Convective Weather PDT analysis of the impact of WRF-RR cores on current and planned convective weather products.

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Executive Summary

This report assess the impact that the two proposed dynamic cores would have on the algorithms developed by the Convective Weather Product Development Team (CWPDT) through statistical and subjective analyses of over 50 cases run in archive mode by the Developmental Test Center (DTC). Statistical comparisons indicate that the NMM severely underestimates convective precipitation rate (threshold > 2 mm hr-1) with biases much lower than that obtained with the ARW evident in both phases of the DTC experiment. These extremely low biases would hinder the performance of 0-6 hr convective weather forecasting algorithms currently underdevelopment by the CWPDT which rely on NWP for storm initiation and evolution. Subjective analyses of each of the archived runs revealed the following findings:

1) The prediction of stability fields and large-scale dynamics used in CWPDT algorithms is very similar in all the runs.
2) The statistical skill in the prediction of precipitation is very similar in the two cores; however, statistics do not tell the whole story.
3) ARW tends to have more structure in the precipitation field particularly in the airmass thunderstorm conditions typical of much of the eastern US in summer.
4) ARW tends to better reproduce the evolution of large convective systems such as squall lines and MCS, particularly in cases where the convection is elevated.
5) Correct simulation of the initiation, character and evolution of convection as well as the structure/variability in the precipitation field is vital for CWPDT algorithms that require a diagnosis of the areas of convective precipitation in the model and information on the evolution of precipitation structures.
6) The pathway for improved assimilation of small scale variability into the forecasts is less certain if the NMM dynamic core is chosen.

1. Introduction

The Rapid Update Cycle (RUC) will be replaced with either the Non-hydrostatic Mesoscale Model (NMM) and the Advanced Research WRF (ARW) and be called WRF-Rapid Refresh or WRF-RR. The two models represent different treatments of dynamics that could possibly have significant impacts on the convective weather products developed for aviation interests that rely on RUC model output. In this report, the impact of using the NMM and ARW Convective Weather Product Development Team (CWPDT) algorithms is assessed through statistical and subjective analyses of over 50 cases run in archive mode by the Developmental Test Center (DTC).

The CWPDT has several storm forecasting algorithms that rely on extrapolation, heuristic techniques and Rapid Update Cycle (RUC) model output to produce short term (0-6 hr) forecasts of thunderstorms that pose a hazard to aviation interests. The forecast systems that utilize RUC model output include the Autonowcaster (ANC), NCWF2 and NCWF6. The ANC is a regional forecast system which runs over a 500 x 500 km domain centered on Chicago, IL which blends input from a number of sources (e.g., satellite, surface met stations, NWP, human-entered boundaries) to produce 1 hr forecasts of storm initiation, growth/decay and movement every 6 minutes. NCWF2 and NCWF6 produce probabilistic forecasts of thunderstorm locations for the CONUS based on extrapolation, observed trends, and RUC model output for determine areas of storm growth and simulated storm locations. NCWF2 produces forecasts out to 2 hours while NCWF6 forecasts out to 6 hours.

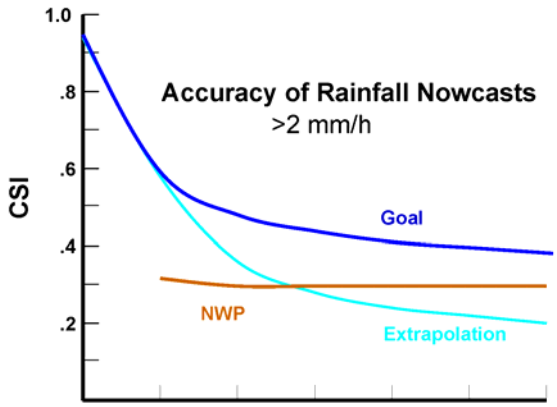

Figure 1. Schematic representing the relative skill of NWP and Extrapolation in forecasting convective precipitation with Goal representing the desired outcome of blending these two forecast products.

A number of RUC fields go into the forecast logic of these systems including convective precipitation, CAPE, CIN, layer average RH, vorticity advection, equivalent potential temperature advection, layer average wind shear, etc. In addition, over the past couple years, the RUC convective precipitation has been post-processed to produce probabilistic forecasts of convection. This field, called the RUC Convective Probability Forecast (RCPF), is an important predictor field in the developmental version of NCWF6 which blends the RCPF product with extrapolation forecasts to produce a single probabilistic forecast of the likelihood of thunderstorms at a particular time and place.

