

Winter Storm Simulations using a Local Mesoscale Model

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1. INTRODUCTION

Major challenges in winter storm forecasting are often associated with mesoscale features, such as heavy snow bands, shallow cold air layers, and small boundaries. These features are not well resolved by current operational models, and as a result, the timing, location, and movement of these features can be poorly forecasted. Accurate timing and location of mesoscale features during a winter event are especially important to the public, particularly because of the high impacts on transportation and utilities.

A local version of the Weather Research and Forecasting (WRF; Michalakes et al. 2001) Environmental Modeling System (EMS) was run for three archived snowstorms (24-26 December 2004, 4-6 December 2005, and 10-12 February 2006; cases A, B, and C, respectively) that impacted portions of the National Weather Service Forecast Office in Wakefield, VA (AKQ) County Warning and Forecast Area (CWFA). Results from these simulations will be presented to illustrate how a local mesoscale model, such as the WRF, can be utilized in improving forecaster confidence of predicted mesoscale features within winter precipitation events.

2. METHODOLOGY

Each of the three events that were simulated had at least one area of significant snow accumulation (storm total greater than 4 inches) in a relatively narrow swath (e.g., Fig. 1). All three events were marked by sharp gradients of snow accumulation, in which the distance between the highest

accumulation and the edge of the swath where only a trace was received was generally 20-40 mi (30-60 km). The borders of the snow swaths were caused by either a sharp boundary of dry air, low-level convergence (Case A) or a distinct rain-snow line (B and C). Mixed precipitation was observed in all three events, but the biggest impacts were from snowfall.

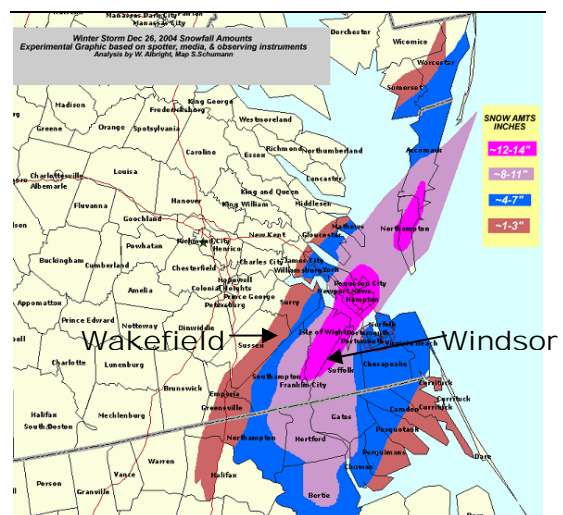


Fig. 1. Winter storm December 26, 2004 snowfall amounts.

All model runs in this study were conducted using the Advanced Research WRF (ARW) core of the WRF EMS (Rozumakski 2006) using no convective parameterization at a 4.1 km grid resolution and 42 vertical levels (Fig. 2a). The Ferrier microphysics and Mellor-Yamada-Janjic boundary layer schemes were used. The domain was centered over the AKQ CWFA (Fig. 2b). All three cases were run using North American Regional Reanalysis data from the National Centers for Environmental Prediction for initial and boundary conditions. Additional runs were conducted for cases B and C using the Global Forecast System for initial and boundary conditions. All simulations were run out to 36 hours, with two runs initialized at approximately 12

