NOTES AND CORRESPONDENCE

Observations of a Severe Left Moving Thunderstorm

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ABSTRACT

Observations have shown that right moving thunderstorms are favored in environments characterized by clockwise-turning hodographs. There are, however, a few observational and numerical studies of long-lived, left moving storms within environments characterized by clockwise-turning hodographs. For example, a documented left mover that occurred on 26 May 1992, near Coldspring, Texas, with a mesoanticyclone and hail spike (also called a three-body scattering signature) produced severe weather. Although a few cases have been documented, left moving thunderstorms have received less study than right moving cells.

The long-lived, severe thunderstorm of 17 May 1996 is presented to improve documentation of left moving thunderstorms. The storm occurred over eastern Nebraska and will be referred to as the York County storm. This left mover resulted from storm splitting and moved to the west of a surface cold front. The relatively isolated storm subsequently split approximately 1 h later, yielding a new right moving thunderstorm. Doppler radial velocities suggested the existence of a mesoanticyclone within the York County storm. Hail, 1.75 in. in diameter, was produced by the storm around the time the updraft split.

There were many similarities between the York County storm and the 26 May 1992 Coldspring left moving severe thunderstorm. Both storms were relatively isolated, contained mesoanticyclones, and produced severe weather after the vertically integrated liquid water obtained a maximum value. Due to the dearth of material on left-moving storms, general statements concerning their evolution are lacking. This current study is a first step toward improving the sparse documentation of such thunderstorms. More work is needed in this area to help identify physical processes that lead to left moving thunderstorms, particularly those that become severe.

1. Introduction

Observations and numerical simulations of left moving thunderstorms have been reported in the literature over the past few decades. Earlier work demonstrated the influence of hodograph curvature on the selective enhancement of right or left moving thunderstorm updrafts (Klemp and Wilhelmson 1978). Splitting of a parent updraft appeared similar to cell mitosis as viewed from radar (Achtemeier 1969). Updraft splitting was suggested to occur after the development of wake vortices in the lee of the obstacle-like parent updraft (Fujita and Grandoso 1968). Additional numerical simulations have shown that updraft splitting is influenced by the midlevel pressure field. Schlesinger (1980) and Rotunno and Klemp (1982, 1985) demonstrated that the pressure field enhances lifting on the flanks of the presplit updraft. Following the completion of splitting, left and right moving updrafts form, relative to the mean tropospheric flow. The first single-Doppler documented case of storm splitting occurred on 1 May 1977 (Bluestein and Sohl 1979). Generally, after completion of the splitting process, the left-moving updraft weakens and sometimes dissipates in an environment characterized by a clockwise-curved hodograph.

There is observational evidence that right moving thunderstorms are more common than left moving thunderstorms (Davies-Jones 1985). Thunderstorm environments characterized by shear vectors that veer with height have been proposed to explain this difference (Rotunno and Klemp 1982). In the Rotunno and Klemp study, they show that in a linearized setting the perturbation pressure field is proportional to $\mathbf{S} \cdot \boldsymbol{\nabla}_h w$, where $\mathbf{S}$ is the temporally constant environmental vertical shear of the horizontal wind vector, and w is the time-varying vertical motion. This relationship was used to show that a high–low pressure couplet forms along the downshear direction. When shear vectors veer with height, high pressure is found above low pressure on the northern flank of the left moving updraft. The resulting vertical profile of pressure acts to inhibit upward motion within the left-moving updraft. Results from a recent simula-

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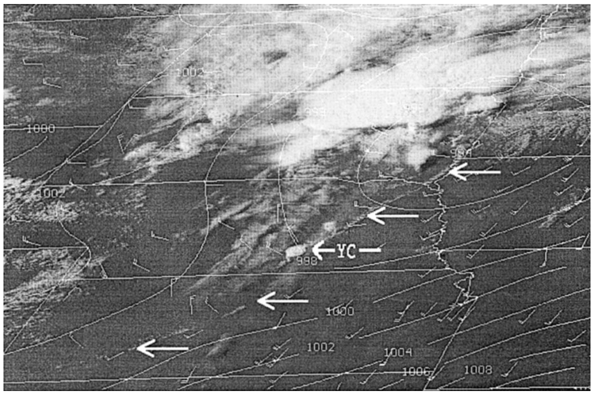


FIG. 1. Surface winds (full barb is 5 m s^{-1}) and pressure (every 2 mb) at 2200 UTC 17 May 1996. Satellite image is the 1 km visible from *GOES-8* at 2145 UTC. Cumulus line delineating the cold front is denoted by arrows. The bold letters YC are used to identify the York County storm.

tion have suggested that the dissipation of a left moving cell, following storm splitting, was in response to an expanding cold pool beneath the updraft (Grasso 2000).

Charba and Sasaki (1971) reported on a long-lived, left moving thunderstorm that was observed on 3 April 1964. Approximately 2 h after the left moving storm developed, the updraft split. An idealized simulation of that event was performed by Wilhelmson and Klemp (1981). A sounding from Fort Sill, Oklahoma, was used to initialize their simulation. The hodograph exhibited clockwise curvature from the surface to approximately 1 km, and unidirectional above 1 km. Results indicated that below 1 km the clockwise curvature of the hodograph was detrimental to the development of the left moving updraft. Wilhelmson and Klemp (1981) suggested that convergence along the gust front was necessary for the longevity of the left moving cell. They suggested that lifting along the gust front was large enough to compensate for the adverse effect of the veering shear vectors on the left mover. This process was supported by rerunning the simulation without rainfall. In that case, the left mover decayed soon after splitting from the parent cell.

The effects of varying wind shear on simulated thunderstorms was performed by Weisman and Klemp (1984). Hodographs used for their simulations had the shape of a half-circle turning clockwise from the surface to 5 km. In each experiment, left moving cells survived in an environment with shear vectors that turned clockwise with height. Their analysis included a decomposition of the pressure field (Klemp and Rotunno 1983; Rotunno and Klemp 1982) into dynamic and buoyant terms. Results indicated the importance of lifting along the expanding outflow boundary beneath the left movers. This result was similar to that of Wilhelmson and Klemp (1981).

The evolution of dominant left moving thunderstorms was reported by Brown and Meitin (1994). The observed thunderstorms occurred over the southern portion of the North Dakota Thunderstorm Project area (Boe et al. 1992) on 27 June 1989. Although a composite hodograph exhibited clockwise curvature from the surface to approximately 3 km, left moving thunderstorms were dominant. Those observations were contrary to expected results from linear theory. One conclusion of the study was the hypothesis that expanding gust fronts may have been important to the longevity of the left moving thunderstorms.

