PICTURE OF THE MONTH

Observations of a Mountain Tornado

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1. Introduction

On 17 August 1984 a tornado was observed by the author in the mountainous terrain of Rocky Mountain National Park in north-central Colorado. The tornado occurred above timberline at about 3475 m on the east flank of 4345 m Longs Peak in the southeast corner of the national park and will be referred to as the Longs Peak tornado. Events such as the Longs Peak tornado are often unrecorded and the influence of terrain on the dynamics of tornado formation has not been investigated. Figure 1 shows that tornado frequency drops to something less than one per year per 26 000 km^2 in the mountain regions of the western United States (Kelly *et al.*, 1978). The low frequency of tornado events may primarily reflect lack of reports in relatively unpopulated areas and not necessarily the physical influence of the mountains on severe weather events. This short paper does not address the theoretical questions of tornado dynamics in mountainous terrain, but is offered as evidence of their occurrence with some speculation that the terrain may have been involved in the generation of a tornado-spawning thunderstorm.

2. Observations and synoptic situation

The Longs Peak tornado occurred at approximately 1330 MDT (1930 GMT). The tornado had an estimated pathlength of less than 2 km and an estimated life span of 2 minutes from first appearance as a funnel cloud to its visual disappearance, which are characteristic pathlengths and lifespans of the majority of tornadoes (Fujita and Pearson, 1973). The photograph shown in Fig. 2 was taken by the author near Chasm Lake at the location marked by the triangle in Fig. 3. The time of the photograph was near the end of the tornado's life cycle. Figure 3 also shows the estimated path of the Longs Peak tornado with the solid part of the line indicating when the funnel was apparently in contact with the ground. Although no visible debris cloud was observed, the funnel tip was observed to be either touching the surface along the background ridge or below the apparent horizon created by the background ridge. Rotation of the funnel was in the cyclonic sense typical of most tornadoes (Davies-Jones, 1982).

Synoptic conditions on 17 August were favorable for the development of thunderstorms, but did not resemble typical tornado soundings found by Maddox (1976) and others. The nearest sounding, taken at Denver at 1200 GMT 17 August, is shown in Fig. 4. Although not necessarily representative of conditions on Longs Peak, the Denver sounding is assumed to be indicative of the atmospheric stability conditions for the region. The Denver sounding is conditionally unstable and indicates that, with sufficient lifting, convection will result with a 12 500 m level of neutral buoyancy. This conditional instability and a lifted index of −3 indicates a moderate thunderstorm potential. Several deep convective cells with tops of 13 700 m were observed to form in about 1.5 h, and are indicated on the 1935 GMT radar chart in Fig. 5. These thunderstorms formed under relatively calm wind conditions aloft, as deduced from the Denver sounding and accompanying synoptic analyses. The 500 mb chart for 0000 GMT 18 August 1984, shown in Fig. 6a, in-

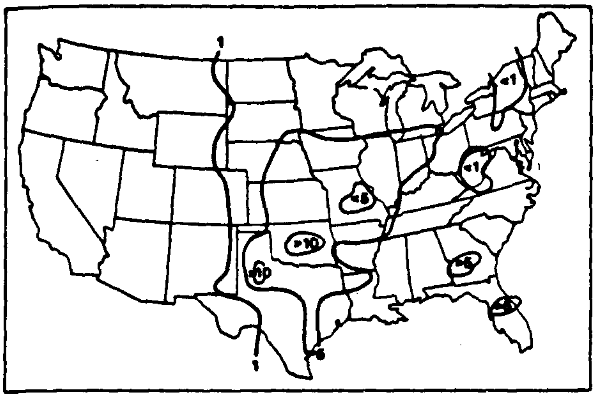

FIG. 1. Frequency of all tornadoes per 26 000 km^2 per year (1953–75). From Davies-Jones (1982).

