JHT annual project report
Year 1

September 13 2012

Project title: Validation of HWRF forecasts with satellite observations and potential use in vortex initialization

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1. **Summary of achievements**

As reported in the mid-year report in the first 6 months of the project the following was accomplished:

1) First version of the satellite simulator module for HWRF model was completed using the latest release of CRTM (Community Radiative Transfer Model, release 2.0.5). For convenience the satellite simulator software is designated HWSS (**H**urricane **W**RF **S**atellite **S**imulator). Brief describtion of HWSS is presented in section 2.
2) HWSS has been tested using HWRF_3.X forecast with 3-grid configuration at resolution 27/9/3 km.

Since the mid-year reporting the following was accomplished

1) Co-PI Tom Greenwald visited EMC June 5-7 2012. He gave a presentation on the HWSS, consulted with members of the operational HWRF team, and developed a plan for transitioning HWSS capabilities to operations.
2) Significant modifications were made in the HWSS to allow for other types of model data formats. Specifically, GRIB1 I/O capability was added per EMC's request. The I/O at execution is however limited to using like formats: GRIB1 input to GRIB1 output and NetCDF input to NetCDF output.
3) The installation and use of the HWSS was simplified by eliminating the configuration file and modifying the main Perl script. This feature allows easy implementation of HWSS off-line for purpose of performing retrospective verification of HWRF forecasts with satellite observations, beyond simple comparison of images, as well as for testing advances features that would be proposed for implantation in UPP (described below in this report).
4) An option to remap the simulated radiance field to the nearest satellite observation points was added. The remapping code was contributed by collaborator on another project, sponsored by HFIP, Dr. Jeff Steward of JPL/NASA.

5) Capability to simulate CloudSat Cloud Profiling Radar was added. This capability does not exist in CRTM. QuickBeam radar model was appended to CRTM.
6) HWRF microphysics capability currently used in V1.1 of the Unified Post Processing system was implemented in HWSS. This capability ensures exact compatibility between UPP and HWSS for the purpose of testing advanced features that would be implemented in UPP. This work was done in collaboration with Brad Ferrier at EMC. HWSS conveniently saves in output files, the internally diagnosed cloud properties and atmospheric variables. Availability of such data that match the simulated brightness temperatures is necessary for diagnosing forecast model deficiencies using verification with satellite observations.

In summary in the first year of the project the off-line satellite simulator HWSS was completed. This simulator is fully compatible with the operational HWRF post-processor (UPP) in terms of background information that is derived from the forecast data and the radiative transfer model (i.e., CRTM) . In addition, HWSS includes the following advanced capabilities

- **Capability to inject actual satellite observation data in order to simulate exact swath for polar orbiting sensors . This feature is necessary for quantitative verification of HWRF forecasts with the polar-orbiting measurements.**
- **CloudSat simulator . This capability is highly desirable for verification of the microphysics as illustrated in Figure 9 (Tom Geenwald presented this result in seminar at EMC in June)**

We plan to add the following capabilities to further improve accuracy of quantitative verification of the forecasts

- **Slant-path representation of the atmospheric column for accurate simulation of radiative transfer along viewing path**
- **Antenna pattern convolution for compatibility between spatial resolution of actual and simulated brightness temperatures**

YEAR 2 plan

The following activities are planned for year 2:

1) Quantitative verification of operational HWRF forecasts on a selection of retrospective cases using satellite observations. We desire to perform the verification on many cases, however the limitation exist with availability of HWRF forecast data. The operational system does not archive full forecast data sets. Only a subset of forecast diagnostics after the post-processing is normally saved for retrospective analyses. Consequently, the simulation of satellite observations to match with the actual satellite observation files would

be limited to cases which could be reproduced. The selection of cases and re-forecasting of them would be discussed with EMC's modeling group

2) Testing of the above advanced new capabilities. This activity would include verification of benefits of the added capabilities for purpose of comparison to actual observations
3) Inter-comparison of UPP and HWSS simulations. The goal is to verify that the basic simulations, without the advanced capabilities are compatible
4) Implementation of the advanced capabilities in UPP

Contributions from staff members working with PI , Co-Pi and collaborators were as follows:

- Significant contribution to the software development was made by James Davies of CIMSS, supervised by Co-PI T. Greenwald
- Tom Greenwald implemented microphysical properties as in UPP and developed capability to simulate CloudSat measurements.
- Significant contribution to visualization/imaging and start-up of diagnostics were made by Kathryn Sellwood of CIMAS, supervised by PI T. Vukicevic.
- T. Quirino of HRD provided forecast data for testing, supervised by S. G. Goapalakrishnan

2. Brief description of HWSS

We developed software to interface HWRF forecast model output with the JCSDA's Community Radiative Transfer Model (CRTM) for generating simulated satellite imagery. The software is called the "Hurricane WRF Satellite Simulator," or HWSS for short. It has been run successfully on jet, the computer used by the HWRF operational forecast system.

