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TORNADO CHARACTERISTICS; THE NASHVILLE TORNADO OF MARCH 14, 1933; A BRIEF REVIEW OF TORNADOES IN TENNESSEE[1]

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Confusion exists in the minds of many persons as to the meaning of the meteorological terms "cyclone," "hurricane," and "tornado." It seems worth while, therefore, to describe some of the characteristics of each in any discussion that involves one or more of these terms. It is especially important that the differences between the terms "cyclone" and "tornado" be pointed out, for these are considered synonymous in the minds of many.

One characteristic is common to all three types of storm, namely, that the winds flow spirally inward around a center of low barometric pressure, turning counterclockwise in the northern hemisphere and clockwise in the southern.

In the tropical oceans such a low pressure area often develops into a violent whirl of large extent, the diameter of which usually ranges from 300 to 600 miles. The isobars are nearly circular and the wind velocity reaches 100 and sometimes approaches 200 miles per hour. At the center of the area is a region of comparative calm, often called the eye of the storm. This briefly is the hurricane, or tropical cyclone. This is the kind of storm that caused the loss of 6,000 lives in Galveston in 1900 and that wrecked Miami in 1926.

In middle latitudes we have the extra-tropical cyclone, the largest of all distinctive storms. This is the ordinary low pressure area shown on our weather maps. It appears "in great number and in almost infinite variety as regards position and form. The ceaseless changes in our weather are due almost entirely to the approach and passage of these areas of low pressure." Such a formation may vary from a few hundred to several thousand miles in diameter, the average

[1]Read before the Tennessee Academy of Science at the Reelfoot Lake Meeting, April 28, 1933.

diameter being about 1,500 miles, and the winds may be gentle, moderate, brisk, or high, depending generally upon the pressure gradient.

The tornado is the smallest and yet the most violent of all storms. Although occurring occasionally in other countries, it is found principally in the United States, for here the atmospheric and physiographic conditions that are necessary for its development exist. Due to the trend of our western mountains and to the broad level plains to the east, extensive areas of cold air sweep down with high velocity into our central valleys, there to meet equally large areas of moisture-laden winds from the warm Gulf region. In the conflict which ensues there often results a sharp temperature difference within a very limited space.

According to Humphreys, the tornado "develops only in connection with a thunderstorm, usually just in front of the rain, and especially in connection with those particular storms that form along a valley 'low,' or between V-shaped isobars where opposing winds of widely different temperatures give rise to that exceptionally strong vertical convection essential to the genesis and growth of the thunderstorm."

Along the sharp wind-shift line that is usually found in such a pressure formation a layer of strong northwest wind of low temperature projects itself into the region of warm southerly air currents. At the cloud level this cold layer advances many miles ahead of similar winds at the surface, the opposing currents intermingle, and an unstable condition results. Quoting further from Humphreys, "Under such conditions, the inflow occurring at various levels that feeds the strong up-draft always just in front of a thunderstorm must occasionally so deflect these counter currents, by drawing both into the same rising column, as necessarily to produce a violent whirl. Here, too, as in all other cases of atmospheric motion, the law of the conservation of areas, * * * applies, except as modified by friction and viscosity. Hence, as the radii of curvature of the opposing currents may at first be comparatively large, and after the deflection relatively small, it follows that the wind velocity within the whirl, in which both the counter currents are taking part, may be very great. This rotation, however, does not check the up-current, hence that convection which is essential to the rotation is maintained, and therefore the rising currents brought in spirally with increasing angular and linear velocity as the axis of spin is approached. * * * Around the axis of rotation the pressure obviously is reduced in proportion to the centrifugal force, the temperature correspondingly lowered, and therefore a cloud spout often formed."

