P113 **ENSEMBLE FORECAST PRODUCTS FOR THE 14 APRIL 2012 SEVERE WEATHER EVENT IN NEBRASKA**

James R. McCormick*
UCAR, Located 16th WS/WXN, Offutt AFB, Nebraska

Evan Kuchera and Scott Rentschler
16th WS/WXN, Offutt AFB, Nebraska

1. Introduction

During the 21 hour period between 15Z 14 April 2012 and 12Z 15 April 2012, widespread severe weather occurred over southern and central Nebraska. All modes of severe weather were noted, including tornadoes, baseball sized hail, and 80 MPH winds [Figure 1]. Severe weather occurred over the course of the 21 hour period, including several rounds of severe weather that included both supercellular and linear storm structures.

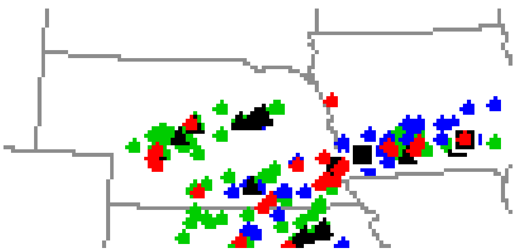

Figure 1: SPC Storm Reports 14 April

The event was well forecast; Storm Prediction Center and National Weather Service forecasts all indicated a strong likelihood of severe weather in Nebraska. These forecasts included a "high risk" designation for much of eastern and central Nebraska. Details of the forecast, however, remained challenging, specifically the timing of convection initiation, convective mode, storm propagation, and the locations facing the greatest severe weather threats.

At the Air Force Weather Agency (AFWA), several severe weather forecast products are routinely developed using the Mesoscale Ensemble Prediction System (MEPS). Included within the suite of MEPS products are various guidance tools for forecasting thunderstorms, supercells, tornadoes, hail, and damaging wind gusts. Deterministic ensemble products such as simulated radar reflectivity, are also available.

Corresponding author email address:

James R. McCormick
James.McCormick.Ctr@offutt.af.mil

These forecast products painted a convoluted picture on 14 April involving early convection and clustered storm modes while maintaining a significant severe weather risk in southeastern Nebraska. The goal of this paper is to discuss the various modes of severe weather that occurred over southern and central Nebraska, as well as to discuss the performance of the AWFA MEPS for this event, particularly in terms of storm type and storm timing.

2. AFWA WRF Ensemble

2.1. Ensemble Details

The AFWA ensemble is comprised of 10 4-KM WRF-ARW v3.1.1 members with mixed initial condition and model physics membership [Table 1]. AFWA runs WRF-ARW version 3.1.1 (Skamarock et al 2008). The model utilizes 32 terrain following sigma levels with a model top of 50 hPa.

#	IC/BC	Surface	PBL	Micro
1	UM	NOAH	YSU	WSM5
2	GFS	RUC	MYJ	GODD
3	GEM	NOAH	MYJ	FERR
4	NOGAPS	NOAH	MYJ	THOM
5	UM	RUC	MYJ	THOM
6	GFS	NOAH	MYJ	THOM
7	GEM	NOAH	YSU	GODD
8	NOGAPS	NOAH	MYJ	WSM5
9	UM	RUC	MYJ	FERR
10	GFS	NOAH	YSU	WSM5

Table 1: MEPS WRF Member Configurations

Forecasts from the 00Z runs on 13 April and 14 April were examined; the AFWA MEPS is only run once per day unless otherwise requested. The products of most interest for this particular project are described below.

2.2. Ensemble Products and Algorithms

Various severe weather products are calculated based upon the output of these WRF members using algorithms developed within AFWA with assistance from the Storm Prediction Center and others.

2.2.1. Reflectivity

Radar reflectivity is computed based on microphysical contributions from each individual grid point, as given by the function (Stoelinga 2005):

$$Z = a*Q_{rain}^{x} + b*Q_{snow}^{y} + c*Q_{graupel}^{z}$$

Where a, b, and c are coefficients that vary with respect to atmospheric pressure, density, temperature, and mixing ratio.