A detailed radar study of a severe left moving thunderstorm was reported by Nielsen-Gammon and Read (1995). The storm occurred on 26 May 1992 near Coldspring, Texas. That storm produced wind damage and golfball-sized hail. The relatively rapid increase of vertically integrated liquid water content (VIL) to 79 kg m^{-2} over 25 min caused the issuance of a severe thunderstorm warning. Local shear values of -5.4×10^{-3} s^{-1} and Doppler angular momentum values of -134.0×10^{-3} m^2 s^{-1} were also noted within that storm. They noted that no Weather Surveillance Radar-1988 Doppler (WSR-88D) radar algorithm existed to detect mesoanticyclones or flare echoes [an extension of echo radially away from highest reflectivity core is called a flare echo (Wilson and Reum 1986)], both of which were observed within the Coldspring storm. They also drew attention to the relative lack of documentation on left moving thunderstorms.

Recently Adlerman et al. (1999) performed a simulation of cyclic mesocyclogenesis. They initialized a model domain horizontally homogeneous with the 20 May 1977 Del City, Oklahoma, sounding. This sounding has been used in other numerical simulations of thunderstorms (Klemp and Rotunno 1983; Grasso and Cotton 1995). Their results indicated a long-lived, left moving updraft that underwent successive splitting. The focus of their study was the morphology of the mesocyclone within the right moving updraft. As a result, a vestige of attention was devoted to the left moving storm.

The studies described above show that when environmental shear vectors veer with height, an adverse environment for left moving updrafts is produced. There are, however, other processes that sometimes allow left moving thunderstorms to strengthen after splitting from the parent storm. The intent of this study is to build on past work by adding to the existing documentation of left moving thunderstorms. A left moving thunderstorm that affected York County, Nebraska, on 17 May 1996 will be described. That particular storm was severe, long lived, and split. This storm (referred to as the York County storm hereafter) was detected by WSR-88D radar located at Hastings, Nebraska (KUEX), and *Geostationary Operational Environmental Satellite-8* (*GOES-8*). The York County storm will be compared with the severe left moving thunderstorm that occurred in Coldspring, as documented by Neilsen-Gammon and Read (1995).

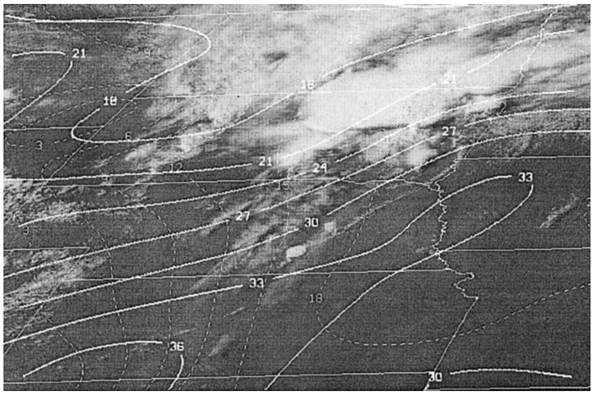


FIG. 2. Same as in Fig. 1 but with temperature (solid) and dewpoints (dashed) every 3°C.

This paper is subdivided into six main sections. Section 2 discusses the storm environment. Section 3 describes the evolution and characteristics of the left moving storm. The split of the York County storm is presented in section 4. Section 5 contains a discussion of the York County and Coldspring storms. Summary and conclusions, along with suggestions for future work, are found in Section 6.

2. The storm environment

A surface low pressure system in central Nebraska moved northeastward during the afternoon of 17 May 1996. At 2200 UTC the center of a low pressure region was located near the southern portion of the common border separating South Dakota and Minnesota. A cold front extended southwestward from the surface low to southeastern South Dakota through eastern Nebraska and central Kansas. The frontal position was delineated by a line of cumulus as seen in the GOES visible imagery. Surface winds were southwesterly at approximately 10 m s^{-1} ahead of the cold front (Fig. 1). Embedded within the southwesterly flow was a thermal ridge where surface temperatures ranged between 33° and 36°C. The ridge axis extended from western Iowa to southeast Nebraska and central Kansas. Surface dewpoints ahead of the cold front were 18°C over Iowa, eastern Nebraska, and northeast Kansas (Fig. 2). Surface winds were west to northwesterly west of the cold front at approximately 10 m s^{-1}. Temperatures decreased 10°C from southeast Nebraska to south-central South Dakota. Surface dewpoints decreased 5°C over the same distance. Due to the orientation of the isodrosotherms, the updraft encountered surface dewpoints that remained somewhat constant over the life of the York County storm.

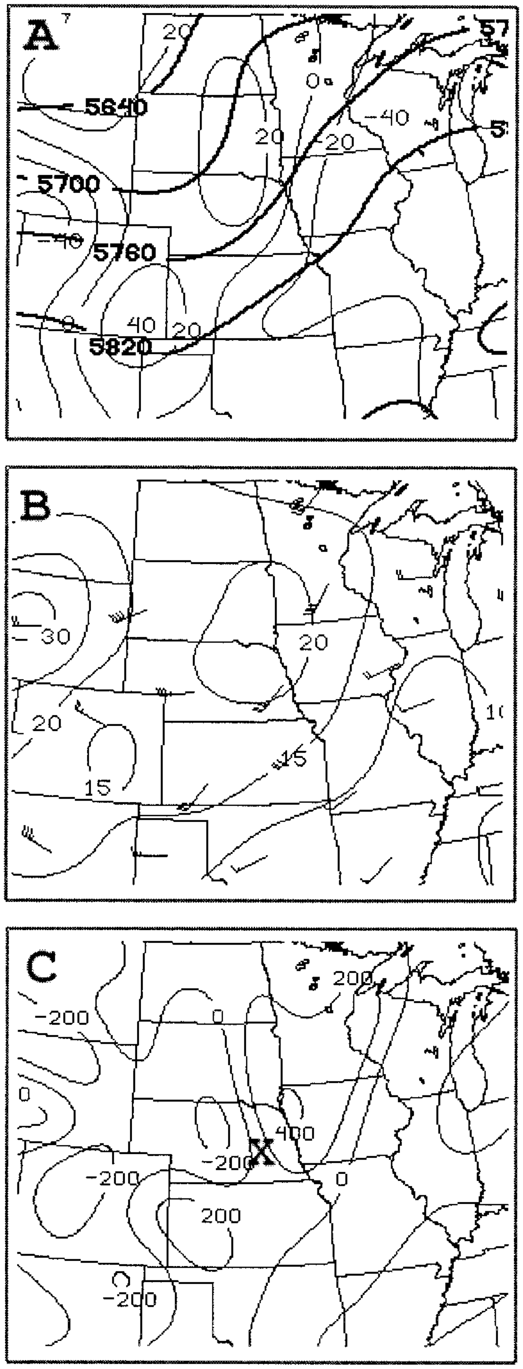


FIG. 3. The 500-hPa surface with (a) geopotential heights (thick) every 60 m and relative vertical vorticity (thin) every 20 × 10^{-6} s^{-1}, (b) wind vectors (full barb is 5 m s^{-1}) and wind speed (thin) every 5 m s^{-1}, and (c) horizontal advection of relative vertical vorticity (every 200 × 10^{-5} s^{-2}). The location of the York County storm is denoted by a bold X in (c).

