PROJECT TITLE: Using synthetic satellite brightness temperatures to evaluate the ability of HWRF parameterization schemes to accurately simulate clouds and moisture in the tropical cyclone environment

INVESTIGATORS:

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PROJECT OVERVIEW:

This project will use synthetic satellite observations to evaluate the ability of different cloud microphysical, planetary boundary layer, and cumulus parameterization schemes in the HWRF model to accurately forecast the spatial characteristics and temporal evolution of the cloud and moisture fields associated with tropical cyclones. Model output from high-resolution HWRF simulations will be converted into synthetic infrared and microwave brightness temperatures using the Community Radiative Transfer Model in the Unified Post Processor (UPP). The satellite simulator capabilities of the UPP will be enhanced by adding a subroutine that computes the effective particle diameters for each hydrometeor species predicted by a given microphysics parameterization scheme based on the assumptions made by that scheme, and by expanding the number of satellite sensors and bands that can be simulated.

We will rigorously evaluate the accuracy of the simulated cloud and moisture fields through comparison of observed and simulated infrared and microwave brightness temperatures. Bulk cloud characteristics such as the horizontal extent and temporal evolution of cloud cover will be examined using neighborhood verification approaches, probability distributions, brightness temperature differences, and traditional point statistics. In addition, the simulated satellite observations will be input to other satellite derived verification methods, such as the Advanced Dvorak Technique (ADT) and the Automated Rotational Center for Hurricane Eye Retrieval (ARCHER) method. Metrics output by these algorithms will be used to assess the accuracy of the satellite-inferred tropical cyclone intensity and the organization and location of deep convection in the eye wall and surrounding areas.

RECENT ACCOMPLISHMENTS:

Our primary accomplishments during the past three months include: 1) using simulated satellite observations to assess the accuracy of HWRF model simulations generated by our group for Hurricane Edouard and by the HWRF model development team at the

Environmental Modeling Center (EMC) for their 2015 operational pre-implementation tests, 2) using dropsonde observations to assess the accuracy of the Hurricane Edouard forecasts, 3) identifying a bug in the UPP code that is used to compute simulated satellite brightness temperatures for the operational Ferrier and Ferrier-Aligo cloud microphysis schemes, and 4) interacting with the HWRF model development team. Each of these accomplishments is described in greater detail below.

1. Model forecast accuracy assessment using satellite observations

We examined the accuracy of several parameterization schemes in the 2014 operational HWRF model using simulated infrared brightness temperatures, with an emphasis placed on assessing the accuracy of the simulated cloud and water vapor fields on the outer 27-km and inner 3-km resolution domains, respectively. We generated model forecasts from cycled data assimilation experiments for Hurricane Edouard (2014) in the Atlantic basin using two cloud microphysics schemes (Ferrier and Thompson), two convection schemes (SAS and Meso-SAS), and two radiation schemes (GFDL and RRTMG). This case study was chosen because of the availability of numerous high quality dropsonde observations that provide valuable information about the moisture and thermodynamic fields within the tropical cyclone environment. For the pre-implementation analysis, we assessed the accuracy of three parameterization schemes for tropical storm Douglas (2014) in the eastern Pacific. This case was chosen after consultation with Zhan Zhang (EMC) to better understand why the tropical cyclone track forecast performance was below average for this particular tropical cyclone.

A comparison of observed and simulated GOES-15 infrared brightness temperatures from the 6.7 μm band sensitive to clouds and water vapor in the upper troposphere is shown in Fig. 1 for three model configurations examined during the EMC pre-implementation tests for Tropical Storm Douglas (2014). A brief description of each model configuration is provided in Table 1. This figure shows satellite imagery on the outer domain at a 120-hr forecast lead-time. Overall, it is apparent that the simulated brightness temperatures are much too cold within clear sky areas over the western half of the domain, which indicates that there is a large positive moisture bias in the upper troposphere throughout the tropics and subtropics. There is also a tendency for the brightness temperatures to be too warm over land where deep convection was weaker than observed while being too cold along the Inter-tropical Convergence Zone. Figure 2 shows probability distributions for the 6.7 μm band valid at a 120-hr forecast lead-time computed using all forecasts during the cycled experiments. The large shift in the distributions toward colder temperatures again indicates that there is a large wet bias in the model forecasts. Overall, the largest errors occurred in the H15F configuration that used the GFDL radiation scheme.

