USE OF HIGH RESOLUTION WRF-ARW OUTPUT AT A NATIONAL WEATHER SERVICE FORECAST OFFICE: THE 21 JULY 2002 & 9 AUGUST 2005 UPPER MICHIGAN BOW ECHO EVENTS

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1. INTRODUCTION

National Weather Service (NWS) Forecast Offices are tasked to deal with a variety of forecast and warning challenges, ranging from very specific short-term (0-3 hour) concerns such as severe thunderstorms and tornadoes to less specific long-term (4-7 day) issues. Traditionally, numerical weather prediction (NWP) guidance to assist NWS forecasters with these issues has come predominately from the National Centers for Environmental Prediction (NCEP) Environmental Modeling Center (EMC). Advances in computing technology in recent years has provided NWS forecasters with NWP guidance from a numerous additional sources running a variety of different modeling systems, including Workstation Eta, MM5, RAMS, WRF-ARW, WRF-NMM, and many others. More recently, NWS offices have developed the capability to run models on station using multiple CPU Linux workstations and small Linux clusters.

The NWS office in Marquette, MI began utilizing local models for operational forecasting in 2001, using the Workstation Eta model, and migrated to the WRF-ARW in 2004. Forecasters have utilized the output from these simulations in a variety of forecast scenarios, including marine winds, lake effect snow, and severe convection. Although computing capacity has increased considerably over the past five years, the domain size over which an NWS office can typically run a local model, particularly at horizontal grid spacing (HGS) of 5 km or less, is limited. However, experiences at the NWS office in Marquette, MI since 2001 have demonstrated that output from such limited area domains, with convective parameterization schemes disabled, can still provide valuable information to forecasters. This information can be helpful in a variety of situations, such as those previously mentioned, but we will focus on performance for a few deep moist convective cases.

During the afternoon of 21 July 2002 a high precipitation supercell formed over western Upper Michigan in a high CAPE/moderate shear environment. This supercell evolved into a bow echo as it moved into central Upper Michigan, grew upscale, and subsequently developed book end vortices and a rear inflow jet. Although the WRF-ARW was not being used locally at the time, this event was simulated using a model construction identical to a 5 km HGS run currently being used operationally at the NWS office in Marquette, MI. Results from this simulation indicate how the information could have been potentially useful to forecasters during the event, not only in providing information on convective initiation and mode, but also intensity.

A WRF-ARW simulation from a similar event from 9 August 2005 also helps demonstrate the potential utility and limitations of such models being run locally at NWS forecast offices. In this case, it is apparent that changes made to the simulation construction, if not well thought out, can have a dramatic impact on the results.

2. NWS MARQUETTE WRF-ARW SYSTEM

During 2004, the NWS in Marquette, MI migrated its local modeling system from the Workstation Eta to WRF-ARW framework. The capability at that time was limited, with twice per day small domain cold start runs at 8 km HGS out to 48 hours. As computing capability increased during the subsequent years, the local modeling system was expanded to its current configuration as detailed in Fig. 1. This configuration consists of an 80 km HGS hemispheric run, a 40 km HGS North American run, a two-way nested 20 km/5 km HGS regional run, and a single domain 5 km HGS local run. Initial conditions come from a combination of the Global Forecast System (GFS) and Local Analysis and Prediction System (LAPS)

