NOTES AND CORRESPONDENCE

Comments on "A Note on the 'Square Cloud'"

Rodger A. Brown

Cornell Aeronautical Laboratory, Inc., Buffalo, N. Y.

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Abdullah (1966) has proposed the interesting theory that Tepper's (1950) pressure-jump-line hypothesis for the formation of squall lines can be applied to explain the appearance of a "square cloud" southwest of Oklahoma City on 19 May 1960. The square cloud (Fig. 1), photographed by the TIROS I weather satellite, was first reported by Whitney and Fritz (1961); upon rectification it was found that the cloud was actually rhombic shaped with the longer diagonal oriented in a northeast-southwest direction.

The general argument of Abdullah's hypothesis is as follows. "When a quasi-stationary front advances as a cold front into an air mass where there is a marked inversion, a pressure jump (associated with a gravity wave) is formed at the leading edge of the disturbed air mass ahead of it. . . . Because of the breaking of the overhanging dense air at the inversion layer, and the release of latent instability caused by it, a line of cumulus formations is created parallel to the jump line. . . . As the jump line continues to advance it continues to stir more air masses and create more cumulus clouds behind it. The cumulus area appears to be growing. These clouds are simply the trace of the jump path. . . . In the observed case study the pressure jump was moving in a direction that made an angle of about 45° with its length, hence the rhombus shape."

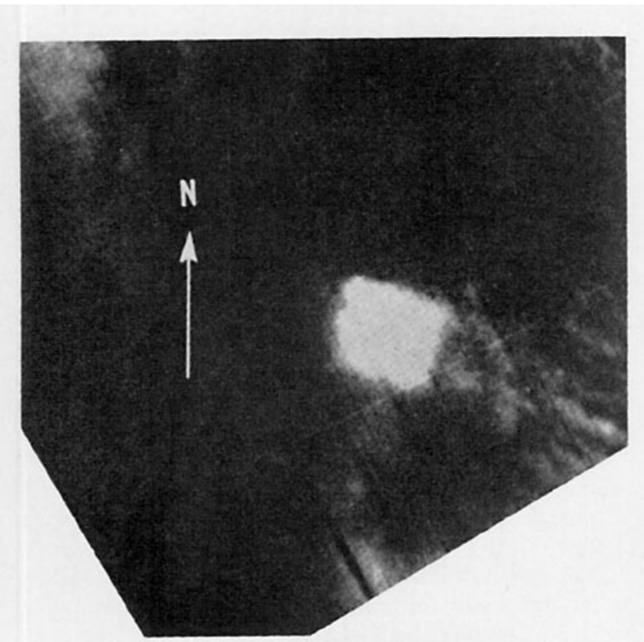

Fig. 1. The "square cloud" as photographed by TIROS I at 1403 CST on 19 May 1960. From Whitney and Fritz (1961).

After mentioning that all of the meteorological conditions satisfied the theory and that only a short segment of the quasi-stationary front accelerated to form a straight jump line about 100 mi long, he concluded his argument in the following way. "In further support of the present suggestion, it may be mentioned that pressure jumps were actually reported in the area affected by the cloud system. The occurrence of tornadoes in this region is another evidence. . . ."

Abdullah's theory appears to be plausible, but there are two basic inconsistencies: 1) most pressure jumps of meteorological significance are not caused in the way proposed by Tepper (1950), and 2) the "square cloud" was not an area of cumulus clouds but was the expanding anvil-shaped top of a thunderstorm system. The following is an attempt to clarify the pressure jump issue and to present some of the information, which apparently is not well known, concerning the "square cloud."

Tepper (1950) envisioned the pressure jump line formed in the manner described above, as a triggering mechanism for clouds which would develop into an organized squall line. That gravity waves can form and travel along inversion layers is not questioned. The problem lies in the interpretation of pressure jumps that are found on a microbarograph. More recent studies (e.g., Fujita, 1955; Fujita *et al.*, 1956) have shown that pressure jumps associated with

