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ESTIMATED GLAZE ICE AND WIND LOADS AT THE EARTH'S SURFACE FOR THE CONTIGUOUS UNITED STATES

Paul Tattelman, et al

Air Force Cambridge Research Laboratories
L. G. Hanscom Field, Massachusetts

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13. ABSTRACT

A climatology of glaze storms occurring in the U.S. from 1919-20 through 1968-69 was compiled. A subjective analysis of these storms was used to develop probability estimates of ice accretion for seven regions in the U.S. east of the Rocky Mountains. Estimates of combined ice and wind loads are also present.

The greatest probability of severe ice storms exists from the central and northern plains through the upper midwest eastward to New England. The single point probability of at least one occurrence of an ice storm ≥ 2.5 cm in one year in the northeastern U.S. is 0.0002. The single point probability of an ice storm ≥ 5.0 in this same area is 0.00018. For the southeastern U.S. the probability of such occurrences in one year are 0.0004 and near zero, respectively.

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1. INTRODUCTION

Ice accretion can be a major destructive force to structures, such as towers, located in middle and high latitudes anywhere in the world. Concurrent, or more probably, subsequent strong winds may be the critical factor in damaging equipment already loaded with ice. There are two types of ice to consider in structural design– glaze and rime. Glaze ice is of most concern because of its relatively frequent occurrence in heavily populated areas. It is the result of the freezing of rain or drizzle upon impact with exposed objects. The resulting ice is usually clear, but may be milky or opaque due to air trapped or dissolved by the water droplets before they freeze. Glaze is hard and usually has a density greater than 0.8 g cm^{-3}.

Rime ice is a localized phenomenon occurring most frequently in isolated locations on hills or mountain tops. It occurs when supercooled clouds or fog droplets freeze upon impact with surfaces colder than 0°C. Because of the large amount of trapped and dissolved air in rime, it is white colored, softer, and less dense than glaze. Macklin[1] discusses in detail the variability in color and density of glaze and rime and the mechanism of their formation.

(Received for publication 12 October 1973)

[1] Macklin, W.C. (1962) The density and structure of ice formed by accretion, Quar. Jour. Royal Met. Soc. **88**(No. 375):30-50.

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Routine observations of glaze and rime are not taken by the National Weather Service; hence, much of the difficulty in determining design values for ice and wind loading is a result of the lack of data. Most of the information that does exist for glaze and rime was recorded only when they caused human distress or a sizable amount of damage. Even then, measurements are often not made and those made are not standardized and are difficult to compare.

The most comprehensive study on the geographical distribution and frequency of glaze, not only for the U.S. but the world, was done by Bennett[2]. He provided the best review of glaze data available in the literature, but he did not specify probability estimates of varying degrees of ice accumulation necessary to provide engineering design goals.

This study is predicated on the assumption that ice storms of unusual severity are noted in meteorological literature. The primary goal was to enumerate the ice storms in which maximum ice thickness of 2.5 cm (1 in.) or more and 5 cm (2 in.) or more occurred during a 50-year period for which weather records were considered most complete. This was to ultimately provide a probability distribution of ice and wind loads for various homogenous areas of the contiguous U.S.

One of the most perplexing problems in working with glaze is the disparity in meaning of reported values of ice thickness. Since most glaze measurements or estimates are observations of amounts on twigs or wires, we take the ice thickness to mean the radial thickness of the ice (measured in the direction of maximum thickness). Considerations affecting ice thickness are discussed in Section 4.2.

Very few occurrences of significant rime accretions were reported. Consequently this report deals primarily with glaze.

2. DATA

Several meteorological publications (Climatological Data for the United States by Sections, Storm Data, Monthly Weather Review, Weatherwise, Bulletin of the American Meteorological Society) were reviewed for reports of ice storms. Bennett[2] and a list of severe ice storms by the Environmental Data Service[3] provided additional references and leads. Approximately 100 storms were described in these records during the 50 winters from 1919-20 through 1968-69. Most storms affected several states. Tabulation of only those storms in which ice

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[2] Bennett, I. (1959) Glaze, Its Meteorology and Climatology, Geographical Distribution and Economic Effects, Tech. Rep. EP-105, Quartermaster Research & Engineering Center, Envir. Prot. Res. Div., Natick, Mass.

[3] Environmental Data Service (1966) Some Outstanding Ice Storms, ESSA, U.S. Dept. of Commerce, L.S. 6212, 4 pp.

thickness equalled or exceeded 2.5 cm, and determination of the states in which this amount of icing occurred was primarily a subjective task. In many instances, the ice thickness reported in the literature appeared to conform with our definition. When interpretation of the reported values of ice thickness wasn't clear, a subjective decision was made as to the meaning intended. When no measurements were provided, as was the case for about 25 percent of the storms, an estimate of whether or not a storm produced 2.5 cm or more of ice was made based on such information as the amount of damage, qualitative descriptions, and pictures.

The following are examples of subjective decisions for the storms of 24 to 31 January 1948 in Arkansas, Mississippi, and South Carolina and 8 to 11 February 1959 in the midwest and northeastern U.S. The first storm was credited with producing at least a 2.5 cm of glaze because of $20 million damage in Arkansas. The second storm was eliminated from the study because the maximum amount of damage reported was a relatively minor $1 million in the hardest hit state, Illinois, and qualitative descriptions placed heavy emphasis on slippery highways and sidewalks, a condition that would accompany even a minor storm.

The original sample was reduced to 61 storms, each covering 3-1/3 states on the average, for a total of 206 storm-states (New England and Maryland-Delaware-District of Columbia were counted as single states). Using the procedure discussed in the previous paragraph, each of the 206 storm-states was rechecked, primarily in Climatological Data for the United States by Sections, in order to determine which states received 2.5 cm or more ice thickness. This resulted in 90 storm-states. The number of times the ice thickness equalled or exceeded 2.5 cm for each state during the 50-year study period is shown in Figure 1.

Of the 61 storms producing 2.5 cm or more ice thickness, 21 produced 5 cm (2 in.) or more in 29 storm-states. Two storms with accretions of 10 and 12.5 cm (4 and 5 in.) occurred in Idaho, and one of 12.5 cm occurred in Utah. These were the result of freezing fog producing rime. One storm producing a 15 cm (6 in.) accretion in Texas appears to have been at least partially wet snow. All of the 21 "5 cm or more" storms were picked on the basis of reported ice thickness, but a subjective evaluation was necessary to determine how the thickness was measured for about half of the reported thicknesses.

