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FORECAST PERFORMANCE OF AN OPERATIONAL MESO-GAMMA-SCALE MODELLING SYSTEM FOR SOUTHERN FLORIDA

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1. INTRODUCTION

In our continuing work on the implementation and applications of an operational mesoscale modellng system dubbed "*Deep Thunder*", we examine its forecast performance for several events in southern Florida.

The *Deep Thunder* system has been running operationally since January 2001 at the IBM Thomas J. Watson Research Center in Yorktown Heights, NY. Initially, it provided model forecasts for the New York City metropolitan area. Over the last few years, it has been extended to provide model forecasts for the greater Baltimore-Washington, Chicago, Atlanta, Miami and Kansas City metropolitan areas. All geographies utilize a triple nested model domain (Treinish and Praino, 2006).

Operations for southern Florida began in October 2005 and afforded the opportunity to study model performance for weather of tropical influence. Model forecasts are run for a 24-hour period typically twice per day.

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 southern Florida. Previous studies have focused on other geographies (Praino et al, 2003; Praino and Treinish, 2004; Praino and Treinish, 2005).

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.

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2. FORECAST MODEL DESCRIPTION

The model is configured in a full three-dimensional, non-hydrostatic mode with two-way interactive nesting for three nested grids. For the southern Florida forecasting region the horizontal resolutions are 24 km, 6 km and 1.5 km for the three grids, respectively, each of which uses a 74 x 74 grid, centered on the Miami-Fort Lauderdale area. Part of this configuration is shown in Figure 1. 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 75, 18.75 and 4.69 seconds were selected to ensure computational stability while also balancing the need to accommodate strong vertical motion that can occur during the modeling 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 initial and boundary conditions are derived from the North American Model (NAM) provided by NOAA/NCEP. After analysis and quality control, these data are used for both background fields as well as lateral boundaries, which are nudged every three hours. Static surface coverage data sets provided by the U.S. Geological Survey at 30 seconds resolution are used to characterize topography and vegetation. In addition, lower resolution data sets are used to define land use and coverage while real-time sea surface temperature data provided by NOAA are utilized (Treinish and Praino, 2006).

All of the processing, modeling and visualization are completed in 60 to 70 minutes on a modest IBM Power 4 computing cluster. This rapid processing cycle enables timely dissemination of forecast products for potential weather-sensitive applications.

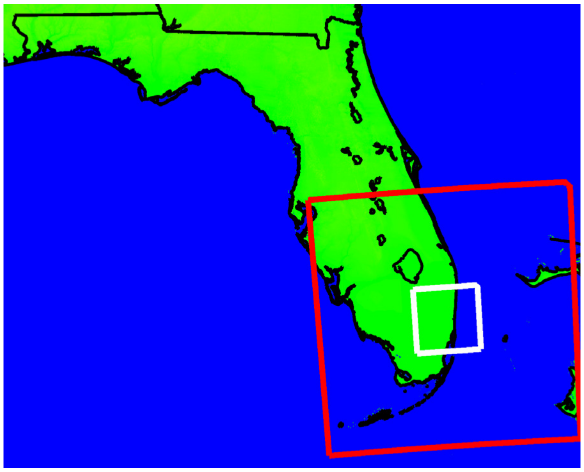

Figure 1. High Resolution (White) and Intermediate Resolution (Red) Nests Covering Southern Florida at 1.5 km and 6 km.

3. METHODS AND DATA SETS

Verification of individual events utilized objective methods (Jolliffe and Stephenson, 2003) for precipitation onset, and ending times by comparing model data with available surface observations. Rainfall totals were verified by using NWS daily climate reports for selected locations as well as radar estimates and other data sources such as local storm reports and public notification statements, where available. Overall storm intensity, timing, and spatial extent were verified by comparing to relevant satellite and 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 sources of error. Other mesoscale model verification issues are discussed in the literature (Davis and Carr 1998).

For location-specific verification, sites were selected in the 1.5 km nest (see Figure 1). These tend to be metar sites and are based upon the availability of continuous observations.

4. EVALUATION OF SPECIFIC EVENTS

In this initial study of modeling for southern Florida, three very different events were examined. They were chosen to represent a broad range of modeling tasks, with differing impact on the affected regions. For location-specific quantitative verification, rainfall and winds were used as criteria for comparing model performance with observations.

4.1 Convective Event

The first event was persistent moderate to heavy showers that led to flash flooding early in the morning of October 22, 2005. The rain fell over portions of eastern Broward County between 0308 and 0345 EDT,. Reports of two to three feet of standing water on streets and parking lots were received along a path from Fort Lauderdale to Oakland Park. Water was deep enough to come inside several homes and vehicles. Minor damage to property was reported. From NWS NexRad radar, it was estimated that five to seven inches of rain fell over the region. Coincidently, the rains were not directly associated with Hurricane Wilma, which struck the region two days later and is discussed in section 4.3, below.

Since the activity was focused on the Fort Lauderdale area, the KFLL (Fort Lauderdale-Hollywood International Airport) metar reporting station was used for observations. KFXE (Fort Lauderdale Executive Airport) observations were not available for the time period examined. Miami (KMIA) was included for comparison. Results are summarized in Table 1, which 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.

For 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.

Model predicted precipitation onset lagged the actual observed precipitation onset by about 2.5 hours. The precipitation ending error was also about 2.5 hours too late. Observational uncertainty as a result of missing or not explicitly reported precipitation starting and ending times is of the order of one hour.

For the difference in predicted versus observed precipitation, the National Climatic Data Center storm reports were used since accumulated precipitation was not reported in the metar observations. The model predicted a two-inch accumulation for Fort Lauderdale with storm reports for the area as high as five to seven inches as estimated from Doppler radar.