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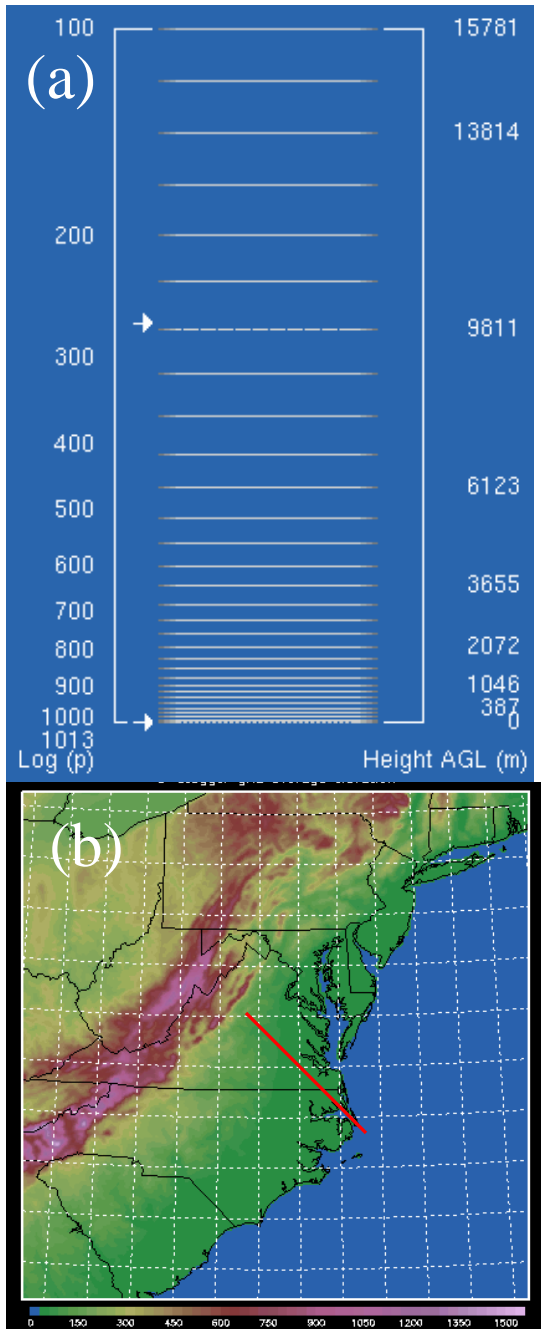


Fig. 2. (a) Vertical grid of 42 levels and (b) the domain for all three simulations at 4.1 km resolution on a 274 x 274 grid. The red line is for the cross section in Fig. 6.

and 24 hours before precipitation began in the AKQ CWFA.

3. RESULTS AND DISCUSSION

Two important mesoscale features that need to be accurately depicted in winter storms will be discussed. The first is the

depiction of important boundaries that may either delineate sharp gradients in temperature, moisture, or significant low-level convergence. The second is mesoscale banding that may be associated with frontogenesis and conditional symmetric instability (CSI) (Schultz and Schumacher 1999).

3.1 Depictions of Mesoscale Boundaries

Mesoscale boundaries introduce one of the biggest challenges to forecasters due to their contribution to narrow banding of heavier precipitation and delineation of precipitation type. The local WRF mesoscale model has the potential to provide useful guidance to forecasters by indicating the possibility of distinct surface boundaries and tight gradients in moisture, precipitation amount, and precipitation type transitions such as rain-snow lines. Figure 3a shows a WRF surface dew point forecast overlaid on a station plot for 1900 UTC 26 December 2004. The WRF shows the dry air being advected into the Virginia Piedmont, with a tight gradient of relatively moist air near the coast. The simulated radar composite reflectivity mosaic (Fig. 3b) reveals that the distinct dew point boundary creates a sharp cut-off for snow accumulation, with much of the precipitation sublimating before reaching the surface. The result of this tight moisture gradient is a very narrow snow band. Market and Cissell (2002) have documented similar dynamics occurring in a Midwest cyclone. In the present case, Wakefield, VA received between 1 and 3 inches of storm total snowfall, while Windsor, VA (17 miles east) received over 12 inches of snow accumulation (Fig. 1). As the storm developed, a distinct NE-SW band formed over southeast Virginia that produced most of the storm total.

A tight gradient of snow to rain on the east side of the snow band set up over southeast Virginia. Precipitation began as rain at the Norfolk International Airport, VA (KORF), and by 1600 UTC 26 December 2004, the rain had changed to light snow. The low level winds were north-northeasterly while the snow was light. The operational models and the local WRF forecasted the winds to back to due north by 2000 UTC 26 Dec 2004. This is evident in the streamlines of both the surface and 925 mb winds (Figs.

