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REPORT

0N THE

CHARACTER OF SIX HUNDRED TORNADOES.

PREPARED UNDER THE DIRECTION OF
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NOTE:

The publication of this monograph as a Professional Paper is merely for the purpose of bringing it to the attention of scientific men, and is not to be taken as an endorsement of the views or theories set forth.

INTRODUCTION.

The tabulated records of tornadoes, as given in the opening pages of this paper, were derived from the following sources of information, some of which were more successfully employed than others, owing to better opportunities for inquiry. From 1794 to 1874 the list of tornadoes is considered somewhat imperfect. In view of unavoidable difficulties encountered in conducting in extended search through old files and records, it is believed that several storms have been omitted from the above period.

It is expected to correct this imperfection, as far as possible, in a future publication of tornado records, when improved facilities for making a full investigation will he available. Notwithstanding the incompleteness of the first portion of the table, the records, taken as a whole, furnish quite a satisfactory basis upon which to formulate many of the deductions which follow. From a consideration of the tabulated record in the years 1874 to 1881, inclusive, it would seem that the relative geographical distribution of tornadoes, as shown on one of the charts accompanying this paper, would he materially affected by completing the record from 1794 to 1874. However, nothing has been disclosed in tornado investigation, up to the present time, that would permit of the least doubt as to the location of that portion of the United States most frequently visited by these storms.

In completing the record from 1794 to 1874, the eastern portion of the country would naturally have the advantage because of its earlier settlement, and, therefore, better opportunity to record the occurrence of violent local storms. However, upon investigation, it is believed that even this advantage, in point of time, will be found to operate in favor of the western country as the region of greatest frequency.

The list of tornadoes is arranged chronologically with respect to years only. Other points of comparison are set forth in the text under the head of deductions and also in the accompanying charts. The principal aim of the tabulated record is to show the prominence. of certain characteristics and their striking invariability.

SOURCES OF INFORMATION.

Monthly Meteorological Reports from Signal Service Stations.
Monthly Meteorological Reports from Voluntary Observers of the Signal Service.
Monthly Meteorological Registers of Army Post Surgeons.
Monthly Meteorological Registers Smithsonian Institution.
Smithsonian Contributions to Knowledge.
American Journal of Science.
Niles' American Register.
The American Almanac.
Special Correspondence.

GENERAL REMARKS.

Several of the most important characteristics of tornadoes have been neglected in the majority of investigations. We, however, possess some important information that ought not to be lost, for it will materially assist in distinguishing the leading features of tornadoes. Therefore, this concise record has been prepared that the knowledge already gained may be readily used for purposes of comparison. The failure to obtain evidence illustrative of some of the striking features of these storms is due, largely, to an imperfect knowledge of their peculiar nature. Greater care should be taken in conducting investigations, and approved methods should be carefully studied by meteorological observers. One difficulty has been, that really valuable facts were overlooked, because they are not always so apparent as facts that are interesting and wonderful to the general readers of journals and newspapers. It is true, nevertheless, that a knowledge of some of the concealed effects of a tornado is not only absolutely essential to a proper understanding of the storm, but is of greater importance than a knowledge of many of those effects which force themselves most strongly on the attention of the observer.

DEDUCTIONS FROM THE FOREGOING TABLES.

I. - No season or month of the year is exempt from the occurrence of tornadoes.

II. - June is the month in which they occur most frequently.

III. - Summer is the season of greatest frequency.

IV. - RELATIVE FREQUENCY - MONTHS.

Month	No. of storms	Month	No. of storms	Month	No. of storms	Month	No. of storms
June	101	July	82	March	37	October	15
April	96	September	49	November	22	December	9
July	97	August	42	February	19	January	7

V. - The relative frequency by seasons, beginning with the season having the largest number of storms, is as follows: summer, spring, fall, and winter.

