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IMPROVED PRECIPITATION NOWCASTING ALGORITHM USING A HIGH-RESOLUTION NWP MODEL AND NATIONAL RADAR MOSAIC

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ABSTRACT

A new precipitation nowcasting algorithm, the Adjustment of Rain from Models with Radar (ARMOR), has been developed at McGill University. This algorithm combines an advanced mesoscale NWP model with national radar mosaics. The technique is presented in comparison to an NWP model and a radar extrapolation algorithm. Statistical and observational evaluation have been performed, showing that this new method is an advancement over coarser mesoscale model forecasts, but still lags the skill of a radar extrapolation nowcasting technique.

1. INTRODUCTION

There are two primary classes of precipitation nowcasting: numerical weather prediction (NWP) and various extrapolation techniques. NWP models include dynamic physical processes to solve for state variables of the atmosphere. These processes result in the initiation of new precipitation and the decay of existing precipitation features. However, NWP forecasts are not the best choice for short-term forecasting (nowcasting) of precipitation because of the scales represented by the relatively coarse grid spacing and the time required for the forecast computations.

Methods of pure time extrapolation using a series of observed precipitation measurements or radar mosaics generally produce much more accurate forecasts in the 0-3 hour time frame, with skill dropping to that of NWP models near the 6 hour forecast (Lin et al. 2005). One such scheme for precipitation nowcasting is the McGill Algorithm for Precipitation nowcasting by Lagrangian Extrapolation (MAPLE), developed at McGill University (Turner et al. 2004). This algorithm has been used operationally by Weather Decision Technologies, Inc. (WDT) since 2003.

A new technique for short-term forecasting (nowcasting) of precipitation has been developed by McGill University, which bridges the gap between these two methodologies. The Adjustment of Rain from Models with Radar (ARMOR) algorithm builds upon the MAPLE algorithm, using a high-resolution NWP model as the background for the precipitation forecast. The resulting ARMOR precipitation forecast is a radar-corrected NWP forecast. WDT has exclusively licensed the ARMOR algorithm and implemented it in an operational mode to evaluate its usefulness.

2. ARMOR OVERVIEW

2.1 Model Specifications

ARMOR requires two input data types: a precipitation forecast from a NWP model and a series of radar mosaics over the same domain. WDT uses a customized implementation of the Weather Research and Forecasting (WRF) model with advanced data assimilation, running with 12 km grid spacing over the contiguous United States (Shaw et al. 2008). A 12-hour WRF forecast is produced every hour with 15 minute output of accumulated precipitation.

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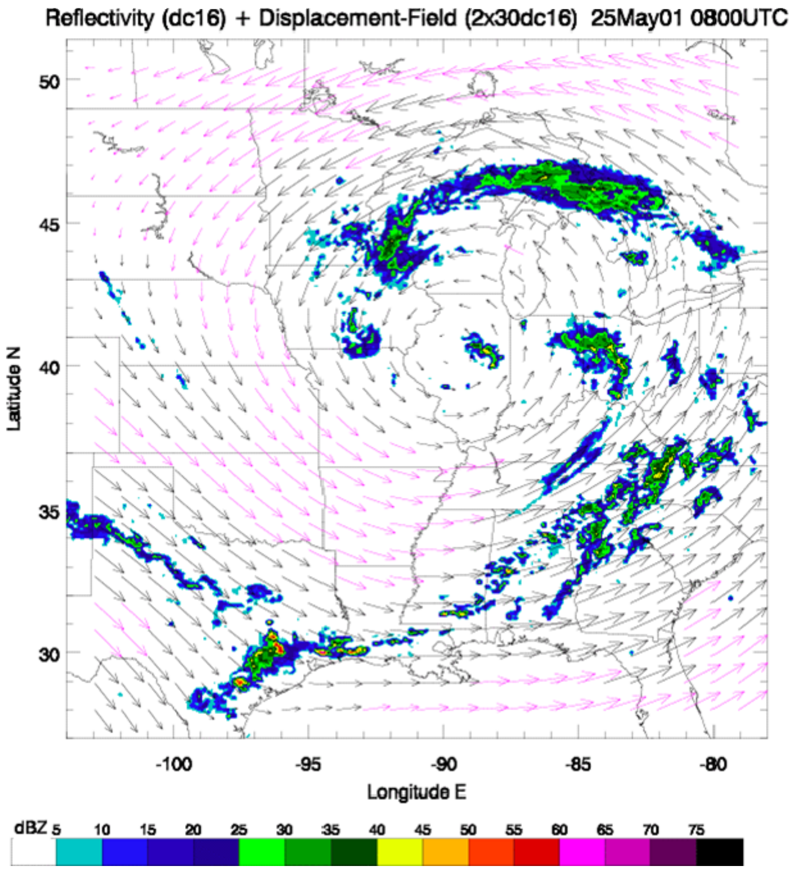