Originally, HWSS was designed with two executables, HWRF_Convert and HWRF_CRTM, that work together under the control of main Perl script HWSS.pl. This configuration was simplified in second half of the first year to using only one executable controlled by a pearl script taking information form a control file. HWSS takes atmospheric profile data, surface properties and satellite sensor characteristics, and inputs them to the CRTM (currently at release 2.0.5) for computing 2D fields of sensor radiances. These sensor radiances are converted to units that users are familiar with, such as brightness temperature (thermal infrared and microwave sensors) or reflectance (visible and near-infrared sensors). The observation geometry is expressed by view zenith angle (and additionally, for visible and near-infrared sensors, by view azimuth angle). Table 1 summarizes the platforms and sensors that we currently support.

HWSS transforms the HWRF condensate profile information to hydrometeor type, size and abundance required by the CRTM. There are currently three options for computing hydrometeor radius: 1) assumes fixed particle sizes (operational approach); 2) assumes fixed number concentrations, and 3) derived from Ferrier microphysics scheme. Also, if the satellite sensor to be simulated is in low earth orbit (LEO), a limited swath of observations through the HWRF domain is simulated; The time and space coincidence information is achieved by accessing sensor observation earth location directly from satellite swath files for the satellite sensors and swaths to be simulated. Sensors aboard geostationary (GEO) satellites take their view geometries from user-specified sub-satellite longitude and from an assumed geostationary altitude.

Table 1. Supported platforms/sensors for the satellite simulator.

Platform	**Sensor**	**Bands**
GOES-13	Imager	Vis/IR
GOES-13	Sounder	Vis/IR
Aqua	AMSR-E	Microwave
DMSP F-20	SSMIS	Microwave
DMSP F-19	SSMIS	Microwave
DMSP F-18	SSMIS	Microwave
DMSP F-17	SSMIS	Microwave
DMSP F-16	SSMIS	Microwave
DMSP F-15	SSM/I	Microwave
TRMM	TMI	Microwave

HWSS.pl accepts on its command line the names of two files to guide its operation, a control file and a command file. The control file specifies the location of the CRTM sensor coefficient files, some parameters that configure CRTM operation, and the locations of HWRF_Convert and HWRF_CRTM executables. The control file comprises the name of the HWRF domain time-step file, and the names of all of the satellite sensors that one wishes to simulate observing this domain time-step, plus any files that specify the swath for LEO satellite sensors. There will be one control file per HWRF file.

The output of one run of HWSS.pl is a set of netCDF or GRIB1 files, one per satellite sensor simulated. Examples of simulated brightness temperature field from HWRF forecast model output are show in the next section.

3. Results

In the following HWSS capabilities are demonstrated on example of single forecast for hurricane Earl for period August 29 00Z – September 3 00Z. For reference, the storm track and intensity forecast are displayed in Figure 2.

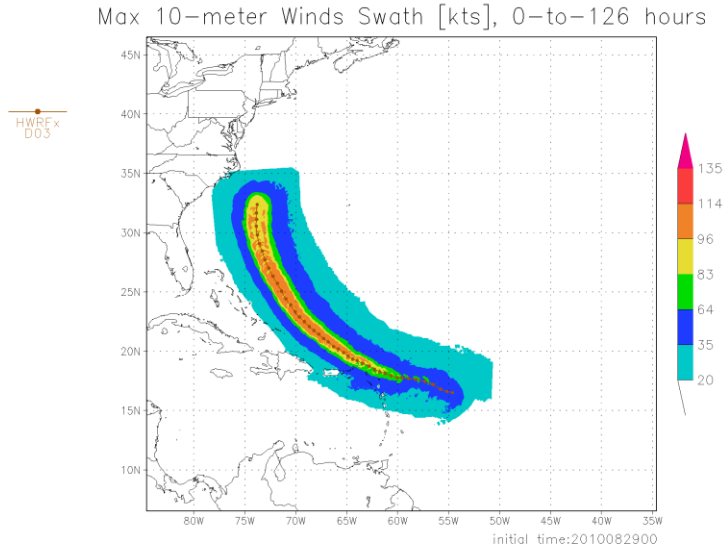

Figure 2: 10 m maximum wind swath from HWRF 27/9/3 forecast, starting on August 29 00Z using the bogus-vortex initialization

