11B.1

RECORD HAIL EVENT – EXAMINATION OF THE AURORA, NEBRASKA SUPERCELL OF 22 JUNE 2003

Jared L. Guyer *
NOAA/NWS Storm Prediction Center

Rick Ewald
NOAA/NWS Hastings, Nebraska

1. INTRODUCTION

During the late afternoon and early evening hours of 22 June 2003, thunderstorms developed from central Nebraska into north central Kansas, quickly becoming severe in an environment favorable for supercell thunderstorms. On this evening, portions of central Nebraska and north central Kansas were affected by tornadoes, destructive hail, and severe flooding.

In particular, a supercell thunderstorm moved northeastward across the community of Aurora, Nebraska, producing extremely large hail and multiple short-lived tornadoes. A record setting hailstone was ultimately discovered in Aurora, measuring 7.0 inches (17.78 cm) in diameter with an 18.75 inch (47.63 cm) circumference. This hailstone broke the previous hail size (diameter and circumference) record of the Coffeyville, Kansas hailstone of 3 September 1970.

2. SYNOPTIC OVERVIEW

The large scale pattern on 22 June 2003 was highlighted by a broad mid to upper tropospheric trough over the western United States. The central Plains was influenced by a strongly diffluent upper flow regime on the southern periphery of a southwesterly upper jet, characterized by a 90 knot 300 mb jet extending from the Great Basin northeastward into the northern Plains (Fig. 1).

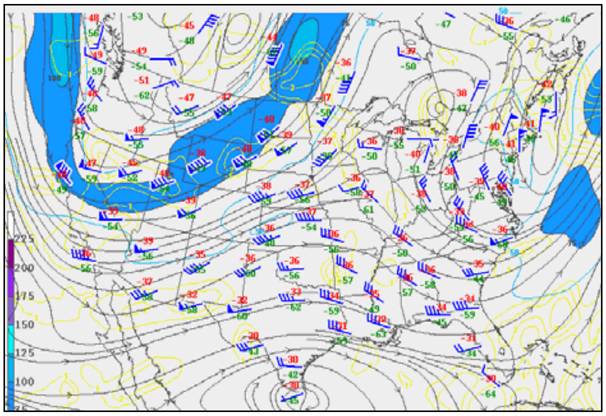

Fig. 1. 300 mb objective analysis for 0000 UTC 23 June 2003. Streamlines are in black. Blue shading denotes wind speeds of 75 knots or greater.

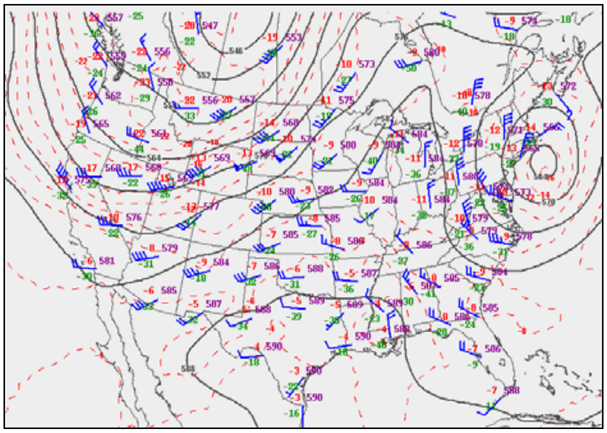

Fig. 2. 500 mb objective analysis for 0000 UTC 23 June 2003. Geopotential height (black) contours analyzed every 60 m, with temperature (red) contoured every 2°C.

Embedded within the west-southwesterly mid level flow were several low amplitude shortwave troughs moving northeastward across the northern and central Rockies (Fig. 2). At the surface, a quasi-stationary frontal boundary extended roughly north to south across the northern and central Plains (Fig. 3). Scattered severe thunderstorms had occurred across the northern Plains on the previous day, with the remnants of this activity persisting into the early morning hours of 22 June.

