Journal of the Minnesota Academy of Science

Volume 32 | Number 1 Article 10

1964

A Comparison Between The Direction of Tornado Movement and the Associated 500 mb. Level Wind Direction

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A Comparison Between The Direction of Tornado Movement And The Associated 500 mb. Level Wind Direction[1]

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An investigation to (1) determine the 500-milli-bar level weather patterns associated with tornadoes moving from northwest toward southeast and from southwest toward northeast and, (2) show the significance of the contrasts between the 500-mb. level weather patterns of the two tornado types. A very high relationship between the direction of the 500-mb. level winds and the tornado direction was substantiated by a coefficient of correlation of +0.88. The typical 500-mb. level low center associated with the northwest to southeast type tornado was located over Hudson Bay about 1300 miles north-northeast of the tornado area. The low center associated with the southwest to northeast type tornado was positioned over northeast Montana about 900 miles northwest of the tornado area.

The purpose of this investigation was (1) to determine the 500-millibar level weather patterns associated with tornadoes moving from northwest to southeast and those moving from southwest to northeast and, (2) to show the significance of the contrasts between the 500-mb. level weather patterns of these two tornado types.

Tornadoes in the United States usually move from some westerly direction. Most travel from southwest to northeast. A smaller number move from northwest to southeast but some of these have been the most destructive in weather history.

The synoptic patterns associated with the southwest to northeast type have been investigated to a considerable extent but the contrasting pattern, northwest to southeast, apparently has not been studied in much detail.

During the 1930-58 period about 58 per cent of the tornadoes in the United States moved from southwest to northeast and 10.5 per cent from northwest to southeast. Statistics of tornado occurrences in Iowa during the period 1916-60 indicate that about 64 per cent of the tornadoes moved toward the quadrant lying between north and east, and about 14 per cent moved toward the quadrant lying between east and south. A survey of Nebraska tornadoes occurring from 1916 through 1938 showed that 63 per cent moved toward the quadrant lying between north and east and 16 per cent toward the quadrant between east and south.

[1] This investigation was conducted during 1962-63 to partially fulfill the requirements for the degree Master of Arts in the Teaching of Physical Science at Drake University, Des Moines, Iowa. The writer wishes to express his great appreciation to Dr. Wallace E. Akin, Dept. of Geography, Drake University, Mr. Paul J. Waite, State Climatologist of Iowa, and Dr. R. R. Haun, Professor of Physical Science, Drake University, for their suggestions, comments and critical reading of the contents of this paper.

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Since many of the tornadoes moving northwest to southeast have been so destructive it is important that a study of weather patterns include them as well as the more numerous tornadoes moving southwest to northeast. If forecasting and warning systems are to be improved, the weather patterns of both types must be known.

A number of tornadoes are worth describing in some detail because of their outstanding characteristics and the resulting losses of life and property. The statistics for most of these tornadoes are reported in terms of number of lives lost, injuries and monetary estimate of property damage. Some of these may not have been so violent as others of the same type but happened to strike large cities or heavily populated areas. Other storms of equal or greater violence have probably occurred in open country with little or no loss of life or property damage. Some of these spectacular tornadoes will be described; the type moving northwest to the southeast is discussed first.

Northwest-Southeast Tornadoes

Records of outstanding tornadoes moving from northwest to southeast date back as far as the Lewis and Clark Expedition. The earliest Iowa tornado was reported by the group as they toiled up the Missouri River along the present boundaries of southwestern Iowa. They observed and recorded the destructive work of a tornado that had passed the year before.

On the afternoon of May 24, 1859, a tornado passed south of Iowa City in a southeasterly direction. Five people were killed, 18 injured and $12,000 damage resulted. "Dr. Gustavus Hinrichs, the first director of the Iowa Weather Service, authenticated this tornado as the first reported tornado in the State after settlement began" (Spohn and Waite, 1962:404).

In addition to the Iowa City tornado (1859), two of the most damaging storms that moved southeastward were the Comanche tornado (1860), reported as a "national calamity," and the Grinnell tornado (1882), that accounted for 100 lives. Another was the Pomeroy tornado (1893), that caused a huge tidal wave in Storm Lake.

