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PERFORMANCE OF REAL-TIME AND POST-IHOP MESOSCALE MODELS IN DETERMINING STORM TYPE AND EVOLUTION FOR THE IHOP-2002 EXPERIMENTAL PERIOD

Edward J. Szoke*, Brent L. Shaw*, and John M. Brown
NOAA Research–Forecast Systems Laboratory, Boulder, Colorado
*in collaboration with the Cooperative Institute for Research in the Atmosphere (CIRA)

1. INTRODUCTION

During the International H2O Project (IHOP), held in the Kansas/Oklahoma area during the late spring of 2002, the NOAA Forecast Systems Laboratory (FSL) ran special configurations of the RUC (Rapid Update Cycle, Benjamin et al. 2004) and MM5 models in real-time to support IHOP forecast and nowcast activities, as well as to assess the ability of such models to capture the variety of convective storms that can occur in the Southern Plains in the spring. A new set of model runs was initialized every 3 h, and the runs for the most part extended through a 12-h forecast period. After an examination of the IHOP runs some changes were made to the MM5 model package, and it was rerun for the entire IHOP period at 6 h intervals. In addition, the WRF model, which had also been run for IHOP but unavailable in real-time, was similarly rerun.

A major focus of our evaluation of the model runs has been the prediction of convective initiation (CI), generally along drylines, as this was one of the key areas of focus for IHOP. In this paper, however, we examine the ability of the models to predict storm type, primarily the organization of convection into lines, and to a more limited extent, supercell storms. Selected graphics from all the model runs are available online at either http://laps.fsl.noaa.gov/forecasts/, or from UCAR's Joint Office for Science Support (JOSS) at http://www.joss.ucar.edu/ihop/catalog/index.html.

IHOP provided an excellent opportunity to test the different models for a wide variety of convective weather. Although the number of supercell storms during the IHOP period was somewhat lower than might be typical, there were several good events where convection organized into fairly long-lived lines. Five of the more notable cases are summarized in this paper, with one of the more complex cases (15 June 2002) covered in more detail.

The various models run by FSL for IHOP are summarized in Table 1. At the time of IHOP the RUC model had just become operational at a new horizontal grid spacing of 20 km, while the 10 km version had been used previously for PACJET in 2001. The RUC model run during IHOP employed a 3DVAR analysis for the mass fields, with initial RUC hydrometeor fields adjusted to correspond to base scan reflectivity patterns at the initial time, but without any modification of the initial vertical velocity field. The other models that were run were all initialized with the Local Analysis and Prediction System (LAPS) (Albers et al., 1996). Over the last few years, LAPS has been enhanced to provide a capability for initializing mesoscale numerical weather prediction models with clouds and precipitation present in the initial conditions (Shaw et al., 2001). This diabatic initialization procedure has been referred to as the “Hot Start” technique.

The basic technique involves the use of the three-dimensional LAPS cloud analysis, which includes all microphysical species (Schultz 1995) to diagnose estimated vertical velocity profiles based on cloud type, depth, horizontal scale, and stability criteria (Schultz and Albers, 2001). These estimates are then used as constraints in a three-dimensional variational (3DVAR) step along with a first-guess field, the LAPS univariate temperature, moisture, height, and wind analyses, to provide initial conditions for the model that are in dynamic balance with the observed cloud field while maintaining consistency with the observations. The LAPS method of balancing the dynamic fields with the cloud analysis is described in McGinley and Smart (2001). What makes LAPS unique in this application is its ability to use virtually all operationally available sources of meteorological information, including wideband WSR-88D data and GOES imagery, in a computationally efficient manner.

For IHOP the Hot Start technique was used to initialize a nested MM5 domain at 12-km grid spacing for the outer grid and 4-km grid spacing for the inner grid (Fig. 1). A similar setup was used for the WRF model, but the output was not able to be formatted correctly to display in real-time during IHOP (Shaw et al., 2004). Since the completion of IHOP, analysis of the runs has indicated areas where the forecasts could be improved by some changes to the hotstart scheme. The main focus of these changes was to reduce often excessive forecast precipitation, and to improve the ability of the model to keep storms that were initialized correctly by the Hot Start procedure, but often lost quickly in the first hour of the simulation, effectively

Corresponding author address: Ed Szoke, NOAA/OAR/FSL, R/FS1, 325 Broadway, Boulder, CO 80305; e-mail: Edward.J.Szoke@noaa.gov

Table 1. FSL IHOP numerical models							
Model	**Horizontal grid**	**Vertical levels**	**Run every x h**	**Forecast duration (h)**	**Convective scheme**	**Microphysics scheme**	**Uses Hot Start?**
Models run in real-time during IHOP							
MM5	4	34	3	12	None	Schultz	yes
MM5	12	34	3	12	Kain-Fritsch	Schultz	yes
RUC	20	50	3	6 to 24	Grell-Devenyi	RUC/MM5 Mixed Phase	no
RUC	10	50	3	6 to 24	Grell-Devenyi Ensemble Closure		no
Models run after IHOP (reruns)							
MM5	12	42	6	12	None	Schultz II	yes
WRF	12	42	6	12	None	NCEP 5-class	yes

canceling the benefits of the hotstart method. The 12 km horizontal grid resolution models for both the MM5 and the WRF were rerun for the entire experiment with the adjustments, and with the major change of eliminating the convective parameterization scheme.

The model forecasts were made available to forecasters and nowcasters supporting the IHOP field operations via FSL's FX-Net software installed on ordinary PCs. This AWIPS-like configuration allowed one to overlay the model fields, at hourly intervals for MM5 and 3 h intervals for RUC, with observed data and/or satellite and radar imagery. FX-Net PCs were set up in a room (the Scientific Support Area, or SSA) adjacent to the NOAA Storm Prediction Center (SPC) operations, at the IHOP operations trailer a short walk from the SPC, and at a key IHOP radar site known as S-Pol in the Oklahoma Panhandle.

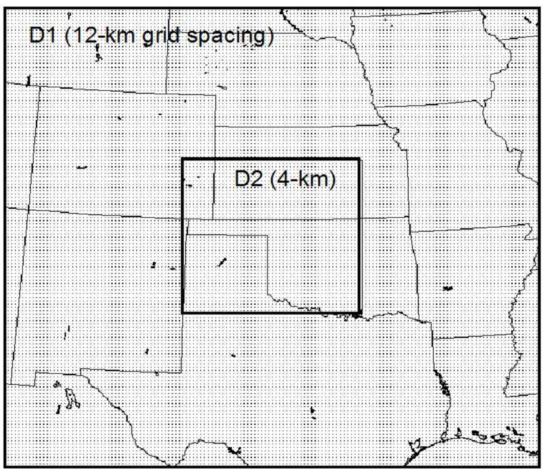

Fig. 1. MM5 domain used for the IHOP field experiment. Grid-spacing on the outer domain is 12 km. The inner nest (box in center of figure) utilized 4 km grid spacing.

