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LUTHER H. HODGES, Secretary
WEATHER BUREAU
F. W. REICHELDERFER, Chief

KEY TO METEOROLOGICAL RECORDS DOCUMENTATION NO. 3.131

HISTORY OF TORNADO OBSERVATIONS AND DATA SOURCES

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PURPOSE

The Key to Meteorological Records Documentation Series has been established to provide guidance information to research personnel making use of climatological data.

This publication, No. 3.131 of the Series, presents a résumé of data collected on the occurrences and characteristics of tornadoes. It discusses the criteria for their observation. The sources, reliability, and completeness of these data, and the method of collection are considered.

Frequently users of such data have found it necessary to spend considerable time establishing the validity of the data and in determining whether the criteria for observing the various elements have changed over the period of record. The presentation of this series may not only conserve valuable time but also may have a direct influence in improving the accuracy of research results.

M. Oliver Asp *
Meteorologist
Weather Records Processing Center
Kansas City, Missouri
August 30, 1962 (Revised March 8, 1963)

* Now Chief, Regional Substation Management Unit, U. S. Weather Bureau, Kansas City, Missouri.

CONTENTS

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CONTENTS

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HISTORY OF TORNADO OBSERVATIONS AND DATA SOURCES

CHAPTER I - INTRODUCTION

Tornadoes differ in character and in intensity. Although several hypotheses have been proposed for their formation, no generally accepted theory has yet been developed /1/. While tornadoes are associated with convective cells they may occur in a meso-low which gives them a life span over many miles, or they may occur as short-lived, numerous cells along a front /2/. They may dip to the ground briefly causing little or no damage, or they may devastate everything in the path killing hundreds of persons and causing property losses in the millions of dollars. Tornadoes often are associated with other severe storms--wind, hail, heavy rain, and hurricane.

Tornadoes as compared with other meteorological events are of infrequent occurrence. They usually have narrow paths and are of short duration. As a result the statistics collected on tornadoes are based on limited data, especially their meteorological characteristics such as rotary movement, reduced pressure, and cloud formation. Only a few tornadoes have occurred where instruments were available to measure perhaps one or two of the elements directly.

Only a few meteorologists or field investigators have actually observed a tornado.

The description or definition of the tornado in the current edition of Circular N follows /3/:

> Description. These storms occur when meteorological conditions are favorable for intense thunderstorm activity. The distinguishing feature is the funnel-shaped appendage that hangs from the base of the cloud. When the vortex is observed to reach the surface, the storm, if over land, is termed a tornado; if over water, is termed a waterspout. It is termed a funnel cloud whenever the vortex does not reach the surface, or the observer is not sure the vortex reaches the surface, i.e., the same storm may be variously described during its life cycle.
>
> In synoptic reports, the term "funnel cloud" includes tornadoes and waterspouts but not dust devils.

This description is the definition as used by observers at the present time in synoptic observations. Earlier editions of Circular N had the same definition of the tornado and the waterspout but did not mention funnel clouds /4/ /5/. Climatological observers also have the same definition but their instructions contain no mention of funnel clouds /6/.

Tornadoes are described in an early edition of Circular N /7/ in a single sentence: "They are recognized by their characteristic funnel-shaped cloud and the noise and destruction accompanying them". This edition of Circular N also stated that "tornadoes are not to be forecast but when reported as occurring on or near an airway this fact will be stated in the next regular or special forecast". Special observations on tornadoes when observed within 7 miles of the station were to be reported every 10 minutes.

The definition of the tornado has not varied greatly over the years. In 1906, Bulletin Q carried the following description /8/:

> A tornado is properly defined as a violent local storm, in connection with which is noted a well-defined, pendant funnel shaped cloud, with attendant rotary winds of sufficient violence to break off and uproot trees, prostrate dwellings or other objects in its immediate path. In the true tornado there is always unmistakable evidence of the action of violent rotary winds over a narrow path. In many cases there is also evidence tending to show that the barometric pressure in the central core of the funnel cloud is extremely low.

Henry, one of the principal scientists of the Weather Bureau during the early years of the organization as a civilian agency, summarized tornadoes for 1889-1896 in the 1895-1896 Report of the Chief of the Weather Bureau /9/. In this report he stated that the chief characteristics of a tornado are assumed to be (1) a pendant funnel cloud, and (2) violent rotary winds over a well-marked but narrow path. He stated that evidences of whirling found in the debris were accepted as indicating the character of the storm and that it was possible to determine the nature of the majority of the storms reported. In a few cases the evidence was not conclusive and the classification of these storms as tornadoes was rejected. This basis for the reporting of tornadoes has, as a rule, been continued without change to the present time.

The Glossary of Meteorological Terms as Part VIII of Weather Bureau Circular M /10/ in 1938 defined the tornado as follows:

> Tornado.-1. A violent vortex in the atmosphere, attended by a pendulous, more or less funnel-shaped cloud. 2. In West Africa, a violent thundersquall.

This Glossary simply defines a waterspout as "A tornadolike vortex and cloud occurring over a body of water", and does not include a definition for a funnel cloud.

A more complete Weather Glossary was published by the Weather Bureau in 1946 /11/. This Glossary describes a tornado as follows:

> tornado, n.- 1. A rotary storm, one of the most violent types of storms known, of small diameter, which travels across the country and leaves great devastation along a narrow path; known popularly as a "twister" in the Central United States where it most frequently occurs and also as a "cyclone". Its chief characteristics are: (a) Under a heavy cumulonimbus cloud there hangs a funnel-shaped cloud which marks the vortex and, as the storm moves along may or may not touch the earth. (b) Heavy precipitation and (usually) hail occur, with thunder. In addition to the thunder there is the roar attending the tornado cloud when it touches the surface. (c) The winds blow spirally upward around the axis of the tornado cloud; their speeds have never been directly measured, but have been calculated from their effects to be as high as, or in many instances higher than, 300 miles an hour. The updraft within the funnel cloud may have a speed of 100 or 200 miles an hour. (d) The speed of the storm itself in travelling over the earth is comparatively slow--25 to 40 miles an hour; its path is short, averaging about 300 miles. 2. Name given in West Africa to the squall which accompanies a thunderstorm.

The "300 miles" for the average length of the tornado path obviously is a misprint. The definition is interesting in that it states that the "funnel-shaped cloud which marks the vortex ... as the storm moves along, may or may not touch the earth". The Glossary also defines a funnel cloud stating that "its small end reaches down toward the earth". The definition of the waterspout recognizes two classes of these one class being "similar to a tornado in function and aspect".

The newest Glossary of Meteorology /12/ defines the tornado as "A violently rotating column of air, pendant from a cumulonimbus cloud, and nearly always observable as a "funnel cloud" or tuba". The Glossary then goes on to describe the principal characteristics of the tornado, and states that "A tornado over water is a waterspout". The funnel cloud is defined as "the popular name for tuba or tornado cloud", and the tuba is defined as:

> tuba-- (Commonly called "funnel cloud"; also called "pendant cloud", "tornado cloud".) In meteorology, a cloud column or inverted cloud cone, pendant from a cloud base. This supplementary feature occurs mostly with cumulus and cumulonimbus; when it reaches the earth's surface it constitutes the cloudy manifestation of an intense vortex, namely a tornado or waterspout.