Figure 1. Example radar reflectivity field with corresponding motion vectors derived with the VET module. The pink arrows represent vectors that were estimated because no precipitation was present.

The other input is WDT's national radar mosaic, which has been quality controlled and cleaned using techniques licensed from the National Severe Storms Laboratory in Norman, Oklahoma. The radar mosaics are produced every 5 minutes at 1 km grid spacing.

The ARMOR forecast is run every 15 minutes, producing a 10 hour forecast of average precipitation rate. The average precipitation rate is given for every 15 minutes of forecast time and is available at 5 km grid spacing. This resolution was chosen as an average between the resolutions of the two data sets being used for input. ARMOR could be run at higher resolution, but the grid size is limited by the number of computations required.

2.2 VET algorithm

The foundation of the MAPLE and ARMOR forecasts is the Variational radar Echo Tracking (VET) algorithm. This algorithm is used to compute the displacement of recognized features from identical grids. When the two compared grids are from consecutive times, the displacement is considered to be the average motion vector over the time spanned by the grids (See Figure 1). When the two grids are a forecast field and a verification field for the same valid time, the displacement vectors are taken to be the phase errors for the forecast. The ARMOR forecast utilizes both of these comparisons to generate the error corrections that are to be applied to the model forecast.

Correction of initial intensity errors				
Radar: $R(t_o, s_i)$	Model: $M(t_o,s_i)$	Model: $M(t_1, s_i)$	Corrected	
No rain	Rain	Rain or no rain	No rain	False Alarm
Rain	No rain	No rain	$R(t_o, s_i)$	Miss, Persistent
Rain	No rain	Rain	$M(t_1, s_i)+ R(t_o, s_i)$	Miss, Growth
Rain	Rain	Rain	$M(t_1,s_i)+ R(t_o,s_i)- M(t_o,s_i)$	Persistent Rain
Rain	Rain	No rain	$R(t_o, s_i)- M(t_o,s_i)$	Decay
No Rain	No Rain	Rain	$M(t_1, s_i)$	Initiation
No rain	No rain	No Rain	No Rain	No Rain

Figure 2. Intensity correction applied to model forecast at time t_1 using the radar precipitation at initial time [$R(t_o,s_i)$], model precipitation at the initial time [$M(t_o,s_i)$], and the model precipitation forecast at time t_1 in the forecasted location s_i [$M(t_i,s_i)$].

2.3 ARMOR forecast process

The final ARMOR forecast is the WRF precipitation forecast, mapped to a 5 km grid, with phase and intensity errors corrected. The radar mosaic field is compared with the WRF precipitation forecast field for the first hour of forecast time, to determine these errors. Therefore, the ARMOR forecast is generated using a WRF forecast that began 1 to 2 hours before the ARMOR forecast base time. The ARMOR forecast is produced following these steps:

1. Radar reflectivity is mapped to the ARMOR forecast grid, converted to precipitation rate and accumulated to 15 minute time intervals.
2. The WRF precipitation accumulation is mapped to the ARMOR forecast grid and converted to precipitation rate.
3. Phase error is determined using the VET algorithm on the model and radar precipitation fields at t_0. The phase error is then applied to the forecast to test the skill of the correction. Assuming the corrected forecast matches the verifying radar field reasonably well, the forecast process continues.
4. The VET algorithm is used to compute 15 minute motion vectors over the past hour for both the model forecast and the verifying radar, separately.
5. The VET algorithm is used to compute phase errors over the last hour using radar and model fields at corresponding times.
6. A trend of phase errors is computed for the progression of phase errors.
7. Motion vectors are determined for all future model forecast times using the VET algorithm.
8. The ARMOR forecast is generated:
   a) Intensity correction is applied to the model forecast, using corresponding pixels in the model and radar at t_0 (See Figure 2).
   b) The forecast is corrected for phase errors using the phase error trend determined in step 6.

