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Historic Ice Storm Patterns

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One of the natural disasters impacting trees are ice storms. Ice storms, or freezing rain events, can damage utilities, communication networks, agriculture, transportation, housing, and trees. Even minimal amounts of ice accumulation can cause serious problems for people and transportation systems.

Trees are damaged by ice storms: along city and country roads and streets; within parks, nature preserves, and greenbelts; in yards, parks, and campuses; and, across the landscape from field edge to forest centers. Ice storm damage is most noticed around houses and roads. Images of catastrophic tree failures under ice accumulation are an especially graphic depiction of ice storm impacts. With tree failures, are associated utility structure and line damage, and blockage of emergency and normal access along streets.

Property Damage

Ice storm damage can be large. Insured property losses from ice storms in the United States averages $326 million (in 2000 dollars) annually. (Changnon & Karl 2003) The large 1998 ice storm which swept through New England caused $1 billion in tree damage alone. (Changnon & Karl 2003) Ice accumulation can also add immense weight on trees and other structures like power lines. The largest ice loading weight ever recorded on an overhead power line (Norway) was ~205 pounds per linear foot. (Fikke et.al. 2008) One of thickest ice accumulation in radius on a power line was 3.5 inches (Iceland). (Fikke et.al. 2008)

Understanding how ice storms have historically damaged the nation is a starting point in preparing for the next ice storm coming at our trees. The enormity of single ice storm area coverage even though most are along a narrow limited band, is great. The disruption of our quality of life from ice storms and associated tree failures can be life-threatening and of long duration, well after an ice storm has past.

Definitions

An ice storm is defined by the United States – National Weather Service as any freezing rain event where ice accumulation is at least 0.25 inches. (Rauber et.al. 2001) Ice storms can be associated with several types of precipitation. Ice storm events have been described as freezing rain, glaze, snow and ice, and blizzard and sleet. (EPRI 1996) These descriptions can be expanded through use of a combination of ice accumulation and wind events, where 0.10" of ice with moderate or higher winds can be considered severe, as per the Sperry-Piltz Ice Accumulation Index (SPIA Index). (NOAA 2009)

In the early part of the last century, resource managers began to measure ice accumulation and ice storm damage. Figure 1 shows one set of measures for the largest ice accumulation (glaze ice thickness in inches) values, and the average ice accumulation (in inches) values, (by region) which occurred on utility wires in a 10 year period. It was found that 75% of all ice accumulation values in ice storms were less than 0.78 inches thick. Average ice thickness for all regions was 0.44 inches. (Changnon 2003) Any ice accumulation over 0.25 inches caused significant tree and infrastructure damage.

Beginnings

In 1948 the United States National Bureau of Standards issued an ice storm map showing where ice glazing events were the most and least damaging across the country. Figure 2. Many insurance and utility companies used this map in preparation for the next storm. Note the nation is divided into three damage zones: heavy, moderate, and light / no glaze.

Now climatic and meteorologists are using historic ice storm events to develop maps and expectations of where damage will be concentrated. Figure 3 provides the area of the county, described with broad categories of either no historic major ice storm, or major ice storms which occurred in a period of 55 years. This map shows a concentration in the Eastern United States with a pocket in the Pacific Northwest. There are a few scattered pockets in the far North, in the far South, across the West, and in small areas just West of the Appalachians which have not generated a major ice storm.

Numbering

In another way of examining historic ice storm events, Figure 4 provides the number of ice storms which occurred in a 52 year period. The number of storms peak in New York state, with a smaller number in the mid-Atlantic states. The Western United States has had ice storms, but they are few in number. The far North edge of the map shows ice storms are reduced in number as temperatures and moist air masses are reduced. In the far North, frozen precipitation is usually snow or ice pellets.

The number of major ice storms (i.e. property loss over $1 million) are concentrated in the Eastern third of the nation, especially along the New England coastline and inland, areas around the Eastern great Lakes, and down along the Eastern side of the Appalachians in the mid-Atlantic states. Figure 5. The West and Florida have much fewer major storms causing property damage over this period of time. Major storm numbers range from 0 - 31 by state.

Dollar$

Another way to examine ice storm damage in the United States (i.e lower 48 states) is through adding up all the property damage, in millions of dollars (year 2000 dollars). Figure 6 provides, by regions of the country, the amount of loss from major ice storms in a 52 year period. It should be noted the South central and Southeast regions sustained heavy property damage, while New England sustained severe damage. Remember tree related damage to utility, transportation, and other infrastructure is a major component of these dollar loss values.

Over a period of ~50 years, based upon insurance property loss data, 87 major ice storms have occurred in the United States. A major ice storm is responsible for property losses in excess of $1 million. Total losses were $16.5 billion (year 2000 dollars). Severe ice storm numbers peaked in the 1993-2000 period with losses of $5.8 billion. A larger percent of catastrophic ice storms occurred in the South than in the North. (Changnon & Changnon 2002) (Changnon 2003) (Houston & Changnon 2007)

From the previous view of dollar loss from ice storms, Figure 7 provides the loss per ice storm event in a 52 year period for various regions. The per ice storm event loss (in year 2000 dollars), show New England and the Southeast having similar amounts of loss per storm, even though New England has many more ice storms. The Western United States have few ice storm events, but each one which does occur causes significant losses.

Storm Counts

There are many ways of examining ice storm event occurrences: number of events, duration of events, dollar loss, ice accumulation amounts, and number of years included in each analysis. Figure 8 shows, by region, the number of ice storm events for a period of 52 years. These values group the information in a different way than previous maps. Here, the Southeastern third of the nation, with a line from Texas to Chicago to Cleveland represents the majority of ice storm events in the nation for the period examined.

Although ice storm events, especially on a small scale, are possible almost everywhere in the United States, the great majority of property damage impacts occur East and South of a line running roughly from West Texas to Michigan. (Changnon & Changnon 2002) Figure 9 provides a general way to appreciate where most major ice storm events occurred over a period of 53 years. Areas South and East of the line shown would be considered a major ice storm event zone for the nation.

A number of maps provide data regarding where ice storms and freezing rain events occur. Figure 10 shows, for the middle and Eastern third of the nation, the number of freezing rain events which have occurred over a 25 year period which included 411 ice storm events. The freezing rain events are centered in the middle of the nation and to the East of the Eastern Great Lakes and in the valleys on the Eastern side of the Appalachians. Moving more North and farther South, diminishes air mass attributes which normally favor freezing rain events.

Severity Levels

Ice storm events can be categorized by their severity of ice accumulation. The range of ice storm severity range from 1-5. Usually only severity levels of 3, 4, and 5 are considered a major damaging event. Figure 11. The ice storm severity levels range from level 1 with no ice to level 5 generating catastrophic destruction to power lines & trees with extreme amounts of ice.

Figure 12 provides the number of ice storm events which have occurred with a severity levels of 3-5. These ice storm events show a concentration along the Eastern shoulders of the Appalachians, the middle Great Plains, and the Pennsylvania and New York areas. Most of the country had less than 12 severity level 3-5 ice storm events over a 36 year period.

Across the nation, the most severe ice storm severity rating to have occurred is given in Figure 13. Some places with many major ice storms, have never reached level 5 severity. A portion of the Southeast (North of Florida), the upper Mid-West, and the Lake States have all experienced at least one severity level 5 ice storm.

Ice Severity Index

Using data from ice storm severities over 37 years, an ice storm severity index was developed. This index provides different weighting for each ice storm severity level, and combines these values into a single index number. The formula for calculating the Ice Severity Index (ISI) is (EPRI 1996):

Ice Severity Index (ISI) =
(0.1 X number of level 3 events) +
(0.2 X number of level 4 events) +
(0.3 X number of level 5 events).

Figure 14 provides the Ice Severity Index categories. (EPRI 1996) ISI category descriptions range from no ice, mild and moderate ice (light), moderately severe ice (medium), severe ice (severe), and most severe ice (extreme). If the ISI formula above is used with no weighting or decimal multipliers (event numbers are multiplied by 1.0), the results are the total number of ice storm events of level 3-5. (EPRI 1996)

Figure 15 provides an ice storm severity index value for a 37 year period. Note this index only uses severity level 3, 4, and 5 ice storms in its calculations. The ice storm severity index reaches extreme levels in the Eastern fifth of the nation (North of Florida) and in pockets in the Central and Northern portions of the Mid-West. Using this index can demonstrate where the worst damaging ice storm events can be expected, based upon this historic examination.

Ice & Wind

The damaging agents within ice storms are both freezing rain and any wind. The combination of freezing rain and wind generate ice accumulation amount which vary across the ice storm's path. Figure 16 shows ice storm ice accumulation (in a uniform thickness) generated by a once in 50 year ice storm. The ice accumulation amounts in inches range from 1.25 inches thickness in select areas down to 0.25 inches for much of the country. The expectation of ice accumulation in a once in 50 year ice storm event is greatest from the central United States following a line to upstate New York, and over to coastal New England.

One critical tree damaging feature of freezing rain events are associated winds during ice accumulation. Figure 17 shows the 50 year ice storm wind gusts expected. Wind speed gusts (based upon a 3 second average), can provide significant acceleration of tree damage, and over ~11.2 mph can be as damaging as ice accumulation alone. Note high velocity winds can be expected within 50 year ice storm events especially along the New England coast and in the upper Great Plains and Northwest.

Ice Days

Ice storms bring freezing rain over a period of time. One ice storm may last less than one hour or more than a day. To better define how much ice is accumulating and where ice storms have occurred, freezing rain days and hours can be used. Figure 18 provides the annual number of days with freezing rain events for a 53 year period. There is a pocket in the Pacific Northwest and the Northeastern quarter of the nation with elevated freezing rain days.

Figure 19 examines the average number of freezing rain days per year (over 53 years) in a different format. The clustering of significantly more freezing rain days from the Mid-West Eastward to New England shows where major ice storms are most likely. The area around the Great Lakes and in New England are especially prone to freezing rain events.

In the previous figure an average annual number of freezing rain days were cited. Figure 20 shows the maximum number of freezing rain days to occur in any one year over 53 years. This map shows a worst case scenario for freezing rain days. Again, the Northeastern quarter of the country shows the most freezing rain days for any single year.

Ice Hours

Instead of examining average annual, or maximum annual, freezing rain days to delineate ice storms, freezing rain hours could be used. Figure 21 provides the number of hours of freezing rain per year which occurred over 15 years. Most of the nation had less than 5 hours of freezing rain per year. Pockets of interior New England had relatively large numbers of freezing rain hours.

Figure 22 shows the total number of freezing rain hours for a 9 year period. These freezing rain hours, summed over the nine years, provide a view of ice storm occurrences. The Eastern slopes of the Appalachians, the central United States, the inland Pacific Northwest, and inland New England just to the East of Lake Erie and Ontario had many freezing rain hours.

Months

Freezing rain events are concentrated in months when air mass movements and contents are ideal. Figure 23 shows when freezing rain events occurred, on a monthly basis, over 15 years. Note by April, freezing rain events were almost zero going into Spring and Summer. Freezing rain events did pick-up after October. There were rare late Spring (May) and early Fall (September) freezing rain events which have occurred.

Figure 24 demonstrates a regional monthly freezing rain event distribution for an area with many events. This figure shows, for the Great Lakes region, most of the freezing rain events occurred in December, January, February, and March. Some freezing rain events did rarely occur in October and May.

The occurrence of the first freezing rain event of the season and the last freezing rain event can be narrowed down to most likely months. Figure 25 shows the earliest month a freezing rain event occurred during a 53 year period. Figure 26 shows the latest month a freezing rain event occurred during the same time period. For most of the nation, freezing rain events occur between November and April.

Storm Life Span

As mentioned previously, freezing rain events can be categorized in several ways, one of which is duration in hours. Figure 27 provides a relative frequency graph of how long freezing rain events last (in hours). A majority of freezing rain events are two or less hours in duration. Some events have been measured at more than 10 hours.

Using a different set of measurements over 74 years, Figure 28 provides the duration of freezing rain events in hours. Only 10% of freezing rain events last 3 hours, but durations have been as much as 14 hours. In the Great Lakes region, duration of freezing rain events in a 15 year period were concentrated under four hours in duration. Figure 29. Freezing rain events longer than 10 hours had occurred.

Location

Where in the lower 48 United States ice storm events occur is controlled by many circumstances, primarily moisture content and temperature gradients combined with altitude of interacting air masses over the continent. The number of ice storm events is related to latitude, with more events occurring as latitude degrees increase. Figure 30. Ice storm events are also related to elevation, with more events occurring as elevation increases. Figure 31.

Temperature

One common means of measuring potential for ice storm events is air temperature. Figure 32 provides the air temperature ~6.5 feet above the ground which facilitated ice storms. For ice to form and accumulate, air temperatures at the surface must be near freezing or below. Temperatures of $21^{o}F$ to $30^{o}F$ generate the best ice accumulation conditions. Below an air temperature of 17°F, freezing rain precipitation does not form, but can strike the ground as ice pellets. Unfortunately for ice storm forecasting, surface temperature forecasts can be off by 6 - 18°F during the period of heaviest ice accumulation. (Rauber et.al. 1994)

Trends?

In examining ice storm events over many years, and in association with climatic change models and predictions projected ahead in time, what are expectation for ice storms? Are ice storm events going to become more severe and/or more common? Figure 33 provides one suggestion of variability over time. For a period of 70 years, the annual distribution of freezing rain events are provided. From year to year variability can be large, but there has been four major peaks of ice storm occurrence, as well as four major quiet times with few ice storms. For this data set, there is no trend or increase in ice storm events over this period.

Figure 34 is a summary of ice storm events across the United States for a 51 year period. This map provides areas where ice storms can play a major role in tree damage, along with other property damage. Areas with similar duration, number of events, and intensity / severity are categorized into five regions. The regions represent similar ice storm generation and potential damage zones. Note zone A is found in two locations. The Northeastward direction tracks of ice storm zones in the Eastern half of the nation demonstrate severity and damage bands. Ice storms tend to damage trees and infrastructure in elongated narrow bands 6.2 - 99.2 miles (10-160 km) wide. (Rauber et.al. 1994)

Glaze Belt

The frequency of ice storm events do not suggest the extent of damage from these events. The area from Texas to the Carolinas average 1 freezing rain event per year, but any one event is more likely to result in major property loss compared with areas farther North. (Changnon & Changnon 2002) An area of the United States from Northwest Texas toward Michigan and on to New England has greater than six days per year of freezing rain events. (Cortinas et.al. 2004) (Rauber et.al. 2001) This is considered the glaze belt of the nation. Most areas of the glaze belt will receive between 0.25" and 0.5" of ice once every three years. (Cortinas et.al. 2004)

In the Southern United States, the number of freezing rain events are relatively low, but each is long lasting and tends to have large ice accumulation levels. (Changnon 2003) For example, across the South in one study, 52 freezing rain events occurred with 15 generating major ice storms. This generates a ratio of 3.5 freezing rain events for every 1 major ice storm (3.5:1) across the South. The ratio of freezing rain events to major ice storm ratios are 12:1 in the Northeast, 16:1 in the Central United States, and 25:1 in the North Central area. Because of warmer and moist Gulf of Mexico air flow, the South has deeper warm air layers stacked over cold air, for longer durations, compared with areas farther North and East. (Changnon & Changnon 2002)

Summing Up

Extremely severe ice storms occur over the Eastern third of the United States where heavy precipitation and strong winds generated by cyclones moving in from the central United States, or cyclones moving up the Eastern seaboard lead to strong icing conditions. (Rauber et.al. 2001) A secondary ice storm maximum occurs along the Eastern side of the Appalachians, especially in the Northern end of the mountain range due to cold air trapped on the Eastern slopes of ridges (termed cold-air damming). (Rauber et.al. 1994) (Rauber et.al. 2001)

Selected Literature

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region	thickest ice	average ice
Northern Plains	1.7	0.4
Northeast	1.7	0.5
New England	2.0	0.4
Upper Midwest	1.5	0.25
Lower Midwest	1.7	0.5
Southern Plains	2.0	0.5
Southern Appalachia	1.6	0.4
Deep South	2.1	0.6

Figure 1: The largest ice accumulation (inches) and average ice accumulation (inches) values, by regions of the nation, which occurred on utility wires over 10 years.
(derived from Changnon 2003)

Figure 2: Ice storm ice accumulation based upon US National Bureau of Standards 1948 map.
(derived from Lemon 1961)

