Historical Roots of Modern Tornado Forecasts and Warnings

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ABSTRACT

Although accounts of tornadoes occurred in ancient writings, few paid much attention to nature's most violent windstorm until the United States Army Signal Corps's John Park Finley began writing about tornadoes in the 1880s. Finley used statistics he had gathered from a network of tornado observers and a study of previous tornadoes that had occurred throughout the country to compile a list of rules for tornado prediction. The Signal Corps in 1884 allowed Finley to issue trial tornado forecasts, but the fear of public panic led the chief signal officer to ban the use of the word ''tornado.'' Finley and his supporters believed the statistics verified the effectiveness of tornado forecasting, but the corps, beset by internal conflicts, ended the experiment in 1886.

The Agriculture Department, which assumed jurisdiction for the civilian-controlled Weather Bureau in 1890, continued the ban on the use of the word tornado in forecasts until 1938. In spite of the loss of thousands of lives to tornadoes during this period, the Weather Bureau not only failed to encourage research on the subject but also failed to institute any type of forecasting or warning system. Residents in tornado-prone areas learned to rely on signs in nature and their own senses to warn of approaching severe weather. A systematic approach to tornado forecasting and warnings was as nonexistent in 1940 as it had been in 1870.

1. Before an established weather service

The tornado's power and fury have fascinated humanity for centuries. Many ancient writings, including the Bible, Aristotle's *Meteorologica,* and Pliny the Elder's *Naturalis Historia,* describe nature's most violent windstorm. Although tornadoes occurred occasionally in Europe, they were not sufficient in number to cause great concern or interest, but movement to the New World opened the field for exploration.

Massachusetts Governor John Winthrop (1972) described in his journal what may be the first recorded tornado in the American colonies. The 5 July 1643 entry notes that a sudden violent wind gust blew down trees and ''lifted up their meeting house at Newbury, the people being in it.'' Whether this was a tornado or a straight-line wind is unknown, but the Reverend Increase Mather (1977) in *An Essay for the Recording of Illustrious Providences* included an account of a July 1680 storm in Cambridge, Massachusetts, which in all probability was the first written record of an actual tornado in what is now the United States. Eyewitness Matthew Bridge declared that a thick black cloud in continuous circular motion produced a great noise in the process of tearing down trees and picking up bushes, trees, and large stones. John Robbins, a servant killed by the storm, may be the first recorded tornado victim. Tornadoes were not common in the American colonies, or at least few were recorded. Ludlum (1970) lists only 20 pre–Revolutionary War tornadoes in *Early American Tornadoes, 1586–1870.* Because of their rarity, tornadoes generated only limited interest among scientists during the colonial period.

Although Benjamin Franklin realized as early as 1743 that storms in the United States generally moved from west to east or southwest to northeast, the lack of rapid communications hindered warning regions in a storm's path. Not until a century later did the opening of the first commercial telegraph line on 1 April 1845 raise the possibility of forewarning communities of approaching severe storms and tornadoes. Joseph Henry, America's premier physicist and first director of the Smithsonian Institution, proposed in an 8 December 1847 letter to the regents that the institution ''organize a system of observation which shall extend as far as possible over the North American continent'' (Hughes 1970). In the *Smithsonian Report* of the same year he wrote that time was ''auspicious for commencing an enterprise . . . an extensive system of meteorological observations, particularly with reference to the phenomena of American storms.'' The following year Henry initiated a volunteer weather observation program. He used the $1000 budget allowance to purchase weather instruments, chiefly thermometers and barometers, and judiciously distributed them to observers throughout the country. By

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1852 the Smithsonian had more than 200 such volunteers. Henry, whose work in electromagnetism was the foundation for telegraphy, persuaded the telegraph companies to transmit at no cost weather reports from volunteer observers, military posts, and surveying parties throughout the nation to the Smithsonian in Washington, D.C., where he synthesized the reports into a daily weather map (Bruce 1987). Henry began displaying weather signals on the building's high tower and posting a large weather map for the public on a wall of the Smithsonian in 1850. The *Washington Evening Star* began issuing newspaper weather reports on 7 May 1857, but these reports were all after the fact (Hughes 1970). The Smithsonian made no attempt to forecast the weather.

