The 2014 NOAA Satellite Proving Ground at the National Hurricane Center – Final Evaluation

Project Title: The 2014 NOAA Satellite Proving Ground at the National Hurricane Center

Organization: NOAA/NWS National Hurricane Center (NHC)

Evaluator(s): NHC Hurricane Specialist Unit (HSU) and Tropical Analysis and Forecast Branch (TAFB) forecasters

Duration of Evaluation: 01 Aug 2014 – 30 Nov 2014

Prepared By: Andrea Schumacher, CSU/CIRA, Mark DeMaria, Michael Brennan, John L. Beven, Hugh Cobb, NOAA/NWS/NHC

Submitted Date: 10 Mar 2015

Table of Contents

1. Executive Summary

This report summarizes the activities and results from the 2014 NOAA Satellite Proving Ground (PG) at the National Hurricane Center (NHC), which took place from August 1st to November 30th. During this time 14 prototype GOES-R Proving Ground products and 1 JPSS product were demonstrated and valuable forecaster experience and feedback were obtained. Three of these products were new to the NOAA Satellite PG at the NHC in 2014, including the GOES-R DEBRA-Dust Product, the GOES-R RGB Nighttime Microphysics, and a GOES-R lightning density product. The 2014 Atlantic hurricane season was relatively inactive and was dominated by short-lived hurricanes that recurved east of the U.S. coast. The eastern North Pacific hurricane season, however, was extremely active and provided several opportunities for evaluations of Proving Ground products, especially those available in both basins.

The primary results from the 2014 Proving Ground include the following: 1) Several demonstration products have been utilized for several years and will probably be part of the initial GOES-R product set for NHC (Hurricane Intensity Estimate, Air Mass and Dust RGB products, some version of a natural color product, and the Saharan Air Layer image combination product); 2) The GOES-R Advanced Baseline Imager (ABI) Super Rapid Scan Operations (SRSO) imagery will be most useful for disorganized systems, especially around sunrise; 3) The GOES-R Geostationary Lightning Mapper (GLM) lightning density product complements the ground-based flash location data currently available in N-AWIPS; 4) Separate versions of the lightning-based rapid intensification index will likely be needed for the east Pacific and Atlantic basins due to differences in the storm sizes in those basins; 5) Efforts should be made to obtain the low-latency VIIRS imagery, especially the Day-Night Band, becoming available from direct readout stations being deployed in Miami and Puerto Rico; 6) There may be value in modification of the standard EUMETSAT GOES-R RGB recipes for tropical applications, as indicated by comparing the standard version of the Dust Product to a version developed by CIRA tuned to delineating dust from non-dust, and de-emphasizing other features.

2. Introduction

The purpose of the NOAA Satellite Proving Ground (PG) at the National Hurricane Center (NHC) is to provide NHC forecasters with an advance look at tropical cyclone-related satellite products for evaluation and feedback during the most active period of the Hurricane season (August 1 – November 30). A total of 15 products were demonstrated during the 2014 NHC PG, including 14 GOES-R baseline products, future capabilities, risk reduction products, and decision aids as well as 1 JPSS baseline product. Demonstration products and algorithms were provided by NESDIS/STAR, CIRA, CIMSS, CIMAS, SPoR,T and OAR. The ABI products are produced using proxy data from Meteosat, GOES, and MODIS. The GLM product is produced from proxy ground-based World Wide Lightning Location Network (WWLLN) data. NHC also has access to the Vaisala GLD360 ground-based lightning data in real time on their NWS National center Advanced Weather Interactive Processing System (N-AWIPS) systems as another proxy for the GLM.

Feedback on the utility of the NHC PG products was gathered through a web based form set up by Michael Brennan from NHC, informal email exchanges between the NHC participants and product providers, and a mid-project review held at NHC on 17 Sep. 2014. The feedback form, new in 2013, has proved to be easy to use and has increased the input from the NHC forecasters. Figure 1 shows an example of the form. The web page automatically sends an e-mail to all of the PG participants. Feedback on PG products was also provided by product developers via blogs, which are available from http://nasasport.wordpress.com and http://rammb.cira.colostate.edu/research/goes-r/proving_ground/blog.

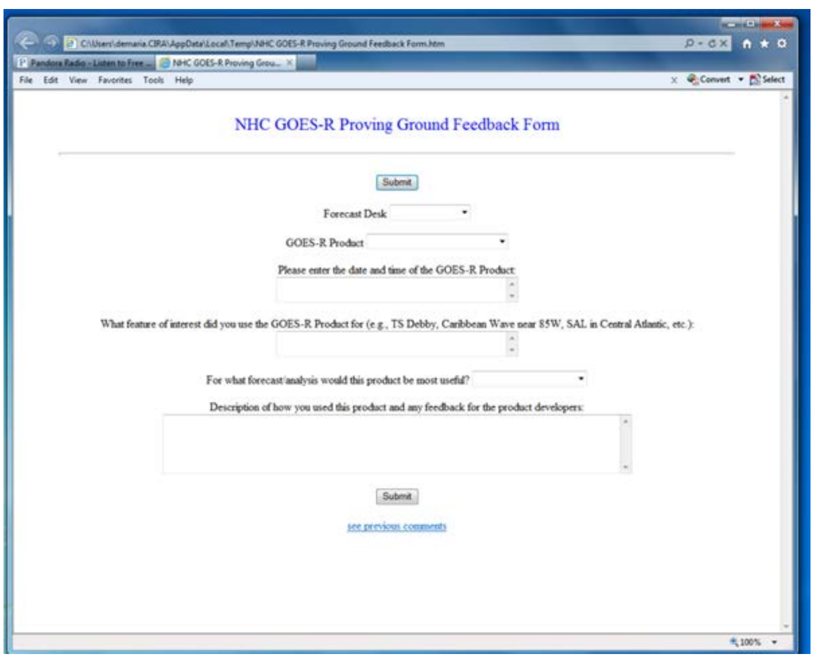


Figure 1. The feedback form used during the 2014 NHC Proving Ground.

2.1 Evaluation Strategies

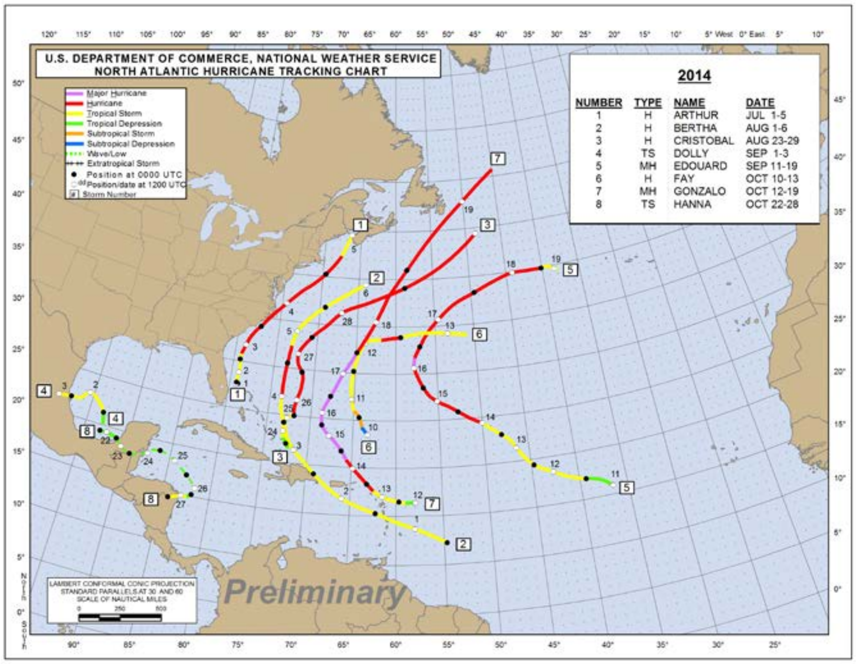
Feedback from 2013 indicated that there may be too many products included in the NHC demonstration. To address this concern and ensure that useful feedback was obtained, the emphasis in 2014 was product-dependent, and specific goals were more clearly elucidated. To facilitate this new approach, the 2014 demonstration was divided into five categories, each with its own evaluation goals (Table 1). Even though three new products were added to the 2014 NHC PG demonstration, this new approach allowed Liaisons to focus current training and evaluation efforts on a smaller subset of products with specific goals in mind.

Table 1. The 2014 NHC PG Evaluation Categories.