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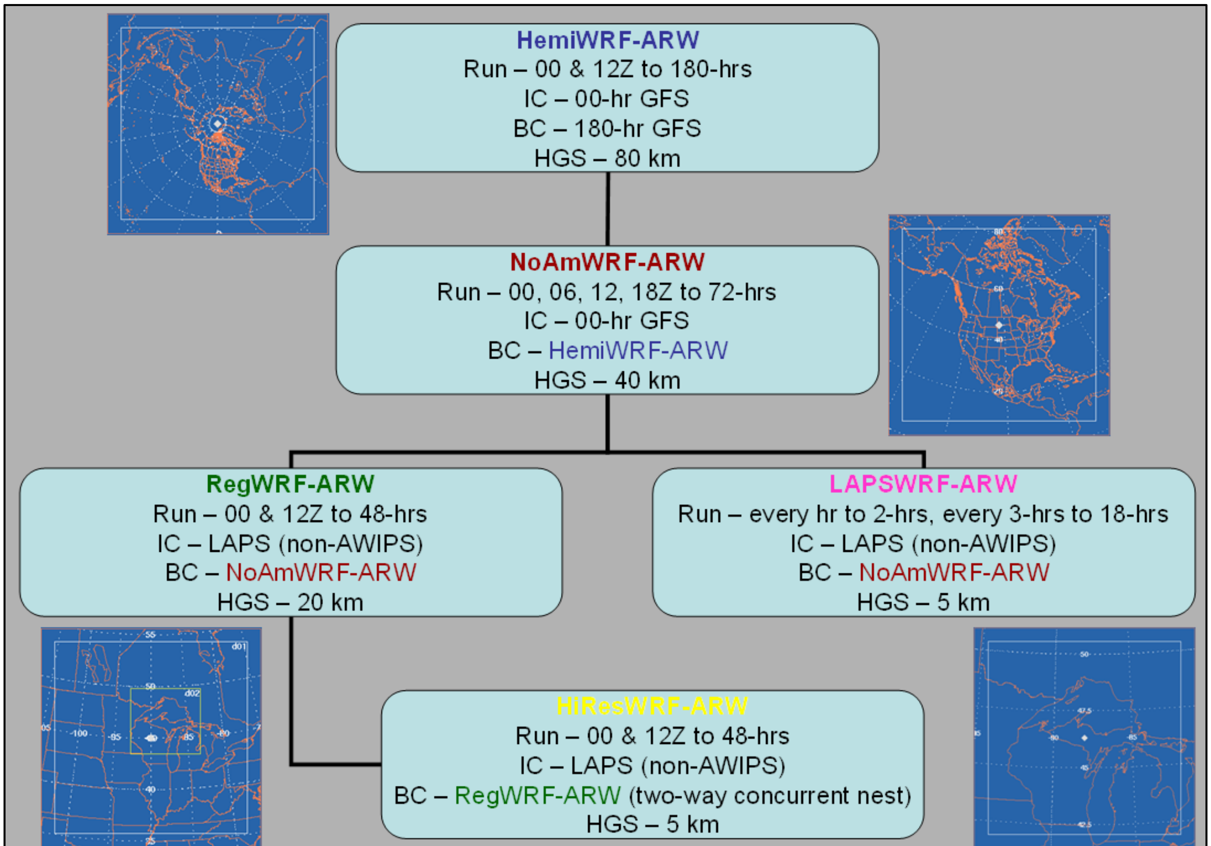

Figure 1. Overview of WRF-ARW modeling system in use at the NWS Marquette, MI forecast office. Boundary and initial conditions indicated by BC and IC respectively.

analyses, with boundary conditions coming from coarser domain runs within the local system as shown in Fig. 1.

This local modeling system provides forecasters with a variety of model output which can be used operationally in real-time. Output from the hemispheric and North American runs is primarily utilized within the long-range forecasting process, while guidance from the 5 km HGS runs is considered when assessing short-term issues such as convection. These 5 km HGS runs not only offer potential qualitative assistance to forecasters, but can also serve as a first guess for many deterministic forecast fields within the local component of the National Digital Forecast Data (NDFD), which coincidentally employs 5 km HGS.

It should be noted that the two high resolution runs within the local modeling system employ LAPS analyses for their initial conditions with the LAPS "hot start" capability enabled. With "hot start" enabled, LAPS includes hydrometeor information within the initial conditions, potentially helping to mitigate issues with model spin up (Etherton et al. 2006). In the case of the LAPSWRF-ARW, the LAPS analysis is cycled each hour with a two our WRF-ARW forecast, and every third hour the WRF-ARW runs out to 18 hours. This rapid updating capability provides potentially useful NWP information during quickly evolving weather situations, and for time critical forecast concerns such as aviation.

The subsequent sections will focus on two specific severe convective events, and will show how output from limited domain high resolution runs of the WRF-ARW can provide beneficial information to NWS forecasters.

3. 21 JULY 2002 BOW ECHO EVENT

3.1 Overview of the Event

On the morning of 21 July 2002 a dissipating mesoscale convective system (MCS) (Maddox 1983) was present over Lower Michigan, with considerable moisture lingering in its wake over eastern Upper Michigan. A 500 hPa vorticity maximum was associated with a short-wave moving through Minnesota. Profiler data from the 500 hPa level showed 25 ms-1 southwest winds ahead of this short-wave trough.