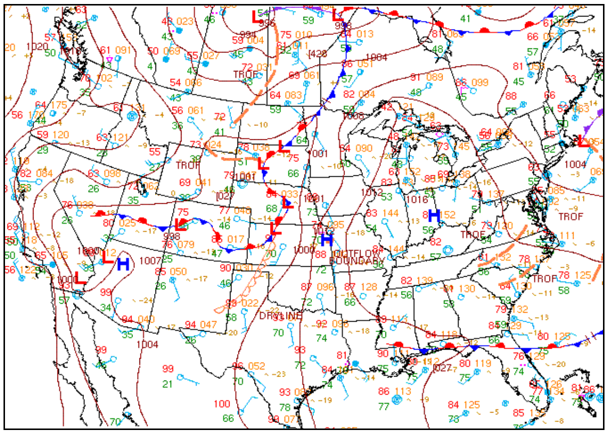

Fig. 3. Hydrometeorological Prediction Center (HPC) surface analysis for 2100 UTC 22 June 2003 with standard station plot. Location of fronts and surface lows and highs are indicated by standard symbols.

---

* Corresponding author address: Jared L. Guyer, NWS/Storm Prediction Center, 1313 Halley Circle, Norman, OK 73069. E-mail: Jared.Guyer@noaa.gov

3. MESOSCALE ENVIRONMENT

During the early morning hours of 22 June, multiple thunderstorm complexes affected portions of eastern Nebraska and northeast Kansas. While these storms migrated eastward into Iowa and Missouri around midday, the thunderstorm complexes induced a westward propagating outflow boundary (Fig. 4). This pronounced outflow boundary ultimately reached central Nebraska and north central Kansas by mid afternoon, nearing the remnant quasi-stationary frontal boundary that was roughly bisecting Nebraska and northern Kansas. A strong instability axis subsequently became established across central Nebraska, largely owing to the deceleration of the westward propagating outflow boundary, and associated pooling of low level moisture and diabatic heating. By early evening, as evident in the regional wind profiler network, a south-southwesterly low level jet progressively increased to 40-45 knots after 00 UTC (Fig. 5).