2.2.2. Supercell Probability

Supercell probability is developed based on the understood idea from research at the NSSL that updraft helicity is directly related to a storm's ability to develop deep, consistent rotation (e.g., Kain et al 2008). The probability is given by the function:

$$\text{Probability} = .02*(\text{Updraft Helicity } [m^2/s^2] - 25)$$

With a maximum value of 1, or 100%.

2.2.3. Tornado Probability

Tornado probabilities are developed based on the probability of a supercell, as well as added discriminators of the level of free convection (LFC, Davies 2004) and a consideration for 0-5 km wind shear. The tornado probability is given by:

Probability = .00025*(2500-LFC [m])*.05*(5 km wind[m/s]-10) * Probability of Supercell

With a maximum value of .5, or 50%.

2.2.4. Hail Probability

Hail probabilities are determined by cloud ice content, grid scale vertical motion, and0-5 km vertical wind shear. The hail probability is given by the function:

Probability = 0.066*(UV[m/s]-25)* 0.057(5KMWS[m/s] - 12.5) * 0.067(cloud_ice - 10.0)

With a maximum of .75, or 75%.

3. WRF Ensemble Forecasts

Radar reflectivity is examined to identify likely timing and modes for convection. During a typical dry line severe weather event in Nebraska ,a strong cap develops in the morning hours as an elevated mixed layer advects over the region from the higher terrain to the west. The resulting negative buoyancy can be aided by the remnants of nocturnal convection. The cap then erodes over the course of the day in the presence of strong surface heating and forcing from mesoscale and synoptic features. The strongest thunderstorms on a typical dry line day remain isolated, free from interference of other storm dynamics and with full access to warm, helicity rich inflow.

It is noted quickly that by 18Z, however, convection is developing in the warm sector, east of the dry line, within a zone of strong moisture and isentropic lift [Figure 2].

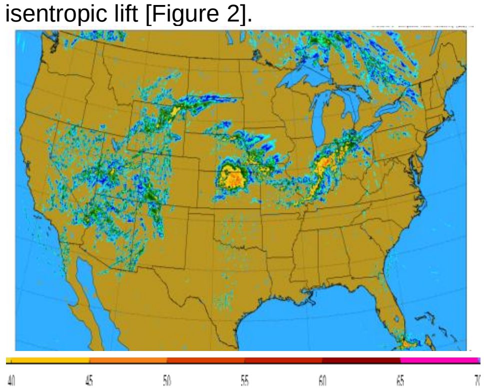

Figure 2: Simulated Ensemble Composite Reflectivity [dBz], valid 18Z 14 April 2012

This activity spreads to the east and north by 21Z [Figure 3], across the high risk area.

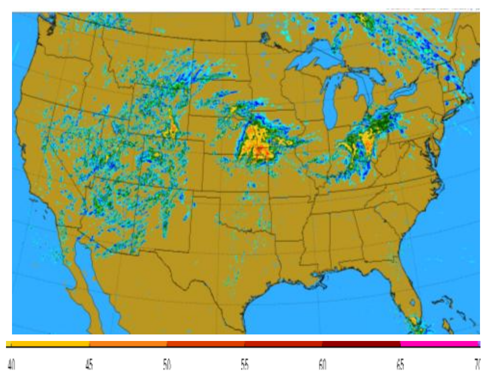

Figure 3: Simulated Ensemble Composite Reflectivity [dBz], valid 21Z 14 April 2012

The activity was then forecast to continue to spread to the north and east through the evening hours. By 03Z 15 April 2012, the activity departed eastern Nebraska, moving into Iowa [Figure 4] as the simulated surface low exited Nebraska by late evening.