One of the difficulties in definition of tornadoes has been whether or not to consider funnel clouds not touching the ground as tornadoes. They generally have not been considered as tornadoes although at times they have been included in the statistical data. At present they are not included and tabulations of tornadoes by years beginning in 1916 published in the Climatological Data, National Summary, annual issues for past several years have a footnote stating that funnel clouds that remained aloft or funnels touching water surfaces are not included. This problem was recognized at an early date. In 1890 Hazen /13/ stated that while it was recognized that a funnel shaped cloud that did not reach the earth could "be regarded only as a seeming tornado ... yet by some such a cloud is counted as a full-fledged tornado".

Although the definitions of the tornado have generally remained unchanged, other names for the tornado have been used by the public such as "twister", "cyclone", "hurricane", or "meteor". Some of these terms are still used by the public despite continued education describing the differences between the terms.

The Weather Bureau, in cooperation with other organizations, is currently obtaining information, especially on the meteorological aspects of severe local storms, including tornadoes, in its National Severe Storms Project. This project is discussed in following section A in Chapter II.

Statistical data on tornadoes have been collected by the Weather Bureau on a more or less systematic basis since 1916. These are discussed in some detail in Section B, giving the sources of information and bringing out items which would affect the criteria used in the collection of the data.

Although not on a regular basis, much information is available about tornadoes prior to 1916, especially during the period from about 1880 to 1900. These are reviewed in Section C.

Section D deals with data collected on tornadoes in the individual states. This gives information supplied by Weather Bureau State Climatologists as a result of a recent survey and supplemented by a review of summaries published in the Monthly Weather Review.

The reporting of meteorological conditions attending tornadoes has varied from year to year and is discussed in Section E.

Chapter III describes the method of collection of statistical data on tornadoes used by the climatologists of the Weather Bureau. Some of the shortcomings of this collection of data are discussed.

The reliability of data collected by the Weather Bureau is discussed in Chapter IV. Although the statistical data have value in that they describe what has happened with regard to tornado occurrences, there are limitations which are inherent in this type of data. These limitations are discussed in some detail since they have a direct influence on any research based on these data. The completeness of data collected, their homogeneity, and the relative reliability of the several items collected are reviewed.

Chapter V summarizes the meteorological records that have been documented on tornadoes and gives a few conclusions as a result of the study.

CHAPTER II - SOURCES OF DATA

Tornadoes are among the more spectacular of nature's phenomena. They often have caused considerable loss of life and much property damage. As a consequence, many articles have been published about these storms, and much information has been collected about them.

Most of the information about tornadoes at the present time deals with the basic data as to place, time, and extent of damage. Brooks /15/ cited Everdingen, a European investigator, in stating that the literature on tornadoes in the United States has, for the most part, been confined to compilation of such statistics as the distribution and frequency of occurrence and description of resulting damage. The need for data on the meteorological aspects of severe storms, including the tornado, is recognized by the Weather Bureau, and many data are now being collected by the Weather Bureau and cooperating agencies in the National Severe Storms Project.

Many articles that have been written about tornadoes are listed in special bibliographies on this subject published by the American Meteorological Society /16/ /17/. Other good sources of information about articles on tornadoes are included in the bibliographies in Weather Bureau Technical Paper No. 20 /18/ and Weather Bureau Technical Paper No. 30 /19/. Flora's Tornadoes of the United States /20/ also has considerable information of value.

A. The National Severe Storms Project.

The National Severe Storms Project /21/ was established in 1955 as part of the U. S. Weather Bureau's responsibility in furthering the science of meteorology. A series of tornado disasters in the early 1950's forcefully indicated a need for more basic information concerning severe convective phenomena. In this project the Weather Bureau, in collaboration with other governmental organizations, and educational institutions, is collecting information needed to accomplish the following research objectives.

1. To investigate the structure and evolution of those parameters of cyclonic-scale disturbances which are responsible for the outbreak of severe convection.

2. To examine and describe the detailed structures of meso- and convective-scale systems so as to understand the mechanisms underlying the growth, movement, and dissipation of squall lines and severe weather cells.

3. To study the distribution and intensity of severe convective by-products (tornadoes, hail, turbulence, lightning, icing, surface gusts) relative to the cloud mass.

4. To develop a qualitative and quantitative classification of convective storms by means of ground-based and air-borne radar.

5. To study the energy budget of severe convective storms.

6. To determine cloud modification methods which may apply to lessening the effects of severe convection.

In this project extensive data are being collected through use of aircraft reconnaissance, radar, special surface and upper-air observations, photography, and other methods. A great amount of data needed for a better understanding of the meteorological characteristics of severe local storms such as tornadoes will become available during the next several years as a result of this extensive research project.

B. Collection and Publication of Data on Tornadoes from 1916 to the present time.

Systematic collection and publication of data on tornadoes by the Weather Bureau has been continuous since 1916. Annual reports on these storms have been published

since that time, showing information as to place, date, time, loss of life and property, and other data. The annual publications in which these summaries appeared were:

1916 through 1934 Report of the Chief of the Weather Bureau.

1935 through 1949 United States Meteorological Yearbook.

1950 through 1961 Climatological Data, National Summary.

In addition to these annual publications, monthly tabulations of tornadoes and other severe storms were published in the Monthly Weather Review from June 1921 through 1949, in the monthly issues of the Climatological Data, National Summary from 1950 through 1958, and in the publication Storm Data beginning in 1959.

Accounts of many individual storms, especially if they are outstanding, were published in the Monthly Weather Review and in the Climatological Data for the State or Section in which the storms occurred. These accounts often supplied details about the special characteristics of tornadoes that did not appear in the monthly or annual summaries.

The data on tornadoes beginning in 1916 have been summarized a number of times /18/ /22/ /23/. The latest summary, Weather Bureau Technical Paper No. 20 - "Tornado Occurrences in the United States" was revised in 1960 and includes data through 1958. Weather Bureau Technical Paper No. 20 contains information on Tornadoes of Early Years, Tornado Characteristics, Tornado Statistics, Tornado Forecasting, Tornado Oddities, Observers' Impressions of Tornadoes, Waterspouts, and Tornadoes in Other Countries, in addition to tables summarizing the tornado occurrences - mostly from 1916 through 1958. Graphs and charts showing the number of tornadoes and tornado days throughout the year, and locations of tornadoes are also shown.

The Report of the Chief of the Weather Bureau included data on tornadoes each year beginning with the 1916-1917 issue. The information was presented in the form of a narrative summary of the tornadoes in each State annually through 1934. In addition to the summary a map showing the geographic location of the tornadoes for the year with arrows to indicate direction of movement was included for each year through 1930.

