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UNITED STATES DEPARTMENT OF COMMERCE
U.S. WEATHER BUREAU
Washington 25, D. C.
March 24, 1955

TORNADO FORECASTING CRITERIA DEVELOPED AT NEW ORLEANS FOR THE NEW ORLEANS FORECAST DISTRICT:

1. MAJOR TORNADOES[1]
2. TORNADO FORECASTING[2]

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1. MAJOR TORNADOES

INTRODUCTION

Tornadoes vary greatly in size and intensity; official reports of tornadoes indicate that they range in diameter at the ground from only a few feet up to at least 2 miles*, and intensity varies from complete destruction of everything in the path of a severe tornado to little if any damage in the path of others. The fact that there is such a great difference in size and intensity of tornadoes has led us to believe that certain synoptic and dynamic conditions in addition to instability must be met in order to produce major tornadoes. The term major tornadoes is intended to include the more violent tornadoes but not the weak ones. In other words, tornadoes that would cause numerous deaths and considerable damage were they given an opportunity would be classed as major tornadoes while those which most likely would cause few if any deaths and destroy only weak structures would not be classed as major

[1]Manuscript received Oct. 19, 1954; revised Nov. 23, 1954
[2]Manuscript received Nov. 18, 1954.
*J. P. Finley cites several cases. Woodward, Oklahoma tornado of April 9, 1947 maximum width 1.8 miles.

tornadoes. It is a safe assumption to say that about 95 percent of the tornado deaths are caused by major tornadoes.

Every severe thunderstorm is potentially a tornado threat but fortunately only a few spawn funnels that reach the ground and only a very few of these can be classified as major tornadoes. Many thunderstorms have pendent clouds or funnels at some time during their life span. Pendent clouds are observed very frequently in the New Orleans area and rather frequently they dip down as waterspouts over Lake Pontchartrain. We have observed many waterspouts over Lake Pontchartrain and from our observations do not believe these should even be considered in the same class as tornadoes; many dust devils we have observed in west Texas and other southwestern areas are larger and more intense and more destructive.

It is obvious that many major tornadoes may occur which do not result in deaths; however, it should also be obvious that most of the casualties must be caused by severe or major tornadoes. With this in mind we initially chose a minimum of 10 deaths on a single day as being a major tornado day. We emphasize that this selection does not say that only days with 10 or more deaths are major tornado days, nor does it preclude the slight possibility of a large number of deaths being caused by a weak tornado or even a strong wind that happens to strike weak structures. Table 1 is a list of all the dates that were used in obtaining the model and minimum values. There are some dates included on which fewer than 10 people were killed; these were included merely because we were interested in them and their addition does not alter the model appreciably or change the minimum requirements for major tornadoes.

Data were generally averaged so as not to smooth out or reduce any elements. Surface low central pressure, eastward pressure gradient, shear value, the maximum velocity of jets, distance of first tornado from low center, distance of 60°F. surface dew point from first tornado, and distance of the jets from the first tornado were all straight averages. Direction of jets and direction of first tornado from surface Low are predominant directions. Isobars and confluence lines were drawn chiefly by inspection.

THE MAJOR TORNADO SYNOPTIC MODEL

Figure 1 is a model of the synoptic map generally observed 6 to 12 hours before major tornadoes occur. With few exceptions the 0630 CST surface and the 0900 CST upper air data were used since most of the tornadoes started in the afternoon. A few of the tornadoes occurred during other hours of the day and maps 6 to 12 hours prior to occurrence were used but for convenience we shall refer to our data as 0630 and 0900 CST.

Observing the model map we note that the central pressure of the Low is 998 mb. (varying from 985 to 1005 mb.). The T (tornado zone) on the map is 350 miles east-southeast of the low center, and is the average

Table 1. - List of tornado cases used in study.

DATE	DEATHS	DATE	DEATHS
Feb. 12, 1945	41	May 15, 1949	7
Apr. 12, 1945	135	May 21, 1949	51
Jan. 4, 1946	30	Nov. 24, 1949	15
Jan. 29, 1947	7	Feb. 12, 1950	35
Apr. 9, 1947	169	Apr. 28, 1950	11
Apr. 29, 1947	24	Mar. 21-22, 1952	208
May 31, 1947	6	Mar. 13, 1953	20
June 1, 1947	36	Apr. 18, 1953	8
July 3, 1947	10	Apr. 30, 1953	20
Dec. 31, 1947	20	May 10, 1953	12
Mar. 18-19, 1948	43	May 11, 1953	125
Mar. 25, 1948	13	June 7, 1953	11
Mar. 26, 1948	23	June 8, 1953	142
Nov. 4-5, 1948	12	June 9, 1953	90
Jan. 3, 1949	59	Dec. 5, 1953	38
Mar. 26, 1949	21	Mar. 13, 1954	8
Mar. 29-30, 1949	4	May 1, 1954	2 or 3
Apr. 30, 1949	9	May 30, 1954	6

