1A.1 A UNIQUE COLD-SEASON SUPERCELL PRODUCES AN EF1 'SNOWNADO'

David Sills[1*], Marie-Ève Giguère[2], and John Henderson[3]

[1]Science and Technology Branch, Environment and Climate Change Canada (ECCC), King City, ON
[2]Meteorological Service of Canada, ECCC, Montréal, QC
[3]Atmospheric and Environmental Research, Lexington, MA

1. INTRODUCTION

On November 23, 2013, the 'forecast problem du jour' in southern Ontario, Canada, was the onset of significant snow squalls to the lee of the Great Lakes following the passage of an Arctic cold front (Fig. 1a). It was discovered a short time later however that, in addition to snow squalls, a tornado had occurred that day.

An EF1 tornado track was identified at Charleville (Fig. 1b) via an on-site damage survey. It was found to have a path length of at least 270 m (Fig. 1c), a path width of 75 m and an event time of 2015 UTC[+]. No fatalities or injuries resulted, but farm structures (Fig. 1d) and trees were damaged.

Eyewitness interviews performed as part of the storm survey revealed the following:

- Children at a party were let outside to catch falling "hail" in their mitts, but were taken back inside as a sudden whiteout occurred,
- A funnel cloud with debris at its base then "came out of nowhere" causing damage,
- The top 60% (empty portion) of a 25 m concrete silo was lifted 3 m into the air before being smashed to the ground, and
- No rain was observed, only balls of frozen precipitation about 1 cm in diameter that one witness emphasized was "not hail".

The goals of this paper are to describe the evolution of the event, the details of the tornadic supercell, and the results of NWP simulations, all with the intent of expanding knowledge of the full spectrum of tornadic supercell types and occurrence.

* Corresponding author address: David M. L. Sills, Cloud Physics and Severe Weather Research Section, ECCC, 14780 Jane Street, King City, Ontario, Canada, L7B 1A3, David.Sills@canada.ca
+ Local time (EST) = UTC - 5 hours

2. STORM EVOLUTION

A weak low-pressure system moved southeast across the Great Lakes area during the morning of November 23rd. An associated secondary low rapidly intensified while traversing the relatively warm (~7ºC) waters of Lake Huron's Georgian Bay (Fig. 2).

Low-level reflectivity images from the Environment and Climate Change Canada (ECCC) radar in Britt, ON, show the transformation from a cluster of showers on the west side of Georgian Bay at 0900 UTC (Fig. 3a) to a well-developed vortex just inland from the east side of the Bay at 1200 UTC (Fig. 3b). Similar cyclone intensification over the Great Lakes was found by Angel and Isard (1997).

The secondary low continued moving east-southeast with deep, moist convection developing at the low centre and along the cold front, and shallower moist convection developing along the trailing trough. Stratiform precipitation occurred in the vicinity of the warm front (see analysis at 1700 UTC, Fig. 4a).

Surface temperatures across eastern Ontario at the time of the tornado ranged from -6^{o}C behind the low to just below 0ºC ahead of the cold front, and were closer to -2^{o}C near the tornado location (see analysis at 2000 UTC, Fig. 4b).

3. THE SUPERCELL

Based on a model-derived vertical profile from the ECCC 10-km Regional Deterministic Prediction System (Mailhot et al. 2006) valid at 1800 UTC close to the location of the tornado, the near-storm environment was characterized by meager instability (MLCAPE <= 100 J kg^{-1}, Fig. 5a), moderate deep-layer shear (~20 m s^{-1}) and moderate storm-relative helicity (~200 m^{2} s^{-2}, Fig. 5b). The US Storm Prediction Center mesoanalysis at 2000 UTC indicated a small area having MUCAPE ~100 J kg^{-1} near the location where the tornado developed, with all other areas of instability being restricted to the far southern continental US (Fig. 5c). Both the Supercell Composite Parameter and the Significant Tornado Parameter from the SPC mesoanalysis failed to indicate any potential near the location of the tornadic supercell storm. However, it is known that such storms can occur in high-shear, low-CAPE (HSLC) environments (defined as having SBCAPE < 500 J kg^{-1} and 0–6-km bulk wind difference $>= 18$ m s^{-1}, see Davis and Parker 2014).

At 2000 UTC, 15 minutes before the tornado developed, the ECCC radar in Franktown, ON, detected a supercell with a small bounded weak echo region, a right-rear flank appendage (Fig. 6a), and a compact mesocyclone with maximum radial velocity difference ~25 m s^{-1} (Fig. 6b). Echo tops reached just over 5 km (Fig. 6a inset). No lightning was detected or observed.

The dual-polarization Doppler radar at Fort Drum, NY, also detected this storm, and the hydrometeor classification algorithm indicated that the storm was composed of mainly dry snow with a graupel core (Fig. 7). This supports witness observations of 1-cm diameter frozen precipitation (assumed to be large graupel) falling at the time of the tornado. The 'frozen' composition of this supercell is expected given this was a surface-based convective storm and surface temperatures in the area were below 0^{o}C. The Fort Drum radar continued to detect the supercell for nearly an hour after the tornado occurred.

4. NWP SIMULATION

The 3-km Weather Research and Forecasting (WRF) model (see Skamarock et al. 2008) was run for this case, initialized at 0600 UTC on the 23rd, using a double-moment 6-class (WDM6) microphysics scheme that includes a graupel class. A weakly rotating graupel-cored cell persisted for two hours starting at 1845 UTC and passed ~5 km southwest of the observed tornado location near 1945 UTC (Fig. 8a-d). Other cells in the vicinity were not nearly as intense. The storm formed along the gradients of notable (for winter) MLCAPE (~300 J kg^{-1}) and 0-1 km storm-relative helicity (up to ~250 m^2 s^{-2}). Storm tops were similar to that observed at 5-6 km. Surface temperatures, however, did not remain below 0ºC as observed but reached above 2ºC behind the warm front.