The data were furnished by Weather Bureau officials in charge of the Climatological Services of the several States, and consisted mostly of information as to places of occurrence, dates and times, direction of movement, length and width of storm paths, loss of life and injury, and property losses. The funnel cloud, rotary movement, dipping and lifting of the tornado, and other special characteristics were mentioned only occasionally. Funnel clouds that remained aloft were not included until 1932. Waterspouts were counted as tornadoes on several occasions - chiefly in 1919, 1924, and 1929. A waterspout in Florida in 1919 was described as being of unusual interest because of the pressure conditions attending its occurrence. The description indicates this storm developed as a waterspout and moved over land in a west-northwest direction for a distance of about 14 miles doing considerable damage. The storm developed in connection with a hurricane, the center of which was about 125 miles distant at the time of the tornado. A few other tornadoes associated with hurricane activity were described, but for one storm in 1917 it was stated that information was received that tornadoes were reported, but it was concluded "that in the absence of more details it seems possible these were merely extra violent wind gusts in connection with an approaching hurricane". Several storms were designated as "probably of tornadic character" especially in 1916. In later years, beginning in 1918, the tendency was to count these probable tornadic-like storms as windstorms rather than tornadoes.

In the reports beginning in 1921 reference is made to the "Severe Local Storm" reports in the Monthly Weather Review, and indicates the annual report in the Report of the Chief of the Weather Bureau contains the information from the monthly issues of the Monthly Weather Review, updated and revised to include any later information. It was pointed out that the annual report differed in some cases from the monthly reports in the Monthly Weather Review due to changes in the classification of the storms as tornadoes or straight winds.

In the Report of the Chief of the Weather Bureau a tabular form of presentation was used beginning in 1930. The tornadoes by States were listed in numbered chronological order with data as indicated by the following headings: State and date, hour, county, direction of advance, length of path (miles), width of path (yards), deaths, property losses, and remarks. By reference notes the number of injuries were indicated as, few (2 to 4), several (5 to 9), and 10 or more. The remarks were chiefly concerned with tornadoes in other States at about the same time, especially those crossing the State boundaries. Some remarks were significant in that doubt was cast on the classification with statements such as "Tornadic character somewhat doubtful". This may be explained by the following statement in the 1933 issue: "It will be noted that in several instances the tornadic character of a storm is given as somewhat doubtful, but in these cases the presence of marked rotary winds over a rather narrow area was taken as sufficient evidence to classify the storm as a tornado". In 1933 the remarks included such statements as "funnel cloud observed", or "5 funnel-shaped clouds observed". The "5 funnel clouds observed" was counted as a single tornado. In 1932 one tornado that may not have dipped to the ground was listed, while in 1933 several cases were listed where the funnel cloud did not reach the ground.

The 1933 table listed the number of persons injured under "Remarks" when a definite number, such as, 38 or 56, was reported. It was stated in the 1934 Report of the Chief of the Weather Bureau that, "Property losses that were reported as a result of tornadoes (crop losses included) were probably much less than the true losses, for it is seldom feasible to secure estimates for all parts of a long track, and often no trustworthy reports can be obtained".

The publication United States Meteorological Yearbook replaced the Report of the Chief of the Weather Bureau beginning in 1935. The tornadoes of each year were presented in the same type of table as in the previous years with one additional column added for showing the number of persons injured. Funnel clouds not reaching the ground were included; sometimes several funnel clouds were observed and listed as a single tornado. Attention was paid to paths of tornadoes "not continuous" and explanation was made that the length of such a path was not the length devastated but rather the entire distance from the first point of damage to the last.

The 1936 issue presented information in more detail. In addition to the table showing the tornadoes of the year there were tables summarizing the tornado destruction, deaths, and injuries by months for each State, and a table showing the summary of the total number of tornadoes, deaths, and injuries from 1916 through 1936. The narrative summary for 1936 was also more detailed than in previous years. An additional column was included to show estimated damage to crops. The remarks were more complete, mentioning such items as the observation of the funnel cloud, the peculiar roar, and waterspouts, as well as types of damage, and storms crossing State boundaries. Funnel clouds not reaching the ground, and waterspouts were included in the listing.

Beginning in 1950 the reports of tornadoes for each year were published in the annual issue of Climatological Data, National Summary. The tornado data are listed for each year by States in the same tabular form as in the 1943-1949 Yearbook. Another table "Tornado Summary" listed for each State with totals for all States, the number of tornadoes, number of tornado days, deaths, injuries, and damage for each month and for the year. Comparative data since 1916 were shown in a third table on tornadoes, number of tornado days, total loss of life, most deaths in a single tornado, total reported property losses, and the number of tornadoes causing losses of $100,000 and $1,000,000. A tornado rose showing percentages of occurrence for indicated directions was shown in the annual summaries from 1952 through 1960. Maps showing the tracks of tornadoes for the year, with arrows to indicate direction of movement for those with longer paths, were also shown.

Each annual Climatological Data, National Summary contained an article "General Summary of Tornadoes in the United States" for the year of issue. In each article the number of tornadoes that occurred during the year was mentioned with statements comparing these with previous years. A greater number of tornadoes was reported in the early 1950's than in previous years. In the 1953 summary it states: "It is impossible

to compare accurately this year's number of tornadoes with those of other years because

(a) the number of tornadoes reported depends largely on the number of observers reporting and

(b) in recent years more persons have been making these observations".

Funnel clouds that did not reach the ground, and waterspouts were included in the listings of tornadoes from 1950 through 1956. It was recognized in 1953 that estimates of damages were not comparable. The following statement appeared in the 1953 publication, "Estimated losses were based on values at time of occurrence. It is impractical to compare damages with those in previous years without corresponding adjustments for the change in price index".

Although the 1956 annual issue of the Climatological Data, National Summary used dollar estimates, monthly issues presented storm damage (for all types of storms) by categories with the following explanation for tornado damage:

> This is a new form of presentation of storm damage estimates. The Weather Bureau has for some time recognized the fact that without detailed expert appraisal of damage all figures published are merely approximations to fact. Since errors in dollars estimates vary in proportion to the total, storms are placed in categories varying from 1 to 9 as follows:
>
> 1 less than $50
> 2 $50 to $500
> 3 $500 to $5000
> 4 $5000 to $50000
> 5 $50000 to $500000
> 6 $500000 to $5000000
> 7 $5000000 to $50000000
> 8 $50000000 to $500000000
> 9 $500000000 to $5000000000

Beginning in 1957 classification of damage by these categories was used in the annual as well as the monthly publications.

In 1954, 1955, and 1956 dust devils were also included in the list. In 1957 and 1958 waterspouts were included with tornado data but dust devil data and funnel clouds aloft were listed in separate tables.

In the 1959, 1960, and 1961 Climatological Data, National Summary publications the detailed listings of tornadoes that occurred during the year were omitted. Reference was made to the listings in the new monthly publication Storm Data. These annual Climatological Data, National Summary publications continued a summary article and tables showing the number of tornadoes, tornado days, and deaths and injuries by months for each State. A table with comparative data, similar to that of previous years, was also published. This table carried the reference that the tabulation did not include funnel clouds that remained aloft or funnels on water surfaces only.

