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Techniques Development Laboratory
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Objective Visibility Forecasting Techniques Based on Surface and Tower Observations

Technical Memorandum WBTM TDL 16

U.S. DEPARTMENT OF COMMERCE / ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

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OBJECTIVE VISIBILITY FORECASTING TECHNIQUES BASED ON SURFACE AND TOWER OBSERVATIONS

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TECHNIQUES DEVELOPMENT LABORATORY

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OBJECTIVE VISIBILITY FORECASTING TECHNIQUES
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ABSTRACT

Three objective techniques are presented for forecasting the morning minimum visibility at Washington National Airport in the fall season. Excluded from forecasts are dates with precipitation or a frontal passage before 1200Z. The basic technique makes use of the 0400Z wind speed and dew-point depression at Washington; the wind speed, wind direction, and wind gustiness recorded on a 300-ft tower; and a simple yes-or-no forecast for any clouds below 7500 ft before 1200Z. Gustiness is measured by the wind direction variability on the tower for one hour, 0300-0400Z. A decision tree approach combined with graphical methods give the probability of visibility occurring in five classes. Three years of data provide the developmental sample. Verification statistics from an independent two-year sample show 66 percent of the forecasts in the correct class and a skill score of .40, slightly exceeding the skill of the official forecast. An alternate second technique uses only surface data from which tower data are objectively estimated; an alternate third technique employs only wind speed and dew-point depression to forecast visibility from isopleths. The technique development procedures are described and illustrated.

I. INTRODUCTION

With computers increasingly producing the long-period forecasts, short-period forecasting is becoming the "bread and butter" of the field forecaster. It is what he can do best and fastest, but to make these forecasts he benefits by having objective forecasting techniques. This report introduces new objective techniques for short-period visibility forecasts.

As is true for most forecast terminals, Washington has some graphical aids for making objective forecasts of the ceiling and visibility. George and Ellett /1941/ have developed some objective aids for predicting low ceilings and fog and for timing the arrival of fog at Washington. C. P. Mook, M. N. Hunter, and others have developed unpublished objective aids that are of a local nature and are in the Terminal Forecasting Manual at Washington. See Mook /1945/. Low visibility, being so variable from place to place in areas about a terminal, must necessarily be treated individually for each locality in any study or forecasting technique. Yet, the principles involved are more or less universal and with some modifications can be used for any terminal.

In recent years mesometeorological research has been applied to the solution of short-range terminal forecasting problems through the operation of mesoscale weather-observing networks called mesonets. The basic technique described in this paper developed from a study of observations from the Washington, D. C., Mesonetwork which included four instrumented, 300-ft microwave relay towers. One of these four towers, located at Silver Hill, Md.,[1] is the site from which data were obtained for this study. Although towers are often sources of data for boundary-layer research, a search of the literature revealed no weather forecasting techniques using tower-derived observational data. One of the techniques in this paper pioneers the use of tower-derived observational data in forecasting and introduces a parameter called "gustiness."

A variation of the basic technique utilizes surface observations to approximate the tower data because tower data are rarely available. A second variation to the basic technique uses a graph of two simple parameters to forecast visibility. This technique should be adaptable to any forecast terminal.

Forecasting with the techniques proved to be competitive with the subjective methods used by experienced forecasters.

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1 See Section X for station details.

II. OBJECTIVE

The objective of this development is to predict the minimum prevailing visibility that will occur between 0500Z and 1300Z or 2 hours after sunrise, whichever is later, at Washington National Airport (DCA) during the months of September, October, and November. Data used are from 0400Z, the latest possible collection time before the 0500Z forecast deadline. Excluded from the technique are data for days which indicate that:

- Precipitation occurred between 0500Z and 1200Z. (Drizzle is not excluded and is treated as a special case.)
- A cold front passed between 0400Z and 1200Z. (A front is considered to have passed DCA if the wind shifts into the northwest or northeast quadrants with a speed of 8 kt or more.)

These exceptions are introduced because they modify the airmass making the 0400Z data unrepresentative of the airmass which will produce the minimum visibility being forecast. The precipitation or frontal passage must be forecast by other means.

The product of the technique is a probability of the visibility occurring within each of 5 classes:

$<\frac{1}{2}$, $\frac{1}{2}$ to 1-3/8, $1\frac{1}{2}$ to $2\frac{1}{2}$, 3 to 6, and ≥ 7 mi.

The "most probable" forecast is determined from the visibility class having the highest probability, which was derived from past records.

III. DATA

The data used in the basic technique are:

- Silver Hill 300-ft mean wind speed, 0300-0400Z,
- Silver Hill 300-ft mean wind direction, 0300-0400Z,
- Silver Hill 300-ft gustiness,[2] 0300-0400Z,
- DCA wind speed, 0400Z,

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[2] "Gustiness," which could be called "turbulence," is defined as the variability in angular degrees of the Aerovane wind-direction analog trace. Examples are shown in Figures 2 and 5; measuring the gustiness is described in Section VII.

- DCA dew-point depression, 0400Z, (all temperatures are in Fahrenheit),

- Cloudiness forecast (yes-or-no) $\leq$ 7500 ft, 0500-1200Z.

The data for the developmental sample were September through November, 1962-1964; the same months for 1965-1966 were used for the verification sample. After the testing was complete, charts and probabilities were prepared for presentation with this report; composites were formed from combining the 5 years of data (1962 through 1966).

IV. FORECASTING METHOD USING SURFACE AND TOWER DATA

Taking data obtained at 0400Z for the above listed items, the forecaster follows the procedure flow shown in the decision tree of Figure 1 to arrive at the final forecast. The flow of the decision tree is self-explanatory. In practice the forecaster will find the procedure faster and simpler if he employs Table 1. (Table 1 and Charts 1 to 9 are in Section XI.) In Table 1 he locates the row which relates the 0400Z conditions to the observed or derived variables in the first five columns; the row also gives the percent of probability for subsequent minimum visibility occurring in each of five classes.

The forecasting procedure in the decision tree is amplified in the following paragraphs. More details are contained in Section VII.

1. Procedure Steps

a. Determine whether precipitation will occur between 0500-1200Z or whether a frontal passage ("FROPA" in Figures 1 and 3) will cause a windshift to the northwest or northeast quadrants with speeds of $\geq$ 8 kt at 0400-1200Z. If so, do not use the technique. Drizzle precipitation is treated as a special case in the decision tree and in Table 1.

b. Use Chart 1 to identify cases which are unusually dry for the date. Do not forecast a lower visibility than that specified.

c. Identify an "area" on Chart 2 with the 0400Z DCA dew-point depression and wind speed. With coordinates in areas A and B, refer to Table 1 for visibility probabilities[3] by classes and to Chart 7 for

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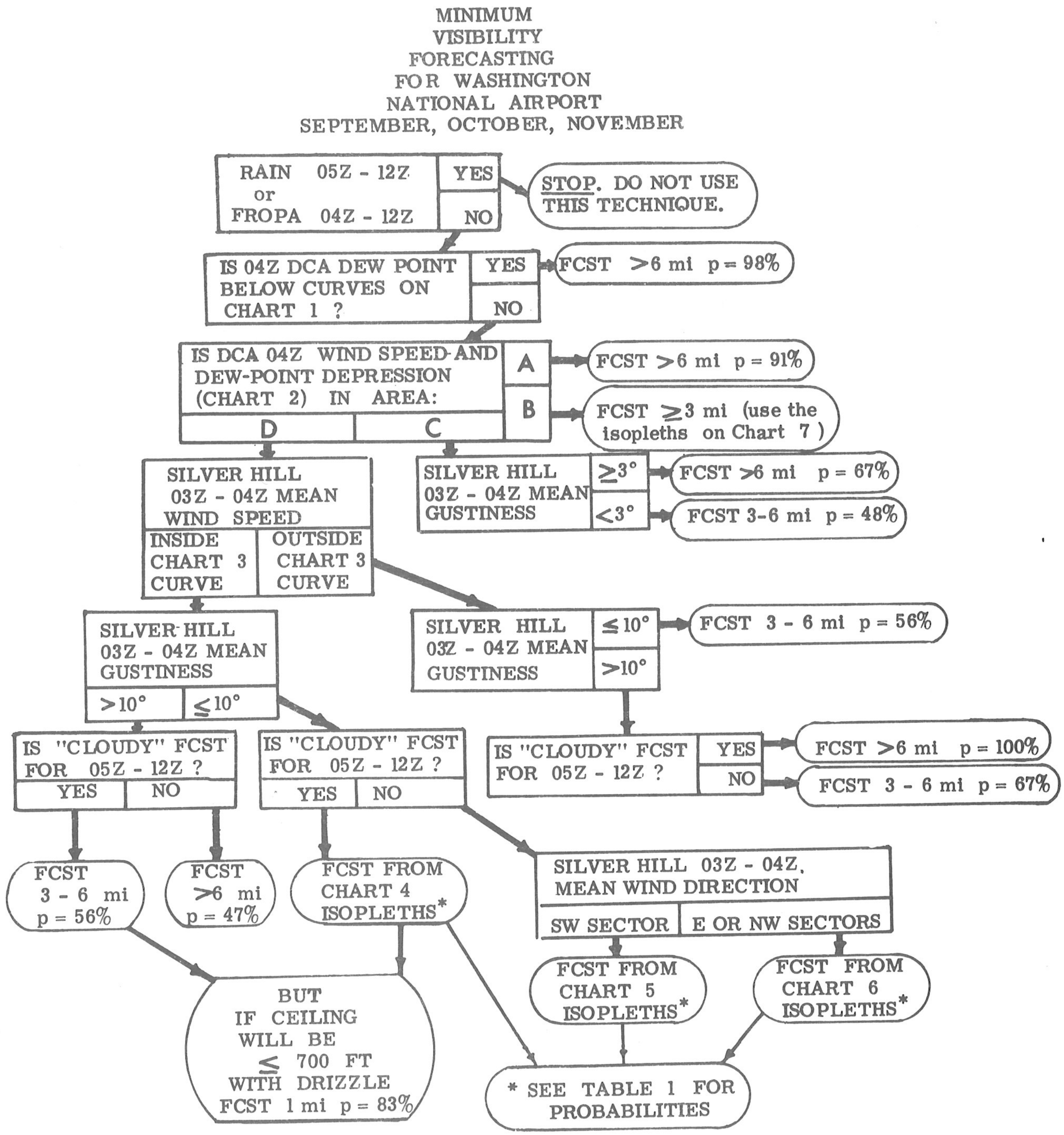
[3] A probability is computed for each visibility class. It is the ratio in percent of the number of observations within a visibility class to the total number of observations within the area or subarea under consideration.