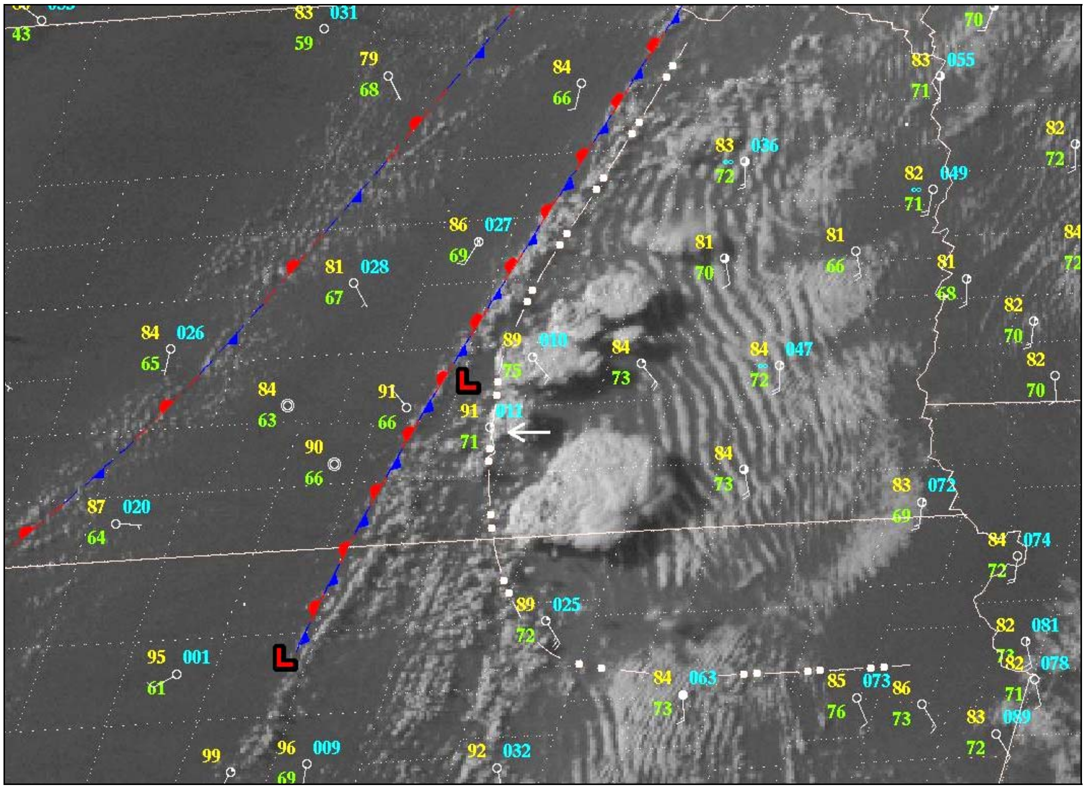

Fig. 4. 2245 UTC 22 June 2003 visible satellite image of eastern Nebraska and northern Kansas with 2300 UTC surface observations. Location of fronts and surface lows indicated by conventional symbols. Dot-dashed line denotes westward moving outflow boundary. An arrow indicates the incipient Aurora, Nebraska storm.

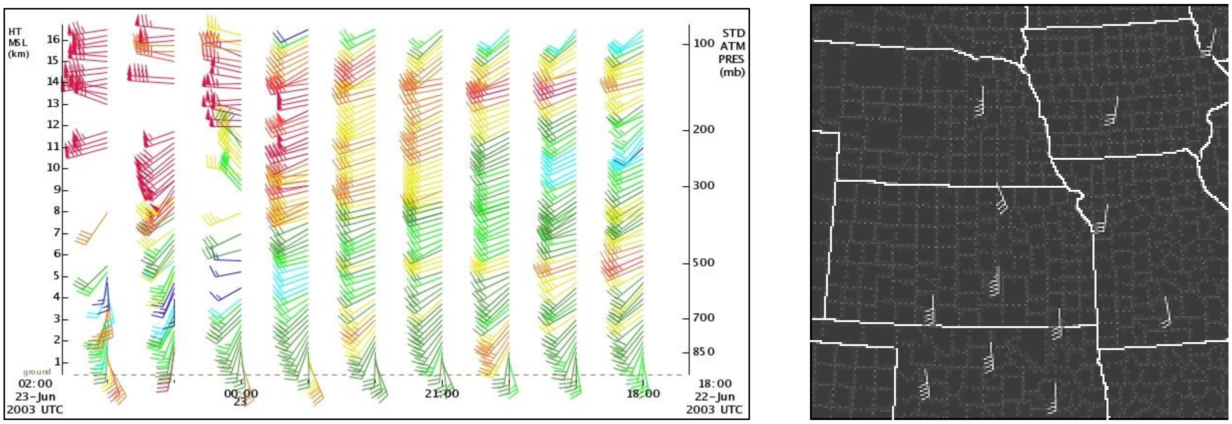

Fig. 5. (*Left*) Fairbury, Nebraska profiler (FBYN1) winds in knots from 1800 UTC 22 June 2003 to 0200 UTC 23 June 2003 (right to left) with QC applied (e.g. omitted observations around 0200 UTC). (*Right*) Observed winds at 1250 m AGL from regional profiler network at 0300 UTC 23 June 2003.

The background mesoscale environment by late afternoon across central Nebraska and north central Kansas was characterized by strong instability and sufficient ambient wind shear for supercells. Surface temperatures in south central Nebraska and north Central Kansas had warmed into the upper 80s to lower 90s°F (lower 30s°C), while surface dewpoints were in the upper 60s to lower 70s°F (upper teens to lower 20s°C).

As an illustration of the representative environment, Fig. 6 shows a modified 2200 UTC Rapid Update Cycle (RUC20 – Benjamin et al. 2004) sounding for Aurora, Nebraska (KAUH) vicinity. RUC soundings have been shown by Thompson et al. (2003) to serve as a reasonable proxy for direct observations in the regional supercell environment. Using the NSHARP sounding analysis program (Hart et al. 1999), the sounding was characterized by extreme instability with a CAPE of 4605 J/kg and a Lifted Index of -12 C based on a 100-mb mean mixed parcel (virtual temperature correction). Around 40 knots of deep layer (0-6 km) shear is evident in the sounding, with a 0-3 km Storm Relative Helicity (SRH) of 247 m^2/s^2. Steep mid level lapse rates were also in place, with 8.6 C/km noted in the 700-500 mb layer. The freezing level was around 13,600 feet (4.15 km) AGL, with a web bulb zero height of 10,700 feet (3.26 km) AGL.