2. STRATEGY

The model runs for IHOP have been and are being evaluated in a number of ways. The quantitative precipitation forecasts (QPF) were verified against point observations and the NCEP Stage IV precipitation analyses via FSL's Real-Time Verification System (RTVS) (Mahoney et al., 2002). A subjective study of model performance for CI along drylines has been done by Szoke et al. (2004). In the current study we undertake a subjective evaluation of how well the models were able to forecast, generally in the 3-12 h range, the upscale growth of convection into lines. A more general quantitative study examining the ability of the models to forecast both linear and other (MCS, MCC) organized structures using the Ebert-McBride technique has been undertaken by Grams et al. (2004).

Here we take a more limited look at a subset of these convective types. Current operational models available to forecasters are generally not able to predict the details of convective evolution. This is only partly a result of horizontal grid spacing, with differing treatments of basic model formulation, numerical diffusion, and model physics all contributing. Since the models run for IHOP are experimental, (the RUC is operational but at a 20-km horizontal grid spacing at this time) we were able to use a variety of configurations different from the operational NCEP Eta and GFS models. This gives the opportunity to better tune a particular model for forecasting convection, as well as to output new fields for forecaster evaluation, such as reflectivity, which was available from the MM5 and WRF models.

Thus far five cases where extensive (at least 200 km in length) convective lines persisting for at least several hours have been examined in detail. There are likely other cases during IHOP that would meet this criteria, and we hope to examine these before the conference. Additionally, this current work does not address the issue of false alarm forecasts of upscale growth, and we hope to conduct a more systematic look at the model forecasts to identify how often this was an issue. The issue of supercell prediction is not as straightforward, and will be examined mainly for our more extensive case study from 15 June 2002.

The procedure was to compare model forecasts of reflectivity with observed composite low-level reflectivity available at hourly intervals for all of IHOP on the JOSS and FSL web pages. A "standard" model reflectivity forecast that was archived for all of IHOP from the MM5 and WRF models consisted of a display of surface reflectivity in contour form on an image of column-max radar reflectivity. A comparison of observed versus model radar reflectivity, rather than precipitation, was used for this study since, 1) we were interested in whether the model could resolve certain convective structures, 2) the observed field of reflectivity was readily available and avoids some of the issues of representativeness associated with observed precipitation fields, and 3) more could be learned about what the model was forecasting through the use of its reflectivity forecast. For instance, using the combined column-max and surface reflectivity output, one could see instances where the model might be generating echoes through the microphysics scheme, but the echoes were not becoming strong enough to produce explicit precipitation (and hence surface reflectivity). The effects of a convective parameterization scheme could then be examined for such cases, since when such a scheme was used (see Table 1) precipitation could be generated without the presence of surface echo. Examples will be shown in the following discussions.

For the RUC model a reflectivity field was not output, so the "convective cloud top height" field was substituted where possible. This gave a rough indication of the predicted mesoscale organization of the convection.

3. IHOP CASES OF CONVECTIVE LINES

Four of the five cases where convective lines were observed in IHOP are discussed briefly below. One case, a rather complex evolution of events on 15 June, is discussed in more detail.

3.1 *16-17 May 2002*

This was the first operational IHOP day, with the focus on the potential for strong convection to develop along a dryline over the far western portion of the IHOP domain. Several strong storms did develop over the Oklahoma and Texas Panhandles, extending into extreme Southeast Colorado, late in the afternoon of 16 May. These storms, some of them supercells, moved east during the evening, with the complex of storms evolving into a line after 0600 UTC (17 May) in west-central Oklahoma. This line then grew in extent, with a solid bowing line of echo 50 dBZ and higher extending for over 200 km in length across southeastern Oklahoma by 1000 UTC, with an extensive trailing stratiform precipitation region. The system became more linear as it exited Oklahoma around 1200 UTC and was still a strong line stretching from central Texas northeastward across Arkansas at 1500 UTC.

The RUC model was not available for this case, but otherwise the IHOP MM5 runs and the reruns of MM5 and WRF are mostly complete. In terms of the supercell storms, none of the 12-km grid resolution models were able to forecast any such activity, although there were forecasts of isolated but shorter-lived cells in the Texas and Oklahoma Panhandles. (For the purposes of deciding whether the model was forecasting or attempting to indicate the possibility of supercell type storms, we examined characteristics of the model surface reflectivity field, including duration of an echo, movement of a longer-lived cell that deviated from the motion of other cells or expected storm motion, and splitting echoes. While certainly not a perfect substitute for a more comprehensive examination of velocity and other reflectivity fields for determining supercell storms, this method was viewed as sufficient for the purposes of this study, and probably more appropriate given the resolution of the models.) The horizontal grid scale of 12 km is acknowledged as being rather large for the modeling of individual storms (although some success for supercells has been shown by Szoke et al., 2000 for a 10 km version of the MM5), and this case does provide a very nice example of what can be gained by finer resolution by comparing the results from the MM5 4-km runs. This contrast is shown in Fig. 2, where a comparison is made between 9-h forecasts from the 1800 UTC runs of the two IHOP MM5 models. The isolated storm in the northeast corner of the Texas Panhandle in the observed reflectivity field (Fig. 2c) was a supercell storm that had developed over the western portion of the Texas Panhandle over 3 h earlier. The weak above-surface echo in the MM5/12 km run (Fig. 2b) that is near the location of the supercell has continuity and can be traced back to an echo developing in the western Texas Panhandle, so it is believed to be the model's simulation of this storm. The stronger echo just to the east actually developed nearly in place and was drifting slowly to the south. By contrast, the MM4/4 km (Fig. 2a) forecast indicates a strong isolated storm in fairly close proximity to the one that is observed. This storm can be traced back to an initial cell developing around 2300 UTC over the extreme western Oklahoma Panhandle. Furthermore, the storm continues moving somewhat to the right over the next 3 h and is close to where the observed supercell is located at 0600 UTC. The position of the forecast storm at 0300 UTC is farther west (lagging) the observed cell, but overall this would

