

10A.7 A CASE STUDY OF A RARE SEVERE THUNDERSTORM WITH SNOWFALL

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1. INTRODUCTION

On the evening of 11 February 2003, thunderstorms raced across northwest and central Illinois (IL) with winds in excess of 50 knots and heavy *snowfall*. Convective snowfall developed ahead of a strong synoptic-scale cold front as it pushed through the area. Severe thunderstorm warnings were issued for several counties across the Lincoln, Illinois (ILX), county warning area (CWA) due to the strong winds, which were accompanied by brief but nearly blinding snowfall. The first severe thunderstorm warning was issued at 0002 UTC 12 February 2003 for Marshall County, Illinois; within an hour, the front and convection had passed leaving wind damage, a thin blanket of snow, and an unusual phenomenon referred to as “snowrollers.”

This event was atypical of thundersnow cases. While most thundersnow events in the Midwest appear to occur in the presence of an extratropical cyclone (Market et al. 2002) resulting from some sort of elevated instability, this event maintained a unique quality more related to warm season and warm sector severe weather. Analysis of the synoptic and mesoscale features using 20-km Rapid Update Cycle (RUC-20) initial fields revealed a scenario with this clipper system that led to such a severe event.

Although in mid-February, insolation was strong that afternoon ahead of a well-developed synoptic-scale cold front. A well-mixed boundary layer along and just behind the frontal zone allowed for thorough mixing of strong wind to the surface. While snow accumulations were minor (< 3 cm), the whit out conditions that ensued briefly made this a dangerous system.

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2. METHODOLOGY

The observational data used in this study were obtained from hourly surface observations taken by Automated Surface Observing System (ASOS) stations including SPECI reports. Vertical profiles of Davenport, IA (DVN), and Lincoln, IL (ILX), were obtained from the normal 12-hourly rawinsonde flights. Diagnostics of the event were explored further using model initializations from the RUC-20 model.

The RUC-20 uses the physical parameterizations from the NCAR/Penn State MM5 mesoscale model (Reisner et al. 1998). While both versions are designed to detect and forecast up to five hydrometeor species within the model domain, the updated parameterization for the RUC-20 is designed to include horizontal advection of cloud variables including its modification by Geostationary Operational Environmental Satellites (GOES) cloud-top pressure assimilation (Benjamin et al. 2002a). Improved cloud microphysics and cumulus parameterizations have been shown to improve precipitation forecasts, particularly in precipitation types (Benjamin et al. 2002b, 2003).

Improving upon the convective parameterization used, the RUC-20 also diagnoses other severe convective parameters as part of its data analysis. In addition to the normal convective variables (e.g., CAPE, Convective Inhibition (CIN)), a maximum surface wind gust variable is generated. The calculation for this latter variable begins with first determining the planetary boundary layer (PBL) depth. From the PBL depth, the model calculates excess wind speed over the surface value at successive levels and then multiplies it by a predetermined coefficient that decreases from 1.0 to 0.5 with height over the depth of 1 km. The maximum value of wind excess is added back to the surface to obtain a high gust potential.

3. SYNOPTIC ANALYSIS

The 0000 UTC 12 February 2003 surface analysis (Fig. 1a) indicated a frontal boundary draped across the northwest sections of Illinois,

after passing through Iowa and Wisconsin. The impact of this front is reflected by surface observations from Davenport, Iowa (DVN). Surface temperatures had fallen 2° F between 2154 UTC and 2242 UTC on the 11th while the dew point rose from 22° F to 27° F in the same period resulting from sublimation of falling snow as well as moisture advection ahead of the cold front. Heavy snow was falling by 2245 UTC, just after frontal passage, with winds out of the northwest at 35 knots and gusts to 43 knots. These trends supported the presence of an intense cold front: the 33-minute snow shower that had begun at 2216 UTC and ended at 2259 UTC; by 2354 UTC, the sky had cleared (below 12,000 ft), while the dew point had dropped to 15° F; a veer of 50° in wind direction in less than an hour was tempered by the persistence of blustery conditions behind the front; the temperature change was gradual at first, but then accelerated at sunset.