Specifying the maximum wind gust when the ice was near maximum thickness required an almost totally subjective approximation. Maximum winds were specifically stated for only a few of the storms. Peak gusts were determined for the remaining storms by examining hourly wind arrows and the pressure gradient on historic surface synoptic maps for the area of interest during the days of below-freezing temperature following the storm. The maximum gust for each storm was then estimated to lie in one of three categories, less than 10 m/sec, 10 to 20 m/sec, and greater than 20 m/sec.

Figure 1. Number of Times by State That Ice Thickness ≥ 2.5 cm Occurred During 50 Years. (New England and Maryland-Delaware-District of Columbia were treated as single states)

Information on less extreme glaze storms in which 1.25 and 0.63 cm (0.5 and 0.25 in.) or more accumulated, and the total number of glaze storms without regard to thickness was provided by Bennett.[2] Results of his analysis, which incorporates data from a nine-year study of the Association of American Railroads, are shown in Figures 2, 3, and 4.

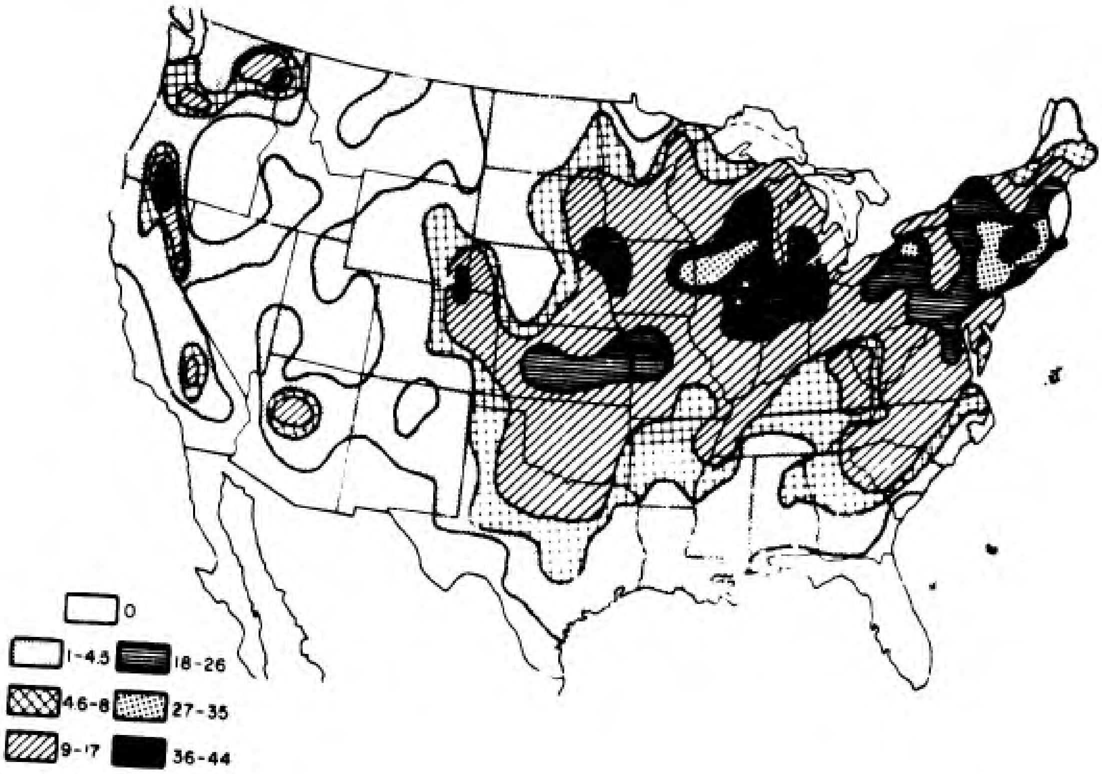

Figure 2. Total Number of Glaze Storms, Without Regard to Ice Thickness, Observed During the 9-year Period of the Association of American Railroads Study (Bennett, 1959)

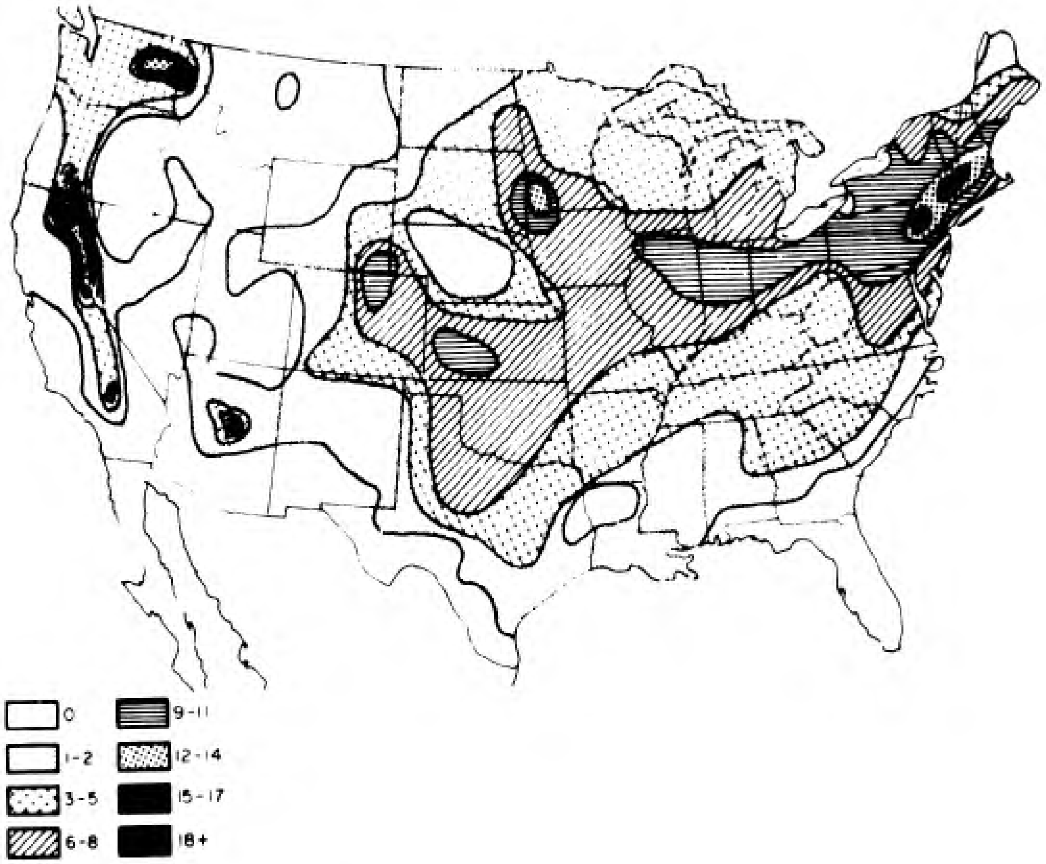

Figure 3. Number of Times Ice 0.63 or More Thick Was Observed During the 9-year Period of the Association of American Railroads Study (Bennett, 1959)