Due to time constraints and limited resources available for this comparison, we focused on the relative performance of the model's ability to simulate the structure and evolution of convection and convective precipitation. The quality of the model forecasts of convective precipitation is vital to the performance of short-term forecasting systems that blend extrapolated areas of convection with model-predicted convection. The curve shown in Figure 1 indicates the relative skill of extrapolation forecasts and model forecasts of convective precipitation. The skill of extrapolation forecasts is relatively high at leadtimes less than 2 hours while NWP skill typically exceeds extrapolation at the longer leadtimes. The goal of these nowcasting systems is to optimally blend extrapolation and NWP convection forecasts such that the skill is maximized (labeled 'goal' in Figure 1). In NCWF6, the blending is done using a weighted average that takes into account the past performance of extrapolation and the model. Thus, the 1 hour forecasts are predominantly based on extrapolation while the 6-8 hour forecasts are heavily weighted toward the model predicted convection. As the skill of the model

increases so will that of the blended system, particularly at the longer leadtimes, thus, in this study we focus on the relative skill of the two dynamic cores at predicting convection (and storm initiation/evolution in particular).

2. Statistical Verification

The testing of the NMM and ARW was highly constrained by using, near-identical grids, identical analyses, lateral boundary conditions and physical parameterizations. The cores were tested using two different parameterization sets. Under Phase 1 (PH1) both cores were run with NMM parameterizations which consist of Ferrier microphysics, BMJ convection scheme and Option '99' land surface model. Under Phase 2 (PH2) both cores were run using RUC parameterizations which consist of Thompson microphysics, Grell-Devenyi convection scheme and RUC land surface model.

An overview of the performance of the model cores and physics packages is given by comparing the CSI and bias in the forecasts of precipitation accumulated over a three hour period (convective scale + resolved) for each dynamic core and physics package. Using three hour accumulation of precipitation is not ideal for assessing model skill in forecasting convection since the convective timescale is much shorter than 3 hours and forecasts of convection get smeared in time and space using a time-integrated quantity. Nonetheless, this statistical comparison gives an idea of the generally tendencies of the two models to forecast summertime precipitation. Since a good fraction of precipitation in summer is convection, this field serves as an adequate, but smoothed, first order proxy of convective precipitation. Here we focus on the 9 hour forecasts since these forecasts will closely resemble the 7 and 8 hour forecasts that would be used in the operational version of the blended convection-forecasting system (taking into account 1-2 hr latency of the WRF-RR output).

The forecast skill scores are calculated separately for the 00 and 12 UTC runs to illustrate differences in the model's ability to predict storm dissipation in the evening (in the 00 UTC runs) and initiation and growth in the morning (in the 12 UTC runs). Please note that statistics shown throughout this talk are for the eastern two-thirds of the CONUS only.

Phase 1 Results

For the 12 UTC runs, both cores tended to underpredict the total precipitation amounts with the bias increasing with increased rainfall amounts (or rates). Skill scores decrease rapidly with precipitation amount; however, the ARW has slightly greater skill at the higher precipitation amounts, and NMM more strongly underpredicts the higher rainfall amounts. Though it is difficult to draw conclusions from 3-hourly accumulations of precipitation (due to the inherent smoothing involved), it appears that the NMM rarely predicts intense rainfall associated with convection – tending to smooth out the precipitation field. The ARW forecasts have a bias closer to unity than the NMM for all precipitation amount thresholds greater than 0.1 inches. The underprediction of higher precipitation amounts is disadvantageous for blending algorithms that use a precipitation

rate threshold (typically ~ 2 mm hr-1) to diagnose areas of convective precipitation that will be matched and blended with extrapolation forecasts.

Phase 2 Results

For the 12 UTC runs in PH2, the CSI scores for NMM and ARW are very similar (and also similar to that found in PH1). However, the biases obtained in the PH2 simulations are much greater than those obtained in the PH1 simulations particularly for precipitation amounts greater than 0.15 inches. The shape of the bias curves is different as well, with peak biases occurring at higher precipitation amounts than that found in PH1 and rapid decrease in bias with increasing precipitation amounts. The shape of this curve results in both models having biases that are far from unity over most of the range of precipitation values. However, the steepness of the NMM bias curve results in it being further from unity than ARW for all but a small range of precipitation amounts. Over the range of 3hr - precip amounts typically associated with convection (> 0.15 inches), the NMM has a bias closer to 1 between only between 0.15 and 0.22 inches.

3. Case Studies

Each of the archive runs (00 and 12Z forecast) from the spring and summer of 2005 were subjectively compared for phase 2. We intercompared CAPE, 3-hourly accumulated precipitation and 3-hourly accumulated convective precipitation for the two cores. The national mosaic of WSR-88D radar reflectivity provided by WSI was used to evaluate the precipitation forecasts while the 00 hour model analysis fields were used to verify the 12 hour forecasts of CAPE from the 12 UTC run of the previous day. The models performed similarly on most days; however, several cases showed significant discrepancies, particularly in the treatment of widely scattered, unorganized convection in the southeastern US and also in the treatment of elevated convection. For a few cases, a more detailed inspection was performed to closely compare the Phase 2 results of the two dynamic cores. It is important to note that for the blended products, more weight is placed on the model's ability to detect areas where convection initiation is likely rather than its ability to get precipitation in the correct location (which can be corrected with extrapolation forecasts).