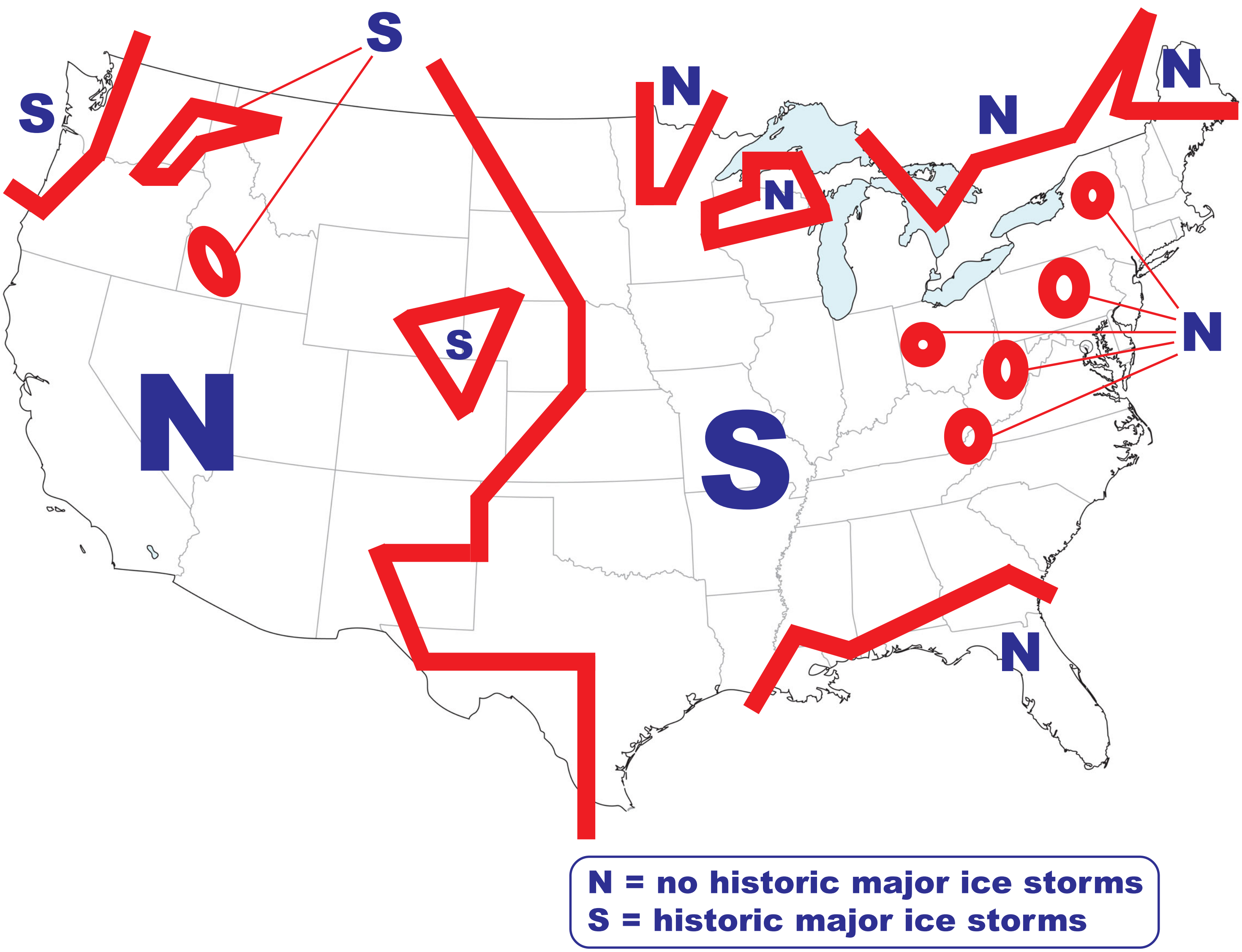

Figure 3: Areas with major ice storm impacts over 53 years. (Jones et.al. 2004)

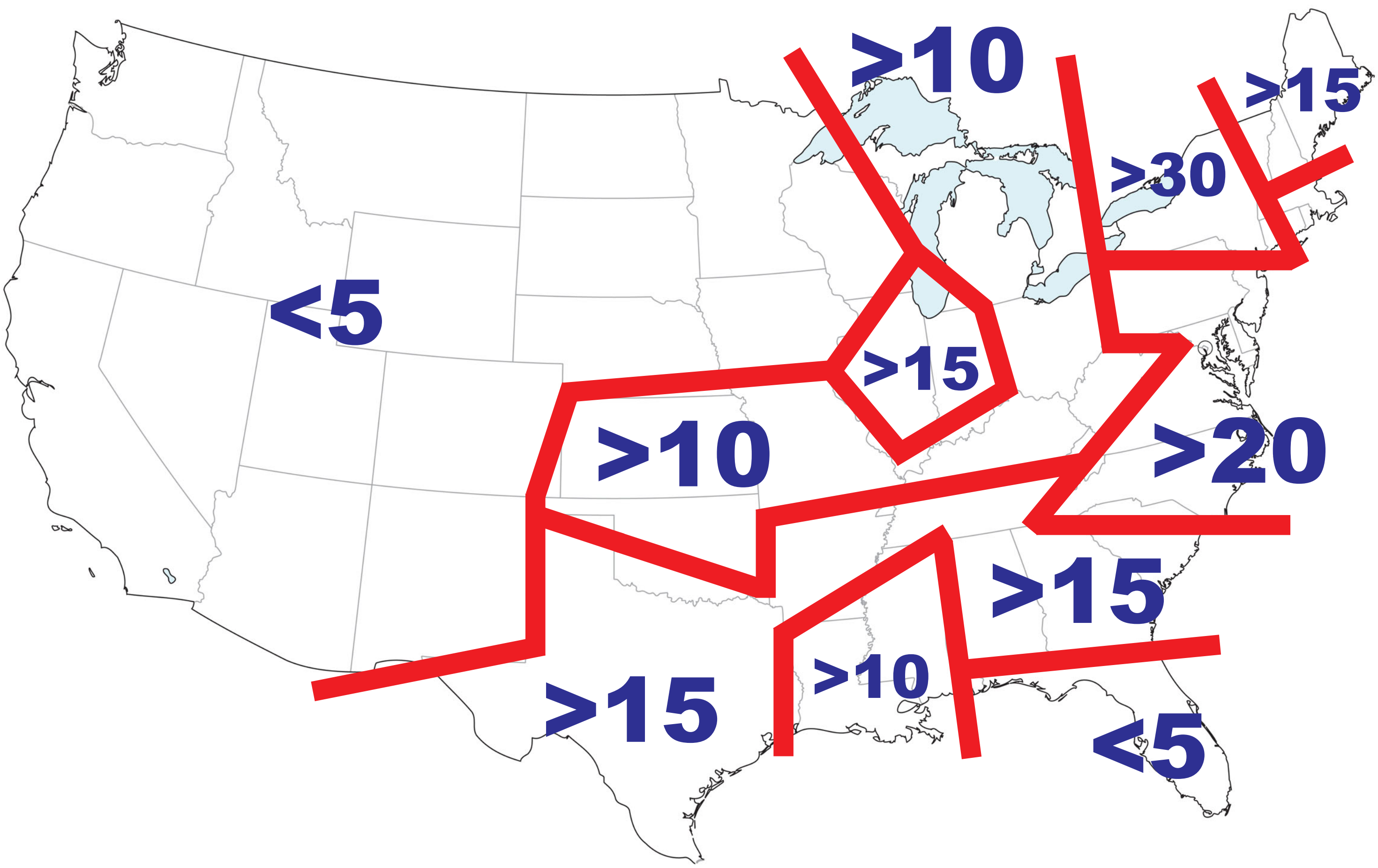

Figure 4: Number of ice storm events in a 52 year period.
(derived from Changnon & Changnon 2002)

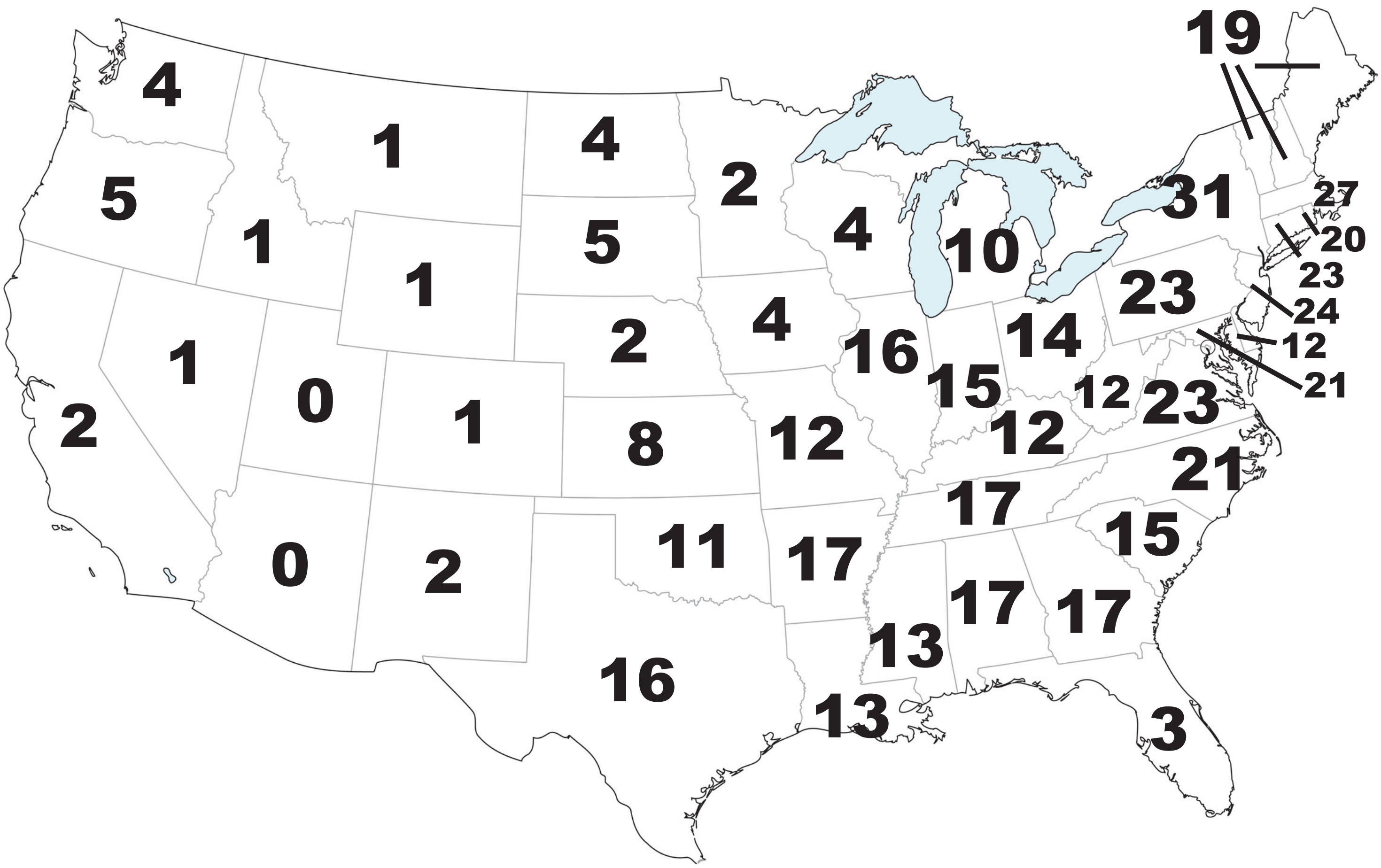

Figure 5: Number of major ice storm events with property loses over $1 million in each state over 52 years.
(from Changnon 2003)

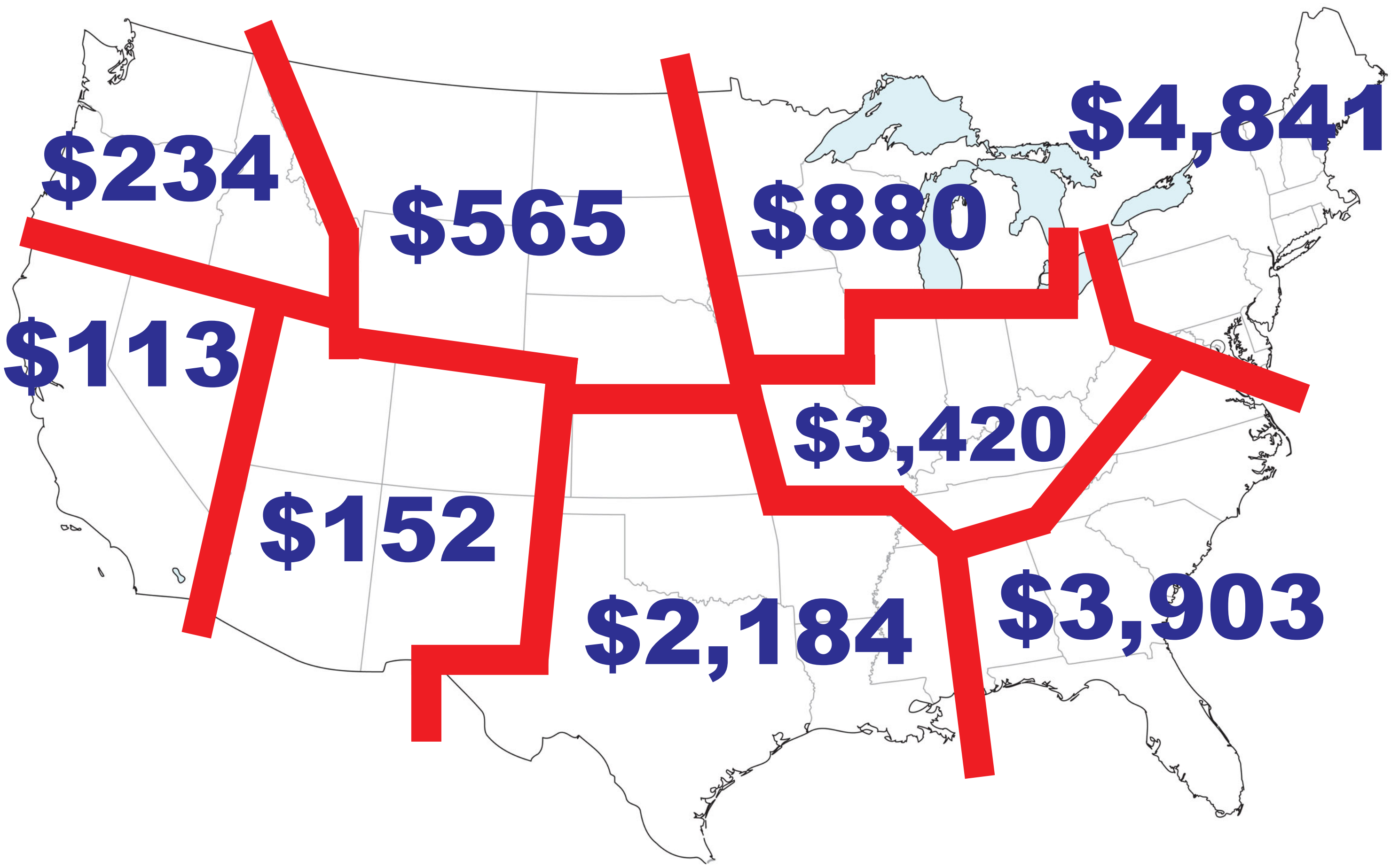

Figure 6: Amount of loss, in millions of year 2000 dollars, from major ice storms during a 52 year period.
(derived from Changnon 2003).