According to Flora (1953), "One of the most violent tornadoes known in Kansas was the one that struck Irving on May 30, 1879, moving from the northwest."

On June 8, 1951, a tornado, developing from clouds about 5,000 feet high near Corn, Oklahoma, seemingly struck out of a clear sky. This slow moving tornado was one of the most photographed ever known. No deaths occurred but $354,000 damage was done.

Cleveland, Ohio, was struck by a tornado on April 27, 1943. As the storm moved east-southeast it passed only two blocks south of the Public Square. No deaths were reported but property losses totaled $1,000,000.

On April 12, 1927, Rocksprings, Texas, was practically wiped out of existence by one of the most violent tornadoes that ever occurred in that state. It moved from the northwest.

On June 23, 1944, a family of southeasterly moving tornadoes crossed the mountainous country of Pennsylvania, West Virginia and Maryland. It caused 153 deaths and effectively exploded the theory that tornadoes do not cause damage in mountainous country.

The largest and most destructive tornado ever to move toward the southeast through western Nebraska occurred on June 27, 1955.

Southwest-Northeast Tornadoes

Most frequently tornadoes move from the southwest to the northeast. Because they are more numerous many more vivid accounts exist of outstanding tornadoes. One of the greatest tornado disasters on record occurred March 21 and 22, 1952, when a series of 31 storms moved northeastward through the states of Arkansas, Tennessee, Missouri, Mississippi, Alabama and Kentucky. The death toll was 343 and property losses totaled over $15,000,000.

The tornado that struck Hutchinson, Kansas, on May 7, 1927, traveled 102 miles, the longest path of any similar storm and one of the most destructive known in the state.

A tornado moving at a rate of 47 mph. through Poplar Bluff, Missouri, practically wiped out the town on May 9, 1927.

The tornado that occurred on March 18, 1925 still stands as the most destructive in life and property known in the United States. It originated in Reynolds County, Missouri, and traveled 219 miles east-northeast across Illinois and dissipated beyond Princeton, Indiana. Over 689 people were killed and property damage totaled $16,632,000. This is referred to as the "Tri-state Tornado."

The Woodward, Oklahoma, tornado of April 6, 1947, was the longest, widest and most destructive that has ever occurred in the southern Great Plains. It traveled over a path 221 miles long from White Deer, Texas, northeast to St. Leo, Kansas.

Omaha, Nebraska, was struck by one of the most destructive tornadoes ever to appear in that part of the country on Easter Sunday, March 23, 1913. The northeasterly moving storm killed 94 people and destroyed over $3,500,000 worth of property. Six years later, on April 6, 1919, Omaha was struck by a second tornado that moved north-northeast through a sparsely settled part of the city.

Literature Review

A limited amount of information has been published on the problem of determining tornado directions. About 25 years ago Byers (1937) wrote that, because of the highly localized horizontal extent and influence of tornadoes, "it is impossible to forecast their paths and movements." This seems reasonable since only recently have forecasters been able to predict a possible tornado region with some accuracy by using upper air data. The upper air region is about 4,000 feet in elevation. Had more been known about upper air features at that time, he would not have used the term "impossible."

More recent literature states that:

> An empirical rule for forecasting the movement of an individual tornado has been given by Showalter and H. C. Willett, namely, that a tornado moves roughly the direction and speed of the Maritime Tropic (mT) stratum just beneath the inversion. Others state simply that the tornado travels roughly parallel to the path of the accompanying cyclone.

This general empirical rule has been commonly used in explaining the direction of movement; however, J. R. Lloyd (1942) has represented the direction of movement by a vector method. His line of reasoning is quite logical.

