Tornado Proximity Soundings

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Abstract

Soundings near the time and site of tornado occurrences are examined to determine the air-mass structure ahead of or near the tornado. From the cases studied here, it is concluded that (a) the "typical" inversion was lifted with time such that it was completely absent at the time and site of the tornado and (b), at the same time, the low-level moisture was lifted to great heights. Examples of the conversion of the precedent sounding to the proximity sounding and of a post-tornado case are shown. Composite charts of the moist layer depth and of the Showalter Stability Index prior to and near the time of tornado occurrences are presented.

The type of sounding that is characteristic of an air mass in which tornadoes develop has been a topic for considerable discussion among meteorologists as well as the subject of numerous papers [1], [2], [3]. These discussions and papers have usually dealt with soundings taken upstream within the warm air and before tornado development. Such precedent soundings are usually removed in both time and space from the actual tornado formation. It seemed necessary, therefore, to examine these precedent soundings in conjunction with those nearer the site and time of tornado occurrence. The objective of this study was to determine the air-mass structure ahead of or near the tornado, not the structure after activity had occurred.

Some preliminary investigations of a number of soundings over different seasons and localities taken at varying distances and times from tornado occurrences brought out two important items. The first was that tornadoes occur in several air-mass types. The second was that as the time and site of tornado occurrence were approached, the "typical" inversion gradually disappeared and the moist layer became increasingly deep. Thus, it is necessary, when attempting to define or study tornado sounds, to set first some limit in time and/or space since the environment in which the tornado forms is undergoing what appears to be a continuous change. Precedent soundings were then defined as those characteristic of the air mass but removed in time and/or space from the vicinity of tornado occurrence. Proximity soundings were tentatively defined as those taken within 50 mi of a point at which a tornado occurred within the following hour. A proximity sounding thus represents the change, over a relatively small area, in an environment previously characterized by the precedent sounding. A proximity sounding is not necessarily characteristic of the air mass itself.

A brief study was made which was aimed at classifying types of upper-air soundings preceding tornadoes. The result of this study of precedent soundings [4] showed that from a thermodynamic viewpoint, there are four broad types of soundings that exhibit convective instability with or without inversions below 15,000 ft.

With this background, all available data were examined in order to select as many upper-air soundings as possible that were taken within 50 mi of a point at which a tornado formed within the following hour. The principal objective of this study was to provide a background upon which to develop and improve practical methods for forecasting severe local storms and tornadoes in particular. A secondary objective, for the present at least, was to provide a basis for a realistic approach in future studies of the microstructure of tornado development and of the tornado itself. Such information should be of much value in the determination of the type of data needed in investigations of the microstructure.

The time and location of all tornado occurrences from 1945 through 1954 were plotted on daily maps so that a total of 2465 individual tornadoes was considered in the selection of data for this study. A tornado proximity sounding was then defined as one in which all of the following criteria are met:

a. Tornado occurrence within 50 mi of a raob station
b. Tornado occurrence within the hour following the release of the instrument

c. Tornado occurrence within the same air mass as that in which the sounding was taken

d. Sounding taken ahead of or near the parent thunderstorm, not behind it. This study deals with the air mass structure ahead of or near the tornado rather than the air mass structure after activity has occurred. However, one example of a post-tornado sounding is shown later in fig. 9.

With such restrictions, 24 soundings were found and selected for study. While these soundings were representative of more than one type of air mass, they all had two common features. The most significant of these was the complete absence of the "typical" inversion and a second common feature was the penetration of moisture to great heights.

The 24 proximity soundings were then classified according to the precedent sounding types and 17 cases were classified as Type I according to the Fawbush-Miller classification [3]. Because of various data limitations, six of these could not be used. For the remaining 11 cases, surface maps were prepared and soundings were plotted for all stations that were within the warm air. These 11 cases represent tornado occurrences in the vicinity of Omaha, Nebraska, Columbia, Missouri, Oklahoma City, Oklahoma, Montgomery, Alabama, Detroit, Michigan, Rantoul, Illinois, and Altus, Oklahoma. The occurrence dates ranged from 20 February to 5 June. These 11 soundings were then analyzed to determine the various parameters currently used in severe local storm forecasting. One of the most interesting features brought out in this analysis was the change in depth of the moist layer over the area in which tornadoes developed. A list of the stations, dates and times of the proximity soundings, along with individual values of the Showalter Stability Index (SSI) and depth of the moist layer, is given in table 1. It may be noted that four of these 11 soundings were released in light rain showers during a thunderstorm. Thus, it might be expected that moisture values would be greater within the cloud area than outside the cloud area. Even so, these are proximity soundings and must be considered here.