21 July 2005: Squall line MCS over Great Lakes Region

In this case we look in detail at the evolution of a simulated squall line Mesoscale Convective System (MCS) that occurred in the Great Lakes region on July 21st. The MCS developed around 0100 UTC along a stationary boundary in S Dakota and had some upper level support. The fact that this MCS already existed and had to be initialized into the models along with the correct surface boundary location/strength and upper level support made this a difficult system to simulate. One hour into the forecast (valid at 13 UTC), the models already begin to loose the convective structure and intensity of the system, particularly in the NMM run; however, the location of the leading edge of the

system is reproduced nicely in both cores (Figure 3a, top). Four hours into the simulation, ARW still has a handle on the orientation and structure on the squall line; while in NMM the convective part of the system has continued to dissipate and loose its characteristics (such as orientation and structure –see Figure 3a - middle).

The simulated squall line moves too slowly in both models as seen at hour 9 of the forecasts in Figure 3b. The observed system has already crossed Lake Michigan at this time which caused it to dissipate significantly. Both models thus have the storm too far to the west and too intense. The position error (slow propogation speed- which was common to both cores) can be corrected through blending with extrapolation. The treatment of the evolution of the storm is more problematic in this case since passing over the lake affected its strength. And while the accumulated precipitation field is similar in both cores (Figure 3b), the convective precipitation associated with the system and thus, the orientation and structure of the MCS was lost early in NMM forecast (Figure 3a – top and middle panels).

31 July 2005: Elevated Convection over Central Iowa

An example of an elevated convection case is shown in Figure NN. This area of convection, which developed around 0700 UTC on July 31st was far removed from any synoptic scale or mesoscale boundaries. It persisted for several hours and likely impacted early morning air traffic between CHI to DEN. The 9 hour forecasts for the two cores initiated at 00 UTC are shown in Figure 4. The ARW predicted a significant area of convective precipitation in roughly the correct location of west-central Iowa while the NMM only hints at precipitation in this area. The ARW continues to develop this area of convection by hour 12 of the forecast, while NMM shows very little in the way of precipitation in this area (not shown). This is a significant forecast bust by the NMM, missing a relatively large area of long-lived convection (i.e., it was not a position or timing error). Further analysis is needed to determine the cause of the missed forecast; however, statistics for the entire day show that the ARW generally performed better over the eastern 2/3 of the country with much higher CSI scores and good (i.e., between 1 and 2) bias numbers (Table 1). This, despite the fact that the 3-hourly accumulated precipitation along the northern border with Canada and in the southeastern US were very similar in the two models (Figure 4 – middle panels).

9 August 2005: Airmass Thunderstorms

This case is representative of a number of cases characterized by large diurnal variations in precipitation, the bulk of which is driven by popcorn convection in the southeastern US. There are two areas of interest on the 9th of August: heavy precipitation along a frontal boundary that extends from the Great Lakes region into northeastern Colorado and the airmass thunderstorms in the southeastern US (Figure 5 and 6). Both cores do a good job simulating convection along the frontal boundary with both ARW and NMM simulating a linear band of storms with the band having the same orientation as observed. It is noted that the NMM is more intense with convection in MN. In the Southeast, while both the NMM and ARW have similar spatial coverage of 3-hourly accumulated

precipitation (Figure 6 – bottom), only the ARW correctly simulates the structure and spatial distribution on the thunderstorms (Figure 5 – bottom and Figure 6 - middle). The ability of the ARW to resolve the convective evolution of airmass thunderstorms is vital for the blending techniques to work properly in this region of the country (as seen also in the July 21 case in the southeastern US (Figure 3b)). This will allow the blended system to indicate the type of storms expected and their coverage which would not be possible with the smoothed, resolved-scale precipitation generated with the NMM model using Phase 2 physics.

Table 1. Date, initialization time, case description, CSI, bias of cases selected for intercomparison. The skill scores are determined using data from the eastern 2/3 of the country to verify the 9 hour forecasts of each run (initialization time varies).

Date	**Initialization Time**	**Case Description**	**CSI**		**Bias**	
			ARW	NMM	ARW	NMM
20050721	12 UTC	Squall Line	0.5	0.35	2.25	1.7
20050731	00 UTC	Elevated Convection	0.6	0.47	1.5	1.2
20050802	12 UTC	Air Mass Thunderstorms	0.4	0.2	2.9	2
20050809	12 UTC	Air Mass Thunderstorms	0.09	0.09	1.4	1
20060419	12 UTC	Boundary Initiated Storms	0.005	0.005	3	0.75

4. Other Considerations

It is important to consider the future ramifications of choosing one dynamic core over the other that are not related to current model performance. One such consideration is the future development of data assimilation systems which are just now beginning to assimilate data at the convective scale (particularly the assimilation of radar reflectivity and radial velocity. Much work is currently underway at NCAR and several other institutions (e.g., AFWA, BMB, CREIPI, MSU) using ARW and these assimilation techniques to improve the assimilation of high temporal and spatial resolution radar data through a variety of techniques including Four Dimensional Data Assimilation (with latent heat nudging), 3D-VAR and 4D-VAR techniques and Ensemble Kalman Filter (EnKF) techniques. In contrast, the GSI 3D-Var is the only data assimilation system for NMM and it was developed with large-scale applications in mind (GFS and NAM all use the same system). The concern is that since much of the research in the assimilation of radar data uses ARW as a testbed, it will be much more difficult to get the benefits of this research into operations if the NMM core is chosen.