This spout, with the turbulent mass of cloud from which it hangs, assumes the shape of a funnel, which sometimes reaches to earth and more often, probably, does not. In the latter case but little effect at the surface is produced, but wherever the funnel touches the earth, great destruction occurs. It is often observed that the funnel cloud apparently lifts and later comes to earth further along the path. What

probably happens is that the lower end of the vortex is worn out through friction at the surface, then after a period of unrestricted development in the free air the lower end again assumes its initial violence and takes up its work of devastation. The diameter of the funnel at the surface varies from a hundred yards to a half mile or more, the average being approximately one-fifth mile. Its rate of travel averages about 25 miles per hour and the vortex usually passes a given point within a half minute or less. It is estimated that the

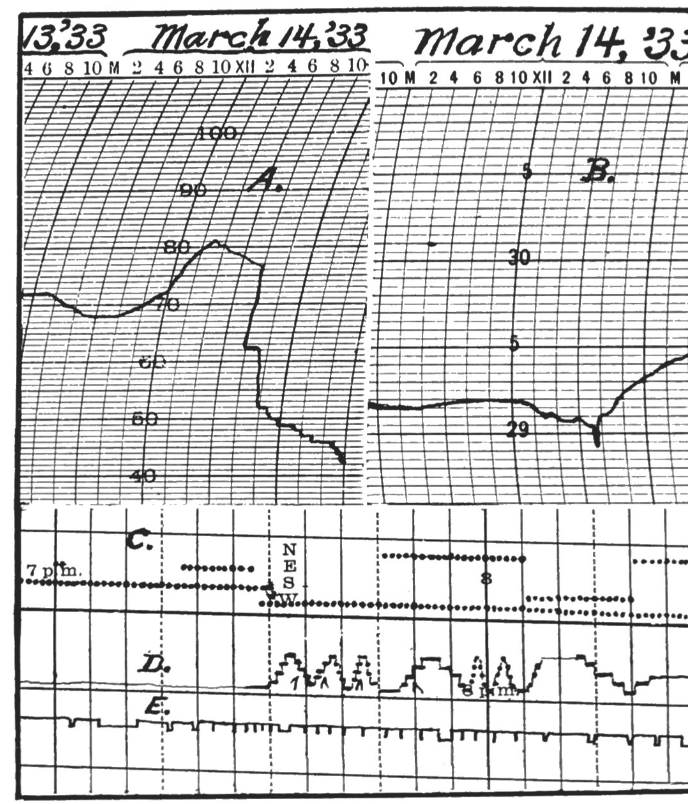

Fig. 1. Weather Conditions at the Time of the Nashville Tornado, March 14, 1933. *A.* Temperature relations. *B.* Barometric pressure. *C.* Wind direction. The dots are made one each minute and represent the wind direction at the end of that minute. If the wind is southwest, two dots are made, one under south and one under west. This is similarly done for all intermediate directions. *D.* Rainfall. The zigzag lines show rainfall, each horizontal dash equaling .01 inch of rain. *E.* Wind velocity. The offsets downward show wind velocity. The interval between offsets equals one mile of wind. Every tenth mile, the offsets downward are connected.

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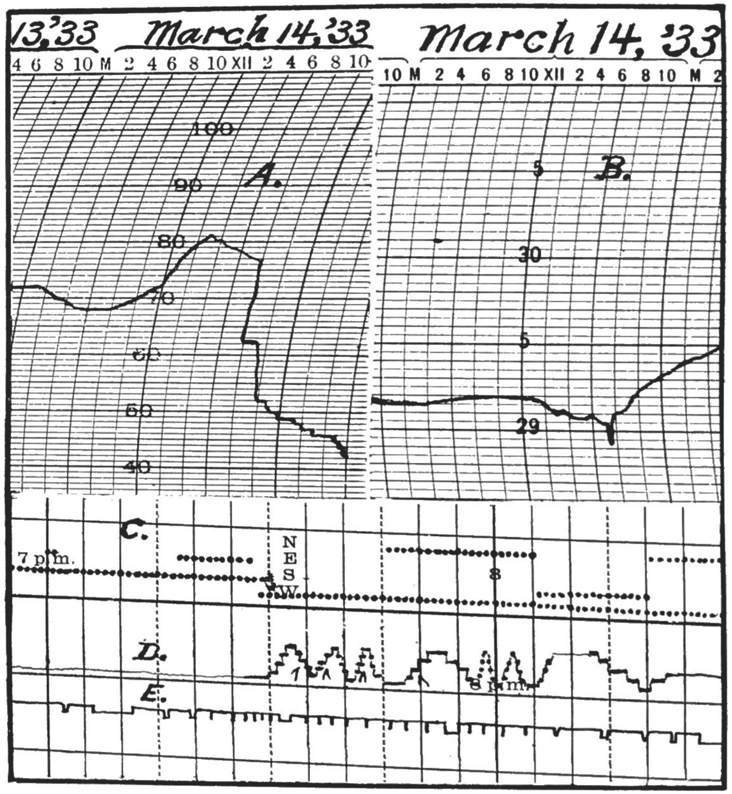

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velocity of winds within the tornado ranges from 100 to 500 miles per hour, the swiftest winds known.

