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CONVECTIVE FORECAST PERFORMANCE OF AN OPERATIONAL MESOSCALE MODELLING SYSTEM

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1. INTRODUCTION

In our continuing work on the implementation and applications of an operational mesoscale modeling system dubbed 'Deep Thunder", we examine its forecast performance for convective events over several geographic regions in the United States.

The *Deep Thunder* system has been running operationally since January 2001 at the IBM Thomas J. Watson Research Center in Yorktown Heights, NY. Operational model forecasts for the New York City metropolitan area (Treinish and Praino, 2004) were begun at that time. Model forecasts for the greater Chicago area were started in late February 2004 with the Kansas City metropolitan area being added in the spring of 2004. Finally, the Baltimore/Washington area was added in October 2004.

In order to evaluate the quality of the forecasts produced by Deep Thunder at a storm scale and its potential skill, we have examined a number of interesting cases for moderate and severe convective events in each of the four aforementioned geographies.

We will compare the model results with observational data as well as the operational availability of specific forecast products. Such performance is [1]examined by considering forecast timing, locality and intensity of the convective cases.

2. FORECAST MODEL DESCRIPTION

The model is configured in a full three dimensional, non-hydrostatic mode with two way interactive nesting for the three nested grids. For New York the horizontal grid resolution is 16km, 4km and 1km. for the three grids. Chicago, Kansas City and Baltimore/Washington use a grid resolution of 32km, 8km, and 2km. All four geographies utilize a triple nested model domain.

Figure 1 shows the modelling domain configuration for the four geographies relative to each other with domain boundaries marked in gray, magenta and white corresponding to each set of three nests. .

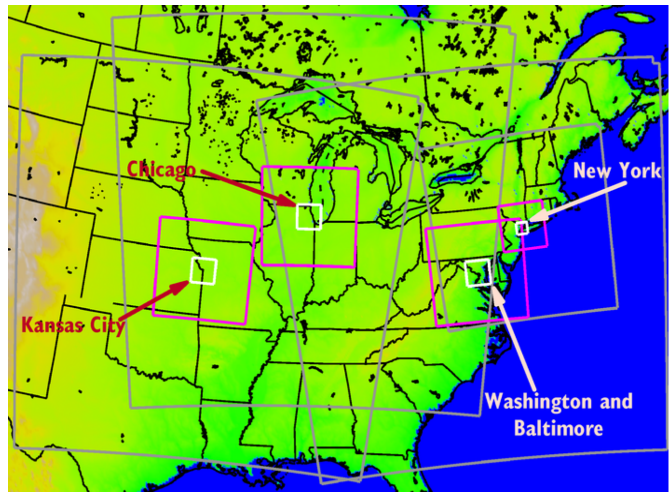

Figure 1. Model Domain Configurations

Domain grid sizing is 62 x 62 for the three nests in the New York geography, and 66 x 66 for the three nests in the Chicago,Kansas City and Baltimore/Washington geographies. Each nest employs a vertical grid using 31 stretched levels with a stretch factor of 1.12. The lowest level is 48 m above the surface with a minimum spacing of 100 m and a maximum spacing of 1000 m. The time steps of 48, 12 and 3 seconds for New York and 100, 25, and 6 seconds for Chicago and Kansas City were selected to ensure computational stability while also balancing the need to accommodate strong vertical motion that can occur during the modelling of severe convection.

The physical parameterizations used include the Mahrer-Pielke short and longwave radiation schemes, the Kuo convective scheme and explicit surface as well as a seven layer soil parameterization. Full cloud microphysics are included which contain five hydrometeor species to enable explicit prediction of precipitation.

Model runs were done once or twice per day for the Chicago, Kansas City and Baltimore/Washington areas and twice per day for the New York area. All model forecasts were

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for a 24 hour period. Model initial and boundary conditions were established after quality control and isentropic analysis on NCEP Eta forecast grids (See Treinish and Praino, 2004, Treinish, Praino and Tashman, 2005 for the details of the approach). Model lateral boundaries are nudged every three hours using Eta-212 grids. Static surface coverage data sets provided by the U.S. Geological Survey at 30 seconds resolution are used to characterize topography and vegetation. Lower resolution data sets are used to define land use and coverage as well as sea surface temperature.