MODIFY ALL FORECASTS FROM CURVES ON CHARTS 1 & 8 (CURRENT DEWPOINT AND 24-HR CHANGE).

REFER TO TABLE 1 FOR COMPLETE PROBABILITIES

Figure 1. Decision tree for minimum visibility forecast using tower data.

specific visibility; in areas C and D, refer to tower data for refining the forecast step-by-step.

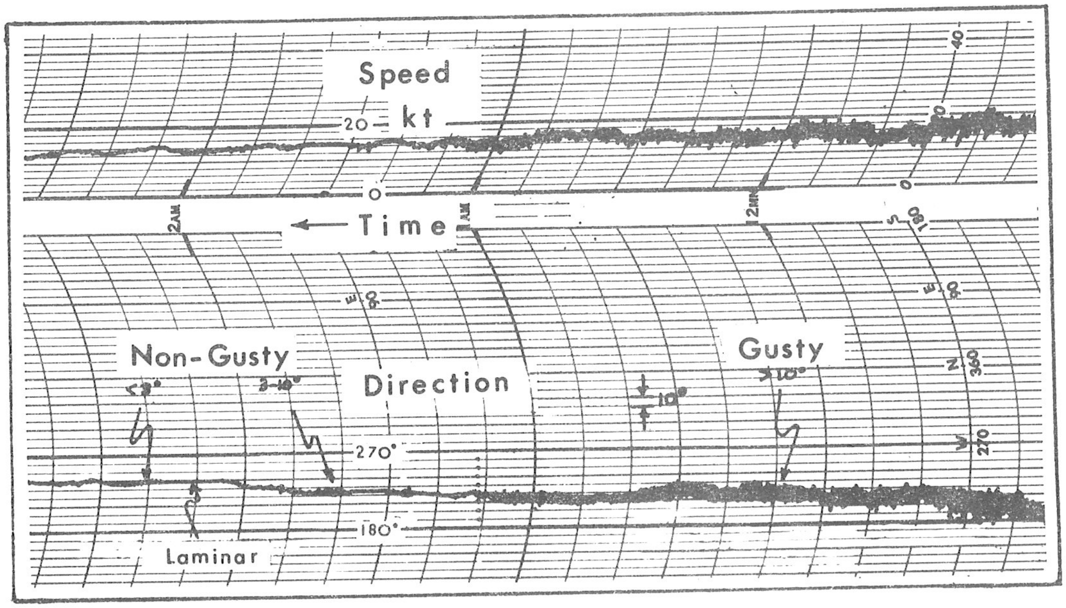


Figure 2. Example of an Aerovane wind speed and direction recording at 300 ft showing various degrees of gustiness.

d. Use only gustiness information from the tower to find a probability forecast in Table 1 when the coordinates of Chart 2 fall in area C.

e. Use tower wind speed, direction, gustiness, and a cloudiness forecast for the subsequent steps if coordinates of Chart 2 fall in area D; utilize Charts 3 through 6 as shown in the decision tree.

f. Give final refinement to the forecast through use of Chart 8 which relates the 24-hour dew-point change before 0400Z to the minimum visibility. This chart is applicable only for an upward modification of the visibility forecast if the visibility shown on Chart 8 is higher than the forecast determined from the above procedures. This upward modification of the visibility is attributed to dry-air advection.

2. An Example of a Forecast Using Tower Data

a. Data

October 1, 0400Z DCA dew point 65°;
October 2, 0400Z DCA temperature 58°, dew point 54°, wind speed 6 kt;

October 2, 0400Z Silver Hill wind at 300 ft: 120°, 14 kt, gustiness 7°;

No precipitation expected;
No frontal passage expected;
No clouds forecasted below 7500 ft.

b. Procedure

(1.) Enter October 2 and the 54° dew point on Chart 1. The point obtained is above the curves which indicates there are no visibility limitations due to unseasonably dry air.

(2.) Enter the DCA wind speed and dew-point depression (4°) on Chart 2. The coordinates are in area D. Area D forecasts require tower data for further refinement.

(3.) Determine the wind direction sectors and limiting wind speeds from Chart 3. This chart shows that the tower wind vector is inside the maximum-speed curve and is in the East sector.

(4.) Use Table 1 with the given and derived data; find the one row in Table 1 which satisfies the requirements of the first five columns. The notation in mid-table refers the forecaster to Charts 4 through 6 to locate a subarea; only Chart 6 applies to the October 2 data because it pertains to the East sector winds, non-cloudy days, and non-gusty ($\leq 10^{\circ}$ direction-vane variability) conditions. The data used in step (2), above, show the subarea to be D-7.

(5.) Locate on the row labeled D-7 the "most probable" forecast; that row gives a 60 percent probability that the minimum visibility will be in the 1½- to 2½-mile range. (Note that if cloudiness had been anticipated, Chart 4 and row D-1 would have been applicable, resulting in the same visibility forecast but with a 50 percent probability.)

(6.) Enter on Chart 8 the 24-hr change of dew point (-11°); the forecaster reads at the diagonal line that the forecast visibility should be not less than 5 miles due to the advection of dryer air. This overrides his forecast from step (5), making his final forecast 5 miles.

With the results from applying the technique, the forecaster should select as the "most probable" forecast category the one with the highest percent probability, but he may wish to change it according to other subjective or objective information he may have from his analysis of the situation. Information usually considered important to a visibility forecast but not included in the technique may include the trajectory of the airmass, existing visibility at the station or nearby stations, advection of low visibility, clouds above 7500 ft, temperature inversion, wet ground surface, warm front lowering of clouds to fog, etc.

V. ALTERNATE FORECASTING PROCEDURES WITHOUT TOWER DATA

1. Estimated Tower Data

Without observations from the tower, the forecaster can make objective estimates of the tower parameters quite successfully. Estimates are not required for areas A and B of Chart 2 because these areas do not use tower data. Area C forecasts need only gustiness estimates, and area D forecasts require estimates of wind speed, direction, and gustiness. Figure 3 is the decision tree adapted to forecasting with estimated tower data.

The following procedures are used for estimating tower data. (A commentary about these procedures is contained in Section VII.)

a. Procedure Steps

(1.) Gustiness

Estimate the gustiness from Chart 9 which relates the wind speeds at DCA and ADW (Andrews AFB) to the gustiness observed at the Silver Hill tower. However, if a temperature difference of $\geq 6^{\circ}$ is present between DCA-ADW at 0400Z, it becomes an overriding parameter that indicates non-gustiness regardless of the condition stipulated on Chart 9. When coordinates on Chart 9 fall in the zone labeled "mixed," the best forecasting results are obtained from the visibility isopleths on Chart 7.

(2.) Wind Speed

Estimate the tower wind speed by using the ADW 0400Z wind speed multiplied by two.

