# The Modern Climatology of Indiana Tornadoes

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## Introduction

The tornado is an event which is quite common to the people of Indiana. On the average the state is affected by approximately 21 tornado events per year, with about 5 of these tornadoes bringing injury and/or death. The destruction created by the tornado, certainly the most violent act of nature, is often unbelievable. During the period from 1905 through 1976 Indiana was considerably above the national average in tornado frequency, and the state was in the midst of two major tornado outbreaks. The Palm Sunday tornadoes in 1965 and the Jumbo Tornado Outbreak of 3 April 1974 together spawned collectively 33 tornadoes and killed 184 people in the state. Since tornado activity is such an integral part of Indiana weather, reliable statistics on these storms should be of great importance to the people of the state.

A paper by Agee (1969) in the Proceedings of the Academy entitled, The Climatology of Indiana Tornadoes, has been the most complete effort to statistically analyze tornadoes in Indiana. The article dealt with tornadoes occurring during a period from 1916 to 1968, which unfortunately was not a homogeneous data period. The National Severe Storms Forecast Center (NSSFC) in Kansas City, Missouri went into operation in 1953, and up until that time records of tornado events were not accurately kept. Many tornado events, especially those occurring primarily in rural areas, surely took place without being recorded. Since 1953 the NSSFC has encouraged the recording of all tornado events in *Storm Data*, a NOAA publication. The impact of this effort can be verified by checking the yearly tornado frequencies in the article by Agee, which after 1953, increased by some 400 per cent.

In this paper, the heterogeneity in the data has been eliminated since the statistics are only for Indiana tornadoes from 1950 to 1976. The "modern day" period of tornado data records was extended back to 1950 (and double checked through 1976 as well) through a nationwide research effort by NSSFC and the U.S. Nuclear Regulatory Commission. This has included a search though all records and archives, as well as local newspapers and state libraries to gather any useful information on storm damage. The goal of this paper has been to investigate and update many of the same statistical relationships as in the Agee article for the modern day period. For instance, the variation of monthly, yearly, and diurnal tornado frequencies will be investigated, as well as a county-by-county comparison of tornado occurrence. Even though such county-by-county statistics may seem significant (politically), they do not provide a reliable estimate of regional tornado frequency in the state because the counties are of unequal area. This problem was alleviated by dividing the state into equal area grids so that tornado statistics could be examined based on each individual grid.

## Data

A computer printout listing each recorded tornado event in Indiana from 1950 through 1976 was complied by the National Severe Storms Forecast Center and sent to the Purdue University Tornado Research Group. The statistics included were date, hour, location of the beginning point, location of the end point, fatalities, and injuries associated with each tornado event. Other information such as the FPP scales (when known) was also provided by this program, but it was not used in this statistical study. Also, waterspouts over Lake Michigan were not included in the tornado records.

## Results and discussion

A total of 553 tornadoes were recorded in the state during the 1950 to 1976 period, with 544 tornadoes originating in Indiana. Six tornadoes entered the state from Illinois, two from Kentucky, and 1 from Michigan. Of the 553 tornadoes that affected the state, 374 were only brief touchdowns with no discernible track length, with the remaining 179 tornadoes creating a damage track.

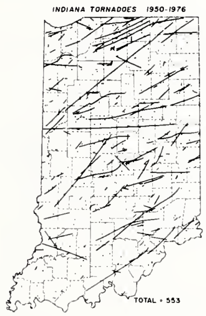


Figure 1. *Paths of the 553 tornadoes affecting Indiana from 1950 through 1976.*

In Fig. 1, the paths of all the tornadoes which affected Indiana during the 27 year period of records have been plotted, with the single dots representing the brief touchdowns. As can be seen, the state has experienced a great deal of tornado activity, with several tracks extending over more than 50 miles of Hoosier countryside. The longest tornado path ever recorded in Indiana was created by the Monticello tornado on April 3, 1974. It began in Benton County in northwestern Indiana and moved northwest over a distance of 121 miles before it finally dissipated over Lagrange county in the extreme northeast corner of the state.