VI. - The state (or territory) in which the greatest number of tornadoes occurred is Kansas.

VII. - RELATIVE FREQUENCY - STATES AND TERRITORIES.

States and Territories	No. of storms	States and Territories	No. of storms	States and Territories	No. of storms
Kansas	62	Pennsylvania	18	Massachusetts	9
Illinois	53	Texas	18	Dakota	9
Missouri	43	Tennessee	18	Virginia	9
New York	35	South Carolina	14	Arkansas	8
Georgia	33	Michigan	15	Maryland	8
Iowa	32	Alabama	14	Connecticut	5
Ohio	28	Nebraska	14	Kentucky	6
Indiana	25	Mississippi	14	Florida	5
Minnesota	22	Louisiana	10	New Hampshire	5
North Carolina	18	Wisconsin	10	New Jersey	6

States and Territories	No. of storms	States and Territories	No. of storms	States and Territories	No. of storms
Maine	3	California	1	Montana	1
Arizona	2	Indian Territory	1	Rhode Island	1
Vermont	2	Nevada	1	West Virginia	1
Colorado	1	New Mexico	1	Wyoming Territory	1

VIII. - Of those tornadoes where the time of their appearance was recorded, eight occurred between the hours of 1 and 2 p. m.; fifteen, between the hours of 2 and 3 p. m.; twenty-seven, between 3 and 4 p. m.; forty-six, between 4 and 5 p. m.; fifty-two, between 5 and 6 p. m.; twenty-five, between 6 and 7 p. m.; fourteen, between 7 and 8 p. m.; nine, between 8 and 9 p. m.: eight, between 9 and 10 p. m.; five, between 10 and 11 p. m.; three, between 11 p. m. and midnight; two, between 1 and 2 a. m.; three, between 2 and 3 a. m.; four, between 3 and 4 a. m.; one, between 4 and 5 a. m.; two, between 6 and 7 a. m.; three, between 7 and 8 a. m.; five, between 11 a. m. and noon; one, in the "early morning"; two, at noon; one hundred and ninety seven "sometime during the afternoon"; one, at "sundown"; twelve, in the "evening";' seven, "at night."

IX. - The hour during which the greatest number of tornadoes, occurred was from 5 to 6 p. m. The next hour was from 4 to 5 p. m.

X. - Tornadoes are most frequent in the afternoon - between noon and 6 o'clock.

XI. - Of the tornadoes the courses of which have been recorded, three hundred and four moved from southwest to northeast; thirty-five, from northwest to southeast; fifteen, from west-southwest to east-northeast; fifteen, from west to east; six, from south-southwest to north-northeast; five, from west-northwest to east-southeast; three, from north-northwest to south-southeast.

XII. - The width of the path of destruction, supposed to measure the distance between the areas of sensible winds on the north and south sides of the storm's centre, varied from forty to ten thousand feet, the average bring 1,085 feet.

XIII. - The velocity of progression of the storm cloud, as determined from the reports in one hundred and thirty cases varied from twelve to sixty miles, the average being 30.08 miles.

XIV. - The time consumed by the tornado cloud, in passing a given point, varied from ten seconds to thirty minutes, the average velocity, as determined from a mean of fifty cases, being 6.52 minutes. In every instance where the velocity is rated at thirty seconds or below, the estimate is very probably too low, and the movement too rapid; where it is rated at eight minutes or above, the estimate is too high, and the movement of the storm cloud too slow.

XV. - Of two hundred and thirty-four cases in which the form of the tornado cloud was reported, tow hundred and nine were designated as "funnel-shaped"; nine, "cone-shaped"; seven, "inverted funnel"; four, "inverted cone"; three, "hour-glass"; one, " basket-shaped" ;one, "two inverted cones point to point"; one, "a serpent-like column"; one, "like a balloon"; and one, "dense, rolling mass."

XVI. - The length of the tornado's track, as reported in one hundred cases, varied from two to two hundred and fifty miles, the average being, 28.35 miles.

XVII. - Of four hundred and seventy-three cases in which the atmospheric conditions preceding tornadoes were observed, four hundred and ten were reported as violent thunder-storms; and one hundred and forty-five as particularly sultry or oppressive.

XVIII. - Of five hundred and twenty-two cases in which the direction of destructive winds reported, one hundred and fifty-six came from the southwest; one hundred and forty-one, from the northwest; one hundred and sixteen, from the west; one hundred and three, from the north, eight, from the northeast; one, from the south; and one, from the southeast.