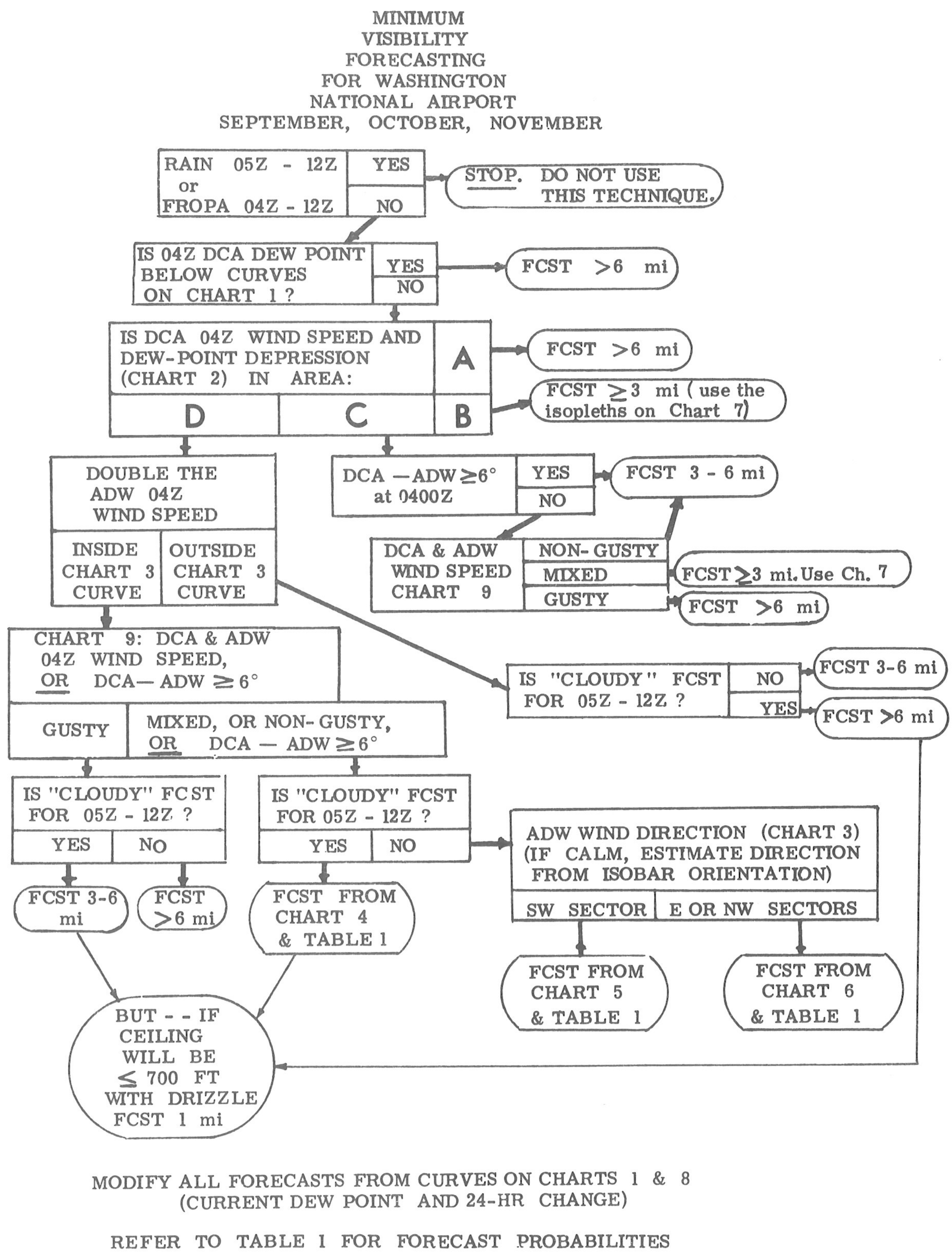


Figure 3. Decision tree for minimum visibility forecast using estimated tower data.

(3.) Wind Direction

Estimate the tower wind direction by using the ADW 0400Z wind direction. If calm is reported, deduce a wind direction from a carefully drawn set of surface isobars, allowing for the wind to cross the isobars at an angle of 30° toward lower pressure.

b. An Example of a Forecast Using Estimated Tower Data

(1.) Data

For an example of a forecast derived from estimated tower data, a few modifications will be made to the example in Section IV. For the same date, October 2, at 0400Z, the ADW temperature is 48° and the wind is 090° and 6 kt.

(2.) Procedure

(a.) See same step of example in Section IV.
(b.) See same step of example in Section IV.
(c.) Double the ADW wind speed to have 12 kt. This still leaves the speed vector <u>inside</u> the maximum-speed curve of Chart 3, and the 090° direction is still in the <u>East</u> sector.
(d.) Estimate the gustiness by referring to Chart 9, using the DCA and ADW wind speeds (both 6 kt) which indicate a gusty condition; however, because the temperature difference at DCA-ADW is 6°, this overriding parameter signifies a <u>non-gusty</u> wind condition ($\leq 10°$) at 300 ft.
(e.) Follow steps (4), (5), and (6) of the example in Section IV with the above-derived data and the given observations to reach the <u>same</u> final forecast. (Had the ADW temperature been warmer, causing the DCA-ADW temperature difference to be less than 6°, the most probable forecast would have been on line 8 of Table 1...56 percent probability of the visibility being 3 to 6 mi ... because the estimated gustiness taken from Chart 9 would have prevailed.)

If the forecaster finds himself too pressed for time when he waits until the 0400Z data are available, he can prepare a preliminary forecast from the 0300Z data; the results will usually be the same as for the 0400Z data except in occasional cases when the points on the charts may fall near a dividing line between chart areas, visibility classes, or when the input parameters are changing significantly. In these cases a quick recheck of the forecast should be made using the 0400Z data.

2. Visibility Isopleth Chart

Another simplified alternate technique is provided in Chart 7 which is essentially the same as Chart 2, but "area" designations are replaced by isopleths of visibility. To make a forecast, use Charts 1 and 8 with Chart 7. The development of Chart 7 is discussed in Section VII. In spite of the simplicity of this technique, it serves well as a first approximation to the minimum visibility. The forecasting accuracy of Chart 7 deteriorates for visibilities below 3 miles because of the effect of "inhibitor variables," which are discussed in Section VII.

VI. VERIFICATION

Data from the years 1962 - 1964 were used for development of the technique, and data from 1965-1966 were used for a verification sample. Visibility was verified in the five visibility classes. The Weather Bureau 0500Z terminal forecast for DCA was available for comparison. The actual forecasts for clouds and precipitation were used in the objective technique so that both forecasts were prepared on identical assumptions. Dates were eliminated when fronts passed, precipitation was predicted, or unpredicted precipitation occurred other than drizzle. The terms "intermittent" or "occasional" in connection with rain or showers were considered as rain forecasts; the terms "chance of...," "scattered showers," "few showers," etc., were considered to be remote possibilities and so were counted as non-rain cases. A brief, very light rain (R--, RW--) report was not eliminated because of its minimal effect upon the boundary-layer moisture conditions. Visibility remarks were disregarded in both forecasts and observations. No forecasts were made for the lowest ($< \frac{1}{2}$ mi) visibility class due to insufficient observations in the developmental sample to define the class. It should be noted that the technique as presented in this report utilized the combined 5-year sample, thus providing enough data to permit forecasts in the lowest visibility class.

Figure 4 shows the percent of correct forecasts by the

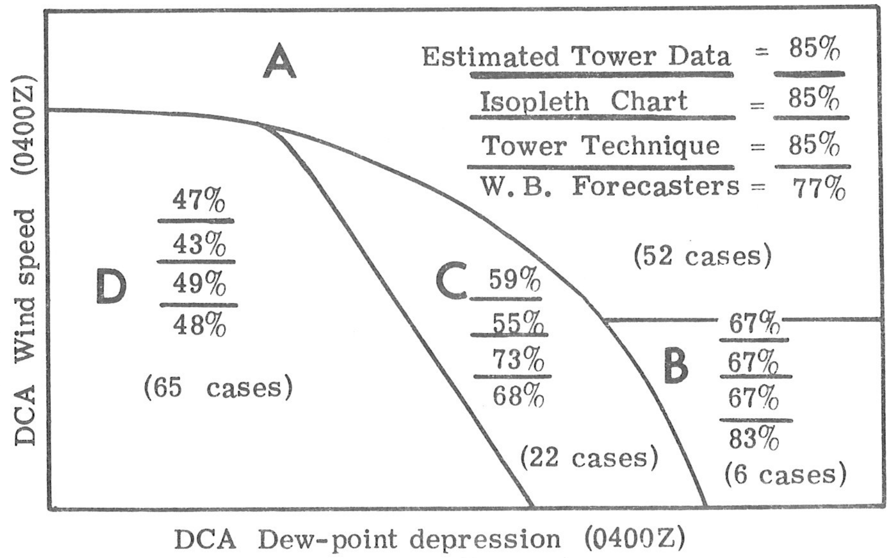


Figure 4. Percentages of correct minimum-visibility forecasts compared by areas using four methods with the verification data, 1965-1966.

forecaster and the objective techniques for each area of Chart 2. The objective technique with tower data shows a small advantage in areas A, C, and D. In area B, the forecaster was correct five times out of six, and so had a better score than provided by the technique. The substitution of estimated tower data results in forecasting scores that are comparable to, but not as good as scores obtained from using real tower data. Visibility forecasts made from Chart 7 isopleths show skill, but the forecasts are less accurate than forecasts produced by the other two methods or the forecaster.

Tables 2A-2D are the contingency tables derived from the verification data. Forecasts are compared to observations by various classes of visibility for three objective techniques and for Weather Bureau forecasts.

Table 3 shows the total percent of right and wrong as well as the skill scores which compare methods to a "chance" forecast. Chance is computed from the contingency tables. A skill of 1.0 is perfect, and 0.0 shows no skill. See Brier and Allen/1951/.