An example of the conversion from the precedent sounding to the proximity sounding is illustrated by the two soundings taken at Oklahoma City shown in fig. 1. Note in fig. 1a (precedent sounding) that the air mass is characterized by a shallow moist layer (2700 ft deep) and marked parcel stability. The proximity sounding taken 5 hr later, fig. 1b, shows that the inversion no longer exists and moisture has penetrated to a depth of over 13,000 ft. (Humidity data above this level are missing.) A tornado was reported 20 mi south-southeast of Oklahoma City about one hr after the sounding shown in fig. 1b.

At the same time that the moist layer deepens over the area where tornadoes develop, the moist layer apparently becomes more shallow upstream. At the next raob station upstream, Ft. Worth, shown in fig. 2, the depth of the moist layer has increasing also, but only from 5400 to 6700 ft. Meanwhile, the depth at San Antonio, fig.

TABLE 1. Tornado proximity soundings, Type I.

Station	Date	Time Z	Stability index		Moisture depth		Time of release	Time of tornado	Location from station	Weather at release time
			Prior	Concurrent	Prior	Concurrent				
Columbia	Apr. 7, 1948	03	+4	−2	2,000	25,000	2136	2140	24 NNW	Tstm, no rain
Omaha	May 5, 1950	03	−1	−2	4,600	16,000	2108	2100	25 SSE	TRW−; TRW+ 2056
Oklahoma City	Feb. 20, 1951	03	+6	0	0	25,000	2100	2200	20 SSE	TRW−; TRW+ 2128
Oklahoma City	May 1, 1951	03	−1	−2	13,000	25,000	2100	2130	5 NE	TRW−; TRW+ 2118
Oklahoma City	Apr. 3, 1953	03	+2	+1	800	25,000	2113	2152	35 S	Tstm ended 2128
Maxwell AFB	Apr. 18, 1953	21	−2	−4	9,800	11,000	1500	1500	30 N	No Wx
Selfridge AFB	June 5, 1953	21	−1	−1	2,000	14,000	1600	1605	25 WSW	No Wx till 1638 TRW−
Chanute AFB	Apr. 7, 1954	21	+1	−3	1,800	10,000	1500	15-1530	40 NNW	No Wx till 1535 TRW—
Columbia	Apr. 30, 1954	21	+3	−2	15,000	25,000	1500	1515	20 N	No Wx till 1513, PX ½ RW
Altus	May 1, 1954	21	−5	−3	6,500	8,200	1430	1530	45 SE	TRW−
Altus	May 24, 1954	02	+4	−7	7,000	6,100	2000	2100	25 SE	No Wx
Average			+1	−2	5,700	18,000				

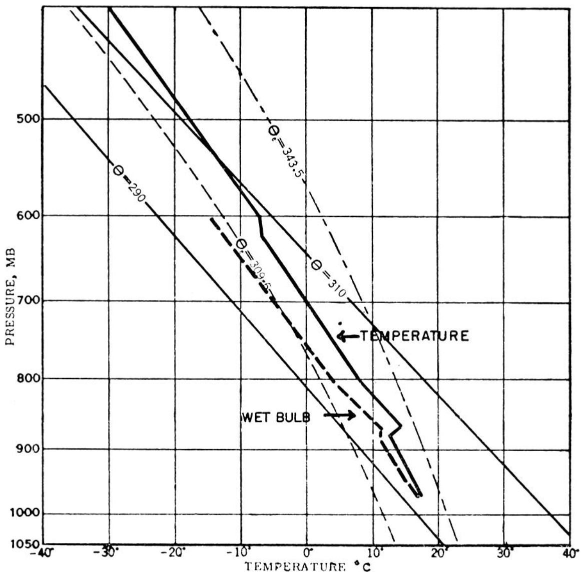

FIG. 1a. Upper-air sounding at Tinker Air Force Base, Okla., 19 Feb. 1951, 1600 CST.

