Comparison of MM5 Forecast Shortwave Radiation with Data Obtained from the Atmospheric Radiation Measurement Program

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ABSTRACT
The performance of the Pennsylvania State University-National Center for Atmospheric Research Mesoscale Model 5 (MM5), in particular the shortwave downwelling (SW) flux calculations, is examined in this paper. Selected quantities output from the MM5 were compared with data from the Department of Energy funded Atmospheric Radiation Measurement (ARM) Program’s Southern Great Plains (SGP) site in central Oklahoma. The data were gathered during an intensive observation period (IOP) at this site from June 18 to July 18, 1997. MM5 was run 29 times with a forecast length of 24 hours, the data were saved and then compared to radisonde and pyranometer data. SW flux calculated from the MM5 deviated severely from that observed at the SGP site. Much of the error probably results from the method by which cloud fraction is calculated within the radiation parameterization. Additional error in the SW flux could be attributed to an overly moist upper troposphere generated by the model. Despite the enormous SW flux errors, the model reproduced the observed surface temperature quite well, with only a slight cold bias. These results echo a number of other verification studies of the MM5, and the SW flux problem bears some resemblance to a SW flux verification study conducted with the Eta regional model.

I. Introduction

With advancing computer capabilities, scientists are efficiently modeling the atmosphere with a marked increase in spatial resolution. The performance and the popularity of these mesoscale models has increased dramatically, as it is now feasible both computationally and economically to run these high-performance models on an operational, or quasi-operational basis. The MM5 (Mesoscale Model 5), developed by the Pennsylvania State University (PSU) and the National Center for Atmospheric Research (NCAR), has become one of the more widely used mesoscale models within the research community. It is currently being used by no less than fifty universities in the United States and over thirty United States government institutions. MM5 is being run operationally at a number of these locales, including the Pennsylvania State University in
State College, PA, the University of Maryland at College Park, MD, and the University of Oklahoma, located in Norman, OK.

Numerous forecast validation studies have been conducted for the meteorological fields produced by MM5 throughout its development at various times and locales. For example, MM5 forecasts used for guidance in the Winter Icing and Storms Project (WISP) were later used for verification with data observed during the field campaign (Manning and Davis 1997). The MM5 model has been studied in numerous model intercomparison experiments, such as those performed by White et al (1999) and for the United States Air Force (Cox, et al 1998).

Nevertheless, the effects of the radiative flux computations of the MM5 forecast are rarely considered for verification. Generally, the effects of a radiation scheme can only be inferred from diagnostic studies. The RADIAT experiment (Manning and Davis 1997), a radiation sensitivity test performed with the MM5 model, studied the MM5 forecasts used for guidance during WISP 94. The results of the MM5 run using a more sophisticated radiation parameterization (Dudhia, 1989) were compared against the control results which utilized a simple cooling scheme (Grell, et al 1994). Dudhia’s radiation scheme included cloud effects on shortwave and longwave radiative fluxes, while the previous scheme did not. The RADIAT experiment did not however measure the actual fluxes. The principle reason for the dearth of radiation validation experiments performed for the MM5 and other models is the lack of observations of these quantities. However, the Atmospheric Radiation Measurement (ARM) program’s Southern Great Plains (SGP) site in the Midwest provides accurate measurements of the radiative quantities useful for the validation of these models.
This study uses data obtained from the SGP Cloud and Radiation Testbed (CART) site during an Intensive Observation Period (IOP) to compare with the model forecasts. The shortwave downwelling (SW) flux is the prime measurement of interest for the purpose of this study, as well as the relationship of the SW flux to meteorological forecast variables that would be useful for operational forecasts, such as temperature and water vapor mixing ratio results. Any attempt to carry out SW flux validation is complicated by the close and intuitively obvious relationship with the determination of the cloud field. Thus, one must carefully consider the associated cloud fraction and its relationship to the SW flux measurements. Also of great import to this experiment, is to comprehend the manner in which the model diagnoses cloud fraction. A secondary focus of the study is to examine the performance of the forecasts with respect to other predictands of interest to operational meteorologists, such as the horizontal wind components.

