were not taken, because the volcano ceased erupting in late February 1965.

Objectives

The objectives of this project were:

1. To determine initial fallout mass deposition patterns around multistory buildings.
2. To determine residual mass deposition patterns around multistory buildings after initial deposits have been redistributed by normal weather effects.

EXPERIMENTAL APPROACH

The experimental approach designed to meet the objectives of this project included (1) selection of structures suitable for ceniza-arena deposition measurements, (2) installation of instrumentation, and (3) field measurements and sample processing.

Site Selection

Arrangements for access into and around structures in the San José area that were suitable for studies of both ceniza-arena ingress and surrounding deposition was one of the first requirements during the December visit.

A survey was made of the metropolitan areas containing existing multistory buildings as possible sites, using the following criteria in making final selections:

1. Number of on-site multistory buildings.
2. Adaptability to experimental measurements.
3. Probability of receiving ceniza-arena deposits based on probable wind directions during periods of planned work.
4. Type and amount of vehicular and pedestrian traffic.

Suitable buildings were found in the downtown area of San José but, due to the high vehicular and pedestrian traffic load between the hours of 6:00 a.m. and 10:00 p.m., it was desirable to select alternate suburban sites where measurements could be taken during daylight hours. Therefore, two of each location, urban and suburban, were chosen (and assigned station numbers) that met all criteria, as follows:

Station 07 The Colegio de Nuestra Señora Sion, a three-story, two-wing classroom building separated by a central courtyard. (Figure 1.) The site is located near Moravia, approximately due west of Volcán Irazú.

- Station 08 The Colegio de Saint Francis, a modern large reinforced concrete church building located near Station 07 (Figure 2).
- Station 09 Downtown complex, bounded by Central Avenue from Central Street to Second Street and by Central Street from Central Avenue to Second Avenue. Included on the site is the new Royal Dutch Hotel, a modern six-story building on the Southwest corner of Central Street and Central Avenue (Figure 3).
- Station 010 The new Banco Central de Costa Rica, a modern nine-story building. This building is isolated from surrounding buildings and is located within a one-block-square area bounded by Central and First Avenues and Second and Fourth Streets (Figure 4).

Locations of the above sites relative to Volcán Irazú are given in Table 1.

Ground level deposition measurements at Stations 09 and 010 were possible only between the hours of 10:00 p.m. and 6:00 a.m., whereas measurements could be made at Stations 07 and 08 and at roof level of Stations 09 and 010 at any time. Stations 07 and 08 are both schools; however, during the collection period, the students were on a 3-month vacation.

Arrangements for the use of these station sites were made with the proper authorities through the U.S. Embassy and U.S. Military Mission.

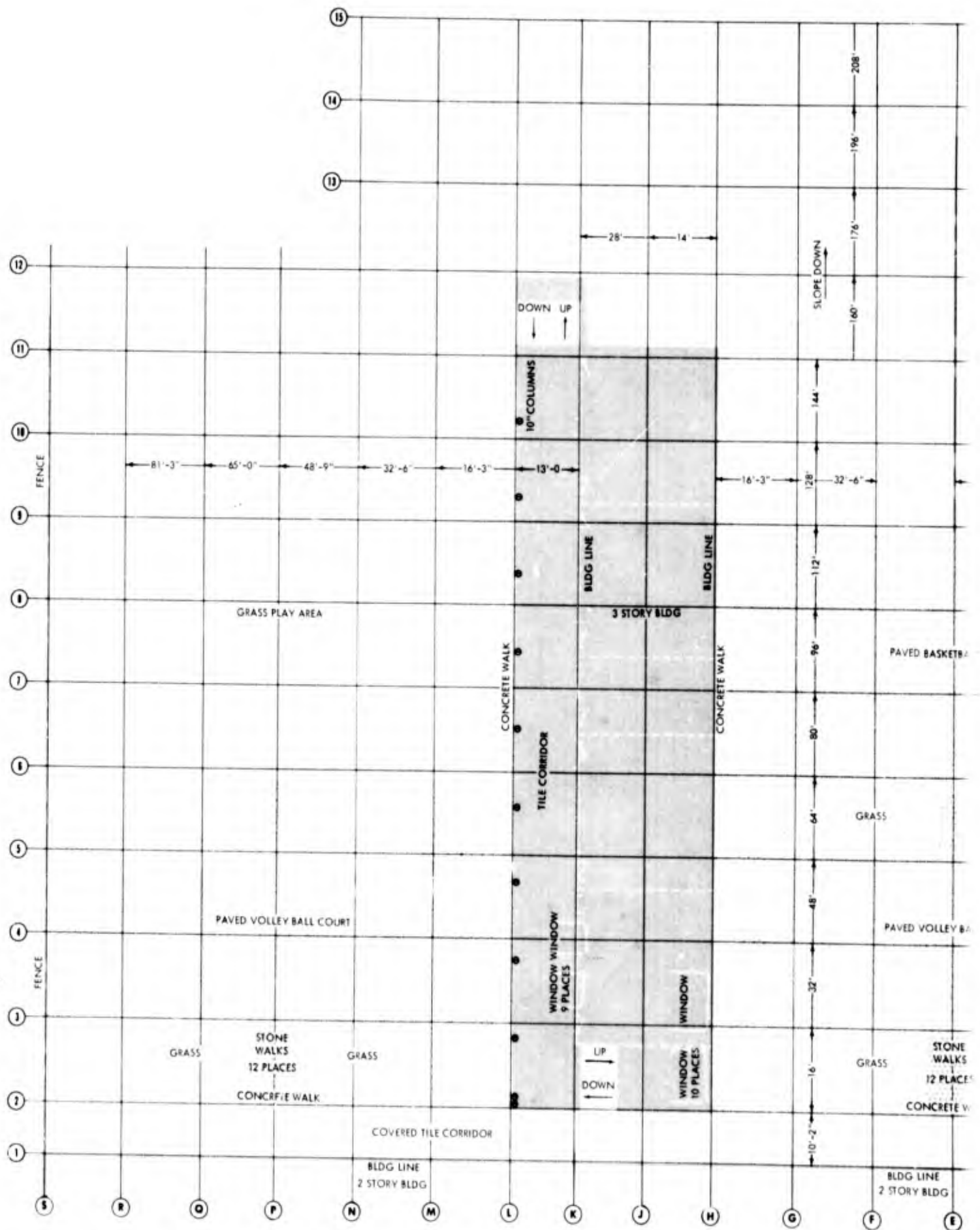
Instrumentation

The principal field measurements were of wind speed and direction and of deposited mass of ceniza-arena particles. The wind speed and direction measurements were obtained with both stationary and portable instruments. Figure 5 shows a stationary anemometer and a wind direction vane mounted in an undisturbed air layer above the roof. Data from these instruments were recorded continuously at Stations 07 and 010.

As shown in Figure 6, portable anemometers for measuring wind speeds at specified heights above the surface were used where plate collectors were located. The wind speeds recorded with the portable anemometer were later correlated with the wind speeds obtained simultaneously with the stationary anemometers. A detailed description of the wind speed and direction instrumentation is given in Appendix A.

Figure 1

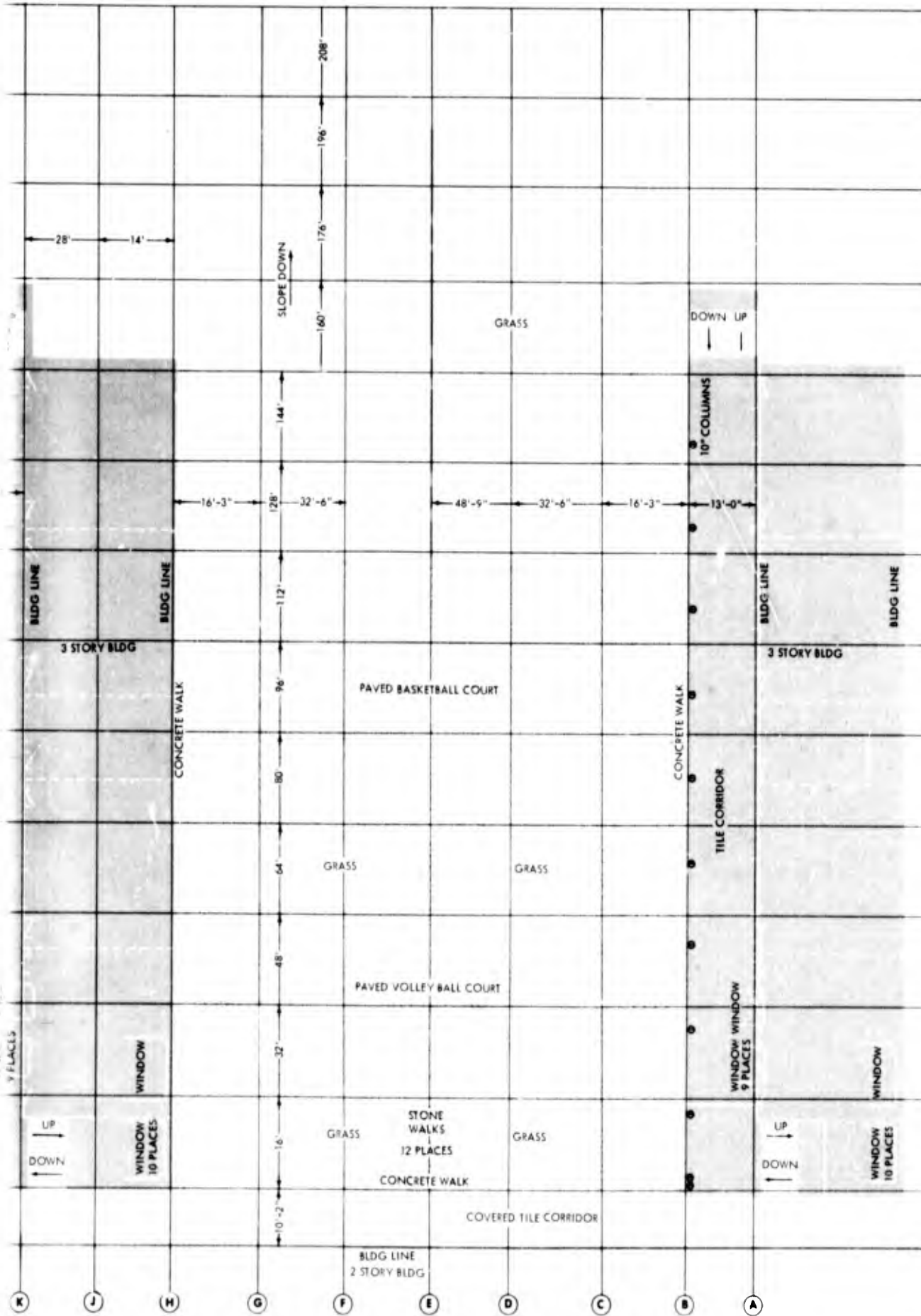
PLOT PLAN OF COLEGIO DE NUESTRA SENORA SION,
MORAVIA, COSTA RICA, C.A., WITH COORDINATE
SYSTEM TO IDENTIFY SAMPLING LOCATIONS: STATION 07



A

SENORA SION,
 COORDINATE
 TIONS: STATION 07

NORTH →



6

Figure 2

PLOT PLAN OF COLEGIO DE SAINT FRANCIS,
MORAVIA, COSTA RICA, C.A., WITH COORDINATE
SYSTEM TO IDENTIFY SAMPLING LOCATIONS: STATION 08

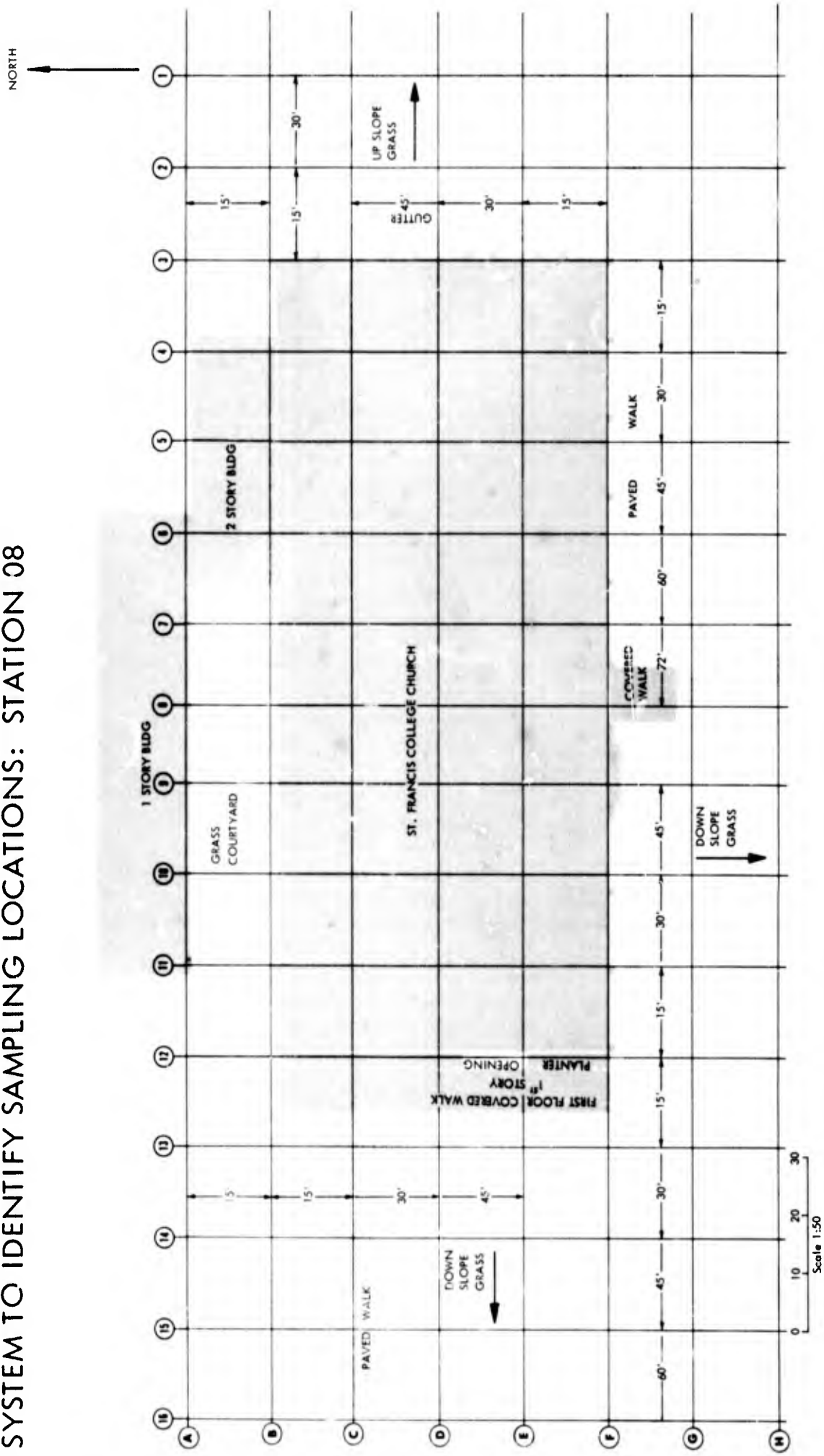


Figure 3
 DOWNTOWN BUILDING COMPLEX IN SAN JOSE,
 COSTA RICA, C.A., WITH ARBITRARY COORDINATE
 SYSTEM TO IDENTIFY SAMPLING LOCATIONS: STATION 09

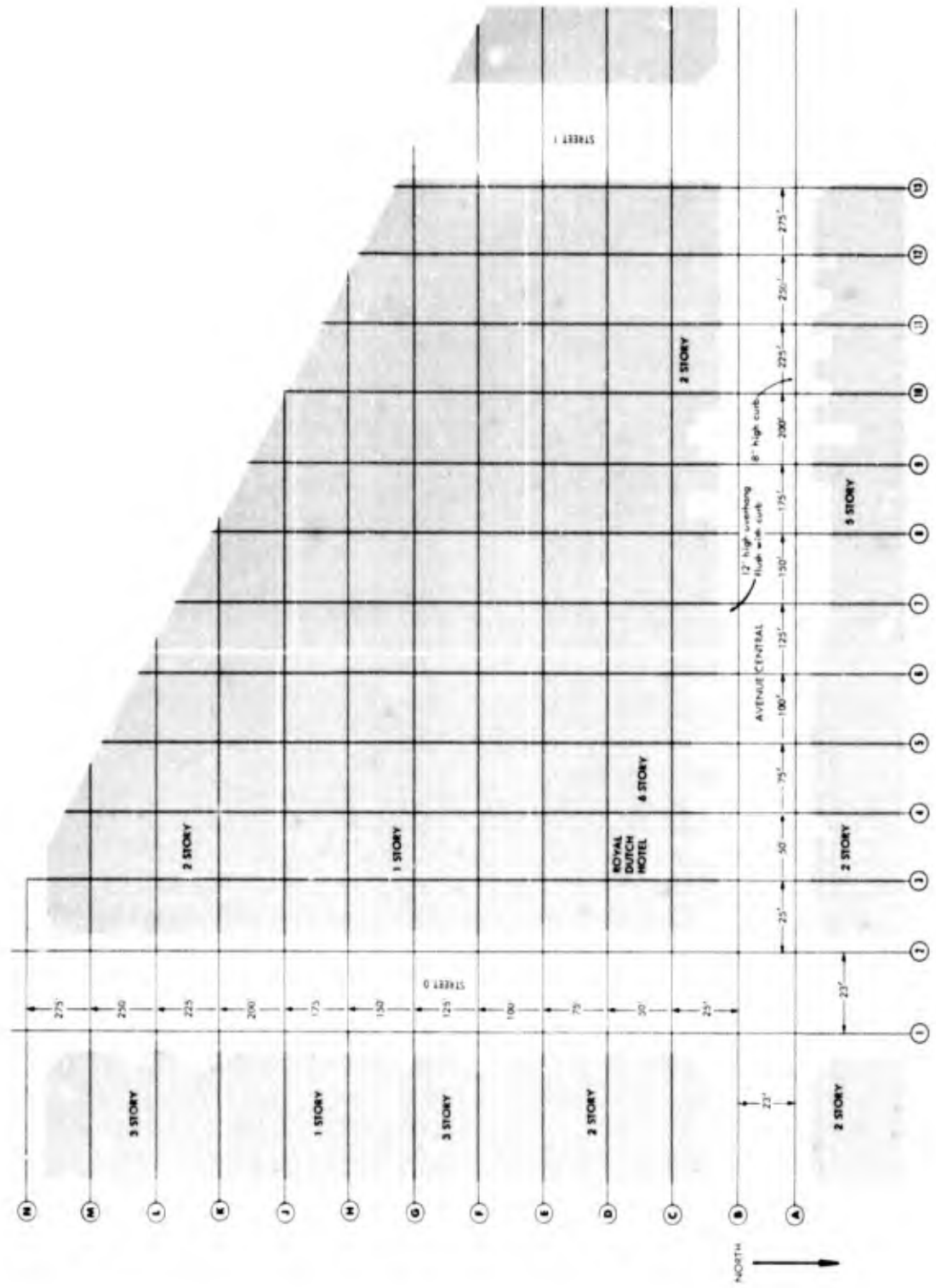


Figure 4
 ROOF PLAN OF BANCO CENTRAL DE COSTA RICA SHOWING
 COORDINATE SYSTEM TO IDENTIFY SAMPLING LOCATIONS: STATION 010

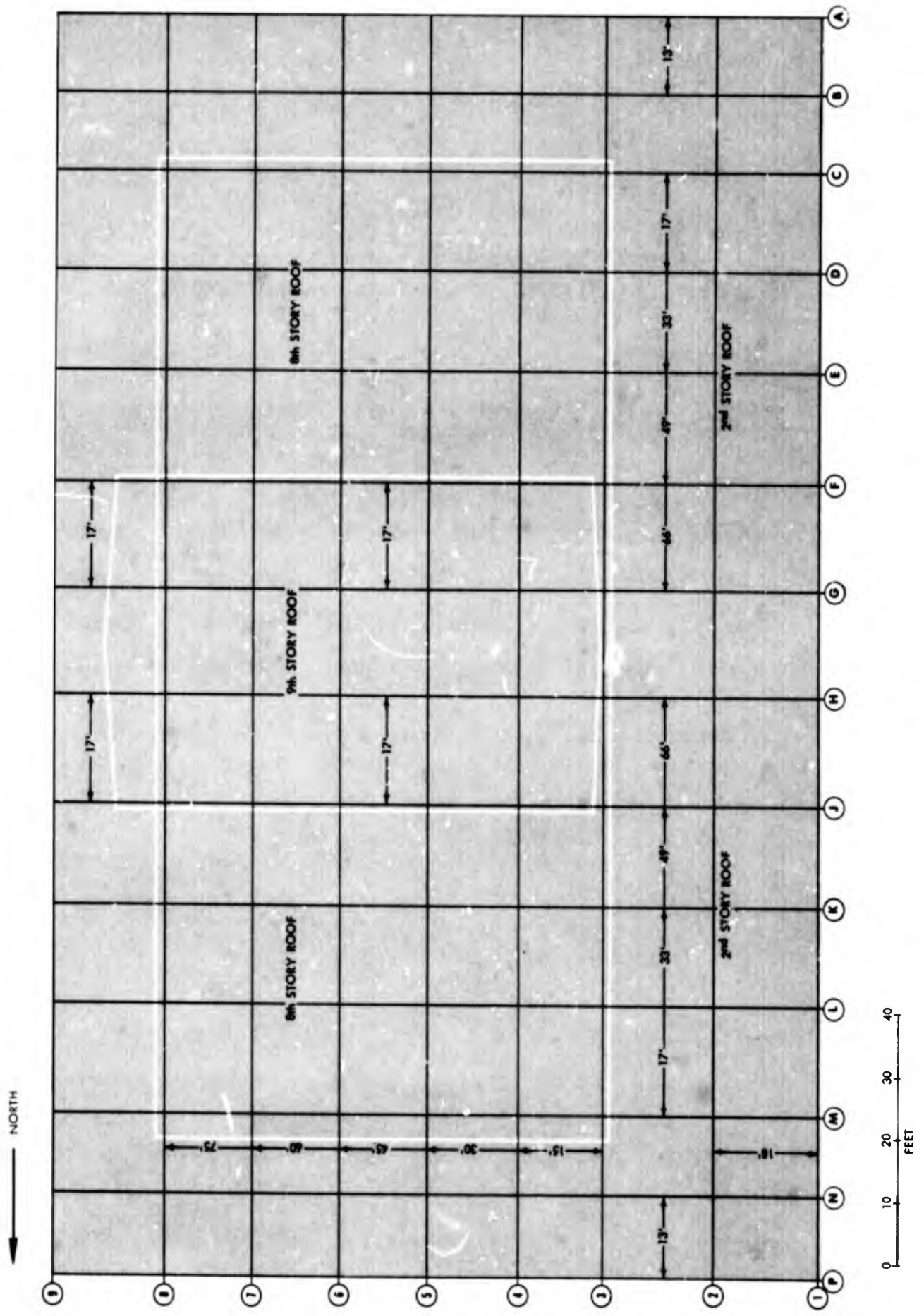


Table 1

OPERATION CENIZA-ARENA STATION DATA
 COORDINATES, DISTANCES, AND AZIMUTHS FROM VOLCÁN IRAZÚ

<u>Station</u>	<u>x (ft)</u>	<u>y (ft)</u>	<u>Distance (ft)</u>	<u>Azimuth*</u>	<u>Elevation (ft msl)</u>
Irazú	0	0	0	--	11,260
07	-74,400	- 9,100	75,000	263° 01'	3,920
08	-73,500	- 8,200	74,000	263° 38'	3,980
09	-82,300	-17,800	84,200	257° 48'	3,800
010	-82,700	-17,600	84,600	257° 59'	3,800

* Measured clockwise from North

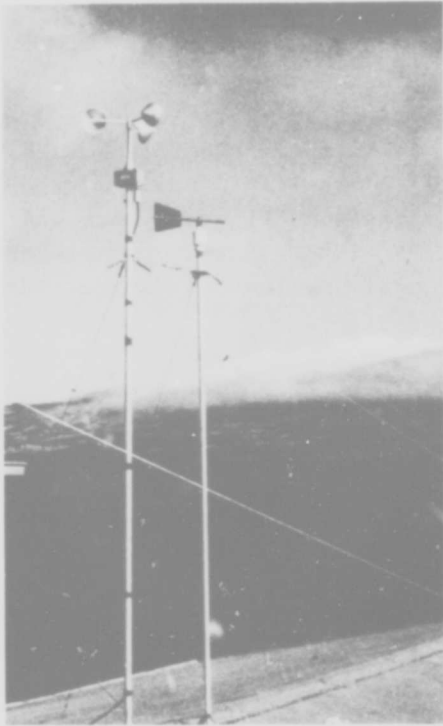


Figure 5

STATIONARY ANEMOMETER AND
WIND DIRECTION VANE ON ROOF
AT STATION 07

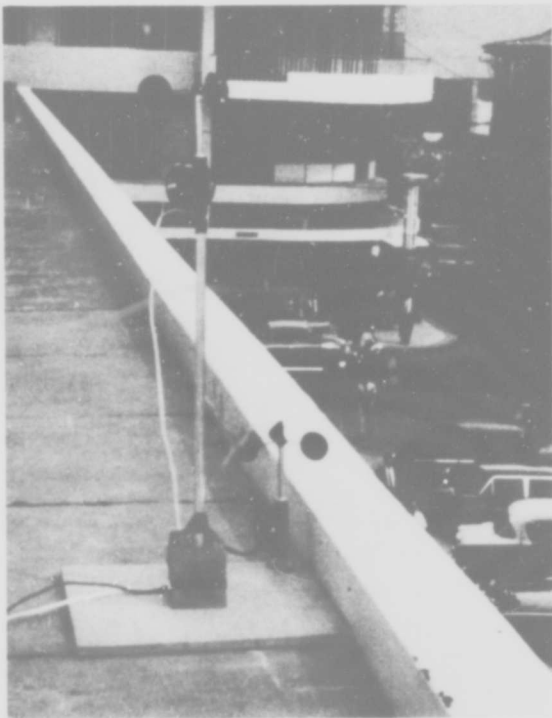


Figure 6

PORTABLE ANEMOMETER MOUNTED
FOR SIMULTANEOUS WIND SPEED
MEASUREMENT AT ONE FOOT AND
THREE FOOT HEIGHTS ABOVE
SELECTED LOCATION

The deposited mass of ceniza-arena particles was measured with 24 x 24 x 2-inch fallout collector trays, 10 x 10-inch plate collectors, and 4-inch-diameter plate collectors.