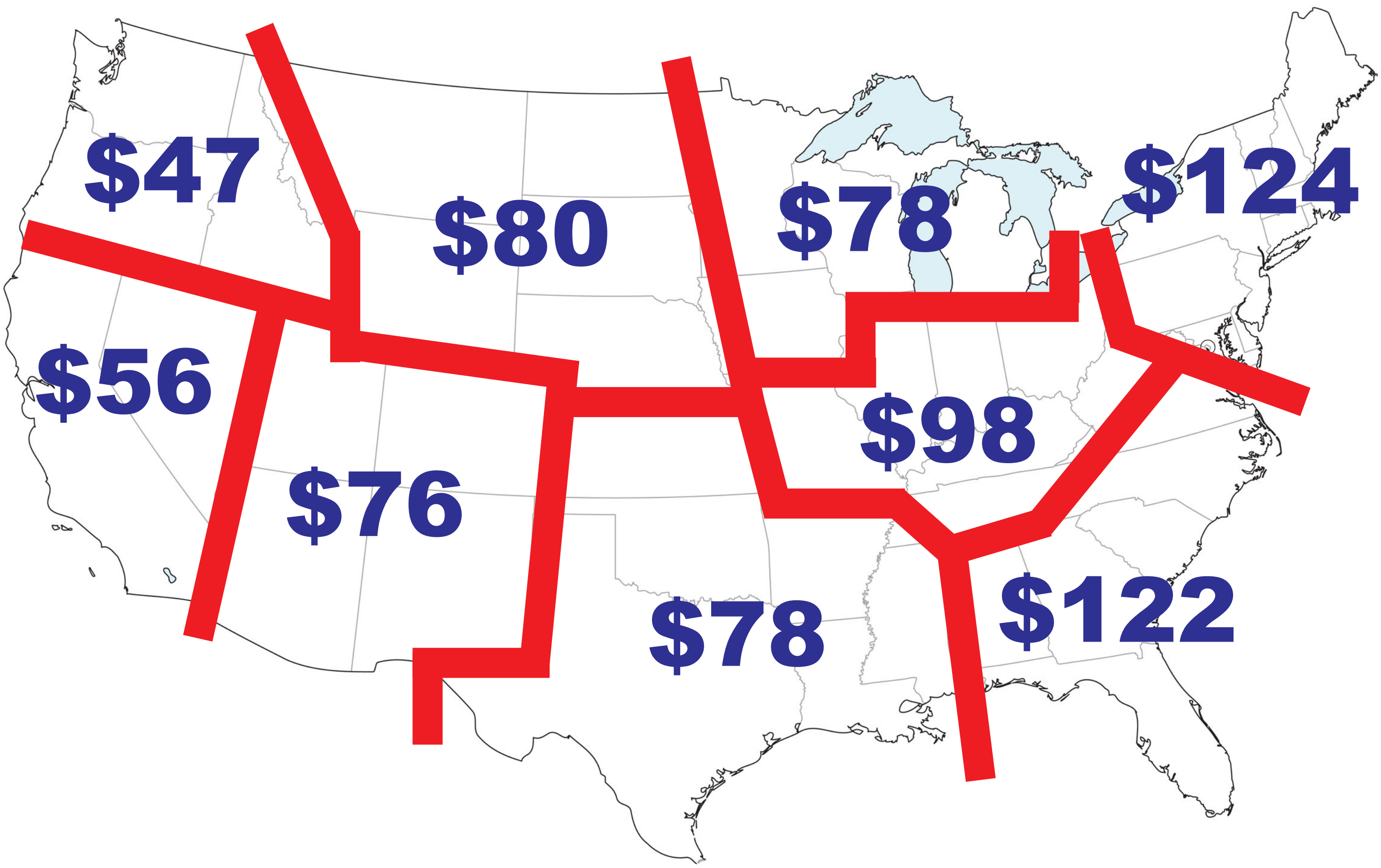

Figure 7: Amount of loss, in millions of year 2000 dollars, per ice storm during a 52 year period.
(derived from Changnon 2003).

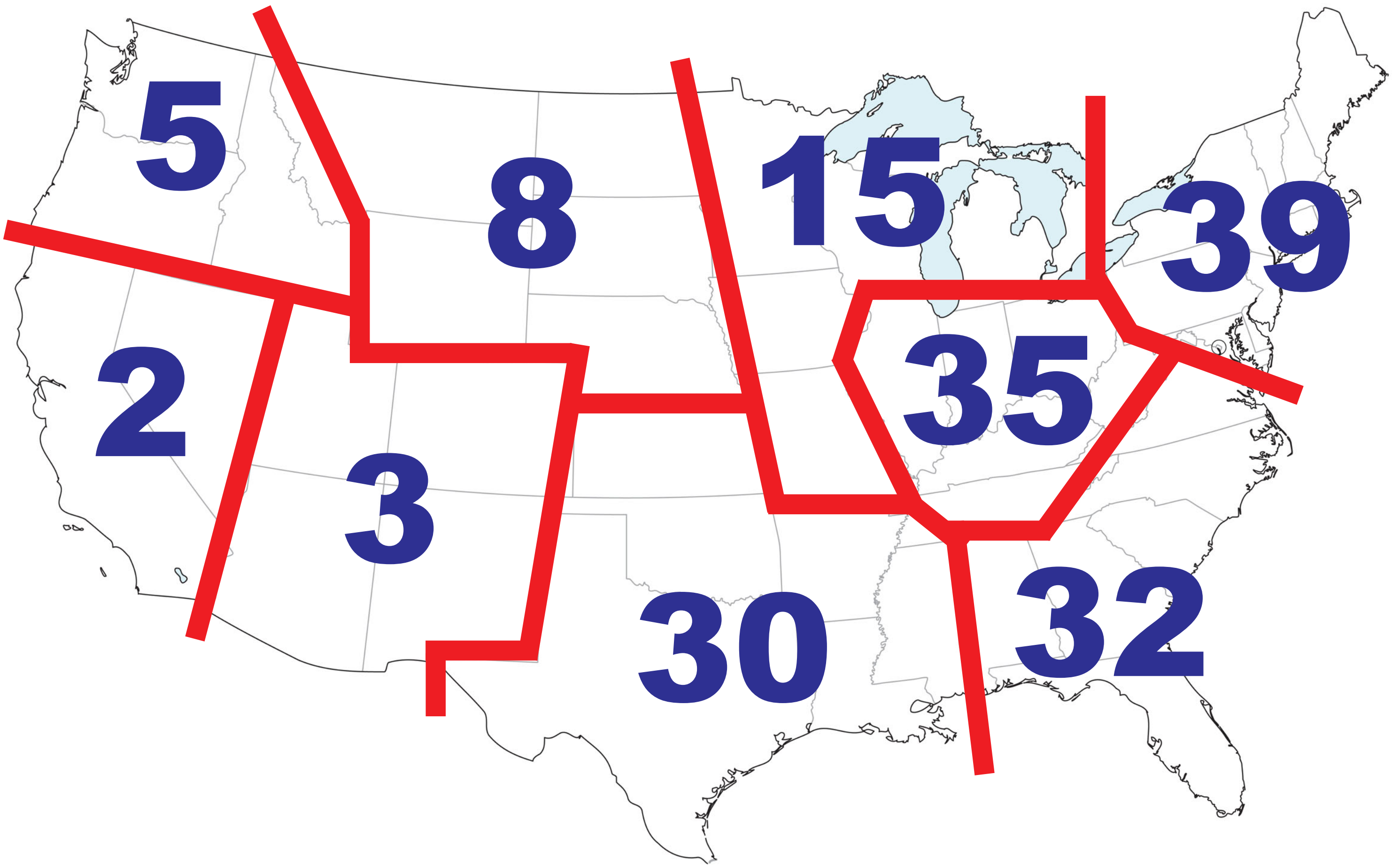

Figure 8: Number of ice storm events
by region over 52 years.
(Changnon & Changnon 2002)

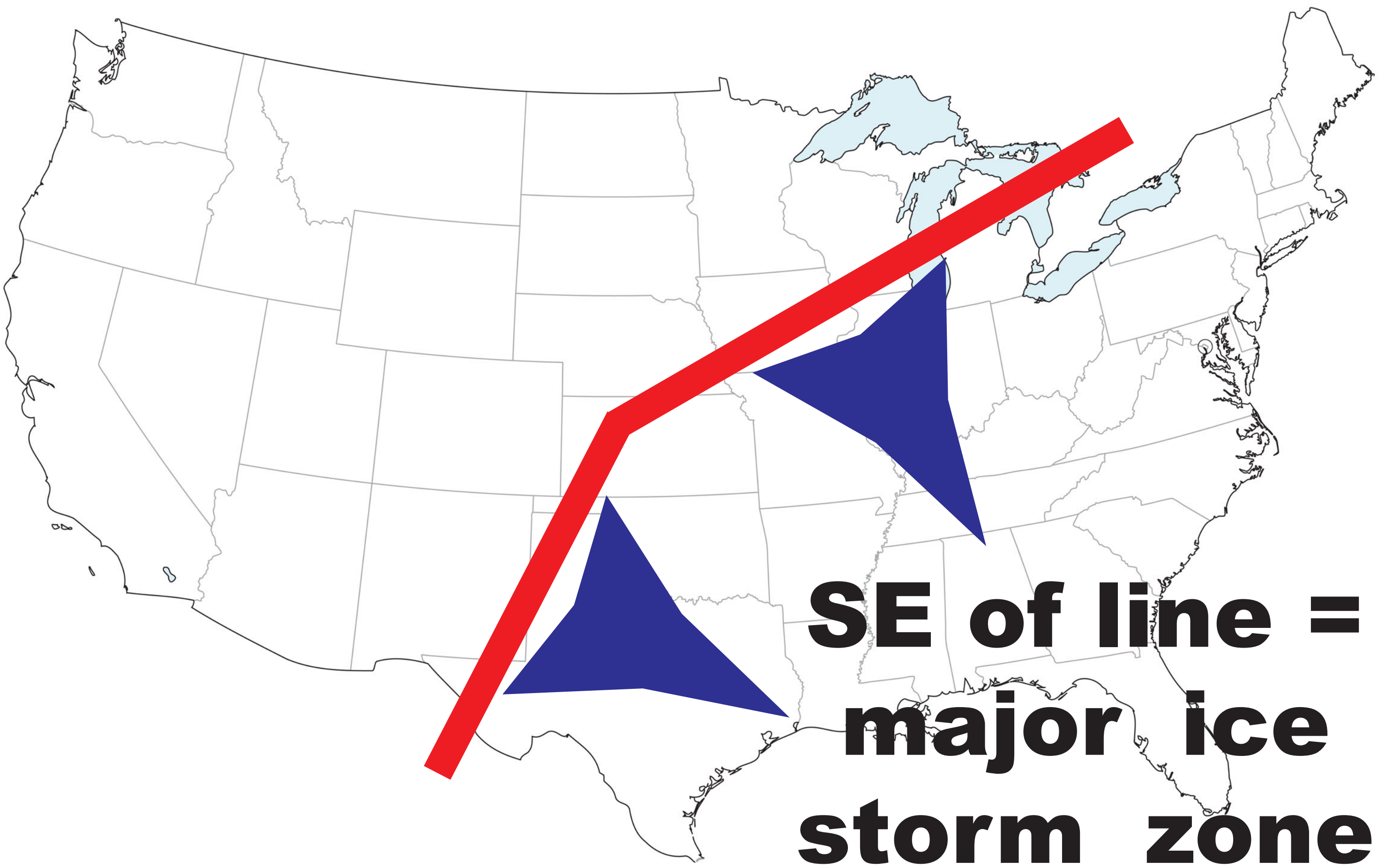

Figure 9: Areas with greater than five major ice storm events (> $1 million property loss) for a period of 53 years.
(derived from Changnon & Changnon 2002)

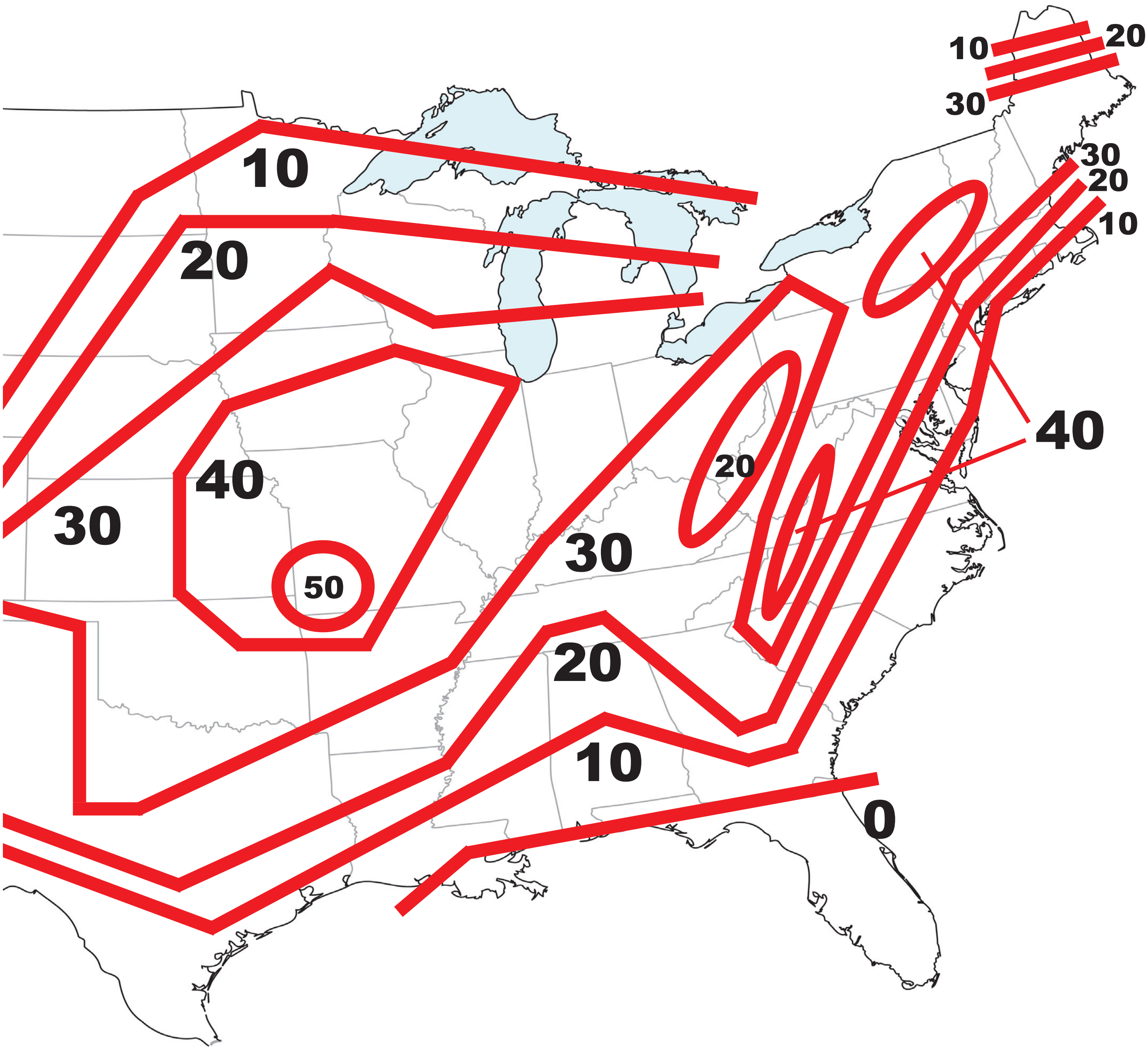

Figure 10: Number of freezing rain events over 25 years.
(derived from Rauber et.al. 2001)

severity level	description of damage
Level 1	no ice
Level 2	small amounts of ice
Level 3	low to medium damage to power lines & trees, or considerable amounts of ice
Level 4	severe damage to power lines & trees, and/or large amounts of ice
Level 5	catastrophic destruction to power lines & trees, and/or extreme amounts of ice

Figure 11: Ice accumulation levels in catagorizing ice storms.
(from EPRI 1996)

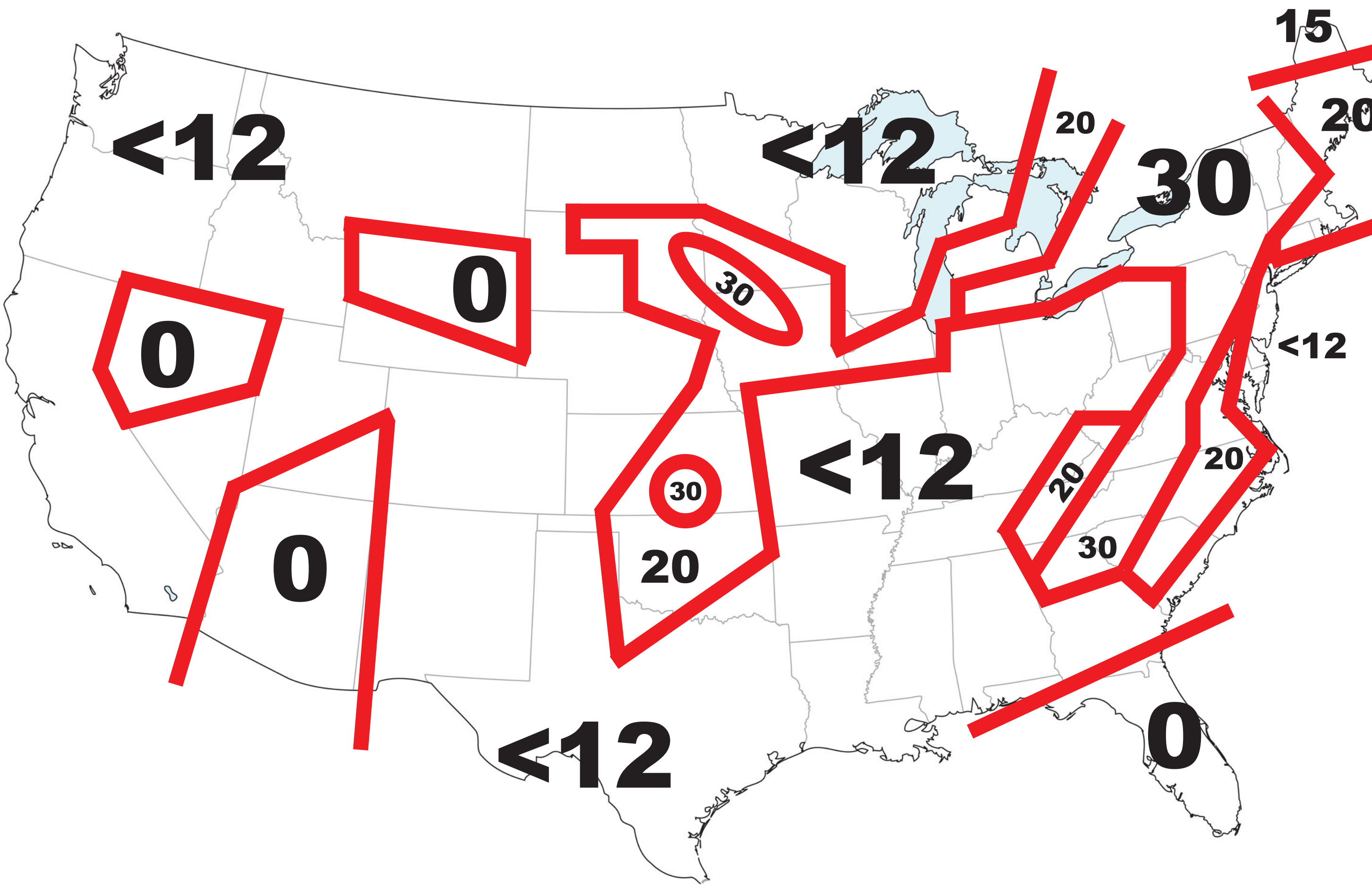

Figure 12: Number of ice storm events with a severity level of 3, 4, or 5.
(derived from EPRI 1996)

