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1. INTRODUCTION

As noted by Mass and Kuo (1998), with the recent phenomenal increase in affordable computer power, coupled with the availability of large-scale model data over the internet, operational regional numerical forecasts are now possible. As a result, several universities (Colle et al. 1999) and National Weather Service offices (Ballenstine et al. 1998) have begun running such models, often providing graphical output on a website for the perusal of interested meteorologists. In addition, the utilization of these regional models by the commercial community is also expanding. This paper documents the validation efforts of one company, User Systems Enterprises, Inc., in developing numerical guidance based on the 2nd version of the Fifth Generation Penn State/NCAR Mesoscale Model, or MM5 (Dudhia et al. 1999; Grell et al. 1995).

To examine the usefulness of regional models, several recent studies have computed forecast validation statistics for the 29 km Eta model (Nutter and Manobianco 1999), MM4 (Stensrud and Skindlov 1996), and RAMS (Gaudet and Cotton 1998), as well as comparisons between different regional models (Cox et al. 1998; Colle et al. 1999; White et al. 1999). Most of these studies were performed on nested grids. Since this project is in its early development phase, and because timely delivery of operational output is a high priority, this study uses a single domain for the validation period.

Section 2 discusses the operational environment for the data ingest and MM5 set-up. Section 3 presents the verification of real-time MM5 forecasts in terms of model bias and absolute error for surface temperature, dewpoint, and wind. Section 3 also presents subsets of these statistics stratified by observed wind speed. Conclusions and future work are discussed in Section 3.

2. OPERATIONAL ENVIRONMENT

The nonhydrostatic version of MM5 was run once daily from 1 April 1999 to 15 May 1999 using

a SGI Octane on one processor. Twelve hours of data assimilation is performed starting at 12Z from the previous day and ending at 00Z. The forecasts were conducted starting at 00Z out to 36 hours. Including the data assimilation and forecast period, forecasts typically were completed in approximately 3 h 10 min. Described below is the model framework and the data ingest procedures.

a. Model description

A single grid domain is used with a horizontal grid spacing of 45 km and 25 sigma levels in the vertical (with the following resolutions: 0, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, 0.50, 0.55, 0.60, 0.65, 0.70, 0.75, 0.80, 0.85, 0.89, 0.92, 0.94, 0.96, 0.98, 0.99, and 1). Ten-minute-averaged terrain and landuse data (Fig. 1) were analyzed to the model grid using a Cressman analysis scheme and filtered by a two-pass smoother/desmoother (Dudhia et al. 1995). A Lambert Conformal projection was chosen. The grid was centered at -90 deg W and 30 deg N with 61 by 61 gridpoints, incorporating the southern US/Gulf of Mexico region. A large domain was chosen to minimize the influence of lateral boundary conditions on the MM5 forecast (Warner et al. 1997) in the main region of interest --- the central Gulf Coast region.

The following MM5 physical options are used in this study: the Burk-Thompson Planetary Boundary Layer scheme (Grell et al. 1995; Burk and Thompson 1989); Kain-Fritsch convective parameterization (Kain and Fritsch 1990, 1993; Gallus 1999; Spencer and Stensrud 1998); grid-resolved microphysics using a mixed-phase ice scheme (Grell et al. 1995; Reisner et al. 1998); and a cloud-radiation scheme to account for longwave and shortwave interactions with explicit cloud and clear-air (Grell et al. 1995).

b. Data ingest and initialization procedures

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The initialization data comes from the Family of Services (FOS) of the National Weather Service. This data is ingested via Ku-band satellite delivery through the Harris Weather Data Service onto a Windows NT machine, then transferred to a UNIX workstation. Data from the Aviation (AVN) model is used for initialization and for boundary conditions.¹ Should the Harris Weather Data Service or FOS experience transmission problems, AVN data is downloaded from the NCEP Data Repository server at <ftp.ncep.noaa.gov> instead.² A description of model analysis formats, known as GRIBed Binary (GRIB), is provided in Dey (1996) and in the World Meteorological Organization publication No. 306 (Secretariat of the WMO 1988). As with all MM5 simulations, the GRIB data must first be preprocessed to MM5's grid points. Bilinear interpolation is used horizontally, and the equations for vertical interpolation are described in Dudhia et al. (1999). At the time of this study, most of the "traditional" MM5 preprocessing shell scripts were written specifically for the NCAR Cray/mass-storage environment, and lacked portability. As a result, many of the preprocessing routines used in this study were written "in-house."