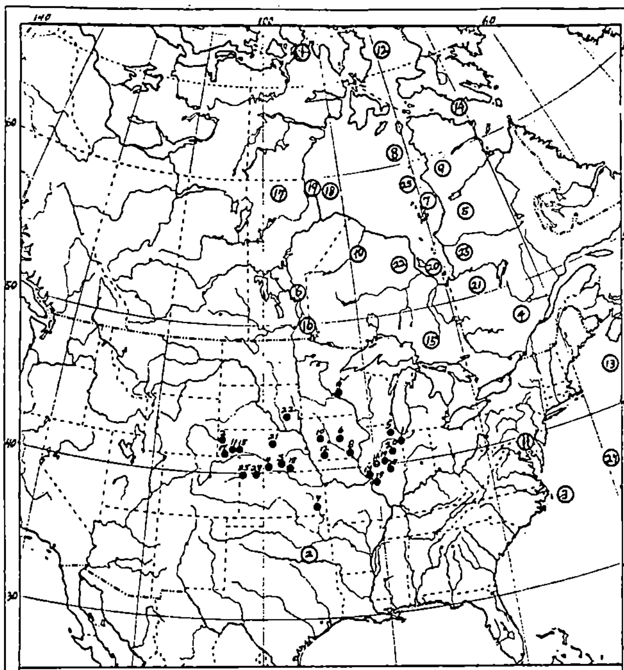
> Tornadoes appear to occur only in connection with upper-air cold fronts. These tornadoes remain on the upper-air cold front throughout their existence, and move up the front with approximately the speed of the wind in the warm air mass immediately ahead of the front, which usually blows approximately parallel to this front. In other words, the direction and speed of movement of the tornado is represented, to a first approximation at least, by the resultant of the direction and speed of movement of the front (or the wind component pushing the upper-air cold front along) and the direction and speed of the wind immediately ahead of the upper-air cold front.

Lloyd's statement does not agree with the empirical rule, but is one of the only attempts to account for the direction of movement of frontal tornadoes.

Conner (1956) has studied some examples of 500-mb. level jet structures that he has found favorable for tornado genesis, although no attempt is made to draw a relation between the direction of movement of the tornado and that of the corresponding 500-mb. level wind.

Brooks (1960) has suggested a cause for the direction of movement of tornadoes in Texas. He states:

> Tornadoes sometimes move from the northwest, especially in Texas, where they may be steered by an upper wind blowing around the high aloft, char-



LEGEND

Position of tornado occurrence ....

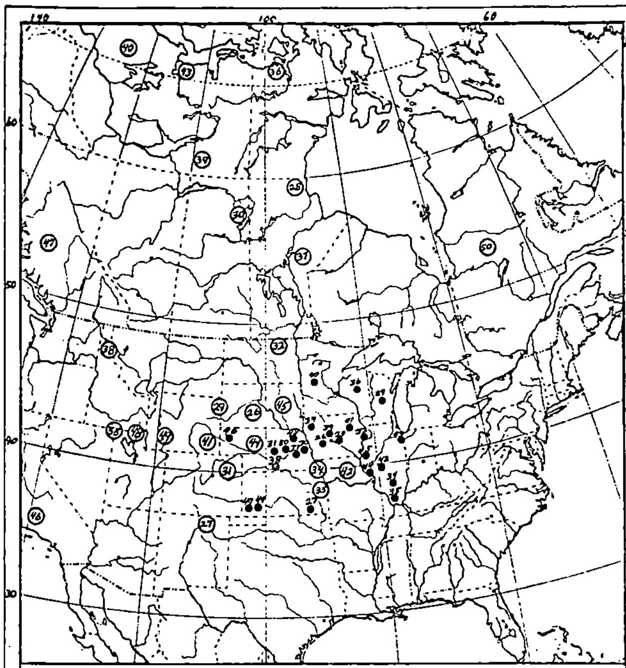
Position of 500-mb. level low center....

(The tornado cases and their associated low centers are represented by like numbers)

SCALE

LAMBERT'S AZIMUTHAL EQUAL-AREA PROJECTION

Figure 1. Positions for northwest to southeast moving tornadoes and their associated 500-mb. level low centers.



LEGEND

Position of tornado occurrence..........