A subsequent 1-km WRF-ARW (Advanced Research WRF) model run using similar settings and initial conditions generated a greater number of intense cells, with the primary cell having a higher graupel concentration and considerably higher updraft helicity (Figure 9a-d). However, the primary cell tracked further south, ~15 km from the observed tornado location at its closest approach as opposed to ~5 km with the 3-km run.

Overall, the model results for this case are fairly impressive in that they do appear to produce a supercell structure at nearly the right time and location in a perhaps unique HSLC environment.

5. CONCLUSIONS

The following are the conclusions of the study:

- A brief EF1 tornado occurred with a low-topped supercell storm in an environment believed to be characterized by below-0ºC temperatures from the surface to storm top – a phenomenon not previously documented to the authors' knowledge
- Witnesses observed large graupel and white-out conditions with the tornado (or 'snownado') but no liquid precipitation, and radar evidence suggests that the supercell storm was composed of mainly dry snow with a graupel core,
- Operational NWP and mesoanalysis indicated limited potential for deep, moist convection, let alone a tornadic supercell, and
- High-resolution simulations with the WRF model appear to capture supercell potential.

REFERENCES

Angel, J. R., and S. A. Isard, 1997: An observational study of the influence of the Great Lakes on the speed and intensity of passing cyclones, *Mon. Wea.Rev*, **125**, 2228-2237.

Davis, J. M., and M. D. Parker, 2014: Radar climatology of tornadic and nontornadic vortices in high-shear, low-CAPE environments in the mid-Atlantic and southeastern United States. *Wea. Forecasting*, **29**, 828-853.

Mailhot, J. and co-authors, 2006: The 15-km version of the Canadian regional forecast system. *Atmos.-Ocean*, **44**, 133-149.

Skamarock, W. C., and co-authors, 2008: A description of the Advanced Research WRF version 3. NCAR Technical Note NCAR/TN–475+STR, 113 pp. [Available online at http://www2.mmm.ucar.edu/wrf/users/docs/arw_v3.pdf].