By 1860 the Smithsonian volunteer network encompassed more than 500 reporting stations. A series of devastating spring and summer tornadoes that year prompted Henry to request information from eyewitnesses. In 1862 the Smithsonian distributed circulars to the public alerting them of tornado dangers and asking for continued reports and data on these storms in their area (Ludlum 1970). The public's response was so great that in 1872 the institution issued a four-page pamphlet listing the questions observers should attempt to answer when reporting a tornado, including the date, location, length and width of path, direction and speed of movement, color of sky, and shape of funnel.

In spite of the Smithsonian's admirable effort to collect storm data, no one used the information to produce weather forecasts. Cleveland Abbe, director of the Cincinnati Astronomical Observatory (1868–1871), suggested that if the observatory issued daily weather forecasts and storm warnings it could improve its stature in the scientific community. He called for the observatory to ''keep a record of regular hourly observations of all phenomena depending upon the atmosphere.'' Concerning weather forecasting, he concluded that ''although we cannot yet predict the weather for a week in advance, yet we are safe in saying that with a proper arrangement of outposts, we can generally predict three days in advance any extended storm and six hours in advance any violent hurricane.'' He proposed collecting daily telegraphic reports of weather conditions from a network of stations much as the Smithsonian had done and incorporating this data into a ''prediction'' that newspapers could disperse to the public. Using telegraph reports from only St. Louis and Leavenworth, Kansas, Abbe published the first forecast in the 2 September 1869 daily *Weather Bulletin*: ''Easterly and Southerly winds prevail. Barometer has begun to fall at Cincinnati and a storm passing over the southern country will not reach Cincinnati. Clouds and warm weather this evening. Tomorrow clear.'' With these few words weather forecasting in the United States began. Abbe continued his experiment for three months (Abbe 1955).

2. The Signal Corps and John Park Finley

In spite of Henry's and Abbe's efforts, loss of life and property on the Great Lakes soared. Increase A. Lapham of Milwaukee, a veteran Smithsonian weather observer and Abbe supporter, believed that a chief cause of loss of life was the lack of forewarning. Anxious to improve the situation, he sought the help of Congressman Halbert E. Paine, who introduced a bill in December 1869 that provided for the army to take meteorological readings at all its posts and to warn shipping interests of approaching storms. Some scientists, particularly Abbe, had hoped that a weather service would be in the hands of civilians rather than the army, but Paine argued that the military could provide the service at lower cost. On 9 February 1870 President Ulysses S. Grant signed a joint resolution authorizing and requiring the Secretary of War ''to provide for taking meteorological observations, at the military stations in the interior of the continent, and at other points in the States and Territories of the United States, and for giving notice, on the northern lakes and on the seacoast, by magnetic telegraph and marine signals, of the approach and force of storms.'' These few words gave birth to a national weather service that through its forecasts and warnings would touch the life of every American.

The responsibility for creating the new weather service lay with Brigadier General Albert J. Myer of the Army Signal Corps, who named the service the Division of Telegrams and Reports for the Benefit of Commerce.[1] Stations throughout the country sent three atmospheric condition reports daily to the telegraph room of its Washington, D.C., headquarters. Some metropolitan newspapers, including Washington's *Evening Star,* began inserting several reporting posts' morning observations on their front pages beginning 1 November 1870 (*Army Times* 1961). The initial 24 field stations telegraphed only the state of the weather (fair or cloudy), but as the number of stations increased to 284 by 1878, the reports expanded to include barometric pressure, temperature, humidity, wind velocity and direction, amount of cloud cover, and general weather conditions.

Although military personnel made the observations, weather predictions and storm warnings were in the hands of civilians the corps hired. Lapham, charged with the responsibility for the Great Lakes region, issued the first storm warnings on 8 November 1870, but he declined a permanent appointment because of ill health. To replace him in 1871 the corps hired T. B. Maury and

[1] The official United States weather organization has changed names and departments several times. From 1870 to 1890 the Division of Telegrams and Reports for the Benefit of Commerce under jurisdiction of the Army Signal Corps was in charge of weather services. In 1891 the weather agency came under civilian control. The United States Weather Bureau was part of the Department of Agriculture from 1891 to 1940. The Department of Commerce assumed control in 1940, and in 1970 the name became the National Weather Service.

