WRF MODEL SIMULATIONS USED IN SUPPORT OF INFRARED HYPERSPECTRAL FORWARD MODEL AND PRODUCT ALGORITHM DEVELOPMENT

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1. INTRODUCTION

SSEC/CIMSS at the University of Wisconsin-Madison is tasked with testing and developing the forward radiative transfer model and retrieval algorithms for the next generation of geostationary infrared sounders, including the Geosynchronous Infrared Fourier Transform Spectrometer (GIFTS) and the Hyperspectral Environmental Suite (HES). In support of this work, sophisticated numerical weather prediction models, such as the Weather Research and Forecasting (WRF) model, have been used to generate realistic high-resolution atmospheric profile datasets for a variety of locations and atmospheric conditions. These datasets, which are treated as the "truth" atmosphere, are subsequently passed through the forward radiative transfer model to generate simulated top of the atmosphere (TOA) radiances. Atmospheric motion vectors along with temperature and water vapor sounding retrievals generated from these radiances are then compared to the original simulated atmosphere to assess the accuracy of the retrieval algorithms.

2. FORWARD MODEL DESCRIPTION

The forward radiative transfer model being developed at CIMSS calculates TOA radiances with very high spectral resolution across the infrared spectrum most likely to be observed by future multi- and hyper-spectral sensors. This generic structure maximizes productivity by allowing forward model development to be applicable to multiple infrared sensors. For the case studies discussed in this paper, the forward model employed the Yang (2003) single layer cloud model, which uses line-by-line radiative transfer code and the discrete ordinate radiative transfer (DISORT) method to parameterize liquid and ice cloud optical properties into transmittance and reflectance functions with high spectral resolution. This version of the cloud model can only accommodate a single cloud layer consisting entirely of ice crystals or liquid water droplets, therefore, a selection rule must be applied in the presence of mixed phase or multi-level clouds. For simplicity, it is assumed that the highest altitude cloud phase within a given column represents the phase of the cloud to be ingested into the forward model. This is a reasonable approximation since the primary source of visible and infrared radiation in a cloudy sky is at or near the cloud top.

3. METHODOLOGY

WRF model output serves as the main component of the simulated atmospheric datasets ingested by the forward radiative transfer model. Simulated fields used by the forward model include the surface temperature, the atmospheric temperature, and the mixing ratios for water vapor, cloud water, rain water, ice, snow, and graupel. Effective particle diameters are calculated for each microphysical species using a method adopted from Mitchell (2002). Total liquid and total ice water paths are calculated using the appropriate mixing ratios. Liquid and ice cloud top pressures are identified by searching downward from the model top until a minimum mixing ratio threshold is exceeded in a given grid cell.

Logarithmic interpolation is used to transfer the simulated 3-dimensional data from the model's sigma coordinate system to the isobaric coordinate system used by the forward model. Temperature and water vapor data on the lowest sigma level is extrapolated downward to fill all forward model pressure levels located beneath the model topography. Temperature profiles from the NESDIS 1200 dataset are used to fill the pressure levels located above the model top, while the water vapor mixing ratio above this level is set to a value representative of dry stratospheric air. Ozone data extracted from 5 different model atmospheres in the line-by-line radiative transfer model (LBLRTM; Clough and Iacono 1995) were used to create representative ozone profiles for each grid point in a given dataset.

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4. CASE STUDY RESULTS

a) ATREC SIMULATION

Version 2.0.3 of the WRF model was used to produce a realistic simulation of an extratropical cyclone that developed along the east coast of the U. S. during the Atlantic THORPEX Regional Experiment. The simulation was initialized at 00 UTC on 5 December 2003 with 1º GFS data and then run for 24 hours on a single 1070 x 1070 grid point domain (Fig. 1) with 2-km horizontal grid spacing and 50 vertical levels. The simulation employed the WRF Single-Moment 6-class (WSM6) microphysics scheme, the Yonsei University PBL scheme, the RRTM longwave and Dudhia shortwave radiation schemes, and the Noah LSM. No cumulus parameterization scheme was used, therefore, only explicitly resolved convection occurred during the simulation.

