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VERTICAL WINDSHEAR BELOW 1 KM FOR BERLIN, GERMANY AND CENTREVILLE, ALABAMA

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Research, Development, and Engineering Center

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Windspeed differences, wind direction differences, and vertical windshear within the layer from surface to 1 km were compared for two locations, Berlin, Germany and Centreville, Alabama. Seasonal variation of the cumulative distributive function of vertical windshear were plotted. Maximum windshear generally occurred during the winter with the exception that above 99% probability, the windshear in the spring usually exceeded the winter windshear. Vertical windshear was found to increase with increasing surface windspeed up until the 90 to 95% probability range.

Wind direction changes associated with extreme windshears were found to be site-specific. For the layer surface to 600m, vertical windshear of greater than 10m/s was accompanied by a wind direction change of greater than 60 degrees six times as often at Centreville as compared with Berlin.

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I. INTRODUCTION

There are many reports in the literature concerning the vertical variation of the horizontal wind (i.e., vertical windshear) in the boundary-layer. The spatial variability of the wind structure below 1 km affects aeronautical activities such as aircraft takeoffs and landings [1], parachute deployment of men and material [2], and missile launchings [3]. The knowledge is also required for prediction of air pollution dispersal [4].

The winds below 1 km have been analyzed using a variety of techniques including optical radar [5,6], acoustic radar [7,8], forward-scatter CW radar [9], single-theodolite pibals [4,10], double-theodolite pibals [11], cinetheodolite [12], radiosondes and rawinsondes [1], meteorological towers instrumented with anemometers [13, 14, 15], and rocketsondes [16]. Most of the investigators mentioned above monitored the wind for periods of a few days to a few weeks. Broadly speaking, most NASA reports that have wind climatology (i.e., statistics based on a few thousand wind profiles) have reported windspeed differences over 5 km intervals [17], or have been concerned with windshears above 8 km in altitude [18]. For example, Johnson [18] computed windshears in 1 km intervals, but only maximum windshears in the layer 10 to 17 km were listed. Grossman and Beran [1] and Abramovic and Glazunov [10] are the only references that provide a climatology of extreme low-level windshear for locations in the U.S. and U.S.S.R., respectively.

The purpose of this report is to establish a long-term climatology of windspeed differences, wind direction differences, and vertical windshear within the layer from surface to 1 km. The discussion will focus on the seasonal variation of the cumulative distribution function of vertical windshears. Wind direction changes associated with extreme vertical windshears will also be discussed.

II. METHODS AND DATA

Two data sets were created for the purpose of analyzing vertical windshear in the lower atmosphere. Each observation in the Centreville, Alabama data set consists of windspeed and wind direction at the surface (approximately 10 m), 300 m, 600 m, and 900 m for the period of record 1975-1983. Due to insufficient data at the 300 m level, the Berlin-Templehof data consist of windspeed and wind direction at the surface, 600 m, and 900 m for the period of record 1976-1983. These data were extracted from the set of upper-air soundings (radiosonde ascents) provided to us by the U.S. Air Force Environmental Technical Applications Center.

Windshear was computed utilizing both windspeed and wind direction differences as indicated by the following notation:

$V_s = V_2 - V_1$	Scalar Shear
$\Delta\theta = \theta_2 - \theta_1, \quad \lvert \Delta\theta \rvert < 180°$	Angular Difference
$\phi_s = 2\sqrt{V_1 V_2}\, \sin(\Delta\theta \,\vert\, 2)$	Angular Shear Magnitude
$S = \sqrt{V_s{}^2 + \phi_s{}^2}$	Total Vector Shear

where V_s is the difference in windspeed between two altitudes, and $\Delta\theta$ is the difference in wind direction between two altitudes. See Essenwanger [19] for a derivation of the equation for the total vector shear.

For both Centreville and Berlin, the cumulative probability of windshear in the layers surface to 600 m and surface to 900 m are presented as a set of figures which includes:

a. The seasonal variation of windshear;

b. Windshear as a function of surface windspeed;

c. Frequency distribution of wind direction change for extreme windshear. For Centreville only, the cumulative probability of windshear in the layers surface to 300 m, 300 m to 600 m, and 600 m to 900 m are also shown.

As a supplement, frequency distributions of windspeed and wind direction differences are listed for the layers surface to 600 m, 600 m to 900 m, and surface to 900 m for both Centreville and Berlin, and surface to 300 m, 300 m to 600 m, and 300 m to 900 m for Centreville only.

III. WINDSHEAR CLIMATOLOGY

Windshear climatology has been established using low altitude winds available from radiosonde upper-air soundings for both locations. In this measurement system the wind data are determined at several points and subsequently averaged over an altitude layer of approximately 600 m. Precision optical radar is not used for tracking, which results in the small-scale fluctuations not being detected. Radiosonde (or rawinsonde) winds have RMS vector errors of a least 2 m/s [20], while errors of 15 m/s have been quoted for high winds usually encountered at high altitudes which are not of interest to us in this report. In contrast, the FPS-16/Jimsphere system and MSS Windsonde were evaluated by NASA [20] to have vector errors of 0.5 m/s and 0.7 m/s, respectively. Wind profiles obtained with such systems retain the small-scale features of the wind field (neither the Jimsphere nor the Windsonde are currently in daily operational use). These considerations should be kept in mind when evaluating the windshear climatology, although any system has error sources, e.g., delay in antenna response, spurious balloon fluctuations, etc.

The cumulative probability (percent) of vertical windshear below 1 km are presented as a set of figures (Figures 1 thru 9) using the extreme-value probability scale. The units of windshear are meters per second per shear interval, with the shear interval indicated on each figure.

The data base used in this study consists of 4,482 observations for Centreville and 6,167 observations for Berlin broken down according to surface windspeed differences and wind direction differences (Tables 1 thru 9).

Surface Windspeed	Berlin (% of total)	Centreville (% of total)
0-2 m/s	19.1%	22.5%
2-3	17.8	35.2
3-5	33.4	26.7
5-6	13.0	8.3
6-7	8.0	4.2
>7	8.7	3.1

The cumulative probability of windshear for the surface-600 m layer and the surface - 900 m layer (annual summary) are shown for Centreville in Figure 1A and Berlin in Figure 1B. Note that two different shear intervals are plotted in the same figure, i.e., that a 600 m shear interval is being compared to a 900 m shear interval.

The seasonal variation of windshear for the layer surface to 600 m are shown for Centreville and Berlin in Figures 2A and 2B, respectively. The largest shear values are consistently observed during the winter, with the exception that the maximum value was often observed in the spring. This seasonal pattern also holds for the 300 m (Figures 6 and 7) and 900 m (Figures 3A and 3B) shear intervals.

The seasonal variation of windshear for the layer surface to 900 m are shown for Centreville and Berlin in Figures 3A and 3B, respectively. For Berlin, the fall shear values are close to the winter shear values in the range of 50 to 99 percent probability.

Three equal shear intervals (300 m) are shown for Centreville in Figure 4, surface-300 m, 300 m - 600 m, and 600 m - 900 m layer. The largest shear values are associated with the surface - 300 m layer except above 98 percent probability, in which the 600 m - 900 m layer revealed the highest shear. This may be attributed to higher mean horizontal windspeeds at the 900 m level.

Windshear in the layer 600 m - 900 m (annual summary) are compared for Berlin and Centreville. The windshear in this layer was found to be considerably larger at Centreville. This may be due to hilly terrain near Centreville which causes a channeling of the winds, which serves to increase the windspeeds.

Figures 6 and 7 display the seasonal variation of windshear in the layers 300 m - 600 m and 600 m - 900 m respectively for Centreville (both are shear intervals of 300 m). The seasonal patterns that are revealed in these two graphs are nearly identical.

Windshear distribution was found to clearly be a function of surface windspeed (m/s). Windshear in the layer surface - 600 m as a function of surface windspeed for Centreville and Berlin are plotted in Figures 8A and

8B respectively. Note that in Figure 8A the curve corresponding to surface windspeed greater than 7 m/s was omitted because it was nearly identical to the curve for surface windspeed 6-7 m/s. Windshear in the layer surface - 900 m as a function of surface windspeed for Centreville and Berlin are plotted in Figures 9A and 9B respectively. The windshear was found to increase with increasing surface windspeed up until about 90 percent probability. Above 90 percent this relationship breaks down, with the largest windshears (above 98 percent probability) being observed for surface winds of 5-6 m/s.

The final set of figures (Figures 10 thru 13) consists of the frequency distribution of wind direction change for extreme windshears in the layers surface - 600 m and surface - 900 m for Berlin and Centreville.

Windshear greater than 10 m/s in the layer surface - 600 m occurred with a frequency of 8.4 percent at Berlin and 9.3 percent at Centreville. The wind direction changes were distributed over a much broader range for Centreville (Figures 10A and 10B). However, for windshear greater than 15 m/s in the surface - 600 m layer the wind direction changes showed similar distributions for both locations (Figures 11A and 11B). Windshear greater than 15 m/s occurred with a frequency of less than 1 percent in this layer.

The wind direction changes for windshear greater than 10 m/s in the layer surface to 900 m were also more widely dispersed for Centreville than for Berlin (Figures 12A and 12B). This pattern also emerges for windshear greater than 15 m/s in this layer (Figures 13A and 13B). Windshear greater than 10 m/s in the layer surface - 900 m occurred with a frequency of 14.3 percent at Centreville and 15.5 percent at Berlin. A noteworthy result is that for windshear greater than 10 m/s in the layer surface - 900 m, wind direction changes of 60 degrees or more occurred 38 percent of the time, compared to only a 10 percent frequency for Berlin. Windshear of greater than 15 m/s in this layer occurred with a frequency of 2.4 percent at Berlin and 3.3 percent at Centreville. Wind direction changes of 60 degrees or more for cases of windshear greater than 15 m/s in the layer surface - 900 m occurred with a frequency of 8.2 percent at Berlin in contrast to 34 percent for Centreville. It should be noted that all wind directions are reported in multiples of 5 degrees.

There were a small number of cases in which windshear was greater than 20 m/s for the 900 m shear interval at both Centreville and Berlin. For the 18 cases at Berlin in which windshear exceeded 20 m/s in the surface - 900 m layer, all wind direction changes were less than 50 degrees. For Centreville 25 cases were observed, but in 11 cases wind direction changes were equal to or greater than 60 degrees.

In the layer surface - 600 m, windshear of greater than 10 m/s was accompanied by a wind direction change equal to or greater than 60 degrees for 2.6 percent of all observations at Centreville compared to 0.4 percent at Berlin. For the thicker layer of surface - 900 m, windshear of greater than 10 m/s was accompanied by a wind direction change equal to or greater than 60 degrees for 5.4 percent of all observations at Centreville in contrast to 1.6 percent at Berlin.

IV. SUMMARY AND CONCLUSIONS

The climatology of vertical windshear below 1 km for Centreville, Alabama and Berlin, Germany has been discussed by analyzing available radiosonde ascents, with emphasis on the occurrence of windshear extremes. Although this measurement technique is not sensitive to small-scale wind fluctuations, extracting the appropriate data from the upper-air soundings allowed us to create the best available long-term record for winds at these heights.

The major findings of this work are:

a. The seasonal variation of windshear within the same layer was shown. Overall, winter was the season for maximum shears, summer the season for minimum shears. An exception was that above 99 percent probability, the value of shear in the spring usually exceeded the winter shear value.

b. Windshear was shown to be a function of surface windspeed. The windshear was found to increase with increasing surface windspeed up until 90 to 95 percent probability. The largest windshears were observed for surface winds of 5-6 m/s.

c. Wind direction changes associated with extreme windshears are site-specific. For the layer surface to 600 m, windshear of greater than 10 m/s was accompanied by a wind direction of greater than 60 degrees six times as often at Centreville as compared with Berlin.

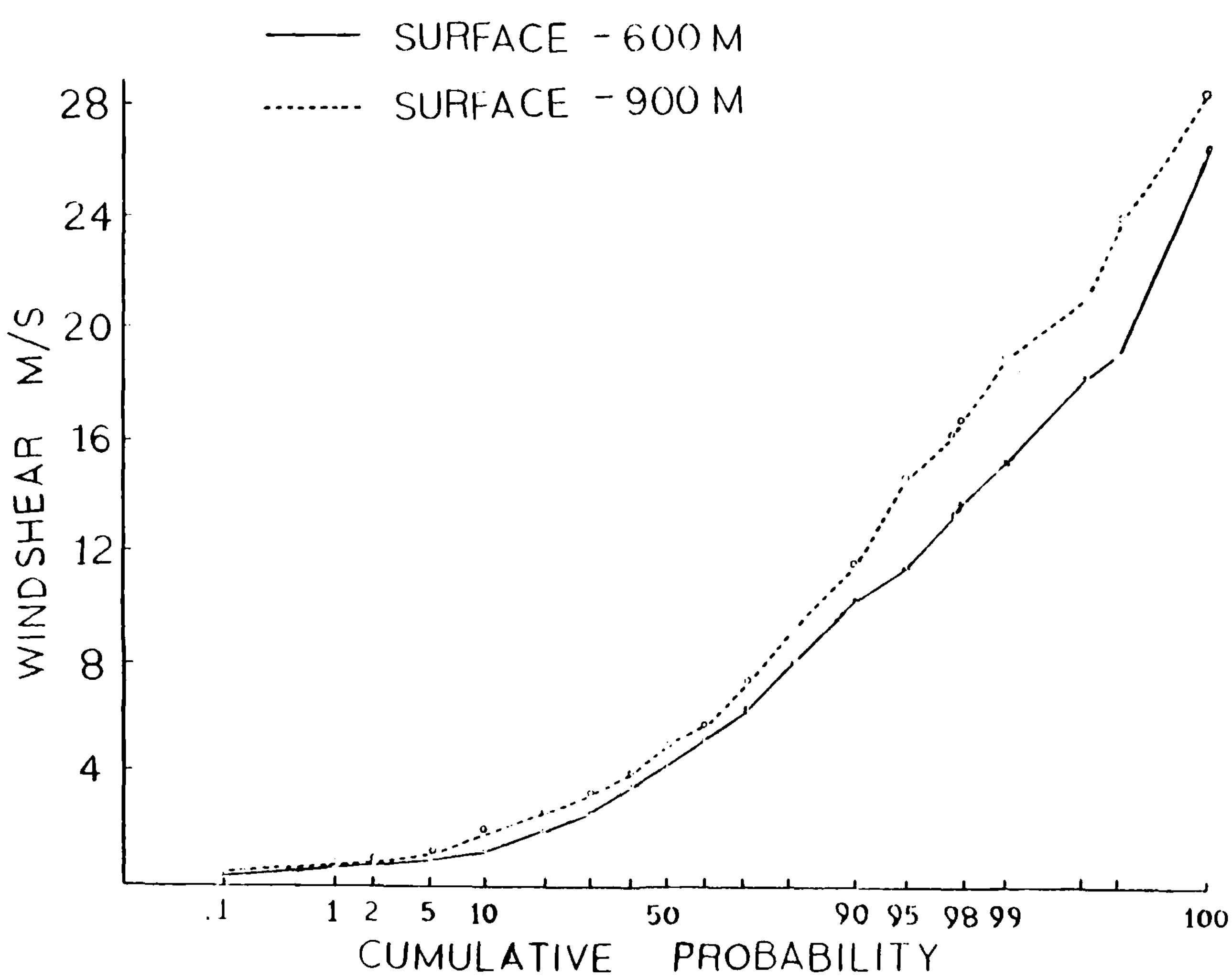

Figure 1A. The cumulative probability (%) of windshear (m/s) in the layers surface to 600 m and surface to 900 m for Centreville, Alabama, 1975-1983 (annual summary).