At 0000 UTC 18 May 1996 (Fig. 3a), the geopotential height field at 500 mb indicated the existence of a negatively tilted trough over the northern high plains. The trough axis extended from southeast Nebraska to eastern Montana. A local maximum of relative vertical vorticity was oriented in a north–south direction from northern Nebraska through eastern South Dakota and southern North Dakota. Values of relative vertical vorticity decreased downstream from 2 to -4×10^{-5} s^{-1}, over

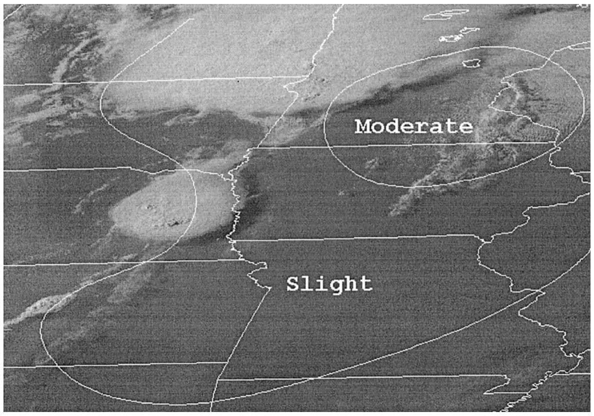


FIG. 4. SPC forecast areas for the probability of severe thunderstorms. Areas outlined are for slight and moderate risk. Risk area is superimposed on the *GOES-8* 1-km visible image at 2339 UTC 17 May 1996.

Minnesota (Fig. 3a). The winds at 500 mb were southwesterly over central Kansas, eastern Nebraska, and southern Minnesota. Wind speeds over the same locations ranged between 15 and 20 $\mathrm{m\,s^{-1}}$ (Fig. 3b). Observations suggested that the York County storm existed in a region were values of horizontal advection of vertical vorticity were near zero (Fig. 3c). Under certain conditions, advection of vertical vorticity may be used to infer regions of vertical motion on the synoptic scale (Dutton 1986, p. 356). Therefore, the York County storm may have formed in a region where upward motion on the large scale was insignificant.

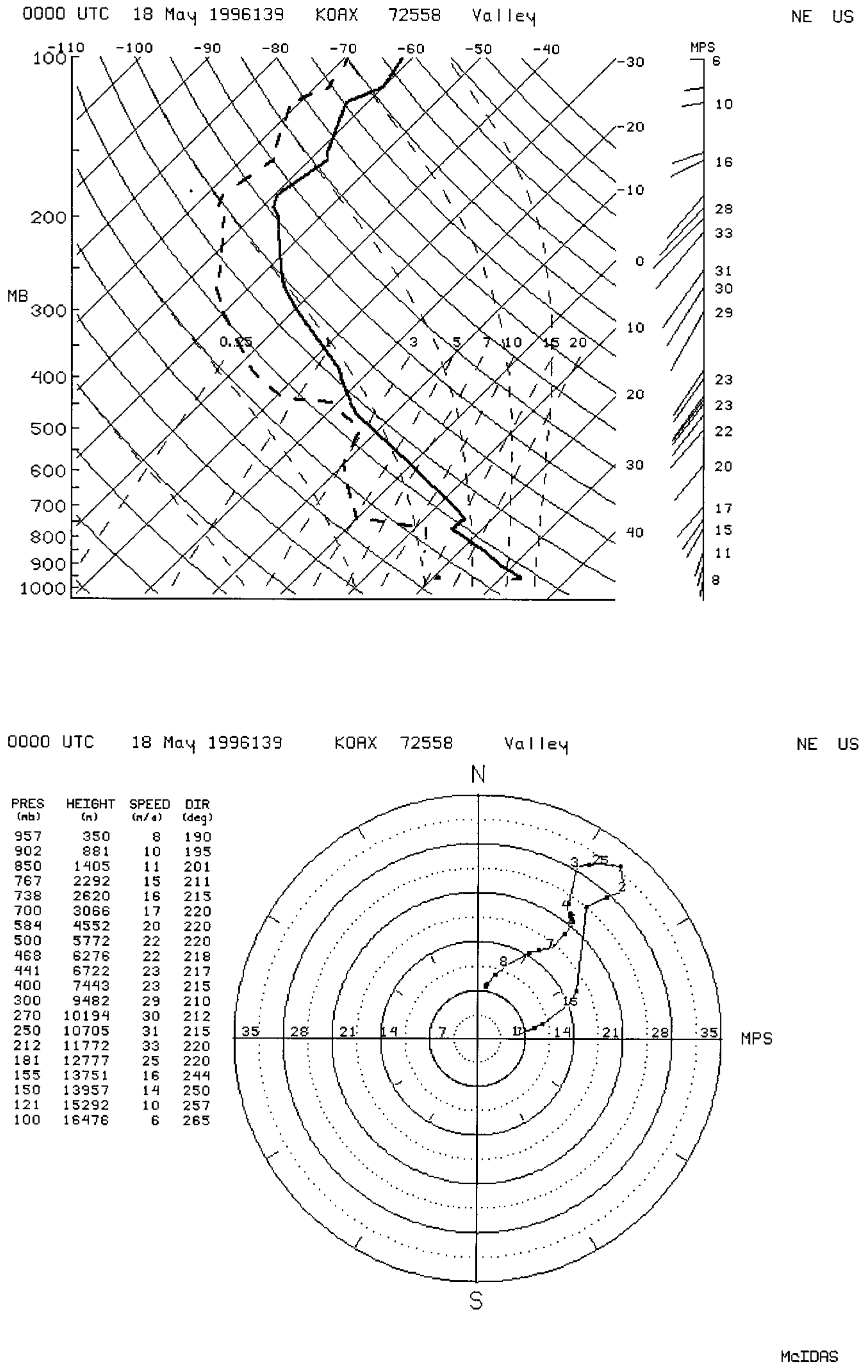
The Storm Prediction Center (SPC) convective outlook for the afternoon and evening of 17 May 1996 indicated a slight risk of severe thunderstorms in eastern Nebraska, east of the cold front (Fig. 4). The York County thunderstorm formed on 17 May 1996 south of York County in southeastern Nebraska at 2200 UTC (Fig. 1). The nearest sounding, approximately 50 km east of the cold front, was from Omaha, Nebraska (KOAX), at 0000 UTC on 18 May 1996 (Fig. 5). Stability indices derived from the sounding indicated a lifted index of $-7°$C. Values of convective available potential energy were near 1349 $\mathrm{J\,kg^{-1}}$, while the convective inhibition number was approximately 10 $\mathrm{J\,kg^{-1}}$. These values, determinded from surface parcels, suggested that the environment would support thunderstorms.