(1945-1953) total deaths attributed to tornadoes 1802
(1945-1953) deaths included in this study 1455

distance and direction from the 0630 CST surface low center of the first tornado reported. The average pressure difference from the surface low to a point 700 miles in an easterly direction was 17 mb. (varying from 11 to 25 mb.). The 60° surface dew point line averaged about 60 miles south of position where first tornado occurred. There is a pronounced confluence on the surface map as well as on the 850 mb. chart a short distance upstream from where the first tornado started.

From the 0900 CST constant pressure charts we found that the average strength of the low level jet (850mb.) was 48 knots (varying from 30 to 90 knots) and the average speed of upper jet (500 mb) was 73 knots (varying from 45 to 110 knots). Since average values are so strong, we readily suspect that it takes rather vigorous synoptic conditions to produce major tornadoes. In general, we would say that major tornadoes are more likely to occur with weaker conditions in summer than in other seasons. The shear value listed as 32 will be discussed later. The positions of the jets in relation to surface Low are (a) low level jet 340 miles east and (b) high level jet 120 miles southeast. Of great significance is the position of the T (tornado zone) in relation to the jets; (a) directly under the low level and (b) 150 miles southeast of upper jet.

The following are temperature and moisture data taken from the 850 and 500 mb. charts. These are the average values of the air aloft over the