XIX. - The temperature following the passage of the tornado cloud was reported, in forty-eight cases, as "chilly"; in twenty-five, as "cold"; in four, is "painfully cold"; once, as "quite chilly" ;and once, as "falling suddenly."

XX. - In one hundred and forty-two cases the character of the formation of the central cloud was reported. In one hundred and thirty-seven, the conditions precedent were stated to be the sudden appearance above the western horizon of peculiar dark and portentous clouds, which, at a certain stage of development, rushed to a common centre from points between south to west and thence to north.

XXI. - Thunder and lightning, as connected with the development or progress of the tornado cloud, were reported in four hundred and twenty-five cases.

XXII. - In seventeen cases electricity in the tornado cloud was reported. The cloud appeared as if filled with balls of fire, or strangely luminous, the light in several instances being the color of red hot iron. In forty-nine cases, the absence of all indications of electricity in the tornado cloud was reported.

XXIII. - The motion of the tornado cloud, as controlled by the whirling air within the vortex, was designated in all descriptions as gyratory, combined at times with other movements, such as bounding along like a ball, rising and falling, or darting from one side to the other.

XXIV. - The velocity of the wind within the cloud vortex was variously estimated at from seventy to eight hundred miles an hour, the average being three hundred and ninety-two miles.

XXV. - The rotary movement of the whirling cloud was invariably from right to left or the opposite movement of the hands of a watch.

XXVI. - In forty-six cases, remarkable noise, in kind and intensity, was reported as accompanying the progress of the tornado cloud. It was described in various ways, as a "terrible, or deafening roar", "continual rumbling," "terrific crash", the "roar of a thousand trains of cars", the "din of innumerable pieces of machinery," etc.

XXVII. - Of two hundred and eighteen cases where the time of rain was recorded, one hundred and twenty-four reported precipitation is preceding the tornado; eighty-five, as following the tornado; and nine, as accompanying it.

XXVII. - Of one hundred and seventy-six cases where the time of hail was recorded, one hundred and nineteen reported the precipitation as proceeding the tornado; twenty-eight, as following it; and thirty, as accompanying it.

XXIX. - One hundred and thirty-five tornadoes were reported as unusually destructive, their distribution by states being follows:

Kansas 25	Michigan 5	North Carolina 2
Illinois 15	Mississippi 5	Tennessee 2
Iowa 12	South Carolina 5	Connecticut 1
Missouri.....12	Arkansas..... 4	Dakota 1
Ohio 7	Georgia 4	Maryland 1
Wisconsin 7	Minnesota 3	Texas 1
Nebraska 6	Pennsylvania 3	Virginia.....1
Alabama 5	Louisiana 2	

SUGGESTIONS FOR METHOD OF INVESTIGATION.

A set of carefully arranged instructions, covering every point bearing upon what are believed to be the invariable, accompaniments of this class of storms, is necessary for a complete investigation. As in some measure answering this demand, the following suggestions are made:

I. - The path of the storm should be carefully considered on its two sides and in its centre, the south side being termed the right, and the north side the left.

II. - In the examination of a tornado, wherever reference is made to areas of destruction, or where prostrations are described, the part of the path in which the destruction occurred, or in which the débris was found, should always, be mentioned.

III. - To avoid confusion, no terms should be used to indicate the sides of the tornado track except "right and left".

IV. - The direction of all prostated objects should be carefully given; if they have subsequently been moved by a force different from that which threw them down, or should the same force continue to act in successively different directions, such separate causes should be carefully distinguished.

V. - The track of the tornado should be examined continuously throughout, and not here and there. The examinations should be carried beyond the path of greatest violence; for although no trees or houses may have been there destroyed, valuable evidence to show the mode of action can often be obtained.

VI. - Groups of trees lying upon each other should receive careful attention, and distinction should be made between the top and bottom prostrations, and their several directions.

VII. - The topography of the ground over which the tornado has passed, and especially of that where destruction begins, should be observed. The comparative destruction on hilly and level ground should also be noted.

VIII. - The atmospheric conditions before and after the appearance of the tornado, especially the presence of a thunder-storm, its severity, extent, and the contrasts of temperature north and south of the central area, should be ascertained.

