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# FORECAST PERFORMANCE OF AN OPERATIONAL MESO-GAMMA-SCALE MODELLING SYSTEM FOR EXTRATROPICAL SYSTEMS

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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 several events of tropical origin over the Northeast 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 began at that time. Recently it has been extended to also provide model forecasts for the Baltimore-Washington D.C., Chicago and Kansas City metropolitan areas. All geographies utilize a triple nested model domain.

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 systems of tropical origin that became extratropical and impacted the New York geography. Previous studies have examined other regimes (Praino, et al, 2003).

We will compare the model results with observational data and other available forecasts as well as the operational availability of specific forecast products. Such performance is examined by considering forecast timing, locality, structure, and intensity of the cases chosen.

## 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 the New York forecasting region the horizontal resolution is 16 km, 4 km and 1 km for the three grids, respectively, each of which uses a 62 x 62 grid. 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 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 species to enable explicit prediction of precipitation.

Model runs were typically done twice per day. All model forecasts were for a 24 hour period. Model initial and boundary conditions were set using the NCEP NAM forecast grids. Model lateral boundaries are nudged every three hours using NAM-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.

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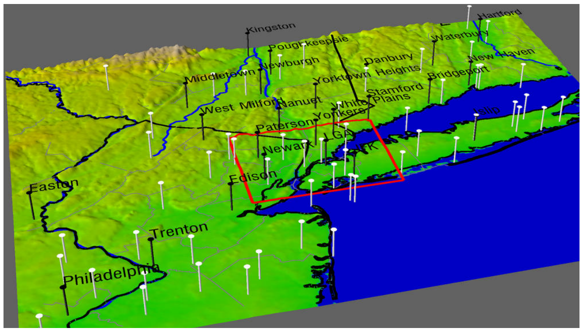


**Figure 1. Inner Model Nests and Metar Reporting Stations**

## 3. METHODS AND DATA SETS

Verification of individual events utilized objective methods (Jolliffe & Stephenson, 2003) for precipitation 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 data sources (local storm reports, public notification statements), 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 (high precision, site-specific) was a determining factor in the methodology used for the case studies. Model site-specific forecasts were compared against available observations for those sites. 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. In addition, variations in reporting times, precipitation sensor limitations and radar precipitation estimation algorithms are all potential error sources. Other mesoscale model verification issues are discussed in the literature (Davis & Carr 1998).

For location specific verification, sites were selected for locations in the 1 km nest (Figure 1). These tend to be metar sites and are based upon the availability and continuity of observations.

## 4. EVALUATION OF SPECIFIC EVENTS

A total of five extratropical events were examined. An event is defined as a weather system of tropical origin which impacts a particular geographic region. For location specific quantitative verification, rainfall and winds were used as criteria for comparing model performance with observations.

Results are summarized in Table 1. The table shows the model predictions and observations for precipitation 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 these cases the observation times noted as estimated, and consecutive metar reporting times were linearly interpolated to arrive at the observation time used in the table.

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 and forecast time boundaries, model precipitation totals were arrived at by using consecutive model forecasts. These were compared against observation totals. In cases where precipitation totals were not reported radar total estimated totals were used.

Precipitation onset times had predominantly negative biases. In 16 of the 25 cases studied the model precipitation starting time lagged observed precipitation start time. In 6 of the cases, the model led observation and in 3 of the cases the model missed the event completely. The mean difference between model predicted precipitation onset time and observed onset time was 6.6 hours.

Precipitation ending errors tended to be more problematic with the model completely missing the cessation of precipitation in 5 of the 25 cases. These cases were defined by the model-integrated precipitation forecast increasing monotonically through the end of the forecast cycle or no precipitation predicted as compared to an observed cessation of precipitation during the period. The model led the observed precipitation cessation in 11 cases and lagged observed precipitation ending in 8 cases. The mean difference between model-predicted precipitation ending time and the observed ending time was four 4 hours. The observational uncertainty is of the order of sixty minutes owing to missed (not reported) observations