Category	**Description**	**Evaluation Goal(s)**
Mature	Products that have been included in NHC PG for several years, have received positive feedback, and proven useful for tropical applications. Less training needed.	Continue to make these products available so additional forecaster feedback can be obtained, time permitting.
Quantitative	Products that provide objective, quantitative guidance.	Perform a quantitative verification in the post-season and provide feedback to product developers, and to help gain forecaster confidence for eventual operational transition.
Introductory	Products introduced in late 2013, forecasters have received little exposure and limited feedback received.	Emphasize these products and obtain feedback on possible tropical applications.
Comparison	Products similar to other NHC PG products. As the GOES-R launch approaches, decisions will need to be made regarding the product sets to be routinely included on NHC AWIPS systems.	Encourage forecasters to display the comparison products along with the originals to provide feedback on the strengths and weaknesses of each.
Underutilized	Products included in the NHC PG for several years yet HSU applications still not clear	Work with HSU to determine if these products should continue to be included in their current form, be modified, or given less emphasis in NHC's eventual operational AWIPS configuration.

2.2 The 2014 Atlantic and E. Pacific Hurricane Seasons

Figure 2 shows the tropical cyclone activity in the Atlantic (top) and eastern North Pacific (bottom) during the 2014 season. The Atlantic season had a below-average number of named storms but average numbers of hurricanes (6) and major hurricanes (2). In general, the Atlantic season was dominated by short-lived hurricanes that recurved well east of the U.S. coast. The U.S. experienced one landfall from hurricane Arthur, which briefly came ashore along the North Carolina coast. By contrast the eastern North Pacific season was extremely active, with 20 named storms. There were 15 hurricanes, 9 of which became major hurricanes, which is almost double that of climatology.



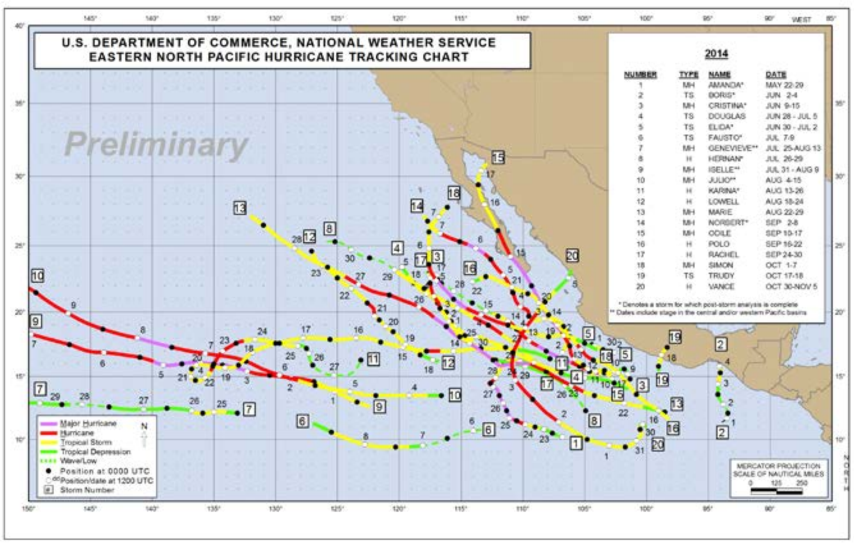


Figure 2. Preliminary 2014 season tropical cyclone tracks and intensities for the Atlantic (top) and eastern North Pacific (bottom).

3. Products Evaluated

Table 2 summarizes the fifteen products demonstrated in the 2014 NOAA Satellite Proving Ground at the National Hurricane Center (hereafter NHC PG). The products were primarily designed for the Hurricane Specialist Unit (HSU), which produces the tropical cyclone forecast product suite, but some were also applicable to the Tropical Analysis and Forecast Branch (TAFB), which provides marine forecast products over a large region of the tropics and subtropics. Product feedback was obtained from both the HSU and TAFB.

Table 2. The GOES-R and JPSS Proxy Products demonstrated in the 2014 NHC Proving Ground.

Product Name	Proxy Data	Product Type	Delivery Mechanism	Category	Evaluation Strategy
GOES-R Proving Ground Products Evaluated					
Natural Color	MODIS	Imagery	Web	Future Capability	Mature
RGB Air Mass	SEVIRI, GOES-E/W sounder, MODIS	Imagery	N-AWIPS	Future Capability	Mature
RGB Dust	SEVIRI	Imagery	N-AWIPS	Future Capability	Mature
Saharan Air Layer	SEVIRI	Imagery	N-AWIPS	Future Capability	Mature
Pseudo Natural Color	SEVIRI	Imagery	N-AWIPS	Future Capability	Mature
Hurricane Intensity Estimate	SEVIRI, GOES –East Imager	Text	Web	Baseline	Quantitative
Rapid Intensification Index	GOES-E/W Imagers, WWLLN	Text	Web	Risk Reduction	Quantitative
RGB Daytime Microphysics	SEVIRI	Imagery	N-AWIPS	Future Capability	Introductory
RGB Nighttime Microphysics	SEVIRI	Imagery	N-AWIPS	Future Capability	Introductory
RGB Convective Storms	SEVIRI	Imagery	N-AWIPS	Future Capability	Introductory
RGB Enhanced Dust (DEBRA-Dust)	SEVIRI	Imagery	Web	Future Capability	Comparison
Lightning Density	GLD-360	Point values	N-AWIPS	Baseline	Comparison
Super Rapid Scan Imagery	GOES-East, -West and -14	Imagery	Web	Baseline	Underutilized
Tropical Overshooting Tops	SEVIRI, GOES-E/W Imagers	Point values	N-AWIPS/Web	Future Capability	Underutilized
JPSS Products Evaluated					
VIIRS Day/Night Band	S-NPP VIIRS	Imagery	N-AWIPS/Web	Baseline	Introductory
Category Definitions: **Baseline Products** - GOES-R/JPSS products providing the initial operational implementation **Future Capabilities Products** - New capability made possible by ABI **Risk Reduction –** Research initiatives to develop new or enhanced GOES-R/JPSS applications and explore possibilities for improving current products					

3.1 GOES-R Natural Color Imagery

The ABI will have blue and red bands, but no green band. Thus, it will not be possible to provide a true color image. As part of the GOES-R Algorithm Working Group (AWG) imagery team, a method to accurately estimate the green band from neighboring bands using look up tables (LUT) has been developed. A look-up table approach is used, where the green band is estimated from the blue, red, and near-IR (0.86 µm) bands, similar to those that will be available on the GOES-R ABI. The green band estimated from the LUT is then combined with the red and blue bands to produce a natural color image. This algorithm was tested using MODIS data to create storm-centered natural color images to demonstrate GOES-R Future Capabilities. MODIS contains the green band so actual true color images were also produced for comparison. These products were distributed as part of the RAMMB/CIRA tropical cyclone real time web page, which is also used to display a number of other experimental tropical cyclone forecast products. Further details on the color algorithm are described by Hillger et al. (2011). Because the natural color product uses MODIS, it cannot demonstrate the high temporal resolution of the ABI. A more qualitative color product that uses SEVIRI will also be demonstrated as described in section 3.5.

3.2 GOES-R Red Green Blue (RGB) Air Mass Product

The GOES-R RGB Air Mass Product is an RGB composite based upon data from infrared and water vapor channels from Meteosat Second Generation (MSG). Originally designed and tuned to monitor the evolution of extratropical cyclones, in particular rapid cyclogenesis, jet streaks and PV (potential vorticity) anomalies by scientists at European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), it is also useful for tropical/subtropical applications as the GOES-R Future Capabilities product highlights differences between dry, tropical and cold air masses. This is accomplished by differencing the two water vapor channels (i.e., ch. 5 at 6.2 µm and ch. 6 at 7.3 µm) as depicted in the red colors, where red is associated with dryer air mass conditions locally; by ozone differences by differencing ch. 8 at 9.7 µm and ch. 9 at 10.8 µm, where green indicates low ozone & typically thus tropical air masses; and by using ch. 5 at 6.2 µm to indicate gross air mass temperature differences. The air mass product helps discriminate tropical air masses (i.e., moist and lower ozone) that are predominantly green, from subtropical air masses (i.e., drier) that are depicted as greenish red, and mid-latitude air masses, which typically have more blue colors. For tropical applications the RGB product should be helpful in determining and tracking the origin of air parcels as they interact with tropical systems, and improve identification of shallow upper-level features (cold lows and jet streaks). For more information on the interpretation of this product see Kerkmann (cited 2010). The use of this product in the GOES-R proving ground will provide important feedback concerning how similar products may be tuned for improved use in tropical applications. Because the product is provided in N-AWIPS format, the forecasters can overlay this on model fields to better understand the relationships with synoptic features in the storm environment. A version of the product was also developed from the GOES sounder.

