13 MAY 2010 SEVERE BOW ECHO EVENT OVER NORTHEAST OKLAHOMA
PART 1: SYNOPTIC AND MESOSCALE ENVIRONMENT

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1. Introduction

A quasi-linear convective system (QLCS) tracked across northeast Oklahoma and far northwest Arkansas during the early morning hours on 13 May 2010. Numerous long track mesovortices developed along the leading edge of the QLCS, producing eleven tornadoes across northeast Oklahoma and one in far northwest Arkansas (Figure 1).

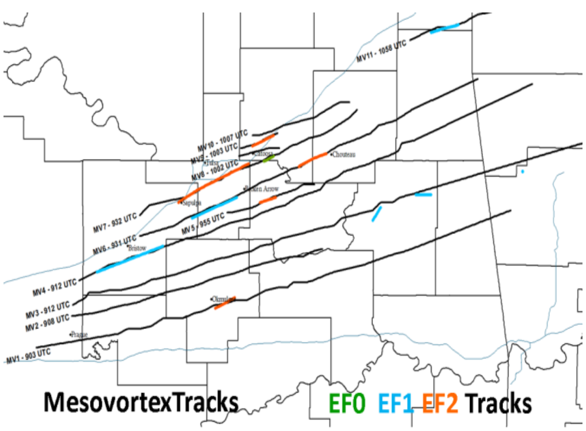

Figure 1: Mesovortex and tornado tracks across northeast Oklahoma and far northwest Arkansas during the early morning hours on 13 May 2010. EF-scale shown in colors.

Severe weather occurred during the evening hours of 12 May 2010 and was preceded by representative convective outlooks, watches, and warnings; however, the portion of the convective event discussed hereafter was not outlooked well by either the Tulsa, Oklahoma, National Weather Service (NWS) Weather Forecast Office (WFO) or the NWS Storm Prediction Center (SPC). As a result, convective watch lead time and appropriate severe weather warnings were impacted.

This event review will discuss the evolution of synoptic and mesoscale feature, along with the performance of numerical weather prediction (NWP) solutions. The analysis will be referenced to conceptual models of QLCS tornadic systems. Additionally, selected output from the Advanced Research Weather and Forecasting modeling system (ARW-WRF; Skamarock et al. 2005) utilizing the North American Regional Reanalysis (NARR 2012) dataset were compared to the North American Mesoscale (NAM) - WRF output produced by the National Centers for Environmental Prediction (NCEP) which was available real-time for this event. The comparison was made in an attempt to subjectively validate the quality of the NAM-WRF initialization during this event and to also provide an example of the potential utility of rapidly updating smaller scale numerical model simulations within the WFO operational environment.

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2. Synoptic Overview

An amplified upper air pattern was in place across the continental United States on 12-13 May 2010 with a 300 hPa trough aligned along the Rocky Mountain chain from western Canada into northern Mexico at 0000 UTC 13 May 2010. A 300 hPa 49 ms-1 jet streak was analyzed across Nevada and Arizona on the western side of the trough axis. The eastern side of the trough featured a jet streak of 56 ms^{-1} extending from northern New Mexico into southern North Dakota. The western jet streak rotated through the base of the trough by 12 UTC 13 May 2010 with the resultant speed maximum oriented from southwest Kansas into northern Minnesota.

A closed low at 500 hPa was centered over southeast Montana at 0000 UTC 13 May 2010, moving to north central South Dakota by 1200 UTC. Subjective analysis at 0000 UTC identified three subtle shortwave troughs within the larger 500 hPa trough with approximate locations being: 1) eastern New Mexico through far south Texas, 2) eastern Wyoming through southern Arizona, and 3) southwest Wyoming through central California. The El Paso, Texas, 0000 UTC upper air data sampled a 36 ms^{-1} 500 hPa wind, revealing a localized speed maxima associated with shortwave number 2.