A sequence of GOES visible images revealed that the York County storm traversed a region that was west of the surface cold front. Surface winds encountered by the storm were northwesterly at approximately 10 $\mathrm{m\,s^{-1}}$. This observation was in contrast to the southwesterly flow at Omaha. As a result, the original wind field from the Omaha sounding from 0000 UTC 18 May 1996 was unrepresentative of the wind field of the York County storm environment. A time sequence of the hodograph was obtained from the KUEX Doppler radar (Fig. 6). The hodograph represented horizontal winds in the layer extending from approximately 900 to 3500 m. Two features indicated by the time series were the reduction of hodograph curvature and increase in vertical shear. As indicated in Fig. 1, the York County storm was developing at 2200 UTC. Prior to that time the hodograph exhibited counterclockwise curvature (Figs. 6a–f). At 2134 UTC (Fig. 6f), approximately the time of convective initiation, the hodograph indicated an increase of vertical shear as the cold front passed to the east of Hastings, Nebraska. During the development of the thunderstorm, however, the hodograph was more unidirectional (Fig. 6g). Approximately 30 min later (Fig. 6h) the hodograph was unidirectional with a value of vertical shear near $7 \times 10^{-3}\ \mathrm{s^{-1}}$ from 3 to 11 kft (2440 m). This value was about twice the value that existed at 2030 UTC (Fig. 6d). Increased vertical shear was in response to the low-level winds veering from southwesterly to northwesterly as the cold front passed Hastings. As shown in past numerical simulations, the increased vertical shear may have aided in the formation and maintenance of a dynamically induced low pressure region (Rotunno and Klemp 1985) on the forward flank of the York County storm. This process may be one possible reason for the longevity of the left moving thunderstorm.

The motion of the York County storm, as determined by radar, was 210° at 15 $\mathrm{m\,s^{-1}}$. As a result, helicity values determined from the hodograph at 2223 UTC (Fig. 6h) were approximately 50 $\mathrm{m^{2}\,s^{-2}}$. The relatively small and positive value of helicity was contrary to the development of a mesoanticyclone within the York County storm. The vertical shear profile shown in Fig. 6h, however, suggested the development of negative values of vertical vorticity within the updraft of the York County storm. Prior knowledge of storm motion needed for helicity calculations along with the positive helicity value at 2223 UTC suggests a limitation on the use of helicity as a predictive tool. Similar conclusions resulted from recent numerical experiments (Weisman and Rotunno 2000).

3. Characteristics of the York County storm

Convection began to form at 2130 UTC on 17 May 1996 near Hastings along the cold front. At 2200 UTC Doppler radar indicated two primary reflectivity cores. Satellite infrared imagery indicated two overshooting tops at 2204 UTC that were approximately 25 km apart. Thirty minutes later, Doppler radar and GOES visible images indicated two diverging cells. One cell moved west of the cold front and became the York County storm while the other thunderstorm moved along the frontal boundary. Ninety minutes later, 0000 UTC, GOES visible images showed that the rightmost cell continued to move along the cold front. Hail ranging from 1.75 to 2.75 in. in diameter was produced by the right moving thunderstorm (National Climatic Data Center 1996). At 0000 UTC, the York County storm



PRES (mb)	HEIGHT (m)	SPEED (m/s)	DIR (deg)
957	350	8	190
902	881	10	195
850	1405	11	201
767	2292	15	211
738	2620	16	215
700	3066	17	220
584	4552	20	220
500	5772	22	220
468	6276	22	218
441	6722	23	217
400	7443	23	215
300	9482	29	210
270	10194	30	212
250	10705	31	215
212	11772	33	220
181	12777	25	220
155	13751	16	244
150	13957	14	250
121	15292	10	257
100	16476	6	265

FIG. 5. Sounding and hodograph at Omaha, NE (KOAX), from 0000 UTC 18 May 1996. Wind speeds are in m s^{-1} while numbers on hodograph indicate pressures divided by 100.

was approximately 120 km west of the frontal boundary. A time sequence of the evolution of the two diverging cells is shown in Fig. 7. The York County storm encountered surface temperatures that decreased from 31°C at 2200 UTC (Fig. 2) to 27°C at 0000 UTC (Fig. 8), while the dewpoints remained somewhat constant at 16°C. The movement of the York County storm relative to the surface cold front may be inferred by comparing Figs. 1 and 8.

The York County storm exhibited maximum reflectivities that varied between 55 and 65 dB*Z* over 2.5 h. The vertically integrated liquid water content decreased from approximately 70 to 40 kg m^{-2} from 2230 to 2330 UTC, followed by an increase to 65 kg m^{-2} at 0030