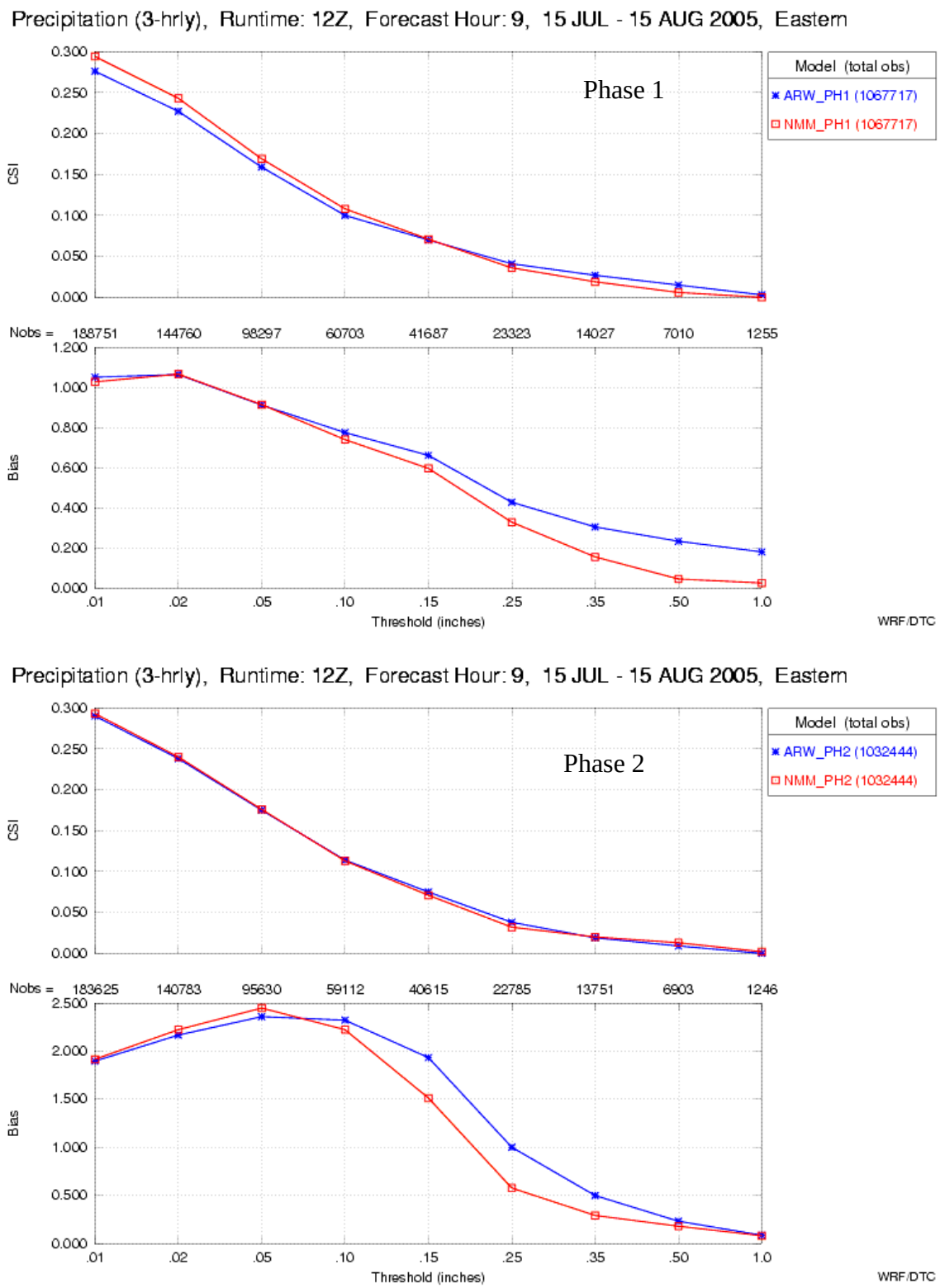

Figure 2. CSI and Bias scores for 9 hour forecast valid at 2100 UTC using NMM (red) and ARW (blue)dynamic cores calculated for the summer 2005 (15 July – 15 Aug) archive runs performed by DTC for (top) Phase 1 parameterizations and (bottom) Phase 2 parameterizations.