Pressure within the tornado has never been measured, but it is certainly greatly reduced as compared with that of the adjacent air, some estimating even as much as one-half. This easily accounts for the apparently explosive effect the vortex has on buildings within its range. For instance, a wall 15x20 feet is, under normal conditions, subjected to atmospheric pressure of about 600,000 pounds. If suddenly this is reduced to, say, 400,000 pounds on the outside but remains in the neighborhood of 600,000 on the inside, an excess pressure of about 100 tons is pushing this wall outward. It is not surprising, then, that walls collapse and roofs are lifted and blown away.

The tornado attains its greatest violence over the more nearly level portions of the United States, but it occasionally invades the valleys and basins of the hill country. It is true, of course, that one is less apt to occur here than over a wide expanse where surface friction is at a minimum. A feeling of comparative security from the tornado lurked in the mind of the average person in Nashville, due to the fact that a row of rather high hills lies a few miles to the south of the city and of somewhat lower hills to the west. This sense of immunity was rudely disturbed on March 14, 1933, when a genuine tornado of more than average violence tore through the heart of East Nashville.

The day had been warm, the maximum temperature reaching 80 degrees at 3 P. M. A thunderstorm was approaching from the southwest at 6:45 P. M. An extensive area of low pressure, with two centers, occupied the Eastern States at 7 A. M. of the 14th. This was a fairly good type of V-shaped depression, with a decided southwest-northeast trend. One center was over the Great Lakes and the other over western Arkansas and southern Missouri, the lowest sea-level pressure in the latter area being 29.56 inches at Fort Smith, Arkansas. At 4 P. M. the southern portion of the depression was long and narrow, extending from Memphis, Tennessee, to Columbus, Ohio, being wedged in between high pressure areas in the Southeast and in the Northwest. At the P. M. observation (6:45 o'clock) the trough extended from Nashville, Tennessee, to Parkersburg, West Virginia, both points registering the same pressure, 29.62 inches. There probably was slightly lower pressure at the Lexington, Kentucky, station, where it is indicated on the Washington weather map that the center was located at 6:45 P. M. The tornado struck Nashville forty-five minutes after the above barometer readings were made. It therefore occurred in the southwest quadrant of the depression, and somewhat ahead of the wind-shift line at the surface.

The wind direction had been southwest most of the afternoon, becoming south-southwest at 6 P. M. and south at 6:50 P. M. (Fig. 1, *C*). Here it remained until 7:18 P. M., when the approaching thunderstorm brought the usual shift to an easterly direction (in this case, southeast). For about ten minutes the wind blew from the

southeast. Suddenly at 7:28 P. M. the wind veered from southeast to southwest, remaining so for one minute, and at 7:30 P. M. it was blowing from the west. The wind velocity increased from 15 miles per hour at 7:20 P. M. to 65 miles per hour at 7:28 P. M. This was the extreme velocity at the station, on the Stahlman Building. During the minute of blow from the southwest the tornado was passing just north of the station, the right side of the path of destruction being only about 400 feet away. After the passing of the tornado the wind direction was west for fifteen minutes, northwest for twenty minutes, west-southwest for fifteen minutes, and finally northwest for the remainder of the night.

Large hail stones preceded the arrival of the tornado by several minutes and heavy rainfall began with the shift of wind to the west (Fig. 1, *D*). The temperature dropped from 75 degrees at 7:30 P. M. to 61 degrees at 8 P. M., due to cooling caused by the thunderstorm (Fig. 1, *A*). The temperature then remained nearly stationary for about one hour. From 9 P. M. to 10 P. M. there was a further drop of 10 degrees to 51. This was the result of the progress eastward of the high-pressure cold-weather area, following the permanent shift of the wind to the northwest. In other words, the thunderstorm and the tornado were running ahead of the cold northwest blast at the surface about one hour. The tornado was not coincident with but preceded the real wind-shift line by about one hour.