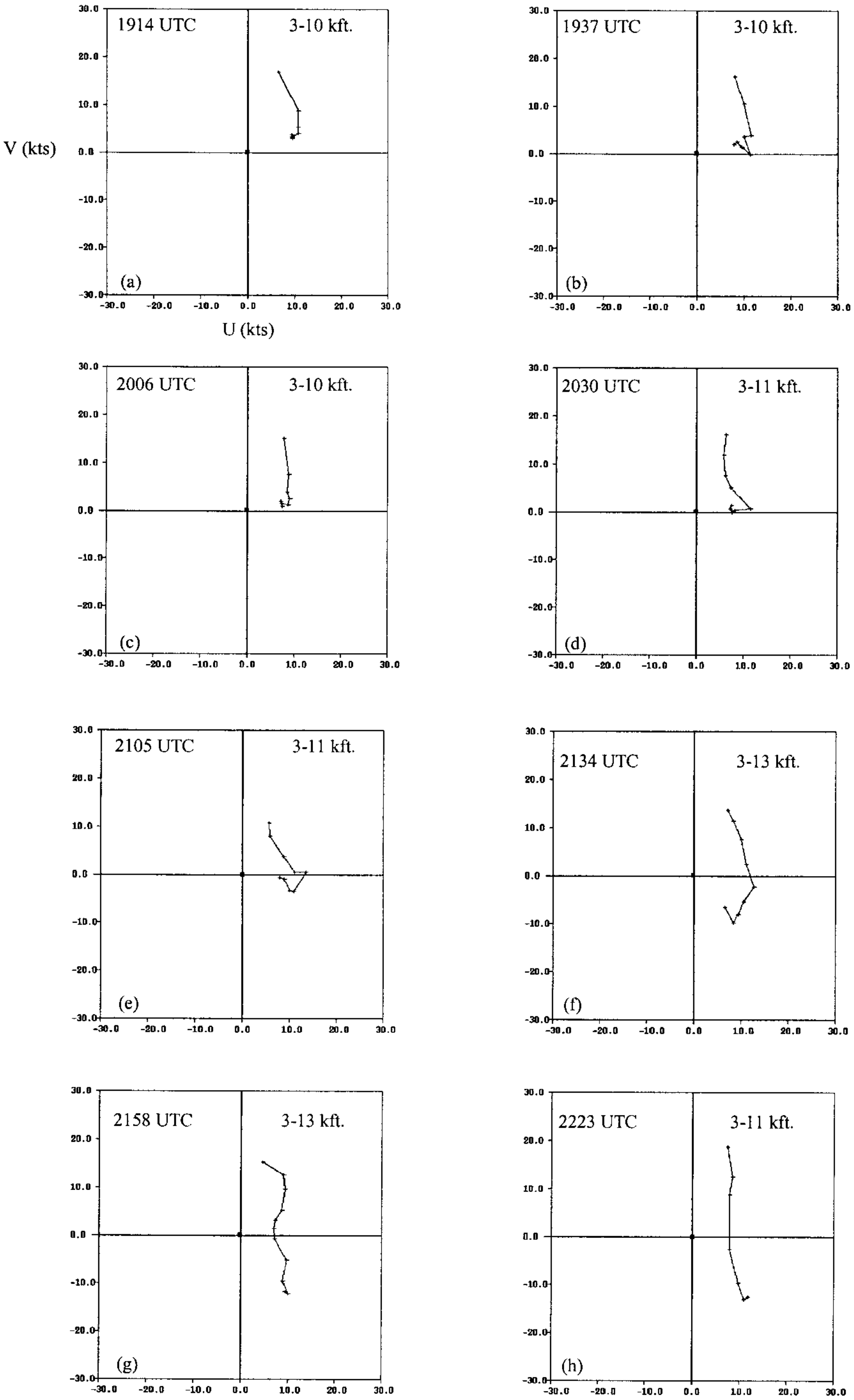


FIG. 6. Time sequence of the hodograph obtained from the Hastings, NE, WSR-88D on 17 May 1996. Wind speeds are in kt while the time is denoted in the upper-left corner of each plot. The layers in which the winds were observed are noted in the upper-right corner of each plot. Axes labeled every 10 kt.

UTC (Fig. 9). During the time period between 2230 and 2330 UTC, when the VIL was decreasing, there were three reports of 1.75-in-diameter hail. One hail report occurred in Hordville, Nebraska, at 2245 UTC (National Climatic Data Center 1996). The location of Hordville is denoted by the letter H in the GOES visible image at 2245 UTC, the approximate time of the hail event (Fig. 10). The relative position of Hordville and the

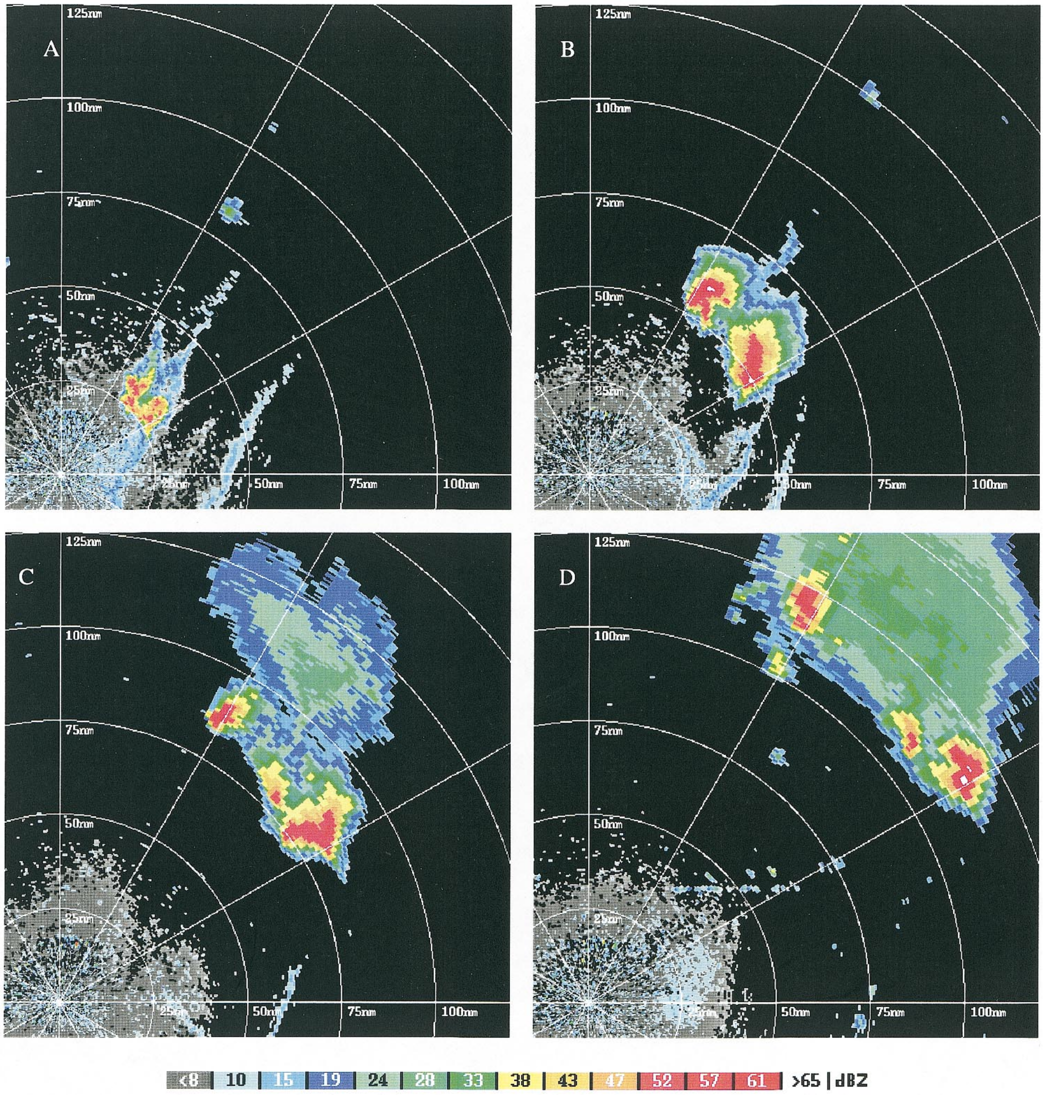


FIG. 7. The 0.5° reflectivity field at (a) 2213, (b) 2258, (c) 2343, and (d) 0027 UTC from the Hastings, NE, WSR-88D on 17 May 1996. The York County storm is the northwestern core in each panel.

overshooting top was further evidence that the York County storm was severe. At approximately 2300 UTC, Doppler radar showed the development of a new right moving thunderstorm that had split from the reflectivity field of the York County storm. After storm splitting, two instances of 1.75-in-diameter hail were reported in York County at 2310 and 2315 UTC, from the left moving York County storm. When hail was produced by the storm, no hail spike [Wilson and Reum (1986); also called a three-body scattering signature, see Lemon (1995)] was evident in the reflectivity field.