The fallout collector trays were utilized so that the gross deposited mass of ceniza-arena particles at each of the sampling station sites could be obtained. The 10 x 10-inch plate collectors were used in a ground level array around structures, and on roofs as shown in Figure 7, for measuring the ceniza-arena deposited at specific locations. Six-inch-diameter plastic containers were used instead of the plate collectors during the December visit.

The 4-inch-diameter plate collectors were oriented in known positions for estimating ceniza-arena particle trajectory directions (1) in the vertical plane of the wind direction (Figure 8) and (2) relative to adjacent structure surfaces (Figure 9). When the horizontal component of wind velocity at the plate collector is known during the ceniza-arena deposition, the air concentration of the ceniza-arena particles can be estimated.

The plate collector array pictured in Figure 8 consisted of seven of the 4-inch-diameter plate collectors mounted at 30-degree increments around a crosswind support rod. The rod was mounted on a pivot bearing and had a tail fin to orient the collectors so they would face the prevailing wind. Relative deposits on collector surfaces were used to compute the particle trajectory angle in the vertical plane of the wind direction.

The plate collector array pictured in Figure 9 was mounted on building walls and other locations where measurement of particle trajectory relative to the adjacent structure was desired. This collector array consisted of seven of the 4-inch-diameter plate collectors, three of which were parallel to the three planes of a rectangular coordinate system. The remaining four collectors were oriented as shown in Figure 17. Relative deposits on collector surfaces were used to determine the predominant particle trajectory direction.

Field Measurements and Sample Processing

Previous experience with collection and analysis of ceniza-arena^{1,2} was used to design the experimental procedures for the measurement of the deposit levels and physical characteristics of the ceniza-arena. Because the available manpower for the field work was limited and because the volcanic activity was decreasing, only the Banco Central (Station 010) and Colegio de Nuestra Señora Sion (Station 07) sites were instrumented in

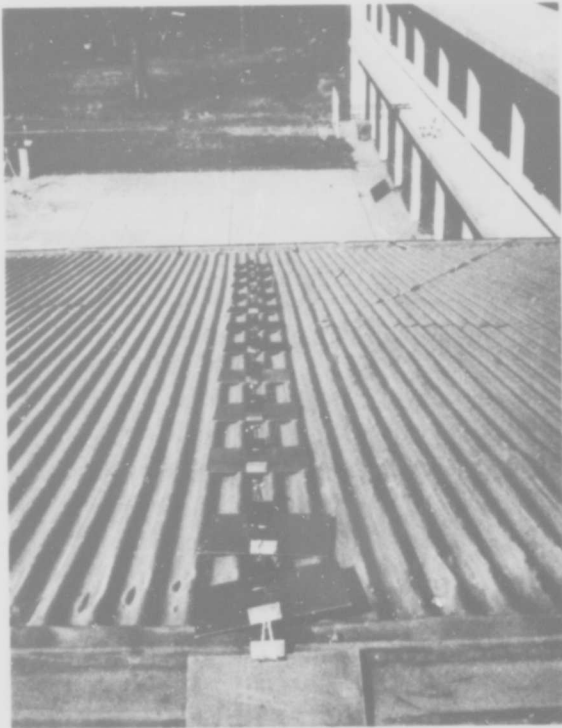


Figure 7

PLATE COLLECTORS ON ROOF TO
DETERMINE CENIZA-ARENA DEPOSITION
RELATIVE TO WIND DIRECTION AND
LOCATION ON ROOF; STATION 07



Figure 8

PLATE COLLECTOR USED
TO ESTIMATE CENIZA-ARENA
PARTICLE TRAJECTORY ANGLE
IN THE VERTICAL PLANE OF
THE WIND DIRECTION



Figure 9

PLATE COLLECTOR USED
TO ESTIMATE CENIZA-ARENA
PARTICLE TRAJECTORY
DIRECTION RELATIVE TO
ADJACENT STRUCTURE
SURFACES

January and February to record continuous routine measurements of wind speed and direction. Each of these stations, in turn, was further instrumented with the remaining equipment so a record, as fully documented as possible, of ceniza-arena deposition and redistribution for correlation with the wind data could be provided.

Particle trajectories around buildings, from roof level to the ground, are of paramount importance to both ingress and deposition studies. The direction in space that a particle will follow depends on the wind velocity, the physical characteristics of the particle, and the force of gravity. It appeared, therefore, that vertical air motions, eddies, and other local perturbations in the airflow pattern would be of first-order importance in determining where airborne particles would deposit.

Wind speed measurements were made simultaneously at rooftop level and at specific places where plate collectors would be exposed. These simultaneous measurements related the wind speed at selected sample locations to the speed of the undisturbed wind at rooftop level for correlation with deposited mass.

The primary objective of the project was to obtain initial deposition data on exposed surfaces of large buildings and on the surfaces in the vicinity of these buildings. However, because of the presence of previously deposited ceniza-arena in the area, many measurements of redistribution of the material were actually made. These became more frequent during the rapid decline of the volcanic eruptions during January and February and were the principal measurements made.

Recorder charts provided a history of wind speed and direction. Charts running at slow speeds (12 inches per hour) gave routine records over long periods of time. Fast speeds (12 inches per minute) gave better pulse resolution for brief wind speed measurements at selected locations. The number of anemometer rotations (pulses on chart) in a time interval (between 1-minute time pulses) were used to compute the average wind speed during the interval. The maximum and minimum pulse spacings within the interval were used to compute the minimum and maximum wind speeds, respectively. Suitable calibration data were used to convert all wind speeds to feet per second.

The plate collectors were coated with petroleum jelly to retain the ceniza-arena particles deposited on them. The exposed plate collectors were processed uniformly as follows:

1. Heated plate so petroleum jelly coating would melt.
2. Flushed melted jelly and ceniza-arena particles into filter paper with xylene solvent.

3. Ashed filter paper and weighed residual ceniza-arena.
4. Coated plates with xylene-petroleum jelly mixture for further sample collections.

The 24 x 24-inch fallout collector trays were brushed clean at the exposure site, and the ceniza-arena was returned to the laboratory for weighing. The recovered particle weights of all samples were converted to units of grams per square foot.

RESULTS

Findings of December 1964 Trip

The preliminary measurements obtained during the December visit consisted of one collection of ceniza-arena at Station 07 and a series of wind speed measurements at four separate sites.

During the period from December 8 to the morning of December 14, an array of fallout collectors was placed in the courtyard between two three-story building wings at Station 07. The volcanic activity and upper altitude winds were such that only one light deposit of ceniza-arena was collected. The results of this collection, obtained on December 9, are given in Table 2. Sample location coordinates listed in the table can be found in Figure 1.

At ground level, the largest deposit was collected at location E 11, at the open downwind end of the courtyard, and the collector at location A6.5, along the building line of the north wing, received the smallest deposit. The A6.5 collector was underneath the second and third floor corridors. The 6-inch diameter plastic containers on the third floor corridor collected twice the amount of those on the second floor corridor. In both instances, the deposit at the rail was largest and diminished toward the building line.

Additional sampling locations would be required for construction of a mass deposition pattern for the whole area, however; the one deposit received indicated that (1) the local variations in the deposits in the vicinity of the building were rather large and (2) the pattern could be established if a sufficient number of collectors were used.

Wind speeds were measured using portable anemometers at four building sites so that variations of wind speed with location near the structures could be determined.

The four sites were:

1. The partially completed, fifteen-story Social Security building, without walls, provided a profile of wind speed with height at an urban area where the average building height is about two stories. The plot of ratios of wind speed at each floor to

Table 2

SUMMARY OF DEPOSITION MEASUREMENTS MADE AT STATION 07 ON DECEMBER 9^a

Sample No.	gm/sq ft	
07001	0.1957	Center basketball court (E 7.5) ^b
07002	0.1567	South wing, center of north wall (H 6.5)
07003	0.1657	North wing, center at corridor edge (B 6.5)
07004	0.0341	North wing, center at building line (A 6.5)
07005	0.0737	East wing, center at corridor edge (E 2)
07006	0.2382	West end of Court (E 11)
07007	0.0103	Third floor corridor at rail (B 9)
07008	0.0029	Third floor corridor at center line (AB 9)
07009	0.0026	Third floor corridor at building line (A 9)
07011	0.0055	Second floor corridor at rail (B 9)
07012	0.0016	Second floor corridor at center line (AB 9)
07013	0.0012	Second floor corridor at building line (A 9)

^a From 12/9/1610 to 12/10/0820

^b See Figure 1

speed at street level (shown in Figure 10) indicates the free air wind speeds above the city buildings (fifth floor and above) are 5 to 6.5 times the wind speed in the street near the building.

2. The six-story Hotel Royal Dutch (Station 09) in the center of the city was used several times to measure the ratio of wind speed at upper floors to wind speed at street level. The plot of ratios of wind speed at each floor to wind speed at street level (shown in Figure 11) indicates a minimum wind speed at the second floor height and gradual increase in speed up to the roof height.
3. Colegio de Nuestra Señora Sion (Station 07) was used to measure wind variation within the courtyard where ceniza-arena deposition measurements would later be made.
4. Colegio de Saint Francis Church (Station 08) was used for wind measurements around the structure, 5 to 6 feet above ground level, at places where ceniza-arena deposition measurements might later be made.

The detailed results of all the above measurements are given in Appendix B, Table B-1.

Findings of January and February 1965 Trips

The field studies during the January and February 1965 trips were centered on obtaining ceniza-arena deposition and redistribution measurements at Stations 07 and 010.

Basic measurements of wind speed and direction were continuously recorded at Stations 07 and 010. The instruments were mounted on the roof at the lowest undisturbed wind layer above the height of the building. These data were used as a basis for a comparison of simultaneously measured wind speeds at other points around the structures. The roof wind speed and direction history at Stations 07 and 010 during January and February are given in Appendix C.

The four portable anemometers were used to make two wind speed measurements at specific locations. One measurement was for a simultaneous comparison of wind speed at a selected location with that of the undisturbed air layer above the roof. The simultaneous wind measurements are summarized in Table 3, and the tabulated wind speeds at specific locations and at the roof level are given in Appendix D. The other measurement was

Figure 10
 WIND SPEED RATIOS AT UPPER FLOORS OF UNCOMPLETED
 SOCIAL SECURITY BUILDING, SAN JOSE, COSTA RICA, C.A., 12/5/64

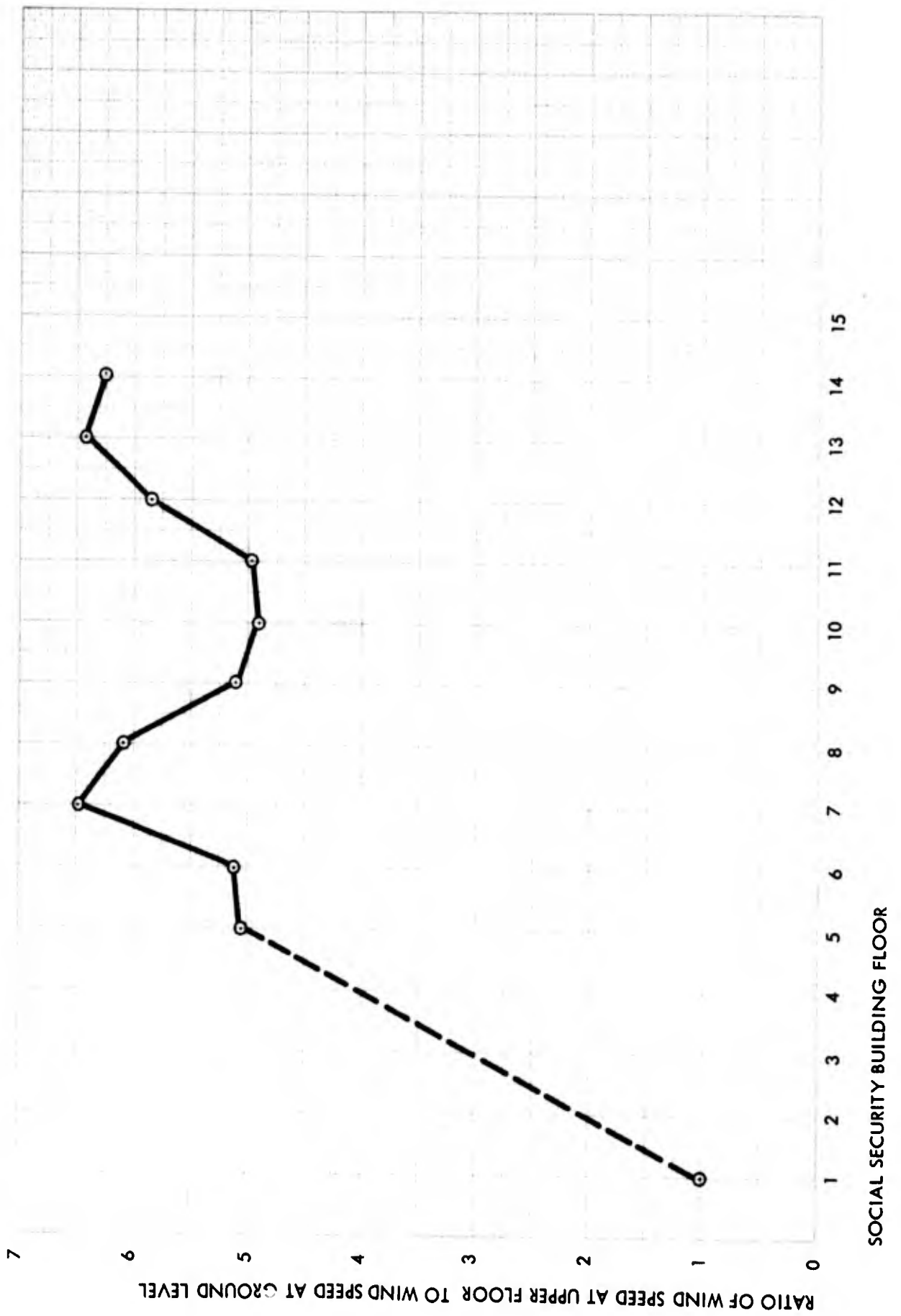


Figure 11
 WIND SPEED RATIOS AT UPPER FLOORS OF HOTEL ROYAL DUTCH
 (STATION 09), SAN JOSE, COSTA RICA, C.A., 12/5 & 6/64

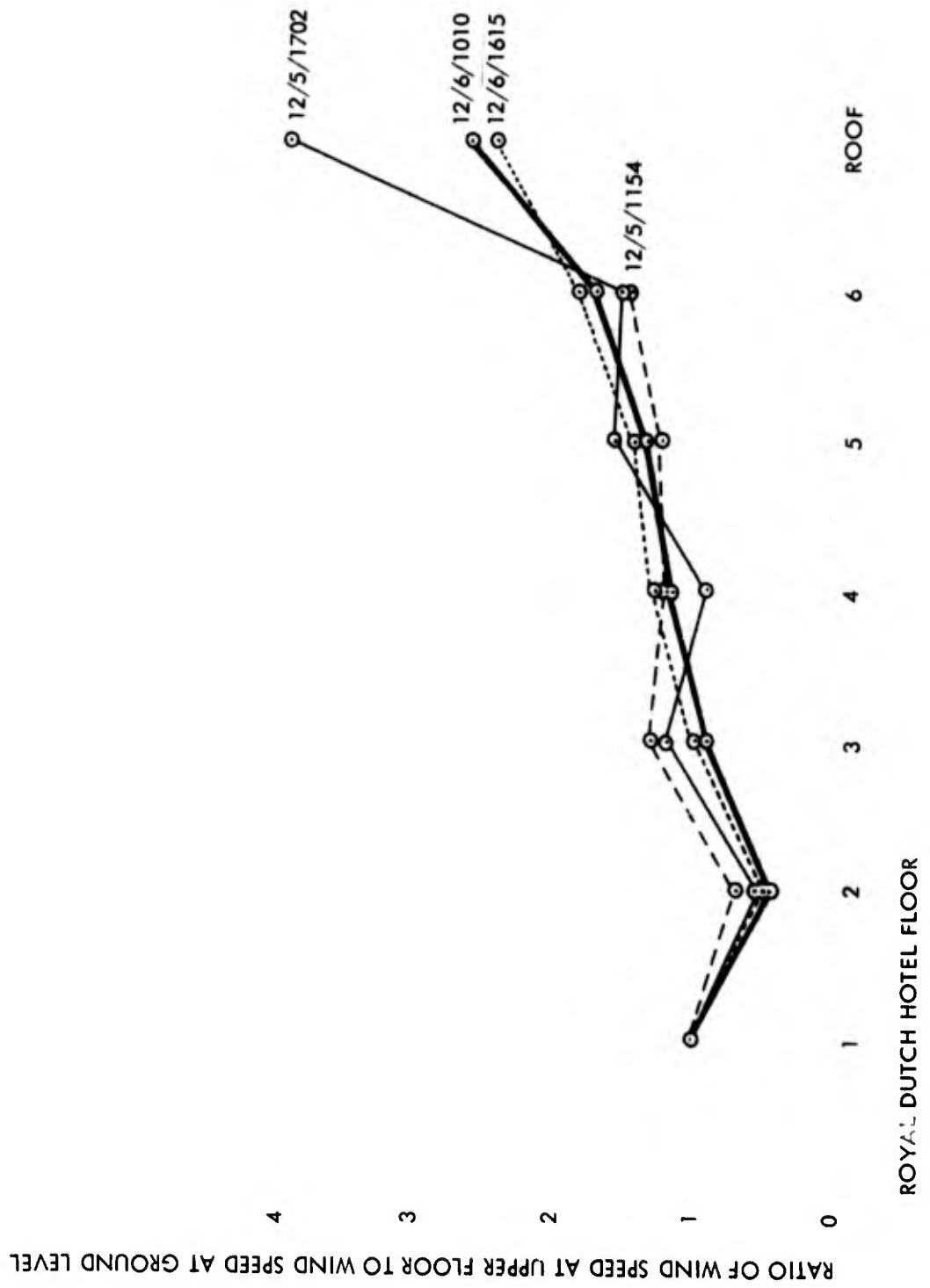


Table 3

SUMMARY OF WIND SPEED SURVEYS

Survey	Date	Time	Sta	Height (ft)	Remarks	Correlation Coefficient ^a
WT-1	1/8/65	1615-1750	07	6	At plate collector locations in courtyard	--
WT-2	1/9/65	1354-1520	07	1 & 3	At plate collector locations in courtyard	0.99
WT-3	1/13/65	1459-1613	010	1 & 3	At plate collector locations on roof (8th and 9th story)	0.43
WT-4	{	1/14/65	07	1 & 3	At plate collector locations in courtyard	0.81
		1/14/65	07	1 & 3	At plate collector locations in courtyard	
WT-5	1/15/65	0907-1037	010	1 & 3	At plate collector locations on roof (second story)	0.97
WT-6	1/15/65	1356-1539	010	1 & 3	At plate collector locations on roof (second story)	0.94
WT-7	1/15/65	1602-1648	010	1 & 3	At plate collector locations on roof (8th and 9th story)	0.58
WT-8	2/11/65	0917-1031	07	1 & 3	At plate collector locations in courtyard	0.99
WT-9	2/13/65	0932-1036	07	1 & 3	At plate collector locations in courtyard	0.94
WT-10	2/15/65	1415-1533	07	1 & 3	At plate collector locations in courtyard	0.98
WT-11	2/16/65	0827-0914	07	1 & 3	At plate collector locations in courtyard	0.92

^a Correlation coefficient between 1' and 3' wind speed values at collector plate locations in Tables D-1 and D-2 computed by rank difference method.

for determining average wind speeds near plate collectors for particle air concentration computations. The average horizontal component of wind velocity during these periods of collector exposure are given in Table 7 later in the report.

A series of 13 experiments or runs, as summarized in Table 4, was made at Stations 07 and 010. Each run, intended to obtain data pertinent to some phase of the project objectives, was carried out, using all available personnel and instrumentation at stations likely to receive ceniza-arena deposits. Detailed ceniza-arena deposit data, obtained from all runs summarized in Table 4, are presented in Appendix E. The deposit samples are identified by run number, collector type, station, and coordinate location.

Correlation of Wind Speed and Ceniza-Arena Redistribution

Wind speeds at specific locations were related to each other by comparisons with the undisturbed wind speed at the roof level. Reasonably steady roof wind speeds were compared with those averaged simultaneously at various locations of interest. If the ratios of wind speed at the location of interest to wind speed at the roof are constant, they apparently would be independent of both speed and direction. Thus, wind survey measurement ratios computed from data in Appendix D can be used in the correlation of wind speed-ceniza-arena deposit data at various locations, eliminating the time variation of wind speed during the course of sequential measurements.