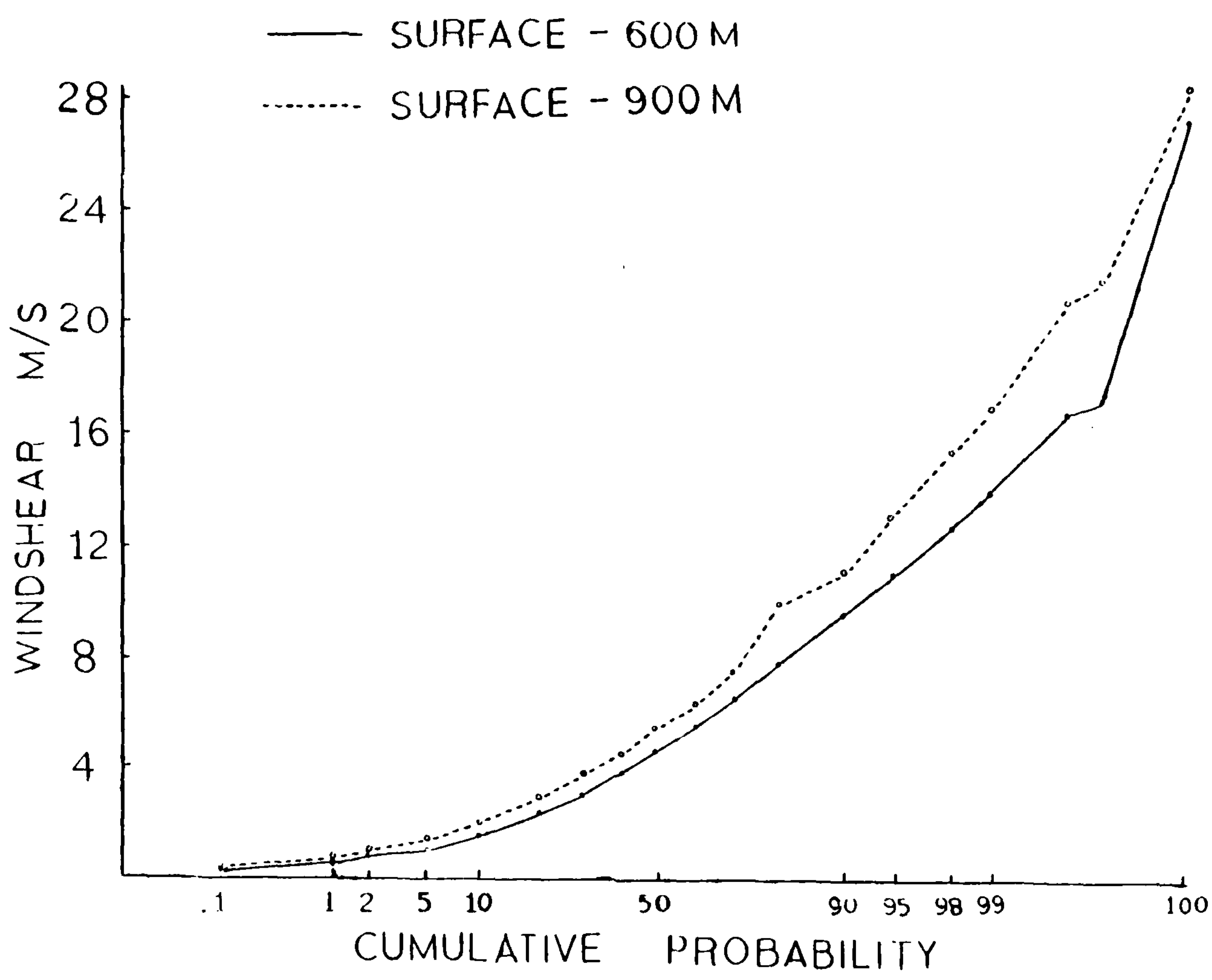

Figure 1B. The cumulative probability (%) of windshear (m/s) in the layers surface to 600 m and surface to 900 m for Berlin, Germany, 1976-1983 (annual summary).

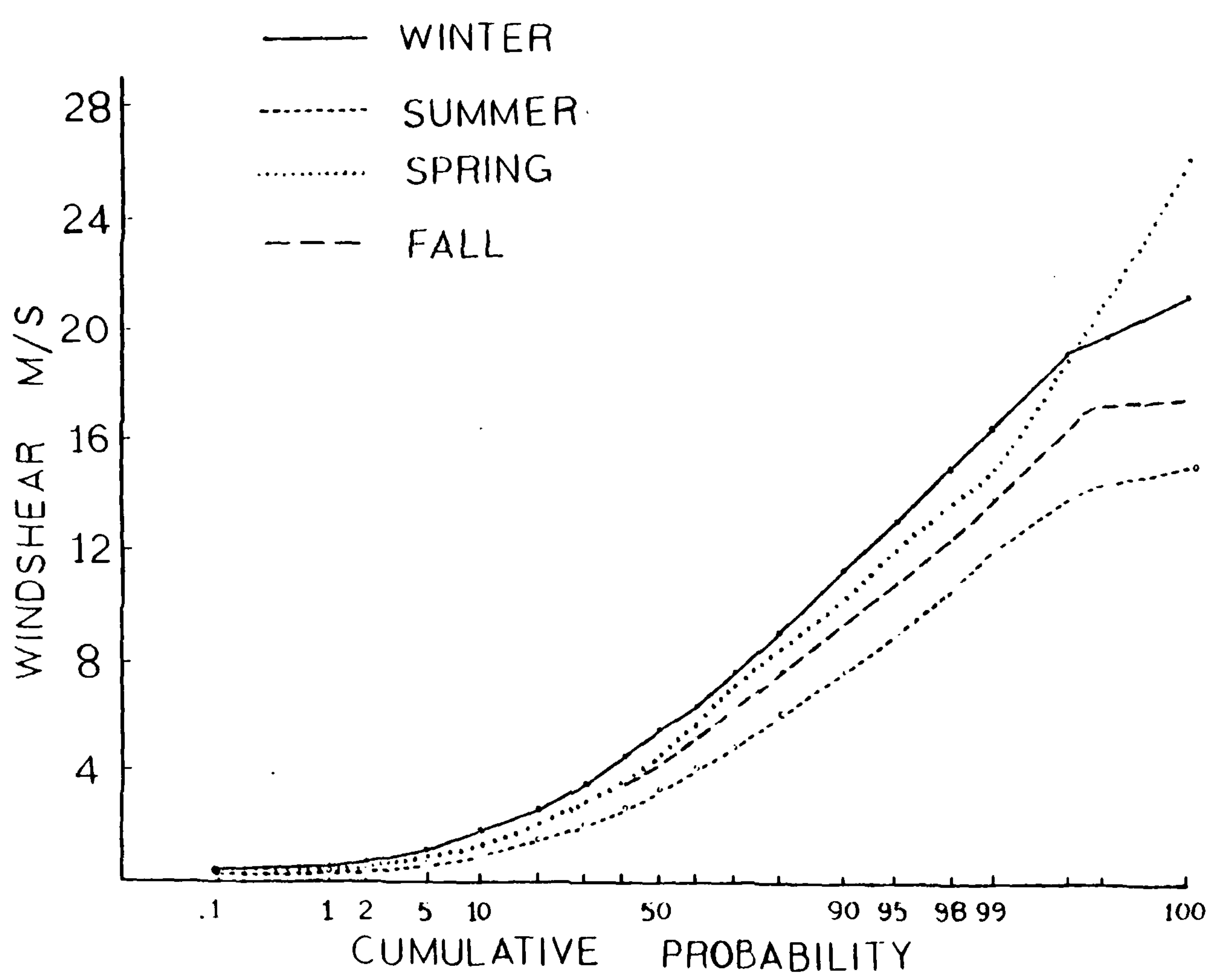

Figure 2A. Seasonal variation of the cumulative probability (%) of windshear (m/s) in the layer surface to 600 m for Centreville, Alabama, 1975-1983.

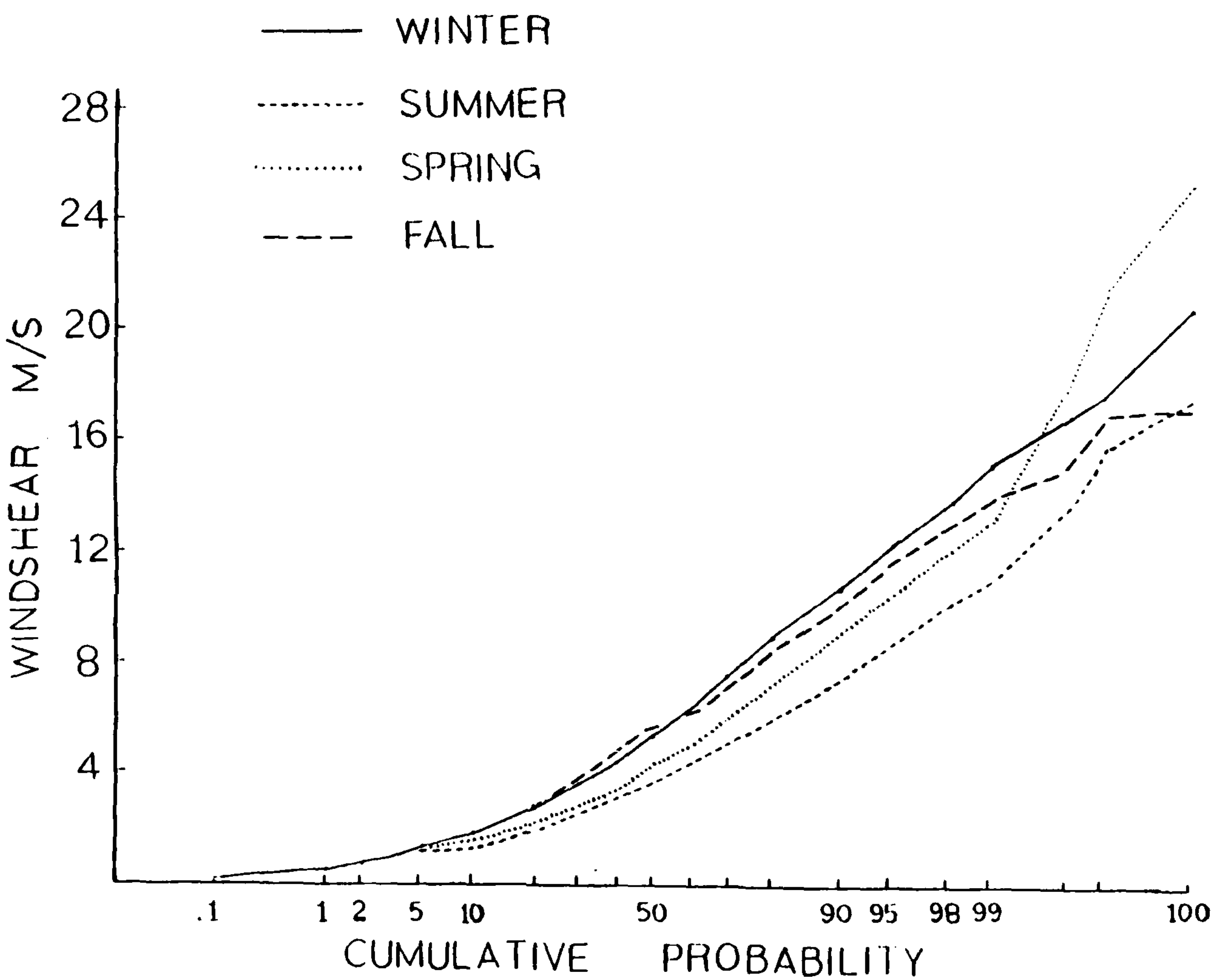

Figure 2B. Seasonal variation of the cumulative probability (%) of windshear (m/s) in the layer surface to 600 m for Berlin, Germany, 1976-1983.

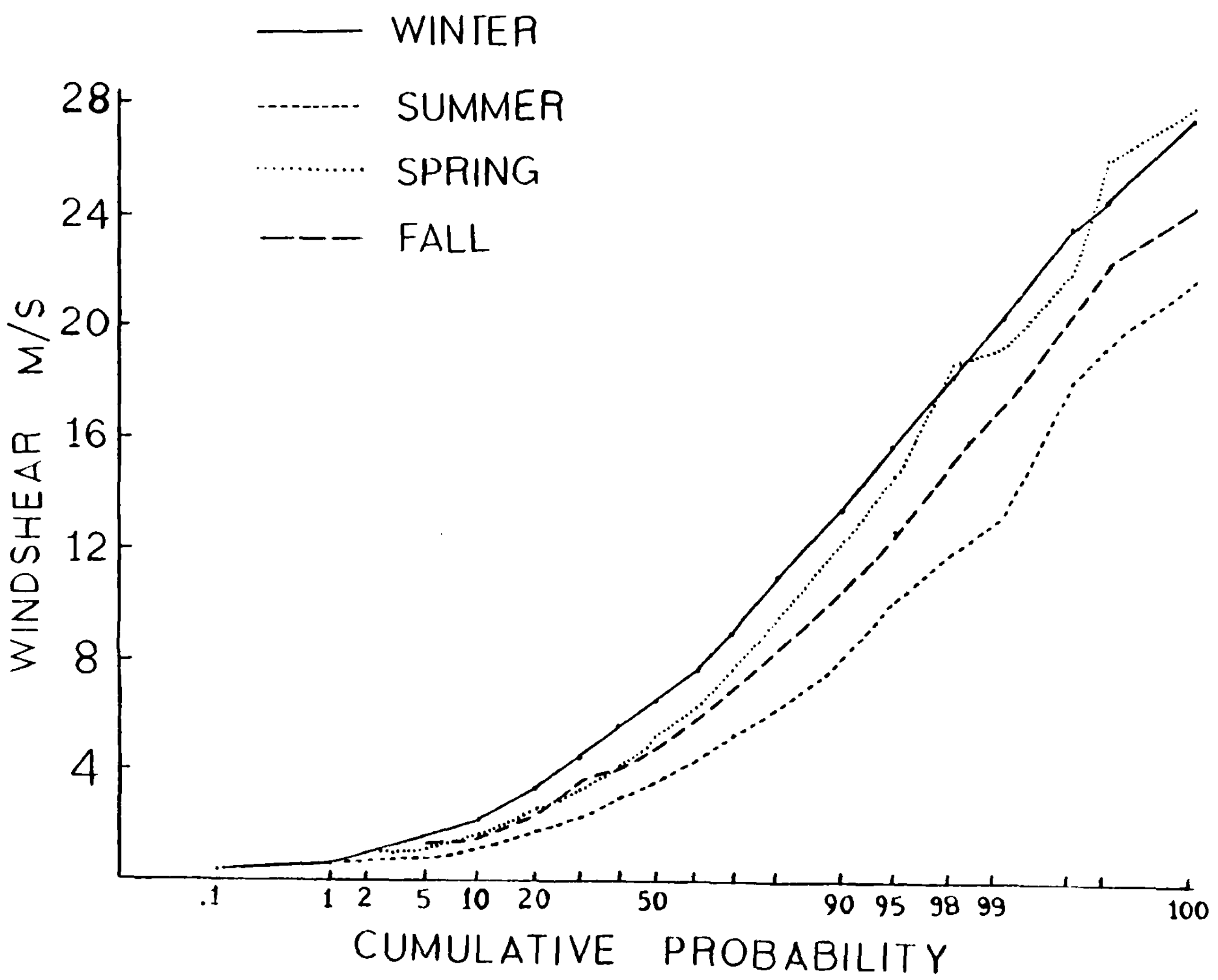

Figure 3A. Seasonal variation of the cumulative probability (%) of windshear (m/s) in the layer surface to 900 m for Centreville, Alabama, 1975-1983.