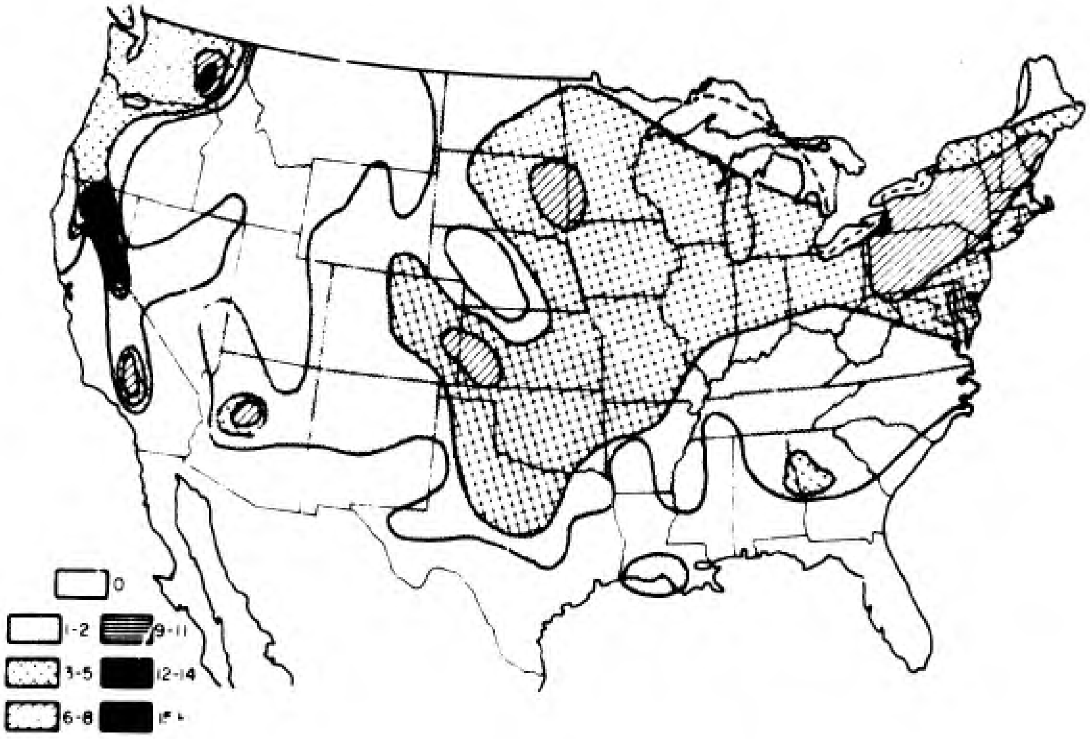

Figure 4. Number of Times Ice 1.25 cm or More Thick Was Observed During the 9-year Period of the Association of American Railroads Study (Bennett, 1959)

3. ANALYSIS

3.1 Glaze

The United States was divided into eight regions (Figure 5) based on a subjective evaluation of areas of similar glaze characteristics. Consideration was given to latitude, land area, geography, climatology and the distribution of ice storms in Figure 1.

Only three ice storms of 2.5 cm or more were found for Region VIII. Two of these were the only occurrences of rime found. Icing probabilities were not developed for this area because of the small data sample; however, frequency of icing there will be discussed in Section 4.3

Figure 5. Regions of Similar Glaze Characteristics

The number of storms affecting Regions I through VII, regardless of how many states within each region were affected, is shown in Table 1. Also shown is the probability of at least one occurrence > 2.5 cm and ≥ 5 cm somewhere in each region in any year. Probabilities were computed using the Poisson approximation, $\lambda^x e^{-\lambda}/x!$ which, for no occurrences, reduces to $e^{-\lambda}$. Therefore,

$$P(\geq r) = 1 - e^{-\lambda}, \qquad (1)$$

where $P(> r)$ is the probability of at least one occurrence of ice ≥ the thickness r in any year and λ is the average number of storms in any year (that is, the number of storms per region divided by the number of years of study).

Table 1. Probability of at Least One Occurrence of an Ice Storm in Any Year Somewhere in the Region

Region	Land Area (km^2)	Number Ice Storms in 50 Years ≥ 2.5 cm	Regional Probability of an Ice Storm in One Year ≥2.5 cm	Number Ice Storms in 50 Years ≥ 5 cm	Regional Probability of an Ice Storm in One Year ≥ 5 cm
I	586,147	8	.15	3	.06
II	633,392	15	.26	3	.06
III	423,362	14	.24	4	.08
IV	734,726	8	.15	3	.06
V	534,380	5	.10	2	.04
VI	769,457	10	.18	3	.06
VII	600,824	5	.10	1	.02

A stochastic model of the spatial variability of a meteorological element has been developed in the Design Climatology Branch (Gringorten[4]; see Appendix A), which relates the probability of an event somewhere in a given area to the smaller probability at a single station within the area. To apply the model to the data in Table 1, it has to be assumed that the chance, or probability of an ice storm is uniformly the same over the whole region. Point probabilities are shown in Table 2.

Table 2. Probability of at Least One Occurrence of an Ice Storm in Any Year at a Representative Point in the Region. (Estimated From Spatial Variability Model)

Region	Point Probability of an Ice Storm ≥ 2.5 cm in One Year	Point Probability of an Ice Storm ≥ 5 cm in One Year
I	.0006	.00020
II	.0060	.00018
III	.0020	.00050
IV	.0005	.00016
V	.000[illegible]	.00012
VI	.0010	.00014
VII	.0004	Negligible

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[4] Gringorten, I. I. (1973) Stochastic Modelling of the Areal Extent of Weather Conditions, to be published by AFCRL.

Figures 2, 3, and 4 were used to estimate the average number of storms for each intensity category (that is, ≥ 0 cm, ≥ 0.63 cm and ≥ 1.25 cm) occurring in each region during one year. Also, the maximum number of storms occurring in each region during an average year was estimated. These values were used in Eq. (1) and the probabilities for each intensity category and region were computed and listed in Tables 3 and 4.