IX.-When prostrations are described on either side of the storm's track, or at the centre, their relative positions, either respecting, each other, the sides of the storm's path, or the centre, should be stated.

X. - The distance at which the surrounding currents of air are sensibly influenced by the cloud vortex ought to be determined, and it should also be noted whether or not any previously

existing currents were immediately, or during the passage of the tornado, changed in their direction.

XI. - The currents of air felt on the two sides, their relative directions and forces, must be carefully mentioned; also the currents at the centre, whether upward, downward, or rotary.

XII. - Any unusual manifestation of force on either side of the track, the width and direction of the path of destruction, the character of the ground passed over, and also of that in the immediate vicinity, and the direction, force, and temperature of air currents should be given.

XIII. - All explosions, the side on which they occurred, the direction and force of the wind at the time, and the character of the ground in their vicinity should be noted.

XIV. - The place, date, time, and direction of the tornado, are essential.

XV. - Observers should state the, width and length of the track, giving, in the former instance, not only the entire breadth of the path of destruction, but of that part over which the greatest violence was exerted.

XVI. - The velocity and duration of the storm, and the shortest time it consumes in passing one point, are important facts.

XVII. - The form of the vaporous cloud, its motion, direction, and velocity (estimating the latter approximately, if it cannot be reached accurately, by its action upon surrounding objects) should be given.

XVIII. - All winds which have been instrumental in directly causing destruction are important facts.

XIX. - The direction and force with which storm clouds were seen to approach before the beginning of the tornado, or any strange and violent agitation of the atmosphere noticed at that time, ought to be stated.

XX. - The appearance and disappearance of the cloud vortex, the character of the section of country over which it disappears, and the conditions of the surface at the points of its departure and return, ought to be noted.

XXI. - The occurrence of thunder and lightning, and all evidence of electrical action, particularly within the tornado cloud, should be given.

XXII. - Particular attention should be paid to the rumbling noise attending the progress of the tornado, its duration, intensity, and the distance at which it can be heard.

XXIII. - The precipitation of hail and rain, the time of its occurrence, whether before, after, or during, the passage of the tornado cloud, the side on which it fell, and the direction of the wind at the time, are necessary elements of the investigation.

XXIV. - Efforts should be made to gather all available data regarding cloud formation, so that, when opportunity is offered, any peculiar development may be preserved by means of a sketch made at the time the information was obtained.

XXV. - In all attempts at sketching a tornado cloud, particular attention should be paid to illustrating the peculiar whirl of the cloud, so that the shading shall show whether the direction was from right to left, or the reverse.

XXVI. - In all sketches, of whatever nature, the supposed centre of the storm's path should always be indicated by a long, arrow pointing in the direction of the storm's progressive movement, so that the relative position of the object acted upon, as compared with that of the tornado's track, may be known.

XXVII. - Every effort should be made to obtain temperature records, particularly where observations have been taken on opposite sides of the storm's path; the time of day and the accompanying wind direction are indispensable facts in connection with these observations.

XXVIII. - It is of great importance that trustworthy data concerning the prevailing direction of the wind over the section of country traveled by the storm (together with the temperature) for at least ten days before the storm, should be obtained.

XXIX. - In entering upon the work of investigation, it is necessary that the observer begin his labors as near as possible to the supposed origin or first appearance of the storm, and then tract, the phenomena in regular order. Such method will often provide the explanation of anomalous effects and materially assist him in following a train of sequences, watching the successive disclosures of the various features of cloud formation and attendant wind directions. Much or most of this valuable information would be lost, or seriously confused, by any other mode of examining the storm's track.

GEOGRAPHICAL DISTRIBUTION.

Two of the accompanying charts are prepared to show the geographical distribution of tornadoes over the United States, for the period eighty seven years now under consideration. They are as accurate as the character and extent of the data will permit. They may, however, be greatly improved, but this must be the result of more patient, cautious, and extensive observations, to be undertaken in the future. The lines of equal distribution are drawn for a common difference of five, and the figures at the ends of the lines indicate the relative frequency with which tornadoes occurred within the various areas bounded by these lines. For example: between the lines numbered five and fifteen the enclosed area has been visited by from five to fifteen tornadoes at different times and places throughout a period of from six to twenty-two years.