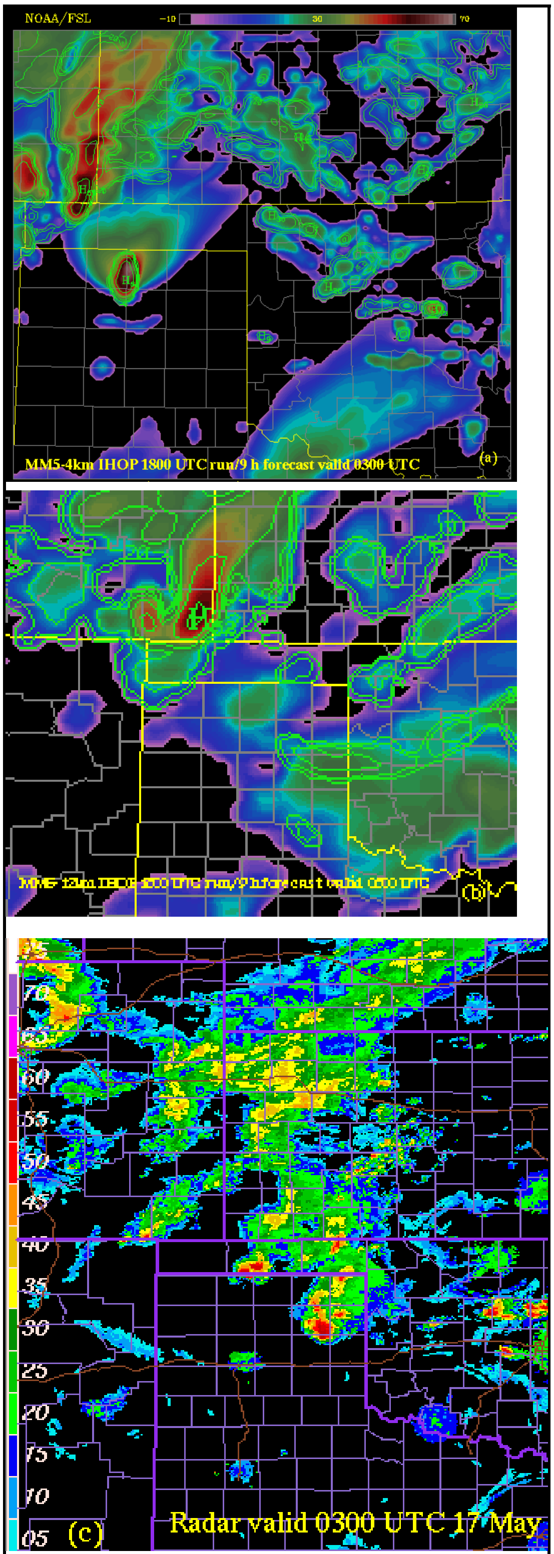

Fig. 2. 9 h forecasts from the 1800 UTC IHOP MM5 4-km (a) and 12-km (b) runs, with observed reflectivity (c) for 0300 UTC on 17 May.

be a useful prediction from a forecasting point of view, not only for indicating storm type but also for an actual prediction of this storm. For at least the scale of this supercell storm, the higher resolution of the 4 km run was needed for a successful forecast. The difference in resolution is also readily apparent when contrasting the character of the scattered, mainly weaker echoes farther east over Oklahoma and Kansas between the two runs.

In terms of the predictability of the line, the results were mixed. Both the IHOP runs and the reruns all predicted upscale growth to a line of some sort, but generally the line was too slow to organize and hence significantly displaced west of the observed line by about 200 km or more. The most successful forecasts were from the two 1800 UTC MM5 runs, which behaved somewhat differently from the other runs that were slower to evolve. In Fig. 2 the line is seen trying to form as it moves across extreme southeast Colorado. The 4 km run ended up organizing the activity emerging from Colorado shown in Fig. 2a into a solid north-south line centered on the eastern Oklahoma Panhandle by 0600 UTC. In reality, however, the actual line that ended up forming appears to have resulted from a combination of the storms moving east out of the Panhandle and additional strong storms to the east over Oklahoma, which were not captured in the model forecast. By missing these eastern storms, the MM5/4 km run essentially developed the line too far west, hence the westward displacement. The MM5/12 km IHOP run had a very similar forecast to the 4 km run. By contrast, the reruns (WRF and MM5) initialized at 1800 UTC and also run at a 12- km horizontal grid spacing, were quite different from the IHOP runs as both failed to produce much of a line at all, though at least in the case of the MM5, it did predict considerably more echo to the east across Oklahoma, so may have just been a little slow but on its way to a better forecast beyond 12 h. One major difference between the IHOP 12- km run and the reruns at the same resolution was that the convective parameterization scheme was turned off for the reruns. Overall, a prediction somewhere between that from the MM5 IHOP runs and the reruns would have been a better forecast than any of the individual runs themselves, suggesting potential value to an ensemble approach.

3.2 *23-24 May 2002*

The focus for CI was again into the Texas Panhandle region where very late afternoon and evening isolated storms developed, with one or two becoming supercells. In this case the models failed to capture any supercell development, with the lone exception again being the finer resolution 4-km run of the MM5 initialized at 1800 UTC. The supercells and other isolated storms that initially formed in the Panhandle moved east and organized into a small line in west-central Oklahoma by 0600 UTC, passing Oklahoma City around 0900 UTC, at which point the line had expanded northwards into western Missouri. By 1200 UTC it was mostly east of Oklahoma. Except for a period between about 0700 and 0900 UTC when the line bowed as it pushed across central Oklahoma, for the most part this was a straight southwest to northeast oriented line, not quite as intense as the one on 16-17 May.

As the line on this day developed, the main trailing stratiform region was in Kansas, with the Oklahoma portion a relatively thin line of strong echo that gradually diminished at the southern end of the line across southern Oklahoma. There was an interesting contrast in the runs for this case in that the models without a cumulus parameterization scheme for the most part failed to produce a line, or had a line only in Kansas, while the other models had relatively good forecasts. When the model runs were examined for CI along drylines, we noted that the models without a parameterization scheme tended to have more problems for cases where the forcing appeared to be somewhat weaker and/or convective development more limited in extent (Szoke et al. 2004). With the similar behavior here for a convective line that was more narrow across Oklahoma, we speculate that the grid spacing of 12 km under such conditions is apparently not sufficient to support sustained updrafts. Under these conditions the parameterization scheme enables the model to at least produce some precipitation. The MM5/4-km run from 1800 UTC did produce a nice line and, since this was run without a cumulus parameterization scheme it bolsters the argument that 12-km grid spacing, as has been generally suspected, is probably too large to capture at least some types of convective development.

3.3 *12-13 June 2002*

This was a major IHOP study day with an interesting small-scale low pressure center that held in place in the Oklahoma Panhandle, centered near the S-Pol radar. Scattered strong to supercellular storms developed by 2100 UTC and became quite numerous by 0000 UTC (13 June), with a broken line of storms extending from southeast Kansas back to the Texas Panhandle. By 0300 UTC the line was well-formed as it pressed south into Oklahoma, and shortly after this time it accelerated to the southeast, moving well past the IHOP Operations Center by 0600 UTC. Despite being quite strong at 0600 UTC and with a substantial trailing stratiform area, the line very quickly diminished after 0900 UTC and was essentially gone as it drifted into Arkansas by 1200 UTC, with the next line (discussed in Section 3.4) already forming in western Oklahoma.

In terms of the supercells, 0-6 h forecasts from the 1800 UTC runs varied considerably, with some of the runs predicting some long-lived isolated cells. The two reruns at 12 km grid resolution actually did have such storms, and in fact an error with both runs was that they persisted as isolated storms for too long. As with the other cases, the 4 km run had a greater number of individual cells, more realistic looking than the 12 km runs, but for the couple that were long-lived, shared the same problem of the storms persisting for too long.

