GLAZE STORMS AND THEIR ECONOMIC EFFECTS

by

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In the eastern United States, one of the serious hazards of winter is the thick layer of ice deposited by glaze storms. With the possible exception of forest and woodlot, the greatest economic loss from these storms is suffered by electric power and telephone companies. It is not uncommon for the cost of repairing damage to lines and poles and the loss of revenue from suspended service to exceed several hundred thousand dollars for a heavy storm, and on many occasions damage has run into millions. The secondary effects on factories, businesses, and schools, which must suspend operation because of loss of electric power service, may swell the loss to even larger totals.

Definition and Physical Properties of Glaze

Among non-meteorologists there is considerable confusion concerning terminology for glaze and the storms producing the phenomenon. As defined by the U. S. Weather Bureau (Haynes, 1947), glaze consists of "....homogeneous, transparent ice layers which are built upon horizontal as well as vertical surfaces either from supercooled rain or drizzle, or from rain or drizzle, when the surfaces are at a temperature of 32° F. or lower." There is no official agreement on proper terminology for the storms, but "ice storm" or simply "glaze storm" are widely used by meteorologists. The supercooled rain that leads to the ice formation is recognized as freezing rain or freezing drizzle. The common practice, particularly among representatives of the electric power and telephone companies of referring to the ice as sleet and the storms as sleet storms is, of course, incorrect. Sleet consists of drops of rain frozen solid in their fall through the air.

Physically, glaze is somewhat related to two other forms of ice -- <u>rime</u> and <u>hoarfrost</u> -- but differs from them by its greater density and hardness. Actually, no clear-cut limits can be established for the specific gravity of the different forms because in nature they often grade from one into the other. There is, for instance, a form of rime recognized by meteorologists which approaches glaze in structure and density -- the so-called "hard rime" indicated by the international symbol ∀. Nevertheless, most cases of what, on the basis of origin, would be considered glaze have been found to have a density ranging from 0.6 to 0.9, while rime and hoarfrost average considerably less. The higher density of glaze, plus its greater ability to cling tenaciously to surfaces on which it forms and its lack of friability, make it a far more dangerous form of ice to trees and outdoor electric power facilities than either rime or hoarfrost. Rime and hoarfrost, however, can be a threat to electric power and telephone facilities, and more will be said of this later.

Synoptic Meteorology of Glaze Storms of the Northeast

Meteorological literature contains little information dealing with the synoptic meteorology of glaze. Studies of this aspect of the subject in the United States were made by Brooks (1914), Frankenfield (1917), and Meisinger (1920), but at a time when modern concepts of synoptic analysis were not fully developed. Riehl (1952) has included a brief description of conditions producing glaze in the Chicago area in his monograph, "Forecasting in Middle Latitudes". Studies have been made by a number of individuals of conditions in Europe, but the results cannot be taken as necessarily representative of situations which produce glaze in the United States. A fairly large number of descriptions of single storms occurring in this country are available, and some include materia dealing with synoptic conditions responsible for the storms (Harlin, 1952, and McQueen and Keith, 1956).

In the discussion which follows, an attempt is made to summarize the combinations of meteorological conditions most favorable for the occurrence of glaze in the northeastern United States. The discussion is based on material taken from the sources mentioned above and from an independent study conducted by the writer. This study was in the nature of a survey and did not by any means exhaust all possible means and areas of investigation.

The widely held belief that most freezing rain is associated with warm fronts is probably true, but it also occurs frequently with cold fronts. In the Northeast, occluded systems are a common type. Furthermore, glaze apparently can result from freezing rain or drizzle that is entirely non-frontal in nature. Indeed, freezing drizzle frequently is non-frontal and can occur in a wide variety of meteorological situations and over a wide range of temperatures. Probably most cases of freezing precipitation at very low temperatures involve drizzle coming from supercooled stratus-type clouds in a non-frontal situation.

For almost every synoptic situation producing glaze, another that is almost identical in origin, history, and final form can be found that did not produce glaze. It is not possible to say, for example, that all or even most of the polar front waves that develop over the eastern half of the Gulf of Mexico in winter and move northward along the Atlantic coast will bring glaze to any location along their path, even though a fair percentage of the glaze experienced in this part of the country is caused by such storms. Nor is it possible to say that such storms will yield glaze when associated with a particular distribution and intensity of high pressure or any other feature of the synoptic pattern. Undoubtedly, an exhaustive and careful study would reveal subtle differences in the history of glaze-forming and non-glaze-forming storms, but they are almost certain to be slight, since very small variations in temperature, both in the overrunning warm air mass and in the cold wedge, determine whether or not glaze is to form. The problem is made more complex when it is realized that glaze-producing storms do not necessarily cause glaze everywhere along their paths. Factors of local weather just prior to the storm and factors of the microclimate may cause one area to experience glaze while another close by escapes entirely or experiences ice of a heavier or lighter intensity.

The most typical synoptic condition for glaze formation in the Northeast is a polar front wave with an active warm front moving in a north or northeasterly direction toward the region. A high pressure area almost always is found north of New England, with the center of the ridge or cell usually located somewhere northeast of Newfoundland. This distribution causes a flow of cP air over the area from the north or east ahead of the warm front and mT air from the south behind the front. The overrunning mT air is frequently warmer than 32° F., while the cold cP wedge has temperatures from 20° to 30° F., and a situation almost ideal for the formation of freezing rain or drizzle results.

The waves originate in almost any part of North America, although few come from northern or eastern Canada; also, they take almost any path as they move toward the Northeast. Out of 69 storms studied, 34 originated in the vicinity of the Gulf of Mexico. The remaining were fairly evenly divided between other North American source regions. Seven out of 26 storms occurring at Caribou, Me., originate as far away as Alberta or the Pacific Coast.