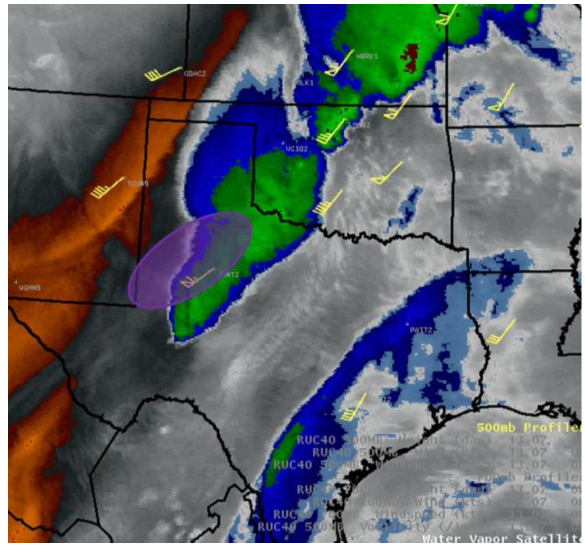

Figure 2: 0700 UTC 13 May 2010 water vapor satellite imagery and 500 hPa profiler winds (kts) in yellow. Purple area depicts subjective analysis of speed maximum.

The 500hPa shortwaves rotated eastward and northeastward, and by 1200 UTC, a broad region of 60-80 dam height falls at 500 hPa were analyzed across the Upper Midwest. The far west Texas 500 hPa speed maxima remained identifiable overnight, as seen in Figure 2, before being absorbed within a much broader and stronger 35-45 ms^{-1} 500 hPa jet, which extended from the Texas Panhandle into the central Missouri Valley by 1200 UTC 13 May.

The 700 hPa data mimicked the 500 hPa layer with a closed circulation over the Northern Plains and three shortwave troughs, all subjectively analyzed within the 0000 UTC 13 May upper air data. Similar to 500 hPa, a 700 hPa speed maximum was located over El Paso at 0000 UTC. This feature rotated eastward and was absorbed into a broader and stronger speed maxima by 1200 UTC 13 May, becoming oriented from central north Texas through eastern

Oklahoma and into western Illinois with sampled winds of 30-35 ms^{-1}.

The 850 hPa 0000 UTC 13 May data revealed a cold front from northern Nebraska southward through central Kansas and then westward into northeastern New Mexico. South and east of this boundary 13-18 ms^{-1} southerly winds prevailed with 14°C dewpoints extending from far south Texas through eastern Oklahoma and into northern Missouri. A notable lack of moisture at 850 mb was sampled across the entire Texas Gulf Coast and into southwest Louisiana. By 1200 UTC, the 850 hPa cold front extended from central Iowa through eastern Kansas into the central Texas Panhandle. Winds ahead of the boundary had veered to the south and southwest with a 25 ms^{-1} speed maximum analyzed from northwest Louisiana into central Illinois.

The drier air at 850 hPa across the Gulf Coast advected northward through east Texas and across western and central Arkansas by 1200 UTC. This resulted in a much more narrow moisture axis with 12°C dewpoints from north Texas through portions of eastern Oklahoma and 14°C dewpoints further northward across eastern Missouri and southern Illinois.

A similar pattern in moisture advection was analyzed at 950 hPa between 0000 UTC and 1200 UTC with Oklahoma City, Oklahoma, and Springfield, Missouri, experiencing 4°C and 2°C degree drops in 925 hPa dewpoints, respectively. The moisture advection zone extended from north Texas into central Arkansas and northward into central Illinois, well south and east of the frontal zone at 1200 UTC.

The surface analysis at 2100 UTC 12 May featured a frontal zone extending from southwest Colorado across the northern Texas Panhandle northeastward through central Missouri. An area of surface low pressure was located across the central Texas Panhandle with a dryline extending southward through West Texas. These surface features were areas of focus for repeated rounds of convection during the late afternoon and evening hours on 12 May across southern Kansas and western Oklahoma. The duration and areal extent of the resultant convection enhanced the temperature gradient along the boundary, contributing to the boundary's southward movement through northwest Oklahoma and into northeast Oklahoma by the early morning hours on 13 May.

At 0400 UTC 13 May, the cold front was located from east central New Mexico into southwest Oklahoma with the boundary becoming virtually stationary from southwest Oklahoma through northeast Oklahoma and curling north to a surface low located near Kansas City, Missouri. Widespread convection was ongoing north of the surface boundary from northwest Oklahoma northeastward into southern Wisconsin. Also noteworthy at 0400 UTC was renewed convection that intensified over West Texas in the vicinity of the dryline. The development and intensification of this convection corresponded with the upward forcing associated with the passing mid-level speed maxima noted in the 0000 UTC upper air analyses and in Figure 2.