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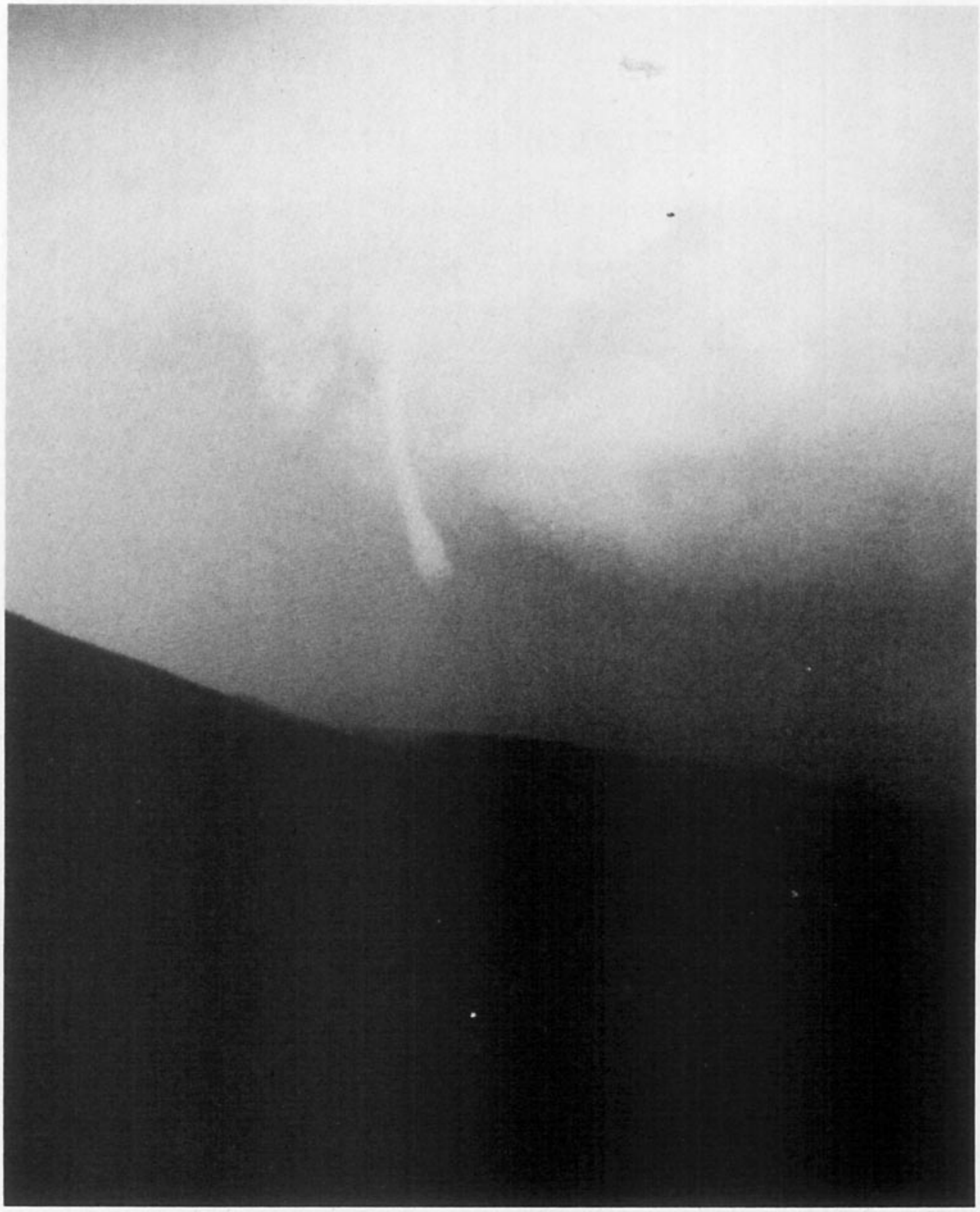

FIG. 2. Late stages of the Longs Peak tornado of 17 August 1984, viewed to the east of Chasm Lake. Moments prior to this photo the tornado touched ground along the ridge in the background.

dicates extremely light (<2.5 m s^{-1}) west-northwest winds for the Denver area and the wind on Longs Peak, near the mountaintop level, was observed earlier in the day to be light and variable from west-northwest. Visually observed cloud motion indicated winds above the mountaintop level were more from the northwest. The accompanying 850 mb chart shown in Fig. 6b shows a weak cyclonic circulation centered in southwest Colorado. In the absence of terrain, low-level southeast winds would result from this weak cyclone and the 1800 GMT and 2100 GMT 17 August surface maps indicate weak southeasterly flow in eastern Colorado.