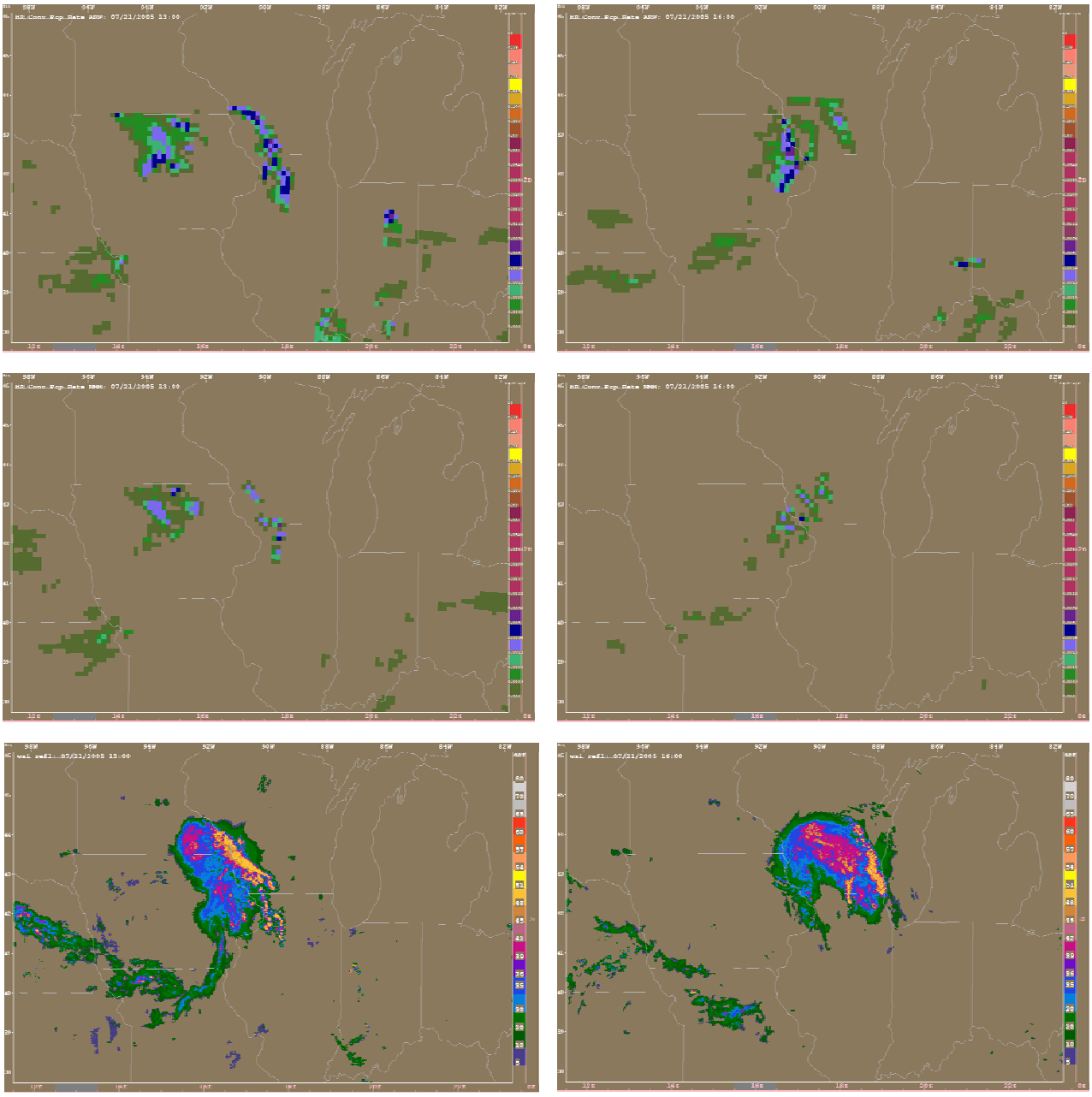

Figure 3a. July 21st MCS Case simulated by (top) ARW (mid) NMM (left) 1 hour forecast (right) 4 hour forecast (bottom) verifying WSR-88D reflectivity.