3. Severe Convection Parameters

Mesoscale analyses produced by the SPC were utilized in this post-event review despite subtle differences noted between the analyses and observed surface conditions across northeast Oklahoma. The impacts of these differences will be noted with respect to specific points; however, the authors believe the SPC analyses to be sufficiently representative of the environment while also providing an example of the data available to forecasters in real-time during the event.

Instability at 0600 UTC was supported by a broad region of mid-level lapse rates (700-500 hPa) of 7.5-8°Ckm^{-1} over Oklahoma and north Texas, yielding most-unstable convective available potential energy (CAPE) values of 2000-3000 Jkg^{-1} over southern Oklahoma and north Texas. This level of instability remained largely in place through the early morning hours with 0900 UTC most-unstable CAPE values around 2000 Jkg^{-1} analyzed over northeast Oklahoma. The notable exception was a marked decrease in instability across far eastern Oklahoma and western Arkansas with a corresponding rise in level of free convection heights (Figure 3).

The boundary layer was analyzed to be capped south of the cold front with 0600 UTC surface based convective inhibition (CIN) less than -150 Jkg^{-1} from southwest Oklahoma northwestward through northeast Oklahoma. Noteworthy is the evolution of the surface based CIN through 0900 UTC as analyses show an area of weaker inhibition developing across central and southern Oklahoma by 0700 UTC and spreading northeastward along the cold front and into northeast Oklahoma by 0900 UTC. This lessening of the low level capping inversion is likely the result of rising motion within the Rapid Update Cycle (RUC) (Benjamin, et.al. 1994) analysis associated with the approaching mid-level speed maxima combined with the warm and moist surface conditions that remained in place across northeast Oklahoma. The low level thermal profile with the zero hour RUC analysis was checked against observational data across northeast Oklahoma between 0800-1000 UTC. The RUC analysis showed a 1-2°C cold bias on surface temperatures immediately south of the cold front across northeast Oklahoma. Surface dewpoints showed less of an error in the analysis. The zero hour RUC forecast soundings were then adjusted using the observational data for locations surrounding the Tulsa metropolitan area for the hours 0900-1000 UTC with the resultant surfaced based CIN values being less than -25 Jkg-1.

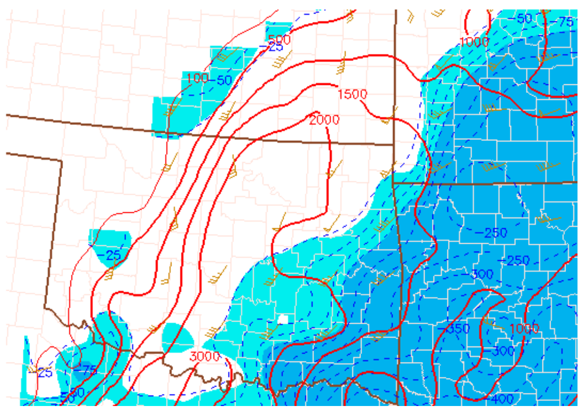

Figure 3: 0900 UTC 13 May 2010 Most-Unstable CAPE (red), Most-Unstable CIN (fill) and effective bulk shear (kts). (Source: SPC)

Environmental winds were strong through a deep layer over the entire Plains region with 0600 UTC effective bulk shear values (Thompson, 2004) of 12-20 ms^{-1} analyzed over far southwest Oklahoma and north central Texas, which became stronger with eastward extent and with time. The 0900 UTC effective bulk shear values of 18-25 ms^{-1} were analyzed from central Oklahoma northeastward through southwest Missouri. Low level shear also remained strong with 0-1km bulk shear analyzed at 21-26 ms^{-1} from southwest Oklahoma through northeast Oklahoma between 0600 and 1000 UTC. Both the effective shear vectors and low-level shear vectors were oriented south-southwest to north-northeast through the overnight hours. Also of note was the 0-3km shear vector given its relation to maintaining upright convection along the leading edge of bow echoes (COMET, 2003 and Pryzbylinski, 2012). The RUC analysis showed 0-3km bulk shear vectors of 18-23 ms-1 for the hours 0600-1000 UTC from south central Oklahoma through northeast Oklahoma. The 0-3km vectors were also oriented from south-southwest to north-northeast.