This product was generated from SEVIRI data at SPoRT and GOES sounder data at CIRA and converted to N-AWIPS format. The N-AWIPS files were provided to NHC via the LDM feed from SPoRT.

3.3 GOES-R RGB Dust Product (EUMETSAT Version)

The GOES-R RGB Dust Product is an RGB composite based upon infrared channel data from the Meteosat Second Generation satellite. It is designed to monitor the evolution of dust storms during both day and night. The Dust RGB product makes use of channel differences that are close to IR windows near 8.7 µm and 10.8 µm. The resulting GOES-R Future Capabilities product depicts dust in magenta and purple colors over land during day and night, respectively. A dusty atmosphere can also be tracked over the water as magenta coloring. The product can also show low-level moist/dry boundaries. For more information on interpretation see Kerkmann et al. (cited 2010). The dust product will allow for the monitoring of dust storms over the African continent and tracking of dust plumes into the tropical Atlantic waters where easterly waves move and sometimes develop into tropical cyclones. The dust serves as a tracer for dry low- to mid-level air that originates over the Sahara Desert and has radiative influences on the atmosphere and affects the microphysics of cloud development. Dust plumes in the tropical Atlantic have been hypothesized to slow tropical cyclone development (Dunion and Velden 2004) and directly affect sea surface temperatures (SSTs) where tropical cyclones form (Evan et al. 2008). This product was generated from SEVIRI data at SPoRT and converted to N-AWIPS format. The N-AWIPS files were provided to NHC via the LDM feed from SPoRT.

3.4 GOES-R Saharan Air Layer (SAL) Product

The Saharan Air Layer (SAL) product is another example of an GOES-R Future Capabilities enhanced image product potentially related to tropical cyclone evolution. The SAL product uses a split window (10.8 and 12.0 µm) algorithm to identify and track dry, dusty air (e.g., Saharan dust outbreaks) in the lower to middle levels of the atmosphere. These dust outbreaks traverse the Atlantic Ocean from east to west and can reach as far west as the western Caribbean, Florida, and Gulf of Mexico during the summer. There is evidence that they can negatively impact tropical cyclone activity in the North Atlantic (Braun 2010). This product can also be used to track low- to mid-level dry air (usually dust-free) that originates from the mid-latitudes. Dry (and possibly dusty) air is indicated by yellow to red shading in the SAL product. Similar to the air mass product, the SAL product is not directly related to the Baseline products, but provides experience with image visualization techniques. The SAL product was provided to NHC in N-AWIPS format via the LDM feed from SPoRT.

3.5 GOES-R Pseudo Natural Color Imagery

Although the natural color product described above is very close to what will be available from GOES-R, the use of MODIS data provides limited time resolution. To provide additional experience with color products with improved time resolution, a pseudo natural color GOES-R Future Capabilities product developed from SEVIRI data was produced. Although not a quantitative algorithm like the MODIS-based natural color products, four SEVIRI bands (2 visible: 0.6 and 0.8 µm and 1 IR: 1.6 µm) are combined and special enhancement tables are applied to highlight ocean, land, aerosol, and cloud features in colors that are qualitatively similar to those in true color imagery. The 3.9 µm channel was used to supplement the visible and near-IR channels by providing continuous coverage through the nighttime hours. This product was provided to SPoRT through coordination with CIMSS and CIMAS and sent to NHC in N-AWIPS format via the LDM feed from SPoRT.

3.6 GOES-R Hurricane Intensity Estimate (HIE)

The Hurricane Intensity Estimate (HIE) is the only hurricane-specific product that is part of the official GOES-R Baseline set. The HIE is a GOES-R algorithm designed to estimate hurricane intensity [mean sea level pressure (MSLP) and max surface wind] from ABI IR-window channel imagery. The code was derived from the current Advanced Dvorak Technique (ADT), which is an objective and fully-automated algorithm that is operational now at the National Environmental Satellite, Data, and Information Service (NESDIS). The Cooperative Institute for Meteorological Satellite Studies (CIMSS) has adapted the current ADT code to operate on 15-minute Meteosat and GOES-East CONUS imagery, as a proxy to an ABI product demonstration. The HIE was run using 15-minute GOES-East CONUS (MSG) imagery for those systems west (east) of 60^{o}W. The HIE was provided to NHC via a web page (http://tropic.ssec.wisc.edu/real-time/adt/goesrPG/adt-PG.html), which is the same method used to provide the ADT.

3.7 GOES-R Lightning-Based Rapid Intensification Index (RII)

A prototype rapid intensification index (RII) was run in real time to demonstrate a decision aid using proxy GLM data from the ground-based World-Wide Lightning Location Network (WWLLN), proxy ABI data from current GOES, in combination with global model forecast fields, and sea surface temperature and oceanic heat content analyses. The various data sources were combined in a discriminant analysis algorithm that provides optimal weights of the independent variables to provide a classification of whether or not a tropical cyclone will rapidly intensify (defined as an increase in intensity of $\geq$ 30 kt) in the next 24 hours (DeMaria et al. 2012). For comparison a version of the experimental RII without the lightning predictors was also run. The RII is a text product that was provided via a web page at CIRA that was also being used by NHC to obtain experimental products as part of the NOAA Joint Hurricane Testbed.

The lightning predictors in the RII are the lightning density in the inner core (0-200 km from the center) and rain band region (200-400 km from the center) calculated over 6-hour time periods. Based on statistical analysis from the past few seasons, the inner core region was expanded from 0-100 km and the rainband region was expanded from 200-300 km. The text product also includes a time series of the storm-relative lightning density values for the life of the storm so the forecasters can see the evolution. In addition, forecasters have the ability to plot the flash locations from the GLD-360 ground based network over shorter time periods, which complemented the RII. Although there are quantitative differences between the GLD-360 and WWLLN data, they are qualitatively similar, and both give an idea of the distribution of the flashes around the storm.

3.8 GOES-R RGB Daytime Microphysics

The RGB Daytime Microphysics product is a GOES-R Future Capabilities RGB product based on visible (0.8-µm) and infrared (3.9-µm and 10.8-µm) SEVIRI channels from Meteosat Second Generation (MSG). The visible reflectance (0.8-µm VIS) in red approximates the cloud optical depth and amount of cloud water and ice. The 3.9-µm shortwave infrared solar reflectance in green gives a qualitative measure of cloud particle size and phase. The 10.8-µm infrared brightness temperature produces blue shading as a function of surface and cloud top temperatures. The warmer the surface, the greater the blue contribution, so warmer land and ocean surfaces appear blueish. Low clouds appear yellow to greenish (small droplets) to magenta (large droplets). High ice clouds appear deep red (large ice particles) to bright orange (small ice particles).

The RGB Daytime Microphysics product has several potential tropical applications. It can help identify severe convective clouds with strong updrafts, which is useful in forecast tropical cyclone intensity and intensity change. This product can clearly distinguish between ice phase clouds at high elevations and water phase clouds at lower elevations. It can also identify subtle microphysical variations within clouds that are not apparent on other images or RGB products and help discriminate between precipitating and non-precipitating water clouds. These characteristics are can be used for convective monitoring in the maritime environment.

More information on the RGB Daytime Microphysics product can be found at http://www.goes-r.gov/users/comet/npoess/multispectral_topics/rgb/navmenu.php_tab_1_page_6.12.0.htm. The RGB Daytime Microphysics product is provided to NHC in N-AWIPS format via the LDM feed from SPoRT.

3.9 GOES-R RGB Nighttime Microphysics

The RGB Nighttime Microphysics product is a GOES-R Future Capabilities RGB product based on infrared (3.9-µm, 10.8-µm, and 12.0-µm) SEVIRI channels from Meteosat Second Generation (MSG). The infrared difference in red (12.0-µm - 10.8-µm IR) in red approximates the cloud optical depth. The infrared difference in green (10.8-µm - 3.9-µm IR) gives a qualitative measure of cloud particle size and phase. The 10.8-µm infrared brightness temperature produces blue shading as a function of surface and cloud top temperatures. The warmer the surface, the greater the blue contribution, so warmer land and ocean surfaces appear bluish. Low clouds appear in shades of tan and light green. Mid-level clouds lean toward green (thin, less red) to light brown (thick, more red). High ice clouds appear deep red (large ice particles) to bright orange (small ice particles).