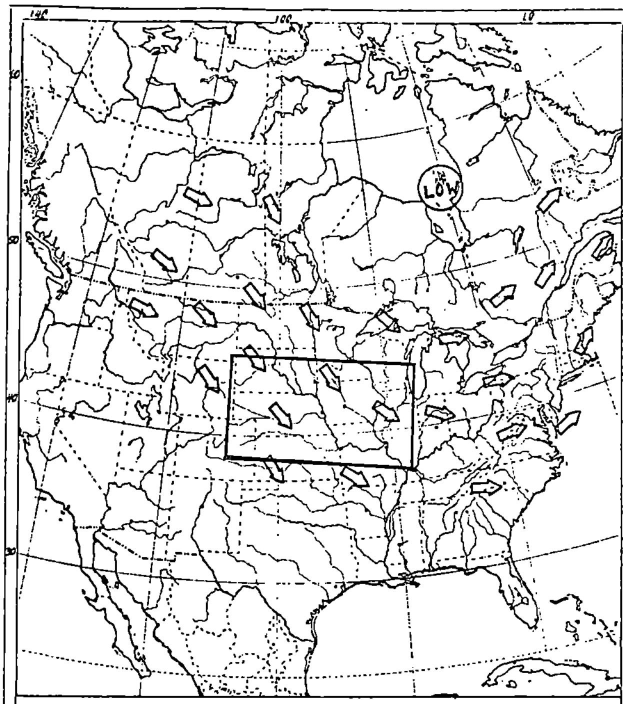
Position of 500-mb. level low center....

(The tornado cases and their associated low centers are represented by like numbers)

SCALE

LAMBERT'S AZIMUTHAL EQUAL-AREA PROJECTION

Figure 2. Positions for southwest to northeast moving tornadoes and their associated 500-mb. level low centers.



LEGEND

Arrows indicating the direction of wind movement at 500-mb. level ....

500-mb. level low center .... LOW

The area inside the rectangle indicates the tornado region.

SCALE

LAMBERT'S AZIMUTHAL EQUAL-AREA PROJECTION

Figure 3. Typical surface and 500-mb. level patterns associated with northwest to southeast moving tornadoes.

LEGEND

Arrows indicating the direction of wind movement at 500-mb. level ....

500-mb. level low center .... LOW

The area inside the rectangle indicates the tornado region.

SCALE

LAMBERT'S AZIMUTHAL EQUAL-AREA PROJECTION

Figure 4. Typical surface and 500-mb. level patterns associated with southwest to northeast moving tornadoes.

acteristic of the southwestern United States in summer.

No mention of the extent of this relation is made. During the investigation of literature Brooks' statement was the only reference found relating tornado direction with upper air wind direction.

Currently, Galway, a forecaster with the Severe Local Storm Forecast Center (SELS), United States Weather Bureau, Kansas City, Missouri, is making a study of severe weather occurrences in the northwest flow which may shed more light on the problem.

Materials and Procedure

One of the basic problems in determining the physical relations between tornadoes and the associated upper air phenomena is the selection of reliable data. Below is a discussion of the materials and methods used in the selection and preparation of data for analysis.

The materials utilized were as follows: (1) "500-mb. Constant Pressure Charts" of the *Daily Weather Map* and, (2) "Storm Data and Unusual Weather Phenomena" in *Climatological Data–National Summary* until December 1958, and then in *Storm Data,* also a monthly report. The specific dates of these sources used coincide with the dates of tornado occurrences. These materials were published by the United States Department of Commerce, Weather Bureau, Washington 25, D.C.

Criteria for selection. A total of 50 tornado cases were investigated of which 25 moved in a southeasterly direction and twenty-five in a northeasterly direction. Tornado statistics, including geographic location, date and time of occurrence, and path length and direction, were recorded.

Since much of the tornado data is subjective, various criteria were established in selecting these 50 cases. The most important standard was that all the cases must have been confirmed as definite tornadoes and not as "possible" tornadoes. There was no reason to doubt the validity of each case. A second criterion, closely associated with the first, involved the path length. The minimum length of ten miles helped assure that the direction and confirmation were more positive.