Vis. Observed \ Forecast Vis.	$<\frac{1}{2}$	$\frac{1}{2}$ - $1^3/_8$	$1\frac{1}{2}$ - $2\frac{1}{2}$	3-6	≥ 7	Total
$<\frac{1}{2}$ mi	0	2	0	2	0	4
$\frac{1}{2}$ to $1^3/_8$	0	0	0	3	2	5
$1\frac{1}{2}$ to $2\frac{1}{2}$	0	1	5	4	1	11
3 to 6	0	0	6	24	14	44
≥ 7	0	0	1	14	66	81
Total	0	3	12	47	83	145

2A. Objective Technique with Tower Data

Vis. Observed \ Forecast Vis.	$<\frac{1}{2}$	$\frac{1}{2}$ - $1^3/_8$	$1\frac{1}{2}$ - $2\frac{1}{2}$	3-6	≥ 7	Total
$<\frac{1}{2}$ mi	0	1	2	1	0	4
$\frac{1}{2}$ to $1^3/_8$	0	0	0	3	2	5
$1\frac{1}{2}$ to $2\frac{1}{2}$	0	1	6	3	1	11
3 to 6	0	1	5	28	10	44
≥ 7	0	0	2	20	59	81
Total	0	3	15	55	72	145

2C. Objective Technique, Estimated Tower Data

Vis. Observed \ Forecast Vis.	$<\frac{1}{2}$	$\frac{1}{2}$ - $1^3/_8$	$1\frac{1}{2}$ - $2\frac{1}{2}$	3-6	≥ 7	Total
$<\frac{1}{2}$ mi	0	2	1	1	0	4
$\frac{1}{2}$ to $1^3/_8$	0	0	0	4	1	5
$1\frac{1}{2}$ to $2\frac{1}{2}$	0	0	4	6	1	11
3 to 6	0	0	3	32	9	44
≥ 7	0	0	4	25	52	81
Total	0	2	12	68	63	145

2B. Objective Technique, Isopleth Chart

Vis. Observed \ Forecast Vis.	$<\frac{1}{2}$	$\frac{1}{2}$ - $1^3/_8$	$1\frac{1}{2}$ - $2\frac{1}{2}$	3-6	≥ 7	Total
$<\frac{1}{2}$ mi	0	2	1	1	0	4
$\frac{1}{2}$ to $1^3/_8$	0	0	3	1	1	5
$1\frac{1}{2}$ to $2\frac{1}{2}$	0	0	2	9	0	11
3 to 6	0	1	7	26	10	44
≥ 7	0	1	1	15	64	81
Total	0	4	14	52	75	145

2D. Weather Bureau Forecasts

Table 2. Contingency Tables of Forecast and Observed Visibility at Washington National Airport
1965-1966 Verification

TABLE 3. 1965-1966 Verification Results

Forecasting Method	Right	Wrong	Skill Score
Objective technique with tower data	66%	34%	.40
Objective technique, estimated tower data	64%	36%	.40
Objective technique, Isopleth Chart	61%	39%	.35
Weather Bureau forecasts	63%	37%	.38

The three objective techniques of this report were tried on a small sample of data from representative months of other seasons -- January, April, and July of 1964. Cloudiness predictions were assumed to be correct. The results gave about the same percent of correct forecasts as is seen in Table 3 and Figure 4. Generally, the other three seasons have better visibility than the fall season for which the technique was developed. The correctness of forecasts in areas A and D was lower, but areas B and C had better forecasts. This small sample only suggested the compatability of the technique for other seasons when the basic 0400Z data fall in areas A, B, and C. In area D, low visibilities were forecast but not in the proper categories; chart adjustments are needed in area D.

VII. TECHNIQUE DEVELOPMENT PROCEDURES

The visibility forecasting techniques presented in this report should be adaptable to many terminals with or without tower information. Guidance is provided in the following paragraphs.

1. Observation Time

The data collection at 0400Z may be too early in the night for obtaining the best results at stations in the Midwest or West due to the necessity for cooling to occur and for the evening wind to increase on the tower. The tower wind speed tends to increase to a maximum within several hours of midnight at Washington during non-gusty conditions. (Blackadar /1957/[4] discussed this situation in reference to the low-level jet.) The wind-maximum influences the subsequent visibility as shown by this tower-data technique. At stations farther west, this development would not have taken place by 0400Z; therefore, data

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[4] This report is summarized in Central Region HQ, SSD Technical Attachment B, May 1968.

observed at 0600Z or even 0900Z would be preferable west of the Atlantic Coast States.

The success of the technique is quite dependent upon the observations being representative of later conditions. Failures of the technique can often be attributed to subsequent large changes in the parameters measured at 0400Z. Examples of subsequent changes are advection (of fog, clouds, or dry air), windshifts, increasing wind speed from pressure changes, etc.

2. Use of Tower Data

If tower data are available to develop the technique at another terminal, the forecaster should develop each of the charts for that particular location. Terrain effects, air pollution sources, heat and moisture sinks, or "fog traps" will have a bearing upon the development. For example, northwest winds at DCA are affected by downslope motion, are likely to be turbulent due to the topography, and are drier due to the general source region (polar). Wind from the east sector is likely to have a moist marine trajectory. The southwest sector has some features of the other two sectors, being favored for non-gusty (laminar) windflow; the air coming from the southwest has a moist source region (Gulf). Because of these effects, Chart 3 has the irregular maximum-speed curve and the three direction sectors.

The use of a tower shorter than 300 ft should be satisfactory in many areas. On smooth terrain with no obstructions nearby (trees or buildings), a 100-ft tower should be satisfactory for wind measurements. The Silver Hill tower is surrounded by 60-ft trees which result in wind at 100 ft nearly always being gusty. The wind record at 200 ft shows more similarity to the record at 300 ft than to the record at 100 ft in regard to gustiness.

3. Development Method

The development of the technique involved successive stratifications of the data. The easiest forecasts were eliminated by the basic parameters having strong winds and/or dry air (area A). Additional parameters were introduced progressively to sift out the more difficult forecasts which were in areas C and D.

In more detail, the first step was the analysis of Chart 2 with minimum visibilities at DCA plotted at the coordinates for wind speed and dew-point depression. This step revealed several areas having similar visibilities; the areas were designated A, B, C, and D. Visibilities in areas A and B were all 3 mi or more (area B visibilities were more frequently 3 to 6 mi while area A visibilities were rarely of

$<$ 6 mi); area C differed from area B by having some visibilities of $<$ 3 mi; and area D had a wide assortment of visibility values. Areas A and B were eliminated from further analysis.

When a wide range of visibilities occurred in one stratum or area, a search was made for "inhibitor variables,"[5] and the following were found:

a. 300-ft wind speed,
b. 300-ft wind direction,
c. gustiness from the 300-ft direction-vane record, and
d. cloudiness of any amount at or below 7500 ft.

Successive stratifications involving these inhibitors yielded the technique presented in this paper. Perhaps more inhibitors could be found among other parameters to improve the skill of the technique by identifying the causes of reduced visibilities in area A or good visibilities in area D.

4. Reading Tower Data

a. Wind Speed

From tower data, wind speed was read as a mean (equal-area method) for one hour; from the same data the gust speed was determined. A mean gust speed was used in the technique on the assumption that it has more bearing upon the boundary-layer stability than the mean speed. (The term "gust" or "gustiness," as used here, is not to be confused with the Circular N definition.) Figure 5 shows an example of a reading from a wind record. About half of the brief peak gusts were used to determine the mean gust speed during very gusty periods.

b. Wind Direction

The tower wind direction also was read as a mean (equal-area method) along the recorded trace for one hour. In the case of a distinct change taking place during the hour which made the later record appear to be representative of a new pattern, the later record was used even though it may have a duration as short as 15 minutes. In no cases were data used after 0400Z.

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5 An "inhibitor variable" is defined by Bryan and others /1967/, as "an antecedent condition such that the event in question does not occur at a stipulated time subsequent to the observance of said antecedent." In this report, "antecedent" is used for conditions occurring at 0400Z and for clouds that occur later but are forecast at 0400Z.

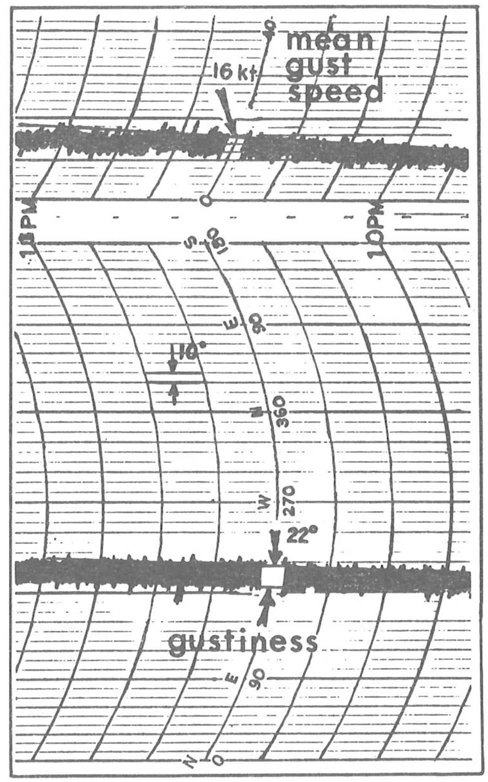

Figure 5. An example of a mean gust speed and a gustiness reading from an Aerovane recording. Arrows at cutaway portions of the recording illustrate mean readings with some of the extreme gusts eliminated.

c. Gustiness

Gustiness was read from the direction trace because it was considered more conservative than the speed trace. The units of measurement were angular degrees of variability of the trace for the hour. When the vane was turning non-linearly with time, short-period increments were averaged. When a distinct change in gustiness occurred during the averaging time period, the later portion was used if it lasted for at least 15 minutes. The angular range of the swinging vane was measured by eliminating about 1/3 of the short-period, extreme swings of the vane, when present, assuming them to be caused partly by the momentum of the swinging vane (Figure 5).