The publication Storm Data issued by the Weather Bureau each month beginning in 1959 contains information about tornadoes and other severe storms in "Storm Data and Unusual Weather Phenomena". This information is supplied directly by the Weather Bureau State Climatologists. The basic data for each storm (place, date, time, length, width, number of persons killed and injured, estimated damage to property and to crops by categories, and the character of the storm) are followed by rather detailed remarks as to type of damage, observation of the tornado cloud, and other information. The categories for classifying property damage are the same as used in the Climatological Data, National Summary. The following note is carried as a reference in Storm Data:

> NOTE: This publication contains our best information on storms, but due to the difficulties inherent in collection of this type of data, it is not all inclusive. Delayed data and corrections will be carried in the June and December issues of this publication.

C. Collection and Publication of Data on Tornadoes before 1916.

The subject of tornadoes is not new. Although more common in the United States, tornadoes were known in other parts of the world and described long before the discovery of America. Brooks /15/ mentions Seneca and Pliny the Elder of ancient times in Rome as having written about them.

Records of tornadoes in the United States go back to colonial times. Wolford /18/ states there are references to approximately 150 tornadoes which occurred in the United States from 1682 to 1874. Finley /24/ stated that in 88 of the years during the period that this record is very imperfect owing to the greater number of cases not reported. Finley also pointed out that an average of 146 tornadoes occurred annually considering the 10-year period from 1878 to 1887.

Captain William Clark of the Lewis and Clark Expedition in 1804 reported the "ravages of a dreddful harican" to timber in a narrow path southeastward across the Missouri River from Nebraska into Iowa /25/. These "timber falls" showing the narrow paths in an easterly direction characteristic of tornadoes were labeled as "hurricane tracks" on many of the early day land survey maps in the central United States /26/. In Wisconsin for example in 1890 there were recorded 425 tornadoes and "windfalls" which Finley /24/ did not use for "want of similar investigation of the subject of 'windfalls' in other States".

Shortly after the establishment of the National Weather Service in the United States in 1870 under the U. S. Signal Service there was a marked increase in the reporting and in the publication of data on tornadoes. No doubt accounts of tornadoes by homesteaders and early day settlers in the central United States led individuals in the U. S. Signal Corps to study and report on this phenomenon. Possibly the outstanding contributor to the collection and publication of data during this period was John P. Finley, an officer in the U. S. Signal Corps. His paper on "The Character of Six Hundred Tornadoes" /27/ in 1881 was the basis for many summaries concerning the climatological characteristics of tornadoes. In this publication, data on 600 tornadoes up to 1881 were presented in tabular form in chronological order beginning with 1794. Data tabulated included place, date, time of day, direction of storm's course, width and length, forward rate of movement, shortest time in passing a point, form of cloud (funnel shaped, cone shaped, inverted cone), direction of whirl (right to left or left to right), temperature preceding storm (sultry, very hot, oppressive, etc.), temperature following storm (chilly, cold, etc.), direction of destructive winds, time of rain in relation to tornado, time of hail in relation to tornado, character of formation of central cloud, electricity in cloud (heavy thunderstorm, none, lightning before, etc.), and remarks (very destructive, waterspout formed, roaring noise, buildings destroyed, property losses, fatalities, etc.). In addition to the tabulation, Finley summarized the information, listing the relative frequency by months, time of day, geographical distribution, and average and extremes in length of paths. Finley's work was not without criticism, however. Hinrichs /28/, head of the Iowa State Weather Service at that time, contended that many of the storms classified as tornadoes by Finley were actually straight-line gusty winds for which he proposed the term "derechoes" as the "straight gusty winds of the prairies" as contrasted to the rotary winds of the tornadoes.

Besides the paper by Finley on "The Character of Six Hundred Tornadoes" there were a number of compilations of data on tornadoes that appeared in the Professional Papers of the U. S. Signal Service in the 1880's /29/and in the Monthly Weather Review which was also published by the Signal Service at that time.

Tornadoes were reported by the Weather Bureau from the beginning of the organization. Accounts of tornadoes frequently appeared in the Monthly Weather Review and in other publications. A. J. Henry in the Report of the Chief of the Weather Bureau, 1895-1896 summarized the tornadoes recorded between 1889 and 1896 /9/. Other accounts of tornadoes appeared in the Climatological Data or Climate and Crops publications for each State or climatological section.

During the 20-year period from 1896 to 1916, the collection of data on tornadoes was fragmentary in nature and limited to accounts of some of the individual storms in the Monthly Weather Review or to the Climatological Data for the Section (one or more States) in which the tornado occurred.

D. Collection of Data on Tornadoes in the Individual States.

Summaries of climatological information on tornadoes for individual states have been prepared by Weather Bureau State Climatologists and others. Most of these summaries are based on the Weather Bureau basic data beginning in 1916, supplemented by other data especially for earlier years, from sources such as local newsclippings or other information. The data collected usually are presented in tabular form with information of the style and type given in the nation-wide annual reports in Climatological Data, National Summary, United States Meteorological Yearbook, or Report of the Chief of the Weather Bureau. In addition, a narrative summary is usually included, highlighting the outstanding tornadoes of record in the State and summarizing the tornadoes that have occurred. Maps showing the location of areas damaged by tornadoes, and tabular summarizations of data also are sometimes included.

Several of these summaries are published. Others are in locally duplicated form and are available for limited distribution. This information, as well as more detailed information about tornadoes in a given state, especially in areas of more frequent occurrence, may be obtained by contacting the Weather Bureau State Climatologist. Addresses of the Weather Bureau State Climatologists are to be found in the Climatological Data for the State or Section.

Several of these summaries for the individual states or sections are listed as items 30 through 48 in the Reference Section.

E. Reports of Meteorological Conditions Attending Tornadoes.

Information as to the meteorological characteristics of tornadoes has been presented in years past mostly in accounts of individual storms published in the Monthly Weather Review, Climatological Data, Bulletin of the American Meteorological Society, Weatherwise, and elsewhere. A few of these are listed below as examples of the types of the information presented in these articles.

Some of the articles such as published in the Monthly Weather Review, June 1957 /49/, and the Climatological Data, Oklahoma, April 1947 /50/ present meteorological information based on field surveys by Weather Bureau meteorologists. Other articles such as in Weatherwise, June 1951 /51/, and Monthly Weather Review, May 1930 /52/ have detailed information based on eyewitness accounts. Other articles give details as to the synoptic weather conditions prevailing at the time of the tornado /53/, or furnish information about pressure conditions associated with the tornado /54/.

Most of the data collected on tornadoes deal only with the basic information as to time and place, effects on life and property, area affected, and direction of movement. Other information that would help explain the dynamics of the tornado formation, on the "how" or "why" of the phenomena in addition to "where" and "when" is limited to occasional statements under "Remarks". During the past few years there has been an increase in the amount of information given under "Remarks". In Storm Data, for example, State Climatologists are not limited in including pertinent remarks of value.