850-mb analysis (Fig. 1b) indicated a trough axis running parallel to the frontal boundary at the surface, extending from the Great Lakes, into Iowa and Missouri. Along the trough axis, dew point depressions remained relatively small, with ILX reporting a dew point depression of 6°C (not shown) and other stations along the trough in Iowa, Wisconsin, and Michigan reporting depressions less than 5°C. A sharp vertical temperature gradient at ILX was present in the 850-500 mb layer; this helped to explain a Total Totals value of 45 in the sounding. Temperatures behind the 850-mb front dropped drastically. Yet, evidence of pre-frontal moisture and a lifting mechanism were present.

The 500 mb (Fig. 1c) height field featured a trough axis running west of Hudson Bay, southwest through Wisconsin, and into Kansas, revealing a significant slope into the cold air consistent with a strong cold front. An absolute vorticity maximum in the base of the low-amplitude trough in central Wisconsin suggested quasi-geostrophic forcing for ascent downstream across eastern Iowa and northern Illinois, under a 300 mb jet (Fig. 1d), a fact revealed in the Q-vector fields (not shown).

Farther aloft at 300 mb (Fig. 1d), the polar jet exhibited a northerly component out of Canada with a jet core present over Kentucky having wind speeds of 160 knots or greater. Central Illinois dwelled under the left entrance region of the jet streak, an area often associated with upper air convergence (not shown). While this is atypical for the ideal occurrence of severe weather, this arrangement suggested the dominance of lower-to mid-tropospheric forcing. Given that thunderstorm winds exceeded severe levels (50 kt) over Illinois, it appears valid to look for regions of large momentum aloft that may have been mixed downward. Indeed, west-northwesterly

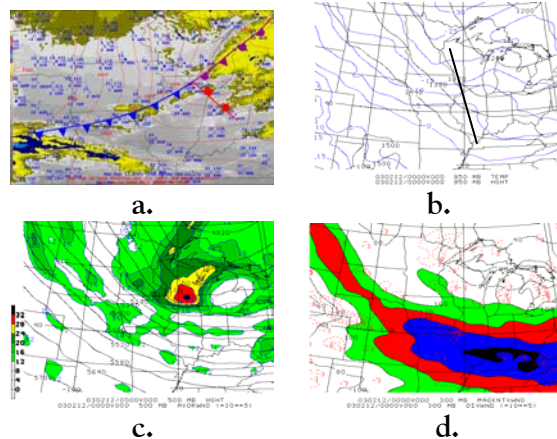


Figure 1. Objective analyses from the RUC-20 initial fields valid at 0000 UTC 12 February 2003 for a) the surface (0015 UTC 4 km infrared satellite base image), with RUC sea level pressure isobars [2 mb; solid], and observed data (plotted standard station models), b) 850 mb (RUC height [60 gpm; black, solid] and temperature [5°C; black]), c) 500 mb (RUC height [60 gpm; black, solid] and absolute vorticity [$2 \times 10^{-5} \text{ s}^{-1}$; shaded]), and d) 300 mb (RUC divergence [every 10^{-5} s^{-1} ; dashed values are negative] and isotachs [20 kt; shaded]). Bold line in b) denotes cross section line in Fig. 2.

winds (285°) of 66 knots (33 m s^{-1}) were present at 850 mb over ILX.

4. MESOSCALE ANALYSIS

The mesoscale conditions observed for atmospheric destabilization include 1) a sharp moisture gradient at the surface, 2) strong mid-tropospheric forcing for ascent, and 3) local processes of daytime heating dependent on sky cover. The presence of moisture and thermal advections helped to make this a case for mesoscale convective processes.

RUC-20 precipitable water (PW; not shown) indicated a significant moisture gradient along and ahead of the frontal zone through eastern Iowa and central Illinois. At 1900 UTC 11 February 2003, the 850-mb surface was moister along the western borders of Iowa. A gradient of PW had formed over Iowa by 2200 UTC, ranging from 0.09 in. (2.4 mm) over northern Iowa to 0.31 in. (8.0 mm) in southeastern Iowa and northern Missouri. The gradient helped to identify the frontal location. Winds at 850 mb indicated a low-level flow out ahead of the front with evidence of speed and directional convergence (not shown). By 0000 UTC 12 February 2003, the moister air to the south had been pushed farther south. Gradient values had changed with cooler, drier air, 0.06 in. (1.6 mm) covering much of Iowa by this time.

A cross section analysis from the RUC-20 model initial fields provided for 0000 UTC (Fig. 2) revealed a strong, near-surface equivalent potential temperature (θ_e) gradient and a potentially unstable layer up to 850 mb near the frontal zone over

central Illinois, ascending to 700 mb just ahead of the frontal zone.

