P 6.11 STATISTICAL COMPARISONS OF MODEL OUTPUT WITH SATELLITE OBSERVATIONS: A SEVERE WEATHER CASE

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1. INTRODUCTION

Geostationary Operational Environmental Satellite-R (GOES-R) and National Polar-Orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) risk reduction activities involve the advanced creation of synthetic imagery and using them to develop new products in advance of satellite launch. It is important to analyze the performance of our models when reproducing actual weather events in order to assess the usefulness of any of the products developed before satellite launch.

Additionally, in 4D-variation data assimilation, modeling errors are either treated as non-existent or on an ad hoc basis in the absence of sufficient information for a more realistic treatment. It is our goal to better understand modeling errors in a mesoscale model (RAMS in our case) based on information from different weather events with the expectation that this work will ultimately enable us to address modeling errors on a firmer footing.

For this work we assume that model output is generated after sufficient time has elapsed from model initialization and the errors are primarily a result of insufficiencies in the model physics and horizontal and vertical model resolution. Given these assumptions the general requirements for comparing different weather events are the following:

(a) Model output from running a state-of-the-art mesoscale model simulating a particular weather event.
(b) High temporal and spatial resolution observations for the comparison.
(c) Model output in a form that is comparable with observations.
(c) A statistical framework through which modeling errors will be computed.

The initial work to assess the feasibility and limitations of this methodology involves using output from the CSU RAMS model at a sufficiently high resolution to match the resolution of GOES satellite observations. We chose a severe weather event in the central US on May 8, 2003 (Figure 1(a),(b) and (c)).

2. MODELS USED

There are two components to the simulation of the satellite imagery. The first part involves actual simulation of the weather event using a mesoscale model. The second part is the computation of radiances in the selected domain using the mesoscale model output. The actual models are described below.

2.1. MESOCALE MODEL

The numerical cloud model used for this study is RAMS43 (Pielke et al. 1992). To simulate a mesoscale weather event the model is run non-hydrostatically and is compressible (Tripoli and Cotton 1982). Momentum is advanced using a leapfrog scheme while scalars are advanced using a forward scheme with both methods using second order advection. The vertical and horizontal turbulence coefficients are parameterized using the Smagorinsky (1963) deformation based eddy viscosity with stability modifications (Lilly 1962). Hydrometeors are predicted with a two-moment bulk microphysical scheme (Meyers et al. 1997). Mass mixing ratio and number concentration are prognosed for six of the seven hydrometeor types while the mean diameter is diagnosed. Cloud droplet mass mixing ratio, however, is predicted using a one-moment scheme. (Work is ongoing to include cloud droplets into the two-moment scheme.) Cloud droplets, rain droplets, aggregates, graupel, hail, snow, and pristine ice are the hydrometeor types considered. Both graupel and hail are mixed phase; that is, liquid water may exist on the surface of each particle. Snow and pristine ice are each divided into five habit categories namely columns, hexagonal, dendrites, needles,

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and bullet rosettes. Other prognostic variables are the three velocity components, perturbation Exner function, total water and ice-liquid potential temperature (Tripoli and Cotton 1981). RAMS uses the Arakawa fully staggered C grid (Arakawa and Lamb 1981). Perturbation Exner function tendencies, used to update the momentum variables, are computed using a time split scheme--similar to Klemp and Wilhelmson (1978). Lateral boundaries use the Klemp-Wilhelmson condition; that is, the normal velocity component specified at the lateral boundary is effectively advected from the interior. A wall with friction layers is specified at the top boundary. Land Ecosystem Atmospheric Feedback model, version 2 (LEAF2) (Walko et al. 2000) is also employed.