In terms of simulating the upscale growth to a line, this was probably the most difficult of the cases for all the different model runs. In basically every case the models tended to organize the cells into an MCS that generally stalled over Oklahoma, rather than organizing into a progressive line. There was no improvement noted between the 1800 UTC runs and those initialized at 0000 UTC. It is possible the forcing was not sufficiently focused to support a line in the model forecasts.

3.4 *13 June 2002*

The next line closely followed the exit of the 12 June system, with a squall line passage by the Operations Center in the late morning hours (before 1800 UTC). The line originated from cells forming on the Palmer Divide east of Denver, Colorado late in the afternoon of 12 June, with these storms combining with other development in west-central Kansas during the night. Between 1200 to 1500 UTC on 13 June the main line quickly organized over western Kansas, and thereafter accelerated eastward. By 2100 UTC a bowed line extended across far eastern Oklahoma, southward past Dallas.

For this case runs initialized at 0000 and 0600 UTC were examined. Since the runs only extended out 12 h, this did not quite cover the organization into a line, but more an MCS, for the 0000 UTC runs. In general, most of the model runs showed such development, but most successful were the MM5/4 km run and the two reruns. So for this case it appears that parameterization was not a necessity, and this goes along with the idea that this was a rather extensive system, compared to some of the other cases. The details of the evolution of the convection did not always follow what was observed, but the resulting reflectivity forecast valid at 1200 UTC compared quite favorably to that observed for these three runs.

The pattern for the 0600 UTC runs followed that for the 0000 UTC runs except that the 4 km run developed more of an MCS than a line. This was also true for the RUC and IHOP MM5/12 km run. The MM5 rerun had some problems with loss of echo during the first hour after the Hot Start. However, it quickly recovered, resulting in a fairly good 12-h forecast, as shown in Fig. 3. The forecast tends to have more reflectivity at the northern end of the system and not enough of a line farther south. Close examination, though,

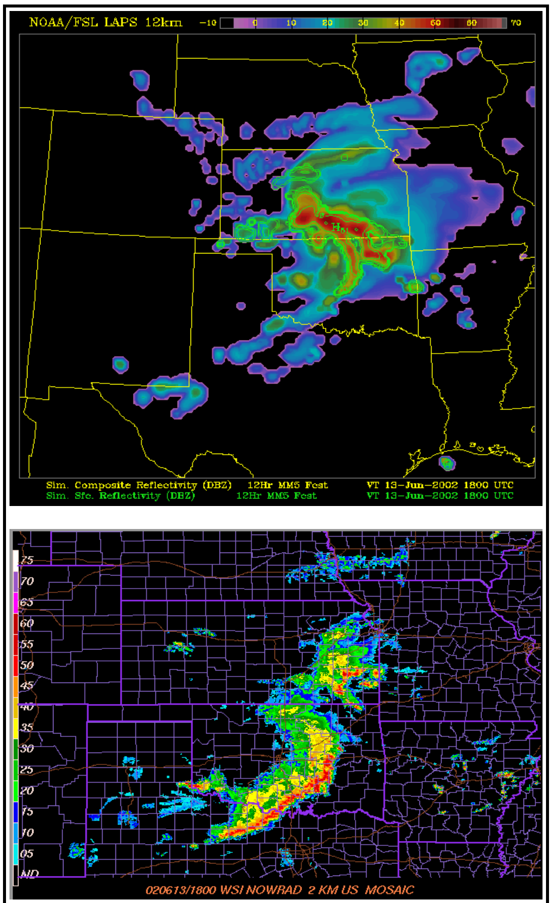

Fig. 3. MM5 12-km rerun 12-h forecast of surface (contours) and composite (image) reflectivity (top), and observed low-level reflectivity (bottom), both valid at 1800 UTC on 13 May.

reveals the MM5 did have a line of reflectivity aloft that agrees rather well with the observed position of the line. Similar to an earlier case, without a convective parameterization scheme the model has trouble resolving the line as it becomes narrower at its southern end.

3.5 *15 June 2002*

Another big day for IHOP came on 15 June. This case has just about every conceivable form of convection, from early morning elevated storms to an isolated supercell storm, and finally to the organization of convection from two areas into a long-lived accelerating line (Szoke et al. 2004). There are many interesting aspects of this case, and both the supercell issue and the upscale growth are examined here.

The first comparison is for a long-lived supercell storm that emerged out of a small group of cells developing on the morning of 15 June east of Colorado on the Palmer Divide. The evolution of this storm system is shown in the radar imagery in Fig. 4. After crossing into Kansas, the small echo complex strengthened and became a supercell storm, moving to the right of the mean flow as it traveled for the next 3 h south-southeast across western Kansas. The supercell eventually produced a tornado north of Dodge City, Kansas after interacting with a north-south dryline that was the focus of IHOP operations on this day.

For this case the MM5 4 km grid was outside the track of the supercell storm, and in the case of the RUC10, it was uncertain from the output available whether the storm was predicted, so in Fig. 4 we show the 12 km runs for this storm. Included in this figure are a pair of special runs that came from an initial set of reruns made after IHOP. The main difference between these two runs and the reruns that have been discussed so far (and labeled "final reruns" in Fig. 4) is that the convective parameterization scheme is turned on, as it was during IHOP, and in addition these first reruns went out to 24 h instead of 12 h for the IHOP runs and the final IHOP reruns. Note then that these special runs are initialized at 0600 UTC, versus 1500 UTC for the other runs shown, so these are considerably longer range forecasts. Also note that the images are reversed from the other model radar images in that the contours show the max column reflectivity and the image is for the surface reflectivity (red indicating echo ~ 50 dBZ or more). It is somewhat remarkable to consider how well the MM5 run was able to capture this storm, with a 15-h forecast valid at 2100 UTC that pretty well predicts the isolated storm's position in western Kansas. The WRF model to a lesser extent also forecast this storm, but it is not as isolated a storm in the WRF solution, nor quite as strong.

Considering the set of runs initialized at 1500 UTC, although they all end up producing a strong storm by 2100 UTC (or 2000 UTC in the case of the IHOP MM5 run), the forecast for the morning hours through 1800 UTC is not as good as with the runs from 0600 UTC. There does not appear to be a great deal of difference between the bottom three runs, except for a somewhat more concentrated echo for the two runs where the convective parameterization scheme was turned off. In comparison to the other cases discussed, this set of simulations was in general far more successful in replicating this supercell storm. We speculate that two features may have conspired to make it possible for a 12-km grid resolution model to be able to reasonably simulate a supercell. One is that the storm was very isolated, basically the only convection that developed and moved from eastern Colorado into western Kansas during this time. The other factor was the initial complex of cells was initiated as a surge of upslope flow following the passage of a cold front reached the higher terrain of the Palmer Divide, and high resolution models typically do a good job with orographic forcing.