The 12 UTC 21 July 2002 Minneapolis, MN (KMPX) sounding, just ahead of the short-wave trough, showed primarily westerly flow, with little directional shear above the nocturnal inversion. Potential instability derived from the sounding using expected afternoon high temperatures near 32°C was substantial, with a surface based lifted index (LI) and convective available potential energy (CAPE) of -9.0°C and 4924 Jkg^{-1} respectively. Relatively high wet-bulb zero and lifted condensation level (LCL) heights of 4600 m and 2500 m respectively were present, along with low relative humidity values in the lower levels of the atmosphere. These thermodynamic characteristics, along with the previously mentioned kinematic profile, were suggestive of the potential for strong winds with any convection that would develop.

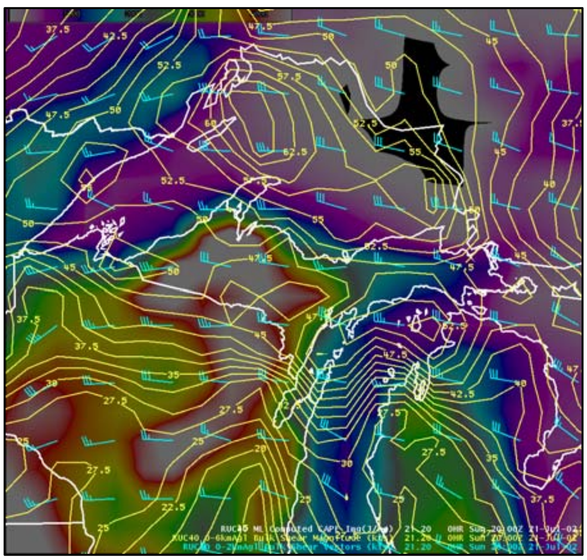

Figure 2. 00-hour RUC forecast valid at 21 UTC 21 July 2002. 0-6 km AGL bulk shear (kt; image), 0-2 km AGL bulk shear (kt; yellow contours)

The airmass apparent on the 1200 UTC KMPX sounding migrated into Upper Michigan during the afternoon hours of 21 July 2002. The 00-hour 20 UTC 21 July Rapid Update Cycle (RUC) model showed mixed layer (ML) CAPE approaching 5000 Jkg-1 over much of the western Upper Michigan. The 0-2 km AGL bulk shear (Fig. 2) in that area was between 15 ms^{-1} and 18 ms^{-1}, which would typically be considered sufficient to provide a balance with the convectively generated cold pool, providing a favorable environment for bow echoes (Przybylinkski 1995). With the 0-6 km AGL bulk shear varying between 22 ms^{-1} and 25 ms^{-1} across all of Upper Michigan, rotating updrafts were also likely, although the unidirectional shear would suggest splitting cells (Weisman and Klemp 1984).

By 1926 UTC, the initial convection, as seen by the Marquette, MI (KMQT) WSR-88D radar, was moving into far western Upper Michigan, aligned southwest-northeast. By 2113 UTC, two supercells were noted, and a subsequent merger of these storms resulted in a change to a more linear convective mode. Between 2113 UTC and 2209 UTC, the line of storms took on a bowed appearance (Fig. 3). An enhanced rear inflow jet (RIJ; Smull and Houze 1987) developed, along with northern and southern book end vortices (Weisman 1993). A storm relative motion (SRM) cross-section from 2139 UTC along the leading edge of the developing bow showed the descending RIJ with values greater than 25 ms^{-1}, the ascending front to rear (FTR) flow (Smull and Houze 1987), and the associated mid-altitude radial convergence signature (MARC; Schmocker et al. 1996).

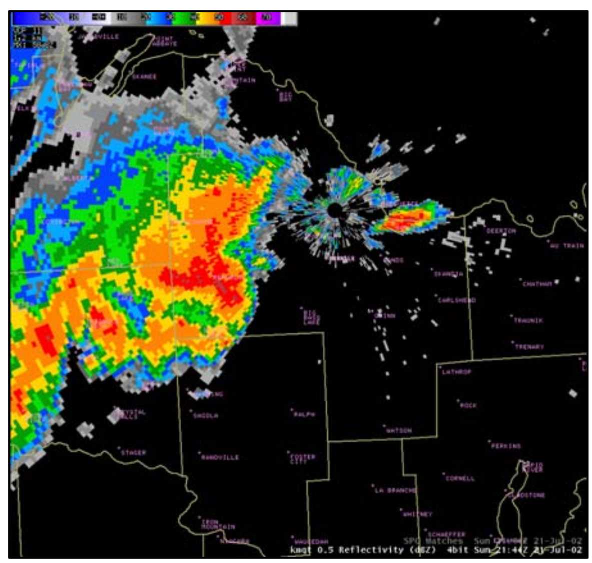

Figure 3. KMQT 0.5° radar reflectivity valid 2144 UTC 21 July 2002

The supercell to bow echo evolution noted in this case was the least preferred mode of bow echo formation discussed by Klimowski et al. (2004). As the system moved across Marquette

County in central Upper Michigan, it evolved into a comma echo (Fujita 1978) that continued across eastern Upper Michigan through the Straits of Mackinac.