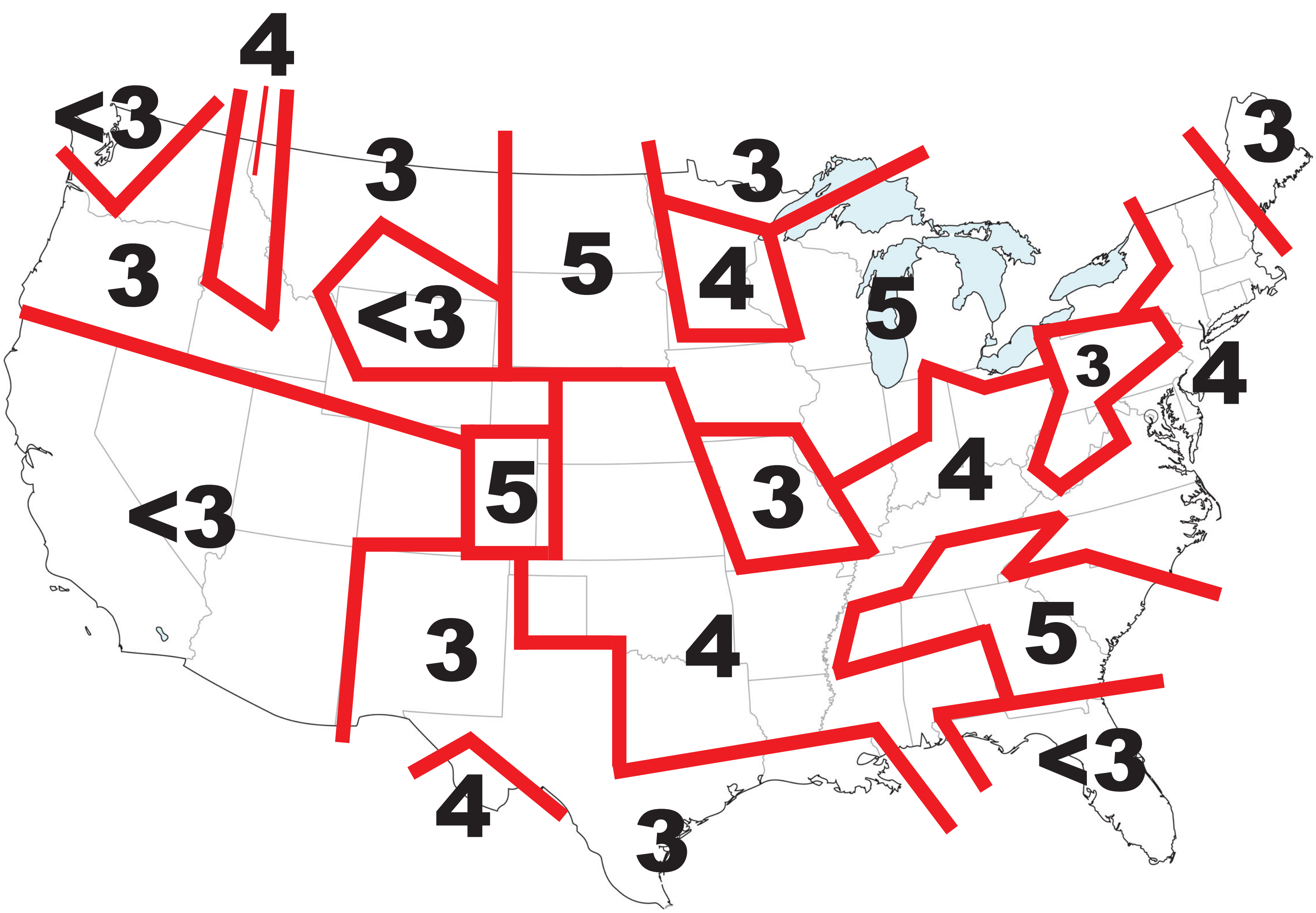

Figure 13: Maxiumum ice severity rating
(<3 = least severe & 5 = most severe).
(derived from EPRI 1996)

category	description	ISI value range
Category 1	no ice	0
Category 2	mild ice (light)	0.1 - 0.5
Category 3	moderate ice (light)	0.6 - 1.1
Category 4	moderate severe ice (medium)	1.2 - 1.7
Category 5	severe ice (severe)	1.8 - 2.3
Category 6	most severe ice (extreme)	>2.3

Figure 14: Ice Severity Index categories developed from ice storm data over 37 years. (from EPRI 1996)

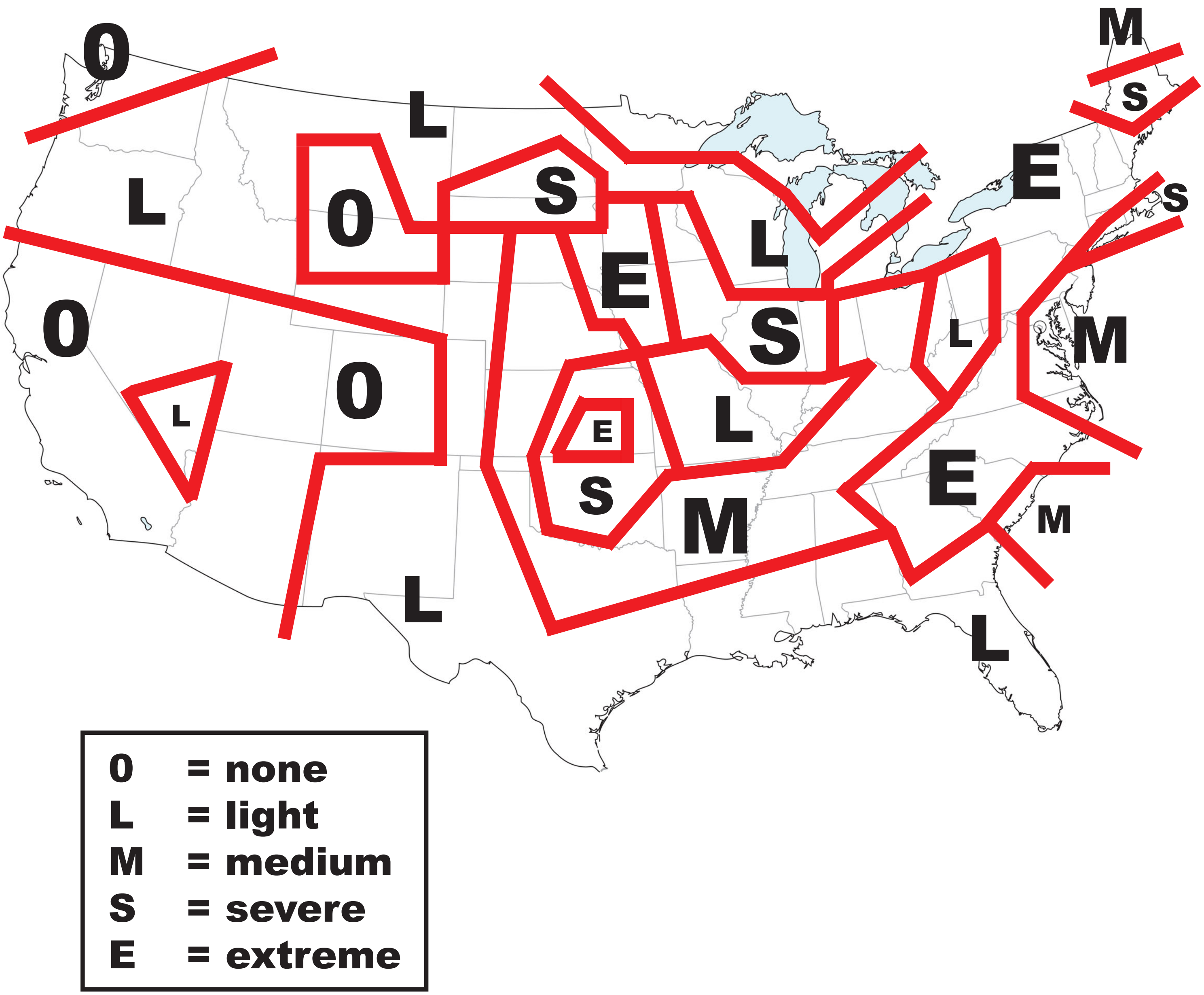

Figure 15: Ice storm severity index. Composite weighted values for level 3, 4, and 5 severity ice storms over 37 years. (derived from EPRI 1996).

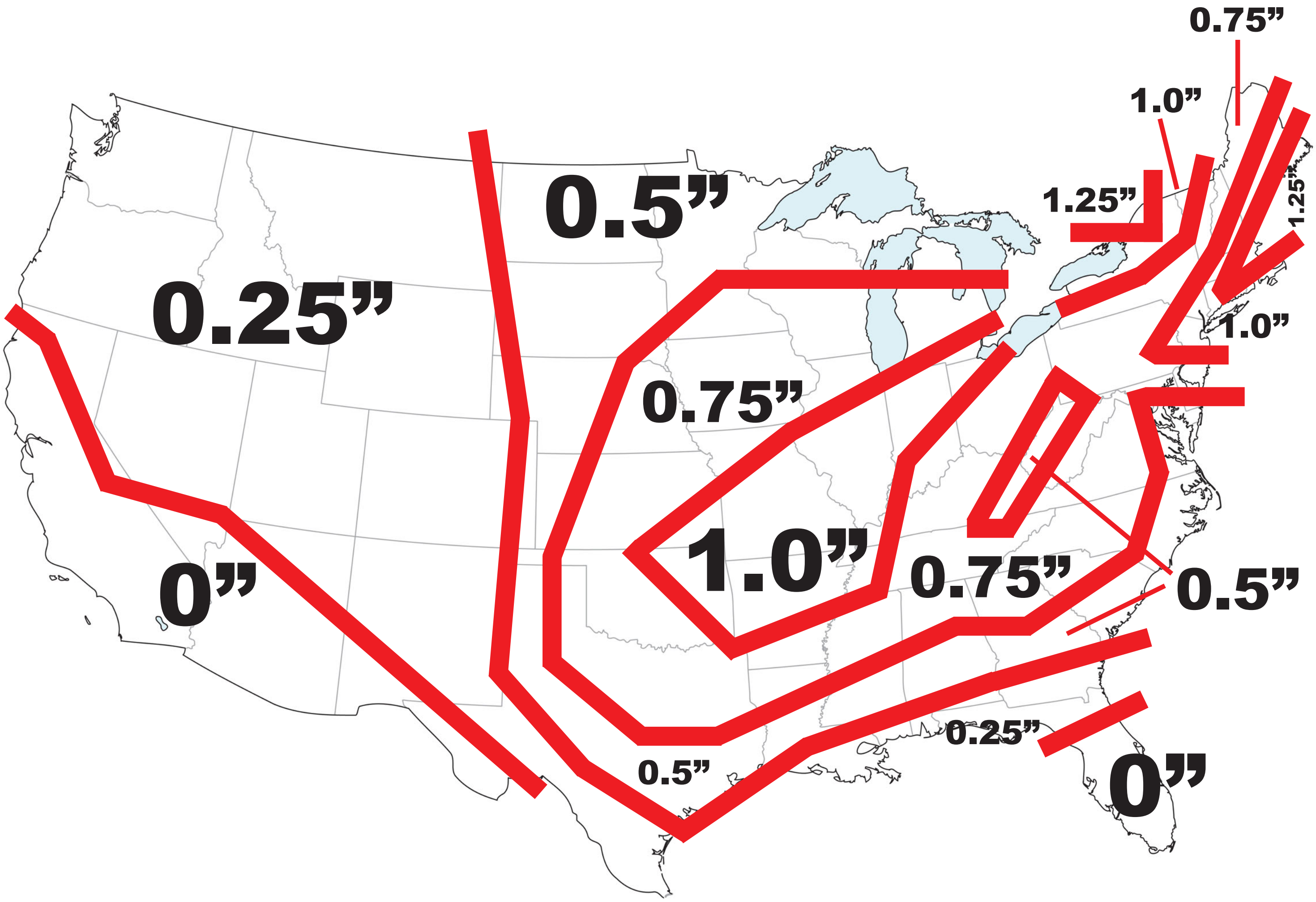

Figure 16: Ice storm ice accumulations (uniform radial thickness in inches) for a once in 50 year storm.
(derived from Jones et.al. 2002)

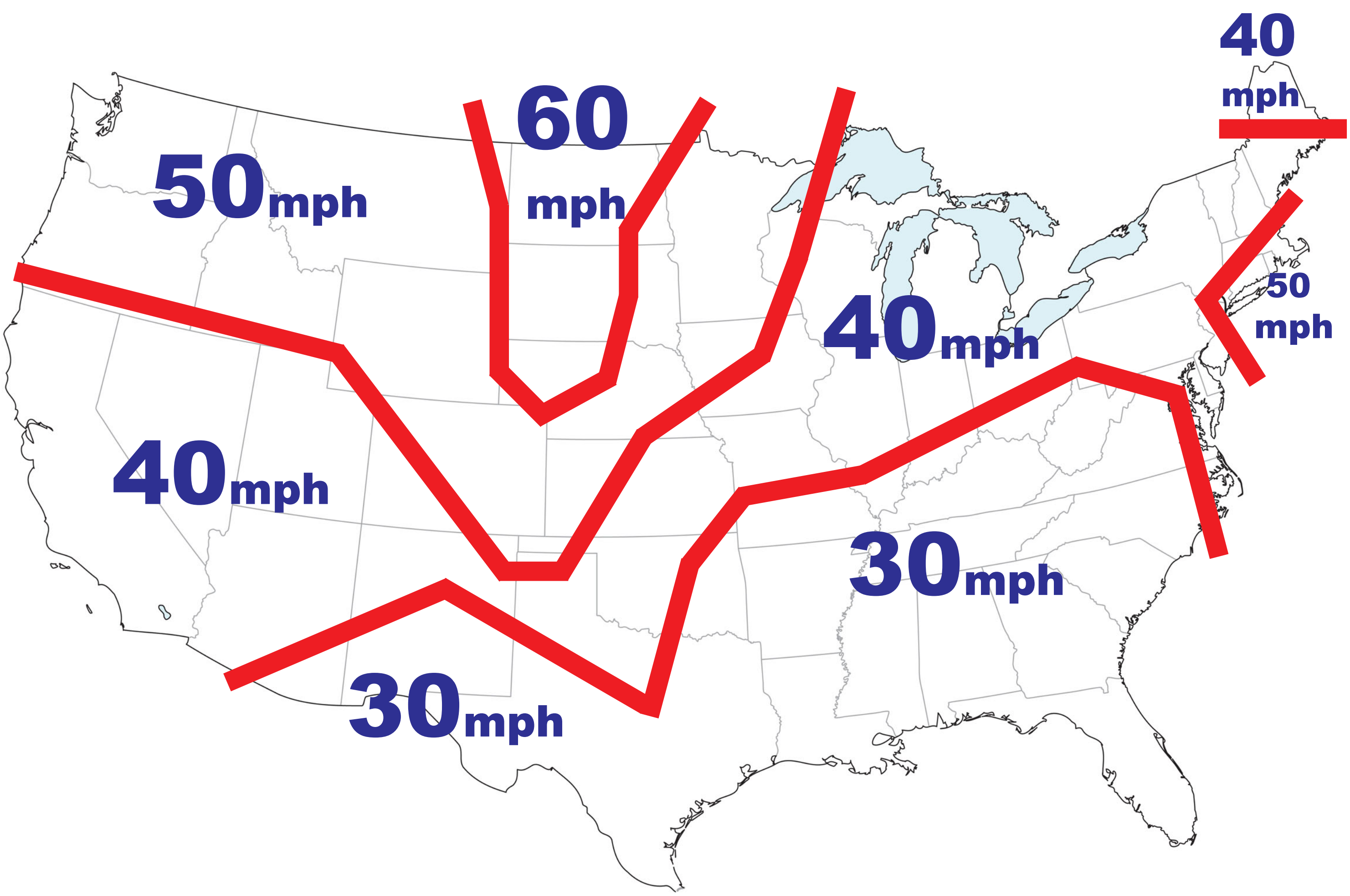

Figure 17: Ice storm wind gusts for a once in 50 year storm (3 second average velocity in mph).
(derived from Jones et.al. 2002)