Fig. 2 gives a county-by-county breakdown of tornado frequency from 1950 to 1976. Marion and Tippecanoe counties both experienced the greatest number of tornadoes with 18. St. Joseph, Elkhart, and Marshall counties were each affected by 17 tornadoes. Here, another problem with tornado recording comes into play. These counties are all highly populated, with the exception of Marshall. Obviously, population density has had a considerable impact on the reporting of tornadoes. Two counties, Floyd and Spencer were not affected by any tornadoes during the 1950 to 1976 period. Fig. 2 also indicates the numbers of tornadoes which originated within each county. The county which had the

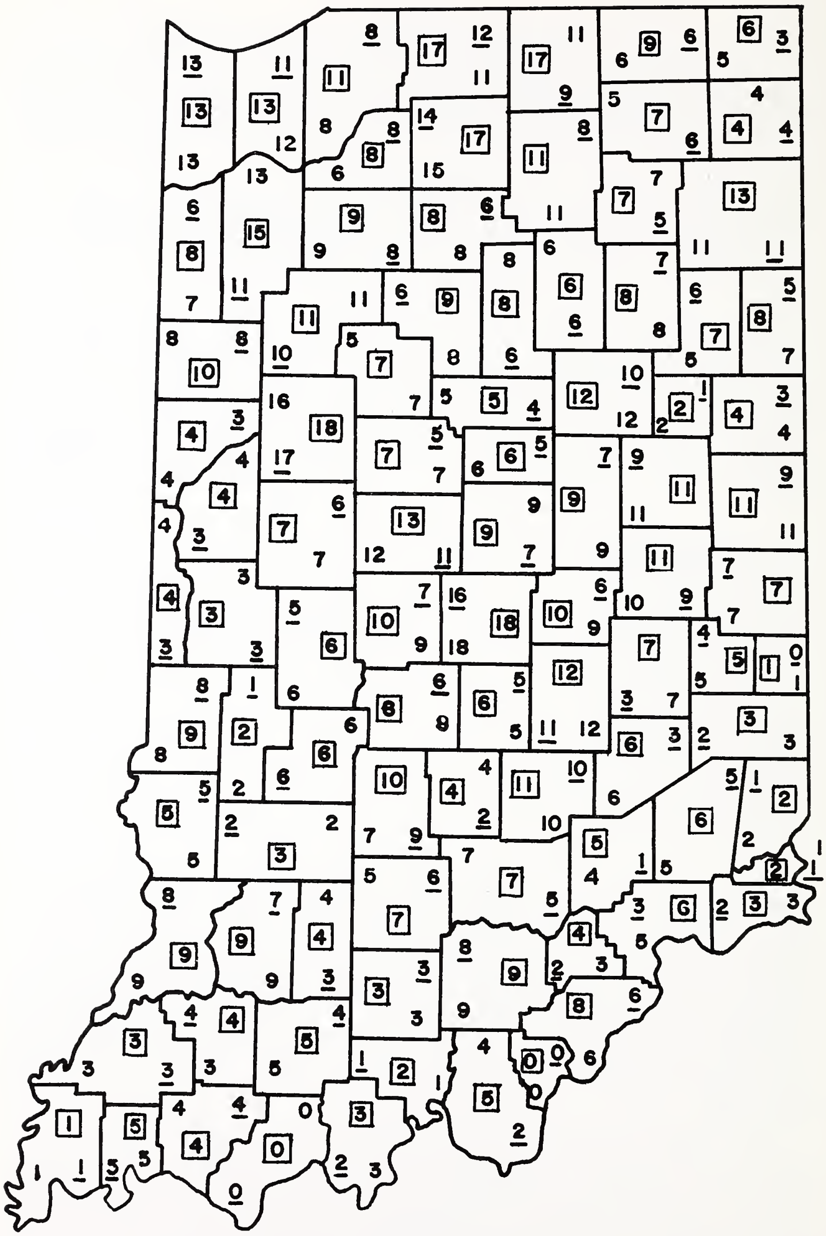

FIGURE 2. *Tornadoes affecting Indiana counties (framed), tornadoes originating in county (underlined), and the number of tornado days per county from 1950-1976.*