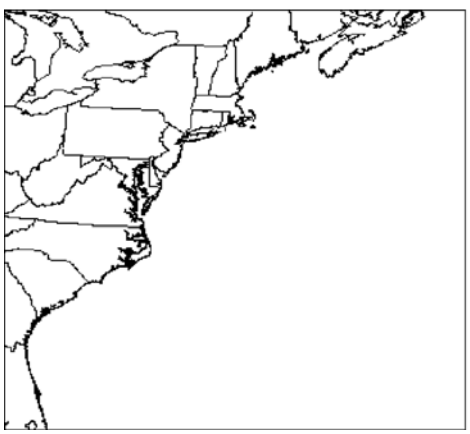

Fig. 1. Geographical domain covered by the WRF simulation.

The main goal of this case study was to realistically simulate the evolution of the moisture, temperature, and cloud fields associated with the extratropical cyclone. GOES-12 satellite imagery and WRF-simulated composite reflectivity (CREF) and vertically-integrated cloud microphysics (ICMP) data are shown in Fig. 2. ICMP represents the total cloud water, rain water, ice, snow, and graupel content within a model column. Together, these data will be used to examine the realism of the simulated cloud field. The visible and infrared satellite images in Fig. 2 illustrate that cloudy conditions were present across much of the domain. The primary cloud features associated with the extratropical cyclone include the extensive mid- and upper-level cloud shield extending from the Atlantic Ocean westward into the Great Lakes region, the low-level cloud cover over the southeastern U. S., and the scattered thunderstorm activity along the trailing cold front. Inspection of the CREF and ICMP data indicates that the WRF simulation contains a realistic representation of these features. For instance, the maximum CREF and ICMP values occurred within the region of deep convection along the cold front. Further north, lesser values occurred within the extensive cloud shield, which is consistent with the predominantly stratiform cloud cover across this region. It is also important to note the very fine scale structure evident in the simulated cloud fields. Taken together, this analysis demonstrates that the WRF model is able to realistically simulate the fine-scale atmospheric structures associated with the extratropical cyclone.

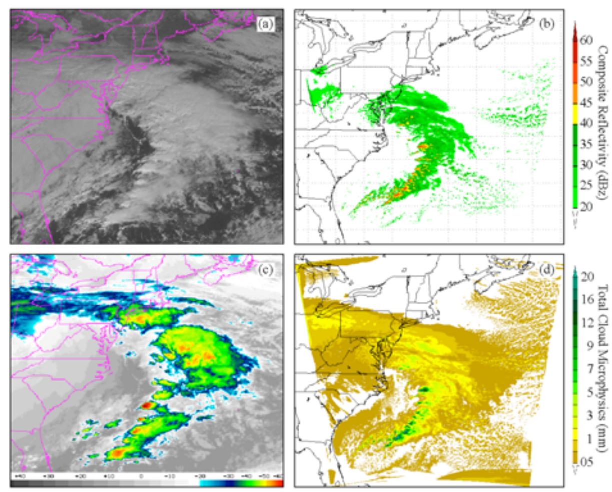

Fig. 2. (a) GOES-12 visible imagery, (b) WRF-simulated composite reflectivity (dBz), (c) GOES-12 10.7 μm infrared brightness temperatures (K), and (d) WRF-simulated vertically-integrated cloud microphysics (mm) valid at 1500 UTC on 05 December 2003.

A simulated atmospheric profile dataset was generated for this case using the procedure outlined in Section 3. This dataset was subsequently ingested into the GIFTS forward radiative transfer model to generate simulated TOA radiances, which were then used to produce simulated temperature and water vapor retrievals. Fig. 3 shows a representative example of simulated infrared brightness temperatures valid at 1500 UTC on 05 December 2003.