4a, b, respectively). The WRF shows colder air moving south from the Eastern Shore and northern Virginia into southeast Virginia. Even though the WRF depicted surface wet-bulb temperatures above freezing (Fig. 4b) across the Norfolk area, timing of the wind shift at 925 mb corresponds well to the change in increasing snow intensity at 1800 UTC and 2000 UTC, as can be seen on the surface observations at KORF (Fig. 4c). According to local forecasters, this particular low level wind shift has been shown to be a good indicator of precipitation type changes at KORF in previous events.

3.2 Mesoscale Banding

The high-resolution WRF has the ability to resolve mesoscale banded precipitation features. Depictions of these features may be used as guidance for the possibility of heavy snow bands. Banding of frontogenesis and associated ascent within favorable thermodynamic environments could increase the confidence that banded precipitation will occur. It was found that because of the high resolution, these fields are very noisy. However, simulated reflectivity (Koch et al. 2005), can reveal mesoscale features that three-hourly or even hourly accumulated precipitation cannot. The caveats of comparing WRF reflectivity with radar composite reflectivity mosaics are described in Koch et al. (2005).

In Fig. 3c, the simulated reflectivity shows a mesoscale band setting up just east of the sharp boundary of dry air. Banding structures were also found in the simulated reflectivity in Cases B and C, with an example from Case C shown in Fig. 5a. The WRF did well in the general timing and distribution of banding structures in all three events, although the areas of highest reflectivity are often displaced from where they were observed (c.f. Figs. 3b and 3c and Figs. 5a and 5b).

Cross sections can be used to help locate the best altitude to view horizontal banding (e.g., the 700 mb level in this case). Once the level is chosen, 2-dimensional frontogenesis or omega fields can be displayed. To illustrate this, a cross section of frontogenesis and ageostrophic