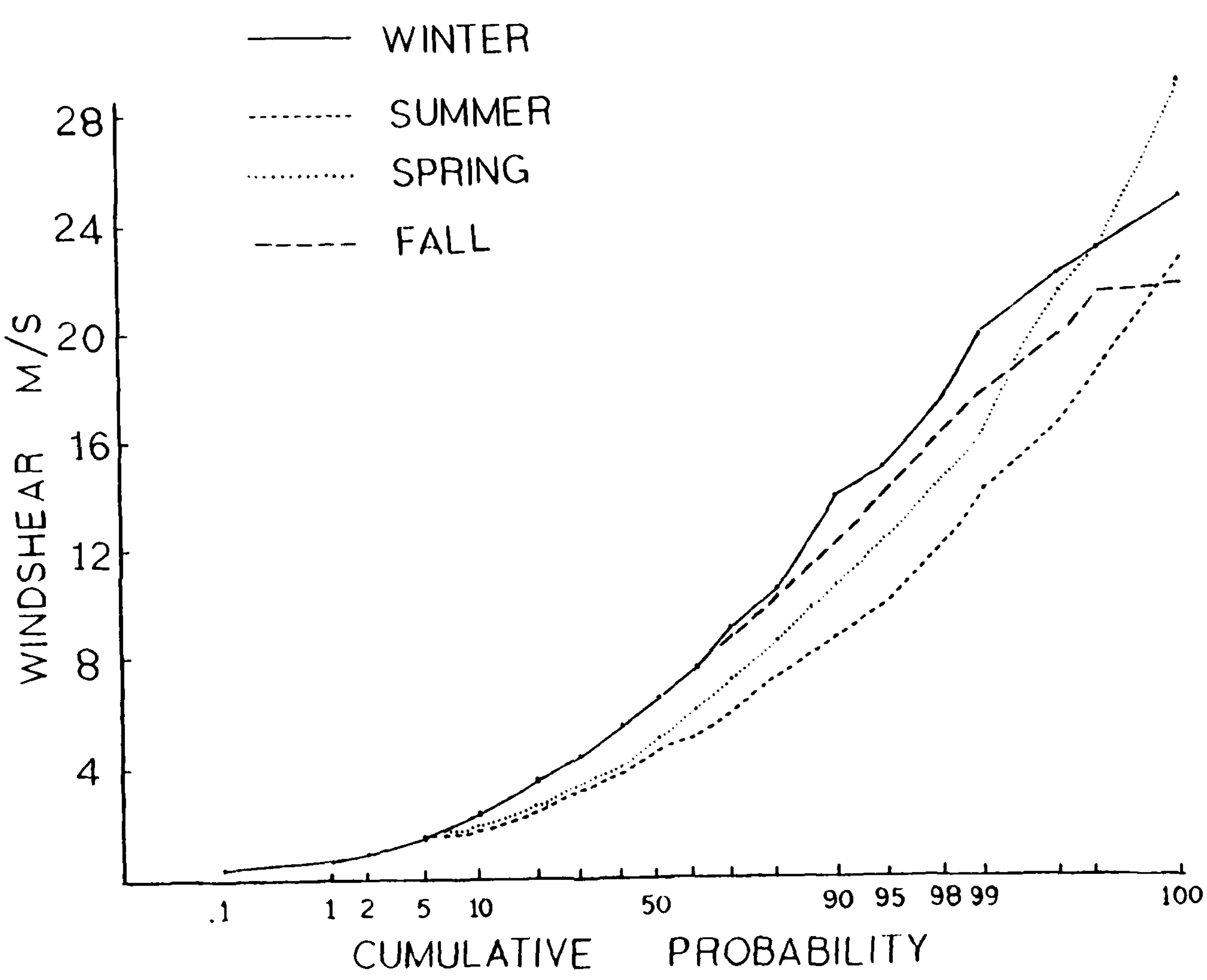

Figure 3B. Seasonal variation of the cumulative probability (%) of windshear(m/s) in the layer surface to 900 m for Berlin, Germany, 1976-1983.

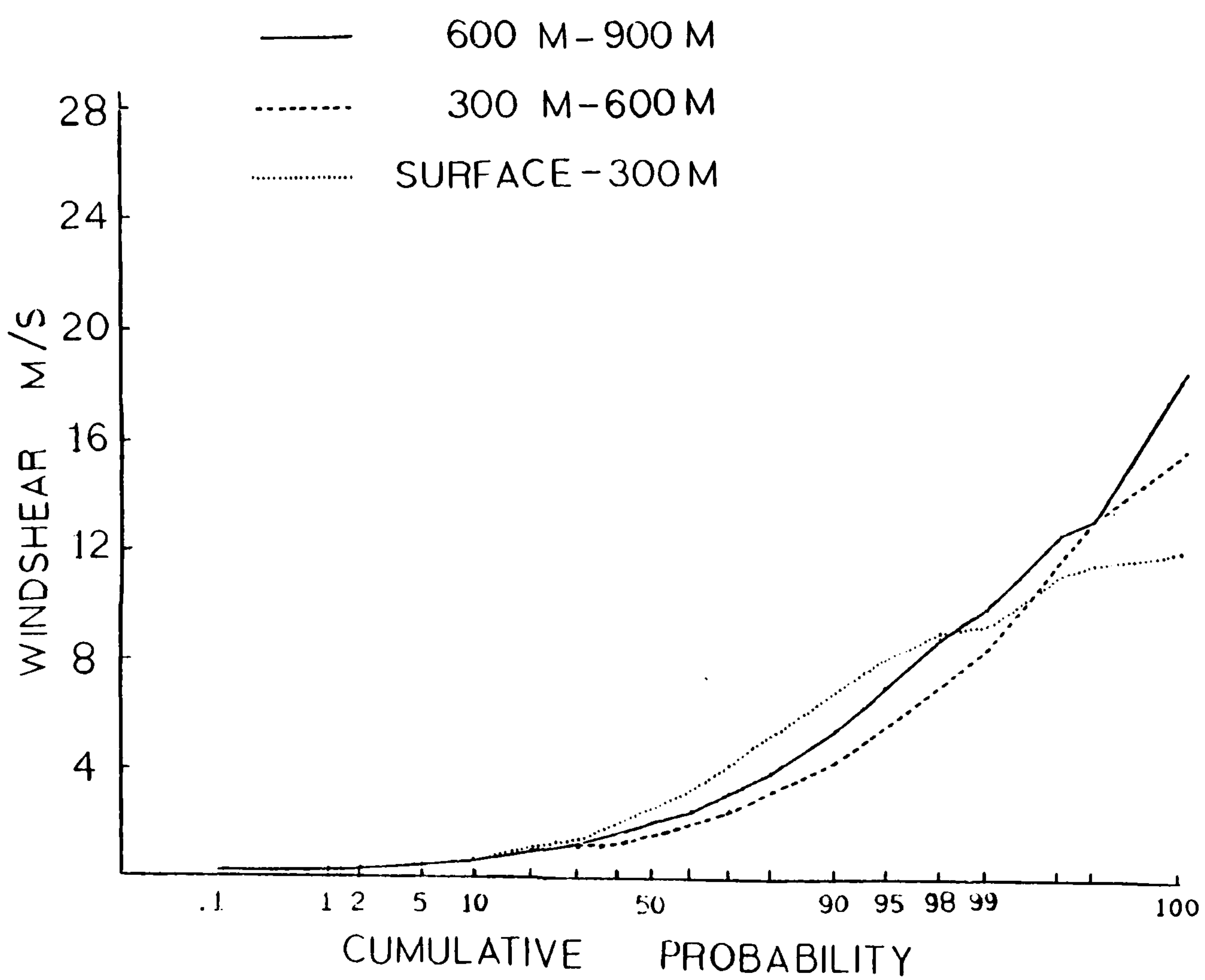

Figure 4. The cumulative probability (%) of windshear (m/s) in the layers surface to 300 m, 300 m to 600 m, and 600 m - 900 m for Centreville, Alabama, 1975-1983 (annual summary).

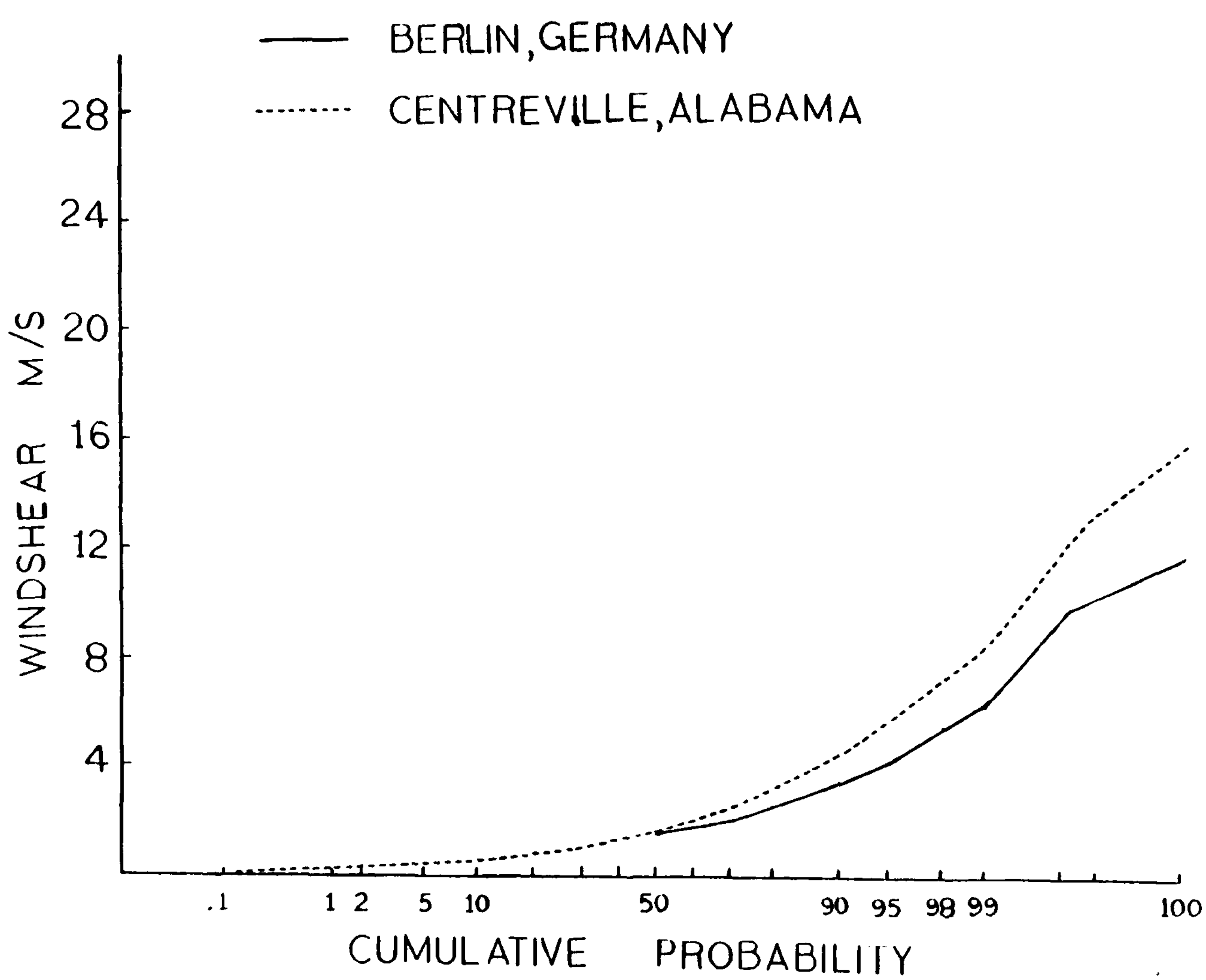

Figure 5. The cumulative probability (%) of windshear (m/s) in the layer 600 m to 900 m for Berlin, Germany, 1976-1983 and Centreville, Alabama, 1975-1983 (annual summary).

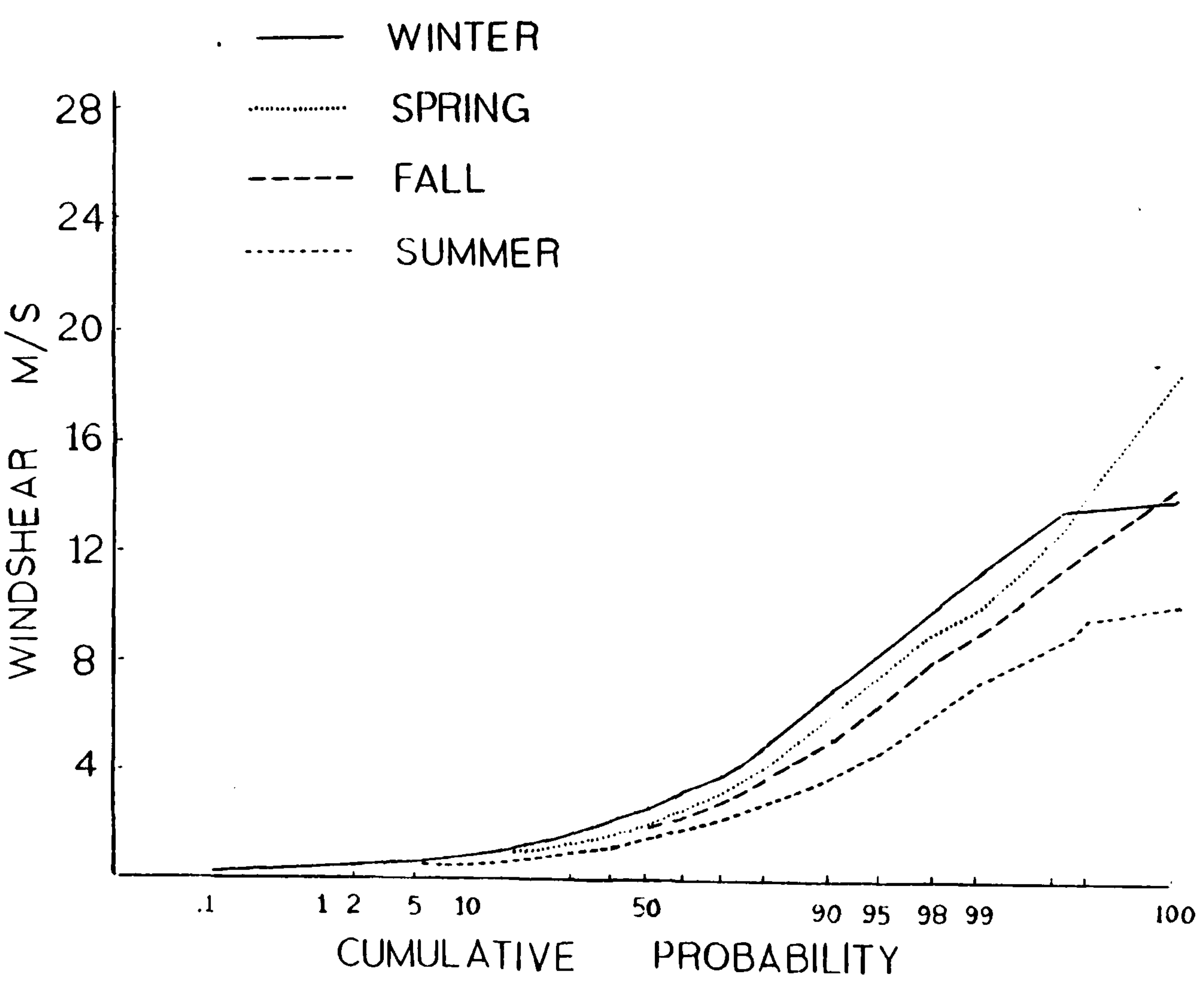

Figure 6. Seasonal variation of the cumulative probability (%) of windshear (m/s) in the layer 300 m to 600 m for Centreville, Alabama, 1975-1983.