The probabilities given in Tables 2 and 3 approximate the probability of a given intensity ice storm at a representative point in each region or, in other words, an average for the region (Figures 6 through 12; curves labelled "AVG"). The frequency of ice accretion ≥ 2.5 cm and > 5 cm in the most severe areas of each region was estimated by using Eq. (1) to compute the probability of an ice storm in one year in the worst State in each region, without regard to where in the State the storms occurred. These values, in Table 5, together with the probabilities in Table 4, were used for the estimates in the worst location in each region (Figures 6 through 12; curves labelled "MAX").

It should be noted that the values in Table 5 are not directly comparable with those in Table 4. The regional maximum number of storms listed in Table 4 all occurred in the same general location. It is unlikely that the same is true for the number of storms listed in Table 5; however, it is felt that these figures provide an approachable maximum for the worst location in each region. The average and maximum frequencies of ice accretion for each region are depicted in Figures 6 through 12. Extrapolation between 5 and 7.5-cm ice thickness was accomplished by extending the slope of the 2.5 to 5-cm line (MAX) in Figures 6 through 12. Extrapolation beyond 7.5 cm was considered totally guesswork. Figures 6 through 12 were used to summarize ice thickness for various return periods. The results are presented in Table 6.

3.2 Combined Glaze and Wind

Maximum wind gusts for each storm of 2.5 cm or more were estimated as described in Section 2. The percentage of ice storms of 2.5 cm or more and 5 cm or more, according to maximum associated wind gusts, are listed in Tables 7 and 8 respectively.

It appears that most ice storms of 2.5 cm or more (88 percent) have maximum gusts greater than 10 m/sec. Storms with gusts greater than 20 m/sec seem to occur in about half of the storms in the northern plains and upper midwest, but only about a fifth of the storms elsewhere. Storms of 5 cm or more with gusts greater than 20 m/sec vary erratically from region to region due to the small data sample, but collectively, a larger percentage of these storms occur with higher winds.

Since the method used to obtain maximum wind gusts was coarse and subjective, and the data sample was small, it would be unreasonable to expect more than a gross generalization of coincident ice and wind loads until more precise data are collected. From the data used in this study, and a subjective evaluation of Tables 7 and 8, the probability of winds greater than 20 m/sec with ice accretions of 2.5 cm or more can be approximated by taking one half of the probability at any point on the "MAX" curve given in Figures 6 and 7, and a third of the probability at any point on the "MAX" curve on Figures 8 through 12. Using this approximation, ice thickness associated with gusts greater than 20 m/sec for return periods of 25, 50 and 100 years was computed for the most severe location in each region and is presented in Table 9.

4. DISCUSSION

4.1 Evaluation of Results

Since the data used in this study do not lend themselves to the usual statistical analysis, error estimates can only be made subjectively. Even the assumptions used to develop the data have inherent errors that result in obvious bias. For example, we have placed much reliance on the number of storms reported in the literature, but this number is undoubtedly less than the actual quantity of storms that have occurred. Estimates used to determine combined ice and wind loads are also subject to skepticism since the sparse station density on once-daily surface synoptic maps makes it almost impossible to determine the maximum gust in the precise location of maximum ice accumulation at the time when the ice was near maximum thickness.

Where it was possible, compensation in an opposing direction was employed to at least partially offset any bias. Using the State with the maximum number of storms in each region to approximate the severe locations is an overestimate, since it is improbable that all the storms affecting that State occurred in the same area. However, this does offer a counter-balance for any storms that might not have been reported. Also, using the number of storms affecting a region to compute the probability of an ice storm at a representative point within that region at least partially offsets an anomalously low number of storms affecting one State (for example, Wisconsin and West Virginia, see Figure 1).

Bennett[2] analyzed data from a nine-year study of the Association of American Railroads, Figures 2, 3, and 4. These data, although different in format and covering only a nine-year period, were considered comparable to our data for the purpose of approximating ice thickness less than 2.5 cm. Data on ice storms greater than 5 cm was limited and unreliable.

In summary, a large portion of the data in this report was subjectively developed, and, at times, subjectively manipulated. The results, Figure 6 through 12, and Tables 6 and 9 should be taken with a "grain of salt"; however, they appear quite reasonable and, until better data are available, provide a justifiable approximation.

4.2 Other Considerations

We have been treating glaze as a uniformly measurable meteorological parameter, which it is not. The thickness of ice accumulating on an exposed object can vary because of the shape of the ice; glaze accumulating on wires is frequently oval or even pear shaped. This is further complicated by icicles hanging from the ice-covered object adding to the strain, but not included in the measurement of the ice thickness. The collection efficiency of the object, its height above the earth's surface and the windspeed during a glaze storm all play important roles in determining the accretion and effect of glaze.

So far in this report, little has been said about rime. Of the 61 ice storms of 2.5 cm or more over a 50-year period, only two were totally the result of rime, both from freezing fog, and, as mentioned earlier, these occurred in the west (Region VIII). It is certain that this is an underestimate of the actual number of severe rime incidents. The estimates of ice thickness developed in this report are, therefore, considered applicable only to glaze. It should be understood that severe occurrences of rime on hilltops or in mountainous terrain exposed to supercooled cloud droplets or freezing fog is an additional icing hazard to those already considered.

4.3 Applications

Estimates of glaze thickness at a representative point and at a point in the most severe general area for each region are presented in Figures 6 through 12 and in Table 6. Table 9 provides combined ice and wind loads for only the most severe location in each region. It is difficult to pin down exactly where the most severe location(s) are; it is recommended that, in general, the severe value be used for design. When the location involved is considered a low frequency area, such as can be seen for southeastern Georgia or northwestern Maine in Figures 2 through 4, the representative value can be applied. The estimates of glaze thickness for a representative point is a useful guide in determining average values for an entire region depending on the deployment of the material involved.

Very few observations of ice accretion have been noted west of the continental divide. The usual mechanism producing glaze in the mid latitudes, a tropical maritime air mass overrunning a polar continental air mass, is notably absent in this area. Nevertheless, glaze does occur there, even some severe cases, but occurrences are fewer and more isolated than in the other regions. In designing for Region VIII, estimates of glaze should be based on past experience for any particular locale, but these should not exceed estimates for Region III, the most severe in the country. Rime accretion should be the primary consideration in higher elevations, particularly in the coastal ranges of the far west.

4.4 Future Prospects

The Design Climatology Branch has frequently been asked to provide estimates of ice accretion and combined ice and wind loading for operations anywhere in the world. The lack of data, or nonexistence in some cases, has prompted the development of a prototype glaze measuring device which is currently being tested. It is hoped that within a few years, glaze and rime measurements will become part of the standard meteorological observing system.