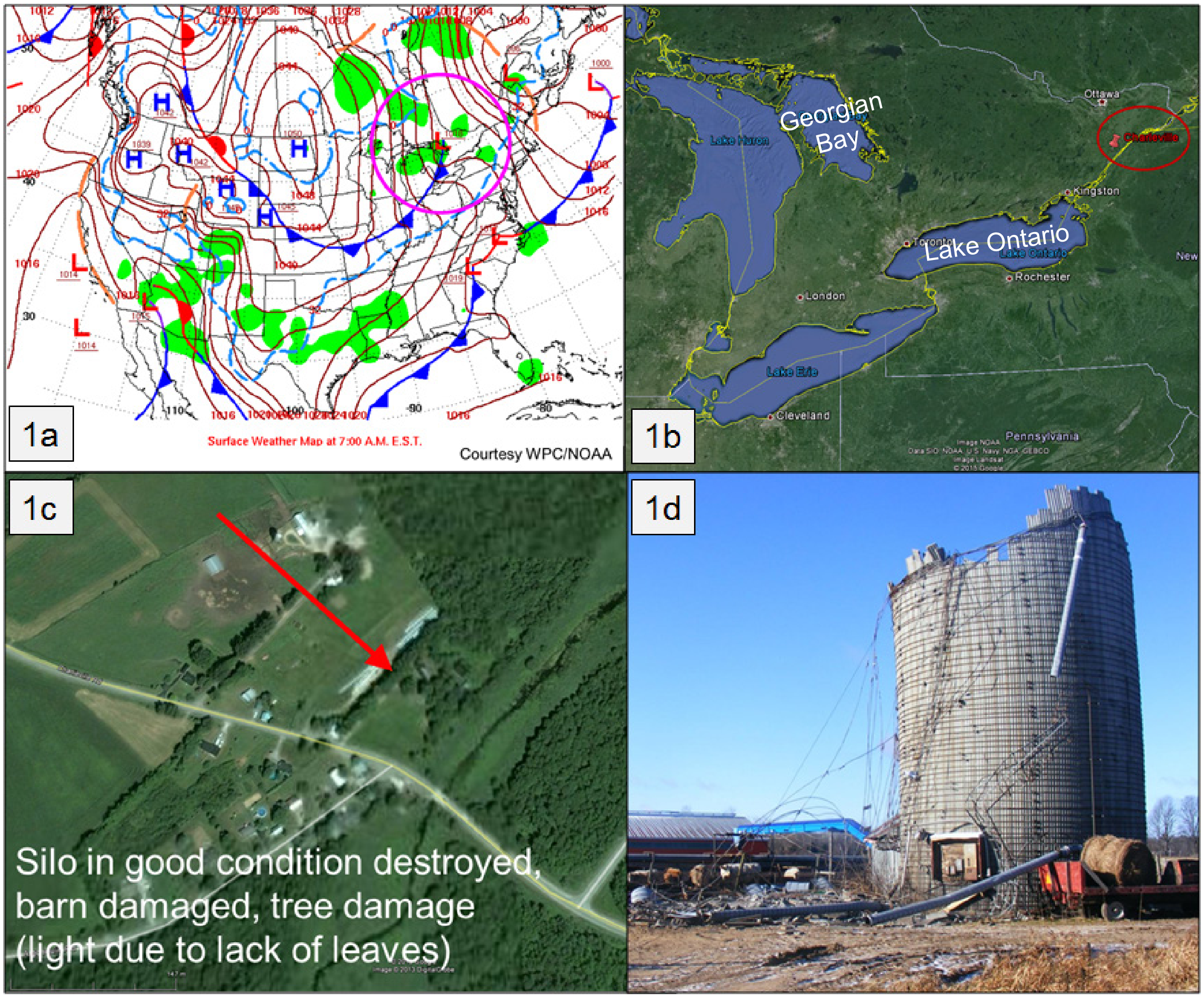

Figure 1 (a) Surface map valid at 1200 UTC 23 Nov 2013 provided by the US Weather Prediction Center showing the weak low pressure system with cold front passing through the Great Lakes area (indicated by magenta circle), (b) Google Earth map (north towards top of image) of southern Ontario with the location of the tornado and the village of Charleville circled, (c) Google Earth map (north towards top of image) of the area of Charleville affected by the tornado with red arrow indicating the track of the tornado, and (d) remains of concrete stave silo destroyed by the tornado, facing roughly northwest.

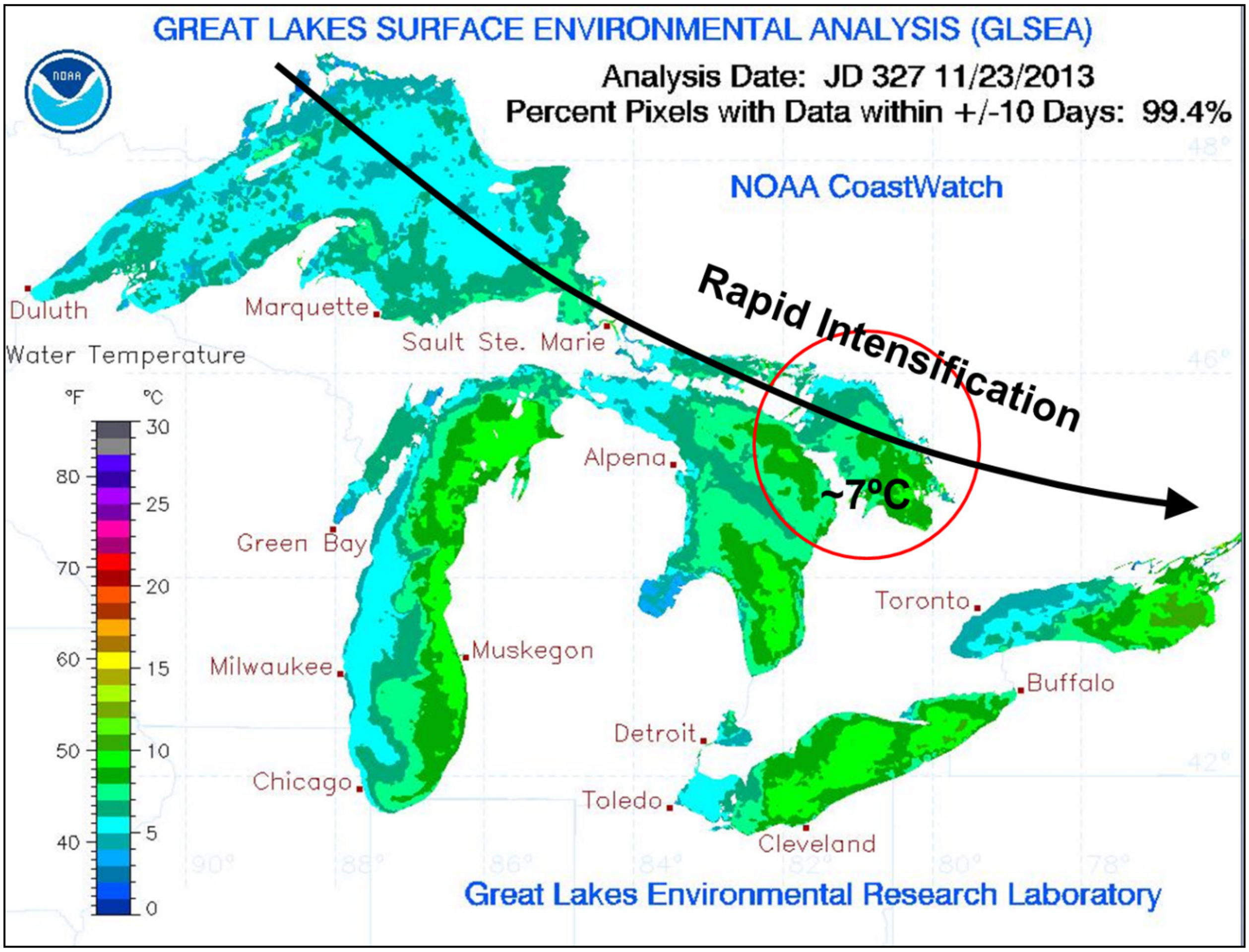

Figure 2. Map of satellite-derived Great Lakes surface temperatures valid on 23 Nov 2013 provided by the NOAA Great Lakes Environmental Research Laboratory. The black arrow shows the path of the secondary low and the red circle indicates where the relatively warm waters of Georgian Bay (at around 7ºC) caused rapid intensification.

