3.B1 The 8 May 2009 Missouri Derecho: Radar Analysis and Warning Implications over Parts of Southwest Missouri

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I. Introduction

An intense squall line of thunderstorms impacted portions of extreme southeast Kansas and most of southern Missouri during the morning hours of 8 May, 2009. National Weather Service storm surveys revealed that these thunderstorms produced straight line wind gusts of up to 40 m s^{-1}, and 26 tornadoes. From the National Weather Service Storm Data, the impacts from this episode of storms led to approximately $115 million in monetary losses, one fatality, and four injuries. Of these monetary losses, the Missouri Department of Conservation estimated that $13 million worth of damage occurred to state forests. Also the United States Forest Service surveyed 39,000 acres of damage in the Mark Twain National Forest, which resulted in $9 million worth of deforestation. Approximately 20,000 acres were considered catastrophically damaged.

It was estimated that 39 m s^{-1} winds impacted the western side of Joplin, Missouri. Along with significant damage to trees, power poles, and small structures, a large television tower was blown down into the KSN-TV station building. No injuries occurred as the building was evacuated prior to the tower falling. However, the station was forced to remain off-air for several weeks.

As the squall line progressed east into the Highway 65 corridor, highly populated areas near the city of Springfield were impacted by the effects of 25 to 40 m s^{-1} wind gusts. Numerous school and commercial buildings experienced major roof damage. Four students were injured at Fair Grove High School in Fair Grove, MO as the roof began to peel off allowing debris to fall into the gymnasium. Damage to trees and structures in and around the Springfield metro area was significant and mounted to $25.3 million in Greene and Christian counties alone.

We will show that non-supercell tornadoes began to develop along the squall line's low-level convergence zone roughly near the Highway 65 corridor. These tornadoes were associated with small comma-shaped echoes anchored along the convergence zone. One fatality resulted from an EF-2 tornado that stuck the community of Charity, MO (approximately 40 km northeast of Springfield, MO).

As the line of thunderstorms continued progressing east over south central and southeast Missouri, several tornadoes were observed in relatively sparsely populated rural areas. No densely populated communities were impacted by these tornadoes east of Highway

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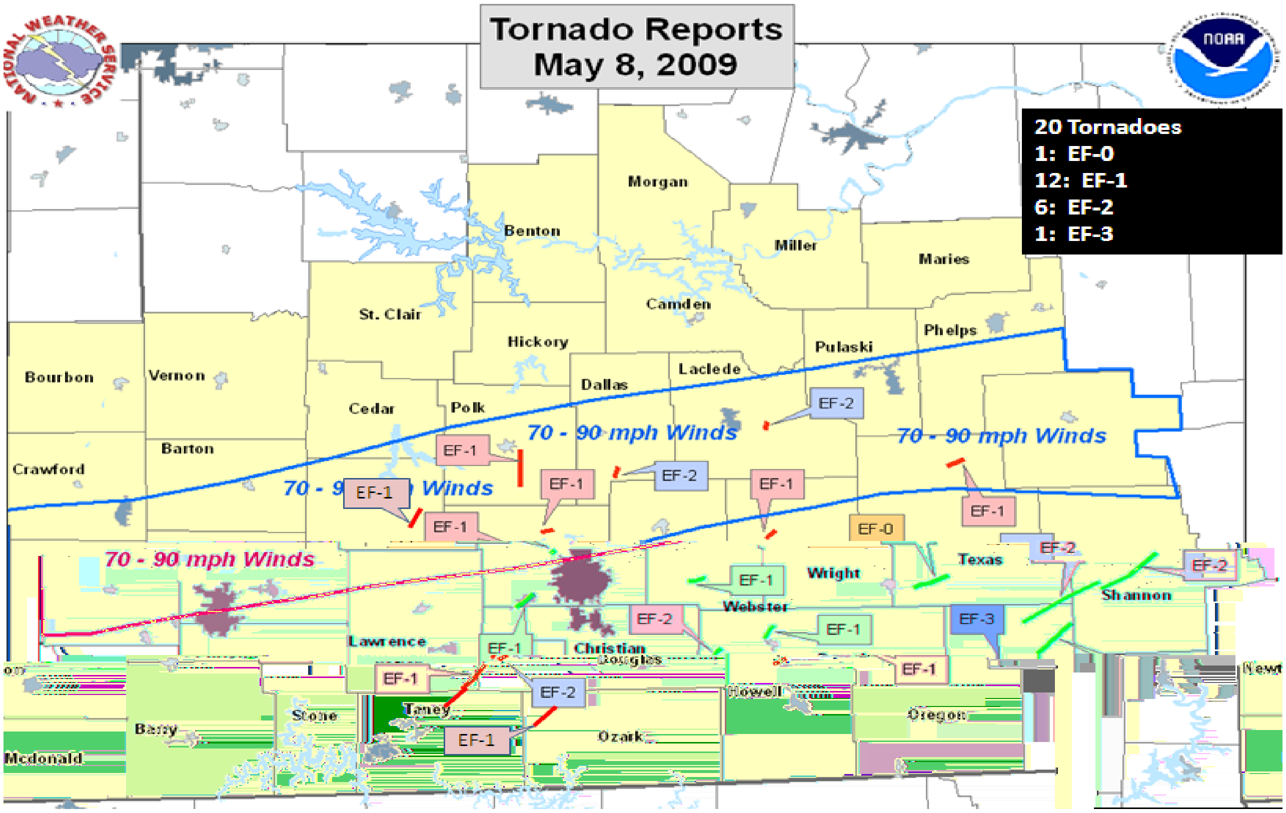

Fig. 1. Damage Survey analysis of the 8 May 2009 Derecho over southwest and parts of south-central Missouri. The red lines represent tornadic damage tracks. The area within the blue contours show the greatest degree of surface damage and surface winds estimated 35 to 45 m s^{-1}. The red contours indicate location of tornadic damage tracks and corresponding EF scale.

65, with mainly farms and forested regions experiencing the majority of the damage. Finally, in the wake of the squall line, another swath of 30 – 40 m s^{-1} wind gusts occurred in response to the development of a meso-scale wake low that extended from southeast Kansas across southern Missouri. Not only did this meso low produce another episode of wind damage, but it likely altered the environmental wind profile, which in turn influenced the evolution and structure of the squall line itself.