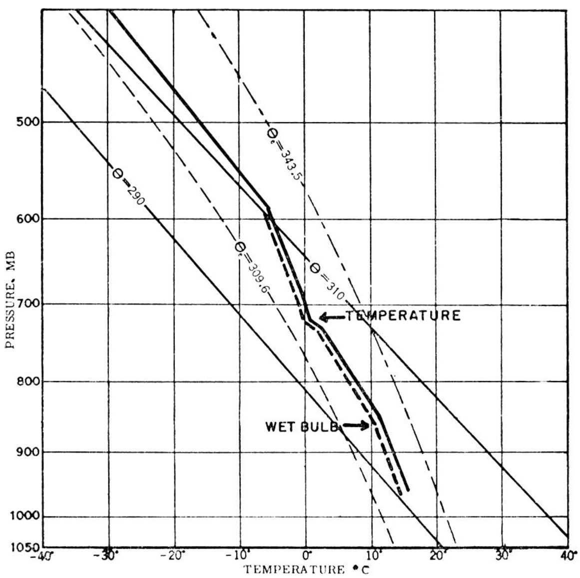

FIG. 2a. Upper-air soundings at Ft. Worth, Texas, 19 Feb. 1951, 0900 C.

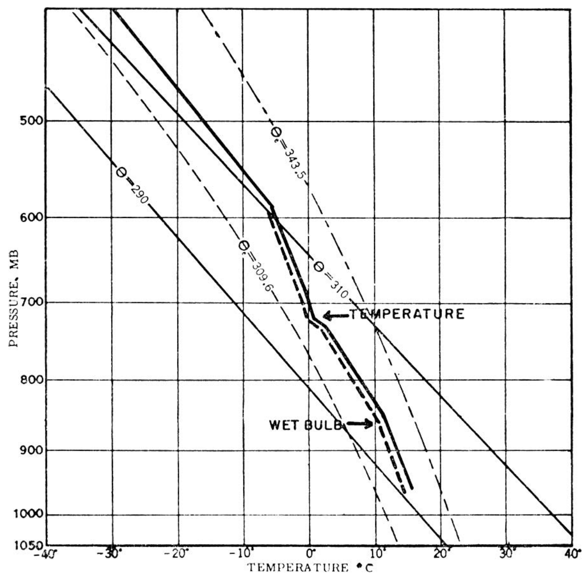

FIG. 1b. Upper-air sounding at Oklahoma City, Okla. 19 Feb. 1951, 2100 C (five hours later than shown in 1a). A tornado was reported 20 mi south-southeast at 2200 C.

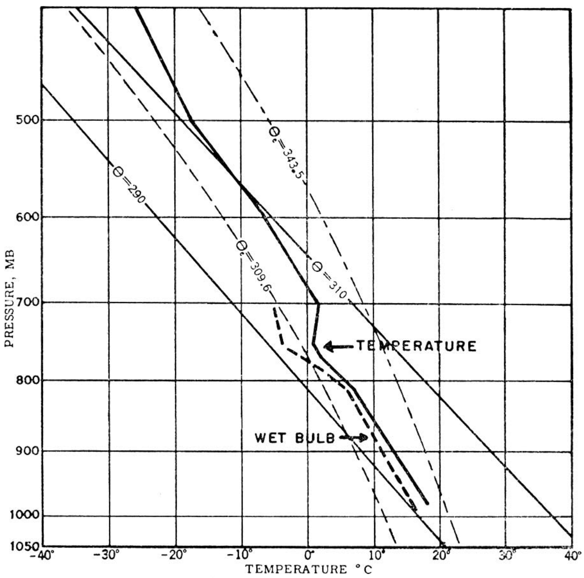

FIG. 2b. Upper-air soundings at Ft. Worth, Texas, 19 Feb. 1951, 2100 C (12 hr later than shown in 2a).

3, has decreased from 4700 to 3800 ft. Farther upstream, Brownsville, fig. 4, the depth has decreased even more markedly, lowering from 4700 ft to a depth of only 2200 ft. (The changes in moist layer depth at these three stations were over a 12-hr period.) Initially, the moist layer was of a more or less uniform depth, but with time increased markedly in the vicinity of the tornado formation, while, simultaneously, it lowered markedly upstream.

With use of data from these 11 proximity sounding cases, a composite chart was prepared by plotting moist layer depths relative to the point of tornado occurrence. Data from 131 soundings were used in the preparation of this composite chart.