A code was developed to describe the various degrees of gustiness encountered in the wind-direction records. Illustrated in Figure 6, this code is especially applicable to nighttime data because daytime

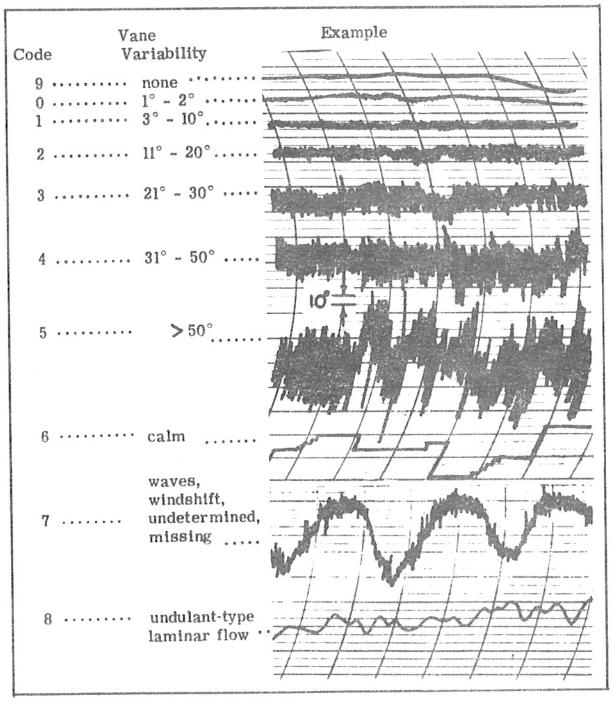

Figure 6. Gustiness code used to classify degrees of gustiness recorded by the Aerovane wind-direction pen.

gustiness is amplified by convection, making most readings more than 50°. Singer and Raynor /1957/ at the Brookhaven Tower used a gustiness code more suitable to daytime conditions, but that code is not detailed enough for nighttime gustiness in this study.

5. An Alternate Technique Without Tower Data

With tower data unavailable, Charts 1, 2, 7, 8, and 9 may be developed and used successfully at many air terminals. The technique is not likely to work well where nighttime wind tends to be calm (such as at a station located in a basin); however, sometimes a nearby, elevated wind report may be substituted in the data to achieve better results. DCA has the advantage of having a low frequency of calms, perhaps because of its location within a metropolitan heat island.

Methods for making objective estimates of the tower data are given in the following paragraphs.

a. Wind Gustiness

Estimates of gustiness made from a graph of the DCA and ADW wind speeds are quite successful, as shown by the probabilities on Chart 9. An estimate of gustiness could be made from a single wind speed, but with less accuracy as evidenced by the curving lines on the chart. Two wind speeds are more likely to give an area-wide indication of gustiness and to cancel any local effect that might be present at one station. The curves on Chart 9 were drawn from plotted tower-gustiness readings.

Strong surface winds are indicative of gustiness. Light winds, especially calms, are highly correlated to non-gusty ($\leq 10^{\circ}$ variability) windflow. Chart 9 has a zone labeled "mixed" which has about an equal number of gusty and non-gusty occurrences at intermediate surface wind speeds; it is in this zone where testing showed that the best forecasting results were obtained by using visibility isopleths from Chart 7.

On some occasions speeds up to 7 kt were reported at ADW, but these were <u>not</u> associated with gustiness. Investigation of these speeds revealed that the winds coexisted with a temperature difference between DCA-ADW of $\geq 6^{\circ}$ and a large temperature inversion between 5 and 300 ft on the tower. Six degrees was accepted as a critical value for suppression of gustiness on the tower when surface wind speeds indicated "gusty" or "mixed" on Chart 9. Apparently, the large DCA-ADW temperature difference is indicative of a large vertical temperature inversion.

To estimate gustiness on the tower, the forecaster uses the wind speeds at ADW and DCA with Chart 9; but if the temperature difference at DCA-ADW is $\geq 6^{\circ}$ at 0400Z, the forecaster considers the 300-ft wind to be non-gusty. This override was correct 93 percent of the time.

b. Wind Speed

Estimates of the tower wind speed are important only as they relate to the maximum-speed curve of Chart 3. Doubling the ADW speed gives a fair estimate of the tower speed, especially in the northwest sector. Actually, the tower wind speed varies from $1\frac{1}{2}$ to as much as 8 times the ADW speed when the ADW speed is ≥ 2 kt at 0400Z. Hanna and Panofsky /1966/ developed some nomograms for estimating the 90-m (300 ft) wind from the 30-m (100 ft) wind during gusty conditions (unstable or neutral temperature profiles). The ratio of the 30-m wind to the 90-m wind ranges from 1.1 to 2.1, depending upon the Richardson Number and the season. These authors do not attempt to find ratios for stable conditions when the ratio becomes much larger.

c. Wind Direction

Estimates of wind direction at the 300-ft level of the tower are better if the ADW direction is used than the DCA direction. The ADW wind directions range within 45° of the tower direction, as compared to 70° at DCA. It is believed that the physical location of DCA in the Potomac River Valley causes the wind direction variability to be greater.

With the wind calm at ADW, direction estimates are made from a local-area synoptic map having all stations plotted with pressures to tenths of a millibar, and analyzed at 1-mb intervals. In making the estimate, allow the wind to cross the isobars at an angle of 30° toward lower pressure. This estimate proved satisfactory in a test. The largest errors occurred with high pressure ridges, weak pressure gradients, and irregular isobars.

d. Cloudiness

Cloudiness of any amount at or below 7500 ft generally tends to inhibit low visibility. The introduction of clouds at night often decreases the low-level stability, which increases visibility by permitting a greater mixing of the air. If clouds increase over a previously established surface temperature inversion, the clouds can cause surface warming from the radiation "greenhouse effect," thus changing the lapse rate and inducing gustiness; or turbulent motions can exist beneath the clouds simply due to their presence.

The 0400Z cloudiness is not satisfactory as a parameter, so a forecast of cloudiness is required. This brings an element of subjectivity into the forecast, but because cloudiness is used in a simple yes-no form, this constraint should not tax the forecaster's ability while improving the accuracy of the area D forecasts. Neither the timing of the arrival or the departure of clouds, nor their amount, is considered in the technique, though clouds undoubtedly have some bearing on the ultimate visibility.

It is reasonable to believe that a more definitive scale for cloudiness could be devised. It might include scattered clouds up to 6000 ft, broken clouds up to 9000 ft, and overcast clouds up to 14,000 ft. At times this would require more precision from the forecaster.

6. The Visibility Isopleth Chart

Chart 7 visibility isopleths were drawn from actual minimum visibilities after a filtering technique was applied to get a single representative visibility value at each coordinate or at combinations of several coordinates where data were sparse. Filtering prevented, for example, one case of an 8-mi visibility from dominating 8 cases of 1/8 mi, resulting in an unrealistic average visibility of 1 mi. The filtering was performed by weighting each visibility with a numerical value from a slightly skewed logarithmic scale shown below.

VISIBILITY:	$<\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	3	4	5	6	≥ 7
WEIGHT:	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

Averaged weights were converted back into a single visibility number which was plotted at the coordinate for use in drawing the visibility isopleths.

VIII. SUMMARY AND CONCLUSIONS

The application of several objective techniques for minimum visibility forecasting shows skill equivalent to that of the field forecasters. The techniques should not only help Washington forecasters but others as well, including air pollution forecasters, by giving them a better understanding of the relationships among visibility-predicting parameters. The techniques could be adapted to other forecasting terminals, it is believed, and the techniques could be adapted to computers, although the manual technique takes only a minute or two.

The basic visibility-forecasting parameters are dew-point depression and wind speed at the surface. Other parameters are cloudiness, tower wind speed, direction, and gustiness which are used in the technique to refine the forecast through successive steps. Tower data are most effective for forecasting if observations are made near midnight.

Tower data, which are used for some of the forecasting parameters, give more accurate predictions than the technique modified to use estimated tower data, although the difference is small. This shows that tower data are useful in forecasting; or, if available only temporarily, tower data can be used to develop techniques that may substitute for tower data.

The technique employing estimated tower data works successfully in seasons other than fall, but adjustments to the charts would provide better forecasts, especially during moist conditions with light winds (area D).

A simplified form of the technique is presented in a single chart with visibility isopleths drawn for two variables, wind speed and dew-point depression. This chart is useful for visibilities above three miles and for first-approximation visibilities below three miles.

IX. REFERENCES

Blackadar, A. K., "Boundary Layer Wind Maxima and Their Significance for the Growth of Nocturnal Inversions," Bull. Amer. Meteor. Soc., vol. 38, No. 5, 1957, pp. 283-290.

Brier, G. W., and R. A. Allen, "Verification of Weather Forecasts," Compendium of Meteorology, Amer. Meteor. Soc., Boston, Mass., 1951, pp. 841-848.

Bryan, J. G., J. A. Russo, Jr., and G. T. Merriman, "Research on the Prediction of Rare Events to Improve Forecasts of Low Ceiling and Visibility," Final Report Weather Bureau Contract No. Cwb 11299, Travellers Research Corp., Hartford, Conn., 1967, p. 5.