Storms originating in the South Atlantic and East Gulf areas generally move directly up the coast, with the tip of the wave passing almost over the af-

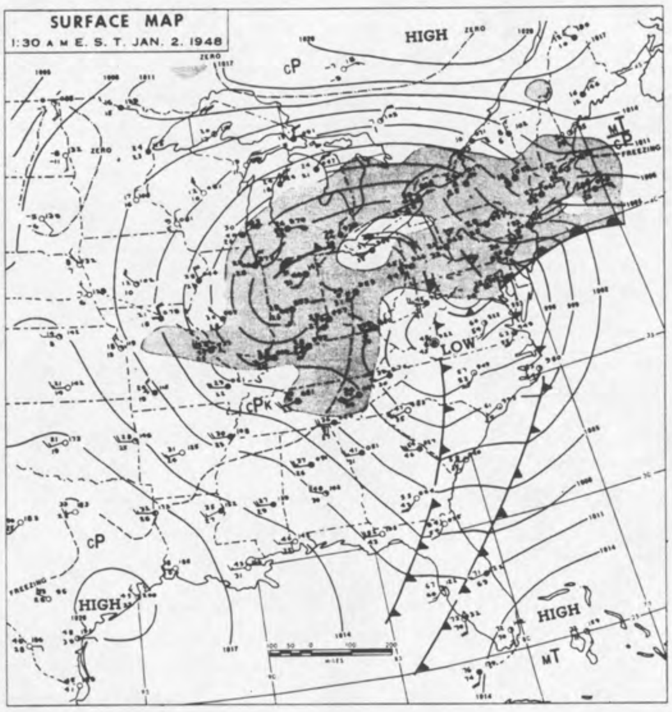

Figure 1. Final stage of the storm of January 1 and 2, 1948. Heavy freezing rain is falling from Pennsylvania to Massachusetts. Map reprinted from Daily Weather Map analyzed Series No. 37, Set No. 2 (M. E. Ellinwood), permission of the U. S. Weather Bureau.

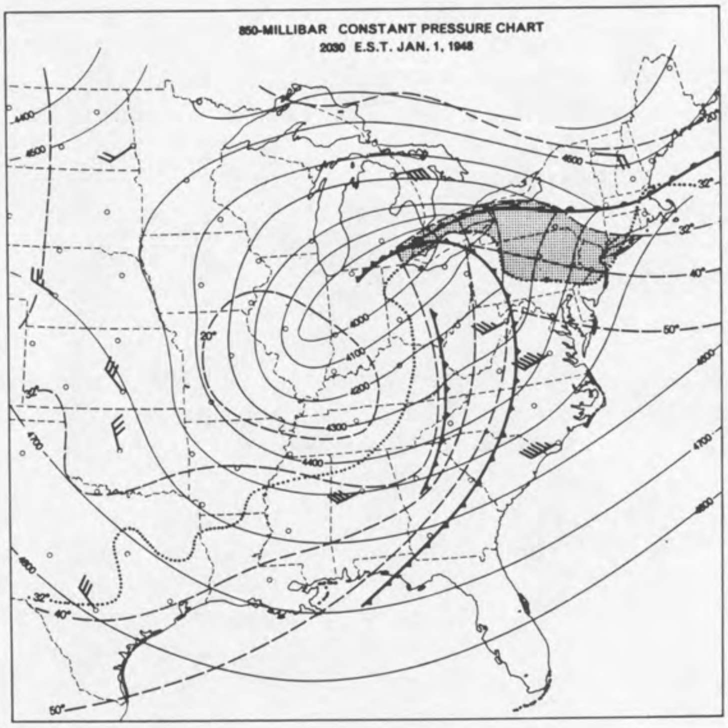

Figure 2. The upper air picture at 2030 EST, January 1, 1948.

fected areas or to the east out to sea. In storms moving over the sea, freezing precipitation seems to occur when the wave tip and warm front are located east or east-southeast of the affected area. In storms moving from the south or southwest with centers passing to the west or northwest of the region, glaze almost always forms when the warm front is oriented in an essentially east-west direction and is located 100 to 300 miles south of the affected location (see Figs. 1 and 2). Even with waves originating in western and northern parts of the country, freezing precipitation most frequently comes from an east-west warm front located south of the region and moving northward. The principal exception to this are waves moving from the west which become occluded and in which the front generally is aligned essentially north-south. The center of low pressure from which these occlusions extend often passes several hundred miles north of the glazed area.

In many storms, the surface air with temperatures above 32° F. in the warm sector of the wave never moves across the glazed area following freezing precipitation; consequently, rapid thawing of the ice does not occur. This is particularly true of occluded waves or, if open, waves in which the tip of the wave passes east or southeast of the affected area. As such storms pass, the surface air temperature usually drops even further below 32° F. as fresh cP air immediately moves over the area. However, examination of temperature conditions in the Northeast on the day following glaze shows in most cases maximum temperature above 32° F. (usually between 35° and 45° F.). If the daily maximum temperature remains below 32° F. after the storm, it generally does so for only one day. Data giving duration of ice on electric power lines in Massachusetts, Connecticut, and New Jersey (Fig. 3) indicate glaze seldom lasts longer than 24 to 36 hours, compared with considerably longer durations in some other sections of the country.

As in other parts of the country, freezing rain or drizzle seldom occurs by itself in the Northeast. Sleet or snow often fall at the same time; and one or both of these, plus non-freezing rain, frequently occurs before or after freezing precipitation. A common areal distribution of precipitation in this part of the country is a strip of non-freezing rain along the immediate coast, some combination of freezing precipitation in a belt next to this farther inland, and then a considerable area with snow over the northern section. This was the pattern in the great New England storm of November 1921. C. F. Brooks (1938) observed this common distribution and commented, "Trees in snowy northern New England are often more shapely than those of the southern New England states because the latter are more subject to ice damage."