Frontogenesis was diagnosed along the surface frontal zone (Fig. 2), with the strongest values ($> 3.0 \text{ K } 100 \text{ km}^{-1} \text{ } 3 \text{ hr}^{-1}$) just ahead of the frontal zone. An elongated zone of frontogenesis sloped upward and northward, running roughly parallel to the 280-K θ_e contour. Above and to the south of the frontogenesis maximum was the fairly narrow upward vertical velocity maximum ($< -3.0 \mu\text{b s}^{-1}$), that was complimented by a broad, sloping area of descent behind the surface front. These analyses help depict a strengthening frontal zone. Such robust values of frontogenesis point to a change in the thermal gradient through the 950 – 650 mb layer, upsetting thermal wind balance and resulting in the ageostrophic circulation.

5. INSTABILITY

The rawinsonde flight from DVN 0000 UTC (not shown) revealed a near-surface dry adiabatic layer from the surface to 925 mb. As a consequence, neither the surface-based parcel (975 mb; the first level above erroneous surface data) nor that lifted from the lowest 100 mb revealed any convective available potential energy (CAPE). Wind speeds at the top of the dry adiabatic layer (457 m above ground level) were 48 knots in this sounding, so the potential for mixing of large momentum values to the surface was found with this case. While environmental mixing through the dry adiabatic layer influenced the strength of the surface winds, the convective nature of the storm also suggests the presence of convective downdrafts. These were supported by WSR-88D velocity data from DVN, which revealed substantial in- and outbound winds at the 0.5° tilt (not shown). Further, regional CAPE values from the Local Analysis and Prediction System (LAPS) at 2100 UTC for surface-based parcels, which exceeded 100 J kg^{-1} .

The sounding from ILX, south of the convection, resembled a moist adiabatic lapse rate near the surface with a PBL depth too shallow for efficient mixing of mass and momentum from the top of the layer. Similar to DVN, this profile revealed little instability. Winds, however, reached an observed value of 50 knots at 288 m above ground level, well within the dry adiabatic near-surface layer. The high winds were confirmed with velocity data from the WSR-88D radar in ILX (not shown).

Surface wind gust calculations in the RUC-20 rely on the depth of the PBL. Analysis indicated a fairly high PBL depth over the Great Lakes region, through Wisconsin and into northern Illinois. Grid point values of PBL depth were as high as 746 m over Clinton, IA (CWI) and 587 m over Galesburg, IL (GBG; Figure 3),

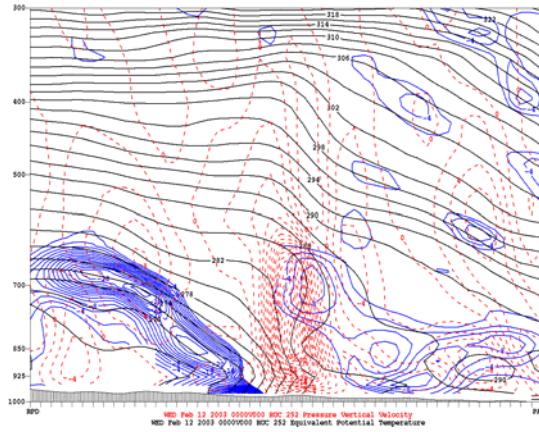


Figure 2. Cross section analysis from the RUC-20 initial fields valid at 0000 UTC 12 February 2003 showing equivalent potential temperature (K; solid black), vertical velocity ($\mu\text{b s}^{-1}$; dashed), and Petterssen frontogenesis ($10^{-1} \text{ K } 100 \text{ km}^{-1} \text{ } 3 \text{ hr}^{-1}$), along a line from Rice Lake, Wisconsin (RPD), to Paducah, Kentucky (PAH).