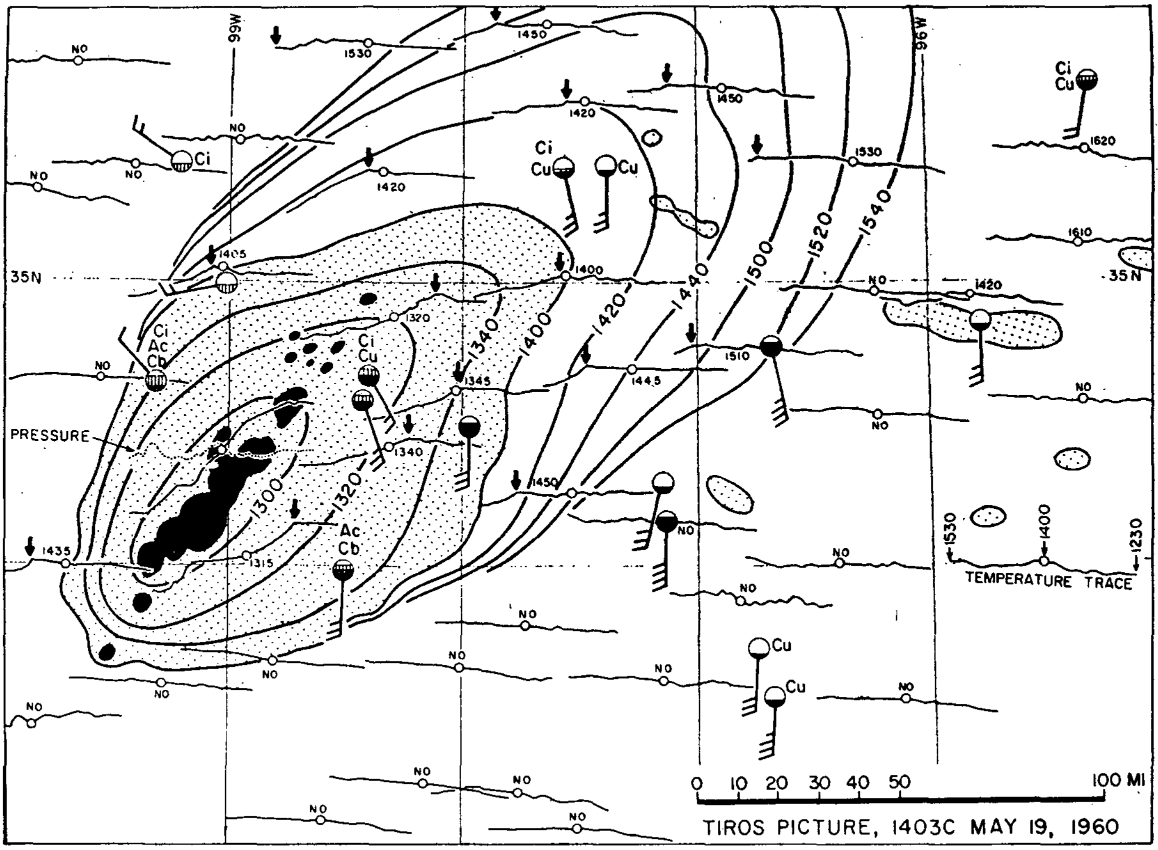

FIG. 2. Rectification of clouds (stippled areas) from the TIROS I photograph at 1403 CST on 19 May 1960. Contours on both sides of rectified "square cloud" are isochrones of temperature drop within the anvil's shadow. Wavy lines are thermograph traces from 1230 to 1530 CST with time of temperature drop indicated next to station circle. NO means no drop was recorded. Radar echoes at 1400 CST (indicated in black) show where the more intense portions of the thunderstorm were located. Long wind barb is 5 kt. Fraction of cloud cover is indicated in the large station circles with zero at bottom and ten tenths at top. From Fujita (1963).

thunderstorms are not the *cause* of thunderstorms but are, instead, the *consequence* of the storms. Denser, evaporationally-cooled air flowing out ahead of a moving precipitation area forms what is called a *pressure surge line*. When a pressure surge line passes over a barograph, the rapid rise in pressure is very similar to the rise in pressure that one would expect with the passage of a pressure-jump-producing gravity wave. In fact, the detailed mesometeorological analyses of Fujita *et al.* (1956) showed both thunderstorm-induced pressure surge lines and one pressure jump line; the pressure jump line caused a temporary shift in the surface winds but there were no surface temperature changes, no precipitation, and only high cirrus and scattered low clouds in the region through which the line passed. The writer is aware of no detailed meteorological analyses which show pressure jumps occurring in a region in which thunderstorms developed during the following hour or two. If gravity waves do initiate convection, their presence is not revealed in the surface pressure patterns.

The nature of the "square cloud" is discussed in studies by Goldman (1962) and Fujita (1963). Fujita made a detailed rectification of the "square cloud," which is shown as the large stippled area in Fig. 2. Knowing that the thick anvil top of the thunderstorm system should cause a slight decrease in the surface temperature at stations within the shadow of the anvil, Fujita then proceeded to use thermograph traces from the National Severe Storm Project's alpha-network stations to draw the outline of the anvil at times both earlier and later than that of the TIROS photograph.

As a further point, which could be taken as additional evidence for the "square cloud" being the top of thunderstorm system instead of a group of cumulus clouds, Fujita compared the outlines in Fig. 2 with a theoretical wind field at the top of a thunderstorm, as computed by McLean (1961). The winds, which were the result of concentric radial outflow being superimposed on a field of mean gradient flow, not only were similar to measurements made by McLean but also could explain the shape of the anvil in Fig. 2.

