A SEVERE STORM RADAR SIGNATURE IN THE SOUTHERN HEMISPHERE

By K. T. Spillane and Bettye Dixon

Central Office, Bureau of Meteorology
Melbourne

ABSTRACT

Radar P.P.I. observations at 10 minute intervals during the passage of a tornado-producing storm across Sydney, Australia, revealed a strikingly close southern hemisphere analogy to the well defined metamorphosis at the onset of the tornadic SR mature stage in northern hemisphere storms as defined by Browning (1965).

1. INTRODUCTION

Browning (1965) and Fujita (1965) have both discussed the evolution and movement of tornado-producing thunderstorms, based on data contained in A.F.C.R.L. special report No. 32 1965.

Browning (1965) proposed the addition of a fourth stage to the life cycle classification of severe storms. This is the SR (severe right) mature stage of quasi steady state updrafts and downdrafts that evolves from the ordinary mature stage of the Byers-Braham (1949) classification. He concluded that at least on some occasions "a thunderstorm goes through a remarkably well defined metamorphosis before it produces a tornado" and pointed out the need for further studies to establish the generality of his findings.

The WF44 radar observations available from the routine conduct of weather watch for aviation operations at Sydney Airport fall far short of the detail available to Browning and Fujita and of the research capabilities of the equipment. However, analysis of the plots - every 10 minutes - of P.P.I. echoes reveal many important features noted by Browning as preceding and accompanying the distinctive organisation of the so-called super-cell and the onset of the SR mature stage. The interpretation of the Sydney storm motion and horizontal structure, with respect to its environment, is in agreement with those features of the Oklahoma severe storms when differences between flows in the different hemispheres are allowed for.

Broadly speaking the most common southern hemisphere situations conducive to severe storms - strong middle tropospheric shear with cold dry air above warm moist surface layers - have a flow pattern that is a mirror image of the northern hemisphere flows associated with the same conditions. It is to be expected that the radar patterns and the motions of southern hemisphere storms will also be, broadly speaking, a mirror image of the northern hemisphere patterns and motions. This is true of the Sydney storm which during its evolution to the tornadic stage changed its direction of travel to the left of its original path. The typical SR (Severe right) storm of the northern hemisphere is thus an SL (severe left) storm in the southern hemisphere. When one considers the northern hemisphere SL mode as claimed by Browning (1968) to also exist, there can be no universal appeal in his classification. Unfortunately, the equator cannot be a universal reference as severe storms have moved to the west.

We hesitate to add confusion, but it must be stressed that the structure and motion of corresponding storms in either hemisphere, following the ideas expressed by Browning (1965), are best described as SH - severe anomalous motion to high pressure side of middle tropospheric wind - or SL - severe anomalous motion to low pressure side of middle tropospheric wind. In this definition SH is universal and corresponds to the Browning SR of the northern hemisphere and its counterpart in the southern hemisphere. Similarly, SL corresponds to SL as used in the northern hemisphere and its southern hemisphere counterpart. Such definitions are employed in this study to avoid the confusion of applying different labels to what are really physically analogous situations in both hemispheres.

The succession of events observed by Browning (1965) as a cell evolves from the ordinary mature stage to the supercell SH stage, are now listed for comparison and discussion.

2. FEATURES OF THE SUPERCELL EVOLUTION AND SUBSEQUENT MOTION

(a) Evolution of Supercell (SH) Stage

(i) Giant hail- diameter exceeding 2 inches - first begins to fall a short time - 10 to 20 minutes - before a hook echo begins to develop.

(ii) A hook echo, as described by Fujita (1958), develops over a period of about 30 minutes. A sharp and fairly upright echo wall at the rear surface relative inflow side of the radar echo, initially almost parallel to the direction of echo travel, slows and becomes almost stationary for about 10 minutes. Then during the following 15 minutes or so this wall turns to form the leading edge of a pendant, then a hook echo.

(iii) About 20 to 30 minutes after the wall begins to turn to form the hook, the storm echo rather abruptly takes up a new direction of travel. This new direction defines the SH stage. The motion has a marked component to the high pressure side of the middle tropospheric winds.

(iv) The supercell structure, once developed, is long-lived - about 2 hours - with reliably estimated cloud tops extending to 60,000 ft, i.e. 20,000 ft about the tropopause.