From 1916 to about 1955, the data reported on such meteorological characteristics of tornadoes as the observation of the tornado cloud and evidences of rotary movement, in most cases, were much less complete than those collected years ago. The Smithsonian Institution /55/ almost a century ago asked observers who reported on tornadoes to answer many questions on such items as the shape, color, and velocity of the storm cloud, thunder and lightning, accompanying rain or hail, evidences of twisting action and explosive action, and the "whirl of the spout" (whether "with the sun" or not). Finley in 1884 /27/ published information, insofar as available, about such data as the shape of the tornado cloud, and thunderstorm and electrical activity before, during, and after the passage of the tornado. He also listed 29 suggestions to observers for the investigation of tornadoes mentioning such items as the appearance of the clouds, noise or roar of the tornado, temperatures before and after the passage of the tornado, and other phenomena.

Reynolds /56/ in 1950 stated that most reports collected on tornadoes are about their "vital statistics" rather than the "kinematics and dynamics of these storms". He then goes on in his thesis to outline items for consideration in the investigation of tornadoes. These items included -- A. Climatology of the tornado giving place, time, data about path. B. Rotary characteristics and the funnel cloud. C. Evidences of low pressure. D. Associated wind, weather, cloud, and electrical phenomena. E. Orographic effects, and other items.

CHAPTER III - METHOD OF COLLECTION OF DATA

The Weather Bureau State Climatologists and their predecessors (prior to 1954), the Weather Bureau Section Directors, have been responsible for the systematic collection of data on severe storms since 1916. These data have been furnished for publication on a regular monthly and annual basis. In addition, since 1959, Meteorologists in Charge of Weather Bureau Offices have been responsible for the reporting of severe storms that have occurred in their county area of responsibility.

Instructions in obtaining these data were that dependance be put only upon the most reliable and unbiased sources and to investigate and fully verify reports of unusual storms, such as tornadoes, before classifying them /18/. Weather Bureau Technical Paper No. 20 also states:

> The storms recorded here as tornadoes were so classified only if the characteristic funnel cloud was plainly seen, or subsequent examination of the destruction clearly indicated the characteristic whirling motion of the winds, the bursting effects on buildings, or the sucking up of objects into the air as the storm passed. It is realized, of course, that the judgment of field classifiers of such storms is not infallible especially in borderline cases.

The most satisfactory method for obtaining data on tornadoes is for a meteorologist from the Weather Bureau or other organization to visit the area affected as soon as possible after its occurrence to question those living in the area and to investigate the damage as thoroughly as possible.

The personal visit is the most desirable method to obtain data, especially when the investigator is checking and reporting on all features rather than only items of specific interest or study. The method is subject to several limitations. It has been impossible for Weather Bureau Officials to investigate every report of tornado damage, especially in the areas of more frequent occurrence. Weather Bureau offices are busy places concerned with observations, public service, forecasting, climatological work, and other responsibilities, especially during and shortly after tornado activity in the area. This leaves little time or opportunity for personal inspection and as a result visits are infrequent and usually limited to those storms causing major loss, ironically those storms already fairly well classified as tornadoes.

Weather Bureau Offices are instructed to report all occurrences of tornadoes. The Manual of Surface Observations, Circular N /3/ provides for the reporting of tornadoes in the surface synoptic observations and these reports of tornadoes, funnel clouds, and waterspouts are marked "URGENT" on long line teletypewriter circuits to give them priority handling. The instructions in Circular N also state "The cooperation of local newsgathering agencies, police departments, and other organizations having special communication facilities will be solicited in obtaining public reports of tornadoes".

Weather Bureau Offices have always been responsible for the reporting of tornadoes. Instructions /57/ in 1903 stated that when a tornado occurred in the vicinity of a station, the official in charge would make diligent effort to obtain an accurate description of all meteorological elements accompanying the tornado. The Instructions then listed the different items for which information was desirable. These items were:

a. The path of the tornado, with the location of buildings destroyed and the distribution of the debris on either side of the storm track. This should be shown by a map.

b. The name of the place and the date and hour of occurrence. If the tornado passed near a town, the distance and direction from, should be noted.

c. The appearance of the cloud; glow, and funnel-shape; the color of cloud; the meeting of clouds; lightning and whether seen to issue from the funnel cloud.

d. Character and amount of precipitation, including hail, size of hail.

e. Nature of attendant noises.

f. Direction of motion of storm.

g. Presence of a whirl, either as seen in the cloud, or as evidenced by the distribution of the debris.

h. General direction in which trees or debris lay in the center line of greatest destruction, and on either side of this line.

i. Length of path and width at point of greatest destruction.

j. Number and names of persons killed.

l. An estimate of the loss due to destruction of buildings, crops, orchards, timber, and other property, from the direct action of the wind; also, under separate heading, an estimate of the loss by hail, lightning, floods, and other causes, but not directly attributed to wind effect.

Circular N, Paragraph 3920, showing the mandatory remarks used for the reporting of tornadoes, is as follows /58/:

3920. Mandatory Remarks. (Col. 13) Enter data pertaining to weather and obstructions to vision as follows: Enter distances as well as direction from station when known and appropriate:

	Observed	Instructions for Entry
(1)	Tornado, Waterspout and Funnel Cloud (see ¶9131.5):	
	(a) Observed by station personnel (still in progress).	Enter time of beginning (or time it was first sighted)[3] and direction toward which it is moving, in subsequent observations, until it ends or disappears from view and until these data have been appropriately transmitted.[4] E.g., FUNNEL CLOUD W MOVG NE B34.
	(b) Observed by station personnel (has ended or disappeared).	Enter times of ending (disappearance from view), beginning and ending, or both,[3] peak speed of gusts in knots and direction of movement in subsequent observations until these data have been appropriately transmitted.[4] E.g., TORNADO G120 MOVD NE E1155E.
	(c) Reported by public.	Enter: (1) Source of report, e.g., STATE POLICE - when source or reliability of report is in doubt, enter UNCONFIRMED. (2) Location relative to a nationally known point, including nearby weather reporting stations (use nautical miles for distance other than visibility). (3) Direction toward which it is moving. (4) Time it was observed (LST) in hours and minutes, with time-zone indicator as a suffix, until it has been appropriately transmitted.[4] E.g., UNCONFIRMED TORNADO 15 W DCA MOVG N 1600E.

In the observations the words "Tornado", "Waterspout", or "Funnel Cloud" are always written out in full followed by direction from station.

The other method for climatologists to obtain data about tornadoes is to follow up on press and public reports on severe storms through use of questionnaires. These questionnaires (WB Form 614-2, formerly WB Form 4035) are sent by the State Climatologist to climatological observers, postmasters, county agents, sheriffs' offices, and others. Queries are also sent to local Weather Bureau Offices, the American Red Cross, governmental offices in the area, and names of persons mentioned in connection with the storm.