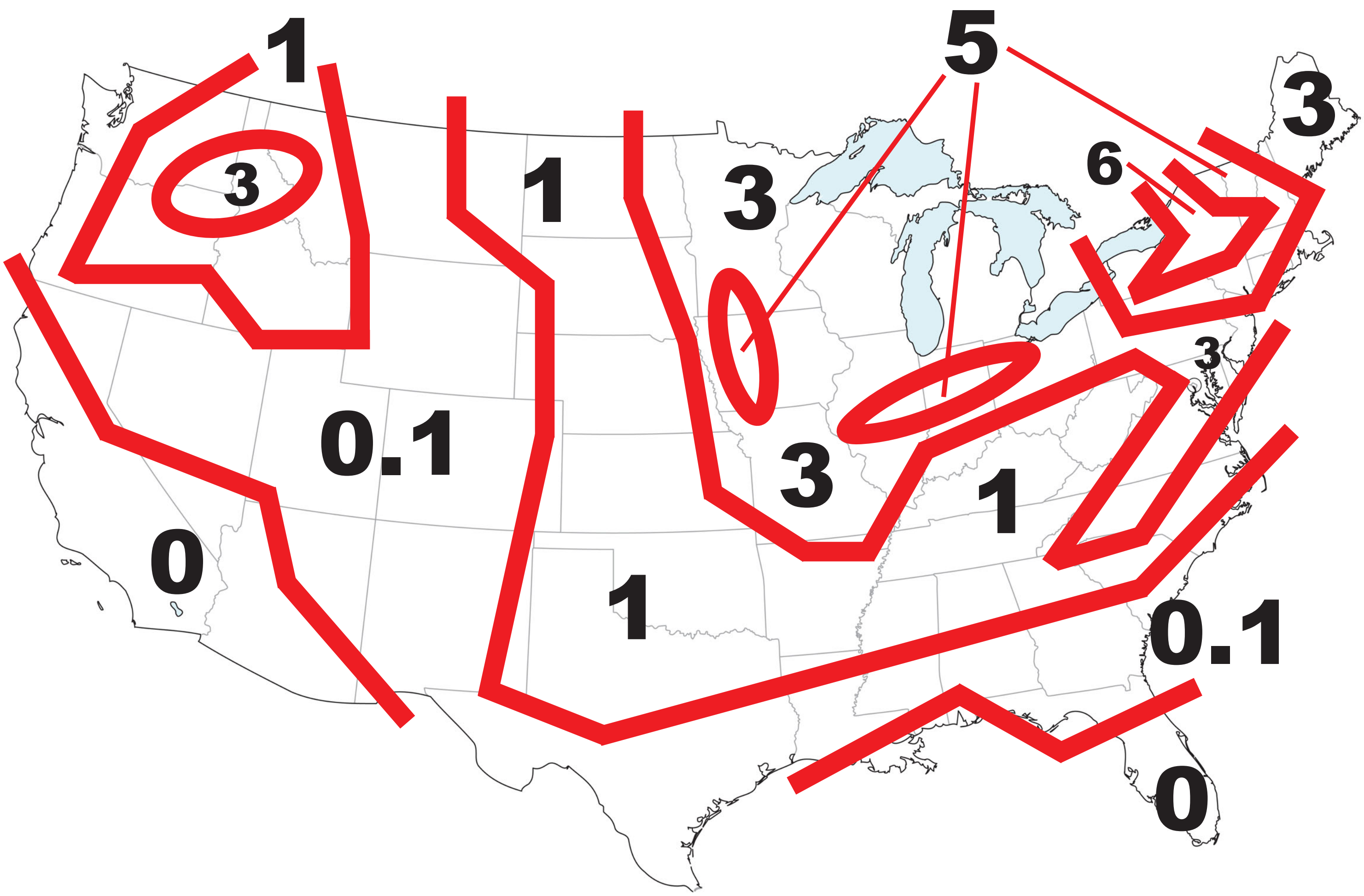

Figure 18: Annual number of days with freezing rain events over 53 years.
(derived from Changnon & Changnon 2002)

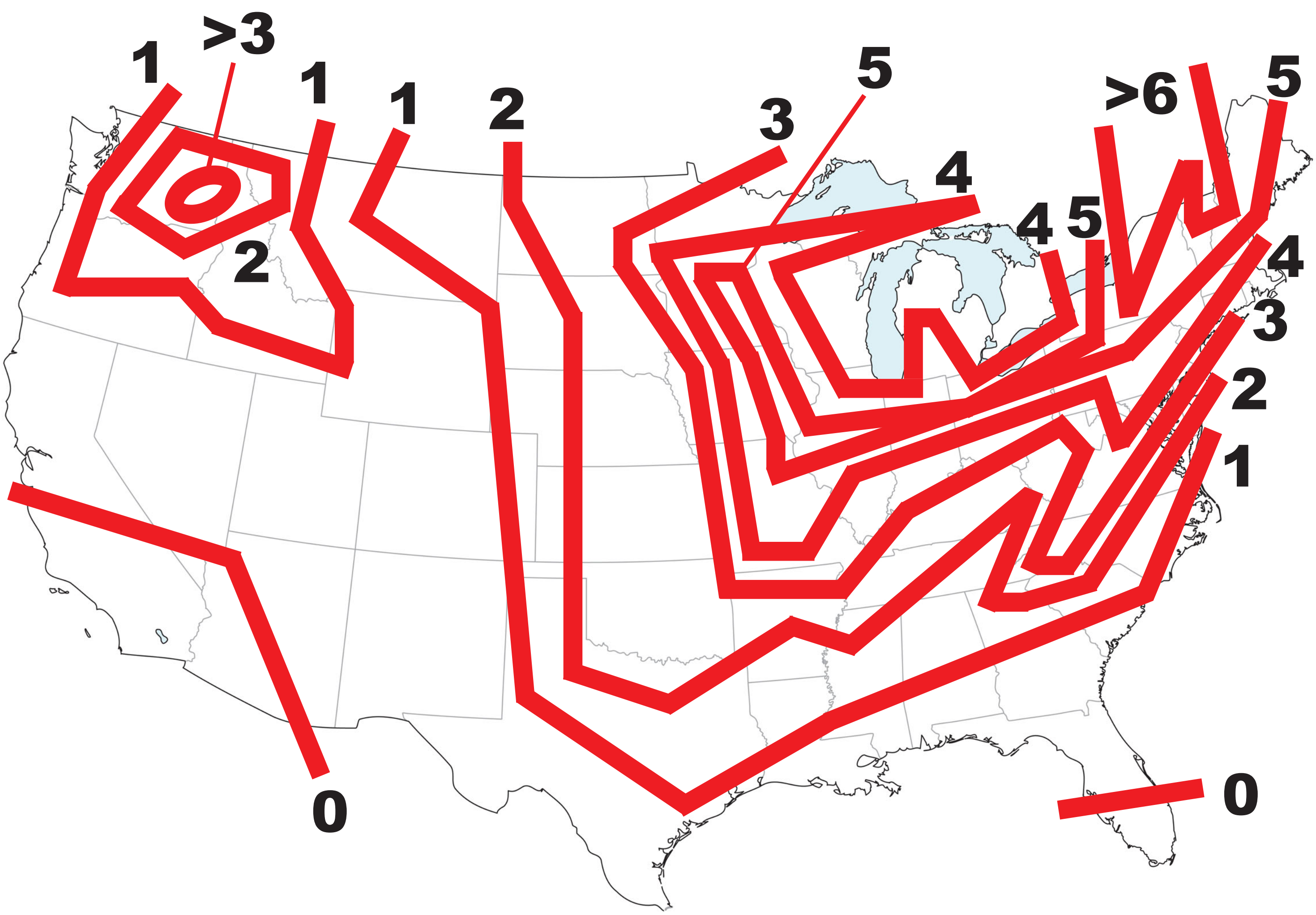

Figure 19: Average number of days with freezing rain per year in a 53 year period.
(derived from Changnon & Karl 2003).

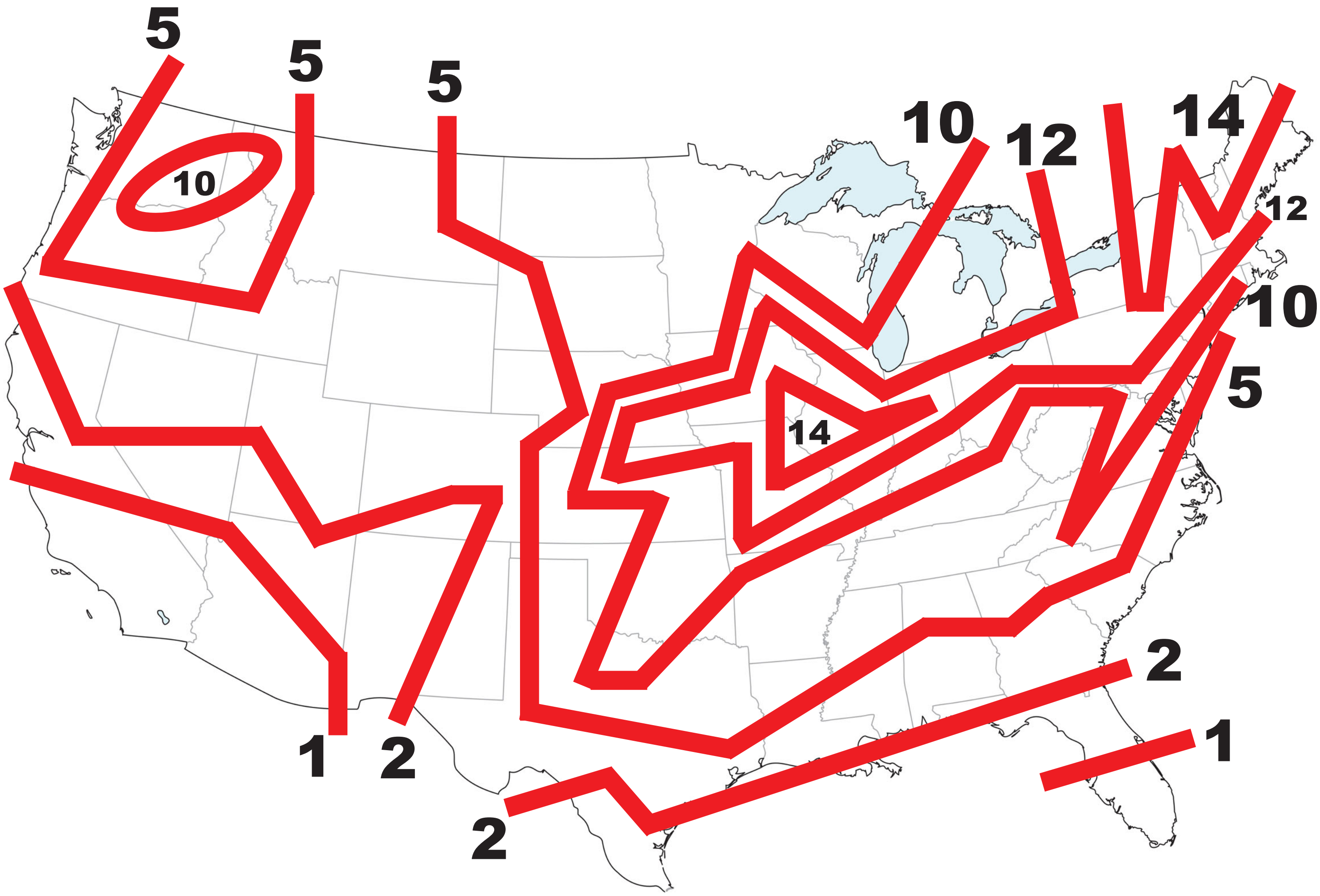

Figure 20: Maximum number of freezing rain days in one year in a 53 year period.
(derived from Changnon & Karl 2003).

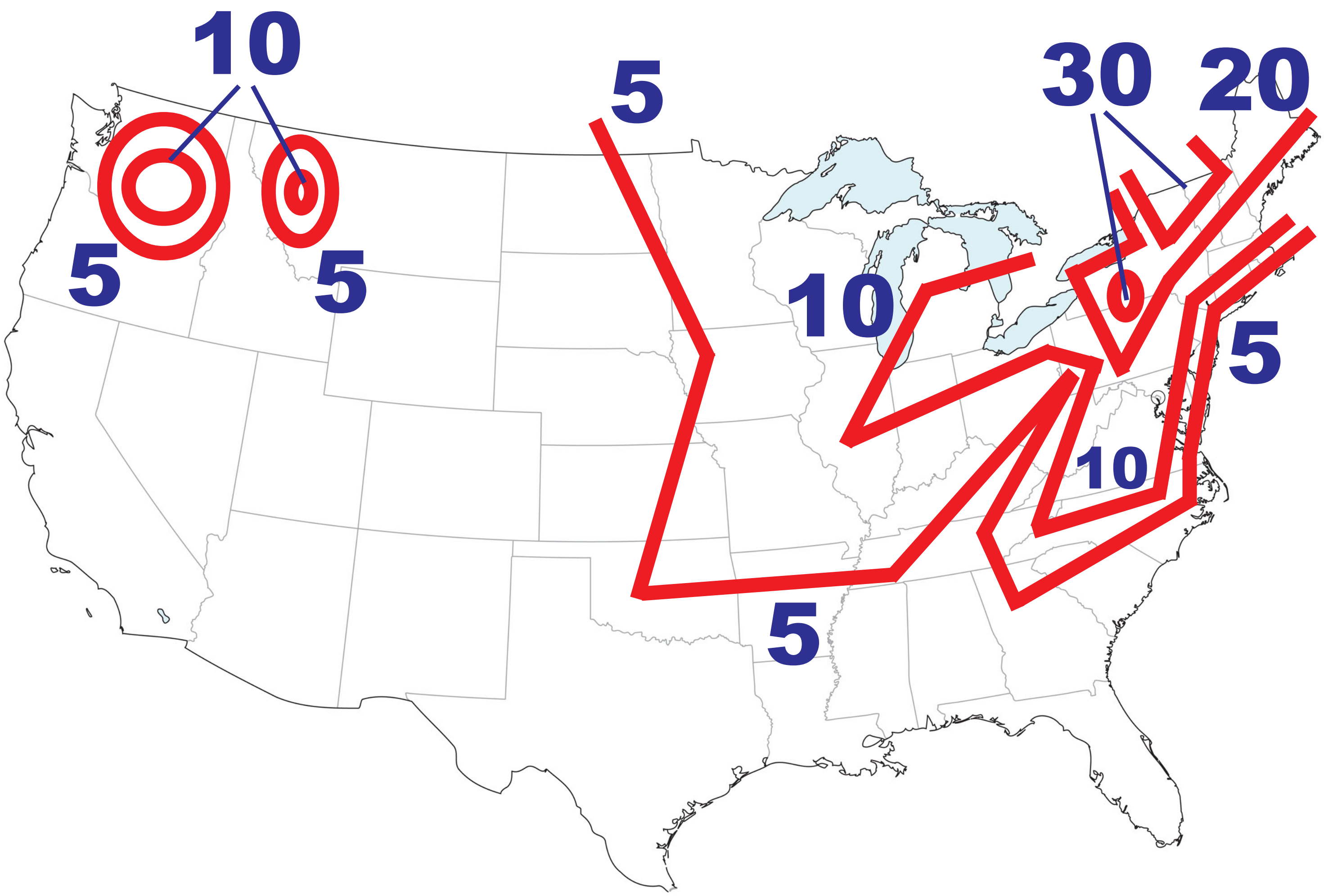

Figure 21: Hours of freezing rain per year across 15 years. (derived from Cortinas et.al. 2004)