Characteristics of Glaze Storms

As a glaze-producing storm moves across the country, it does not necessarily deposit ice everywhere along its path. In addition, most storms show a wide variation in the thickness of ice deposited. Frequently, ice of markedly different thickness is found in close proximity (Fig. 4).

Often the conditions just described can be explained on the basis of the influence of purely local factors related to the microclimate. In fact, in probably no other major type of storm will the complexity of the microclimate, as determined by elevation, aspect of slope, exposure to wind, composition of ground surface, etc., have as great an opportunity to express itself and cause variations in storm intensity over short horizontal or vertical distances.

The heat conducting and storing ability of exposed materials is important because of the direct bearing on the surface temperatures of these materials. Because glaze usually forms when surface air temperature is fairly close to 32° F. and the falling precipitation is not supercooled more than a few degrees,

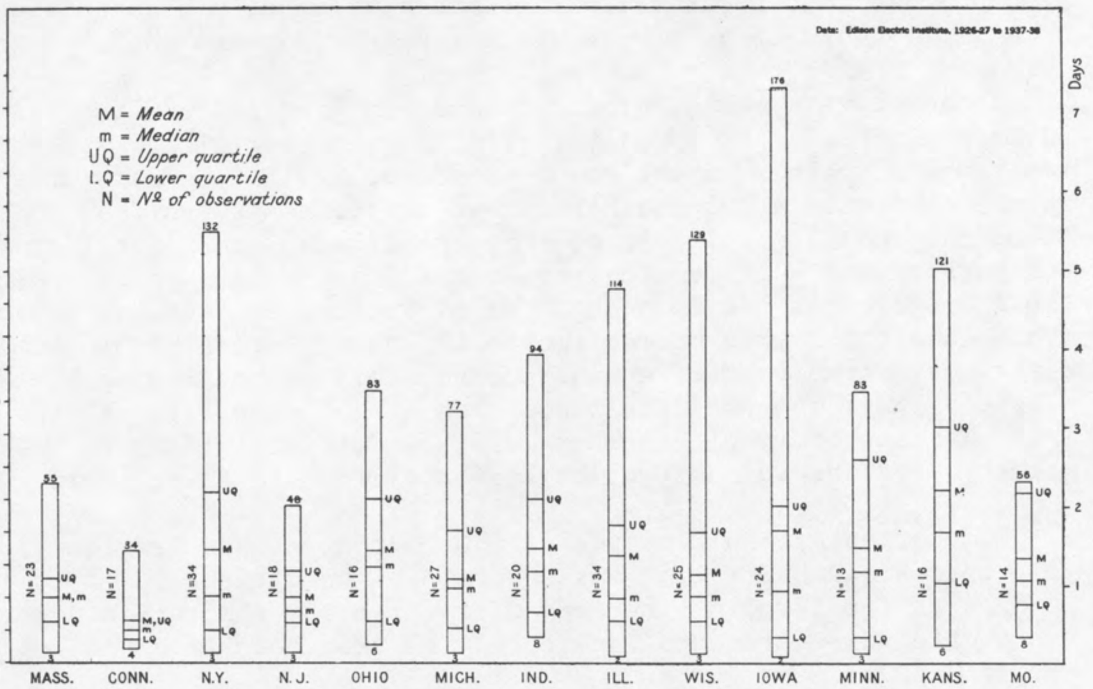

Figure 3. Duration of glaze on utility wires for selected states. If conclusions can be drawn on the basis of so few observations, the deposits do not persist nearly as long in New England as in the interior of the country.

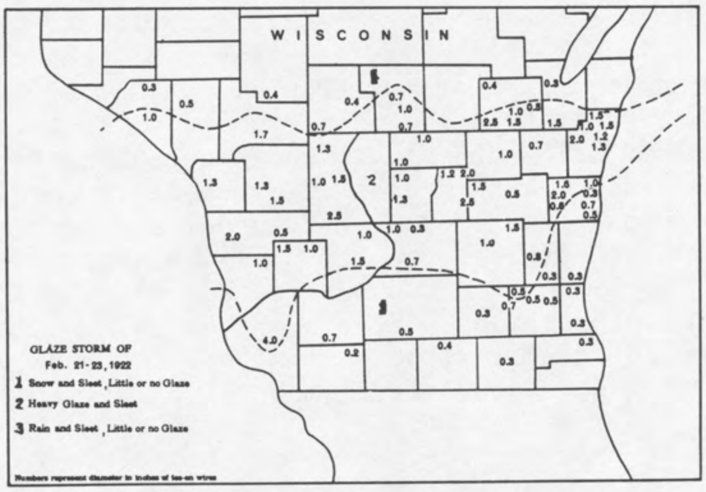

Figure 4. Distribution of ice thicknesses in Wisconsin resulting from the heavy glaze storm of February 21-23, 1922. Note the great variation of thickness over short distances. After a map in Lockwood (1922).

the variation in surface temperature from material to material can control the formation and thickness of glaze. There is general agreement among highway maintenance men that glaze will not form as readily on macadam compared with concrete due to the darker surface and consequently higher heat absorption of macadam. Observations by the Weather Bureau confirm this.

Air temperature near the ground is another factor, and like the temperature of surface materials, it usually is limited whenever glaze is developing to a narrow range of values in the neighborhood of 32° F. Temperatures during freezing rain and drizzle at 95 Weather Bureau stations between 1939 and 1948 were between 25° and 32° F. 75 per cent of the time. Such a small range is less than the variations in temperature sometimes found within short horizontal and vertical differences due to changes in microclimate, even under cloudy and windy storm conditions when microclimatic influences are at a minimum. Brooks (1914) describes storms that were confined entirely to the top of Blue Hill because of slightly lower temperatures there than at the base. In writing about the Massachusetts storm of December 1929, he describes (Brooks, 1930) the sharp demarcation of the boundary of a glaze storm due to temperature change:

> "In Worcester, an altitude of 570 feet above sea level divided ice from bare areas. The line was so definite on trees that it could be described as at the level of the tops of first story windows in a certain house. While lower branches were bare, the tree tops bent under 1/4 inch of glaze."