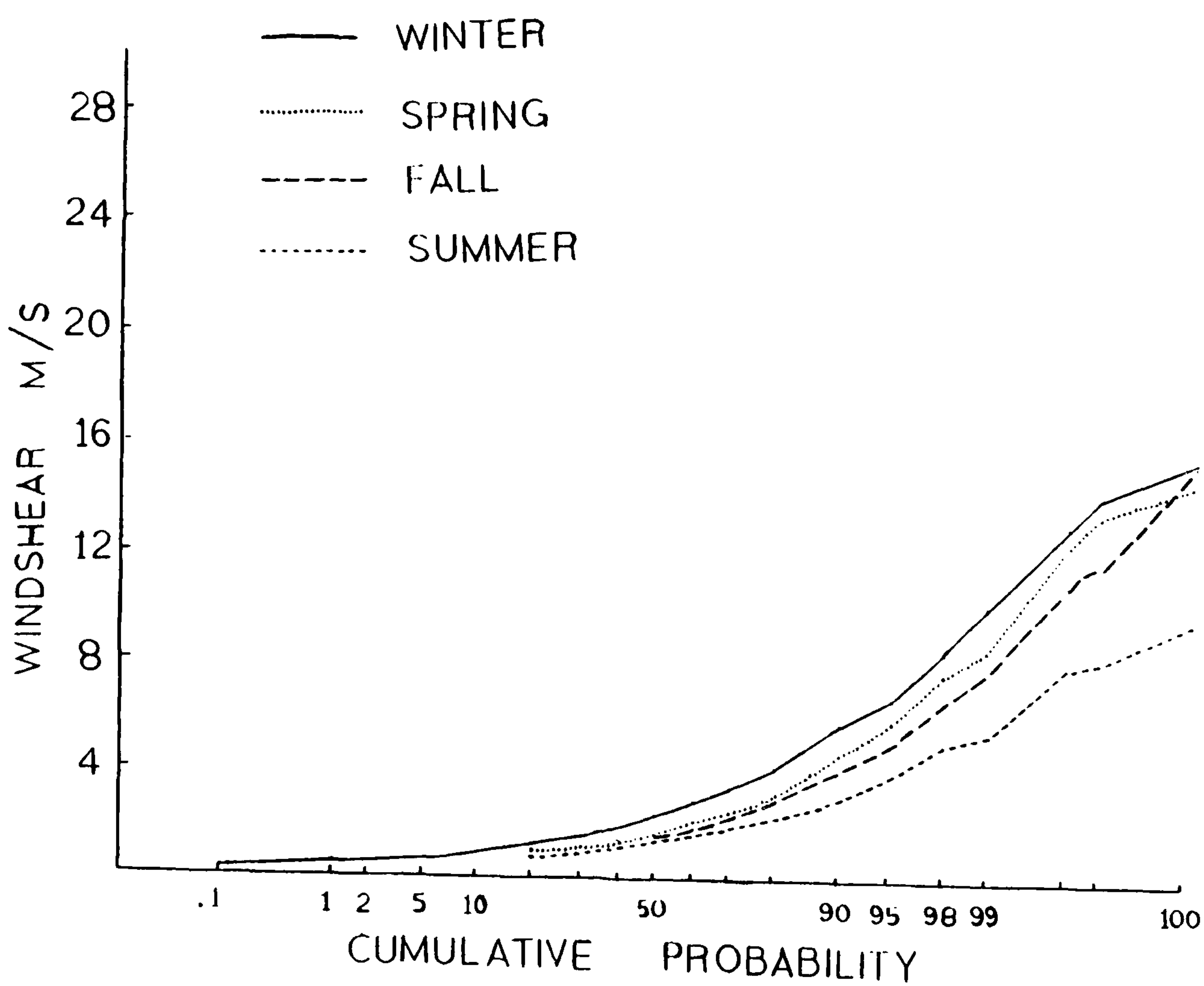

Figure 7. Seasonal variation of the cumulative probability (%) of windshear (m/s) in the layer 300 m to 600 m for Centreville, Alabama, 1975-1983.

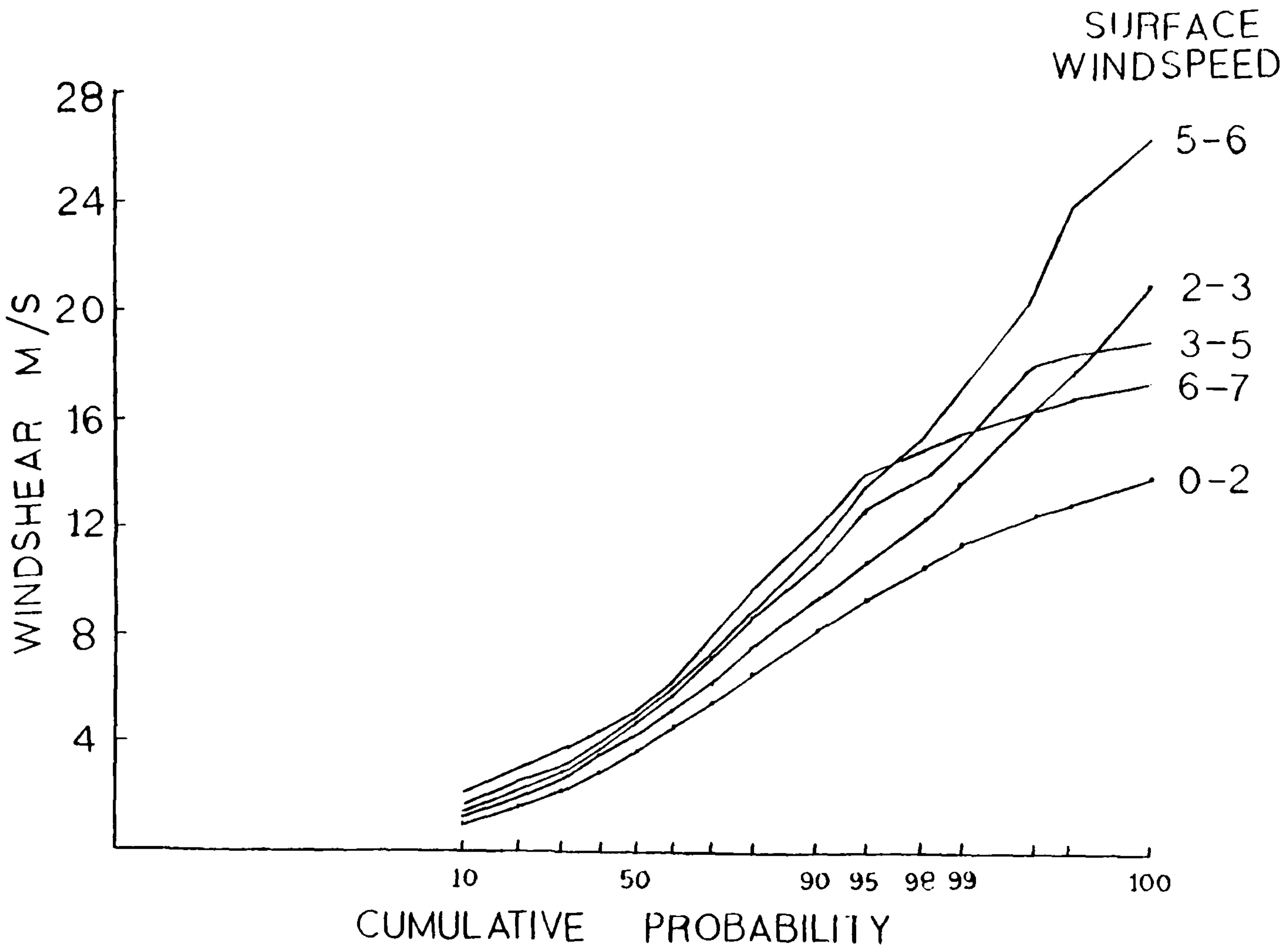

Figure 8A. Variation of the cumulative probability (%) of windshear (m/s) with surface windspeed (m/s) in the layer surface to 600 m for Centreville, Alabama, 1975-1983.

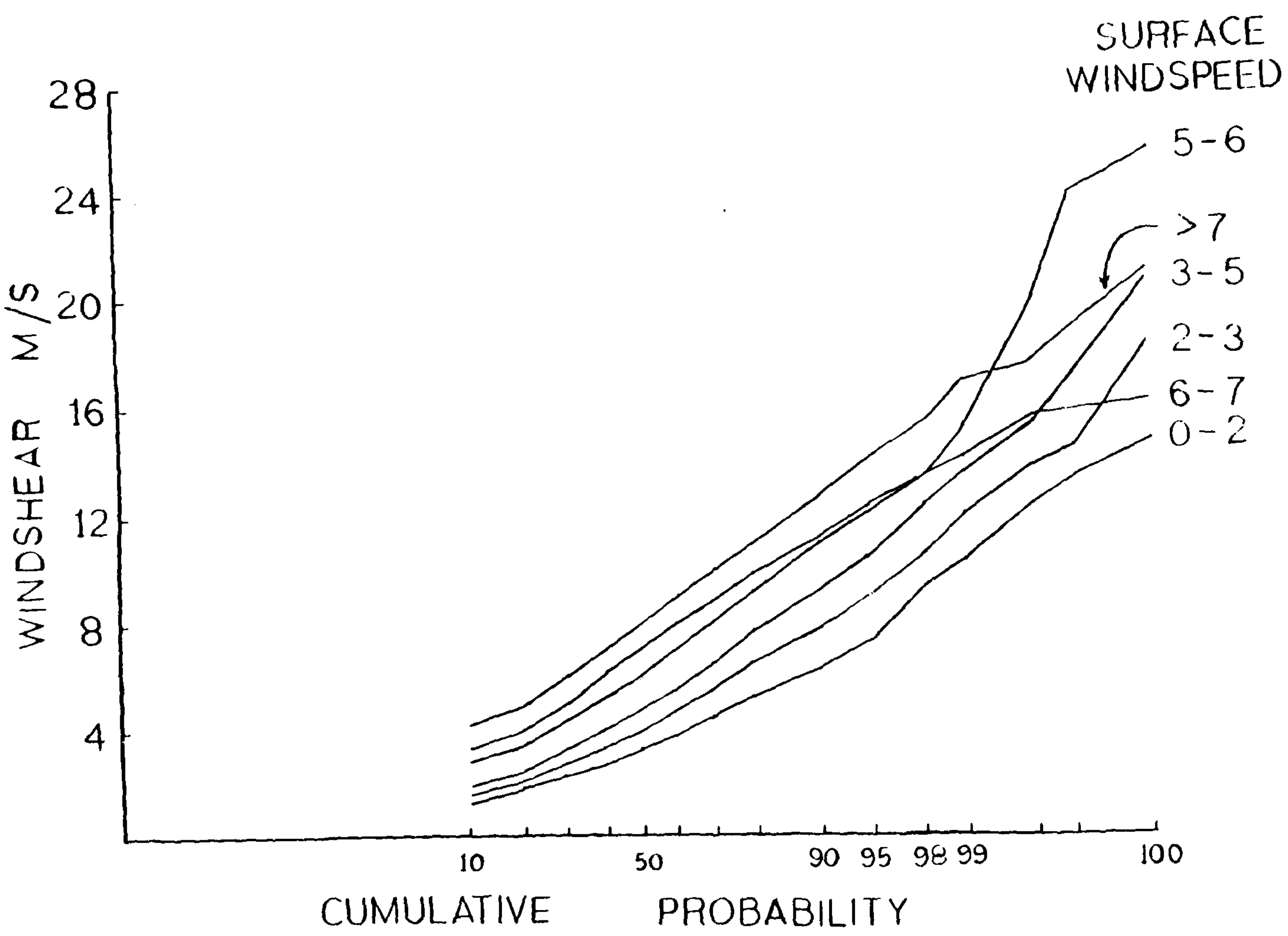

Figure 8B. Variation of the cumulative probability (%) of windshear (m/s) with surface windspeed (m/s) in the layer surface to 600 m for Berlin, Germany, 1976-1983.

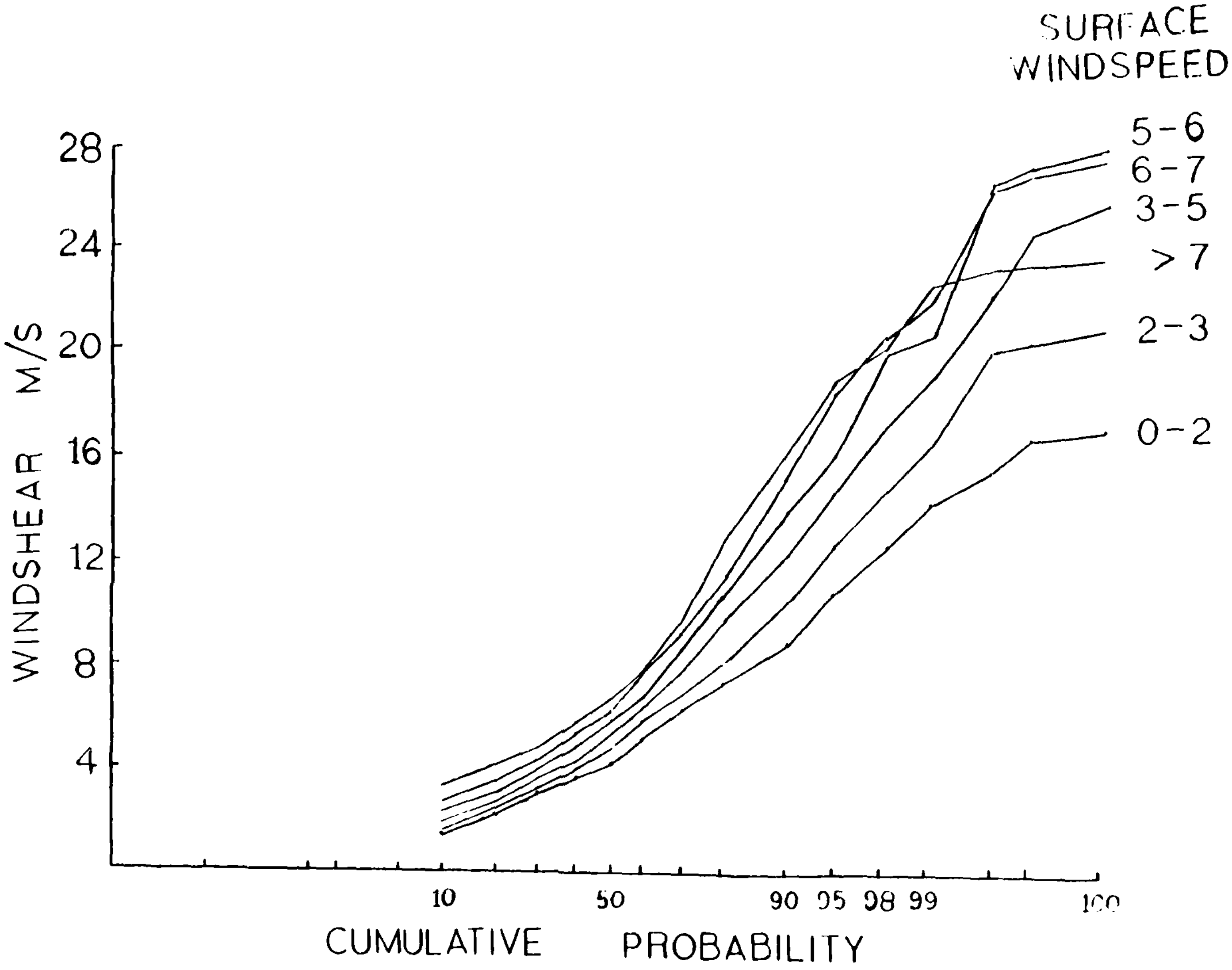

Figure 9A. Variation of the cumulative probability (%) of windshear (m/s) with surface windspeed (m/s) in the layer surface to 900 m for Centreville, Alabama, 1975-1983.