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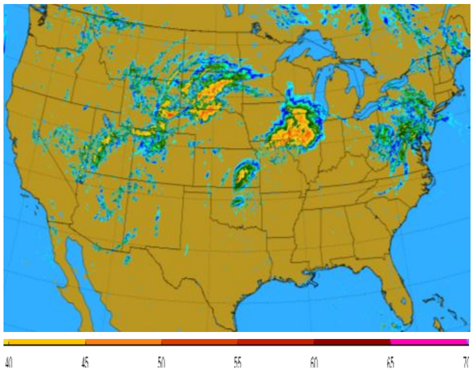

Figure 4: Simulated Ensemble Composite Reflectivity [dBz], valid 03Z 14 April 2012

It is also noted that by 03Z, more isolated convection has developed along the dry line in southern Kansas, and it is also noted that the convection in Kansas possesses a more isolated nature than the convective complex that passed through eastern Nebraska into Iowa.

Products designed to delineate specific threats were also examined. Supercell probabilities of 5-10% or greater within 20 n. mi. of a given point were indicated within the broad complex moving through southeastern Nebraska [Figure 5], indicating a threat for rotating thunderstorms. Non-zero tornado probabilities were also indicated within the complex during both the daytime [Figure 6] and nighttime [Figure 7] hours, continuing the threat past sundown. Likewise, non-zero hail probabilities were indicated within the complex during the daytime hours [Figure 8].

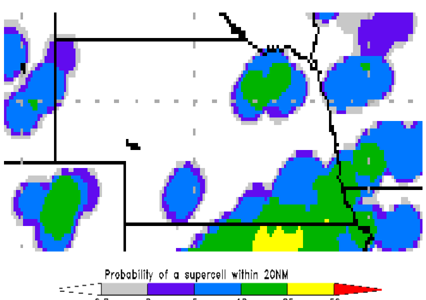

Figure 5: Supercell probability [%] within 20 n. mi of a given location, valid at 21Z 14 April 2012.

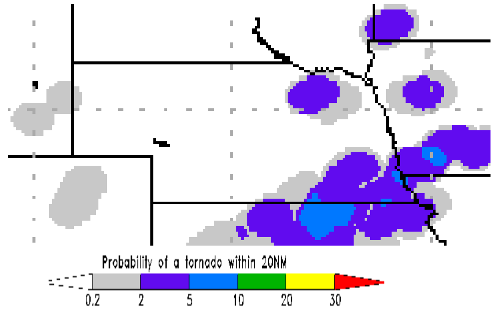

Figure 6: Tornado probability [%] within 20 n. mi. of a given location, valid at 21Z 15 April 2012.

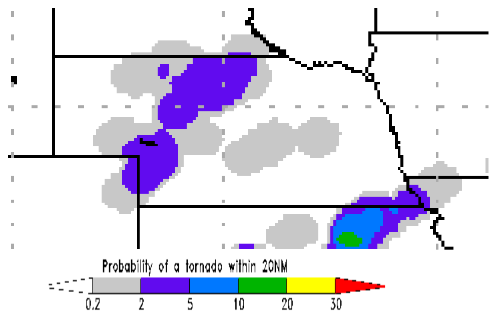

Figure 7: Tornado probability [%] within 20 n. mi. of a given location, valid at 03Z 15 April 2012.

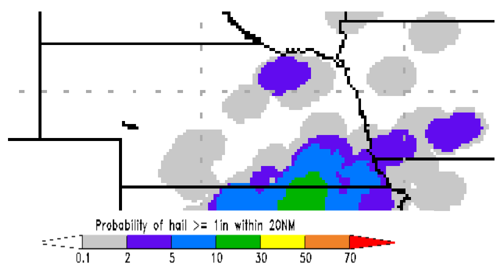

Figure 8: Hail probability [%] within 20 n. mi. of a given location, valid at 18Z 14 April 2012.

These images indicated that a range of severe threats was possible. Despite the congested nature of the simulated reflectivity images, the potential for rotating thunderstorms and tornadic activity was indicated by the ensemble. Given the nature of the expected convection, tornadoes should be expected not from isolated supercells, but from embedded supercells and from rotations within larger precipitation complexes. Though QLCS tornadoes are not a frequent threat in Nebraska (Trapp et al 2005), more commonly found in the eastern Midwest and in the southeastern United States, conditions are favorable for a non-traditional tornado threat. Hail probabilities are present, but somewhat lower due to the early timing of convective initiation and the congested nature of the convection.