maximum number of tornadoes originating in it was Tippecanoe with 17. Sixteen tornadoes originated in Marion county, 14 in Marshall county, and 13 in Lake county. The number of tornado days per county is also shown in Fig. 2. Marion led all counties with 18 tornado days. Again it should be noted that counties do not represent equal geometric areas.

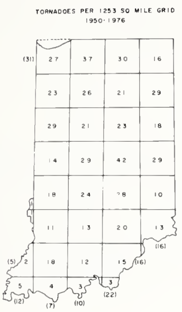


FIGURE 3. *Total number of tornadoes affecting each 1253 square mile grid (for 1950-1976). Numbers in parenthesis next to border-line grids are the number of tornadoes which would affect that grid if it would have the same area as the square grids (based on a proportion).*

Fig. 3 gives a more workable statistical model. Here, the state has been divided into equal grids, each representing an area of 1253 square miles. Along the Wabash and Ohio River boundaries in the southern part of the state it was impossible to arrive at these equal area grid divisions. The number within each grid indicates the number of tornadoes that affected that grid between 1950 and 1976. Along the borderline regions, the numbers in parenthesis give the number of tornadoes which one could consider to have occurred in that region if it had had the same area as the equal area grids. Fig. 3 also shows that the maximum number of tornadoes affecting any grid occurred in a grid near the central part of the state. The value here was 42. The minimum number of tornadoes in a grid was 5, the converted value in a borderline grid in the southwest corner of Indiana.


FIGURE 4. *Isopleths of total number of tornadoes per 1253 sq. mile grid (for 1950-1976).*

In Fig. 4, lines of constant number of tornadoes for the grids called isopleths, have been drawn. The solid isopleths are given in increments of 5 tornadoes. These isopleths of total number of tornadoes from 1950 to 1976 point out three major areas of maximum tornado activity. The first maximum area during this period was located in the central portion of the state, just northeast of the Indianapolis area; 42 was the maximum value here. The second maximum, with a value of 37 tornadoes, was located in the South Bend—Elkhart area in extreme north-central Indiana. Another maximum region was present near Lafayette, where 29 tornadoes were counted in a 1253 sq. mile grid. This isopleth map shows a well-defined minimum region for tornado activity located in extreme south-western Indiana, where a minimum of 7 tornadoes was identified. Other minimum areas occurred in extreme southeast Indiana (10), in east-central Indiana (18), and in the extreme northeastern part of the state (16). Generally, Fig. 4 shows that tornado activity dropped off substantially toward the southern part of the state, while the northern two-thirds of the state experienced a relatively high frequency of tornado activity, except for a slight drop in frequency in the Logansport-Peru area of north-central Indiana. The geographical variation in tornado activity in Indiana can probably be explained in part by the variation in the topography of the state. The northern half of the state consists of primarily flat farm-land with few trees, this is especially true in northwestern Indiana. By contrast, in the southern half of the state the land becomes increasingly more hilly with numerous forested areas present. The effect of the rougher terrain may be to disrupt the boundary layer flow so as to dissipate the weaker tornadoes.

