P3.17 THE DEVELOPMENT OF MULTIPLE LOW-LEVEL MESOCYCLONES WITHIN A SUPERCELL

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1. INTRODUCTION

A region severe weather outbreak occurred on 5 May, 2007. Tornadoes were reported in the states of Oklahoma, Kansas, Nebraska, Iowa, and South Dakota (Fig. 1). This paper will concentrate on the part of the outbreak that affected northeast Nebraska and southeast South Dakota. Here, the convection and associated tornadoes were associated with an advancing warm front.

The mesoscale environment across northeast Nebraska and southeast South Dakota was characterized by strong environmental shear and instability. Thunderstorms developing in this atmosphere quickly became severe on the afternoon of 5 May, and several were also tornadic. Warning meteorologists on 5 May using high resolution velocity data from the KOAX and KFSD WSR-88Ds, located in Omaha NE and Sioux Falls SD respectively, noticed an interesting mesocyclone evolution, with several of the tornadic supercells showing what appeared to be dual cyclonic low-level mesocyclones within one supercell. In addition, several real-time spotter reports indicated the presence of more than one tornado at the same time. Figure 2 is example of dual nature of the low level mesocyclones and wall clouds.

The occurrence of multiple tornadoes from different low-level cyclonic mesocyclones presented a significant operational challenge to warning forecasters. First, conveying the threat of multiple tornadoes within the framework of National Weather Service (NWS) warnings to local officials and the general public was difficult. Next, deciphering the locations of the multiple tornado reports from spotters was complicated. Finally, the erratic nature of the development of the low-level mesocyclones made creating warning polygons difficult.

This case study documents the occurrence of the development of multiple low-level mesocyclones within a single supercell, looks at the synoptic environment that created an atmosphere supportive of the event, and reviews the evolution of one of the dual mesocyclone storms.

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2. DATA AND METHODOLOGY

Upper air and surface data were objectively analyzed using a Barnes analysis scheme within the General Meteorological Package software (GEMPAK; DesJardins et al. 1991). Hodographs were developed using the observed velocity azimuthal display (VAD) wind profiler from the KFSD WSR-88D radar and modified for surface observations. Supercell motion and low-level kinematic shear profilers were completed using the internal dynamics method (Bunkers et al. 2000)

Rotational velocity (V_r) traces were computed using high resolution velocity data from the KFSD WSR-88D to show the evolution of the mesocyclone development and dissipation. For a given rotational velocity to be considered, it must have vertical continuity. Rotational velocity was computed by averaging the maximum inbound and outbound values. In areas where divergence (convergent) rotation exists, the rotational velocity may be underestimated (overestimated). The distance between the maximum inbound and outbound data had to be less than or equal to 10 km. If V_r could not be determined, the elevation angle was listed as bad data (BD).

3. SYNOPTIC OVERVIEW

3.1. Upper Air

The upper air analysis on 5 May appears favorable for severe storms across a large part of the central and southern Plains. Figure 3a indicates a large upper level

Figure 1. Storm reports from 5 May 2007. Source: NOAA/NWS Storm Prediction Center.

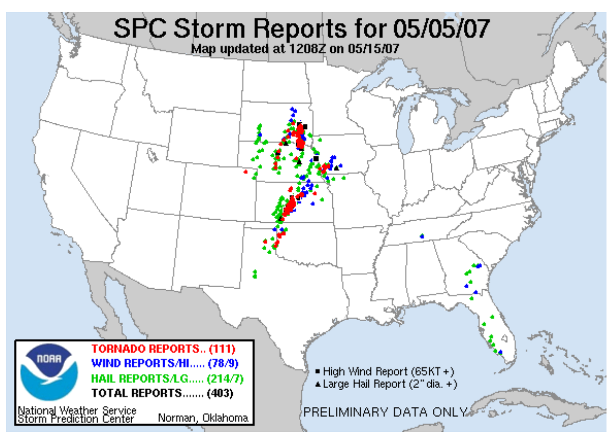


Figure 2. Video capture of dual mesocyclones, with vortex tube extending between. Source: Video courtesy of Mike and Amy Reifenrath of Crofton

low over the western United States at 1200 UTC. The upper level trough was associated with a seasonably strong 300 hPa jet maximum of 35 ms^{-1}. By 0000 UTC 6 May, the large upper level trough has only shifted slightly eastward into the western High Plains as the 300 hPa jet maximum of 30 ms^{-1} ejected into Kansas and Nebraska (Fig. 3b). A broad area of diffluence is occurring over the central and northern plains creating an environment favorable for large-scale ascent. Cold air advection is also occurring through the day on 5 May across Nebraska and South Dakota as the upper level low to the west approaches.