Tropical applications of the RGB Nighttime Microphysics product are the same as for the daytime version described in the previous section.

More information on the RGB Nighttime Microphysics product can be found at http://weather.msfc.nasa.gov/sport/training/rgb_ntmicro/RGB%20Nighttime%20Microphysics%20Reference%20Guide.pdf. The RGB Nighttime Microphysics product is provided to NHC in N-AWIPS format via the LDM feed from SPoRT.

3.10 GOES-R RGB Daytime Convective Storms

The RGB Daytime Convective Storms product is a GOES-R Future Capabilities RGB product based on visible (0.6-µm), near-infrared (1.6-µm), water vapor (6.2-µm and 7.3-µm), and infrared (10.8-µm) SEVIRI channels from Meteosat Second Generation (MSG). The product is generated by differencing various SEVIRI MSG channels. Red is produced by differencing the two water vapor (6.2-µm and 7.3-µm) channels, green is produced by differencing the two infrared (3.9-µm and 10.8-

µm) channels, and blue is produced by differencing the near-infrared and visible (1.6-µm and 0.6-µm) channels.

This product shows the background as blue/magenta. High-level, thick ice clouds, including convective cumulonimbus clouds, are red. Yellow is usually indicative of small particles within convective cloud tops. Compared to many satellite images, this RGB shows the most intense cells, which can help distinguish new convection from dissipating convective activity. This lends to tropical applications such as cloud discrimination (e.g., convective vs. stratiform), genesis, and intensity forecasting.

More information about the RGB Daytime Convective Storms product can be found at http://www.goes-r.gov/users/comet/npoess/multispectral_topics/rgb/navmenu.php_tab_1_page_6.9.0.htm. The RGB Daytime Convective Storms product is provided to NHC in N-AWIPS format via the LDM feed from SPoRT.

3.11 S-NPP VIIRS Day/Night Band

The VIIRS Day-Night Band (DNB) is a new low-light sensing capability on the current Suomi National Polar-orbiting Partnership (S-NPP) satellite, the first of 3 next-generation polar-orbiting satellites in the JPSS series. The DNB has numerous NWS applications, including nighttime tropical cyclone center fixing, and cloud, fog and smoke detection. The DNB can also be used in conjunction with the ABI to give high resolution snapshot to complement the high time resolution from the ABI. The DNB senses reflected moonlight at night. It can be used in similar ways to the visible channel during the day. It measures reflected moonlight and emitted light from surface sources such as city lights and fires. To provide a more uniform image as the moon phase changes, a reflectance product is generated using the moonlight algorithm from CIRA. The reflectance product is available twice per day from the ascending and descending passes of S-NPP. The DNB is obtained from servers at CIMSS and provided to NHC from SPoRT via the LDM. The CIRA moonlight code is applied at SPoRT to create the reflectance product before the data is posted for distribution. The imagery from the SPoRT LDM feed only includes data from direct readout systems at UW and along U.S.West coast, which provides coverage to only a small part of the Atlantic and East Pacific tropical cyclone basins. Longer latency DNB imagery was made available via the CIRA web page to complement the LDM data.

3.12 GOES-R RGB Dust Product (CIRA DEBRA-Dust)

The GOES-R Dynamic Enhancement Background Reduction Algorithm (DEBRA-Dust) is an MSG SEVIRI-based product designed to monitor the onset of lofted mineral dust events over the African interior and track plumes across the eastern/central Atlantic Ocean (to the extent of Meteosat Second Generation SEVIRI spatial coverage). DEBRA-Dust employs dynamic land surface emissivity and temperature background information to estimate the clear-sky signal of common dust-detection tests, and uses these values as a baseline for determining the presence of lofted dust. The result is a confidence factor (0=no dust, 1=confident dust) which, when presented as color-enhanced Red/Green/Blue imagery, provides a visually intuitive way of isolating dust from other elements of the complex scene, while suppressing land-surface artifacts. DEBRA-Dust complements the EUMETSAT RGB Dust product, attempting to refine/simplify identification of the salient features of interest.

The GOES-R DEBRA-Dust product is based on Meteosat Second Generation SEVIRI data. Although it is foremost a quantitative product (meaning that it can be thresholded on confidence factor value to isolate dust regions), it is presented in imagery form for this demonstration. Here, the areas of high dust confidence appear in yellow hue, with saturation values tied to the confidence factor strength (brightest yellow = highest confidence). To first order higher confidence factors correlate with optically thicker dust, but this is not a hard/fast rule and the foremost purpose of this product is a mask. A special version of DEBRA has been developed for this provisional demonstration which provides a more aggressive enhancement over water backgrounds. DEBRA-Dust products are generated every 15 minutes at CIRA and hosted online. If DEBRA becomes a formal demonstration product in the future then it will be further refined and converted into a format suitable for N-AWIPS and provided via ftp server or LDM.

3.13 GOES-R GLM Lightning Detection (GLD-360 Lightning Density proxy)

The GLD-360 Lightning Density product provides an 8x8 km boxed average estimation of CG lightning activity within the Vaisala GLD-360 network. It takes the raw lightning observations from the Vaisala GLD-360 network and recombines them into a flash extent gridded field.
These data are then mapped to a GLM resolution of 8 km and are available at 2, 5, 15, and 30-minute refresh rate. With the flash data, when a flash enters a grid box, the flash count will be increased by one and no flash is counted more than once for a given grid box.

The GLD-360 Lightning Density product was is meant to prepare forecasters to receive data at the spatial resolution of the GLM. It gives forecasters the opportunity to use and critique a demonstration of GLM type data to help improve future visualizations of these data and serves as reference for comparison with full GLM proxies and derived products. The GLD-360 lightning feed is used to create the 8x8 density grids at OPC. These grids are then made available to WPC, OPC, and SAB through the NCEP network for use in N-AWIPS.

3.14 GOES-R Super Rapid Scan Operations (SRSO) Imagery

NHC indicated an interest in super rapid scan operations (SRSO) data during hurricane landfalls to gain experience with the utility of the high time resolution observations from GOES-R. Because rapid scan operations (RSO) are automatically triggered during a U.S. hurricane landfall, which precludes the possible use of SRSO, alternate approaches were planned for 2014. If there was a hurricane landfall outside the U.S., SRSO would be called if possible. Also, the auto-trigger of RSO is for the satellite closest to the landfall point (usually GOES-East). When possible, SRSO would be called on the other operational GOES satellite if the cyclone is within its field of view. Based on experience from the 2012 NHC PG, the SRSO data is most useful near sunrise for center fixing and aircraft go/no-go decisions. The plan included short periods of SRSO will be called centered around sunrise when possible. The current satellite systems at NHC are not set up to ingest 1-minute imagery, so SRSO imagery was ingested at CIMSS and CIRA and made available via web pages.

GOES-14 was brought out of storage during part of 2014, so there was a potential to collect much longer periods of SRSO data (SRSO for GOES-R, SRSOR). The SRSOR data provides 1 min imager data for 26 min during a 30 min period.

3.15 GOES-R Tropical Overshooting Top Detection

The GOES-R Tropical Overshooting Tops (TOT) product uses infrared window channel imagery to identify domelike protrusions above cumulonimbus anvils associated with very strong updrafts. OTs are identified using a brightness temperature threshold method. Details can be found in Monette (2011). OTs can help to identify vortical hot towers, which are related to tropical cyclone formation (Montgomery et al. 2009) and intensification (Guimond et al. 2010). Real time OT timing and location over the tropical and subtropical Atlantic east of 55^{o}W based on 15-min Meteosat imagery was provided via a web page at CIMSS (http://cimss.ssec.wisc.edu/goes_r/proving-ground/nhc/ot/). GOES-East and GOES-West were used to identify TOTs over the western Atlantic and eastern Pacific. The TOT locations were also provided in N-AWIPS format so they could be overlaid on other products routinely utilized by NHC forecasters.

4. Evaluation Results

Product feedback was obtained using the mechanisms described in section 2. This feedback, related results, and plans for 2015 are summarized below.

4.1 GOES-R Natural Color Imagery

Evaluation Strategy = Mature

Figure 3 shows an example of the product during Hurricane Cristina. Loops of this product will be very valuable for public outreach, some feature identification, such as cloud structure. Because the GOES-R version of the product is somewhat complex, utlizing a look-up table to estimate the green channel from neighboring channels, it may be necessary to first generate this product externally and then deliver it to NHC's AWIPS systems, to provide time for local development at NHC.