Abbe, who handled all of the forecasting duties until mid-1872 when General Myer assigned five lieutenants to aid the civilians. Abbe, special assistant to the chief signal officer, began issuing forecasts entitled ''Weather Synopsis and Probabilities'' based on the 0735 local time (LT) observations of the weather stations in 1871. While the original resolution covered only the Great Lakes and Gulf and Atlantic coasts, a 10 June 1872 Congressional appropriations bill provided that the Signal Corps establish a ''system of observations and reports in charge of the Chief Signal Officer for such stations, reports and signals as may be found necessary for the benefit of agriculture and commercial interests'' (Grice 1998a). The weather service became national in scope.

The Signal Corps began issuing weather predictions for 24 h in advance in October 1872, and in 1874 forecasts included not only the type of weather but also the wind, barometric pressure, and temperature. Local Signal Corps offices distributed forecasts to thousands of rural post offices, which posted the notices on their buildings beginning in 1873. Signal flags replaced the bulletins in 1881, and by the end of 1886 they flew daily in 290 locations. Although these early predictions were frequently incorrect, they did give the average American some help in planning daily activities that the weather might affect (Grice 1991).

John Park Finley, destined to be the corps's tornado expert, enlisted in 1877. He completed army training in telegraphy, signaling, and meteorology at Fort Whipple, Virginia, in preparation for assisting in the office of the chief signal officer, but his orders sent him first to Philadelphia for three months. While there William Blasius's book *Storms, Their Nature, Classification, and Laws* (1875) caught his attention and motivated him to begin a systematic study of tornadoes (Grice 1998b).

In accordance with the Signal Corps's custom to send an observer to survey locales that had suffered great tornado damage, Finley visited areas throughout the central plains in May 1879. His report appearing in the *Report of the Chief Signal Office* for 1880 suggested that the corps establish a station manned by a special observer at Kansas City, Missouri, during the months of May, June, and July to warn of possible tornadic activity in the area (Galway 1984).

General Myer died in 1880, and his replacement, General William B. Hazen, established a research unit called the ''Study Room'' in 1881. Finley received permission to continue the work begun in Philadelphia on his collection of tornado reports spanning the years 1794 through 1881. The resulting report *Character of Six Hundred Tornadoes* (Finley 1884a) was the most comprehensive study of the climatology of tornadoes to that date and became the basis for his belief that he could develop a viable system of forecasting these storms based upon rules deduced from his data. When the corps assigned him the task of testing the feasibility of forecasting tornadoes, Finley moved his ''tornado studies'' headquarters to Kansas City in April 1882 and during that spring traveled extensively in Arkansas, Missouri, Kansas, Nebraska, Iowa, Illinois, and Michigan enlisting tornado spotters or ''tornado reporters'' for his network. The spotters collected and reported to the chief signal officer storm data that included instrumental observations, photographs, diagrams, illustrations, and charts (Finley 1886).

Finley knew in this period of interest in weather modification that it was impractical to try to destroy a tornado cloud or prevent its formation. Instead, he proposed forecasting conditions that might lead to a tornado's appearance. He realized that the successful forecast of an approaching twister would not prevent the destruction of buildings, crops, or machinery, ''but it will give opportunity for preparation to protect such destruction of life, and much personal property, the latter in the shape of valuables, that are readily moved from place to place.'' A corollary to the preservation of life was the alleviation of anxiety and excitement in tornado-prone areas of the country where factories and businesses often closed at the first sign of a black cloud on the horizon (Finley 1886). The same reasons for tornado forecasting, protection of life and alleviation of fear, motivated meteorologists more than 100 years later.