According to Zikeev (1940), elevated areas open to the wind are especially subject to heavy glaze and he cites a case in the southern part of the Soviet Union where at an exposed location ice thickness reached 37 millimeters (1 1/2 inches) while a sheltered site had only 12 millimeters (1/2 inch). He also points out that simultaneous observations at 2 and 6 meters (6.6 and 19.7 feet) above the ground show glaze thickness can increase significantly in even this short distance. Zikeev (1940a) also observes that the warmer microclimate of large cities affects the occurrence of glaze, as evidenced by records showing Stalingrad receiving glaze of less intensity than the surrounding country.

In addition to its effect on thickness, microclimate can influence the duration of glaze. Root (1924) gives an example of greater exposure to wind causing ice on trees to disappear more rapidly than ice on the ground. That glaze can be lost through evaporation when exposed to the wind even when the air temperature is far below 32° F., is shown by an observation by S. D. Flora (1922). In this case, a thin coat of glaze disappeared during the night as temperatures dropped from 17° to 5° F. under a strong wind from the northwest. By dawn of the next morning, the ice "... was entirely gone, except in a few patches where the wind did not have free access to it." The heat-conducting and heat-storing capacity of surfaces may be an important factor in determining the duration of glaze, although most observations would indicate that ice will disappear almost as rapidly from one type of material as from another.

Of particular interest to electric power companies are the wind conditions associated with glaze. Reliable information concerning wind speeds during the period ice remains on exposed surfaces is scarce, despite great efforts of interested parties to collect it. In three of the large groups of data giving ice thickness and duration on wires available to the writer*, information concerning wind velocity was included; however, in almost all cases observations

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* Association of American Railroads data, 1927 to 1937; Edison Electric Institute data, 1926 to 1938; American Telephone and Telegraph Co. data, 1917 to 1925 (all three unpublished).

of ice and wind were made at different locations. The ice measurement usually was taken at a point on a power line where trouble developed, while the wind observation was obtained from the nearest Weather Bureau station, in some cases as much as 100 miles away. However, a few observations are available in which ice thickness and wind velocity were taken at the same location. These have been summarized in Table I. The speeds given are the maximum 5-minute average during the period ice was on the wires, and the thickness the greatest during the icing period. The two did not necessarily occur simultaneously. The wind speeds for the 148 cases vary from calm to 50 miles an hour. The mean is 17.5; and 33.1 per cent of the cases indicate wind speeds of 20 or more mph. Fourteen and nine-tenths per cent have speeds of 25 or more mph. Of the 32 cases with ice 0.25 inch or more thick, 27 are associated with a wind of 15 or more mph and 12 with speeds of 20 or more mph. Considering some of the cases of extreme thickness, ice 2.87 inches in radius (probably not glaze but the wind pressure effect on the lines would be the same) is associated with a 30 mph wind, and for others the relationship is: ice 1.71 inches, wind 18 mph; ice 1.5 inches, wind 21 mph; ice 1.1 inches, wind 28 mph; ice 1.0 inch, wind 18 mph (3 cases). Considering the 6 cases with wind velocity 35 mph or greater, the relationship is:

Ice Thickness (inches)	Wind Speed (mph)
0.39	35
0.78	35
0.30	40
0.26	45
0.79	45
0.19	50

TABLE I

WIND VELOCITIES DURING PERIOD ICE WAS ON UTILITY WIRES
(Data: Edison Electric Institute, 1926-27 to 1936-37)

Wind Velocity (mph)*	All cases No. of cases	All cases % of cases lower limit of category	No. of cases where ice was 0.25 inch or more in maximum thickness (radial thickness)
50 - 54	1	0.7	0
45 - 49	2	2.0	1
40 - 44	1	2.7	0
35 - 39	2	4.1	1
30 - 34	6	8.1	1
25 - 29	10	14.9	3
20 - 24	27	33.1	6
15 - 19	46	64.2	15
10 - 14	35	87.8	3
5 - 9	17	99.3	2
0 - 4	1	100.0	0
	148		32

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* Fastest average 5-minute wind speed during period ice was on wires

In an occasional glaze storm, high winds may result from an accompanying thunderstorm. This is more likely to happen in the southern part of the country, but on at least one occasion, the great New England storm of November 1921, severe thunderstorms added considerably to the havoc.

Geographical Distribution of Glaze

The geographical distribution of glaze in the United States is shown in Figs. 5 - 9. Construction of maps of the type shown in these figures is difficult because systematic measurements of glaze thickness and duration for the country as a whole or large parts of it are rare. The Weather Bureau has conducted no large-scale systematic program of glaze observations; although, of course, freezing rain and drizzle are regularly observed. Daily measurements of the thickness of snow and ice on the ground are made at most Weather Bureau stations, but no distinction is made as to the nature of the ice or its origin. Fortunately, various railroad, electric power, and telephone associations have taken great interest in the collection of glaze data. Among these, the Association of American Railroads, the Edison Electric Institute, and the American Telephone and Telegraph Company have compiled useful data; and these are used as the basis for the maps and most of the comments that follow. For a discussion of these data and the method used to construct the maps see Bennett, 1959, pp. 58-74.