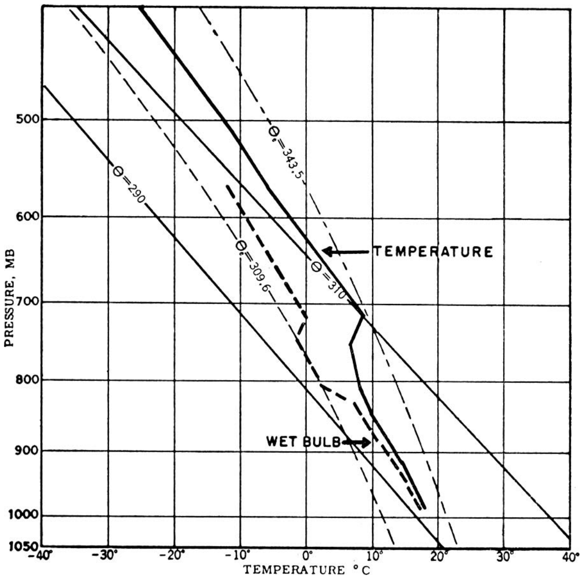

FIG. 3a. Upper-air sounding at San Antonio, Texas, 19 Feb. 1951, 0900 C.

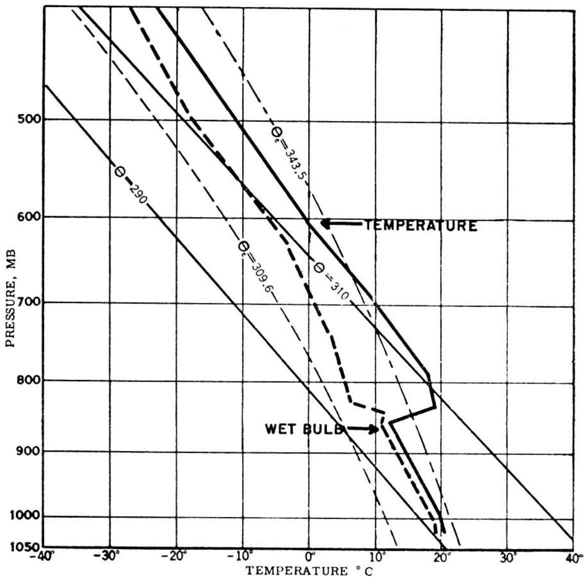

FIG. 4a. Upper-air sounding at Brownsville, Texas, 19 Feb. 1951, 0900 C.

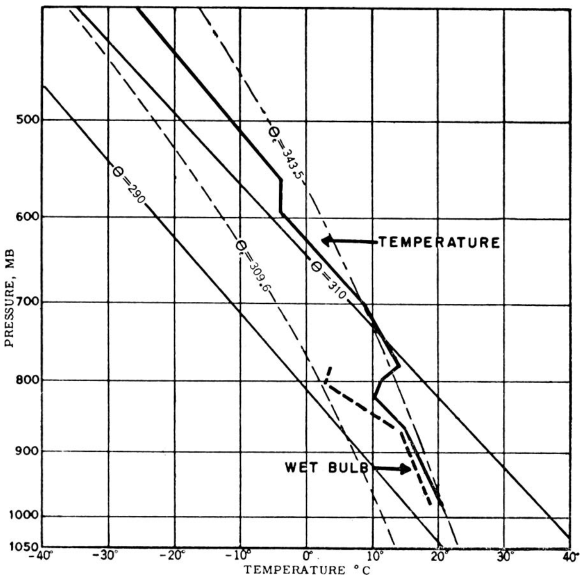

FIG. 3b. Upper-air sounding at San Antonio, Texas, 19 Feb. 1951, 2100 C.

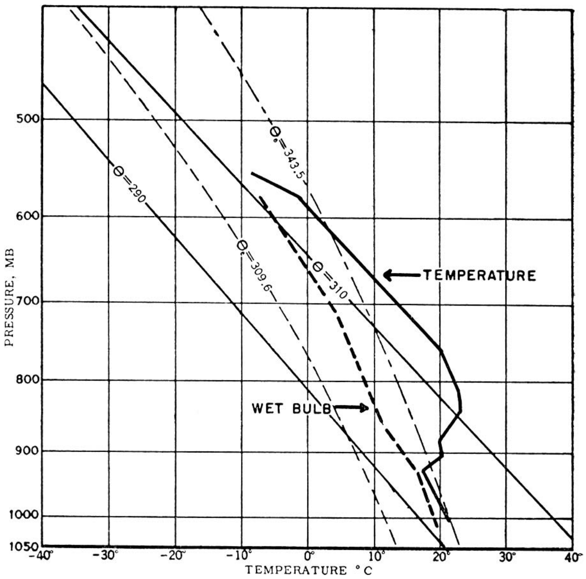

FIG. 4b. Upper-air sounding at Brownsville, Texas, 19 Feb. 1951, 2100 C.