(b) Surface Weather Sequence

Severe weather of all kinds follows the onset of the SH stage. A typical sequence and relative pattern of occurrence of events are illustrated in Figs. 1(a) and (b), and 2. These are adapted from Browning (1965) and, apart from the above features, show:

(i) The fall of giant hail is restricted to the very beginning of the SH stage, with a rapid diminution of hail size soon after onset of the SH stage.

(ii) A pre-tornado vortex may begin to form at the same time as the hook echo. Approximately 20 to 30 minutes after the wall begins to turn to form the hook and just after the storm has taken up its new direction of travel - the SH stage - the first tornado touches down and/or the first major wind damage occurs.

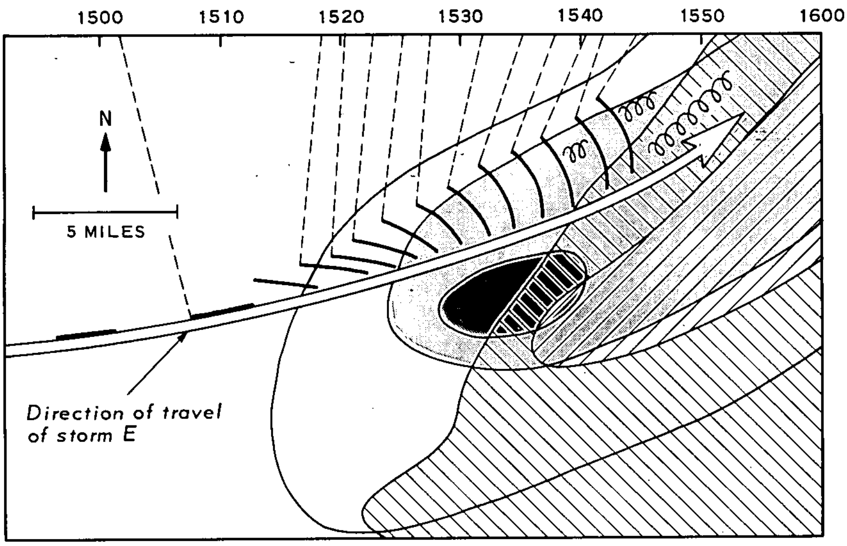
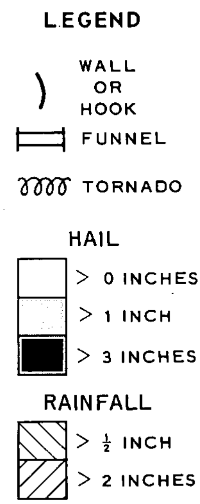


Fig. 1 (a) Storm E in Browning (1965) study.



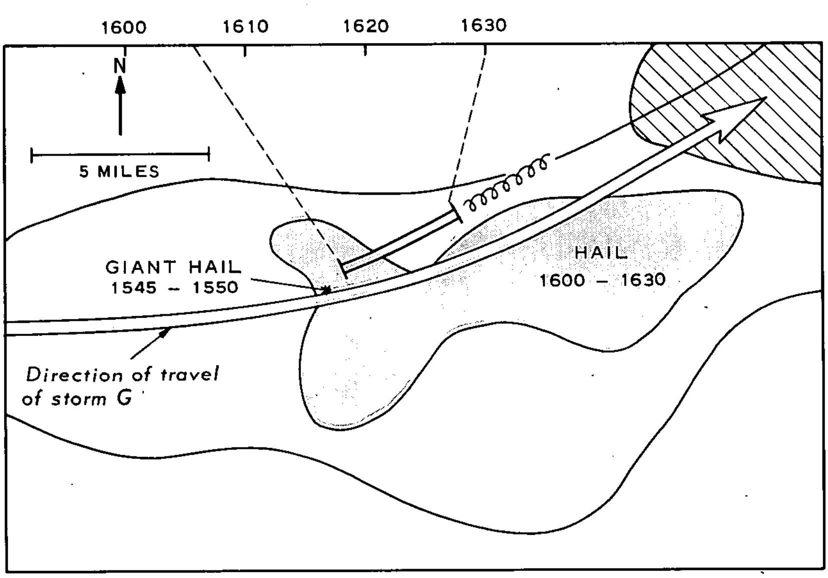


Fig. 1 (b) Storm G in Browning (1965) study.

Fig. 1 (a) and (b) Relationship of surface weather to storm position for storms E and G respectively in the Browning (1965) study of a family of storms at Oklahoma (May 1963).
Note: Storms have been transposed into the corresponding Southern Hemisphere wind regime and hence show the onset of a SL (Severe Left) stage designated as SH in this test.