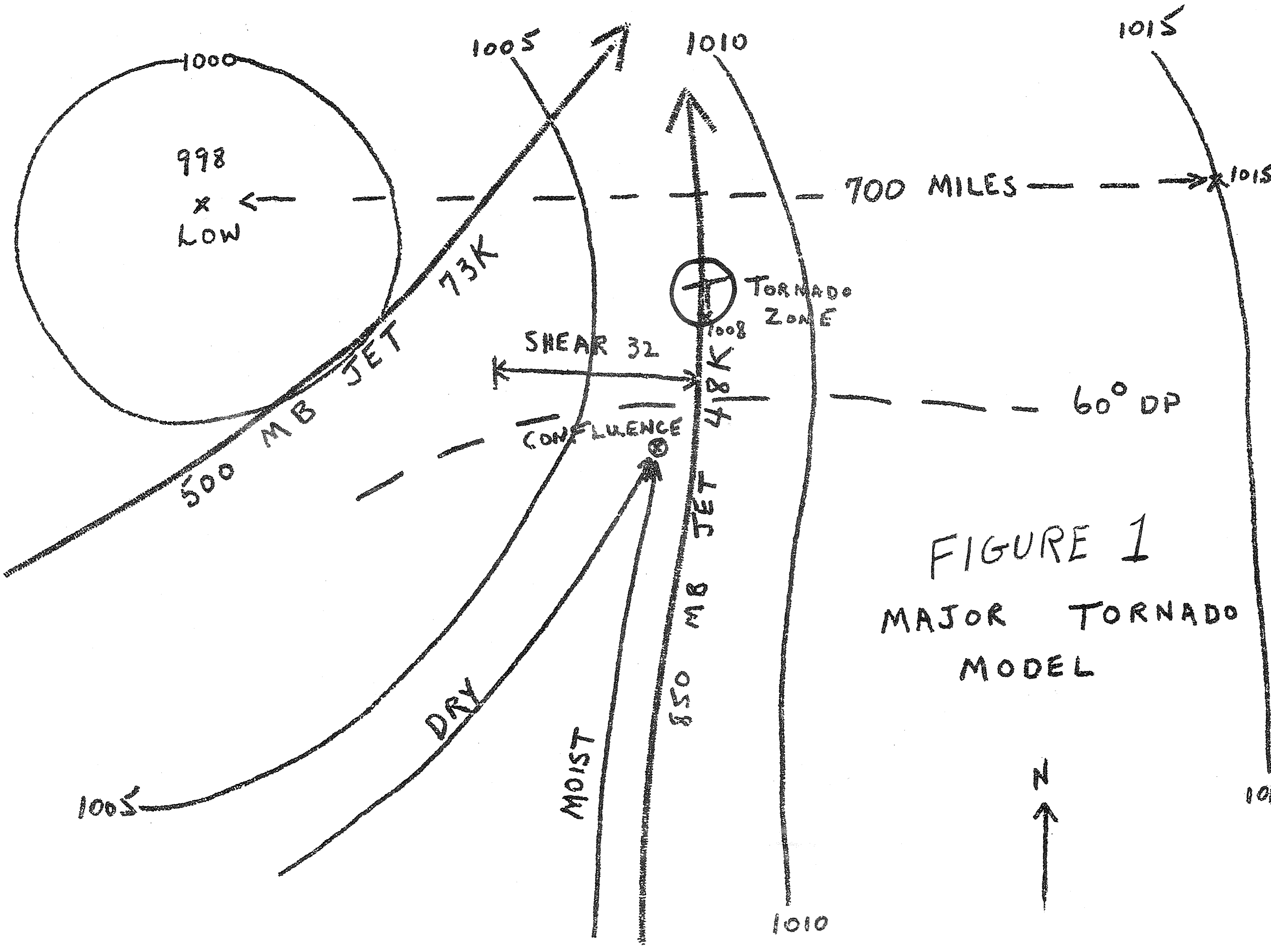


FIGURE 1
MAJOR TORNADO
MODEL

spot where the first tornado occurred, generally 6 to 9 hours before occurrence. (a) From the 850-mb. chart the average temperature was 15° C. (varying from 8 to 22° C.) and average dew point 10° (varying from 5° to 14° C.). (b) From the 500-mb. chart the average temperature was -14° C. (varying from -9° to -18° C.). This gives an average stability index of -2, which varied from + 3 to -8. These values are not too significant since considerable change could take place before the actual tornado occurred. It is likely that the stability index reached at least -3 in most cases before the tornado occurred.

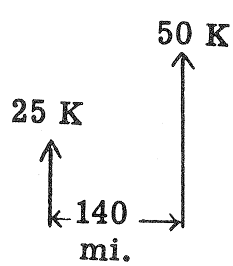
COMPUTATION AND IMPORTANCE OF SHEAR VALUE

The shear value is computed by determining the strength of the low level jet and subtracting the wind speed at 2 degrees of latitude (or approximately 140 miles) to its left. This method was used for simplicity and because any error is slight; the actual shear will almost always be equal to or greater than this value.

This low level shear has proved to be very important for tornado-genesis. We have found that a narrow strong low level jet is much more favorable for producing severe tornadoes than a broad zone of strong winds. This shear also indicates low level convergence and conversely the shear to the right of upper jet indicates divergence. Also usually accompanying a narrow strong southerly low level jet is a sharp tongue of moist air which further enhances tornado-genesis. In some of the tornado cases studied, large shear values were found even though the low level jet was below average value (example 2 below). A good example of this was the 0900 CST data on May 11, 1953, the day of the San Angelo, Texas tornado. On that day the low level jet over San Angelo was only 40 knots but the shear value was at least 35 since 140 miles to left of jet there was little if any parallel component of the wind. The average

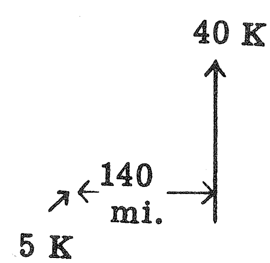
Examples:

1



Shear value 25 K / 140 mi.

2



Shear value 35+ K / 140 mi.

shear value for all the tornadoes studied was 32 with the weakest value about 20. The shear values, 2 degrees to right of upper jet, were also roughly computed and averaged out about 30. Both the upper level shear and the low level shear are important but perhaps, because more data are available at the lower levels, the low level shear appears to be the more significant.

MINIMUM REQUIREMENTS FOR MAJOR TORNADOES

Things to look for on the 0630 CST synoptic map and 0900 CST constant pressure charts for possible afternoon tornadoes are:

1. Surface pressure of 1005 mb. or less.
2. 850-mb. low level jet of 30 knots or more.
3. Surface pressure gradient of 11 mb. or more 700 miles in an easterly direction.
4. 500-mb. upper level jet of 45 knots or more.
5. Low level shear value of 20 knots or greater per 140 miles.

If these criteria are present with sufficient moisture in low levels, major tornadoes are likely. Even if only one of these is missing, chances of major tornadoes are quite slim.