Nolen (1959) and Hamilton (1970) first recorded observations and noted the relationship between bow-shaped convective lines (referred to as a line echo wave pattern) and straight-line damaging surface winds and tornadoes. Fujita (1978) documented the kinematic structure and time evolution of a radar echo he coined as the “bow echo.” He showed that bow echoes were frequently associated with straight-line wind damage or downbursts at the surface. Rapidly moving severe bow echoes can result in significant property damage and loss of life (e.g. Fujita and Wakimoto 1981, Johns and Hirt 1987 and Przybylinski 1995). Fujita’s conceptual model suggests that the strongest wind damage occurred during the “bow echo” stage. However, recent observations and numerical simulation studies have shown that during the “early stages” of bowing, damaging winds and even weak tornadoes may result from mesovortices which form along the leading edge and generally at and north of a developing bow echo. These vortices can rise to heights of 5 to 6 km while there strongest rotation frequently remains at low-levels of the vortex column (below 3.0 km) (Atkins et al 2004; Atkins et al. 2005; Funk et al. 1999; Przybylinski et al. 2000). System-scale vortices known as “bookend vortices” may also form at the ends of a large bow echo and be responsible for the production of damaging winds along the southern (northern) periphery of the large vortex (Atkins et al 2004; Weisman

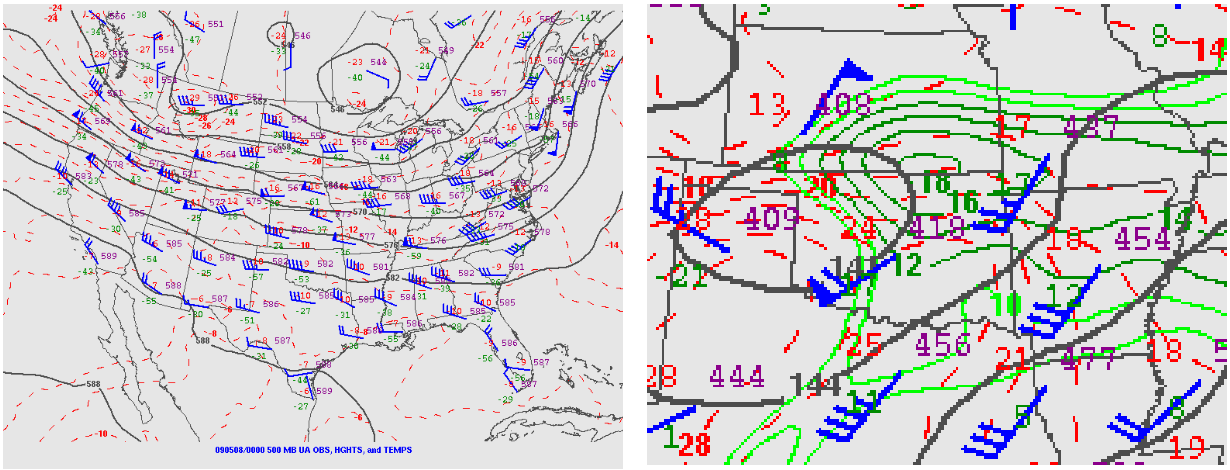

Fig. 2. 500 hPa analysis for 1200 UTC (Left). 850 hPa analysis for 1200 UTC (Right).

(1993). In a minority of long-lived severe bow echo cases, system and sub-system scale vortices may be absent as they only produce severe downburst swaths and intense microbursts (Przybylinski et al. 1993; 2008). These convective systems evolve in highly unstable – weak shear environments. These convective systems can last for over eight to ten hour periods and can fit the classification of a Derecho.

There are many facets of this case; too many to thoroughly discuss in one paper. Thus we centered our investigations on the storm reflectivity and Doppler velocity patterns mainly south and southeast of Weather Forecast Office (WFO) Springfield (SGF) Missouri for the time period of 1230 – 1330 UTC. In our investigation of the 08 May 2009 severe wind storm, we will first examine the near storm environment over southwest Missouri. This will be followed by a survey of the storm evolution during two time periods (a) 1230 – 1317 UTC – west and south of KSGF, and (b) 1317 – 1330 UTC – east of KSGF to the Missouri-Arkansas state line. The last section will focus on the characteristics of two of the three intense mesovortices that formed near and just south of the apex of the bow echo at 1307 and beyond.

II. Environmental Settings

The synoptic scale pattern on the morning of May 8 2009 featured a zonal flow in the middle and upper levels. Analysis of the 0000 UTC and 1200 UTC RAOBS indicated that the main belt of mid and upper level westerlies extended from the Pacific Northwest, east into the middle Mississippi Valley. Meanwhile, several transient short wave troughs were resent from the northern Rockies, east into the Ohio Valley. At 0000 UTC on the 8th, one weak short wave trough was analyzed across western portions of South Dakota and Nebraska. A second, stronger short wave trough was noted across southern Alberta and western Montana.

In the lower levels, a nocturnal low level jet developed and strengthened in response to the lead short wave trough (Fig. 2). The low level jet initially developed across the central and southern Plains during the late evening hours of the 7th, then strengthened and veered by the early morning of the 8th. By 1200 UTC, objective analysis of RAOBS, vertical wind profilers, and RUC initializations indicated the nose of the low level jet was located from northeast Oklahoma into southwest Missouri.

A low level synoptic scale front was also draped from southwest to northeast across the region (not shown). At 1200 UTC, the surface front extended from a weak surface low across southwest Oklahoma, northeast into central Missouri. Meanwhile,the 850 mb front initially extended along the Interstate 70 corridor from Kansas into Missouri at 0000. This front did begin to make a southward surge by 1200 across the high plains of Kansas and Oklahoma.

Thunderstorms initially developed across west central Kansas around 0600 UTC as the low level jet strengthened and intersected the low level frontal boundary. Elevated parcels ascending over the frontal boundary initially resulted in these storms taking on a west to east linear orientation. Thermodynamic profiles across western and central Kansas were indicative of strong elevated instability. Objective analysis of RUC initializations indicated that parcels lifted from around 850 mb yielded MUCAPES over 2500 J/Kg with little effective inhibition.

Kinematic profiles across the initiation region were very supportive of storm organization due to the positioning of the upper level westerlies. Ambient 0-6 km bulk shear values ranged from 25 to 30 ms^{-1} from western Kansas into all but extreme southern Missouri. The combinations of adequate instability as well as strong and deep tropospheric shear are common parameters necessary for long lived severe squall lines (Evans and Doswell, 2001). Investigation of NCDC Storm Data yields multiple reports of large hail and damaging winds were received across western and central Kansas between 0600 UTC and 0900 UTC.

Up until 0900 UTC, inspection of radar data across western and central Kansas revealed that this developing MCS was initially upwind propagating in nature (Corfidi et al. 2003). RUC initializations indicated that Corfidi vectors were orientated towards the east-southeast at 15 to 17 ms^{-1}, with the general motion of this MCS closely following suit.

Storm morphology then began to change around 0900 UTC, likely for a number of reasons. Initially, several mergers of differing segments took place within the larger MCS. These mergers likely resulted in the conglomeration of multiple cold pools. The maturation of the cold pool was likely a key initial player in the transformation of this MCS into what would eventually become a forward propagating MCS.

Moving beyond the 0900 UTC timeframe, it should be noted that the 1200 UTC KSGF RAOB will be heavily utilized from a thermodynamics standpoint. Close comparison and analysis between the KSGF RAOB and RUC indicate that the RUC did a poor job representing the true thermodynamic profile across southwest Missouri near the 1200 UTC synoptic time. However, comparison of wind fields with the RAOB and KSGF VWP indicated that the RUC did a respectable job with wind directions and magnitudes.