An aerial storm survey completed by the Michigan Department of Natural Resources (DNR) indicated that thousands of trees were downed across central Upper Michigan. In addition, wind gusts in excess of 35 ms^{-1} were recorded at K.I. Sawyer International Airport (KSAW).

3.2 Numerical Simulations of the Event

Although this event was not modeled in real-time, it was simulated using a model construction identical to a WRF-ARW 5 km HGS nested configuration currently used at the NWS in Marquette, MI (Fig. 1). Below are some specifics regarding the model simulation:

- Model Version: WRF-ARW 2.1.2
- Initial/Boundary Conditions: North American Regional Reanalysis (32 km)
- 20 km outer nest, 5 km inner nest (two-way nesting)
- 31 vertical levels
- 100 mb model top
- Kain-Fritsch CP scheme (outer nest), no CP scheme (inner nest)
- Lin et al. microphysics
- RRTM longwave radiation scheme
- Dudhia shortwave radiation scheme
- Noah land surface model
- YSU PBL scheme

Several simulations were conducted using different initial times in order to determine which initial time produced the most accurate representation of what occurred. The simulation from 1200 UTC 21 July 2002 proved to be the most representative of reality in comparison to the simulations which were initiated at 0000 UTC and 0600 UTC. A subjective review of real-time simulations over the past few years suggests that 1200 UTC simulations tend to produce better results, perhaps owing to the fact that they start during the typical convective minimum, although a more thorough and objective assessment needs to be completed to substantiate this claim.

Convection developed within the simulation in near the correct location, although it was delayed by approximately 2 hours with respect to observational data. The convection within the simulation quickly evolved from discrete cells to a linear bowing mode (Fig. 4), exhibiting a very similar evolution to what was observed. The simulated convective system moved across the

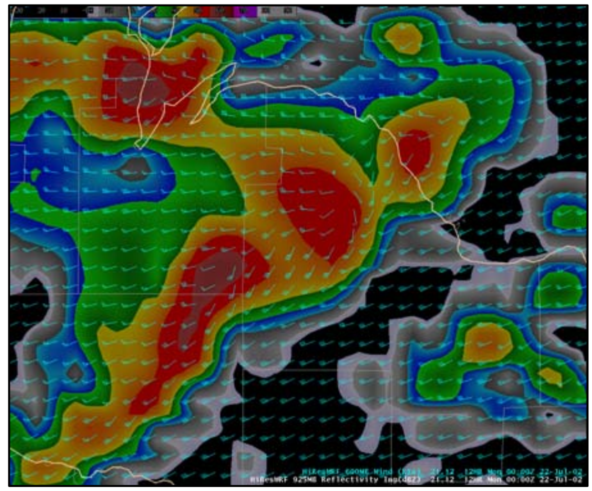

Figure 4. 0000 UTC 22 July 2002 925 hPa pseudo reflectivity from 5 km HGS simulation (image), 600 hPa wind (kt; blue barbs)

area and grew upscale in a very similar fashion to that which was seen in radar data. Additional features that were observed in the radar imagery, such as mid-level rotation and book end vortices, the RIJ, FTR flow, and echo overhang, were also noted in the model simulation (Fig. 5). In addition, the simulation produced boundary layer wind speeds of around 25 ms^{-1}, similar to those which were observed. Forecasters could have potentially utilized the information from the model simulation to better anticipate the development, evolution, and intensity of convection on the afternoon of 21 July 2002.

An additional simulation was conducted, incorporating an inner 1 km HGS nest over Upper Michigan. The addition of this inner nest did not significantly impact the overall results of the simulation, but there were some characteristics worth mentioning. Most notable of these was an improvement in the timing of convective development, which reduced the delay in comparison with reality to approximately 90 minutes. Intensity of boundary layer winds within the bowing system increased to around 30 ms^{-1} (Fig. 6), which more closely matched observed and estimated wind speeds. Although computational resources currently preclude running such high resolution simulations in real-time, this simulation did suggest that further beneficial information cloud be gleaned from such simulations.