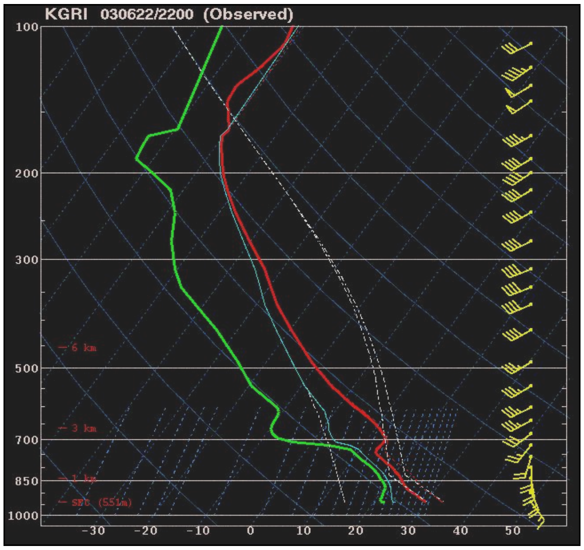

Fig. 6. 00-hr RUC sounding for 2200 UTC 22 June 2003 modified with 2200 UTC Aurora, Nebraska (KAUH) surface conditions (86°F temperature and 72°F dewpoint).

The National Weather Service (NWS) Storm Prediction Center (SPC) had issued a categorical moderate risk of severe weather in the initial 06 UTC 22 June 2003 Day 1 Convective Outlook for eastern Nebraska, in addition to adjacent portions of Iowa, South Dakota, and Minnesota. In subsequent outlooks, this was adjusted to incorporate central Nebraska into the moderate risk by late morning (1630 UTC). The NWS Forecast Office (WFO) Hastings, Nebraska reflected a similar threat in local forecast products, with severe weather anticipated for late afternoon and evening. In recognition of extreme severe weather potential, a tornado watch with a "Particularly Dangerous Situation" designation was issued by SPC for central and eastern Nebraska at 2035 UTC.

4. STORM EVOLUTION

Initial thunderstorm development occurred from central Nebraska into north central Kansas between 2200 and 2230 UTC near the low level confluent region of the quasi-stationary front and outflow boundary. The Aurora supercell initially developed approximately 25 miles southwest of Aurora, Nebraska (KAUH), as evident in visible satellite imagery at 2245 UTC (Fig. 4 – incipient Aurora supercell denoted with an arrow). The first radar echoes associated with the Aurora supercell were evident in KUEX (Hastings-Blue Hill) WSR-88D volumetric data at that time as well (not shown). The storm rapidly intensified over the next hour as it progressed northeastward through Hamilton County (including the town of Aurora), in the "cool" air east of the outflow boundary (Figure 7 – storm A).

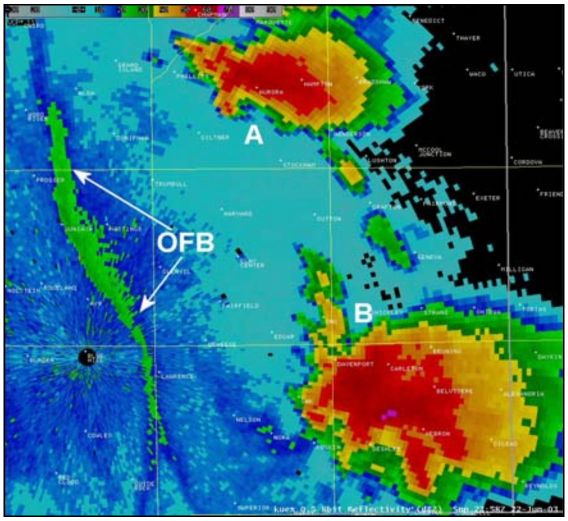

Fig. 7. 0.5 degree Reflectivity from KUEX (Hastings-Blue Hill) WSR-88D at 2358 UTC 22 June 2003. "A" denotes the Aurora storm and "B" denotes cyclical tornado producing storm near Deshler. Outflow boundary is labeled as "OFB".