4. Convective Evolution

The convection previously noted across West Texas at 0400 UTC 13 May continued to develop northeastward, organizing into a QLCS with the northern portions of the convective line entering southwest Oklahoma around 0600 UTC. The QLCS continued along the Red River strengthening and obtaining a bow echo configuration by 0700 UTC while propagating eastward across far southwest Oklahoma and the bordering north Texas counties. Severe criteria winds with associated damage were observed in Jackson County in far southwest Oklahoma during this timeframe. The bow echo maintained its intensity between 0700 and 0800 UTC while tracking farther eastward along the Red River Valley and continued to produce severe criteria winds. The southern portion of the bow echo also began to weaken during this timeframe with a pronounced trailing stratiform precipitation region expanding northwest of the bow apex from southwest into west central Oklahoma.

The bow echo began to lose organization from 0800-0900 UTC as it tracked across south central Oklahoma with the severe weather reports across central Oklahoma clustering near the intersection of the cold front and northern portion of the weakening bow echo. The aforementioned trailing precipitation region continued to expand and lift north-northeastward across west central and north central Oklahoma with the surface pressure pattern showing considerable evolution.

Oklahoma Mesonet (Brock et al. 1995) data at one minute resolution were utilized to construct plan view objective analysis of surface pressure along with time series plots of selected locations. Figure 4, valid at 0800 UTC 13 May, is the plan view pressure analysis with an overlay of composite 0.5° radar reflectivity from the area WSR-88Ds. The radar data in Figure 4 show ongoing convection from central Oklahoma through northeast Oklahoma which was occurring on the cold side of the surface cold front; the bow echo extended from south central Oklahoma into north Texas. A localized area of higher surface pressure was analyzed across southwest Oklahoma beneath the stratiform precipitation region.

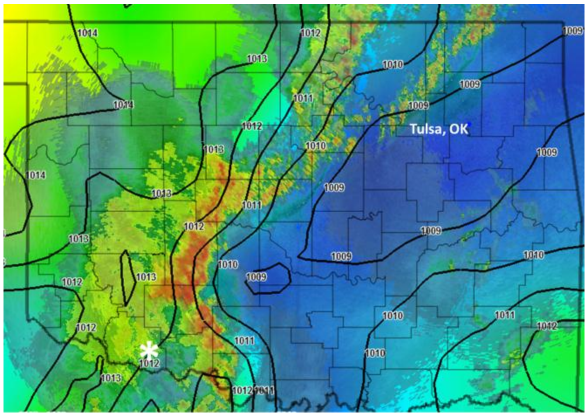

Figure 4: 0800 UTC 13 May 2010 composite 0.5 degree WSR-88D 0.5 reflectivity overlaid with color filled and contoured MSLP. Grandfield, OK marked by the white star (*).

The time series plot in Figure 5 is valid for Grandfield, Oklahoma, in the southwest portion of the state. This plot shows the influence of the passing convection on the ambient surface conditions and the strong surface pressure rises which were evidence of the building mesohigh.

Figure 6, valid 0900 UTC 13 May, shows the mesohigh expanding in areal coverage and in strength as it became centered over central Oklahoma, beneath the broad stratiform rain region.

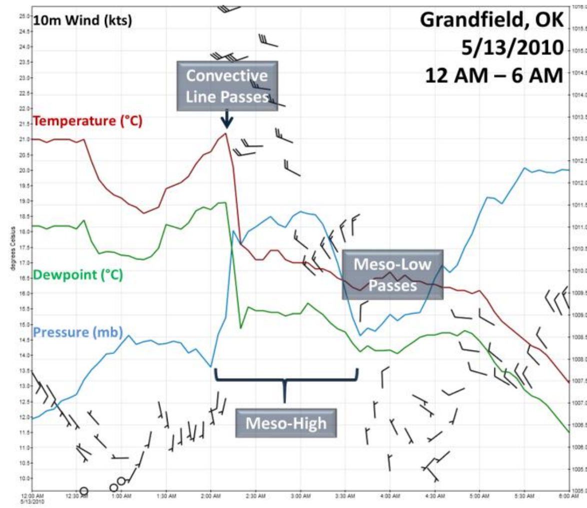

Figure 5: Grandfield, OK Mesonet Station Time Series from 0500 UTC - 1100 UTC (12am-6am CDT) 13 May 2010. 10-m winds (kts) shown in black, MSLP (hPa) in blue, dewpoint (°C) in green and temperature (°C) in red.