These data tend to emphasize the basic routine statistical information rather than information about the meteorological characteristics of the tornado. The questionnaire WB 614-2 (formerly 4035) used before 1957, for example, asked specific questions only on items such as to place or area, date, time, direction of movement, length and width, casualties, estimate of damage caused by different types of severe storms (tornado, other damaging wind, hail, etc.) followed by the statement "additional information on special phenomena such as unusual cloud formation, will be appreciated". Several of the Weather Bureau officials supplemented this questionnaire with additional questions. For example, in Oklahoma in the early 1950's there were questions about observation of the funnel cloud and other phenomena. In Kansas more specific data also were requested as to exactly where the storm occurred with request to show section, township, and

range. The WB Form 614-2 revised February 1957 contained places for more information: such as, was the funnel seen, how many funnels, aloft or reaching ground, unusual sounds, evidence of tornadic winds, peculiarities, nature of debris, unusual cloud formation, unusual lightning, excessive precipitation, etc.

Other questionnaires, WB Form 614-4 and 614-5, were also used for a time beginning in 1954 and 1955 and these contained very detailed questions. This type of form would be very useful as a guide for Weather Bureau or other special investigators. The shorter WB Forms 614-2, however, usually had a better return when mailed out as questionnaires.

The questionnaires, WB Form 4035 and the edition of the WB Form 614-2 before 1957, avoided the need for the recipient of the questionnaire to classify the type of storm. The only provisions for this were under remarks, or indirectly by indicating the amount of damage caused by each of the several types of storms. This presumably was done to leave the decision as to whether or not the storm was a tornado up to the Weather Bureau official collecting the data.

The classification of these severe storms, to a considerable extent, was based on scanty information since the questionnaires had no spaces other than under remarks to answer such items as: Was there a funnel cloud? Was there any distinctive sound? or What evidences were there of rotary movement? The questions had only two items -- the direction of movements and width of path -- that would provide clues as to the type of storm.

Summaries of the data collected by the Weather Bureau State Climatologists are furnished for each state to the National Weather Records Center, Asheville, for assembly and publication in Storm Data. Present instructions are to include all reliable tornado reports (including funnel clouds aloft) and waterspout reports. (These, of course, are properly labeled as "tornado", "funnel cloud", or "waterspout"). "Reliability" in these cases means that the State Climatologist tends to believe the report covered a probable occurrence /59/.

During the past several years a greater number of news stories about tornadoes has been made available to State Climatologists through use of press clipping services. This service began to be used in a few areas in 1951 and expanded to include all states east of the Rocky Mountains by 1954 /60/.

The Severe Local Storms Center (SELS) at Kansas City, in connection with their forecasting service for severe storms, keeps a tabulation or "log" of all accounts of severe storms reaching them. These are from press-wires, reports by Weather Bureau Offices received by telephone and those placed on the several teletypewriter circuits, as well as other sources. The Weather Records Processing Center in Kansas City, until its closing in January 1963, received a copy of this log and forwarded the information to the appropriate State Climatologists /61/.

CHAPTER IV - RELIABILITY OF DATA

Tornado statistics are difficult to handle. They are valid for most elements, but are subject to limitations in use. Their reliability depends on the data being considered.

Tornado data are not complete. All tornadoes are not observed, all those observed are not reported, and some tornadoes are not called tornadoes but are classified as windstorms. The current publication Storm Data recognizes this incompleteness by the following reference note:

> This publication contains our best information on storms but due to the difficulties inherent in the collection of this type of data it is not all inclusive.

This statement applies to data for the entire period from 1916 to the present time; in fact it is more applicable to data for earlier years than for the present time. The completeness of the data is considered further in a later section.

Data on the time of year, time of day, direction of movement, and number of persons killed are more reliable than the total number of occurrences and property losses. The narrow width of the path of these storms is well established but the length of the path often is subject to question. Information about characteristic features of the tornado is often lacking, especially for the period before 1950, since only occasional reference is made to such items as the observation of the funnel cloud, the "roar" of the tornado, evidence of rotary action in the scattering of the debris, pressure reduction shown by barometer reading, evidences of suction, and the explosive effects.

The number of tornado occurrences is oftentimes difficult to tally. When two or more pendant clouds are observed dangling from the same parent cloud, some investigators call this one tornado while others count them as two or more tornadoes. Some count only those pendant clouds when they touch the ground as separate tornadoes. At other times a tornado funnel cloud will form and dip to the ground, then go back up into the cloud. Later from what appears to be the same cloud a funnel will again form and dip to the ground. Then there is the question as to whether to consider this as one tornado forming, dissipating, and reforming or to consider this to be separate tornadoes.

This is an old problem. It was considered in the 1890's, and has recurred from time to time without any clear-cut solution. It is possible that radar observations can assist in standardization.

One solution to the problem is to count the number of tornado days rather than the number of tornadoes. This was proposed as early as in the 1890's by Moore /62/ and has been used by a number of investigators since that time. The number of tornado days as well as the number of tornadoes have been shown in the tables in the Climatological Data National Summary.

The time of day of tornado occurrence seems well established although there is some difficulty in handling these data because of differences in standard of time in use, daylight savings or war time, and whether to consider only the time of beginning of tornado activity rather than time of dissipation. Most data list the time of beginning of activity supplemented by the times different places are struck.

Data on the time of year tornadoes occur are well established. Close agreement as to time of year tornadoes occur in Oklahoma was found by two investigators working independently, one using data prior to 1952 /63/; the other using data between 1954 and 1960 /64/.

An example of close agreement in time of day and in month of occurrence is between the data published in Technical Paper No. 20 /18/ and those by Lee in 1957 /65/. Technical Paper No. 20 used data from 1916 through 1958; Lee used data from 1950 through 1955. The principal difference noted by Lee was in the total number of tornadoes. Between 1950 and 1956 there was an average of 458 reported tornadoes per year as compared with 149 per year for the 1916-1950 period.

The pattern from year to year of the wind rose is consistent in showing that most tornadoes move in a northeasterly direction. Paths of damage by tornadoes are almost invariably narrow; in fact many persons question the correct classification of the storm as a tornado or have doubt about the validity of the data when the width of the path is given in miles rather than in yards. Some of the more outstanding tornadoes, however, have been more than a mile wide.

The length of the tornado path is often questioned because of the difficulty in determining whether there is one tornado with a longer path or several--each with shorter paths. Then too, there is doubt about how to determine the length when the funnel cloud dips and lifts as it travels on its way. Usually most investigators show the length as the distance between the point of first damage and the last place where damage occurred.