A severe thunderstorm warning was issued by WFO Hastings for Hamilton County at 2301 UTC, with a subsequent upgrade to tornado warning at 2326 UTC. The first reports of very large hail having occurred in Aurora were received around 0000 UTC (NCDC 2003). Though not a prolific tornado producer, three weak (all rated F0 – Fujita 1970) short-lived tornadoes were reported between 0007 UTC and 0130 UTC in Hamilton and York Counties.

Supercell characteristics quickly became evident with the Aurora storm in the KUEX volumetric data by 2300 UTC, concurrent with 50 dBZ echoes reaching in excess of 50,000 feet (15.24 km) AGL. Radar signatures of a strong mesocyclone became progressively evident beginning approximately 2318 UTC, with greater than 90 knots of mid level rotation at

2358 UTC (Fig. 8a) and presence of a hook echo, tight reflectivity gradient, and bounded weak echo region (BWER) signature at 0003 UTC (Fig. 8b). Vertically Integrated Liquid (VIL) values were indicative of large hail for much of the supercell's mature life cycle, with an 85 kg/m^2 VIL value evident for the Aurora storm (storm A) at 0008 UTC (Fig. 8c). Furthermore, very strong storm top divergence was observed for an extended period, with 100 knots of outbound and 92 knots of inbound velocities evident between 45,000 feet (13.72 km) to 50,000 feet (15.24 km) in the vicinity of Aurora at 0008 UTC (Fig. 8d).

While the Aurora supercell produced extremely large hail, a more pronounced tornadic and ultimately heavy rain producing supercell affected areas near the Nebraska-Kansas border (Figure 7 – Storm B). This supercell remained nearly stationary for several hours (Wakimoto et al. 2004). This storm was associated with an F2 tornado in Deshler, Nebraska, with four tornadoes in all across Thayer County, including a death (the first tornado fatality in Nebraska since 1988) and 7 injuries (NCDC 2003).

Extremely heavy rainfall occurred across Thayer County, Nebraska and Republic County, Kansas as the supercell evolved into a quasi-stationary Mesoscale Convective System (MCS), as its western flank intercepted an increasing low level jet (e.g. Figure 5) and associated warm air advection and moisture transport regime. Official rainfall measurements by the early morning hours of 23 June 2003 (occurring in less than 12 hours duration) were as high as 9.39 inches (23.85 cm) at Lovewell Dam, Kansas, with an unofficial measurement of 12.50 inches (31.75 cm) in Hebron, Nebraska. KUEX Storm Total Precipitation (STP) estimates, impacted by hail contamination, were as high as 15.60 inches (39.62 cm) across the aforementioned counties (not shown).