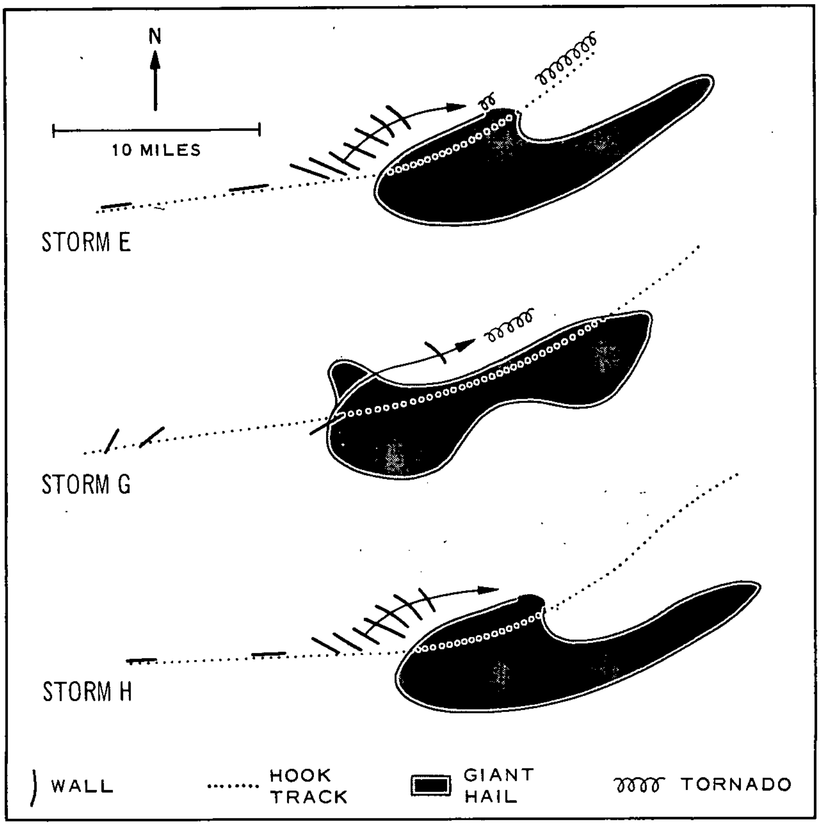


Fig. 2 Relationship of swathes of giant hail and tornado tracks to the developing hook echoes.
Note: Storms transposed to SH stage in a Southern Hemisphere regime.

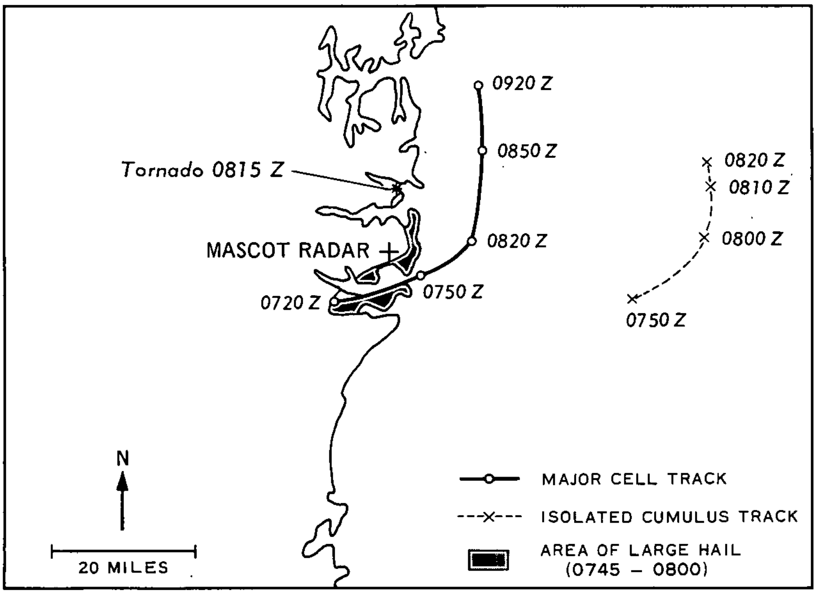


Fig. 3 Diagram showing the storm motion and distribution of associated surface weather reported in the Sydney area on 14.12.1967.
(SL stage extending from 0815 Z to 0850 Z)

(iii) The wind damage occurs within the path of the hook echo itself and is thus located downtrack of the area of large hail on the "H" side of the main echo. In the Oklahoma storms, which were moving at about 25 kt, the first wind damage was around 8 to 10 miles downtrack of the point about which the wall began to turn.