The position of the centres if greatest frequency, it will be seen, occupy peculiar regions, which are situated long distanced from each other.

That part of the great basin lying west of the Mississippi, and including the states of Iowa, Missouri, Kansas, and Nebraska. appears to be, the region in which tornadoes develop most favorably.

Attention has been called to the peculiar atmospheric conditions preceding the formation of the tornado, which show, as the result of extended observation, the fact that high contrasts of temperature invariably form to the north and south of the region traversed by the storm. There is reason to believe, *a priori*, that the large number of storms reported from this locality has some relation to the general physical features of the region. One of the necessary conditions precedent to the formation of a thermal belt of high contrasts is the existence of a wide range of country offering no obstacle, like mountain ranges or large bodies of water, to the free sweep of air currents either north or south. Now this condition is most completely realized in the vast extent of country (largely unbroken prairie) reaching from the Gulf (east of the Mississippi) northward to the British possessions. In connection with the development of every tornado (which almost invariably takes place in the southwest quadrant of an area of comparatively low-pressure) the wind previous to its inception has been found blowing from a

southerly quarter south of the central area of barometric minima, and from a northerly quarter of the central area, for a period of from five days to two weeks. These conditions prevail until the range of temperature on opposite sides of the central area of disturbance frequently attains fifty degrees. An illustrating this point, the accompanying map, marked "A", has been prepared. This map displays the conditions of temperature, barometer, and wind direction in connection with the violent tornadoes of June 12, 1881. For other information bearing directly upon this subject, the writer refers to this report of the tornadoes of May 29 and 30, 1879, published as Professional Paper No. IV, of the Signal Service.

There appear upon the charts of geographical distribution two other area of a marked degree of frequency, viz: New York and Georgia (Maps "B" and "C"). What applies to Kansas and the adjoining states, does not apply with equal force to these two states. The frequent passage of areas of barometric minima northeastward, just south of the lower lakes and thence across New York, affords opportunity for a long-continued movement of warm, southerly winds from the right side of the central area of disturbance, opposed to the northward or left side, by cold, northerly winds from Canada and the British possessions. The Wallingford tornado (Wallingford, Connecticut, August 6, 1878). although it did not occur within the state of New York, is, nevertheless, a case in point. The contrasts of temperature ranged from thirty to sixty degrees, and the change was very sudden.

Over Georgia, situated just beyond the extreme southern limit of the Appalachian system of mountains, opportunity is afforded for the formation or a thermal belt of high contrasts, as illustrated in the development of the great tornadoes of March 20, 1875. While an area of barometric minima is passing, northeastward along the western slope of the Appalachian mountains, the southwestern quadrant of the area will often reach to the Gulf.

It is during the recovery of the atmospheric equilibrium in this part of the general disturbance that opportunity occurs for the formation of a thermal belt of high contrasts, by the rapid descent of an area of barometric maxima from the northwest. The warm, moist, southerly, air currents from Gulf are now opposed by the cold, northerly winds of the high pressure area, and the effects which follow have already been too frequently stated in similar cases to call for repetition of this instance.

PECULIARITIES OF TORNADO CLOUDS AND SUGGESTIONS FOR AVOIDING THEIR VIOLENCE.

The approach of a tornado is announced from a distance by the appearance of a cloud that is usually two or three miles away when it is first seen. It consists of a very black, threatening mass, from the under side of which a projection descends to the earth's surface. Below this cloud is a small area of destructive winds. In severe cases a warning noise comes from the cloud, which is audible at a distance of several miles.

In the following paragraphs will be found some suggestions, which may be of service in aiding those who are in the vicinity of a tornado to escape the destructive force of the storm. These statements are founded on the supposition that the tornado cloud moves from some point west, say between southwest and northwest, to some point east, say between southeast and northeast:

I. - The track pursued by the tornado cloud has an imaginary centre, and the two halves are denominated the right side, or south of the centre, and the left side, or north of the centre.

II. - The tornado cloud invariably moves forward; that is, from a westerly point to an easterly one. The cloud may, and does very frequently, sway from one side to the other of its central line of movement, but at the same time there is a progressive easterly motion.