Table 1. Model Predictions and Observed Results on October 22, 2005.

Location	Model Forecast Available 10/22/05	Model Precipitation Start Time 10/22/05	Model Precipitation End Time 10/22/05	Model Rainfall Total (inches)	Observed Precipitation Start Time 10/22/05	Observed Precipitation End Time 10/22/05	Observed Rainfall Total (inches)	Model Wind Max (mph)	Observed Wind Max (mph)
MIA	0300Z	0700Z	0830Z	2.0	0953Z	1053Z	NA	36 0800Z	9 1353Z
FLL	0300Z	0730Z	1100Z	2.0	0453Z	0818Z	NA	26 0930Z	29 0732Z

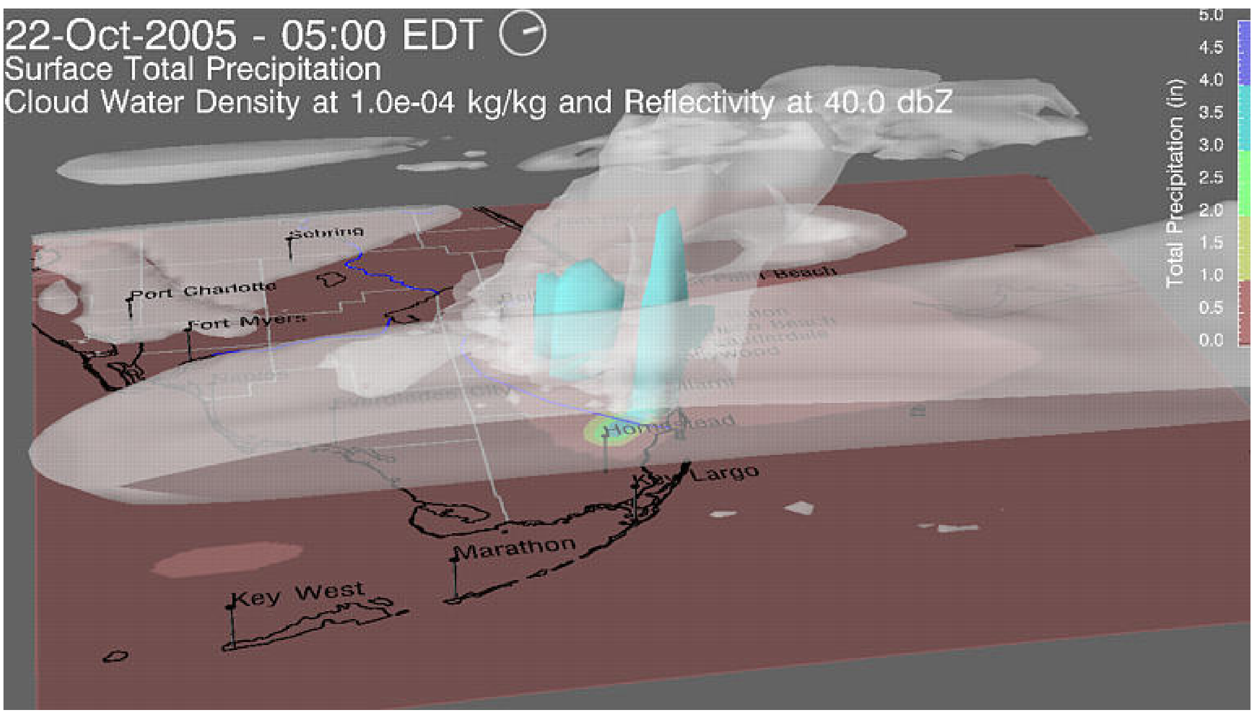

Figure 2. Model Prediction of Convection Over Southeastern Florida – 0900 UTC October 22, 2005.