Correlation coefficients between 1-foot and 3-foot height wind speed values at plate collector locations are given in Table 3. Good correlation existed for all wind surveys except WT-3 and WT-7, made at the 8th and 9th story roof of Station 010 where large variations in the ratios of wind speed at 3-feet height to wind speed at 1-foot height were observed. The ratios varied from a maximum of 2.8 at location E-8 near the windward edge of the roof to a minimum of 0.9 at location D-5 near the center of the roof.

Comparisons of different wind surveys were made where measurements coincided in number and locations. Wind surveys WT-8, 9, 10 and 11 at Station 07 met these criteria and the following correlation coefficients were computed by the rank difference method for 1-foot height to roof height speed ratios obtained from Table D-1.

Table 4

SUMMARY OF CENIZA-ARENA DEPOSITION MEASUREMENTS

<u>Run No.</u>	<u>Time</u>	<u>Date</u>	<u>Remarks</u>
<u>Station 07 (Colegio Sion)</u>			
1	2000 0700	1/7/65 1/8/65	Plate collectors exposed at 24 locations - ground level Recovered Run 1 - H-3 blown out of position
2	1920 0710	1/8/65 1/9/65	Plate collectors exposed at 24 locations - ground level; FB-1,-2 Recovered Run 2 - light rain occurred overnight
4	1915 1107	1/9/65 1/10/65	Plate collectors exposed at 24 locations - ground level; FB-3,-4 Recovered Run 4, E-5 blown by wind
5	0900 1017	1/11/65 1/11/65	Plate collectors exposed at 29 locations - ground level; FB-5,-6 Recovered Run 5
6	1755 1805 0655	1/11/65 1/11/65 1/12/65	Plate collectors exposed at 24 roof locations Plate collectors exposed at 24 ground locations Recovered Run 6
7	1800 2200	1/15/65 1/15/65	Plate collectors exposed at 24 roof and 24 ground locations; FB-7,-8 Recovered Run 7
8	2315 0600	1/15/65 1/16/65	Plate collectors exposed at 24 roof and 24 ground locations Recovered Run 8
9	1330 1800	2/16/65 2/16/65	Plate collectors exposed on third floor corridor for redistribution; FB-10,-11,-12 Recovered Run 9
10	1115 0900	2/18/65 2/19/65	Plate collectors exposed on third floor corridor for redistribution; FB-13,-14,-15 Recovered Run 10
14	1130 1145	2/19/65 2/22/65	Plate collectors exposed at 24 roof locations Recovered Run 14
<u>Station 010 (Banco Central)</u>			
3	1800 0830	1/9/65 1/10/65	Plate collectors exposed at 96 locations; second, eighth, and ninth story roofs Recovered Run 3; Plates M-7, N-5 and M-3 disturbed
12	1300 0630	2/20/65 2/21/65	Plate collectors exposed at 48 locations; eighth and ninth story roofs Recovered Run 12
13	1300 0550	2/20/65 2/22/65	Plate collectors exposed at 48 locations; second story roof; FB-20,-21,-22,-23 Recovered Run 13

<u>WT</u>	<u>8</u>	<u>9</u>	<u>10</u>	<u>11</u>
9	0.834	-	-	-
10	0.878	0.748	-	-
11	0.880	0.793	0.906	-
Wind Speed (ft/sec)	18	15	22	21
Wind Direction	NE	SE	NE	NE

The wind speed and directions given are representative values at the undisturbed air layer above roof obtained from Figure C-1.

Correlation coefficients were computed by the rank difference method for redistribution measurements of Runs 1, 2, 4, 6, and 8 at Station 07 given in Table E-2. These runs were chosen for correlation because of similar exposure conditions. Representative wind data was obtained from Figure C-1.

<u>Run</u>	<u>1</u>	<u>2</u>	<u>4</u>	<u>6</u>	<u>8</u>
2	-0.080	-	-	-	-
4	0.610	0.284	-	-	-
6	0.458	0.554	0.651	-	-
8	-0.320	0.830	0.018	0.255	-
Wind Speed (ft/sec)	-	-	12	12	10
Wind Direction	-	-	SE	SE	SE

The correlation of the redistribution data is noticeably poorer than the wind survey data correlations. The chief cause of low correlation in this case is the unknown ceniza-arena deposit locations and amounts that are redistributed by variable winds. Therefore correlation between wind and ceniza-arena redistribution data is obscure. However, the following analysis was carried out and showed logical relationships, even with widely dispersed sets of data points.

The Banco Central de Costa Rica (Station 010), because of its simple geometric configuration and steady wind environment, was selected for correlation of wind and ceniza-arena redistribution. Using wind survey data WT-6 and WT-7 with redistribution data from Runs 12 and 13, four sets of data comparisons were made. The wind speeds at 1-foot and 3-foot heights above the roof surface and ceniza-arena deposits at two sets of

approximately 48 plate collector locations each were correlated by a least squares fit of the equation

$$\text{Log } y = a(\text{Log } x) + b \quad (1)$$

which seemed to fit the data best, where y is the ratio of wind speed at location of interest to wind speed at roof, x is the ceniza-arena deposit in grams per square foot at location of interest, and a and b are mathematically determined constants.

The results of four sets of wind speed/ceniza-arena redistribution correlations are plotted in Figure 12.

Relationships made evident from the figure are:

1. Wind speed and deposit are inversely related.
2. Wind speeds at 1 foot and 3 feet are approximately proportional for the same run at all deposit values.
3. The dispersion of the data points for each set of data can be judged by the marked \pm standard deviation from the centroid of the data points. The scatter of the data points is such that only general trends can be inferred.

The correlation coefficients for the sets of wind speed/ceniza-arena redistributions plotted in Figure 16 are

<u>Run</u>	<u>Wind Speed at</u>	
	<u>1 Ft.</u>	<u>3 Ft.</u>
12	-0.45	-0.59
13	-0.58	-0.48

with the negative sign indicating the inverse relationship of 1 above.

Roof Deposits

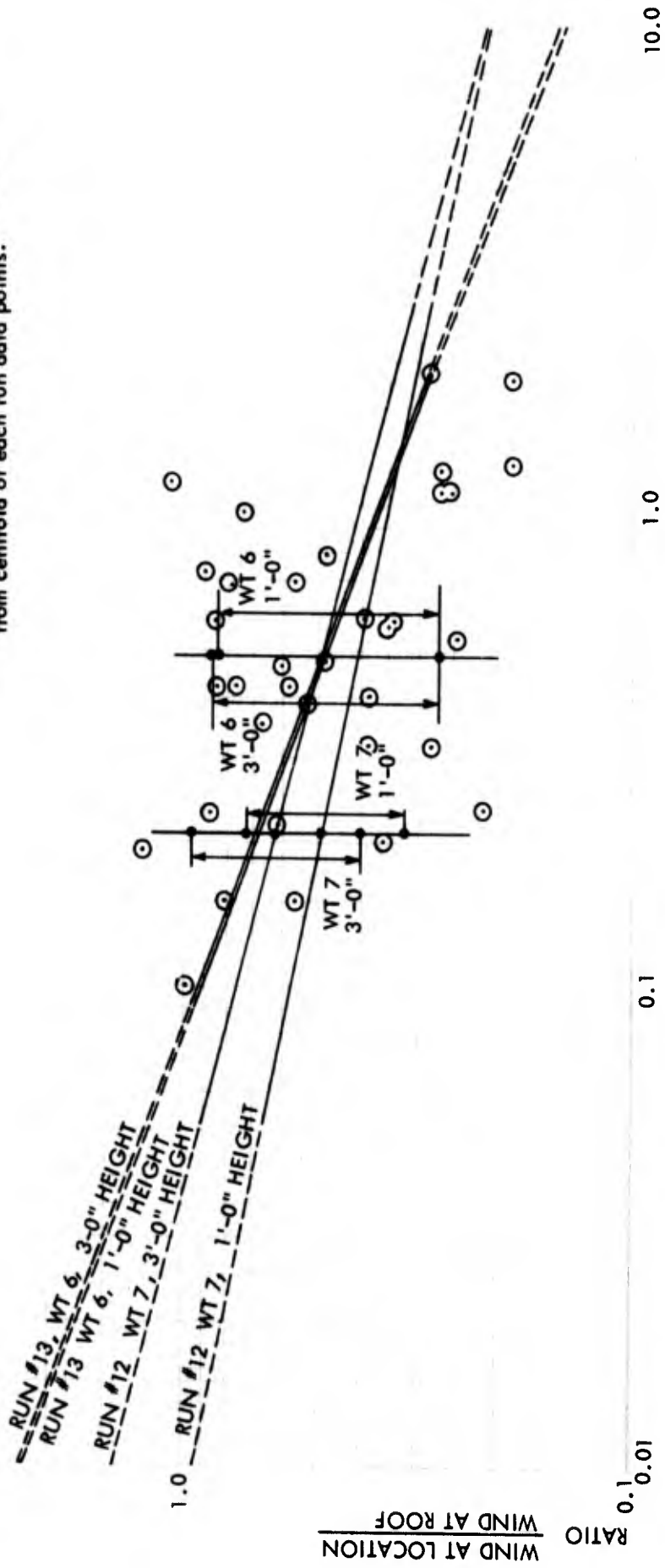
Twenty-four plate collectors were exposed on the east and west slopes of a second story roof at Station 07 (Figure 7). The 12 collectors on each roof slope were spaced at 2-foot intervals starting 1 foot from the ridge and ending 4 feet from the eaves of the 2-5/16-inch in 12-inches slope.

Figure 12

CORRELATION OF WIND SPEED AND CENIZA-ARENA
REDISTRIBUTION AT STATION 010

10.0

- NOTES:
1. Solid lines are range where data was taken.
 2. Ratio range indicated is ± 1 standard deviation from centroid of each run data points.



DEPOSIT (g/ft^2)

POINTS PLOTTED ARE FOR RUN# 13, WT 6, 3'-0" HEIGHT

The predominant wind direction from the east was parallel to the east-west roof profile on which the plates were exposed.

Figure 13 is a plot of the deposit data from Table 5. Larger deposits are generally found on the downwind slope of the roof on all runs. This finding is consistent with the wind speed-deposit correlations shown in Figure 12, since the leeward slope would be expected to have wind currents of lower speed and of more complex direction than the windward slope. The lesser deposit peak at plates 7 and 8 on the windward slope are due to wind downdrafts deflected from the 2-story wall at the building.

Figure 14 is a plot of the ratios of the deposit at each location to the average for the run. This ratio plot normalizes the different run deposit levels and shows the deposition similarities for the different runs by location. It should be noted that there is a variation of 0.4 to 2.2 in deposits ratio to average deposit across the roof, resulting in a total factor of about 5.5 between maximum and minimum deposits on the roof. Figure 15, a photograph taken at an earlier time of a different building roof, shows a typical deposit on the leeward side of a roof peak.

Redistribution on Tile Corridor Floor at Station 07

Ceniza-arena redistribution deposition measurements, on the third floor tile corridor of the north wing at Station 07 (Table 6) were quantitatively inconsistent with visual observations (Figure 16). The cleaned tile floor was observed after a few hours, and it showed an accumulation of concentrated ceniza-arena deposit along a line 20 inches from the rail for the length of the corridor. The deposit measurements do not confirm the observed location of this deposit line. The deposit on the plate collectors could not migrate as easily after deposition as the material on the smooth tile floor. Redistribution may not be properly measured by greased collectors whose (1) thickness may impede particle migration and (2) sticky surfaces retain most transit particles and bias the redistribution with respect to that achieved on a uniformly smooth surface.

Particle Trajectory Analysis

Plate collectors (Figure 9) were designed to collect ceniza-arena for particle trajectory determinations. Figure 17 is a diagram identifying the "a" and "b" faces of each of the seven plates in relation to a set of coordinate axes for mathematical analysis. At the bottom of the figure are tabulated the direction cosines of lines normal to the "a" faces of the plates; these are used to establish particle trajectory direction from deposited ceniza-arena mass on three selected plate faces.

Table 5

SUMMARY OF CENIZA-ARENA DEPOSITION MEASUREMENTS
 10" × 10" PLATE COLLECTORS
 (Station 07 - Colegio Sion - Roof)
 (Grams per Square Foot)

Location	Run Number			
	6	7	8	14
CR-1	0.1212	0.1764	1.0264	0.1627
CR-2	0.0704	0.1838	0.9339	0.1624
CR-3	0.1421	0.2056	1.2136	0.1395
CR-4	0.1441	0.2152	1.2483	0.1173
CR-5	0.2989	0.2175	1.2363	0.2207
CR-6	0.2626	0.1556	1.2680	0.1882
CR-7	0.2712	0.2118	1.2556	0.1899
CR-8	0.3424	0.1170	1.2104	0.2108
CR-9	0.2687	0.2280	1.1819	0.1771
CR-10	0.1031	0.1041	1.1041	0.1925
CR-11	0.1110	0.2063	1.0320	0.2430
CR-12	0.1009	0.1287	0.8550	0.1563
CR-13	0.1238	0.1692	0.7228	0.3216
CR-14	0.1370	0.2687	1.4777	0.4180
CR-15	0.1490	0.2337	1.3380	0.4052
CR-16	0.1477	0.2424	1.5288	0.4711
CR-17	0.1353	0.2861	1.5397	0.5577
CR-18	0.3281	0.3100	1.5744	0.5725
CR-19	0.3849	0.4008	1.8676	0.7025
CR-20	0.4201	0.2292	2.0155	0.6672
CR-21	0.5747	0.3833	1.7390	0.8233
CR-22	0.6255	0.4165	1.3226	0.7951
CR-23	0.2463	0.2363	1.5494	0.5620
CR-24	0.4754	0.3784	1.5478	0.4891
Average Deposit/Plate Collector	0.2494	0.2377	1.3245	0.3727
Predominant Wind Direction	East	East	East	
Wind Average Speed ft/sec	10.0	12.4	9.3	
Wind Speed Range, ft/sec	8.3-14.5	8.7-17.3	5.7-13.3	
Exposure time, hrs	12.8	4.0	6.7	72.2
Medium particle size (microns)	76.0	43.0	62.0	84.0

Figure 13
 PLOTS OF STATION 07 ROOF DEPOSITS --
 4 RUNS OF 24 PLATE COLLECTORS EACH

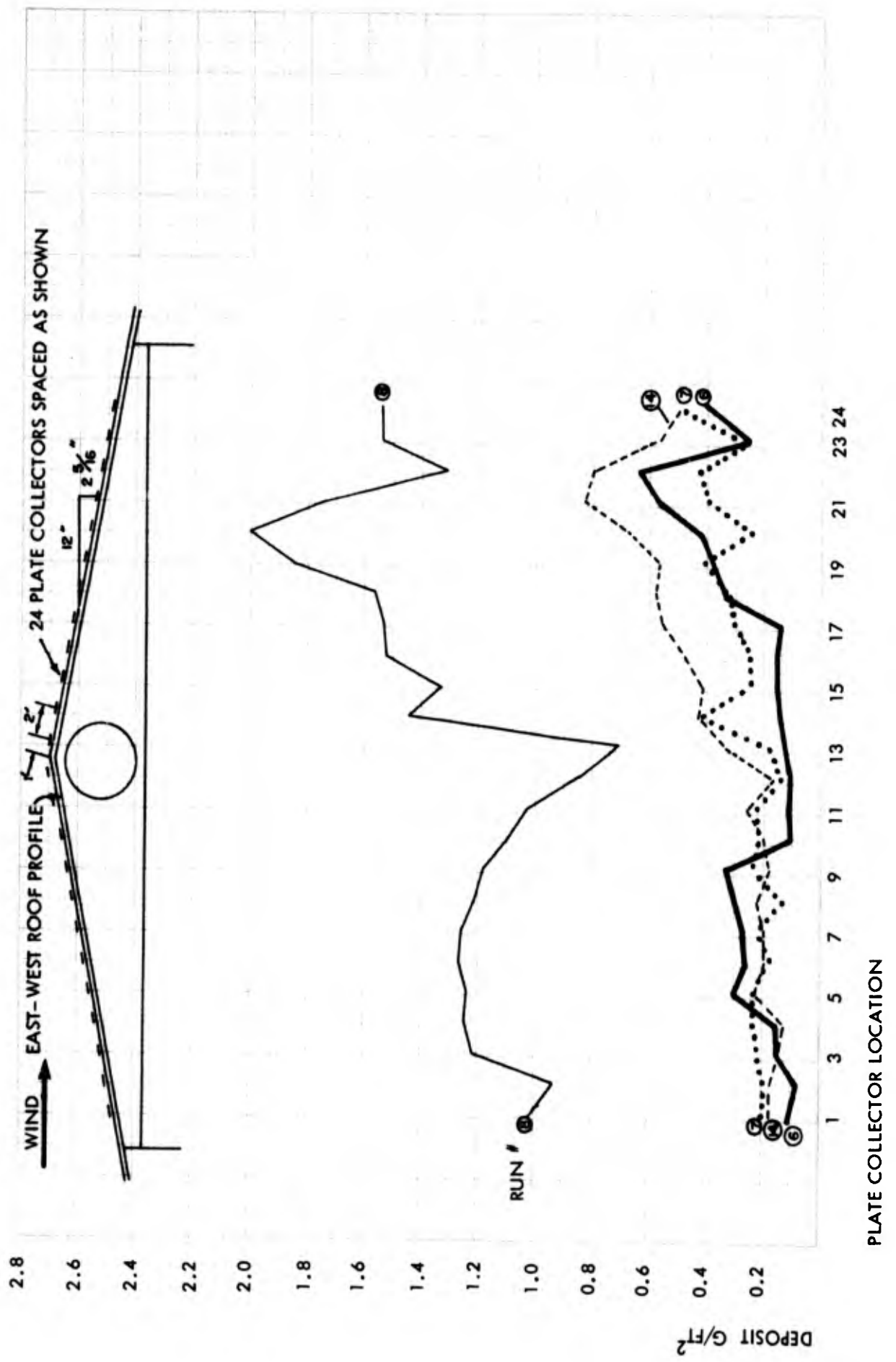
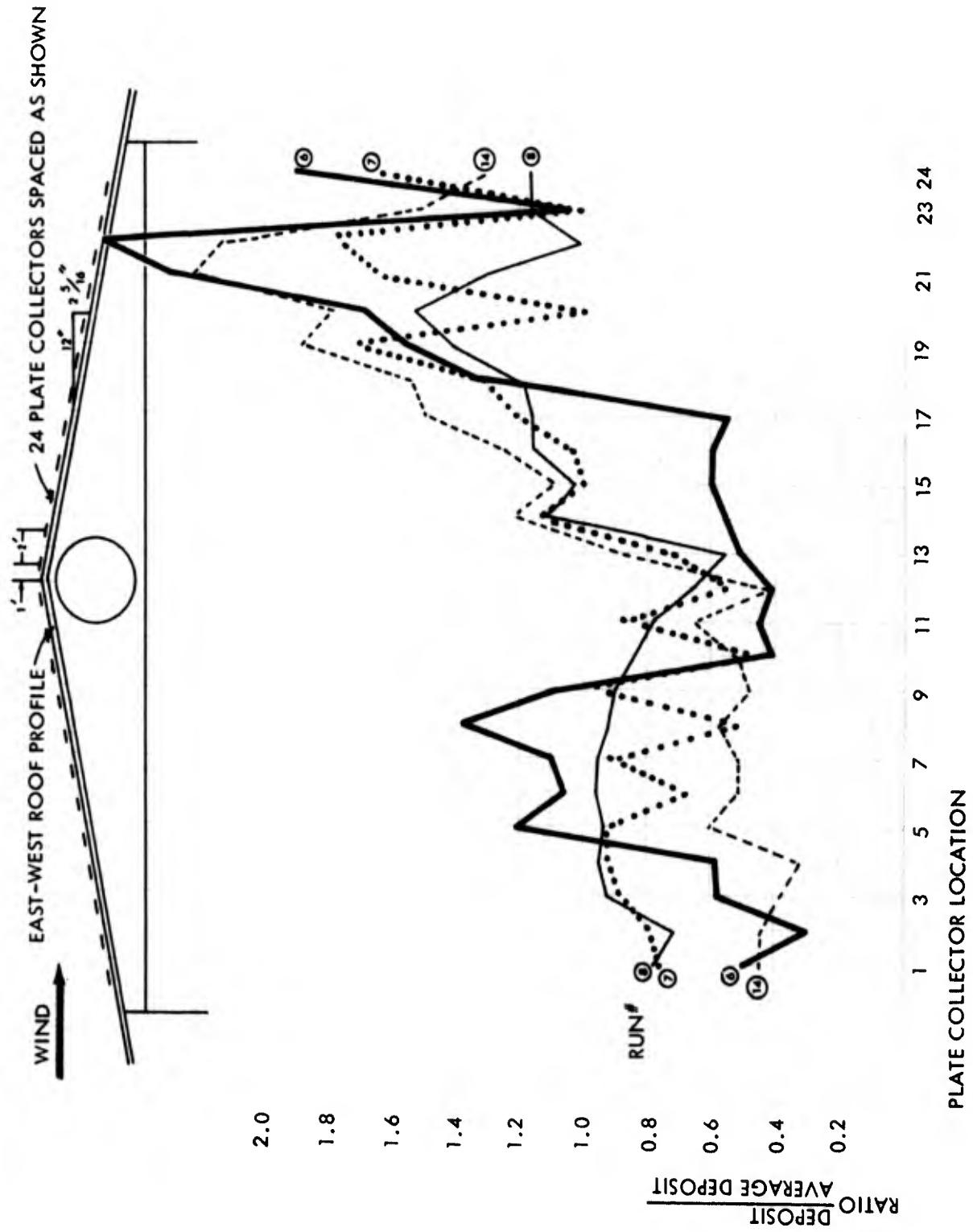


Figure 14

PLOTS OF STATION 07 ROOF DEPOSIT RATIOS --
 4 RUNS OF 24 PLATE COLLECTORS EACH



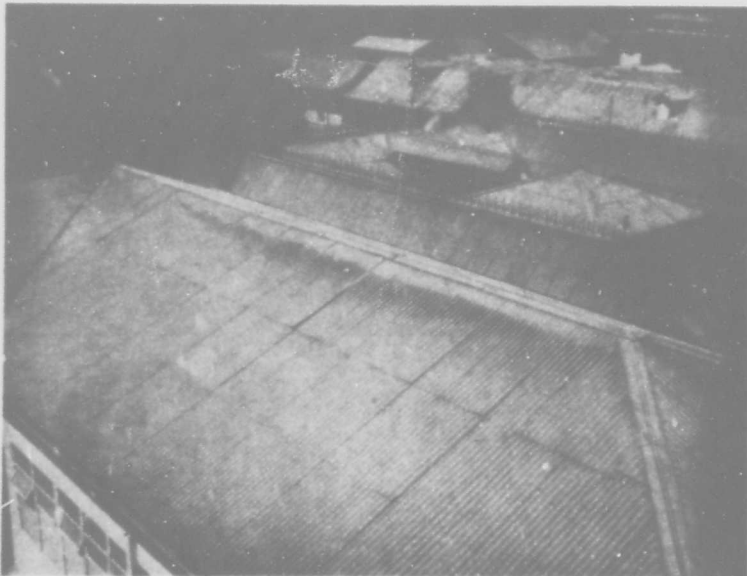


Figure 15
TYPICAL CENIZA-ARENA
DEPOSIT ON LEEWARD
SLOPE OF ROOF

Table 6

SUMMARY OF CENIZA-ARENA REDISTRIBUTION MEASUREMENTS
 10" × 10" PLATE COLLECTORS
 (Station 07 - Colegio Sion - Third Floor Corridor)

(Grams per Square Foot)

<u>Location</u> ^a	<u>Run Number</u>	
	<u>9</u>	<u>10</u>
B-6.5a	0.1840	0.0387
B-6.5b	0.0442	0.0450
B-6.5c	0.1123	0.0568
B-6.5d	0.1640	0.0671
B-7.5a	0.1510	0.0456
B-7.5b	0.1144	0.0384
B-7.5c	0.0912	0.0408
B-7.5d	0.1052	0.0658
B-8a	0.3098	0.0789
B-8b	0.3974	0.1036
B-8c	0.1293	0.0672
B-8d	0.1431	0.0957

^a Coordinate system as in Figure 1. "a" plate collectors nearest to rail as shown in Figure 16.