In section IIa of this paper, the MM5 modeling system is described in a general fashion. The specific parameters of the model for the purpose of this study, including grid spacing and physics options are outlined later, in section IV. Section III gives a brief overview of the ARM program and the CART site. The manner in which the data was collected and analyzed is discussed in section IV. Section V summarizes and discusses the results. Pertinent results of other studies are outlined and compared to the results of this paper in section VI and finally concluding remarks are offered in section VII.
II. General MM5 Model Description

The version of the model, MM5 version 2, used for this study descends from the model developed by Anthes in the 1970s at PSU. Anthes and Warner (1978) documented this early version of the model. MM5v2 has a terrain-following sigma coordinate in the vertical domain. The model has the options for multiple 2-way interactive nesting, with up to nine nested and interactive domains possible. Either hydrostatic or non-hydrostatic dynamics can be implemented, depending on the horizontal grid resolution. Non-hydrostatic dynamics must be employed as the ratio of the horizontal scale to the vertical scale (approximately 10 km) approaches unity. MM5v2 is also equipped with a four-dimensional data assimilation capability, as well as several new physics parameterizations not included in the previous release of the modeling system. The physics options introduced in version 2 were the Betts-Miller, Kain-Fritsch and Fritsch-Chappell cumulus parameterizations, the Burk-Thompson planetary boundary layer scheme, two new cloud microphysical schemes and the CCM2 radiation package (MM5 Modeling System Overview, 1998).

Dudhia’s radiation scheme, with cloud interaction, was the parameterization used for this experiment. Downward solar flux in this scheme is described by the equation

\[ S_d(z) = \mu S_o - \int_{z_{top}}^z (dS_{cs} + dS_{ca} + dS_s + dS_a) \]  

(1)

Where \( S_d(z) \) is the SW flux at level \( z \), \( \mu \) is the cosine of the solar zenith angle and \( S_o \) is the solar constant. The terms \( dS_{cs} \) and \( dS_{ca} \) delineate the SW flux that is diminished by cloud scattering/reflection and cloud absorption, respectively. The amount of SW flux scattered in clear air is denoted by \( dS_s \), while \( dS_a \) represents the absorption of water vapor. The cloud albedo and absorption are interpolated from tabulated functions of \( \mu \).
and $\ln(w/\mu)$, where $w$ is the vertically integrated liquid water path. These tables are derived from Stephens’ (1978) theoretical results. Absorption by water vapor in clear air is calculated using Lacis and Hansen’s (1974) absorption function of $\mu$ and $w$.

### III. The ARM program

#### a. Brief ARM program history

The Department of Energy (DOE)-funded ARM program began in January 1990. The core objective of the program is to improve the radiation and cloud parameterizations for General Circulation Models (GCM) used in climate prediction. Plans were made to construct CART sites in regions representing significant climate regimes. Three different sites were chosen to host permanent or semi-permanent CART facilities: SGP, the Tropical Western Pacific (TWP) and the North Slope of Alaska (NSA) (Ferrell, et al 1998). Collectively, these sites offer a wide range of cloud and radiation measurements integral to the development and verification of GCM cloud/radiation systems.

#### a. The SGP site

The SGP CART site occupies approximately 55,000 square miles of central Oklahoma and south central Kansas. Located to the southeast of Lamont, OK is the hub of the CART site, the central facility. The central facility ($36^\circ 37' \text{ N}, 97^\circ 30' \text{ W}$), where the bulk of the instruments reside, is situated on about 160 acres of fields and pastures. Comprising the rest of the semi-permanent CART domain are four boundary, twenty-four extended and three intermediate facilities. Approximately the size of a GCM grid box, the SGP CART site measures approximately 225 miles on a side (ARM SGP Web Site, 2000).
Dozens of sophisticated instrument arrays are clustered around the central facility. These arrays are grouped into the general categories of aerosol-measuring, cloud-measuring, atmospheric profiling, radiometric, surface eddy flux and surface meteorological instruments. The National Aeronautic and Space Administration's (NASA) GOES-7 geostationary satellite supplies other data derived from its atmospheric soundings.