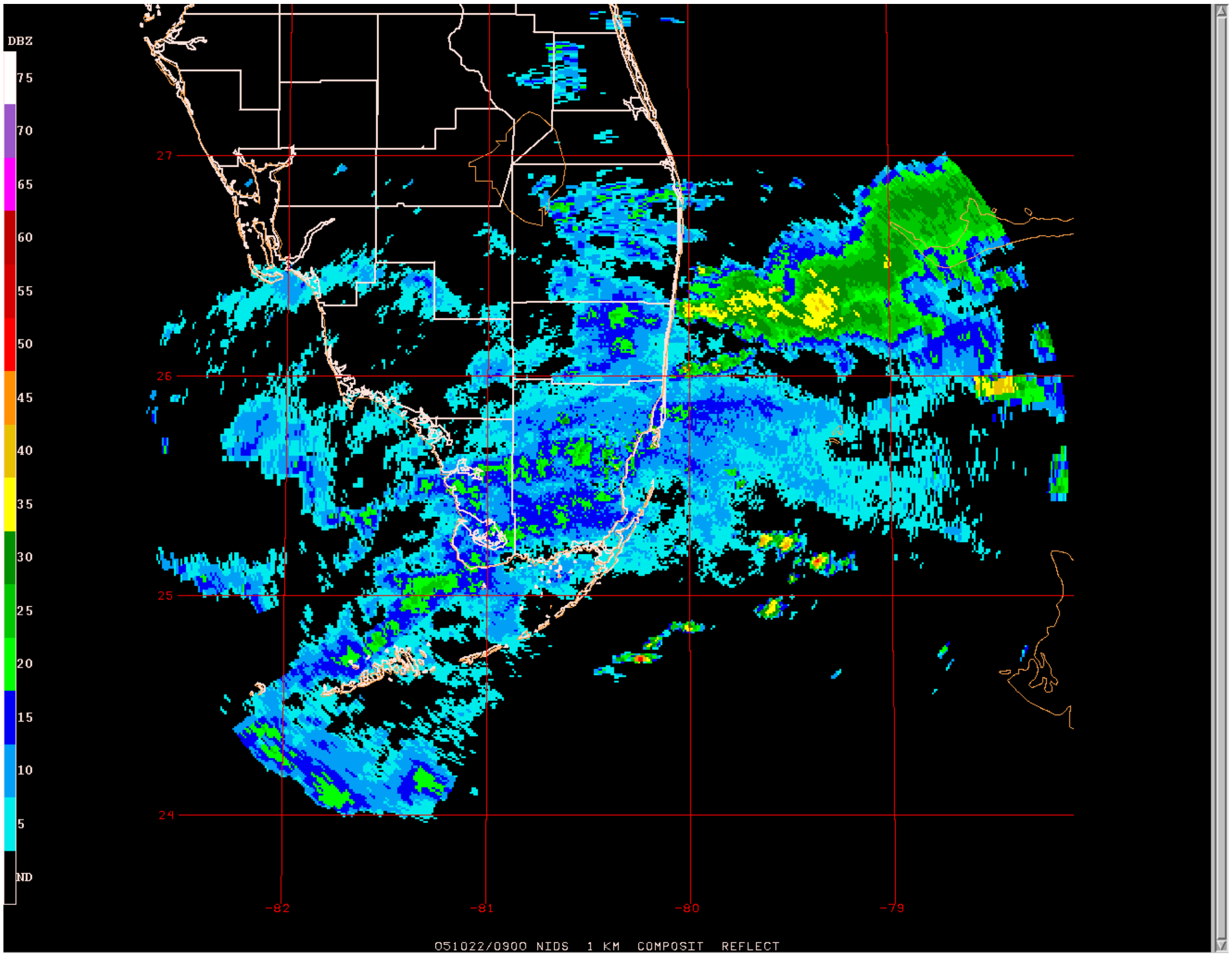

Figure 3. Composite Reflectivity Radar Image for Southern Florida – 0900 UTC October 22, 2005.

The mean difference between predicted and observed maximum wind speed was three mph with the observed wind maxima occurring about two hours after the model prediction.

Given that the time the showers and convection developed and moved eastward into the Fort Lauderdale area was near the beginning of the model forecast cycle time, it is likely that there was some delay as a result of model microphysics spin-up time. This would result in a time delay relative to the beginning of the cycle for the model to resolve and simulate the activity.

To better assess the model performance for the event over a broader area and from a qualitative perspective, we compare model forecast output in visual form for the inner high resolution nest with radar imagery for the same geographic region (Praino and Treinish, 2003, 2004). The analysis relies more on visualization techniques for determination of model skill.

In general for the events studied here the model prediction visualization images (Treinish and Praino, 2006) were compared with available radar images for comparable times. Figure 2 shows a snapshot of a model forecast visualization. Figure 3 is the corresponding composite reflectivity from the NWS radar in Miami, FL for 0900 UTC on October 22.

It can be seen from the radar that the convection and shower activity has moved off the coast to the east of Fort Lauderdale while the model prediction depicts the activity slightly to west and south of the area. What is not apparent from these images is that the rainfall persisted over the region for several hours and the model image shows the beginning of the event while radar observation is showing the end of the event. This is consistent with the metar observations in revealing the bias in model prediction times.

4.2 Fog

The second event studied involved dense fog which formed along the southern portion of Lake Okeechobee and covered U.S. Highway 27, halfway between South Bay and the Broward County line in the early morning hours of March 7, 2006. Reduced visibility resulted in a massive traffic accident involving 11 vehicles and multiple injuries. Eight of the vehicles were tractor-trailers.

Forecast discussions in the overnight hours focused on a cold front over northern Florida which was expected to move south of the lake by mid-morning. No clouds or precipitation were forecasted and there was no mention of the potential for fog.

No metar or mesonet observations were available in the vicinity of the accident and in general there is poor surface weather observational coverage for the southern end of Lake Okeechobee. The determination of fog coverage for the area is verified by eyewitness reports as well as some suggestion via satellite imagery.

Figure 4 depicts a time slice of the one of the model visualization products while Figure 5 shows the GOES visible image. Both images are for approximately the same time. The model prediction shows local cloud cover and fog on the southern end of the lake. There is some evidence in the satellite image of low altitude stratiform cloud cover over the southern Florida peninsula.

Given the satellite look angle and image resolution however it is difficult to confirm the existence of fog at the surface. Regional surface observations at the time were reporting light winds and differences between temperatures and dewpoints of only a few degrees which are favorable conditions for the formation of fog.