Significant low level moisture axis (not shown) extends from Texas into the northern plains. The 1800 UTC 5 May sounding from KOAX (Fig. 4) indicates the presence of steep mid level lapse-rates above the low level moisture, creating a potentially strongly unstable atmosphere.

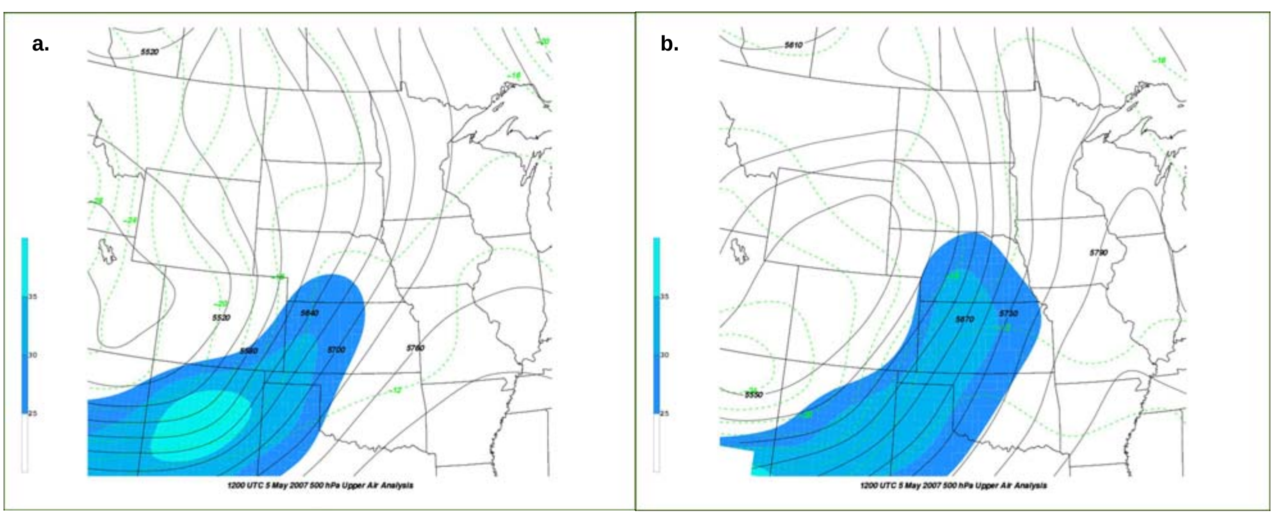
3.2. Surface

An objective surface analysis at 2100 UTC 5 May indicates low pressure is located over eastern Colorado, with a warm front extending along the Nebraska and South Dakota border into western Iowa (Fig. 5a). Strong surface convergence is indicated along the warm front, creating low-level forcing for vertical motion (Fig. 5b). In additional to the strong surface convergence, pressure falls of 2 to 3 hPa per 3 hours is noted ahead of the surface low (Fig. 5c). South of the advancing warm front, an axis of rich equivalent potential temperature in the boundary layer extends into the mid Missouri Valley (Fig. 5d).

3.3. Kinematic Environment

Observations from the VAD at the KFSD radar indicated a significant amount of both low-level and deep-layer bulk shear. The KFSD VAD profile was located by 2100 UTC just to the north of the advancing warm front and allowed for a representative sampling of the deep-layer wind field across northeast Nebraska and southeast South Dakota. A hodograph from the 2100 UTC KFSD VAD is presented in Figure 6, with the observed storm motion plotted as V_{obs}. For the observed storm motion, the hodograph indicates supercell thunderstorms are in an environment characterized by extreme low-level shear. This includes 18 ms^{-1} of 0 to 1 km bulk shear, 270 m^2s^2 of storm relative helicity, and 36 ms^{-1} of 0 to 8 km bulk shear.

Figure 3. 500 hPa height (contours) and 300 hPa winds (shading) at (a) 1200 UTC 5 May 2007 and (b) 0000 UTC 6 May 2007.