The 1200 UTC KSGF RAOB (Fig. 3) revealed that several key ingredients were in place to support a forward propagating MCS. The sounding indicated MUCAPE values exceeding 3000 J/Kg. Interestingly, the most unstable parcel was rooted near the surface.

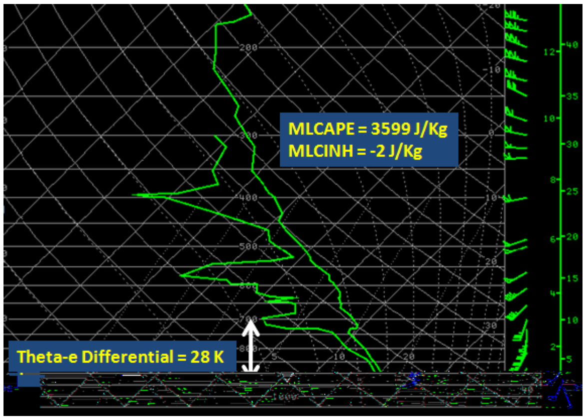

Fig. 3. Thermodynamic sounding launched from WFO Springfield at 1100 UTC 8 May 2009.

Lifting a mean layer parcel also yielded CAPES of 3600 J/Kg, but with virtually no inhibition. Weisman (1993) found a minimum CAPE value of 2000 J/Kg was necessary for long-lived systems. Evans and Doswell (2001) also indicated that higher CAPE values were generally present for weakly forced derecho events. This event would fall into the weak forcing category given the relatively weak vorticity maximum present with the parent short wave trough.

Also noted in the sounding were multiple layers of drier air between 2 and 6 km. Atkins and Wakimoto (1991) showed that theta-e differentials that exceeded 25 K between the surface and a minima between 3 and 6 km AGL suggested an atmosphere favorable for severe hybrid or wet microbursts. In the case of microbursts, the theta-e differential is an attempt to quantify the effects of dry air entrainment and evaporative cooling, and ultimately the cold pool strength. We are conveying that the presence of this layer of dry air would support a stronger system cold pool versus a scenario where this dry layer was not present. The 1200 UTC KSGF sounding indicated a theta-e differential around 28 K between the surface and 700 mb.

III. Storm Evolution

The overall storm evolution for the time periods of 1203 UTC, 1302 UTC, 1402 UTC, and 1503 UTC are shown in Fig. 4. The radar reflectivity sequence shows how the large bow echo rapidly accelerated after 1203 UTC and how reflectivity structures significantly changed during this sequence across southwest and parts of south central Missouri.

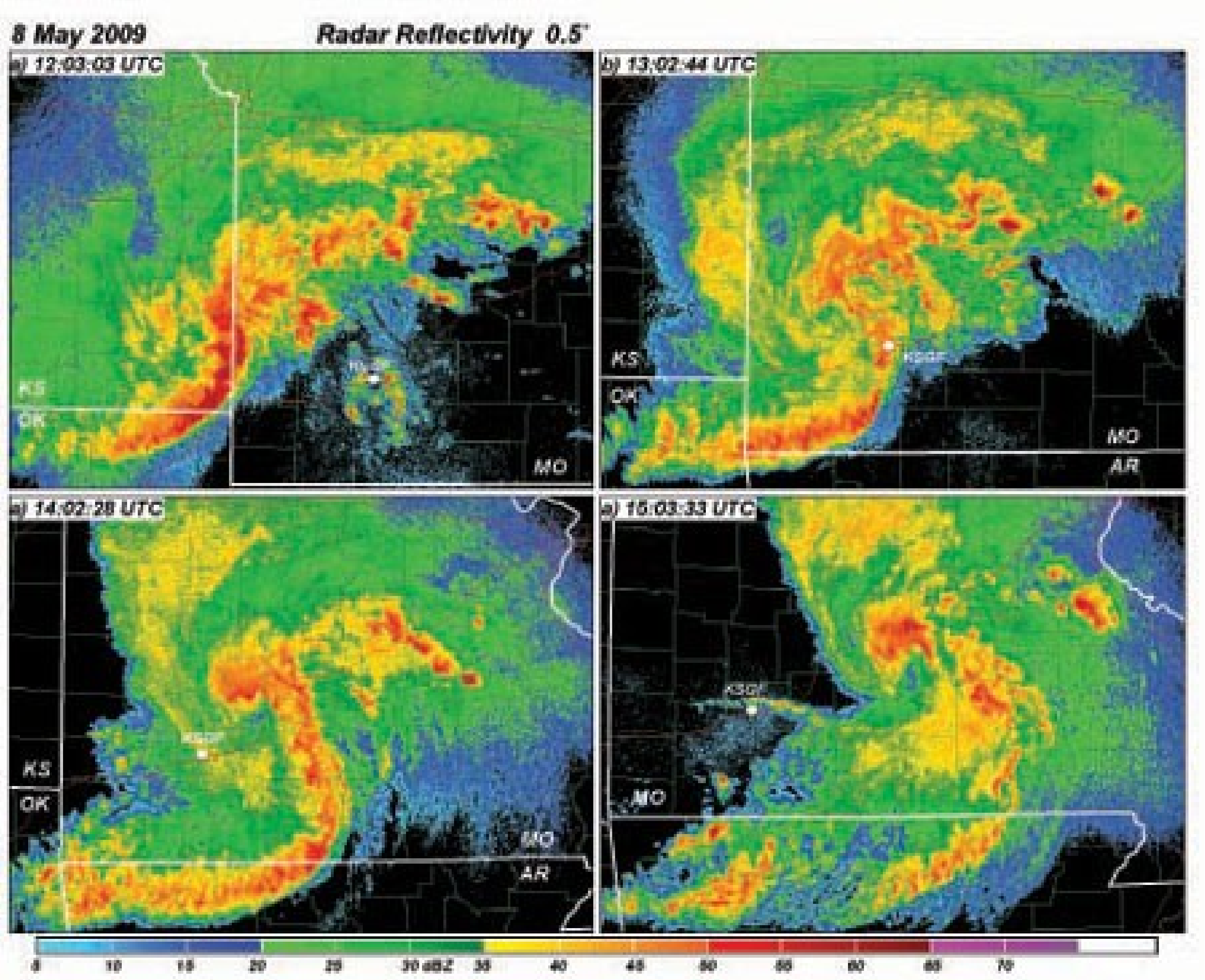

Fig. 4. Sequence of radar reflectivity images from WFO Springfield MO (KSGF).

(a) Radar Analysis 1230-1316:

Analyses of the reflectivity and Doppler velocity images over southwest Missouri were obtained by single Doppler data collected at Springfield Missouri (KSGF). The KSGF Doppler radar was operating in Volume Coverage Pattern (VCP) 212. Tornado, damaging wind reports came from National Climatic Data Center (NCDC). Detailed damage assessments for the tornadic damage tracks and parts of the wind damage were conducted by personnel at WFO SGF.