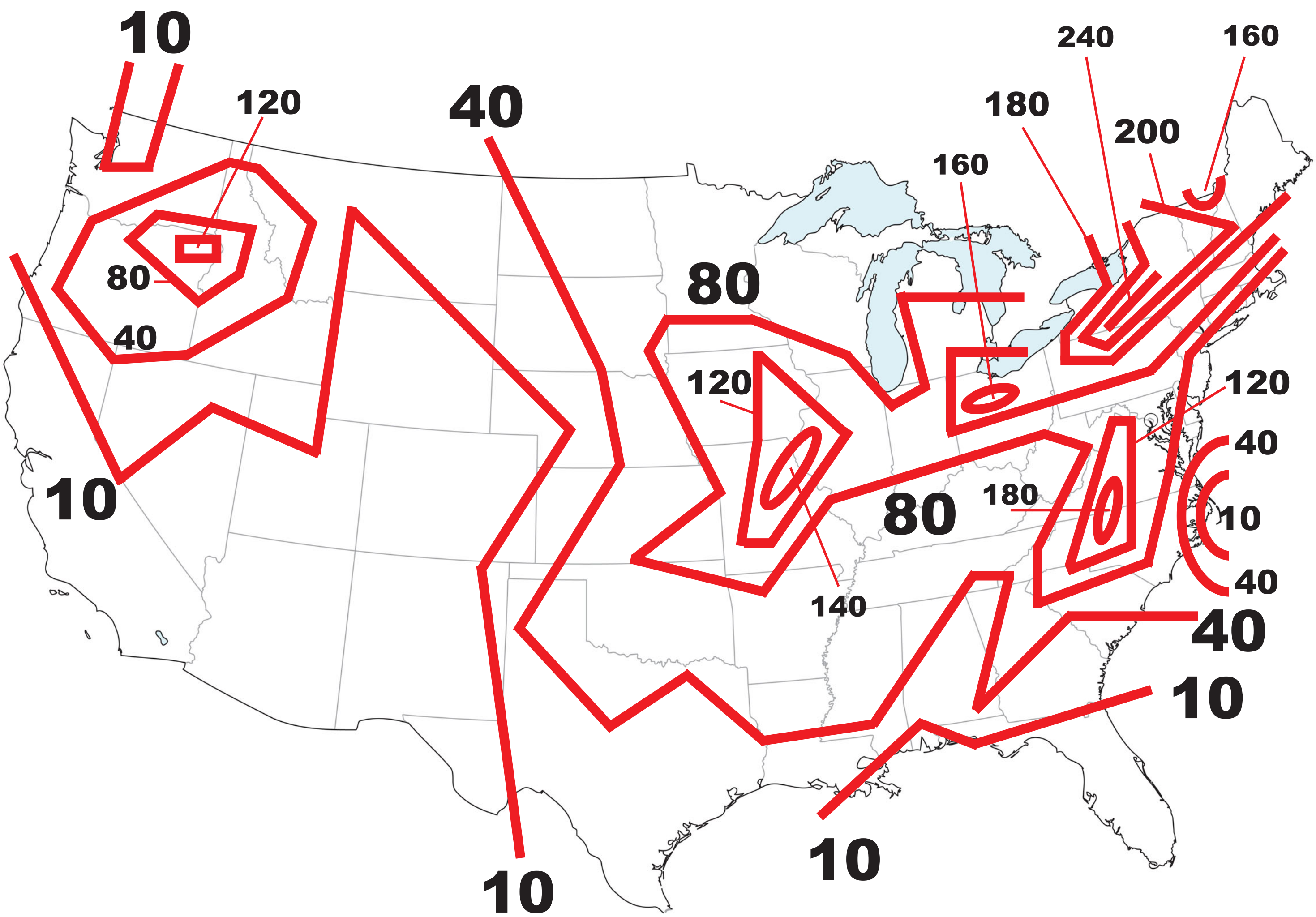

Figure 22: Total hours of freezing rain in 9 years.
(derived from NOAA)

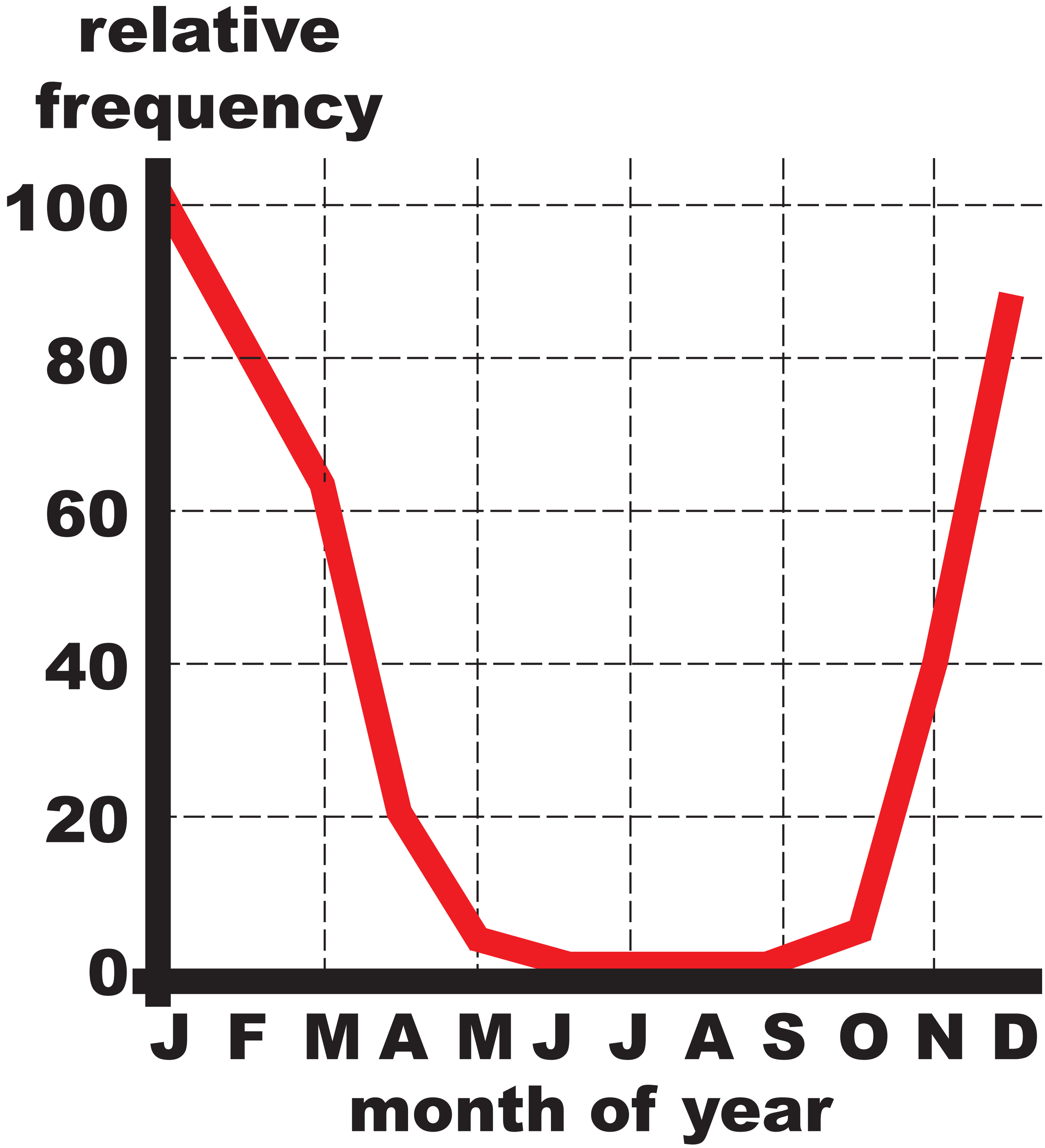

Figure 23: Monthly distribution of freezing rain events over 15 years. (after Cortinas et.al. 2004)

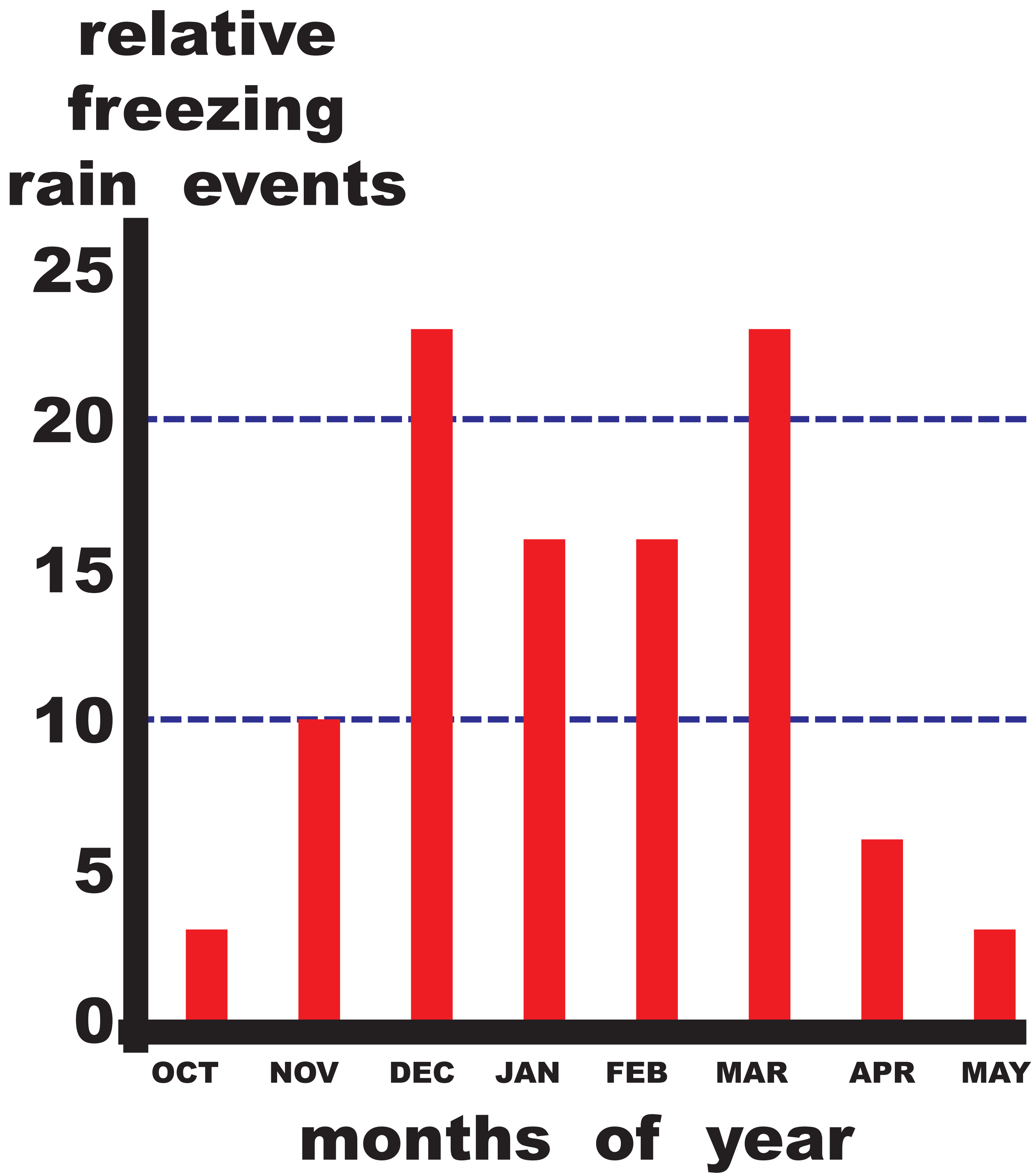

Figure 24: Monthly distribution of freezing rain events in a 15 year period (Great Lakes Region).
(derived from Cortinas 2000)

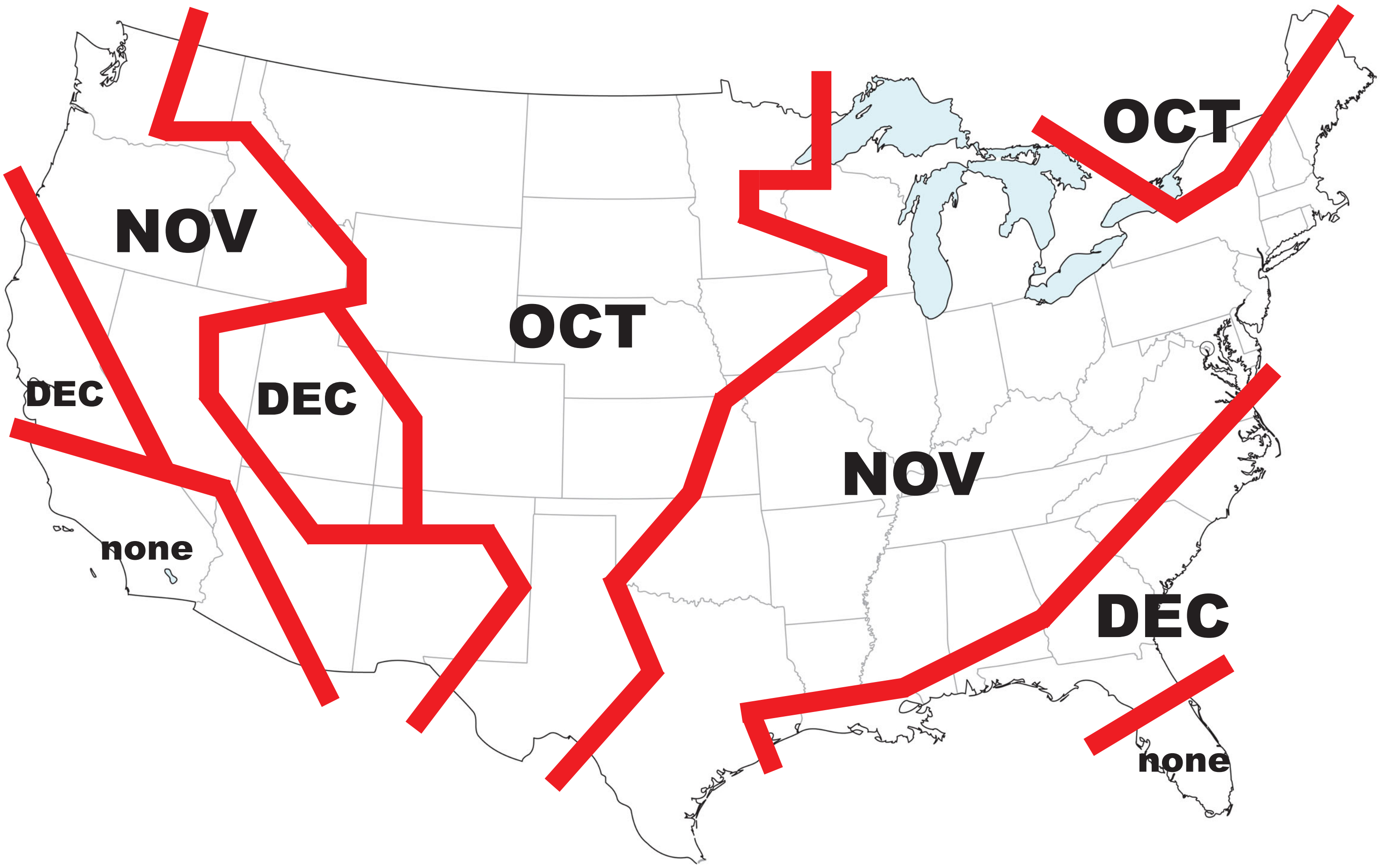

Figure 25: The earliest month for freezing rain events during a 53 year period. (derived from Changnon & Karl 2003).