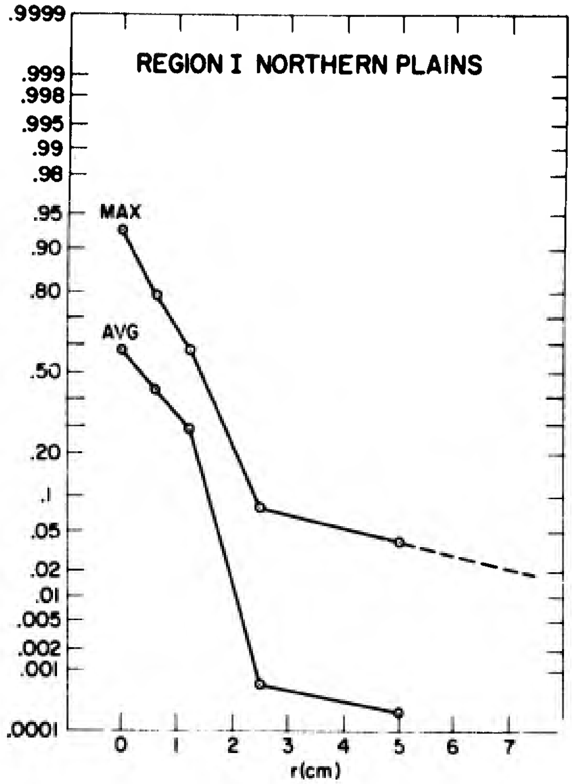

Figure 6. Estimated Probability of Ice Thickness, r, Occurring at Least Once in Any Year at a Representative Point in Region I (AVG) and in the Most Severe Part of Region I (MAX)

Table 3. Probability of at Least One Occurrence of an Ice Storm in Any Year at a Representative Point in the Region. (Estimated from Bennett, 1959)

Region	Regional Average No. Storms in 9-Year Study	Probability of an Ice Storm (Any Thickness in 1 Year	Regional Average No. Storms ≥ 0.63 cm in 9-Year Study	Probability of an Ice Storm ≥ 0.63 cm in 1 Year	Regional Average No. Storms ≥ 1.25 cm in 9-Year Study	Probability of an Ice Storm ≥ 1.25 cm in 1 Year
I	8	.59	5	.43	3	.28
II	18	.86	7	.54	3	.28
III	20	.89	10	.67	6	.49
IV	15	.81	5	.43	3	.28
V	8	.59	4	.36	2	.20
VI	6	.49	4	.36	2	.20
VII	4	.36	2	.20	0.5	.05

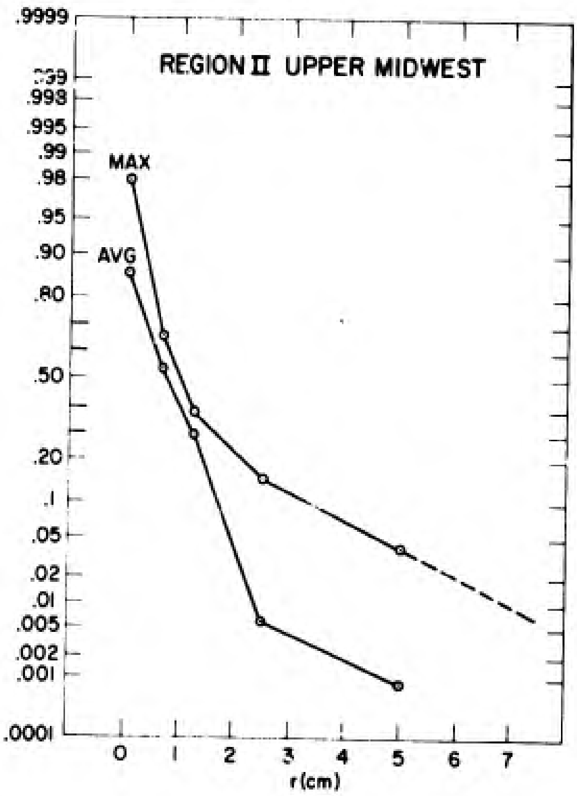

Figure 7. Estimated Probability of Ice Thickness, r, Occurring at Least Once in Any Year at a Representative Point in Region II (AVG), and in the Most Severe Part of Region II (MAX)

Table 4. Probability of at Least One Occurrence of an Ice Storm of Stated Intensity in Any Year at a Point in the Most Severe Part of the Region. (Estimated From Bennett, 1959)

Region	Regional Maximum No. of Storms in 9-Year Study	Probability of an Ice Storm (Any Thickness) in 1 Year	Regional Maximum No. of Storms ≥0.63 cm in 9-Year Study	Probability of an Ice Storm ≥0.63 cm in 1 Year	Regional Maximum No. of Storms ≥ 1.25 cm in 9-Year Study	Probability of an Ice Storm ≥ 1.25 cm in 1 Year
I	24	.93	14	.79	8	.59
II	35	.98	10	.67	4	.36
III	44	.99	19	.88	9	.63
IV	35	.98	11	.71	8	.59
V	20	.89	9	.63	6	.49
VI	16	.83	8	.59	5	.43
VII	11	.71	4	.36	4	.36

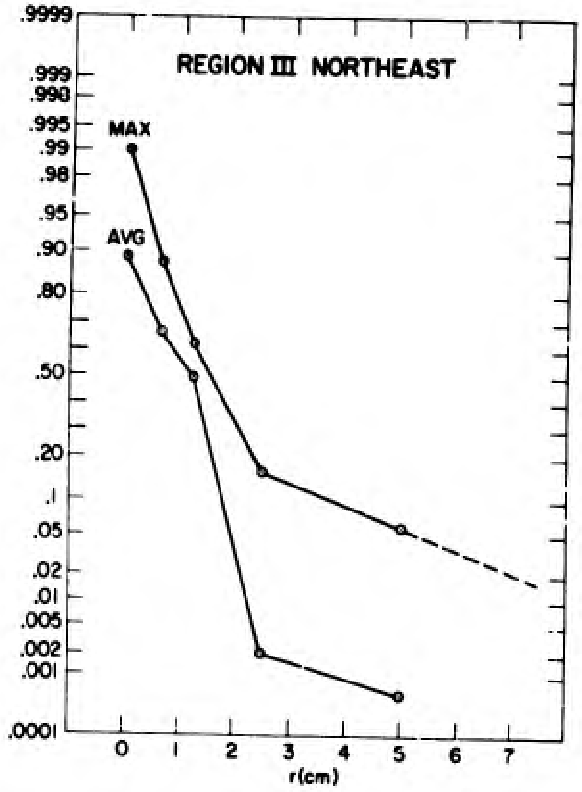

Figure 8. Estimated Probability of Ice Thickness, r, Occurring at Least Once in Any Year at a Representative Point in Region III (AVG), and in the Most Severe Part of Region III (MAX)