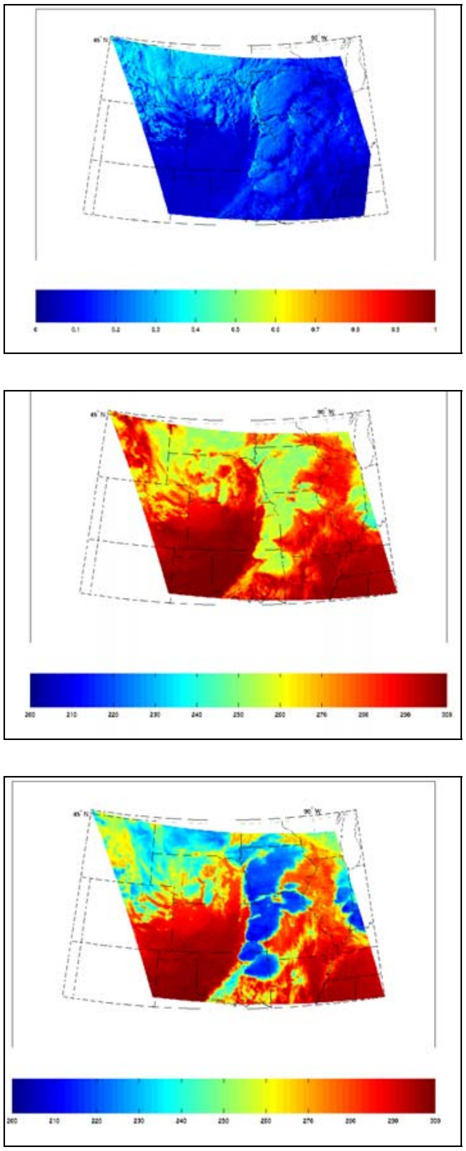

Figure 1: Reflectivity from (a) Channel 1 (0.65 microns), and brightness temperatures (K) from (b) Channel 2 (3.95 microns) and (c) Channel 4 (10.7 microns) of the GOES-12 satellite for 23:45 UTC on May 8, 2003.

2.2. RADIATIVE TRANSFER MODELS

We have developed a forward observational operator consisting of multiple models that can compute atmospheric gas and cloud optical properties and then compute radiances across both visible and infrared wavelengths. There are effectively three stages to the radiance computation using the mesoscale model output.

The first stage is the computation of gaseous absorption. As simulating satellite imagery requires calculations in multiple vertical columns with different gaseous and cloud optical properties, single band models are generally the only practical option. If the spectral band is narrow, which is the case with satellite measurements, single-band models are expected to provide sufficient accuracy. For computation of gaseous absorption we use OPTRAN (Optical Path Transmittance) model (Mcmillin et al. 1995). This model uses regression coefficients dependent on various combinations of pressure and temperature to compute transmittance through a fixed amount of absorber. The gaseous absorption coefficient in a model atmospheric layer is computed with OPTRAN using the model output layer temperature, pressure and water vapor mixing ratio.

The second stage is the computation of cloud optical properties. For clouds we require an extinction coefficient, a single-scatter albedo and the scattering phase function. The extinction coefficient and single-scatter albedo is computed using a modified form of the anomalous diffraction theory (MADT; Mitchell 2000; van de Hulst 1981). As the mesoscale model predicts only two moments of the particle size distribution-namely the mixing ratio and the number concentration-we use a gamma distribution to characterize the hydrometeor distribution. Non-spherical particles are considered using appropriate projected area and mass-dimension relationship (Mitchell 1996), material density and refractive index. The asymmetry parameter for infrared wavelengths is obtained from anomalous diffraction theory while an empirical parameterization is used for the visible (Greenwald et al. 2002). The asymmetry parameter is sufficient for radiative transfer calculations at infrared wavelengths, but the full scattering phase function needs to be specified at solar wavelengths. The Henyey-Greenstein phase function, a smooth function, is used to allow for faster computation.

Finally, we compute radiances using an appropriate 1-dimensional radiative transfer model based on wavelength. For infrared wavelengths greater than 3 μm, where the angular scattering characteristics of particles is relatively smooth, we use a two-stream method based on the Eddington approximation (Deeter and Evans 1998) which uses Delta-M scaling for highly peaked phase functions

(Wiscombe 1977). For computing cloudy sky radiance with a solar source, for wavelengths less than 5 μm, we use the plane parallel version of Spherical Harmonics Discrete Ordinate Method (SHDOM; Evans 1998), which uses discrete ordinates while characterizing the angular radiance field using spherical harmonics. This 1-dimensional version is called SHDOMPP.

3. MODEL RUNS

The RAMS mesoscale model was run at 2 km resolution, with initialization from ETA realanalysis, to simulate the resolution of the future GOES-R satellites. The output from RAMS was then used in a forward radiative transfer model to compute satellite radiances for pre-selected satellite bands.

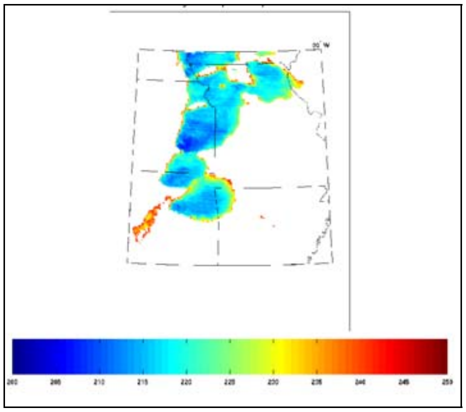

Figure 2: Region of interest (less than 243 K) extracted from the brightness temperatures from Channel 2 (3.95 microns) of the GOES-12 satellite for 23:45 UTC on May 8, 2003.