All of the processing, modelling and visualization are completed in one to two hours on relatively modest hardware to enable sufficiently timely dissemination of forecast products for potential weather sensitive applications.

3. METHODS AND DATA SETS

Verification of individual convective events utilized objective methods for precipitation intensity, onset, and ending times by verifying against surface observations where available. Rainfall totals were verified by using NWS daily climate reports for selected locations as well as radar estimates and other reports (co-op, skywarn, hydrological) where available. Overall storm intensity, timing, and spatial extent were verified by comparing to available radar data.

From a quantitative standpoint the nature of the forecast model results (precision site-specific) was a determining factor in the methodology used for the evaluation of the individual cases. Model site specific forecasts were compared against available observations for those sites. For the four geographies examined in this study, the limited number of surface observation sites (Metar and other) introduces potential uncertainty in verification of model performance throughout the forecast domain as a result of the limited sample size and geographic distribution. Surface observations are reported on an hourly basis which limits the temporal resolution of the data. In addition there are variations in reporting times which affect the temporal precision of the measurements. Overall data accuracy and precision are limited by the sensor resolution and measurement error (Praino et al, 2003). The radar precipitation estimates used for comparison against the model predictions in the qualitative performance study are also potential sources of error (Bellon et al, 2002).

Specific verification sites were selected for locations in the 1 km nest for New York and the 2 km nests for Chicago, Kansas City and Baltimore/Washington. based upon the availability and continuity of observations.

4. EVALUATION OF SPECIFIC EVENTS

A total of seven convective events are examined distributed across the four model forecast geographies. Only cases which are defined as singular distinct events for a particular region are included. Convective events which were part of larger scale (synoptic scale, extra-tropical or tropical) systems are not included. [2]

Results are summarized in Table 1. The table shows the model predictions and observations for convective precipitation (defined as moderate to heavy) onset and ending times, accumulation as well as maximum wind speed. In the case of observed rainfall, the hourly reporting frequency limits the temporal resolution for observed onset and ending unless starting and ending times are explicitly reported. In the case of observed wind speed maxima the same temporal resolution constraints apply along with potential error introduced by using reported wind gust speeds for maximum winds in lieu of explicitly reported maximum wind speeds. For events that occurred across day boundaries model precipitation totals were taken as of midnight when compared against daily climate summaries used for observed totals. In cases where precipitation totals were not reported radar total estimated totals were used.

Precipitation onset errors were predominantly negative (13 of 16 cases) with model results lagging observed precipitation start time. The mean difference between model predicted precipitation onset time and observed onset time was 1.8 hours. The mean uncertainty in observation time for precipitation onset was 39 minutes.

Precipitation ending errors were also predominantly negative (13 of 16 cases) with model predictions of precipitation cessation after actual observed ending times. The mean difference between model predicted precipitation ending time and observed ending time was three hours. The mean uncertainty in observation time for precipitation cessation was 38 minutes.

The mean precipitation accumulation error was 0.6 inches. There were seven cases where the model underpredicted the total precipitation and 9 cases where the model overpredicted precipitation. Given the lack of uniformity in reported precipitation totals and the associated uncertainty, these results show considerable skill.