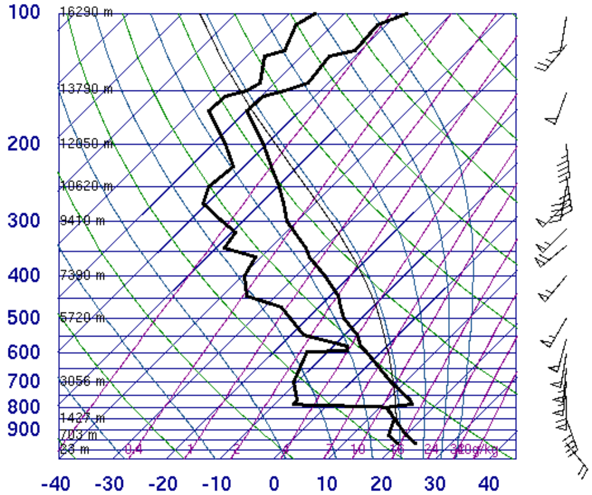


Figure 4. KOAX observed sounding at 1800 UTC 5 May.

Of particular note in the 2100 UTC hodograph is the distribution of shear. Total shear in the 0 to 6 km layer is 64 ms^{-1}, but nearly half of this extreme amount of shear, 31.2 ms^{-1}, is located in the lowest 2 km of the hodograph.

4. MESOCYCLONE EVOLUTION

The development of strong low-level mesocyclones was anticipated by operational forecasters on 5 May given the favorable shear profile. Figure 7 shows the track of the mesocyclones associated with a supercell on 5 May. Like several of the supercells, this storm displayed a dual low-level mesocyclone for the majority of its lifespan. Overlaid are the NWS tornado warnings for this storm. The development of mesocyclones 3 and 4, to the west of the original persistent circulation, presented challenges to operational forecasters tracking the more persistent area of rotation to the east and led to a number of circumstances where the track of the western mesocyclone was nearly out of the warning polygon and required the issuance of additional tornado warnings. Figure 8 is a high resolution storm-relative velocity (SRM) image from the KFSD radar at 2232 UTC and is an example of the dual cyclonic structure of the low-level mesocyclones as seen by Doppler radar.

The V_r graph for both western circulations 3 and 4, and the long-lived eastern circulation 2, is presented in Figures 9a and 9b, respectively. The western and eastern circulations of this supercell both exhibit a strong mesocyclone, but the evolution of the circulations