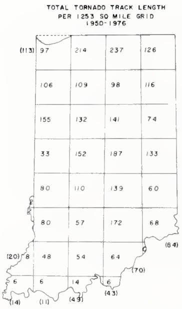


FIGURE 5. *Total tornado track length, in miles, within each 1253 sq. mile grid (for 1950-1976). Numbers in parentheses next to border-line grids are the total tornado track lengths which would be located in that grid if it would have the same area as the square grids (based on a proportion).*

While identifying the number of tornadoes affecting a certain grid may be an important statistical study, it probably is not as significant as studying the total length of tornado tracks within the grids. The number of tornadoes affecting an area is surely biased to some extent by the population of that area. However, this bias can be removed by looking at only tornado track length in a grid as is done in Fig. 5. The length of all the tornado tracks during the 1950 through 1976 period in each grid was totaled, with brief touchdowns given a length of one mile. Again total tornado track length in borderline grids was corrected to the value shown in parenthesis based on the proportion developed earlier. A total of 237 miles of tornado tracks affected the grid in the Elkhart area; this was the highest value for a grid in Indiana. The lowest value was recorded in the borderline grid along the Ohio River near Evansville where a corrected value of 11 miles of tornado tracks would have occurred if this grid could have expanded to an area of 1253 square miles.

An isopleth map of the total tornado track length within each grid for the 27 year period is shown in Fig. 6, with an increment between these isopleths of 20 miles of tornado track length. Three large maximum areas can be seen, with the

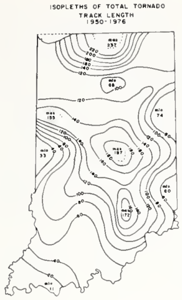


FIGURE 6. *Isopleths of total tornado track length, in miles per 1253 sq. mile grid (for 1950-1976).*

largest maximum, 237 miles of tornado tracks, in the grids in the South Bend—Elkhart region. Two other maximas occured, one in the Indianapolis area of 187 miles and another in the area between Indianapolis and Louisville of 172 miles. Another maximum of 155 miles was present northwest of Lafayette. Minimum areas occurred in southwestern Indiana, 11 miles; in the extreme southeast corner of the state, 60 miles; in extreme west central Indiana, 33 miles; and in extreme east central Indiana, 74 miles. This pattern is somewhat similar to that in Fig. 4, however the maximum in track length in the sparsely-populated region between Louisville and Indianapolis was not pointed out as a maximum region for number of tornadoes in Fig. 4. Again, topography may have played an important role in tornado track length distribution.

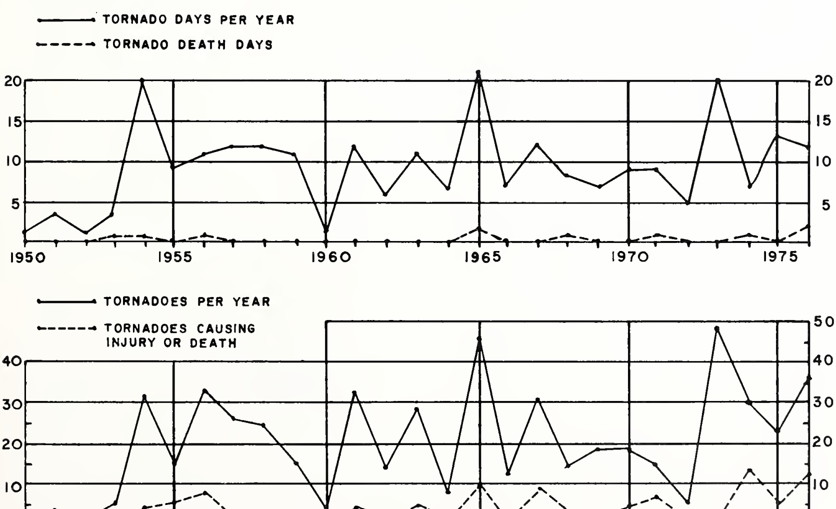


FIGURE 7. *Yearly distribution of tornadoes, tornadoes causing injury or death, tornado days, and tornado death days for Indiana (1950-1976).*

