P3.21

VERIFICATION OF MESOSCALE NUMERICAL MODEL FORECASTS USING REMOTELY-SENSED OBSERVATIONS

Derek J. Posselt*[1], Wayne F. Feltz[1], Tim Schmit[1], and David D. Turner[1,2]

[1]Cooperative Institute for Meteorological Satellite Studies,
Space Science and Engineering Center, University of Wisconsin–Madison
[2]Pacific Northwest National Laboratory, Richland, Washington

1. INTRODUCTION

As real-time numerical forecasting at horizontal grid spacing of less than 50 km becomes increasingly common, there is a growing need to develop and implement new methods of mesoscale forecast verification. Traditional statistical verification scores often reward successful prediction of smooth, large-scale features, and do not accurately assess forecast skill with respect to representation of smaller-scale cloud structure and temperature and moisture gradients.

Since May 2002, SSEC/CIMSS at the University of Wisconsin-Madison (UW-CIMSS) has been running version 3.5 of the PSU/NCAR MM5 once daily over the Southern Great Plains DOE Atmospheric Radiation Measurement site. During this time, MM5 forecasts of boundary layer temperature and water vapor have been continuously validated against retrievals from five ground-based Atmospheric Emitted Radiance Interferometer (AERI) instruments. More recently, techniques have been developed for the comparison of fields of temperature and moisture from MM5 with soundings from the Atmospheric InfraRed Sounder (AIRS) instrument flying on the polar-orbiting AQUA platform. Prediction of small-scale cloud features in MM5 are being evaluated by comparing brightness temperatures derived from MM5's radiation parameterization against GOES-08 10.7 micron (IR channel) brightness temperatures.

In this paper, we present a number of methods though which forecasts from MM5 can be validated against the above-mentioned remote-sensing instruments. Using a number of case studies as examples, we demonstrate the utility of passive infrared measurement systems as tools for the verification of forecasts of mesoscale temperature, water vapor, and cloud features.

2. MM5 CONFIGURATION

MM5 version 3.5 is run once each day over the SGP ARM site on a 2-way interactive nest at 60 km and 20 km horizontal resolution (Figure 1) with 38 terrain-following vertical sigma levels. Simulations are initialized from 1 degree 0000 UTC AVN model output and run for 48 hours. The model employs Reisner mixed-phase microphysics (Reisner 1998), the MRF boundary layer scheme (Hong and Pan 1996), the Kain-Fritsch cumulus parameterization (Kain and Fritsch 1993), and the RRTM radiation scheme (Mlawer et al. 1997).

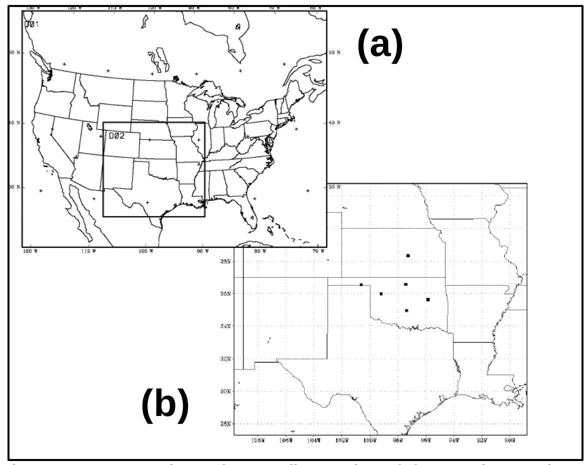

Figure 1. MM5 domain configuration (a) Continental US domain, with embedded SGP nest. (b) SGP nest with AERI sites depicted as filled boxes.

3. VALIDATION VS AERI

The AERI is an upward-looking passive instrument that measures downwelling infrared radiation in wavelengths between 3 and 19 micrometers at less than one wavenumber spectral resolution and ten-minute temporal resolution. The AERI has been deployed since March 1993 in an ongoing field campaign funded by the Department of Energy
(DOE) Atmospheric Radiation Measurement (ARM) program. High spectral-resolution radiances collected by the AERI are converted to vertical temperature and water vapor profiles in the lowest 3 km of the earth's atmosphere through inversion of the infrared radiative transfer equation (Smith et al. 1999). Temperature and water vapor profiles retrieved from the five AERI locations at the Southern Great Plains (SGP) ARM site have been automated since 1998, and have been used to track the passage and evolution of mesoscale meteorological features including boundary-layer destabilization, cold-frontal passages, and warm-air advection events (Feltz et al. 1998, Turner et al. 2000).

