NOTES AND CORRESPONDENCE

Storm Motion as Related to Boundary-Layer Convergence

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ABSTRACT

Data presented indicate that severe thunderstorm areas may become anchored to intense, boundary-layer convergence zones. In such cases, the mean cloud-layer wind vector has little relation to the movement of regions of large hail, wall clouds and tornadoes. Suggestions for improving severe thunderstorm warnings are offered based on this possibility.

1. Introduction

The notion that thunderstorms move primarily with the velocity of the mean cloud-layer winds has long been prevalent amongst meteorologists (e.g., Espy, 1861; Humphreys, 1914). As recently as 1949, upper air and radar data from the well-known "Thunderstorm Project" showed cell movement to be in good agreement with the mean cloud-layer wind vector (Byers and Braham, 1949). The first published study of storm motion deviating from the mean flow in large, long-lived thunderstorms was presented by Newton and Katz (1958). These authors utilized high-density rainfall data to illustrate several cases of storms whose motion vectors were to the right of mean cloud-layer winds. They attributed this deviation to propagation, i.e., growth of new convection on the right flank of existing activity. The propagation theory was reinforced by Browning and Ludlam (1962) in their analysis of radar data from the Workingham, England storm. Right-moving storms have been discussed by many authors such as Newton and Fankhauser (1964) and Browning and Fujita (1965); left-moving storms have been documented by Hammond (1967), Charba and Sasaki (1971), and others.

The predominant theme throughout most of these studies (regarding the mechanism of storm propagation) seems to relate this new growth exclusively to features such as the micro-cold front, updraft rotation, etc. While these thunderstorm-scale factors are important contributors to storm propagation, another significant source of deviate motion may lie in preexisting synoptic and subsynoptic boundary-layer features. Data are presented herein to illustrate this point. The case of a strong convergence zone on 30 May 1976 is treated in a rather detailed manner and results from other cases are presented in tabular form.

2. Analysis

The data for these cases were collected in central Oklahoma during the 1976 National Severe Storms Laboratory (NSSL) spring data collection season. [For a summary of other 1976 NSSL data, see Alberty *et al.* (1977).] The data utilized included National Weather Service (NWS) surface and upper air teletype data, NWS facsimile maps, information from the NSSL based WSR-57 radar, subsynoptic surface and upper air data (special NSSL sites) and GOES satellite photographs. The combined data network is shown in Fig. 1.

a. 30 May 1976

Severe storm potential was clearly indicated by morning synoptic data as shown in Fig. 2. A frontal boundary at the surface divided air masses over Oklahoma diagonally from southwest to northeast (Fig. 2a) with a well-defined low-pressure center located southeast of Altus (LTS), Oklahoma. The 850 mb analysis (Fig. 2b) showed a somewhat similar pattern. The 500 mb map revealed a major shortwave trough in western New Mexico with cyclonic curvature of nearly 90° between TUS, ELP and ABQ (Fig. 2c). An extremely unstable air mass prevailed in both Oklahoma and Texas, as implied by lifted indices (Galway, 1956) ranging from −8 to −14 [see,