As the developing bow echo system moved eastward over southwest Missouri at 1235 UTC a nearly solid line of 50 to 60 dBZ echo extended from Greenfield Missouri to east of Neosho (Fig. 5a). The strongest low-level reflectivity gradients and leading high reflectivity cores extended along the southern third of the bow while the high reflectivity cores near the center of the bow was slightly tilted downshear from the southern part. Base velocity data at 0.5 degree slices revealed the leading gust front from the leading high reflectivity core region near the center of the bow to along the high reflectivity core gradients over the southern part of the bow (Fig. 5a**)**. A well mature mesoscale Rear Inflow Jet (RIJ) with wind speeds of 40 to 50 ms^{-1}, extended over 150 km from the rear of the convective towers southwest of Mount Vernon Missouri rearward to northwest of Joplin. Base velocity data also showed a mature mesovortex in the vicinity of the comma-shaped echo east of Jasper Missouri. This mesovortex was not associated with any tornadic activity.

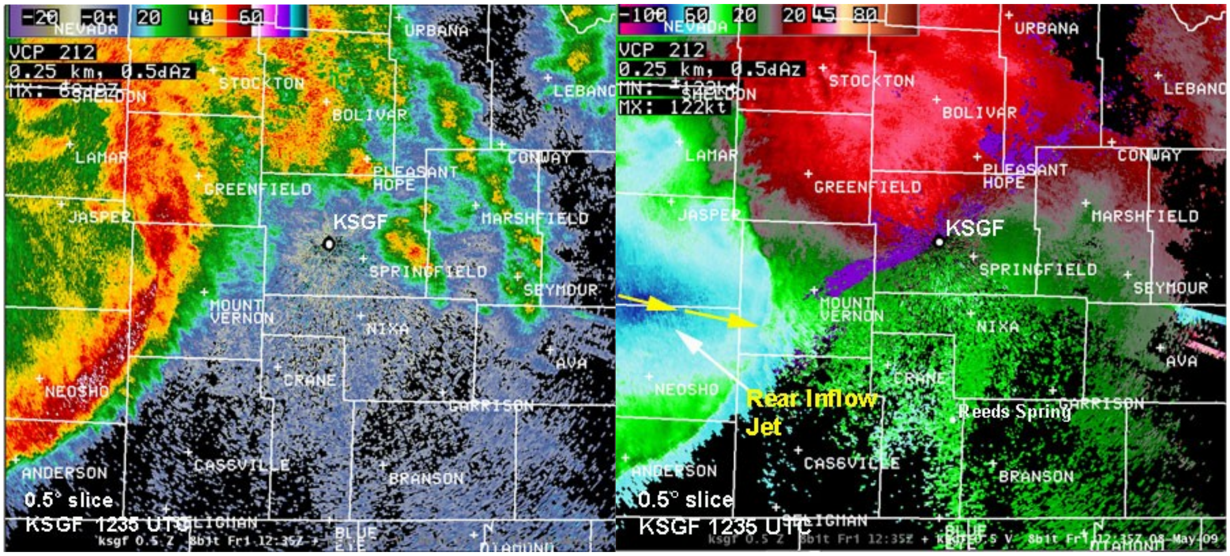

Fig. 5. **(a)** (left) Reflectivity image for 0.5 degree elevation slice for 1235 UTC. **(b)** Base velocity image for 1235 UTC at 0.5 degree elevation slice. The mesoscale Rear Inflow Jet (RIJ) is highlighted in with yellow arrows.

At 1302 UTC the reflectivity pattern significantly changed in which the storms near and north of the apex of the bow weakened and fragmented while south of the apex a leading line trailing stratiform region was observed east and south of Crane Missouri (Fig. 6a). At this time the apex of the bow is located between Republic and Crane Missouri. North of the apex, base velocity data showed a well defined low-level convergence zone which trailed along and behind the higher reflectivity mass to the east over the KSGF radar site (Fig. 6b). The strength of the mid and upper level winds strengthened between 1230 UTC to 1302 UTC resulting in the demise of several convective towers north of the apex of the bow at 1302 UTC. The 0-3 km shear vector over this area was *normal* to the weak convective cells along and downshear of the convergence axis suggesting the presence of a *strong sheared environment* (Fig 6b).

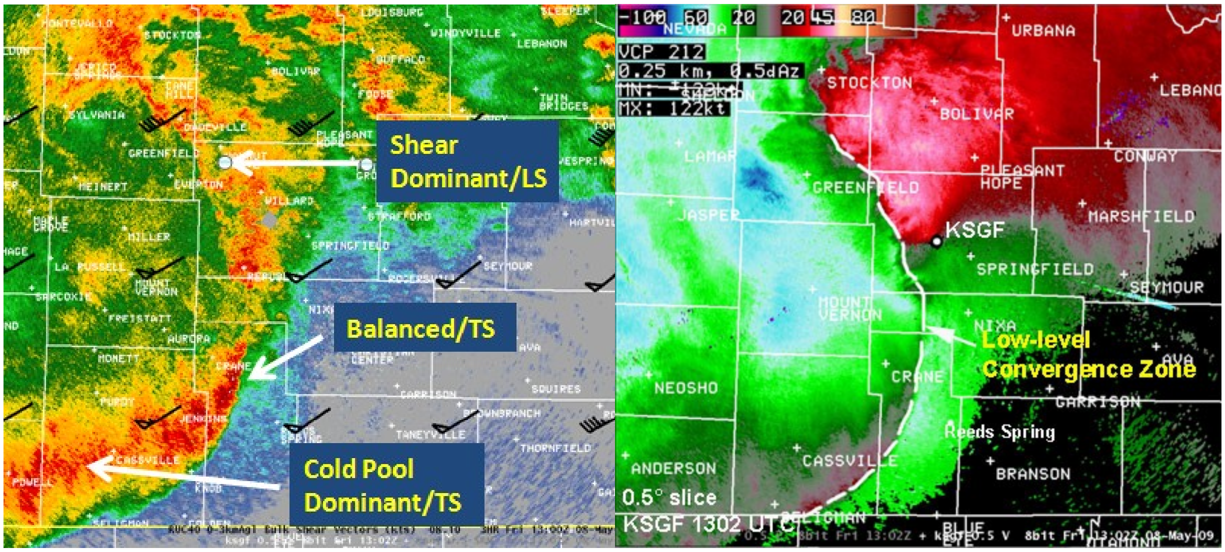

Fig. 6. Same as Fig. 5a except for 1302 UTC. 0-3 km shear vectors overlaid on reflectivity image. Right side base velocity image with dash line showing the location of the low-level convergence zone.

We believe that both the mesoscale *rear inflow jet (RIJ)* and the *intense mid-level flow from the rear and southerly periphery the line end vortex* appeared contribute to the weakening convective towers northwest as well as south of KSGF. Velocity Wind Profiler (VWP) data from the WSR-88D KSGF radar site further supports the presence of strong mid to upper winds for an extended period of time. (Fig. 7).