Finley did not arbitrarily decide a tornado would appear on a particular day. He had developed stringent rules based upon his personal observations in tornado country, statistical data gathered from the tornado observers, and historical records. In an 1884 article in *Science* (Finley 1884b) Finley reported the principle results of his studies, which were the first list of rules for tornado forecasting. According to Finley,

1) there is a definite portion of an area of low pressure within which the conditions for the development of tornadoes is most favorable, and this has been called the dangerous octant;
2) there is a definite relation between the position of tornado regions and the region of high contrasts in temperature, the former lying to the south and east;
3) there is a similar definite relation of position of tornado regions and the region of high contrasts in dewpoint, the former being, as before, to the south and east;
4) the position of tornado regions is to the south and east of the region of high contrasts of cool northerly and warm southerly winds—a rule that seems to follow from the preceding and is of use when observations of temperature and dewpoint are not accessible;
5) the relation of tornado regions to the movement of upper and lower clouds has been studied and good results are still hoped for;
6) the study of the relation of tornado regions to the form of barometric depressions seems to show that tornadoes are more frequent when the major axis of the barometric troughs trends north and south, or

northeast and southwest, than when it trends east and west.

In 1886 Finley restated these rules in the *Journal of the Franklin Institute* and added weather map features, which the forecaster must study to adequately predict the occurrence of a tornado.

Finley began issuing regular tornado predictions on an experimental basis on 10 March 1884. During March and April he posted an 8-h prediction based upon the 0700 LT weather map and a second based upon the 1500 LT one. In May, June, and July, he made only one daily prediction of 16-h duration based on the 0700 LT map. Finley divided the country between the 77d and 102d meridians into 18 districts, then subdivided each district into four equal parts. A prediction could cover an entire district or any part of one and had a dual nature—it advised whether conditions were favorable or unfavorable for tornado development (Finley 1884c).

Were these initial attempts to forecast tornadoes successful? Finley reported in the *American Meteorological Journal* in 1884 that he had attained a 95.61%–98.65% degree of success for the months March, April, and May. He explained that ''in no instance where it was predicted that conditions were favorable for the development of tornadoes did violent storms fail to occur, either hail, hurricanes, or tornadoes.'' Lead time for all of the destructive tornadoes was at least 5 h. No prediction was entirely successful unless the characteristic funnel-shaped cloud appeared, the tornado track was within the district for which the prediction had been made, and the storm occurred within the designated 8- or 16-h period (Finley 1884c).

G. K. Gilbert did not accept Finley's statistics. In his article ''Finley's Tornado Predictions'' Gilbert (1884) acknowledged that Finley's work showed ''encouraging progress,'' but he questioned Finley's method of counting nonoccurrences on equal footing with tornado occurrences. When Gilbert used only actual tornado occurrences to recalculate Finley's success quotient, the result was 23%.[2]

Finley supporters were not quiet on the subject. The 31 October 1885 *Scientific American* contained a letter confirming Finley's forecasting success. William A. Eddy, a tornado reporter in the Signal Corps, reported that 3201 of the 3228 forecasts for no tornado occurrences Finley made in 1884 were correct (Eddy 1885). Predictions for tornado formation were not as successful. Tornadoes occurred only 18 of the 38 times Finley issued forecasts for them in April through June 1884. Nineteen predictions for a tornado appearance resulted in 15 tornado occurrences in 1885. In every instance when Finley had predicted tornadoes a violent storm occurred. Eddy blamed the failure of some predictions on inadequate reports from sparsely settled regions. His report concluded with an appeal to Congress to finance a system of tornado flags or disks at every telegraph station throughout the Great Plains, the Midwest, Georgia, and South Carolina during the spring and summer months.