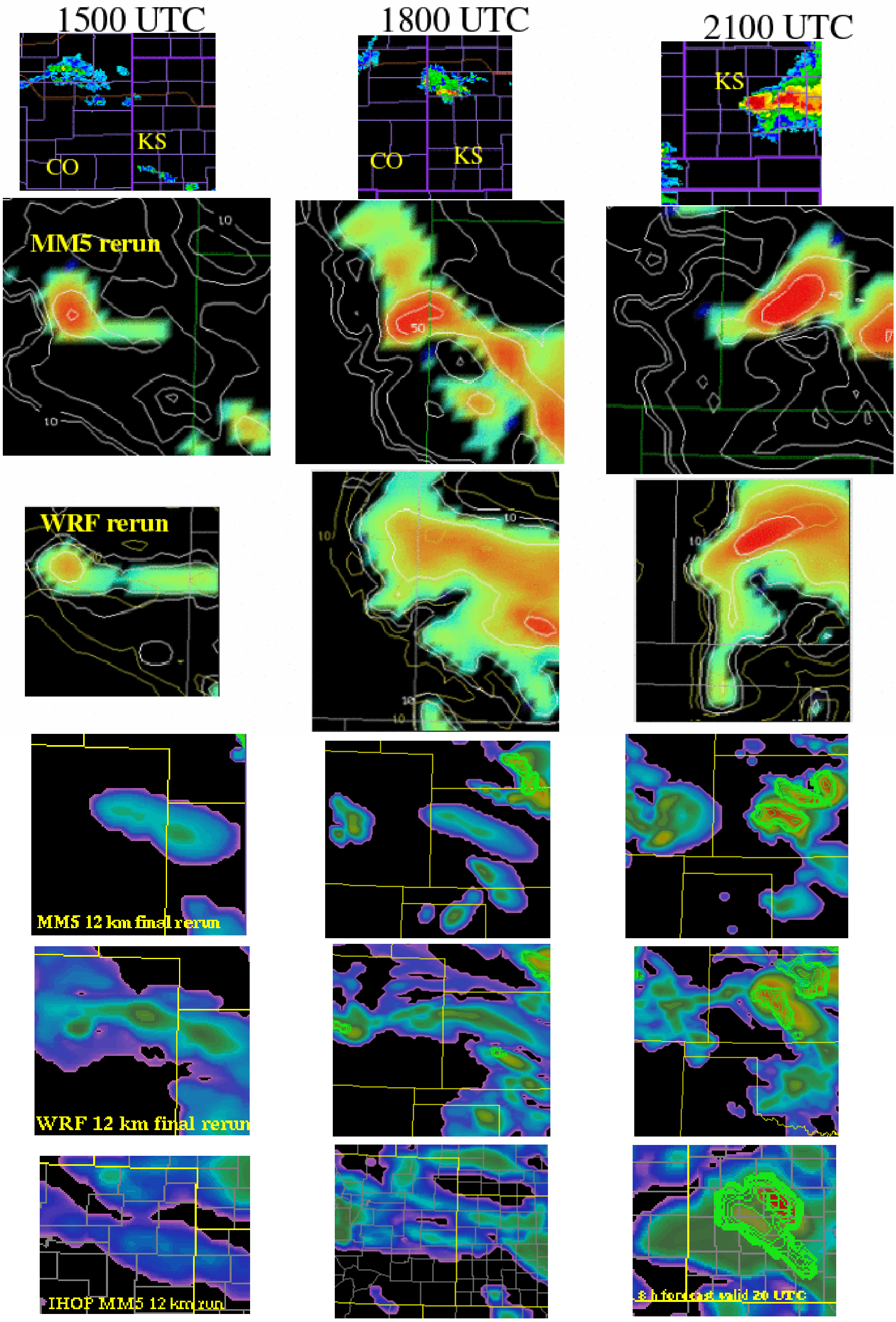

Fig. 4. Collection of forecasts for the simulation of the supercell on 15 June, the top two rows (MM5 and WRF rerun) are for a special rerun initialized at 0600 UTC, otherwise runs are initialized at 1500 UTC.

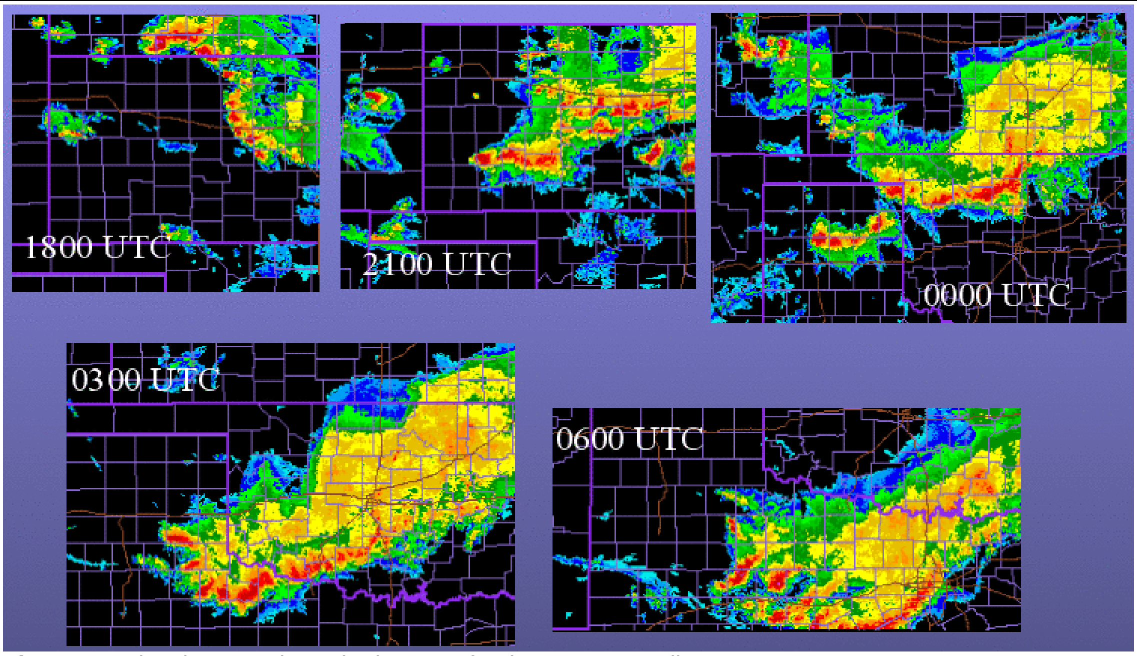

Fig. 5. Low-level composite radar imagery for the 15-16 June line.