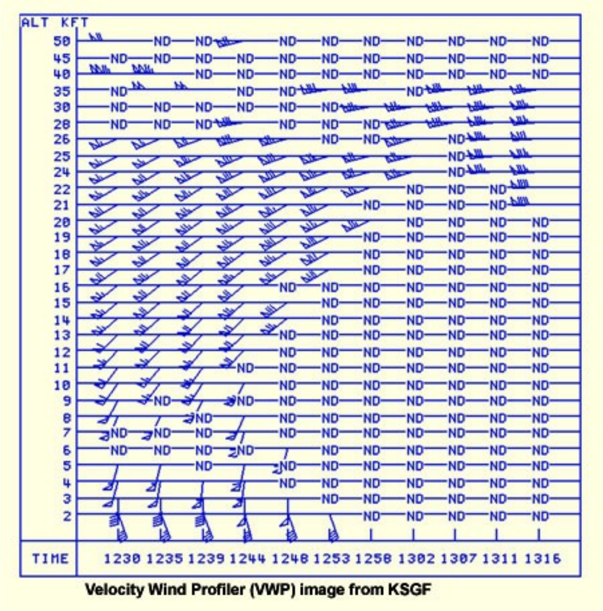

Fig.7. Velocity Wind Profile (VWP) for KSGF for the time period of 1230-1316 UTC.

Northwest of KSGF, base-velocity imagery at 1.3 degree slice (not shown) revealed strong inbound (outbound) velocities outlined the intensifying line end vortex. The magnitude of the inbound couplet exceeded 40 ms^{-1}while the magnitude of the inbound couplet exceeded 30 ms^{-1}. It is interesting to note that this corridor of higher inbound velocities from the line-end vortex extended southeast behind the shear axis towards the town of Republic Missouri (just south of KSGF) where a weak tornado occurred southeast of the town. However damage assessment results revealed that the corridor of the strongest surface winds of 35 to 45 ms^{-1} occurred within the vicinity and along the southern periphery of the line-end vortex while only isolated to scattered areas of downburst-microburst winds occurred south of the main corridor of highest winds (See Fig.1).

In the vicinity and just south of the apex of the large bow echo at 1302 UTC, the reflectivity pattern revealed a leading convective line – trailing stratiform precipitation region with strong low-level reflectivity gradients along the leading edge (Fig. 6a). This area should be closely monitored for mesovortex initiation since the convective towers are nearly vertically erect or slightly tilted downshear. The convergence axis (or gust front) was located along the leading edge of the convective line segment.. Weakening convective towers were noted along the southwest part of the bow suggesting that the system cold pool overwhelmed the ambient shear. Over this region the gust front was accelerating southeast ahead of the higher reflectivity region.

The low-level convergence zone north of the apex of the bow echo at 1307 UTC continued to remain along the developing line of weak convective towers and a expanding enhanced stratiform rain region from northwest of KSGF to west of Nixa Missouri (Fig. 8a**)** . The enhanced stratiform rain region which extended downshear appeared to resemble the "Leading Stratiform (LS)" mode coined by Parker and Johnson (2000). Shear vectors within the 0-3 km layer remained nearly normal to this part of the convective line with magnitudes reaching near 25 ms^{-1}. This part of the convective line remained *shear dominated*.

Near and south of the apex of the bow the convective line accelerated eastward to which the leading convective line was oriented nearly north-south west of Reeds Spring Missouri (Fig. 8a). Strong low-level reflectivity gradients persisted along the leading edge of this segment with the convective towers remaining nearly vertically erect or slightly tilting downshear. Surface theta-e fields (00 Hr RUC) from the Storm Prediction Center (SPC) were used to determine the strength of the system cold pool between 1300 and 1500 (not shown). Based on the surface theta-e fields the system's cold pool strengthened during this period mainly from the apex of the bow echo southwest to northwest Arkansas.

The first (M1) of three cyclonic mesovortices formed near the apex of the bow at 1307 UTC 8 km north of Reed Springs on the low-level convergence zone (gust front) just downshear from the accelerated convective line segment (Fig. 8b). M1 formed within the 1.0 to 2.5 km layer and rapidly deepened and intensified during the subsequent volume scans (See Section 4 for more details). Arnott and Atkins (2002) indicated that the strongest

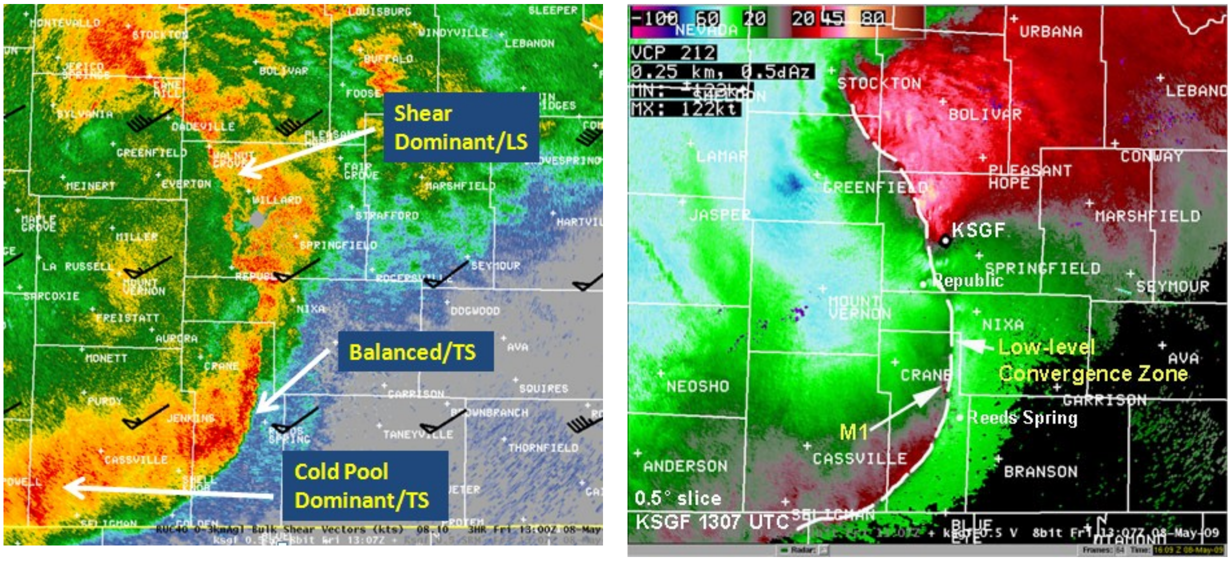

Fig. 8a. (left) Same as Fig. 5a except for 1307 UTC. Shear vectors overlay the reflectivity field. (**8b)** (right) Same as Figure 5b except for 1307 UTC..

mesovortices may occur near the apex. Recent numerical simulations from Atkins and St. Laurent (2009a) also showed that mesovortices can form in the vicinity or just north of the apex during the phase from nearly linear to early bowing of the line segment. A second mesovortex (M2) formed approximately four minutes later at 1311 UTC and south of M1 in the vicinity of the gust front north of Branson Missouri (Fig. 9a and b). M2 developed within the lowest 2 km and also rapidly deepened and intensified during subsequent volume scans and became tornadic at 1324 UTC. The third mesovortex M3 formed at 1321 a few kilometers south of M2 and northeast of Branson Missouri (not shown). A map of the tracks of M1 through M4 is shown in Fig. 10.