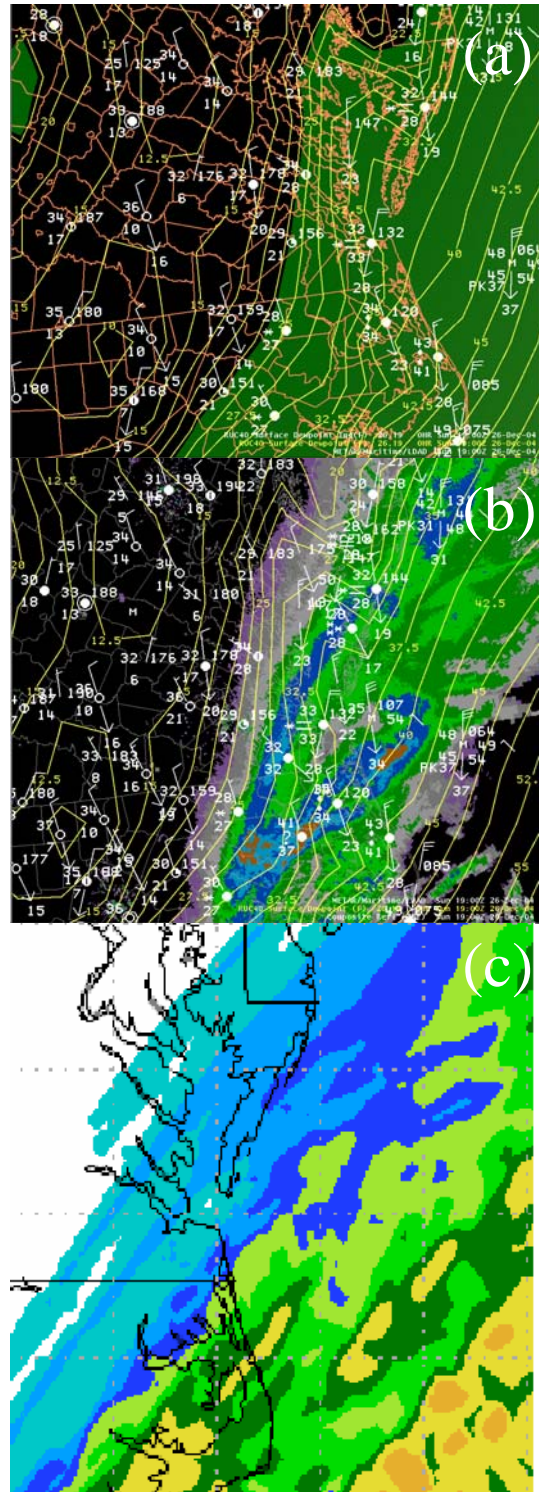


Fig. 3. (a) WRF surface dew point image with 23°F or greater shaded green, (b) radar composite reflectivity mosaic at 1900 UTC 26 Dec 2004, (c) and simulated reflectivity at 1800 UTC 26 Dec 2004.