Temperature and water vapor retrievals based on infrared radiances can only be calculated down to the earth's surface during clear-sky conditions and above the cloud top during cloudy-sky

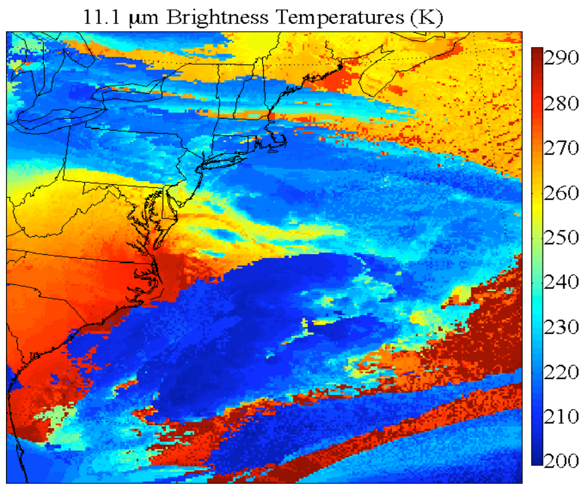

Fig. 3. Simulated 11.1 μm brightness temperatures (K) valid at 1500 UTC on 05 December 2003.

conditions. The ability to perform retrievals above the cloud top is very important since clouds cover much of the earth's surface at any given moment. The substantial impact that above-cloud retrievals can have on the geographical coverage of the retrieved fields is clearly illustrated in Fig. 4. In the lower troposphere (Fig. 4a, b), the widespread cloud cover associated with the extratropical cyclone severely limits the sampling area of the GIFTS retrievals. Although the retrievals capture a portion of the moisture field surrounding the cyclone, it is clear that a large portion of the water vapor field is simply not observed. In the upper troposphere (Fig. 4d), however, the geographical coverage is nearly complete since all but the highest cloud tops occur below this level. The improved coverage at higher altitudes demonstrates that above-cloud retrievals greatly enhance the usefulness of retrievals based on infrared radiances.

B) FULLDISK SIMULATION

Version 2.1 of the WRF model was used to generate a realistic simulation for a very large domain encompassing most of the geographical region to be observed by the GOES-R satellite. The simulation was initialized at 00 UTC on 24 June 2003 with 1º GFS data and then run for 30 hours on a single 1580 x 1830 grid point domain with 8-km horizontal resolution and 50 vertical levels. As such, this domain (refer to Fig. 5) covers most of North and South America, as well as portions of the Atlantic and Pacific Oceans, with fine spatial resolution. The simulation employed

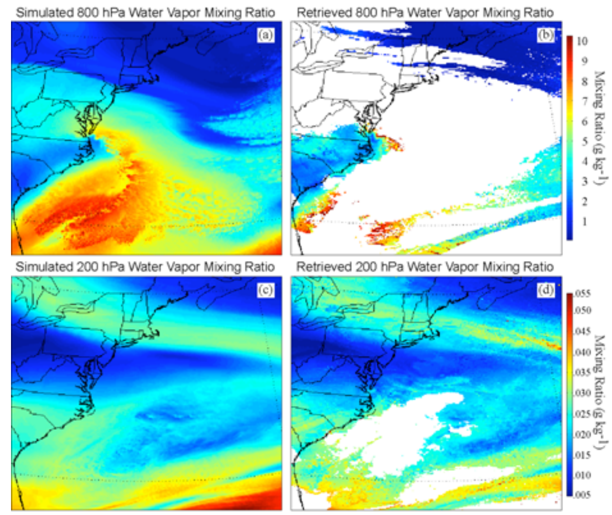

Fig. 4. (a) 800 hPa water vapor mixing ratio (g kg^{-1}) from the WRF simulation. (b) 800 hPa water vapor mixing ratio (g kg^{-1}) from the simulated GIFTS retrievals. (c) Same as (a) except for 200 hPa. (d) Same as (b) except for 200 hPa. All images valid at 1500 UTC on 05 December 2003.

the WSM6 microphysics scheme, the Yonsei University PBL scheme, the RRTM and Dudhia shortwave radiation schemes, and the Noah LSM. No cumulus parameterization scheme was used during this simulation.