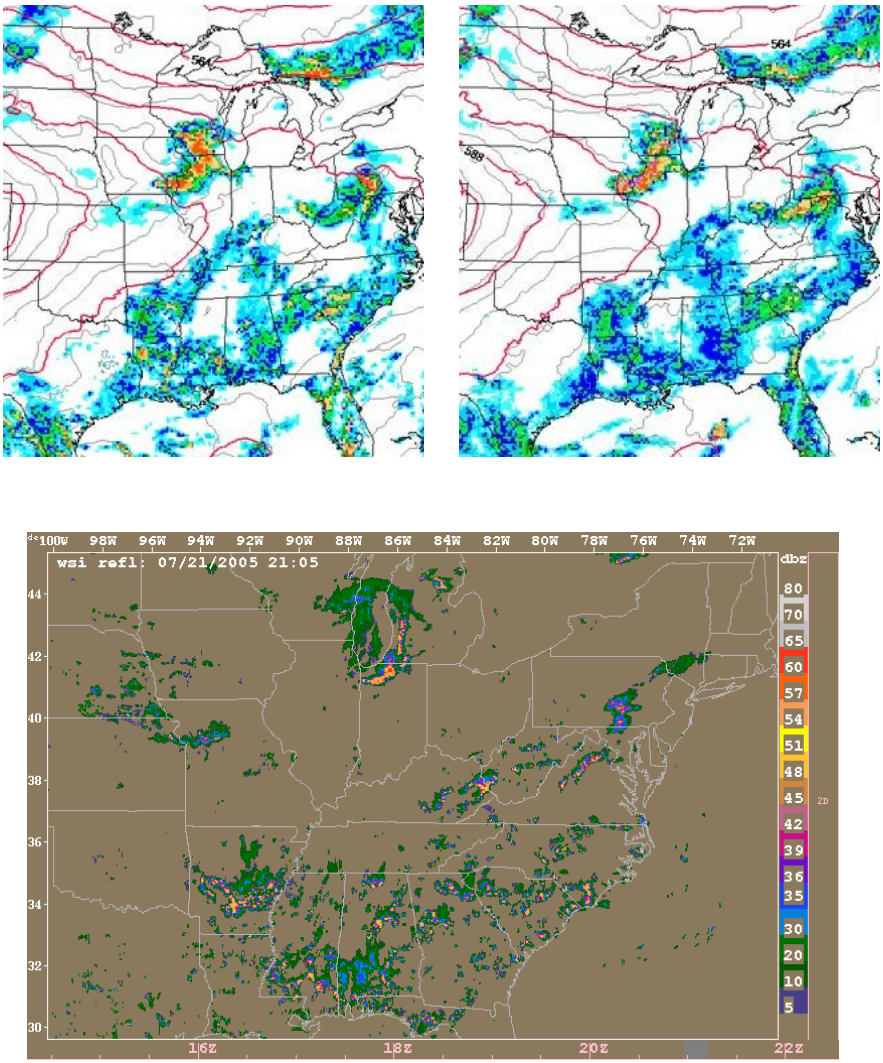

Figure 3b. July 21st MCS Case (top) simulated 3-hourly accumulated precipitation at 2100 UTC for (left) ARW and (right) NMM for 9 hour forecast and (bottom) observed verifying WSR-88D reflectivity.