Reflectivity and velocity fields, focusing on the two initial cells at 2219 UTC, are shown in Fig. 11. The combination of the scan angle and the distance from the radar to the echoes resulted in the radar beam intersecting the storms near 3.9 km above ground level (AGL). Doppler velocity fields of the York County storm indicated the existence of anticyclonic shear approximately 15 min after the storm formed. The anticyclonic shear signature existed for the next few hours. The velocity field indicated a gate-to-gate shear value of approximately -30×10^{-3} s^{-1}. The magnitude of the calculated value exceeded the minimum value for a mesocyclone, that is, 4×10^{-3} s^{-1} (OFCM 1990). Results from the radial velocity field suggested the existence of a mesoanticyclone within the York County storm. The position of the inferred mesoanticyclone was along the western edge (left flank) of the reflectivity field. The rightmost storm, by comparison, had a mesocyclone detected by the operationally used objective algorithm (yellow circle in Figs. 11b and 11d) and had a shear value of 12×10^{-3} s^{-1}. Both the mesocyclonic and mesoanticyclonic circulations exhibited vertical continuity. Although the values of the mesocyclonic and

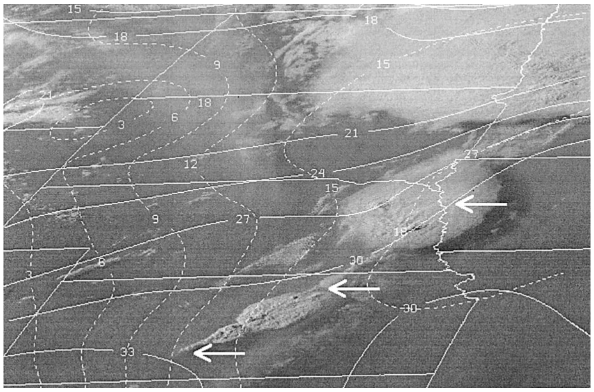


FIG. 8. Same as in Fig. 2 but valid approximately at 0000 UTC 18 May 1996. Arrows denote position of surface cold front. The overshooting top of the York County storm was collocated with the 27°C isotherm in northeast Nebraska.

mesoanticyclonic shears were similar, the objective algorithm was and currently is not designed to detect mesoanticyclones. This result is similar to that found by Nielsen-Gammon and Read (1995).

4. Split of the York County storm

At 2244 UTC the lowest elevation scan reflectivity field (with the radar beam at approximately 5.5 km AGL in this region) exhibited a hooklike appendage on the southeastern flank of the York County storm. As a result, the York County storm resembled a right moving supercell with a hook appendage, along with a weak echo vault (Figs. 12a and 12b). At the same time, the radial velocity field indicated a new mesocyclone on the right flank of the hooklike appendage. Maximum values of gate-to-gate shear were approximately 12×10^{-3} s^{-1} at midlevels within the new mesocyclone.

The existence of the hooklike appendage and mesocyclone suggests that a new updraft had developed on the right flank of the York County storm. A negative–positive vertical vorticity couplet had formed across the parent storm. Over the next 15 min, the hooklike appendage and the new mesocyclone moved to the right of the York County storm as the splitting process was completed (Figs. 12c and 12d). Satellite visible images supported the existence of a new updraft on the right flank of the York County storm. At 2259 UTC, an overshooting top of the new cell was evident to the east of the York County updraft (Fig. 13). As mentioned above, the left moving York County storm continued to produce severe weather after the splitting process was complete.

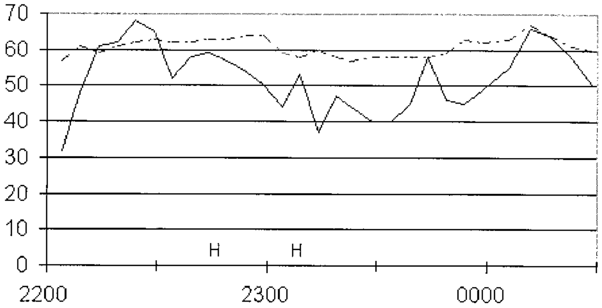


FIG. 9. Maximum reflectivity (dBZ, dashed) and maximum VIL (kg m^{-2}, solid) for the York County storm. All times are UTC along the horizontal axis. The vertical axis is used for both reflectivity and VIL. Hail events are denoted by the letter H.

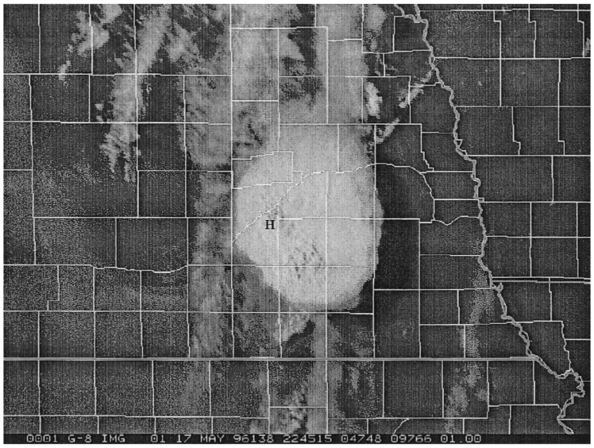


FIG. 10. *GOES-8* 1-km visible image valid at 2245 UTC 17 May 1996. Hordville is denoted by the letter H where 1.75-in.-diameter hail was reported.