**Table 1. Model Predictions and Observed Results.**

| 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 – Isabel | 0300Z 09/19/03 | 0230Z 09/19/03 | 0500Z 09/19/03 | 0.20 | 0337Z 09/19/03 | 0543Z 09/19/04 | 0.13 | 38 1800Z | 42 0651Z |
| NY – LGA – Frances | 0300Z 09/08/04 | 0730Z 09/08/04 | 2300Z 09/08/04 | 2.5 | 1522Z 09/08/04 | 1733Z 09/08/04 | 3.83 | 26 0900Z | 29 1835Z |
| NY- LGA – Ivan | 0300Z 09/18/04 | None | None | None | 0005Z 09/18/04 | 2030Z * 09/18/04 | 1.77 | 26 2330Z | 38 1651Z |
| NY–LGA – Jeanne | 1500Z 09/28/04 | 1630Z 09/28/04 | 0900Z 09/29/04 | 5.80 | 0550Z 09/28/04 | 0926Z 09/29/04 | 1.98 | 49 0315Z | 38 0020Z |
| NY–LGA – Tammy | 0300Z 10/07/05 | 0100Z 10/08/05 | 0100Z 10/09/05 | 1.50 | 0930Z * 10/07/05 | 2030Z * 10/08/05 | 1.42 ** | 33 1730Z | 37 1851Z |
| NY- NYC – Isabel | 0300Z 09/19/03 | 0230Z 09/19/03 | 0630Z 09/19/03 | 0.23 | 0335Z 09/19/03 | 0830Z 09/19/03 | 0.33 | 35 0830Z | 33 0051Z |
| NY- NYC – Frances | 0300Z 09/08/04 | 0930Z 09/08/04 | 2230Z 09/08/04 | 2.6 | 0851Z * 09/08/04 | 1414Z 09/08/04 | 3.75 | 28 1000Z | 22 1851Z |
| NY- NYC – Ivan | 0300Z 09/18/04 | None | None | None | 0359Z 09/18/04 | 0340Z 09/18/04 | 2.30 | 26 2100Z | 37 1651Z |
| NY- NYC – Jeanne | 1500Z 09/28/04 | 1630Z 09/28/04 | 0900Z 09/29/04 | 5.0 | 0430Z * 09/28/04 | 0930Z * 09/29/04 | 2.66 | 35 0630Z | 28 2351Z |
| NY- NYC – Tammy | 0300Z 10/07/05 | 1300Z 10/08/05 | 0700Z 10/09/05 | 1.85 | 1945Z * 10/07/05 | 2145Z * 10/08/05 | 1.54 ** | 34 1730Z | 31 1830Z |
| NY- EWR – Isabel | 0300Z 09/19/03 | 0230Z 09/19/03 | 0700Z 09/19/03 | 0.25 | 0341Z 09/19/03 | 0540Z 09/19/03 | 0.27 | 36 0700Z | 44 0751Z |
| NY- EWR – Frances | 0300Z 09/08/04 | 1000Z 09/08/04 | 2200Z 09/08/04 | 2.7 | 2019Z 09/08/04 | 2046Z 09/09/04 | 2.07 | 26 1030Z | 20 1551Z |
| NY- EWR – Ivan | 0300Z 09/18/04 | 0330Z 09/18/04 | 1100Z 09/18/04 | Trace | 0138Z 09/18/04 | 1930Z * 09/18/04 | 1.44 | 25 2300Z | 39 1451Z |
| NY- EWR – Jeanne | 1500Z 09/29/04 | 1700Z 09/28/04 | 0900Z 09/29/04 | 3.25 | 0530Z* 09/28/04 | 0130Z * 09/29/04 | 2.24 | 38 0300Z | 29 0551Z |
| NY- EWR – Tammy | 0300Z 10/07/05 | 1300Z 10/08/05 | 0700Z 10/09/05 | 2.40 | 1930Z * 10/07/05 | 2130Z * 10/08/05 | 2.07 ** | 35 2100Z | 27 1951Z |
| NY – JFK – Isabel | 1500Z 09/18/03 | 0815Z 09/19/03 | Continue 09/19/03 | 0.39 | 0451Z * 09/19/03 | 0816Z 09/19/03 | 0.13 | 38 0730Z | 45 0651Z |
| NY-JFK – Frances | 0300Z 09/08/04 | 0900Z 09/08/04 | 2300Z 09/08/04 | 1.2 | 0630Z * 09/08/04 | 2230Z * 09/08/04 | 2.76 | 26 0400Z | 38 1851Z |
| NY-JFK – Ivan | 1500Z 09/18/04 | None | None | None | 0951Z 09/18/04 | 2230Z * 09/18/04 | 0.42 | 29 0200Z | 39 1651Z |
| NY-JFK – Jeanne | 1500Z 09/29/04 | 1945Z 09/28/04 | 0815Z 09/29/04 | 4.80 | 0330Z * 09/28/04 | 1030Z * 09/29/04 | 2.28 | 43 0045Z | 36 0551Z |
| NY-JFK – Tammy | 0300Z 10/07/05 | 1300Z 10/08/05 | 0630Z 10/09/05 | 2.13 | 2030Z * 10/07/05 | 2130Z * 10/08/05 | 0.54 ** | 36 0130Z | 36 1951Z |
| NY-HPN – Isabel | 1500Z 09/18/03 | 1030Z 09/18/03 | 0300Z 09/18/03 | 0.45 | 0312Z 09/19/03 | 0930Z * 09/19/03 | 0.58 | 31 1200Z | 33 0556Z |
| NY-HPN – Frances | 0300Z 09/08/04 | 1000Z 09/08/04 | 2130Z 09/08/04 | 2.9 | 2353Z 09/08/04 | 0030Z 09/08/04 | 5.85 | 20 1100Z | 30 1656Z |
| NY-HPN – Ivan | 1500Z 09/18/04 | 1300Z 09/18/04 | 0230Z 09/19/04 | 0.15 | 0203Z 09/18/04 | 1924Z 09/18/04 | 1.92 | 27 1700Z | 38 1356Z |
| NY-HPN - Jeanne | 1500Z 09/28/04 | 1700Z 09/28/04 | 0900Z 09/29/04 | 6.00 | 0650Z 09/28/04 | 1030Z * 09/29/04 | 1.82 | 33 0700Z | 28 0856Z |
| NY_HPN - Tammy | 0300Z 10/07/05 | 1630Z 10/07/05 | 2200Z 10/07/05 | 5.15 | 0830Z * 10/07/05 | 2130Z * 10/08/05 | 2.52 ** | 28 2000Z | 40 1956Z |