The model is initialized using the previous day's 12Z AVN forecast. Then, MM5's Four-Dimensional Data Assimilation (FDDA) procedure is employed using observational nudging (Parsons and Dudhia 1997; Dudhia et al. 1999; Grell et al. 1995). Observations used in FDDA include ship, buoy, CMAN, METAR, and wind profiler data. Also included are any satellite-derived surface wind speeds from SSM/I and TOPEX (supplemented with wind direction based on the AVN forecast), and ERS-2 scatterometer winds. At 00Z, rawinsonde observations are also incorporated in the FDDA.

Quality control is performed on the rawinsonde data in two ways. First, if the difference between the observation and nearby observations within 100 km exceeds a certain threshold, it is discarded. Second, if the observed value exceeds a certain value, it is discarded. Observed data which exceed these thresholds are removed from the FDDA procedure. In summary, MM5 is initialized using AVN data from the previous 12Z run, then twelve hours of data assimilation is performed ending at 00Z, from which a 36-hour forecast is performed.

3. VERIFICATION RESULTS

¹ FOS model data is transmitted as one variable and one sigma level per file, known as "thin grids." These files must be concatenated together before initializing MM5.

² A description of the GRIB filename convention and of the Family of Services is provided on the National Weather Service website <http://www.nws.noaa.gov>

Verification is performed on the following surface values: temperature, dewpoint, wind speed, and wind direction. Furthermore, these verifications are performed against the following observation platforms: METAR data, CMAN data, buoy data, and ship data. The METAR data are the basis for land verification, and the other platforms are for marine observations (divided into the three categories to check systematic differences between these platforms). Since the lowest sigma level is approximately 38m, wind speeds are reduced to 10-m height using the following empirical formula:

$$u_{10} = u_{38} \left(\frac{10}{38} \right)^{.143} ; v_{10} = v_{38} \left(\frac{10}{38} \right)^{.143}$$

No such reduction is performed on temperature currently, which introduces a bias as discussed below.

Biases and absolute errors for the predicted surface values are shown in Tables 1-4 against METAR, buoy, CMAN, and ship data respectively for forecast hours 30 and 36. In general, the statistics suggest MM5 generates good forecasts even at the relatively coarse resolution used in this study. However, a noticeable cool bias is seen over the ocean for reasons discussed above. This bias is not seen over land. In contrast, dewpoint temperature is too large over land, but too low over the ocean.

Table 5 shows wind forecasts stratified by observed METAR wind speed. As can be seen, forecast errors increase with wind speed. This is to be expected to some extent, since regions with weak pressure gradients cannot produce large wind forecast errors. However, most of the error in windy situations is associated with a negative bias, indicating that the model is underforecasting wind speed. An analysis of buoy data reveals the same bias (not shown). In general, this is a problem many models have, not just MM5. We will investigate whether higher resolution forecasts reduce this negative wind speed bias in the future.

A methodology to correct the surface temperature forecasts is currently being developed based on Monin-Obukhov theory. Accumulated rainfall forecasts also are being verified. A statistical comparison against rawinsonde data is also being done. These results will be reported at the conference.

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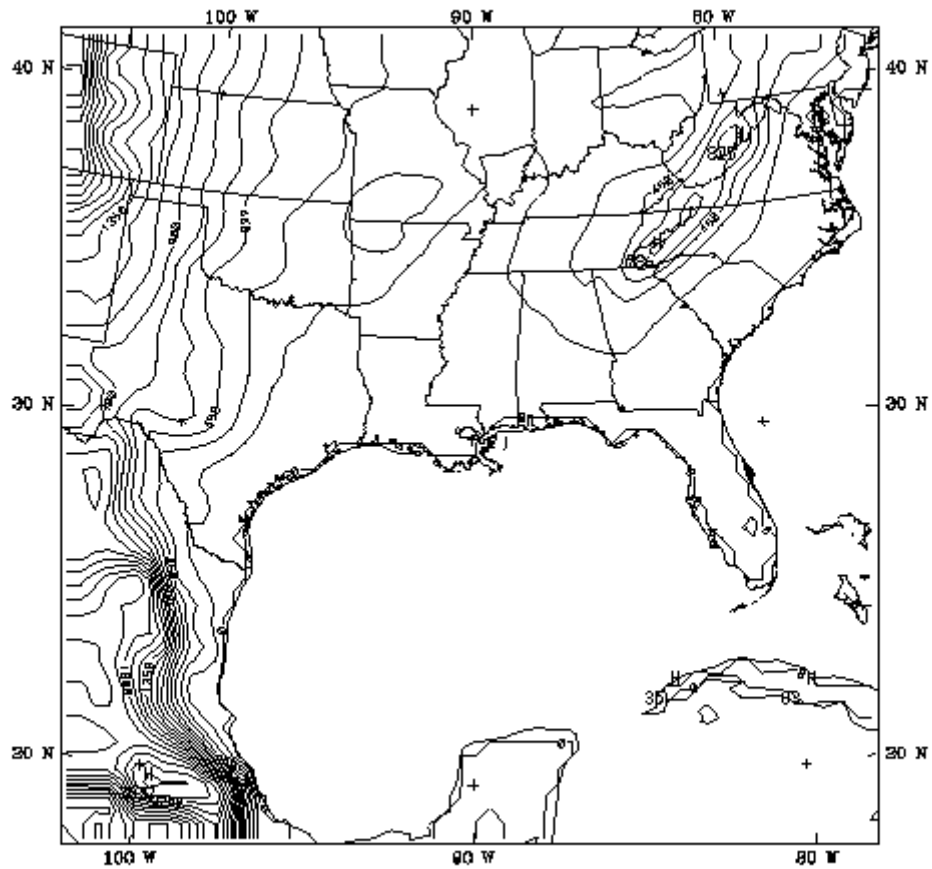