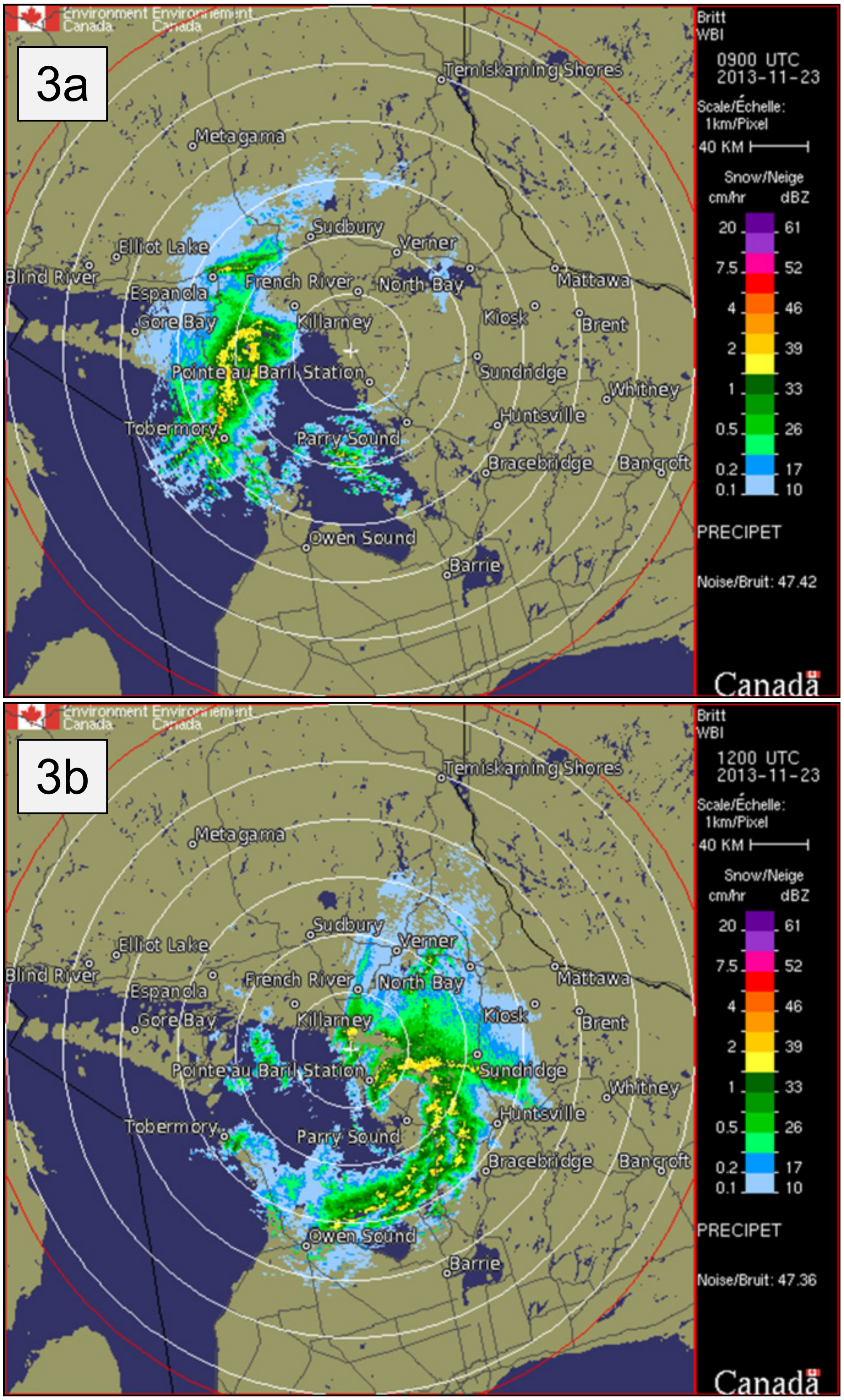

Figure 3. Radar images from ECCC's Britt Doppler radar showing precipitation rates at (a) 0900 UTC and (b) 1200 UTC. The two images illustrate the transformation from a cluster of showers on the west side of Georgian Bay to a well-developed mesoscale vortex just inland from the east side of the Bay.