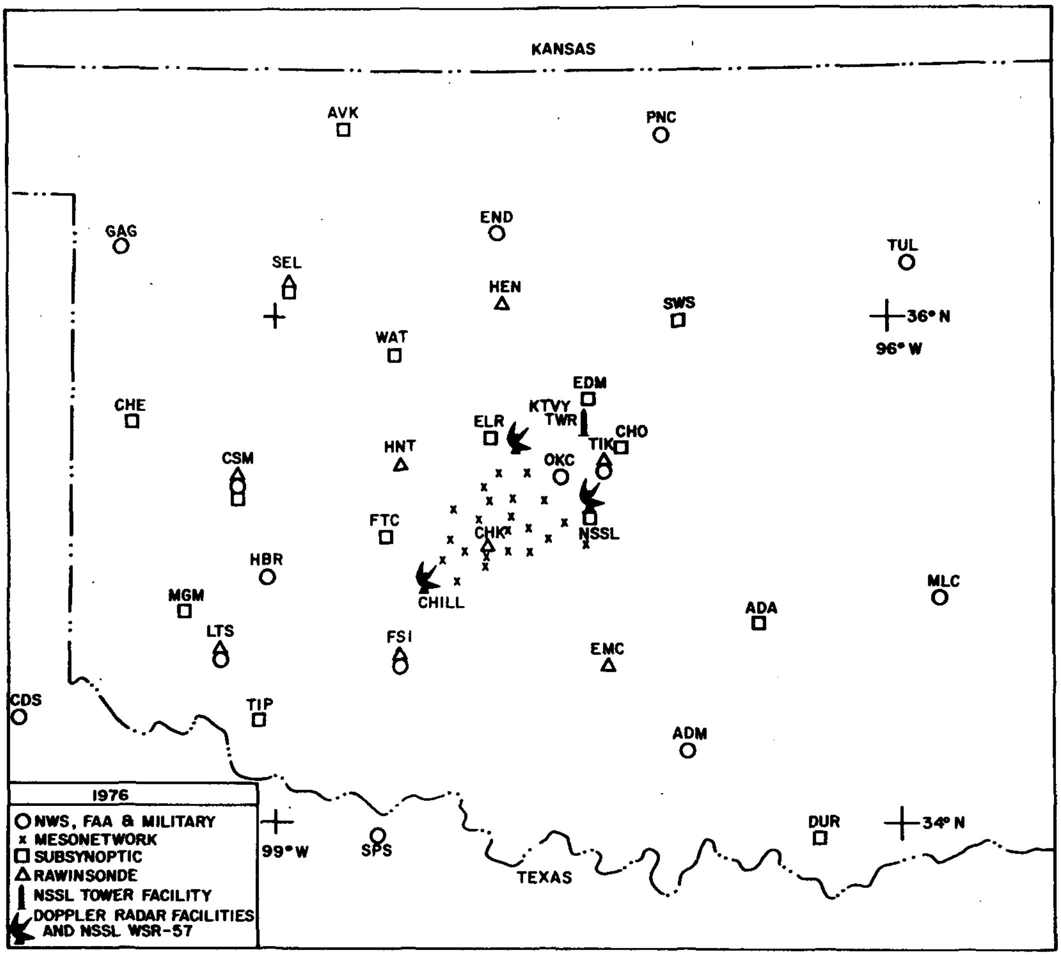


Fig. 1. Deployment of various data sensors in the NSSL study area for spring 1976.

e.g., the 0900 CST, OUN sounding, (Fig. 2d)]. The 300 mb flow over Oklahoma was strongly diffluent.

Very little change occurred in the primary surface features throughout the day (Figs. 3 and 4). Especially evident was the intense and nearly stationary circulation center to the southeast of FSI. Strong convergence of the surface airflow in that region suggested that thunderstorm activity would develop there first (e.g., Hudson, 1971; Doswell, 1977), and that is what occurred. Fig. 5a illustrates the position of radar echoes (≥20 dBZ) at 1500 CST. The storm which subsequently became tornadic is located near Ringling, Oklahoma, at 195° and 120 km from the NSSL radar site.

In attempting to predict the area threatened by potentially severe local storms, the forecaster would next consider expected storm motion. In this case, identification of the mean cloud-layer wind vector was facilitated by an abundance of proximity data. Rawinsondes were released on 30 May from the nine NSSL sites (triangles in Fig. 1) at 0900, 1300, 1430 and 1700 CST. Vector averaging of winds at over 70 levels per sounding between 850 and 300 mb from 1430 CST sounding releases at FSI, EMC and NSSL gave a mean wind from 250° at 15 m s^{-1}, with no single station average deviating more than 10° or 2.5 m s^{-1} from this value. A first approximation of storm motion would be generally along this vector. In the case of strong cells, a deviation slightly to the right might be anticipated.

In the case of the Ringling storm, motion bore little relation to the mean wind (Figs. 6a–6f). While the echo did expand slowly northeastward with time, the eastern portion of the activity consisted of heavy rain and small hail only. Integrated reflectivity radar data showed that the most intense core remained on the western side of the storm. As can be seen from Fig. 6, the southwestern flank was nearly stationary (motion computed from digital data was 090°/2.5 m s^{-1}). The location of this region is significant