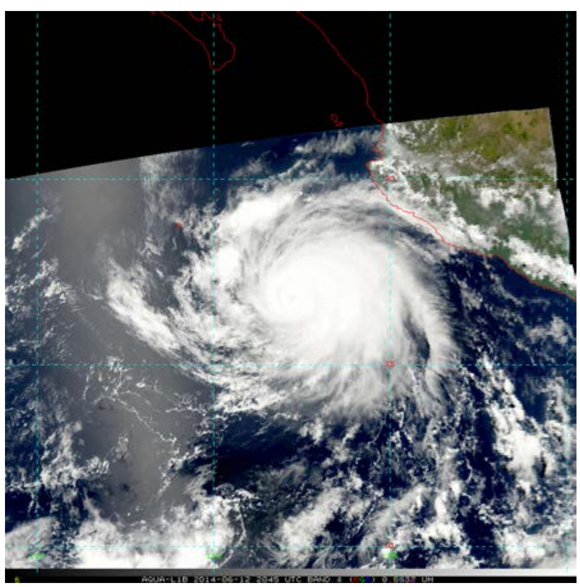


Figure 3. Proxy (MODIS) GOES-R Natural Color imagery for Hurricane Cristina on 12 June 2014.

4.2 GOES-R RGB Air Mass Product

Evaluation Strategy = Mature

The RGB Air Mass product continues to be one of the most highly utilized PG products. The training provided by Michael Folmer has helped forecasters better understand the application of this product. TAFB analysts often mention this product in Tropical Weather Discussions in reference to the discrimination between moist tropical air masses and drier mid-latitude air masses. In addition, four feedback forms were submitted by TAFB regarding this same use. Several of these forms suggested that the RGB Air Mass product complements the SSMI total precipitable water (TPW) product and that using both of these products together provides a 3-dimensional representation of atmospheric moisture. An example of the RGB Air Mass Product from 2014 is included in Fig. 4.

4.3 GOES-R RGB Dust Product (EUMETSAT Version)

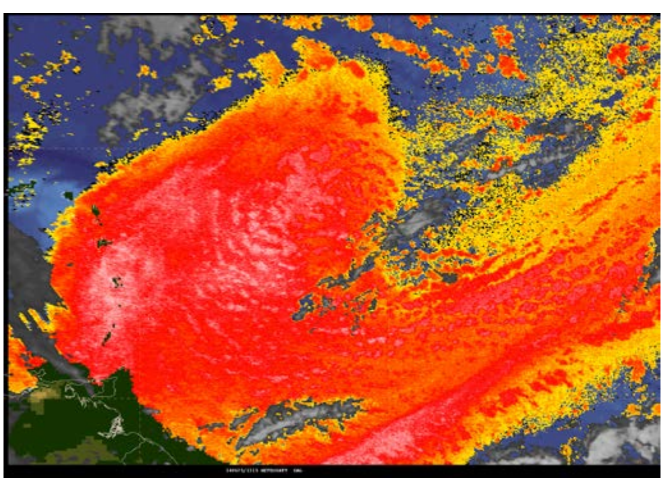
Evaluation Strategy = Mature

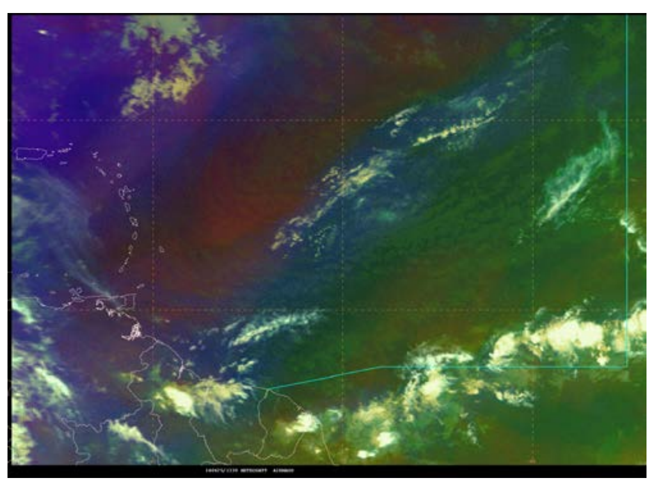
Along with the RGB Air Mass Product, The RGB Dust product continues to be one of the most highly utilized PG products. The use of the RGB Dust product to identify regions of dust was mentioned in at least four TWDs this year. Since the RGB Dust product is considered a Mature PG product, the main focus in this year's NHC demonstration was to compare it with the CIRA DEBRA-Dust product (see section 4.4.1).

4.4 GOES-R Saharan Air Layer (SAL) Product

Evaluation Strategy = Mature

The SAL product is a mature NHC PG product that continued to be available in N-AWIPS format this year. It was mentioned in several Tropical Weather Discussions this season, particularly in reference to SAL regions near tropical waves. TAFB analysts said it continues to be used routinely to identify dry and dusty air masses. The SAL product was used in conjunction with the RGB Air Mass product to identify a SAL/Dust boundary around 25 June 2014 (Fig. 4)





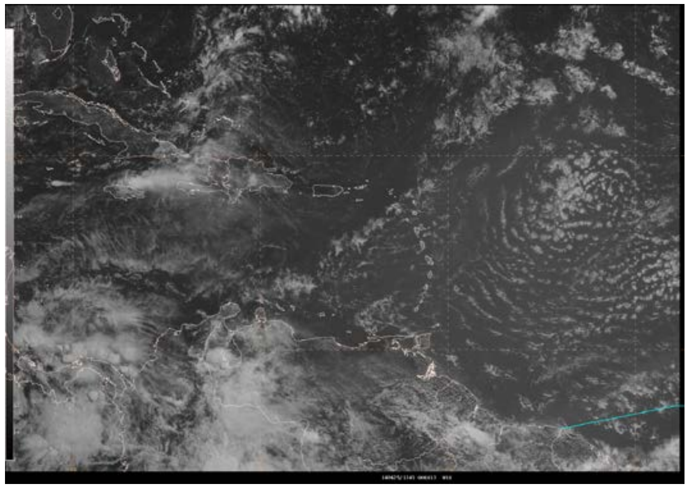


Figure 4. The RGB SAL product (upper left), RGB air mass product (upper right) and visible imagery (bottom) from the 25 June 2014 SAL/dust outbreak.

A few feedback forms submitted this year made references to areas identified by this product as SAL regions that did not have a clear signature in other RGBs, such as the air mass product. These comments suggest training efforts for 2015 might want to focus on elaborating on the similarities and differences of the various NHC PG RBG products, their respective strengths and weaknesses, and examples of how multiple products may complement each other during analysis and forecasting.

4.5 GOES-R Pseudo Natural Color Imagery

Evaluation Strategy = Mature

Although no specific feedback on this product was obtained in 2014, this could be a complement to the natural color product described above. This product is much easier to implement locally at NHC since its generation primarily involves image combinations and does not require implementing a look up table.

4.6 GOES-R Hurricane Intensity Estimate (HIE)

Evaluation Strategy = Quantitative

The HIE product was generated from MSG and GOES-East and available to the NHC forecasters via a web page. Feedback from TAFB analysts indicate the ADT and HIE are used semi-regularly. Feedback was received from the HSU regarding HIE guidance during Hurricane Edouard. Around 16 September 2014, microwave and aircraft reconnaissance data both suggested Hurricane Edouard had a double eyewall (Fig. 5). At this time, the HIE was predicting an intensity of 110 kt, about 15 kt higher than the official intensity of 95 kt. The ADT was also over-predicting the intensity of Edouard at ~105 kt, but was not quite as high as the HIE. This case may warrant further investigation during the off-season.