Examination of the maps makes it clear that the Northeast suffers from glaze as much or more than any section of the country. The worst area in the nation from the standpoint of high frequency and severity of storms extends from eastern Iowa across northern Illinois, Indiana, and Ohio into Pennsylvania, southern New York and northern New Jersey and southern New England. Most parts of this belt will have one or more storms every winter and experience ice between 0.25 and 0.50 inch thick once every three years or so. As many as 18 to 26 storms have deposited ice on most parts of the area within a 9-year period. The eastern section from eastern Ohio to southern New England appears to have higher frequencies than the west. From 27 to 35 storms of varying intensity have occurred in nine years in this eastern section and approximately one-third of these recorded glaze of 0.25 inch or more in thickness. Northern Connecticu and most of Massachusetts had from 36 to 44 storms in the nine-year period represented by Fig. 5. However, only 1 out of 5 of these storms deposited as much as 0.25 inch of ice. Northward into northern New York and northern New England frequencies fall off sharply from these high values, as snow replaces freezing rain in many storms; and over the Cape area of Massachusetts and the immediate coastal sections of Connecticut and Rhode Island glaze is less frequent due to its being replaced by non-freezing rain.

Although some sections of the Northeast may experience glaze much less often than others, virtually every section can expect to receive a heavy deposit sooner or later (Fig. 9). Most areas have experienced ice 0.50 to 0.75 inch thick and the majority have seen deposits of 1.00 inch or more. Ice 1.50 to 1.74 has been measured at several locations, and up to 2.5 and 3.0 inches in rare storms.

Throughout the Northeast, most storms occur between mid-November and mid-March. In southern New England, southeastern New York, eastern Pennsylvania, and New Jersey, 75 per cent or more of the storms are concentrated in this period; but to the north and west the number falls to near 50 per cent, particularly near the Canadian border. December, January, and February lead as the months with greatest number of storms, with March also ranking high. At most locations January has a slightly larger total than either December or February, and this grows larger west of the Appalachians.

Damage to Electric Power and Telephone Facilities

The damage inflicted by glaze storms on utility operations most commonly is of a mechanical nature and is limited primarily to the wire system. Electrical damage can also occur; and mechanical injury may extend to insulators, trans-

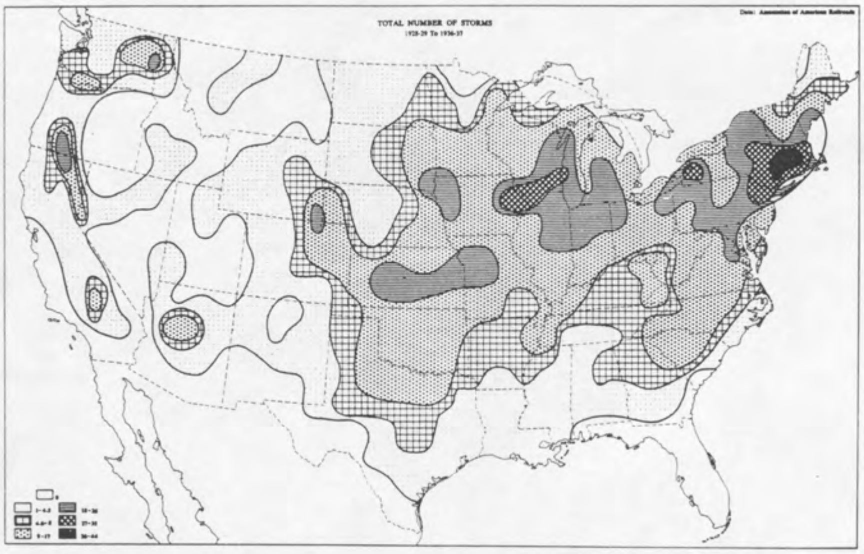

Figure 5. Total number of glaze storms, without regard to ice thickness, observed during the 9-year period of the Association of American Railroads study (undated).

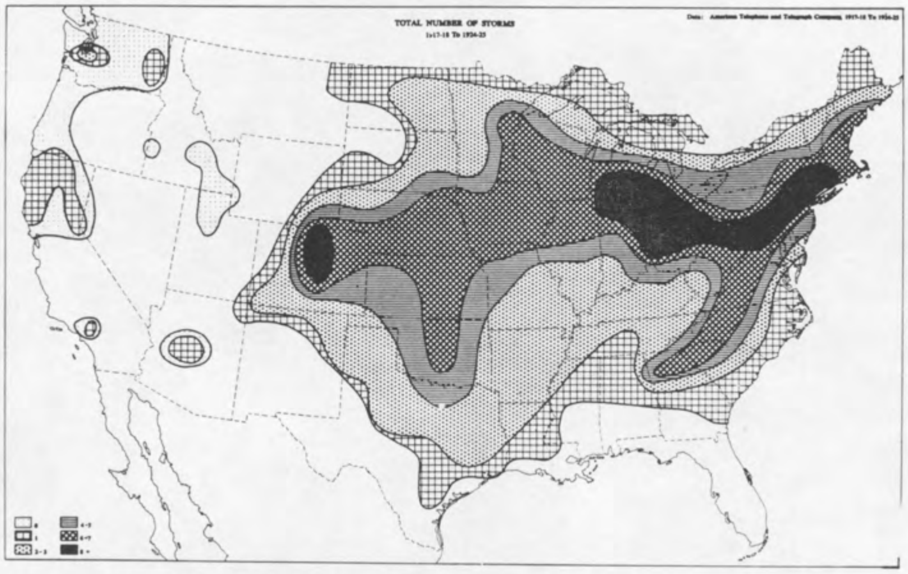

Figure 6. Total number of glaze storms observed during the 8-year period of a study conducted by the American Telephone and Telegraph Company. Only storms inflicting damage on lines or poles were reported; consequently, the map must be considered as representing only the heavier-than-average storms occurring during the period.