Because the work was experimental, these initial forecasts did not reach the public, but by 1885 Finley's perceived success and his belief that these predictions should appear in the official releases of the Signal Corps created a change in official policy. The chief signal officer agreed to include a special warning when violent storms were possible, but he forbade the use of the word ''tornado.'' Almost as abruptly as they had begun, tornado forecasts ceased. Accusations of the Signal Corps's misappropriation of funds and dissension within the ranks led to the Allison Commission's investigation of it. The Commission's final report issued in 1886 urged the placement of the weather service under the jurisdiction of the War Department and the closure of the training center and study room at Fort Myer (Whitnah 1965). Finley, who had testified unfavorably before the Allison Commission, lost favor with Hazen. The general ordered Finley's Tornado Studies Project moved to Washington, D.C., in 1885 and shortly thereafter reassigned him to the Meteorological Records Division where his job was to check the accuracy of weather data. Hazen died in 1887, and the new chief signal officer, General Adolphous W. Greely, closed the Study Room and relegated Finley to the records division where Finley no longer participated in weather forecasting. The demise of Finley's tornado forecasting plan appeared officially in the *Report of the Chief Signal Officer* for 1887, which stated that ''it is believed that the harm done by such a prediction would eventually be greater than that which results from the tornado itself.'' Although the corps's official view was that tornado forecasts would lead to public panic (a belief that lasted well into the twentieth century), Finley's tornado project was undoubtedly a casualty of the civilian–military feud over control of weather forecasting and research.

Although Finley was no longer officially a tornado forecaster, his book *Tornadoes: What They Are and How to Observe Them; with Practical Suggestions for the Protection of Life and Property* appeared in 1887 (Finley 1887). This composite of his previous publications included pictures, charts, maps, a list of 143 tornado characteristics, instructions for observing storms, and 23 tables. Among the tables were the total number of tornadoes observed from 1682 to 1886, the month of occurrence, and relative frequency by state, hour of occurrence, temperature before and after the tornado, direction of storm movement, and form of the tornado cloud. Of a more practical nature were the sections on ''premonitory signs,'' local observations that could indicate a tornado's development, and advice on seeking protection from tornadoes. Finley urged citizens in tornado-prone areas to become their own tornado fore-

[2] For a lengthy discussion of Finley's tornado verification statistics and responses to his methods see Murphy (1996).

casters by paying particular attention to the development of peculiar clouds on the western horizon on sultry, oppressive days from 1 April through the last of September and to have a tornado cave or dugout located where they could take shelter.

One Finley supporter was Edward S. Holden. After reading Finley's *Character of Six Hundred Tornadoes*, Holden (1883) devised a system for warning towns of approaching tornadoes. He believed that the Signal Corps had the capability to send out tornado ''warnings'' (actually forecasts) for a large region, perhaps an entire state, a day in advance, but because the area in question was so large, some type of local warning would be needed. Holden proposed to warn each household in a small town by a continuous ringing of a bell when a wind of destructive force (he proposed 70 miles per hour) was approaching. The five-minutes' lead time would give those in the storm's path adequate time to seek shelter and probably save their lives. To counteract the objection that a person might take shelter only to find that the storm was not a tornado but a strong gale, Holden wrote that because violent storms would not occur more than once a year, ''it would seem that one could afford to be frightened as frequently as this for the sake of immunity from an occasional tornado.''

Holden envisioned an arc of telegraph poles at a distance of 2–2.5 miles to the town's south, southwest, and west. A single wire connecting the poles would end at the telegraph office, and additional telegraph wires would connect houses within the town to the office. A battery at the office would send a constant current over the wire. A magnet at each house would hold a detent that would prevent a bell from ringing as long as the circuit remained unbroken. In the event of a strong wind or tornado the line connecting the poles outside of town would break and the bell would ring in each house. In addition, a ''simple device'' could fire a cannon to warn people in the fields and streets to take shelter. In a large town the circuit could end at the local fire station, which could then forward the warnings. Holden emphasized that in light of the great loss of life to tornadoes in 1883 (270 deaths occurred before the publication date of the article) communities should consider this cheap system of local warning.

The 1890 *Report of the Chief Signal Officer* contained a statement: ''Impressed with the number and violence of destructive tornadoes during the past year, it is believed that an investigation of phenomena of this kind on their numbers, area devastated, lives lost, and other such information might be of current interest. This work was intrusted to Professor H. A. Hazen, who has given much time and attention to these phenomena.'' Henry A. Hazen, a civilian employee of the corps, had served as weather forecaster and editor of *Monthly Weather Review* for a time before taking over the tornado project. For some unknown reason the report mentioned neither Finley's previous study on tornado prediction nor his statistical work.