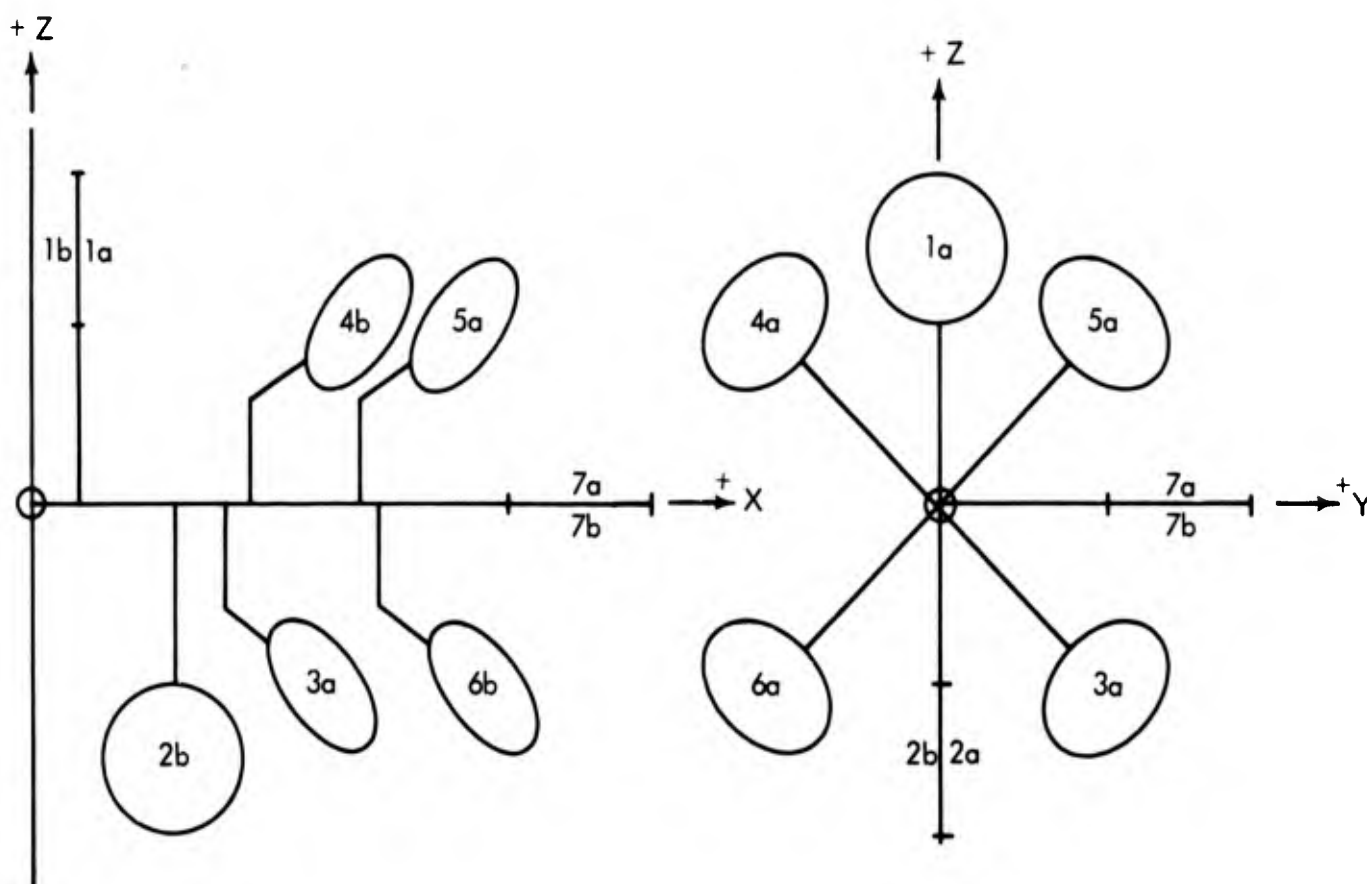


Figure 16

PLATE COLLECTOR AND ANEMOMETER
ARRAY FOR MEASURING CENIZA-ARENA
REDISTRIBUTION AT THIRD FLOOR
CORRIDOR AT STATION 07

Figure 17

PLATE ORIENTATION USED TO ESTIMATE PARTICLE TRAJECTORY RELATIVE TO ADJACENT STRUCTURE SURFACES



DIRECTION COSINES OF LINES NORMAL TO PLATE SURFACES

PLATE SIDE	X	Y	Z
1a	1	0	0
2a	0	1	0
3a	0.5774	-0.5774	0.5774
4a	0.5774	0.5774	-0.5774
5a	0.5774	-0.5774	-0.5774
6a	0.5774	0.5774	0.5774
7a	0	0	1

"b" PLATE SIDE HAVE OPPOSITE DIRECTIONS - OPPOSITE SIGNS

For derivation of the equations, the following assumptions are made for deposition calculations. The same assumptions were also used in redistribution calculations although assumptions 1 and 2 probably do not apply for redistribution.

1. The deposited material on all plate faces arrives from a single direction during the exposure time.
2. The mass of deposited particles is proportional to the projected area of the plate in the single direction from which the particles arrive.
3. The influence of the plates on the wind flow and particle trajectory near each plate is negligible so that the impaction coefficient is unity for all plates and particle sizes.

The particle trajectory direction can be computed by solving three simultaneous equations of the form:

$$\frac{M}{M_0} = A\alpha + B\beta + C\gamma \quad (2)$$

where

M = the deposited mass on the selected plate

M_0 = the deposited mass on a plate normal to the particle trajectory direction

$A, B, C,$ = direction cosines of a line normal to the selected plate with deposit mass M

α, β, γ = direction cosines of a line opposite to the particle trajectory and normal to a plate with deposit mass M_0 .

Solution of three simultaneous equations (2) for three selected plates, using third order determinants, leads to the following relationships:

$$M_o \alpha = K_1$$

$$M_o \beta = K_2$$

$$M_o \gamma = K_3$$

Recognizing that $\alpha^2 + \beta^2 + \gamma^2 = 1$, then

$$M_o = \sqrt{K_1^2 + K_2^2 + K_3^2}$$

and

$$\alpha = \frac{K_1}{M_o}$$

$$\beta = \frac{K_2}{M_o}$$

$$\gamma = \frac{K_3}{M_o}$$

Deposits on plates, other than those used for solutions of equations (2), can be calculated using M_o and α , β , and γ in equation (2) and substituting direction cosines A, B, and C of the plate deposit that is sought.

If the computed $M < 0$, then the plate considered has no deposit under the assumptions of the derivation. The degree of agreement between measured and calculated deposits shows consistency of the data as well as possible variations due to invalid assumptions for deposition dynamics. Impaction efficiency may vary with particle size, wind speed, and shape and orientation of the collection surface but has not been considered here. However, it may be possible to obtain impaction efficiencies in the future, if additional sets of collector deposits, wind speeds, and particle size analysis become available and if absolute impaction measurements are made in still air using horizontal plates.

The selection of three plates for the solution of equation (2) is arbitrary. If the data were totally consistent and impaction efficiencies were 100 percent, then any set of three plates receiving a measurable deposit would yield the same trajectory direction. Practical considerations of the problem suggest choosing plates with the greatest mass deposits, because these faces are more nearly normal to the particle trajectory direction and should have the highest impaction efficiency.

A computer program to solve all possible combinations of the 14 plate sides taken three at a time, would be useful. Each of the 364 solutions could be used to compute the deposit expected on each plate face from equation (2). Each solution could be compared with the data to determine which computed trajectory direction most closely matched the data.

To correlate the computed trajectory direction α , β , γ with the physical conditions of collector exposure listed in Table 7, it is convenient to use two angles. A rotation or azimuth angle θ ($\tan^{-1} \frac{\alpha}{\beta}$) is measured in the horizontal xy plane from the +y axis toward the +x axis. A vertical angle φ ($\cos^{-1} \gamma$) is measured from the zenith or +z axis to the trajectory of the particles. The possible range of angles is $0 \leq \theta \leq 360^\circ$ and $0 \leq \varphi \leq 180^\circ$, but the expected values would be $0 \leq \theta \leq 180^\circ$ and $0 \leq \varphi \leq 90^\circ$ for most conditions of deposition.

The plate collectors shown in Figure 18 are designed to rotate around a vertical axis and to remain normal to the vertical plane of the wind direction. The computations of ceniza-arena on the faces of the plates reduce to a two-dimensional mathematical treatment.

A summary of all plate collector measurements is given in Table 7 and results of the mathematical treatment described above are presented in Table 8.

The estimates of expected values of φ and θ discussed above assume primary deposition conditions of low wind speeds with particles moving in a downward direction. However, the φ and θ values computed in Table 8 show some unexpected values (5 cases where $90^\circ \leq \varphi \leq 180^\circ$ and 7 cases where $180^\circ \leq \theta \leq 360^\circ$). These values might occur because the deposits were caused by a redistribution process in which higher wind speeds move previously deposited particles in an upward direction toward the underside of the collectors and eddy currents or the deflection of particles from wall surfaces cause deposits on the wall side of the collectors.

Analyses of collector sets FB-20, 21, 22, and 23 exposed simultaneously on the four faces of the central tower of the bank building at Station 010 show particle trajectories that are reasonable for the prevailing wind direction during the time of exposure.

Figure 18

PLATE ORIENTATION USED TO ESTIMATE
PARTICLE TRAJECTORY ANGLE
IN THE VERTICAL PLANE OF THE WIND

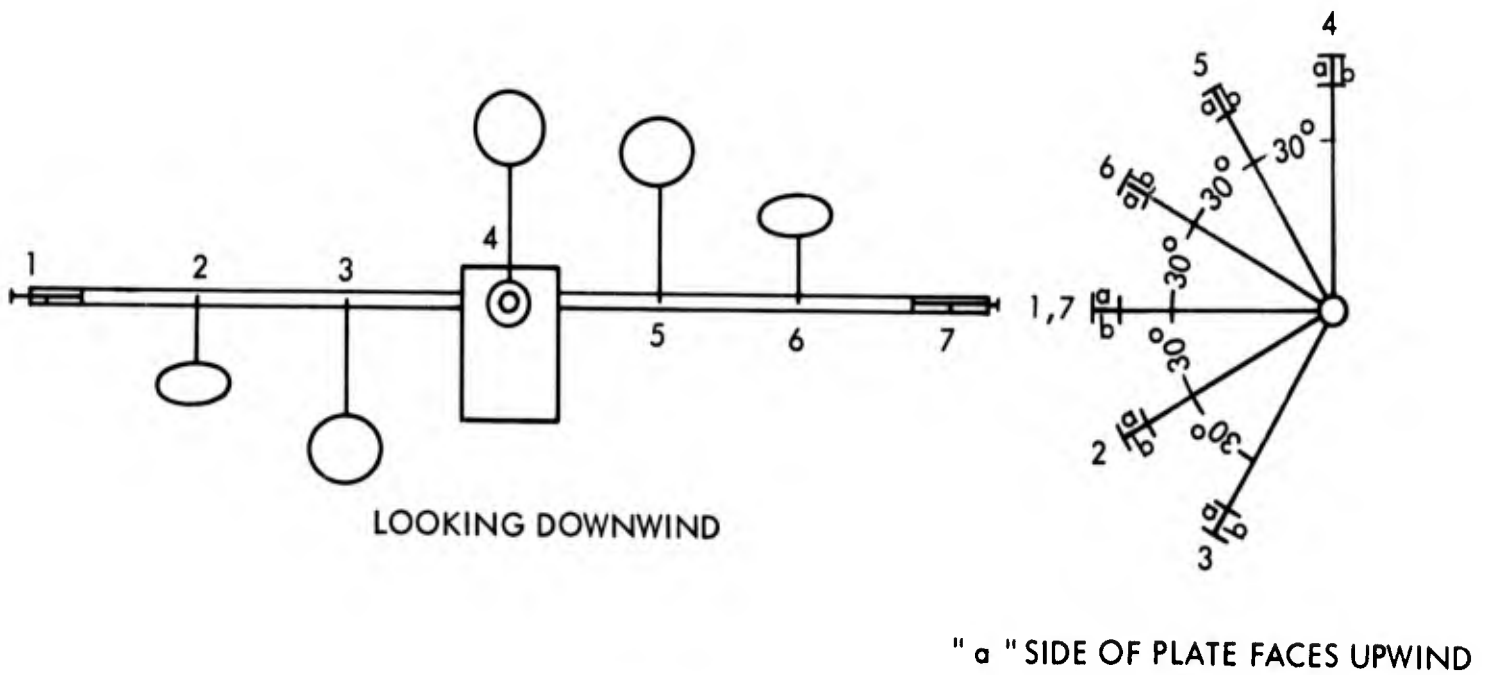


Table 7

SUMMARY OF 4-INCH DIAMETER PLATE COLLECTOR MEASUREMENTS
(Grams per Square Foot)

Set No.	Station	Location ^a	Coordinate Axis Orientation			Exposed	Recovered	Exposure (hr)	Plate Face ^b	Horizontal Wind Component During Exposure ^c (ft./sec.)									
			X	Y	Z					1	2	3	4	5	6	7	Average	Range	
FB-1	07	South wing north wall @ H6 5.5' elev.	North	West	Zenith	1/8/1907	1/9/0710	12.0	a	0.01123	0	0.00401	0.00149	0	0.00298	0	0.00126		
FB-2	07	North wing post @ B6.5.5' elev.	South	East	Zenith	1/8/1914	1/9/0710	12.0	a	.00722	0	.00138	.00160	0.00309	.00218	0	.00218		
FB-3	010	West wall third floor G3-H3 @ 6' elev.	West	South	Zenith	1/9/1830	1/10/0830	14.0	b	0	.00378	.02853	0	.00539	.02326	0	.04309		
FB-4	010	East wall third floor G7-H7 @ 6' elev.	East	North	Zenith	1/9/1830	1/10/0830	14.0	b	.00275	.00550	.03014	.00126	.02876	.00516	0	.00516		
FB-5	07	North wing south wall B6.6 @ 14' elev.	South	East	Zenith	1/11/0900	1/11/1020	1.3	a	.01593	.00619	.03403	.04160	.00034	.03736	0	.03736		
FB-6	07	South wing north wall H6.5 @ 14' elev.	North	West	Zenith	1/11/0905	1/11/1020	1.3	a	.00138	.00401	.01753	.00355	.02549	.04492	0	.04492		
FB-7	07	South wing north wall H6.5 @ 14' elev.	North	West	Zenith	1/15/1800	1/15/2220	4.3	b	.02154	.01902	.02200	.01696	.02830	.01112	.06280	0	.06280	
FB-8	07	North wing south wall B6.15 @ 14' elev.	South	East	Zenith	1/15/1800	1/15/2220	4.3	b	.00561	.08296	.03862	.00401	.03037	.00871	.01833	0	.01833	
FB-9	07	Third floor window Rm 13, H10.5	North	West	Zenith	2/13/0800	2/16/0800	72.0	a	.00791	.00561	.00561	.00561	.00779	.02968	0	.02968		
FB-10	07	North wing third floor corridor B7 @ 10-1/2" elev.	East	North	Zenith	2/16/1330	2/16/1600	2.5	b	.02040	.13843	.01914	.14118	.02498	.07047	.02704	.02704		
FB-11	07	North wing third floor corridor B7 @ 47' elev.	East	North	Zenith	2/16/1330	2/16/1600	2.5	b	.11642	.15264	.03165	.03185	.02590	.02567	.05523	.05523		
FB-12	07	North wing south wall B7 @ 12' elev.	South	East	Zenith	2/16/1330	2/16/1600	2.5	b	.09202	.05271	.45985	.04274	.12112	.04297	.50030	.50030		
FB-13	07	Same as FB-10	East	North	Zenith	2/18/1115	2/18/1500	3.8	a	.07804	.99652	.06222	.54797	.08789	.41207	.08950	.08950		
FB-14	07	Same as FB-11	East	North	Zenith	2/18/1115	2/18/1500	3.8	a	.02235	.02945	.01249	.00997	.00619	.03415	.02028	.02028		
FB-15	07	Same as FB-12	South	East	Zenith	2/18/1115	2/18/1500	3.8	a	.02086	.01283	.01902	.02120	.03220	.01616	.00802	.00802		
FB-19	07	Third floor window Rm. 13, H10.5	East	North	Zenith	2/17/0900	2/18/1700	32.0	a	.03472	.01593	.03552	.01444	.01513	.04629	.03988	.03988		
FB-20	010	West wall third floor G3-H3 @ 6' elev.	West	South	Zenith	2/19/1500	2/22/0550	62.8	b	.02361	.01524	.01421	.03277	.02567	.01008	.00768	.00768		
FB-21	010	South wall third floor D5.5 @ 6' elev.	South	East	Zenith	2/19/1500	2/22/0550	62.8	b	.04057	.01684	.09946	.04068	.01203	.14542	.02532	.02532		
FB-22	010	East wall third floor G8.5-H8.5 @ 6' elev.	East	North	Zenith	2/19/1500	2/22/0550	62.8	b	.00642	.01501	.00516	.00688	.00252	.01639	.01914	.01914		
FB-23	010	North wall third floor M5.5 @ 6' elev.	North	West	Zenith	2/19/1500	2/22/0550	62.8	b	.00814	.00699	.02063	.02097	.04710	.02796	.02383	.02383		
WB-1	07	E 7 @ 6' elev.	Into Wind	Cross-Wind	Zenith	1/11/0900	1/11/1005	1.08	a	.00997	.00241	.00768	.00183	.00997	.00241	.01318	.01318		
									a	.01146	.02223	.02406	.00825	.00435	.03598	.04756			
									b	.00997	.01123	.00607	.02819	.03472	.00768	.01203			
									a	.03335	.01123	.22964	.00722	.12319	.02659	.14645			
									b	.03323	.38617	.04607	.19286	.03953	.12009	.02601			
									a	.06635	.23869	.06245	.10462	.19217	.06921	.18449			
									b	.01547	.06944	.09557	.06532	.02670	.19400	.03610			
									a	.06990	.19377	.31971	.20821	.26975	.17097	.22403			
									b	.01604	.40325	.02429	.09568	.03862	.08422	.04469			
									a	.02303	.11780	.03587	.05271	0	.10497	.07460			
									b	.00435	.06211	.03839	.01146	.14610	.0802	.01742			
									a	.02166	.05088	.08136	.02074	.06600	.04102	.08629			
									b	.01134	.09878	.01272	.09167	.02406	.05409	.01719			
									a	.02487	.06474	.09924	.20626	.04744	.03885	.02418			
									b	.00481	.00103	.00034	.02567	.07552	.01833	.02647			

^a Location coordinates shown in Figures 1 and 4
^b Plate Orientation Relative to Coordinate Axes shown in Figure 17 or 18^c
^c From Portable Anemometer at Collector Location

Table 8

4-INCH DIAMETER PLATE COLLECTOR COMPUTATION RESULTS

Set No.	α	β	γ	φ	θ
FB-1	0.6801	0.6315	0.3720	68° 10'	47° 07'
FB-2	.0404	-.1052	.9937	6° 27'	158° 02'
FB-3	-.0878	.3752	.9229	22° 39'	346° 50'
FB-4	.3129	.1718	.9342	20° 54'	61° 14'
FB-5	.0844	.7065	-.7027	134° 38'	6° 49'
FB-6	.0006	.4846	.8748	28° 59'	0° 04'
FB-7	-.2256	-.8691	.4406	63° 52'	194° 33'
FB-8	-.3912	.9186	.0532	86° 57'	336° 56'
FB-9	.0676	-.7028	.7082	44° 55'	174° 30'
FB-10	.5929	.7814	.1949	78° 46'	37° 11'
FB-11	.6030	.1809	.7771	39° 0'	73° 18'
FB-12	.0248	.9227	-.3846	112° 37'	1° 32'
FB-13	-.8110	.5039	-.2972	107° 17'	301° 51'
FB-14	-.5789	-.5839	.5690	55° 19'	224° 45'
FB-15	.0218	.2769	.9606	16° 08'	4° 30'
FB-19	.0821	-.9952	-.0523	92° 00'	175° 43'
FB-20	-.0026	.3845	-.9232	157° 23'	359° 37'
FB-21	.2556	-.9612	.1033	84° 05'	165° 54'
FB-22	-.2250	.7439	.6292	51° 0'	343° 10'
FB-23	.1966	-.7384	.6450	49° 50'	165° 05'

Note: Reference coordinate axes are identified in
Table 7. Collector sets are shown in Fig. 17.

CONCLUSIONS

Most of the data gathered during this project was for redistribution of ceniza-arena material already deposited. The unidentified sources of material, the long collector exposure times, and variable wind condition each contributed to uncertainties in data analysis. However, some conclusions may be drawn from the data collected on redistribution trends on what might be expected of nuclear weapon fallout.

Preattack estimates of the location of potential hot spots would be useful for postattack recovery in that (1) radiological monitoring time could be reduced; (2) decontamination could be more effectively planned and executed in terms of required manpower, equipment, and supplies; and (3) potential recontamination hot spots could be identified. The correlation between wind velocity and fallout deposition at a specific location as displayed in Figures 12, 13, and 14 could be used to predict the location of accumulated fallout (hot spots).

Recently developed fallout particles sampling techniques were proof-tested. The results in Costa Rica reflect only the determination of particle behavior by the measurement of physical properties (size, weight, shape, density, etc.). If these sampling techniques were to be used for nuclear weapon fallout, their usefulness would be increased because of (1) increased measurement sensitivity by radiation detection and (2) measurement of all other weapon fallout properties not simulated by ceniza-arena.

REFERENCES

1. Miller, Carl F., and Hong Lee, Operation Ceniza-Arena: The Retention of Fallout Particles from Volcán Irazú (Costa Rica) by Plants and People, Part One, Stanford Research Institute, Project No. MU-5779, January 1966
2. Miller, Carl F., Operation Ceniza-Arena: The Retention of Fallout Particles from Volcán Irazú (Costa Rica) by Plants and People, Part Two, Stanford Research Institute, Project No. MU-5779, in preparation
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Appendix A

DESCRIPTION OF WIND INSTRUMENTATION

Appendix A

Description of Wind Instrumentation

The following instruments were used to make wind measurements in the field:

Three (3) Esterline-Angus (EA) Model AW 20-pen operation recorders with 48-volt DC coils to actuate individual pens. Recorders were adapted for a 110-volt, 60-cycle synchronous drive motor and fitted with gears to provide 3/4, 1-1/2, 3, 6, and 12 inch/minute or inch/hour chart speed, respectively, on manually selected fast or slow speeds. A 48-volt DC power supply was used to actuate pen coils through contacts in anemometers and wind direction transmitters. A synchronous clock motor in the power supply package actuated a limit switch, wired to record 1-minute time pulses on EA chart Channel 11. Two EA recorders were used for stationary routine measurements at Station 07 and Station 010, and the third was used as a portable unit for wind direction and speeds. A specially built 4-channel, electrically actuated mechanical counter was used in conjunction with the recorders during some wind measurements to reduce the EA chart data interpretation effort of hand counting the anemometer pulses during a 2-minute measurement interval.