To demonstrate capability for direct comparison between the observed and simulated images, the satellite data simulation was applied for LEO sensors which had significant capture of the storm during the forecast period and were within ½ h of the forecast time. The matching forecast and observation instances are presented in Table 2 together with sensor, satellite and frequency specification for each time. The simulations of GOES13 imager were performed over the entire forecast grid, as expected. A sample of comparison between the simulated (forecast) and observed images is shown in Figure 3. It is readily observed in this figure that the simulated and observed swats are matching. This illustrates the important feature of HWSS capability to use the observed data files to exactly match the geometry of the observations in the simulations for the forecast evaluation.

Figure 3 displays simulated (top row) and observed (bottom row) 37H and 85H for AMSR-E (panels a-b) and GOES 13 water vapor channel (the channel 3), (panel c) and equivalent observed . Reader should notice that color tables are reversed for the water vapor images between the observed and simulated . The sample in Figure 3 shows consistent forecast fields with the observed. In Figure 4 an example of using the multiple channel images for GOES imager (channels 2-5) is shown for evaluating the spatial variability of water vapor in different regions outside cloud covered core region. The equivalent observed images are not displayed due to current visualization software problem with the observation data files. An illustration of simulated image for the outer domain is shown in Figure 5.

In addition to the 2D images, the diagnostics developed so far include frequency diagrams for each channel using the simulated and observed brightness temperatures over water surface. Comparison of such diagrams would provide quick evaluation of gross biases in the forecasts in terms of cloud presence, height and thickness and also in terms of water vapor gross distribution. The example of frequency diagrams is shown in Figure 6.

A sample comparison to CloudSat concident observations is presented in Figure 8. Comparison of forecast of warm core anomaly time series for case of hurricane Earl with AMSU-based estimate is shown in Figure 9.

HWSS is also used in post-procession of near real-time implementation of experimental data assimilation and forecast system using the current operational version of HWRF. The experimental system is HEDAS (HWRF Ensemble Data Assimilation System) supported by HFIP Samples from HEDAS post-processing application of HWSS using standard NRL's imaging palette for tropical cyclones are displayed in Figure 10. The example is for hurricane Isaac (2012).

Table 1 : Cases of simulated and observed satellite data for direct comparison

Year	Month	Day	Model time	Satellite time	Sensor	Satellite	CRTM key word and channels
2010	Aug	30	1800	1806	AMSR-E	Aqua	amsre_aqua_ 37 and 85 GHz
2010	Aug	21	2100	2107	SSM/I	DMSP F15	ssmi_f15 21, 37 and 85 GHz
2010	Sep	1	0000	2332(Aug 30)	SSMIS	DMSP F18	ssmis -f16 37, 55 and 91 GHz
2010	Sep	1	1200	1151	TMI	TRMM	tmi_trmm all
2010	Sep	1	1800	1756	AMSR-E	Aqua	amsre_aqua
2010	Sep	2	0600	0601	TMI	TRMM	tmi_trmm all
2010	Sep	2	0900	0917	TMI	TRMM	tmi_trmm
2010	Sep	2	1200	1135	SMMIS	DMP F16	ssmis_f16