Certainly a major event on this day was the eventual development of a strong line of convection that surged rapidly southward across Oklahoma, as shown in the time series of radar images in Fig. 5. The extensive line that had formed by 0300 UTC can be seen to develop from two separate areas. The main source of the line was from a large area of storms seen at 1800 UTC across parts of Kansas and Nebraska that organize into a broken ~east-west line in Kansas by 2100 UTC. This activity was at the leading edge of a southward moving cold front (the same front that had entered Colorado in the morning and pushed the upslope across the Palmer Divide, initiating the eventual supercell storm). There was also extensive thunderstorm activity in Nebraska well before the cold front pushed southward that developed north of a warm front that had been quasi-stationary across southern Nebraska from the previous night and through the morning hours of 15 June. A second area of storms developed ahead of the cold front near a dryline in the Texas/Oklahoma Panhandle region after 2100 UTC. As the front continued south, the two lines joined together, with the entire line then accelerating southward out of the IHOP domain by 0600 UTC.

We first consider the MM5 runs that were available to the IHOP forecasters, shown for the runs initialized at 1800 UTC in Fig. 6. Both the 12-km and 4-km MM5 produced a line in about the right location, with the line bowing southward with time. The 4-km run has a more bowed line that emerges much earlier and accelerates faster to the south, likely a result of a better representation of convection and stronger downdrafts. Still, even with its rapid acceleration to the south, the forecast line was always behind the observed line, though closer than in the 12 km forecast.

The 12-km reruns also initialized at 1800 UTC are presented in Fig. 7. Both the WRF and the MM5 runs produce a line with about the same timing. The MM5 forecasts a somewhat more extensive and bowing line, closer to what was observed, though again, in both cases, the line does not move fast enough to the south. A comparison of the IHOP MM5/12-km run and the MM5 rerun provides an opportunity to see if there are any effects from the cumulus parameterization scheme. The solutions for this case are very similar through 0000 UTC, thereafter the rerun, without the parameterization, has a somewhat more extensive line, and it is thus not surprising that by 0600 UTC it has accelerated the line farther to the south than the IHOP run. The small differences between these two solutions indicates that at least for this case of extensive convective development, more than likely the convection could be captured without invoking the convective parameterization.

In Fig. 8 a comparison is made between the IHOP MM5 runs initialized closer to the event, at 2100 UTC. The 2100 UTC forecasts end up being both better and worse than the runs that were initialized 3 h earlier. The MM5/4-km 2100 UTC run is not as good a forecast, as the cells never organize into a solid line, although the “broken line” of cells does end up being closer to the position of the observed line by 0600 UTC. It is likely that the 4-km forecast is adversely affected by the close proximity of the southern boundary to the active

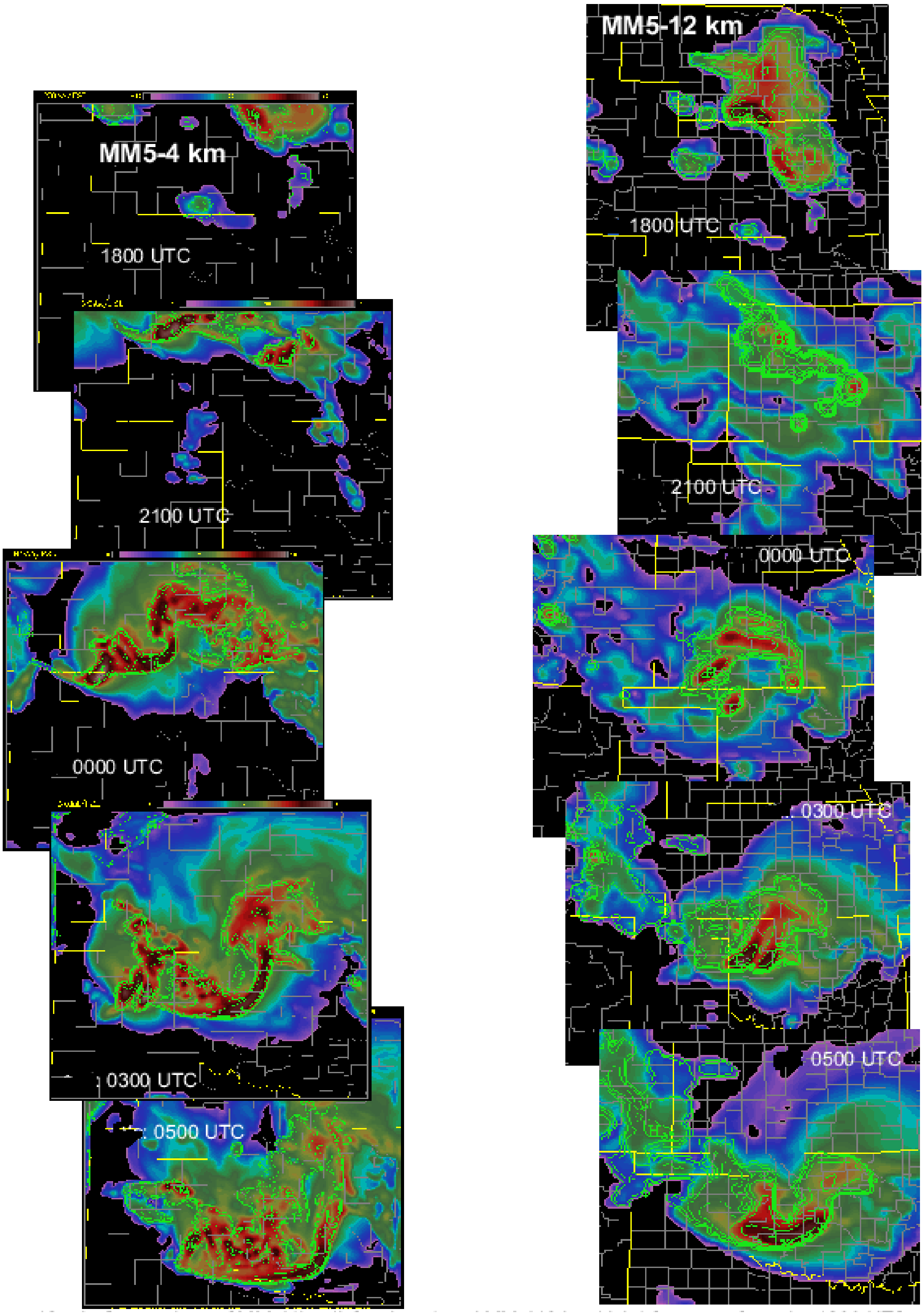

Fig. 6. Comparison of the IHOP MM5 4 and 12-km runs initialized at 1800 UTC on 15 June for the evolution of the convection to a bowing line on 15-16 June 2002. The 12-h forecasts valid at 0600 UTC were not available.