III. - A tornado cloud has four well-recognized motions; viz.: first, a motion directly forward at about a constant elevation; second, a darting from one side to the other of the central path; third, a violently whirling motion near the earth, and apparently upon a fixed pivot; fourth, a rising and falling motion.

IV. - The four motions of a tornado cloud may be divided into two classes, primary or certain and secondary or uncertain. The former comprises the first and second motions, and the latter the third and fourth motions. The first class is called certain because the attending circumstances of the peculiar movement are premonitory. The second class is called uncertain, because the peculiar movement is without significance as to resulting effects.

V.-The secondary or uncertain class of motions, generally preclude the primary or certain class, but they may alternate, without regularity. No damage need be apprehended from this class of motions by persons moving in front of or behind the tornado cloud.

V. - In the third motion (belonging to the secondary or uncertain class) the change to one of the other motions, generally the second, is made very suddenly and without warning. The cloud generally moves to the northeast, though sometimes, to the southeast. The following directions should be followed in the event of the change of motion indicated: When the observer's position is directly east of the cloud, or at any point south of east-northeast of the cloud and at some distance, he should move rapidly to the south. If his position is directly northeast or at any point north of east-north east of the cloud, he should move rapidly in a direct line to the north. If within a very short distance of the almost stationary cloud, the observer should run directly east at first, bearing slowly southward as he advances.

VII. - In the primary, or certain class of motions, the danger is particularly great if the observer's position is to the eastward of the cloud. In case the first motion is prevailing, the following course, should be taken: If a person is on the right or south side of the central line of cloud movement, he should move rapidly to the south; if on the left or north side, he should move to the northwest.

VIII. - When the second motion prevails, safety depends upon the oblique direction of the advancing cloud. A person's position being east of the cloud, if it sways to the right or south of the central line of movement, he should move directly north. If, on the contrary, the cloud sways to the left or north of the central line of cloud movement, he should move south.

IX. - A movement to the east or toward any point between east and north-northeast, should never be continued.

X. - A position west of an imaginary line drawn through the centre of the cloud is perfectly safe.

XI. - Generally speaking, the right or south side of the storm's path is by far the most dangerous, and should, if possible, be avoided.

XII. - Persons who find themselves east of an imaginary line drawn through the centre of the tornado cloud, should make every effort to move directly to the north or northwest.

XIII. - The least danger to life and property is on the left side, or north of the central line of movement.

XIV. - A position on the right, or south side of the central line of cloud movement, that is, twelve hundred feet or more front the imaginary centre of the storm's path, is safe from

destructive winds attending any movement of the tornado cloud. This distance is the maximum, the minimum being about seven hundred feet.