As the AERI vs. MM5 comparison has been operating longer than validations vs. AIRS and GOES, we give a much more complete description of this validation technique. In the first of two validation

*Corresponding author address: Derek J. Posselt, SSEC/CIMSS Univ. of Wisconsin–Madison, 1225 W. Dayton Street, Madison WI 53706-1695. email: dposselt@ssec.wisc.edu, phone: (608) 263-1116, fax: (608) 262-5974

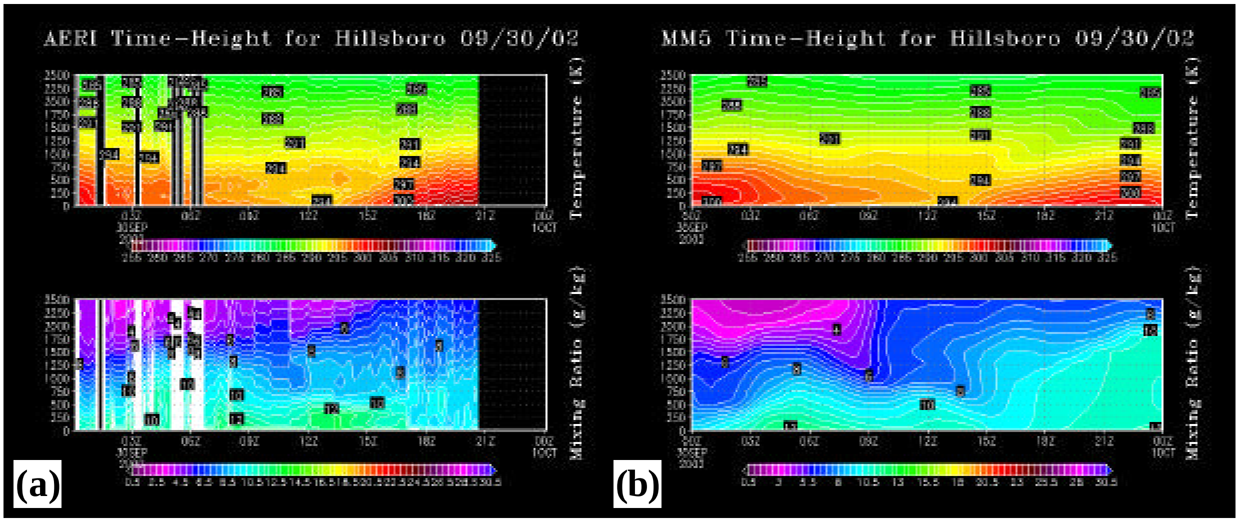

Figure 2: Comparison of time-height cross-sections of temperature in degrees K (top) and mixing ratio in g/kg (bottom) from (a) AERI and (b) MM5.

methods, AERI time-height cross-sections are produced for each of the five AERI locations at the SGP ARM site. Temperature and mixing ratio profiles retrieved from the AERI update continuously to a web page (http://barrage.ssec.wisc.edu/~dposselt/ihop/index.html) , and are plotted alongside forecast MM5 time-height cross-sections. Sample time-height cross-sections from AERI and MM5 on 30 September 2002 are depicted in figures 2a and 2b respectively. These plots, obtained from the AERI site located near Hillsboro KS, exhibit fair agreement between the observations and model with respect to temperature. However the smoothness of the model time series compared to the AERI is immediately apparent, as is the fact that the MM5 develops a deep moist and well-mixed boundary layer after 1600 UTC, while the AERI profiles are much drier.

RRTM Band	Wavenumber (cm^{-1})
1	10-250
2	250-500
3	500-630
4	630-700
5	700-820
6	820-980
7	980-1080
8	1080-1180
9	1180-1390
10	1390-1480
11	1480-1800
12	1800-2080
13	2080-2250
14	2250-2380
15	2380-2600
16	2600-3000

Table 1. RRTM bands and associated wavenumber ranges.

In the second comparison, we use the fact that RRTM long-wave radiative parameterization computes radiances over a spectral region that includes the full AERI spectral range. MM5 is modified to carry 16 new two-dimensional prognostic variables, which correspond to radiances in each of the 16 discrete RRTM wavenumber bands (Table 1). Radiances observed with the AERI are then averaged over each of RRTM bands 4-11, and compared with output from the MM5's RRTM radiation scheme. This method of comparison allows a more direct evaluation of the performance of MM5 compared with AERI, as the AERI observations have not been processed through a retrieval scheme.