For this study, atmospheric profiles were taken from the Balloon-Borne Sounding System (BBSS) located at the central facility, while SW flux data were furnished by the pyranometers of the Base Line Radiation Network (BSRN). Cloud Fractions were derived from GOES-7 data. The data used in this study were gathered during the summer 1997 Single-Column Model (SCM) Intensive Observation Period that took place from June 18 to July 18. An IOP is period chosen for the gathering of large datasets, in this case for the initialization and validation of SCMs. Radiosondes were launched every three hours from the central facility, four times the temporal resolution generally available.

**IV. Methodology**

*a. MM5*

Using the NCEP global analysis fields (2.5° X 2.5°) for initialization, 29 24-hour forecast runs were made from June 18 to July 17, 1997, corresponding to the data available from the SCM IOP archive. The runs were initialized at 0000Z and terminated at 0000Z the following day. For this study, two domains were used, a coarse domain with a resolution of 36 km, with an inner domain using 12 km grid spacing. The coarse
grid was centered over the SGP CART site's central facility, with the fine high-resolution domain oriented to imitate the domain of the CART site (fig. 1).

Twenty-three vertical levels were used, with more levels clustered close to the surface and boundary layers with fewer aloft. Cloud microphysics were diagnosed by the simple ice scheme for the coarse domain and the GSFC graupel scheme for the nested domain. The Grell cumulus parameterization was implemented, as was the Burk-Thompson planetary boundary layer scheme. Dudhia's radiation package, the subject of examination here, was used for both domains. Data were saved both at the grid point lying closest to the SGP CART site's central facility and each vertical level. Quantities saved were the following: temperature, water vapor mixing ratio, the zonal (u) and meridional (v) components of the horizontal wind, vertical velocity (w), total radiative heating rate, downwelling SW flux and longwave (LW) upwelling flux.

Atmospheric profiles from the BBSS and the SW flux from the BSRN were provided at 3-hour intervals by the SCM IOP data archive. The data were given on 18 vertical levels, so the data were interpolated to the same sigma coordinates as the model by means of a cubic spline. From this data, daily mean values were computed for
temperature, water vapor mixing ratio, the zonal wind component and the meridional wind component at each vertical level.

For each variable, at each point in the temporal and vertical domains, error was computed as error = \( x_n^f - x_n^o \), that is the MM5 forecast value minus the observed value. Bias error, or systematic bias error, is a measure of the correspondence between the average forecast and the average observed value of the predictand (Wilks, 1995, p236). Bias error is calculated for selected variables at pre-selected levels. The bias error is given by:

\[
B(x) = \frac{1}{N} \sum (x_n^f - x_n^o) \tag{2}
\]

Where \( N \) is the total number of forecasts, and the superscripts \( f \) and \( o \) denote forecasted and observed values of the quantity \( x \), respectively. To examine the net effect, surface SW flux, was averaged over 12 daylight hours, from 1200Z to 0000Z the next day, ignoring the trivial contribution to the SW flux during the night and morning hours. The error was computed for the daily-averaged values as well. Bias was calculated at each of the aforementioned levels for the temperature and water vapor mixing ratio, and the surface for the SW flux.

The daily cloud fraction data were averaged over 12 hours, so as to ignore the impact of nighttime clouds, which obviously have no impact on the amount of SW flux received at the surface. These data were then used to compare against the mean daily errors for the shortwave flux. Cloud Fraction was divided into three categories: clear (C), broken (B), or overcast (O). The cloud field was considered clear if the cloud fraction was less than 30%, broken if the cloud fraction was between 30% and 70%, and overcast
for any cloud fraction greater than 70%. SW flux daily errors were then grouped into three separate divisions (Table 1).