Three (3) Belfort Instrument Co. Model No. 1411A wind direction (WD) Transmitters (Figure 5). Dual pen actuation by the 8-segment commutator indicated wind direction within $22\text{-}1/2^\circ$ sectors. Two WD units were used at Stations 07 and 010 on the roof for continuous measurements, while the third unit was used with the portable EA recorder as required. Data from the WD was recorded on Channels 1 to 8 of the EA charts.

Two (2) Belfort Instrument Co. Model 5-349 totalizing anemometers (Figure 5). A 3-conical-cup rotor drove a mechanism which registered units and tenths of statute miles of wind in a digital register, and closed contacts each 1 mile and 1/60 mile for external recording. EA recorder Channels 9 and 10 were used to record 1-mile and 1/60-mile pulses at Stations 07 and 010.

Four (4) Science Associates, Inc. Model 442A portable sensitive anemometers, electric contact type (Figure 6). A 3-conical-cup rotor drove a mechanism that closed a contact for remote recording twice in each three revolutions. Each portable anemometer was capable of being mounted on a stand at 1, 3, and 6 feet above the base and was connected to the EA recorder by a 300 foot cable for simultaneous sequential recording of wind at various locations and on the roof. They were used for wind speed surveys at plate collector locations.

Appendix B

SUMMARY OF DECEMBER WIND VELOCITY MEASUREMENTS

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Table B-1

SUMMARY OF DECEMBER WIND VELOCITY MEASUREMENTS

Site and Location	Date	Time	Wind Speed V_w at Reference Point ^a (ft./sec)	V_w at Location	
				V_w at Reference Point	V_w at Location
Social Security Building (NE Wind) ^b					
5th floor	12/2/64	1337	15.5	1.240	5.03
6th floor			13.1	1.262	5.12
7th floor			12.8	1.600	6.49
8th floor			12.6	1.498	6.08
9th floor			18.3	1.254	5.09
10th floor			17.9	1.213	4.92
11th floor			17.2	1.223	4.96
12th floor			16.5	1.445	5.86
13th floor			15.6	1.584	6.43
14th floor			15.7	1.537	6.24
Street, NW side			14.8	0.262	1.00
Street, center of building			14.3	0.231	
Street, NE corner		1527	13.2	0.596	
Hotel Royal Dutch (Figure 3) (NE Wind) ^b					
2nd floor (D2)	12/5/64	1144	9.7	0.68	
3rd floor (D2)			12.4	1.29	
4th floor (D2)			9.8	1.18	
5th floor (D2)			10.4	1.21	
6th floor (D2)		1204	7.4	1.43	

Table B-1 (continued)

Site and Location	Date	Time	Wind Speed V_w at Reference Point ^a (ft/sec)	V_w at Location	
				V_w at Reference Point	V_w at Location
Hotel Royal Dutch (Cont.) (NW - Variable Wind) ^b					
2nd floor (D2)	12/5/64	1645	3.8		0.52
3rd floor (D2)			3.4		1.17
4th floor (D2)			3.1		0.90
5th floor (D2)			2.4		1.55
6th floor (D2)			3.3		1.25
Roof (D3) (N Wind)		1720	3.1		3.88
2nd floor (D2)	12/6/64	1003	4.5		0.43
3rd floor (D2)			5.1		0.89
4th floor (D2)			11.1		1.15
5th floor (D2)			9.1		1.32
6th floor (D2)			8.0		1.69
Roof (D3)			10.8		2.58
SW street corner (B2)			12.3		0.77
NW street corner (A2)			10.4		0.74
NE street corner (A1)			8.1		0.63
SE street corner (B1)			4.7		0.58
Across street (D1)			9.6		0.77
50 feet W on S Street (B4)			9.6		0.83
50 feet W on N Street (A4)		1130	11.7		1.59

Table B-1 (continued)

Site and Location	Date	Time	Wind Speed V_w at	V_w at Location	
			Reference Point ^a (ft/sec)	V_w at Reference Point	Point
Hotel Royal Dutch (Cont.)					
(NE - Light Variable Wind) ^b					
2nd floor (D2)	12/6/64	1552	7.8	0.47	
3rd floor (D2)			7.1	0.98	
4th floor (D2)			7.2	1.27	
5th floor (D2)			8.1	1.41	
6th floor (D2)			8.6	1.81	
Roof (D3)			7.3	2.39	
SW street corner (B2)			8.6	0.67	
NW street corner (A2)			6.5	0.44	
NE street corner (A1)			5.1	0.13	
SE street corner (B1)			8.1	0.43	
Across street (D1)			4.9	0.65	
50 feet W on S Street (B4)			9.0	0.90	
50 feet W on N Street (A4)		1655	8.9	1.23	
Colegio de Nuestra Señora Sion (Figure 1)					
(NE Wind) ^b					
NE corner S Wing (H2)	12/9/64	1123	5.8	2.18	
Center S Wing (H6.5)			10.1	0.76	
NW corner S Wing (H11)			7.7	1.67	
SW corner N Wing (B11)			13.3	0.38	
W end court at center line (E11)			14.1	1.22	
Center N Wing (B6.5)			10.9	0.14	
NE corner court (B2)			8.2	0.077	

Table B-1 (concluded)

Site and Location	Date	Time	Wind Speed V_w at Reference Point ^a (ft/sec)	V_w at Location	
				V_w at Reference Point	V_w at Location
Colegio de Nuestra Señora Sion (cont.)					
E end court at center line (E2)			9.3	0.56	
NE corner court, 2nd floor (B2)			9.3	0.041	
NE corner court, 3rd floor (B2)			7.2	0.35	
NW corner court, 3rd floor (B11)			8.3	0.32	
NW corner court, 2nd floor (B11)			7.8	0.42	
SE corner court, 2nd floor (H2)		1159	12.0	0.51	
Colegio de Saint Francis (Figure 2) (NE wind) ^b					
NE corner (B3)			12.8	0.77	
E center (D3)	12/9/64	1423	12.6	0.77	
SE corner (F3)			11.4	1.63	
S center (F7.5)			12.3	0.37	
SW corner (F12)			9.8	0.27	
W center (D12)			12.3	0.35	
NW corner (B12)		1445	11.6	0.35	

^a Reference Points:

1. Social Security Building--street level
2. Hotel Royal Dutch--street level, east side of building (Figure 3, D2)
3. Colegio de Nuestra Señora Sion--center of courtyard (Figure 1, E7)
4. Colegio de Saint Francis--open area, east of building (Figure 2, C1)

^b General direction of undisturbed wind at roof level

Appendix C

WIND SPEED AND DIRECTION RECORDINGS, STATIONS 07 AND 010

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Figure C-1

WIND SPEED AND DIRECTION ON THE ROOF AT STATION 07
DURING THE PERIODS OF EXPERIMENTAL MEASUREMENTS

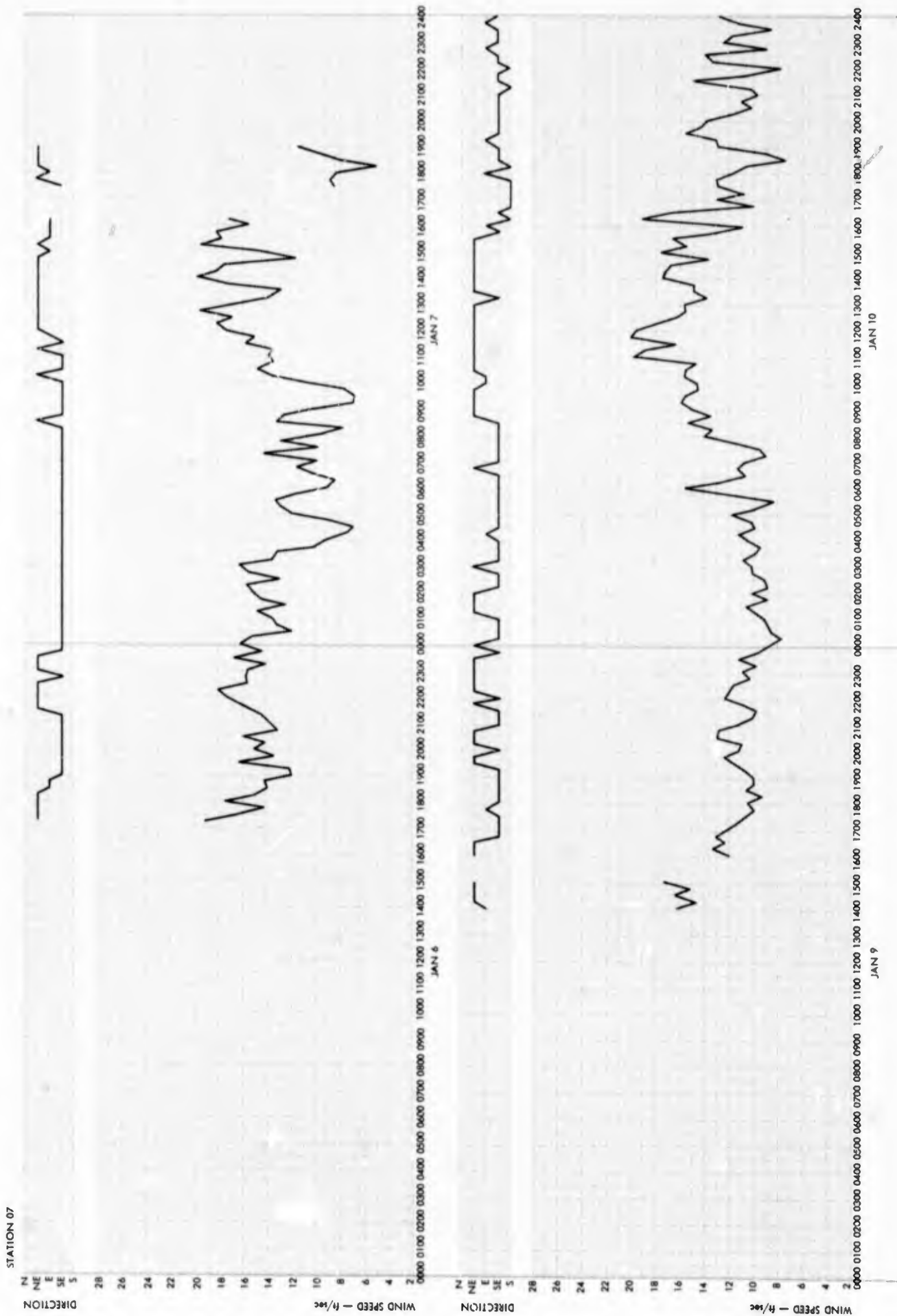


Figure C-1 (Continued)

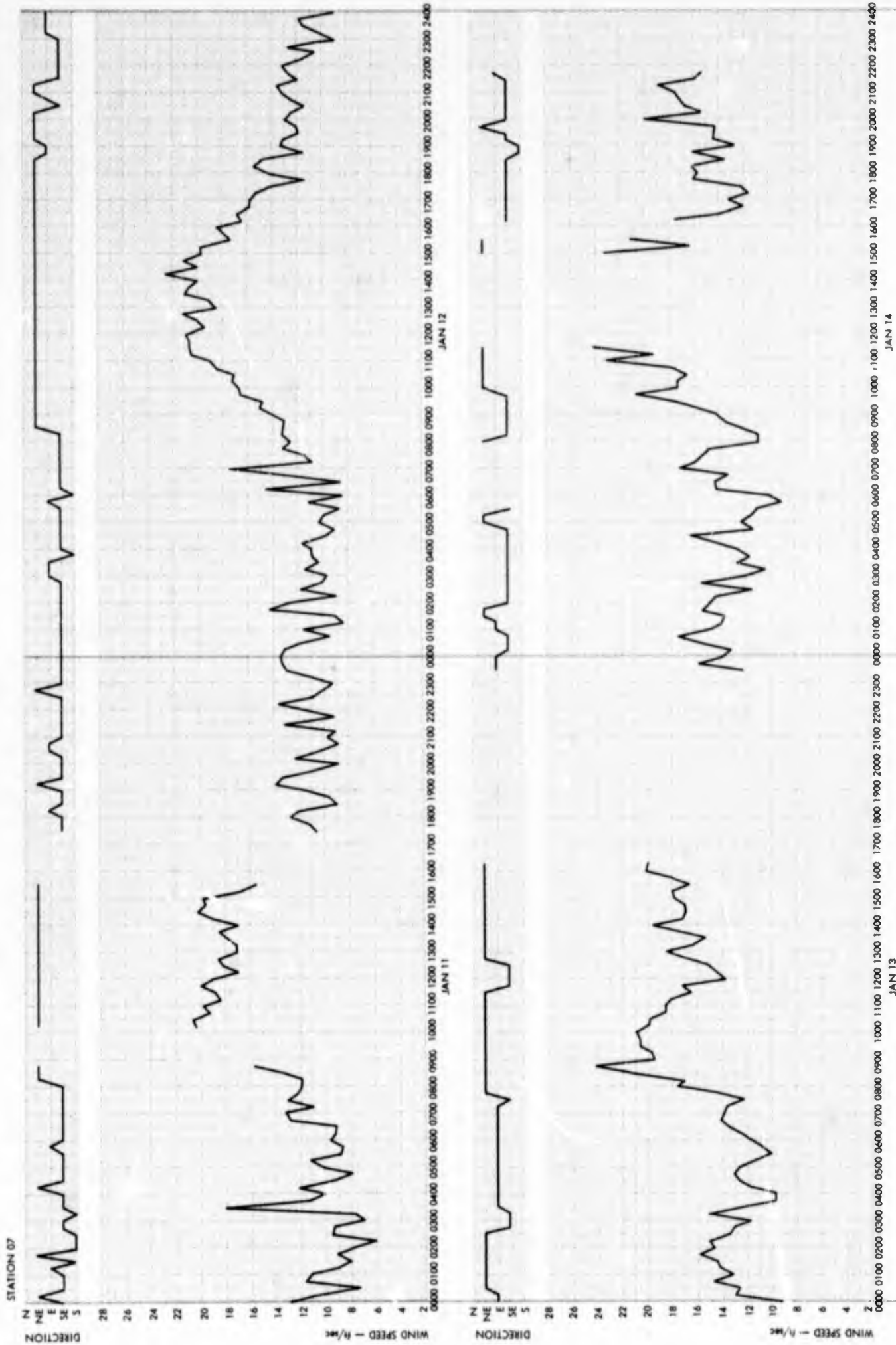


Figure C-1 (Continued)

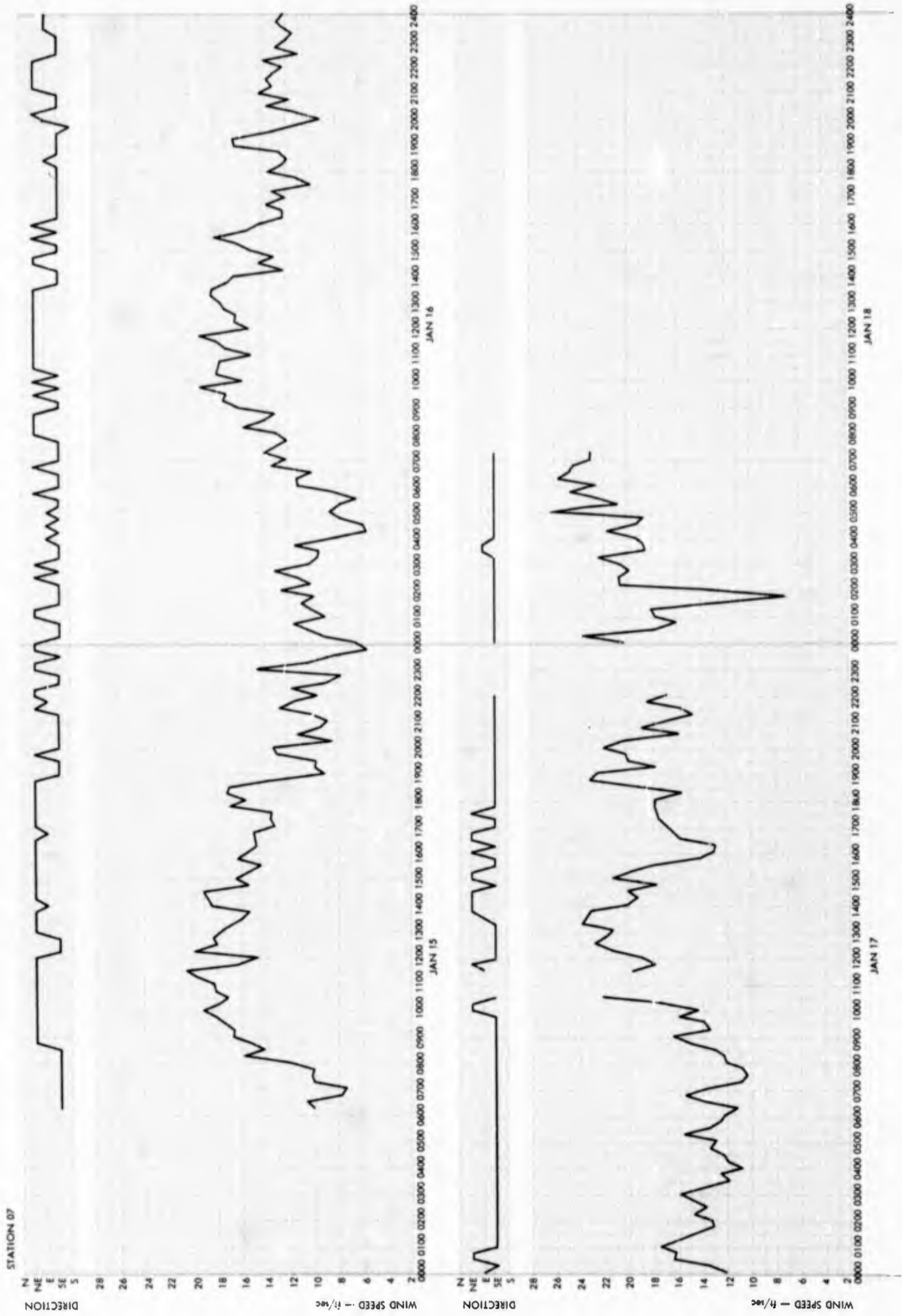


Figure C-1 (Continued)

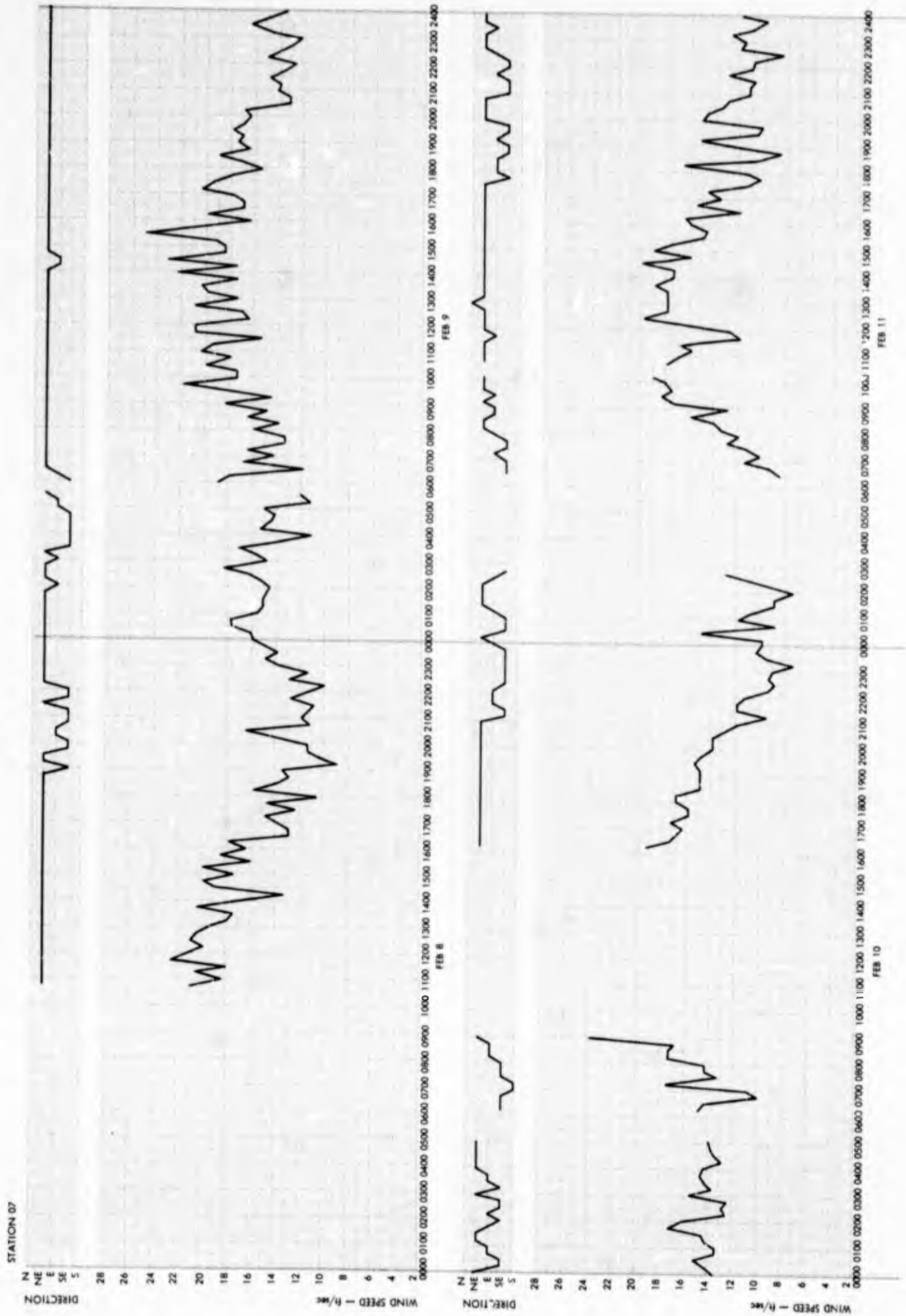


Figure C-1 (Continued)