The ARMOR forecast is run every 15 minutes, using the latest completed WRF forecast. In operational implementation, the processing that requires only the WRF forecast field is separated from the other ARMOR forecast processing and run each time that a new WRF forecast is available. This portion of the forecast takes as much as 15 minutes on a single Intel Xeon 3.2 GHz processor with 16 GB of RAM. By removing the WRF processing, the ARMOR forecast can be produced in just 2.5 minutes, using the latest complete WRF forecast.

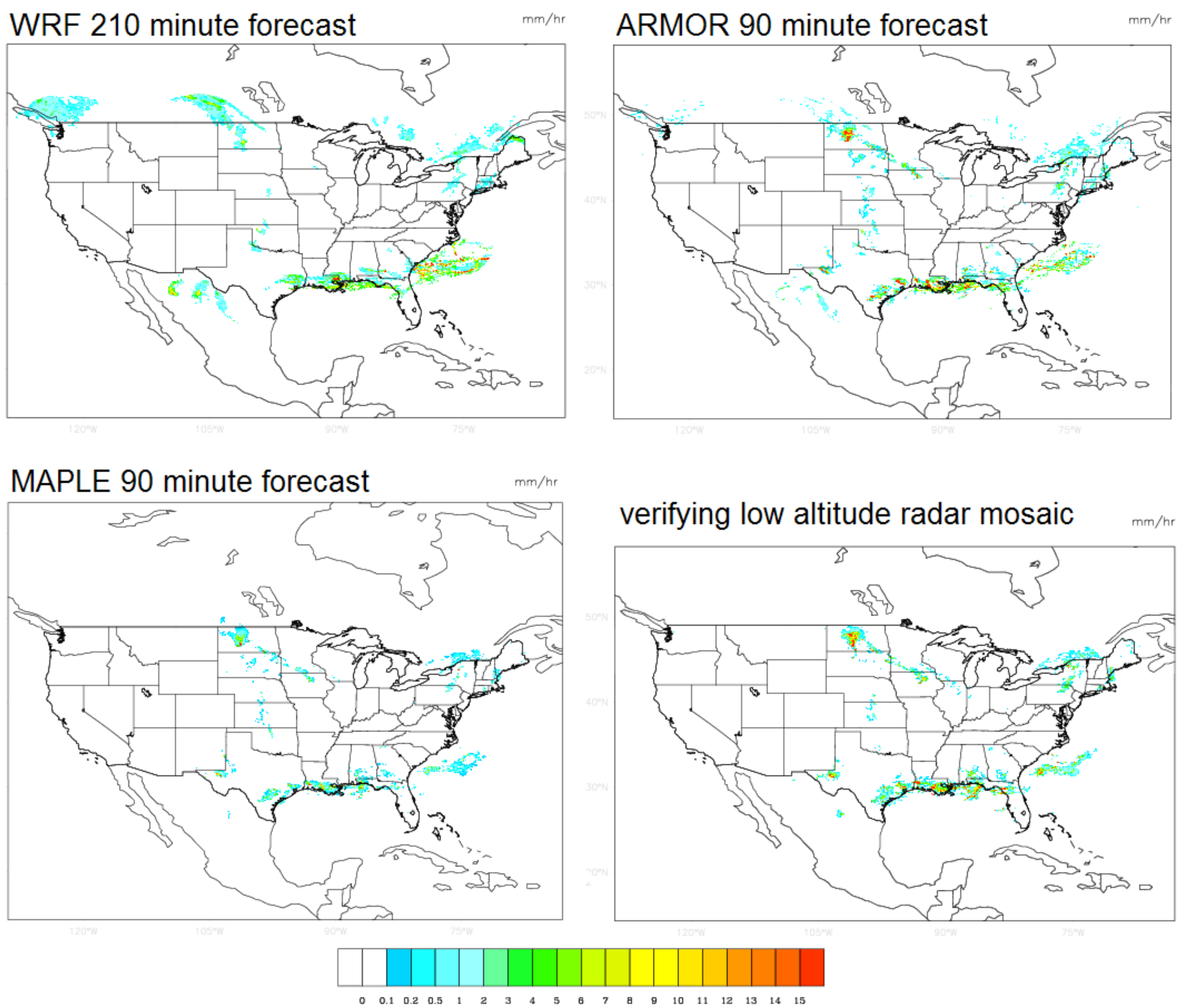

Figure 3. Example forecasts of precipitation rate along with the verifying radar grid at 2009-07-07 1230.

2.4 Forecast examples

Figure 3 shows the forecasts of ARMOR, MAPLE and WRF, along with the radar mosaic for the same time. The ARMOR and MAPLE forecasts are 90 minute forecasts and the WRF forecast is a 210 minute forecast.

The wide band of precipitation that stretches along the Gulf of Mexico coastline is forecast reasonably well by all three models, but the ARMOR forecast appears to match the areas of high intensity most closely.

Additionally, the ARMOR forecast most closely matches the convection in North Dakota. Notice that the ARMOR forecast of intensity for this precipitation feature is much improved over the WRF forecast for this same feature. Because the WRF forecast is produced on a coarser grid, the areas of heaviest intensity are effectively dampened.

The WRF forecast shows broad regions of light precipitation in the Northwest and northern Midwest that do not appear in the verifying radar image. Some of this potentially spurious precipitation is included in the ARMOR forecast, but is reduced from the WRF forecast. Additionally, there are areas of precipitation at the farthest extent of the radar domain, where the WRF forecast might reasonably match the precipitation field, but the region is not well sampled by the radar network used for verification.