4. Atmospheric Conditions

4.1. Forecasts

The 14 April 2012 severe weather event was forecast well in advance, with particular emphasis placed upon the high-end potential of the event. Nebraska was first placed in a high risk for severe weather within the 0600 UTC Day 2 outlook issued on 13 April 2012. On the morning of 14 April, the high risk designation was continued [Figure 9], with a 45% risk of tornadoes located across much of southern and eastern Nebraska [Figure 10].

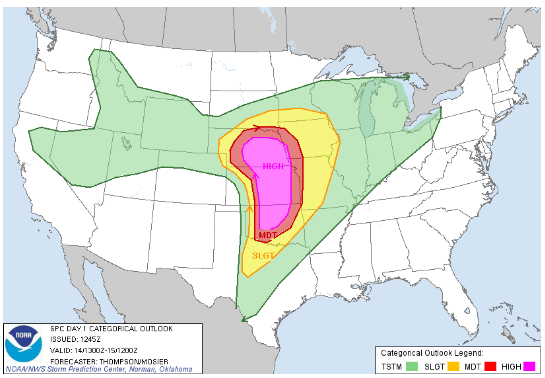

Figure 9: 13Z 14 April 2012 Day 1 SPC Convective Outlook [Courtesy SPC].

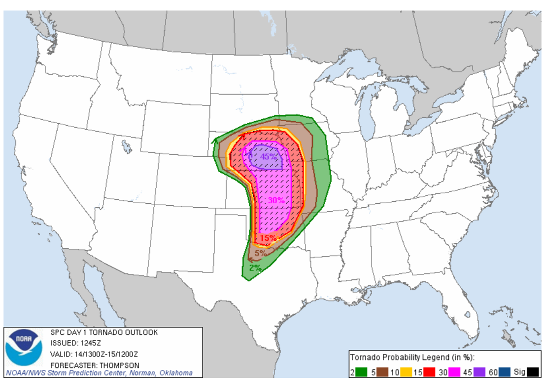

Figure 10: 13Z 14 April 2012 Day 1 SPC Tornado Probabilities [Courtesy SPC].

4.2. Upper Air Conditions

As expected, conditions became extremely favorable for severe thunderstorms across the central plains by the morning of 14 April 2012. A strong upper level trough located over the desert southwest ejects towards the central US with a 140 kt jet streak beginning to round the base of the trough [Figure 11].

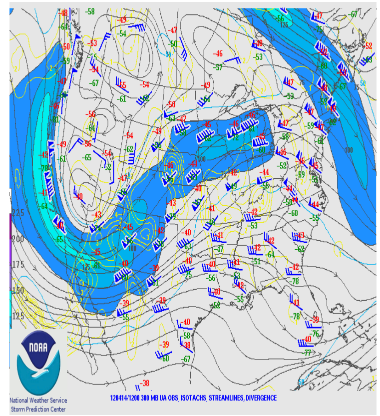

Figure 11: 300 hPa upper air observations (station plots), objectively-analyzed streamlines (black lines), divergence (yellow contours), and isotachs (kt, shaded) valid at 12Z 14 April 2012 [Courtesy SPC].

Strong winds were observed in the lower levels of the atmosphere [Figure 12], along with the northward advection of a very warm, humid air mass. Significant 850 hPa diffluence is noted in northern Kansas by 12Z 14 April 2012 as well.

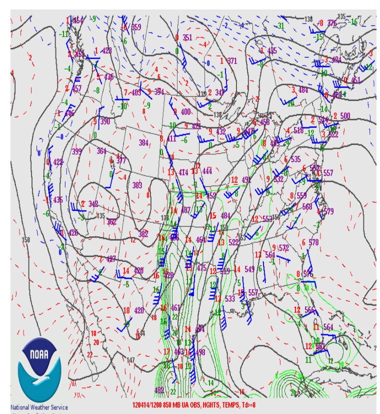

Figure 12: 850 hPa upper air observations (station plots), objectively-analyzed geopotential height (m, black contours), temperature (°C, red dashed contours), and dewpoint temperature (°C, green contours) valid at 12Z 14 April 2012 [Courtesy SPC].