A study was made to determine the percentage of tornado occurrences in which these minimum values were present. Time did not permit a study of all days in the last 10 years but 6 months in 1953 and portions of other years were checked to establish a trend which we consider representative. It was found that tornadoes (many of which were weak) were reported about 60 percent of the time when these minimum requirements were present. A few weak tornadoes were reported on days when minimum requirements were not present. On 30 days from 1945 through 1953, 10 or more people were killed by tornadoes. On only one day (Aug. 17, 1946, when 11 were killed in southern Minnesota) were the minimum requirements not met. The remaining 29 cases all met or exceeded the minimum requirements for major tornadoes.

Since finishing this study, Finley's remarkable First Prize Essay on tornadoes published in 1890 in the American Meteorological Journal came to our attention. It is gratifying to find that many of our conclusions are very similar to those of Finley.

2. TORNADO FORECASTING

INTRODUCTION

Major tornadoes occur only when there is sharp contrast in weather elements, both horizontally and vertically. The primary purpose of tornado forecasting for the general public is to save lives. Since about 95 percent of the tornado deaths are caused by major tornadoes, we believe that only situations with chance of major tornado activity should be given the public as possible tornadoes. Weaker affairs can be included as severe thunderstorms.

The major tornado belt lies about 300 miles north and south of a line from Big Springs, Tex. east-northeast through Little Rock, Ark. to extreme northeast Tennessee. This is the area where the warm moist Gulf air meets the cold dry air most frequently. There is no definite tornado season in this belt although they occur most frequently in March, April, and May. Major tornadoes are possible anywhere, but favorable conditions for major tornadoes occur far more frequently in this belt.

Since over 42 percent of all tornado deaths in the United States during the last 37 years occurred in the New Orleans Forecast District, we have spent much time trying to determine just what dynamic and synoptic conditions are necessary to produce major tornadoes. We are convinced that, if we can issue tornado warnings on days when major tornadoes are likely, the number of tornado deaths can be reduced. Major tornadoes like other major weather phenomena vary in intensity and frequency from year to year. In some years there are several major tornado days, for instance 1953, and other years there are few if any.

Major tornadoes occur in two different types of air masses.[1] Type I is characterized by moist air in lower levels, usually 5000-6000 feet deep, and dry air aloft. In type II, the air is moist to high levels. There appears to be no difference in synoptic patterns necessary to produce major tornadoes in either air mass. However the tornadoes associated with each type have different characteristics. In type I, we believe that the tornadoes form and dip down from the sides or rear of Cumulonimbus cloud.[2] The funnel cloud is usually visible in this case. In type II, we believe that the tornadoes usually form near center of Cumulonimbus cloud[2] or at least in the rain area. The funnel cloud, if there is one, is usually obscured by precipitation. If the low clouds are practically on the ground, there is no visible funnel cloud, only the vortex. Tornadoes in type II air mass offer great threat to life since they usually can not be seen when approaching. We believe that type I tornadoes are more severe but that they offer less threat to life because the funnel cloud is usually visible. A good example of tornadoes of the two types occurred on the same day, at San Angelo

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[1]Type I and Type II, as typed by Fawbush and Miller.
[2]This opinion is based strictly on observation.

(Type I) and at Waco (Type II). One of the authors (W. C. Conner) inspected the paths of these two tornadoes soon after they happened, and it is his opinion that the San Angelo tornado was the more severe. Advance warning was credited by the Texas Department of Public Safety with saving many lives in San Angelo.

CRITERIA FOR MAJOR TORNADOES

In a study of "Major Tornadoes" it was found by the authors that the following criteria should be present before major tornadoes are likely:

Criteria to look for on the 0630 CST surface and on the 0900 CST constant pressure charts prior to major tornado activity:

1. Surface pressure of 1005 mb or less.
2. 850-mb jet of 30 knots or more.
3. Surface pressure gradient of 11 mb or more from low center to a point 700 miles in an easterly direction.
4. 500-mb jet of 45 knots or more.
5. Low level cyclonic shear value of 20 knots/140 miles or greater.

If all of these criteria are met and there is sufficient moisture in low levels, major tornadoes are likely. (It was found that the stability index should be at least minus 2 in T Zone[3] by time of occurrence. This requires sufficient moisture in low levels to be able to forecast at least -2 stability index in T Zone within 3 to 9 hours). As was pointed out in the preceding report, tornadoes were reported on about 60 percent of the days when these criteria were present and on many of these days only minor tornadoes were reported which caused a few deaths. This means that these criteria were present when over 95 percent of the tornado deaths occurred.