*Estimate **1600Z to 1600Z observed precipitation

The mean difference between predicted and observed maximum wind speed was 8 mph with a mean uncertainty in observation time of 30 minutes. The performance was slightly skewed toward underprediction with 14 of 25 cases underpredicting wind speed maxima and 10 of 25 cases overpredicting wind speed maxima. In one case the model prediction matched observation.

## 5. QUALITATIVE STUDY OF EVENTS

In order to study model performance over broader areas, we compare results in a more qualitative fashion for the forecast geography (Praino & Treinish, 2003, 2004). These results tend to rely more on visualization techniques for determination of model predictions. In this study, model prediction visualization images (Treinish & Praino, 2006) were compared with available radar images for comparable times.

For the five events examined in this study, we have observed good model skill in the prediction, timing, location and intensity of local events driven by the extratropical systems.

Consider for example the second of three extratropical events which impacted the NYC metropolitan area in 2004. The remnants of Hurricane Frances, which impacted eastern Florida as a Category Two Hurricane moved up the eastern seaboard and began to affect the NYC metropolitan area with bands of showers on the morning of September 8. As an extratropical cyclone, Frances briefly had gale-force winds as it accelerated northeastward across New York on September 9. The cyclone turned eastward across northern New England and southeastern Canada, dissipating over the Gulf of St. Lawrence late on September 10.

A band of heavy showers and thunderstorms moved from the coastal Atlantic northwest into New York City, Long Island, Westchester County and Coastal Connecticut. The heaviest rainfall occurred in an area stretching from northeastern New Jersey through central Westchester County, New York with amounts in excess of four inches for some locations.

There was significant flooding and widespread disruption of transportation systems with road closures, airport delays and mass transit system impacts. Model predictions for this event were available about 6 hours before the showers and thunderstorms impacted the region.

Figure 2 depicts a timeslice of the one of the model visualization products along with the NWS radar from Upton, NY. Both images are for approximately the same time. The model prediction is in good agreement with the location and intensity of the convective cells although the extent of the areal coverage is somewhat less than what is observed on the radar. Total precipitation accumulation predictions were in good agreement with automated surface observing station reports of two to three inches in the New York City and surrounding suburbs.