The midday OAX sounding, though slightly convectively contaminated, revealed strong low and deep layer shear [Figure 13], with 24 kts of 0-1 km shear and 80 kts of 0-6 km shear measured. A moderately unstable air mass is already in place, with only a small amount of surface based convective inhibition remaining. Conditions are favorable for severe weather, but conditions are also favorable for widespread convection and early convection given the lack of inhibition and the presence of strong large-scale forcing for ascent [Figures 11,12]. The 3 KM wind shear vector, noted for aiding in the organization of convective complexes (Przybylinski et al 2010), varied between 205 and 220 degrees between the morning and midday soundings.

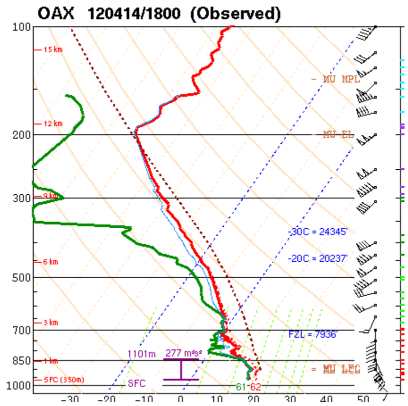

Figure 13: Skew-T diagram for Omaha, NE (OAX) valid at 12Z 14 April 2012 [Courtesy SPC].

4.3. Surface Conditions

The 15Z 14 April 2012 HPC surface analysis [Figure 14] indicated that the main surface low was located in eastern Colorado with a warm front stretching eastward from the low up along the Nebraska/Kansas border. Temperatures and dew points in the low 60s °F were present south of the warm front; temperatures in the low 50s °F and dew points in the mid 40s °F were common north of the boundary. Southeast and easterly surface winds were also common along and north of the warm front.

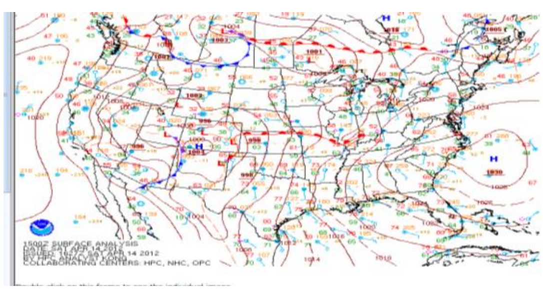
Figure 14: 15Z 14 April 2012 HPC surface analysis [Courtesy SPC/HPC].

5. Convective Evolution

With strong moisture and substantial synoptic lift present early in the day, widespread convection developed across portions of north central Kansas by 18Z [Figure 15], quickly moving to the north towards southern Nebraska. An additional early storm was noted in central Nebraska [Figure 16], elevated in nature but possessing supercellular characteristics and a very strong hail core. Remnants of nocturnal convection, though not severe, continued to push across southeastern Nebraska, with very heavy rains noted as well.

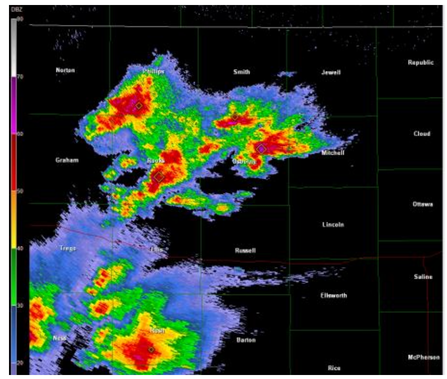
Figure 15: 0.5° Level II base reflectivity [dBz] valid at 1704 UTC 14 April 2012 from the Hastings, NE (KUEX) WSR-88D Doppler Radar.