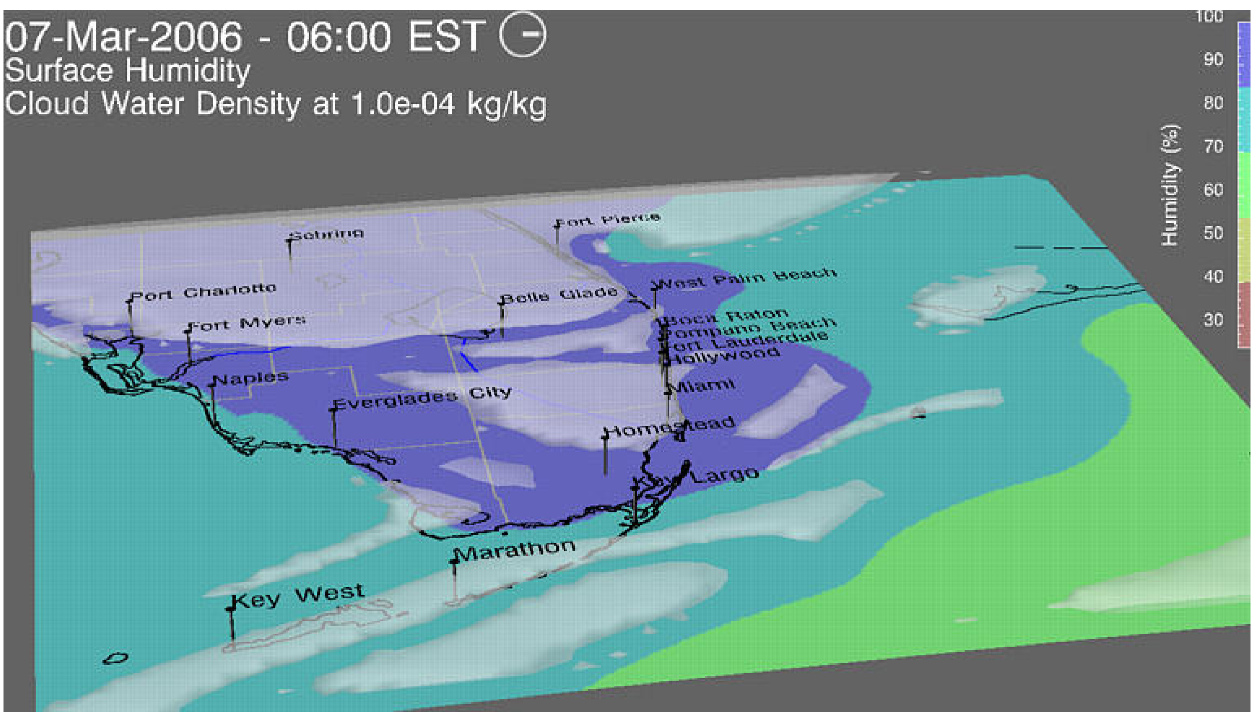

Figure 4. Model Image for Southern Florida – 1100 UTC March 7, 2006.

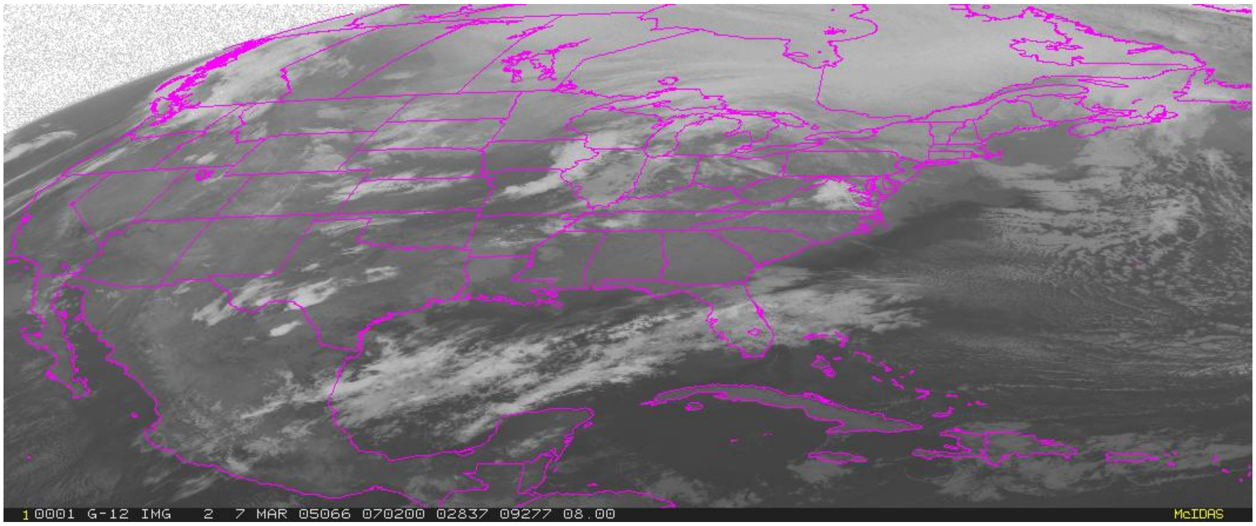

Figure 5. Satellite Image for Southern Florida – 1100 UTC March 7, 2006.

4.3 Hurricane Wilma

The final case that is examined considers the impact of Hurricane Wilma on southern Florida on October 23, 2005. Wilma was a Category 5 hurricane with the lowest recorded central pressure (882 mb) of an Atlantic basin hurricane prior to its landfall on southwest coast of Florida. The hurricane made landfall as a Category 3 storm shortly before 0700 EDT Monday, October 24th between Everglades City and Cape Romano with maximum sustained winds of 125 mph and an estimated minimum central pressure of 950 mb. Wilma moved rapidly to the northeast with an average speed of 25 mph. It exited the east coast in northeastern Palm Beach County near Palm Beach Gardens around 1100 EDT as a Category 2 hurricane.

Wilma exhibited a very large eye (55 to 65 miles in width) while crossing the state covering significant portions of southern Florida. The influence of the winds in the vicinity of the eye wall affected virtually the entire region. Sustained winds in the mid-morning hours on the south end of Lake Okeechobee were reported at 103 mph. Sustained hurricane force winds (74 mph or greater) were observed over most of southern Florida. The highest recorded gusts were in the 100-120 mph range.

Rainfall amounts generally ranged from two to four inches across southern sections of the peninsula compared to four to six inches across western Collier County and near Lake Okeechobee. A rainfall amount of 7.31 inches was reported along the southwest shore of Lake Okeechobee with some areas to the northeast exceeding 9 inches.

The southwest coast of Florida experienced a storm surge in the range of four to eight feet which caused extensive flooding. The southeast coast experienced a maximum storm surge in the range of four feet. Minor flooding for storm surge was noted in Coconut Grove, downtown Miami, and northeast Miami.