Table 1. Model Predictions and Observed Results

Model & Observation Data Location	Model Forecast Available	Model Precipitation Start Time	Model Precipitation End Time	Model Rainfall Total (inches)	Observed Precipitation Start Time	Observed Precipitation End Time	Observed Rainfall Total (inches)	Model Wind Max (mph)	Observed Wind Max (mph)
NY - LGA	0430Z 09/23/03	1615Z 09/23/03	1900Z 09/23/03	1.0	1351Z 09/23/03	1620Z 09/23/04	1.45	39 1515Z	30 1351Z
NY - LGA	1630Z 10/27/03	2330Z 10/27/03	0215Z 10/28/03	0.665	2128Z 10/27/03	0030Z 10/28/03	1.76	35 2030Z	24 2151Z
NY - LGA	1500Z 05/31/04	2100Z 05/31/04	0000Z 06/01/04	1.15	2051Z 05/31/04	2130Z 05/31/04	0.20	25 2330Z	24
NY - NYC	0430Z 09/23/03	1600Z 09/23/03	1830Z 09/23/03	1.2	1351Z 09/23/04	1451Z 09/23/04	1.19	39 1500Z	32
NY - NYC	1630Z 10/27/03	2300Z 10/27/03	0215Z 10/28/03	0.87	2351Z 10/27/03	0030Z 10/28/03	1.86	39 2145Z	20 2051Z
NY - NYC	1500Z 05/31/04	2100Z 05/31/04	0000Z 06/01/04	1.15	2051Z 05/31/04	2130Z 05/31/04	0.21	25 2315Z	20
NY - EWR	0430Z 09/23/03	1515Z 09/23/03	1730Z 09/23/03	0.67	1319Z 09/23/04	1451Z 09/23/04	0.91	40 1445Z	39
NY - EWR	1630Z 10/27/03	2030Z 10/27/03	0200Z 10/28/03	0.65	2200Z 10/27/03	0130Z 10/28/03	1.43	33 2230Z	NA
NY- EWR	1500Z 05/31/04	2100Z 05/31/04	2300Z 05/31/04	0.75	2009Z 05/31/04	2130Z 05/31/04	0.36	25 2300Z	21
DC FDK	1030Z 10/16/04	1900Z 10/16/04	2015Z 10/16/04	0.13	2004Z 10/16/04	2100Z 10/16/04	< 0.3 radar est	17 1915Z	39 2004Z
CHI - ORD	1030Z 03/01/04	0015Z 03/02/04	0215Z 03/02/04	0.95	2117Z 03/01/04	2221Z 03/01/04	0.86	34 2200Z	41
CHI - ORD	1030Z 03/28/04	0130Z 03/28/04	0530Z 03/29/04	0.41	2322Z 03/28/04	0056Z 03/29/04	0.67	33 0100Z	38
CHI - MDW	1030Z 03/01/04	0200Z 03/02/04	0300Z 03/02/04	0.87	2153Z 03/01/04	2250Z 03/01/04	< 0.1 radar est	37 0200Z	39 2153Z
CHI -MDW	1030Z 03/28/04	0130Z 03/29/04	0600Z 03/29/04	0.63	2353Z 03/28/04	0030Z 03/29/04	0.2 radar est	31 0130Z	24
KC - MCI	1030Z 05/18/04	1045Z 05/18/04	1115Z 05/18/04	0.13	1239Z 05/18/04	1353Z 05/18/04	0.67	12	32
KC - MKC	1030Z 05/18/04	1100Z 05/18/04	1115Z 05/18/04	0.14	1254Z 05/18/04	1554Z 05/18/04	1.0 radar est	12	37

The mean difference between predicted and observed maximum wind speed was 9 mph with a mean uncertainty in observation time of 30 minutes. The performance was almost evenly distributed with 9 of 17 cases overpredicting wind speed maxima and 7 of 17 cases underpredicting wind speed maxima.

5. QUALITATIVE STUDY OF EVENTS

In order to study model performance over broader areas, we compare results in a more qualitative fashion for the four forecast geographies. These results tend to rely more on visualization techniques for determination of model predictions. In this study model prediction visualizations were compared with available radar images for comparable times.

For the seven events examined in this study, we have observed substantial model skill in predicting the , timing, location and intensity, and structure of convective storms.

Consider for example the second of three events examined in the NYC metropolitan area which occurred on 10/27/03. A line of heavy showers and thunderstorms to the east of a frontal boundary moved east through the New York-New Jersey metropolitan area. The storms spawned an F0 tornado which touched down in Staten Island, NY.

Wind speeds were estimated at 70 mph with numerous uprooted trees and light structural damage to several houses. Model predictions for this event were available about 7 hours before the showers and thunderstorms occurred. Standard forecast products available prior to the time when the storms impacted the area predicted occasional showers with scattered thunderstorms. Figure 2 shows an image of one of the visualizations produced from the model prediction which was available 1630 UTC on 10/27/03, five hours before the thunderstorms impacted the region. The model visualization snapshot is paired with the local NWS Upton radar image for the same time. The two-panel radar image shows composite reflectivity on the left and radar estimated precipitation on the right side. The model visualization shows the 1km domain with the prediction of cloud water density in white and a model-derived reflectivity surface in cyan which indicates the location of the convective activity. The surface is color contoured by predicted precipitation amount. The timing, location, distribution and intensity of the model predicted precipitation is in good agreement with the radar image. Both images depict a squall line structure in eastern New Jersey. The model predicted spatial distribution and amounts correspond well to radar-estimated distribution and totals on the right side of the radar image.