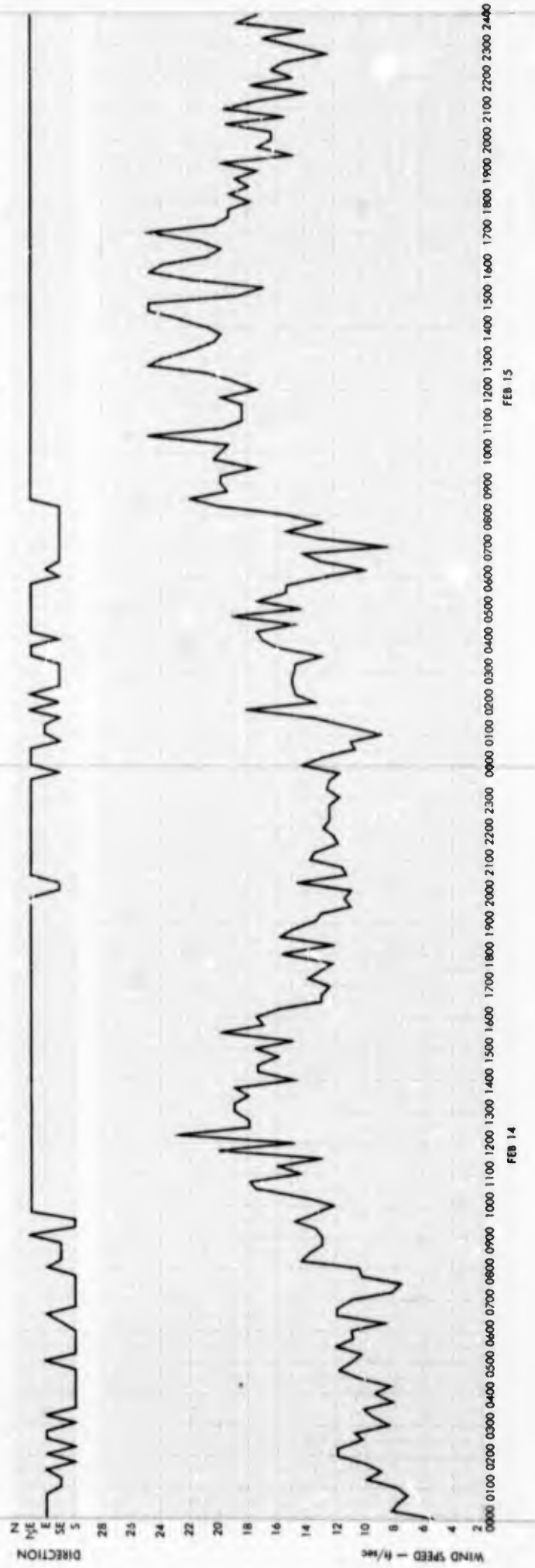
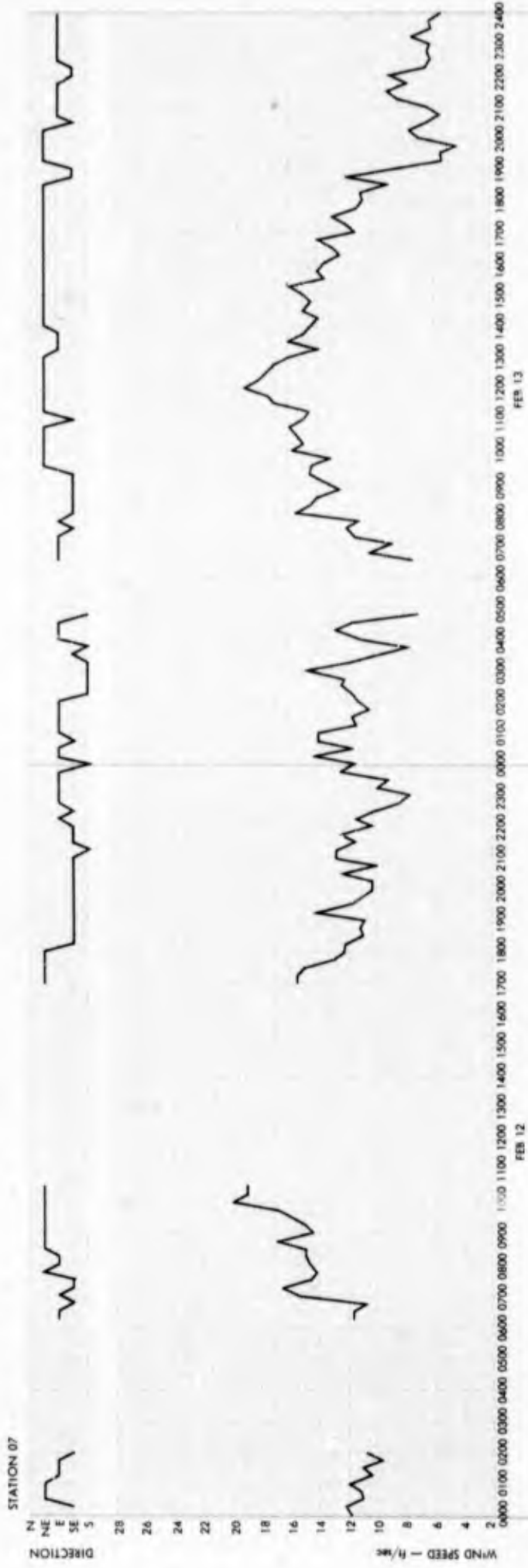


Figure C-1 (Continued)

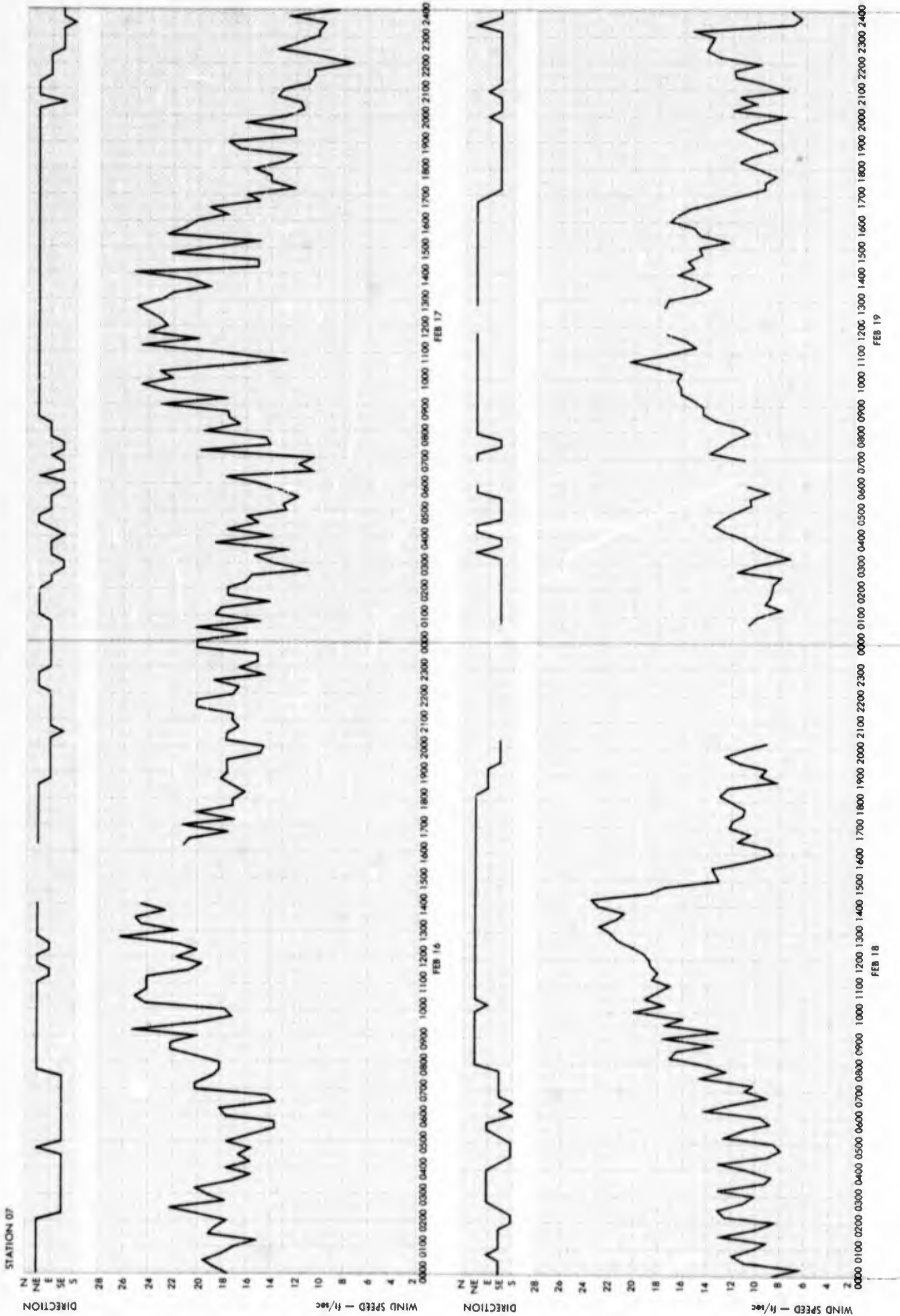


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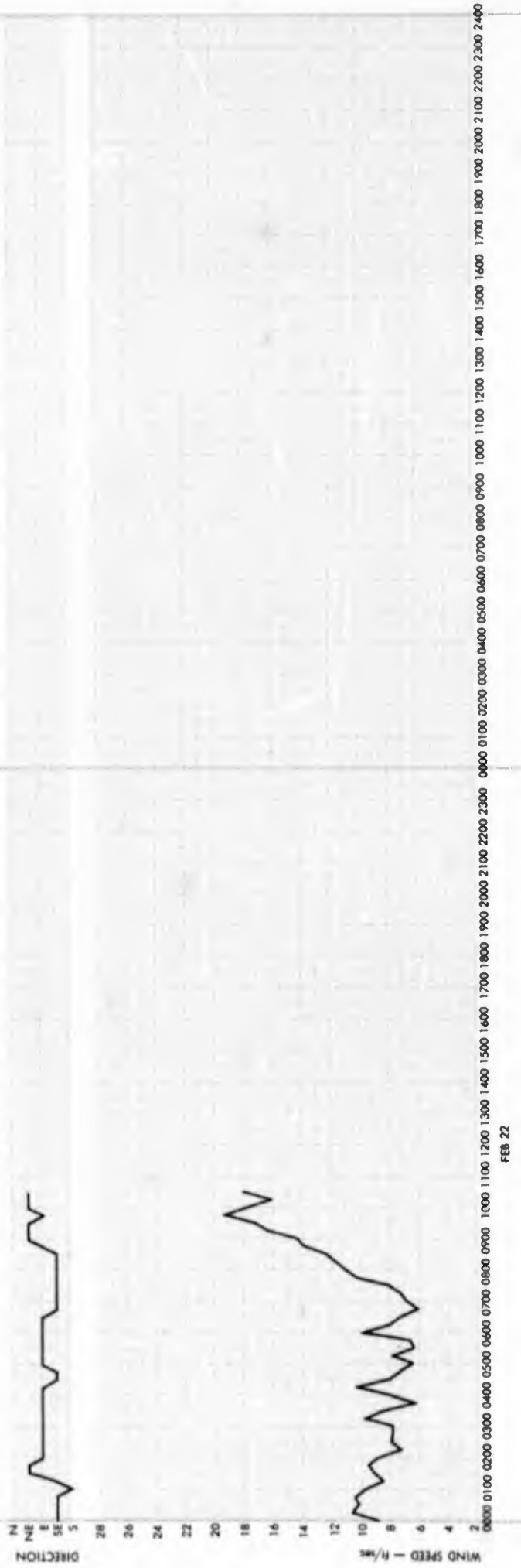
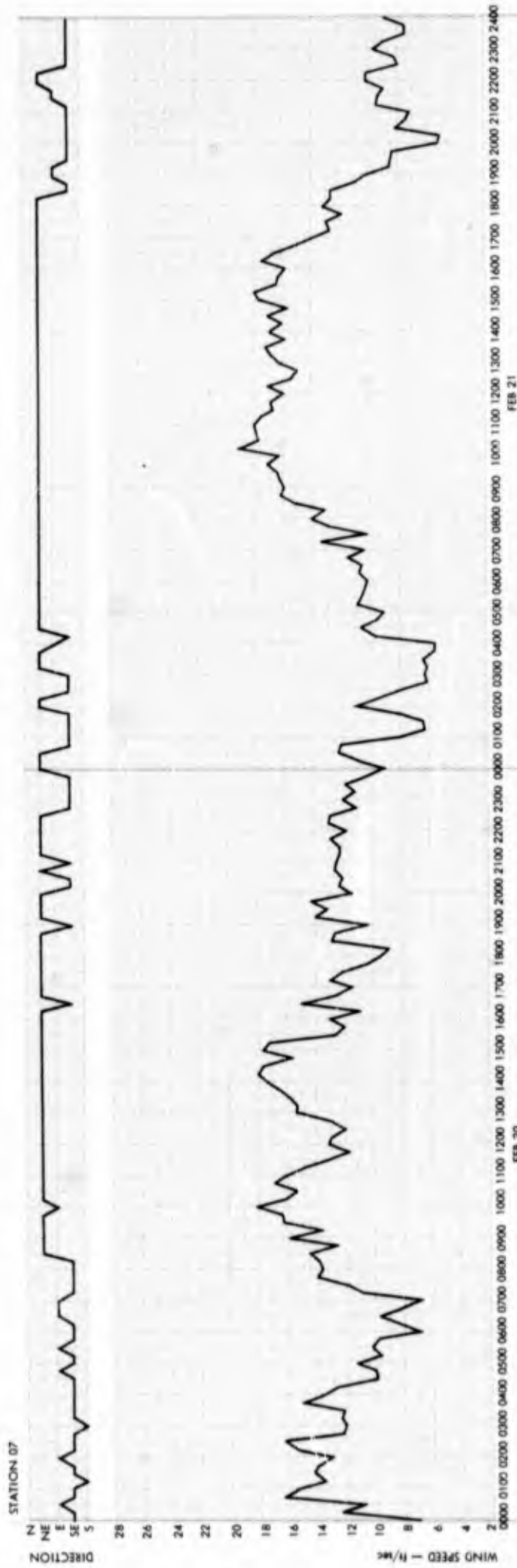


Figure C-2

WIND SPEED AND DIRECTION ON THE ROOF AT STATION 010 DURING THE PERIODS OF EXPERIMENTAL MEASUREMENTS

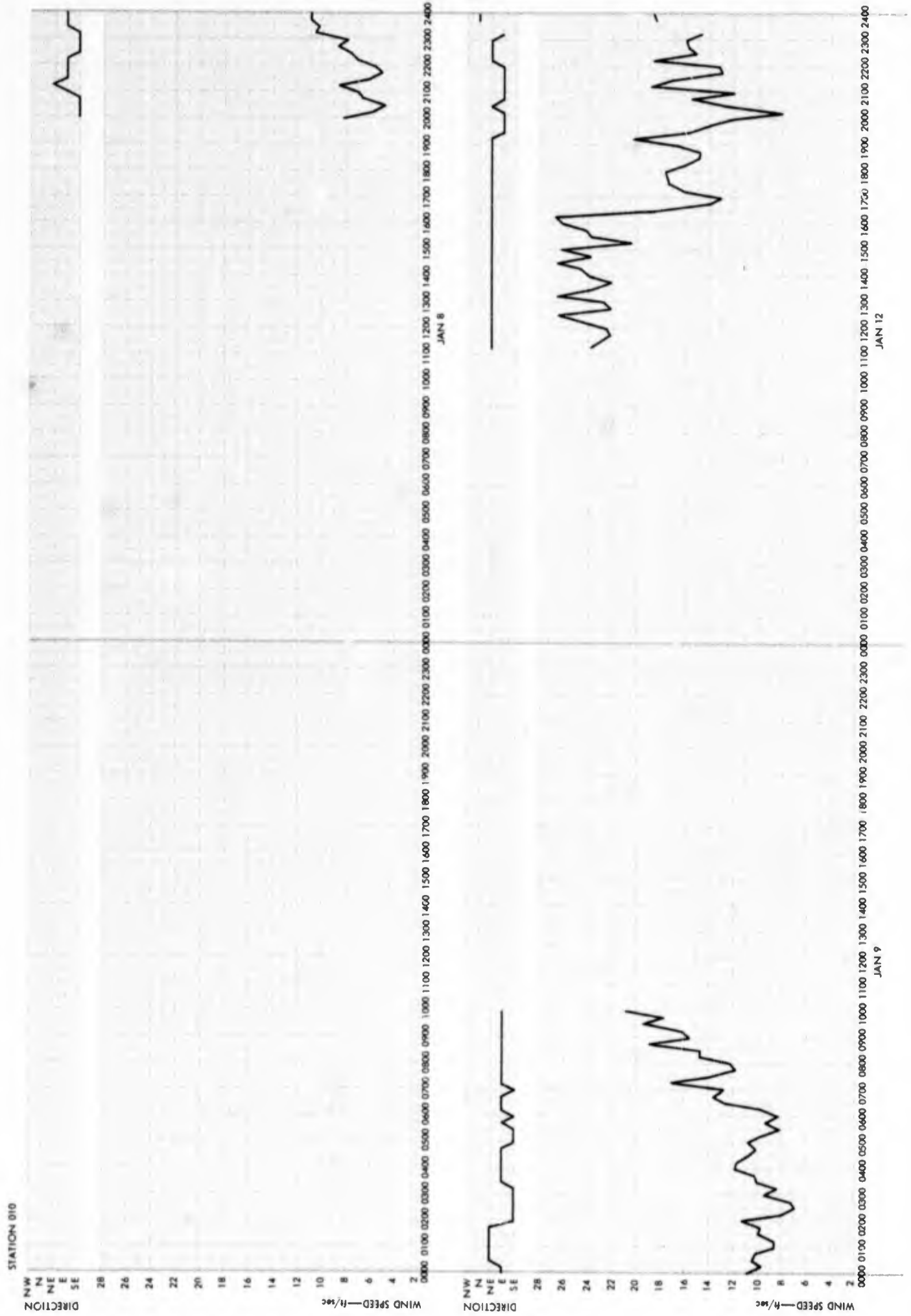


Figure C-2 (Continued)



Figure C-2 (Continued)

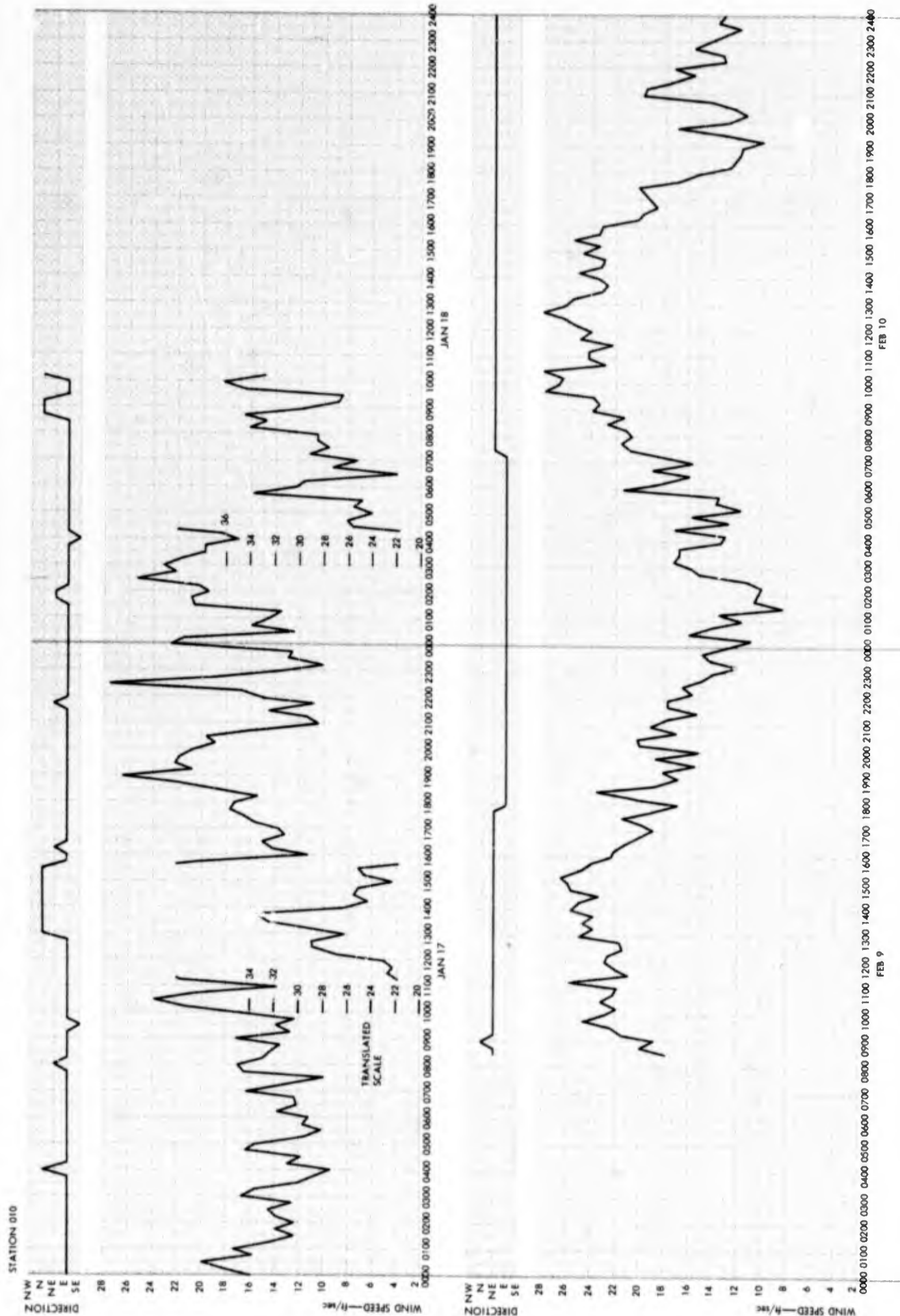


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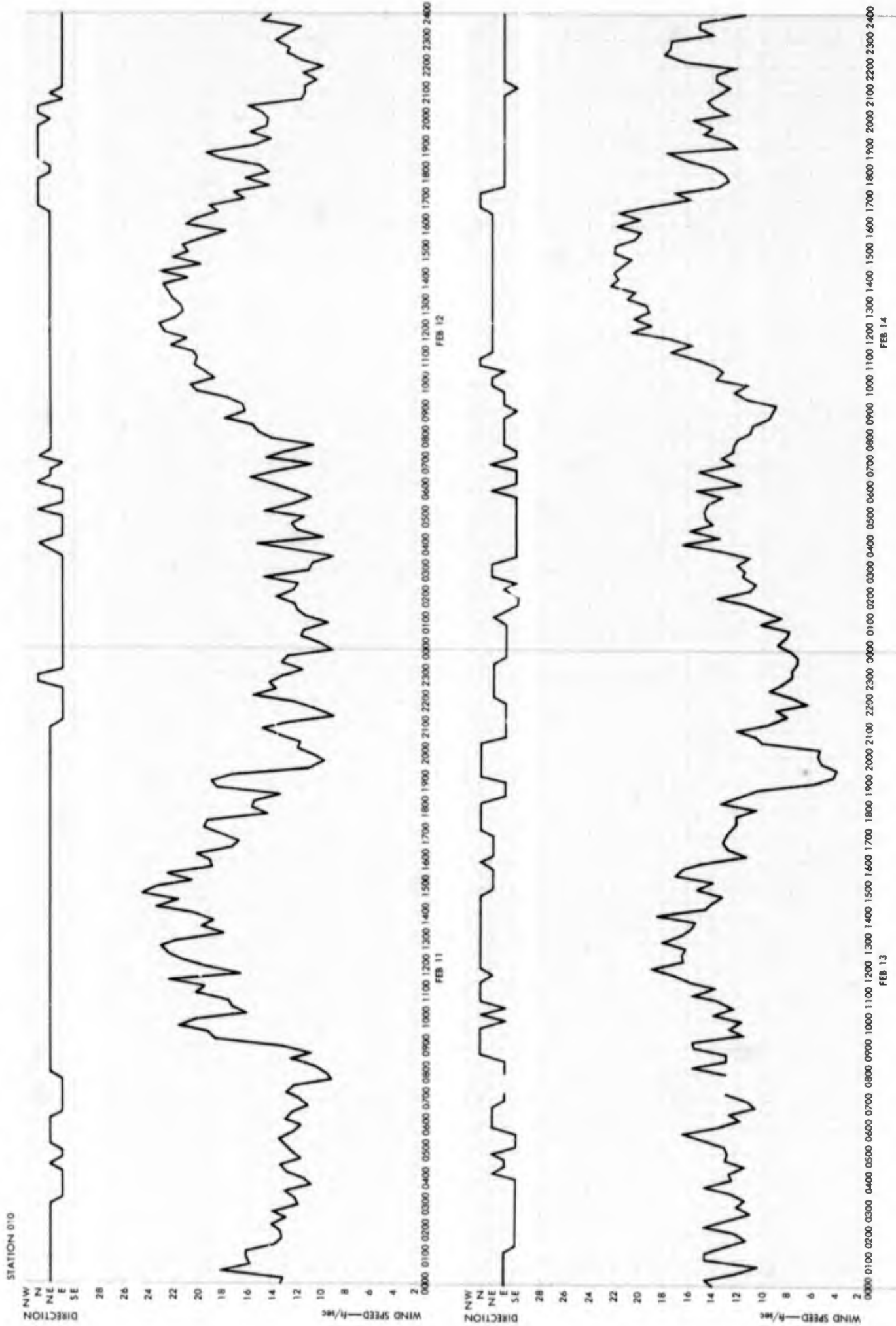