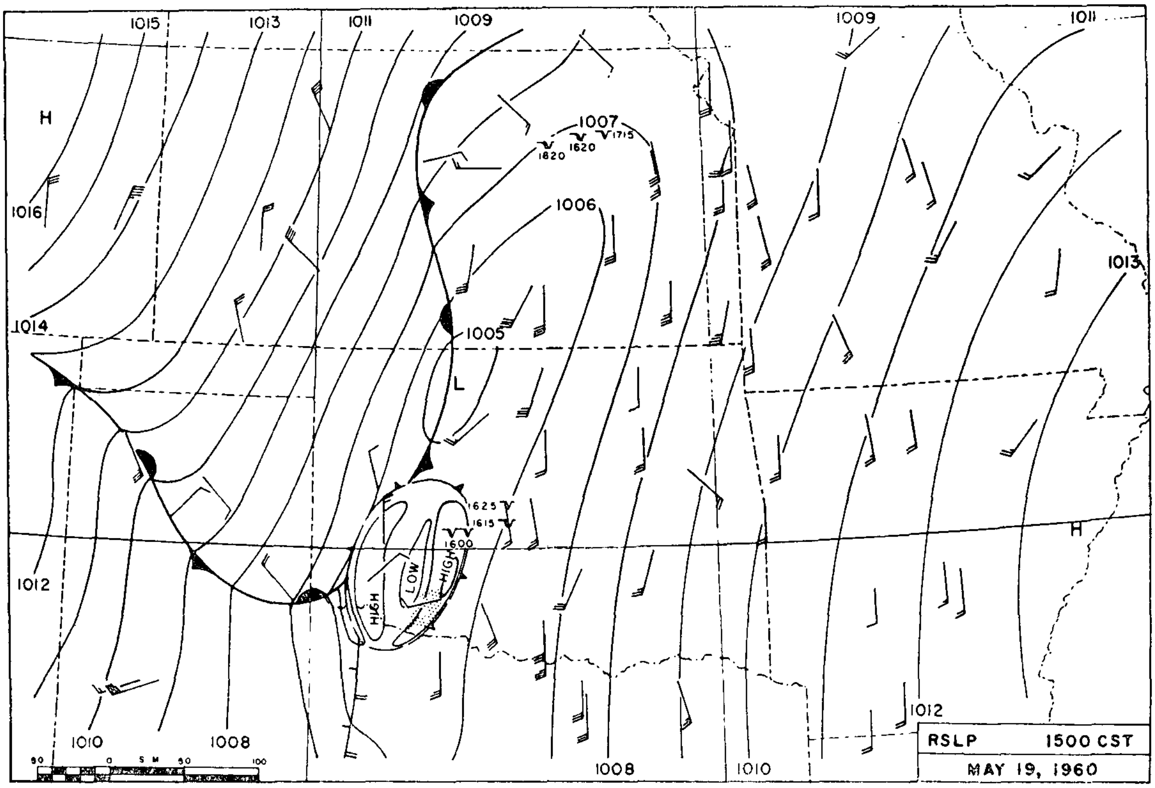

Fig. 3. Reduced sea level pressure analysis and related weather phenomena at 1500 CST on 19 May 1960. Solid lines are isobars 1 mb apart. Long wind barb is 5 kt. Mesosystem is within dashed oval. Stippled area within mesosystem is region where precipitation rate was greater than 0.5 inch hr^{-1}. Line extending south from mesosystem is a dry front, with single spines in dry air and double spines in moist air. Tornadoes (winged-V) and funnels aloft (truncated winged-V) that occurred within 3 hr of 1500 are indicated. From Goldman (1962).

Goldman (1962) used all available meteorological data from the alpha-network to study the growth of the mesosystem associated with the thunderstorm system that had the "square cloud" as its anvil top; a mesosystem is that part of the subcloud environment which is influenced by the cold-air outflow from one or more thunderstorms. Fig. 3 shows the general synoptic situation at 1500 CST, one hour after the TIROS photograph. The mesosystem is within the dashed oval in southwestern Oklahoma. Note that there is a steep pressure gradient, i.e., pressure surge line, along the advancing eastern edge of the mesosystem. Also, tornadoes which descended about 1600 CST from the thunderstorm system as it moved northeastward are indicated in the figure. These are the same pressure jumps and tornadoes to which Abdullah made reference.

In conclusion, this note has brought up two points concerning the "square cloud" to which Abdullah (1966) made reference. The first is that the "square cloud" was the top of a thunderstorm system and not an area of cumulus clouds. The second point is more basic and involves the distinction between a pressure jump line (caused by the passage of a gravity wave) and a pressure surge line (caused by the surface outflow of evaporationally-cooled air from a region of rainfall). Contrary to Tepper's (1950) original hypothesis, the pressure jump associated with squall lines is not the gravity wave type which would initiate convection, but is, rather, a consequence of a well-developed, precipitating thunderstorm system.

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