George, J. J., and M. W. Ellett, "A Study of Fog and Low Ceilings for Washington Airport," U. S. Dept. of Commerce, Weather Bureau, Washington, D. C., 1941, 22 pp.

Hanna, S. R., and H. A. Panofsky, "Estimation of the 90m Wind from Low Level Observations," Final Report Weather Bureau Contract No. Cwb 10951, Pennsylvania State University, University Park, Pa., 1966, 58 pp.

Mook, C. P., "Visibility Forecasting," U. S. Dept. of Commerce, Weather Bureau, Washington, D. C., January 1945. 22 pp.

Singer, I. A., and G. S. Raynor, "Analysis of Meteorological Tower Data, April 1950 - March 1952, Brookhaven National Laboratory," Associated Universities, Inc., Upton, N. Y., 1957, pp. 9-10.

X. APPENDIX ON OBSERVING STATIONS

DCA, three miles south of downtown Washington, is built near sea level on fill ground on the west side of the Potomac River where the Potomac is joined by the Anacostia River. The tidal waters of the river are more than a half mile wide at this point. Gently rolling hills constitute the river banks, sloping up to 150 to 200 ft within one to two miles of the river.

The Silver Hill tower is located about 5 mi east of DCA on the edge of rolling terrain sloping northwestward toward the Anacostia River and the City of Washington, D. C. Comparatively level terrain is to the southeast where Andrews AFB is located. The tower, situated at 290 ft msl, is an open-frame, steel, microwave relay tower, 32 ft wide at the top level; it is 308 ft above the ground. The Bendix-Freiz Aerovane wind instrument is on a 14-ft mast near the south corner of the tower. No corrections were made for any speed or direction effects from the tower structure; gustiness corrections were made for several dates in 1962 because of a temporary microwave reflector affecting the west to northwest flow. (When such a windflow occurred, it was usually during conditions not requiring the gustiness parameter.) Later, the reflector was removed.

Wind data available from the 100-ft and 200-ft levels were not used. Lower elevation wind data would have produced a different speed curve on Chart 3 and sometimes a different gustiness value. Tower temperature and dew-point data were examined but not used.

XI. TABLE 1 AND CHARTS 1-9

(See next 5 pages for the charts.)

AREA OR SUB-AREA CHART 2	TOWER SPEED IN OR OUT OF MAX.-SPEED CURVE CHT.3	GUST'NS FROM TOWER WIND DIR. RECORD	TOWER WIND DIR. SECTOR CHT. 3	CLOUDS ≤7500′ FORECAST 05Z-12Z YES OR NO	PERCENT PROBABILITY BY VISIBILITY CLASSES					TOTAL CASES
					>6 MI	3-6 MI	$1\frac{1}{2}$ - $2\frac{1}{2}$ MI	$\frac{1}{2}$ - $1\frac{3}{8}$ MI	< $\frac{1}{2}$ MI	438
A	-	-	-	-	90%	9%	1%	1%	0	194
B	-	-	-	-	65%	35%	0	00	0	29
C	-	< 3°	-	-	44%	48%	8%	0	0	27
C	-	≥ 3°	-	-	67%	27%	3%	3%	0	33
D	OUT	> 10°	ANY	YES	100%	0	0	0	0	8
D	OUT	> 10°	ANY	NO	33%	67%	0	0	0	3
D	OUT	≤ 10°	ANY	EITHER	44%	56%	0	0	0	9
D	IN	> 10°	ANY	NO	32%	56%	4%	0	8%	25
D	IN	> 10°	ANY	YES	47%	40%	0	13%	0	15
D	IN	ANY	ANY	< 700 FT + DRIZZLE	0	0	17%	83%	0	6
D SUB-AREA:	IN	≤ 10°	REFER TO CHARTS 4, 5, OR 6 TO IDENTIFY SUB AREAS OF "D" FROM WIND DIRECTION & CLOUDINESS.							
D-1	IN	≤ 10°	ANY	YES	30%	20%	50%	0	0	10
D-2			ANY	YES	14%	65%	14%	7%	0	14
D-3			SW	NO	0	25%	13%	25%	37%	8
D-4			SW	NO	9%	36%	41%	9%	5%	22
D-5			SW	NO	0	100%	0	0	0	3
D-6			E, NW	NO	0	0	0	0	100%	2
D-7			E, NW	NO	30%	10%	60%	0	0	10
D-8			E, NW	NO	25%	60%	15%	0	0	20

Most probable forecast visibility class indicated by arrow.
Data from 5 years of DCA records, 1962-66.

TABLE 1. Forecast probabilities, DCA minimum visibility, September, October, November.

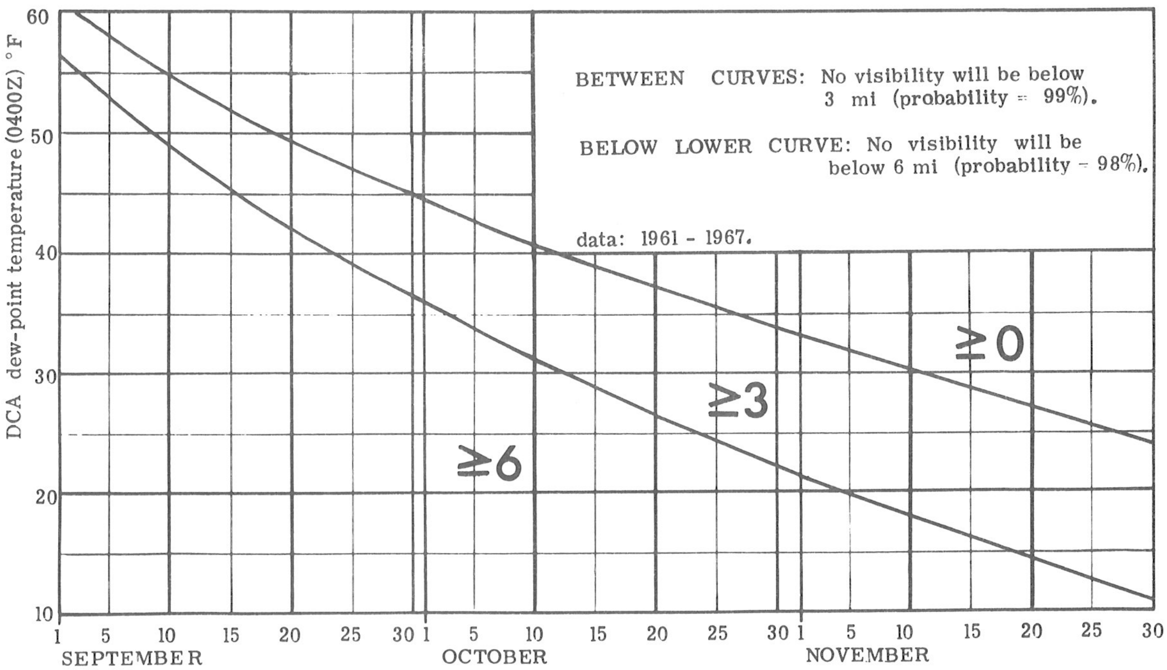

Chart 1. Limiting dew-point temperatures for restricted minimum visibility at Washington National Airport.

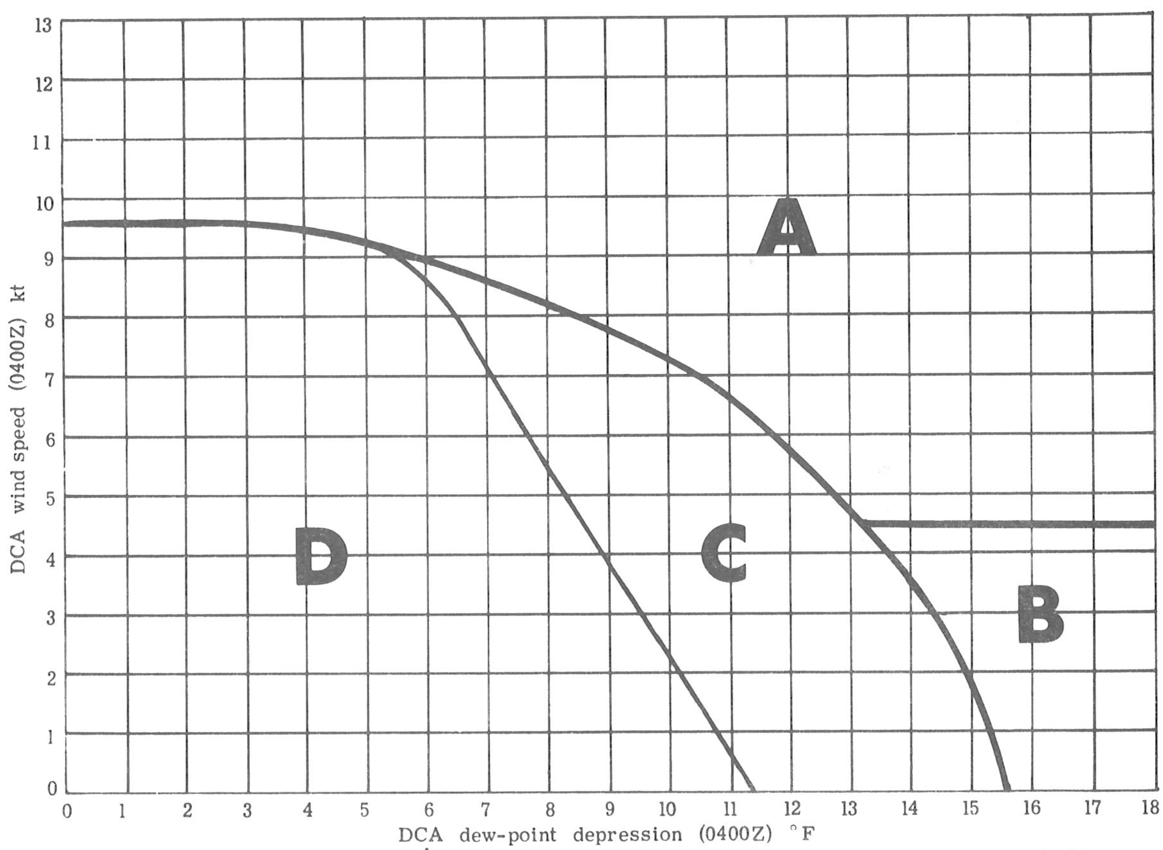

Chart 2. Morning minimum visibilities at Washington National Airport, designated by Areas A to D, for September - November.