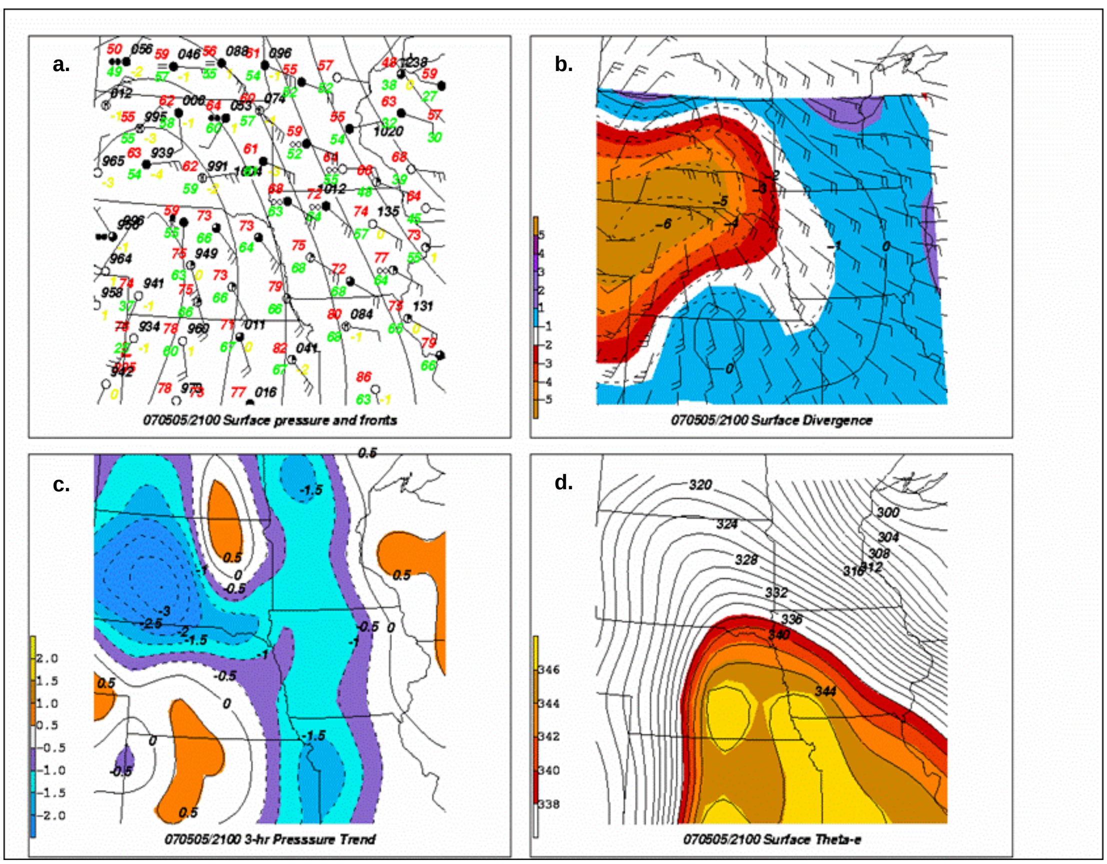


Figure 5. Objective surface analysis, including (a) surface observations and pressure, (b) surface divergence and winds, (c) 3 hr pressure change, and (d) surface equivalent potential temperature.

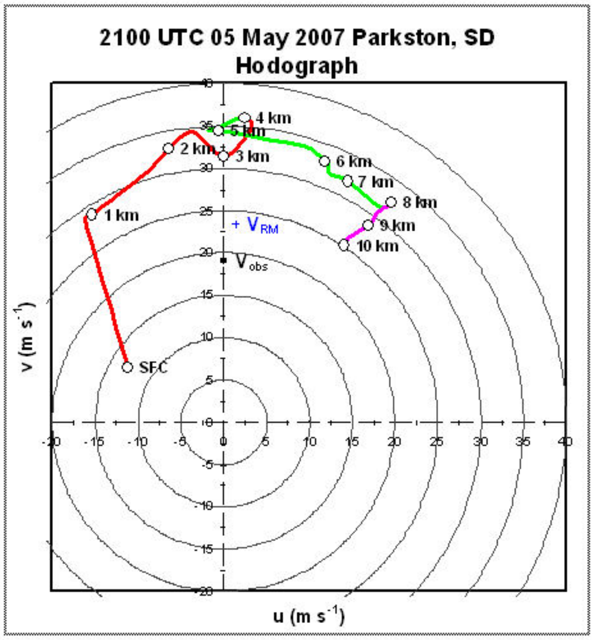


Figure 6. Hodograph derived from the KFSD WSR-88D VAD wind profile at 2100 UTC 5 May.

is atypical for classic supercells. First, the mesocyclones develop very rapidly, generally within 8 min. Next, instead of the mesocyclones developing near the mid levels of the thunderstorm and descending toward the surface, the circulations appear to develop vertically from near the surface up rapidly after development. This evolution seems to be more of a hybrid between the rapid low level non-supercell tornadogenesis described by Trapp and Weisman 2003 and the more classic mesocyclone evolution described as a descending mesocyclone in Trapp et al. 1999. Finally, although there is at least a moderate mesocyclone throughout the life of the supercell, which lasted over 3 hours, for the majority of the time the strongest rotation is centered below 6 km.

The Vr graphs also indicated that mesocyclone intensification appeared to be generally unpredictable. Although initial intensification of the eastern mesocyclone occurred as the storm was in close proximity of the surface warm front, subsequent intensification reasoning is less clear. This is also true during dual-mesocyclone phase. While the eastern circulation associated with the supercell went through several intensification and weakening phases, this did not necessarily correspond to the intensification and dissipation phase of mesocyclones 3 or 4.

5. SUMMARY

The case of 5 May 2007 is presented to highlight the occurrence of dual mesocyclones associated with several supercells near a warm front over southeast South Dakota and northeast Nebraska. The dual nature to the mesocyclones created several challenges to operational forecasters during the event.