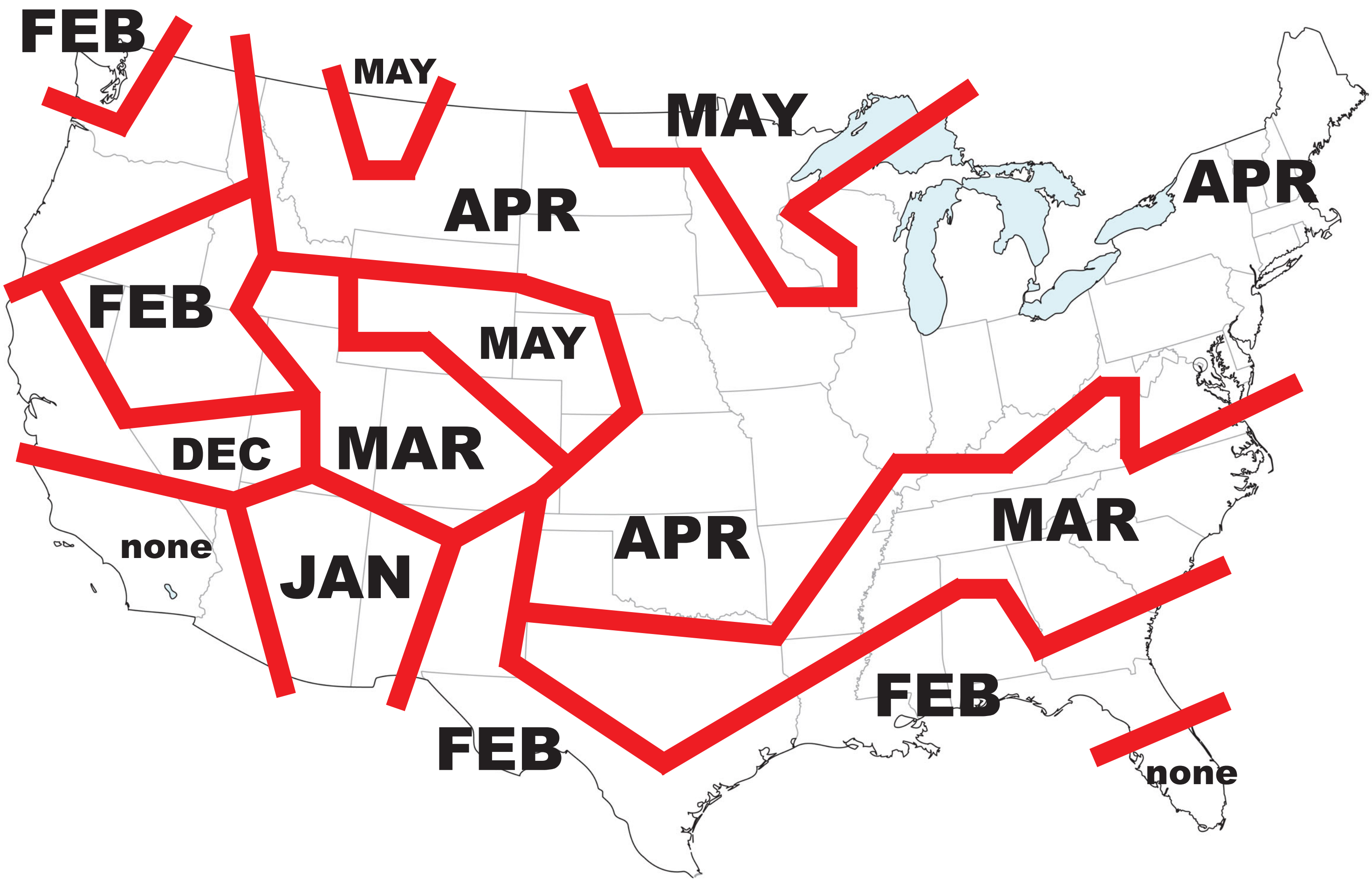

Figure 26: The latest month for freezing rain events during 53 year period. (derived from Changnon & Karl 2003).

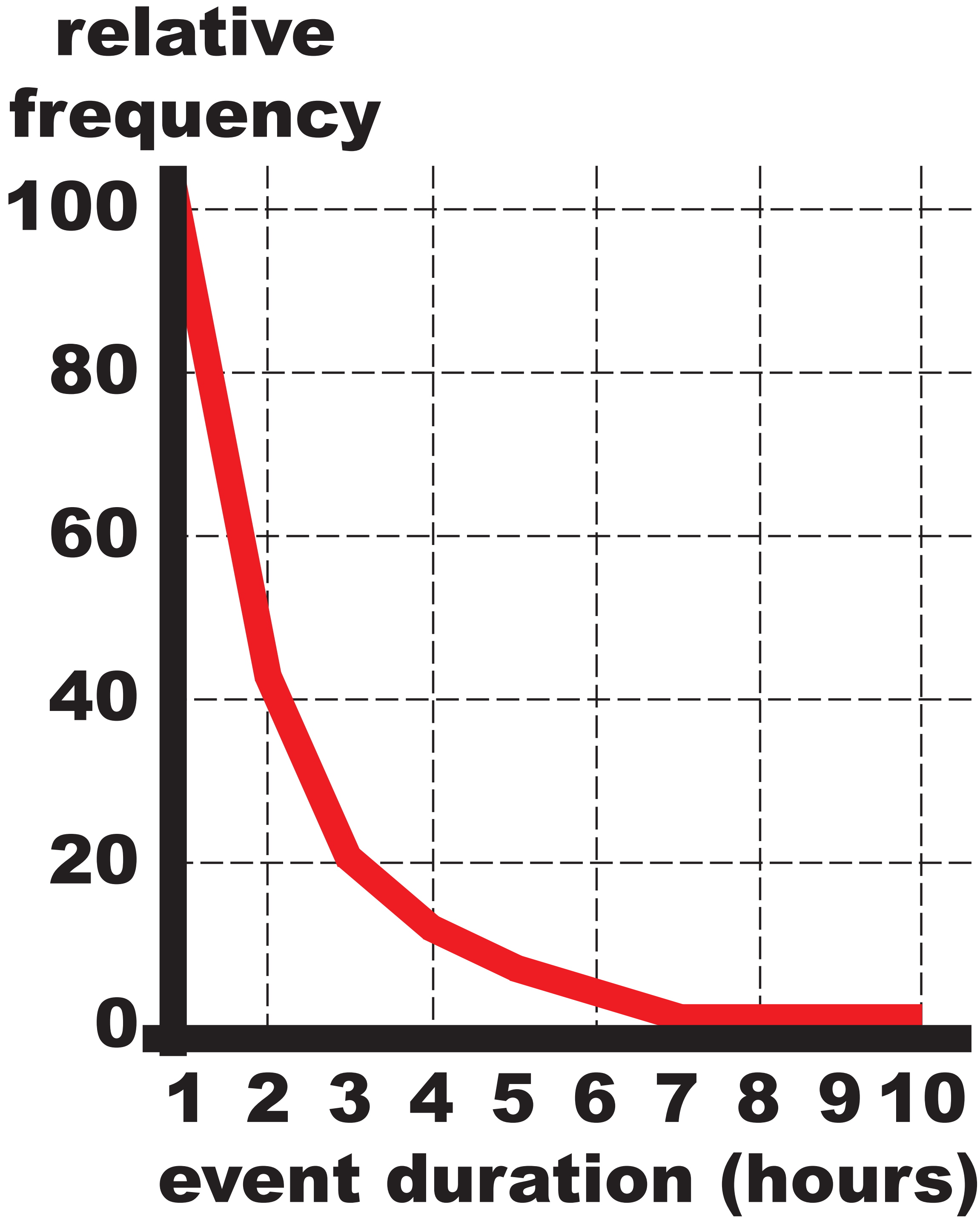

Figure 27: Duration of freezing rain events.
(after Cortinas et.al. 2004)

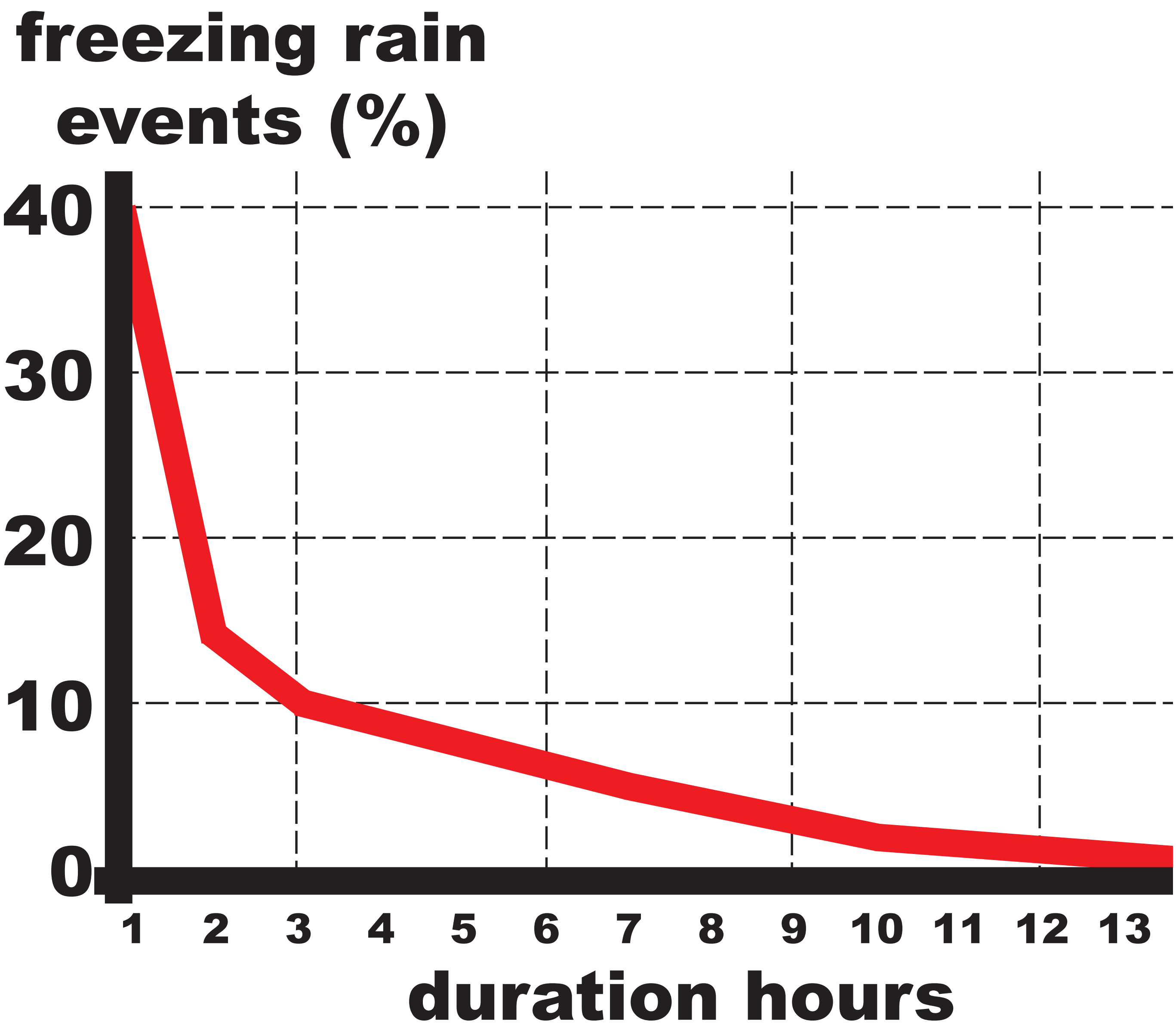

Figure 28: Duration of freezing rain events over 74 years.
(derived from Houston & Changnon 2007).

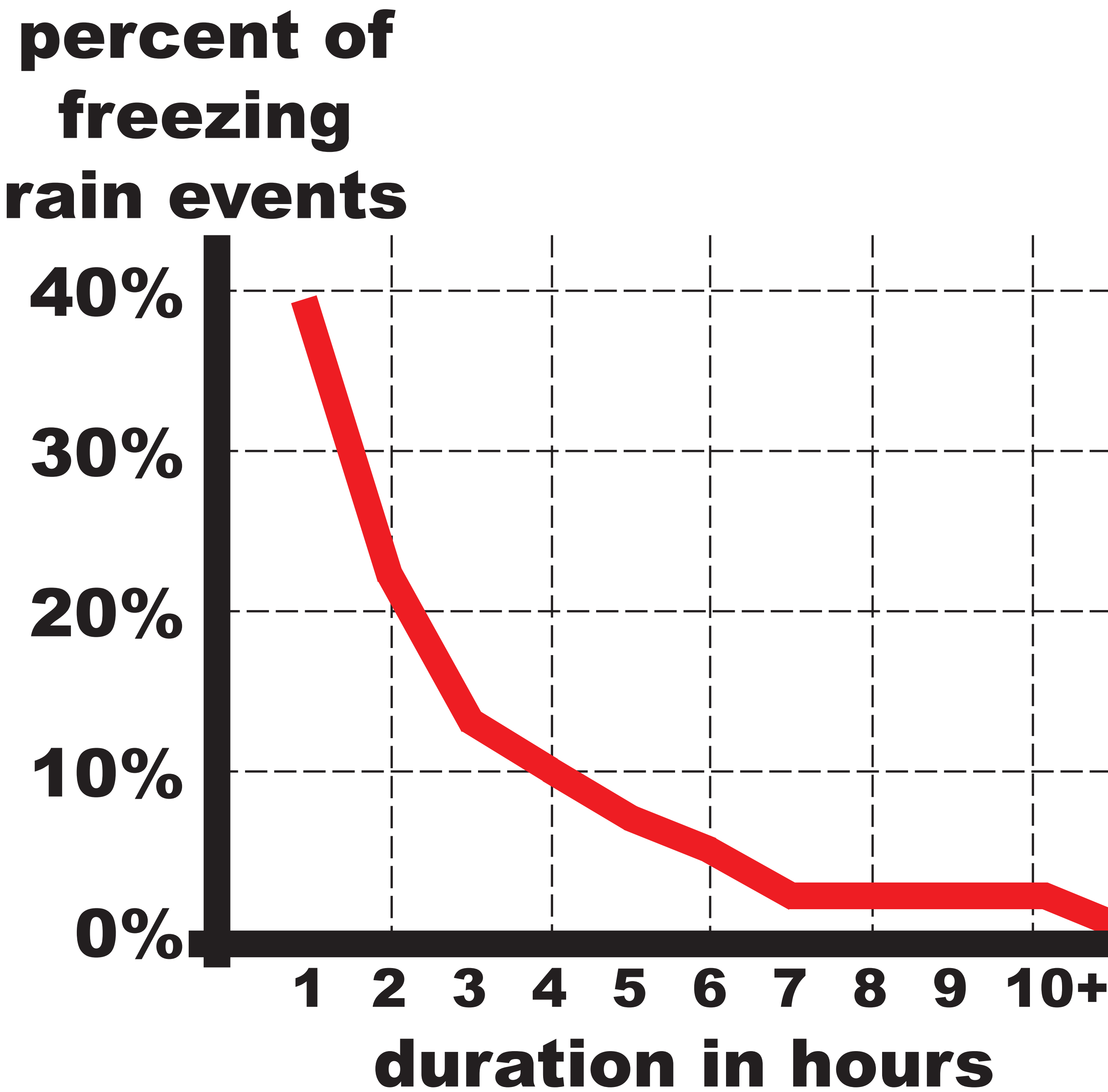

Figure 29: Duration of freezing rain events over 15 years (Great Lakes Region). (derived from Cortinas 2000)

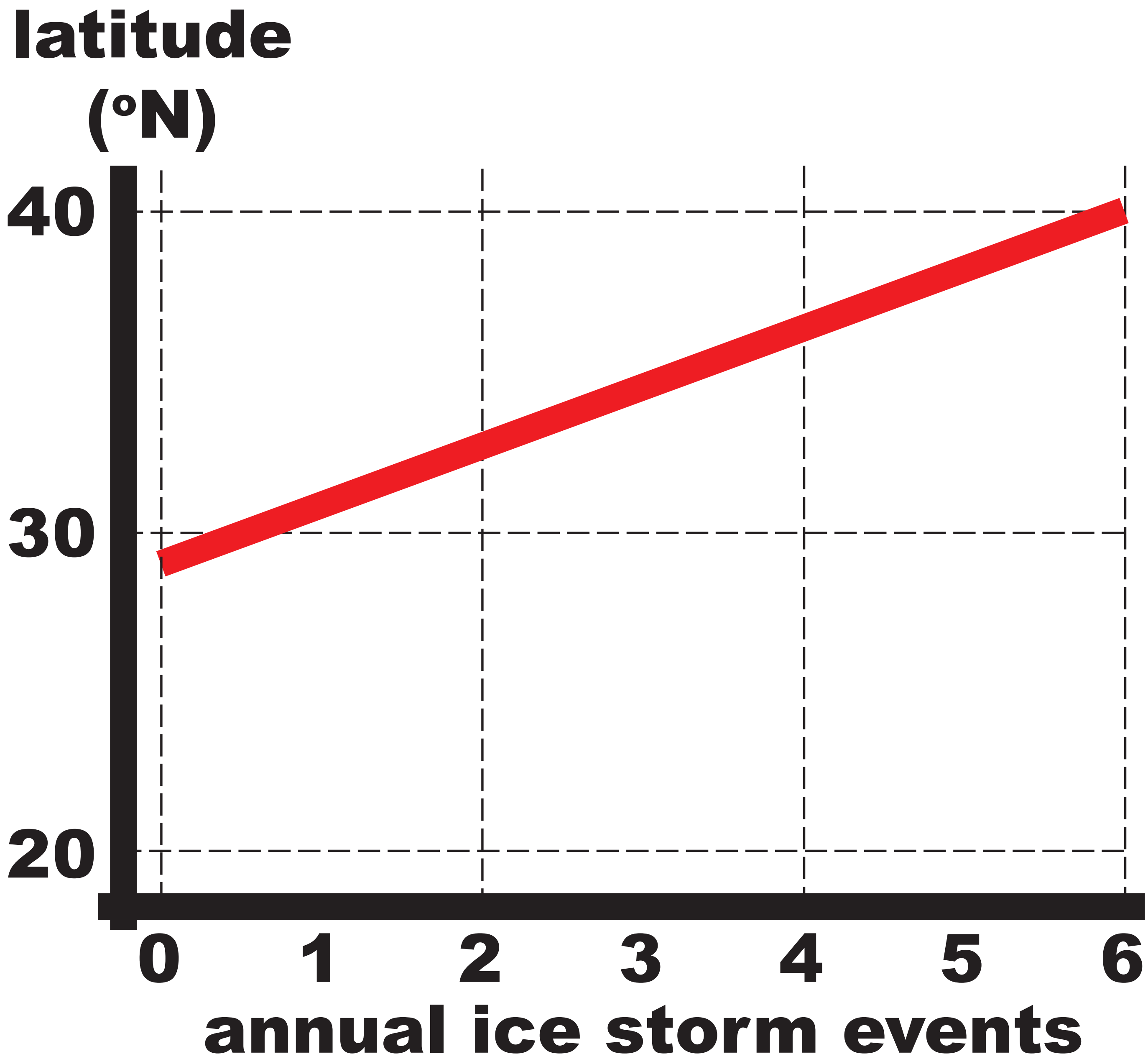

Figure 30: Ice storm events per year by latitude.
(derived from Gay & Davis 1993)