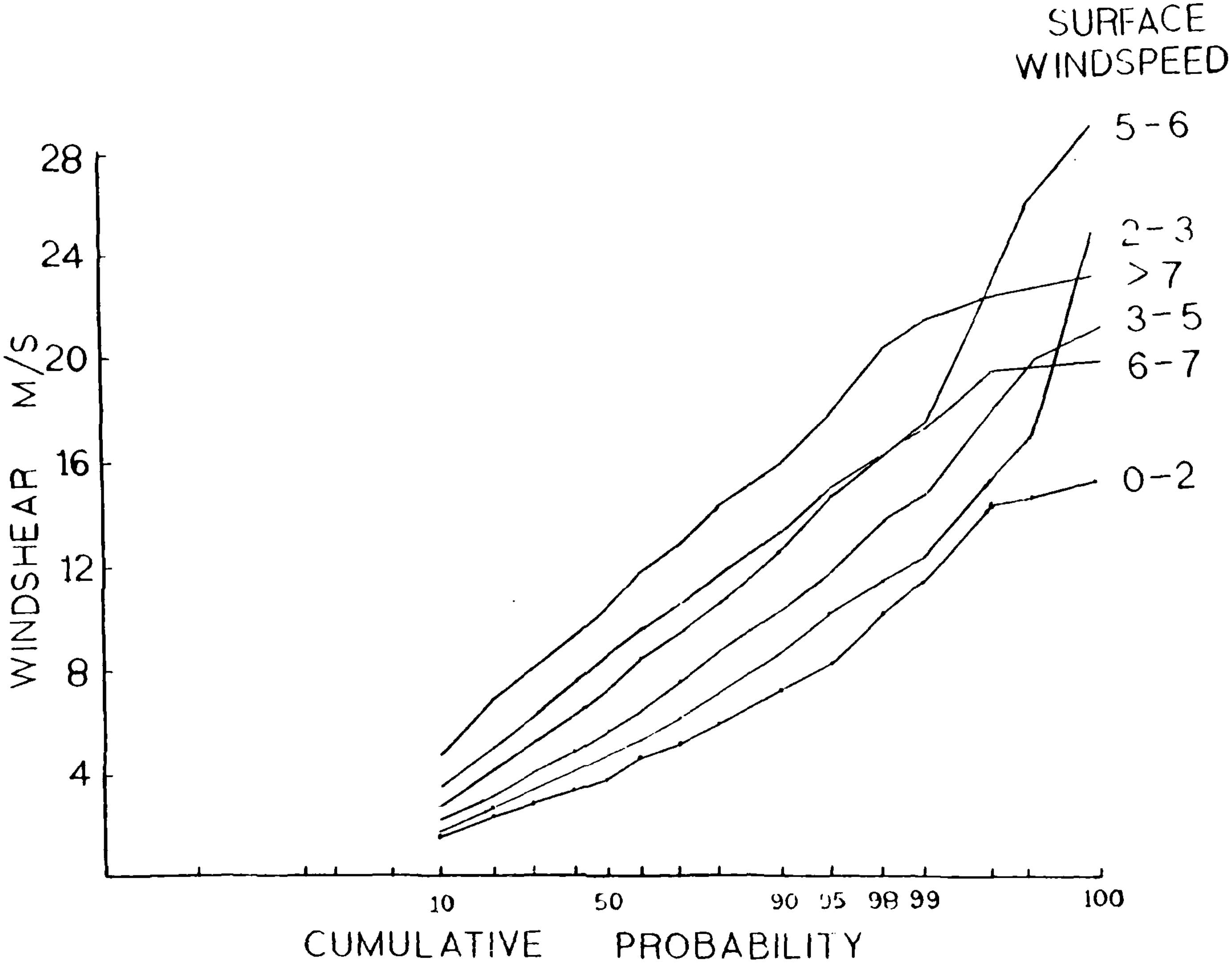

Figure 9B. Variation of the cumulative probability (%) of windshear (m/s) with surface windspeed (m/s) in the layer surface to 900 m for Berlin, Germany, 1976-1983.

TABLE 1A. Cumulative Percent Occurrence of the Windspeed Differences (meters/second) between Surface and 600 Meters for Berlin, Germany 1976-1983.

DATE	0-2	3-5	6-8	9-11	12-14	≥15
Jan (570)	28.60%	62.11%	84.74%	95.96%	99.65%	100.00%
Feb (509)	35.36	74.07	92.73	98.04	100.00	100.00
Mar (568)	29.05	60.56	86.80	97.71	99.47	100.00
Apr (525)	41.71	80.57	94.86	99.24	99.81	100.00
May (562)	47.51	81.85	96.26	99.82	100.00	100.00
Jun (490)	48.98	88.16	97.55	99.59	100.00	100.00
Jul (500)	43.40	84.20	98.00	99.80	99.80	100.00
Aug (514)	39.11	83.46	97.67	99.81	100.00	100.00
Sep (461)	30.37	70.50	93.93	99.57	100.00	100.00
Oct (502)	24.30	63.15	87.25	97.81	100.00	100.00
Nov (503)	20.68	54.87	83.90	96.42	99.40	100.00
Dec (463)	21.38	53.13	77.54	95.90	99.57	100.00
Winter (1542)	28.66	63.36	85.21	96.63	99.74	100.00
Spring (1655)	39.34	74.14	92.57	98.91	99.76	100.00
Summer (1504)	43.75	85.24	97.74	99.73	99.93	100.00
Fall (1466)	24.97	62.62	88.20	97.89	99.80	100.00
Annual (6167)	34.33	71.41	90.95	98.30	99.81	100.00

NOTE: Number of observations in parentheses.

TABLE 1B. Cumulative Percent Occurrence of the Wind Direction Differences (degrees) between Surface and 600 Meters for Berlin, Germany, 1976-1983.

DATE	0-25	30-55	60-85	90-115	120-145	150-180
Jan (570)	56.32%	91.05%	96.67%	98.25%	98.95%	100.00%
Feb (509)	53.05	90.57	96.66	97.64	99.02	100.00
Mar (568)	59.51	92.08	97.18	98.77	99.65	100.00
Apr (525)	58.86	91.24	96.38	98.86	99.62	100.00
May (562)	56.41	88.79	93.59	96.62	98.22	100.00
Jun (490)	55.92	85.71	92.86	96.33	97.96	100.00
Jul (500)	65.60	89.40	94.00	96.00	98.00	100.00
Aug (514)	58.17	86.58	93.19	96.30	99.20	100.00
Sep (461)	57.70	88.29	94.36	96.53	97.83	100.00
Oct (502)	50.40	87.45	96.02	97.41	98.41	100.00
Nov (503)	58.05	94.43	98.21	99.40	99.80	100.00
Dec (463)	57.02	92.87	98.27	99.35	99.78	100.00
Winter (1542)	55.45	91.44	97.15	98.38	99.22	100.00
Spring (1655)	58.25	90.69	95.71	98.07	99.15	100.00
Summer (1504)	59.91	87.23	93.35	96.21	98.40	100.00
Fall (1466)	55.32	90.11	96.25	97.82	98.70	100.00
Annual (6167)	57.26	89.90	95.62	97.63	98.88	100.00

NOTE: Number of observations in parentheses.

TABLE 2A. Cumulative Percent Occurrence of the Windspeed Differences (meters/second) between Surface and 600 Meters for Centreville, AL, 1975-1983.

DATE	0-2	3-5	6-8	9-11	12-14	≥ 15
Jan (366)	27.60%	65.57%	86.34%	95.36%	98.36%	100.00%
Feb (321)	43.61	72.59	88.47	97.82	99.69	100.00
Mar (369)	38.21	66.12	84.82	95.66	99.19	100.00
Apr (367)	44.14	70.03	89.92	97.00	99.18	100.00
May (381)	51.44	78.74	92.65	98.16	100.00	100.00
Jun (387)	60.47	82.17	96.12	98.71	100.00	100.00
Jul (377)	62.33	87.27	97.08	99.73	99.73	100.00
Aug (400)	71.25	94.50	99.00	99.75	100.00	100.00
Sep (396)	59.09	86.36	97.73	99.75	99.75	100.00
Oct (408)	44.36	79.66	92.40	98.53	99.75	100.00
Nov (348)	32.47	68.10	85.92	97.13	99.14	100.00
Dec (362)	30.39	59.67	80.66	92.54	98.34	100.00
Winter (1049)	33.46	65.68	85.03	95.14	98.76	100.00
Spring (1117)	44.67	71.71	89.17	96.96	99.46	100.00
Summer (1164)	64.78	88.06	97.42	99.40	99.91	100.00
Fall (1152)	45.83	78.47	92.27	98.52	99.57	100.00
Annual (4482)	47.57	76.28	91.14	97.57	99.44	100.00

NOTE: Number of observations in parentheses.

TABLE 2B. Cumulative Percent Occurrence of the Wind Direction Differences (degrees) between Surface and 600 Meters for Centreville, AL, 1975-1983.

DATE	0-25	30-55	60-85	90-115	120-145	150-180
Jan (366)	57.38%	81.15%	89.89%	96.17%	97.81%	100.00%
Feb (321)	61.99	81.62	89.72	94.39	97.20	100.00
Mar (369)	60.98	84.55	90.51	96.21	98.37	100.00
Apr (367)	55.31	80.65	89.92	95.10	98.37	100.00
May (381)	54.86	76.64	86.88	91.60	95.54	100.00
Jun (387)	50.13	77.00	87.86	95.87	97.93	100.00
Jul (377)	45.89	70.03	84.62	92.84	97.61	100.00
Aug (400)	41.25	62.25	80.25	91.25	96.00	100.00
Sep (396)	41.67	68.69	83.84	90.15	95.71	100.00
Oct (408)	52.70	76.72	85.78	93.63	98.28	100.00
Nov (348)	53.16	79.02	88.22	94.54	99.14	100.00
Dec (362)	56.63	78.73	89.78	94.48	97.24	100.00
Winter (1049)	58.53	80.46	89.80	95.04	97.43	100.00
Spring (1117)	57.03	80.57	89.08	94.27	97.40	100.00
Summer (1164)	45.70	69.67	84.19	93.30	97.16	100.00
Fall (1152)	49.05	74.65	85.85	92.71	97.66	100.00
Annual (4482)	52.39	76.19	87.15	93.80	97.41	100.00

NOTE: Number of observations in parentheses.

TABLE 3A. Cumulative Percent Occurrence of the Windspeed Differences (meters/second) between Surface and 900 Meters for Berlin, Germany, 1976-1983.

DATE	0-2	3-5	6-8	9-11	12-14	≥ 15
Jan (570)	21.75%	53.33%	76.14%	90.70%	97.19%	100.00%
Feb (509)	29.86	66.60	87.43	96.46	99.02	100.00
Mar (568)	25.18	52.11	77.46	93.31	98.42	100.00
Apr (525)	35.81	71.43	91.62	98.48	99.43	100.00
May (562)	41.64	78.29	94.13	99.11	100.00	100.00
Jun (490)	40.41	78.78	95.10	98.57	99.80	100.00
Jul (500)	34.00	74.80	96.20	99.60	99.80	100.00
Aug (514)	34.24	75.49	94.94	99.03	100.00	100.00
Sep (461)	22.56	59.87	84.60	97.18	100.00	100.00
Oct (502)	19.72	56.37	79.88	95.22	98.61	100.00
Nov (503)	15.90	44.53	73.16	89.86	97.22	100.00
Dec (463)	16.85	46.87	71.06	87.69	97.62	100.00
Winter (1542)	22.96	55.77	78.34	91.70	97.92	100.00
Spring (1655)	34.14	67.13	87.61	96.92	99.27	100.00
Summer (1504)	36.17	76.33	95.41	99.07	99.87	100.00
Fall (1466)	19.30	53.41	79.06	94.00	98.57	100.00
Annual (6167)	28.31	63.27	85.16	95.44	98.91	100.00

NOTE: Number of observations in parentheses.

TABLE 3B. Cumulative Percent Occurrence of the Wind Direction Differences (degrees) between Surface and 900 Meters for Berlin, Germany, 1976-1983.

DATE	0-25	30-55	60-85	90-115	120-145	150-180
Jan (570)	43.33%	84.56%	94.39%	98.07%	98.95%	100.00%
Feb (509)	39.69	82.71	92.93	96.46	98.62	100.00
Mar (568)	47.18	87.68	95.42	98.24	99.12	100.00
Apr (525)	52.76	87.05	95.24	98.10	100.00	100.00
May (562)	51.25	83.81	91.81	97.15	98.40	100.00
Jun (490)	50.61	81.43	89.59	95.31	98.16	100.00
Jul (500)	56.00	86.00	92.60	95.40	97.20	100.00
Aug (514)	52.33	82.68	91.83	95.91	98.25	100.00
Sep (461)	52.28	84.38	94.14	96.10	97.18	100.00
Oct (502)	38.45	81.08	94.02	96.81	98.21	100.00
Nov (503)	41.95	88.27	98.01	99.01	99.60	100.00
Dec (463)	43.41	83.80	96.98	99.35	99.78	100.00
Winter (1542)	42.15	83.72	94.68	97.92	99.09	100.00
Spring (1655)	50.33	86.16	94.14	97.82	99.15	100.00
Summer (1504)	52.99	83.38	91.36	95.55	97.87	100.00
Fall (1466)	44.00	84.58	95.43	97.34	98.36	100.00
Annual (6167)	47.43	84.50	93.90	97.18	98.64	100.00

NOTE: Number of observations in parentheses.

TABLE 4A. Cumulative Percent Occurrence of the Windspeed Differences (meters/second) between Surface and 900 Meters for Centreville, AL, 1975-1983.

DATE	0-2	3-5	6-8	9-11	12-14	≥ 15
Jan (366)	24.86%	54.64%	78.42%	90.71%	96.45%	100.00%
Feb (321)	39.25	65.42	84.42	93.77	97.51	100.00
Mar (369)	33.60	60.98	78.05	88.89	96.48	100.00
Apr (367)	41.69	69.48	83.11	93.73	96.73	100.00
May (381)	45.67	76.38	90.55	96.59	98.69	100.00
Jun (387)	57.88	81.91	96.38	97.93	99.74	100.00
Jul (377)	62.60	89.39	95.23	98.94	99.73	100,00
Aug (400)	70.50	93.75	99.00	99.75	100.00	100.00
Sep (396)	57.07	84.09	95.71	99.24	99.75	100.00
Oct (408)	41.67	77.21	90.69	96.81	98.77	100.00
Nov (348)	30.17	61.21	83.33	93.39	97.99	100.00
Dec (362)	23.76	53.59	72.93	87.29	94.20	100.00
Winter (1049)	28.88	57.58	78.36	90.47	96.00	100.00
Spring (1117)	40.38	69.02	83.97	93.11	97.31	100.00
Summer (1164)	63.75	88.40	96.91	98.88	99.83	100.00
Fall (1152)	43.49	74.74	90.19	96.61	98.87	100.00
Annual (4482)	44.56	72.85	87.62	94.89	98.06	100.00

NOTE: Number of observations in parentheses.

TABLE 4B. Cumulative Percent Occurrence of the Wind Direction Differences (degrees) between Surface and 900 Meters for Centreville, AL, 1975-1983.