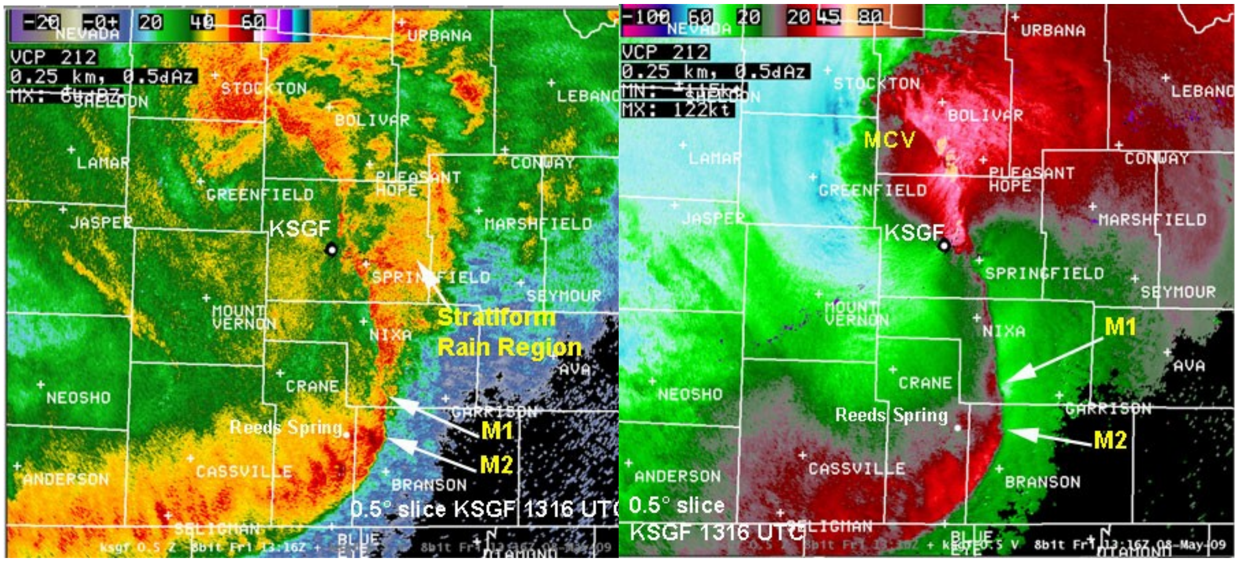

Fig 9. (a) (left)Same as Fig, 5a except for 1316 UTC. M1 and M2 represents the location of Mesovorticies 1 and 2; **(b)** (right) Same as Fig.5b except for 1316 UTC.

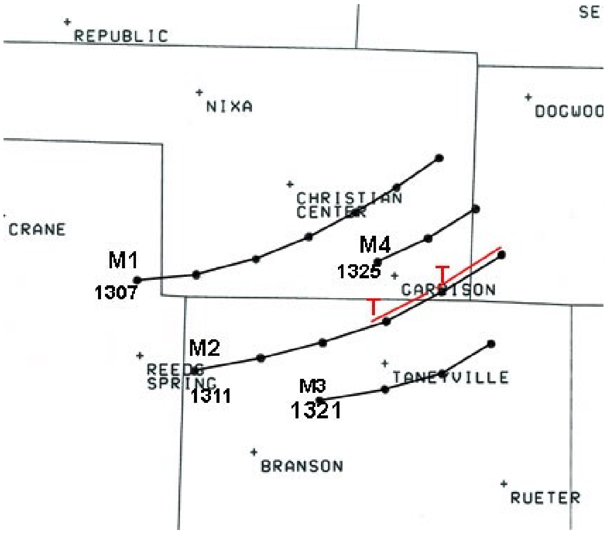

Fig 10. Tracks of mesovortices M1, M2, M3 and M4.

The environmental shear and cold pool balance appeared to play an indirect role in the early development and persistence of these low-level mesovortices. Several studies including observations and numerical simulation work completed by Arnott and Atkins (2002); Atkins et al.(2004); Weisman and Trapp (2003) and Przybylinski et al. 2000 have shown that QLCS tornadoes often developed near a convergence zone or just behind the system's gust front within the potential temperature gradient region. Work completed by Weisman and Trapp (2003) have shown that low-level shear vectors have been used to show mesovortex potential. Using numerical modeling simulations they revealed that 0 to 2.5 km unidirectional shear magnitudes greater than 20 ms^{-1} readily resulted in the development of significant cyclonic surface vortices. Between 1302 through 1311 the convective line from the apex of the bow southward evolved into a north-south oriented segment. Since the shear vector was approximately 45° to the linear convective line, we calculated the Sin of 45° and arrived at 70% contribution of the shear vector or 17 ms^{-1}. Thus this part of the convective line revealed the best balance (nearly vertically erect updrafts-downdrafts) between the environmental shear and system cold pool and greatest potential for mesovortex development. Johns (1986) stated that warning forecasters should monitor movement clues of convective line segments and bow echoes which may produce an increasing threat for damaging winds and tornadoes. Recent numerical simulations from, Atkins and St. Laurent (2009a) showed that mesovortices can develop in the vicinity or just north of the apex of the bow during the phase of an accelerated line segment to early bowing of the line They indicated that the mesoscale RIJ can also play a role in the development of these mesovortices. It is interesting to note that Weisman and Trapp's (2003) numerical simulations showed cyclonic (anticyclonic) members in which the cyclonic member was north of the anticyclonic member. Close inspection of the Doppler velocity data between 1307 UTC and 1325 UTC at low levels did not reveal any anticyclonic members adjacent to the cyclonic member over this part of the line. In contrast, recent numerical simulations completed by Atkins and St. Laurent Part II (2009) showed that only cyclonic mesovortices formed along a low-level convergence zone or just behind the it.

Further along the southwest part of the large bow echo, convective towers continued to weaken and tilt upshear while the surface gust front surged southeast ahead of the convective system across northwest Arkansas (Fig. 8a). It should be noted to warning forecasters that damaging winds can occur along and just behind the gust front over this part of the convective line. The 0-3 km shear vectors were nearly parallel to this part of the convective line suggesting that the system cold pool overwhelmed the ambient shear and convective towers would continue to weaken. From 1258 UTC to 1325 UTC, all three convective orientations (shear dominant – north; balanced – central; and cold pool dominant – southwest) existed simultaneously along the large bow echo. These observations are similar to numerical simulation results shown by Weisman (1993).