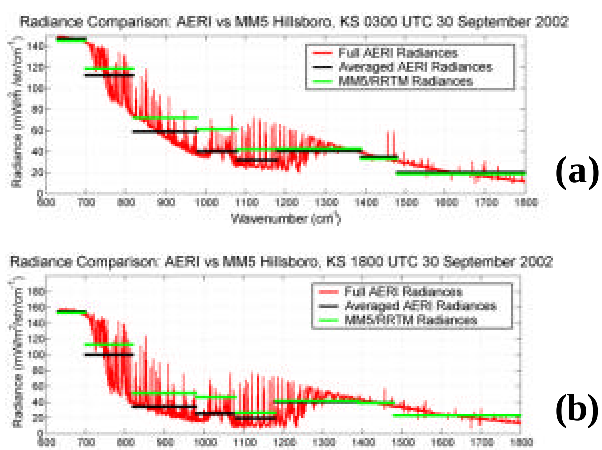

Figure 3: Radiance spectra from MM5 and AERI at (a) 0300 UTC and (b) 1800 UTC 30 September 2002.

In figures 3a and 3b, radiance spectra from AERI and MM5 are plotted for 0300 and 1800 UTC 30 September 2002 respectively. The full AERI spectrum is depicted in red while the black and green horizontal lines correspond to averages over each of the RRTM bands for MM5 and AERI respectively. At 0300 UTC there was cloud cover over the AERI instrument, while at 1800 UTC, the sky was clear. Note the relatively close correspondance between the AERI spectrum and the

MM5's RRTM output at the shorter and longer wavelengths at both times, while MM5 radiances are consistently biased high over the RRTM bands 5–8. A detailed inspection of both spectra reveals that the greatest high biases in the MM5 radiances are located in the vicinity of 1000 wavenumber (RRTM band 7), a region sensitive to ozone concentration. Higher errors in this spectral region may result from improper specification of ozone in the MM5 RRTM parameterization, where a climatological profile is used, or from temperature errors in layers where ozone is concentrated most strongly in the model.

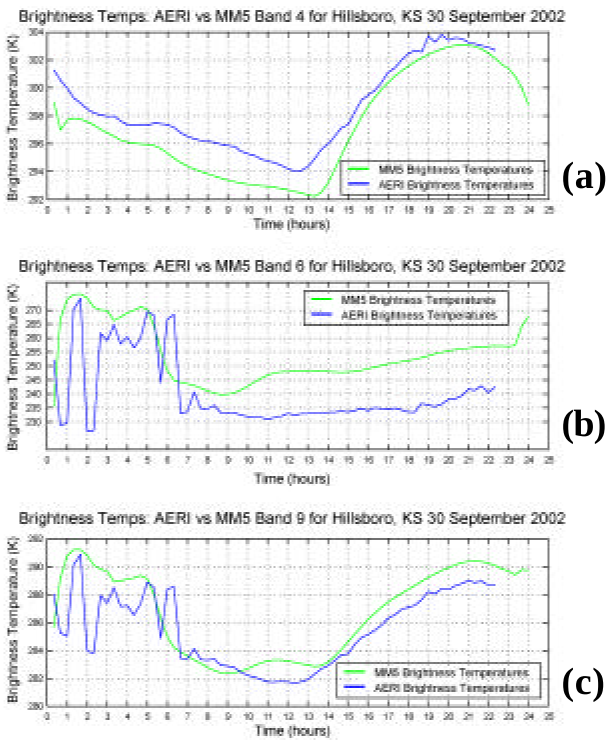

Figure 4: Time series comparison of MM5 with AERI brightness temperatures for RRTM bands (a) 4 and (b) 6 between 0000 UTC 30 September and 0000 UTC 1 October 2002.

In addition to an examination of wavenumber spectra at discrete times, time-series of brightness temperatures from discrete RRTM bands can be computed from MM5 and AERI and compared over the length of the forecast. Brightness temperature time series from RRTM bands 4, 6, and 9 are depicted in figures 4a, 4b, and 4c respectively. Radiances in RRTM band 4 are primarily used to retrieve lower-tropospheric temperature, while radiances across RRTM band 9 are used to retrieve water vapor mixing ratio. RRTM band 6 lies in the atmospheric window region, a spectral region in which there is less absorption by atmospheric gaseous constituents relative to other parts of the long-wave spectrum. Thus, radiances in this band can be used to determine whether or not clouds were present over the AERI instrument. From RRTM band 4 brightness temperatures, it is apparent that the near-surface temperatures were biased slightly high in the MM5 simulation throughout the day. Simulated mixing ratio (fig. 4c) follows the observations fairly closely, though there are slight errors late in the day associated with greater amounts of moisture in the MM5 boundary layer. The band of cloud over the Hillsboro AERI can be seen in the relatively high band 6 brightness temperatures between 0000 and 0630 UTC (figure 4b), and was well represented in the MM5 simulation, though the temporal variability in the actual cloud feature was smoothed compared with the AERI. Late in the day, brightness temperatures in the simulation diverge fairly significantly from the observations, likely due to lingering low clouds in the MM5 simulation.