As the thunderstorm neared the station the barograph trace was falling with fair speed (Fig. 1, *B*). About 7:30 P. M. it dropped suddenly 0.12 inch and immediately recovered 0.15 inch. This was during the passing of the tornado and was the direct result of it. A close examination of the barograph trace makes one suspect that the pen was lifted entirely off the sheet and therefore did not record the complete pressure fall. It may be also that the fact that the office was tightly closed had the effect of preventing as much pressure fall within the room as without, during the brief moments that the storm was near at hand. At any rate, the comparatively small change in pressure occurring just outside the tornado path indicates the limited influence of the tornado proper. If the barograph had been near the center of the vortex, it would doubtless have shown a sudden pressure fall of several inches instead of a tenth or so. After the passing of the tornado there was fluctuation in the pressure—the usual thunderstorm effect—for about forty minutes—then followed the steady increase in pressure due to the approaching HIGH.

The following description of the storm cloud was given by an eyewitness who was stationed on Gallatin Road, about three-fourths mile north of the tornado's path: "The tornado cloud was first observed while watching the unusual hail which fell prior to the storm. The cloud approaching from a westerly direction appeared like a huge inverted cone moving rapidly across a light-colored background of

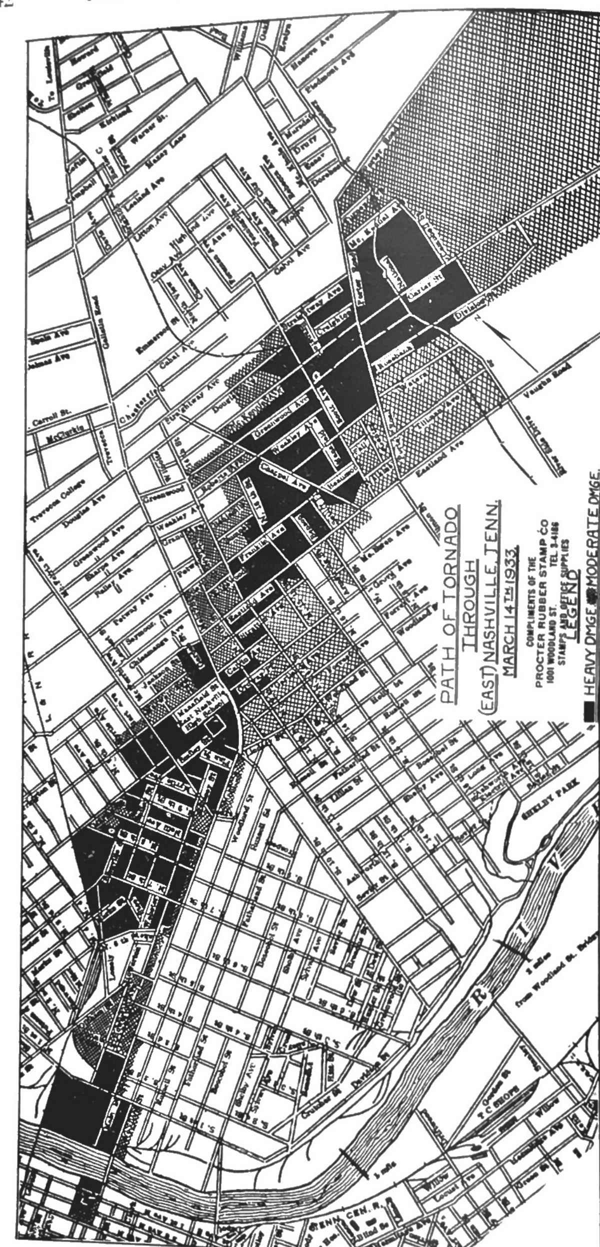

Fig. 2. Path of tornado through East Nashville, March 14, 1933.

rain, looking very much similar to a shadow moving across a motion picture screen." The usual roar, as of a freight train thundering along at high speed, was attested by many.