The second system of tropical origin which moved into the Northeast US in 2004 was the remnants of Hurricane Ivan. It passed through the New York metropolitan area only ten days after Frances on September 18, 2004. Ivan reached Category 5 status twice during its long lifecycle of 22 days. It made landfall for the first time as a Category 3 hurricane over eastern Alabama before moving inland. It moved northeastward weakening to a tropical storm and then to a tropical depression before moving off of the DelMarVa peninsula on September 18.

Figure 3 shows a snapshot of a model forecast visualization and the corresponding NWS radar from Upton, NY for 1150 UTC on September 18th. The radar composite reflectivity depicts several intense convective cells in the 45-55 dbZ range over NYC and western Nassau County as well as a line of less severe activity (40-50 dbZ) over Westchester County and southeastern Connecticut.

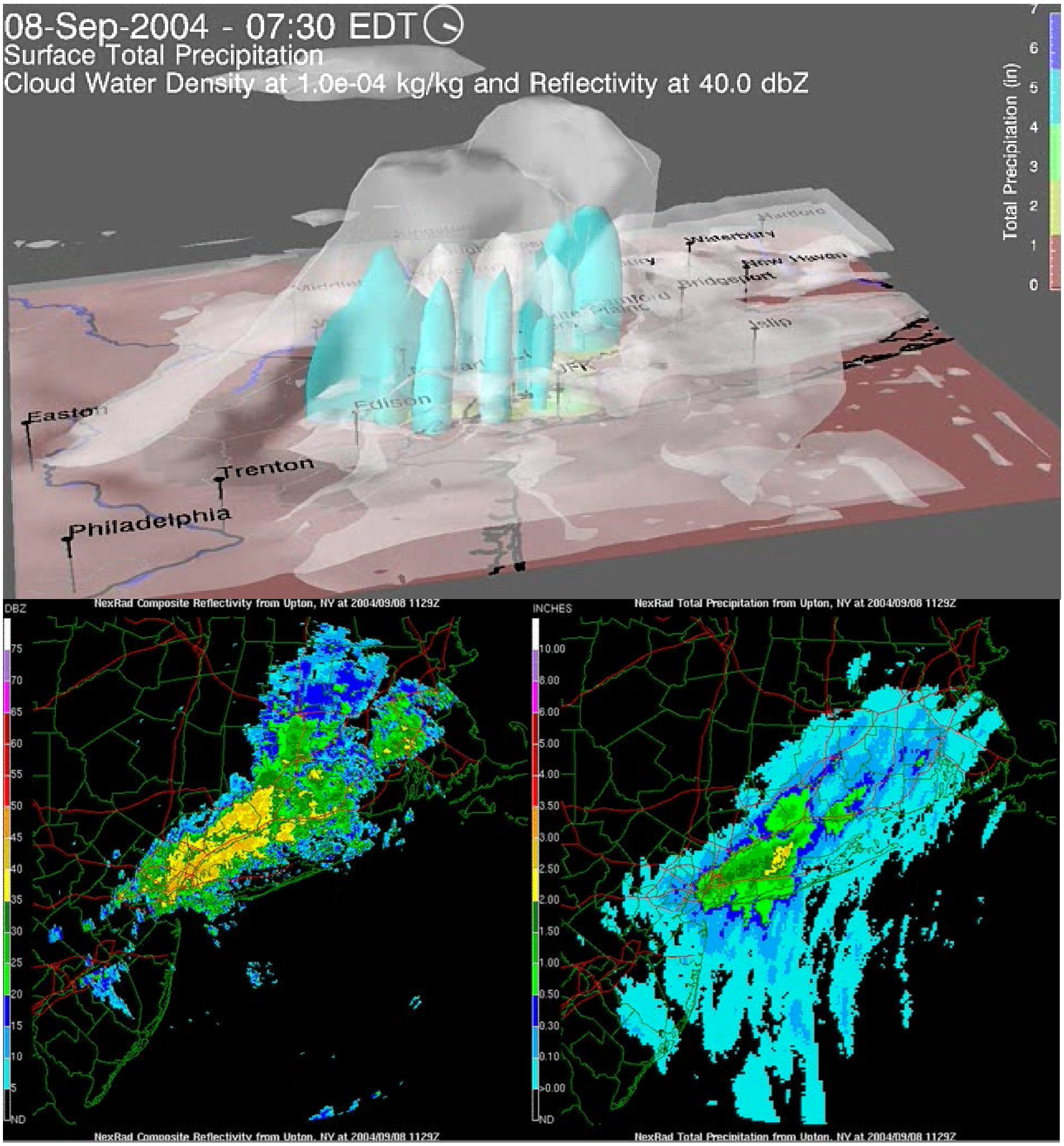


**Figure 2. Model and Radar Images for the NY Region – 1130 UTC Sept. 08, 2004.**

The model forecast visualization for the same time shows a single 50 dbZ reflectivity surfaces, which corresponds to one of the intense cells depicted in the radar to the northwest of New York City. From this perspective the model forecast did not capture the spatial extent of the activity. Later forecast visualizations did show increased convective activity indicating a temporal phase lag in the model results. Model predicted precipitation accumulation did correspond well in location and amounts with observation.

The final case examined was the torrential rains in the Northeast caused by the remnants of Tropical Storm Tammy from October 7-9, 2005.

Tammy developed just east of the central Florida coast and made landfall along the northeastern Florida coast before moving westward over southern Georgia and southeastern Alabama. The remnants of Tammy became absorbed by a larger extratropical low before moving northeast. and impacting the mid-Atlantic and Northeast regions.