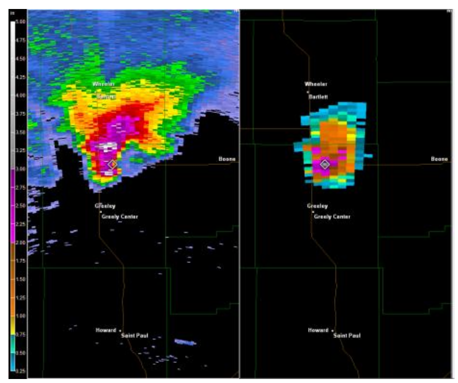
Figure 16: 0.5° Level II base reflectivity [dBz; left] and maximum estimated hail size [in; right] valid at 1636 UTC 14 April 2012 from the Hastings, NE (KUEX) WSR-88D Doppler Radar.

As the complex moved to the north, two areas of convection remained isolated, and the storms each gained supercellular characteristics [Figure 17] The supercellular structure of these storms was classic in nature while the storms remained isolated, and at this time, a tornado was reported near Hardy, NE.

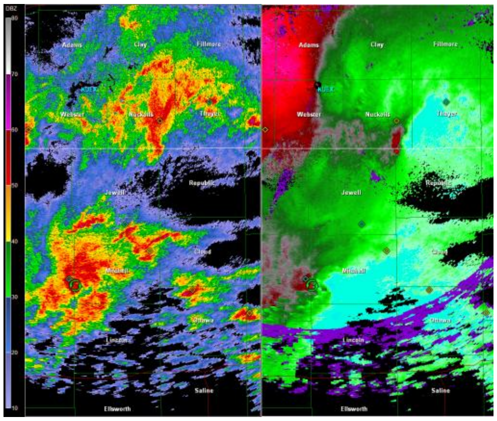

Figure 17: 0.5° Level II base reflectivity [dBz; left] and base velocity [kt; right] valid at 1910 UTC 14 April 2012 from the Hastings, NE (KUEX) WSR-88D Doppler Radar.

The supercellular nature of these storms was soon lost, however. Additional convection within the warm sector raced northward, and interference between these storms with the ongoing supercells soon resulted in the morphology from supercell thunderstorms to a broader complex of precipitation that did not produce any severe weather [Figure 18]. No severe weather was noted from this complex during its time in Saline, Fillmore, Thayer, and Jefferson Counties in southeastern Nebraska. It is noted at this time that convection develops to the southeast of the dissipating supercell at an angle that is normal to the 3 KM wind shear.

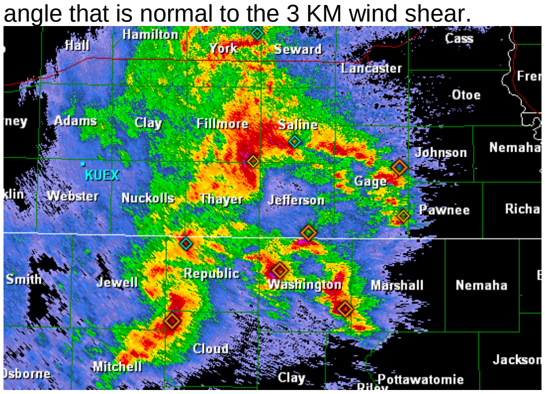

Figure 18: 0.5° Level III base reflectivity [dBz] valid at 2001 UTC 14 April 2012 from the Omaha, NE (KOAX) WSR-88D Doppler Radar.

The complex remained in a helicity-rich environment, and as the system began to accelerate towards the east and northeast, regained organization as a quasi-linear convective system [Figure 19]. Several embedded rotations quickly appeared within the line and numerous tornadoes were reported, including strong EF-2 damage in Cook, NE and later in Thurman, IA, from the rotations within this line.