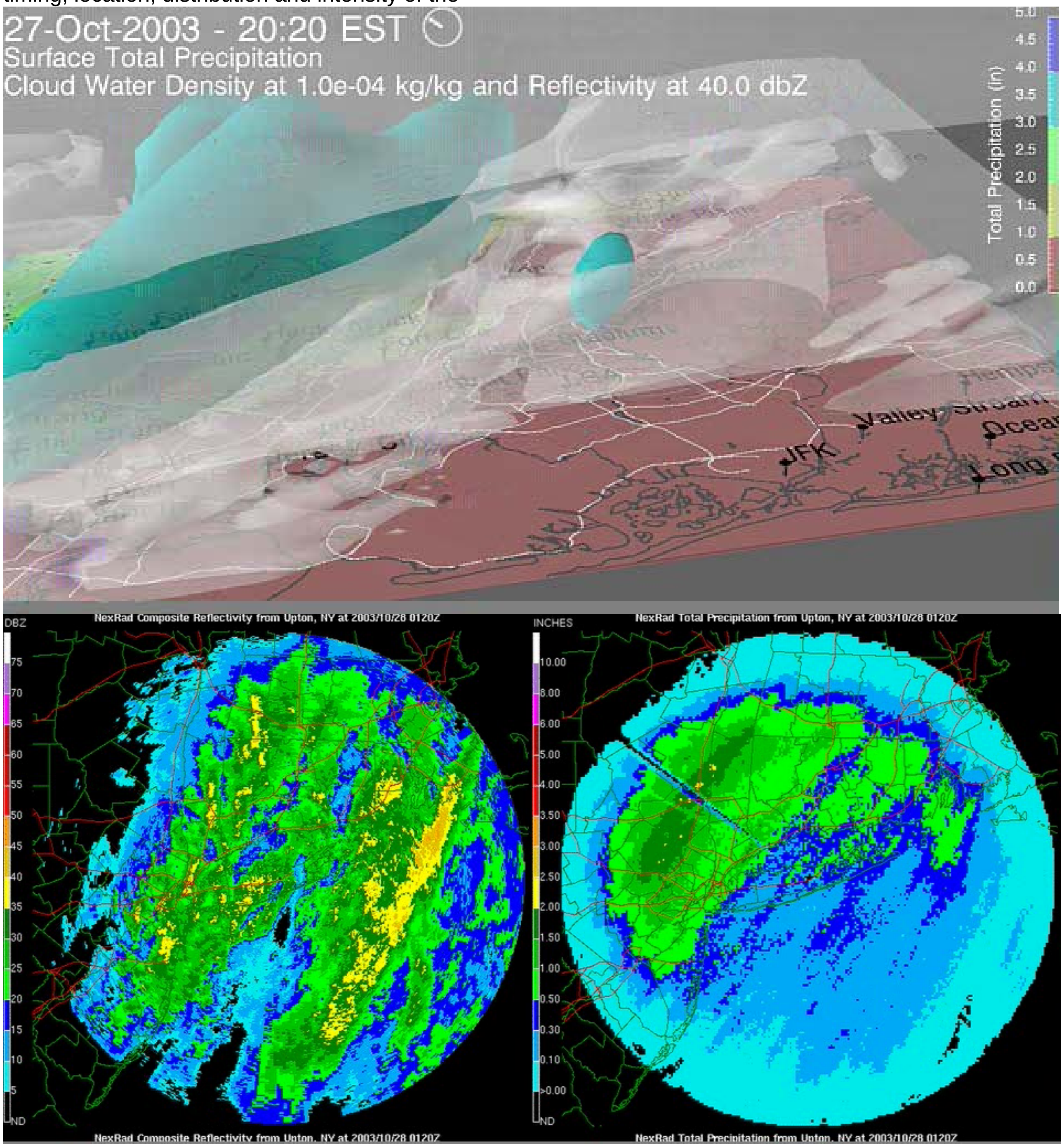

Figure 2 Model and Radar Images for the NY Region at 0120 UTC October 28, 2003.