More theoretical than Finley's volume, Hazen's book *The Tornado* (1890) summarized his views on tornadoes including their forecastability. He believed that, because the storms were ''exceedingly rare'' and very localized, the best predictions would have to cover thousands of square miles. Citizens of the forewarned districts should not be disturbed but should give adequate attention to the appearance of threatening clouds. Hazen addressed the question whether it would be better to omit tornado prediction entirely with the belief that ''if the right view be take of it, that it is a warning to look out, and not a positive statement, no one should be unduly disturbed.'' He hoped that in the future meteorologists would have a better understanding of conditions a few thousand feet above the ground, which would enable them to issue better predictions. Hazen believed it was impossible to issue pinpoint forecasts for destructive tornadoes such as the one that struck Louisville, Kentucky, in 1890. Rather, ''all that we can do is to predict a disturbed region.'' The Signal Office had issued predictions for severe local storms throughout the lower Ohio Valley region nearly 12 h in advance of the Louisville twister.

Finley's belief that meteorologists could predict tornadoes and Holden's idea that an alarm system could warn communities of approaching tornadoes disappeared for 60 years. Meanwhile, the responsibility for weather forecasting in the country shifted from the military to the civilian sector.

3. The civilian years (1890–1940)

Congress, dissatisfied with the Signal Corps's internal disharmony and lack of financial accountability, agreed with President Benjamin Harrison that the national weather service should be under civilian control. The president signed the act transferring the job of nation's weatherman from the Army Signal Corps to the Agriculture Department on 1 October 1890.

Mark W. Harrington, professor of astronomy and director of the observatory at the University of Michigan, took control of the new civilian United States Weather Bureau, but a lengthy feud between Harrington and Secretary of Agriculture J. Sterling Morton led to the appointment of Willis L. Moore, a severe critic of the Signal Corps's tornado reporters and their questionable methods of collecting data, as bureau chief in 1895. The new chief did not propose adoption of any new tornado counting methods but ordered Alfred J. Henry, chief of the Division of Records and Meteorological Data, to review the tornado reports from 1889 to 1896 and to adjust the statistics to reflect only death and destruction by actual tornadoes, not all windstorms. Moore believed that ''in almost all cases of great disaster there is a pronounced tendency to exaggerate the actual facts,'' and blamed journalists and tornado insurance companies for inflating statistics. Unquestionably, the United States had suffered great loss of life from tornadoes during the

eight years under consideration,[3] but Moore hoped to dispel the idea that the frequency or severity of tornadoes was increasing. Henry's report in the *Report of the Chief of the Weather Bureau 1895–1896* included the date, place, time, pathlength and width, direction of movement, casualties, and property losses for each tornado.

Three 1899 *Monthly Weather Review* articles by editor Abbe reflected the state of tornado study during the period. In April Abbe asserted that the number of tornadoes was not increasing; instead, the proliferation of telegraph lines and daily newspapers had brought the storms to the public's attention (Abbe 1899a). A second article in the same volume addressed the lack of a warning system. A *Chicago Tribune* article questioned whether the Weather Bureau could have warned Newtown, Missouri, of an approaching tornado that killed 12 on 27 April 1899. The *Tribune* realized that the bureau could not have warned Kirksville, Missouri, because the tornado formed immediately outside town, but the newspaper asked ''is it not possible, in these days of telephone and telegraphs, to send a warning to others in its course?'' In reply Abbe gave four reasons for not issuing warnings: 1) lack of knowledge of which way the tornado would move might precipitate warning the wrong town; 2) tornadoes dissipate at will; 3) telephone operators, concerned for their own safety, would fail to forward the message to the next town; and, 4) three-fourths of the tornadoes would slip unobserved between far-flung telegraph and telephone stations. Abbe explained that, to be of any use, stations would have to be within a mile of each other to catch every tornado and determine its path. He did urge that large cities with adequate telephone lines, such as St. Louis, Chicago, New York, Boston, Philadelphia, Detroit, Buffalo, Baltimore, Washington, and New Orleans, begin a serious effort to establish such a warning system. He concluded that the chance of being injured by a tornado was so slight, only about once in every 10 000 years, that the Weather Bureau had ''no right to issue numerous erroneous alarms. The stoppage of business and the unnecessary fright would in its summation during a year be worse than the storms themselves.'' In addition, because ''the certainty of destruction is absolute when the tornado comes, then it follows inevitably that there is no material advantage to be derived from any, even the most perfect, system of forewarnings and attempts at protection'' (Abbe 1899b).