3. Discussion

Unstable conditions plus winds that veer with height are favorable for the occurrence of tornadoes (Davies-Jones, 1982; Fawbush and Miller, 1954); however, extremely low winds or, more importantly, low vertical shears are not typically associated with tornado-pro-

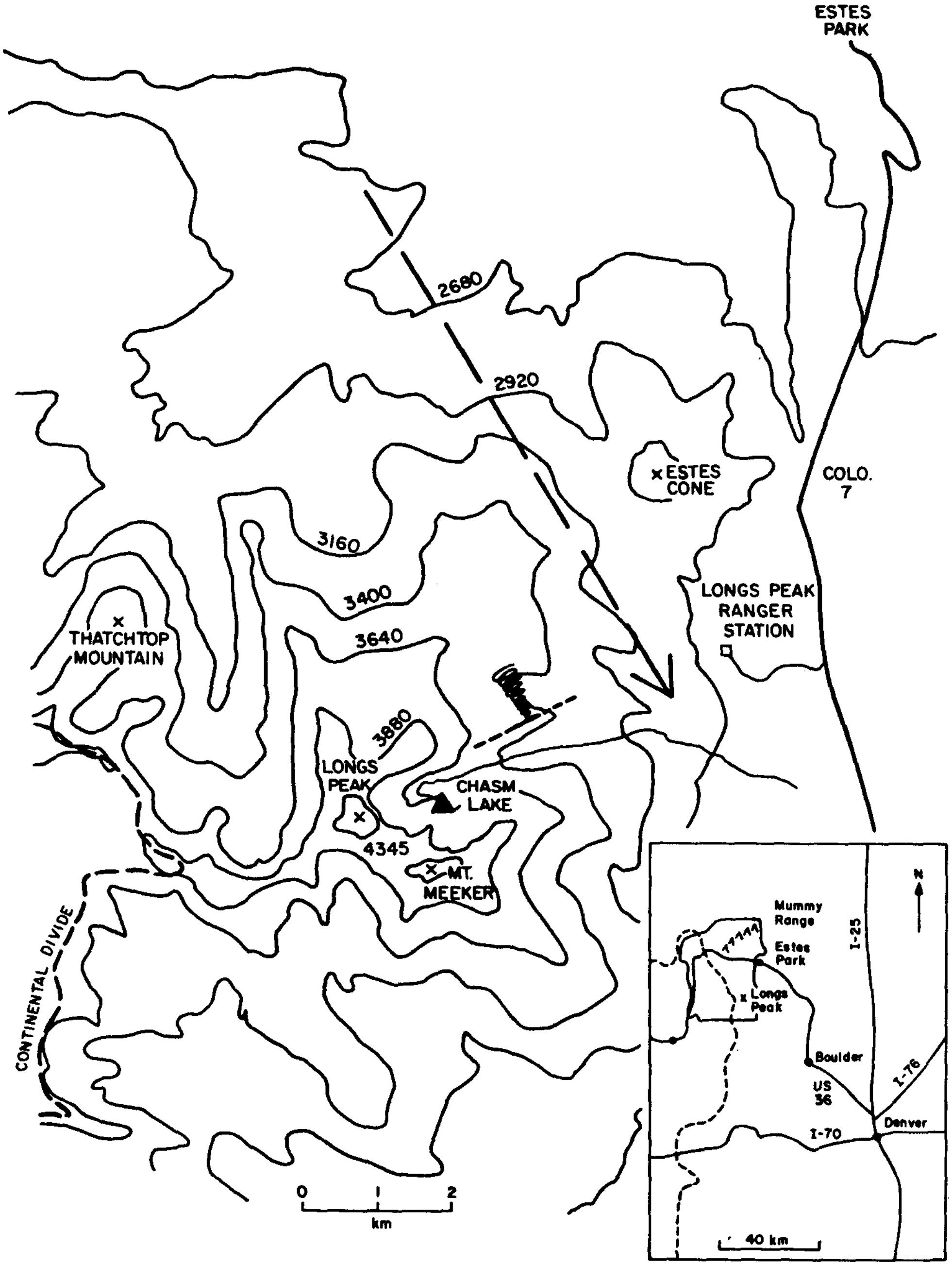

FIG. 3. The map shows the detailed terrain structure of the Longs Peak area. Contours are every 240 m of elevation. Estimated tornado track is indicated by the solid and dashed line marked by the spiral. The photo was taken at the location indicated by the triangle. Storm motion is indicated by the long dashed arrow. The inset map shows the location of Longs Peak in Rocky Mountain National Park and its location with respect to Denver.

ducing storms in other regions over flat terrain. Maddox (1976) indicates typical wind speeds of 20 and 12.5 m s^{-1} at 500 mb and 850 mb, respectively, for westerly-type tornado producing conditions. Although substantial variability is noted, winds of 4 and 1.5 m s^{-1} at 500 mb and 839 mb, respectively, for the Denver region are well outside the one standard deviation range given by Maddox (1976). Even in comparison to more closely related Denver tornadoes, the wind conditions were not particularly favorable for tornado formation. Low-