The occurrence of dual cyclonic mesocyclones within the supercells were identifiable using high resolution velocity data from WSR 88-D in Sioux Falls, SD, and confirmed from pictures and video from spotters and storm chasers. Investigation into the synoptic and mesoscale environment on 5 May indicated a large-scale pattern favorable for a regional outbreak of severe weather across parts of the central and southern plains. The 2100 UTC VAD from KFSD indicated extreme low level shear near the supercells, which created a favorable set-up for tornadoes.

V_r graphs of the mesocyclones associated with one of the supercells that tracked from northeast Nebraska into southeast South Dakota indicated atypical mesocyclone evolution for a classic supercell. The circulations in this supercell developed rapidly and appeared to ascend through the vertical. In addition, the strength of the circulation is generally centered in the lower levels of the supercell. This characteristic of the circulations may be associated with the distribution of the shear toward the lowest 2 km of the hodograph. The development and persistent of dual low-level cyclonic mesocyclones, however, does not seem to be able to be explained by just the presence of extreme low level shear, and likely is dictated by internal supercell dynamics and requires further study and numerical modeling.

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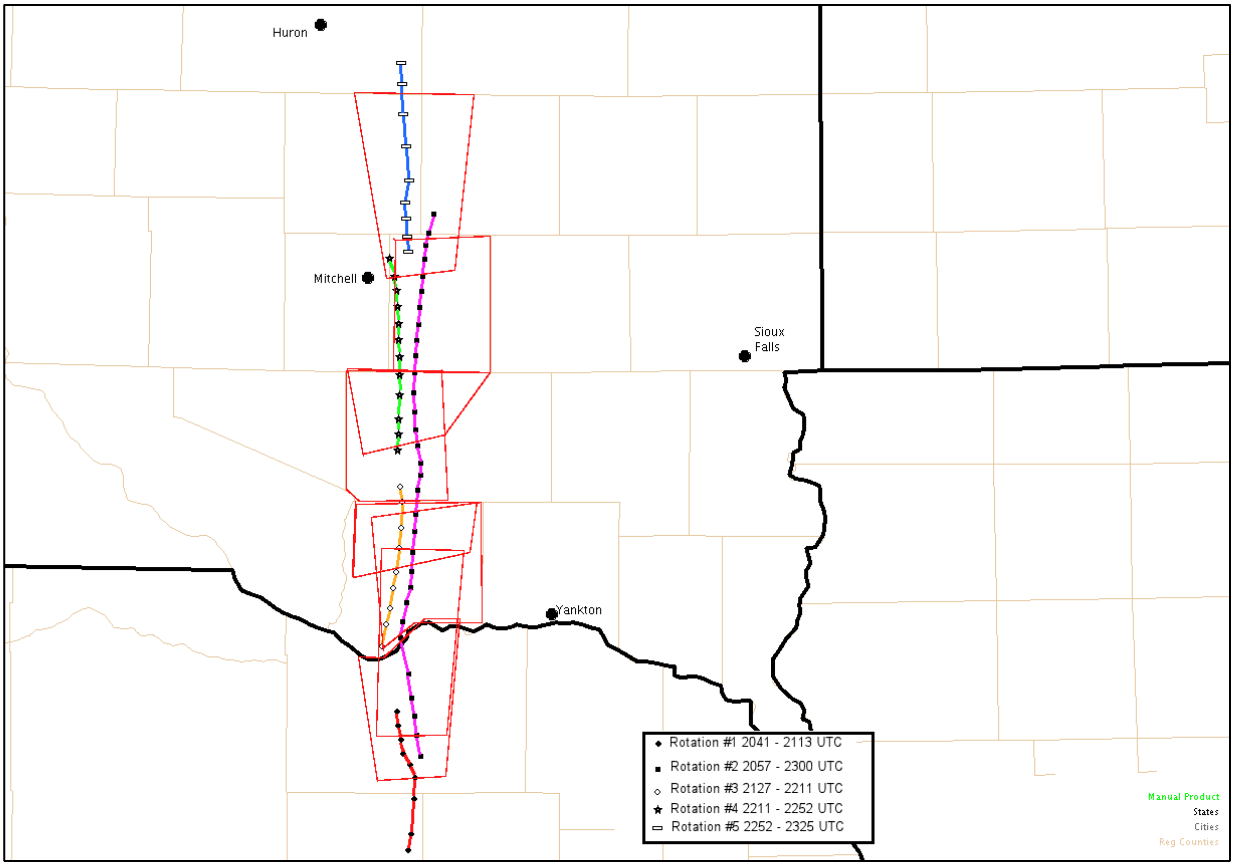