The individual values were averaged over interlocking areas and an analysis of the average depth of the moist layer was made as shown in fig. 5. The average moist layer depth for the 11 proximity soundings was 18,000 ft. Thus, it appears that the tornadoes actually occur within areas of deep moist layers which are surrounded by decreasing depths, with the most pronounced decrease to the south.

A similar composite chart was prepared for moist layer depths 6–12 hr prior to tornado occurrence. Six proximity soundings were taken at 2100 CST and five at 1500 CST. Because of data limitations in the earlier years, prior moisture depths were measured at 0900 CST for both the 1500 CST proximity soundings (a 6-hr time interval) and the 2100 CST proximity soundings (a 12-hr time interval). Data from 173 sound-

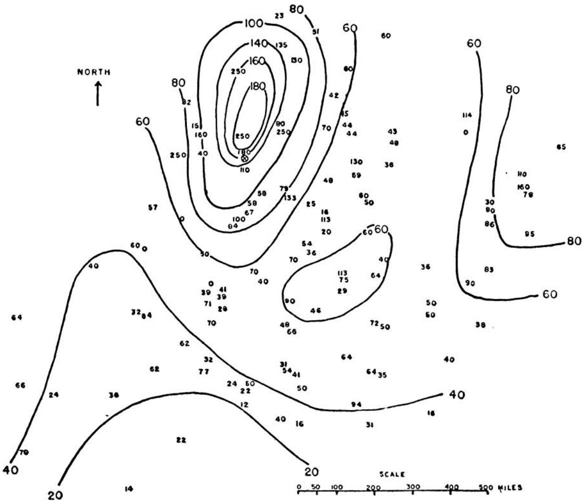

Fig. 5. Composite chart showing moist layer depths in 11 Type I cases. (X) represents the tornado location and the number above represents the average value for the 11 cases.

ings were used in the preparation of this composite chart. In general, data from the same stations were used plus some others which do not take observations at 1500 CST (five proximity soundings were taken at 1500 CST). An analysis of the average moisture depths from these prior soundings is shown in fig. 6. Two features of this analysis are noteworthy. The moisture depth to the south of the area where tornadoes subsequently occurred was rather uniform around 5000 ft whereas in fig 5, the depths decreased markedly to the south to around 2000 ft. Also, in fig. 6,

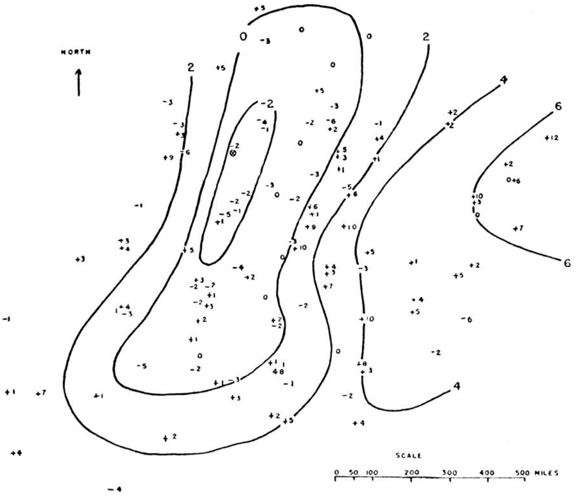

Fig. 7. Composite chart showing the Showalter Stability Index in 11 Type I cases.

the moist layer depths were considerably less in the vicinity of and to the north of the area where tornadoes subsequently occurred than at the time of the proximity soundings.

A composite chart was prepared for the stability index as defined by Showalter [5] and is shown in fig. 7. The average value of the stability index from the 11 proximity soundings was − 2 while the range was from + 1 to − 7. The center of maximum instability is about 100 mi south of the occurrences.