A similar analysis was performed using output from the cycled experiments we ran for Hurricane Edouard. Figures 3 and 4 summarize the results for four model configurations employing two cloud microphysics schemes and two radiation schemes (refer to Table 2 for a description of these configurations). Overall, the results again indicate that there is a wet bias in the model forecasts. Simulations using the operational Ferrier scheme (dark blue and green lines in Fig. 4) also had a much higher frequency of very cold brightness temperatures (< 230 K) when compared to the Thompson microphysics scheme. As will be discussed in Section 3, after additional analysis it was determined that this particular cold bias was due to an incorrect specification of the ice effective diameter for the Ferrier scheme in the UPP code.

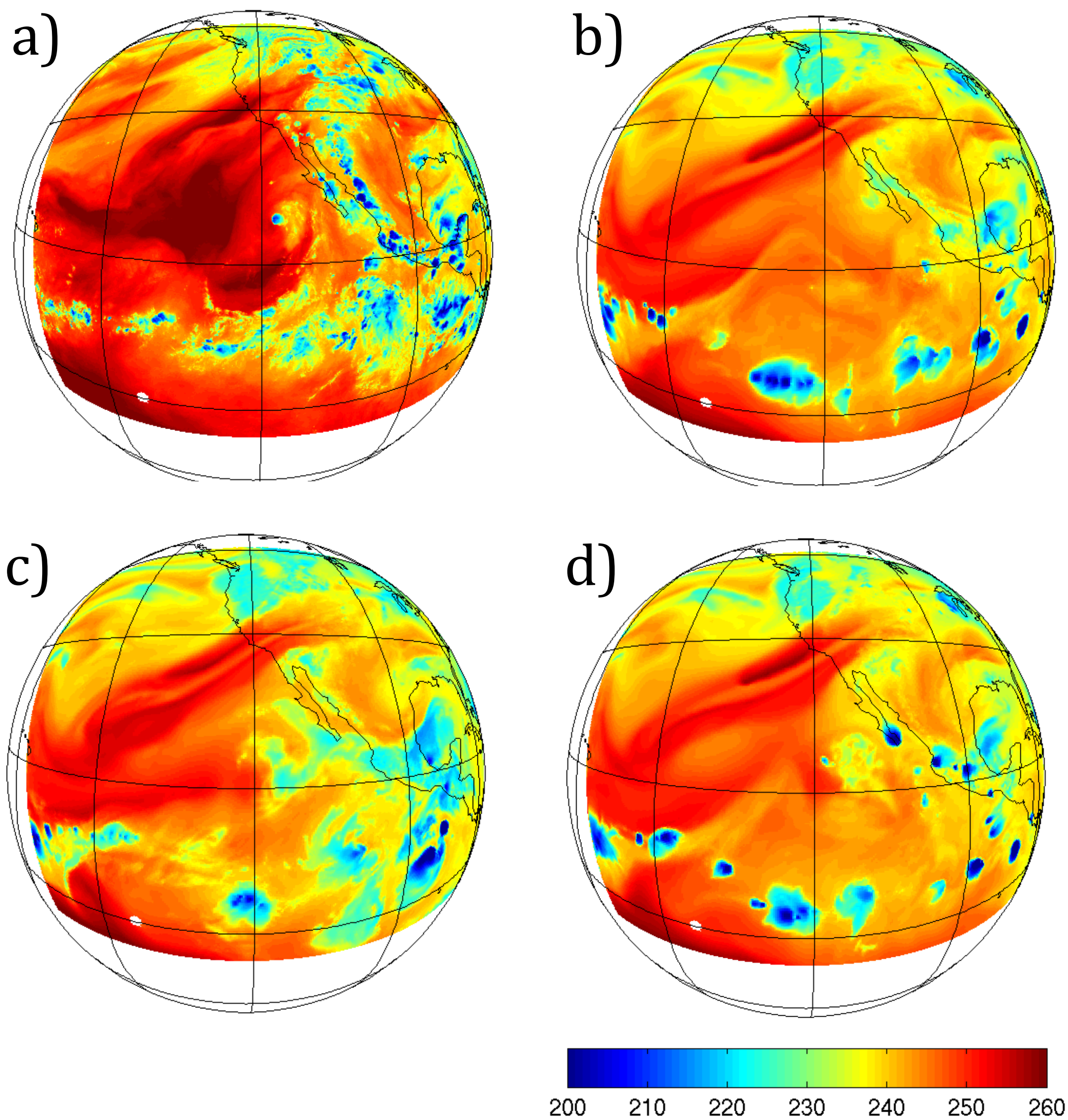