Table 5. Number of Ice Storms ≥ 2.5 cm and ≥ 5 cm in 50 Years and the Probability of at Least One Occurrence in One Year in the Most Severe State in Each Region

Region	Number Ice Storms ≥2.5 cm in 50 Years	Probability of an Ice Storm ≥ 2.5 cm in 1 Year	Number Ice Storms ≥ 5 cm in 50 Years	Probability of an Ice Storm ≥ 5 cm in 1 Year
I	4	.08	2	.04
II	8	.15	2	.04
III	9	.16	3	.06
IV	4	.08	2	.04
V	2	.04	1	.02
VI	4	.08	1	.02
VII	3	.06	1	.02

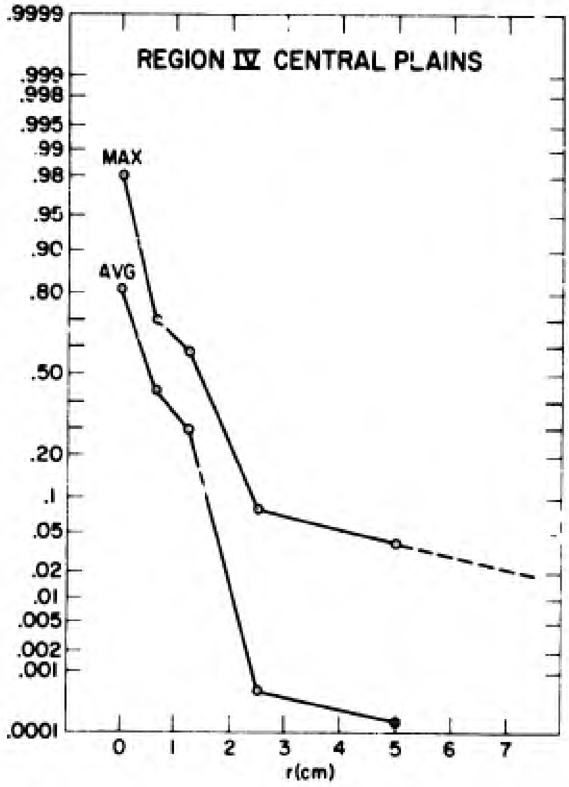

Figure 9. Estimated Probability of Ice Thickness, r, Occurring at Least Once in Any Year at a Representative Point in Region IV (AVG), and in the Most Severe Part of Region IV (MAX)

Table 6. Ice Thickness, Estimated to the Nearest 0.1 cm, for Different Return Periods, at a Representative Point (AVG), and at a Point in the Most Severe Location (MAX) for Each Region

	Return Period (Years)											
	2		5		10		25		50		100	
Region	AVG	MAX	AVG	MAX	AVG	MAX	AVG	MAX	AVG	MAX	AVG	MAX
I	0.4	1.4	1.4	2.1	1.6	2.4	1.8	5.0	1.9	7.1	2.1	>7.5
II	0.7	1.0	1.4	2.1	1.7	3.3	2.0	5.0	2.2	6.0	2.4	7.0
III	1.2	1.6	1.6	2.4	1.8	3.8	2.0	5.8	2.1	7.2	2.3	>7.5
IV	0.5	1.4	1.4	2.1	1.6	2.4	1.8	5.0	1.9	7.2	2.1	>7.5
V	0.2	1.2	1.2	1.8	1.5	2.2	1.7	2.5	1.8	5.0	2.0	7.0
VI	0	1.0	1.2	1.9	1.5	2.4	1.7	3.8	1.9	5.0	2.1	6.0
VII	0	0.4	0.6	1.8	1.0	2.2	1.3	3.4	1.5	5.0	1.7	6.3

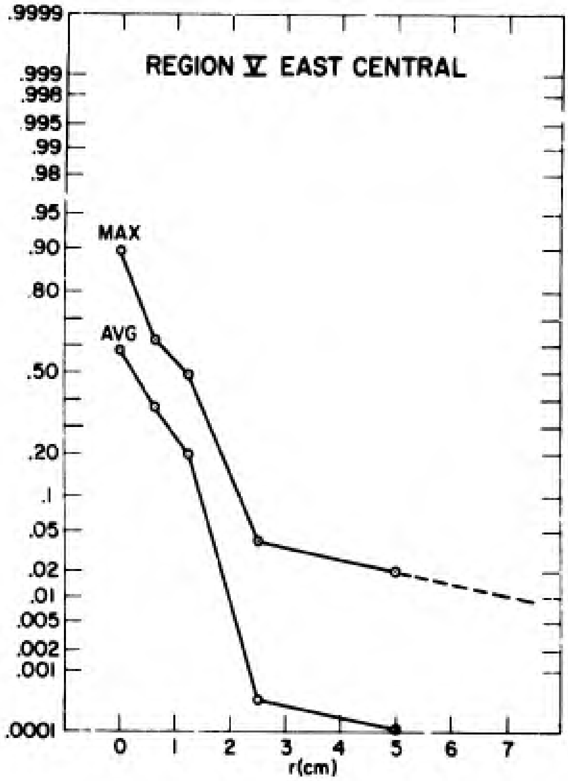

Figure 10. Estimated Probability of Ice Thickness, r, Occurring at Least Once in any Year at a Representative Point in Region V (AVG), and in the Most Severe Part of Region V (MAX)

Table 7. Maximum Wind Speeds With Ice Storms ≥ 2.5 cm

Region	Total Number Storms	Storms With Max Gusts ≥ 10 m/sec	Percent of Total	Storms With Max Gusts ≥ 20 m/sec	Percent of Total
I	8	7	88	4	50
II	15	14	93	9	60
III	14	10	71	3	21
IV	8	8	100	2	25
V	5	5	100	1	20
VI	10	9	90	2	20
VI	5	5	100	1	20
I-VII	58*	51*	88	18*	31

*This figure is less than the total for Regions I-VII since some storms affected more than one Region.