The path of the storm across the city was approximately east-northeast (Fig. 2). It first appeared in West Nashville in the vicinity of Charlotte Pike and Fifty-first Avenue, about four miles from the Public Square. So far as known, this was the point of origin of the storm. From that vicinity to the Public Square moderate damage occurred here and there, such as trees broken off and a few walls down. Upon reaching Capitol Hill it caused the breaking of a few windows in the State Capitol Building and then descended upon the buildings on the north and east sides of Public Square with terrific fury. The path here was probably not over 200 yards wide, but the destruction was great. Some fifteen or more brick business houses, ranging from three to five stories high, were affected. The top stories of some of the buildings on the east side of the Square had both the west and the east ends blown out, the main portion of the roof remaining intact. Several on the north side of the Square were almost completely demolished. Proceeding thence across Cumberland River the storm widened to about 400 yards and partially wrecked a row of four-story factory buildings along First Street and took out a large section of brick wall of the building occupied by the National Casket Company at Second and Woodland Streets. From this point, for a distance of three miles it tore through a district of residences, churches, schools, and storehouses, the width of the path ranging from 600 to 800 yards. The total length of the path across the city was about eight miles, but the storm's track can be traced through Davidson County, Wilson County, and into Smith County, a total distance of about forty miles.

Evidences of tornadic action were so plain and so numerous that no one questioned the true nature of the storm. A two-by-four-inch timber was driven endwise into the east slope of the roof of the writer's home, clearly the result of a counterclockwise wind blowing into a vortex. At many places in the beautifully wooded portions of East Nashville uprooted trees along the outer edges of the whirl, of which there were hundreds, lay practically at right angles to the direction of the storm's path and toward the center (Fig. 3. *C*). Scores of buildings showed the explosive effect of the sudden lessening of pressure—roofs lifted and walls blown outward (Fig. 4). Many of these were completely demolished. Frame structures succumbed to the fury of the storm more readily than brick and stone, but the latter were by no means spared. Wreckage of many large brick buildings occurred and the damage was great (Fig. 3. *D*). Notable among such examples were the brick buildings on the Square and those just across the river, already referred to, the new East Nashville High School, where the roof of the large gymnasium was lifted off, and the new Bailey High School, which was probably half wrecked. Numbers of instances were observed where walls and roofs inclosing large

Fig. 3. Effects of the Tornado in East Nashville. *A*, General view back of Calvin Avenue. *B*, General view looking southeast from Greenwood viaduct towards the rear of Riverside Drive. *C*, Blown-down trees on the grounds of the Bailey High School. *D*, Injury to the Eastwood Christian Church, showing badly damaged trees. *E*, The Grissom home at the corner of Sixteenth Street and Franklin, where six people were trapped but none harmed. *F*, A home at the corner of Gartland Avenue and Gallatin Road where five people were injured, some seriously. *G*, Carl Dixon's home in which his wife and baby were injured. *H*, A high tension transmission tower twisted and bent to the ground but not pulled from its foundation.

rooms were damaged while those around smaller adjacent rooms were left intact. The hearing of some persons was affected by the reduced pressure.

The tornado killed eleven persons in Nashville and injured scores of others. The small loss of life was one of its remarkable features, considering the fact that it traversed an area occupied by about ten thousand persons. The property damage included 1,400 homes, of which 1,100 were frame structures and 300 brick or stone; also 16 churches, 36 stores, 5 factories, 4 schools, 1 library, and 1 lodge hall. Some of the best residences of East Nashville were in the damaged area. The property loss within the city, exclusive of trees, automobiles, and other personal property, was estimated at $1,450,000, and in the suburbs $150,000. Loss of personal property is estimated at $400,000.

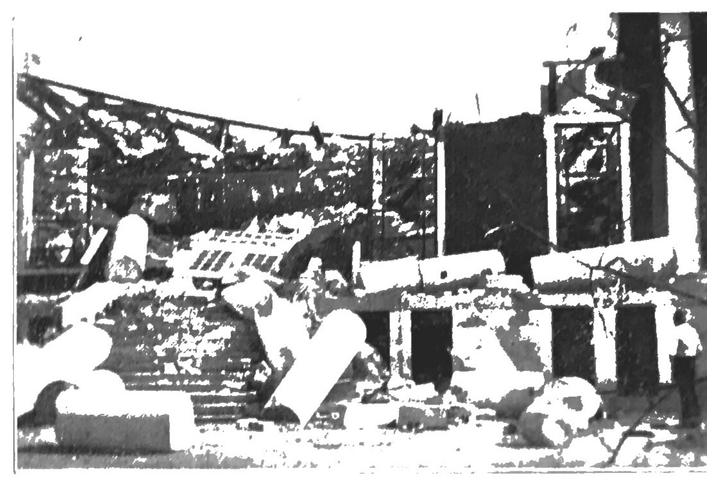

Fig. 4. The Entrance to the Auditorium of the Bailey High School. The auditorium exploded, *i. e.*, the walls were forced outward, allowing the roof to cave in.