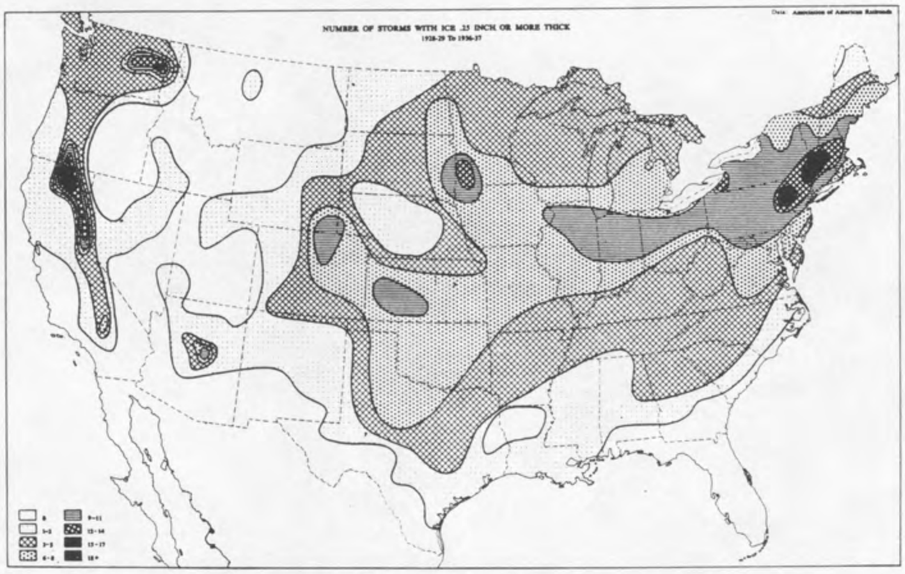

Figure 7. Number of times ice 0.25 inch or more thick was observed during the 9-year period of the Association of American Railroads study (undated). Note that the Columbia River gorge area, in which thick glaze is fairly common, does not show up as an area of high frequency on this map.

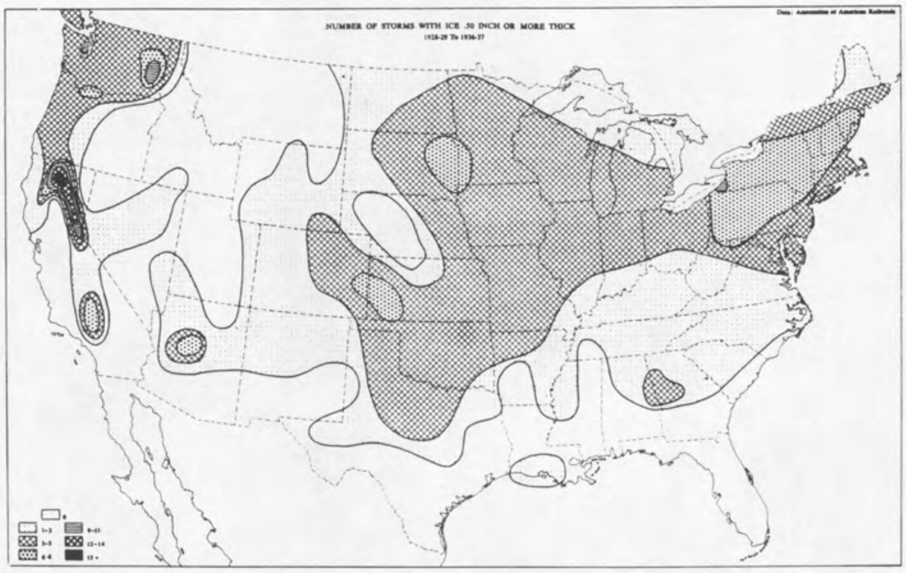

Figure 8. Number of times ice 0.50 inch or more thick was observed during the 9-year period of the Association of American Railroads study.

formers, switches, poles, and even house meters, usually as a consequence of wire trouble in the form of greatly increased tension, violent agitation, or outright breakage. Any study of the effects of glaze storms on utility operations should, therefore, be focused on the methods of formation and the thickness, frequency, and duration of ice on wires and the wind conditions associated with ice of different intensities.

Although this paper is concerned primarily with glaze, other types of ice, such as rime, hoarfrost, and wet snow, may form on utility wires and do great damage. These types, however, are usually not as serious a danger as glaze, except in high mountain areas where the weight of rime and wet snow on lines can reach considerable proportions.

Heavy snow loads may build on lines from a series of storms, leaving successive layers of wet snow on lines. This results when alternate thawing and freezing of the snow between storms causes it to cling more tenaciously and therefore remain until the next storm deposits a new load of snow. Snow may also cause trouble by unloading rapidly and unevenly from lines when the temperature rises, causing slapping together of conductors and consequent arcing. To prevent burn-downs at such times, it is often necessary to take affected lines out of service if winds are strong enough to whip the spans together.

Hoarfrost is a common phenomenon on utility wires, but seldom is the cause of mechanical damage. In the rare case where hoarfrost is responsible for injury to conductors, it apparently is because with the aid of the wind, it has initiated the phenomenon known as "dancing conductors".

Rime more nearly approaches glaze as a serious peril to utility wires. Rime may occur wherever temperature conditions are favorable for ice formation, but is most common in mountains, where it probably occurs much more often than glaze. Although the specific gravity of rime is much less than that of glaze, in mountain regions subject to invasion by moist, stable air masses, it can reach such great thicknesses that sufficient weight is added to wires to cause their failure.

True glaze probably is not observed on utility wires as frequently as hoarfrost and rime, or even wet snow; but except for a few special areas it undoubtedly is responsible for more damage to outdoor utility installations than all the other types combined.