Fig. 7 shows the yearly distributions of tornadoes, tornado days, tornado death days, and tornadoes causing injury and death. This indicates that the reporting of tornadoes, and deaths and injuries due to tornadoes, increased tremendously after 1953 when the NSSFC was initiated and began keeping accurate records of tornado activity. Fig. 7 tends to show an increasing trend in the number of tornadoes per year during the 27 year period. In fact the first half of the period averaged 17 tornadoes per year while the second half averaged 25 per year. The trends in tornado days, tornado death days, and tornadoes causing injury or death have also increased in more recent years. The year 1965 had the greatest number of tornado days with 21; a total of 47 tornadoes occurred that year with 12 of these occurring on April 11 (Palm Sunday). 1973 was also a big tornado year with the largest number of tornado events for any year, 48, and a total of 20 tornado days. Surprisingly 1974, the year of the Jumbo Tornado Outbreak, did not have the largest frequency of tornadoes. Thirty were recorded that year and 21 of these occurred on April 3. The most tornadoes causing injury or death, however, did occur in 1974 with a total of 13 causing human casualties. Another important statistic was that of the 553 tornadoes affecting Indiana between 1950 and 1976, 110 ($\simeq$20%) caused injury and/or death.

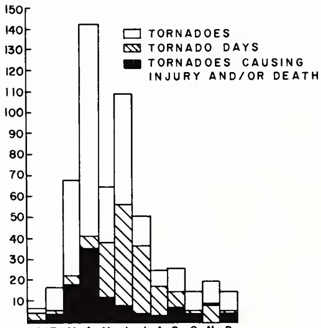


FIGURE 8. *Indiana tornado occurrences by month from 1950 through 1976.*

Fig. 8 shows the monthly distribution of Indiana tornadoes for the 1950 to 1976 period. This indicates that April was the leading month for tornado activity, however, this distribution of tornadoes was actually bimodal since another maximum showed up in June, even though it was not as high as for April. The period of March through July experienced 78% of the total tornadoes during the 27 year period of records. This is explained by the fact that during the spring and early summer months there is an increase in frontal activity, and a potentially strong temperature gradient between warm-moist air brought northward ahead of cold fronts and the remaining cold polar air masses and snow-covered ground north of these fronts. The frequency of tornado activity drops off in August as frontal activity decreases but increases slightly in September when frontal activity increases once more (but contrasts are not as great). January had the least number of tornadoes with only 7. The maximum number of tornado days occurred in June, due mainly to the fact that more days with thunderstorms occur in this month than any other. Unlike the situation in April, however, the thunderstorm (in the event that it is severe enough to produce tornadoes) will probably spawn only a single tornado. In April, the single severe thunderstorn can easily spawn a family of 3 to 6 individual tornadoes. April was the leading month of the occurrence of tornadoes causing injury and/or death. It should be noted that a higher proportion of tornadoes caused injury and/or death in early spring than in summer. For instance, 26% of the tornadoes in March caused casualties whereas only 7% caused casualties in June. This would indicate that the tornadoes in the spring are more severe. The late fall and early winter months also experienced a high proportion of tornadoes causing injury and/or death; i.e. October 28%, November 47%, and December 36%. This seems to indicate that people may not take tornado warnings seriously this time of year.

Table 1 gives the number of Indiana tornado deaths and tornado death days by month of the 27 year period. April was the month of greatest number of deaths, as would be expected with the two major outbreaks of the period occurring in that month. Of the 197 deaths due to tornadoes in Indiana from 1950 to 1976, 184 or 93% were due to either the Palm Sunday or April 3, 1974 tornado outbreaks. In the Palm Sunday outbreak 12 tornadoes killed 137 people while the 21 April 1974 tornadoes killed 47 people. This may indicate that in recent years people have become more aware and advised of tornado activity, and have been better prepared in the way of seeking shelter in the event a tornado warning is issued.