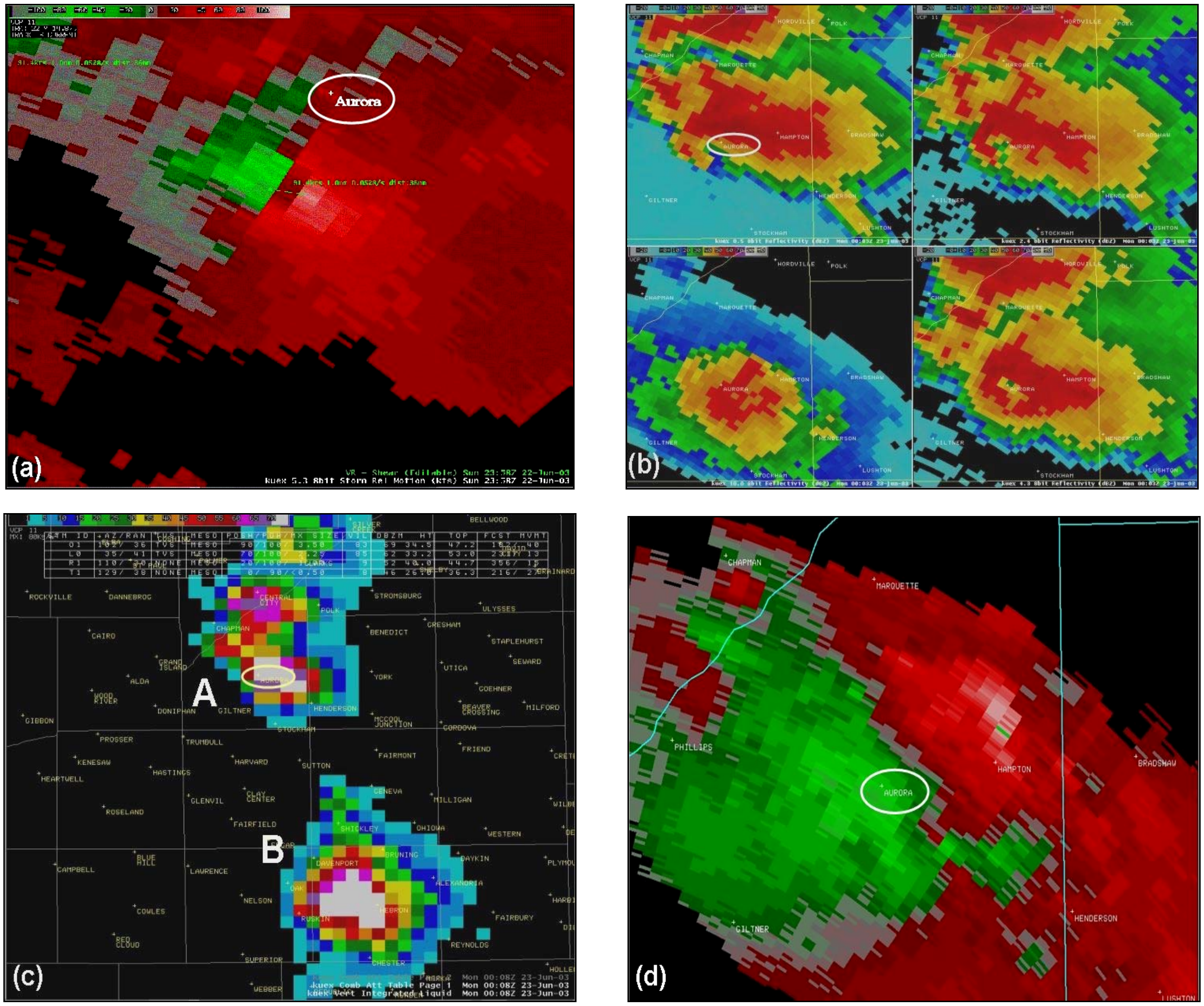

Fig. 8. All images KUEX WSR-88D with oval highlighting Aurora, Nebraska. (a) 5.3 degree Storm Relative Velocity (SRM) at 2358 UTC 22 June 2003. (*b*) Reflectivity four panel of 0.5, 2.4, 4.3, 10.0 degree elevations (clockwise from upper left) at 0003 UTC 23 June 2003. (*c*) Vertically Integrated Liquid (VIL) at 0008 UTC. Storm "A" is Aurora supercell and "B" is Deshler tornadic supercell. (d) 10.0 degree elevation Storm Relative Velocity (SRM) at 0008 UTC.

5. AURORA, NEBRASKA HAILSTONE

The largest hail associated with the Aurora supercell was confined to the northern portions of the town. The largest hailstone ultimately measured 7.0 inches (17.78 cm) in diameter, with an 18.75 inch (47.63 cm) circumference (Fig. 9). Since the hailstone struck a house roof in its descent and partially broke (survey by second author), an accurate weight of the hailstone was not possible. Property damage from the large hail was estimated at $500,000, with $1 million estimated in crop damage across Hamilton County (NCDC 2003). Large hail left craters in the ground up to 14.0 inches (35.56 cm) in diameter and 3.0 inches (7.62 cm) in depth in Aurora (NWS Hastings survey and UCAR).

The measured size of the Aurora hailstone exceeded the previous record of the Coffeyville, Kansas hailstone of 3 September 1970. In accordance with the National Climatic Data Center's (NCDC) Climate Extremes Committee, the Aurora, Nebraska hailstone of 22 June 2003 is now officially recognized as the largest hailstone, in terms of diameter and circumference, in United States history. The previous record of the Coffeyville, KS stone weighed 1.65 pounds (0.75 kg) with a diameter of 5.7 inches (14.48 cm) and circumference of 17.6 inches (44.70 cm) (UCAR). The Coffeyville hailstone still retains the U.S. record for maximum hailstone weight.