The most reliable tornado statistics are the number of deaths reported. Linehan /19/ in Weather Bureau Technical Paper No. 30, "Tornado Deaths in the United States" points out that while the death of a person might be an incontrovertible and easily accountable statistic, the recording and summation of fatalities is subject to such errors as might occur because some victims linger for a long time before death while others are killed instantly. Other sources of error are overlapping partial reports, and incomplete data from remote areas. Linehan then goes on to comment as follows with regard to the reliability of the data:

> In spite of these and other potential causes of error, storm-by-storm death totals recorded in the annual tornado summaries published by the Weather Bureau seem to be remarkably complete and correct. The impression of correctness derives from repeated agreement between Weather Bureau totals and those reported by other apparently reliable sources, as revealed in the course of a thoroughgoing search for additional details of tornado-death occurrence. The completeness, at least of the roster of death-dealing tornadoes, is suggested by the pattern of annual tornado-death day totals during the 38-year period.... It will be observed that in spite of a progressive rise in number of tornadoes reported and in number of tornado days, there is no significant change in the number of tornado-death days. Thus, although many tornadoes have, in the past, obviously been unreported, and although the number of tornadoes reported has increased remarkably in recent years in response to concerted efforts to detect their occurrence, there has been no corresponding increase in the number of tornado-death days. It would appear, then, that throughout the 38-year period death-dealing tornadoes have always attracted sufficient attention to become a matter of record.

Data on injuries are much less reliable than are the statistics on deaths from tornadoes. Injuries range from those nearly fatal to those merely scratches. Many of the statistics on the number injured include only those requiring hospital attention; others include those with lesser injuries, or those requiring only first aid treatment. For a number of years in the early 1930's the annual tabulations of tornado data counted injuries as 1, few meaning 2 to 4, several meaning 5 to 9, and 10 or more. In many instances data on the number of injuries were not obtained.

Estimates of the amount of property damage by tornadic activity are often of little value. The Weather Bureau has for some time recognized the fact that without detailed expert appraisal of damage all figures published are merely approximations to fact. Accordingly the Weather Bureau in recent years generally has published storm damage estimates grouped in rather broad categories ranging from "1" for losses of less than $50 to "9" for damages between five hundred million dollars and five billion dollars.

The fact that data on damage estimates are approximations to fact was recognized by Hazen /13/ as early as 1890 when he pointed out the inherent difficulty in the canvass of tornadoes and stated that wild estimates of the damage done were sometimes made.

The amount of property subject to damage has increased tremendously over the years. Comparisons on estimates of losses due to tornadoes from one year to another are therefore impracticable. Besides the amount of property that can be damaged the values of the property also have changed. In 1953 the following statement was published in the annual Climatological Data: "Estimated losses are based on values at time of occurrence. It is impractical to compare damages with those in previous years without corresponding adjustments for the change in price index."

The difficulty of proper classification of the type of storm that causes proper damage also has an undetermined effect on data showing the property damages as the result of tornadoes. Insurance companies providing coverage for losses from local windstorms do not as a rule distinguish between damage caused by a tornado or by straight-line windstorms.

The damage losses published by the Weather Bureau in years past have tended to be conservative and therefore they have more likely been underestimates of the losses that have occurred rather than overestimates. They are incomplete estimates at best. In the Report of the Chief of the Weather Bureau in 1924 and for several years thereafter this was recognized in the following statement: "The property losses that were reported are probably considerably less than the true losses, for it is seldom feasible to secure estimates for all parts of a long track, and occasionally no estimate whatever can be had."

The damage estimates of losses due to tornadoes and windstorms published by the Weather Bureau in the Climatological Data, National Summary from 1950 through 1954 are low when compared with the total losses paid by insurance companies /67/. In most states the sum of losses by insurance companies on tornado, wind, cyclone, and hail property insurance, and the losses by extended coverage is generally greater than the total damage reported by the Weather Bureau. The data based on insurance losses also represents only an undetermined percentage of the total loss since much property is not insured.

Only a limited percentage of the tornadoes that occur are reported and appear in the Weather Bureau Records.

Severe local winds are difficult to classify. Some have been called tornadoes, others have been called "straight-winds", "thundersqualls", "plow winds", "derechoes", and "rip storms". In the data on tornadoes expressions such as "probable tornado", "tornado like winds", indicate doubt as to the classification of these storms. Insurance companies usually do not attempt to classify the type of winds that damage insured property--they pay for "wind damage" rather than damage by "tornadoes" or "thunderstorm squall winds". There are many storms in the severe local storm data that have been called either tornadoes or straight-line winds depending on the opinion of those reporting the storm and the Weather Bureau officials involved. These opinions have been based on scanty evidence in many cases.

Brooks /15/ points out that the number of tornadoes reported will depend upon the classification of the severe storms. In the Compendium of Meteorology he stated:

> A tabulation of tornadoes which occurred over a long period of years is needed to determine frequencies. Unfortunately many severe windstorms are difficult to classify correctly. The number of tornadoes is erroneously decreased by unreported tornadoes or by tornadoes classified as other storms, and it is erroneously increased by non-tornadic storms reported as tornadoes.

There has been a marked increase in the number of tornadoes reported since about 1950. This has been due to a number of factors. According to Reichelderfer /68/ these are (1) greater density of population to report tornadoes in areas which formerly were relatively unpopulated, (2) greater public awareness and observation of tornadoes through tornado forecasts disseminated over radio and television stations, (3) improved storm reporting networks and techniques, (4) more trained cooperative observers, and (5) the establishment of community warning networks.

A. Completeness of Data.

The number of tornadoes reported has generally increased from the beginning of the National Weather Service in 1870 up to the present time, except for a period of about 20 years from 1896 to 1916.

Many investigators have indicated that the increase in the number of tornadoes is due to more complete reporting of the phenomenon rather than an actual increase in number. Statements by several authorities follow.

Finley in 1888 /69/ stated:

> A comparison of earlier records with those of recent years might easily lead one to suppose that the occurrence of tornadoes was increasing, but the facts in the case will not permit such a conclusion. In recent years better means of observations and records, and greater facilities for the collection of reports have existed. With the rapid growth of the country more destruction to life and property has been occasioned, and a greater zeal of the press has brought to light many occurrences which under other circumstances would have been unobserved or disregarded. A careful study of tornado development and distribution shows that there are as many considerations to justify the belief that tornadoes were quite as frequent a hundred years ago as now and that this degree of frequency will not be diminished for a hundred years to come.

Moore, then Chief of the Weather Bureau, stated in 1896 /62/:

> I am satisfied that the number of these storms is not increasing, that the breaking of virgin soil, the planting or the cutting away of forests, the draining of land surface by tile, the stringing of thousands of miles of wire, or the laying of iron and steel rails, has not materially altered the climatic conditions or contributed to the intensity or frequency of tornadoes. To be sure, as towns become more numerous and population more dense, greater destruction will ensue from the same number of storms.

Henry /8/ in 1906 stated that:

> It is difficult to form a correct idea of tornadoes in the United States. The extremely local character of the phenomena on the one hand and the sparseness of population on the other make it almost impossible to obtain an accurate record of the number and distribution of tornadoes. There is also difficulty at times in distinguishing between the true tornado and straight-line squall winds, especially on the part of uninformed persons. Many so-called tornadoes are found upon investigation to have been simply severe thunderstorms with more or less violent squall winds.