Figure 1. Depiction of the model domain with 10-deg terrain data.

Table 1. MM5 Bias and absolute errors for predicted surface values against METAR observations.

	Bias	Bias	Bias	Bias	Absolute error	Absolute error	Absolute Error	Absolute Error
Forecast hour	T ($^{\circ}\text{C}$)	T_d ($^{\circ}\text{C}$)	Wind Speed ($m\text{S}^{-1}$)	Wind direction (deg)	T ($^{\circ}\text{C}$)	T_d ($^{\circ}\text{C}$)	Wind Speed ($m\text{S}^{-1}$)	Wind direction (deg)
30	-0.1	2.1	1.1	1	2.3	2.9	1.9	52
36	0	1.5	1.0	5	2.2	2.6	1.9	52

Table 2. MM5 Bias and absolute errors for predicted surface values against buoy observations.

	Bias	Bias	Bias	Bias	Absolute error	Absolute error	Absolute Error	Absolute Error
Forecast hour	T ($^{\circ}$ C)	T_d ($^{\circ}$ C)	Wind Speed ($m s^{-1}$)	Wind direction (deg)	T ($^{\circ}$ C)	T_d ($^{\circ}$ C)	Wind Speed ($m s^{-1}$)	Wind direction (deg)
30	-1.9	-0.2	-0.5	10	2.1	1.5	1.9	37
36	-2.0	-0.4	-0.4	5	2.2	1.3	1.9	32

Table 3. MM5 Bias and absolute errors for predicted surface values against CMAN observations.

	Bias	Bias	Bias	Bias	Absolute error	Absolute error	Absolute Error	Absolute Error
Forecast hour	T ($^{\circ}$ C)	T_d ($^{\circ}$ C)	Wind Speed ($m s^{-1}$)	Wind direction (deg)	T ($^{\circ}$ C)	T_d ($^{\circ}$ C)	Wind Speed ($m s^{-1}$)	Wind direction (deg)
30	-1.6	-0.1	-0.6	-4	2.3	1.5	2.1	40
36	-1.9	-0.1	-0.5	-5	2.5	1.8	2.0	39

Table 4. MM5 Bias and absolute errors for predicted surface values against ship observations.

	Bias	Bias	Bias	Bias	Absolute error	Absolute error	Absolute Error	Absolute Error
Forecast hour	T ($^{\circ}$ C)	T_d ($^{\circ}$ C)	Wind Speed ($m s^{-1}$)	Wind direction (deg)	T ($^{\circ}$ C)	T_d ($^{\circ}$ C)	Wind Speed ($m s^{-1}$)	Wind direction (deg)
30	-2.0	-0.6	-1.5	-5	2.3	1.5	2.8	41
36	-2.1	-1.4	-0.9	-5	2.7	1.9	2.5	42

Table 5. MM5 surface wind biases stratified by observed METAR wind speed

	Bias	Bias	Bias	Bias	Bias
Forecast hour	0 to 3 ($m s^{-1}$)	3 to 5 ($m s^{-1}$)	5 to 10 ($m s^{-1}$)	10 to 15 ($m s^{-1}$)	15 to 20 ($m s^{-1}$)
30	2.1	0.8	-0.4	-3.6	-6.9
36	2.0	0.7	-0.6	-3.6	-7.0
	Absolute Error	Absolute Error	Absolute Error	Absolute Error	Absolute Error
30	2.3	1.4	1.6	3.7	6.9
36	2.2	1.4	1.7	3.7	7.0