Just because these criteria are present does not mean that a tornado forecast is mandatory. At times, the synoptic pattern is changing rapidly. If the synoptic conditions barely meet the requirements, then the future intensification or weakening will determine the likelihood of major tornadoes. Usually if the surface low is not filling and is moving rapidly or even at a moderate speed, chances for major tornadoes are good. Also if tornadoes or funnels aloft were reported on the preceeding day and all criteria are present, chances for major tornadoes are very good. No completely objective method can be used for tornado forecasting, many decisions must still be made by forecasters as

[3]Area where first tornado occurred or is expected to occur used throughout report.

to whether or not a synoptic situation warrants a tornado forecast.

DETERMINATION OF T ZONE

After it has been determined that major tornadoes are likely and that a forecast should be issued, the all-important question is:

In what area are tornadoes likely to occur?

The following rules are used to determine the T Zone and the area to be warned:

1. Locate jet on 500-mb. chart. The upper (500-mb.) jet is located by using available winds, contour lines, and isotherms. The area under the upper jet and 300 miles to its right is the likely area for tornado occurrence.

2. Classify tornado situation. The tornado situation is classified into Eastern and Western types, according to the position of the upper jet in relation to the surface low center. If the upper jet is more than 250 miles to right (or southeast) of the surface low, it is classified as Eastern type. If upper jet is less than 250 miles to right of low center, it is Western type. The Eastern type is usually an occluded low and the Western type an open wave. Most of the Eastern type occur east of the Mississippi River and western type to west but this is not always the case. Tornadoes of the Eastern type usually occur far from the surface low (400-600 miles ESE to SSE), while the western type occur nearer the low (250-450 miles NE to SE). (See fig. 1) If the upper jet is to left of the surface low, tornadoes usually occur northeast of the low. As the upper jet advances to the right in relation to the surface low, the T Zone also revolves to the right from northeast toward southeast around the surface low. See diagram below:

It was found with the Western Type that the first tornado begins within 85 miles of a point 350 miles ESE of the 1230 GMT surface low center in about 65 percent of the cases. (See fig. 2)

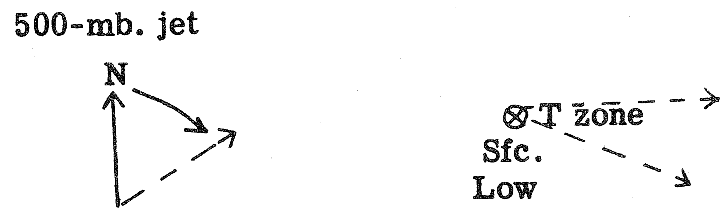
3. Locate and analyze the 850 mb jet. This is considered one of the most important steps to determine where the first tornado is likely to occur. The strength and structure of low level jet, cyclonic shear value, and moisture pattern are determined. At times. scarcity of

wind data in an area makes it difficult to determine just where and how strong the low level jet is. In these cases, the mid-morning surface winds and the low level moist tongue indicate the position and strength of the jet. The first tornado usually begins under the position of this low level jet and in almost all cases within 75 miles of this position. This limits the T Zone.

4. The 60° F. dew point line is sketched in on the 0630 CST surface chart. This is usually near the warm front if there is one. Most major tornadoes begin near or slightly north of this line, but not more than 300 miles to the north and a few have occurred well to the south. The low level jet was very strong (over 60 knots) when tornadoes began well to the north of this line. Tornadoes occur along or south of a warm front but not on the ground to the north of a strong warm front.

5. Low level confluence. Using both the surface and 850-mb. charts sketch in the line where the warm moist flow and the dry air to its left converge. This confluence line should always be present. Tornadoes usually begin just to the right of this confluence line but not to the left. At times it is possible to locate a confluence focal point along this line. The T Zone will be a short distance upstream (parallel to upper jet) from this focal point. The confluence method has given excellent results, especially when the focal point can be located.

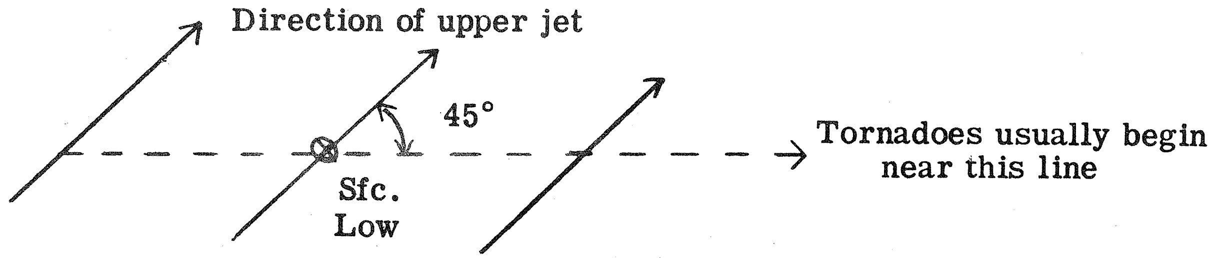
6. Direction of upper jet. If the direction of the upper jet is S to SSW, tornadoes usually occur near or just east of the surface Low. The more westerly the component of the jet, the farther east or southeast from the surface low center the tornadoes are likely to begin. (See diagram below.) (This reference to the position of the surface low is at the time the tornadoes occur and not the 0630 CST position.) This