(iv) There is an abrupt onset of heavy rain downtrack of the giant hail.

(v) Due to varying storm orientations, the area of large hail seems to vary in position relative to the track - compare (a) and (b) of Fig. 1; however, all storms change their direction of travel in the same relative position with respect to the hail swath (see Fig. 2).

(c) Storm Movement

Fujita (1965) also reported on this storm situation and pointed out that after about two hours of anomalous travel the echoes tended to return to their original courses. From the data Fujita presented, the echo motions after the anomalous phase still remained at angles of up to 30° to their tracks prior to the SH phase. However, the middle-level flow in the environment of the storms had changed from SW to W during the period of the SH phase, and the subsequent echo motion was not anomalous with respect to the changed middle-level flow. Such a motion history produces a characteristic "S" track, the first presentation of which appears to be by Hoecker (1957). Newton and Frankhauser (1964) have discussed this characteristic "S" track in relation to echo size and the varying rate of processing of air in moving on such tracks, but did not relate such tracks to changes in middle-level environments of storms. Both Browning and Fujita ascribe the hook formation and the anomalous storm echo motion to the "H" side of the middle tropospheric winds, to rotation within the updraft. The fact that a pre-tornado vortex at cloud base was observed to move to the right - "H" side - from its moment of formation early in the hook formation was taken as evidence to support this view. The delay in the veering of the storm echo itself was attributed to the lag in readjustment of the rain echo in space.

Browning interpreted the SH hail sequence as meaning that rotation only occurs when the updraft has reached an intensity capable of sustaining giant hail, and suggested that some form of natural hail suppression then operated in the storm.

A conclusion from these studies is that a hook echo does not always accompany tornadoes, but the probability of observing tornadoes near the path of a hook echo is extremely high when compared to ordinary thunderstorm echoes.

3. SYDNEY STORM OF 14 DECEMBER 1967

On this occasion, radar watch of storms for aviation approach control (JACMAS) at Sydney Airport began at 0720Z and concluded at 1050Z. From the records of this watch, the form of P.P.I. echoes of areas with equivalent radar reflectivity factors "Z" above $9.10^4 mm^6 m^{-3}$ have been obtained. In the following Section these observations are processed in a form and scale identical with that used by Browning and are compared with his results.

The radar is a 10 cm WF44 unit used in the weather watch mode. Swept gain adjustment is applied out to the 60 naut. mi. range. For storms within 60 naut. mi. the aerial elevation used is 3°, rising to 10° for storms within 20 naut. mi. The conventional beam width is 2.8° and pulse length is 1.5 μs. Step

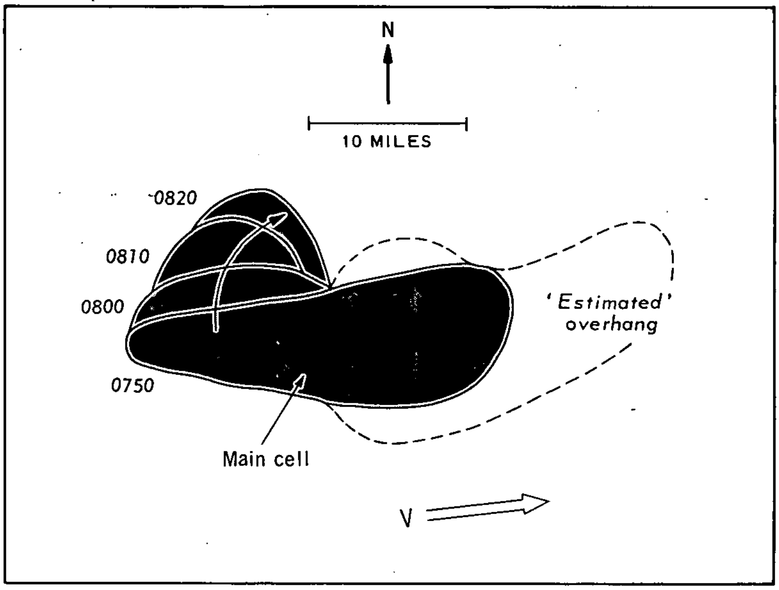


Fig. 4 Development of hook echo during the Sydney storm successive positions shown at 0750, 0800, 0810, and 0820Z 14.12.1967. (SH stage).