6. PREDICTABILITY OF HAIL SIZE

Regarding the potential predictability of record magnitude hail, an objective methodology of maximum hail size prediction was examined. The HAILCAST model (Brimelow et al. 2002) was run on the RUC-based Aurora sounding (Fig. 6), producing a maximum hail size of 3.6 inches (9.14 cm), with an ensemble average of 3.1 inches (7.90 cm) for the ambient Aurora supercell environment. Although the HAILCAST model does underestimate the literal size of the Aurora hailstone by several inches, it is notable that derived values of that magnitude are a rare occurrence based on a large hail proximity sounding database as compiled by Jewell and Brimelow (2004).

7. CONCLUDING REMARKS

The synoptic and mesoscale conditions during the late afternoon and early evening hours of 22 June 2003 were supportive of significant supercells, which ultimately produced record hail, tornadoes, and flooding. Although the specific predictability of a “historic” event such as record hail is nearly impossible for a myriad of meteorological and non-meteorological factors, the ambient environment and observed supercell characteristics were favorable for the production of very large hail across south central Nebraska.

In addition, this case illustrates how a variety of supercell phenomena can occur within a mesoscale region. Clearly, there was variability in the environment in order for the variety of events to occur. This case, like others, illustrates the complexity of atmospheric conditions and processes that take place on smaller scales.

Acknowledgements. The authors would like to thank Nancy Knight of NCAR and the NCDC Climate Extremes Committee for their assistance in officially certifying the Aurora hailstone. Furthermore, WFO Hastings meteorologists Steven Kisner, Todd Holsten, and Larry Wirth are acknowledged for their efforts in documenting this record hail event. Steve Weiss is thanked for his valuable comments and suggestions regarding this manuscript.

8. REFERENCES

Benjamin, S. G., D. Dévényi, S. S. Weygandt, K. J. Brundage, J. M. Brown, G. A. Grell, D. Kim, B. E. Schwartz, T. G. Smirnova, T. L. Smith, and G. S. Manikin, 2004: An Hourly Assimilation–Forecast Cycle: The RUC. *Mon. Wea. Rev*., **132**, 495–518.

Fig. 9. Pictures of the Aurora, Nebraska hailstone. It measured 7.0 inches (17.78 cm) in diameter with an 18.75 inch (47.63 cm) circumference.

Brimelow, J. C., G. W. Reuter, and E. R. Poolman, 2002: Modeling Maximum Hail Size in Alberta Thunderstorms. *Wea. Forecasting*, **17**, 1048–1062.

Fujita, T.T., 1971: Proposed characterization of tornadoes and hurricanes by area and intensity. SMRP Res. Paper 91, Univ. of Chicago, 42.

Hart, J. A., J. Whistler, R. Lindsay, and M. Kay, 1999: NSHARP, version 3.90. Storm Prediction Center, National Centers for Environmental Prediction, Norman, OK.

Jewell, R., and J. Brimelow, 2004: Evaluation of an Alberta Hail Growth Model Using Severe Hail Proximity Soundings in the United States. Preprints, *22nd Conf. Severe Local Storms*, Hyannis, MA, Amer. Meteor. Soc.

NCDC, 2003: *Storm Data*. Vol. 45, No. 6, 4 & 191-195.

Thompson, R. L., R. Edwards, J. A. Hart, K. L. Elmore, and P. Markowski, 2003: Close Proximity Soundings within Supercell Environments Obtained from the Rapid Update Cycle. *Wea. Forecasting*, **18**, 1243–1261.

UCAR Communications, Staff Notes, July/August 2003. http://www.ucar.edu/communications/staffnotes/0308/hail.html

Wakimoto, R. M., H. Cai, and H. V. Murphey, 2004: The Superior, Nebraska, Supercell During BAMEX. *Bull. Amer. Meteor. Soc.*, **85**, 1095-1106.