The third article addressed the concern of J. I. Widmeyer, Oklahoma section director, who wrote on 12 May that long-range forecasters, through their tornado predictions, were causing unnecessary alarm among Oklahomans. Although no tornadoes had occurred in the state that year[4] and the Weather Bureau had not issued a single severe local storm forecast, Oklahoma residents were fleeing to caves and cellars whenever rain clouds or thunderstorms appeared. Widmeyer believed that exposure to the shelters' dampness resulted in more deaths than all the tornadoes that had ever occurred had caused and that the constant fear of the storms induced nervous troubles. Abbe agreed that the Weather Bureau should do everything possible to allay the population's fears. He blamed sensational writers of earlier decades who painted distorted pictures of the country's severe weather for alarming the public and for labeling Kansas, Iowa, and surrounding areas ''tornado states.'' Newspapers and residents of the plains acknowledged that they had occasional twisters, cyclones, whirlers, hailstorms, or hurricanes, but never tornadoes. Abbe concluded with a statement that tornadoes really caused no more destruction than lightning, high winds, hailstorms, droughts, or floods did, so citizens should not stop their daily routine and flee for shelter until they saw the funnel cloud approaching (Abbe 1899c).

Former Weather Bureau Chief Harrington calculated the odds of seeing a tornado or being injured by one. Harrington (1909) wrote in *About the Weather* that tornadoes were quite uncommon, numbering only about 50 per year. The prospect of a reader in the tornado area (the Mississippi Valley east of the Great Plains) seeing a tornado in any one year was 1 in 625 000, and the chance of being injured by a tornado during a 100-year lifetime was only 1 in 1 000 000, which was definitely not worth worrying about. Those who lived outside the tornado area had no reason to be concerned about tornadoes; they would never see one. Because of the minute chance of injury from a tornado, no need for warnings existed.

The Weather Bureau had no central collection point for tornado reports until 1916. Accounts of intense storms might occasionally appear in *Monthly Weather Review* or the *Monthly Weather Summary* of states. During Moore's tenure (1895–1913) the meteorological establishment exhibited little interest in tornadoes. Of the 131 papers presented at national meetings of Weather Bureau officials in 1898, 1901, and 1904 none addressed severe storms or tornadoes.

Meteorologists appeared to have reached a general consensus that forecasts of tornadoes would do more harm than good in panicking the public. Continuing the precedent set by the Signal Corps, the Weather Bureau Stations Regulations of 1905 contained the statement, ''Forecasts of tornadoes are prohibited.'' The ban was reiterated in the 1915 and 1934 regulations. When con-

[3] The total deaths from 523 tornadoes occurring from 1889 through June 1896 were 1458 (Grazulius 1997).

[4] During 1899 the southern Great Plains witnessed very few tornadoes. Oklahoma reported only three significant tornadoes (F2 or greater) for the year, all which occurred after Widmeyer's May article, while Texas reported only one. Strangely, Kansas reported no significant tornadoes for the entire year (Grazulius 1997).

ditions were favorable to tornado formation, district forecasters could use the term ''severe thunderstorm'' or ''severe local storms,'' but only the chief of the Weather Bureau or, in his absence, the chief of the Forecast Service could use the phrase ''conditions are favorable for destructive local storms.'' The morning forecast for St. Louis on 27 May 1896 read ''Conditions are favorable for severe local storms.'' That day 255 residents of St. Louis and East St. Louis perished in one of the country's worst tornadoes. The restriction remained in place until 1938.