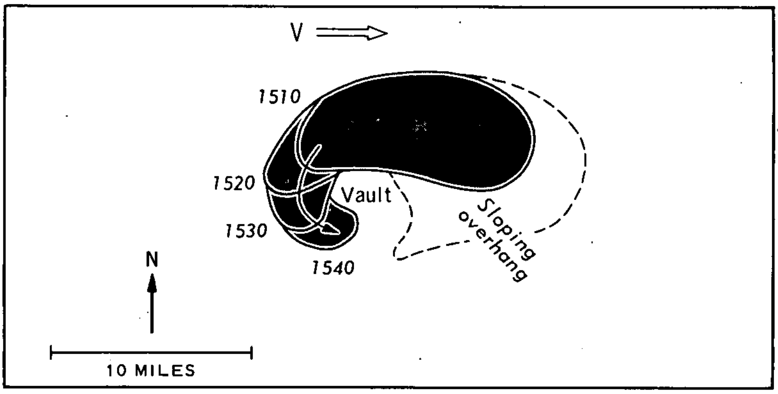


Fig. 5 Schematic diagram illustrating the development of a hook echo, successive positions of the hook shown at 1510, 1520, 1530, 1540 CST (Oklahoma storm showing SH stage) after Browning 1965)

gain P.P.I. and R.H.I. data are not available, and hence the wall and supercell structure cannot be positively identified. At 0720Z a large echo was located SW of the radar and moving ENE at approximately 25 kt (see Fig. 3). By 0740Z a large single cell was identified and during the following 20 minutes the first sign of development was apparent in its left rear quadrant, i.e. rear of echo on its relative-surface inflow side as discussed in Section 2.

Fig. 4 shows shows the development over a 30-minute period of firstly a pendant and then a hook echo, drawn relative to the storm echo itself. For comparison, the development in the Northern Hemisphere of the hook echo of a SH storm presented schematically by Browning is reproduced in Fig. 5 on the same scale and for a similar interval of time. The similarity in hook echo development is marked, and the storms differ only in the apparent lack of relative rearwards extension of the echo in the Sydney storm.

In Fig. 6, the space-time history of the leading edge of the radar echo that defined the developing hook- and taken to be a "wall" - together with the reported hail swath, is shown on the same scale as Fig. 1(a). The "wall" followed the expected evolution, initially parallel to the direction of travel; it gradually turned and by 0810Z was aligned almost at right angles to the direction of storm motion. A slight deceleration of the wall was evident after 0800Z when its turning was most marked, but the first suggestion of rotation was possibly by 0750Z. From 0820Z an abrupt change in the direction of echo motion occurred and the storm moved to the north on a new path approximately 60° to the "H" side of the original track.

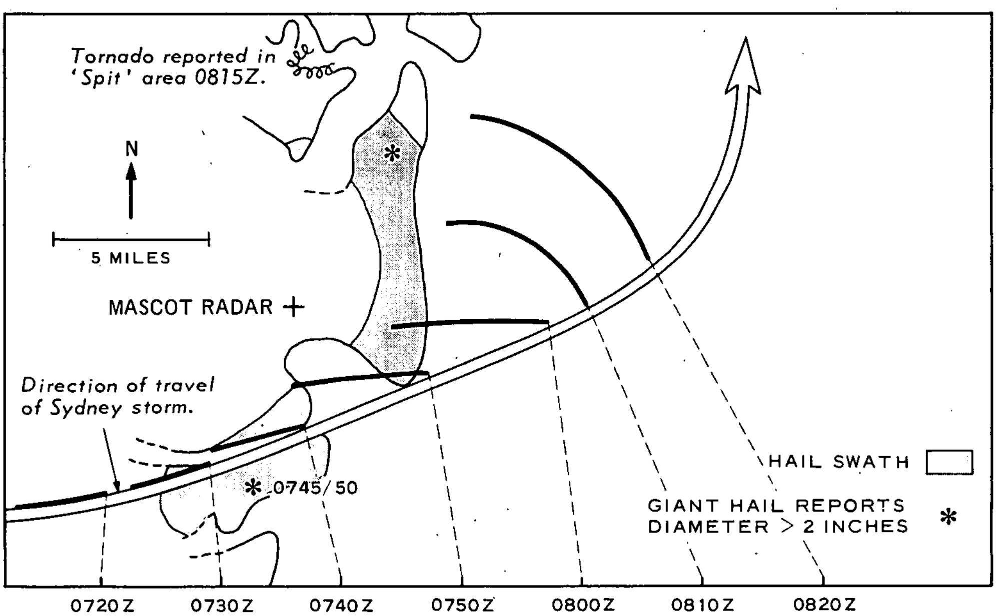


Fig. 6 The onset of the SH stage in the Sydney storm showing successive positions of the leading edge of the developing hook.