Figure 1. (a) Observed and (b-d) simulated GOES-15 6.7 μm brightness temperatures (K) on the outer domain valid at 00 UTC on 01 July 2014 for tropical cyclone Douglas in the eastern Pacific. The simulated brightness temperatures are from a 120-hour forecast initialized at 00 UTC on 30 June 2014 for the three HWRF pre-implementation configurations listed in Table 1.

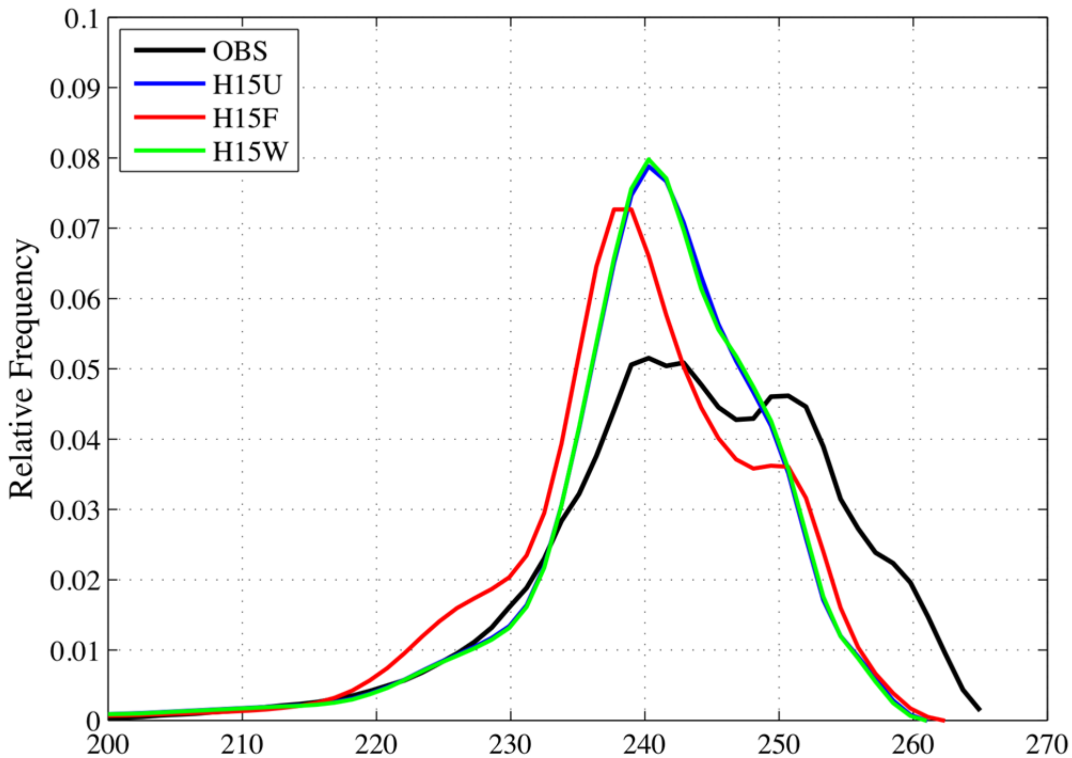

Figure 2. Probability density functions for GOES-15 6.7 μm brightness temperatures (K) on the outer domain computed at forecast hour 120 for each HWRF configuration listed in Table 1.

Table 1. Brief description of the HWRF 2015 pre-implementation test configurations.

Configuration	*Description*
H15U	Final FY2015 configuration
H15F	As H15U, but with FY2014 radiation
H15W	As H15U, but with new enthalpy exchange coefficient.

Table 2. Brief description of the Hurricane Edouard test configurations.