Figure 7. Tracks of the mesocyclones and associated with the 5 May supercell

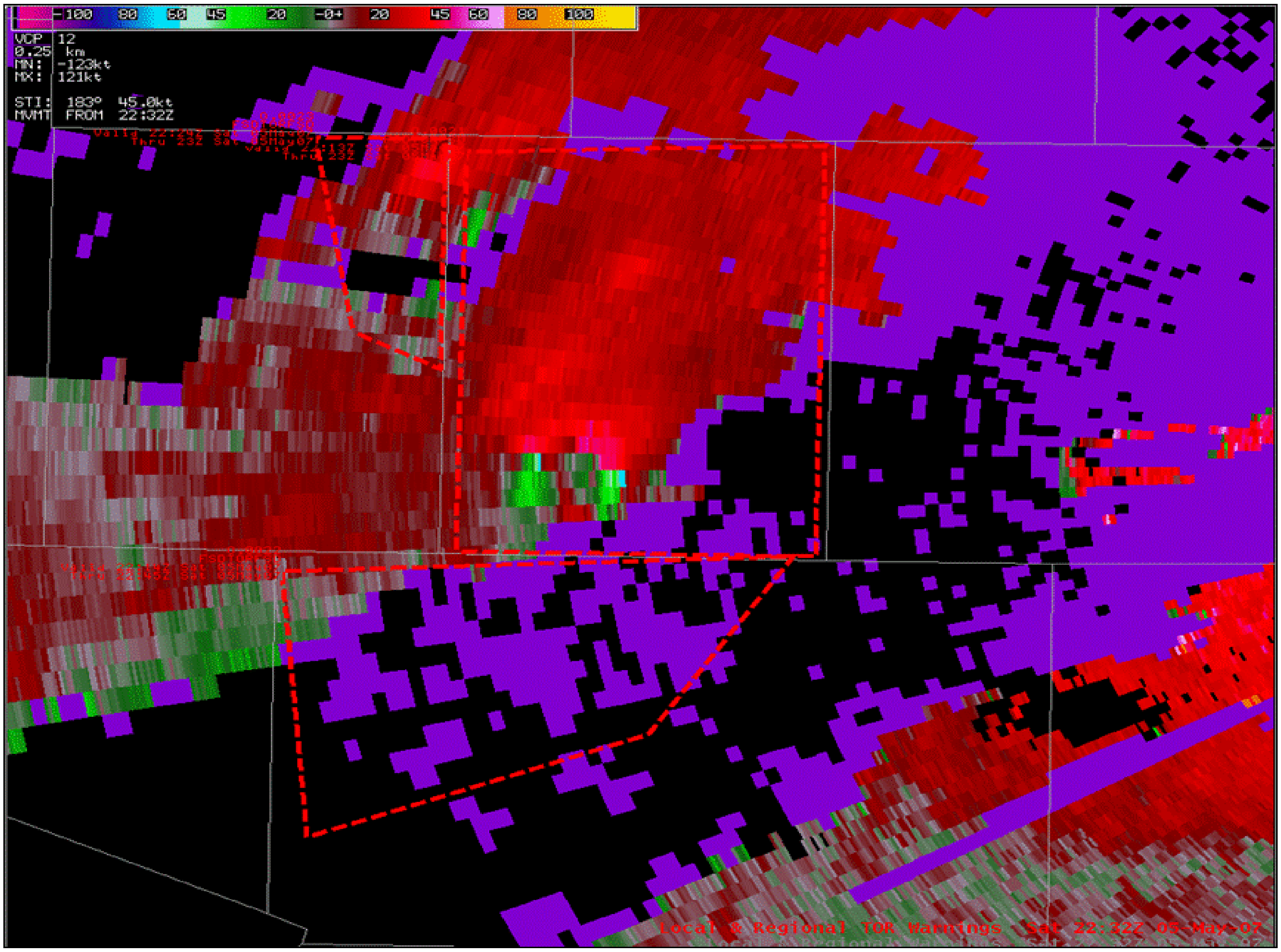

Figure 8. SRM from KFSD WSR-88D at 2232 UTC 5 May. Tornado warning polygons are overlaid.