Rapid changes in the reflectivity pattern were observed after 1307 UTC across the northern part of the line in which a thin but solid convective line extended from the Mesoscale Convective Vortex (MCV) southward to near the apex of the bow northeast of Branson at 1316 UTC (Fig. 9a). Several very small 50 dBZ cores formed and were embedded within this thin convective line as it rapidly moved to the east. The convective thin line continued to mark the location of the low-level convergence zone and can easily be identified on the base velocity image from KSGF to west of Branson (Fig 9b) at

1316 UTC. The stratiform rain region east of the thin convective line continued to expand down shear while a small second band of convection west of Marshfield Missouri (northeast of KSGF) rapidly formed along the eastern edge of the stratiform rain region. This convective band moved northeast away from the larger stratiform rain region at 1321 UTC. At 1316 UTC, M1 intensified and was located over the weakest reflectivity part of the low-level convergence zone just north of the apex of the bow and northwest of Garrison. The low-level convergence zone served as a source of local vorticity to help amplify all three mesovorticies.

Simutaneously, M2 initially formed along the leading gust front in the region of the intense low-level reflectivity gradient of the small bowing segment north of Branson at 1307 UTC. This mesovortex was also anchored to the low-level convergence zone in the vicinity of the small but intense convective towers at 1316 UTC.

(b) Radar analysis (1317 – 1325)

The highly reflective thin convective line became further defined from east of KSGF to south of Garrison Missouri and began to show a slight wavy pattern at 1325 UTC (Fig. 11a). The enhanced stratiform rain region became well developed as it expanded downshear east of the thin convective line. M1 was detected in the vicinity of the thin highly reflective narrow convective line and appeared to redistribute the reflectivity field in which a small area of 50 dBz echo was displaced to the west along the northern side of the mesovortex (Fig. 11b) exhibiting a comma-like reflectivity pattern. Severe tree damage was reported along the path of M1 southeast of Nixa Missouri. M2 was also located along the low-level thin convective line west of the higher reflectivity region and 5 km southwest of Garrison. This vortex further strengthened and exhibited very intense rotation (Delta V exceeding 50 ms^{-1} at low-levels) while the core diameter was 0.7 km. M2 spawned two tornadoes and caused EF1 damage 5 km southwest to 3 km east southeast of Garrison. It is interesting to point out that M2 formed south of M1 and M3 formed just south of M2 along the leading edge of the small bowing segment in the vicinity and south of the apex of the larger bow echo. This type of mesovortex evolution when three mesovortices form in a sequential order from north to south associated with a convective line has not been documented in previous literature relating to bow echo evolution. Atkins et al. 2004 and Atkins et al 2005 have recorded a single tornado mesovortex significantly south of the apex of the large bow echo with the 1998 June 29 Derecho, and the St. Louis 2003 June 10 bow echo during the BAMEX project. As with the 10 June 2003 case the southern mesovortex was located near the cyclonic shear side of a small bow echo south of the larger bow. During the period of M1 through M3 growth, the mesoscale RIJ may have played an important role in which the

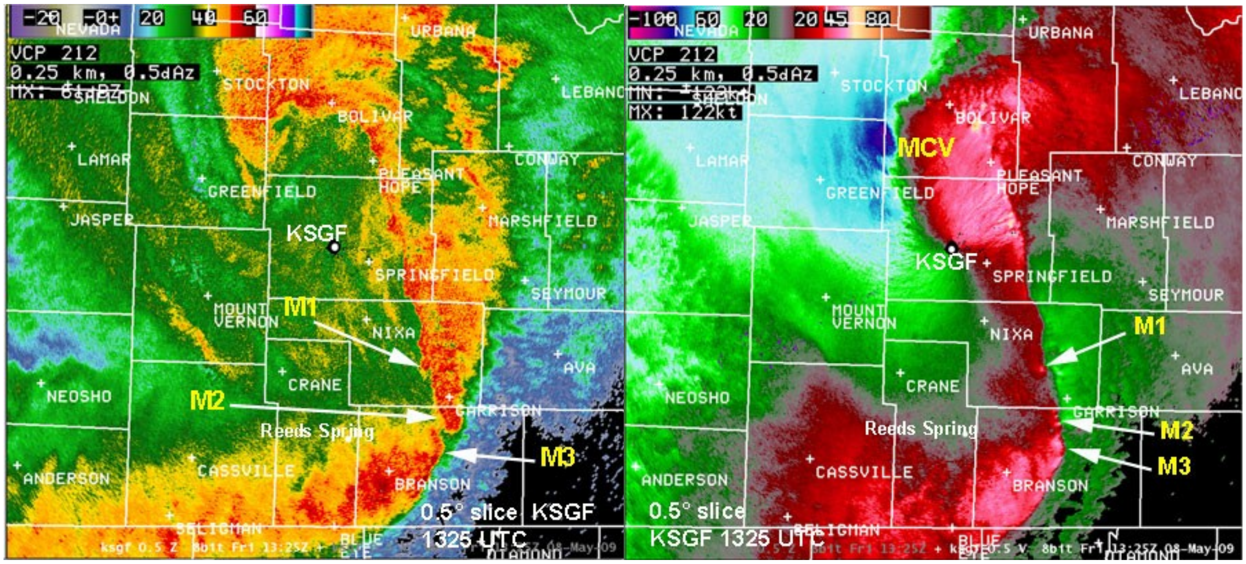

Fig. 11. (a) (left) Same as Fig. 5a except for 1325 UTC. Arrows point to the locations of M1, M2 and M3. (b) (right) Same as Figure 5b.

descending core of the jet may have transitioned southward with time keeping the *balance* between the environmental shear and the system cold pool resulting in vertically erect convective towers. Atkins and St Laurent (2009) revealed this evolution in their numerical simulations.

At 1330 UTC several low-level mesovortices were beginning to form north of M1 along the low-level convergence zone and began to redistribute the intense stratiform precipitation field in which small comma-shaped or “S” shaped echoes were documented revealing a wavy line structure (not shown) M1 also showed a comma-like shaped echo while M2 was located in 35 to 40 dBZ field. Similar to M2, M3 at this time was located between the LS region and the strong leading convective line.

IV. Mesovortex characteristics of M1 and M2

Rotational velocity (Vr) traces and mesovortex core diameters were completed for M1 and M2 while a core diameter trace was completed for MV2 (Figs. 12 13). The rotational velocity trace for MV1 is shown in Fig, 12a. The mesovortex initially formed at 1307 UTC with the strongest rotation identified between 1.2 and 2.2 km (18 $\mathrm{m\,s^{-1}}$) and greater. An investigation of four other bow echo events over Missouri and Illinois showed that some mesovortices which form near the apex may originate aloft within the 1.0 to 2.5 km while others may show the initial couplet at and below the 1.5 km level. MV1 deepened and intensified five minutes later with Vr magnitudes reaching 20 $\mathrm{m\,s^{-1}}$. Peak rotational velocities of 28 $\mathrm{m\,s^{-1}}$ occurred at the 1.3 km level. It should be noted that the strongest Vr magnitudes remained below 2.5 km at this time. However witnesses reported severe tree damage at 1325 UTC southeast of Christian Center Missouri. The Vr trace for MV2 shown in Figure 13a was slightly different at the beginning of its lifetime in which the strongest rotation (18 $\mathrm{m\,s^{-1}}$) was observed within the lowest 2.0 km at 1311 UTC and rapidly deepened and intensified at 1316 UTC. The strongest rotation continued within the 1.5 to 2.5 km layer and finally reached peak rotational velocities at 1325 UTC (greater than 30 $\mathrm{m\,s^{-1}}$). The first of two tornado touchdowns occurred just prior to peak Vr magnitudes. In this case there was a small lead time of greater than 10 minutes from first detection of MV2 to the time of first tornado touchdown.