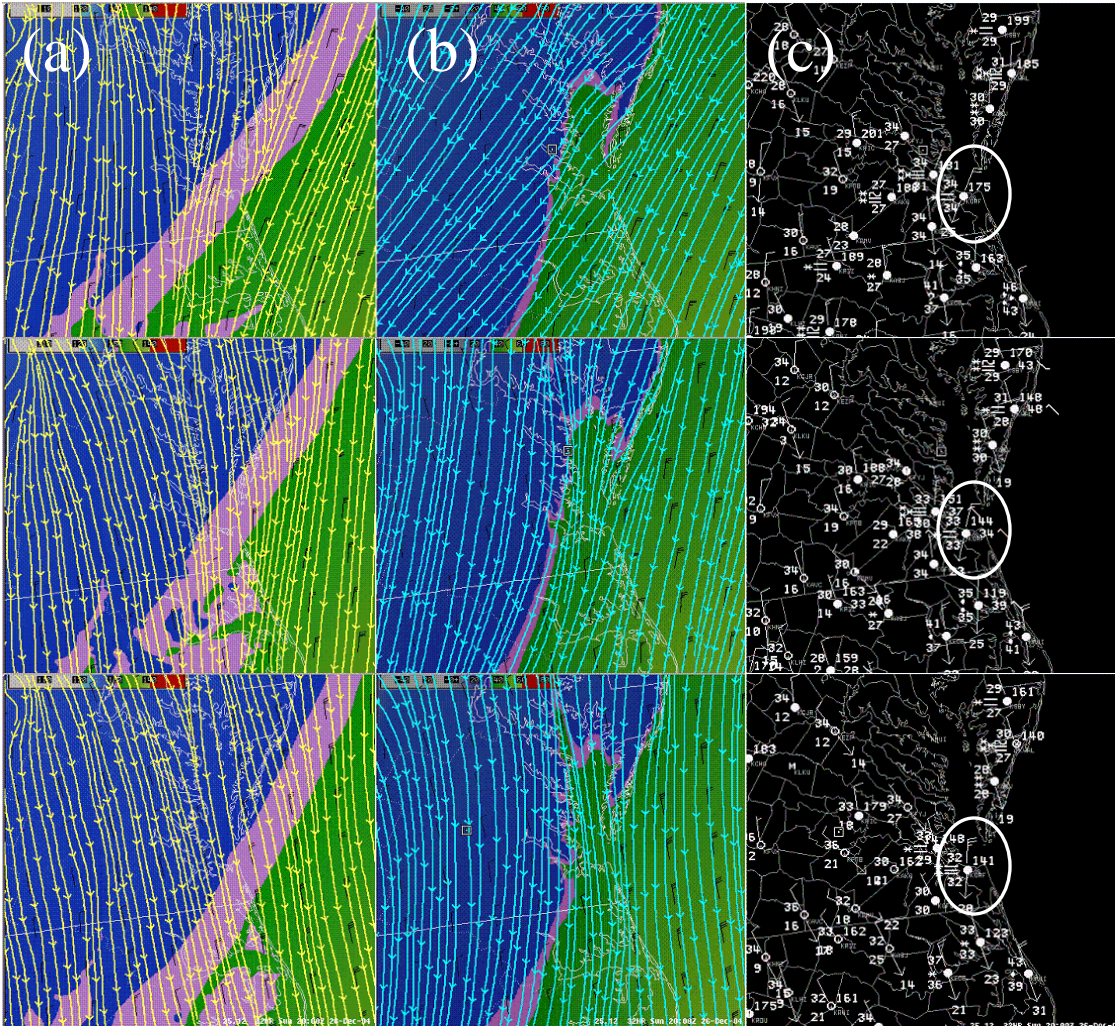


Fig. 4. (a) Surface wind streamlines over 1000-850 mb thickness image (<1295 m blue, 1295-1305 m pink, >1305 m green), (b) 925 mb wind streamlines over surface wet bulb temperature (<32F blue, >32F green), and (c) surface observations for 1600 UTC (top), 1800 UTC (center), and 2000 UTC (bottom) 26 Dec 2004. KORF is circled.

circulation from case C is shown in Fig. 6. One notable feature is a large zone of frontogenesis that occurred within the preferred ice growth region over an area in which a snow band set up.

4. SUMMARY

All the WRF simulations were found to provide useful information on important mesoscale features within winter storms including tight gradients, boundaries, and banding structures. The improved temporal and spatial resolution of the local WRF data allowed more detail in depictions of mesoscale features than data available from current operational models. Fine details in

the strict interpretation of timing and location of such features cannot be made. However, many additional factors can be addressed in the future to improve the accuracy of these details, such as using different model physics, and different initial and boundary conditions.

When minor adjustments requiring a sound understanding of mesoscale features are being made during warning and/or watch situations, guidance from the local WRF may be useful. After a forecaster establishes that the local WRF has been initialized well (e.g., showing current boundaries and/or bands, and its depiction of the evolution of these features looks sound), the WRF

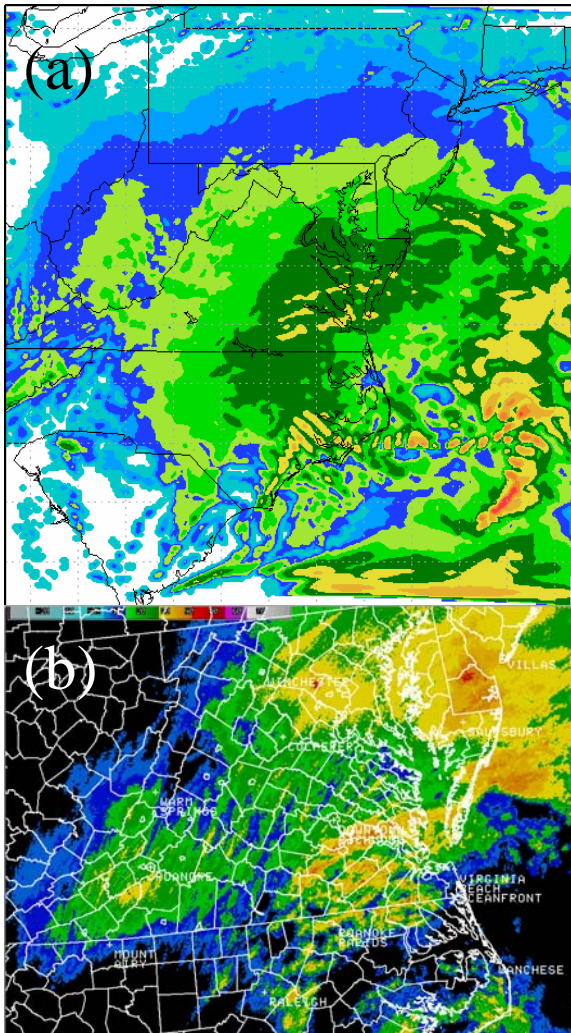


Fig. 5. (a) Simulated reflectivity and (b) radar composite reflectivity mosaic for 2200 UTC 11 February 2006.

guidance may be used to increase confidence that these features will be significant factors in the forecast of a high impact winter weather event.