Five fatalities were recorded for the areas impacted by the storm. Total damage estimates from all the effects ranged from $9 to $12 billion. Extensive agricultural damage was reported, with an estimated cost of $222 million in crop damage for Miami-Dade County alone. Impacts were widespread, with large trees and power lines down over a large portion of southern Florida, causing over three million people to lose power. Structural damage to building roofs and power poles was heaviest in Broward and Palm Beach counties. Urban, high-rise buildings suffered considerable damage, primarily due to broken windows.

Figure 6 depicts a single frame from an animation that was created as a result of a model forecast run initiated at 0000 UTC on October 24, 2005. It shows the model prediction at the time of Wilma's observed landfall (via radar) at about 0700 EDT. The corresponding radar composite reflectivity graphic is shown in Figure 8. The predicted position is slightly north of the radar observed position at landfall.

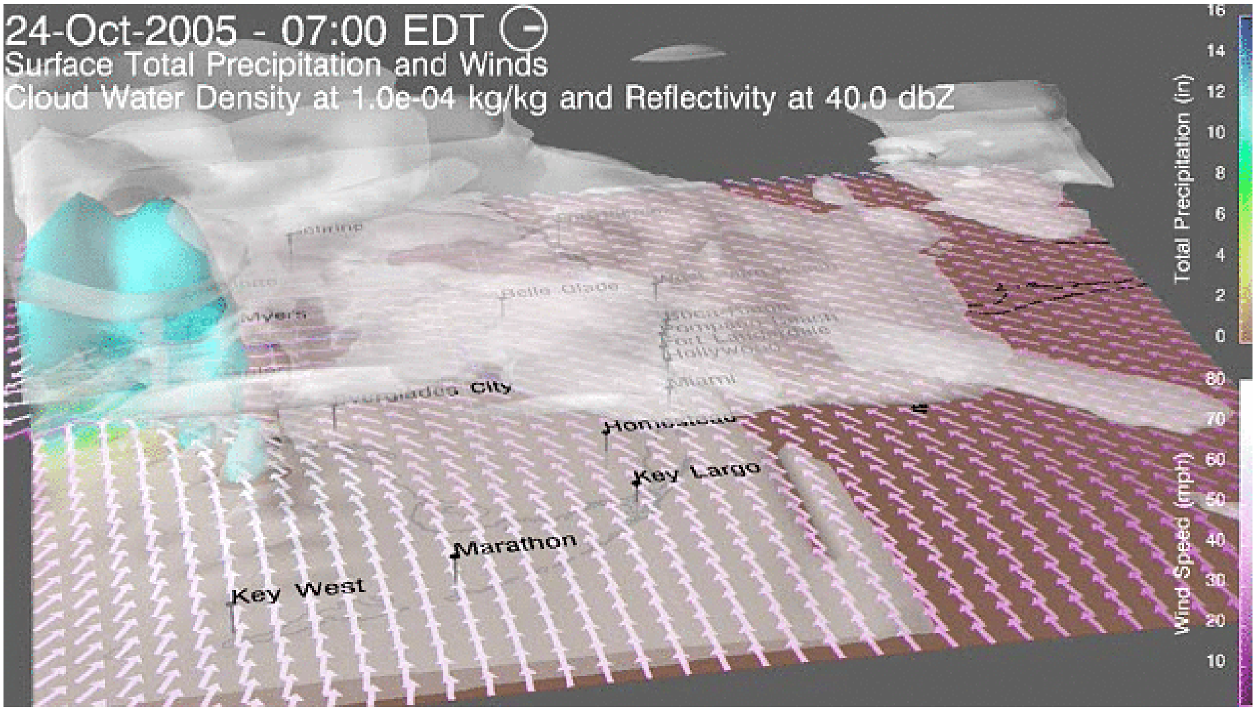

Figure 6. Model Predicted Position of Hurricane Wilma at Observed Landfall along the Southwest Florida Coast – 1100 UTC October 24, 2005.