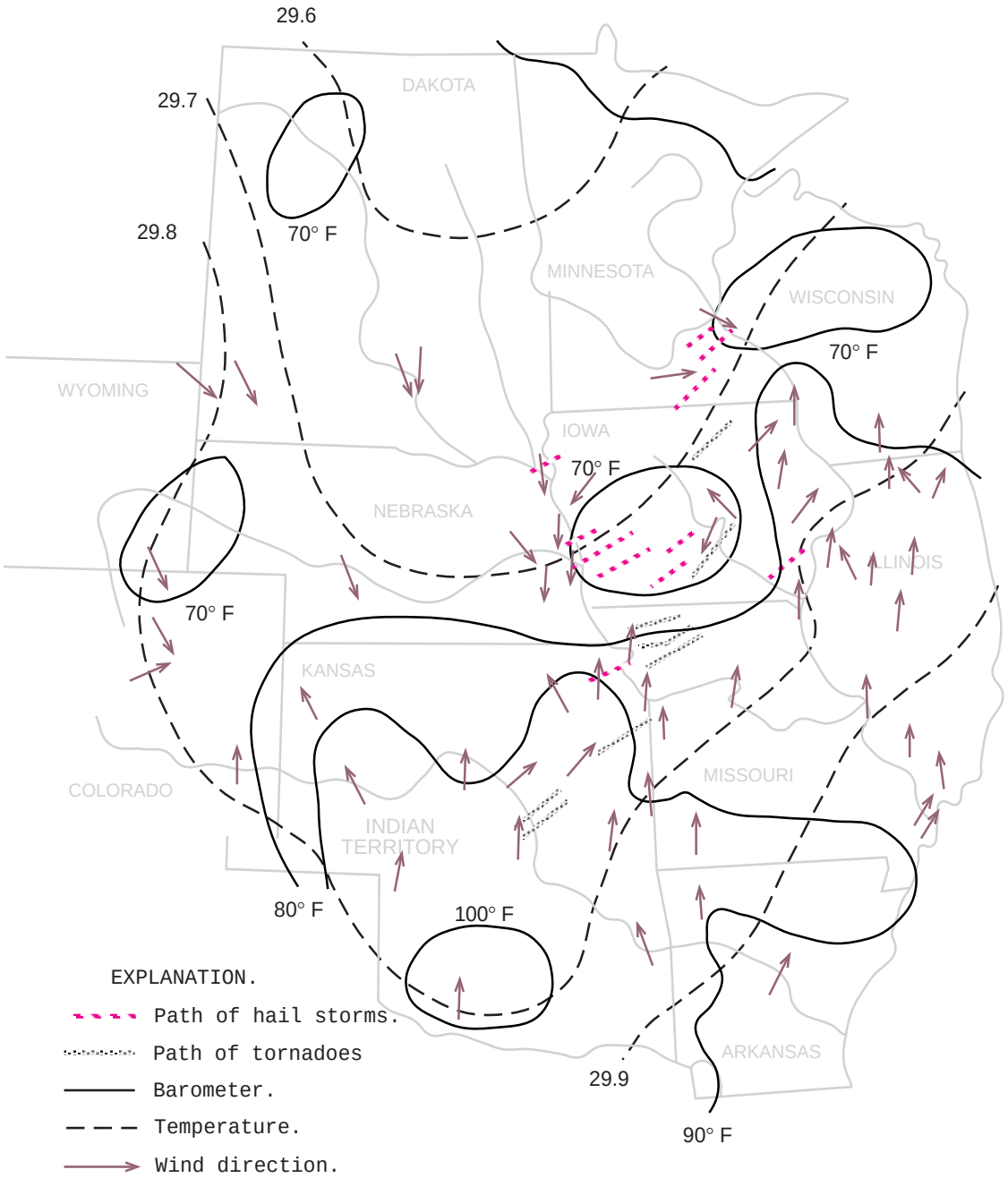
XV.- A position about six hundred feet distant from the imaginary centre of the storm's path is safe from destructive winds attending any movement of the tornado cloud. This distance is the maximum, the minimum being about three hundred feet.

XVI. - Very few wooden buildings, however constructed, except perhaps a square, low building with hip roof, will withstand the terrific whirl of the tornado cloud, or the powerful inrushing currents from the south side of the storm's centre.