As upper jet veers, T zone moves to right from Low

is probably due to the form of the divergence pattern aloft. A good prognosis of the direction and speed of movement of the surface low helps to pin down the T Zone. If a line, which is at a 45° angle to the right of the upper jet, is extended through the surface low (0630 CST) the first tornado will usually occur near or along this line. (See diagram on next page.)

<u>After deciding that major tornadoes are likely the following rules are</u>



<u>helpful to determine T Zone (area tornadoes likely to begin)</u>
(Based on 1230 GMT surface map and 1500 GMT upper air):

1. Within 75 miles of low level jet (850 mb).

2. Within 300 miles to right of upper jet (500 mb).

3. Within 300 miles of 60° F. dew point (usually near).

4. Short distance upstream from low level confluence focal point or just to right of confluence line. (Confluence line should always be present, at times difficult to locate focal point.)

Western Type

1. Within 85 miles of a point 350 miles ESE of surface low (65% of cases).

2. If upper jet is to left of surface low center, T Zone is NE to E of low (200-450 miles).

3. If upper jet is near or less than 250 miles to right of surface low center, T Zone is ENE to ESE of low (between 200-450 miles).

4. If direction of upper jet is S to SSW, T Zone is near or slightly E of surface low.

5. If direction of upper jet is SW to W, T Zone is usually quite a distance E to SE of the surface low.

6. T Zone is usually located along a line extending through the surface low at an angle of about 45° to right of upper jet.

Eastern Type

1. If upper jet is over 250 miles to right of surface low, T Zone is usually 400 to 600 miles ESE to SSE from low.

2. Same as No. 6 above.

DETERMINATION OF AREA TO BE WARNED

After the T Zone has been established, the following rules are used to determine the area to be warned:

<u>If there is considerable cross-over of the upper and lower jets, SW over S</u>:

From the T Zone, a line is extended 200 miles parallel to the upper jet and another line from T Zone outward 200 miles and at 45° angle to the first line. The area between these two lines is the most likely area for tornadoes. These distances are more or less averages and depend upon the strength of the tornado set-up and also upon the movement of the system. Any extension of the area should be made from area of heaviest activity and parallel to upper jet but never north of where a strong warm front is expected to be. See figures 3 and 4.

<u>If there is little cross-over of the jets, almost parallel</u>:

The area to be warned should be parallel to the jets and not far from the low level jet. (See fig. 5.) The length of the area is hard to define but usually it should be more than 200 miles. These conditions usually occur with a long north-south trough; sometimes there are separate low centers in the north and south ends of the trough. The area of warning should at least extend from a position ESE of the southern low to a point ESE of the northern low. If it is possible to locate a low-level confluence focal point, start area of warning a short distance (usually 50-100 miles) upstream from this point and extend it parallel to upper jet.

Tornadoes almost always occur in the area where the isobars have cyclonic curvature. Therefore, most of them will occur along cold fronts, instability lines, pressure jump lines, or warm fronts. Occasionally, small low centers will develop in the warm sector when conditions are favorable for major tornadoes. The formation of these lows can be anticipated by watching the pressure changes carefully to the east and southeast of the parent center. Locally excessive pressure falls to the east or southeast in the warm air may indicate that a small center is forming. As soon as it is evident just where the low center is forming, warnings should be issued to include the area along the expected path for about 200 miles, and as long as the Low maintains itself, the threat is present. On February 12, 1950 there was an excellent example of a small Low. It was near Bryan, Tex. at 6 a.m. CST and moved northeastward during the day. Tornadoes occurred near or a little to the east of this Low that afternoon and caused 28 deaths. Another example occurred on December 5, 1953 (day of Vicksburg, Miss. tornado). The small Low developed just south of Shreveport in the early afternoon and moved northeastward into southeast Arkansas. One severe tornado occurred in connection with this Low. The total length of its path was 55 miles and it stayed on the ground continuously for a

21 mile stretch through a forest. Fortunately, this tornado did not strike a populated area.