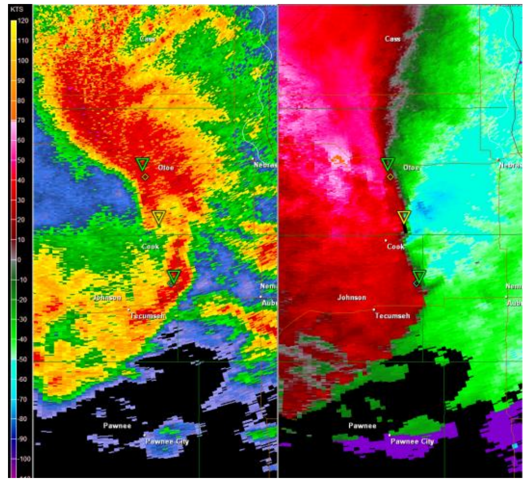

Figure 19: 0.5° Level II base reflectivity [dBz; left] and base velocity [kt; right] valid at 2207 UTC 14 April 2012 from the Omaha, NE (KOAX) WSR-88D Doppler Radar.

To the west, isolated convection behaved as expected along the dry line, with two isolated thunderstorms developing in southwestern Nebraska, each producing tornadoes [Figure 20]. Away from the deepest moisture, these tornadoes were not particularly intense.

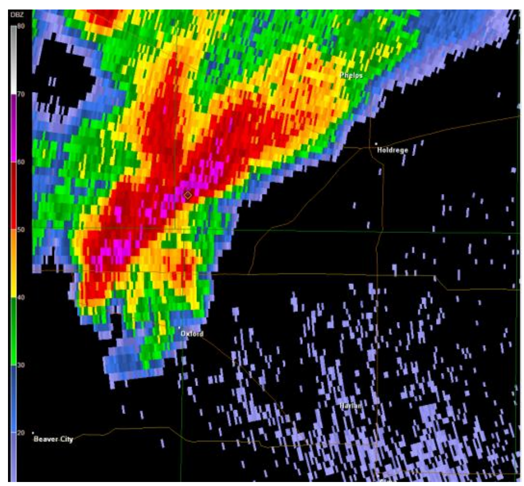

Figure 20: 0.5° Level III base reflectivity [dBz] valid at 2303 UTC 14 April 2012 from the Hastings, NE (KUEX) WSR-88D Doppler Radar.

Quick recovery of the atmosphere in the wake of this convective system was noted; cumulus clouds based near the boundary layer were noted again in the Omaha area by 00Z 15 April 2012 [not shown]. Convection moving into southeastern Nebraska from the west was able to take advantage of the recovered atmosphere, and as convection approached Lincoln, NE, one thunderstorm regained supercellular characteristics [Figure 21].

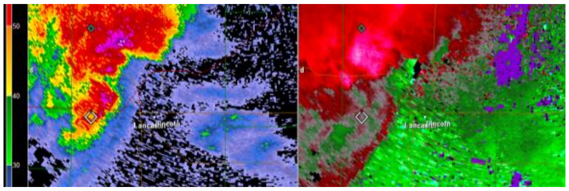

Figure 21: 0.5° Level II base reflectivity [dBz; left] and base velocity [kt; right] valid at 0438 UTC 15 April 2012 from the Omaha, NE (KOAX) WSR-88D Doppler Radar.

As this complex moved east of Lincoln, it too began to morph into an organized mesoscale convective complex, and one particular embedded rotation signature developed near Omaha, strengthening east of the city and producing a confirmed tornado near Council Bluffs, IA [Figure 22].

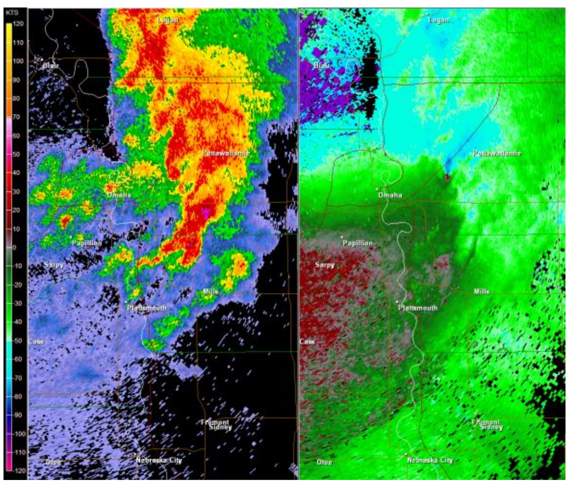

Figure 22: 0.5° Level II base reflectivity [dBz; left] and base velocity [kt; right] valid at 0555 UTC 15 April 2012 from the Omaha, NE (KOAX) WSR-88D Doppler Radar.