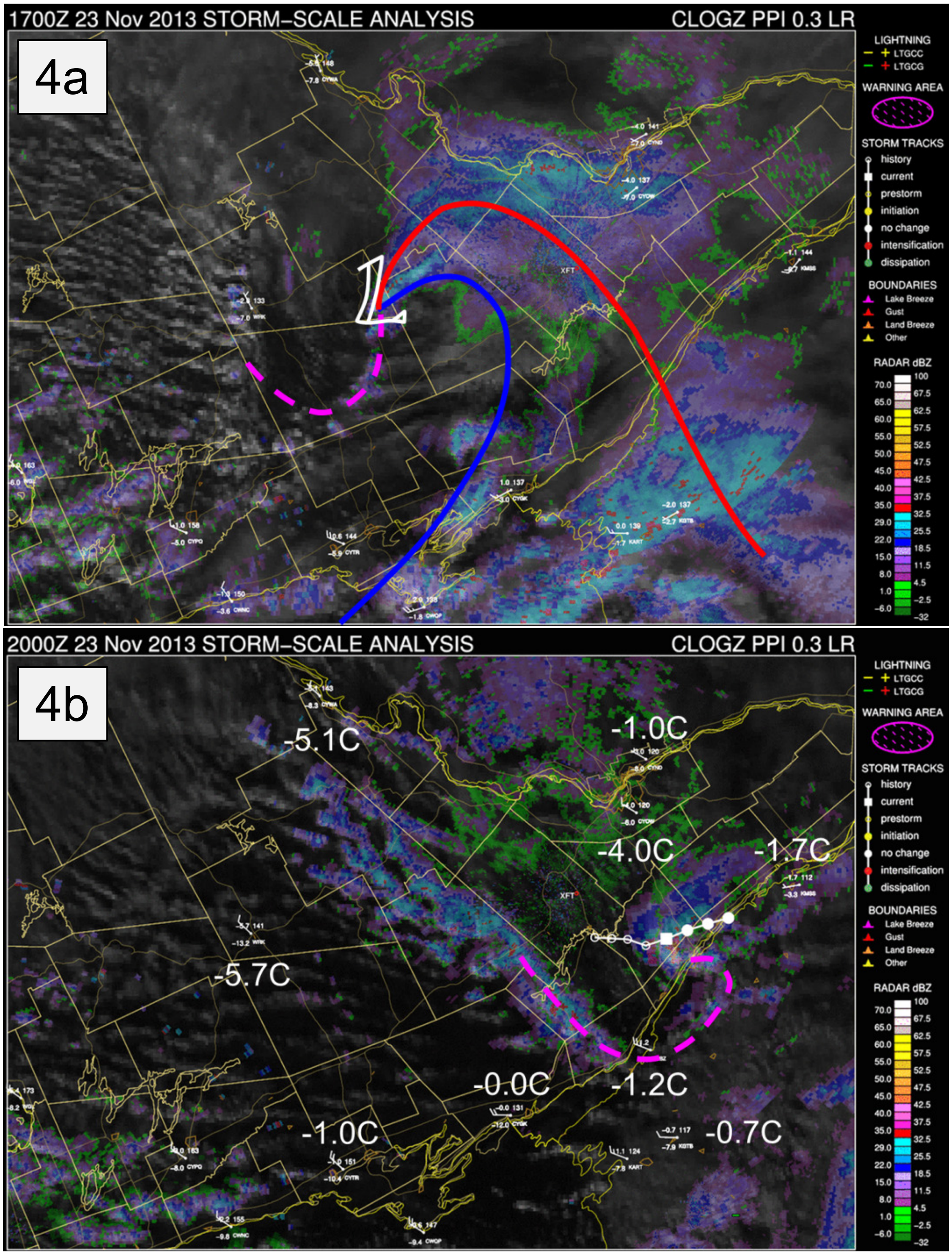

Figure 4. Composite analysis maps showing radar reflectivity, visible satellite imagery and surface observations at (a) 1700 UTC and (b) 2000 UTC. A low centre with warm front (red line), cold front (blue line) and trailing trough (dashed magenta line) is shown in (a). The position of the surface trough, the track of the supercell (white nodes connected by lines), and observed surface temperatures are shown in (b).