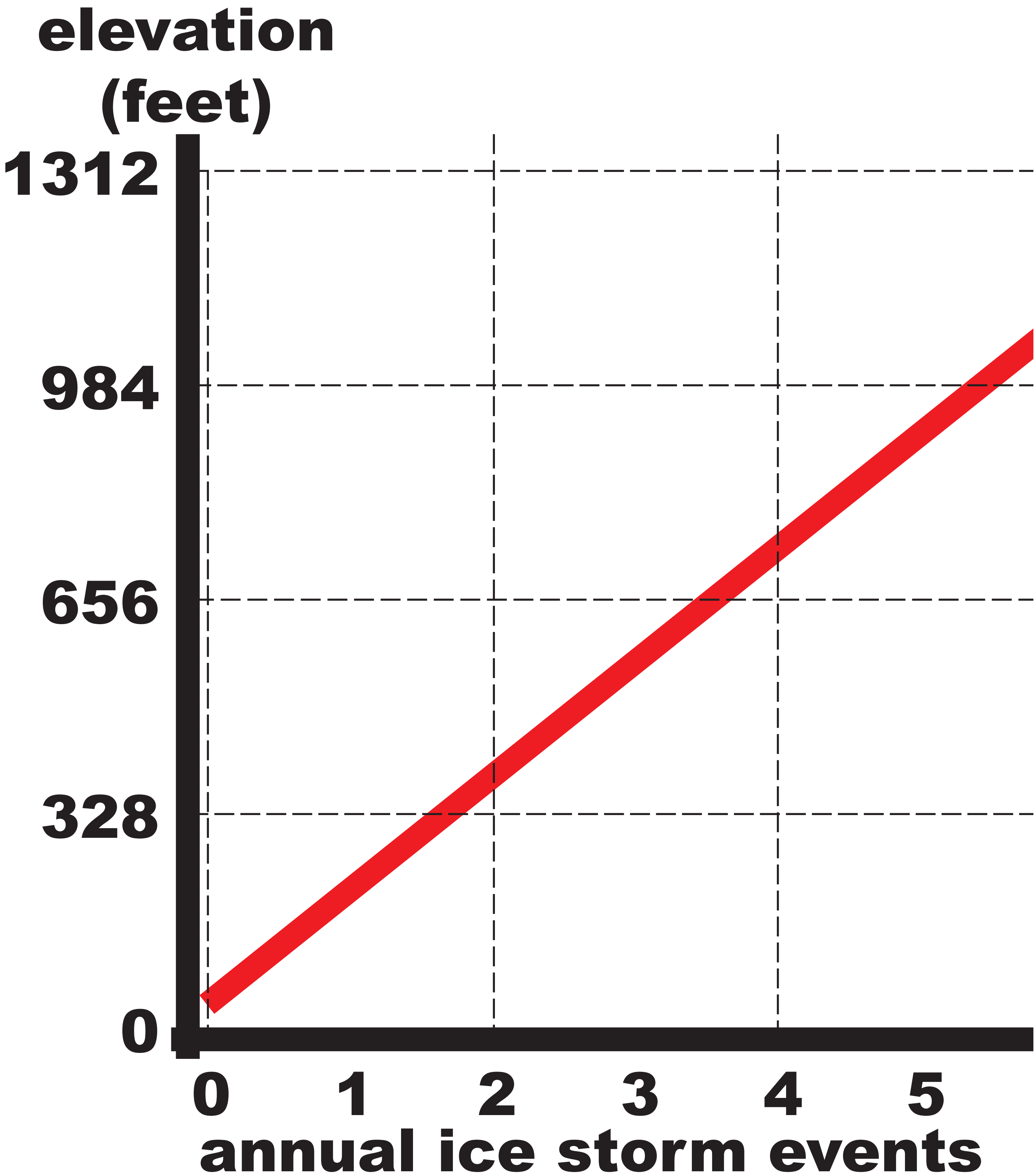

Figure 31: Ice storm events per year by elevation.
(derived from Gay & Davis 1993).

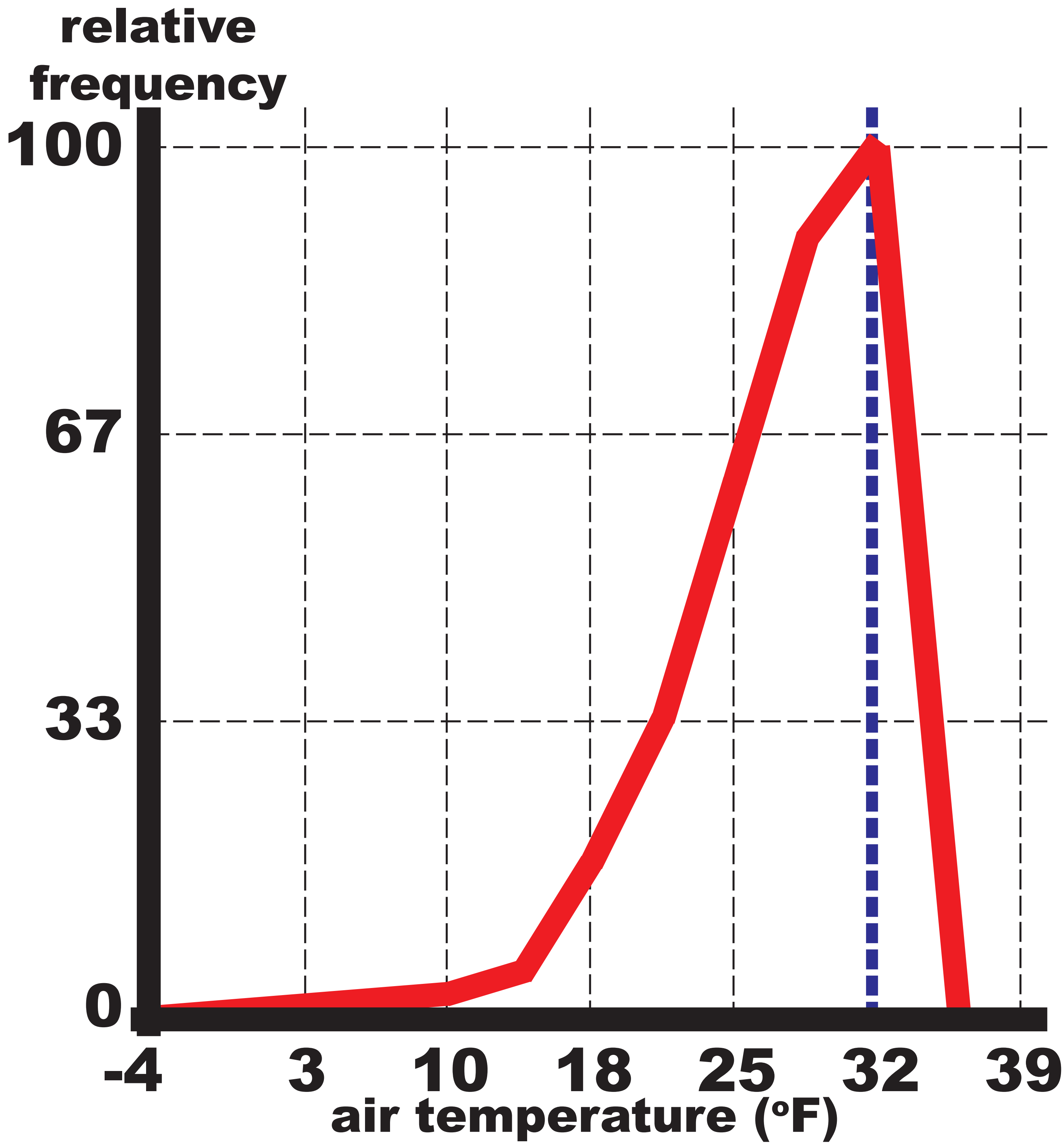

Figure 32: Air temperature at 2 meters (~6.6 feet) above the ground associated with freezing rain.
(derived from Cortinas et.al. 2004).

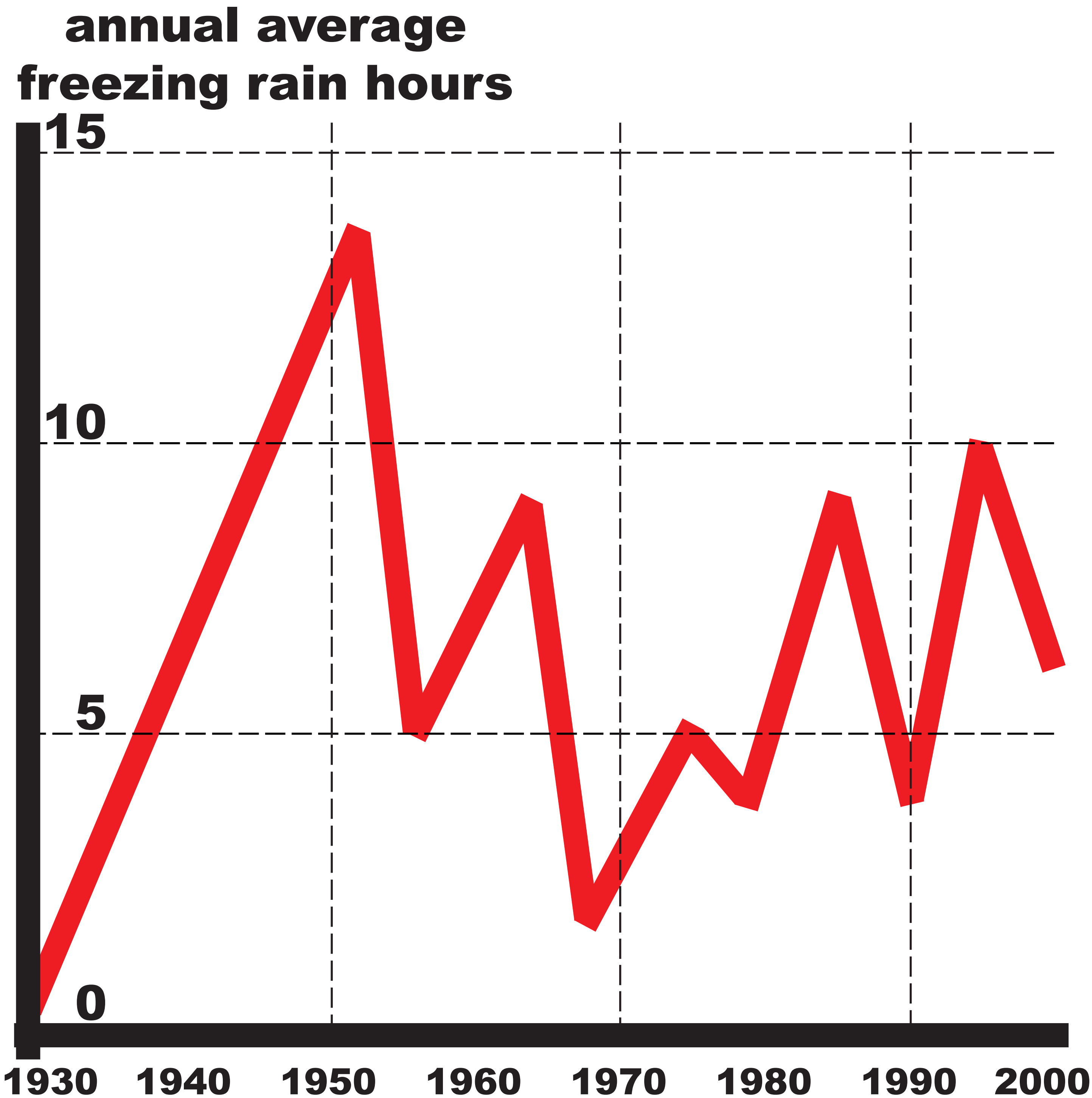

Figure 33: Distribution of annual freezing rain event hours for a 70 year period.
(derived from Houston & Changnon 2007).

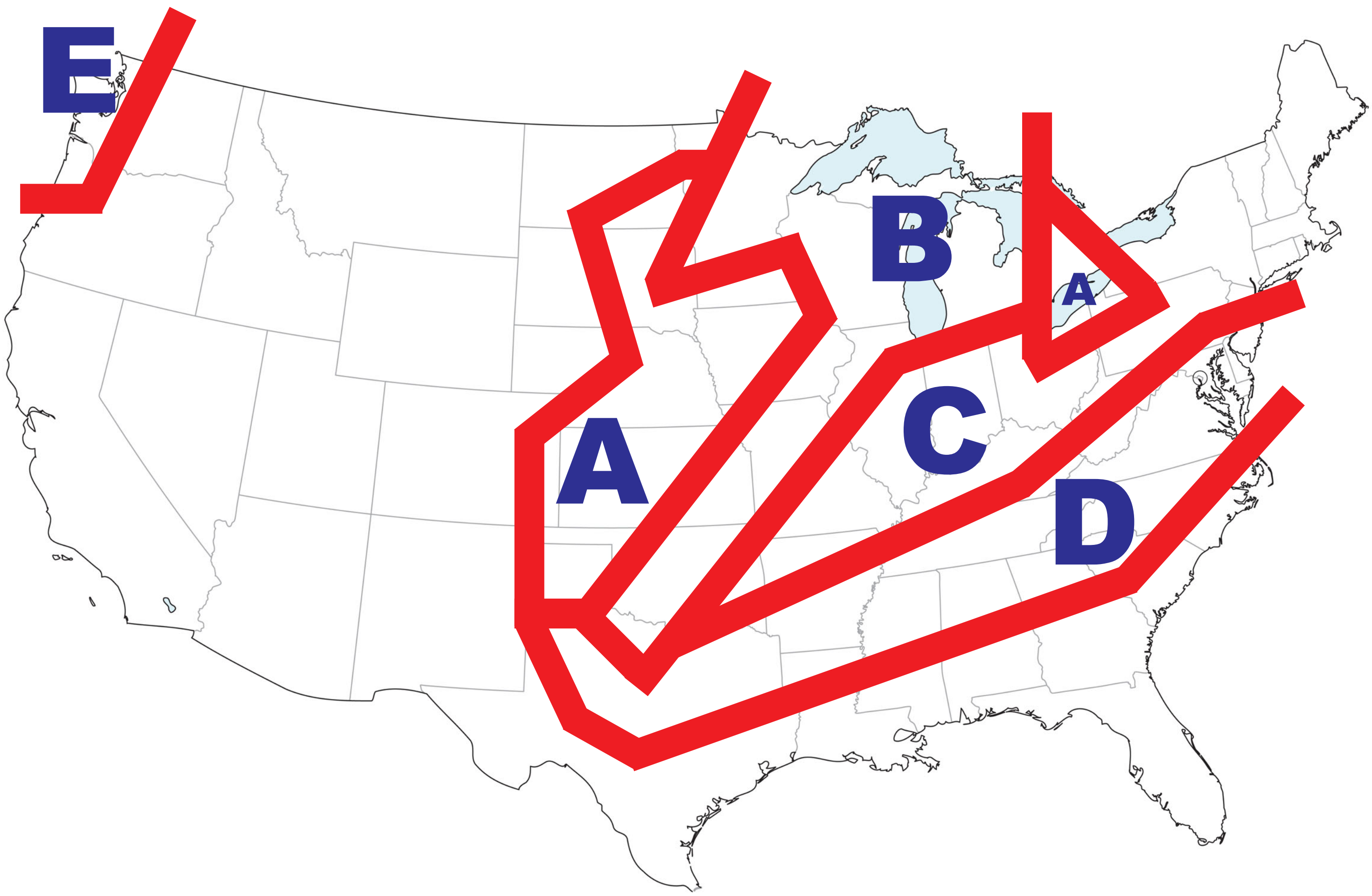

Figure 34: Similar regional ice storm zones
for a 51 year period.
(derived from Changnon & Bigley 2005).

Citation:

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