Table 1. Error Categories for the SWE (Swmodel-Swobs)

<table>
<thead>
<tr>
<th>Category</th>
<th>SWE (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme Underforecast (U)</td>
<td>&lt; -100</td>
</tr>
<tr>
<td>Moderate under/over (M)</td>
<td>-100 &lt; SWE &lt; 100</td>
</tr>
<tr>
<td>Extreme Overforecast (O)</td>
<td>&gt; 100</td>
</tr>
</tbody>
</table>

V. Results and discussions

a. SW Flux

As shown in Table (2a), SW flux has a negative bias of 44 W/m² over the 29 days, originally 232 data points. This bias, however, is not consistent, as the error shows a high degree of variability. Absolute differences range from 5 to 371 W/m². As discussed previously, the SW flux errors were placed in bins, according to their magnitude and sign of the deviance. SW errors having an absolute value of greater than 100 W/m² were considered cases of extreme error, while those errors less than 100 W/m² were considered to be moderate. Of the 28 cases considered in this study, 16 were considered to have extreme error, while only 12 cases could be listed as having moderate error (Table 3)

Table 2a. Statistics on surface measurements and predictions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model Mean</th>
<th>Observed Mean</th>
<th>Model Std Dev.</th>
<th>Observed Std Dev.</th>
<th>Bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW Flux</td>
<td>515</td>
<td>564</td>
<td>195.3</td>
<td>81.4</td>
<td>-44.0</td>
</tr>
<tr>
<td>Temp (K)</td>
<td>298.7</td>
<td>298.7</td>
<td>2.1</td>
<td>2.5</td>
<td>-0.1</td>
</tr>
<tr>
<td>Qvap</td>
<td>16.6</td>
<td>15.1</td>
<td>3.0</td>
<td>1.9</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Table 2b. Biases of upper-level T and Q, units as in Table 2a

<table>
<thead>
<tr>
<th>Variables</th>
<th>Bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature 700 hPa</td>
<td>3.5</td>
</tr>
<tr>
<td>Temperature 500 hPa</td>
<td>5.8</td>
</tr>
<tr>
<td>Mixing Ratio 700 hPa</td>
<td>1.1</td>
</tr>
<tr>
<td>Mixing Ratio 500 hPa</td>
<td>8.8</td>
</tr>
</tbody>
</table>
Table 3. Cases binned in SW error category and cloud cover category

<table>
<thead>
<tr>
<th>Cloud Cover (%)</th>
<th>SW error(W/m²)</th>
<th>&lt; -100</th>
<th>&lt; -100 &lt; &lt; 100</th>
<th>&gt; 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>C 0-30</td>
<td>2</td>
<td>6</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>B 30-70</td>
<td>7</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>O 70-100</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Of the 16 cases classified as extreme, 12 of them occurred when the daily averaged cloud fraction was in the broken cloud regime. The importance of the presence of clouds to the determination of the SW flux is evident from Equation 1. Clouds diminish SW flux through absorption, scattering and reflection. Clearly the accurate representation of clouds within the radiation routine is critical to the calculation of realistic SW flux values.

Like many models, the MM5 predicts cloud fraction as either 0 or 1. If the cloud-water mixing ratio at any of the grid points is greater than 0, then the entire grid is considered cloudy. Knowing this property of the model, forming a hypothesis as to the cause of the extreme SW errors becomes intuitive. One would expect that the greatest deviations between the forecasted and observed SW values would occur when the cloud field is broken. The cloud-radiation scheme should perform the best when the skies are either completely clear or completely overcast, as those are the two conditions that could be forecast by the model.