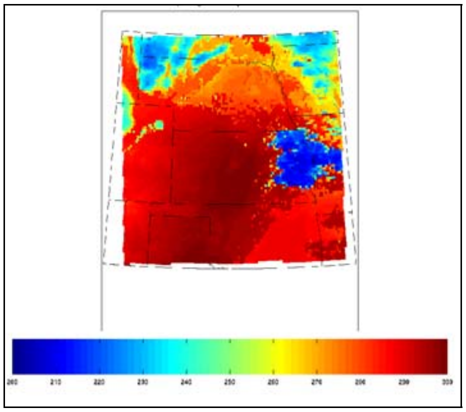

Figure 3: Modeled brightness temperature using RAMS for 10.35 microns. (Ch13 GOES-R)

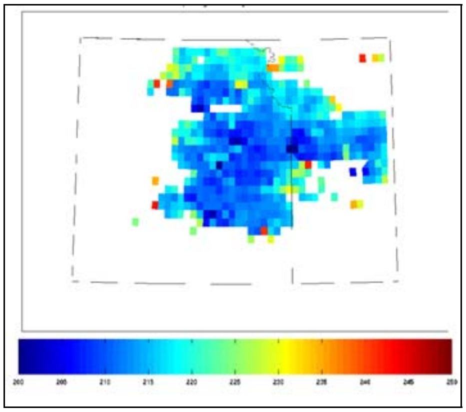

Figure 4: Region of interest from the modeled brightness temperature (less than 243 K) using RAMS for 10.35 microns. (Ch13 GOES-R)

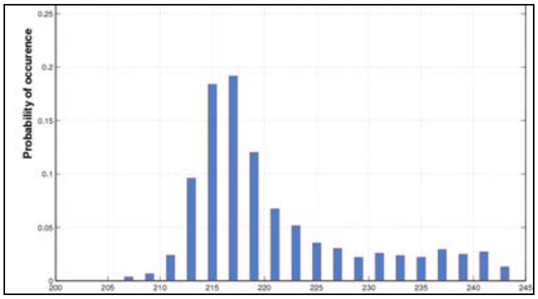

Figure 5: Histogram of the observed cloud top brightness temperature from GOES 12 Channel 4 for 23:45 UTC of May 8, 2003. The mean is 221 K, median 218 K and the standard deviation is 8.14. The number of observations is 9851.

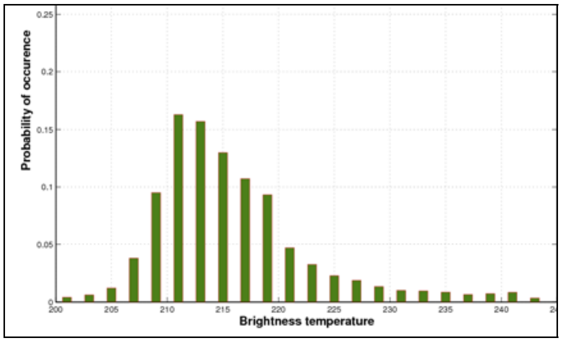

Figure 6: Histogram of brightness temperature from the modeled output with mean of 216 K, median of 214 K and standard deviation of 7.12 K. The number of data points is 14301.

Statistics	Observations	Model
No. of points	9851	14301
Mean	221	216
Median	218	214
Std. Deviation	8.14	7.12

Table 1: Statistics of the observed and modeled distributions of brightness temperatures.

4. INITIAL RESULTS

We computed infrared radiances from model output for the severe weather case for 2 hours of simulation at 15-minute intervals (e.g. Figure 3). These radiances were computed for a 10.35 micron window channel (Channel 13 of GOES-R) after averaging model output to 4kmX4km. The observations (Figure 1(c)) for comparisons were taken from Channel 4 of the GOES 12 satellite. Our region of interest was then extracted (Figures 2 and 4) from both the observations and modeled output.

Histograms of the brightness temperatures were plotted (Figures 5 and 6) and it is observed that there is a bias in cloud top temperature (Table 1) that is probably the result of differences in tropopause temperatures. A Lilliefors test for goodness –of-fit (a version of Kolmogorov-Smirnoff test but with parameters of the normal distribution estimated from the data) shows that both the modeled and observed data do not follow either a gaussian or log-normal distribution. A Wilcoxon test was used to compare the equality of the medians. This test was used, as our distributions are non-parametric. The null hypothesis was rejected both at a 5% and 1% level of significance.

5. FUTURE WORK

Our future work involves the possible use of spatial statistical methods to include the impact of distance on correlations in the data. Temporal comparisons will also be considered. In addition, we will be comparing computations in the visible (0.65 microns) and near-infrared (3.95 microns) with the observations (Figures 1 and 2). This assessment will provide a better insight into the observed and modeled microphysics.

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Figure 4: Region of interest from the modeled brightness temperature (less than 243 K) using RAMS for 10.35 microns. (Ch13 GOES-R)

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