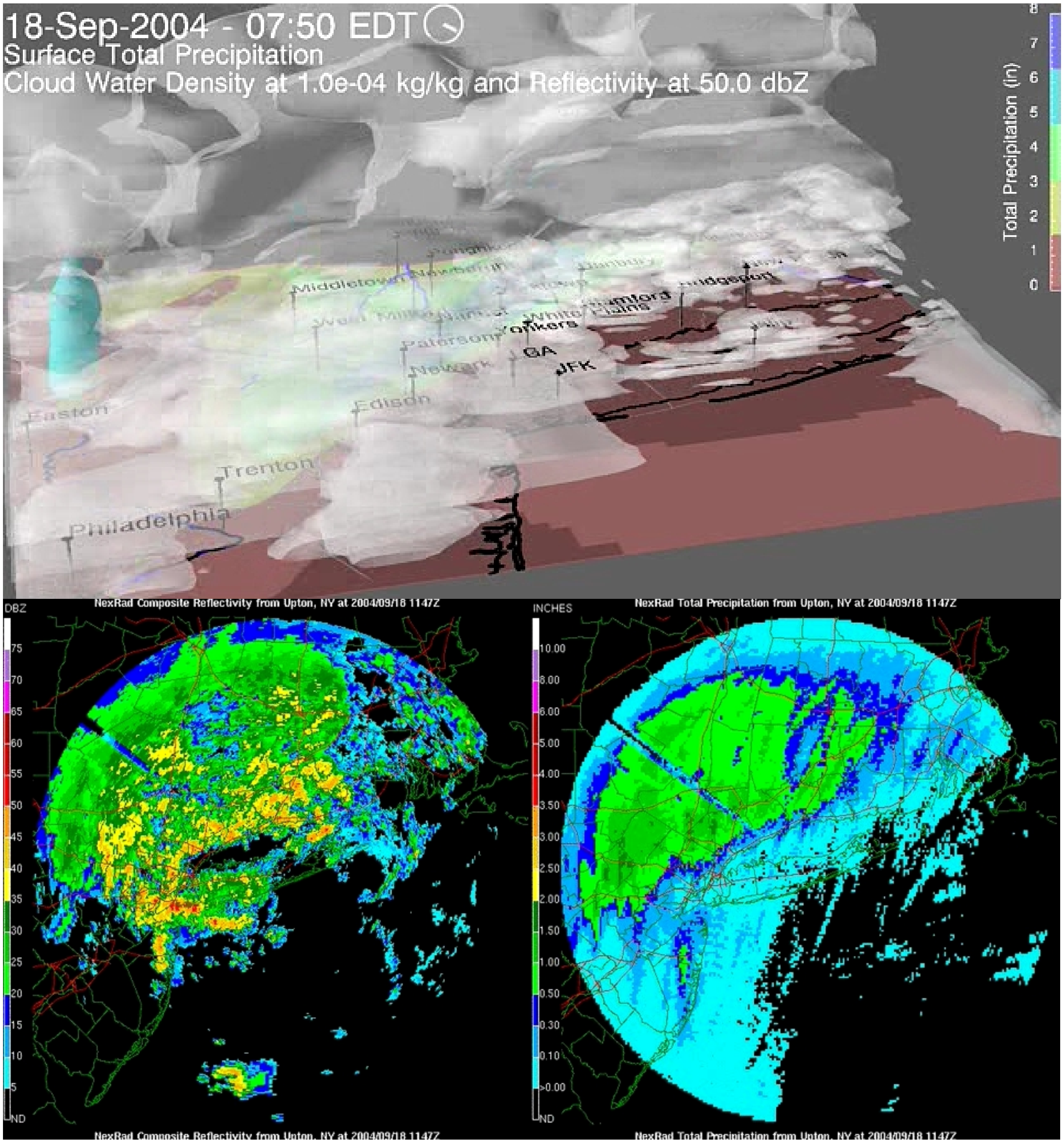


**Figure 3. Model and Radar Images for the NY Region – 1147 UTC Sept. 18, 2004.**

The combined storm system produced record rainfall amounts for much of the region Rainfall totals were in the 4 to 6 inch range for much of southeastern New York and New England with some areas receiving 10 to 12 inches of rain.

Figure 4 shows the model forecast for 2000 UTC on October 8, 2005 as well as the NWS radar for the same time. Both images depict a band of heavy precipitation via the 40 to 50 dbZ reflectivity surface to the north and west of New York City. The model predicted rainfall totals are in good agreement with the location and distribution of the observed precipitation.