The radar data in Figure 6 show the bow echo weakening between 0800 and 0900 UTC over south central Oklahoma. However, there was renewed convective organization across north central Oklahoma where an initial bowing structure was evident. Also noteworthy is the area of low pressure–moving into southwest Oklahoma behind the departing mesohigh. This surface low was not readily apparent in the broader sampling of surface data across northwest Texas, but became more defined once it entered the higher density measurements of the Oklahoma Mesonet. This surface low was likely the reflection of upward forcing associated with the approaching wind maxima noted previously ejecting northeastward through far west Texas.

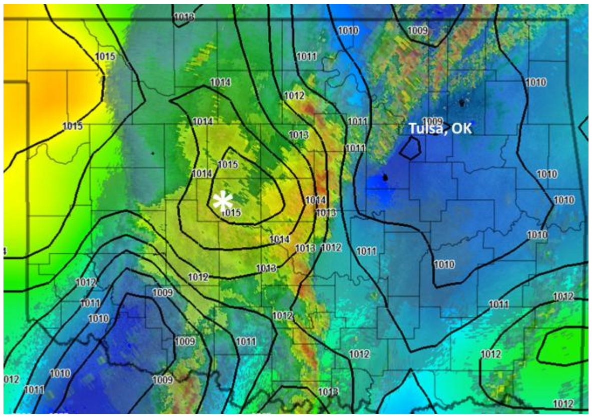

Figure 6: 0900 UTC 13 May 2010 with the same convention as Figure 1. El Reno, OK marked by a white star (*).

Synoptic scale upward motion also likely influenced the expansion of the trailing stratiform precipitation region while also providing background forcing for sustained deep convection from southwest through central Oklahoma. Figure 7 again shows the strength of the mesohigh with a surface pressure rise of approximately 4 hPa in 45 minutes measured at El Reno, Oklahoma. The pressure trace in Figure 6 also shows the passage of the mesolow as it tracked from southwest through central Oklahoma.

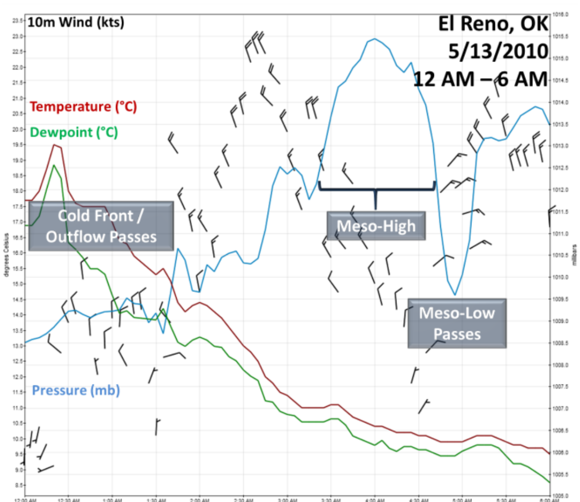

Figure 7: El Reno, OK Mesonet station time series from 0500 UTC-1100 UTC (12am-6am CDT) 13 May 2010. Line colors as in Figure 2.

Convection rapidly organized and obtained a bow echo configuration between 0900 and 1000 UTC from north central Oklahoma into northeast Oklahoma. Figure 8 shows the placement of the bow echo at 1000 UTC with the leading edge of the bow apex moving through the Tulsa metropolitan area. Also apparent is the location of the stratiform precipitation region and the associated mesohigh, as well as the mesolow, over central Oklahoma both marking the continued advance of the synoptic lift. Closer inspection of the reflectivity data associated with the bow echo shows the rapid decrease in reflectivity west of the leading edge convection, marking subsidence associated with the descending rear inflow jet (RIJ) which further indicates a highly organized complex (Houze et. al. 1989). Additionally, the radar composite shows the location of the cold front across northeast Oklahoma near the Interstate 44 corridor from Tulsa northeast, which further provided a favorable zone for enhanced severe weather potential (Pryzbylinski 1995).

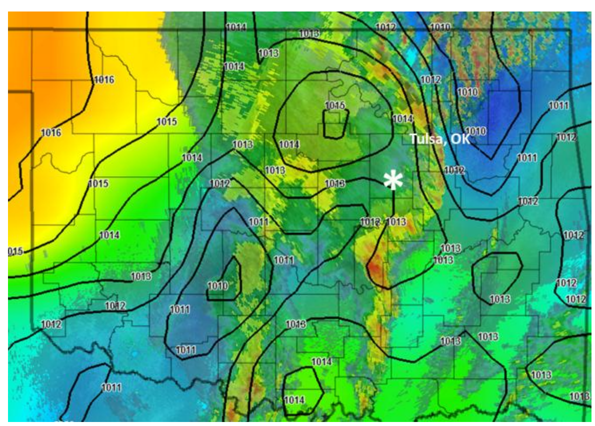

Figure 8: 1000 UTC 13 May 2010 using same convention as Figures 1,3. Bristow, OK marked by the white star (*).