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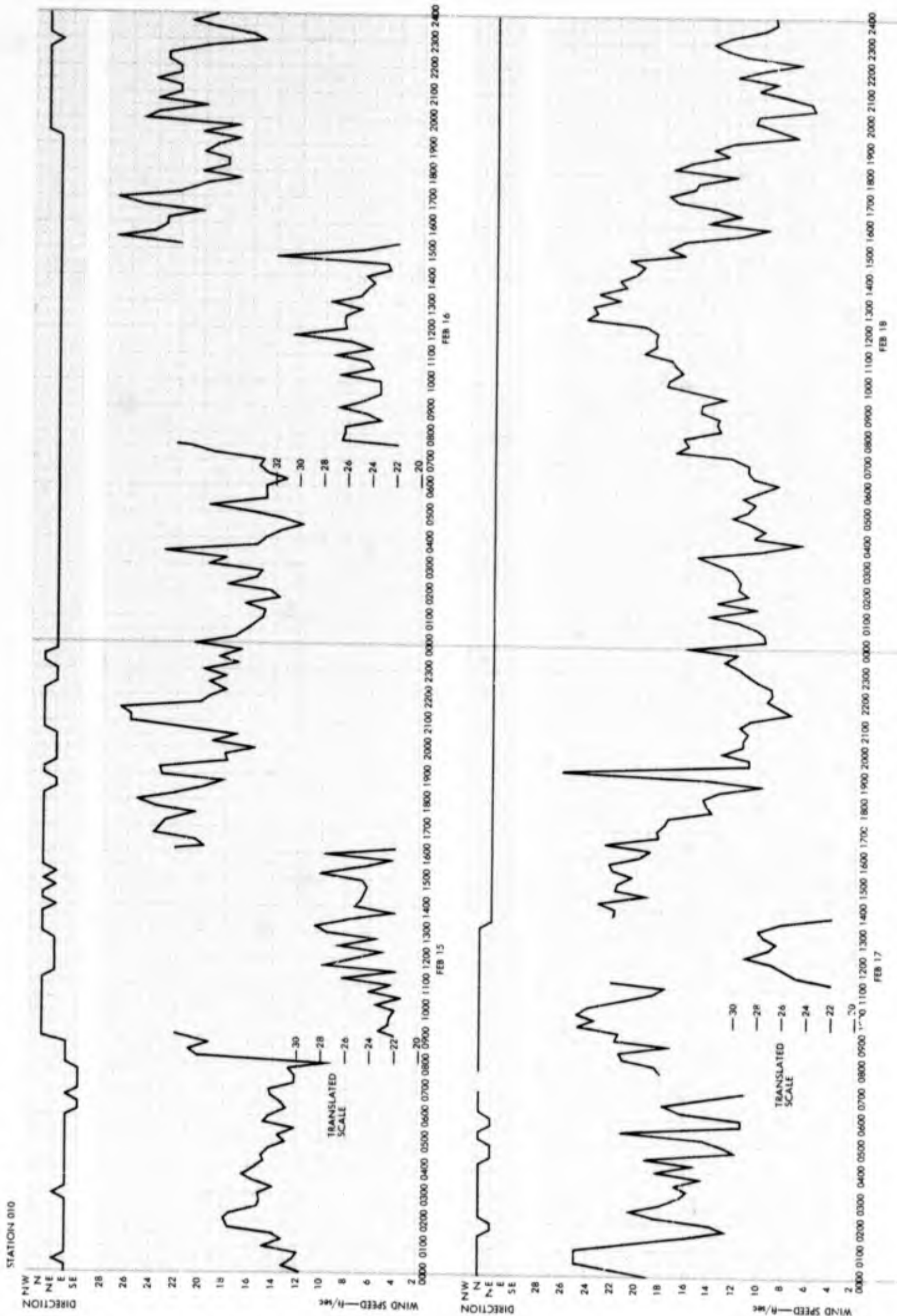
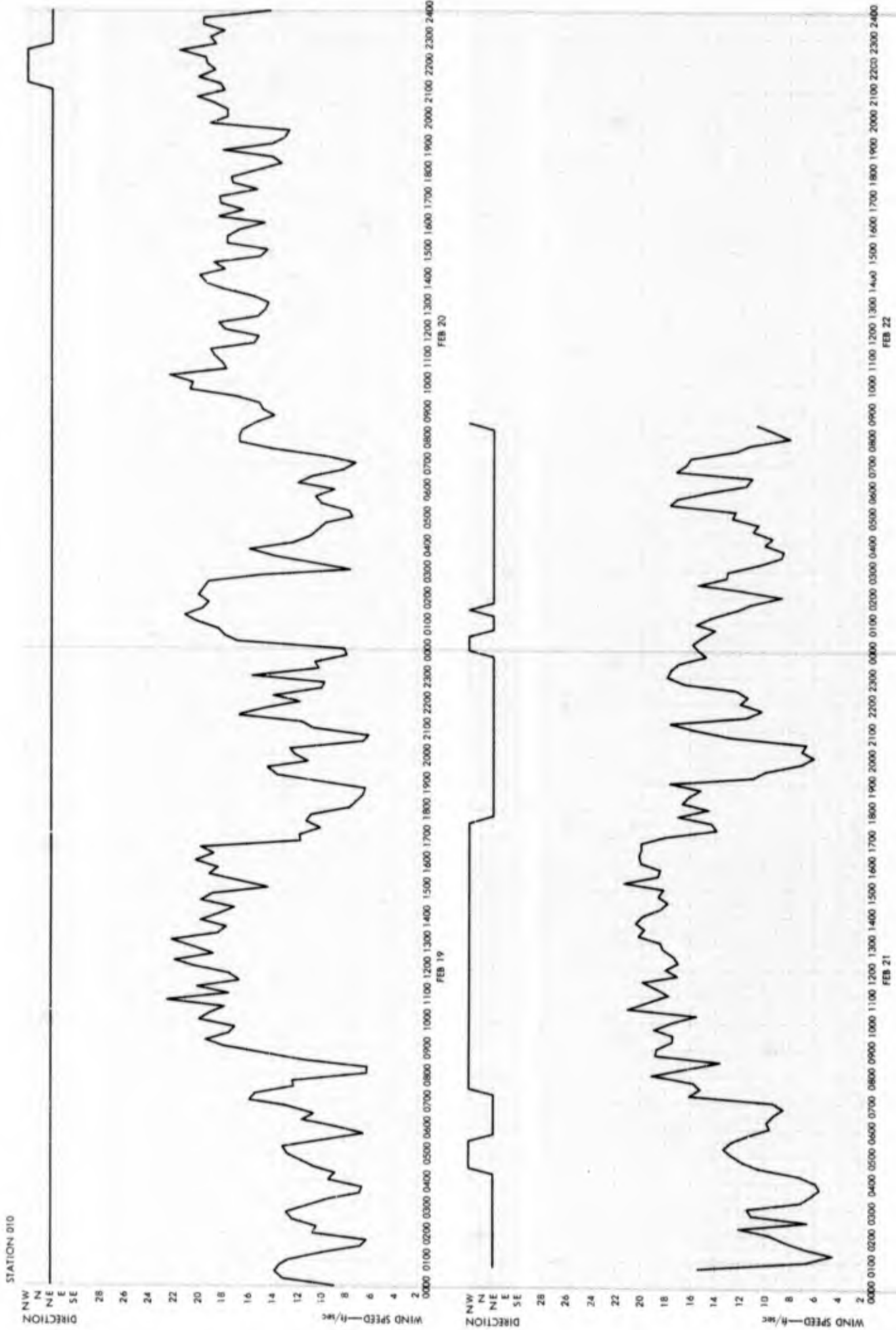


Figure C-2 (Concluded)



Appendix D

SIMULTANEOUS MEASUREMENTS OF WIND SPEEDS AT ROOF AND SELECTED
PLATE COLLECTOR LOCATIONS, STATION 07 AND 010

Table D-1

SIMULTANEOUS MEASUREMENTS OF WIND SPEEDS (FT/SEC) AT ROOF AND AT SELECTED PLATE COLLECTOR LOCATIONS
 STATION 07: SURVEYS FROM TABLE 3

Location	Speed at 6 feet	Roof		Location	Speed at 6 feet	Roof	
		Speed ^a	Direction			Speed ^a	Direction
A1	5.3	14.7	NE	D5	7.8	14.0	E, SE
B1	5.5	14.7	NE	A6	4.5	15.2	SE
C1	4.5	14.7	NE	B6	3.9	15.2	SE
D1	4.3	14.7	NE	C6	6.6	15.2	SE
A2	1.7	12.3	E, SE	D6	6.7	15.2	SE
B2	2.4	12.3	E, SE	A7	2.3	13.8	NE
C2	4.9	12.3	E, SE	B7	3.7	13.8	NE
D2	4.7	12.3	E, SE	C7	9.1	13.8	NE
A3	3.6	14.5	SE	D7	9.1	13.8	E
B3	4.4	14.5	SE	A8	4.1	17.8	SE
C3	3.3	14.5	SE	B8	4.9	17.8	SE
D3	3.6	14.5	SE	C8	8.4	17.8	SE
A4	3.3	14.6	SE	D8	8.8	17.8	SE
B4	3.8	14.6	SE	A9	3.3	17.0	SE
C4	4.3	14.6	SE	B9	6.3	17.0	SE
D4	4.8	14.6	SE	C9	10.6	17.0	SE
A5	3.8	14.0	E, SE	D9	11.1	17.0	SE
B5	4.8	14.0	E, SE	A10	4.5	20.1	SE
C5	6.2	14.0	E, SE	B10	6.1	20.1	SE

WT-1 (continued)

WT-1

^a Roof anemometer values corrected by 1.060 calibration factor relative to portable anemometer values.

Table D-1 (continued)

Location	Speed at 6 feet	Roof		Location	Speed at 6 feet	Roof	
		Speed ^a	Direction			Speed ^a	Direction
	WT-1 (continued)						
C10	11.4	20.1	SE	E15	11.7	17.0	SE
D10	12.8	20.1	SE	F15	12.3	17.0	SE
A11	3.3	13.7	E, SE	G15	12.6	17.0	SE
B11	4.5	13.7	E, SE	H15	12.9	17.0	SE
C11	9.5	13.7	E, SE	E14	13.4	17.7	NE, SE
D11	10.5	13.7	E, SE	F14	15.4	17.7	NE, SE
A11	2.9	16.2	SE	G14	16.7	17.7	NE, SE
B12	3.8	16.2	SE	H14	15.8	17.7	NE, SE
C12	8.6	16.2	SE	E13	10.5	16.9	NE
D12	10.9	16.2	SE	F13	11.0	16.9	NE
A11	3.8	14.8	NE, SE	G13	11.8	16.9	NE
B11	4.1	14.8	NE, SE	H13	13.1	16.9	NE
C13	13.9	14.8	NE, SE	E12	11.9	15.2	NE, SE
D13	10.1	14.8	NE, SE	F12	13.1	15.2	NE, SE
A11	4.6	20.7	NE, SE	G12	14.1	15.2	NE, SE
B14	6.9	20.7	NE, SE	H12	13.3	15.2	NE, SE
C14	11.2	20.7	NE, SE	E11	13.6	16.2	NE, SE
D14	12.5	20.7	NE, SE	F11	14.1	16.2	NE, SE
A11	3.9	13.1	NE	G11	14.8	16.2	NE, SE
B15	6.4	13.1	NE	H11	12.5	16.2	NE, SE
C15	8.1	13.1	NE	E10	9.2	3.9	SE
D15	9.3	13.1	NE	F10	10.3	13.9	SE

^a Roof anemometer values corrected by 1.060 calibration factor relative to portable anemometer values.

Table D-1 (continued)

Location	Speed at 6 feet	Roof		Location	Speed at 6 feet	Roof	
		Speed ^a	Direction			Speed ^a	Direction
G10	11.7	13.9	SE	E4	4.4	15.5	SE
H10	7.6	13.9	SE	F4	4.4	15.5	SE
E9	6.1	10.8	E,SE	G4	4.4	15.5	SE
F9	6.3	10.8	E,SE	H4	4.3	15.5	SE
G9	7.8	10.8	E,SE				
H9	4.3	10.8	E,SE				
E8	6.1	13.2	E,SE				
G8	7.3	13.2	E,SE				
H8	3.5	13.2	E,SE				
E7	6.4	12.4	SE				
F7	6.7	12.4	SE				
G7	7.4	12.4	SE				
H7	3.0	12.4	SE				
E6	5.2	11.6	SE	D1	6.7	6.3	NE
F6	5.2	11.6	SE	B1	3.9	3.7	NE
G6	5.5	11.6	SE	D2	8.5	8.6	NE
H6	2.3	11.6	SE	B2	4.8	5.0	NE
E5	3.7	16.3	SE	D3	10.0	10.5	NE,E
F5	3.8	16.3	SE	B3	3.5	2.9	NE,E
G5	6.6	16.3	SE	D4	12.0	11.2	NE,E
H5	3.4	16.3	SE	B4	5.0	5.0	NE,E
				D5	8.7	8.4	NE,SE
				B5	4.3	4.1	NE,SE
				D6	9.7	9.2	NE,SE
				B6	5.0	5.0	NE,SE

WT-1 (continued)

WT-2

Speed

1 foot 3 feet

Speed^a

Direction

^a Roof anemometer values corrected by 1.060 calibration factor relative to portable anemometer values.

Table D-1 (continued)

Location	Speed		Roof		Location	Speed		Roof	
	1 foot	3 feet	Speed ^a	Direction		1 foot	3 feet	Speed ^a	Direction
D7	12.9	12.5	21.6	NE, SE	H13	6.1	7.9	11.7	SE
B7	5.2	4.5	21.6	NE, SE	F13	8.6	5.6	11.7	SE
D8	17.6	17.0	16.1	NE, E	H12	8.9	10.9	16.9	SE
B8	5.3	4.8	16.1	NE	F12	15.3	10.6	16.9	SE
D9	9.5	9.4	12.7	NE	H11	11.9	14.3	14.2	NE, SE
B9	4.1	3.9	12.7	NE	F11	15.2	14.1	14.2	NE, E
D10	11.2	13.5	18.0	NE	H10	7.0	11.3	15.2	NE, E
B10	5.9	4.9	18.0	NE	F10	16.7	15.4	15.2	NE
D11	15.3	17.2	17.7	NE, N	H9	10.9	12.8	20.8	NE
B11	8.6	8.5	17.7	NE	F9	18.9	19.5	20.8	NE
D12	5.3	7.0	16.6	NE	H8	10.0	13.2	23.2	NE
B12	5.3	4.3	16.6	NE	F8	17.4	18.6	23.2	NE
D13	8.1	11.5	17.7	NE	H7	7.9	9.2	20.4	NE
B13	6.1	4.9	17.7	NE	F7	12.6	13.3	20.4	NE
D14	12.3	13.4	22.1	NE, SE	H6	7.8	8.9	18.4	E, SE
B14	7.1	4.0	22.1	NE	F6	12.0	10.7	18.4	SE
D15	10.3	12.1	17.8	NE, E	H5	6.3	7.4	15.8	NE
B15	6.6	5.0	17.8	NE	F5	11.5	13.0	15.8	NE
H15	18.1	19.3	19.0	NE	H4	5.4	5.7	16.1	NE
F15	17.5	16.3	19.0	NE	F4	9.7	11.9	16.1	NE
H14	12.8	14.2	16.4	NE	H3	12.5	12.9	18.2	NE, E
F14	12.6	11.0	16.4	NE	F3	12.8	15.6	18.2	NE, E

WT-2 (continued)

WT-2 (continued)

^a Roof anemometer values corrected by 1.060 calibration factor relative to portable anemometer values.

Table D-1 (continued)

Location	Speed		Roof		Location	Speed		Roof	
	1 foot	3 feet	Speed ^a	Direction		1 foot	3 feet	Speed ^a	Direction
H2	13.8	11.8	17.0	NE, E	D9	21.0	19.6	24.4	NE
F2	10.6	11.6	17.0	NE, E	B10	5.6	5.2	24.2	NE
					D10	15.3	10.6	24.2	NE
					B11	4.3	5.1	17.8	NE
					D11	10.6	8.5	17.8	NE
B1	3.0	3.6	27.2	NE, E	B12	7.0	7.6	29.9	NE
D1	16.2	18.5	27.2	NE	D12	10.0	6.6	29.9	NE
B2	8.9	8.1	21.8	NE	B13	7.3	6.0	25.3	NE
D2	11.7	11.7	21.8	NE	D13	9.0	6.9	25.3	NE
B3	8.2	5.0	23.2	NE	B14	6.2	6.2	23.2	NE
D3	11.2	11.2	23.2	NE	D14	7.8	10.0	23.2	NE
B4	6.1	6.4	21.5	NE	F15	19.9	17.4	27.1	NE, E
D4	9.6	14.3	21.5	NE	H15	21.5	20.9	27.1	NE, E
B5	3.9	5.0	21.2	NE	F13	19.3	11.9	25.7	NE, E
D5	10.3	10.9	21.1	NE	H13	21.7	17.9	25.7	NE, E
B6	5.2	5.9	19.1	NE, SE	F12	20.5	11.7	20.1	NE, E
D6	12.3	12.9	19.1	NE	H12	15.2	12.1	20.1	NE, E
B7	4.7	6.0	17.3	NE	F14	21.4	19.1	23.7	NE, E
D7	16.8	17.1	17.3	NE	H14	23.4	21.5	23.7	NE, E
B8	3.6	4.3	16.1	NE	F11	20.6	18.0	23.1	NE
D8	15.3	15.1	16.1	NE	H11	19.6	17.7	23.1	NE
B9	6.6	6.6	24.4	NE					

WT-2 (continued)

WT-4 (continued)

WT-4

^a Roof anemometer values corrected by 1.060 calibration factor relative to portable anemometer values.

Table D-1 (continued)

Location	Speed		Roof Speed ^a	Roof Direction	Location	Speed		Roof Speed ^a	Roof Direction
	1 foot	3 feet				1 foot	3 feet		
WT-4 (continued)									
F10	16.5	14.0	19.3	NE	A3	1.5	3.1	17.9	NE, E
H10	13.6	8.2	19.3	NE	B3	3.6	4.8	17.9	NE, E
F9	12.6	12.4	15.2	NE	A5	3.7	4.2	17.1	NE, E
H9	8.7	8.9	15.2	NE	B5	4.8	5.5	17.1	NE, E
F8	10.0	9.9	17.2	NE, E	A7	4.5	4.8	17.9	NE, E
H8	7.3	7.2	17.2	NE, E	B7	5.1	5.8	17.9	NE, E
F7	10.8	11.5	14.5	NE, E	B9	4.3	6.1	17.9	NE, E
H7	8.6	8.4	14.5	NE, E	B11	8.5	7.7	17.9	NE, E
F6	11.0	9.7	15.9	NE, E	B13	4.9	5.8	17.1	NE, E
H6	7.3	6.4	15.9	NE, E	B15	4.6	7.5	17.1	NE, E
F5	14.0	16.0	21.8	NE, E	E15	15.3	17.1	21.0	NE, E
H5	8.7	7.9	21.8	NE, E	H15	18.0	20.6	21.0	NE, E
F4	12.5	15.3	19.0	NE	E13	10.2	15.6	18.7	NE, E
H4	8.3	8.2	19.0	NE	H13	11.0	17.4	18.7	NE, E
F3	11.6	13.6	19.2	NE, SE	E11	12.5	16.5	17.1	NE, E
H3	13.1	12.0	19.2	NE, SE	H11	12.5	15.6	17.1	NE, E
F2	3.9	5.1	23.9	NE	E9	12.3	13.7	15.6	NE, E
H2	8.7	8.4	23.9	NE	H9	10.2	10.4	15.6	NE, E
WT-8									
A1	3.0	3.7	16.3	NE, E	E7	16.2	17.4	20.2	NE, E
B1	2.8	4.6	16.3	NE, E	H7	9.4	10.9	20.2	NE, E
					E5	18.7	17.6	20.2	NE, E
					H5	9.1	10.1	20.2	NE, E
					E3	15.6	14.6	19.4	NE, E

^a Roof anemometer values corrected by 1.060 calibration factor relative to portable anemometer values.

Table D-1 (continued)

Location	Speed		Roof		Location	Speed		Roof	
	1 foot	3 feet	Speed ^a	Direction		1 foot	3 feet	Speed ^a	Direction
H3	11.9	13.9	19.4	NE, E	H15	10.2	12.0	14.1	NE, E
E1	8.2	9.3	16.3	NE, E	E13	6.1	8.6	9.7	E
H1	7.1	7.6	16.3	NE, E	H13	8.4	9.5	9.7	E
E4	16.6	15.6	21.7	NE, E	E11	14.0	15.7	15.0	NE, N
E4	18.7	15.4	21.7	NE, E	H11	12.5	14.4	15.0	NE, N
					E9	12.6	13.4	16.6	NE
					H9	8.1	8.2	16.6	NE
					E7	12.9	12.3	14.7	NE
A1	3.7	2.9	15.9	NE	H7	8.9	9.8	14.7	NE, E
B1	3.2	3.9	15.9	NE	E5	15.3	13.2	15.2	NE, E
A3	5.8	5.5	12.6	NE, E	H5	5.7	7.0	15.2	NE
B3	3.6	6.1	12.6	NE, E	E3	10.0	8.6	12.9	NE
A5	3.3	3.2	15.3	SE	H3	7.3	7.9	12.9	NE
B5	2.6	2.5	15.3	SE	E1	6.1	7.2	15.3	E, SE
A7	3.6	3.2	11.3	NE, E	H1	4.7	6.0	15.3	E, SE
B7	3.8	4.9	11.3	NE, E	E4	9.2	8.1	13.9	NE
B9	4.0	4.5	16.8	NE, N	H4	10.3	8.4	13.9	NE
B11	4.9	4.8	16.8	NE, N	E4	12.6	11.5	16.2	NE, E
B13	4.3	5.1	15.5	NE	H4	14.0	11.9	16.2	NE, E
B15	4.3	7.2	15.5	NE					
E15	9.2	10.9	14.1	NE, E					

WT-8 (continued)

WT-9 (continued)

^a Roof anemometer values corrected by 1.060 calibration factor relative to portable anemometer values.