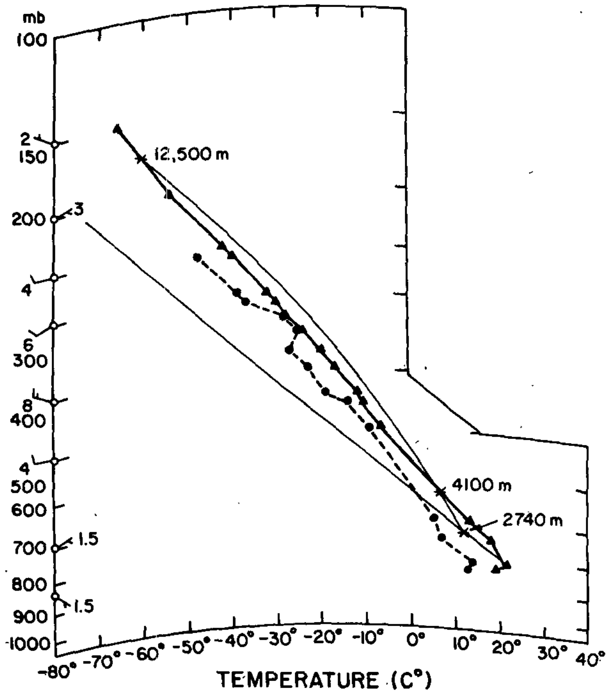

FIG. 4. The 1200 GMT 17 August 1984 Denver sounding is plotted on an adiabatic chart. The lifting condensation level, level of free convection, and level of neutral buoyancy are indicated by the crosses at 2740, 4100, and 12 500 m, respectively. Solid lines are appropriate dry and moist adiabats. Winds plotted along left side of the chart are the direction and speed in m s^{-1} with a full barb equal to 5 m s^{-1}. Wind speed is indicated by the plotted number also.

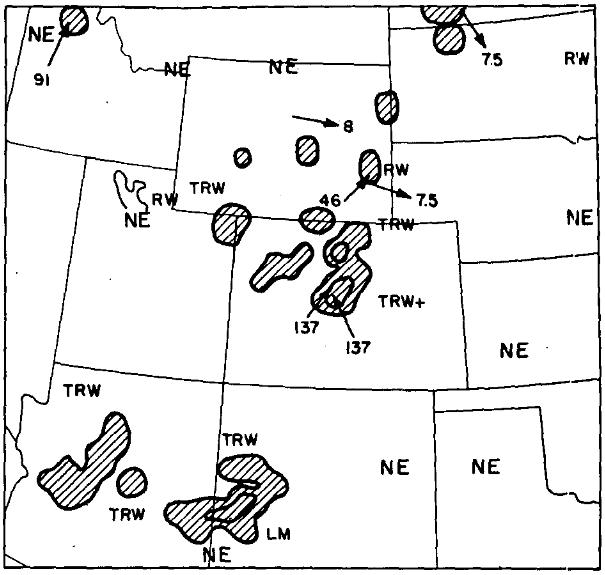

FIG. 5. The 1935 GMT radar chart for 17 August 1984, corresponding to the time of the Longs Peak tornado indicates thunderstorms with 13 700 m tops over the northern Colorado mountains. Cell movement of adjacent storms in southern Wyoming is southeastward. Heights are in hundreds of meters and speed of cell movement in m s^{-1}.

level southeasterly winds with westerly winds aloft, common to Denver tornadoes, are present in the Longs Peak tornado; however, wind speeds, particularly at low levels, are less than half those reported by Szoke *et al.* (1984) for the 3 June 1981 Denver tornadoes. The low wind speed is also the most significant difference between the Longs Peak tornado and typical synoptic-scale features of High Plains severe thunderstorms reported by Doswell (1980). However, the surface layer θ_w of 24°C and 500 mb temperature of −5°C are much higher than for other Denver tornado soundings and are more like the warm, moist soundings associated with Gulf Coast tornadoes (Fawbush and Miller, 1954). These warm, moist conditions with low wind speeds are reminiscent of the flash flood soundings described by Maddox *et al.* (1978). The 0000 GMT 1 August 1976 sounding at Loveland, Colorado reported by Maddox *et al.* (1978) for the Big Thompson flood had a surface layer θ_w of 25°C and a 500 mb temperature of −5°C. However, there is one important difference between the Longs Peak tornado and Big Thompson flood situations. Low-level winds increased to greater than 20 m s^{-1} in the Big Thompson flood case, and no substantial wind speed changes were found for the Longs Peak tornado case as deduced from the 0000 GMT 18 August 1984 Denver sounding and accompanying synoptic charts.