The main purpose of the simulation was to generate a simulated atmospheric profile dataset that realistically portrayed the evolution of the large-scale flow and cloud distribution over the expected GOES-R domain. The very large size of the resultant datasets could also be used to estimate the necessary hardware infrastructure that will be required to process the massive amount of data from GOES-R in a reasonable amount of time. Fig. 5 shows the simulated 2-m surface temperature at 00 UTC on 25 June 2003 while a representative example of the simulated brightness temperatures is shown in Fig. 6.

5. CONCLUSIONS AND SUMMARY

CIMSS at the University of Wisconsin-Madison has been tasked with developing the forward radiative transfer model and retrieval algorithms for several future satellite instruments. To support this work, the WRF model has been used to generate simulated atmospheric profile datasets with fine horizontal and vertical resolution. The simulated datasets, which are treated as the "truth" atmosphere, are subsequently passed through the instrument forward model to generate

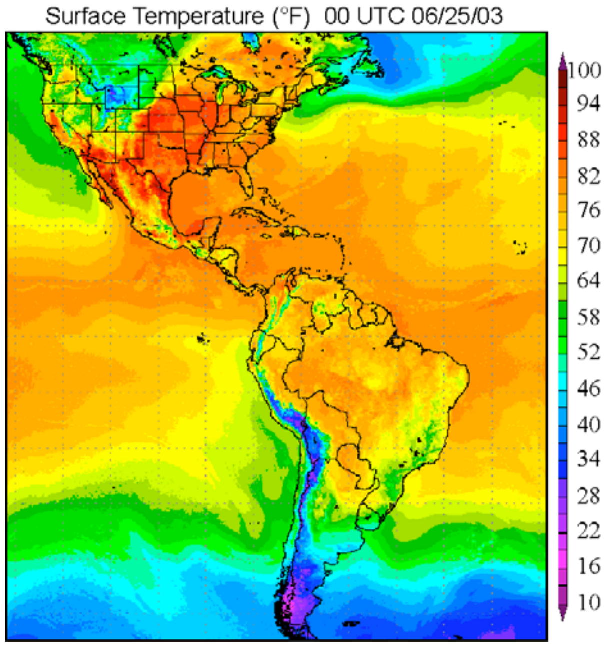

Fig. 5. 2-m surface temperature valid at 0000 UTC on 25 June 2003.

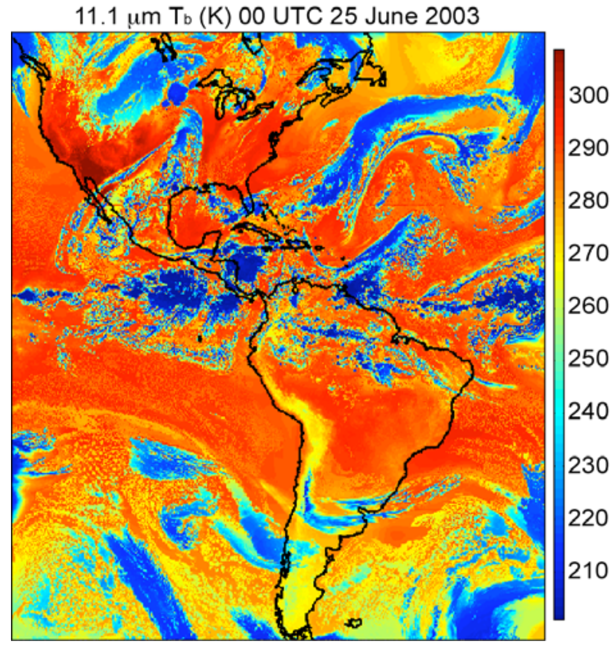

Fig. 6. 11.1 μm brightness temperature (K) valid at 00 UTC on 25 June 2003.

simulated TOA radiances. Atmospheric motion vectors and temperature and water vapor retrievals generated from the TOA radiances are then compared with the original model simulated atmosphere to assess the accuracy of the wind and retrieval algorithms. Case study results demonstrate that the WRF model is able to realistically simulate mesoscale cloud, temperature, and water vapor structures present in the real atmosphere. These results indicate that TOA radiances derived from numerical model output can serve as an effective alternative for real radiances observed by infrared sensors.

6. ACKNOWLEDGEMENTS

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