Configuration	*Description*
H14	Final FY2014 configuration
H14+T	As H14, but with Thompson microphysics
H14+R	As H14, but with RRTMG SW/LW radiation
H14+TR	As H14, but with Thompson microphysics and RRTMG radiation

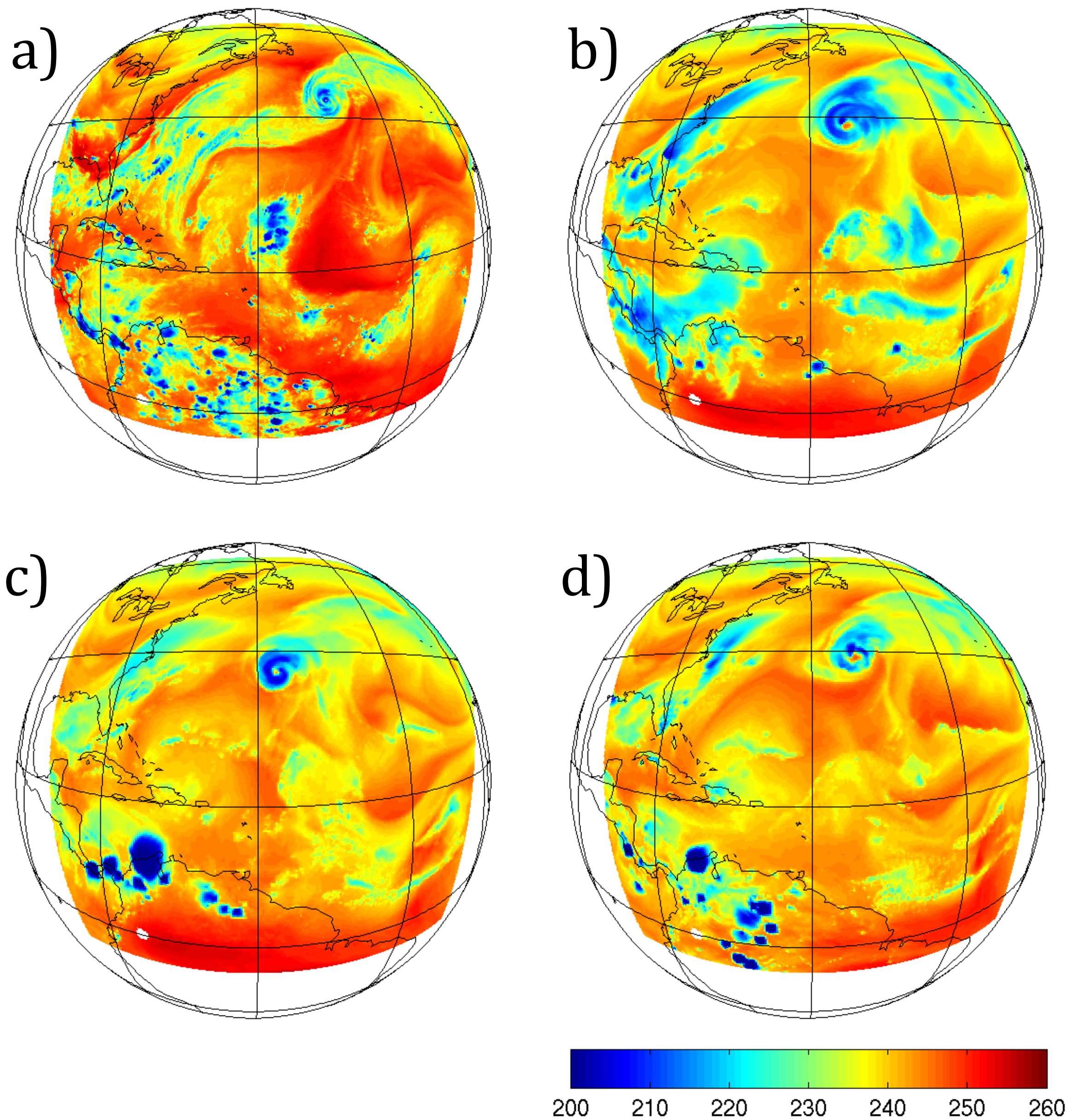

Figure 3. (a) Observed and (b-d) simulated GOES-13 6.7 μm brightness temperatures (K) on the outer domain valid at 00 UTC on 18 September 2014 for hurricane Edouard. The simulated brightness temperatures are from 120-hour forecasts initialized at 00 UTC on 13 September 2014 for the three HWRF configurations listed in Table 2.