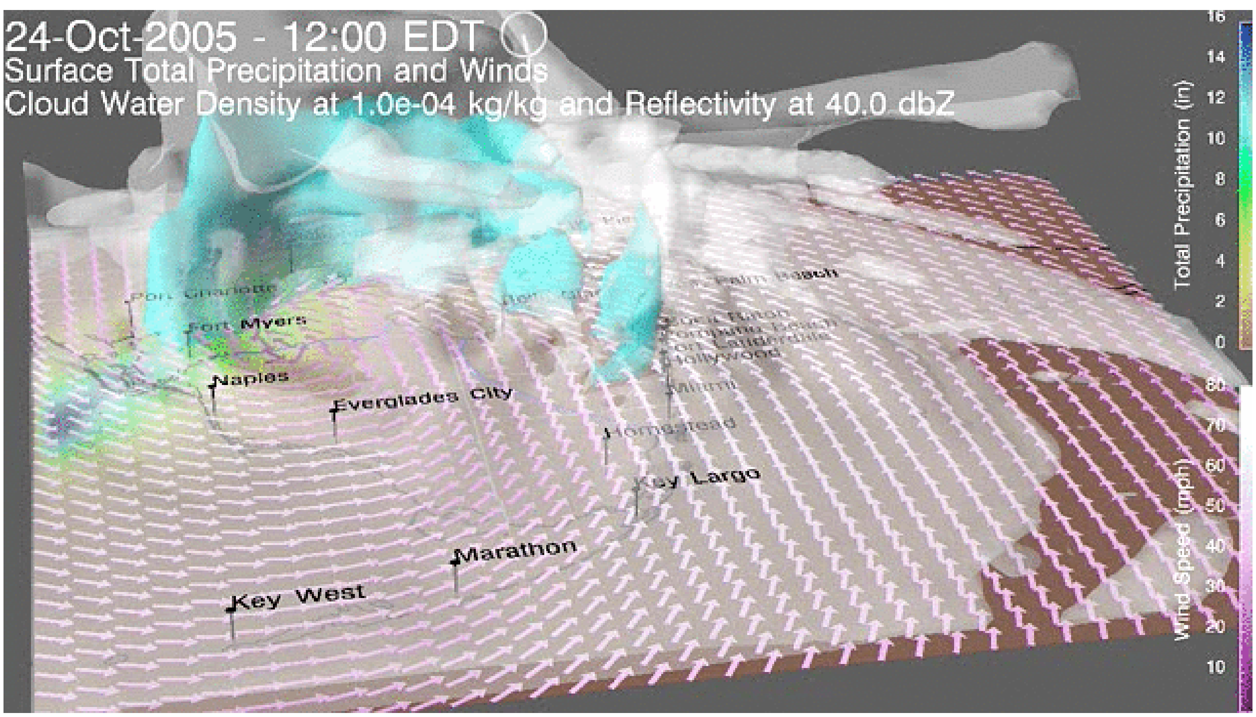

Figure 7. Model Predicted Position of Hurricane Wilma at Time of Observed Radar Exit from the Eastern Florida Coast – 1600 UTC October 24, 2005.

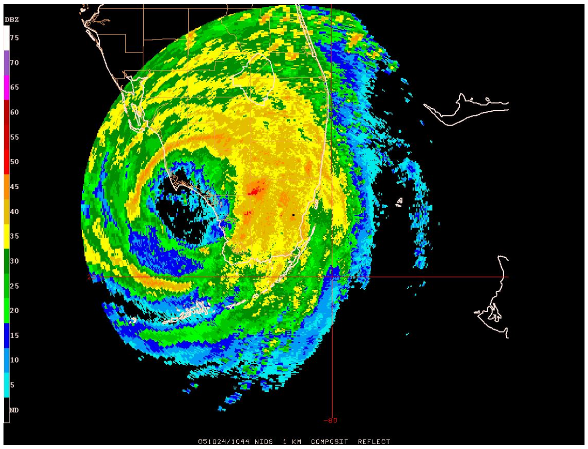

Figure 8. Radar Composite Reflectivity of Hurricane Wilma shortly before Observed Landfall along the Southwestern Florida Coast - 1044 UTC October 24, 2005.

Overall the model demonstrated good skill in simulating the structure and dynamics of the storm qualitatively. The timing is in good agreement with observed landfall but the predicted location and track of the storm are biased to the northwest of the observed track (Figure 9).

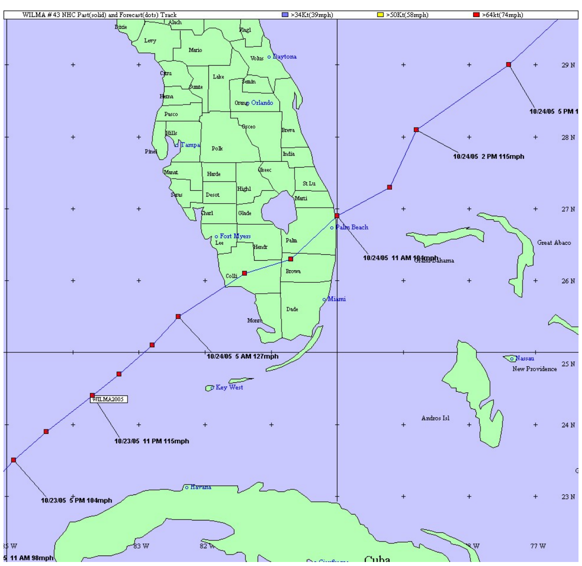

Figure 9. Track of Hurricane Wilma.

The model also moved the storm more slowly than what was observed taking about 12 hours to cross the state. Figure 7 depicts the model prediction of the Wilma at the observed time of the storms exit on the east coast at 1100 EDT. However, the model position is over south central Florida as compared to the corresponding radar observation in Figure 10, which shows Wilma much further east with the center off the east coast.

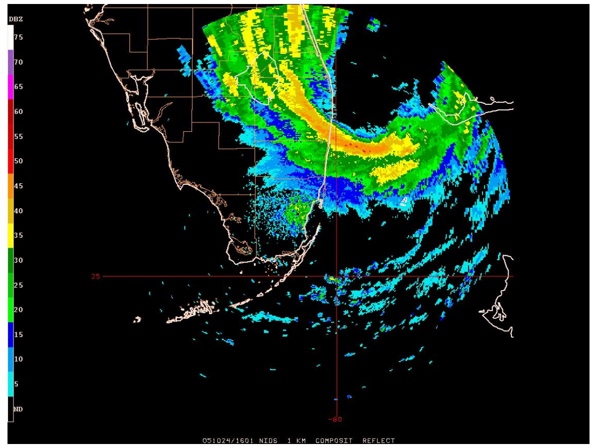

Figure 10 Radar Composite Reflectivity of Hurricane Wilma as It Exited the Southeastern Florida Coast – 1601 UTC October 24, 2005.

Predicted rainfall totals (Figure 11) were in good agreement when compared with radar estimates with regard to distribution although biased two to three inches higher and to the northwest in agreement with the track bias. The relatively slow predicted passage time may have led to the positive bias in rainfall amounts. In comparison, the estimated actual rainfall totals are shown in Figure 12, which illustrates the two day totals and details areas of maximum precipitation over the Florida peninsula.