DATE	0-25	30-55	60-85	90-115	120-145	150-180
Jan (366)	46.72%	72.13%	85.52%	90.71%	95.08%	100.00%
Feb (321)	50.47	71.96	83.80	90.97	94.70	100.00
Mar (369)	49.32	79.13	86.99	92.95	96.48	100.00
Apr (367)	49.05	74.66	85.56	92.37	97.28	100.00
May (381)	49.87	70.08	81.63	89.76	94.49	100.00
Jun (387)	45.48	72.35	83.72	92.51	96.64	100.00
Jul (377)	34.48	59.68	77.45	87.80	93.37	100.00
Aug (400)	35.75	59.00	74.50	87.00	94.25	100.00
Sep (396)	35.35	62.88	77.02	85.10	92.17	100.00
Oct (408)	45.10	69.85	80.88	90.20	97.06	100.00
Nov (348)	43.10	71.26	83.91	90.52	96.55	100.00
Dec (362)	43.09	71.82	82.87	90.06	95.03	100.00
Winter (1049)	46.62	71.97	84.08	90.56	94.95	100.00
Spring (1117)	49.42	74.57	84.69	91.67	96.06	100.00
Summer (1164)	38.57	63.66	78.52	89.09	94.76	100.00
Fall (1152)	41.15	67.88	80.47	88.54	95.23	100.00
Annual (4482)	43.82	69.41	81.86	89.94	95.25	100.00

NOTE: Number of observations in parentheses.

TABLE 5A. Cumulative Percent Occurrence of the Windspeed Differences (meters/second) between 600 Meters and 900 Meters for Berlin, Germany, 1976-1983.

DATE	0-2	3-5	6-8	9-11	12-14	≥ 15
Jan (570)	90.00%	98.95%	99.65%	100.00%	100.00%	100.00%
Feb (509)	96.27	99.80	100.00	100.00	100.00	100.00
Mar (568)	91.73	99.82	100.00	100.00	100.00	100.00
Apr (525)	96.38	99.81	100.00	100.00	100.00	100.00
May (562)	98.04	100.00	100.00	100.00	100.00	100.00
Jun (490)	96.33	100.00	100.00	100.00	100.00	100.00
Jul (500)	99.20	100.00	100.00	100.00	100.00	100.00
Aug (514)	97.47	99.81	100.00	100.00	100.00	100.00
Sep (461)	93.71	99.78	100.00	100.00	100.00	100.00
Oct (502)	93.82	99.60	99.80	100.00	100.00	100.00
Nov (503)	91.45	100.00	100.00	100.00	100.00	100.00
Dec (463)	89.42	98.92	100.00	100.00	100.00	100.00
Winter (1542)	91.89	99.22	99.87	100.00	100.00	100.00
Spring (1655)	95.35	99.88	100.00	100.00	100.00	100.00
Summer (1504)	97.67	99.93	100.00	100.00	100.00	100.00
Fall (1466)	92.97	99.80	100.00	100.00	100.00	100.00
Annual (6167)	94.49	99.71	99.95	100.00	100.00	100.00

NOTE: Number of observations in parentheses.

TABLE 5B. Cumulative Percent Occurrence of the Wind Direction Differences (degrees) between 600 Meters and 900 Meters for Berlin, Germany, 1976-1983.

DATE	0-25	30-55	60-85	90-115	120-145	150-180
Jan (570)	96.31%	99.47%	99.82%	100.00%	100.00%	100.00%
Feb (509)	92.53	98.43	99.41	99.80	100.00	100.00
Mar (568)	95.25	99.30	99.65	100.00	100.00	100.00
Apr (525)	95.81	99.24	100.00	100.00	100.00	100.00
May (562)	95.02	99.29	99.64	100.00	100.00	100.00
Jun (490)	94.49	98.98	99.80	100.00	100.00	100.00
Jul (500)	95.40	98.80	99.60	99.60	100.00	100.00
Aug (514)	95.33	99.03	99.81	100.00	100.00	100.00
Sep (461)	96.53	99.35	100.00	100.00	100.00	100.00
Oct (502)	95.82	99.20	99.60	100.00	100.00	100.00
Nov (503)	98.01	99.80	100.00	100.00	100.00	100.00
Dec (463)	96.54	100.00	100.00	100.00	100.00	100.00
Winter (1542)	95.14	99.29	99.74	99.94	100.00	100.00
Spring (1655)	95.35	99.27	99.76	100.00	100.00	100.00
Summer (1504)	95.08	98.94	99.73	99.87	100.00	100.00
Fall (1466)	96.79	99.45	99.86	100.00	100.00	100.00
Annual (6167)	95.57	99.24	99.77	99.95	100.00	100.00

NOTE: Number of observations in parentheses.

TABLE 6A. Cumulative Percent Occurrence of the Windspeed Differences (meters/second) between 600 Meters and 900 Meters for Centreville, AL, 1975-1983.

DATE	0-2	3-5	6-8	9-11	12-14	≥ 15
Jan (366)	82.51%	97.27%	100.00%	100.00%	100.00%	100.00%
Feb (321)	86.92	98.44	99.69	100.00	100.00	100.00
Mar (369)	87.80	97.29	99.46	100.00	100.00	100.00
Apr (367)	87.19	98.09	99.46	99.73	100.00	100.00
May (381)	92.65	99.74	100.00	100.00	100.00	100.00
Jun (387)	95.09	99.22	100.00	100.00	100.00	100.00
Jul (377)	95.49	99.47	100.00	100.00	100.00	100.00
Aug (400)	98.00	100.00	100.00	100.00	100.00	100.00
Sep (396)	92.17	99.75	99.75	100.00	100.00	100.00
Oct (408)	93.38	99.51	100.00	100.00	100.00	100.00
Nov (348)	88.51	98.85	100.00	100.00	100.00	100.00
Dec (362)	83.70	98.90	99.72	100.00	100.00	100.00
Winter (1049)	84.27	98.19	99.81	100.00	100.00	100.00
Spring (1117)	89.26	98.39	99.64	99.91	100.00	100.00
Summer (1164)	96.22	99.57	100.00	100.00	100.00	100.00
Fall (1152)	91.49	99.39	99.91	100.00	100.00	100.00
Annual (4482)	90.47	98.91	99.84	99.98	100.00	100.00

NOTE: Number of observations in parentheses.

TABLE 6B. Cumulative Percent Occurrence of the Wind Direction Differences (degrees) between 600 Meters and 900 Meters for Centreville, AL, 1975-1983.

DATE	0-25	30-55	60-85	90-115	120-145	150-180
Jan (366)	80.59%	95.07%	98.90%	99.45%	100.00%	100.00%
Feb (321)	83.49	96.88	99.38	100.00	100.00	100.00
Mar (369)	88.08	96.48	99.19	100.00	100.00	100.00
Apr (367)	87.47	97.55	99.18	99.73	100.00	100.00
May (381)	83.20	95.80	98.69	99.74	100.00	100.00
Jun (387)	85.27	95.09	99.22	99.74	100.00	100.00
Jul (377)	80.90	94.69	98.14	99.73	100.00	100.00
Aug (400)	82.50	96.50	99.00	99.75	99.75	100.00
Sep (396)	83.59	95.96	99.24	99.75	100.00	100.00
Oct (408)	87.99	96.32	98.53	99.75	99.75	100.00
Nov (348)	85.06	97.99	99.14	99.71	100.00	100.00
Dec (362)	83.70	96.69	98.07	99.45	100.00	100.00
Winter (1049)	82.55	96.19	98.76	99.62	100.00	100.00
Spring (1117)	86.21	96.60	99.02	99.82	100.00	100.00
Summer (1164)	82.90	95.45	98.80	99.74	99.91	100.00
Fall (1152)	85.59	96.70	98.96	99.74	99.91	100.00
Annual (4482)	84.34	96.23	98.88	99.73	99.96	100.00

NOTE: Number of observations in parentheses.

TABLE 7A. Cumulative Percent Occurrence of the Windspeed Differences (meters/second) between Surface and 300 Meters for Centreville, AL, 1975-1983.

DATE	0-2	3-5	6-8	9-11	12-14	≥ 15
Jan (366)	43.72%	87.16%	98.63%	100.00%	100.00%	100.00%
Feb (321)	56.70	85.67	97.82	99.69	100.00	100.00
Mar (369)	50.41	82.93	98.64	100.00	100.00	100.00
Apr (367)	52.86	85.83	99.18	100.00	100.00	100.00
May (381)	60.89	90.81	99.21	100.00	100.00	100.00
Jun (387)	63.82	89.66	99.74	100.00	100.00	100.00
Jul (377)	69.23	92.57	100.00	100.00	100.00	100.00
Aug (400)	76.50	95.75	99.75	100.00	100.00	100.00
Sep (396)	67.42	91.67	100.00	100.00	100.00	100.00
Oct (408)	50.00	85.54	98.77	100.00	100.00	100.00
Nov (348)	44.54	87.64	97.99	100.00	100.00	100.00
Dec (362)	41.44	80.66	96.96	99.72	100.00	100.00
Winter (1049)	46.90	84.46	97.81	99.81	100.00	100.00
Spring (1117)	54.79	86.57	99.02	100.00	100.00	100.00
Summer (1164)	69.93	92.70	99.83	100.00	100.00	100.00
Fall (1152)	54.34	88.28	98.96	100.00	100.00	100.00
Annual (4482)	56.76	88.11	98.93	99.96	100.00	100.00

NOTE: Number of observations in parentheses.

TABLE 7B. Cumulative Percent Occurrence of the Wind Direction Differences (degrees) between Surface and 300 Meters for Centreville, AL, 1975-1983.

DATE	0-25	30-55	60-85	90-115	120-145	150-180
Jan (366)	76.50%	92.62%	98.09%	99.45%	99.73%	100.00%
Feb (321)	79.75	91.28	95.64	99.38	99.69	100.00
Mar (369)	76.42	93.77	97.29	98.92	99.73	100.00
Apr (367)	75.75	88.83	95.64	98.94	99.18	100.00
May (381)	71.13	88.45	95.54	98.95	99.74	100.00
Jun (387)	68.48	87.86	96.38	99.74	100.00	100.00
Jul (377)	67.90	86.21	94.43	98.14	99.20	100.00
Aug (400)	59.00	84.00	95.75	99.25	99.50	100.00
Sep (396)	60.86	85.10	94.70	99.75	99.75	100.00
Oct (408)	69.61	85.54	93.63	98.53	100.00	100.00
Nov (348)	72.41	89.37	96.84	99.14	99.71	100.00
Dec (362)	76.80	91.16	95.03	99.45	100.00	100.00
Winter (1049)	77.60	91.71	96.28	99.43	99.81	100.00
Spring (1117)	74.40	90.33	96.15	98.84	99.55	100.00
Summer (1164)	65.03	86.00	95.53	99.05	99.57	100.00
Fall (1152)	67.45	86.55	94.97	99.13	99.83	100.00
Annual (4482)	70.93	88.55	95.72	99.11	99.69	100.00

NOTE: Number of observations in parentheses.

TABLE 8A. Cumulative Percent Occurrence of the Windspeed Differences (meters/second) between 300 Meters and 600 Meters for Centreville, AL, 1975-1983.

DATE	0-2	3-5	6-8	9-11	12-14	≥ 15
Jan (366)	70.22%	93.44%	98.09%	99.45%	100.00%	100.00%
Feb (321)	72.27	94.08	99.69	100.00	100.00	100.00
Mar (369)	71.27	91.33	98.37	99.46	99.73	100.00
Apr (367)	78.75	94.82	98.91	99.73	100.00	100.00
May (381)	82.15	97.11	99.74	100.00	100.00	100.00
Jun (387)	89.41	98.45	100.00	100.00	100.00	100.00
Jul (377)	93.37	99.20	99.73	100.00	100.00	100.00
Aug (400)	96.25	99.50	100.00	100.00	100.00	100.00
Sep (396)	92.17	98.99	100.00	100.00	100.00	100.00
Oct (408)	85.78	97.06	99.51	100.00	100.00	100.00
Nov (348)	72.70	94.25	99.71	100.00	100.00	100.00
Dec (362)	67.96	89.50	97.24	99.72	100.00	100.00
Winter (1049)	70.07	92.28	98.28	99.71	100.00	100.00
Spring (1117)	77.44	94.45	99.02	99.73	99.91	100.00
Summer (1164)	93.04	99.05	99.91	100.00	100.00	100.00
Fall (1152)	84.03	96.87	99.74	100.00	100.00	100.00
Annual (4482)	81.46	95.76	99.26	99.87	99.96	100.00

NOTE: Number of observations in parentheses.

TABLE 8B. Cumulative Percent Occurrence of the Wind Direction Differences (degrees) between 300 Meters and 600 Meters for Centreville, AL, 1975-1983.

DATE	0-25	30-55	60-85	90-115	120-145	150-180
Jan (366)	82.51%	93.99%	98.36%	99.45%	100.00%	100.00%
Feb (321)	79.75	93.46	97.51	99.69	100.00	100.00
Mar (369)	84.55	94.04	97.83	99.46	100.00	100.00
Apr (367)	84.47	96.46	99.46	99.73	100.00	100.00
May (381)	77.43	91.08	97.90	99.74	100.00	100.00
Jun (387)	80.62	95.09	98.19	99.48	100.00	100.00
Jul (377)	74.01	89.92	97.35	99.73	100.00	100.00
Aug (400)	69.00	89.75	98.50	99.75	100.00	100.00
Sep (396)	74.24	90.40	96.97	99.49	100.00	100.00
Oct (408)	83.09	94.85	98.53	99.51	100.00	100.00
Nov (348)	82.76	94.25	99.43	99.71	100.00	100.00
Dec (362)	83.70	94.48	98.34	99.45	100.00	100.00
Winter (1049)	82.08	93.99	98.09	99.52	100.00	100.00
Sping (1117)	82.09	93.82	98.39	99.64	100.00	100.00
Summer (1164)	74.48	91.58	98.02	99.66	100.00	100.00
Fall (1152)	79.95	93.14	98.26	99.57	100.00	100.00
Annual (4482)	79.56	93.11	98.19	99.60	100.00	100.00

NOTE: Number of observations in parentheses.

TABLE 9A. Cumulative Percent Occurrence of the Windspeed Differences (meters/second) between 300 Meters and 900 Meters for Centreville, AL, 1975-1983.

DATE	0-2	3-5	6-8	9-11	12-14	≥15
Jan (366)	50.82%	82.24%	94.26%	97.54%	99.45%	100.00%
Feb (321)	59.19	85.98	95.95	99.07	99.69	100.00
Mar (369)	59.35	82.11	93.50	97.29	99.73	100.00
Apr (367)	65.94	87.47	96.19	98.37	99.46	100.00
May (381)	66.93	92.39	98.16	99.21	100.00	100.00
Jun (387)	79.07	95.87	98.97	99.48	100.00	100.00
Jul (377)	84.08	97.08	98.94	99.73	100.00	100.00
Aug (400)	87.25	99.50	100.00	100.00	100.00	100.00
Sep (396)	79.04	96.21	99.49	99.75	100.00	100.00
Oct (408)	69.61	93.87	98.53	99.26	100.00	100.00
Nov (348)	57.18	87.07	96.26	98.85	99.71	100.00
Dec (362)	47.51	79.83	93.09	98.90	99.45	100.00
Winter (1049)	52.24	82.55	94.38	98.47	99.52	100.00
Spring (1117)	64.10	87.38	95.97	98.30	99.73	100.00
Summer (1164)	83.51	97.51	99.31	99.74	100.00	100.00
Fall (1152)	69.10	92.62	98.18	99.31	99.91	100.00
Annual (4482)	67.65	90.23	97.03	98.97	99.80	100.00

NOTE: Number of observations in parentheses.