Another case examined was an area of early spring thunderstorms which developed over northern Illinois and northwestern Indiana on 3/01/04. These were low-topped storms that developed in an environment of significant cold air aloft. There were several reports of hail between 0.75 and 1.00 inches in diameter. The storms also produced wind gusts as high as 59 knots.

The *Deep Thunder* model forecast for the period of 0600 UTC on 3/01/04 until 0600 UTC on 3/02/04 was completed at about 1030 UTC. Products were available 10 hours prior to the storms which moved into the greater Chicago area. Other forecasts for the area several hours prior to the occurrence of the storms predicted showers and thunderstorms likely with the chance of rain at sixty percent.

A snapshot of the model forecast visualization is shown with the local NWS radar in figure 3. In this case, spatial distribution and intensity of the predicted convective activity was in good agreement with radar observations Distribution of the model predicted rainfall was also in good agreement with radar estimated precipitation both spatially and in total amounts. However, the timing of the event was off with the model prediction lagging the actual passage of the storms through the region by about three hours. Considering the model products availability, there was still significant lead time (7 hours) in predicting convective activity for the region.

In the Kansas City region a line of early morning thunderstorms developed and moved southeast through the metropolitan area on 5/18/04. Wind gusts as high as 65 mph were recorded with some trees down and some structural damage.

Model forecast results for the 24 hour period beginning 0600Z on May 18, 2004 were available at 1030UTC, about 1.5 hours prior to the storms impacting the area. Figure 4 shows the model forecast visualization for 1230 UTC along with the local NWS radar image for approximately the same time.

Comparison of the images show that the model forecast timing was good for the overall convective activity in the region.although the specific convective cells which impacted the Kansas City metropolitan area were displaced a few kilometers to the south of Kansas City as compared to radar observation showing the storms to the north of the city. The model was somewhat less organized and of lesser intensity than the radar observations show during this time interval. Later model times show more structure and intensity to the southeast of Kansas City.

In this particular case model physics spin-up time had a likely impact on the timing and intensity of the storms in the forecast domain. The storms developed and moved through the region relatively close to the beginning of the forecast cycle. An earlier model run may have captured the structure and intensity of the convection with better skill.