Fig. 8 is a composite chart of the values of the Showalter Stability Index 6–12 hr prior to

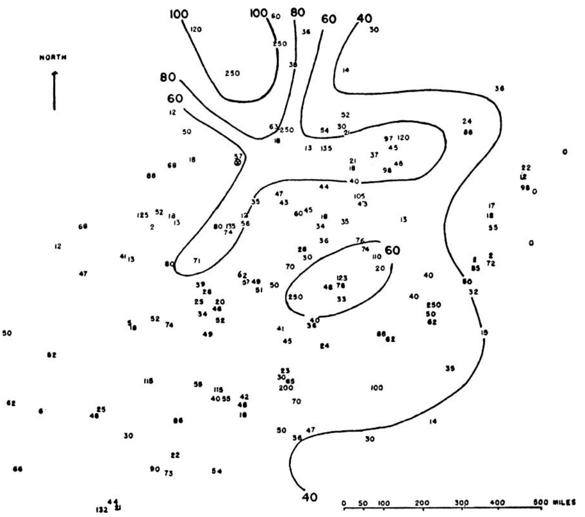

Fig. 6. Composite chart showing moist layer depths 6–12 hr prior to tornado occurrence in the same 11 Type I cases.

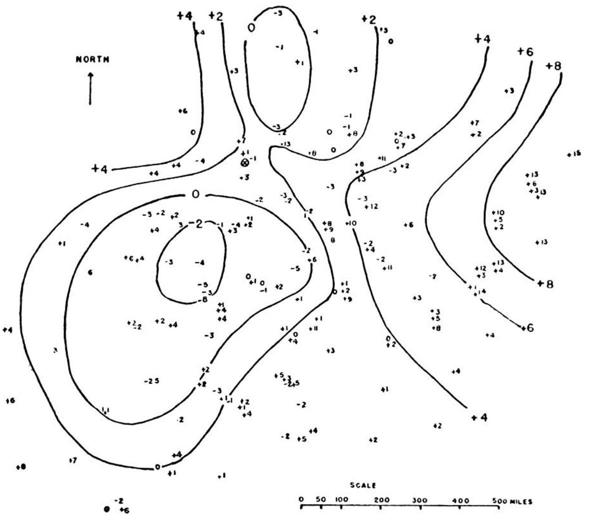

Fig. 8. Composite chart of Showalter Stability Index values 6–12 hr prior to tornado occurrence in the same 11 Type I cases.

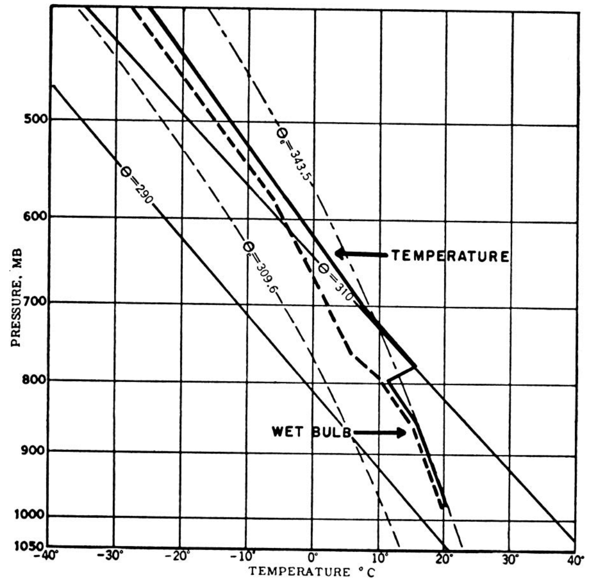

Fig. 9a. Upper-air sounding at San Antonio, Texas, 28 April, 1953, 1000 C.

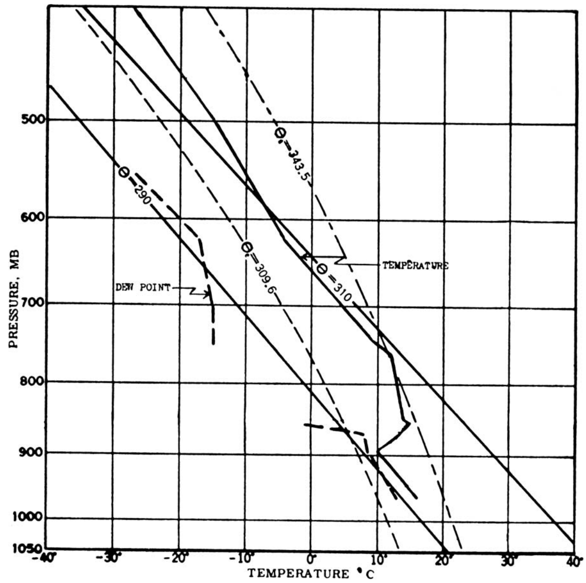

Fig. 10a. Upper-air sounding at Oklahoma City, Okla., 0900 C, 11 April 1955.