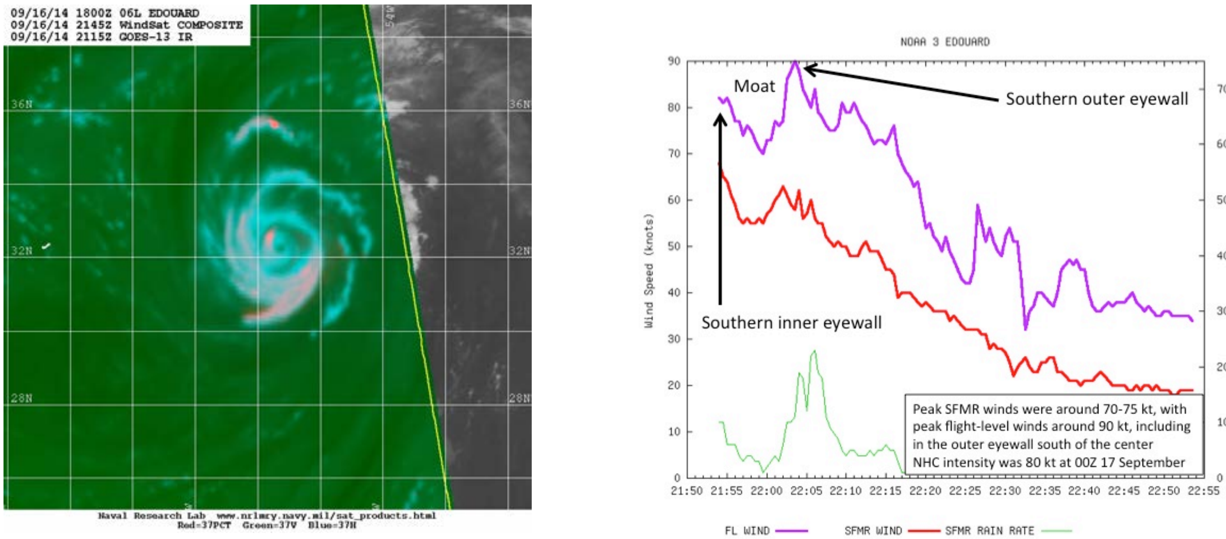


Figure 5. Evidence of a secondary eyewall in Hurricane Edouard on 16 September 2014 as seen in WindSat microwave (left) and aircraft reconnaissance (right) data.

4.7 GOES-R Lightning-based RII

Evaluation Strategy = Quantitative

Like 2013, a considerable amount of feedback was obtained in 2014 on the quantitative lightning product, and the qualitative interpretation of the lightning location data. The experimental RII was run in real time for all cases in the Atlantic and eastern North Pacific during the 2014 season. Two versions of the experimental RII were run; one that includes the lightning data and a version that is identical except that it does not include the lightning input. This allowed a direct evaluation of the impact of the lightning input. The coefficients of the RII show that an increase in inner core lightning activity is often associated with increasing vertical shear and makes intensification less likely. Conversely, lightning in the rain band regions indicates intensification is more likely. This behavior was included in forecaster training on the lightning RII product. As described above in section 3.2.2, the quantitative RII product used the WWLLN data, while the NHC forecasters used the GLD-360 data in N-AWIPS for qualitative applications.

An increase in rain band lightning density was noted by HSU forecasters prior to the rapid intensification of Tropical Storm Cristina. The Tropical Cyclone Discussion from 10 June 2014 at 8 PM EDT states "…a considerable amount of lightning has been occurring in a rain band located about 120 n mi to the south-southwest of the center. Recent research has documented that lightning in the rain bands of the tropical cyclone circulation is often a precursor of significant intensification." As can be seen in Fig. 6, Christina did indeed intensity rapidly shortly thereafter.

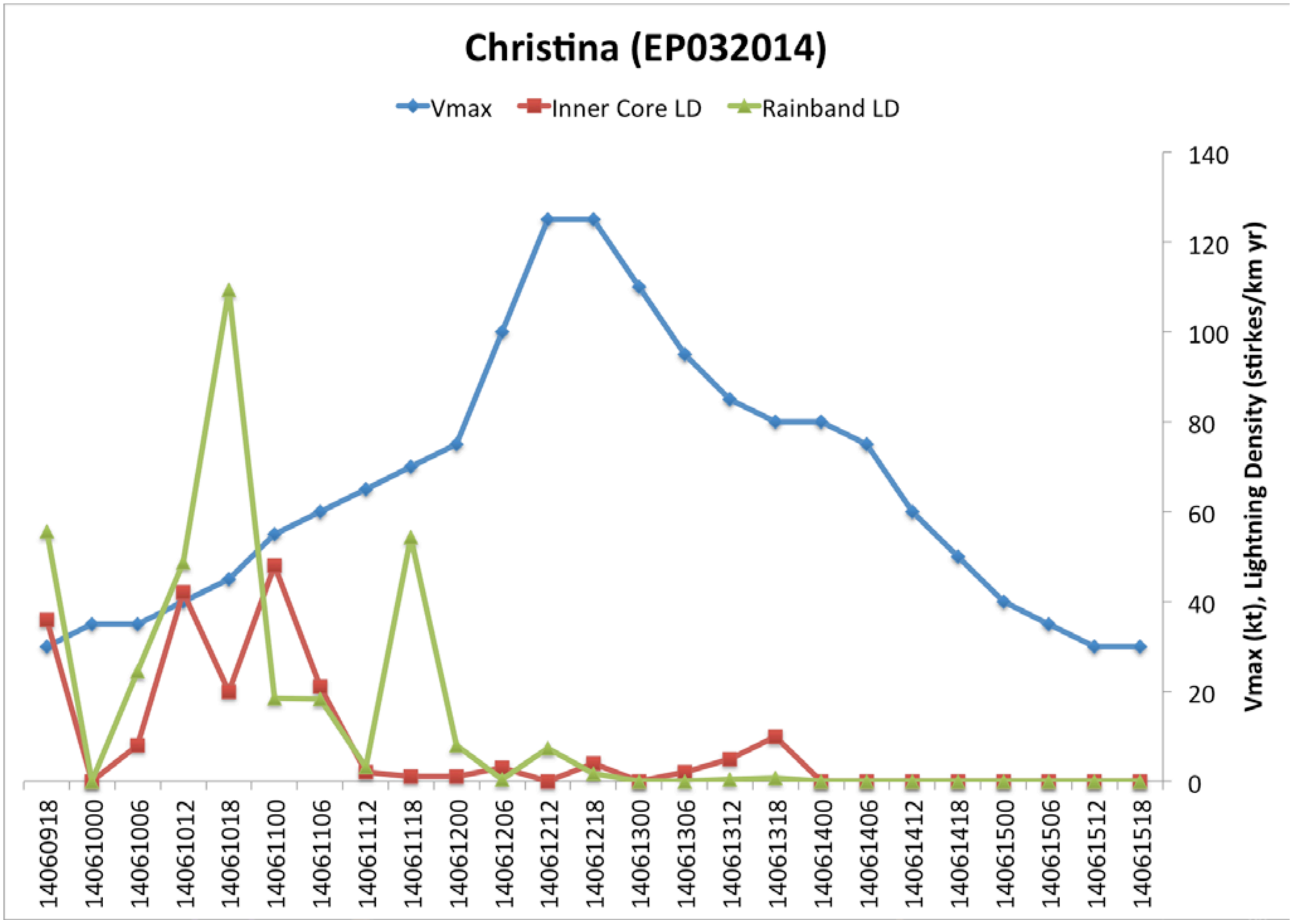


Figure 6. Rain band lightning density increased just prior to the rapid intensification of Hurricane Cristina.

Feedback submitted by HSU indicates that the theory behind the RII algorithm, in addition to the raw lightning density contours, influenced their forecast reasoning with respect the intensity change. A form submitted during Hurricane Simon stated "Lightning and lightning density data showed no significant inner core lightning with Simon during the rapid intensification or during the 12 hours leading up to the rapid intensification. Several bursts of lightning were noted in the outer band to the northwest." The lightning data was also utilized as an indicator of interaction of tropical cyclones with vertical shear, which is in turn related to short-term intensity change. A form submitted regarding use of lightning data for Tropical Depression 16E and Hurricane Odile stated "Lightning density counts for TD 16E were declining, while they were increasing for Odile. Also, the storms were somewhat sheared systems, so the lightning near the center was consistent with that (bursting pattern). Odile was forecast to rapidly intensify (after shear subsides), but the lightning near the center suggested that might be delayed. Later in the afternoon the lightning in Odile began to decrease, suggesting the shear might be letting up."

Because the RII provides a quantitative estimate of the probability of RI, a quantitative product validation can be performed. Three metrics commonly used for probabilistic forecasts were utilized. These included the Bias, Brier Score and Threat Score (TS).

The Bias is usually calculated as the average of all forecasted probabilities divided by the observed percentage of RI cases in the verification sample. This provides an indication of whether RI is being over- or under-forecasted over a large number of cases.

The Brier Score is analogous to a Root Mean Square (RMS) error for probabilistic forecasts. It is the square root of the square of the difference between the predicted and observed probabilities, where the observed probability is 1 if RI occurred or 0 if RI did not occur for that case. This value is summed over all the forecast cases.