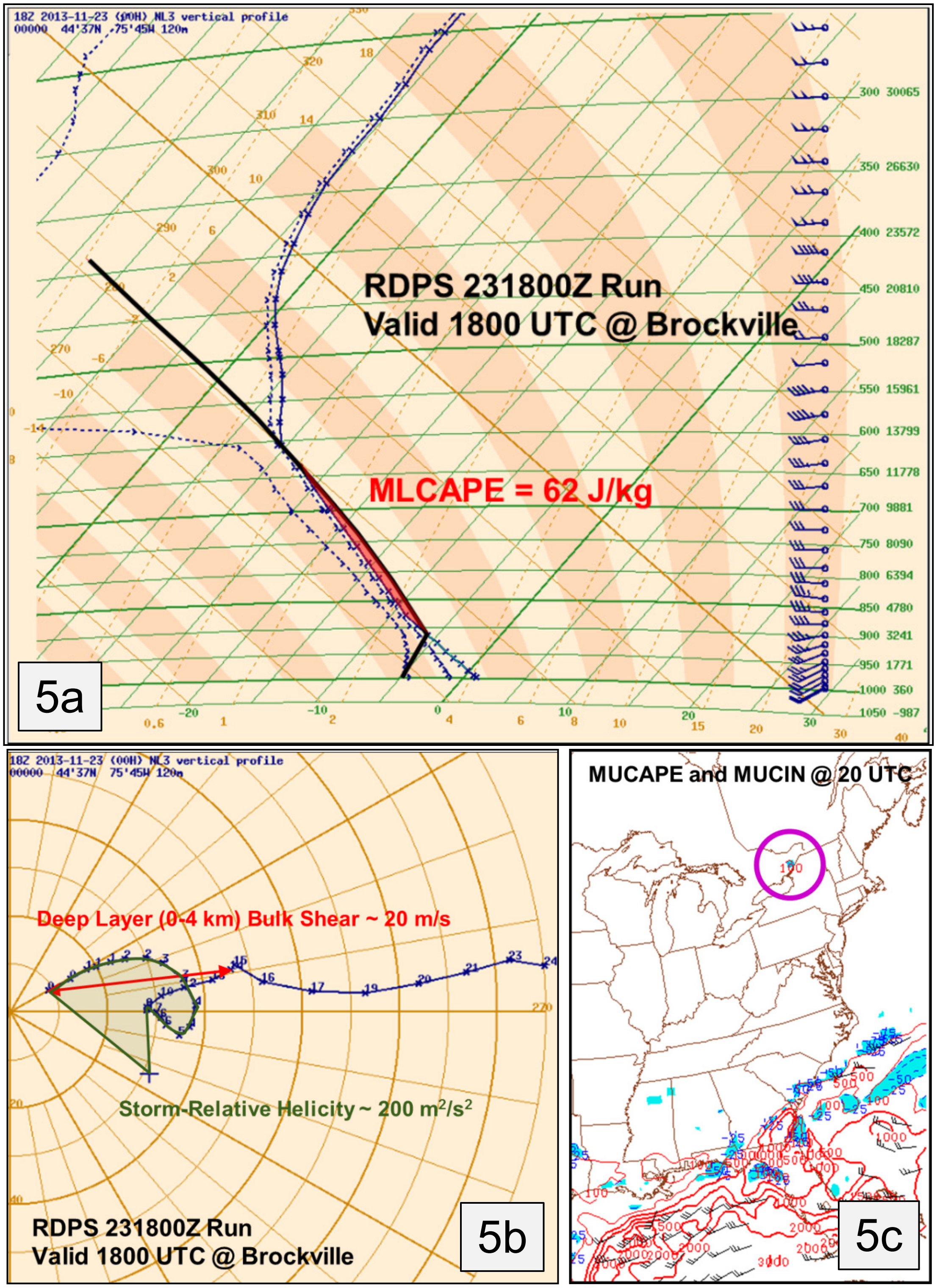

Figure 5. (a) RDPS-derived tephigram valid at 1800 UTC on 23 Nov 2013 near the location of the tornadic supercell, (b) the RDPS-derived hodograph for the same time and location, and (c) the MUCAPE and MUCIN fields from the US Storm Prediction Center mesoanalysis (magenta circle indicates the location of the tornado event).

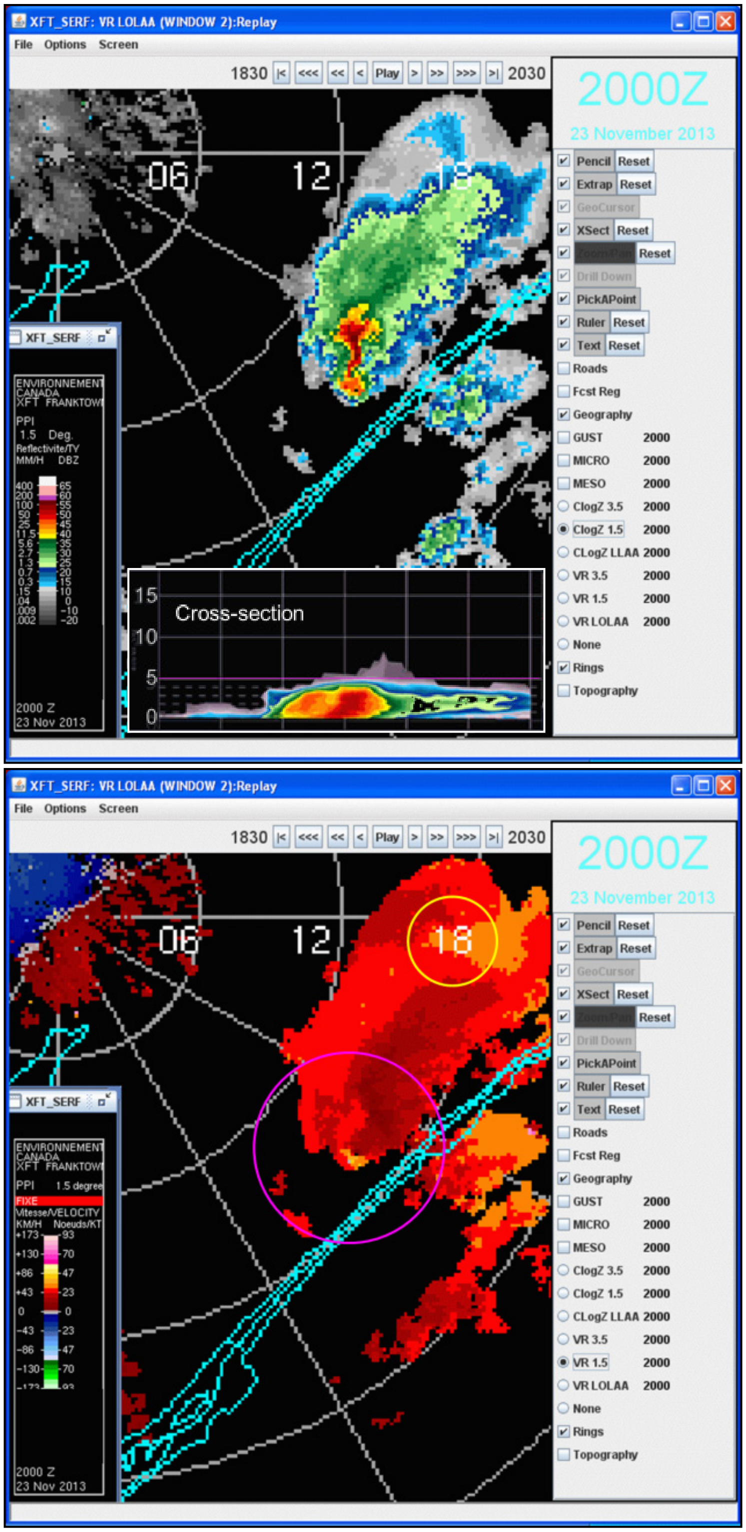

Figure 6. (a) The 1.5º reflectivity with reflectivity cross-section (inset), and (b) 1.5º radial velocity from ECCC's Franktown radar, valid at 2000Z on 23 Nov 2013. The reflectivity image suggests an appendage on the rear-right flank of the storm, while the radial velocity data show strong azimuthal shear (highlighted by the magenta circle) at 1.8 km AGL indicative of a mesocyclone and co-located with the reflectivity appendage. The inset cross-section image shows that the radar echo tops near 5 km.