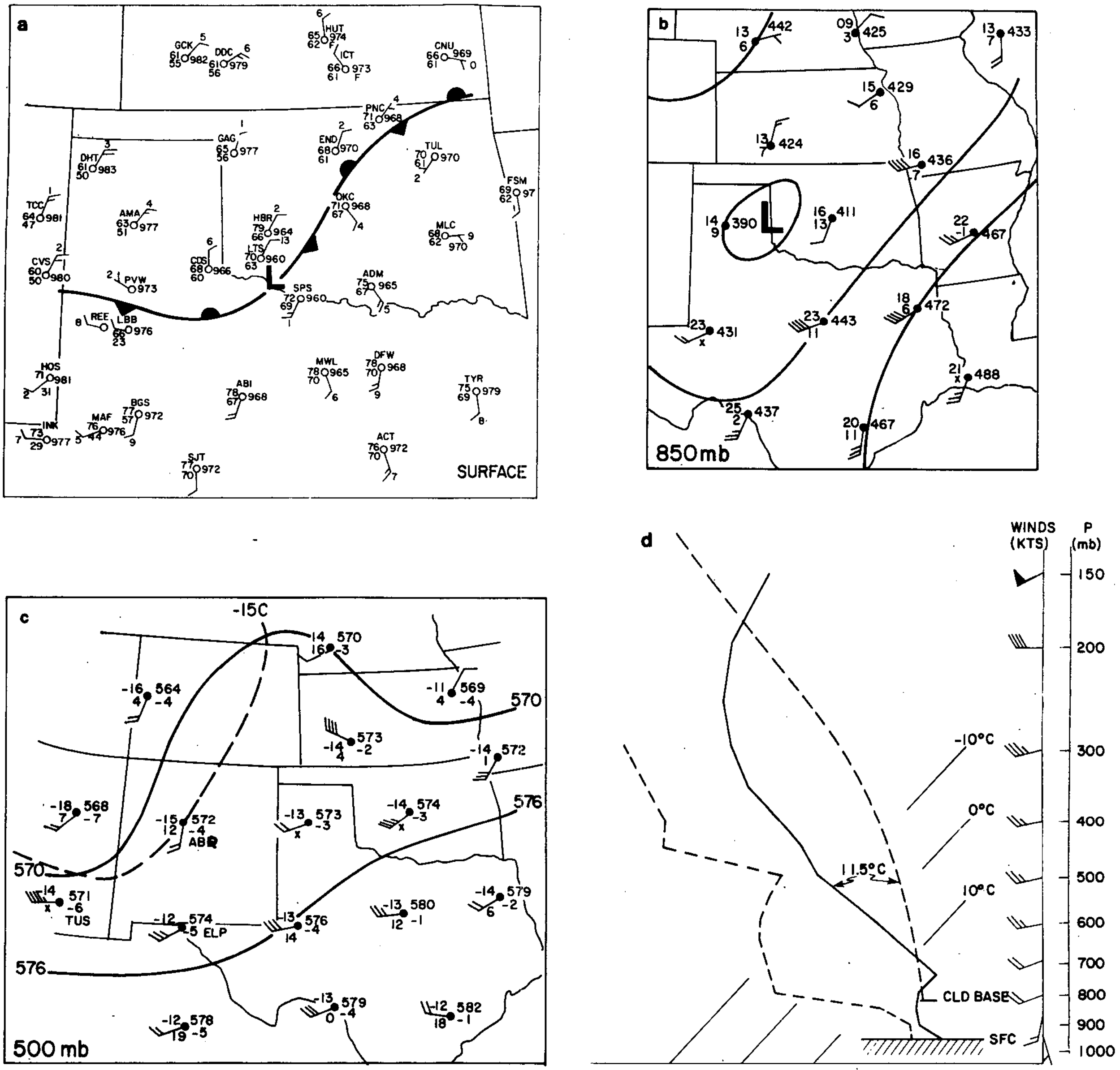


FIG. 2. Regional maps showing morning synoptic conditions on 30 May 1976. (a) 0800 CST surface map showing, for each station, wind direction, wind speed (kt) and [counterclockwise (CCW) from upper right (UR)] the last three digits of altimeter setting in inches of mercury, temperature (°F) and dew point (°F). Stationary front and low are located as shown. (b) 0600 CST, 850 mb analysis with winds as in (a) and (CCW from UR of each station) the last three digits of the 850 mb height (m), temperature (°C) and dew point (°C); 30 m isoheight intervals are analyzed. (c) 0600 CST, 500 mb analysis as in (b) except heights shown are in decameters and dew-point depression is given; 60 m isoheight intervals are analyzed. (d) Norman (OUN) sounding, 0900 CST, plotted on a skew *T*-log *P* diagram. Lifted parcel moist lapse rate from estimated afternoon boundary-layer conditions.

since, in most cases, severe weather events occur near the storm's southwest flank (e.g., Davies-Jones and Kessler, 1974). Continuous (within the resolution of NSSL radar data) propagation occurred as a result of the new convection forming in the vicinity of the strong boundary layer convergence zone (Fig. 4b) and in this case the propagation vector apparently offset the mean cloud-layer wind vector. A short-lived tornado touched down near the extreme southwestern edge of the storm at 1625 CST, while a second tornado occurred with the same storm about 15 km northwest of the first one at 1900 CST.