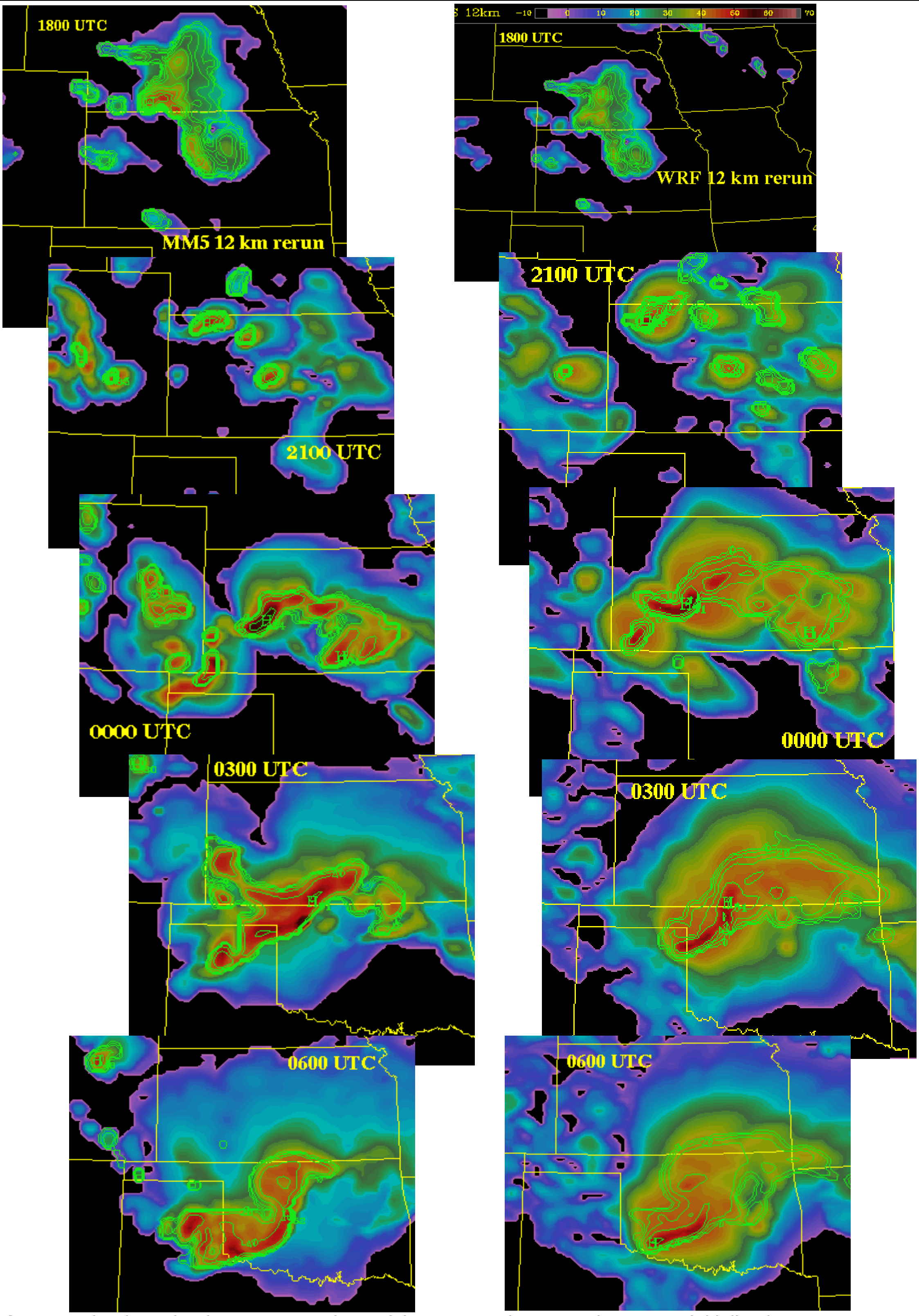

Fig. 7. As in Fig. 6, but here a comparison of the MM5 and WRF 12-km reruns initialized at 1800 UTC on 15 June for the evolution of the convection to a bowing line on 15-16 June 2002.

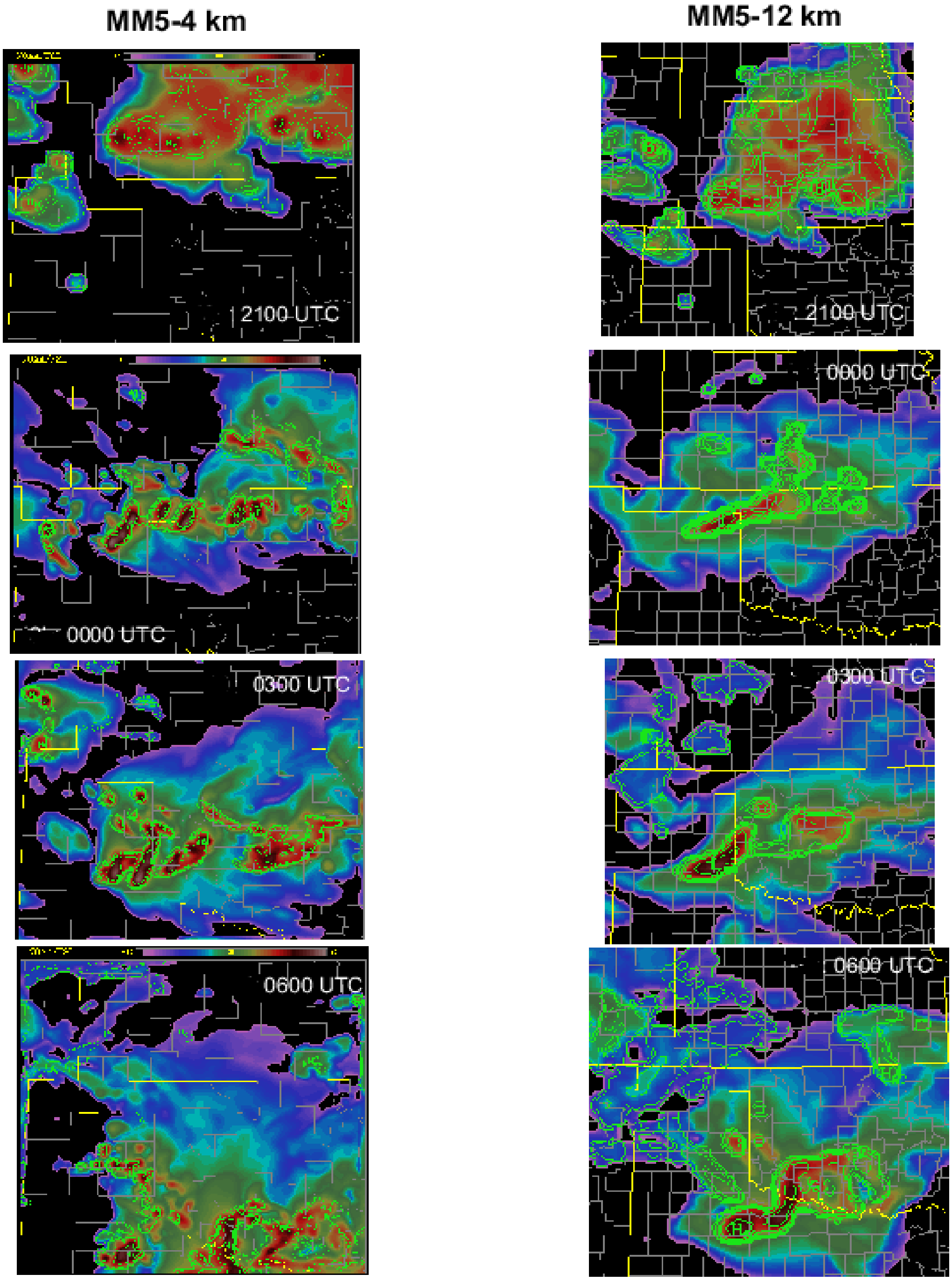

Fig. 8. As in Fig. 6, but here a comparison of the IHOP MM5 4 and 12-km runs initialized at 2100 UTC on 15 June for the evolution of the convection to a bowing line on 15-16 June 2002.