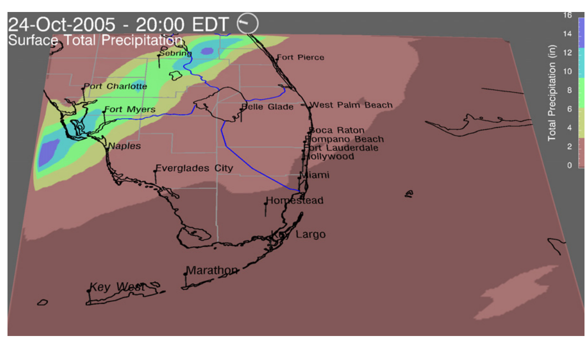

Figure 11. Model Predicted Precipitation at 6 km Resolution for October 24, 2005.

Predicted winds with speeds for various locations during the passage of the hurricane across south Florida agreed well with available observations. In addition, it should be noted that this model run was produced operationally. The results were available around midnight local time, thus provided a significant lead time with detailed information about the event

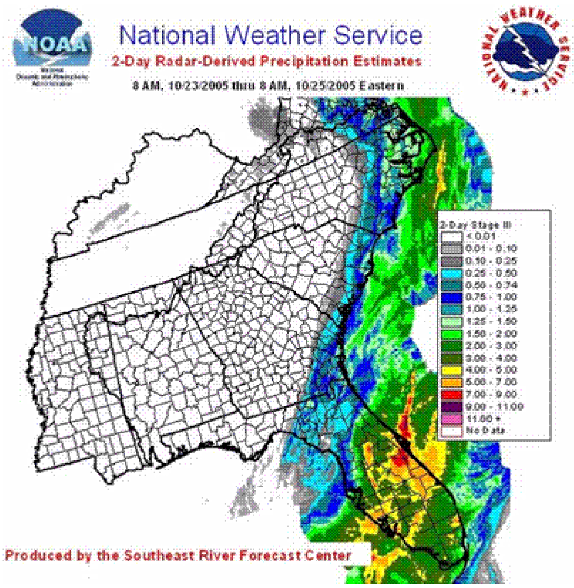

Figure 12. Radar Estimated Precipitation October 24 - 25, 2005.

Although these operational model results were reasonable, we wanted to understand the implications of alternative configurations and how they could improve the performance. So, the same Hurricane Wilma case was run as a 'hindcast', initiated at 0000 UTC on October 24, using the same input data sets in the initial run.

The model domain was reconfigured using two, two-way interactive nested grids. The inner grid was set at 203 x 203 to cover the entire state of Florida at 4 km resolution with a centroid over the eastern Gulf of Mexico. The outer grid was set to 178x178 with the same centroid. It covered much of the southeastern United States as well as the Gulf of Mexico at 12 km resolution.

Since NAM products for the continental United States were used for background fields and lateral boundaries, this constrained the coverage of the outer nest. As with the earlier model run, 31 vertical levels were used with time steps of 36 and 12 seconds, respectively. Land- and soil characteristics were representative of the entire state not just the southern portion. Model physics were the same as those used earlier. The forecast cycle time was significantly longer at about 2.5 hours.

Model forecast results for the 4 km nest are shown in Figures 14, and 15. They depict the same times as the visualizations of the earlier run. The first characteristic of this reconfigured model run is that the storm track is further south. The predicted landfall is fairly close to the Everglades City area where the storm was observed to make landfall. The predicted exit along the east coast was nearer what was observed at Palm Beach. The overall timing of the storm was better with the prediction of Wilma's movement across Florida closer to what was observed.

The most significant improvement was in storm track and structure as well as precipitation distribution (Figure 13). The reconfigured model exhibited more detail in the structure and movement of the convective bands and eye wall.

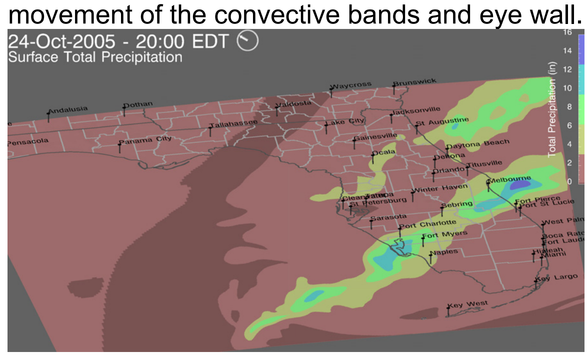

Figure 13. Revised Model Run: Predicted Precipitation at 4km Resolution - October 24, 2005.

Since the model physics and other parameters with the exception of land and soil parameterizations were the same, the improved skill is likely the result of the higher resolution domains, their locations and relative sizes.

We expected that covering more of the Gulf of Mexico at 12 km rather than a smaller area at reduced resolution coupled with a higher resolution grid covering all of the Florida penninsula would allow better simulation of storm motion and dynamics. On the other hand, the innermost nest of the initial configuration included the area where Wilma exited the coast at 1.5 km resolution. Admittedly, the increased meteorological realism comes with additional computational cost.