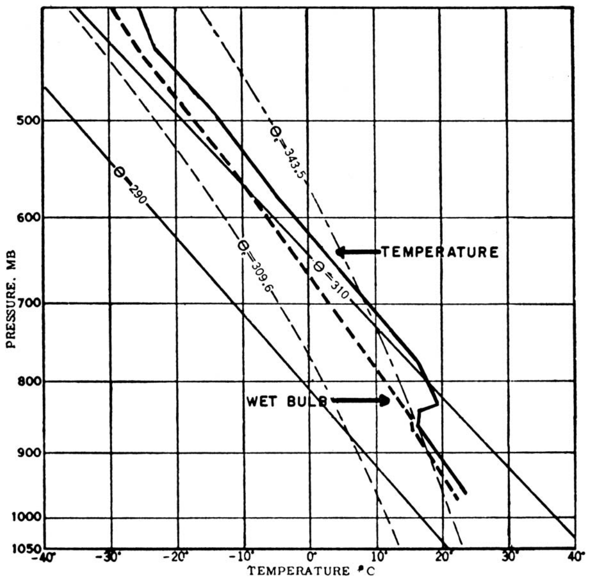

Fig. 9b. Example of a post-tornado sounding at San Antonio, Texas, 28 April, 1953, 2134 C. A tornado was reported three miles north of the San Antonio Airport at 0245 GMT.

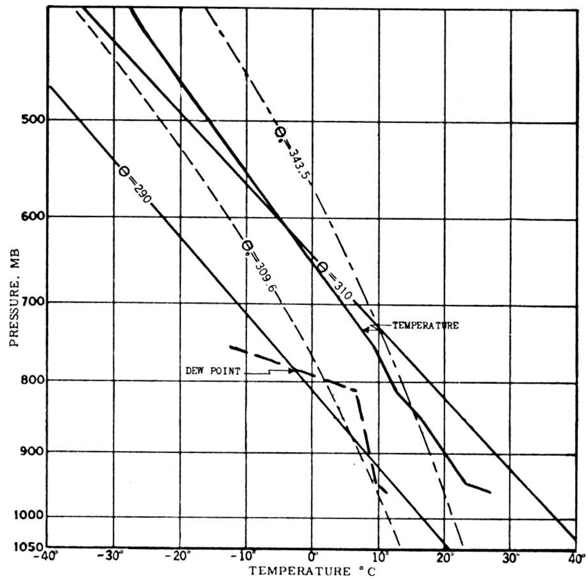

Fig. 10b. Upper-air sounding at Oklahoma City, Oklahoma, 1500 C, 11 April 1955.

tornado occurrence. Data from 173 soundings, all taken at 0900 CST, were used in the preparation of this chart. It may be noted that the center of maximum instability is located about 300 mi to the south-southwest of the area where tornadoes subsequently developed.

As previously noted, this study of proximity soundings has not included post-tornado or post-thunderstorm cases since the principal interest here was with conditions prior to tornado development. However, quite a number of these cases was found, and fig. 9 illustrates a striking example of a precedent sounding followed by a post-tornado sounding. Fig. 9a illustrates the

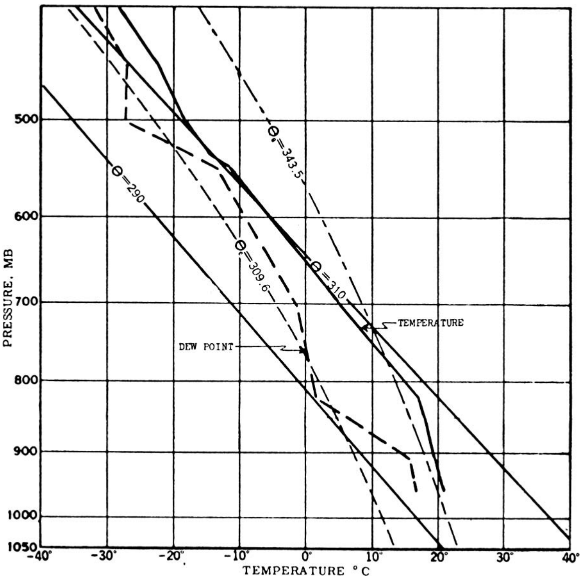

Fig. 10c. Upper-air sounding at Oklahoma City, Oklahoma, 2100 C, 11 April 1955.