There are many areas of uncertain knowledge regarding glaze formation on utility lines, and one of the principal ones concerns the thickness of ice deposited on a wire by a given quantity of precipitation. The various significant factors are so variable and so difficult to measure that no meaningful relationship between them has ever been established. Among the factors that have to be considered are: wind velocity, air temperature, and humidity at wire height; rate of fall of the water drops; size, conductivity, and specific heat of the wire; rate and duration of precipitation; and size and temperature of the drops. Some of these could be readily determined, but others would defy accurate quantification. If an adequate number of appropriate observations were available, an empirical relationship might be established, but such observations have not been made. Little value would result from examining the vast quantity of measurements taken by utility companies because in almost all instances the observations were taken some distance from a weather station where the coincident precipitation and other meteorological data are available. Lenhard (1955) attempted to use these data to predict the weight of ice on wires associated with given amounts of precipitation, but the results are of no practical value.

Many utility engineers believe that the radial thickness of ice on conductors

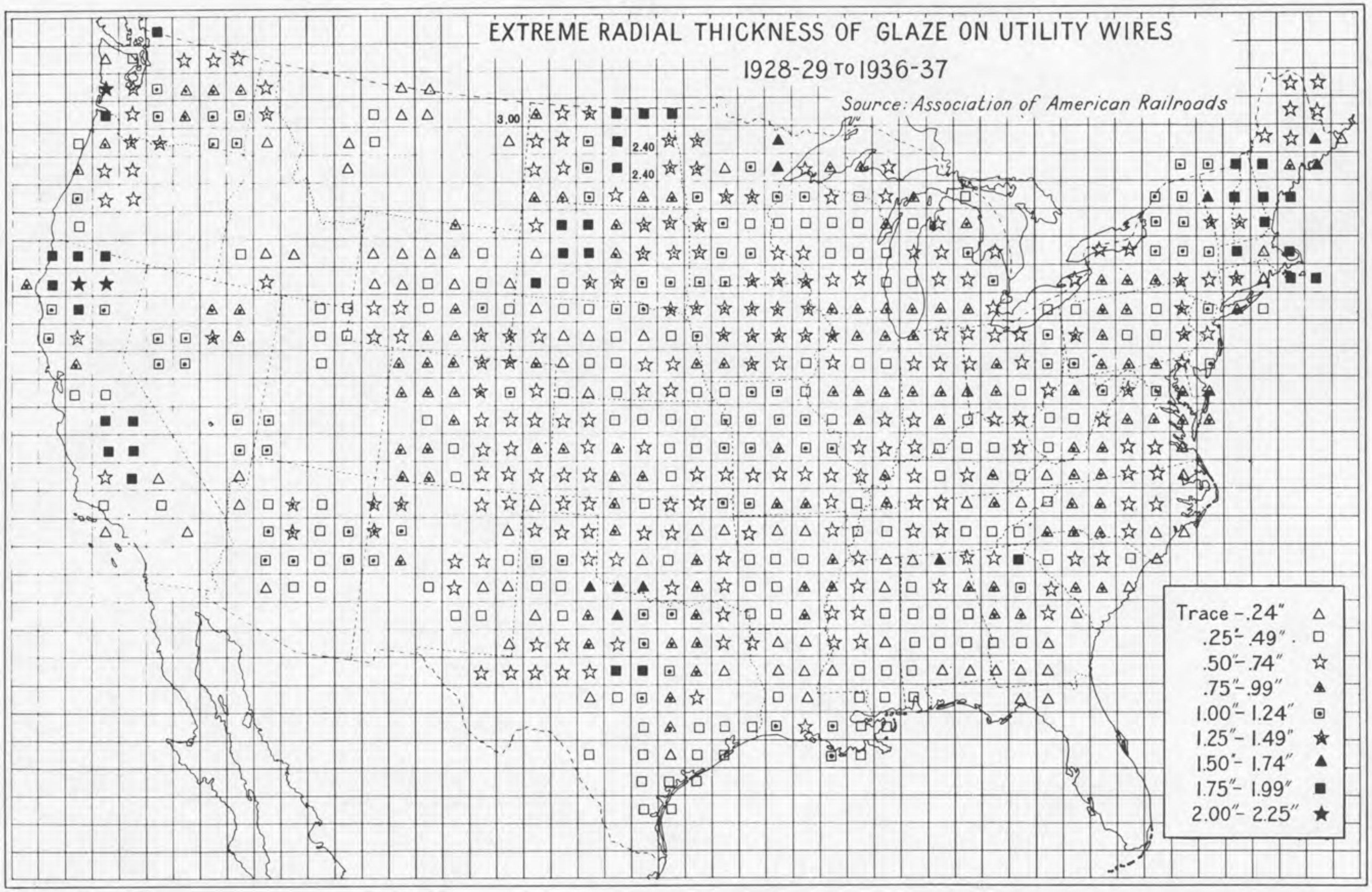

Figure 9. Greatest thickness of ice observed in each grid square during the 9-year period of the Association of American Railroads study.

is of the order of 30 to 40 per cent of the precipitation. This apparently stems from an analysis made in the early 1900's (Fowle, 1910) in which several erroneous assumptions were made, including one that all precipitation striking a line would freeze and adhere and would be deposited uniformly over the surface of the wire. Usually a good deal of water will flow or be blown off wires before freezing, with the proportion lost rising rapidly as the wind velocity, rate of precipitation, and drop size increase (Arenberg, 1940). There is a possibility, however, that the overall effect of greater wind speed is to cause an increase in ice thickness because the increased number of drops striking the wire at higher wind speeds offsets the greater loss through "blowoff". A decrease in air temperature, on the other hand, causes the percentage that adheres to grow larger. Lower air temperature generally means greater supercooling of rain drops and a larger proportion of any one drop freezing upon impact.