TABLE 1. *Indiana tornado deaths and tornado death days by month from 1950 through 1976.*

| | J | F | M | A | M | J | J | A | S | O | N | D | T |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tornado Death Days | 0 | 0 | 3 | 3 | 2 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 10 |
| Tornado Deaths | 0 | 0 | 5 | 186 | 2 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 197 |

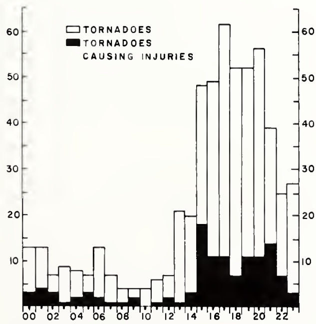


FIGURE 9. *Diurnal variation of Indiana tornado activity from 1950 through 1976.*

The diurnal variation of Indiana tornado activity is shown in Fig. 9. Tornadoes occurred most often around 5:00 p.m. local standard time (L.S.T.), with the period of 3:00 p.m. to 9:00 p.m. L.S.T. having produced 65% of all the tornadoes studied. It is during this time of day that convection can most readily occur due to daytime solar heating of the earth's surface. Of course, tornadoes could occur at any hour but the period from 8:00 a.m. to 10:00 a.m. L.S.T. was the least likely time for tornado activity to occur. Secondary maxima appeared at midnight to 1:00 a.m. L.S.T. and at 6:00 a.m. L.S.T. which might be associated with nocturnal thunderstorm activity which can occur in the

Midwest. Fig. 9 also shows the diurnal variation in tornadoes causing injuries. A maximum appeared at 1:00 p.m. L.S.T. and remained high through the afternoon and early evening hours in conjunction with the high frequency of tornadoes during these hours.

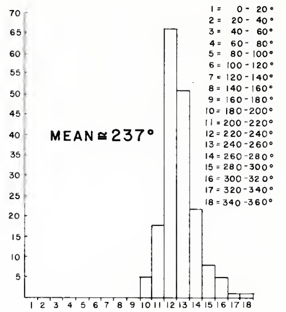


FIGURE 10. *Distribution of Indiana tornadoes by direction from which they came (1950-1976).*

In Fig. 10, the distribution of Indiana tornadoes by direction is portrayed. This is based only on those tornadoes with discernible tracks, while those consisting of only brief touchdowns were ignored. The directions, listed in 20° intervals, indicate the direction from which the tornado came. Standard meterological convention is used here with north indicated is 0°, east as 90°, south as 180°, and west as 270°. Fig. 10 shows that nearly all of the tornadoes had an eastward component in their direction of movement, while none showed a westward component in their direction of movement. The mean direction from which the Indiana tornado arrived during the 27 year period was 237°, out of the west southwest. Around 84% of the tornadoes during the period moved from southwest to northwest (categories 11 to 14). This is basically due to the fact that extratropical cyclones (low pressure systems) in the Midwest which create thunderstorms that spawn tornadoes generally move in a southwest to northeast direction.

A method of determining the probability of a tornado striking a geometrical point on the earth's surface was developed in 1963 by H.C.S. Thom of the Office of Climatology of the then U.S. Weather Bureau. The probability of a tornado striking a point in one year is simply the ratio of the total area covered by tornadoes in a year to the area over which the tornadoes may occur. The probability formula can be expressed as $P = \bar{t}/A$, where t is the average area covered by tornadoes in the grid in one year and A is the area of the grid. Since Indiana has been divided into equal area grids and the total track length within each grid has already been determined, the value for P will be easy to compute. An average width for Indiana tornadoes of 250 yards has been determined from the data provided by the NSSFC. This converts to .142 miles. Multiplying this value by the total track length in the grid gives the total area within the grid affected by tornadoes. This number is then divided by 27 years to get an average for the total area affected by tornadoes in a single year. Finally, this value is then divided by A, the total area of the grid (1253 square miles) to get the probability that a point in the grid will be affected by a tornado in a single year. The results of