It is concluded from the 30 May data that the Ringling storm was anchored to the low-level con-

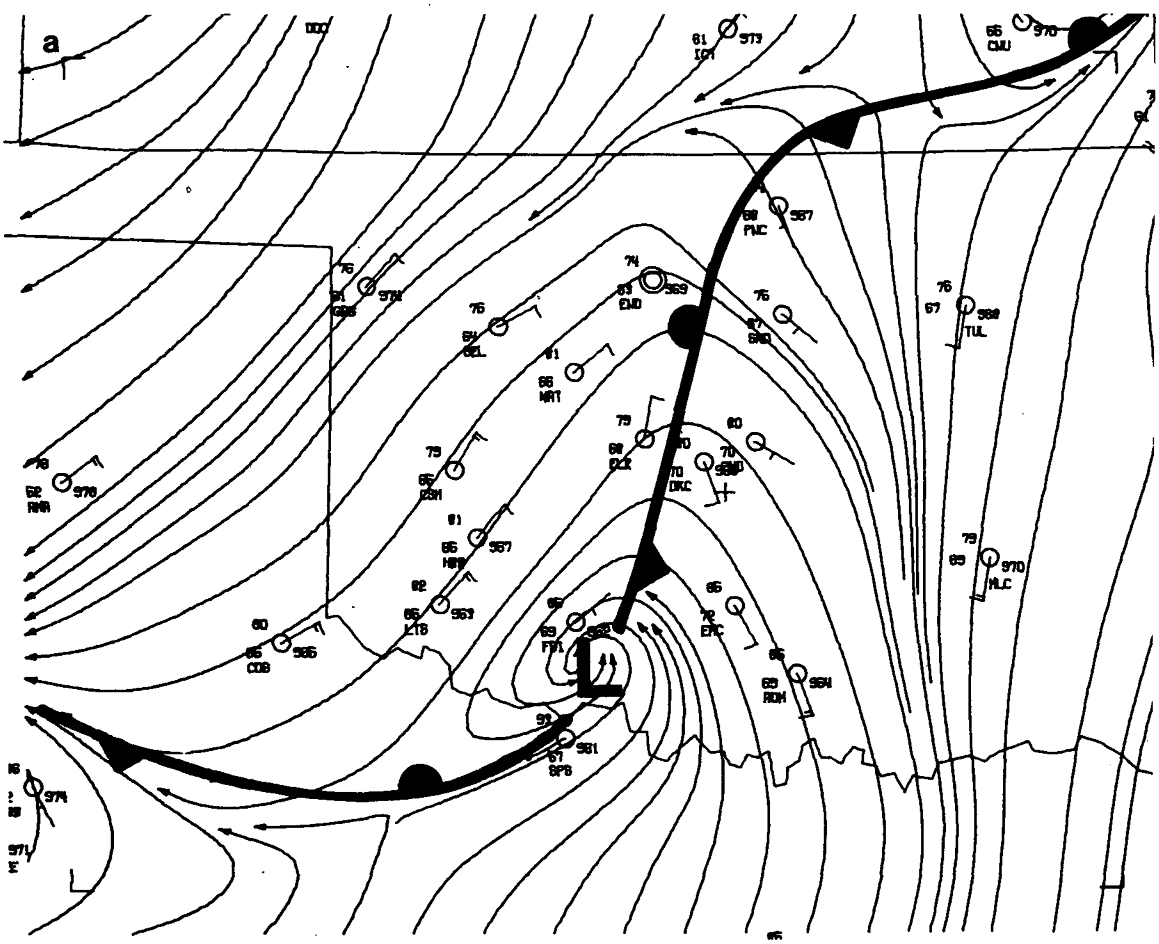


FIG. 3a. 1300 CST surface analysis for 30 May 1976. Station models as in Fig. 2a with objectively analyzed streamlines superimposed. [For a complete discussion of objective technique (see Barnes, 1973).] Low and stationary front placed subjectively from pressure and streamline analysis.