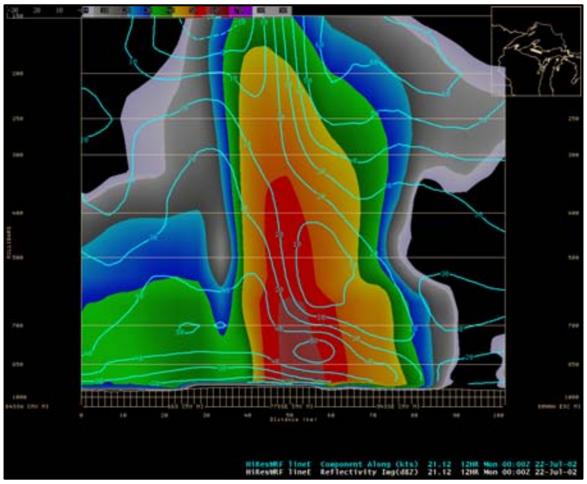

Figure 5. 5 km HGS pseudo reflectity cross-section (image), wind speed along cross-section (kt; blue contours)

4. 9 AUGUST 2005 BOW ECHO EVENT

4.1 Overview of the Event

Convection which developed over the Northern Plains during the overnight hours of 8 August 2005 evolved into a bow echo as it moved east toward Upper Michigan during the mid morning of 9 August 2005. The synoptic scale environment in place during the event was similar to that identified in many other bow echo events (Funk et al. 1999; Klimowski et al. 2003; Klimowski et al. 2004; Przybylinkski et al. 2005). A stationary frontal boundary was in place across the area, with moisture and enhanced instability pooled along the boundary. The environment was characterized by deep layer (0-6 km AGL) bulk shear values of approximately 15-17 ms^{-1}, which would typically suggest multi-cellular convection, while low layer (0-2 km AGL) bulk shear values were on the order of 10-12 ms^{-1}, suggesting the potential for the development of bow echoes.

4.2 Numerical Simulations of the Event

Several high resolution simulations of this event were made to determine if a model configuration similar to the current operational configuration could have provided forecasters with useful information to help anticipate the event. A nested configuration was used, with nests of 60 km, 20 km, and 4 km HGS. Each grid utilized 31 vertical levels, and the GFS was used for initial and boundary conditions. Model physics and dynamics were the same as described with the 21 July 2002 case in section 3.2 for a control run, but in this case several additional runs were made, varying the convective parameterization used on the outer (60 km and 20 km) nests and the microphysics scheme used on all nests. In all cases, the convective parameterization scheme was disabled on the 4 km nest. Parameterizations were changed to provide some qualitative assessment of the potential for results from high resolution simulations such as these to vary significantly when key parameterizations are changed. This is an important issue not be overlooked since WRF (-NMM and –ARW) are now being run at many NWS forecast offices where local modeling knowledge and experience may be limited.

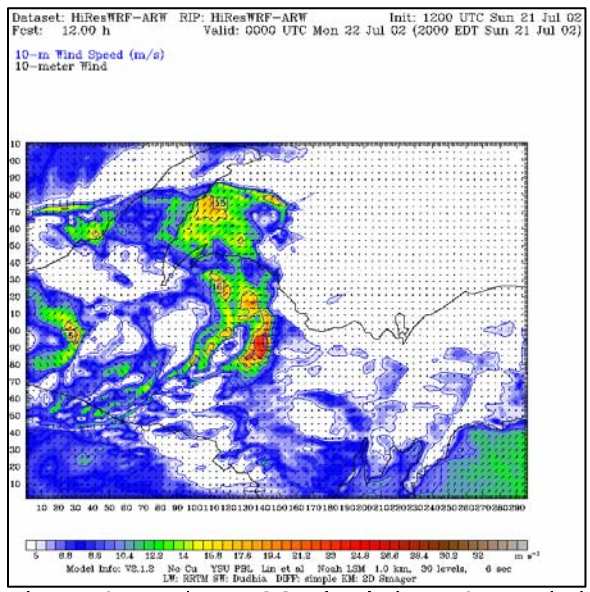

Figure 6. 1 km HGS simulation 10 m wind vectors and speed (ms^{-1}, image)

A well defined bow echo was traveling through upper Michigan at 1600 UTC on 9 August 2005. Pseudo reflectivity output from the control simulation at the lowest model level for the same time exhibited close correlation with the observed radar data (Fig. 7). Timing and location, as well as the bowed structure, were quite similar to what was observed.