Only cases occurring from June 1954 through August 1962 which were considered as upper air data prior to this period were recorded on the 700-mb. Constant Pressure Chart of the *Daily Weather Maps.* Since then the 500-mb. data have been recorded but are not readily available for dates prior to 1954. Since the 700-mb. (10,000 ft.) and 500-mb. (18,000 ft.) levels differ by about 8,000 ft. in altitude, it was essential that the data be limited to one level. Taylor (1954) has stated, "The vertical axes of both lows and troughs range from practically vertical to highly tilted." Because the low centers may not be vertical, it makes the interchange of 700-mb. and 500-mb. data very impractical and uncertain because the corresponding wind directions may not be located over the tornado locality. Confining the data selection to that recorded since 1954 has also insured the greatest reliability and accuracy in reporting because of better trained observers and the use of more accurate instrument detection, such as radar.

The geographical distribution of both types of tornado occurrences was limited mainly to the same central Great Plains area that is comprised of the states of Nebraska, Kansas, Iowa and Illinois. The number from each state is as follows: Nebraska, 15; Kansas, 6; Iowa, 10; and Illinois, 14. The remaining 5 cases were selected from South Dakota, Minnesota and Wisconsin. Missouri data were incomplete as to direction and path length. This area comprises the northern region of the Tornado Belt in which over one-fourth of all U. S. tornadoes occur.

Five hundred-millibar level data. The weather features of the 500-mb. Constant Pressure Chart were studied for patterns related to tornado direction. These patterns included the wind direction over the tornado region and the position of the 500-mb. low center associated with these winds.

The direction was determined by the true direction of the "wind arrows" that are plotted as flying with the wind. Some extrapolation was required in a small number of cases as the time lapse between recording the 500-mb. data and the reported time of tornado occurrence was quite large. If the time difference was more than four hours, a comparison with the previous, or succeeding, chart was made. If a substantial change in wind direction occurred during this time, extrapolation was employed.

The position of the 500-mb. low pressure center was clearly indicated on the corresponding chart. Again, if the time lapse was over four hours between the tornado occurrence and upper-air plotting time and the low center was found to have moved quite rapidly, extrapolation was used.

The northeasterly moving tornado cases and their associated low centers were plotted on the same outline map of North America. The southeasterly type tornado cases and low centers were also plotted on a separate map and an effort was made to draw comparisons and contrasts between the two types. These maps are represented in Figures 1 and 2.

Results

In analyzing the data, it was necessary to make a specific breakdown of the 50 tornado cases with regard to direction. A breakdown of the associated 500-mb. level wind directions for each tornado direction was also made as shown in Table I.

A strong relation between tornado direction and associated 500-mb. level wind direction is evident. In 62 per cent of the cases the 500-mb. level winds blew in exactly the same direction as the associated tornado movement. An extremely high relation exists with the southeastward moving tornadoes. Of the 20 cases, the 500-mb. level winds were blowing toward the southeast in 17 cases, toward the eastsoutheast in 2 cases and toward the east in one case.

A measure of the degree of relation or correlation between tornado directions and 500-mb. wind directions

TABLE I. Breakdown of tornado directions with associated 500-mb. level wind directions.

Direction of tornado movement	Number of cases	Direction towards which 500-mb. winds were blowing	Number of cases
NNE	4	NNE	2
		NE	2
NE	18	NNE	6
		NE	8
		ENE	2
		ESE	2
ENE	3	NE	1
		ENE	2
ESE	2	E	1
		ESE	1
SE	20	E	1
		ESE	2
		SE	17
SSE	2	E	1
		SSE	1
S	1	ESE	1

was obtained by finding the coefficient of correlation for ungrouped data. The value for the 50 cases was +0.88, which is considered very good for weather phenomena.

To justify that this correlation is significant, a "τ-test" was made. The value for "τ" was approximately 12, indicating that the correlation is highly significant to .005.

The second part of the analysis was devoted to seeking a relation between the position of tornado occurrences and position and distance of the associated 500-mb. low center. This part was subdivided into cases of northeasterly moving tornadoes and those of southeasterly moving tornadoes. Using the consolidated plottings for each subdivision, definite trends were found.

Analyzing the data for northeasterly moving tornadoes, it was found that the 500-mb. low centers were well scattered in the northwestern quadrant from the tornado in 80 per cent of the cases. Seventy-two per cent of the low centers were located in an area bounded by 95° and 120° West Longitude and 40° and 70° North Latitude.