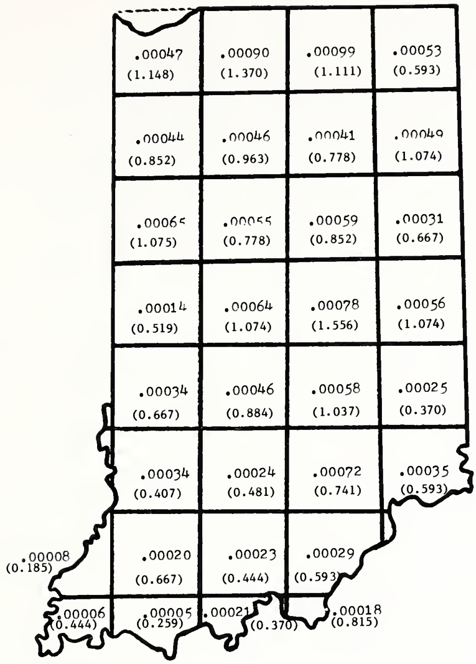


FIGURE 11. *The probability of a tornado striking a given point within each 1253 sq. mile grid in Indiana for any single year. Numbers in parenthesis are the average number of tornadoes affecting the grids per year.*

this study are shown in Fig. 11. The grid surrounding the Elkhart region has the highest probability with a value of 0.00099. A grid in the extreme southwest corner of the state has a probability value of 0.00005 which is the lowest for any grid in Indiana. The numbers in parenthesis below these probability values are the average number of tornadoes affecting each grid per year during the 27 year period.

Thom also has shown that the recurrence interval for a tornado striking a point (i.e. the predicted number of years between successive tornado touchdowns at a given point) can be given by $R = \frac{1}{p}$, where p is the probability value computed in the previous paragraph. Fig. 12 shows the recurrence interval (in years) for a given point on each grid based on the p values for that grid. A point in the Elkhart grid has a recurrence interval of 1,010 years, the lowest in the state. The highest recurrence interval value is 20,000 years, located in the grid in extreme southwestern Indiana near Evansville.

## Summary

Tracks of all tornadoes occurring in Indiana from 1950 to 1976 have been plotted. Also, the state has been divided into equal-area grids (1253 sq. miles) and the total number of tornadoes occurring within each grid and the total tornado track length within each grid have been computed. Isopleths based on these quantities have been drawn for the entire state. In addition, yearly, monthly and diurnal variations of tornado frequencies, injuries, and deaths for

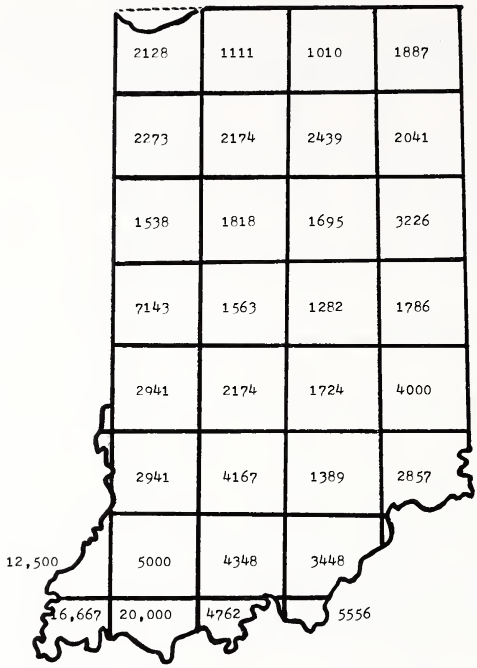


FIGURE 12. *The predicted number of years between successive tornado touchdowns at a given point within each 1253 sq. mile grid for Indiana.*

Indiana have been presented along with directional variation of tornadoes for the period of 1950 through 1976. Finally, a point probability of tornado occurrence, and a recurrence interval for tornadoes for each grid at an arbitrary point in the grid have been determined. All of these data are summarized in Figs. 1-12 and in Table 1. The importance of population bias and the importance of equal area studies of geographical tornado frequencies have been discussed. Also, the effect of topography on regional tornado distribution has been noted; however, more research will need to be done in this area before a definite correlation between topography and tornado frequency can be accurately presented.

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