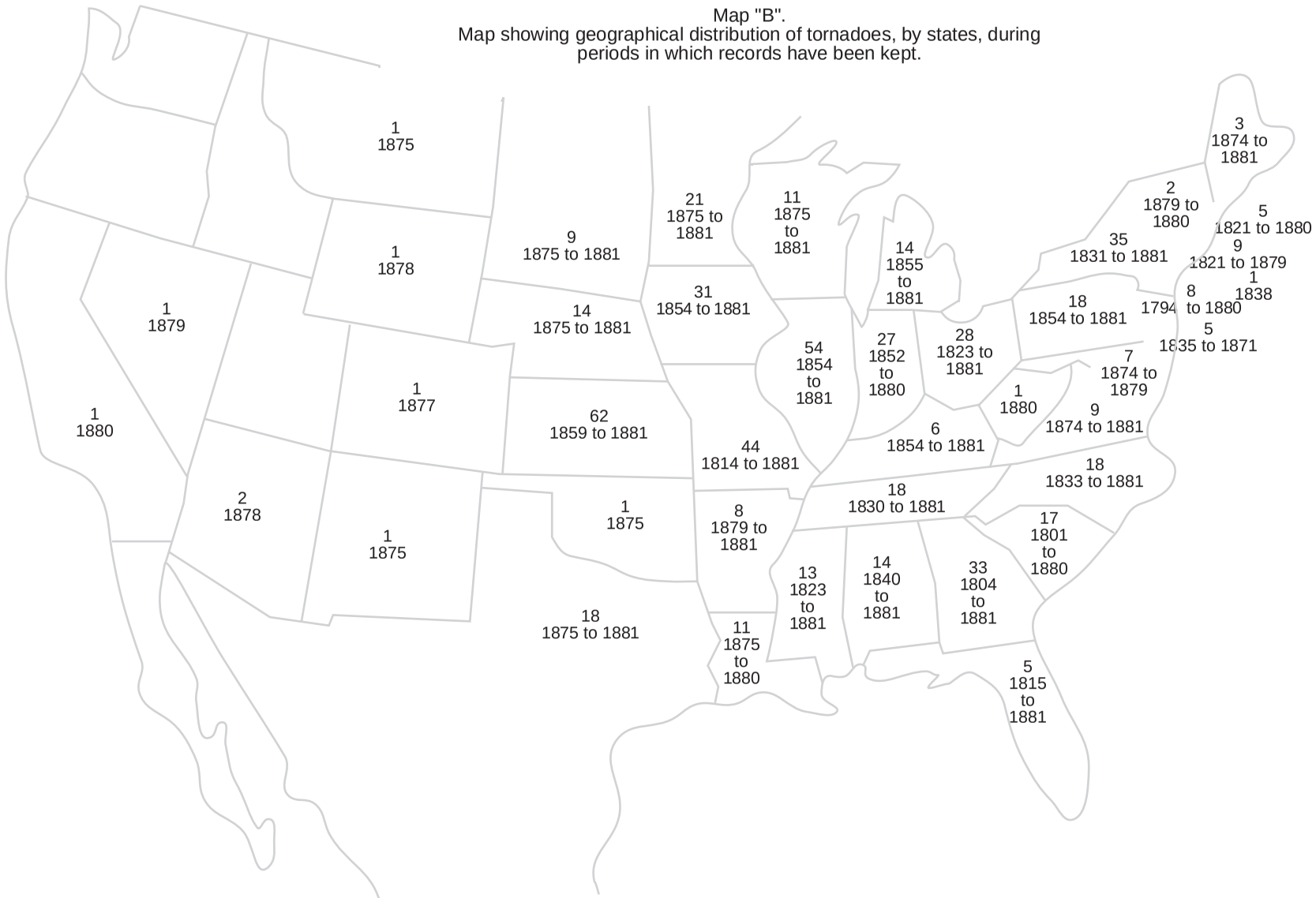
XVII. - Persons living in region frequented by tornadoes, should prepare underground dwellings, at convenient distances from their houses, which should be large enough to admit at least from ten to fifteen persons, and to hold valuable articles. In selecting a locality, all things considered, it would be best, if possible, to cut into a side hill or knoll, and to make the entrance of the retreat flush with the adjoining sides of the bank. In any event the underground dwelling should be so constructed as to present the least, possible obstruction to the free sweep of the wind during the passage of the storm. The natural contour of the earth, properly supported from beneath, forms the roof, and the ventilation should be, by means of one or more box pipes, about eight inches square, the upper ends of which should be level with the surface and covered with a network of iron rods. The entrance door should be made of heavy timbers, with strong bolts, and the openings in it should be as small as possible, and also protected by a network of iron rods. By reference to tables of relative distribution, on **page 23** [page 10 of the restored document]**,** it will be seen that tornadoes occur most frequently during the months of April, May, June, July, August, and September. This embraces the tornado season, "par excellence," for the entire country. South of parallel thirty-five, and east of the one hundredth meridian, tornadoes are reported in the late fall, winter, and early spring. Persons residing in this section of country will govern themselves accordingly, as to time of year in which to have the underground retreats ready for use.

Map "A".

Showing the Pressure, Temperature and Wind Direction, at about 3 p. m., June 12, 1891, over the territory visited by the violent tornadoes and hail storms of that date.



Map "B".
Map showing geographical distribution of tornadoes, by states, during periods in which records have been kept.



Map "C".
Map showing geographical distribution of tornadoes during a period of years, from 1794 to 1881, inclusive.