Although a small sample size, this experiment supports the previous hypothesis, as an overwhelming 75% of the extreme SW error cases were accompanied by a broken cloud field. For the 12 moderate SW error cases, 8 of them occurred when the sky was either very nearly clear or very nearly overcast. This information, coupled with the negative
bias infers that in the majority of the cases, the model is predicting too high a cloud fraction, which minimizes the SW flux incident on the surface. The inverse is also suggested to be true, meaning that on some occasions, the model generates completely clear skies when a significant cloud deck verifies. In this situation, the model will allow too much solar flux to be computed at the surface.

Before being truly able to attribute the flux deficiency to the cloud representation within the radiation scheme, it would be prudent to test the shortwave radiation formulation by itself. This could be accomplished by several different methods. One method could be to test this radiation code against more detailed line-by-line radiative transfer models using a standard atmospheric composition profile (Fouquart et al). Halthore, et al (1997), compared clear-sky direct-normal solar irradiance (DNSI) calculated from a radiative transfer model (MODTRAN3) and measured at the ARM SGP site. The model slightly underestimated DNSI by 1.8 %, +/- .94 %. These results were quite good, as the range of uncertainty was less than that of the composite uncertainty of the instruments and the model calculations. This shows that solar radiation in clear-sky cases is reasonably well understood and can be modeled accurately.

However, numerical weather prediction models generally are not equipped with the most accurate, or computationally expensive, radiation codes. Some of these codes may contain significant errors, even for clear-sky cases. For example, Morcrette (1991) compared the first two versions of the European Center for Medium Range Weather Forecasts (ECMWF) radiation code with results from a more detailed band model. It was revealed that the first two versions of the ECMWF radiation code overestimated shortwave absorption by roughly 20%, which diminished SW flux at the surface by 5-
10%. The third version fared much better with respect the narrow band model, with differences between 1% and 3%, as compared to 6% and 11% for the various cases.

\[ \text{b. Temperature} \]

SW flux incident on the surface of the earth is obviously the driving force of the temperature of the boundary layer. It should follow that if the model does not predict enough SW flux on average, then the surface temperatures calculated by the model should also be too cold on average. Indeed the temperature displays a slight cold bias for the surface layer, about 
\[ -0.07 \text{ K}, \]
but considering the tremendous differences in MM5 SW flux and the observed SW flux, this is surprisingly minute. The SW flux error is probably mitigated by initializing the model daily, constraining the temperature to more realistic values, as well as the large contribution by temperature advection.

Temperature also exhibits very robust upper-level biases (Fig. 2). Biases computed for the 500 hPa and 700 hPa levels (Table 1b), further reveal that MM5's upper troposphere is consistently and significantly too warm. MM5 temperatures near the stratopause are also markedly high, but an examination of the causes for these phenomena is beyond the scope of this paper.
Fig. 2. Contour plot of temperature errors

c. Water Vapor Mixing Ratio

The SW flux incident on the surface is also sensitive to the prediction of water vapor, more specifically the column-integrated water vapor. As evident from equation 1, water vapor in the atmosphere absorbs some SW flux, so an excess of water vapor aloft might contribute somewhat to the negative bias exhibited by the SW flux at the surface. All three levels for which bias values were computed showed significant positive biases (Tables 1a, 1b). The water vapor mixing ratio contour plot (Fig. 3) reveals a nearly uniform wet bias in the model, with some extremely wet layers aloft, particularly towards the middle of July. Few instances may be observed where the model predicts too little water vapor.
One aim of this study was to determine whether the SW flux calculated by the model has a profound effect on the temperature forecasts. Pearson correlation coefficients derived from the data reveals a very weak relationship between the SW flux and the temperature generated by the model (Table 4). The correlation coefficients of the SW flux and temperature errors have an even poorer statistical relationship (Table 4). These results are somewhat counter-intuitive, as one would expect a stronger relationship between the surface temperature and SW flux incident upon it. However, the mitigating factors mentioned before in section Vd, become dominating factors for a short time scale like this.