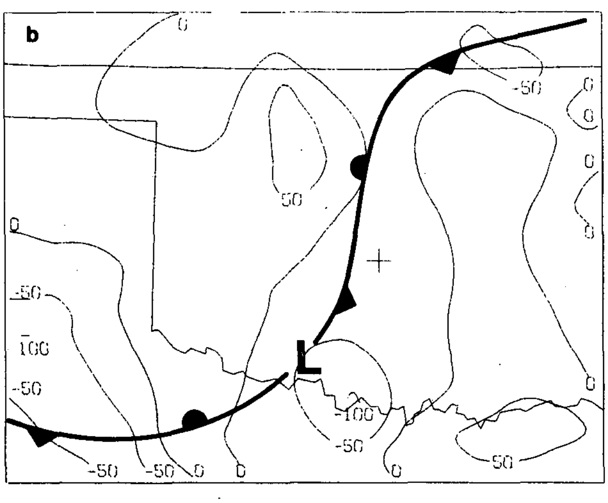


FIG. 3b. Surface divergence ($\times 10^6$ s^{-1}) computed as by Barnes (1973).

vergence area associated with a stationary subsynoptic low and thus did not drift with the mean wind of the cloud-bearing layer. Furthermore, other data from 30 May indicate that storms which formed along the cold front remained essentially anchored to the frontal convergence zone.

b. Other cases

A large data set is currently being assembled and examined by the author. Many environmental characteristics are being compared for severe, as well as nonsevere, thunderstorm days. Table 1 lists some pertinent parameters from the first few severe storm cases synthesized. While storm motion in cases 2, 3 and 6 seem to be a combination of mean cloud-layer wind with movement of boundary-layer features, cases 1, 4, 5, 7 and 8 show a clear and direct relation to the boundary layer alone.

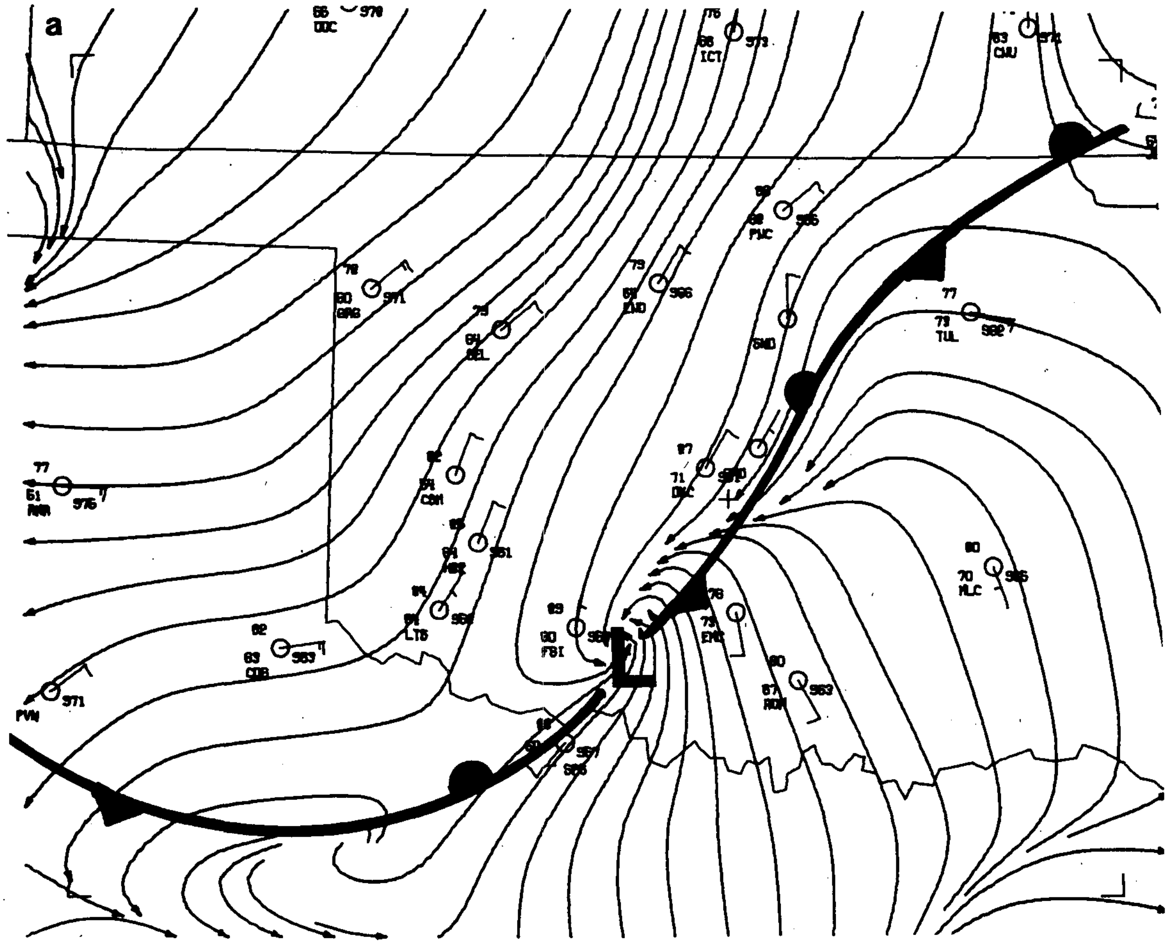


FIG. 4a. As in Fig. 3a except for 1700 CST.

