P 2.1 VALIDATION OF MESOSCALE MODEL OUTPUT WITH SATELLITE OBSERVATIONS

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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.

Also 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.

In this paper we present results from the simulation of Hurricane Lili that occurred between October 1-3, 2002 (Fig. 1 and 2). The results are analyzed for GOES-8 channel 4 (10.7 μm) and statistically compared with observations (Fig. 3 and 4).

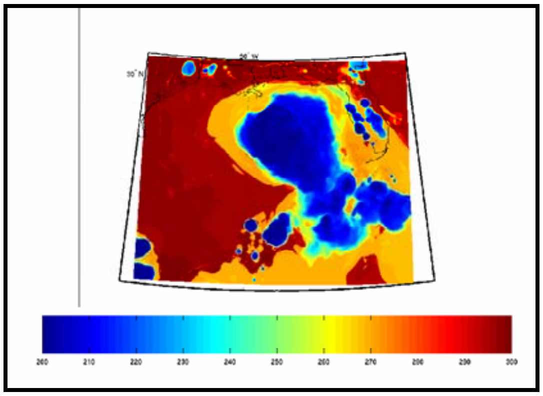

Figure 1: Computed Brightness temperature for model simulation at beginning of hour 4 coinciding with 21:00 UTC on October 2, 2002.

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.

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

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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, 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.

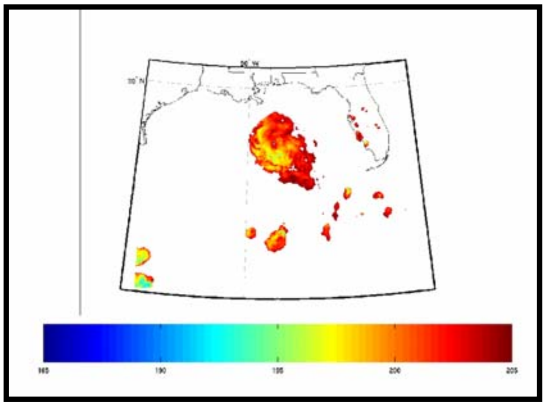

Figure 2: Cloud top temperatures extracted from Figure 1 for comparison with similar screened observations. Only cloud tops below 205 K are considered.

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. Effectively there are 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 plain 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.

MODEL RUNS

The RAMS mesoscale model was run at 2 km resolution, with initial from ETA re-analysis, 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. As GOES-8 data for 10.7 μm is available at 4 km resolution the radiances are averaged to 4 km before comparisons are made.

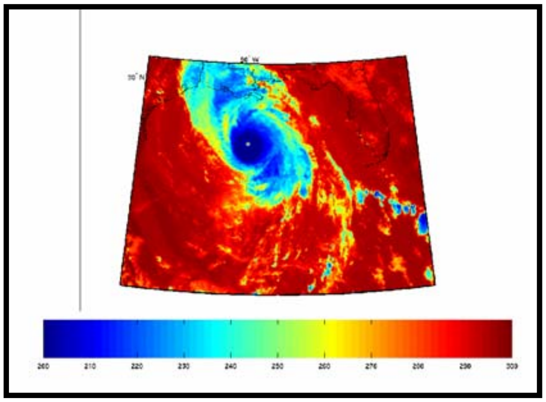

Figure 3: Observation of 10.7 μm GOES-8 brightness temperature for October 2, 2002 at 21:11 UTC.

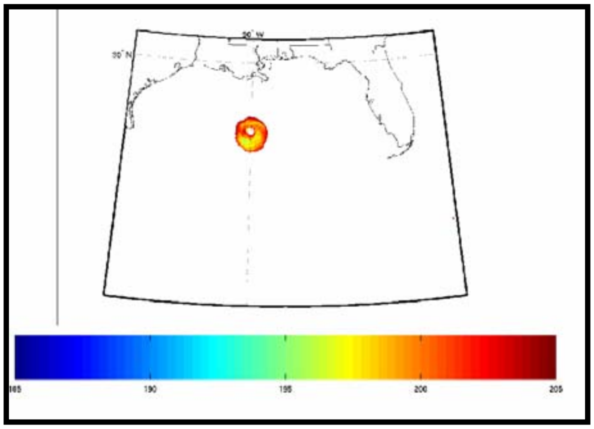

Figure 4: Hurricane cloud top screened from Figure 3 to represent cloud tops below 205 K.

INITIAL RESULTS

We computed infrared radiances from model output for Hurricane Lili for 6 hours of simulation at 5-minute intervals (e.g. Figure 1). These radiances were computed for a 10.7 micron window channel (Channel 4 of GOES-8) after averaging model output to 4kmX4km. The observations (Figure 3) for comparisons were taken from Channel 4 of the GOES 8 satellite. Our region of interest was then extracted (Figures 2 and 4) from both the observations and modeled output. As our objective is to analyze cloud top temperature histograms for the hurricane we screen brightness temperatures to be below 205 K.

Percentiles of brightness temperatures were computed for 1 hour of data from observations and model output and plotted as a scatter plot (Figure 5). It is observed that model brightness temperatures are slightly higher than observations. Table 1 shows the statistics which shows that the model results are slightly warmer than observations.