The Bristow, Oklahoma, Mesonet station measured a wind gust of 35.5 ms^{-1} (69kts) at 0935 UTC (Figure 9) during the intensification of the bow echo into northeast Oklahoma. This wind was later determined to be associated with a tornado spawned by one of the numerous mesovortices that developed along the leading edge of the bow echo. Numerous mesovortices became apparent as the bow echo moved closer to both the Weather Surveillance Radar-1988 Doppler (WSR-88D) located in Inola, Oklahoma (KINX), and the Federal Aviation Administration's Terminal Doppler Weather Radar (TDWR) located in Tulsa, Oklahoma (KTUL). The evolution of the multiple mesovortices and associated tornadoes will be discussed further in Part 2 of this event.

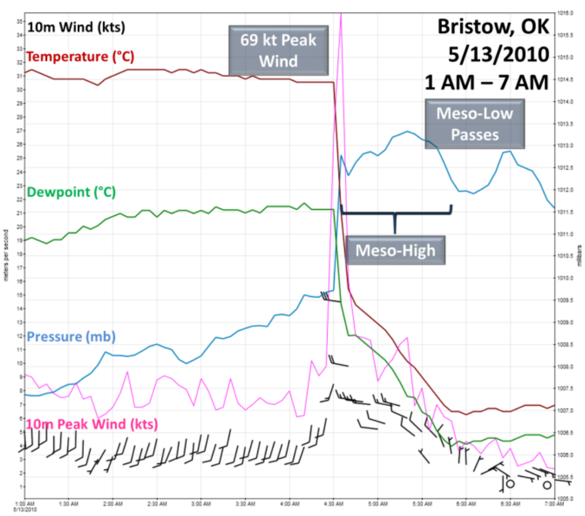

Figure 9: Bristow, OK Mesonet station time series from 0600 UTC-1200 UTC (1am-7am CDT) 13 May 2010. Line colors as in Figure 2 except peak 10-m wind shown in purple.

The bow echo continued east-northeast through 1100 UTC with continued mesovortex and tornado production near and north of the bow apex similar to the conceptual model proposed by Atkins and St. Laurent (2009). However, the northward extent of the severe weather was limited by the strong cold front and the considerable boundary layer stability north of the front. The bow echo began to lose organization between 1100 and 1200 UTC with one weak tornado produced in far northwest Arkansas and another in far southwest Missouri. The weakening phase of the bow aligned with the eastern edge of the deeper moisture noted in the synoptic analysis and the resultant rise in LFC heights and decrease in available CAPE.

5. Event Simulations

The ARW-WRF was utilized to simulate the 13 May event with the NARR dataset providing the model initialization fields. The model was run with a 7km horizontal resolution and 45 vertical layers. Convection was parameterized using the Kain-Fritsch method (Kain and Fritsch 1990, 1993; Kain 2004) and output was viewed at hourly intervals (further model specifics are available upon request). The simulation began at 0600 UTC May 13 and ran for 12 hours. The output was compared to the 0600 UTC 13 May 2010 NCEP NAM-WRF which was available real-time to forecasters.

The ARW-WRF reanalysis simulation produced a more realistic convective solution than the NAM-WRF when comparing simulated radar reflectivity patterns (Figure 10). The reanalysis simulation intensified and expanded convection from central Oklahoma through northeast Oklahoma between 0900 and 1200 UTC. The operational NAM had weak and sporadic convective signals within its simulated reflectivity. Additionally, vertical cross sections through the simulated reflectivity produced by the reanalysis revealed a strengthening RIJ as the convection moved through northeast Oklahoma. Local maxima of both surface wind speeds and updraft maximum helicity (Kain 2008) were also produced within the simulation in the stronger convective cores.

However, the reanalysis forecast did not advance the cold front far enough southward and was delayed in developing the strongest convection when compared to the actual event.