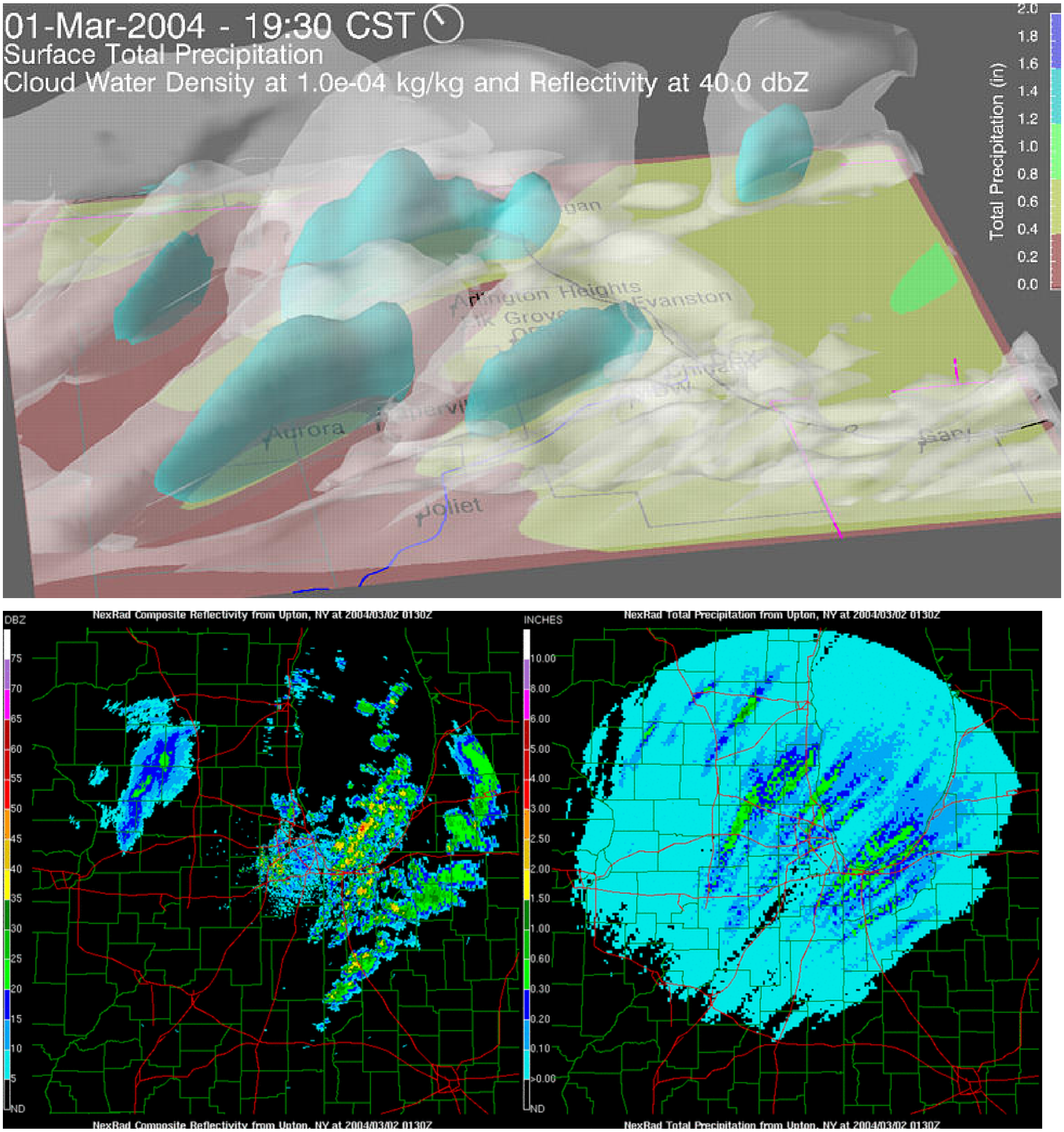

Figure 3 Model and Radar Images for the Chicago Region at 0130 UTC on March 2, 2004

The final case examined is a convective event which occurred in the Washington D.C.-Baltimore, MD area on October 16, 2004. A line of thunderstorms developed in the late afternoon and moved quickly eastward through the metropolitan area. The storms impacted traffic on Interstate 95 north of Baltimore with heavy rain and pea sized hail causing eleven separate traffic accidents including one involving 90 vehicles.