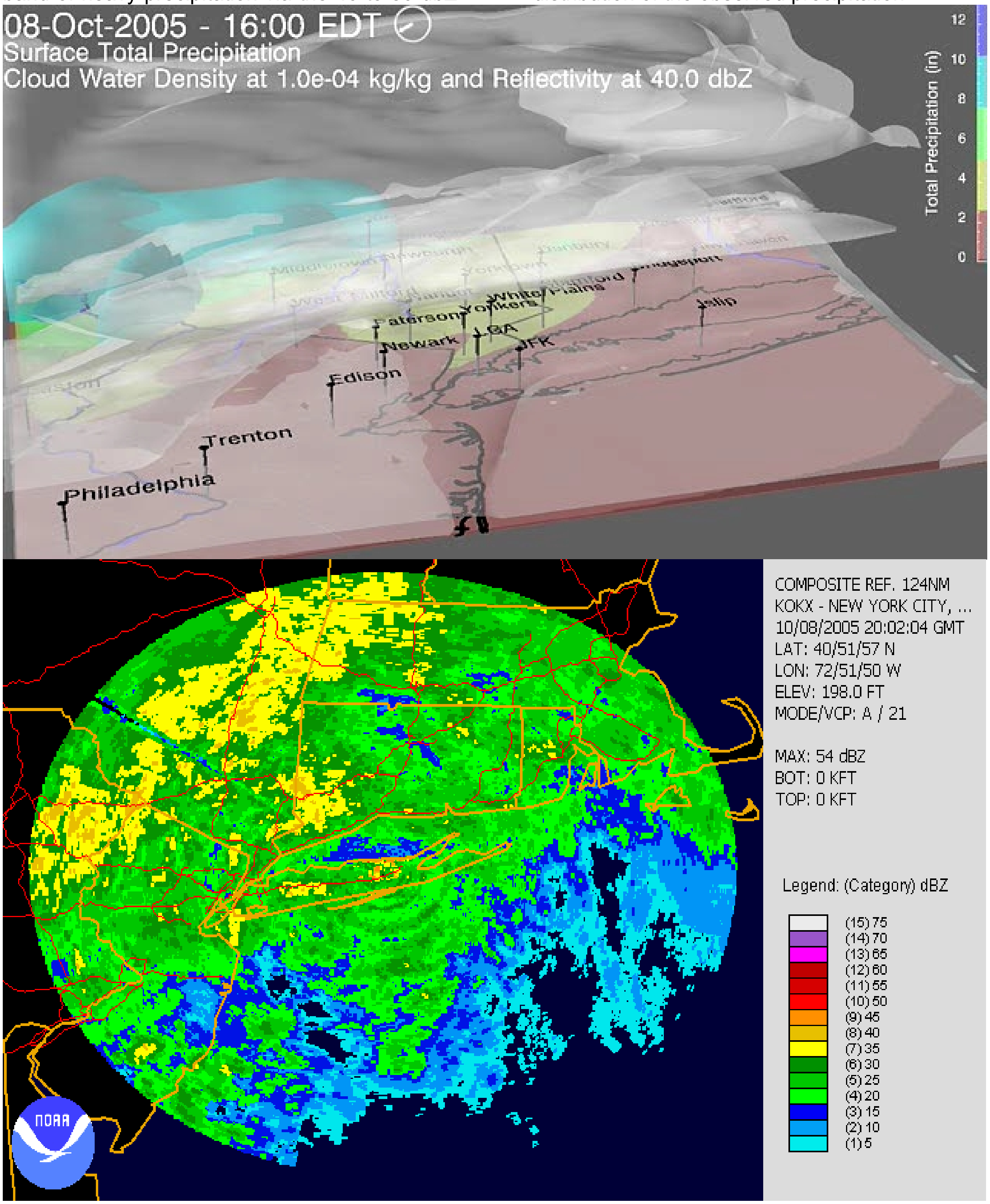


**Figure 4. Model and Radar Image for NY Region - 2000UTC Oct. 8, 2005.**

## 6. DISCUSSION

Overall results for the five events studied were good with some notable exceptions. The model performance for location-specific events was less skillful when compared with a more qualitative regional-scale examination. For location specific modeling, small spatial errors can result in an event being completely missed or having significant timing error.

Another factor may be the nature of the event. In previous studies of individual convective events (Treinish and Praino, 2005) the model demonstrated better skill in location specific forecasting. The events studied here tended to have a more prolonged duration with numerous periods of precipitation of varying intensity reflecting the extratropical nature of the storms.

Model performance may benefit from simulating the physical and dynamical features of singular well-characterized events when compared with extratropical systems of tropical origin. These systems exhibit characteristics of synoptic scale stratiform cyclones with embedded tropical features.

Taken at a regional qualitatively scale, the results are better with the model showing skill in predicting the structure, distribution, intensity and timing of the storms.

## 7. FUTURE WORK

While this study focused on model performance of positive forecast results, future work will address issues related to overall categorical forecast performance (Doswell, Jones, Keller 1990) 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.

Another significant body of work remains in the application of ensemble techniques from an operational and forecast performance perspective (Treinish and Praino, 2006)

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.