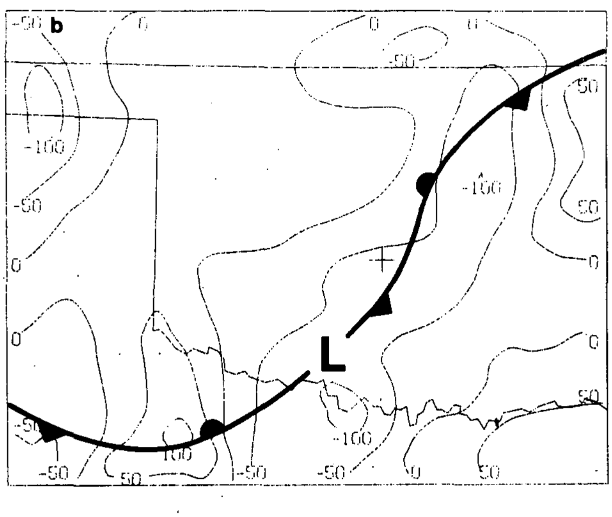


FIG. 4b. As in Fig. 3b except for 1700 CST.

3. Discussion and comments

The cases discussed above are merely a few of the many such cases observed by the author while serving as a severe thunderstorm forecaster for the yearly NSSL spring data collection. Clearly, not all cases are so directly related to the boundary layer. It is speculated that most often, storm motion is a blending of three factors, namely, the mean cloud-layer wind vector, boundary-layer convergence zones (particularly their strength, orientation and movement), and thunderstorm-induced convergence features. Obviously, the factor which dominates motion for a given storm depends on the relative intensities of these three mechanisms. The next step is to determine under what circumstances the boundary layer does dominate storm motion. However, simply being aware of the possibility may prove useful.

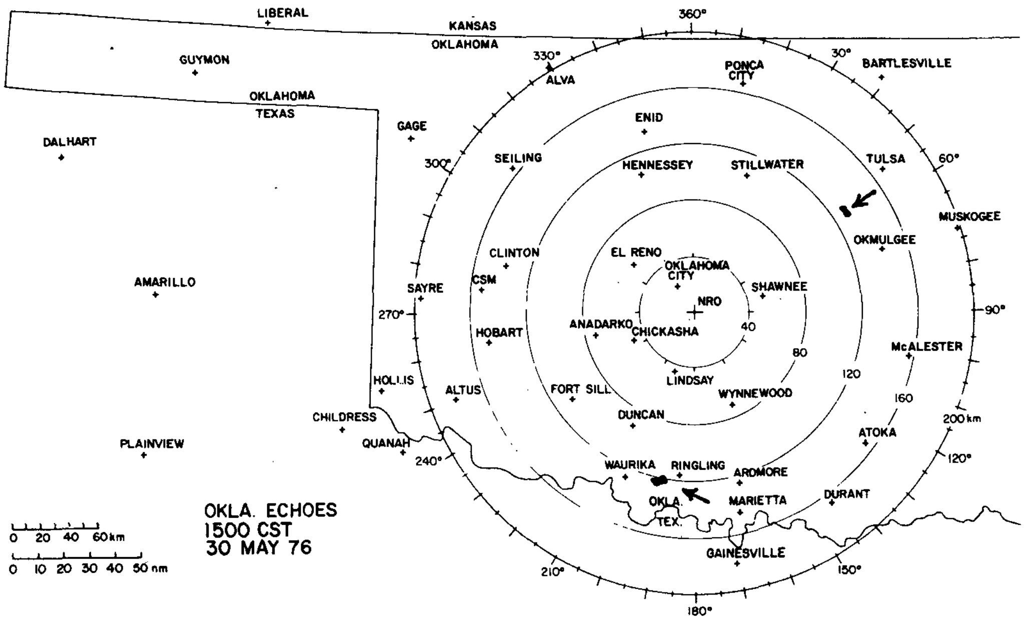


FIG. 5. Map of Oklahoma with azimuth and range from Norman radar superimposed. Shaded areas are radar echoes of 20 dBZ or greater intensity at 1500 CST 30 May 1976. Echoes beyond the Oklahoma border are not shown.