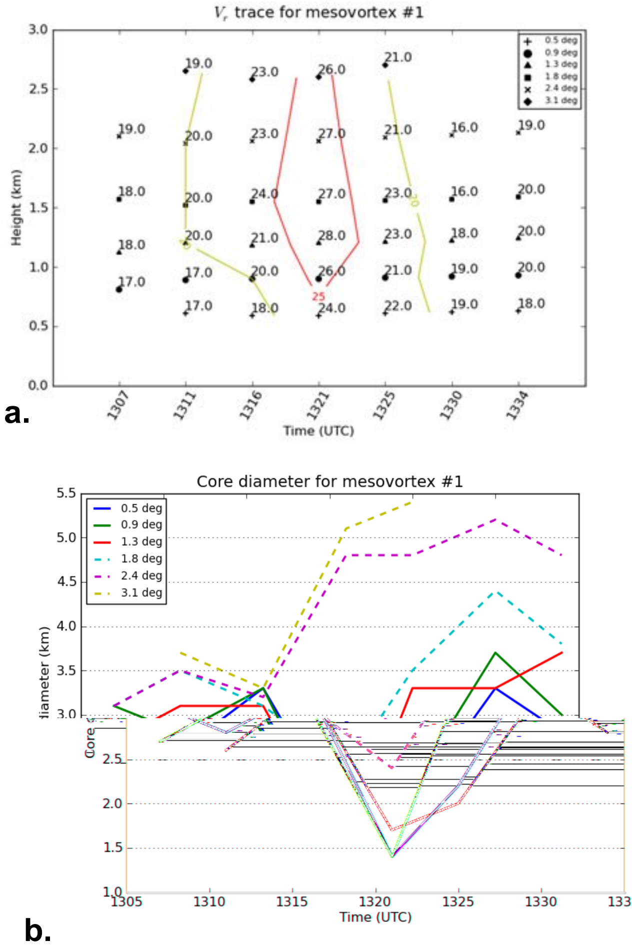

Fig. 12. (a) Rotational velocity trace for MV1. **(b)** Core diameter trace for MV1.

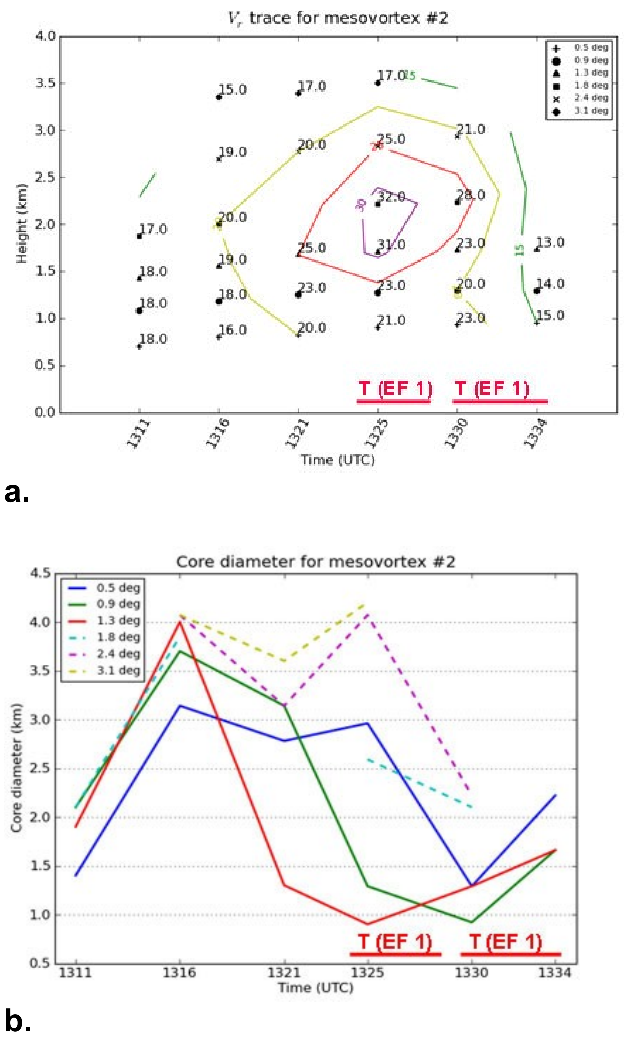

Fig. 13. (a) Rotational velocity trace for MV2. (b) Core diameter trace for MV2.

V.Summary

The 08 May 2009 Derecho was a unique severe wind storm which spawned 20 tornadoes over the WFO Springfield CWA, a corridor of continuous severe wind damage with surface wind speeds estimated between 35 to 45 $m s^{-1}$, and scattered areas of intense wind damage south of the main corridor. The main corridor of intense wind damage was associated with an intense Mesoscale Convective Vortex (MCV) which maintained its intensity from southwest Missouri to south-central Illinois. Over southwest Missouri three different environmental shear regimes existed simultaneously mainly after 1255 UTC, **(1)** *strongly sheared* environment north of the apex of the bow resulting in weakening convective cells and the gradual development of a thin but solid convective line, **2)** a *balance* between the environmental shear and system cold pool near the apex of the bow resulting in vertically erect convective towers and **3)** system cold pool *overwhelming* the ambient shear over the southwest part of the large bow echo resulting in a surface gust front accelerating away from the weakening convective towers. The low-level (0-3 km) shear vectors were normal to the convective line north of the apex, slightly angled in the vicinity of the apex of the bow, and parallel to the weakening convective line over the southwest part of the bow. North of the apex of the bow after 1302 UTC, an enhanced stratiform rain region formed east of the developing thin and narrow convective line resulting in precipitation particles transported downshear by the stronger middle and upper level tropospheric flow. That part of the convective line took on the characteristics of a Leading Stratiform (LS) precipitation region.

During the 1300 to 1330 time frame, mesovortex development took place in the balanced or slightly shear dominant portion of the line. Low level shear increased substantially across southwest Missouri owing to the RIJ and increased flow around the southern flank of the northern line end vortex. The increase in 0 to 3 km shear magnitude to around 25 $m s^{-1}$-likely aided in mesovortex development. Due to the increase in low level shear, the balanced portion of the line was located where shear vectors were orientated at about a 45° angle to the line. The area of greatest balance tended to shift south with time due to the southeastward motion of the RIJ. This southward shift of the RIJ and balanced portion of the line may have also resulted in the subsequent southward development of mesovortices. While remaining anchored to the low-level convergence zone, some of these mesovortices then redistributed intense leading stratiform precipitation resulting in small comma.-shaped reflectivity signatures.

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