The same tornado killed four persons in Lebanon and caused property damage of about $125,000. The total loss of life was 15 persons and the total property loss probably $2,200,000.

The writer, who was near the center of the storm's path on Eastland Avenue, fortunately (for him) did not attempt to observe the storm's approach, for an outside observation might have cost him his life. During the terrifying fraction of a minute when walls, roofs, chimneys, garages, and trees were crashing only a few yards away and his own house was quivering under the pressure and was partially demolished, he and his family were in the front portion and were unharmed, in spite of a feeling of intense expectancy. Numbers of his neighbors, however, were less fortunate. Some were crushed in the wreckage and others were blown out with the walls. If it were possible to keep doors and windows open during such a blow, relieving somewhat the inside pressure, the walls and roofs of a building would doubtless suffer less, but the contents, including the occupants themselves, would be sucked into the open and made targets for flying debris.

Among the freakish incidents of this storm were the following:

A cornstalk was observed driven endwise through a piece of weatherboarding (Fig. 5 *C*). A 2″ x 4″ timber plunged through a panel door without causing the slightest splitting or splintering (Fig. 5. *B*). The

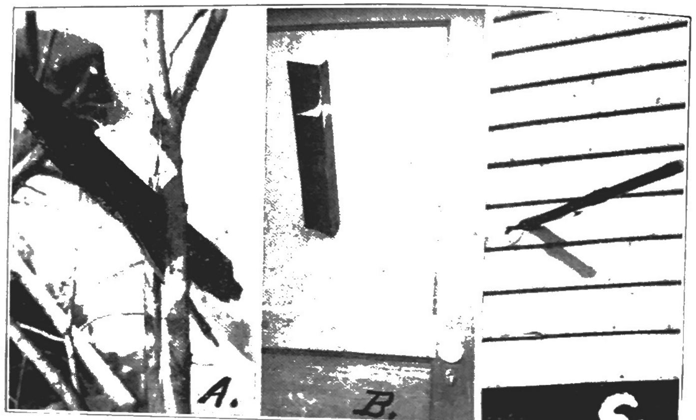

Fig. 5. Freaks of the Nashville Tornado. *A.* A piece of plank driven through a two-and-a-half-inch limb of a Mississippi Hackberry tree. *B.* A two-by-four driven through a door panel without leaving splinters. *C.* Weatherboarding pierced by a cornstalk.

timber fit the opening perfectly. A 1″ x 6″ plank was forced through a limb of a sturdy young tree, splitting the limb in half (Fig. 5. *A*). A high tension tower was bent to the ground in a tangled mass without breaking loose from its concrete moorings (Fig. 3. *H*).

It is not believed that this tornado was as violent as many that have occurred in other states, nor even in Tennessee for that matter, else the loss of life and property would have been much greater. Its significance lies in the fact that it pierced the heart of one of our large cities. This was not Davidson County's first tornado. During the last twenty years at least six others have occurred within the county, three of them being within a few miles of the city; but they were less severe than the recent one and the amount of destruction insignificant as compared with the Nashville tornado of March 14.

Both Central and Western Tennessee are occasionally visited by these terrific storms, while they occur with less frequency in the

eastern part of the State. In the *Monthly Weather Review* of September, 1922, Roscoe Nunn reviewed the history of tornadoes in Tennessee from the beginning of records through the year 1921. His investigation revealed the fact that in fifty-one years there were 79 tornadoes in the state, or an average frequency of 1.5 per year. A survey of the records shows that since that time, or during the twelve-year period from 1922 to 1933, inclusive, 43 additional tornadoes occurred in the state, bringing the total for the sixty-three-year period to 122, or about two per year.