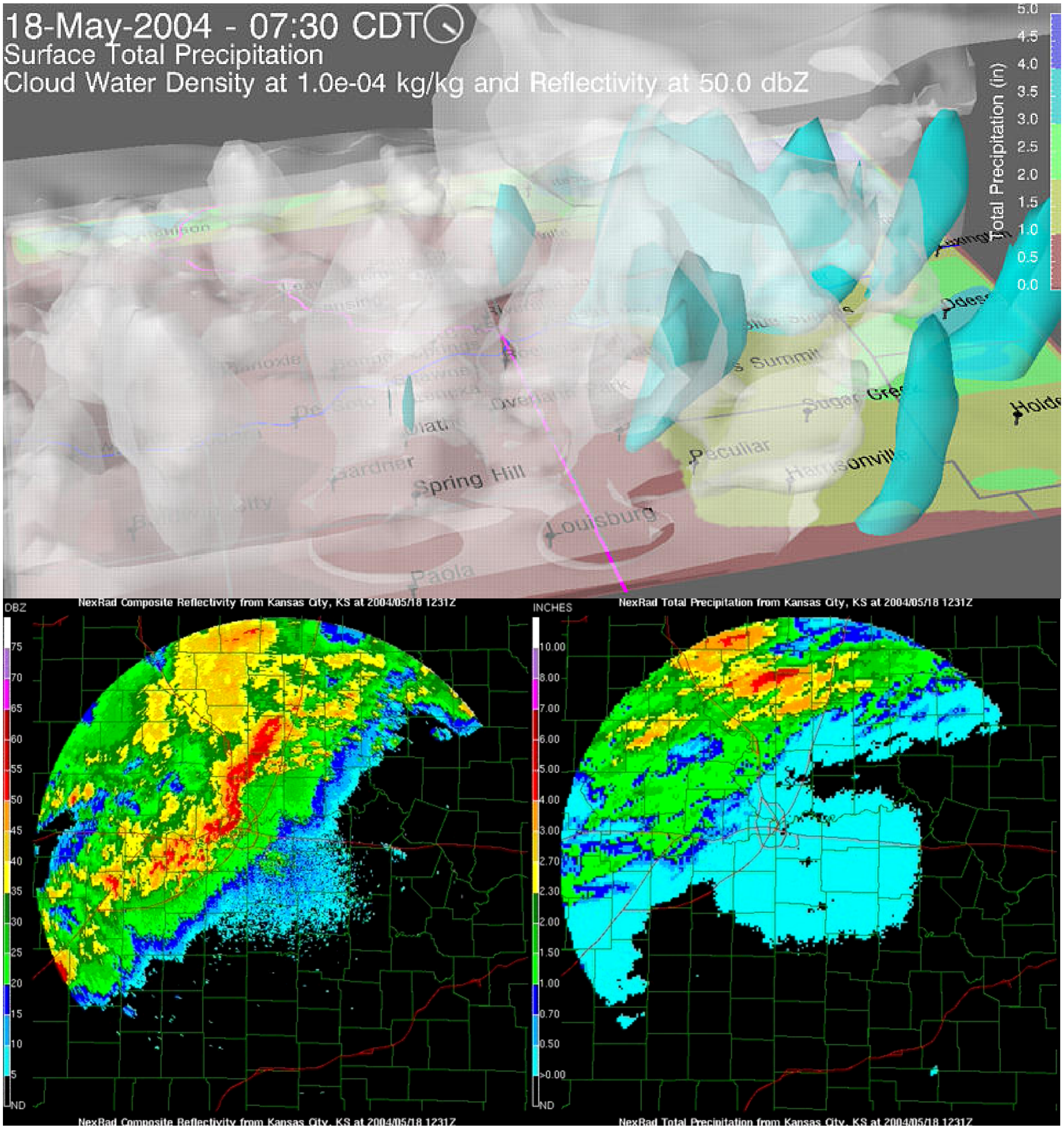

Figure 4. Model and Radar Images for Kansas City Region at 1230 UTC on May 18, 2004.

Model forecast products for the Washington-Baltimore region were completed at 1030 UTC, more than 9 hours before the storms occurred. Figure 5 shows the model forecast visualization for 2030 UTC along with the local weather service radar image at 2038 UTC.

Comparison of the images shows the model results to be in good agreement with radar observation in timing, intensity and structure northern and middle sections of the squall line.

The model did not do well in predicting the southern portion of the line which was partially outside of the highest resolution grid The model may have had difficulty in predicting the convection in this area as a result of lower resolution and the fact that the southern extent of the convection was generally of lower intensity. In addition to the timing, the spatial distribution and total accumulation of the precipitation matched well with the radar estimates.