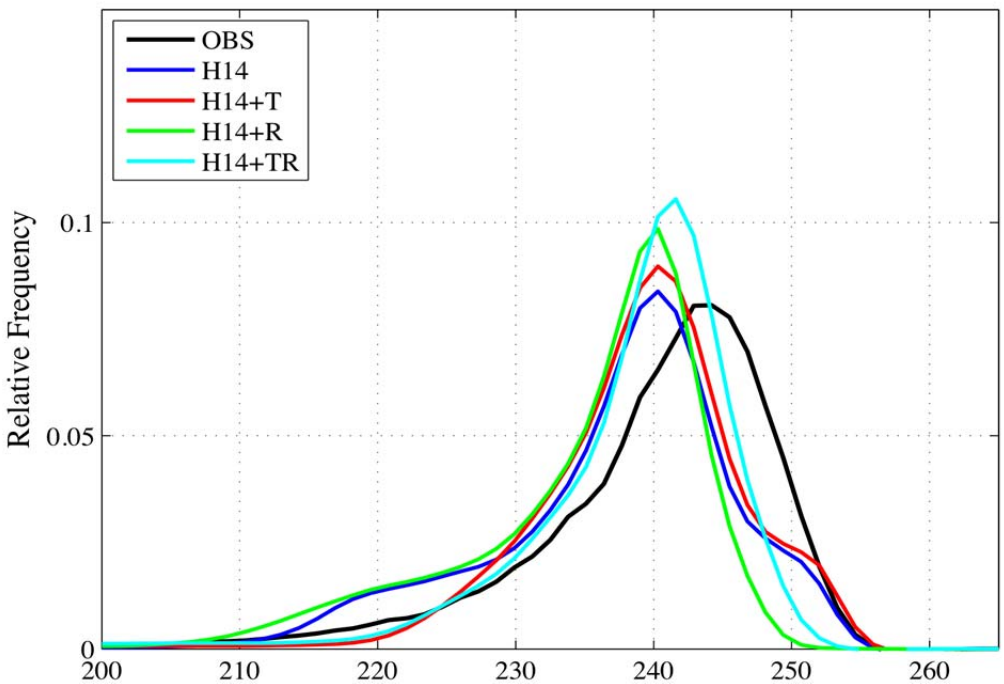

Figure 4. Probability density functions for GOES-13 6.7 μm brightness temperatures (K) on the outer domain computed at forecast hour 120 for each HWRF configuration listed in Table 2.

2. Model forecast accuracy assessment using dropsonde observations

To support the satellite-based model evaluation, a dropsonde analysis was also performed using output from the Hurricane Edouard simulations. Dropsondes from the NASA Global Hawk aircraft were used as "truth" for several variables, including temperature, relative humidity, specific humidity, and wind speed. The model runs that were analyzed were initialized at 00 and 12 UTC so it was beneficial to select dropsondes occurring very close to those times for the analysis. A total of four dropsondes falling within ten minutes of the analysis times were chosen for the analysis. These include dropsondes near 00 UTC on 15 September and 00 UTC on 17 September.

For each dropsonde, the model data was interpolated to the dropsonde position at each available vertical level, while accounting for horizontal advection of the dropsonde. The actual distance and bearing of the dropsonde relative to the observed storm center was calculated and then the model vertical profiles were taken from the same storm-relative position, thereby accounting for model track error in each forecast. Forecast-minus-observed differences and root-sum-of-squares (RSS) errors were then calculated for each model configuration.

Figures 5 and 6 show the observed dropsonde relative humidity profile in the left panel and the corresponding model difference profiles at the analysis time and at the 72 hour forecast time. The storm-relative location of the vertical sounding is shown in the title above each plot. Large differences are evident between the various simulations.