NWS severe storm warnings are issued on a county basis only after storms are in progress and severe weather is observed or suspected. Warnings are thus immediately important to the general public and it is here that storm motion becomes significant. The common practice seems to be to calculate storm motion from the movement of echo centroids.[1] However, as illustrated by the cases presented here, this may be misleading. The echo may indeed be expanding downwind with time as an area of rain and small hail, but the region significant to severe weather may not be moving at all or moving quite differently than the centroid. The author has often observed warnings to state that a severe storm is moving (for example) toward the northeast at 30 kt when, because of continuous regeneration on the storm's southwestern flank, the area of severe ac-

[1] Automated storm motion computations also apply only to the echo centroid.

TABLE 1. Motion parameters.

Case	Date	Low-level convergence feature	Storm time (CST)	Storm location	Motion of convergence feature* (deg/m s^{-1})	Mean cloud-layer winds* (deg/m s^{-1})	Storm motion* (deg/m s^{-1})
1	5-24-73	Intersection point of wind shear line with cold front	~1500	Central OK	$290/10.0_{1,3,4}$	$275/20.0_{8}$	$285/10.0_{5}$
2	5-24-73	Wind shear line	~1500	Central OK	$260/12.5_{1,3,4}$	$275/20.0_{8}$	$270/15.0_{5}$
3	5-23-74	** Subsynoptic-scale cold front from old thunderstorms	~1800	Central OK	$360/10.0_{1,2,3}$	$270/30.0_{8}$	$310/15.0_{5,6}$
4	5-26-76	Cold front	~1630	N. central TX	$270/5.0_{1,2}$	$250/25.0_{8}$	$270/5.0_{6}$
5	5-30-76	Surface low	~1630	S. central OK	~Stationary$_{1,3}$	$260/15.0_{8}$	$090/2.5_{5}$
6	5-19-77	Outflow boundary from large area of nearby storms	~1730	Central OK	$270/5.0_{1,2,3}$	$220/20.0_{8}$	$240/12.5_{5,6}$
7	5-27-77	Dryline	~1700	Western OK	$310/5.0_{1,3}$	$275/20.0_{8}$	$310/5.0_{5}$
8	5-28-77	** Subsynoptic-scale cold front from old thunderstorms	~1800	Central OK	$010/5.0_{1,3}$	$285/15.0_{8}$	$010/5.0_{5}$

* Motion computed via subjective surface analysis (1), satellite data (2), objective analysis of synoptic and subsynoptic surface data (3), mesoscale data included (4), NSSL radar data (5), NWS radar data (6), synoptic sounding data (7), and NSSL proximity sounding data (8).