Figure 3. Contour plot of water vapor mixing ratio errors

d. Statistical relationships

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Based on the information from equation 1, it should be expected that the significant positive water vapor mixing ratio bias should negatively impact the SW radiation field, as the positive mixing ratio bias implies a positive column-integrated water vapor bias. Pearson correlation coefficients (Table 4) for the surface and 700 hPa layers display small positive relationships, while the 500 hPa level values are slightly stronger and negative. The strongest, though still not statistically robust, relationship is the negative correlation between the SW errors and the 500 hPa water vapor error.

**Table 4: Pearson-moment correlation coefficients between SWE and other variable errors**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cor Coeff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tsurface</td>
<td>.07</td>
</tr>
<tr>
<td>T700</td>
<td>.11</td>
</tr>
<tr>
<td>T500</td>
<td>-.07</td>
</tr>
<tr>
<td>Qsurface</td>
<td>.22</td>
</tr>
<tr>
<td>Q700</td>
<td>.19</td>
</tr>
<tr>
<td>Q500</td>
<td>-.39</td>
</tr>
</tbody>
</table>

c. The horizontal wind components

A contour plot of the zonal (u) component errors (Fig. 4) of the horizontal wind displays MM5’s prowess in forecasting the zonal wind speed. Most of the wind speeds deviate less than three m/s from the observe winds of the radiosondes. The only large errors represented within this field are in the upper troposphere, at the jet stream level. Here, a small error in the spatial orientation of a jet streak could lead to a large error.
The meridional (v) component of the horizontal wind is not predicted quite as well as the zonal, as evidenced from Figure 5. MM5 seems to substantially exaggerate the southerly component of the horizontal wind, particularly in the boundary layer. v-component wind speed errors are rarely negative, or northerly, with positive difference generally lying between 2-4 m/s.

**Figure 4. Contour plot of zonal wind field error**

The meridional (v) component of the horizontal wind is not predicted quite as well as the zonal, as evidenced from Figure 5. MM5 seems to substantially exaggerate the southerly component of the horizontal wind, particularly in the boundary layer. v-component wind speed errors are rarely negative, or northerly, with positive difference generally lying between 2-4 m/s.
VI. Comparisons with other studies

As noted above, few studies have been attempted to verify the SW radiation scheme of the MM5 and quantify the relationships of predicted SW flux to other forecast variables. However, a number of other studies have focused on the performance of the MM5 versus observations for the meteorological quantities. Several of these studies are outlined here, with their results compared with those from this paper.

Manning and Davis (1997) performed a statistical verification of the MM5 forecasts for the WISP 94 field campaign. They used some of the older parameterizations of the MM5, including the simple cooling radiation scheme. Later on in their study, they did use the cloud radiation scheme used in this study for a sensitivity

![Fig. 5. Contour plot of meridional wind error](image)
test. As in this study, cold and wet biases were detected in the boundary layer. Manning
and Davis only indirectly investigated the radiation scheme. They re-ran some of the
cases with the new parameterization and compared the results obtained with the old one.
It was determined that radiation scheme played only a minor role in explaining the model
biases, but other model deficiencies contributed more, such as the soil model.

Cox et al (1998) and White et al (1999) each used MM5 as one of the models in
intercomparison studies. The experiment by Cox et al once again showed a small
negative bias for the surface temperature. MM5 did score very well overall compared to
all of the other models, with the exception of the Colorado State RAMS model. An
intercomparison between MM5 and several other research and operational models by
White et al once again detected a slight cold bias for the MM5 s surface layer.