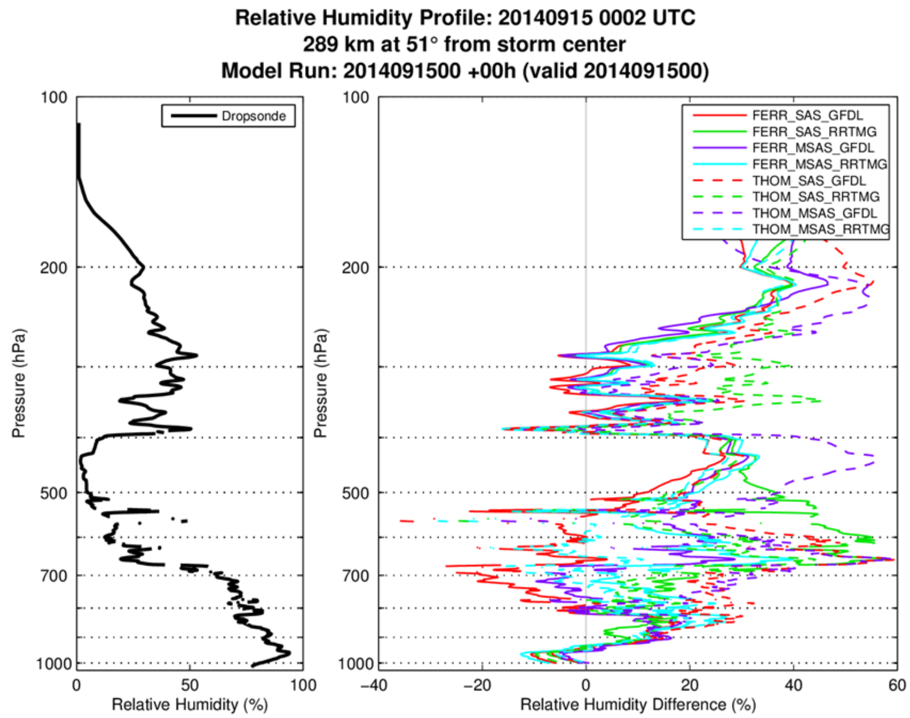

Figure 5. Observed (left panel) and forecast-observed (right panel) differences for the relative humidity field at the analysis time valid at 00 UTC on 15 September 2014.

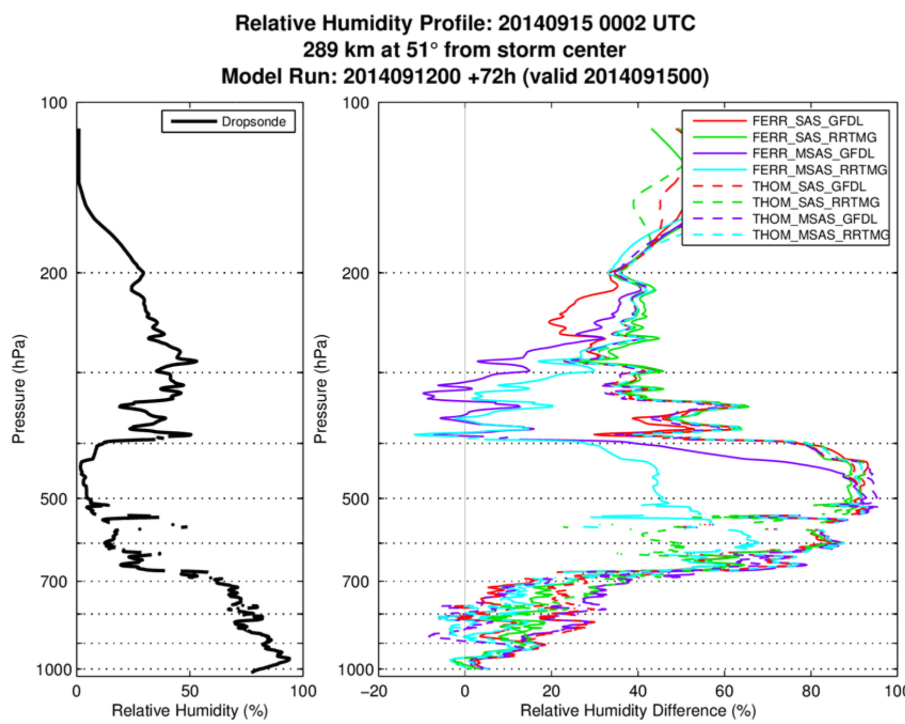

Figure 6. Observed (left panel) and forecast-observed (right panel) differences for the relative humidity field at the 72-hr forecast time valid at 00 UTC on 15 September 2014.