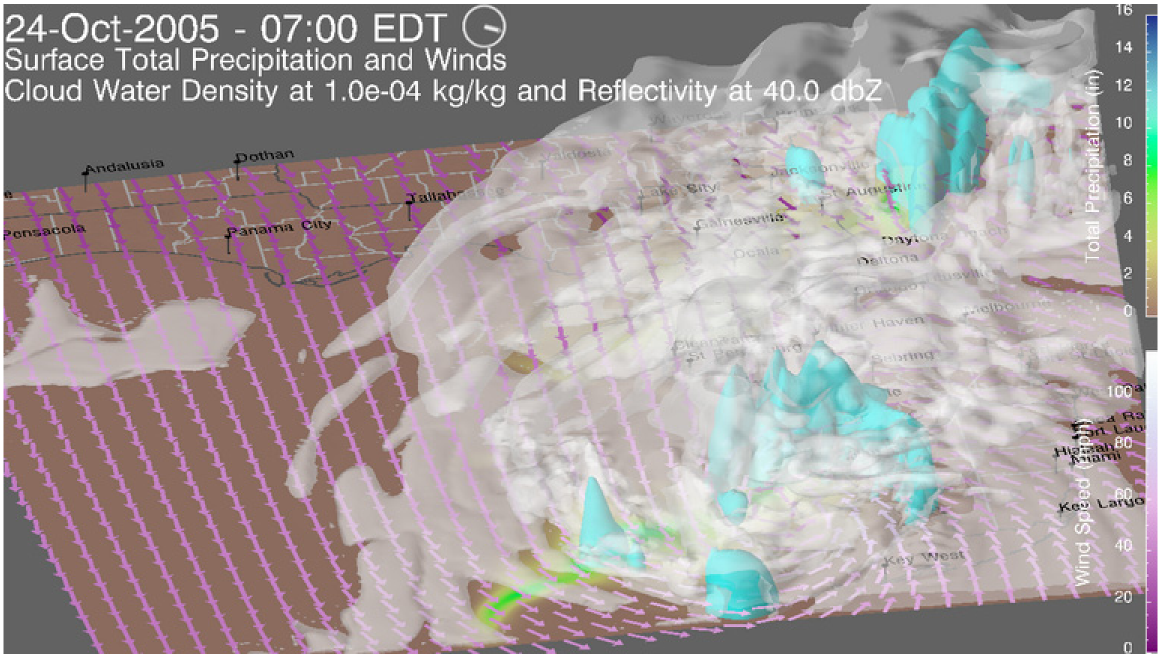

Figure 14. Revised Model Run: Predicted Position of Hurricane Wilma at Observed Landfall along the Southwest Florida Coast – 1100 UTC October 24, 2005.

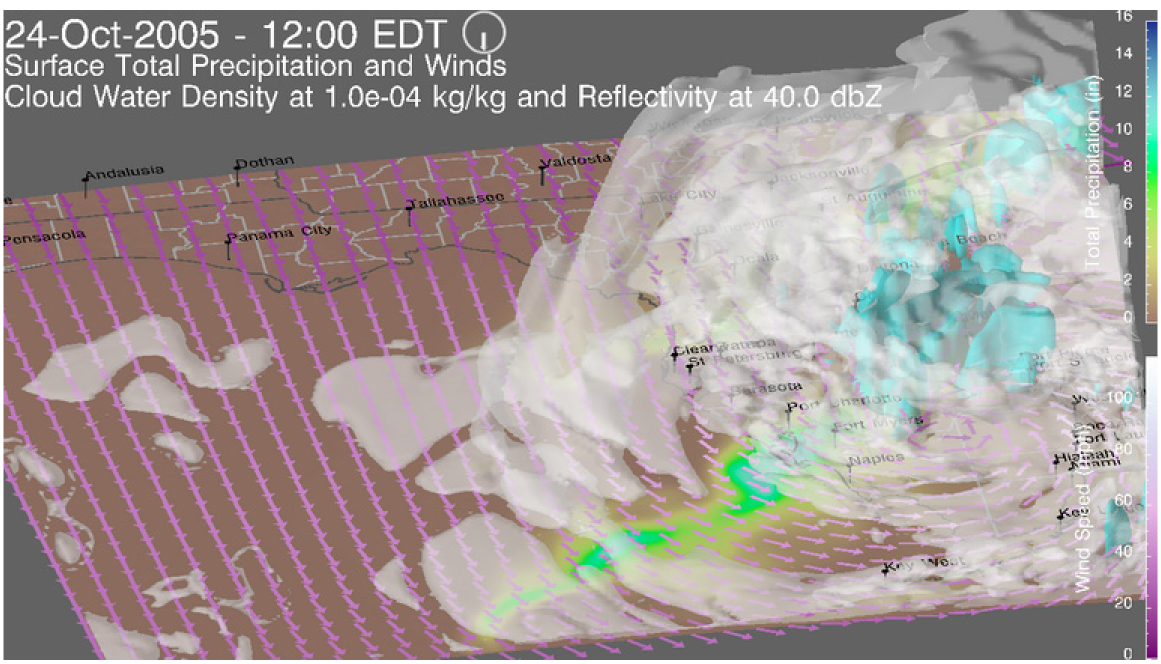

Figure 15. Revised Model Run: Predicted Position of Hurricane Wilma at Time of Observed Radar Exit from the Eastern coast of Florida – 1600 UTC October 24, 2005.

5. DISCUSSION

Overall results for the three events studied were good, especially at a broader-scale, where significant detail in structure and distribution is realized. In comparison, the model performance for location-specific events was less skillful where small spatial errors can result in an event being completely missed or having significant timing error.

Another factor may be the nature of the events. The events studied here were more varied in their origin and evolution than in previous studies focusing on events of a particular type (e.g., Praino and Treinish, 2004; Praino and Treinish, 2005). In the case of Hurricane Wilma the event was much larger in geographic scale as well as having a more prolonged duration. It also has both regional and local scale characteristics and impact. Hence, it should be more likely to be successfully simulated using this class of NWP model assuming the correct configuration.

Model performance clearly benefited from increased horizontal resolution over a larger area. Visualization was also a key component in creating highly usable products from model data in a timely manner.

6. FUTURE WORK

While this study focused on a small number of events there was a considerable skill in modeling events of different scale and nature. Future work will continue to address issues related to forecast performance improvement meteorologically as well as operational enhancements related to throughput and model tuning. Additional studies into the role of the model microphysics, model time step resolution and land/soil parameterizations will also be investigated.

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 modeling, a continued focus will be on the customization of model products and related metrics for end-user applications.

7. ACKNOWLEGEMENTS

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