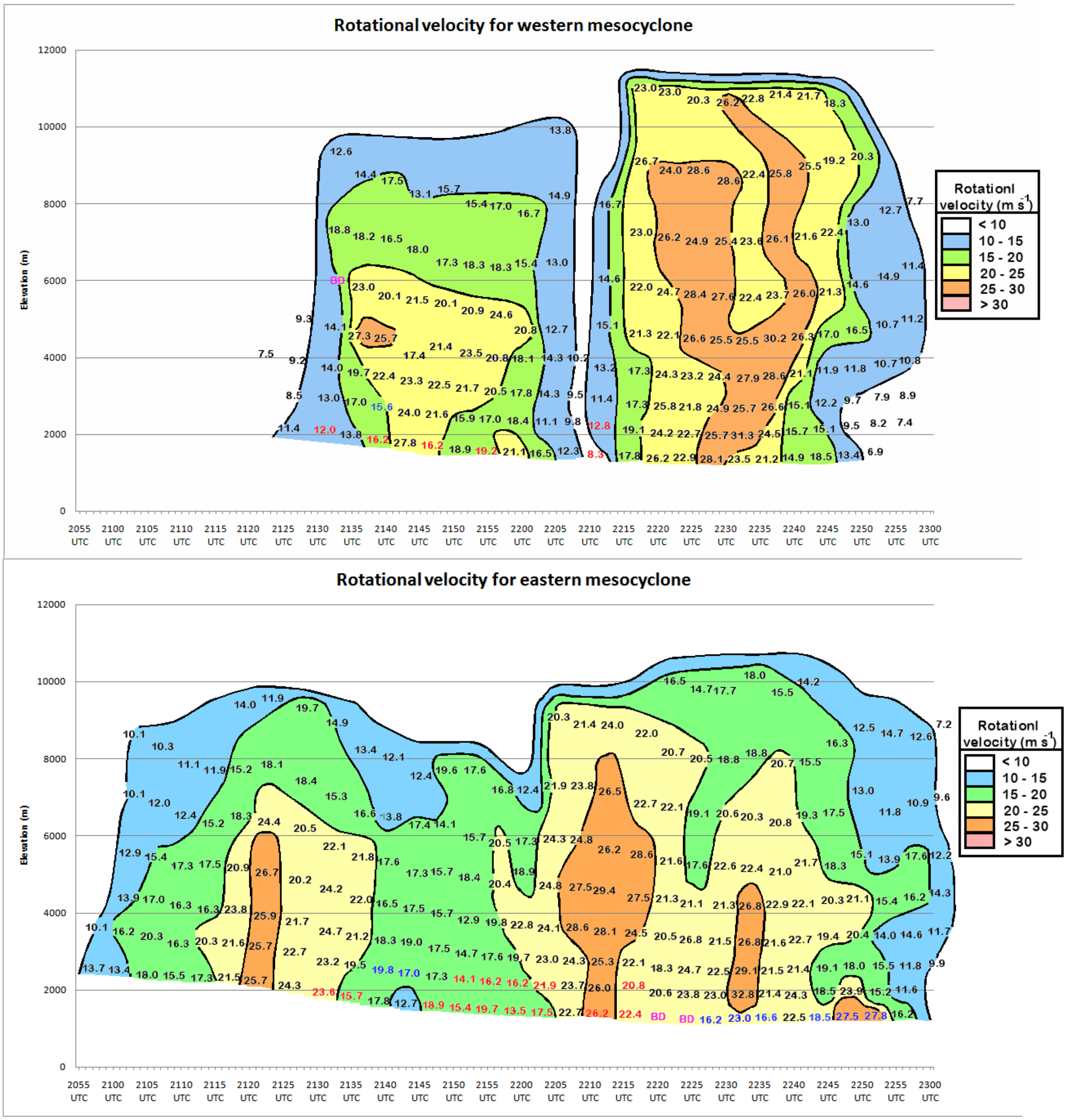

Figure 9. Rotational velocity (v_r) shear diagrams for (a) mesocyclones 3 and 4 and (b) mesocyclone 2, according to labeling given in Figure 7.