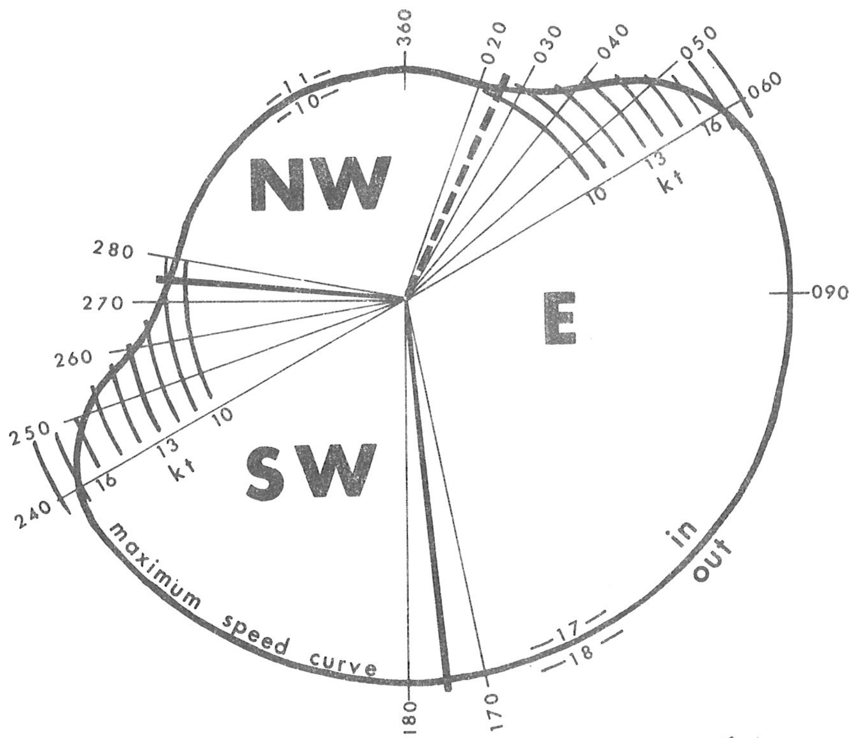

Chart 3. Wind direction sectors and limiting wind speeds for the Silver Hill 300-ft wind or ADW wind.

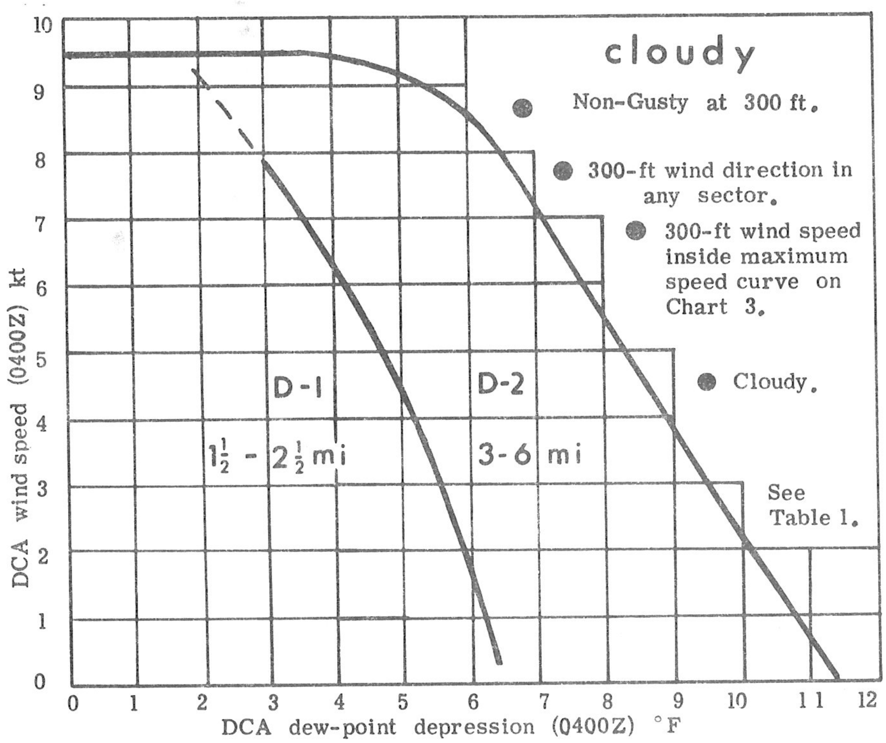

Chart 4. Sub areas of Area D, Chart 2, for specified conditions.

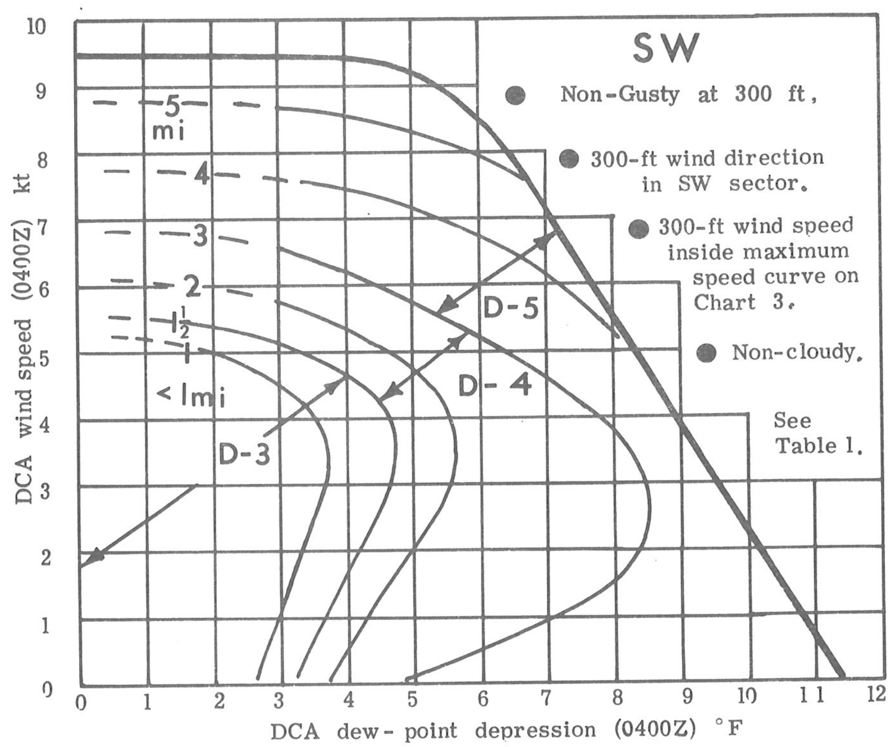

Chart 5. Sub areas of Area D, Chart 2, for specified conditions.

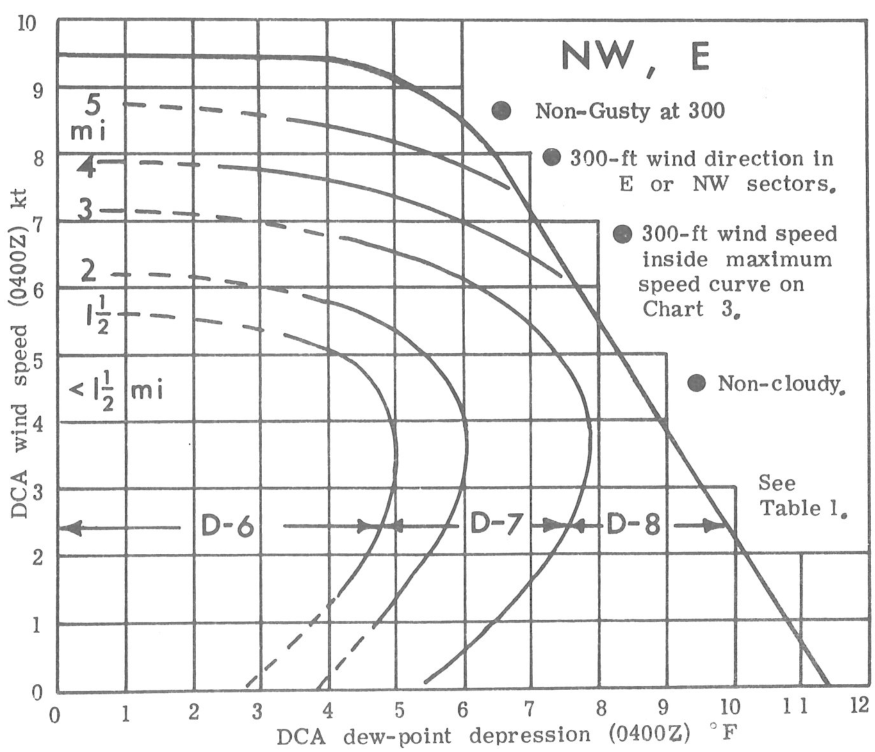

Chart 6. Sub areas of Area D, Chart 2, for specified conditions.