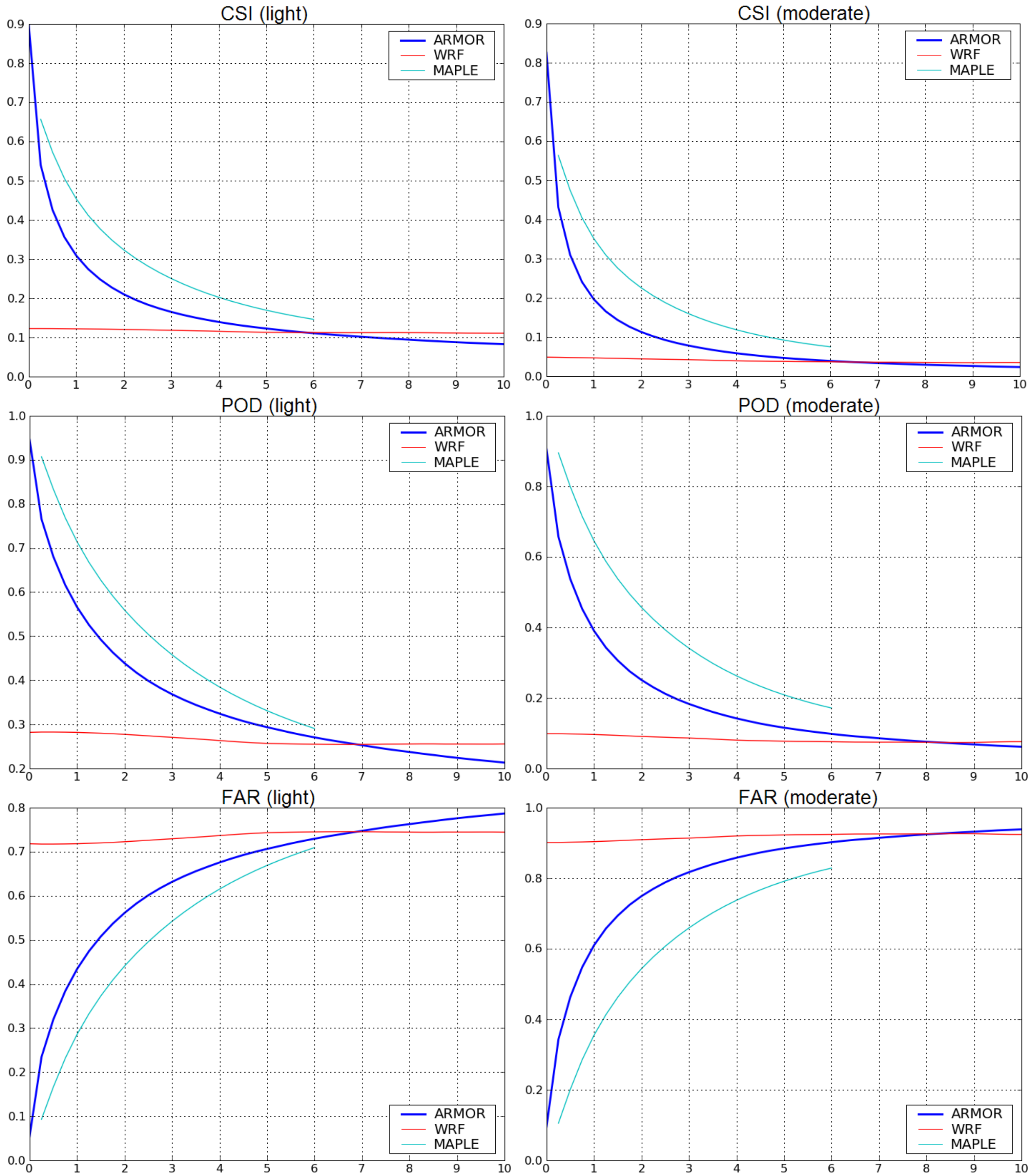

Figure 4. Verification statistics plotted with respect to forecast time (hours). The plots labeled "light" use the precipitation threshold of 13.5 dBZ. The plots labeled "moderate" use the 30 dBZ threshold. These statistics were compiled over a 10 day period ending 2009-07-06, in which 855 WRF and ARMOR forecasts were compared with 932 MAPLE forecasts.

3. FORECAST VERIFICATION

Over the past several months, WDT has carried out extensive evaluation of the three precipitation nowcasts: ARMOR, MAPLE and WRF. Forecasts are verified with the radar reflectivity field converted to 15 minute average precipitation rates. The coverage of the radar mosaics is superior to any observations of precipitation in both time and spatial scales, even though it is not a perfect representation of the precipitation field. The main detraction of using this field as truth is the perceived lack of skill for numerical models over complex terrain. In these areas, terrain may block the line of sight from radars to precipitation, resulting in inflated false alarms for forecasts that predicted rain in those locations.