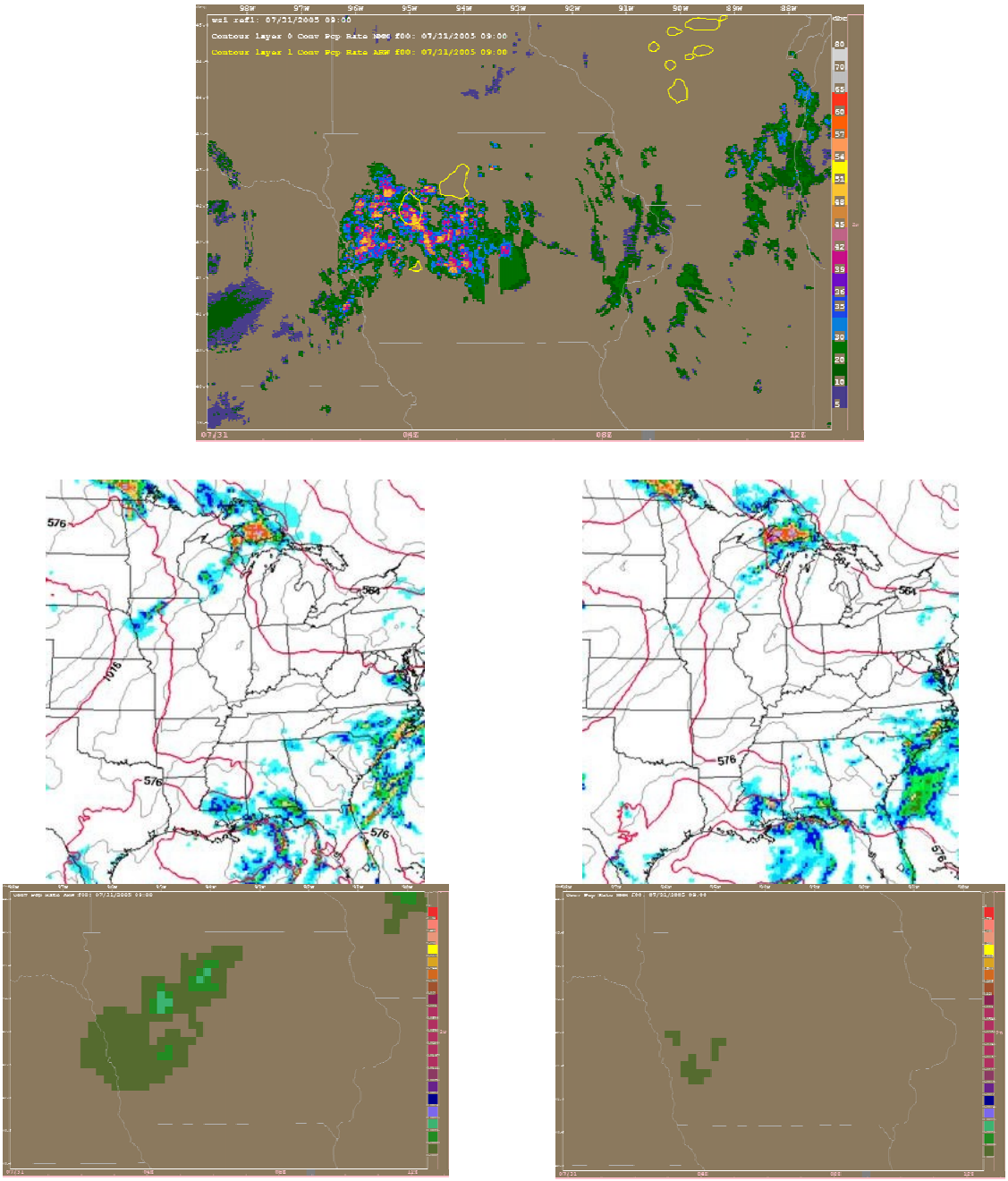

Figure 4. Comparison of NMM (right) and ARW(left) 9 hr forecast initialized at 0000 UTC on 31 July 2005. ARW (yellow contours) and NMM (white contours) forecasts of instantaneous convective precipitaiton and radar reflectivity are shown in top panel. Contours are at the 3.5 mm hr-1 threshold which NMM does not exceed. Middle panels depict the 3-hour accumulation of precipitation (convective + resolved). Bottom panels give the instantaneous convective precipitation rate from (left) ARW and (right) NMM.

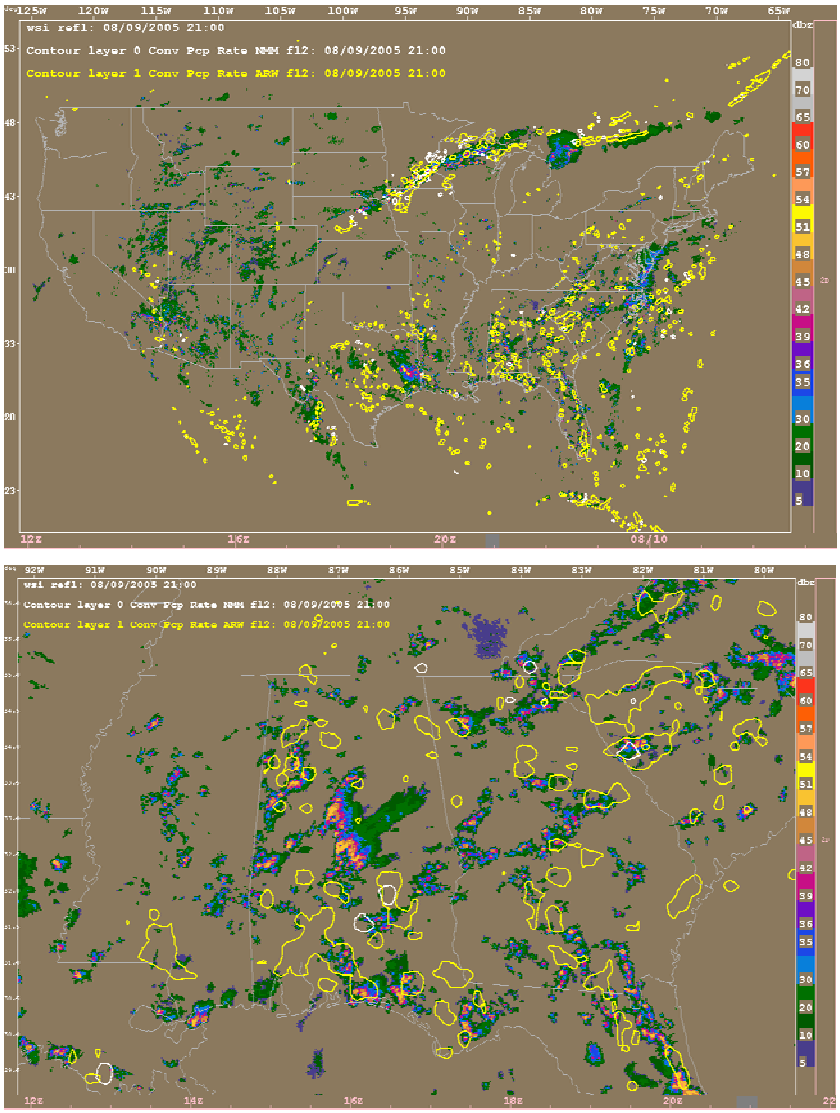

Figure 5. Comparison of 9 hr forecast initialized at 1200 UTC on 9 August 2005 for NMM (white contours) and ARW(yellow contours) with WSR-88D radar reflectivity. Contours are at the 3.5 mm hr-1 threshold. Middle panels depict the 3-hour accumulation of precipitation (convective + resolved). Bottom panels zooms in on the southeastern US..