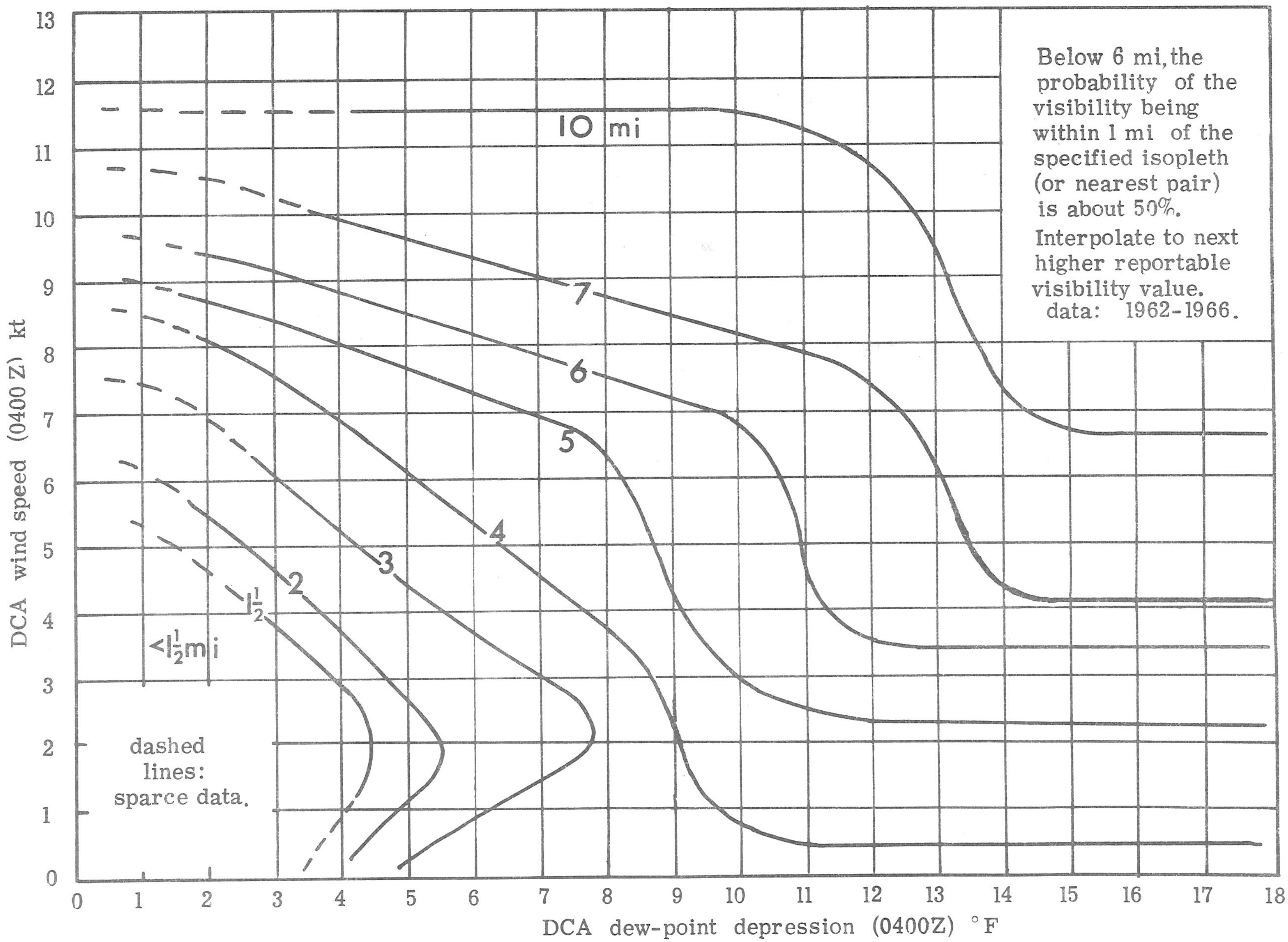

Chart 7. Isopleth chart for morning minimum visibility at Washington National Airport for September through November.

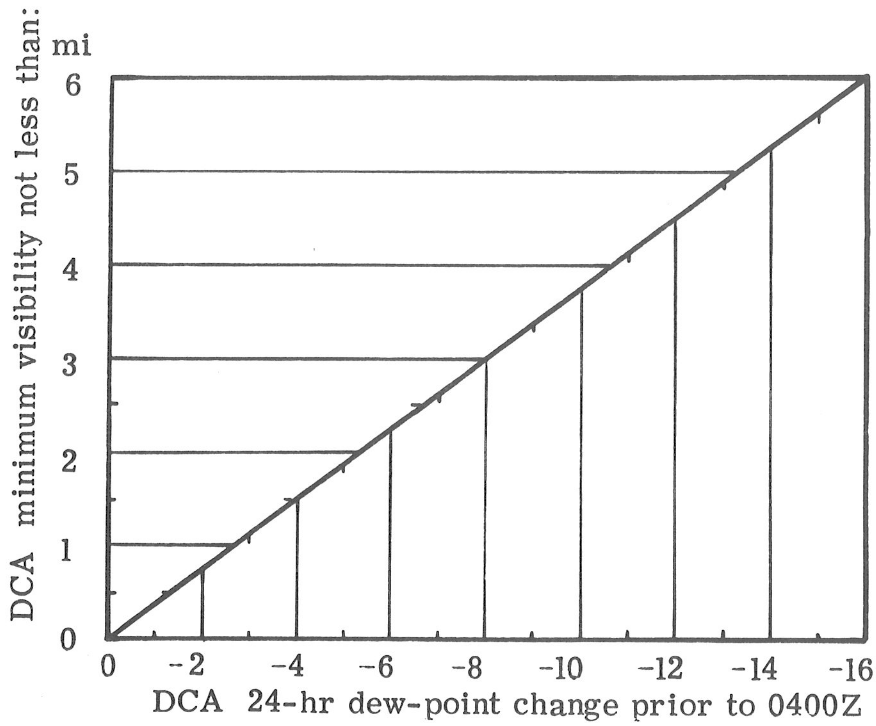

Chart 8. Dew-point change chart for DCA, September through November. The minimum visibility will not be below the value specified by the diagonal. Probability=93% for 1961-1967.

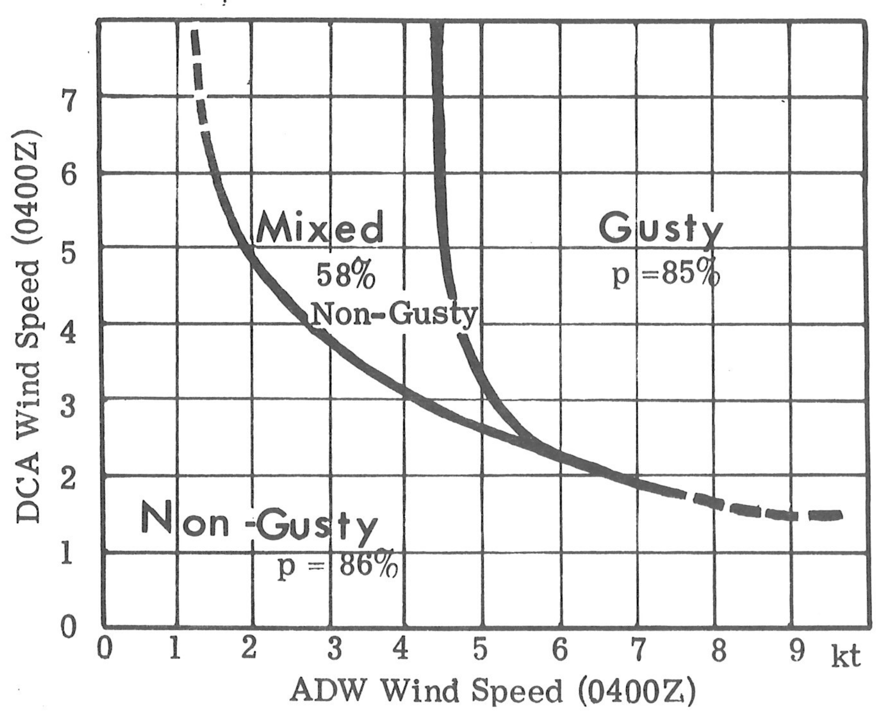

Chart 9. 300-ft gustiness estimating chart for Silver Hill. (Use temperature over-ride with this chart by assuming non-gustiness if DCA-ADW $\geq 6^{o}$F at 0400Z. If either speed $\geq$ 10 kt, probability = 92% for gusty conditions at 300 ft.