convection. On the other hand, the 2100 UTC MM5/12-km run actually develops a line more quickly than in the 1800 UTC runs, and by 0000 UTC is closer to what was observed than any of the other runs. Beyond this time the model is better able to keep up with the speed of the observed line, and the forecast position of the line is not far off the observed position by 0600 UTC.

The forecasts from the RUC10 (not shown) generally organized the convection into a line (as best as could be determined), but, similar to the other forecasts, it was not as extensive as observed, nor did the line accelerate southward as rapidly. Overall though, the models were mostly successful in being able to predict the upscale growth of convection into a linear feature, and provided useful forecast guidance. The more general success for this case is probably linked to the relatively well-defined main forcing feature, the southward-moving cold front. Nonetheless, convection that developed well ahead of the front added complexity to this case.

4. SUMMARY AND FUTURE WORK

Several cases of well-defined and long-lived convective lines from the IHOP period were chosen to determine how effectively the special model runs made by FSL were able to forecast the features. In all cases the lines grew from an organization of cellular convection over the period of the model forecasts (rather than a well-defined line simply moving across the domain), so the forecasts involved a prediction of upscale growth from scattered convection to a line. In a number of the cases, some of the pre-line cells were isolated supercell storms. The models in general appear to provide useful forecast guidance that indicated that convection would indeed organize into lines. The most difficult events were those where the observed line tended to be fairly narrow, in which case the 12 km grid resolution of the models appeared to be insufficient to capture the (apparent) more concentrated forcing with the line. In such cases having a cumulus parameterization scheme at this resolution helped to at least predict some precipitation along the more narrow parts of the line. More effective for this problem, though, was having a finer horizontal grid resolution, as the 4 km results indicate. In other cases, generally where the systems were broader in extent, the gain in predictability by reducing the resolution to 4 km was not as obvious.

The effects of horizontal grid resolution noted above were generally not the case for simulating supercell storms, with most of the storms for the cases studied generally missed by the 12 km grid resolution models, but at times captured by the MM5/4 km run. There was an exception to this, however, for the long-lived single isolated storm on 15 June, where it appears a resolvable forcing mechanism, upslope onto the higher terrain of the Palmer Divide, and perhaps the isolated nature of the particular storm, apparently conspired to allow some relatively successful forecasts at 12-km resolution and fairly far (more than 12 h) in advance.

Our results have shown there is often considerable variability among model runs for the same initialization time, and that the model verifying the best often changes from day to day. This suggests that an ensemble strategy of running several different high-resolution models might be of value over running just a single model. Results presented here indicate that an ensemble could be created by having different microphysics schemes, as well as considering explicit-only versus parameterized convection.

We have not addressed here the very valid question, often noted by forecasters, of false alarms. We hope to at least make a cursory examination of more of the IHOP period to see how often this was a problem. It his hoped that between this subjective type of evaluation and other studies employing more objective verification techniques, more improvements can be made to the Hot Start procedure as well as other aspects of the modeling system.

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6. REFERENCES

Albers, S., J. McGinley, D. Birkenheuer, and J. Smart, 1996: The Local Analysis and Prediction System (LAPS): Analysis of clouds, precipitation, and temperature. *Wea. Forecasting,* **11**, 273-287.

Benjamin, S.G., G.A. Grell, J.M. Brown, T.G. Smirnova, and R. Bleck, 2004: Mesoscale Weather Prediction with the RUC Hybrid Isentropic–Terrain-Following Coordinate Model. *Mon. Wea. Rev.*, **132**, 473–494.

Grams, J.S., W.A. Gallus, L.S. Wharton, S. Koch, E.E. Ebert, and A. Loughe, 2004: Use of a modified Ebert-McBride technique to verify IHOP QPF as a function of convective system morphology. *20th Conf. on Wea. Anal. and Forecasting/16th Conf. on NWP,* Seattle, WA, Amer. Meteor. Soc., J13.4.

Mahoney, J. L., J. K. Henderson, B. G. Brown, J. E. Hart, A. Loughe, C. Fischer, and B. Sigren, 2002: The Real-Time Verification System (RTVS) and its application to aviation weather forecasts. *10th Conference on Aviation, Range, and Aerospace Meteorology*, Portland, OR, Amer. Meteor. Soc., 323-326.

McGinley, J. A., and J. R. Smart, 2001: On providing a cloud-balanced initial condition for diabatic initialization. *14th Conference on Numerical WeatherPrediction,* Fort Lauderdale, FL, Amer. Meteor. Soc., 40-44.

Schultz, P. J., 1995: An explicit cloud physics parameterization for operational numerical weather prediction. *Monthly Weather Review,* **123,** 3331-3343.

Schultz, P., and S. Albers, 2001: The use of three-dimensional analyses of cloud attributes for diabatic initialization of mesoscale models. *14th Conference on Numerical Weather Prediction,* Fort Lauderdale, FL, Amer. Meteor. Soc., J122-124.

Shaw, B. L., M. Kay, J. Mahoney, J. McGinley, J. Smart, P. Welsh, A. Wildman, J. Savadel, P. Bogenschutz, and P. Ruscher, 2004: Applying the Weather Research and Forecast (WRF) model to National Weather Service forecast office operations. *20th*

Conf. on Wea. Anal. and Forecasting/16th Conf. on NWP, Seattle, WA, Amer. Meteor. Soc., P3.7.

Shaw, B. L., J. A. McGinley, and P. Schultz, 2001: Explicit initialization of clouds and precipitation in mesoscale forecast models. *14th Conference on Numerical Weather Prediction,* Fort Lauderdale, FL, Amer. Meteor. Soc., J87-J91.

Szoke, E. J., and A. Marroquin, 2000: Some remarkable supercell simulations from a quasi-operational local-scale model: Skill or "shear" luck? *Preprints, 20th Conf. On Severe Local Storms,* Orlando, FL, Amer. Meteor. Soc., 555-558.

Szoke, E. J., J. Brown, and B. Shaw, 2004: Examination of the performance of several mesoscale models for convective forecasting during IHOP. *20th Conf. on Wea. Anal. and Forecasting/16th Conf. on NWP,* Seattle, WA, Amer. Meteor. Soc., J13.6.