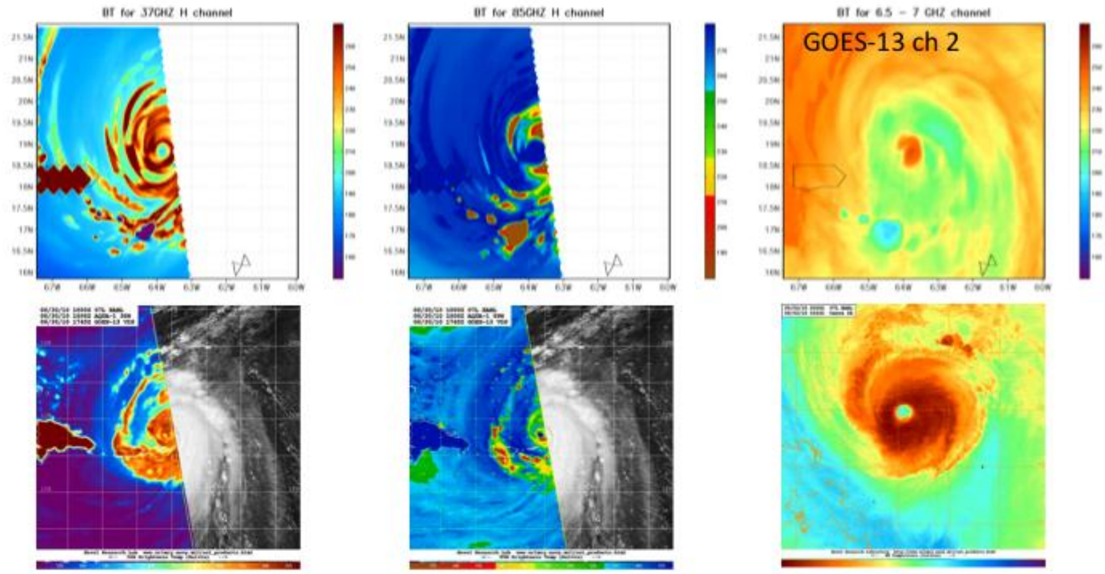

Figure 3 : Simulated (top row) and observed (bottom row) micro wave and infra red brightness temperatures for August 30 1800Z 2010.

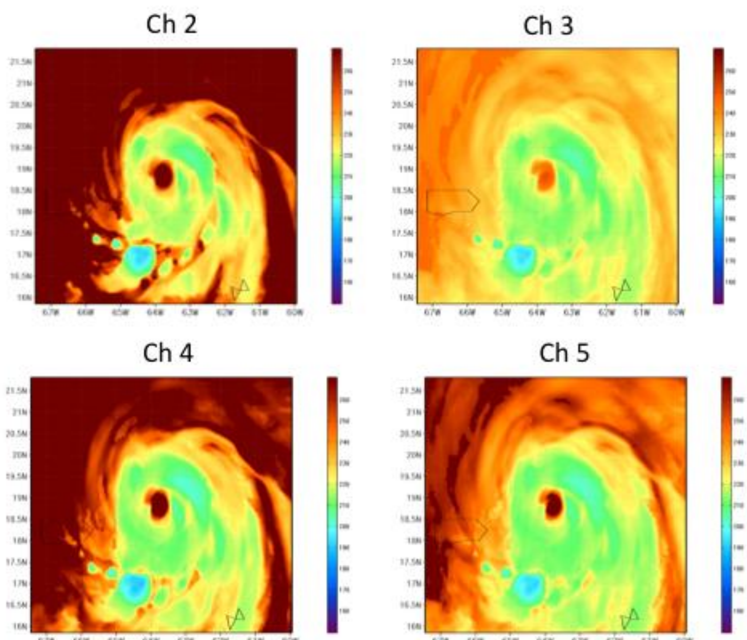

Figure 4 : Simulated different channels for GOES imager for the same time as in Figure 3.