CONCLUDING REMARK

Throughout this report, the importance of the dynamic and synoptic conditions in tornado forecasting has been stressed. Nothing has been said about trigger action since it appears that the trigger is present when conditions are favorable for major tornadoes.

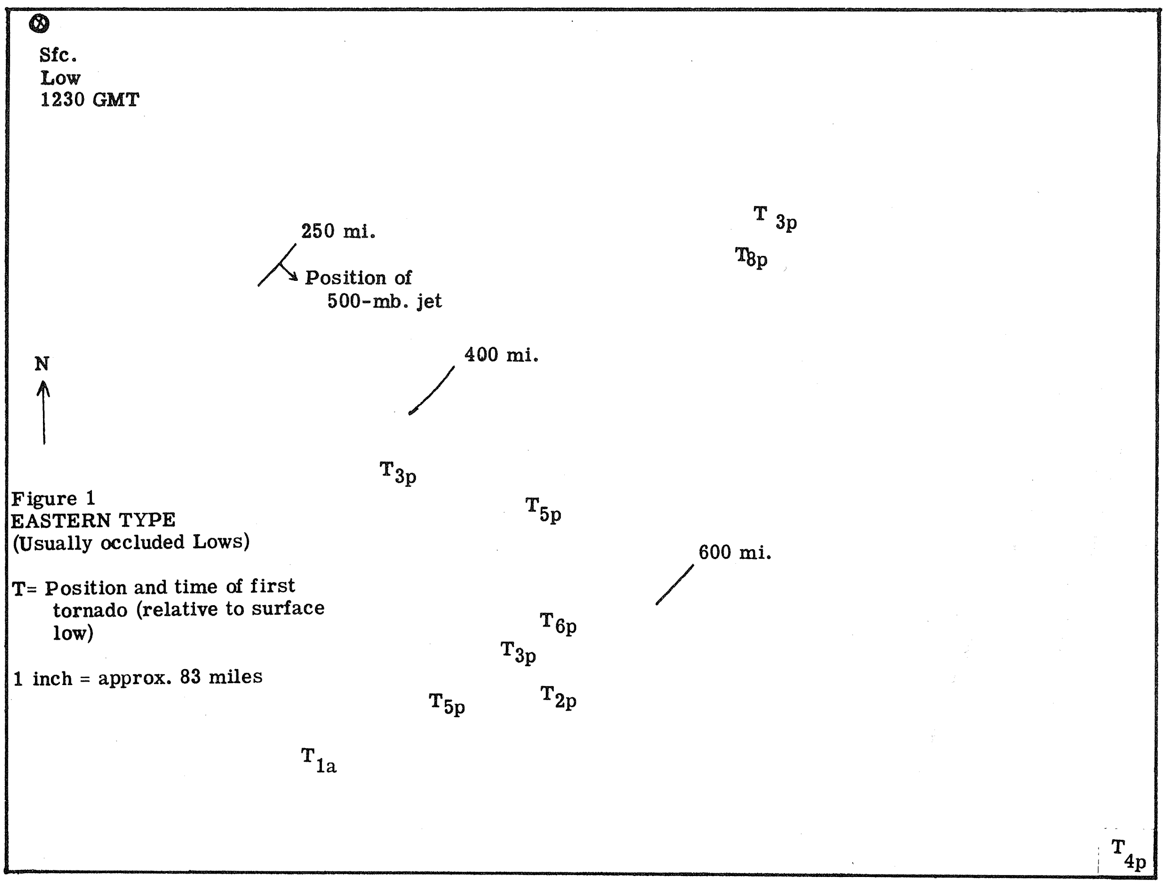


Figure 1
EASTERN TYPE
(Usually occluded Lows)

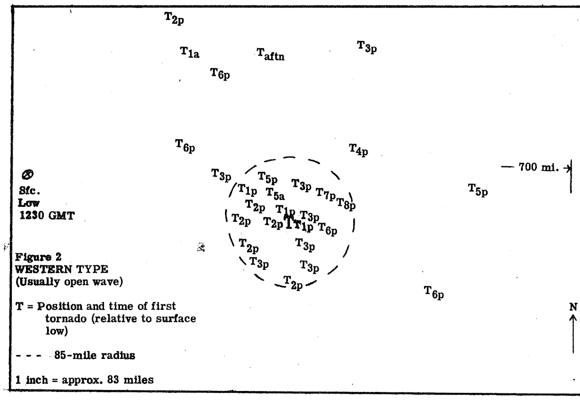


Figure 2
WESTERN TYPE
(Usually open wave)