Averaging across all available verifying forecasts begins to reveal some patterns among the model configurations (Fig. 7). Note that at the time of these dropsondes, verifying forecasts only extend to 72 hours. The Ferrier microphysics simulations (squares) generally had lower errors than the Thompson microphysics runs (triangles). Simulations using RRTMG radiation (cyan and green) are generally more accurate than the GFDL radiation simulations (red and purple). The differences between the SAS convection (red and green) and MSAS convection (purple and cyan) simulations are mixed. Overall, the smallest errors were obtained during the FERR_MSAS_RRTMG simulation.

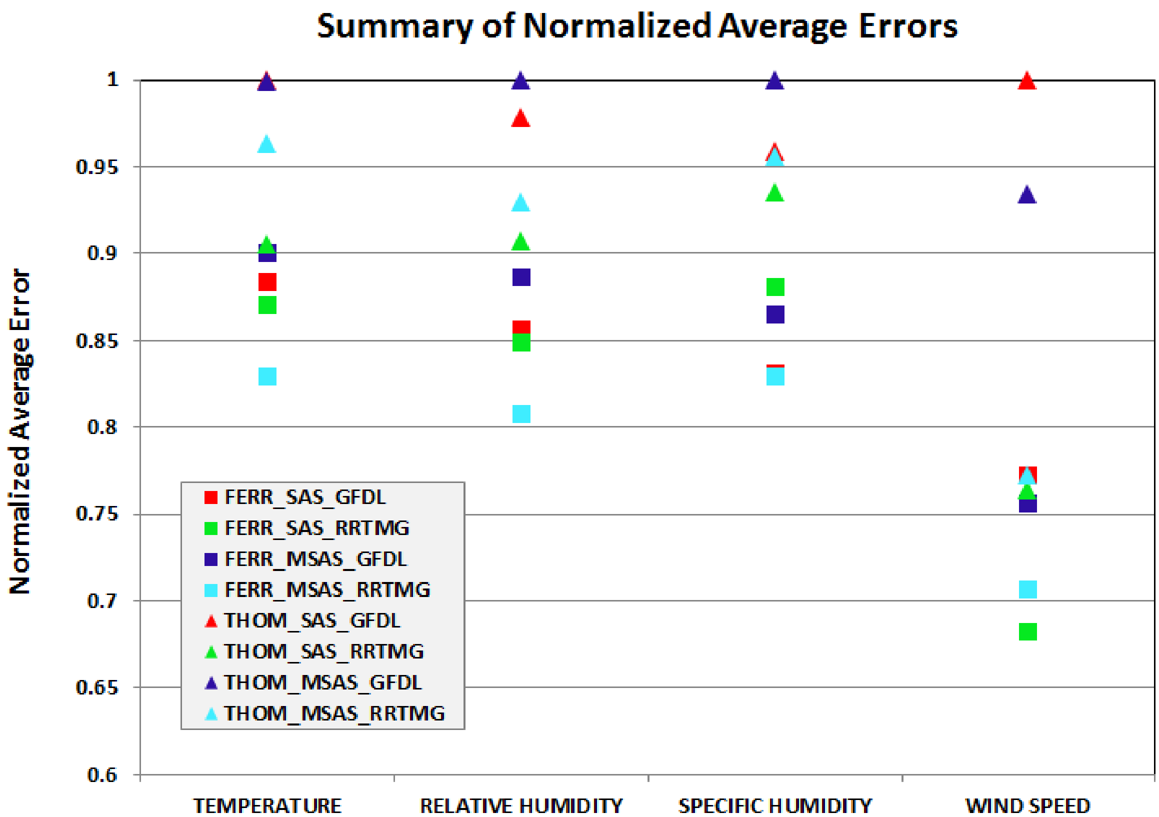

Figure 7. Root-sum-of-squares (RSS) errors for each model configuration averaged over all forecast times for each variable listed along the x-axis.