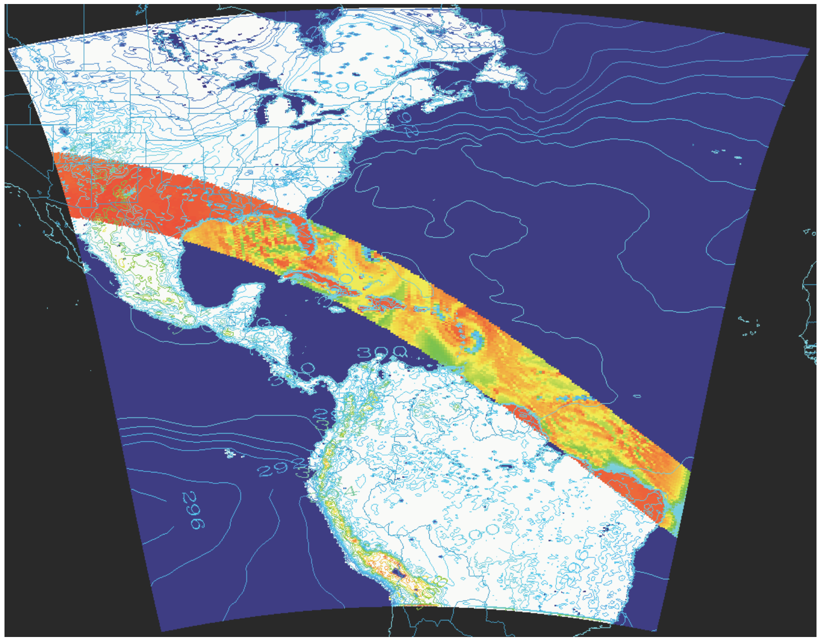

Fig. 5. Simulation of the 85.5H GHz band of the TMI for the outer HWRF model grid on 1200 UTC 2 September, 2010.

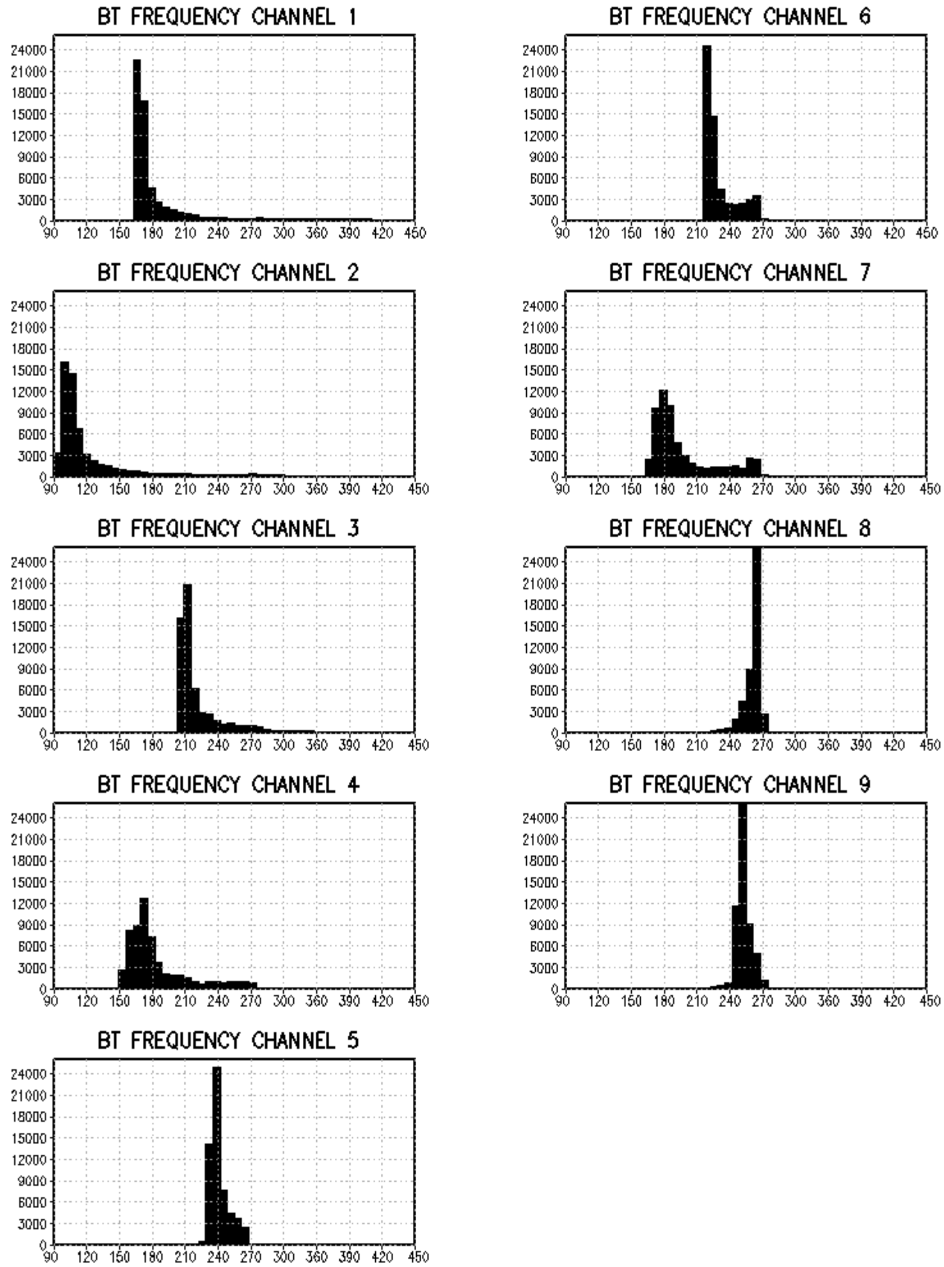

Figure 6: Example of frequency diagrams of simulated brightness temperatures for TMI channels