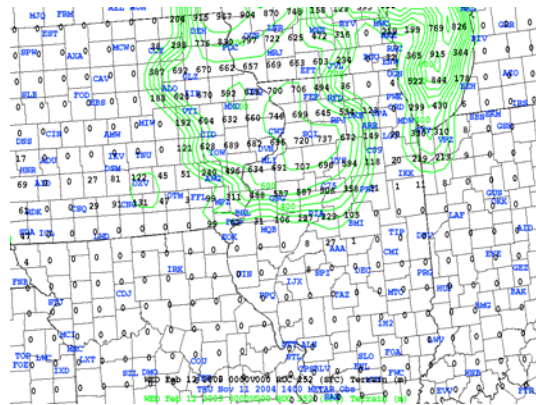


Figure 3. Plan view analysis from the RUC-20 initial fields valid at 0000 UTC 12 February 2003 of planetary boundary layer depth in meters both contoured [every 100 m; solid green] and labeled with every grid point value. ICAO identifiers are included in blue.

where the first severe storm reports occurred. A deep layer in the PBL can lead to more efficient mixing of mass and momentum to the surface. The observed winds from DVN were 48 knots at the top of the dry adiabatic layer, which, according to the sounding, resided under 1000 m and well within the PBL allowing for mixing to the surface. Initialized RUC-20 soundings from 0000 UTC at GBG show this same dry adiabatic layer within the PBL, below an inversion layer. 50 knot winds were present in the sounding at the top of the dry adiabatic layer around 925 mb. A parcel lifted from 850 mb on the DVN sounding produced an unstable parcel calculating a CAPE of 33 J kg^{-1} , Total totals of 51, and a K-index of 10 with a convective temperature of 32°F . RUC-20 soundings of DVN at the same time produced similar profiles, but less instability.

6. STORMSCALE ANALYSIS

Satellite imagery at 2131 UTC on 11 February showed a narrow band of cloudiness (Fig. 5) oriented along and parallel to the frontal location. A relatively clear area at DVN appeared just before the front passed. This break in the overcast allowed insolation and surface heating to occur. Pyranometers located at PIA and Knox County in Missouri (180 miles SSW of DVN) recorded total daily solar radiation values in megajoules per square meter (MJ m^{-2}).

Hourly radiation data are available in watts per square meter (W m^{-2}) for 11 February at Knox County only. While Knox County received no severe reports, it laid in the path of the advancing front, therefore experiencing similar atmospheric properties (earlier in the day) such as cloud cover and solar heating. These data were compared to data from an observed clear air day, which are typically about 14.00 MJ m^{-2} (personal communication, Patrick Guinan 2005). Observed daily values at PIA on 11 February 2005 were 10.72 MJ m^{-2} , which was a clear air day, while values for the same day in 2003 were 9.25 MJ m^{-2} . Yet, hourly data at Knox County for the same date in 2003 would suggest clearing skies during the afternoon in advance of frontal passage. Solar radiation peaked at 600 W m^{-2} around 1900 UTC on 11 February compared to 618 W m^{-2} for the same date and time in 2005, which represented clear air.

Farther south the presence of a snow swath (Fig. 5) was observed across central Illinois, which was analyzed by the RUC-20 initial fields at 0000 UTC. RUC-20 CAPE (not shown) was additionally analyzed just north of the snowfield. Grid point values of initialized CAPE up to 12 J kg^{-1} over central Illinois were found in this analysis. CAPE initialized in the RUC-20 is determined from a parcel lifted from the lowest 50 mb, so these low values still represent potential energy available near the surface (Benjamin 2002a). Nevertheless, by 0015 UTC 12 February 2003, cloud-top temperatures of -26°C (Fig. 1a) suggested the presence of convection, albeit low-topped. We postulate that insolation, while weak, on the north edge of the pre-existing snow swath helped to initiate convection.

In the absence of direct microphysical measurements of the cloud or dual-polarized Doppler radar observations, only inferences could be made regarding the cloud's electrical characteristics. In this case, a temperature of -26°C corresponded to a pressure level of $\sim 650 \text{ mb}$ ($\sim 3.5 \text{ km}$). Such a range of temperatures in the cloud suggests a variety of cloud and precipitation particles. In addition to updrafts discussed previously, a variety of cloud particles is believed to be necessary for the creation of charge separation sufficient to permit a lightning

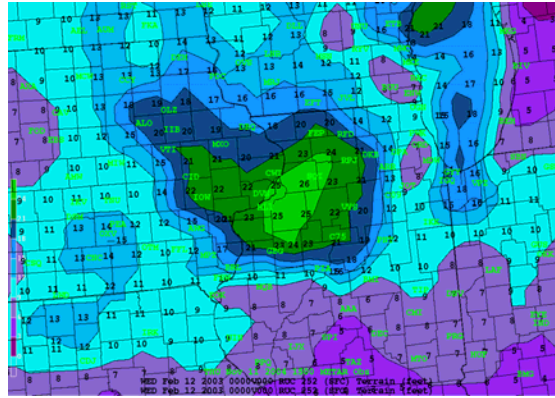


Figure 4. Maximum surface wind gusts from 0000 UTC 12 February 2003 RUC-20 initialization, contoured every 4 ms^{-1} and shaded with grid point gust values displayed every 20 km over eastern Iowa and north central Illinois.