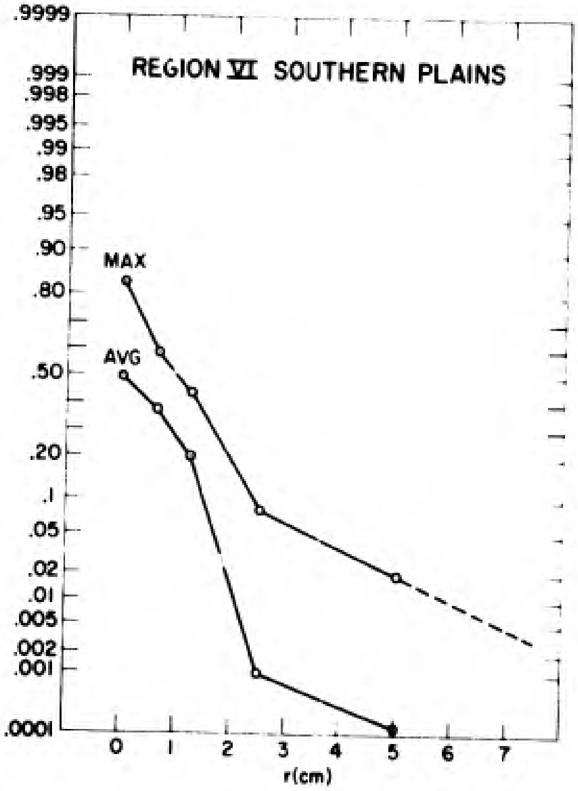

Figure 11. Estimated Probability of Ice Thickness, r, Occurring at Least Once in Any Year at a Representative Point in Region VI (AVG), and in the Most Severe Part of Region VI (MAX)

Table 8. Maximum Wind Speeds With Ice Storms ≥ 5 cm

Region	Total Number Storms	Storms With Max Gusts ≥ 10 m/sec	Percent of Total	Storms With Max Gusts ≥ 20 m/sec	Percent of Total
I	3	2	67	2	67
II	3	3	100	3	100
III	4	4	100	1	25
IV	3	3	100	0	0
V	2	2	100	0	0
VI	3	3	100	1	33
VII	1	1	100	1	100
I-VII	19	18	95	8	42

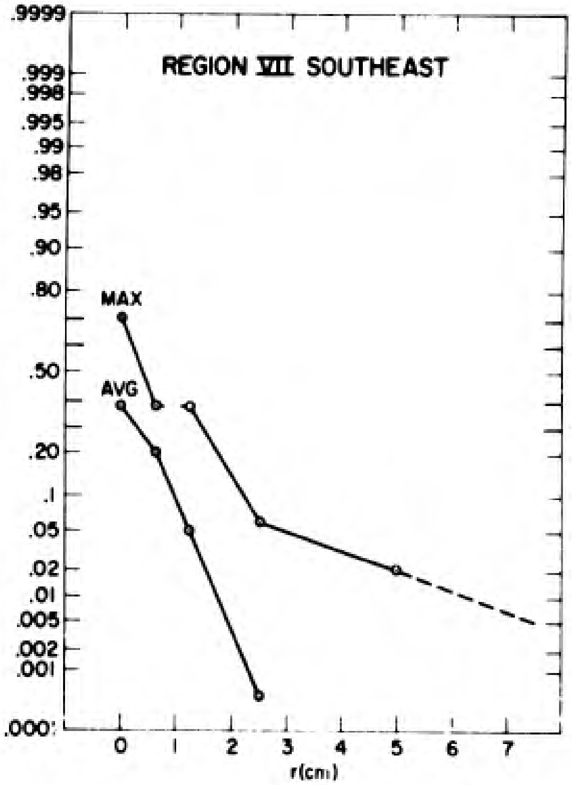

Figure 12. Estimated Probability of Ice Thickness, r, Occurring at Least Once in Any Year at a Representative Point in Region VII (AVG), and in the Most Severe Part of Region VII (MAX)

Table 9. Ice Thickness, Estimated to the Nearest 0.1 cm, Combined With Wind Gusts ≥ 20 m/sec in the Most Severe Location in Each Region

Region	Return Period (Years)		
	25	50	100
I	2.5	5.0	6.5
II	3.7	5.0	6.5
III	2.6	5.0	6.6
IV	<2.5	3.5	5.6
V	<2.5	<2.5	3.6
VI	<2.5	3.0	4.5
VII	<2.5	2.5	4.1

Acknowledgment

Robert Lenhard of the Design Climatology Branch, AFCRL, participated in helpful discussions and contributed useful suggestions during the course of this study.

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Appendix A

Analysis of Region II Heavy Ice Storms

Region II witnessed 15 ice storms in the 50 years (Fall 1919 through Spring 1969) during each of which there was an accretion of 2.5 cm or more. Each storm was spread, on the average, over 1-1/3 states. In Table A1, the first column gives combinations of adjacent States, the second column gives their combined area (A km^2), the third column gives the number of storms in that combination over the 50-year period. Assuming a Poisson distribution, the fourth column gives the probability (P) of one or more ice storms in any one year, estimated by:

$$\overline{P} = 1 - e^{-\lambda}$$

where λ is the average number of occurrences per year. The fifth column in Table A1 is for s' (km) given by

$$s' = \sqrt{A}$$

In Figure A1, P is plotted against s' for the 13 pairs of values (Table A1).

Table A1. The Frequency of Glaze Storms With an Accretion ≥ 2.5 cm in Region II, During 50 Winters (1919 through 1969)

Combination of States	Area (km^2)	Number of Storms	P	s' (km)
All 5 States	633,392	15	.26	796
Illinois, Indiana, Michigan, Ohio	491,888	15	.26	701
Wisconsin, Michigan, Illinois, Indiana	527,339	13	.23	727
Michigan, Indiana, Ohio	347,202	9	.16	589
Illinois, Indiana, Ohio	344,391	12	.21	587
Wisconsin, Michigan	289,002	4	.06	537
Illinois, Indiana	238,337	10	.18	489
Indiana, Ohio	199,705	6	.11	447
Wisconsin	141,504	1	.02	376
Michigan	147,498	4	.08	384
Illinois	144,686	8	.15	381
Indiana	93,651	4	.08	306
Ohio	106,054	4	.08	325