TABLE 9B. Cumulative Percent Occurrence of the Wind Direction Differences (degrees) between 300 Meters and 900 Meters for Centreville, AL, 1975-1983.

DATE	0-25	30-55	60-85	90-115	120-145	150-180
Jan (366)	58.75%	84.16%	92.08%	96.72%	98.36%	100.00%
Feb (321)	60.12	84.74	93.15	96.57	98.75	100.00
Mar (369)	67.21	86.72	94.04	97.29	98.92	100.00
Apr (367)	69.21	86.28	95.10	98.64	99.18	100.00
May (381)	63.25	81.63	91.60	95.54	98.95	100.00
Jun (387)	64.60	86.30	93.80	96.90	98.19	100.00
Jul (377)	53.85	76.92	91.25	96.02	98.41	100.00
Aug (400)	54.50	78.75	92.00	97.25	99.00	100.00
Sep (396)	59.34	80.81	89.65	95.96	98.74	100.00
Oct (408)	66.42	85.78	94.36	97.79	99.51	100.00
Nov (348)	57.76	86.78	94.25	97.70	99.14	100.00
Dec (362)	57.46	85.91	93.92	96.69	98.34	100.00
Winter (1049)	58.72	84.94	93.04	96.66	98.47	100.00
Spring (1117)	66.52	85.50	93.55	97.14	99.02	100.00
Summer (1164)	57.65	80.67	92.35	96.74	98.54	100.00
Fall (1152)	61.37	84.37	92.71	97.14	99.13	100.00
Annual (4482)	61.07	83.82	92.90	96.92	98.80	100.00

NOTE: Number of observations in parentheses.

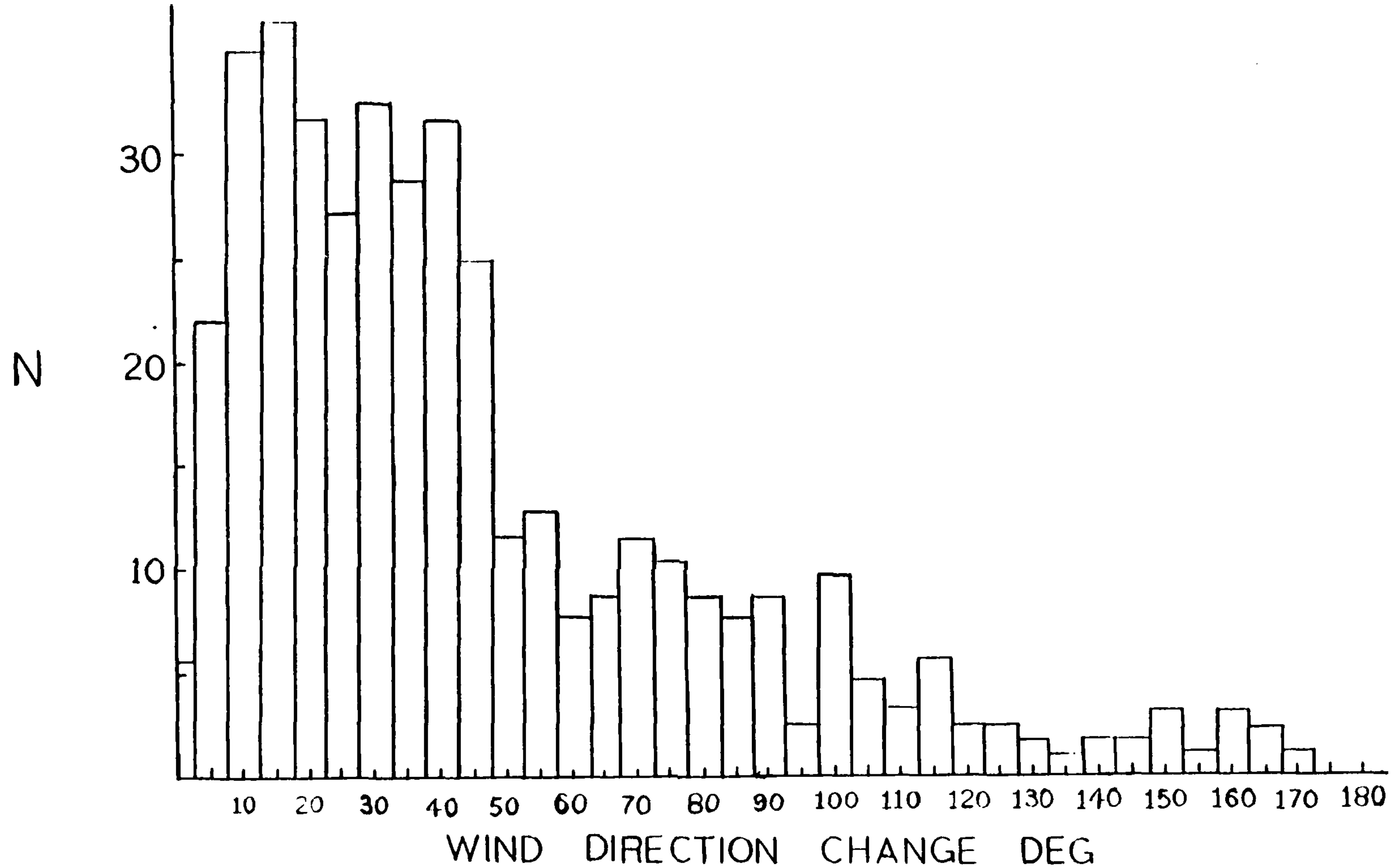

Figure 10A. Frequency distribution of wind direction change for windshear > 10 m/s in the layer surface to 600 m for Centreville, Alabama, 1975-1983.

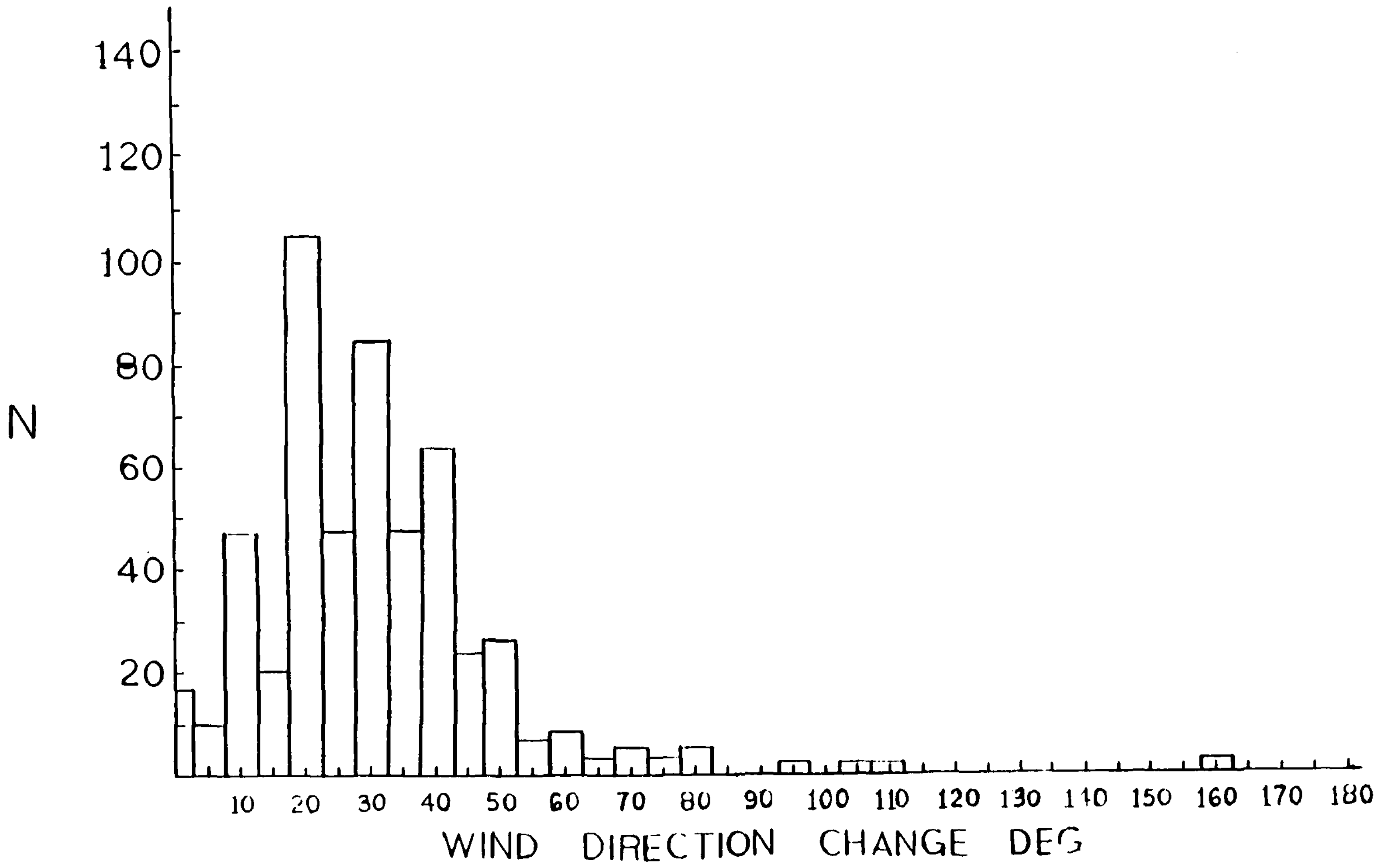

Figure 10B. Frequency distribution of wind direction change for windshear > 10 m/s in the layer surface to 600 m for Berlin, Germany, 1976-1983.

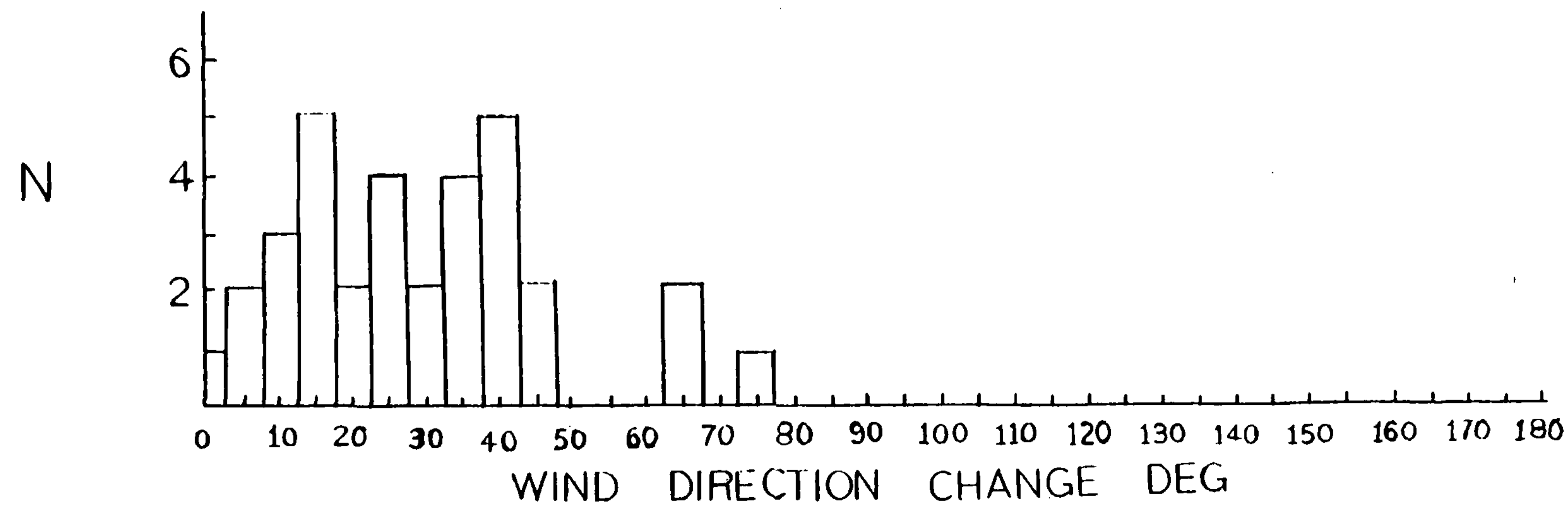

Figure 11A. Frequency distribution of wind direction change for windshear > 15 m/s in the layer surface to 600 m for Centreville, Alabama, 1975-1983.

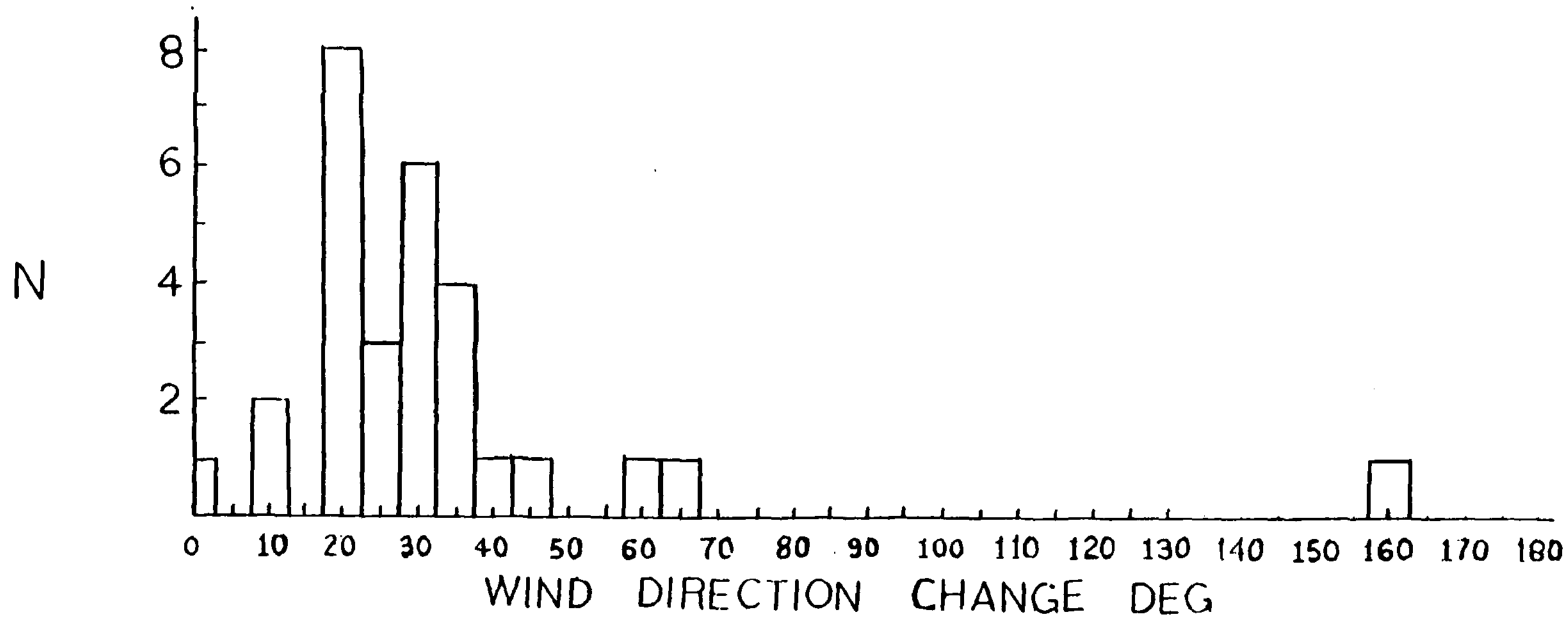

Figure 11B. Frequency distribution of wind direction change for windshear > 15 m/s in the layer surface to 600 m for Berlin, Germany, 1976-1983.