The mean distance, along with its associated standard error, between the tornado and the 500-mb. low center for this type was 900 ± 500 miles. Fifty-six per cent of the cases fell inside this range. The total range was from 200 to 2,000 miles or 1,800 miles. Figure 2 is a geographic presentation of this subdivision of analysis.

The analysis of the data for southeasterly moving tornadoes brought forth a marked contrast to the previous investigation. Seventy-seven per cent of the 500-mb. low centers were located in the northeastern quadrant from the associated tornado. The centers were very concentrated over the Hudson Bay Region of eastern Canada, which is north-northeast of the tornado area. Seventy-two per cent of the low centers were located in an area bounded by 70° and 100° West Longitude and 45° and 70° North Latitude.

The mean distance, along with its associated standard error, was 1,300 ± 360 miles between the tornado and the low center. Sixty-four per cent of the cases fell inside this range. The total range was from 500 to 2,000 miles. Figure 1 is a geographic presentation of this subdivision and it also points up the concentration of low centers.

The 95th meridian was the main geographic boundary between the two cases with 92 per cent of the northeasterly type on the west side and 88 per cent of the southeasterly type on the east side.

To explain the significance of the findings, it is necessary to associate them with the upper air waves. While the circumpolar westerlies are primarily zonal, i.e., parallel to the parallels, they undergo north-south undulations so that the isobars and wind directions generally coinciding have a somewhat sinuous or wavy pattern.

Conclusions

In conclusion, the investigation has disclosed definite relations between the direction of a tornado and its position with respect to associated upper air wave and its parent low center. Figures 3 and 4 emphasize the contrasting upper air features associated with the southeasterly and northeasterly moving tornadoes. The direction of tornado movement coincides very closely with the 500-mb. wind direction as the wind blows counterclockwise around the parent low center. A correlation coefficient of + 0.88 substantiates this finding.

The axis of the upper air wave for the northeasterly moving tornadoes lies along the 105th meridian with the general position of the low center located near the U.S.-Canadian boundary. The heart of the tornado area is located approximately 900 miles southeast of the 500-mb. low center.

The axis of the upper-air wave associated with the southeasterly moving tornadoes lies along the 80th meridian with the approximate position of the low center over the southern region of Hudson Bay. The center of the tornado belt is roughly 1,300 miles southwest of the parent upper air low center.

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Office of Education Support for Research in Problems in Science Education

In a release dated March 1964, the United States office of Education, through its Cooperative Research Branch, invites applications for the support of projects that are designed to improve science education. The purposes of this program are to (1) develop new knowledge about major problems in education and (2) devise new applications of existing knowledge in solving such problems.

Research proposals may be submitted to any of six programs. They are (1) the Basic and Applied Research Program, (2) the Curriculum Improvement Program, (3) the Developmental Activities Program, (4) the Demonstration Program, (5) the Small Contract Program, and (6) the Research and Development Center Program. The Cooperative Research proposals may relate to one or more of the following problem areas of science education:

1. scientific literacy–clarifying the definition of scientific literacy and ascertaining the characteristics of a scientifically literate person;
2. structure of the science curriculum–examining the structure of the science curriculum throughout all grades, kindergarten to 12, particularly in relation to selection and incorporation of new curriculum materials and methods;
3. evaluation–research and development of new and improved techniques and instruments for evaluating both process and product outcomes of science instruction;
4. teacher education–both inservice and preservice;
5. science for children with learning handicaps–research, development and demonstration of the problem of modifying science instruction to meet the needs of children who are handicapped by learning difficulties;
6. science for the gifted–solving the continuous problem of educating gifted children to their maximums;
7. science youth activities–research into problems that have arisen out of the impact of science youth activities on science education;
8. regional science education improvement projects–assessment, improvement or development of science education programs on a regional basis.

Detailed information on any phase of the programs may be obtained from the Cooperative Research Branch, office of Education, U.S. Department of Health, Education and Welfare, Washington D.C. 20202.