A second simulation was conducted which utilized the Betts-Miller-Janic (BMJ) convective scheme on the outer (60 km and 20 km) nests. Although all other aspects of the simulation remained unchained, it was apparent that changing the convective parameterization scheme on the outer nests had a significant impact on the simulation's ability to adequately depict the convection over Upper Michigan.

Simulations also struggled to properly generate convection when the microphysics parameterization scheme was modified from that used in the control run. When the Ferrier microphysics scheme was employed, virtually no precipitation was generated over the area of interest at 1600 UTC 9 August 2005. The simulation performed most poorly with regard to this convection when both the Ferrier and BMJ parameterizations were employed.

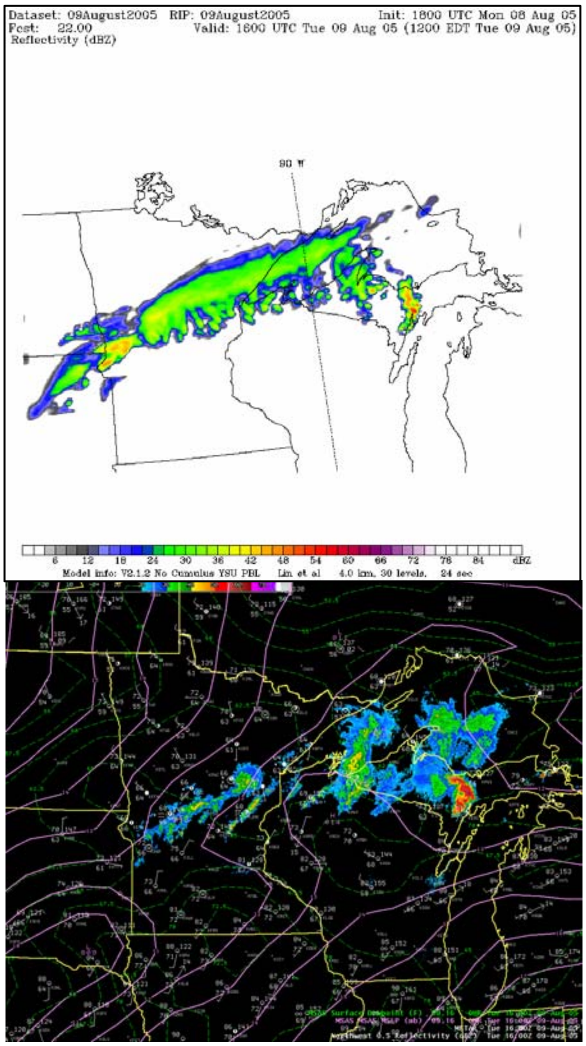

Figure 7. 1600 UTC 9 August 2005 4 km HGS simulation pseudo reflectivity (top; image) and 0.5 radar reflectivity (bottom; image), METARs, MSLP (magenta countours)

5. CONCLUSION

Use of high resolution models at NWS Forecast Offices can provide potentially beneficial information to forecasters. Information from simulations which do not employ convective parameterization schemes can be leveraged to better anticipate convective initiation, mode, and evolution. However, it must be noted that such information must only be used in combination with the myriad of observational and NWP information at the forecaster's disposal. Real-time high resolution NWP guidance is fraught with potential pitfalls, and although not shown, there are numerous instances when such information could mislead the forecaster. A thorough understanding of how a model behaves, and how seemingly slight changes in model configuration can alter the model solution, is paramount. As computing capacity increases, local NWS offices will have the opportunity to enhance local modeling efforts by increasing resolution and/or expanding forecast domains. Although it appears that useful information can be gleaned from simulations which employ ~5 km HGS, it is clear that finer resolution is needed to avoid convective feedback and other issues associated with scale.

The 21 July 2002 and 9 August 2005 cases provide examples of when locally run models could provide forecasters with useful information. In each case, model configurations which are supportable at a NWS forecast office did an adequate job of simulating convective development and evolution, and provided some information on potential intensity. Continued and expanding use of high resolution models such as the WRF-ARW at NWS forecast offices will likely result in additional forecast successes and failures. More comprehensive verification of such local model runs needs to be conducted to better assess their performance and to determine the most optimal model configurations for the various forecast challenges which face NWS forecasters. It is imperative that the results of local modeling at NWS offices find their way back to researchers and model developers so that improvements can continue to be made.

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