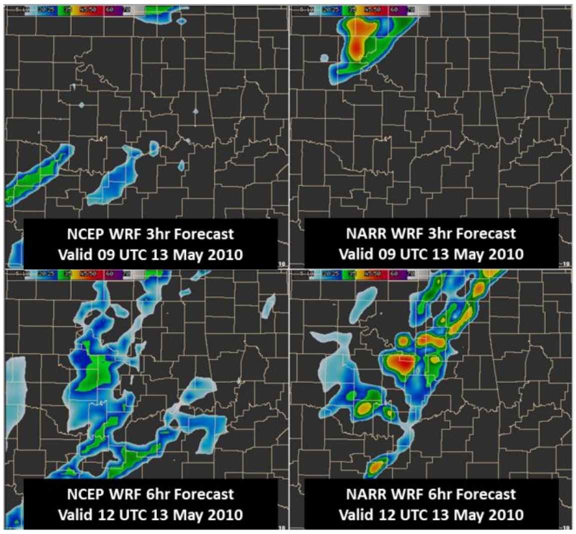

Figure 10: Model simulated surface level radar reflectivity (dBZ) for 0900 UTC and 1200 UTC 13 May 2010. Left panels are the 0600 UTC NCEP NAM-WRF. Right panels are the 0600 UTC ARW-WRF produced post event and initialized using the NARR reanalysis. Note: Model physics differ.

A comparison of the initialization fields within the NARR analysis and those within the zero hour 0600 UTC NAM-WRF showed the NARR to have a stronger 850-800 hPa wind streak across West Texas, with this being the most notable difference amongst various wind and instability comparisons.

An additional likely influence provided by the NARR initialization was in the precipitation analysis compared to that available for the real-time NAM-WRF. The NARR depiction of the ongoing QLCS along the Red River at 0600 UTC is likely to have resulted in a more realistic development of the associated surface pressure patterns prior to the development and strengthening of the northeast Oklahoma QLCS.

The purpose of reanalysis simulation was to determine if this event could have been modeled with meaningful lead time to provide decision support in an operational forecast setting. A secondary purpose was to provide an example of numerical model output that could be available within an operational setting. The reanalysis simulation was purposefully constructed to simulate the resolution and time step that would allow for repeated model runs utilizing hardware routinely available within a WFO operational setting. While it is beyond this case review to focus on the exact potential that local numerical modeling would have had on the forecast of this event, this reanalysis does highlight the potential that rapidly updating fine scale NWP modeling can have during evolving convective events.

6. Summary

The severe convective event of 13 May 2010 across northeast Oklahoma and far northwest Arkansas resulted in a rapidly evolving QLCS which produced numerous mesovortices and associated tornadoes. The event was not forecast well prior to its intensification across northeast Oklahoma. This resulted in a severe thunderstorm watch with zero lead time and warnings that did not accurately represent the tornadic threat. An analysis of the synoptic and mesoscale environments was consistent with that found in other documented tornadic QLCS events with moderate CAPE present within a strongly sheared low level flow field.

The 13 May case offered its unique challenge by initially not being depicted well by short range NWP models. It was further complicated by a rapidly evolving surface pressure pattern that aided the onset of the renewed QLCS development from central Oklahoma into northeast Oklahoma. Once the QLCS development was underway the evolution was similar to the conceptual model of a strong RIJ developing with upright convection being achieved where the system cold pool shear balanced the environmental shear. The development of numerous long lived mesovortices during the time of upright convection was atypical both in the duration and evolution of the individual vortices, and with multiple tornadoes reaching EF2 intensity. The details of these features and associated tornadoes will be discussed in Part 2 of this event review.

Additionally, an attempt was made to determine whether or not this event could have been better forecast by numerical models, and if so, how would the event have appeared to operational forecasters utilizing local mesoscale models? The reanalysis simulation utilizing the NARR dataset suggested that this event could have been simulated more accurately, but only if a more robust initialization was available. Additionally, the reanalysis solution provided an example of how a rapidly evolving QLCS could appear within a high resolution numerical model via the presence of a strong RIJ and local maxima in surface winds and updraft helicity.

This event review, like many others, provides an example of the importance of observational data to successful short term convective forecasts. It also provided an example of how rapidly updating numerical modeling could be utilized within an operational setting to recognize convective mode and associated impacts.

Acknowledgments. The authors wish to acknowledge and thank James Frederick, Information Technology Officer NWS Tulsa, OK, for his help with archiving data and facilitating NWP modeling efforts.

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