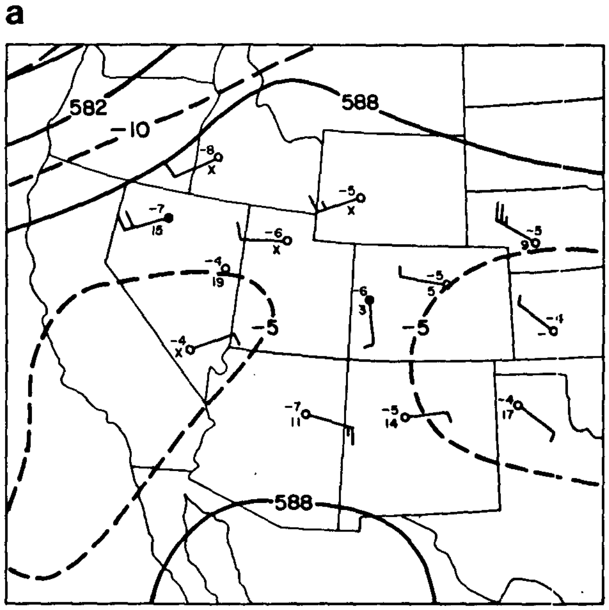

FIG. 6a. The 0000 GMT 18 August 1984 500 mb analysis shown is valid for conditions 4½ h after the occurrence of the Longs Peak tornado. Temperature and dew point depression in °C are plotted for select stations. Wind flags are in m s^{-1} with a full flag equal to 5 m s^{-1} and a half flag equal to 2.5 m s^{-1}.

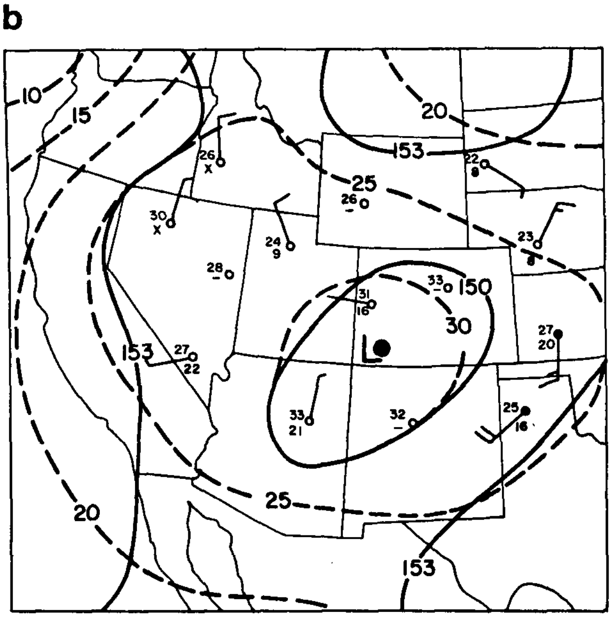

FIG. 6b. The corresponding 850 mb chart is shown at 0000 GMT 18 August 1984. Temperature and dew point depression are plotted in °C. Wind flags are similar to Fig. 6a.

The synoptic conditions discussed above are not indicative of a large tornadic thunderstorm potential for the region, particularly in a location of very low probability of occurrence. Nevertheless the Longs Peak tornado did form and it presents interesting questions as to why and whether the terrain played a crucial role. Without definite observations these questions cannot be conclusively answered. However, the obvious local difference from the synoptic scale environment is the mountain location, which suggests that the mountains favorably modified the local environment to produce a tornadic thunderstorm.

Evidence from other studies indicates that the terrain should have a damping effect on tornado formation, although none of these studies have directly examined the influence of large terrain features on the flow around thunderstorms. Elson and Meaden (1982) found that the increased friction due to urban areas suppressed the number of weak tornadoes relative to the surrounding countryside. Their results confirm the damping effect of increased surface roughness on vortex formation found in the laboratory study of Dessens (1972). However, these studies of surface roughness influences overlook the possible modification of the wind flow by terrain features the size of or larger than the thunderstorm or mesocyclone from which the tornado forms. Low-level wind flow modified through channeling by the mountains and induced mountain-valley circulations might provide locally favorable wind shear and updraft configurations for tornado genesis even though they are not present in the synoptic scale flow. Apparently, this was the case in the Longs Peak region on this day, although the details of the influence of the mountains can only be guessed at from these data.

Although the preceding discussion about potentially favorable modification of the local flow by terrain is speculative, the effect of terrain should not be ignored in attempting to explain a rare event that is not well documented. The fact remains that a tornado did occur in highly varied mountain terrain under synoptic conditions that seem only moderately favorable for their development.

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