The MAPLE and WRF forecasts have been scored on the same temporal and spatial grid as the ARMOR forecast. The MAPLE forecasts of radar reflectivity (dBZ) are available every 5 minutes on a grid at 1 km resolution. These forecast grids have been mapped to the 5 km ARMOR grid, using a spatial average of surrounding points. The MAPLE forecasts have also been converted to precipitation rate and averaged to 15 minute intervals. The WRF forecasts are remapped using the nearest neighbor to each ARMOR grid point.

The precipitation forecasts have been scored using a precipitation threshold to compile a contingency table. This study includes a light threshold of 13.5 dBZ (0.254 mm/hr) and a moderate rain threshold of 30 dBZ (2.73 mm/hr). Therefore, a "hit" means that both the forecast and radar grids had precipitation values at or exceeding the threshold value. The contingency table is determined for each model at each grid point inside the radar domain.

Figure 4 includes critical skill index (CSI), probability of detection (POD), and false alarm ratio (FAR) statistics for the three precipitation forecasts. The ARMOR forecast shows considerable improvement over WRF out to at least 6 hours. ARMOR has higher CSI and POD and a lower FAR. Like most nowcasting techniques, ARMOR demonstrates the rapid decrease in skill over the first couple of hours, contrasting the consistent skill of WRF over the forecast period. The large extent of precipitation in the WRF forecasts is reflected in the high FAR.