The threat of severe convection in eastern Nebraska ended after 6Z after this line passed into Iowa and the surface low passed to the east.

6. Summary and Conclusions

A complicated and dangerous severe weather scenario developed across much of Nebraska on 14 April 2012 where all modes of severe weather were observed over a 21 hour time frame, with vertical wind shear and thermodynamic profiles favoring all forms of severe weather not just from isolated supercells, but also from clustered cells and quasi-linear convective systems. Widespread convection developed in north central Kansas in the late morning hours and pushed into south central Nebraska. Embedded supercells in the complex produced tornadoes, hail, and strong winds. Another single supercell developed well north of the warm front in central Nebraska, producing damaging baseball-sized hail. As the main convective complex moved into southeastern Nebraska, supercellular structure was lost as the widespread coverage of storms caused various storm mergers and interactions. Little severe weather was noted during this time, including no reports of any severe hail. Due to a 3 KM shear vector nearly normal to the storm's morphology, however, the convective complex matured and developed into an organized line with numerous embedded mesocyclones, many of which were associated with confirmed tornadoes producing up to strong EF-2 damage. Because a lack of hail within the complex meant that a strong cold pool failed to develop in southeastern Nebraska, the atmosphere recovered uncharacteristically quickly, and after sunset, severe thunderstorms again moved into eastern Nebraska within an unstable air mass along a helicity-rich warm front. These storms necessitated tornado warnings near the Lincoln, NE, and Omaha, NE metropolitan areas, with confirmed tornadoes near South Bend, NE, and Council Bluffs IA.

Ensemble models within AFWA provided valuable information about both the danger and the complexity of the scenario, though specific details about convective evolution remained elusive.

Several successful features important to the forecast were noted within the ensemble model details. Scattered severe hail north of the warm front was noted as the initial threat. A widespread convective system was forecast to develop within the warm advection regime, affecting southern Nebraska by 18Z 14 April 2012 well in advance of the dry line. Model reflectivity products noted this system to be much more congested than later convective development along the dry line in Kansas and Oklahoma, indicating a more complicated storm mode. Relatively low probabilities of hail that were forecast within the first convective storm system left open the possibility that the early warm-advection regime convection would not create a strong, stable cold pool, allowing at least the possibility that late day heating would allow the atmosphere to regain instability as the warm front lifted north, creating a second environment favorable for severe thunderstorms. Furthermore, the model identified the potential for embedded mesocyclones and tornadoes to be present within the first convective complex. The model continued to identify the threat for rotating thunderstorms well after sunset along the warm front.

Several mesoscale details were not particularly well resolved by the model, however. Bowing structures were not deciphered within the reflectivity output. In addition, simulated convection was not present in eastern Nebraska in the 0300-0600 UTC 15 April time frame when a second severe event occurred. A couple of potential reasons are likely responsible for this shortcoming. First, no cold pool developed over southeastern Nebraska during morning and mid afternoon convection, and the atmosphere remained favorable for convective redevelopment. Second, many operational numerical models progressed atmospheric features to the east too quickly, shifting the threat of severe weather away from the area too soon. For this case, MEPS also suffered from such errors. A useful possibility for future research would be to examine the fundamental predictability of this event through the conduct of additional WRF-ARW numerical simulations utilizing different initial conditions to better reflect the behavior of the synoptic atmospheric conditions.

Despite these limitations, however, it is believed that the ensemble WRF forecasts for this event helped provide information about a varied severe weather event in which the forecasting of storm timing, storm mode, and severe weather type proved to be a significant challenge.

Acknowledgements: The co-authors would like to sincerely thank Dr. Clark Evans and Dr. Rebecca Adams-Selin for their contributions and reviews of this presentation. We would also like to thank Mr. Edward Hildebrand and Mr. Shane Young for discussions of this particular case study. Finally, we would like to acknowledge Gibson Ridge for products used to display and analyze radar imagery.

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