Giant hail first fell in the period 0730-0745Z just preceding the onset of the SH stage, and the reported swath of large hail diam. ≥ $\frac{3}{4}$" and location of giant hail diam. ≥ 2" are shown on Figs. 6 and 3. An insignificant amount of precipitation in the form of rain fell over the land. It is considered that only the fringe of the hail swath was observed and further conclusions concerning the change in storm travel with respect to the hail swath is not possible.

A tornado was reported at 0815Z in the location marked on Figs. 6 and 3. This tornado was approximately aligned with the "wall" but 5 miles further to the NW. The tornado was of brief duration - minutes only - and moved on an erratic track. Its initial motion on touchdown was to the WNW, followed by a sharp swing to the NNE then NE. The erratic path and short duration is characteristic of less intense tornadoes, and is in agreement with the large distance between tornado touchdown and parent echo, which is suggestive of the end of the severe mature stage according to Fujita (1965). Subsequent to entering the SH stage, the cell echo could be identified for about 1 hour.

4. SUMMARY OF SYDNEY STORM

In examining the Sydney storm for features of the Oklahoma SH supercell evolution as listed in Section 2 above, we find all features are closely duplicated save for (a) iv and (b) iii (of Section 2) in part. The development of a hook echo was preceded by falls of giant hail and followed some 20 minutes later by an abrupt change in the direction of storm motion. The tornado touched down just after this directional change, whilst the reported hail and rain distribution conformed to the expected relative pattern.

The slight departures from features (a)iv and (b)iii appear to be related. The subsequent life of the supercell after recurvature was about 1 hour, tropopause penetration was not confirmed, and the wind damage was not located in the path of the hook echo but was further to the "H" side by some 5 miles. This latter feature together with erratic path and brief life of the tornado is a feature of the end of the severe stage and is in agreement with the shorter identity of the cell after recurvature. It is concluded that the Sydney storm briefly achieved the SH stage but was of lesser intensity or degree of organisation than those studied by Browning and Fujita.

5. CONCLUSION

A study of the storm environment is the subject of a separate paper being prepared by the authors for submission to the next issue of this journal. The degree and detail of anomaly in storm motion will be discussed in that paper. It is concluded here that a strikingly close analogy existed between the Sydney storm and the well defined metamorphosis at the onset of the tornadic SR mature stage as described by Browning in Northern Hemisphere storms.

ACKNOWLEDGMENT

Mr. M. Moss made available hail data collected by himself and Messrs. J. Armstrong and D. Eversson of the Sydney Regional Office of the Bureau of Meteorology.

REFERENCES

Browning, K.A. 1965 "The Evolution of Tornadic Storms" J. Atmos. Sci. 2, pp. 664-668.

1968 "The Organization of Severe Local Storms" Weather, October 1968, 10 pp. 429-434.

Browning, K.A. and Fujita, T. 1965 AFCRL Special Report 32

Byers, H.R. and Braham, R.R. 1949 "The Thunderstorm" Washington D.C., U.S. Government Printing Office, 287 pp.

Fujita, T. 1958 "Meso analysis of the Illinois tornadoes on 9 April 1953" J. Met., 15, pp. 288-296.

1965 "Formation and Steering Mechanisms of Tornadic Cyclones and Associated Hook Echoes" Mon. Weath. Rev., 93, pp. 67-78.

Hoecker, W.H. (Jr.) 1957 "Abelene, Texas, Area tornadoes and associated radar echoes of May 27, 1956" Proc. of the Sixth Weather Radar Conference Boston, Amer. Met. Soc. pp. 143-150.

Newton, C.W. and Fankhauser, J.C. 1964 "On the Movement of Convective Storms, with an Emphasis on Size Discrimination in Relation to Water Budget Requirements" J. of App. Met. 3, pp. 651-668.