4. VALIDATION VS AIRS

The AIRS instrument flies on the EOS AQUA polar orbiting platform, and is a high spectral-resolution passive IR sensor that measures upwelling infrared radiation in wavelength ranges of 3.74 to 4.61, 6.20 to 8.22, and 8.8 to 15.4 micrometers with a spectral resolving power of 1200. AIRS was launched 4 May 2002, and has been producing calibrated measurements since early June. AIRS is currently undergoing extensive validation, and the data is still generally regarded as preliminary.

High spectral-resolution radiances collected by AIRS are converted to vertical temperature and water vapor profiles on pressure levels between surface and 100 hPa, spanning the depth of the troposphere. Because AIRS flies on a polar-orbiting platform, temporal coverage over the southern great plains is limited to twice daily; approximately 0830 and 1930 UTC. At these times, temperature and water vapor mixing ratio are retrieved over the SGP ARM site, with horizontal resolution of 50 km and vertical resolution of 1 km and 2 km for temperature and water vapor mixing ratio respectively. Although a direct comparison between MM5's RRTM radiative transfer scheme and AIRS radiances is technically possible, it is not yet implemented due to the intricacies of dealing with a changing satellite view angle. Thus, only the comparison between MM5 fields of temperature and water vapor and AIRS retrievals is performed at this time.

5. VALIDATION VS GOES-08 IMAGER

GOES-08 imager brightness temperatures from the 10.7 micron channel are commonly used to depict cloud position and relative height, as brightness temperatures in this atmospheric window region are generally indicative of the temperature of the surface (in clear conditions) or of the cloud top in the presence of cloud. As such, a comparison between 10.7 micron brightness temperatures derived from MM5 and those observed by GOES can provide an indication of model performance with respect to the presence and height of clouds. In clear conditions, it can also give an indication of how well the model is performing with respect to near-surface temperature.

The procedure used to obtain the approximate 10.7 micron brightness temperatures from MM5 is similar to

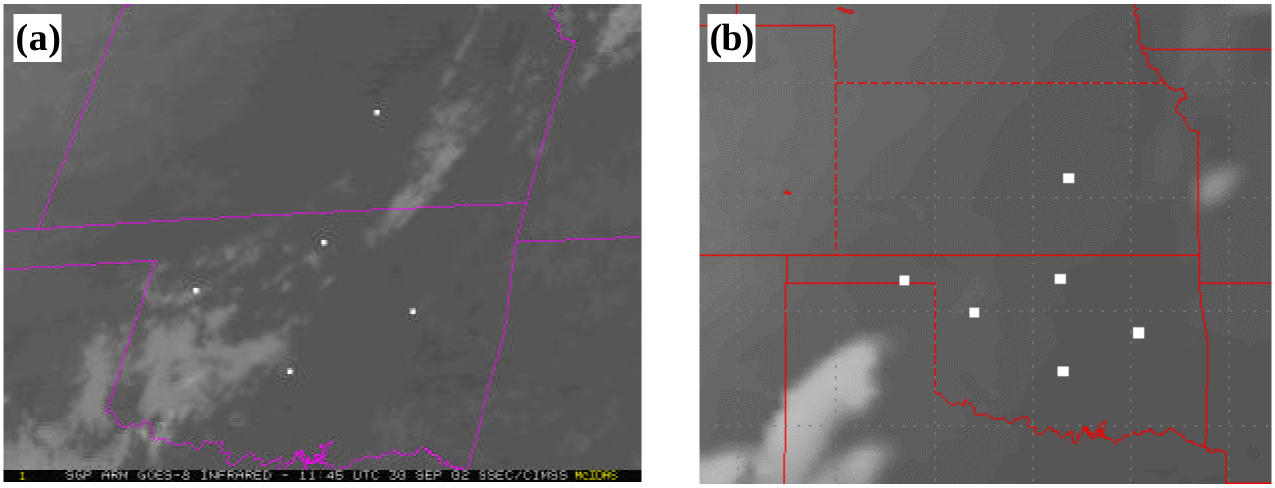

Figure 5: Example of validation vs. GOES-08 imager. (a) GOES-08 infrared image valid 1145 UTC 30 September (b) simulated infrared image generated with MM5 valid 1200 UTC 30 September.

extraction of radiances for comparison with AERI. RRTM bands 6 and 7 surround the 10.7 micron wavelength, and are averaged together to obtain radiances in the GOES-08 IR channel. These radiances are then converted to brightness temperature through inversion of the Planck function and then compared directly to the GOES-08 IR image. Although the GOES-08 imager view angle differs from the zenith angle used in the RRTM radiative transfer computations, sample calculations using the GOES-08 forward model with widely varying view angles yielded brightness temperature differences between 0.0-0.5 degrees Kelvin. Thus, we assume a negligible view angle bias for the purposes of this validation method—especially given the approximate nature of the validation procedure.