** Large arcus cloud observed on satellite prior to convection as well as cold front on surface analysis.

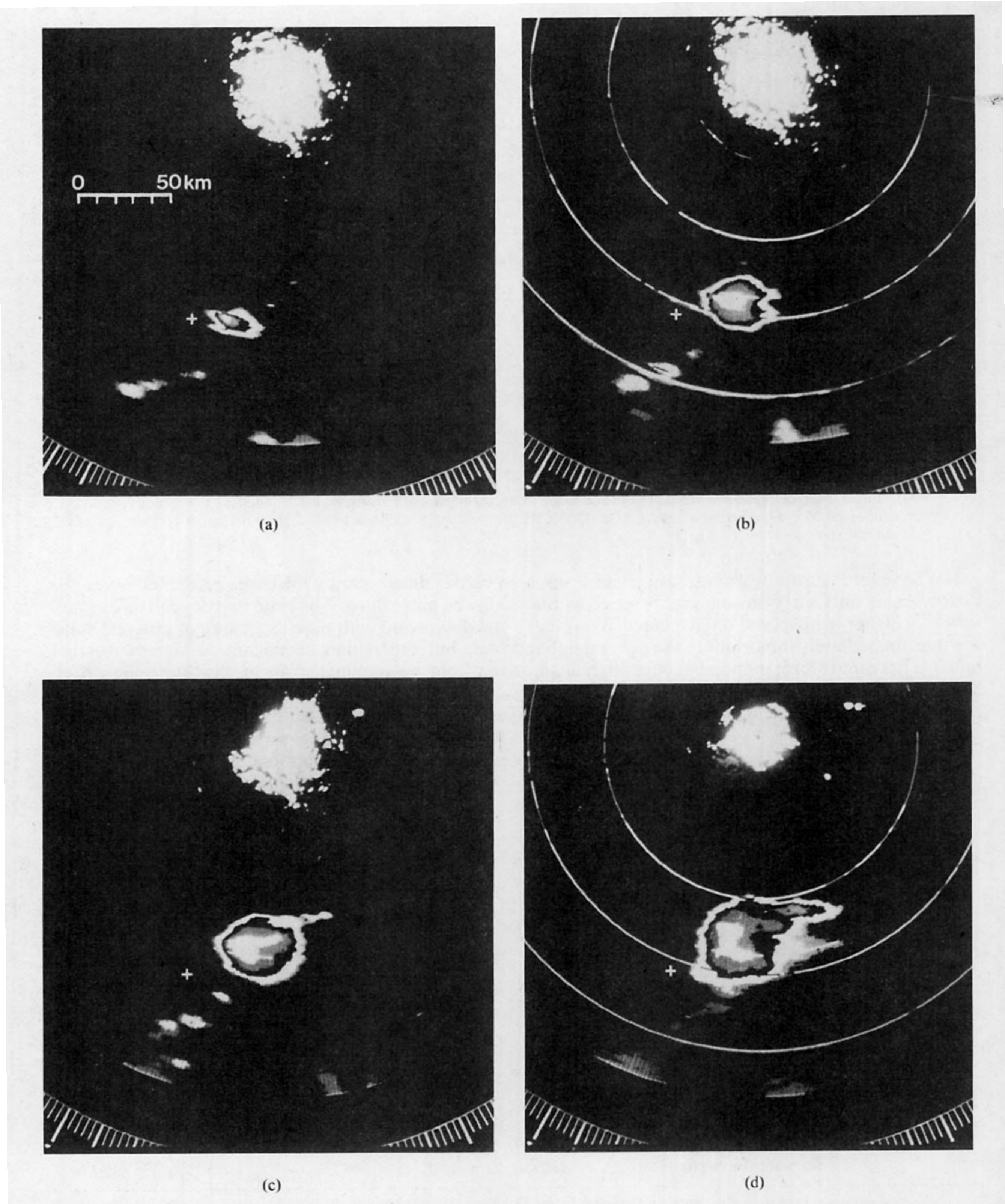
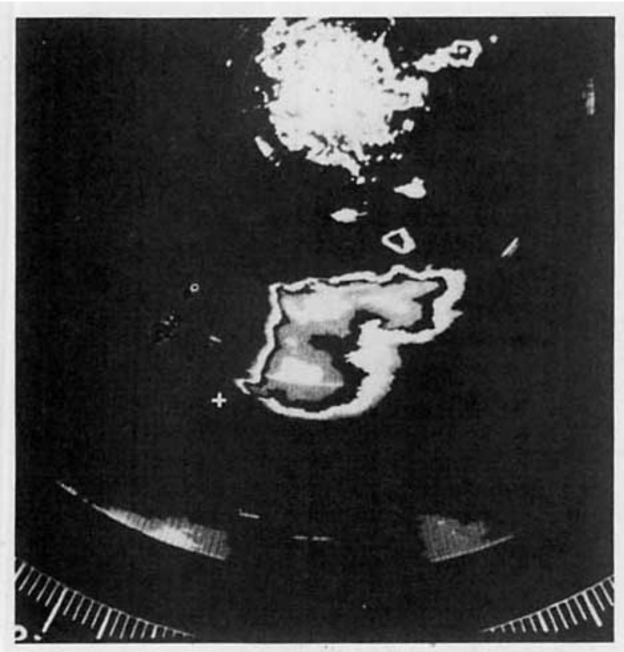


FIG. 6. (a) NRO centered, WSR-57 radar photo from 1515 CST on 30 May 1976. VIP contours at 10 dBZ increments beginning at 20 dBZ. Fiducial mark is Waurika, Oklahoma. (b) As in Fig. 6a for 1530 CST; (c) 1546 CST; (d) 1600 CST; (e) 1630 CST. Range circles missing (cf. Fig. 5).



(e)

Fig. 10. (*Continued*)

tivity is confined to one or two counties for several hours. In such cases, it is possible that downstream counties may be alarmed falsely, while regions in imminent danger might prematurely relax their guard. Perhaps operational radar meteorologists should include in both their radar reports and severe storm warnings the location and movement of intense reflectivity gradients (especially on the southwest flank of severe storms), hook echoes, etc., in addition to the normal procedure of reporting echo centroid behavior. If the warnings are public oriented, perhaps the wording could be "the most intense portion of the storm is moving . . ." or a similar statement. The resulting increase in descriptive accuracy and consequent increase in credibility may well justify the additional effort.

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