## 8. ACKNOWLEGEMENTS

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## 9. REFERENCES

Davis, C and F. Carr., *Summary of the 1998 Workshop on Mesoscale Model Verification*, **Bulletin of the American Meteorological Society**, **81**, N4, pp. 810-819, April 2000.

Doswell, C.A., Davies-Jones, R, Keller, D.L. *On Summary Measures of Skill in Rare Event Forecasting Based on Contingency Tables* **Weather And Forecasting,** N5 1990 pp. 576-585.

Jolliffe, I.T., Stephenson, D.B. **Forecast Verification**. John Wiley & Sons, Canada Ltd, 2003.

Praino, A.P., Treinish, L.A., Christidis, Z.D., Samuelsen, A. *Case Studies of an Operational Mesoscale Numerical Weather Prediction System in the Northeast United States.* **Proceedings of the 19th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology,** February 2003, Long Beach, CA.

Praino, A.P., Treinish, L.A., *Winter Forecast Performance of an Operational Mesoscale Numerical Modelling System in the Northeast United States,* **Proceedings of the 20th Conference on Weather Analysis and Forecasting/16th Conference on Numerical Weather Prediction,** January 2004, Seattle, WA.

Treinish, L.A. and Praino, A.P. *Applications and Implementation of a Mesoscale Numerical Prediction and Visualization System,* **Proceedings of the 20th Conference on Weather Analysis and Forecasting/16th Conference on Numerical Weather Prediction**, January 2004, Seattle, WA.

Praino, A.P., Treinish, L.A. Convective Forecast Performance *of an Operational Mesoscale*

*Numerical Modelling System,* **Proceedings of the 21st International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology,** January 2005, San Diego, CA

Treinish, L.A. and Praino, A.P. *The Role of Meso-γ-scale Numerical Weather Prediction and Visualization for Weather-Sensitive Decision Making*. **Environmental Risks and Impacts on Society**, January 2006, Atlanta, GA.