For precipitation at or exceeding the moderate threshold, the skill decreases for all models. WRF experiences the greatest loss of skill for higher precipitation thresholds, giving ARMOR an advantage over WRF for as much as 7.5 hours. At a grid spacing of 12 km, WRF is more likely to produce widespread, low-magnitude precipitation than heavy, localized convection. After the corrections are applied to the WRF forecast, ARMOR matched the radar field of precipitation much more closely, including areas of high intensity. For all statistical measures, MAPLE is still a superior tool when compared to ARMOR and WRF.

MAPLE forecasts have previously been compared with other NWP model forecasts, yielding similar results (Lin et al. 2004). That study noted the time at which the NWP model skill exceeded that of the MAPLE forecast. Using a scoring threshold of 0.1 mm of precipitation, the cross-over point for POD was 5-6 hours and the cross-over point for CSI and FAR was 7-8 hours. The results of this study show that the MAPLE forecast skill exceeds that of WRF for the entire 6 hour MAPLE forecast period.

The previous study found no variation of cross-over time with varying thresholds. This study shows that the cross-over time for ARMOR can be as great as 1.5 hours for the POD and FAR and 0.5 hours for the CSI, when the threshold varies between light and moderate thresholds.

From a qualitative standpoint, ARMOR forecasts precipitation patterns very well when the features are mesoscale or larger. ARMOR forecasts are superior to WRF precipitation forecasts for the first 6 hours of forecast time, by reducing the areal extent of precipitation and increasing the intensities of specific locations. However, the WRF forecast does remain superior to ARMOR in the final hours of the forecast period.

ARMOR also offers some aspects that are not available in the MAPLE forecasts. Convective initiation often occurs in areas where ARMOR develops new precipitation echoes. ARMOR demonstrates some skill in producing growth and decay of existing precipitation features, which was the impetus for developing ARMOR. While the exact location and timing of the convection may not be perfectly forecast, an experienced forecaster can use ARMOR to determine areas where convective initiation, growth or decay is likely.

4. CONCLUSIONS

The goal of the ARMOR forecasts was to enhance the nowcasting skill of MAPLE by including changes to the intensity and shape of precipitation echoes with time. By correcting the WRF precipitation forecasts to more closely match the first hour of radar return, the ARMOR forecast has greatly increased skill in the first six hours, but is still inferior to the skill of MAPLE. The ARMOR forecast is a compromise between the two technologies of which it is composed, but does not represent the best aspects of each forecast.

MAPLE has an intrinsic advantage over ARMOR in that the temporal and spatial resolutions are finer. Additionally, MAPLE forecasts have been found to be more skillful than ARMOR in a statistical sense, even though ARMOR includes dynamic processes. ARMOR is a useful tool as a corrected NWP model forecast of precipitation, but adjustments will need to be made for ARMOR to become a useful tool for precipitation nowcasting. The temporal resolution of ARMOR is tied to the output of the background mesoscale model (WRF), but the spatial resolution could be improved in two different phases. ARMOR could be run at higher resolution over a regional area and could also use a WRF model forecast with finer grid spacing. This would make ARMOR more skillful and more equivalent to the MAPLE product. WDT has setup a US Southern Plains WRF domain with 3 km grid spacing, for wind industry applications (Carpenter et al. 2009, this volume). This domain will also be used to test ARMOR at higher resolution.

Ideally, a precipitation nowcast would track individual storm cells forming, growing and decaying in time and space that closely matches the verifying radar. Presently, mesoscale models covering the continental United States are run with grid spacing on the order of 10 km. Smaller domains usually have a grid spacing on the order of 5 km. At this range, convection must be parameterized, and does not match realistic storm scale features. With the continual advancement of cumulus parameterizations and finer horizontal resolution model runs, ARMOR could begin to simulate individual cells much more accurately. With time, the skill of ARMOR could match and maybe exceed that of the MAPLE nowcasting algorithm.

Acknowledgements

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