Landsberg /70/ in 1947 in commenting about the number of tornadoes between 1916 and 1945 stated:

> It is likely that these figures are smaller than the actual number of tornado occurrences because a good many tornadoes in the less densely populated areas are not noted. Others, while observed, do not enter the official records because they did not produce any damage and were far from localities with meteorological observers.

Flora, who as Climatological Section Director for Kansas, was responsible for collection of tornado data for many years in that state, stated in 1928 /71/:

> "that beginning in 1914 special care has been taken to record important facts concerning each tornado that has occurred in Kansas" and ... that while some tornadoes in less populated western counties may not have been reported "Certainly none of consequence has escaped notice."

In the following year Flora's article on "Tornadoes in Kansas" /72/ contained the statement "Tornadoes are undoubtedly more numerous than most persons realize."

In 1953 Flora /20/ stated:

> In recent years more emphasis on the need of collecting reports, a closer network of reporting stations, and pilot reports have materially increased the number of storms tabulated, although there is no reason to think that tornadoes are becoming more frequent than formerly. The case of Kansas will illustrate the point. Prior to 1951 tornado reports in this state were chiefly obtained from Weather Bureau stations about 175 in number, and such newspaper accounts as happened to be available. The outstanding storms were reported, but it is known that many escaped tabulation. The average annual number for the 37-year period ending with 1950 was 18. In May 1951, just as the tornado season was opening, arrangements were made with a clipping bureau to furnish clippings concerning tornadoes from all the state newspapers. The surprising result was that 106 of these storms were listed--more than twice the number reported in any previous year. It is true that 1951 was a record breaking wet year and tornadoes are usually associated with wet spells, but the next wettest year, 1915, is credited with only ten of the storms.

Flora goes on to state that:

> The clinching proof that many tornadoes have not been reported or recorded is the fact that cities where fully staffed offices of the Weather Bureau have been maintained over a long period, are credited with many more tornadoes than are towns where no such detailed and permanent records have been kept.

There has been a remarkable increase in the number of tornadoes reported beginning about 1950. Weather Bureau Climatological Data National Summary publications have recognized this increase in frequency and have cautioned those using the data in comparison with those of earlier years. In the 1952 Annual Climatological Data National Summary, for example, the following statements are included in the general summary of tornadoes in the United States for the year 1952:

> However, caution must be observed in comparing 1952 tornado occurrences with those of past years. The number of tornado reports received is very largely dependent on the number of observers reporting such storms. In more recent years our tornado reporting network has become more dense than previously. Consequently, we would expect to have more tornadoes reported simply because there are a greater number of people alerted to make observations.

B. Homogeneity of Data.

Although all officials concerned have operated under uniform instructions from the Weather Bureau in Washington, the data collected on tornadoes have not always been homogeneous. Weather Bureau officials have had, and still have varying degrees of interest in this phenomenon, and there are differences in the amount of time, help, and facilities available to them for the collection of the data.

Considerable subjectivity is involved in the collection of data on tornadoes. The number reported, for example depends on the number observed, reported, and classified as such. Because of the differences in opinion on the classification "threshold" some State Climatologists tend to classify many severe windstorms of limited extent as straight winds while others will call them tornadoes.

In some areas, especially in earlier years, there was a tendency to report a tornado only when the funnel was observed. As a result a lesser percentage of the total number of tornadoes was reported as such when darkness or obscuring clouds and rain prevented observation of the tornado cloud. Joos /73/ also pointed out that tornadoes from the Mississippi River eastward often move from 40 to 65 miles per hour and these are often incorrectly classified because the length of time that a tornado could be observed is reduced so that there is lesser chance for it to be seen by a reliable observer. In fast moving storms, additional wind speed associated with the storm would concentrate wind damage on the right side of the path with little or no damage to the left with the result such damage would be confused with straight-wind damage.

There is a tendency for data on tornadoes to be weighted toward the centers of population. There is also a further tendency for the data to be biased in that more tornadoes are likely to be reported to the Weather Bureau from those areas near Weather Bureau Offices /72/. It is likely this bias toward the centers of population and Weather Bureau Offices has become less in recent years due to more widespread interest and improved communication facilities by press wires, radio, and television.

Because the data are not entirely homogeneous, comparison of data on tornadoes from place to place and from one period of time with another should be used with care. Some investigators have attempted to mitigate this inhomogeneity by dealing only with tornadoes considered to be outstanding ... with loss of life, extensive property damage, or unusually long paths. Spohn and Waite /37/ did this in their study in the hope better statistics would be furnished since such outstanding tornadoes could scarcely escape observation, reporting, or correct classification. They reported that even these criteria did not furnish an unbiased picture since fewest tornadoes with great property loss occurred during depression years when prices were low. They also pointed out that tornadoes causing death have diminished with time in relation to the total population, which most likely was due to improved forecasting, warnings, and communication facilities. Kraft and Conner /74/, in developing tornado forecasting criteria, considered major tornadoes (those causing 10 or more deaths in a day) to avoid dealing with those cases where there would be a possibility of using data where storms were not classified correctly.

There have been a number of tabulations comparing tornadoes or tornado days by States. Changnon and Stout /34/ point out that States are not the ideal geographic unit for a comparison since they are political entities of unequal size and shape. The basis of comparison by states is convenient since the data have been accumulated by states.

Various means have been used to remedy the inequities as a result of using state boundaries. Day in 1930 /75/ divided the country into 100 mile square areas counting the number of tornadoes in each square. Brown and Roberts in 1937 /76/ considered the areal frequency of tornadoes by counties. The Hydrometeorological Section of the Weather Bureau in 1945 /77/ published data including the monthly variation in tornado days and total number of tornado days per 10,000 square mile area per state or section for the period 1880-1942. Fawbush, Miller, and Starrett /78/ in 1951 prepared isoline maps based on the total number of tornadoes per 50 mile square reported for the period 1920-1949. Weather Bureau Technical Paper No. 20 /18/ shows maps of the United States showing tornadoes 1916-1955 with isolines based on total number by 2 degree squares, and tornadoes by 1 degree squares for the period 1953-1958. These maps were in addition to the charts showing the tracks of the tornadoes by months from 1916-1958. Charts with dots or tornado tracks to show location of tornadoes have been used by many investigators beginning in the 1880's.

CHAPTER V - SUMMARY AND CONCLUSIONS

There is much material available about tornadoes. The material is worthwhile in furnishing information as to what damage tornadoes have done, and where and when they have occurred. More data are needed as to the "how and why". Greatest paucity of data is in the meteorological characteristics of the tornado.

Statistical data on tornadoes are difficult to manage. Tornadoes are generally so limited in number and extent that only small samples are available for statistical treatment. There are varying degrees of reliability depending upon the items under consideration.

As a result of increased public interest in tornadoes following successful forecasting by SELS, Weather Bureau, and SWS, Air Weather Service, of conditions favorable for the development of tornadoes, there has been a marked increase in recent years in the number of reported tornadoes. Therefore the data collected in recent years are more complete. Comparisons from time to time and from place to place should be made with caution, keeping in mind the limitations in the collection of the data.

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