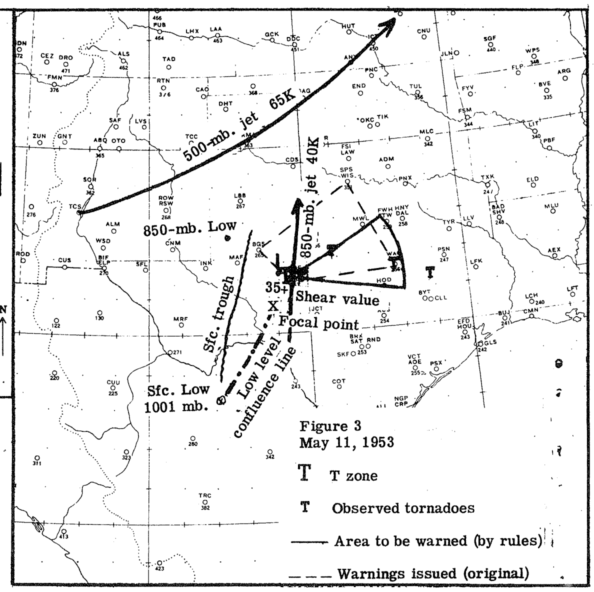


Figure 3
May 11, 1953

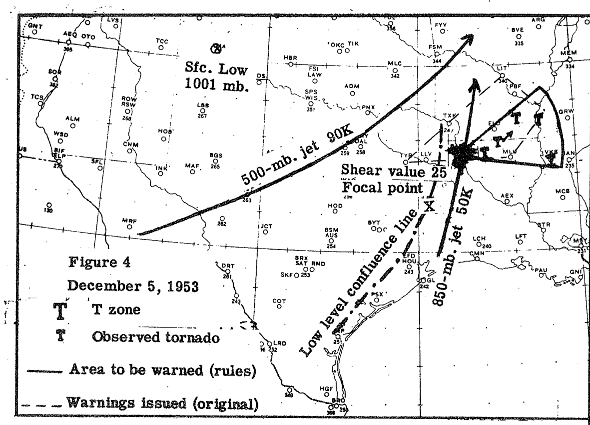


Figure 4
December 5, 1953

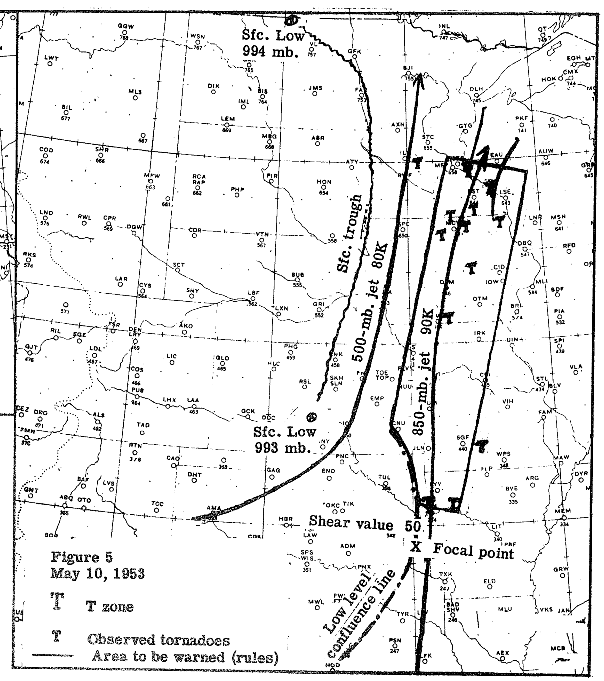


Figure 5
May 10, 1953

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU
Washington 25, D. C.

March 30, 1955 R-3.1

MEMORANDUM

(To: All District Forecast and FAWS Centers, and 1st order stations in New Orleans District)

Subject: Papers on "Tornado Forecasting Criteria Developed at New Orleans for the New Orleans Forecast District"

Attached are two companion papers which present some observations of synoptic relationships associated with tornado occurrences in the New Orleans Forecast District. It is believed that stations in the District will find these results interesting and helpful.

Harry Wexler
Chief, Scientific
Services Division

Attachments

File: 701 MEMO (Papers on "Tornado Forecasting Criteria Developed at New Orleans for the New Orleans Forecast District") Washington, D. C. 3-30-55