The greater frequency of tornadoes during the last twelve years is more apparent than real and was brought about by the fact that there were several occasions when a series of tornadoes occurred within the state on a single day. For example, in 1928 there were four tornadoes on one day, in 1932 five on one day, and in 1933 six on one day. There have been similar occasions in the past, but not so many within such a short span of years.

In the twenty years from 1914 to 1933, inclusive, 51 of the 95 counties in Tennessee are named in the records as having been affected by these storms. Sixteen of these are in the western division, 24 in the central division, and 11 in the eastern division. This represents 80 per cent of the western counties, 59 per cent of the central, and 32 per cent of the eastern. The following table gives the number of times the respective counties were visited by tornadoes during the twenty years:

Bedford	6	Hancock	1	Obion	2
Bradley	2	Henderson	1	Perry	1
Cannon	1	Henry	2	Polk	1
Campbell	1	Hickman	1	Robertson	1
Chester	1	Lake	1	Rutherford	5
Claiborne	2	Lawrence	1	Shelby	1
Carroll	3	Lauderdale	1	Smith	2
Cocke	2	Lewis	1	Stewart	2
Crockett	1	Lincoln	1	Sullivan	1
Cumberland	1	McNairy	1	Sumner	3
Davidson	7	Madison	1	Tipton	3
Dickson	2	Marion	1	Trousdale	2
Dyer	1	Marshall	7	Washington	1
Dekalb	3	Maury	2	Wayne	1
Fayette	1	Meigs	1	Weakley	1
Gibson	5	Monroe	1	Williamson	3
Giles	3	Montgomery	3	Wilson	5

It is more than likely that some of the other counties in the state have suffered from tornadoes that were not reported.

Nunn characterized April 29, 1909, as the most disastrous tornado date in Tennessee's history, due to the fact that a series of tornadoes on that date caused the death of sixty persons in the state and property loss of about $800,000. From the standpoint of loss of life alone, that characterization still holds good, but if loss of life and property both are considered, the date of the East Nashville tornado, March 14, 1933, takes leading rank, for on that date a series of tornadoes within the state killed 43 persons and caused property losses of approximately $3,000,000. Eleven of the deaths and two-thirds of the property damage occurred in Nashville.

It may be of interest to know that one's chances of being in the path of a tornado are extremely small. Approximately fifty years elapsed before the writer had that experience, and comparatively few persons ever experience one. When it is remembered that the average width of the path is only a few hundred yards, its length seldom more than 25 miles, and its occurrence in Tennessee not more than twice a year on the average, one need not be apprehensive as to his safety until he actually sees one approaching.

The forecasting of such storms is forbidden by the Weather Bureau, and very properly so. No one can tell exactly when nor where a tornado will strike. The disturbed state of mind that would result from an attempted prediction would, in the aggregate, be far more serious than the losses actually incurred by the few who are affected.

NOTES HERE AND THERE

Dr. A. Richard Bliss, Jr., has presented his resignation, effective August 15, 1933, as Chief of the Division of Pharmacology in the University of Tennessee, to accept the position of Director of the Research Laboratories of the William A. Webster Company of Memphis. This position will allow Dr. Bliss to devote his whole time to research. He will continue also as Director of the Reelfoot Lake Biological Station at Walnut Log, Reelfoot Lake.

The spring number of the *Alumni News* of the University of Virginia paid a splendid tribute to the late Dr. Samuel Marx Barton, a charter member of the Tennessee Academy of Science and at various times its treasurer, vice-president, and president, in an article, *Virginia's First Doctorate,* by Dr. Joseph Kent Roberts, Professor of Geology at the University.

The Emergency Conservation Committee, 734 Lexington Avenue, New York, offers a prize of $5 for the best slogan against the use of live decoys in luring wild fowl. Slogans and the name and address of the sender should be sent as soon as possible to the above committee.

The letters and correspondence of Dr. Augustin Gattinger with Asa Gray, John Coulter, Trelease, Engelmann, Bailey, Chapman, Parish, and others have been presented to George Peabody College for Teachers, together with about 500 volumes of books and pamphlets, including many rare botanical books in English and German. This valuable collection has been presented by Dr. Gattinger's two surviving daughters, Misses Augusta and Pennie Gattinger, as a memorial to their father.