The Threat Score (TS) is calculated using

$$TS = N_{f\ and\ obs}/(N_f + N_{obs}) \qquad (1)$$

where N_f is the number of cases that were forecast to undergo RI, N_{obs} is the number of cases that were observed to undergo RI based on the NHC final best track, and $N_{f\ and\ obs}$ is the number of cases that were forecast to undergo RI and did undergo RI. The TS ranges between zero (no correct forecasts) and one (correct forecasts of all observed events with no false alarms). The TS depends on the probability threshold used to separate a forecast of a yes versus no event. For the verification, the TS was calculated for a range of thresholds from 0 to 100%, and the value that maximized the TS was utilized as a measure of the performance of the algorithm.

The Bias Error, BS and TS were calculated for lightning and no-lightning versions of the RII, and the percent improvement in each parameter was calculated for the Atlantic and East Pacific samples. The Atlantic (East Pacific) sample included 131 (451) cases. There were 8 Atlantic cases that underwent RI, and 40 East Pacific cases. In the developmental sample about 8% (9%) of the Atlantic (East Pacific) cases were RI cases; in 2014, 6% (9%) were RI cases.

Figure 7 shows the percent improvement of the verification metrics due to the inclusion of the lightning input. For the 2014 Atlantic sample, the inclusion of the lightning data improved all three verification metrics. However, there was some degradation in the metrics for the East Pacific cases. As described above, the averaging areas of both the inner core and rainband regions were expanded for the 2014 season. This may have led to the degradations in the RII with the lightning since east Pacific tropical cyclones are generally smaller than Atlantic cyclones (Knaff et al. 2014). This result suggests that different averaging areas may be needed for each basin, or application of a more sophisticated algorithm that uses the IR imagery to provide an estimate of storm size, which can then be used to provide appropriate averaging areas on a case by case basis.

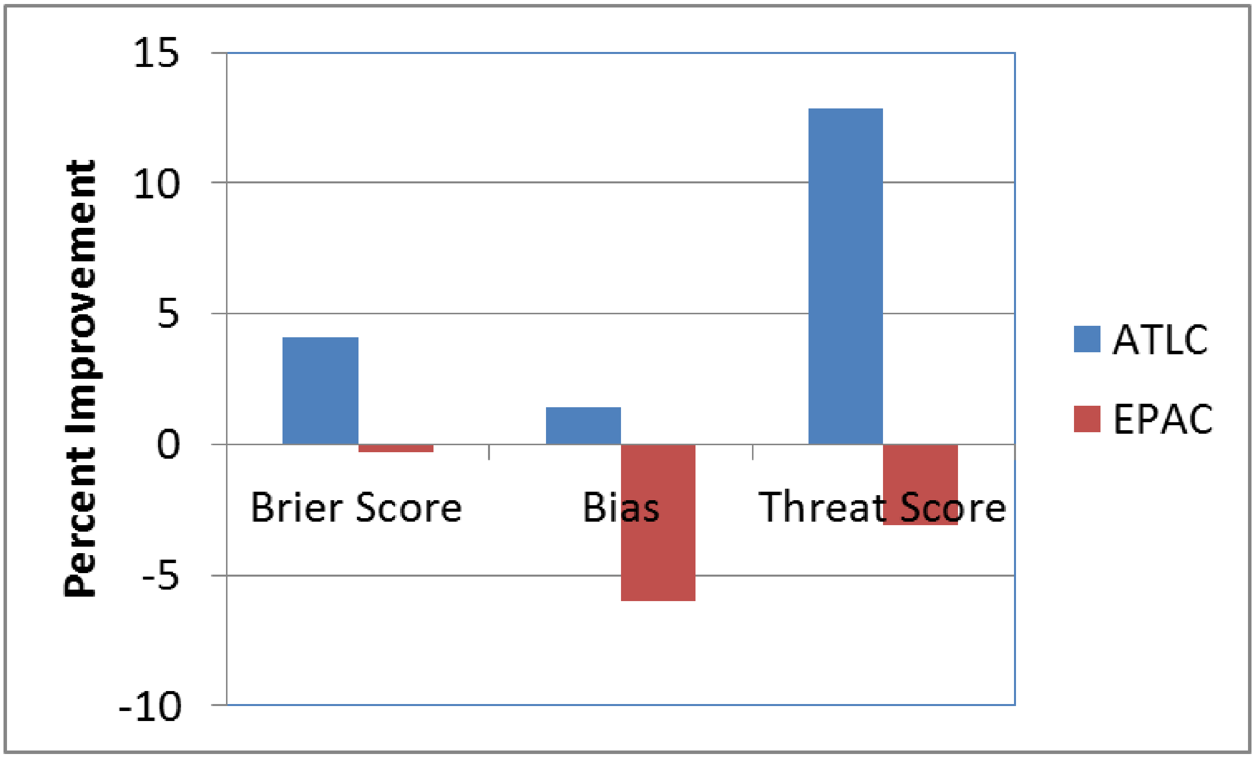


Figure 7. The percent improvement in the Brier Score, Bias and Threat Score when the lightning data was added to the RII for the 2014 Atlantic and East Pacific forecasts.

4.8 GOES-R RGB Daytime Microphysics

Evaluation Strategy = Introductory

The RGB Cloud-top Microphysics product was new to the NHC PG in 2013, and HSU forecasters spent that time getting familiar with the product. During the 2014 NHC PG, very little feedback was received on this product. In general, HSU forecasters suggested that the RGB products being demonstrated in the NHC PG are all helping forecasters at analyzing and understanding the large-scale environment, but now they need help using them to analyze the TCs themselves. This includes storm-scale features related to TC track, intensity, and structure.

4.9 GOES-R RGB Nighttime Microphysics

Evaluation Strategy = Introductory

The RGB Nighttime Microphysics product was new to the NHC PG in 2014. As such, HSU forecasters and TAFB analysts were getting familiar with this product during the 2014 season, comparing it with other products (e.g., RGB Air Mass) with which they had more experience. The general observation was made that, although the product can be used at night, the imagery lost a good amount of detail at night making it difficult to identify storm-scale convective features. It was, however, useful for identifying large scale moist air masses at night.

4.10 GOES-R RGB Daytime Convective Storms

Evaluation Strategy = Introductory

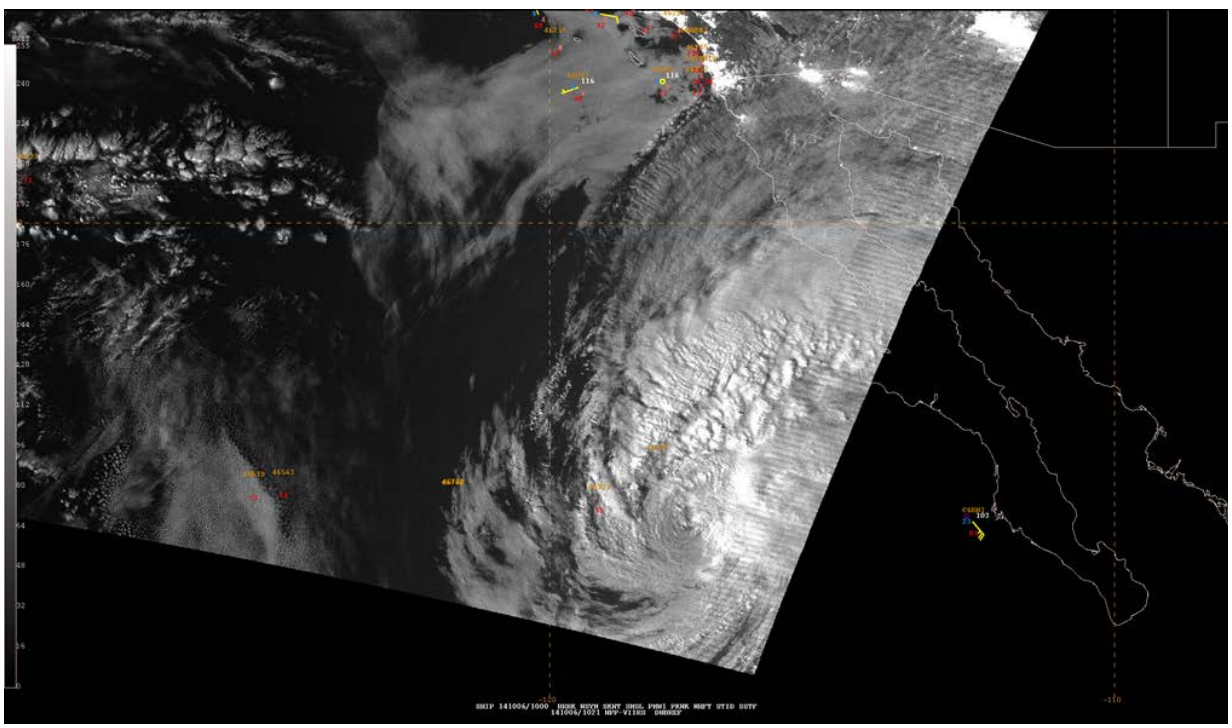
The RGB Daytime Convective Storms product was new to the NHC PG in 2013, and HSU forecasters spent that time getting familiar with the product. Limited feedback was received on this product during the 2014 NHC PG. TAFB analysts did note that the product was useful in identifying deep, active convection building on the SW side of Edouard.