Although no other radiation verification experiments for MM5 were documented,
Hinkelman and Ackerman (1998) conducted an experiment parallel to the one
documented in this paper, in some aspects, involving the NCEP Eta model. They also
used data collected from the ARM SGP site to test against the SW flux generated by the
model. SW flux was averaged for the daytime hours from January to June 1997. In
contrast to the MM5, the eta model overpredicted the amount of incident SW flux. The
Eta s SW flux showed a greater relationship to that of the observed, than the MM5 did in
this paper. The mean of the Eta SW flux was 435.8 while the SW flux measured by the
BSRN was only 336.0, but the correlation coefficient between them was a robust .9766
(Table 5). One reason for this stronger correlation in their study could be that a much
longer time series was considered. The results of this study also show another case in
which a numerical weather prediction model correctly predicts the surface temperature despite an aberration of the model SW flux from that of the observed.

| Table 5. SW flux and temperature data from Hinkelman and Ackerman (1998) |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
|                                | Mean            | Std. Deviation  | # of data points| Corr. Coeff.    |
| Eta SW flux W/m²               | 435.8           | 121.9           | 170             |                 |
| ARM SW flux W/m²               | 336.0           | 147.4           | 170             | .9766           |
| Eta surface Temperature °C     | 10.5            | 9.8             | 170             |                 |
| ARM Surface Temperature °C     | 11.0            | 8.9             | 170             | .9915           |

Collectively, the biases detailed in the three MM5 studies presented here agree with the biases found in this study. These are the slight, but persistent cold bias at the surface and a positive mixing ratio bias present in the model forecasts.

VII. Conclusions

For the IOP studied herein, MM5’s radiation scheme does not accurately replicate the observed SW flux field measured from the ARM SGP central facility. It has a net negative bias and repeatedly has errors of the same order of magnitude as the quantity itself. Errors in the SW flux are likely due, at least in part, to uncertainties or discrepancies in the cloud fraction used for the radiation scheme. Most of the large errors, 75% of the sample, in the SW flux predictions correspond to days when the cloud field was neither very clear nor very cloudy. These results agree with what might be expected from the model, but should be treated cautiously, because of the small sample size. Overprediction of water vapor in the upper layers of the troposphere may also contribute to the net negative bias of the SW flux, as water vapor is an absorber for SW radiation.

Surface temperature exhibits a small cold bias that is consistent with results from other studies. Otherwise, errors in SW flux do not seem to have a noticeable effect on the
surface temperature, it seems quite irresponsible to extreme variations of SW flux for a 24 hour forecast. Theoretically, the SW radiation incident on the surface should be the dominant forcing mechanism on the temperature near the surface, but differences in the temperature field are largely uncorrelated with differences in the SW flux. This result asserts the presence of strong compensations for this model, at this forecast length. Clearly, SW flux computations have a minimal impact under these conditions. The model produces a robust warm bias in the upper troposphere, the positive bias increasing with height. This feature may be partially attributable to the wet bias, as SW radiation will be absorbed by water vapor.

Water vapor mixing ratio is exaggerated by the model at all levels. This bias has been observed in other verification studies of the MM5 also. It is probable that this wet bias, particularly in the upper atmosphere contributes to the errors of the SW flux. The zonal wind components predicted by the model, compare very well with the observed values, except for a few instances at or near the upper-level jet stream region. Meridional wind values are consistently too southerly, relative to the observed values, but are largely acceptable.

In closing, it is apparent that the cloud-SW radiation parameterization is insufficient to accurately predict this important forcing mechanism. The SW radiation algorithms must be tested outside of the 3-dimensional MM5 for clear and cloudy sky cases to determine the error attributable to the actual SW calculations. Most likely, these errors will be found to be inconsequential to the errors in the combined error of the clouds and radiation. New methods to diagnose cloudiness in the radiation scheme are necessary. Until the operational models can be resolved down to the cloud level, cloud
fraction will still need to be more realistically represented. Another powerful incentive to improve the radiation schemes for mesoscale or regional forecast models is that longer forecasts may be more meaningful. As evident from this study, short-term forecasts are relatively invariant to the SW flux calculation. Ideally, at some future juncture, high-resolution forecasts will be available for longer forecast times, i.e. greater than 48 hours. To accomplish this feat, improved data assimilation procedures, more powerful computers, and accurate parameterizations of all subgrid-scale processes, including shortwave radiation.

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References