Table D-1 (continued)

Location	Speed		Roof		Location	Speed		Roof	
	1 foot	3 feet	Speed ^a	Direction		1 foot	3 feet	Speed ^a	Direction
A1	4.9	3.7	20.5	NE, E	H7	8.6	8.8	18.0	NE, E
B1	4.0	4.3	20.5	NE, E	E5	15.8	20.0	27.1	NE, E
A3	5.3	5.7	22.9	NE, E	H5	10.3	10.6	27.1	NE, E
B3	4.5	6.1	22.9	NE, E	E3	12.0	16.4	25.6	NE
A5	4.8	5.7	19.0	NE, E	H3	17.5	18.8	25.6	NE
B5	8.8	10.2	19.0	NE, N	E1	8.5	10.8	22.1	NE
A7	5.2	7.1	25.3	NE, E	H1	6.5	8.0	22.1	NE
B7	6.9	7.0	25.3	NE, E	E4	23.0	16.9	27.0	NE, E
B9	5.6	6.9	20.6	NE, E	E4	22.5	18.0	27.0	NE, E
B11	8.3	8.8	20.6	NE, E					
B13	6.7	8.2	22.3	NE, E					
B15	9.5	9.7	22.3	NE, E					
B13	7.4	8.7	27.4	NE, E	A1	2.9	4.2	22.3	NE
B15	7.7	9.8	27.4	NE, E	B1	3.2	3.3	22.3	NE
E15	14.9	17.9	26.5	NE, E	A3	5.3	4.6	27.0	NE
H15	14.2	17.0	26.5	NE, E	B3	6.1	7.7	27.0	NE
E13	12.7	19.1	29.1	NE, E	A5	5.0	4.2	23.9	NE
H13	16.4	19.2	29.1	NE, E	B5	7.0	8.0	23.9	NE
E11	26.6	28.7	28.4	NE, E	A7	4.3	4.5	23.3	NE
H11	23.9	25.9	28.4	NE, E	B7	5.1	7.4	23.3	NE
E7	14.1	14.8	18.0	NE, E	B9	6.4	5.5	21.6	NE

WT-10 (continued)

WT-10

WT-11

^a Roof anemometer values corrected by 1.060 calibration factor relative to portable anemometer values.

Table D-1 (concluded)

Location	Speed		Roof	
	1 foot	3 feet	Speed ^a	Direction
WT-11 (continued)				
B11	7.3	6.7	21.6	NE
B13	6.5	5.9	18.4	NE
B15	5.7	7.5	18.4	NE
E15	20.4	18.9	25.0	NE, E
H15	21.7	24.9	25.0	NE, E
E13	16.8	11.6	23.9	NE, E
H13	15.8	21.3	23.9	NE, E
E11	22.3	21.0	22.2	NE
H11	22.9	22.7	22.2	NE
E9	13.8	13.6	16.8	NE
H9	8.7	9.7	16.8	NE
E7	15.9	16.8	21.4	NE
H7	10.4	11.2	21.4	NE
E5	12.9	15.9	23.0	NE, SE
H5	7.3	8.2	23.0	NE, SE
E3	15.2	17.3	21.1	NE
H3	15.3	16.6	21.1	NE
E1	9.2	8.9	15.6	NE
H1	6.3	6.4	15.6	NE
E4	15.0	20.5	21.9	NE
E4	19.9	15.7	21.9	NE
E4	12.3	14.6	24.5	NE, SE
E4	14.7	12.9	24.5	NE, SE

^a Roof anemometer values corrected by 1.060 calibration factor relative to portable anemometer values.

Table D-2

SIMULTANEOUS MEASUREMENTS OF WIND SPEEDS (FT/SEC) AT ROOF AND AT SELECTED PLATE COLLECTOR LOCATIONS
STATION 010 - SURVEYS FROM TABLE 3

Location	Speed		Roof		Location	Speed		Roof		
	1 foot	3 feet	Speed ^a	Direction		1 foot	3 feet	Speed ^a	Direction	
	WT-3 (continued)									
M3	12.4	20.9	25.6	NE	J8 ^b	13.5	25.8	21.5	NE	
M5		24.6	25.6	NE	J7 ^b		24.4	21.5	NE	
M6	23.5	27.4	25.8	NE	H8 ^b	24.6	18.1	26.6	NE	
M8		28.2	25.8	NE	H7 ^b		18.6	26.6	NE	
L6	27.2	28.8	27.4	NE	G8 ^b	8.8	9.1	14.7	NE	
L8		24.2	27.4	NE	G7 ^b		11.3	14.7	NE	
L3	16.0	18.4	20.1	NE	F8 ^b	10.6	12.6	20.1	NE	
L5		18.7	20.1	NE	F7 ^b		11.2	20.1	NE	
K3	17.0	21.0	21.3	NE	H5 ^b	8.9	9.8	15.2	NE	
K5		18.2	21.3	NE	H3 ^b		10.3	15.2	NE	
K6	19.4	18.8	27.7	NE	G5 ^b	11.6	12.5	15.3	NE	
K8		24.3	27.7	NE	G3 ^b		11.7	15.3	NE	
J6	11.2	13.2	29.5	NE	F5 ^b	16.7	18.4	20.4	NE	
J8		27.2	29.5	NE	F3 ^b		17.8	20.4	NE	
J3	7.5	9.4	21.3	NE	C5	8.8	9.9	18.0	NE	
J5		11.6	21.3	NE	C3		12.7	18.0	NE	
J5	9.9	22.0	20.5	NE	C8	8.9	18.3	22.4	NE	
J3		24.3	20.5	NE	C6		10.8	22.4	NE	

^a Roof anemometer values corrected by calibration factor of 1.106 relative to portable anemometers values.
^b 9th story roof.

Table D-2 (continued)

Location	Speed		Roof		Location	Speed		Roof	
	1 foot	3 feet	Speed ^a	Direction		1 foot	3 feet	Speed ^a	Direction
WT-3 (continued)									
D8	8.2	20.6	27.2	N	J3	3.0	3.3	17.2	N, NE
D6		11.0	27.2	N	L1	12.3	11.3	18.9	N, NE
E8	6.6	18.7	24.6	N	L3	2.3	2.7	18.9	N, NE
E6		7.3	24.6	N	M1	24.6	26.9	28.1	N, NE
F8	4.8	8.4	25.1	N	M3	22.1	33.4	28.1	N, NE
F6		8.3	25.1	N	P1	21.6	24.4	27.7	N, NE
D5	10.2	11.0	20.8	N	P3	19.7	21.3	27.7	N, NE
D3		12.2	20.8	N	P4	16.1	16.0	21.2	N, NE
E5	4.5	6.8	24.8	N	M4	11.6	13.0	21.2	N, NE
E3		8.9	24.8	N	P5	17.5	14.0	23.4	N, NE
WT-5									
A1	8.1	10.3	29.1	N, NE	M6	14.1	9.9	25.7	N, NE
A3	7.8	9.3	29.1	N, NE	P7	23.4	23.6	30.2	N, NE
C1	5.3	6.9	18.2	N, NE	M7	10.1	11.3	30.2	N, NE
C3	7.2	7.2	18.2	N, NE	P8	17.1	14.7	27.1	N, NE
E1	4.0	7.3	22.5	N, NE	P9	14.7	13.8	27.1	N, NE
E3	3.9	5.2	22.5	N, NE	M8	11.6	10.2	14.8	N, NE
G1	2.8	4.8	16.2	N, NE	M9	7.4	6.2	14.8	N, NE
G3	3.3	3.6	16.2	N, NE	L9	8.4	7.9	20.0	N, NE
J1	2.5	3.6	17.2	N, NE	L8	5.4	5.9	20.0	N, NE

^a Roof anemometer values corrected by calibration factor of 1.106 relative to portable anemometers values.

Table D-2 (continued)

Location	Speed		Roof		Location	Speed		Roof	
	1 foot	3 feet	Speed ^a	Direction		1 foot	3 feet	Speed ^a	Direction
J9	12.6	13.2	21.5	N,NE	A1	6.6	12.2	23.4	N,NE
J8	4.5	4.3	21.5	N,NE	A3	4.6	6.1	23.4	N,NE
A4	6.3	7.3	19.8	N,NE	C1	5.9	10.0	26.6	N,NE
C4	5.3	5.2	19.8	N,NE	C3	6.7	8.9	26.6	N,NE
A5	3.9	6.1	24.6	N,NE	E1	3.6	6.7	21.0	N,NE
C5	3.7	3.4	24.6	N,NE	E3	5.3	5.2	21.0	N,NE
A6	6.6	6.7	17.9	N,NE	G1	5.4	7.9	22.1	N,NE
C6	3.6	3.3	17.9	N,NE	G3	5.7	6.0	22.1	N,NE
A7	7.1	7.0	20.4	N,NE	J1	4.5	6.0	24.0	N,NE
C7	2.7	2.5	20.4	N,NE	J3	3.7	5.2	24.0	N,NE
A8	25.9	28.1	27.7	N,NE	L1	20.9	18.7	23.8	N,NE
A9	24.6	26.8	27.7	N,NE	L3	2.7	2.5	23.8	N,NE
C8	25.9	25.3	24.7	N,NE	M1	15.4	16.3	15.2	N,NE
C9	22.6	24.5	24.7	N,NE	M3	15.1	18.7	15.2	N,NE
E8	6.2	8.5	24.2	N,NE	P1	19.5	20.8	21.7	N,NE
E9	15.7	17.6	24.2	N,NE	P3	18.7	18.5	21.7	N,NE
G8	10.8	11.4	20.9	N,NE	P4	15.9	17.5	23.2	N,NE
G9	12.1	12.9	20.9	N,NE	M4	11.8	13.4	23.2	N,NE
					P5	16.5	19.1	24.3	N,NE
					M5	13.2	12.7	24.3	N,NE
					P6	15.2	15.4	25.2	N,NE

WT-5 (continued)

WT-6

^a Roof anemometer values corrected by calibration factor of 1.106 relative to portable anemometers values.

Table D-2 (continued)

Location	Speed		Roof		Location	Speed		Roof	
	1 foot	3 feet	Speed ^a	Direction		1 foot	3 feet	Speed ^a	Direction
M6	9.4	9.6	25.2	N,NE	C9	19.3	19.4	22.1	N
P7	13.9	12.6	26.2	NE	C8	21.9	21.7	22.1	N
M7	6.4	7.3	26.2	NE	E9	12.8	13.2	16.1	N
P9	13.0	13.2	27.5	NE	E8	5.7	6.4	16.1	N
P8	17.6	15.5	27.5	NE	G9	14.6	15.4	23.1	NE
M9	9.5	7.7	19.4	NE	G8	13.3	13.1	23.1	NE
M8	10.9	11.9	19.4	NE					
L9	9.5	7.6	21.1	NE					
L8	7.0	7.2	21.1	NE					
J9	10.2	9.5	20.0	E					
J8	3.9	3.6	20.0	N,NE	C3	16.0	18.0	23.8	N
A4	7.5	8.6	24.2	N,NE	C5	14.4	15.3	23.8	N
C4	6.6	6.3	24.2	N,NE	D3	6.8	8.2	14.0	N
A5	5.7	7.3	18.4	N,NE	D5	8.8	7.8	14.0	N
C5	5.9	5.0	18.4	N,NE	E3	8.3	9.5	20.8	N
A6	5.1	6.6	23.6	N,NE	E5	9.9	9.1	20.8	N
C6	4.4	4.4	23.6	N,NE	F3	6.6	7.5	24.1	N
A7	14.3	13.2	17.4	N,NE	F5	5.8	7.6	24.1	N
C7	3.4	3.2	17.4	N,NE	F6	5.5	7.1	21.0	N
A9	25.4	26.1	30.1	N	F8	3.8	5.0	21.0	N
A8	27.2	27.8	30.1	N	E6	5.7	5.4	14.9	N
					E8	5.3	10.7	14.9	N

WT-6 (continued)

WT-7

WT-6 (continued)

^a Roof anemometer values corrected by calibration factor of 1.106 relative to portable anemometers values.

Table D-2 (concluded)

Location	Speed		Roof	
	1 foot	3 feet	Speed ^a	Direction
WT-7 (continued)				
D6	7.4	8.3	18.2	N
D8	6.4	11.8	18.2	N
C6	9.7	11.6	23.0	N
C8	11.2	19.3	23.0	N
F3 ^b	12.0	14.3	16.9	N
F5 ^b	14.1	16.0	16.9	N
G3 ^b	15.6	17.7	24.8	N
G5 ^b	17.5	19.6	24.8	N
H3 ^b	12.2	15.4	24.1	N
H5 ^b	14.3	14.7	24.1	N
J3 ^b	11.9	27.0	21.2	N
J5 ^b	12.4	23.3	21.2	N
J7 ^b	11.0	28.4	24.0	N
J8 ^b	9.4	30.9	24.0	N
H7 ^b	13.2	14.8	21.4	N
H8 ^b	19.8	19.6	21.4	N
F7 ^b	14.3	13.8	19.6	N
F8 ^b	8.5	11.3	19.6	N
G7 ^b	18.6	19.6	23.4	N
G8 ^b	15.0	12.4	23.4	N

^a Roof anemometer values corrected by calibration factor of 1.106 relative to portable anemometers values.
^b 9th story roof.

Appendix E

SUMMARY OF CENIZA-ARENA DEPOSITION MEASUREMENTS

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Table E-1

SUMMARY OF CENIZA-ARENA GROSS DEPOSITION MEASUREMENTS

Louvered Trays
(24" x 24")

Sample Number	Exposed		Collected		Δt (hours)	m (gm/sq ft)	m/ Δt (gm/sq ft/hr)	Remarks
	Day	Time	Day	Time				
Station 07 (Colegio Sion)								
07027	1/7	1710	1/9	0710	38.0	0.1991	0.0052	At Location E-7
07028	1/9	0710	1/11	0801	48.9	0.2593	0.0052	At Location E-7
07029	1/11	0803	1/11	1000	1.95	0.2799	0.1435	At Location E-7
07030	1/11	1000	1/12	0715	21.25	0.0928	0.0044	At Location E-7
07031	1/12	1715	1/15	1800	82.75	0.0243	0.0003	At Location E-7
07032	1/15	1800	1/15	2220	4.33	0.2835	0.0655	At Location E-7
07033	1/15	2220	1/16	1615	6.92	1.4253	0.2060	At Location E-7
Station 09 (Hotel Royal Dutch)								
09001	12/8	1815	12/9	1735	23.2	0.1857	0.0080	6th story roof, east slope
09002	12/9	1740	12/11	1030	40.8	0.2564	0.0063	6th story roof, east slope
09003	12/11	1040	1/5	1000	599.3	8.1478	0.0136	6th story roof, east slope
Station 010 (Banco Central)								
010001	1/6	1000	1/9	0940	71.67	1.4527	0.0203	9th story roof, center
010002	1/9	0940	1/10	0850	23.83	0.2800	0.0117	9th story roof, center
010003	1/9	0940	1/16	1540	150.0	0.2781	0.0019	9th story roof, on ventilator
010004	1/9	1815	1/10	0840	14.42	0.0569	0.0039	2nd story roof @ G-2 and H-2
010005	1/10	0915	1/11	1840	33.42	2.5629	0.0767	2nd story roof @ G-2 and H-2
010006	1/10	0850	1/16	1550	151.0	0.9028	0.0060	9th story roof, center
010007	1/11	1840	1/16	1530	116.83	0.4904	0.0042	2nd story roof @ G-2 and H-2

Table E-2

SUMMARY OF CENIZA-ARENA DEPOSITION MEASUREMENTS AT STATION 07
COLEGIO SION COURTYARD

Plate Collectors
(10" × 10")
(gm/sq ft)

Location	RUN NUMBER							
	1	2	4	5	6	7	8	
A-1	0.0910	0.0054	0.0243	0.0375	0.0453	0.0152	0.0146	
A-3	0.1766	0.0041	0.0456	0.1762	0.2380	0.0432	0.0374	
A-5	0.1595	0.0069	0.0695	0.3606	0.1215	0.0401	0.0639	
A-7	0.1218	0.0054	0.0689	0.2044	0.1044	0.0851	0.0580	
B-3	1.2911	0.0095	0.0904	0.0964	0.4308	0.0587	0.0329	
B-5	0.5493	0.0419	0.7341	0.7084	0.4177	0.2757	0.3084	
B-7	0.9011	0.1049	0.5628	1.0769	0.1981	0.3764	0.4160	
B-9	0.8310	0.1052	0.6575	0.0121	0.4662	0.3636	0.7063	
B-11	0.8098	0.0524	0.0944	1.6621	0.2649	0.1110	0.2524	
B-13	0.0603	0.1219	0.0171	0.0457	0.0933	0.1751	0.9060	
B-15	0.1764	0.0668	0.0194	0.0413	0.1036	0.2221	1.0441	
E-3	0.1128	0.5436	0.1480	0.4344	0.4825	0.5634	1.5405	
E-5	0.0898	0.5436	0.1065	0.2079	0.6176	0.3909	1.4243	
E-7	0.0648	0.2236	0.0312	0.2669	0.2311	0.4135	1.5909	
E-9	0.0943	0.6886	0.0573	0.1545	0.4826	0.5902	1.3154	
E-11	0.0246	0.1016	0.0084	0.0429	0.1041	0.1677	1.1340	
E-13	0.0305	0.1212	0.0493	0.0387	0.1133	0.2092	1.1689	
E-15	0.1591	0.1121	0.1625	0.3392	0.0972	0.1326	1.1039	
H-3	0.1931	0.1278	0.4397	9.4222	0.5241	0.2908	0.4561	
H-5	0.1388	0.1313	0.5376	0.5676	0.3031	0.0823	0.2651	
H-7	0.1874	0.2954	0.5348	0.6805	0.5148	0.2792	0.6135	
H-9	0.1941	0.8015	0.6636	0.8445	0.7600	0.5654	2.0164	
H-11	0.0576	0.0967	0.2936	0.1828	0.1428	0.1368	0.2139	
H-13	0.0326	0.0973	0.0259	0.0470	0.1118	0.1772	1.0437	

Table E-3

SUMMARY OF CENIZA-ARENA DEPOSITION MEASUREMENTS AT STATION 010
ROOF OF BANCO CENTRAL

Plate Collectors
(10" × 10")

RUN NUMBER 3

8th Story		9th Story		2nd Story	
Roof	(gms/ft ²)	Roof	(gms/ft ²)	Roof	(gms/ft ²)
C-3	3.3937	G-3	1.2647	M-8	0.2583
C-5	2.4492	G-4	0.3281	N-8	0.1198
C-7	1.8632	G-5	0.2560	N-1	3.0947
D-3	1.0596	G-6	0.2351	N-2	0.4671
D-4	0.4178	G-7	0.2507	N-3	0.3643
D-5	0.5688	G-8	0.6298	N-4	0.3767
D-6	0.8012	H-3	0.4780	N-5	0.3381
D-7	1.4119	H-4	0.3988	N-6	0.2665
D-8	11.9177	H-5	0.2229	N-7	0.2018
E-3	1.5647	H-6	0.2122	N-9	0.4564
E-4	0.4680	H-7	0.1529	M-2	0.2609
E-5	0.5389	H-8	0.0603	M-3	0.1788
E-6	0.6336			M-5	0.5353
E-7	1.3063	<u>2nd Story Roof</u>		M-7	0.4367
E-8	10.8298	B-1	5.9116	L-2	0.4874
F-3	1.7167	B-2	1.2238	K-2	1.1685
F-5	4.2036	B-3	1.0869	J-2	0.4645
F-7	4.5165	B-4	1.3410	H-2	0.3296
J-3	1.8103	B-5	1.7627	G-2	0.2509
J-5	0.7320	B-6	0.3222	F-2	0.5921
J-7	0.7621	B-7	1.4198	E-2	1.0785
K-3	3.4201	B-8	0.2203	D-2	0.7960
K-4	0.4341	B-9	0.4305	D-3	0.1624
K-5	0.3765	C-2	1.5369	F-3	0.1513
K-6	0.4396	C-3	1.1056	H-3	0.1601
K-7	0.9164	C-5	2.1886	K-3	0.0277
K-8	2.7954	C-7	2.7508		
L-3	1.7854	C-8	0.0836		
L-4	0.2475	D-8	0.1418		
L-5	0.1843	E-8	0.2073		
L-6	0.2626	F-8	0.5575		
L-7	0.0442	G-8	0.5898		
L-8	2.5777	H-8	0.2858		
M-3	1.4024	J-8	0.1251		
L-5	0.4328	K-8	0.2263		
M-7	0.4199	L-8	0.2659		

Table E-3 (concluded)

RUNS NUMBER 12 AND 13					
8th and 9th Story Roof (#12)		8th and 9th Story Roof (#12)		2nd Floor Story (#13)	
	(gms/ft ²)		(gms/ft ²)		(gms/ft ²)
C-3	0.4210	J-3	0.3016	A-3	7.2957
C-5	0.6494	J-5	0.1524	A-4	8.6594
C-6	0.5307	J-6	0.1490	A-5	5.1943
C-8	0.2269	J-8	0.3277	A-6	1.8738
D-8	0.3589	K-8	0.7056	A-7	0.9341
D-6	0.1857	K-6	0.0650	C-7	1.8305
D-5	0.1198	K-5	0.0525	C-6	1.2340
D-3	0.2208	K-3	0.4007	C-5	1.1864
F-3 ^a	0.2142	L-3	0.2689	C-4	1.0782
F-5 ^a	0.5054	L-5	0.0277	P-4	0.4371
F-7 ^a	0.4855	L-6	0.0309	M-4	0.4204
F-8 ^a	0.2727	L-8	0.9210	M-5	0.3860
G-8 ^a	0.3974	M-8	0.0648	P-5	0.6680
G-7 ^a	0.0750	M-6	0.0339	P-6	0.4563
G-5 ^a	0.0574	M-5	0.0472	M-6	0.4141
G-3 ^a	0.2187	M-3	0.5591	M-7	0.3106
H-3 ^a	0.0959			P-7	0.4780
H-5 ^a	0.0444	2nd Story Roof (13)		P-8	0.6837
J-5 ^a	0.0512			M-8	0.2125
H-7 ^a	0.0515	A-1	3.6846	M-9	0.5772
H-8 ^a	0.0663	C-1	6.3133	P-9	0.7899
J-8 ^a	0.1368	E-1	10.9774	L-9	0.1964
J-7 ^a	0.0879	G-1	11.6062	L-8	0.5729
J-3 ^a	0.0362	J-1	3.6583	J-9	0.2024
E-3	0.3695	M-1	1.1060	G-9	0.3561
E-5	0.1882	P-3	0.5852	G-8	0.1504
E-6	0.2257	M-3	0.1853	E-8	0.3189
E-8	0.1976	L-3	1.1583	E-9	0.1517
F-8	2.7973	J-3	2.3322	C-9	0.2344
F-6	1.6830	G-3	1.0650	C-8	0.0954
F-5	1.1610	E-3	0.5397	A-8	0.7277
F-3	0.5817	C-3	0.5610	A-9	0.4193

^a 9th story roof

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13 ABSTRACT <p>The continuing eruptions of Volcán Irazú and the consequent deposition of volcanic debris on the city of San José, Costa Rica, offered a unique opportunity to improve our understanding of deposition and redistribution of fallout-like particles (ceniza-arena) around structures. The techniques for the measurement of the deposition and redistribution of fallout were proof-tested and evaluated during the series of field measurements. The results were limited by the lack of volcanic activity during the measurement periods; however, the measurements showed a possible relationship between wind speed and the mass of fallout deposited.</p>		

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT

Volcán Irazú
 Volcanic debris
 Fallout
 Deposition
 Redistribution
 Particles
 Weathering
 Fallout collectors
 Wind measurements

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