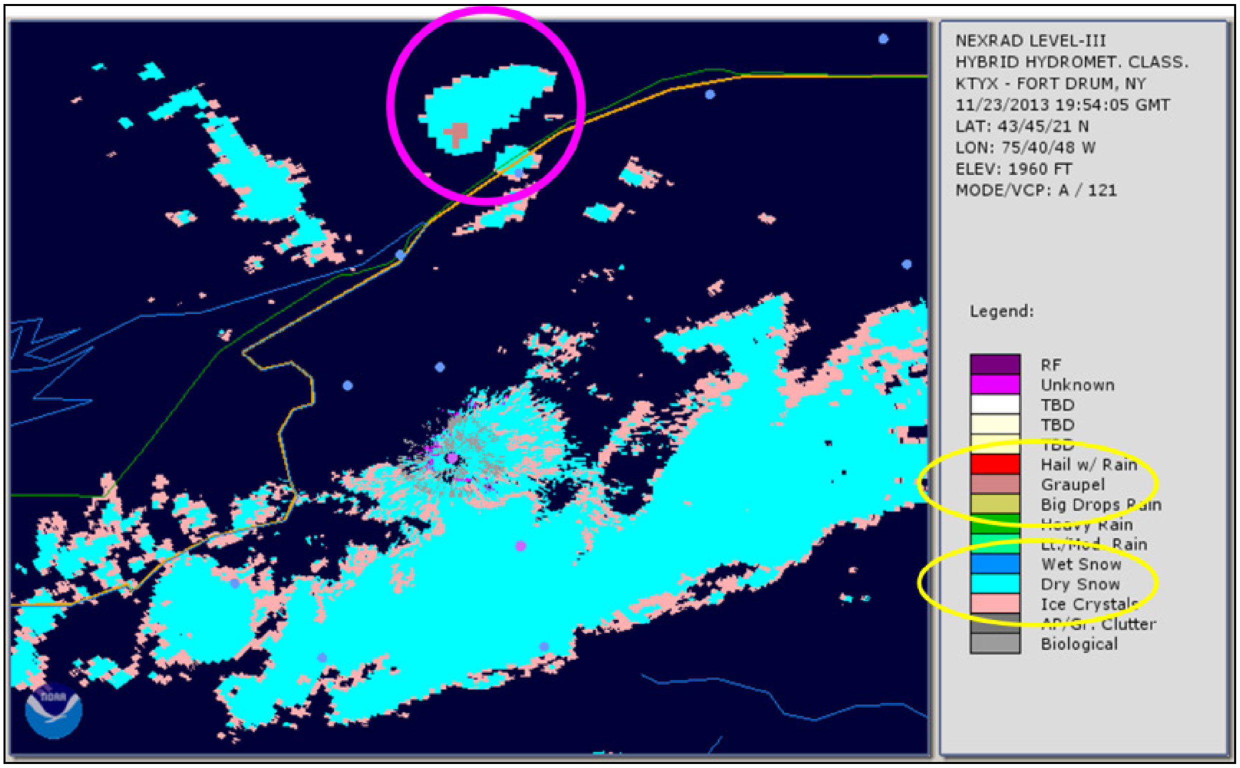

Figure 7. The hybrid hydrometeor classification from the Fort Drum, NY, radar valid for 1954 UTC on 23 Nov 2013. The classification algorithm suggests that the tornadic supercell (magenta circle) is composed mainly of dry snow with a graupel core (both types circled in yellow in the legend).