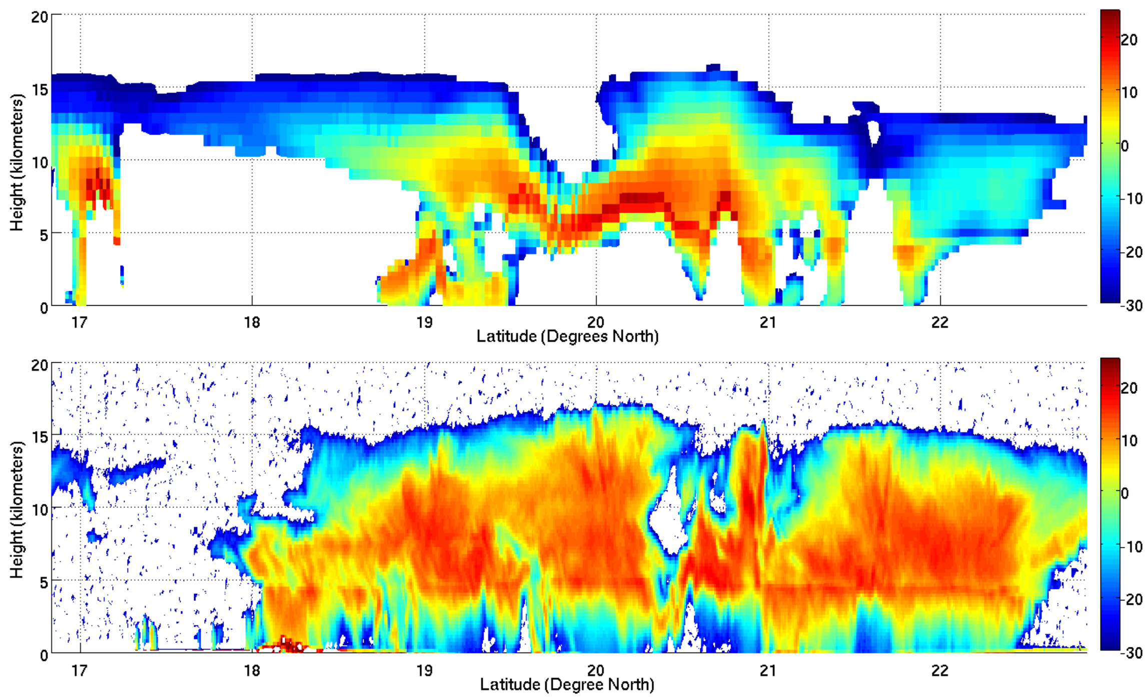

Figure 7: Comparison of simulated and observed CloudSat data for a single case

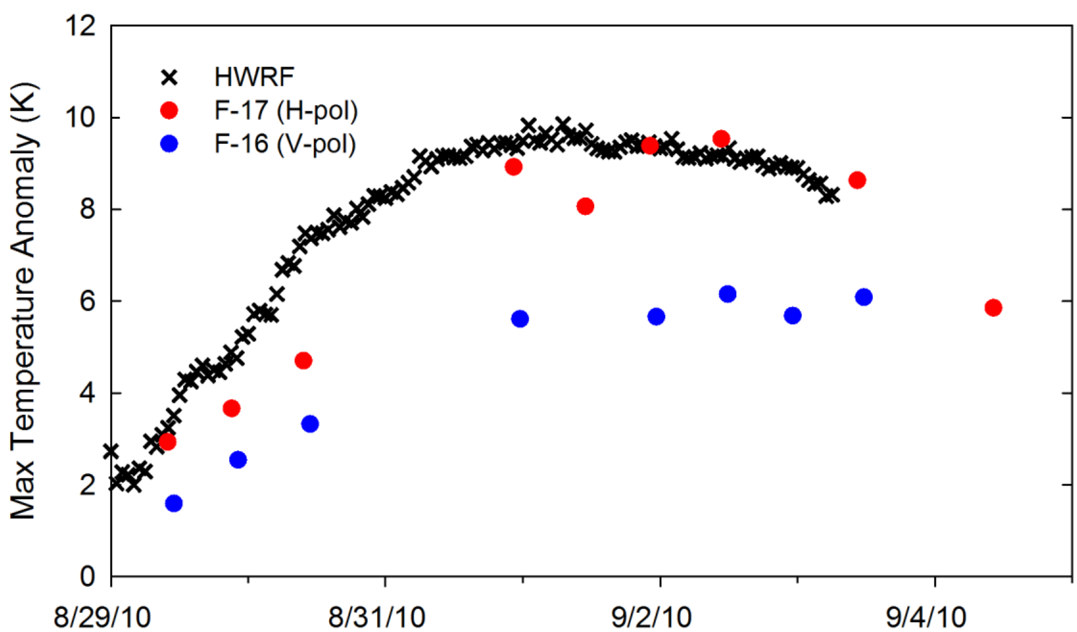

Figure 8: Time series of maximum warm core temperature anomaly for hurricane Earl (2010) : AMSU-based estimates (color) and forecast (crosses)

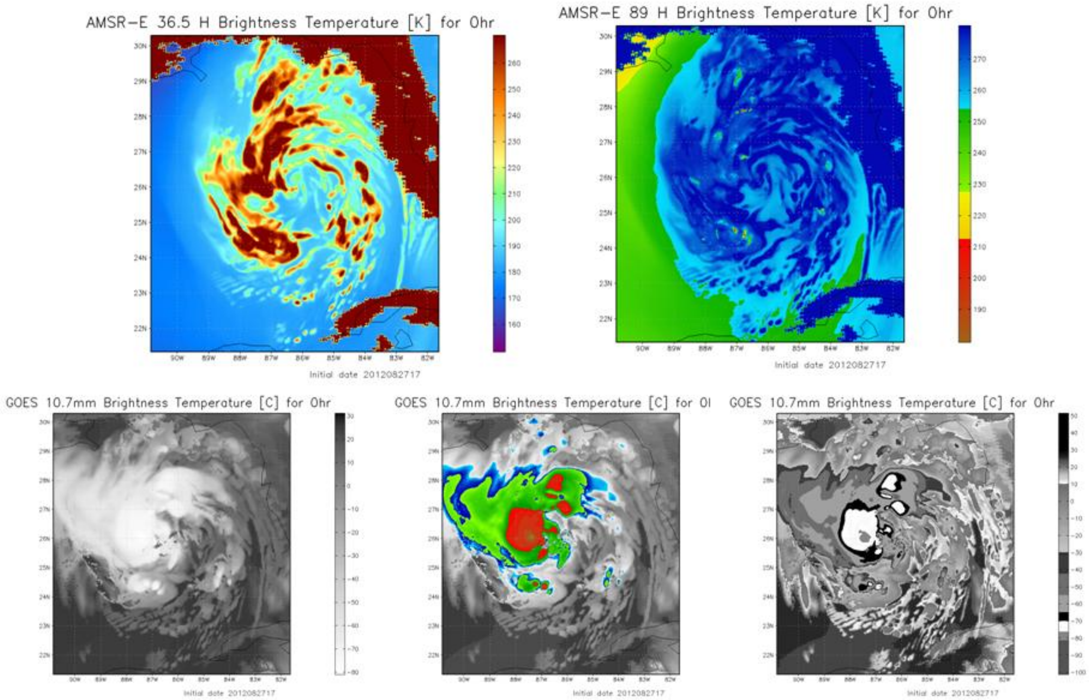

Figure 9: Examples of simulated satellite images displayed using standard selection of sensors and color tables as expected by NHC forecasters and as provided in NRL's tropical portal. The HWRF inner-nest 3 km resolution forecast for hurricane Isaac was used; the forecast was made using HRD's experimental HWRF Ensemble Data Assimilation System (HEDAS) at HRD The example includes 37 GHz H (top left), 89 GHz H (top right) and three ways of displaying IR 10.7 micron window channel of GOES.