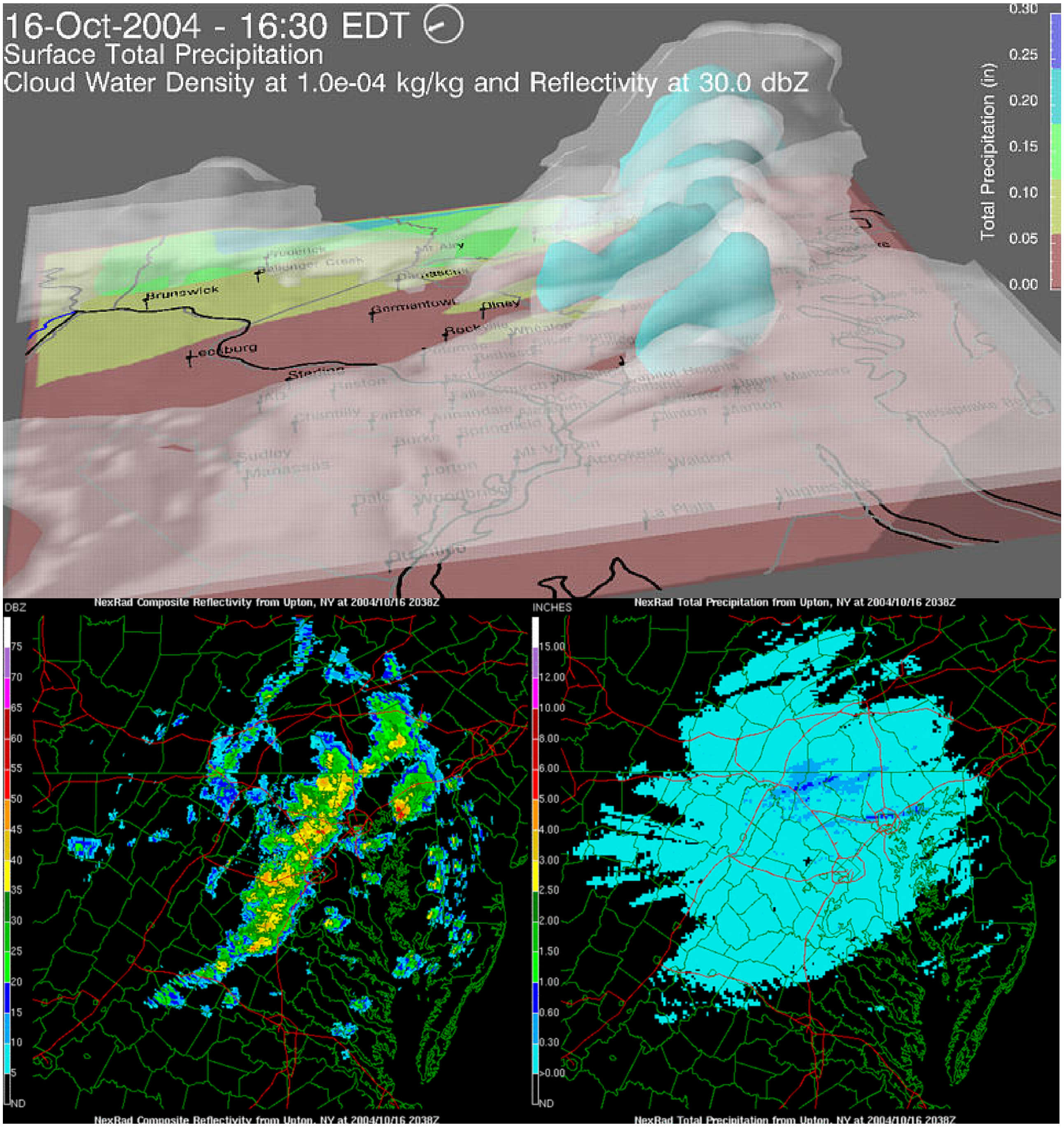

Figure 5 Model and Radar Images for Washington-Baltimore October 16, 2004.

6 DISCUSSION AND FUTURE WORK

Overall results for the seven events studied in four distinct geographies were quite good. *Deep Thunder* demonstrated considerable skill in both regional and local-scale prediction of convective storms. In several cases the model predictions were available with considerable lead time when compared with other forecast data and with the actual occurrence of the event.

Quantitatively the model exhibited a negative bias in both precipitation onset and ending time prediction. There is also some positive bias in the prediction of precipitation amount. These biases as well as timing errors may be influenced by the efficiency of the model microphysics as well as phase errors propagated from inaccurate inital conditions. Model wind speed predictions show little bias for the cases examined and exhibit considerable skill given the temporal and measurement uncertainty in observations. It should be noted that very little overall model tuning was performed in any of the geographies.

Taken at a regional qualitative scale, the results are very encouraging with the model showing significant skill predicting the structure, distribution and intensity of convective storms.

While this study focused on model performance of positive forecast results, future work will address issues related to overall categorical forecast performance (Brown et al, 2004, Luppens et al, 2004, Kay, 2004) as well as operational improvements related to throughput and model tuning. Additional studies into the role of the model microphysics on precipitation timing and amounts will also be conducted.

Since much of the motivation for the work is on applications of the modelling, a continued focus will be customization of model products and related metrics for end user applications.

7. ACKNOWLEGEMENTS

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