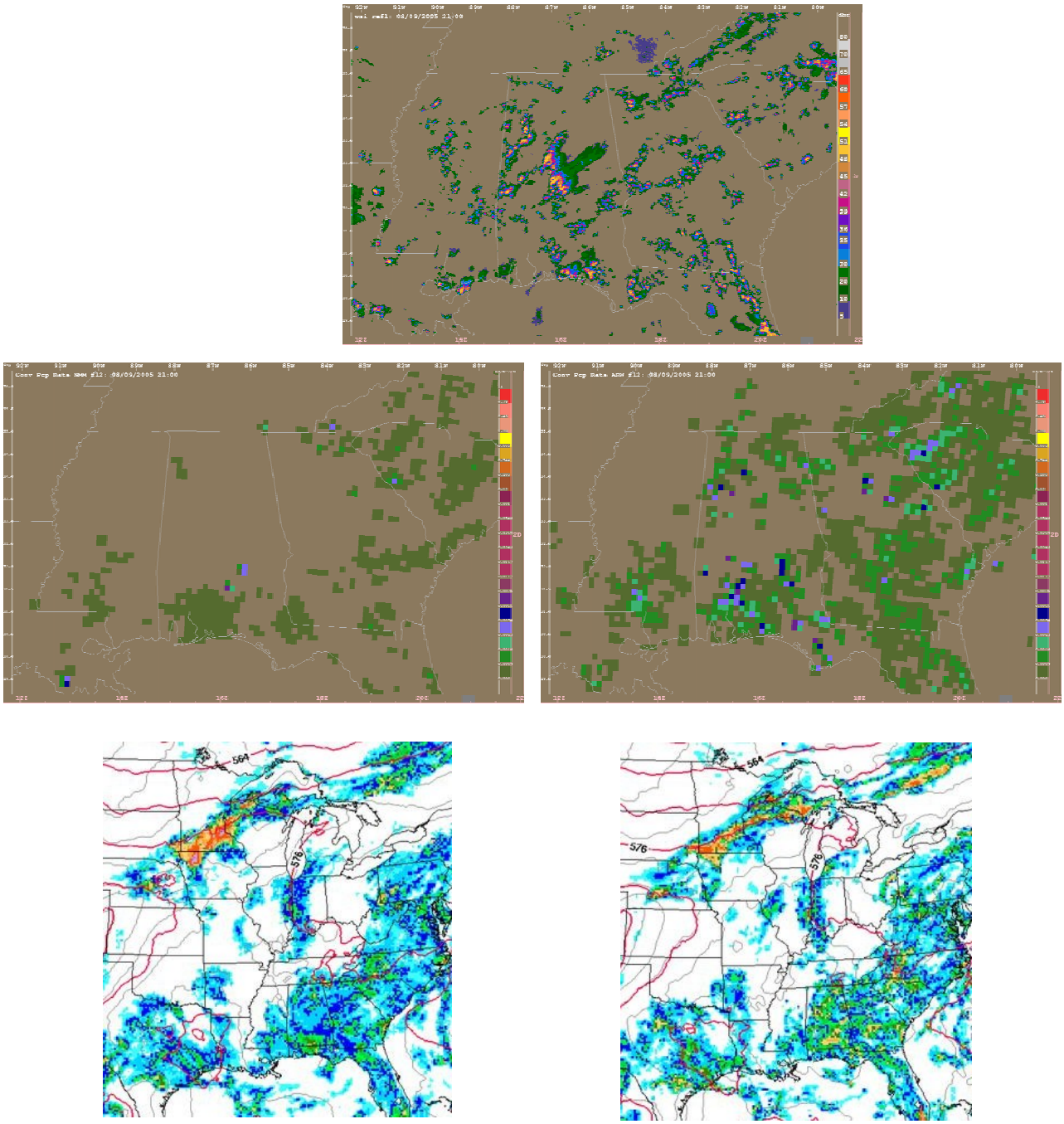

Figure 6. Comparison of 9 hour forecasts of precipitation obtained from 12 UTC run with ARW (right) and NMM (left) with observed WSR-88D radar reflectivity (top). Instantaneous convective precipitation (middle) and 3-hr accumulated precipitation between 6 and 9 hours (bottom).