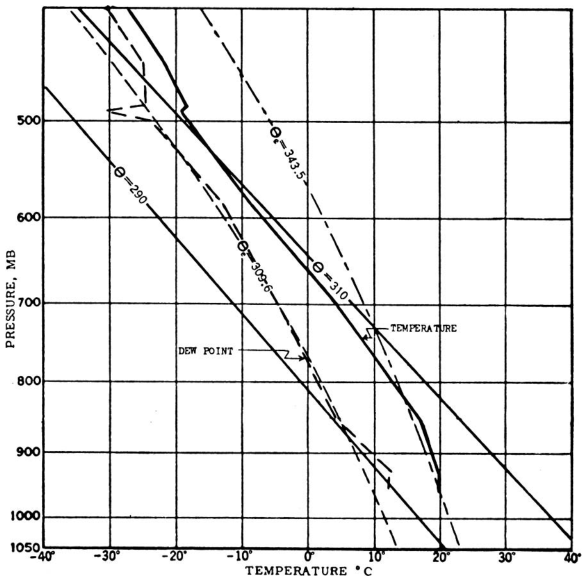

Fig. 10d. Upper-air sounding at Oklahoma City, Oklahoma, 2323 C, 11 April 1955.

San Antonio sounding on 28 April, 1953, 1600 GMT, which was about 11 hr prior to tornado formation. Fig. 9b illustrates the air mass structure about 45 min after a tornado occurred just three miles north of the San Antonio airport.

The following series of soundings illustrates a typical conversion of the environment from the precedent sounding to the proximity sounding in the same general air mass. Fig. 10a shows the Oklahoma City sounding at 0900 C, 11 April 1955. The depth of the moist layer at this time was around 2000 ft, with a stability index of + 6. Six hours later (fig. 10b), 1500 C, the moisture depth increased to 4500 ft and the stability index lowered to − 3. Twelve hours after the first sounding (fig. 10c), moisture has penetrated to at least 400 mb, although there is some drying around 800 mb, which may well have resulted from mixing. A tornado occurred 65 mi south-southwest of Oklahoma City 45 min after this sounding, so this is not strictly a proximity sounding. Fig. 10d shows the Oklahoma City sounding just 20 min before a squall line struck, with gusts to 80 kn.

The discussion thus far has centered around the Type I tornado air mass or one in which the precedent sounding is characterized by dry air overlying a moist layer. Another air mass type [6], which has been termed "inverted V," has been noted in connection with tornadoes. Seven proximity soundings in this air mass type have been found and while these cases have not been studied in detail as yet, some preliminary work shows that the stability index averages − 3 (range 0 to − 8).

From the study and analysis of these data, the following conclusions have been drawn:

1. Data available at this time clearly show that, at the time and site of tornado occurrence (within the definition of proximity sounding), the typical inversion and presence of relatively dry air aloft are not characteristic of the two air-mass types investigated here.

2. Tornado forecasting research on the Type I sounding must take into account the manner in which the conversion from the precedent sounding to the proximity sounding is effected.

REFERENCES

1. Showalter, A. K., and J. R. Fulks, 1943: *Preliminary report of tornadoes,* U. S. Weather Bureau, Washington, D. C.
2. Fawbush, E. J., and R. C. Miller, 1952: A mean sounding representative of the tornadic air-mass environment. *Bull. Amer. meteor. Soc.,* **33**, 303–307.
3. Fawbush, E. J., and R. C. Miller, 1954: The types of air masses in which North American tornadoes form. *Bull. Amer. meteor. Soc.,* **35**, 154–166.
4. Beebe, R. G., *Types of upper-air soundings preceding tornadoes.* U. S. Weather Bureau, Washington, D. C. Unpublished.
5. Showalter, A. K., 1953: A stability index for thunderstorm forecasting. *Bull. Amer. meteor. Soc.,* **34**, 250–253.
6. Beebe, R. G., 1955: Types of air masses in which tornadoes occur. *Bull. Amer. meteor. Soc.,* **36**, 349–350.