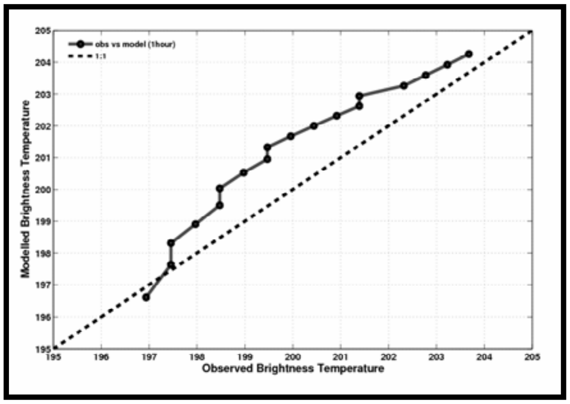

Figure 5: Comparison of percentiles of the cloud top temperatures for observations (Figure 4) versus model results (Figure 2). One hour of data from both model and observations were considered.

Statistics	Observations	Model
Mean	200	202
Median	200	203
Std. Deviation	2.4	2.6

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

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. This assessment will provide a better insight into the observed and modeled microphysics.

REFERENCES:

Arakawa, A., and V. Lamb, 1981: A potential entrophy and energy conserving scheme for the shallow water equations. Mon. Wea. Rev., 109, 18-36.

Byerly, W. P. and S. W. Miller, 2002: Radiometric calibration: Visible/Infrared Imager/Radiometer Suite algorithm theoretical basis document version 5. SRBS no. Y3261.

Deeter, M., and K. F. Evans, 1998: A hybrid Eddington-single scattering radiative transfer model for computing radiances from thermally emitting atmospheres. Quart. J. Roy. Meteor. Soc., 60, 635-648.

Dvorak, V. F., 1984: Tropical cyclone intensity analysis using satellite data. NOAA Tech. Rep. NESDIS 11, National Oceanic and Atmospheric Administration, Washington, DC, 47 pp. [Available from National Technical Information Service, U.S. Dept. of Commerce, Sill Bldg., 5285 Port Royal Road, Springfield, VA 22161.]

Evans, K. F., 1998: The spherical harmonics discrete ordinate method for three-dimensional atmospheric radiative transfer. J. Atmos. Sci., 55, 429-446.

Greenwald, T. J., R. Hertenstein and T. Vukićević, 2002: An all-weather observational operator for radiance data assimilation with mesoscale forecast models. Mon. Wea. Rev., 130, 1882-1897.

Klemp, J. B. and R. B. Wilhelmson, 1978: The simulation of three-dimensional convective storm dynamics. J. Atmos. Sci., 35, 1070-1096.

Lilly, D. K., 1962: On the numerical simulation of buoyant convection. Tellus, 14, 148-172.

Mcmillin, L. M., L. J. Crone, M. D. Goldberg and T. J. Kleespies, 1995: Atmospheric transmittance of an absorbing gas, 4. OPTRAN: A computationally fast and accurate transmittance model for absorbing gases with fixed and variable mixing ratios at variable viewing angles. Appl. Opt., 34, 6269-6274.

Meyers, M. P., R. L. Walko, J. Y. Harrington, and W. R. Cotton, 1997: New RAMS cloud microphysics parameterization. Part II: The two-moment scheme. Atmos. Res., 45, 3-39.

Mitchell, D. L., 2000: Use of mass- and area-dimensional power laws for determining precipitation particle terminal velocities. J. Atmos. Sci., 53, 1710-1723.

Mitchell, D. L., 2000: Parameterization of the Mie extinction and absorption coefficients for water clouds. J. Atmos. Sci., 57, 1311-1326.

Pielke, R. A., W. R. Cotton, R. L. Walko, C. J. Tremback, W. A. Lyons, L. D. Grasso, M. E. Nicholls, M. D. Moran, D. A. Wesley, T. J. Lee, J. H. Copeland, 1992: A comprehensive meteorological modeling system-RAMS. Meteor. and Atmos. Phys., 49, 69-91.

Smagorinsky, J., 1963: General circulation experiments with the primitive equations. Part 1: The basic experiment. Mon. Wea. Rev., 91, 99-164

Tripoli, G. J., and W. R. Cotton, 1981: The use of ice-liquid water potential temperature as a thermodynamic variable in deep atmospheric models. Mon. Wea. Rev., 109, 1094-1102.

Tripoli, G. J., and W. R. Cotton, 1982: The Colorado State University; Three dimensional cloud mesoscale model,1982. Part I: General theoretical framework and sensitivity experiments. J. Rech. Atmos., 16, 185-220.
Van de Hulst, H. C., 1981: Light Scattering by Small Particles. Dover, 470 pp.

Walko, Robert L., L. E. Band, J. Baron, T. Kittel, G. F., R. Lammers, T. J. Lee, D. Ojima, R. A. Pielke, C. Taylor, C. Tague, C. J. Tremback, P. L. Vidale, 2000: Coupled Atmosphere-Biophysics-Hydrology Models for Environmental Modeling. J. Appl. Meteor., 39, 931-944.

Wiscombe, W. J., 1977: Delta-M method: Rapid accurate radiative flux calculations for strongly asymmetric phase functions. J. Atmos. Sci., 34, 1408-1422.

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