discharge. Saunders (1993) stated that updrafts strong enough to carry electrical charges throughout the cloud are sometimes needed in addition to the collision-coalescence processes generated by the updrafts to create regions of accumulated charge within the cloud. Moreover, reflectivity values $\sim 40 \text{ dBz}$ were found near the -10°C level, at $\sim 2000 \text{ m}$ ($\sim 6000 \text{ ft.}$), over GBG at 2340 UTC; that threshold was met in the vicinity of the majority of lightning strikes providing another condition thought necessary for rapid electrification to commence (Zipser and Lutz 1994). However, the reflectivity lapse rates found with eight of the lightning strikes regularly exceeded the values of Zipser and Lutz (1994), ranging from 4.7 dBz km^{-1} to 12.6 dBz km^{-1} . This is due in part to the low-topped nature of the convection and the limitations of the WSR-88D radar as the range increases.

The shallow nature of the convection is highlighted by cross sections of the WSR-88D radar data from ILX (not shown), with most of the returns ($<30 \text{ dBz}$) limited to the lowest scan. Yet, at 2357 UTC 11 February 2003, ILX revealed 0.5° scan reflectivity near 40 dBz over Marshall County, the first to be placed under a warning. Indeed, cloud-to-ground lightning was reported near the Marshall County cell by the National Lightning Detection Network (NLDN), continuing the history of activity that had been established at DVN during the hour prior (2254, 2257, and 2304 UTC observations). In a two hour period, between 2225 UTC and 0035 UTC, 33 cloud-to-ground flashes were observed; all flashes maintained a negative polarity. Although not uncommon, this behavior is more typical of warm-season convection, and more notably associated with low top convection expected not to be severe (Williams 2001). Thus, this case is one of low-topped convection, with internal cloud dynamics sufficient to generate occasional lightning and mixing sufficient to generate strong winds at the surface, which met the severe criterion.

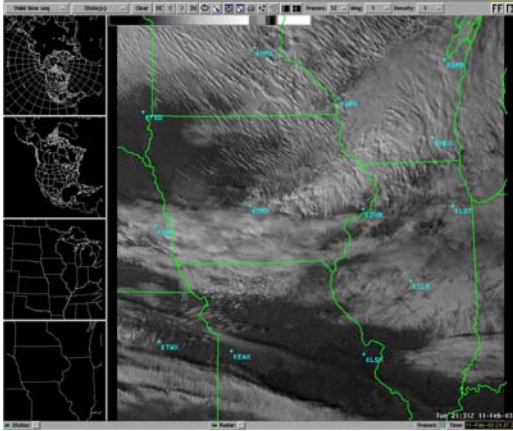


Figure 5. Visible satellite imagery with 1 km resolution from 2131 UTC 11 February 2003.

7. SUMMARY

On the evening of 11 February 2003, a line of severe thunderstorms moved across northern and central Illinois bringing high winds and blinding snowfall at *rates* of up to several inches per hour. Spawned along the leading edge of a cold front, the resulting low-topped convection had its roots in the boundary layer. The bulk of the severe weather came just after sunset as the line of convection propagated southward. While this event spawned in a sudden fashion, RUC-20 analysis supported the formation of convection along the cold front along with a deep layer mixing of strong winds through a dry adiabatic layer in the PBL. The RUC-20 initializations for 0000 UTC 12 February 2003 depicted synoptic and mesoscale conditions consistent with observations taken at the event. Of particular interest was the RUC-20's ability to diagnose the wind gusts to be at as severe a level as they were.

In support of the spotter observations, a number of cloud-to-ground discharges, mostly negative, were recorded by the NLDN. Although not a significant severe weather event in terms of injuries or damage, the manifestation of thundersnow in this fashion is quite unusual. Yet, both the vertical motions and mixture of precipitation particles necessary for cloud electrification and eventual lightning discharge both appear to have been present in this case.

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