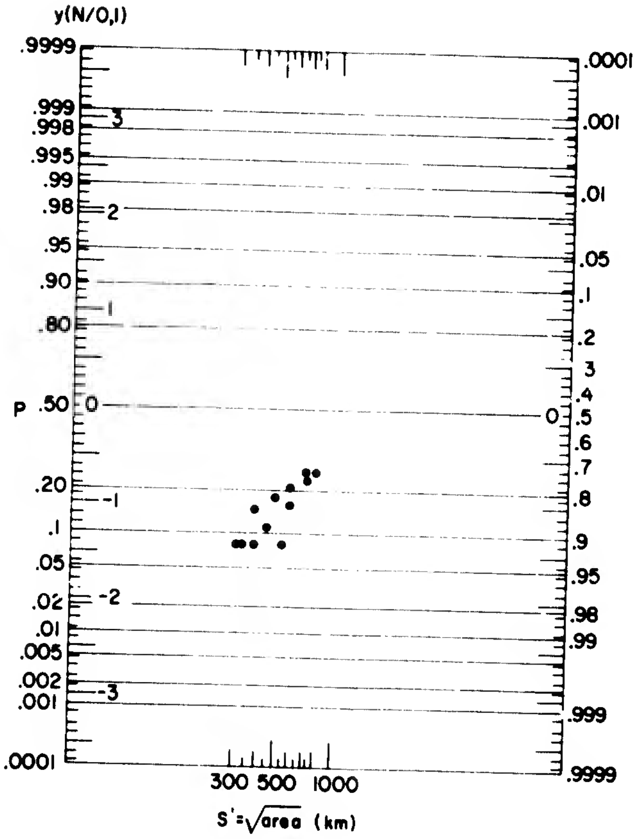

Figure A1. Plot of Frequency (P) of an Ice Storm of Thickness ≥ 2.5 cm (1.0 In.) in One Year Somewhere in the Area (A) of Region II. (Ordinate is P. Abscissa is $S' = \sqrt{A}$ km)

In the Design Climatology Branch a stochastic model has been under development to relate the probability of a meteorological event at a single location to the probability of occurrence somewhere within a specified area. While not yet published, this model has clear application to the records of incidence of glaze storms. The frequencies of occurrence in Table A1, (P), are linked to the areal size of the States, and are only estimates of the 'true' probability of occurrence. They still do not answer the question on the probability, or risk, of damage by an ice storm at a single location, for example, to an antenna tower. In the following paragraphs, the results of applying the model are presented, without a full explanation of all the steps. There is much subjectivity because of the brevity of the records on glaze.

Figure A2 is a product of the stochastic model. Each curve is drawn for one value of $y(0, 1)$ from -3.5 at the top to 4.5 at the bottom. The right-hand vertical scale gives $P(\leq y_{max}; s)$, defined as the probability that the maximum value of y is equal to or less than y_{max} throughout the space of area s^2 sq. units, where s is given on the horizontal scale. For example, the value of $y = 3.0$, which has a single-point probability

$$P(y \leq 3.0) = 0.9986,$$

will be the maximum in an area of 100 sq. units with probability

$$P(y_{max} \leq 3.0;\ s = 10) = 0.995$$

(the intersection of the curve y = 3.0 and s = 10).
Likewise

$$P(y_{max} \leq 2.0;\ s = 50) = 0.82$$

and so on.

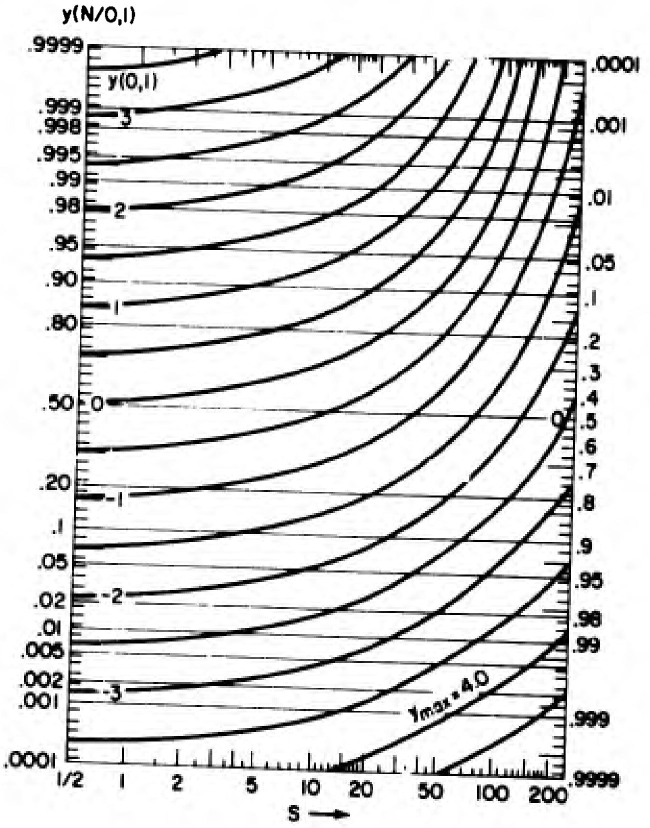

Figure A2. A Chart for the Model Estimates of Probability P ($\leq y_{max}$;s) That the Value of y Will Be Equal to, or Less Than y_{max} Throughout the Space of Area s^2 Sq. Units. On the Ordinate the scales are for P and y. On the abscissa the scale is for s. The curves are for y_{max} at intervals of 0.5 from 4.5 to -3.5.

The scale of distance on the abscissa (Figure A2) is such that the correlation coefficient between values of y separated by one unit of distance is 0.99. For any other distance (s) between stations the correlation coefficient $\rho(s)$ is, for this model, given by

$$\rho(s) = \frac{2}{\pi} \left[\sin^{-1} \sqrt{1 - \sigma^2} - \sigma\sqrt{1 - \sigma^2}\right]$$

where $\sigma = s/128$. This makes $\rho(s) = 0$ for $s = 128$ units.

Scale distance (r) is defined as the distance (in km) over which the correlation coefficient is 0.99. Thus, if distance is measured in km, then r km corresponds to the unit distance on the s-scale; if a distance is s' km, then s is given by

$$s = s'/r.$$

Application of this model required that the scale distance (r) be determined or estimated so that s can be substituted for s' before entering Figure A2. With the kind of information that is contained in Table A1 and Figure A1, it is virtually impossible to make an objective estimate of the scale distance. Subjectively, the lowest acceptable curve (Figure A2) to fit the data in Figure A1 is for $y = 3.0$. This gives (on the right-hand vertical scale) the single-point probability $(1-P) = 0.9986$, or, on the left-hand scale, $P = 0.0014$. This leads to the estimate (a description of the procedure is not attempted here):

$$r = 2.9 \text{ km}.$$

The above treatment was limited to glaze storms equal to, or exceeding, 2.5 cm in Region II. In other regions there were fewer storms. However, the assumption is made that the scale distance (r = 2.9 km) is the same for all glaze phenomena, not only in the different geographic areas, but also for different intensities (≥ 0, ≥ 0.13, ≥ 1.25, ≥ 2.5, ≥ 5.0 cm). In other words, they share the same characteristic of horizontal persistence. For the areas and probabilities given in Table 1, using r = 2.9 km, the model gives the single-point probabilities as shown in Table 2.