5. REFERENCES

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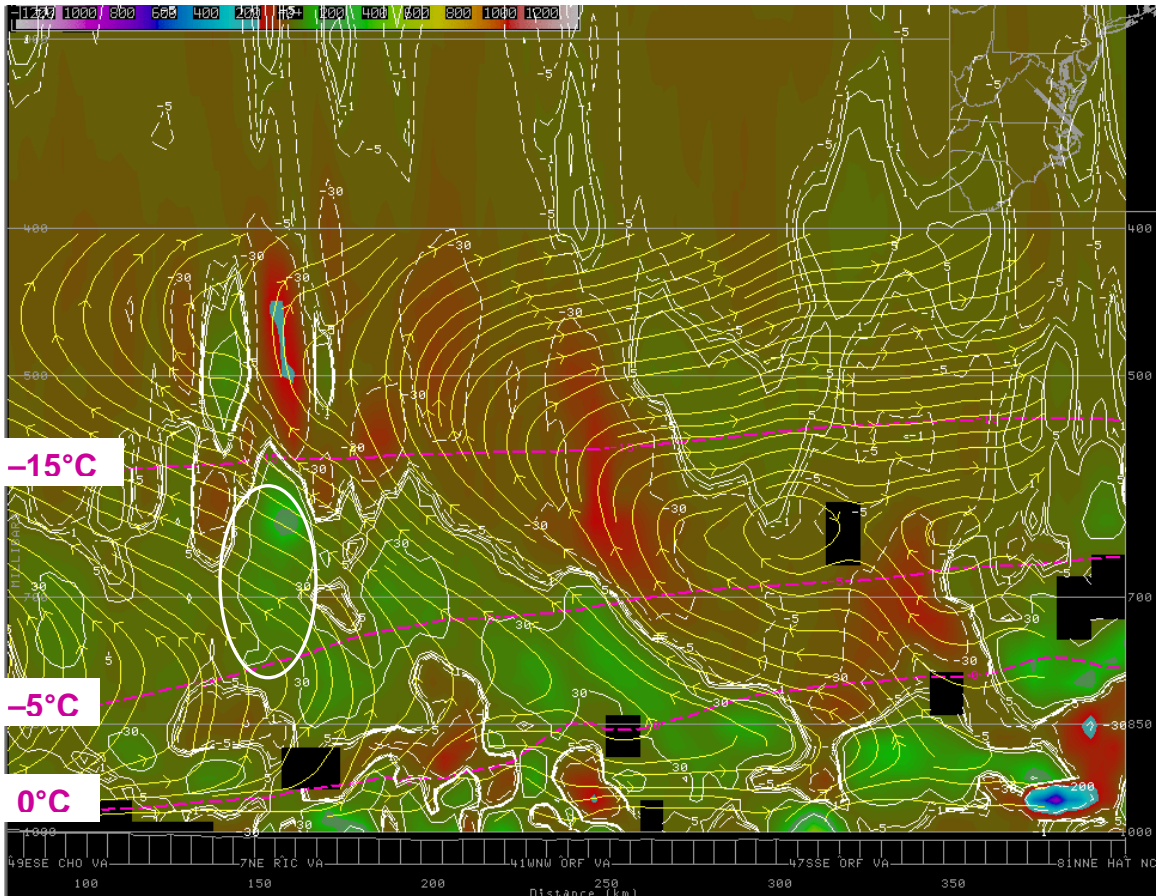


Fig. 6. Cross-section of frontogenesis magnitude in $K/m/10^{10}$ s (green positive, red negative), ageostrophic circulation (yellow streamlines), and preferred ice growth isotherms (magenta) at 2200 UTC 11 Feb 2006 (white oval is shown where approximate location of snow band was occurring).