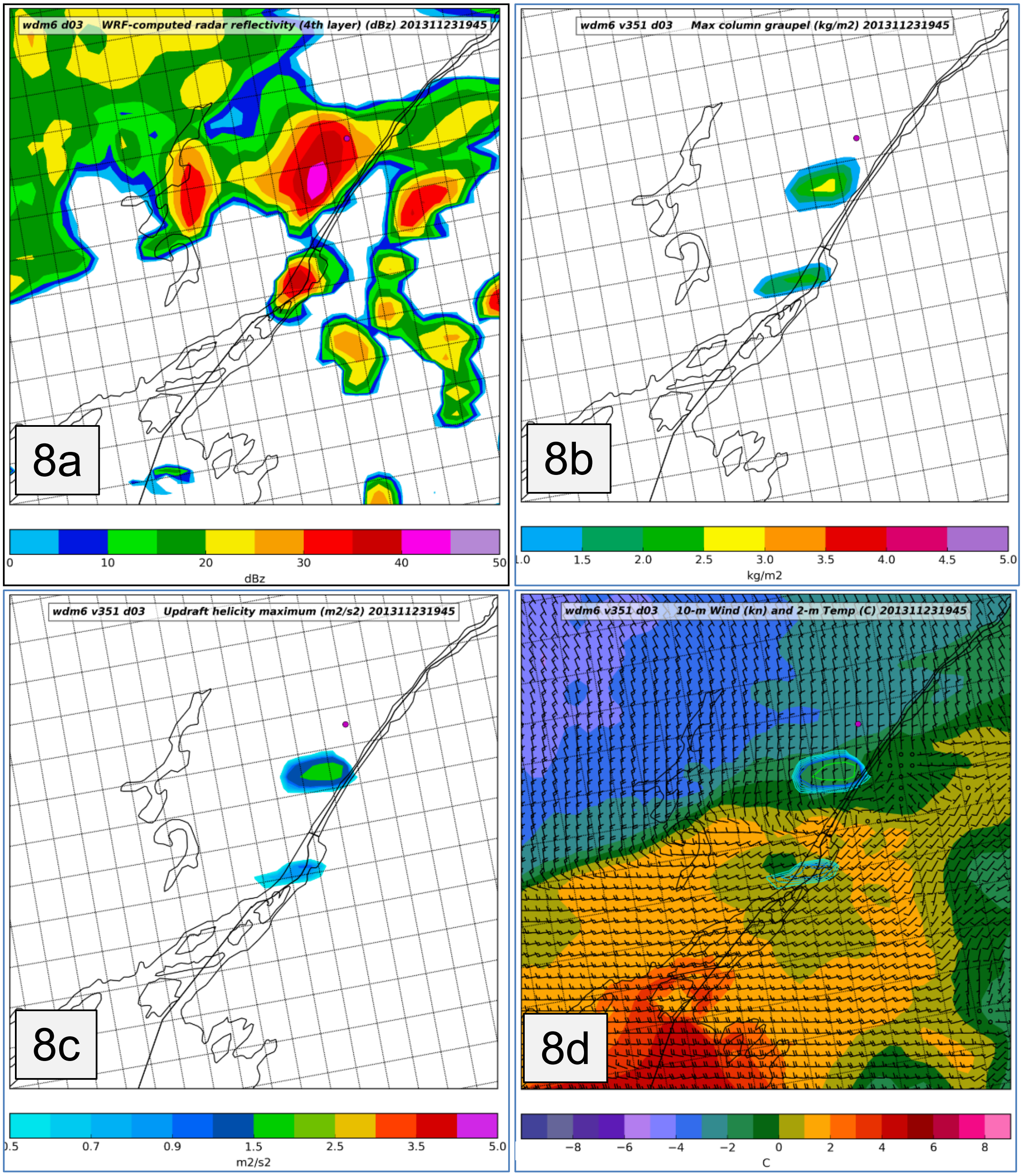

Figure 8. Output from the WRF NWP model with 3-km horizontal grid size (a) simulated radar reflectivity, (b) maximum column graupel content, (c) maximum updraft helicity, and (d) surface temperature (shaded), 10-m winds in knots and superimposed maximum updraft helicity (blue contours). The location of the tornado event is indicated by the magenta circle.

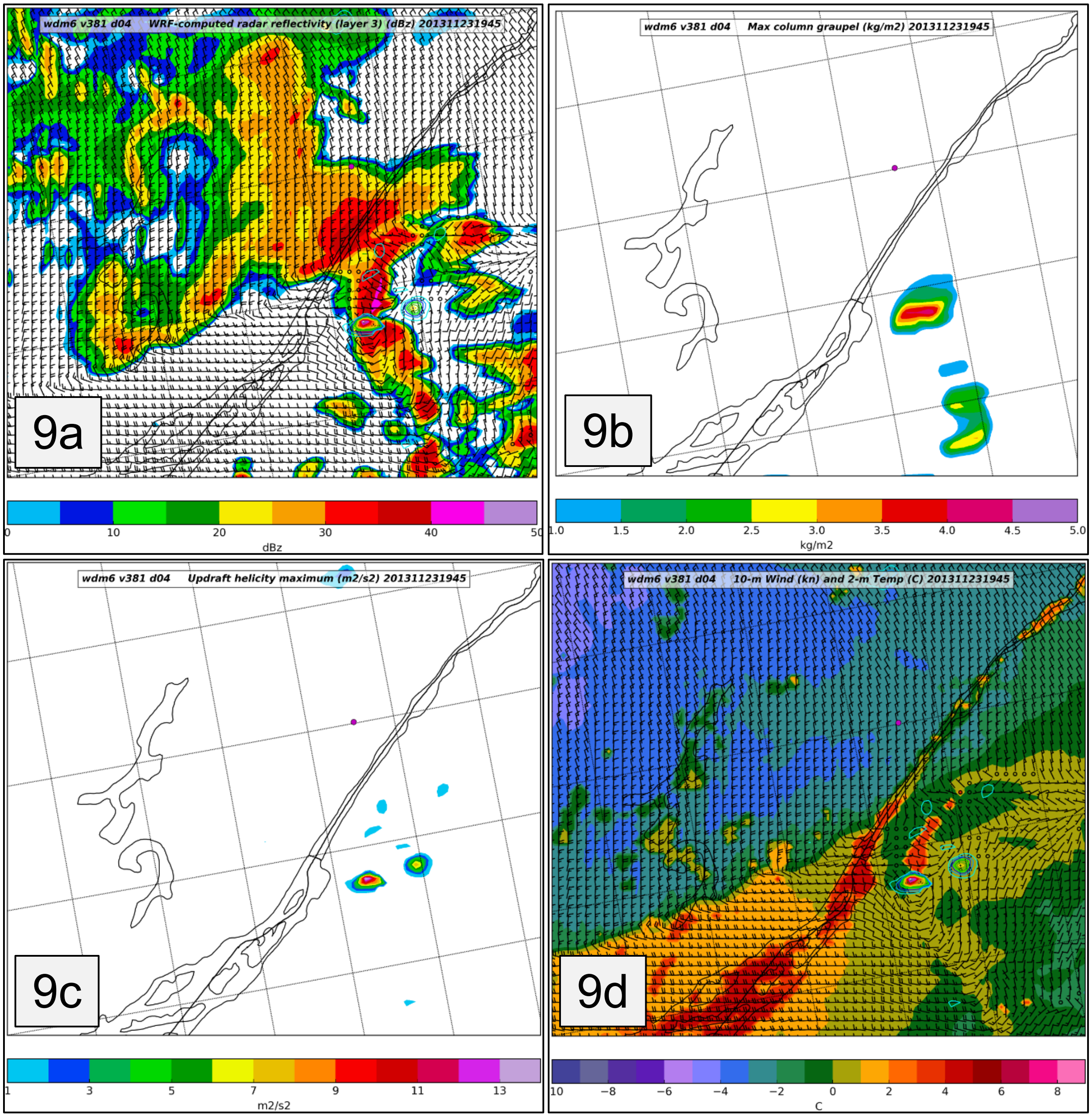

Figure 9. As in Fig. 8, except the WRF NWP model was run using a 1-km horizontal grid size, and for (a) the 10-m winds and maximum updraft helicity contours are superimposed.