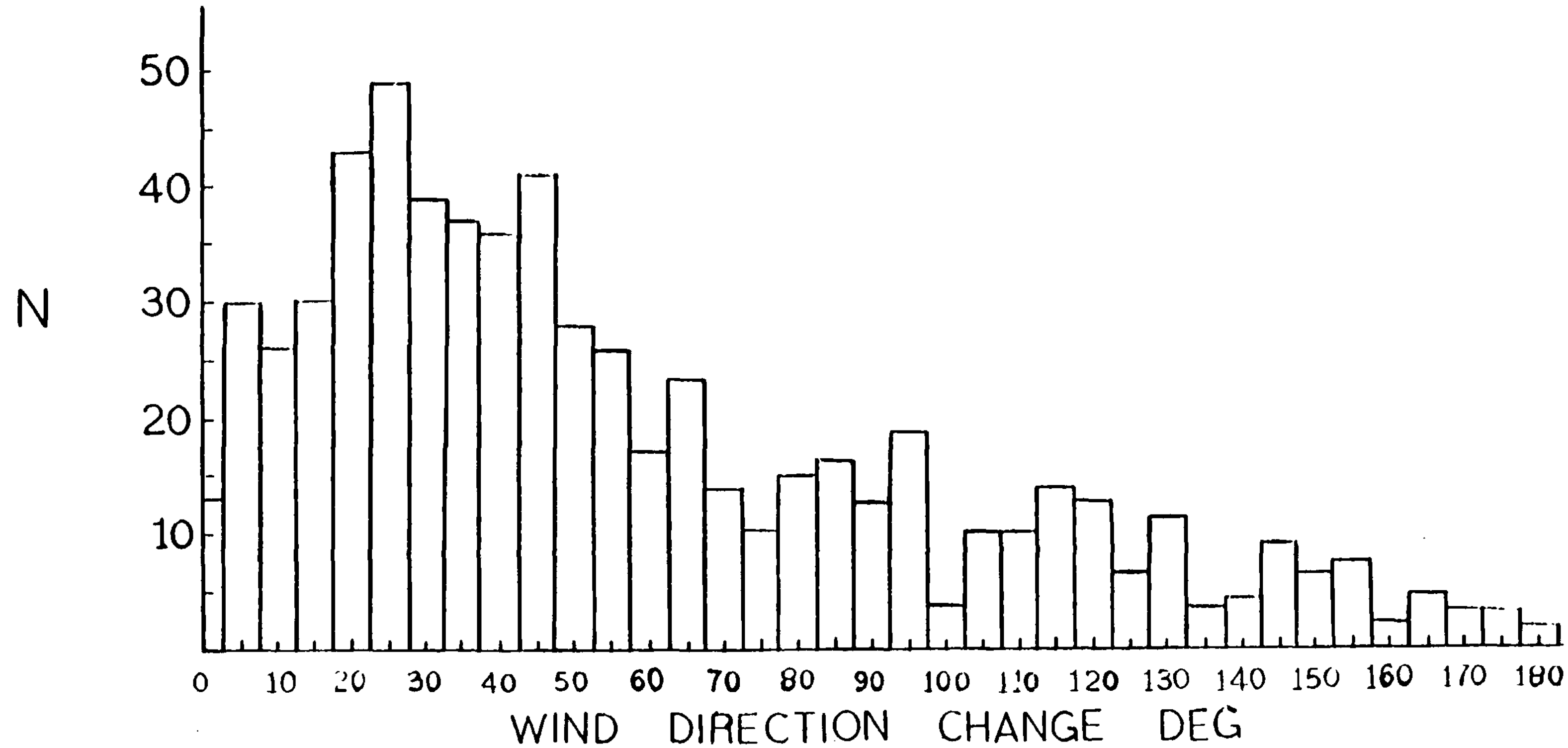

Figure 12A. Frequency distribution of wind direction change for windshear > 10 m/s in the layer surface to 900 m for Centreville, Alabama, 1975-1983.

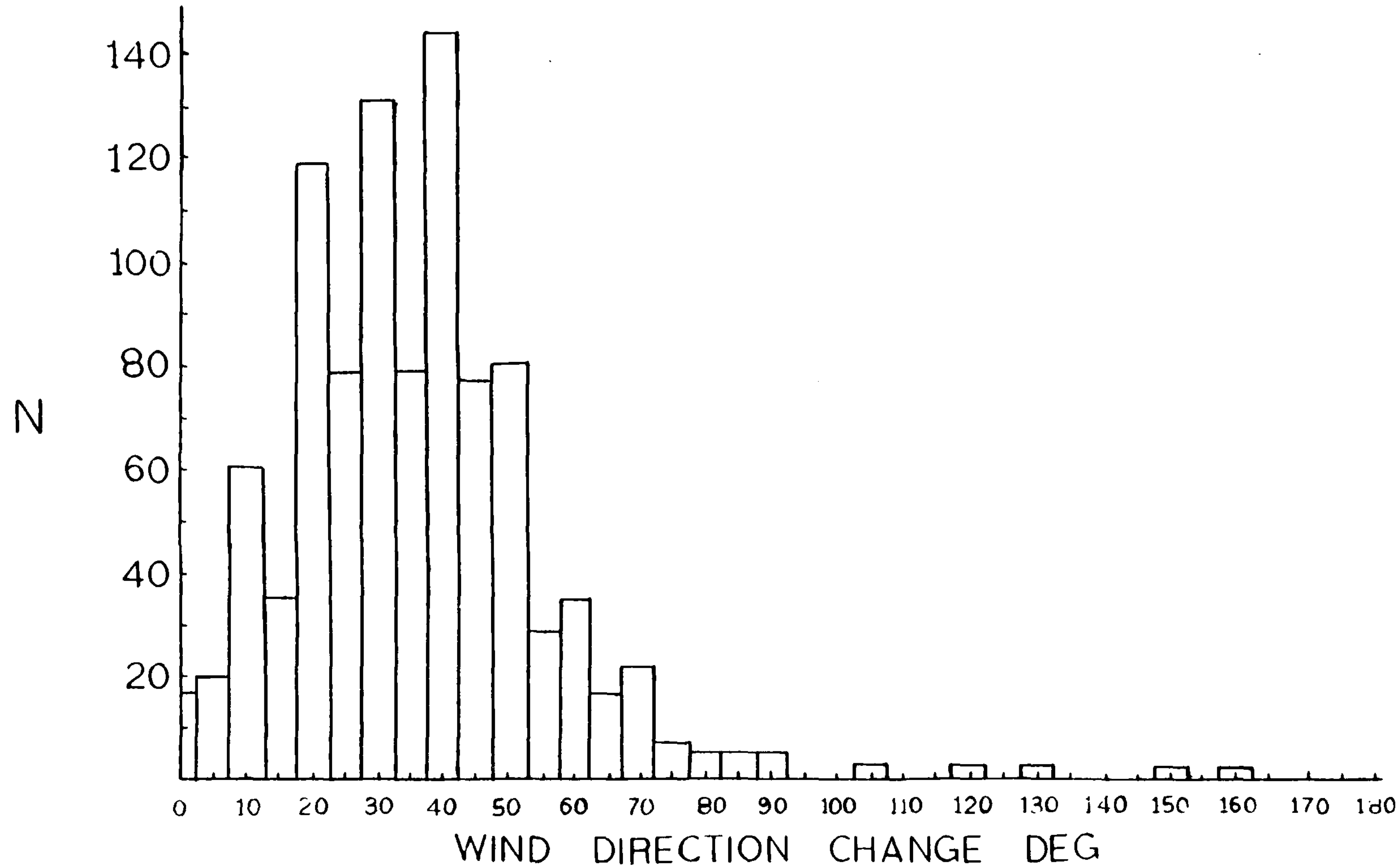

Figure 12B. Frequency distribution of wind direction change for windshear > 10 m/s in the layer surface to 600 m for Berlin, Germany, 1976-1983.

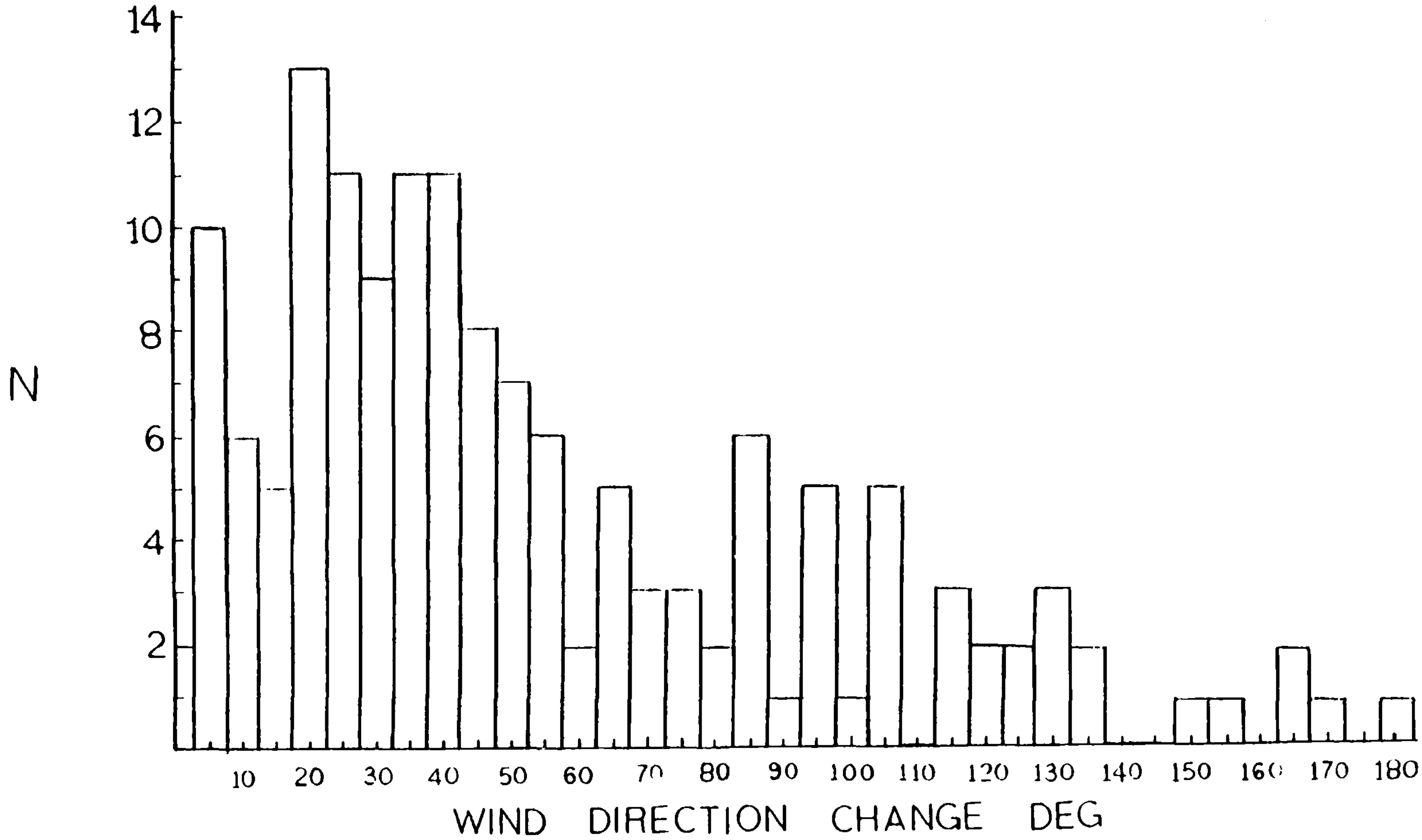

Figure 13A. Frequency distribution of wind direction change for windshear > 15 m/s in the layer surface to 900 m for Centreville, Alabama, 1975-1983.

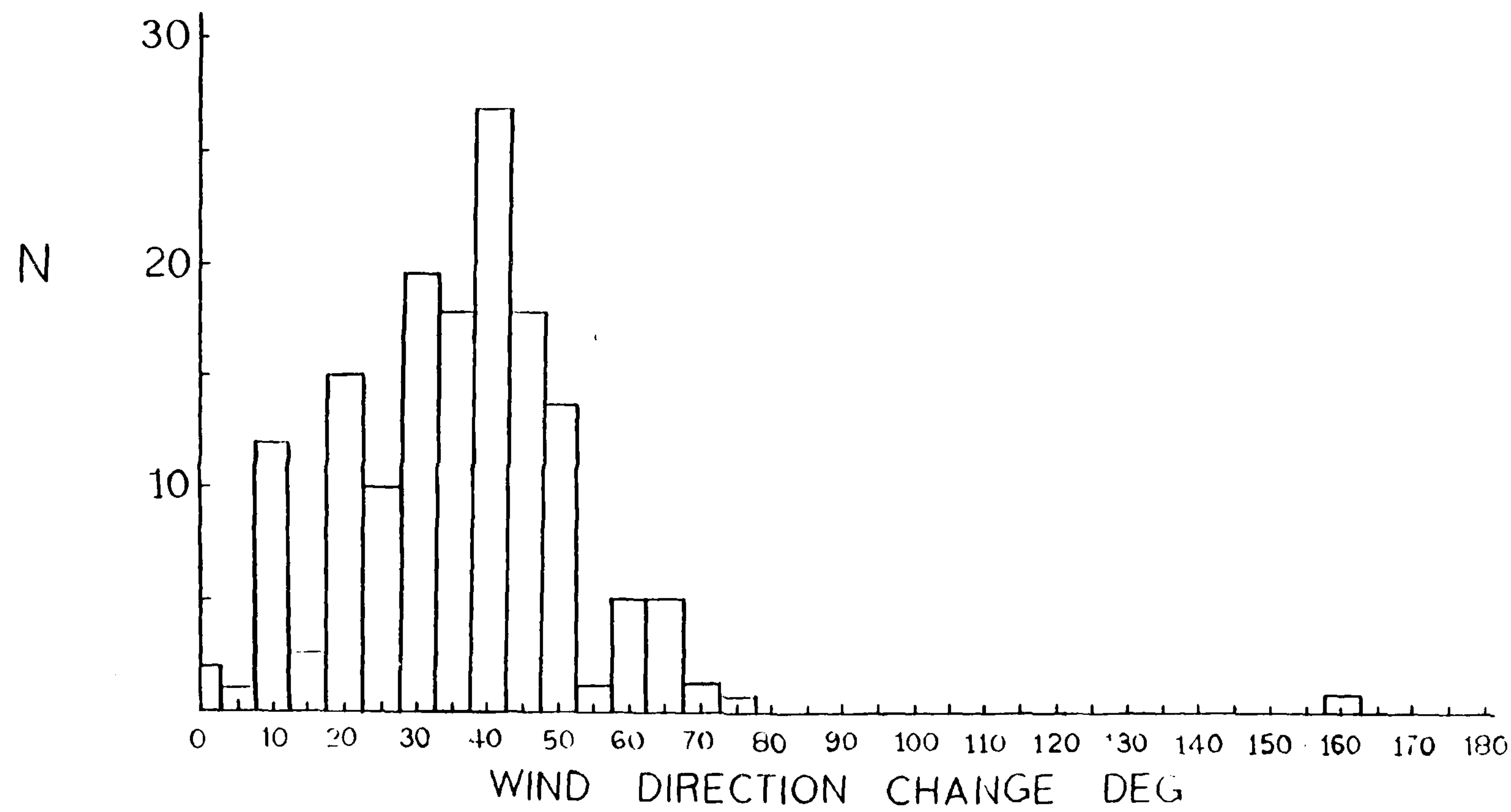

Figure 13B. Frequency distribution of wind direction change for windshear > 15 m/s in the layer surface to 900 m for Berlin, Germany, 1976-1983.

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