There is considerable question whether there is a relationship between wire diameter and thickness of ice deposits. Some investigators have suggested that less ice should be expected on larger wires, others that less should be expected on smaller wires, and still others that there is no relationship. The only data collected (that of the Association of American Railroads) on which such a decision can be based shows no consistent relationship between thickness of glaze deposits and wire diameter.

Ice is seldom completely uniform in its development around a utility line. Sometimes it is thicker on the top of the wire and sometimes on the bottom, depending on such factors as the rate of rainfall, drop size, temperature, and wind velocity. Frequently, there is a difference between horizontal and vertical thickness. Several hundred measurements under the auspices of the Edison Electric Institute show that horizontal and vertical dimensions, in cases where there is no icicle formation, can differ by as much as 3 to 1.

A highly developed formation of icicles will completely upset the essential symmetry of ice formations and add considerably to the total load upon the line. Fortunately, icicles do not form at all, or are relatively small and unimportant, in about four storms out of five. In measurements conducted by the Association of American Railroads, half the storms produced no icicles, and 79 per cent icicles of one inch length or less. The longest reported were four inches and were spaced along the wire at an average distance of one per inch. Other sources of information indicate icicles on lines may sometimes be at least 6 to 8 inches in length.

There likewise is uncertainty concerning the difference, if any, in ice accumulation between live and dead electric conductors and between electric conductors and telephone wires. The answer, based on the Association of American Railroads data, apparently is that all of these are equally capable of acquiring loads, but because of structural differences some telephone lines are subject to considerably more damage than most electric power lines. Data collected by the Pennsylvania Electric Association (Zehfuss, 1945) substantiate this in that they indicate there is no difference in shape or thickness of ice coating between dead and live conductors.

In severe storms, utility lines may have to support unusually heavy loads of ice. One week after the Michigan storm of February 1922, a one-foot length of telephone wire weighed 11 pounds (Seeley, 1922). In this same storm, a three-foot length of electric conductor weighed 12 pounds with its load of ice.

Despite such heavy loads of ice, instances of wire breakage by the sheer dead weight of ice are probably not too common in the United States. Usually the wind or some other factor, such as previous weakening of the line by a lightning strike, will have played a major role in causing the break. Modern construction makes it possible for lines to carry well up to one inch of radial ice without danger as long as other factors do not come into play; observations have shown that even greater loads can be tolerated without serious consequence

A common way ice load alone inflicts damage on the wire system of utility companies is through unequal unloading of ice from lines. Often the ice will fall off some lines earlier than off others. When this happens to the lower wires in a line, they may rise suddenly and come in contact with higher level wires, causing a short circuit and possibly breaking of the affected wires.

Because of the strength of design currently used in constructing utility lines and poles, wind by itself rarely is a source of damage to such facilities. However, when lines are loaded with ice, even moderate winds of 10 to 15 mph can create havoc. The angle at which the wind strikes the line is extremely important, with maximum danger when the wind is at right angles, and minimum danger when it is parallel to the line. Cases have been reported where, in the same storm, lines running across the wind direction were heavily damaged and those running parallel to the wind escaped injury.

The combined effects of ice and wind on lines are twofold: (1) they increase by many times the transverse loading (pressure exerted at right angle to the line) upon wires and poles and (2) they upset the equilibrium of wires so that they become subject to violent and erratic movements. Unusually high transverse loading is a major factor in wire breakage but is of even greater significance in damage to poles. It is the major consideration in determining pole strengths.

One of the most serious conditions arising from the combined effects of ice and wind is the phenomenon of "dancing" conductors. It has been reported occurring in the absence of ice deposits, but such cases are rare and not well authenticated. "Dancing" is a term given to a type of wind-induced vibration in which the wire involved vibrates only a few times a second but with high amplitude (consisting of several inches or even feet), as compared to the rapid, low amplitude vibrations normally seen (or rather heard) whenever wind blows across wires. The uneven distribution of ice load along the wire often is a contributing factor. "Dancing" usually involves an entire span of wire which jumps up and down as a unit. The different wires in a span may or may not "dance" in synchronism, and when "dancing" is strong it may become decidedly irregular with large and violent movements. Wire in 130- to 150-foot spans may move through vertical distances of 4 to 6 feet. Most cases of "dancing" apparently are caused by moderate winds of 10 to 25 mph. The principal effects of dancing are to cause wires to come in contact and short circuit or tangle with each other, loosen ties and insulators, cut and chafe wires at insulators, cause fatigue breaks in the span, and break and chap insulators. Wire fatigue, as a result of "dancing", may cause difficulty long after the storm and after all apparent damage has been corrected. As yet, no sure means to eliminate "dancing" have been found, although various mechanical methods of damping the motion have been tried.

One of the most common sources of trouble to utility lines during glaze storms is from trees or limbs falling across wires, causing them to break. This is particularly true in small towns and villages where large shade trees commonly grow close to lines. In many storms the only serious damage to lines is produced by falling limbs and trees.

In conclusion, it can be pointed out that there are four principal ways in which utility companies can limit the serious effects of glaze storms on their operations:

(1) Avoiding sites known to have heavy and frequent glaze, and where there is a good chance of strong winds during glaze storms. Such sites cannot be

avoided entirely, of course, because lines must go to the customer no matter where he is located.

(2) Avoiding trees. In small towns, this problem may have no real solution except burial of lines underground, a step which usually is too expensive.

(3) Increasing structural strength of lines and poles. There is no doubt lines could be designed which would withstand the most severe conditions, but the cost might well put the cost of electric power and telephone service prohibitively high. By and large, it appears that utilities are following sound practices in the design of their outdoor facilities.

(4) Artificial heating of lines through the application of increased current loads. Unfortunately, this practice cannot be carried out by telephone companies on their lines.

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