During the period when the Weather Bureau did not issue tornado forecasts citizens of tornado-prone areas learned to rely on their senses, observations of nature, and *The Farmer's Almanac* for weather predictions. Animals often became restless when dark clouds gathered on the western horizon. When the air would become so still breathing became difficult, the plains residents knew a bad storm, probably a twister, was approaching. Folk wisdom had taught them that the sky would turn green just before a tornado. The appearance of any of these signs or the roar of the wind would alert the family's weather observer, usually the father, to lead the family into the underground storm cellar located near the house.

Research on tornadoes came to a virtual halt during the time of the ban. Europeans were especially surprised that in the United States, home of the majority of the world's deadly tornadoes, the literature on the storms consisted of compilations of statistics and descriptions of damage (Varney 1926). European meteorologists produced the few articles on tornado formation and prediction that appeared in the *Monthly Weather Review* during the 1910s and 1920s. Frenchman E. Durand-Gréville (1914) wrote that ''tornadoes *always* originate on the front edge of the squall-zone.'' Because these squall-zones (or squall lines) in the United States advance from west to east, the central bureau in Washington could plot storm reports received by telegraph on maps and could predict the squall's passage over a particular location several hours in advance. When the front edge of the squall had passed, the threat of tornadoes would be over. Durand-Gréville admitted that France had not yet adopted his method, but he would be ''very happy if the application of the law of squalls and tornadoes were to be made in a country which tornadoes seem to have selected as the land of their predilection.'' Although forewarning could not divert the storm's fury, it could save many lives.

Had the American weather establishment heeded Durand-Gréville's suggestion and instituted some type of warning system, perhaps the greatest tornado disaster in the country's history would not have occurred on 18 March 1925. A warm, moist layer of Gulf air covered the Midwest corn belt that day, but a cold air mass from Canada was rushing southward. Citizens of Illinois and Indiana were looking forward to the approaching spring. No one, not even the Weather Bureau, realized the imminent danger. The bureau predicted thunderstorms in Indiana, Illinois, and Kentucky for that afternoon. There was no mention of tornado danger because regulations prohibited such a prediction, but neither was there the dreaded allowable forecast ''conditions are favorable for destructive local storms.'' At 1301 CST snapping trees at Ellington, Missouri, heralded the beginning of three and one-half hours of the most intense tornado destruction in the country's history. By day's end 695 citizens of Missouri, Illinois, and Indiana were dead, including 234 in Murphysboro, Illinois. Injuries numbered over 2000. Estimated property losses totaled $16.5 million. The tornado established all-time records for pathlength (219 miles) and ground speed (an average 62 miles per hour). No warning system could have saved the property, but many lives could have been saved. Some tornadoes do not follow a predictable path, but this was not true of the tristate tornado. For 183 miles the tornado followed a slight topographic ridge and maintained an exact heading. The appearance of the storm, a boiling mass of clouds about three-quarters of a mile wide rather than the typical visual funnel, did not give people enough time to react (Felknor 1992). However, the question remains—Could a warning to the communities in the tornado's path have saved lives?

In spite of 4151 tornado deaths from 1920 to 1939, including 794 in 1925 alone, the Weather Bureau did nothing to try to reduce the loss of life from these natural disasters. An adequate watch/warning system has four essential components: 1) the issuance of a tornado forecast or watch, 2) the implementation of a method for tornado spotting or identification, 3) the distribution of a warning of the tornado's approach through an extensive communications system, and 4) the appropriate reaction of an educated public. All of these elements must be present in order to save lives. In 1940 none of the required elements was in place. The Weather Bureau had no tornado forecasting program and seemingly had little interest in instituting one in spite of the high death toll. No networks of spotters searched the skies for approaching tornadoes, and weather radar did not exist. Although telephones and radios were common items in American households, many rural communities in the country's tornado-prone areas lacked these basic communication instruments. The American people, even those who lived in ''Tornado Alley,'' had no formal instruction on tornado survival; they relied on their instincts or experience to escape a tornado's fury. In reality, the state of tornado forecasting and warnings was as nonexistent in 1940 as it had been in 1870.

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