As an illustration of how this validation method can be used, consider a comparison between MM5-generated 10.7 micron brightness temperatures and a GOES-08 IR image valid at 1200 UTC 30 September 2002 (Figures 4a and 4b, respectively). In both cases, the sky is clear over much of the simulation domain, with a band of cloud stretching from northern Texas through northwestern Oklahoma. Lighter shades of gray in western Kansas at 1200 UTC (fig. 4a) indicate colder surface temperatures in the cloud-free high plains. Note that the MM5 represents the cloud band with relatively high accuracy, but not as much horizontal variability.

6. SUMMARY

Three methods of validating MM5 with passive infrared remote-sensing observations have been developed for use over the SGP ARM site. Comparisons between MM5 and AERI have been in progress since May 2002, and are performed using two methods. In the first method, an approximate comparison between time-height cross-sections of temperature and mixing ratio from MM5 output and AERI retrievals lends insight into the timing and variability of mesoscale features in the boundary layer. In the second method, a direct comparison between radiances measured by the AERI and calculated by RRTM in MM5 allows the user to evaluate the evolution of simulated temperature water vapor, and cloud through the the RRTM radiative transfer scheme. Comparison between MM5 and AIRS, while lacking the temporal resolution of comparison with AERI, gives a better indication of model performance with respect to horizontal temperature and water vapor structure through the depth of the troposphere. Comparisons between GOES-08 IR images and simulated MM5 brightness temperatures lend insight into the effectiveness of cloud representation in MM5, as well as providing information on cloud height and near-surface temperature.

ACKNOWLEDGEMENTS

This research is funded by the DOE ARM program through grants to SSEC/CIMSS at the University of Wisconsin–Madison.

REFERENCES

Dudhia, J. 1989: Numerical Study of Convection Observed During the Winter Monsoon Experiment Using a Mesoscale Two-Dimensional Model. *Jour. Atm. Sci.*, **46**, 3077-3107.

Feltz, W. F., W. L. Smith, R. O. Knuteson, H. R. Revercomb, H. B. Howell, Harold H. Woolf, 1998: Meteorological Applications of Temperature and Water Vapor Retrievals from the Ground-Based Atmospheric Emitted Radiance Interferometer (AERI). *Jour. Appl. Meteor.*, **37**, 857-875.

Hong, S.-Y., and H.-L. Pan, 1996: Nonlocal boundary layer vertical diffusion in a medium-range forecast model. *Mon. Wea. Rev.*, **124**, 2322-2339.

Kain, J. S., and J. M. Fritsch, 1993: Convective Parameterization for Mesoscale Models: The Kain-Fritsch Scheme. In *The Representation of*

Cumulus Convection in Numerical Models, Meteor. Monogr. K. A. Emanuel and D. J. Raymond, Eds. No. 46, Amer. Meteor. Soc., Boston, 165-170.

Mlawer, E. J., S. J. Taubman, P. D. Brown, and M. J. Iacono, 1997: Radiative Transfer for Inhomogeneous Atmospheres: RRTM, a Validated Correlated-k Model for the Longwave. *J. Geophys. Res.*, **102**, p16663-16682.

Reisner, J., R. J. Rasmussen, and R. T. Bruintjes, 1998: Explicit Forecasting of Supercooled Liquid Water in Winter Storms Using the MM5 Mesoscale Model. *Quart. J. Roy. Meteor. Soc.*, **124B**, 1071-1107.

Smith, W. L., W. F. Feltz, R. O. Knuteson, H. R. Revercomb, H. B. Howell, Harold H. Woolf, 1999: The Retrieval of Planetary Boundary Layer Structure Using Ground Based Infrared Spectral Radiance Measurements. *Journal of Atmospheric and Oceanic Technology*, **16**, 323-333.

Turner, D. D., W. F. Feltz, and R. A. Ferrare, 2000: Continuous Water Vapor Profiles from Operational Ground-Based Active and Passive Remote Sensors. *BAMS*, **81**, 1301-1317.