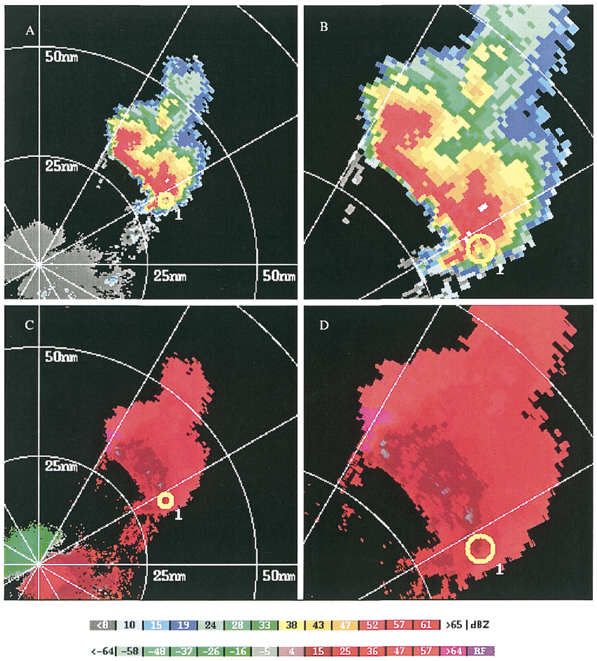


FIG. 11. York County (a) WSR-88D reflectivity (dBZ), (b) enlargement of the reflectivity field, (c) radial wind field, and (d) enlargement of the radial wind field. All images at 2219 UTC 17 May 1996 from Hastings, NE. Yellow circle indicates the location of a detected mesocyclone. Approximate height is 3.9 km AGL.

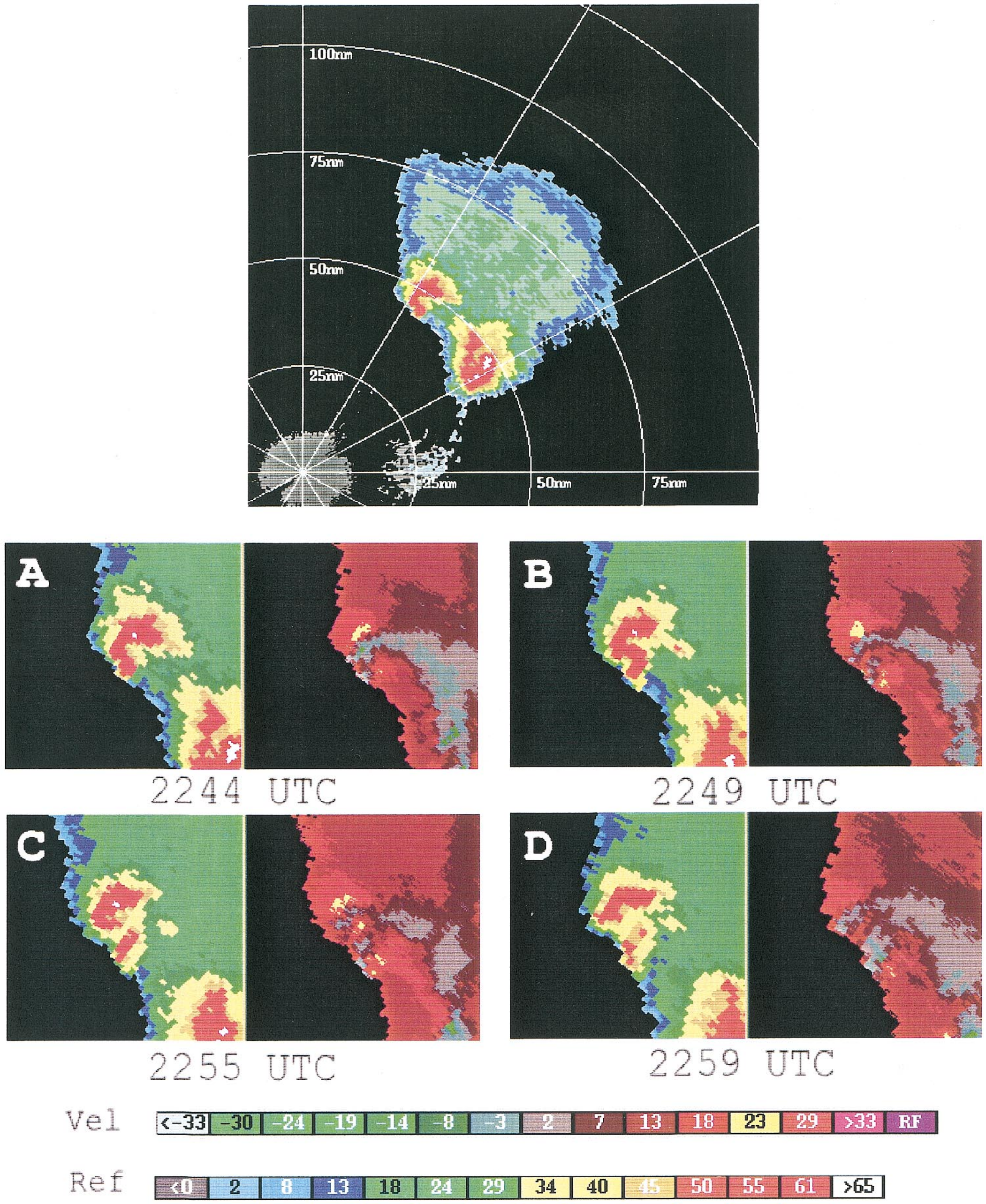


FIG. 12. Same as in Fig. 10 but showing a time sequence of a new right mover splitting from the York County storm. Reflectivity is at left while radial winds are on the right at (a) 2244, (b) 2249, (c) 2255, and (d) 2259 UTC 17 May 1996. Top panel represents a larger view of (a) with range rings included.

The right mover that split from the York County storm moved east-northeastward at 20 m s^{-1}. Following the splitting process, the York County storm continued to move northeastward. Maximum reflectivity values remained somewhat steady at 52 dBZ and the VIL was near 22 kg m^{-2} prior to the decay of the right moving cell. Values of gate-to-gate shear decreased from approximately 12×10^{-3} s^{-1} at the time of the split to 6×10^{-3} s^{-1} 1 h later. The depth of the mesocyclone was approximately 3 km. Although the new updraft had an embedded mesocyclone, the storm did not produce severe weather.

