A Note on the "Square Cloud"

ABDUL JABBAR ABDULLAH
National Center for Atmospheric Research, Boulder, Colo.

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The so-called "Square Cloud" was observed by TIROS I in Oklahoma and Kansas during the afternoon of 19 May 1960. An excellent description of this cloud, and the meteorological conditions attending its formation, has been given by Whitney and Fritz (1961). The main features of this cloud, as described by these authors, were that it had a rhombus shape with nearly straight sides and sharp angles. A surge of cold air was advancing towards the southeast and pushing a short segment of the quasi-stationary front ahead of which the cloud formed. The dew-point lines were parallel to the frontal segment, and there was a marked inversion at the 850-mb level, in the air mass in which the cloud formed. The cloud was associated with the genesis of several tornadoes and cumulus activity.

It seems to the present writer that all of these features may be explained by the mechanism of squall line formation as advanced by Tepper (1950). Thus, when a quasi-stationary front advances as a cold front into an air mass where there is a marked inversion, a pressure jump is formed at the leading edge of the disturbed air mass ahead of it. Let all velocities be measured relative to a system of coordinates that is translated with the basic undisturbed current ahead of the jump. The pressure jump will then have a velocity which is nearly equal to $u+c$, where u is the particles' velocity behind the jump and c is the velocity of gravitational disturbances at the inversion layer, both of which are measured relative to this moving system of coordinates. 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. This cumulus line moves relative to the assumed system of coordinates with a velocity that is nearly the same as the particles' velocity behind the jump, namely u. Hence the pressure jump line has a velocity c relative to the cumulus 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. If the jump line is straight and if it is moving parallel to itself, the shape of the cloud is that of the locus of a straight line moving parallel to itself, namely a quadrangle. If the jump line is moving as a whole in a direction that is perpendicular to its length, the shape would be rectangular. 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. At any rate, the quadrangular cumulus area formed in this way grows in width such that it has a width of $c\tau$ at the instant τ after its birth.

A square cloud seems to be a rare phenomenon. In order to have it formed, the mother cold front must be nearly straight, it must have the same motion at all its advancing parts, and it must advance into an air mass where the meteorological conditions are nearly uniform. This is best realized when the advancing segment is short. When, on the other hand, a long front is accelerated the different segments usually have different motions, and hence the ensuing jump line may have any geometrical shape corresponding to these motions. Moreover, when a large area is involved, the conditions are expected to vary from one region to the other. These conditions include, for instance, the height of the inversion layer, its strength, the moisture content, the wind velocity and the topography of the underlying ground. Hence a long jump line is expected to have different motions at different points along its length. The shape of the cumulus clouds formed behind such a jump may not be expected to be a regular geometrical figure. Moreover, in order that the cloud may be clearly visible to a satellite, it must form in nearly clear skies.

In the case study of the cloud observed by TIROS I, all these conditions were satisfied. Thus, only a short segment of the quasi-stationary front was accelerated causing the generation of a straight jump whose length was about 100 miles. The meteorological conditions in the region into which the jump moved were uniform, as may be seen from the surface maps and the soundings reproduced by Whitney and Fritz. TIROS just happened to be passing over the vicinity a short time after the birth of the cumulus cloud associated with the passage of the jump. Rough computations based on the soundings give c the value 22 m sec^{-1}. Since the jump was moving at an angle of 45° with the direction of its length, the width of the cloud would be about 54 miles after one hour and a half of the birth of the first cumulus line. This is about the same order of magnitude as the observed cloud. The fact that the dew-point lines were parallel to the mother cold front, and hence to the jump line, made the cumulus line appear parallel to the jump line and hence gave the cloud its straight edge.

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. The meridional growth of the cloud system agrees with the fact that pressure jumps usually grow in the meridional direction.

REFERENCES

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Reply

Abdul Jabbar Abdullah
State University of New York at Albany
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Mr. Brown raises two points in connection with my theory concerning the "square cloud." The first point calls for distinguishing between a pressure jump line and a pressure surge line. The second point seems to favor the Goldman-Fujita theory which states that the square cloud was actually the thick anvil of a thunderstorm system.

With regard to the first point I wish to say that I agree with Mr. Brown that a pressure surge line is not the same as a pressure jump line. However, I do not agree with him on the idea that a pressure jump line is incapable of producing convective activity. The significance of the pressure jump line lies in the idea that soon after breaking occurs it develops into an atmospheric bore which is mainly a line of instability, penetrating deep into the underlying fluid. This, of course, does not preclude the possibility of the formation of pressure surge lines as a result of the thunderstorm activity. Which one of the two lines leaves a more marked trace on the barograph does not greatly affect the main hypothesis.

As to the second point, I wish to say that an examination of Fig. 2 of Mr. Brown's comments reveals the fact that the area covered by the square cloud was also an area of considerable convective activity where cumulonimbus and cumulus clouds were observed. The argument must center around the mechanism which triggered this activity. The fact that this activity was so well organized must be taken as a confirmation of the mechanism suggested in my paper.

As a matter of fact I don't see any contradiction between the Goldman-Fujita theory and mine. It is well known that thunderstorms resulting from strong convective activity do not usually form a continuous deck at low levels. They rather appear as separated individual cells. The spreading out of the anvils would act to connect these cells and make them appear as a continuous deck at higher levels. It, therefore, seems to me that the two theories supplement, rather than contradict, each other.

Reply

Abdul Jabbar Abdullah
State University of New York at Albany
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Dr. Wexler is to be commended for calling my attention to three points which seem to remain ambiguous about my theoretical model, and which need further elaboration.

The first point is that the motion of the individual cells within the band must be distinguished from the motion of the band itself. I concur with Dr. Wexler that the two motions must be distinguished from each other. According to my model the band is to be associated with the gravity wave after breaking. The individual cells may be associated with the convection cells that arise from instability triggered by the breaking. It appears, therefore, that although the two phenomena are distinct, yet the appearance of the cells must be organized by the breaking mechanism. The motion of the individual cells themselves may not be the same as that of the band.

The second point is related to the speed with which the band moves relative to the basic current. The velocity of the basic current, as implied in my model, is best approximated by the weighted mean velocity over the depth of the fluid involved in the lower layer. This mean velocity, as may easily be inferred, is usually smaller than the wind velocity above the frictional layers. Hence, even though the band may be moving with a speed which is greater than the mean speed of the basic current, its speed may be comparable with that of the wind at some upper level. At the same time my theory does not necessarily predict that the bands move faster than the basic current. There is provision in the theory for the generation of two possible families of gravitational waves, one moving with the velocity $u+c$ and the other with the velocity $u-c$. This latter family may be responsible for the slowly moving, or the stationary, bands which are occasionally observed. The main point remains that the bands are not simply drifted with the winds, but they have a different velocity.

The main point in mentioning the radial movement of the individual cells is that the bands grow radially with great rapidity. The apparent movement of the cells was taken to indicate the rate at which the band spreads along its length. The fact that this rate is quite rapid is well borne out by observations. As to the numerical magnitude of this growth, it may be mentioned that my theory leaves three parameters as arbitrary. They may be determined from detailed observations. These parameters are A, c and ω which appear in Eqs. (32) of my paper. By a suitable combination of these parameters it is possible to obtain the right order of magnitude.

It seems to me that some more careful and detailed observations are needed in order to judge the validity of my model.