3. Code Updates in the Unified Post Processor

As mentioned in Section 1, comparison of the microphysics parameterization schemes indicated that there was a large cold brightness temperature bias for upper level clouds when using the operational Ferrier scheme. We more closely investigated this bias and with the help of Brad Ferrier identified an error in the UPP code that accounted for a large portion of this cold bias. The error was located in the function that computes the effective particle diameters for each cloud hydrometeor species passed to the Community Radiative Transfer Model (CRTM) in the UPP. The effective diameter for ice was set to 25 microns in the original version of the UPP code that we started working with at the beginning of the project. This value, however, should have been set to 75 microns based on the assumptions made by the Ferrier scheme. We did not notice this mistake in the original version of the UPP because the Ferrier scheme is unique amongst the cloud microphysics schemes that we have worked with because it assumes a "large particle" mode for cirrus clouds instead of a "small particle" mode, which means that it contains larger ice crystals than other microphysics schemes. This will in turn have a large impact on the simulated infrared brightness temperatures because larger ice crystals will not be as optically deep as smaller crystals, thereby resulting in warmer brightness temperatures because more radiation will be coming from below the cloud top. Figure 8 shows the impact that this post-processing change had on the simulated brightness temperatures for one of the Hurricane Edouard forecasts. Overall, the brightness temperatures are much warmer where there are upper level clouds, such as surrounding the hurricane when the larger effective diameter was used (Fig. 8c). The cold brightness temperature bias was substantially reduced for the upper level clouds; however, it was not entirely eliminated, which indicates that further improvements could be made to the operational Ferrier and Ferrier-Aligo schemes in regard to their treatment of upper level clouds.

Please note that as of early August that the new version of the UPP code using a 75 μm effective ice diameter for the operational Ferrier and Ferrier-Aligo microphysics schemes has been transferred to the Developmental Testbed Center and EMC UPP trunks. It is also being tested in the parallel NAM model for inclusion in the operational NAM model.

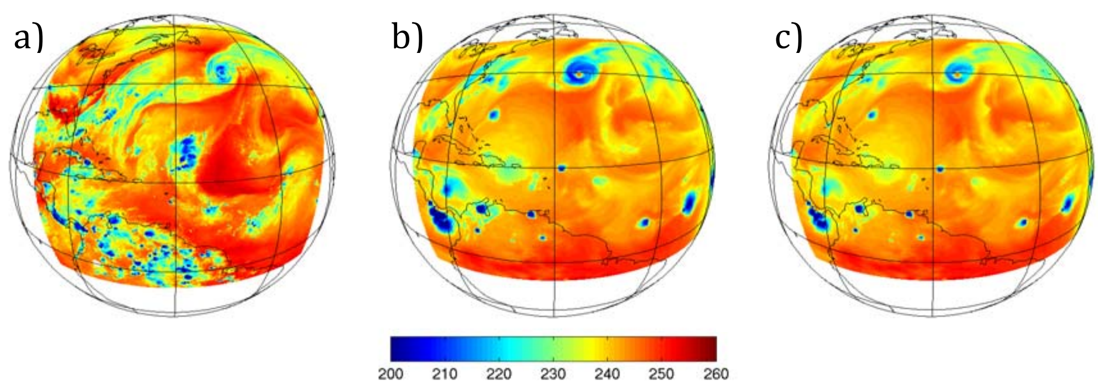

Figure 8. Comparison of (a) observed and simulated GOES-13 6.7 μm brightness temperatures for HWRF model forecasts valid at 00 UTC 18 Sep 2014 when using a (b) 25 micron or (c) 75 micron effective diameter for ice.

4. Interactions with EMC HWRF model development team

We have also been interacting with the operational HWRF model development team. In particular, we identified several errors in the HWRF model forecast and post-processing scripts on jet. These include identifying cycles where the regribber went into an infinite loop, the completion step was not performed, or the satellite post processor did not run. Problems also occurred when jet changed modules, but the HWRF trunk did not have the new module names. We assisted Sam Trahan in his efforts to fix these errors. We are also beginning to work with Brad Ferrier to optimize his cloud microphysics scheme (see next section).

PLANS FOR THE NEXT THREE MONTHS

During the next three months, we are planning to collaborate with model developers at EMC and model evaluators at the DTC to investigate sensitivities in the Ferrier-Aligo and Thompson microphysics schemes, with the goal of improving their accuracy through modifications to various parameters. The HWRF model accuracy will be examined using simulated satellite brightness temperatures generated from cycled forecast experiments performed for Hurricane Edouard. These simulations will be run using the 2015 version of the operational HWRF model.