5. Discussion

The sections above described the environment and morphology of the York County storm. In this section, similarities and differences of the York County and

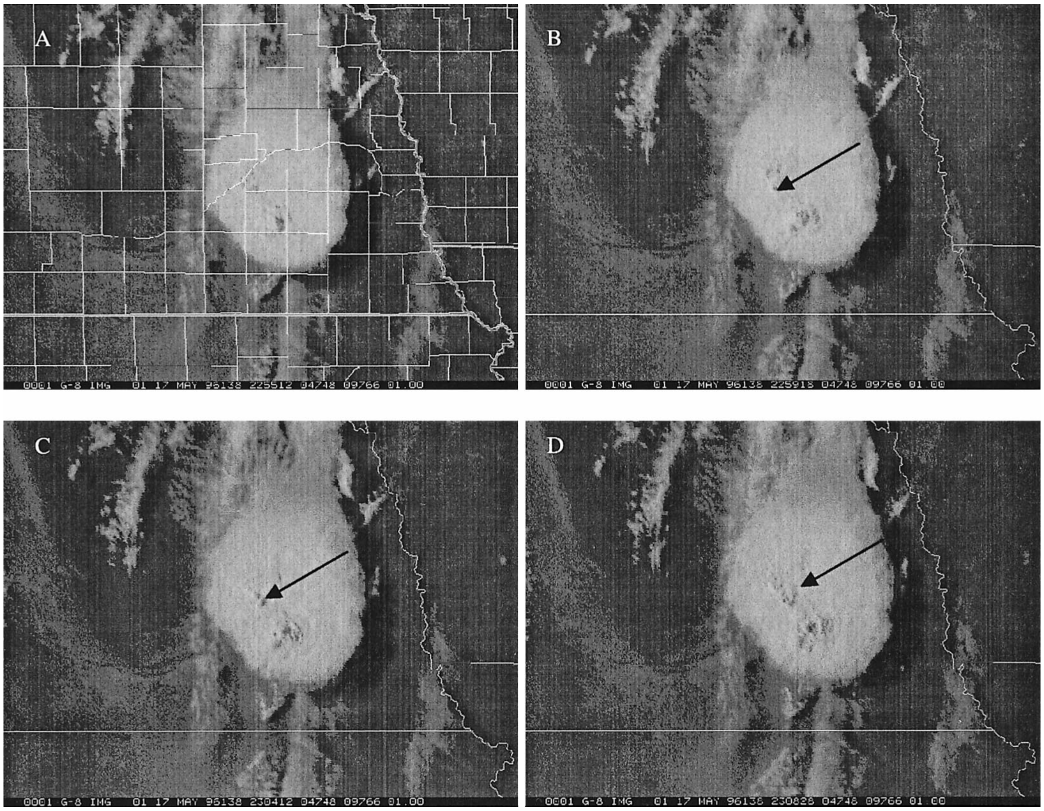


FIG. 13. A time sequence of the *GOES-8* 1-km visible images at (a) 2255, (b) 2259, (c) 2304, and (d) 2309 UTC 17 May 1996. Dark arrow is used to denote the location of the overshooting top of the new right moving storm that split from the York County storm.

Coldspring, Texas (Neilsen-Gammon and Read 1995), storm's are discussed. This section is provided to aid in formulating some type of general statement about long-lived, left moving thunderstorms. Four characteristics of the Coldspring and York County storms that are described here are the storm environments, lifetimes, VIL, and the midlevel mesoanticyclones.

The York County storm split from a thunderstorm that formed along a cold front. In time the left moving storm moved to the west of the frontal boundary in a region characterized by cold air advection. Similarly, the Coldspring storm split from a thunderstorm and moved northeastward toward cooler air at the surface. Both storms were relatively isolated from other thunderstorms.

Both left moving thunderstorms were relatively long lived. The Coldspring storm lasted over an hour while the York County storm survived nearly 3 h. In both cases the closest rawinsondes were relatively far away from the storms. Inferences were made in each case in an attempt to re-create the vertical wind profile in the environment of the storms. Helicity may be used to infer rotational characteristics of thunderstorm updrafts. The inferred value of storm-relative helicity of the York County storm was approximately 50 $m^2 s^{-2}$. This value had a similar magnitude but of opposite sign compared to the inferred value of -78 $m^2 s^{-2}$ for the Coldspring storm. The magnitudes of both values were, however, smaller than the empirically derived value for weak mesocyclones of 278 $m^2 s^{-2}$, based on 28 tornadic storms (Davies-Jones et al. 1990). In both cases mesoanticyclones existed. Detection of a mesoanticyclone within a left moving thunderstorm may be an important forecasting issue. Studing the relationship between left moving thunderstorms and helicity in the storms environment may be useful.

Vertically integrated liquid water content of thunderstorms has been shown to be a good indicator for the potential of severe weather (Winston and Ruthi 1986). The vertically integrated liquid water content of both left moving thunderstorms had similar trends prior to the onset of severe weather. The Coldspring storm exhibited an increase in VIL from 32 to 80 kg m^{-2} over 25 min. As a result, the Houston Area Weather Service Office issued a severe thunderstorm warning for the Coldspring storm. The York County storm also had a similar increase in VIL. The VIL changed from 32 to 68 kg m^{-2} over a period of 30 min. In both cases, severe weather was produced by the left moving storms when the VIL decreased from the maximum value. In contrast to the Coldspring storm, a hail spike (flare echo) was not evident in the reflectivity or radial velocity data during the time period when the York County storm produced hail.

Inferred values of the magnitude of storm relative helicity were well below the minimum value that would have suggested the existence of a mesocyclone. In both storms, however, the magnitude of local gate-to-gate anticyclonic shear values exceeded 4×10^{-3} s^{-1} over a 6-km depth. These observations suggest the existence of embedded mesoanticyclones within both updrafts of the left moving storms. Neither of the mesoanticyclones were detected by an operationally used objective algorithm due to the design. The correlation between mesoanticyclones and severe weather by left moving thunderstorms is, at present, unknown. Further documentation of left moving storms is needed to determine the value of the correlation.

6. Summary and conclusions

Past numerical and observational studies have shown that clockwise turning hodographs exist in environments that favor right moving thunderstorms. There are, however, observations of long-lived, left moving thunderstorms within environments that favor right moving storms. Some left moving storms have produced severe weather along with mesoanticyclones. Operationally used WSR-88D objective algorithms are not currently designed to detect such mesovortices. There are, however, too few studies about left moving thunderstorms to make general statements about their morphology.

In this paper a severe long-lived, left moving thunderstorm, that subsequently split, was presented. The storm was referred to as the 17 May 1996 York County storm. After formation, the storm moved to the west of a surface cold front to a region characterized by cold air advection in the boundary layer. Doppler radial velocities suggested the existence of an embedded mesoanticyclone within the relatively isolated parent updraft. Approximately 1 h after the York County storm formed, the reflectivity field indicated storm splitting and the subsequent formation of a new right moving storm. The York County storm produced 1.75-in.-diameter hail prior to and immediately following the splitting process. Although no hail spike was evident in the WSR-88D data, the morphology of the York County storm was similar to the Coldspring, Texas, storm of 26 May 1992.

Continued observational and numerical studies of left moving thunderstorms are important for improving the sparse documentation on such storms. Improved documentation may prove useful to aid in the formation of general statements concerning left moving thunderstorms. For example, do left moving thunderstorms generally produce severe weather when values of vertically integrated liquid water decrease from a maximum? Is there a relationship between mesoanticyclones and severe weather produced by left moving storms? Future work could involve the examination of archived satellite and radar data on left moving storms. Emphasis could be given to those left moving storms that produce severe weather and tornadoes.

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