4.11 S-NPP VIIRS Day/Night Band

Evaluation Strategy = Introductory

Efforts last year focused on making the VIIRS DNB imagery available on N-AWIPS. Since this didn't happen until mid-September 2013, this is the first full season HSU forecasters have had routine access to the product. The main feedback received on the VIIRS DNB during the 2014 NHC PG was the desire for better coverage. To help with that, storm centered DNB imagery was added to the CIRA Tropical Cyclone Real Time web page. This data has longer latency, so the real time utility is not as good as for the data provided by SPoRT, but can be used later to view cases of interest.

Despite the limited area coverage, feedback from HSU was received for a case from Hurricane Simon. On 6 Oct 2014, VIIRS DNB imagery (Fig. 8) showed that the low level circulation in Hurricane Simon was displaced to the west of the deepest convection. This is yet another example of how the VIIRS DNB imagery can provide important information regarding TC structure at night that cannot be easily diagnosed with infrared-based imagery alone.



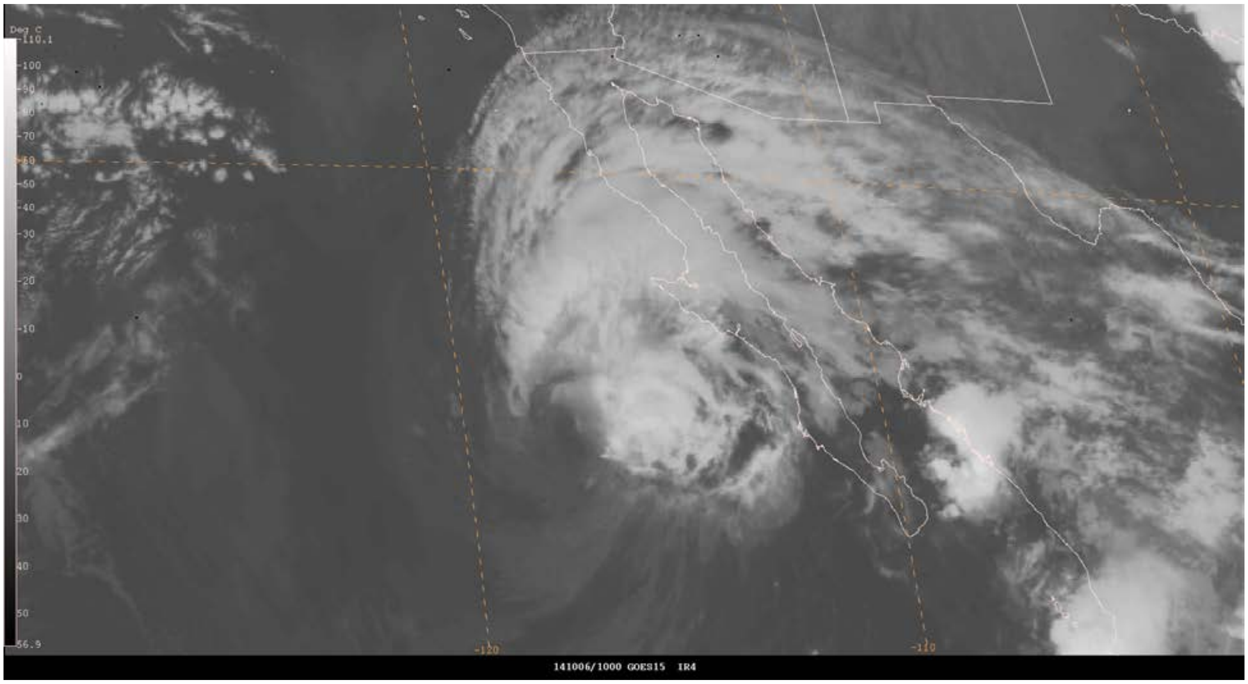


Figure 8. Day-night band image (top) versus the standard IR image (bottom) for Hurricane Simon on 6 Oct 2014 ~10 UTC (3am PDT).

4.12 GOES-R RGB Dust Product (CIRA DEBRA-Dust Version)

Evaluation Strategy = Comparison

As the GOES-R launch approaches, decisions will need to be made regarding the product sets to be routinely included on NHC AWIPS systems. The standard EUMETSAT Dust product has been demonstrated for several years, and has proven its utility for several HSU and TAFB applications. A more sophisticated product has been developed by CIRA, which shows promise. However, the new product is somewhat more difficult to implement. A decision needs to be made as to whether the enhancements are worth the additional complications.

The main goal for this GOES-R Future Capability product was to compare it with the EUMETSAT RGB Dust product. HSU feedback noted that the DEBRA-Dust product excels at identifying dust and dust boundaries. However, the EUMETSAT version also highlights large scale features such as tropical waves and moisture boundaries in addition to dust, which may be more useful depending on the type of analysis being performed. It was suggested that the two products complement each other. Another interesting piece of feedback given about the DEBRA-Dust product was that it might be helpful in learning to better interpret the EUMETSAT product. DEBRA-Dust clearly defines regions with high reliability of dust in yellow. TAFB analysts matched the yellow in DEBRA-Dust with areas of pink in the corresponding EUMETSAT image to gain a better understanding of what level of EUMETSAT coloring corresponds with areas of high-confidence dust (Fig. 9).

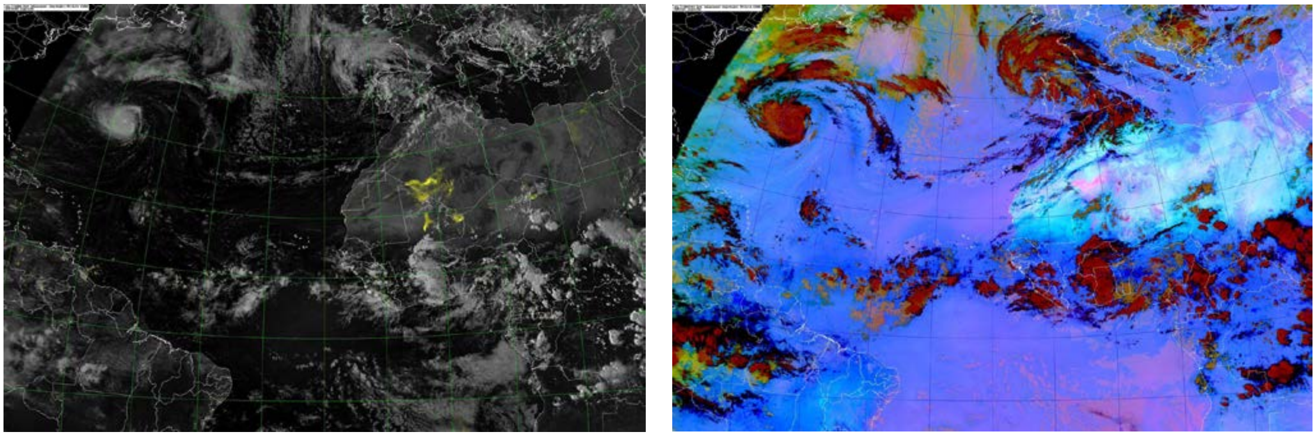


Figure 9. The DEBRA-Dust (left) and EUMETSAT (right) RGB dust products at 15 UTC on 16 September 2014. This was a cases where TAFB analysts suggested comparing the two products proved particularly useful, whereby the high-reliability dust regions in DEBRA-dust (yellow) helped analysts identify the corresponding pink color in the EUMETSAT product.

4.13 GOES-R GLM Lighting Detection (GLD-360 Lightning Density proxy)

Evaluation Strategy = Comparison

Considerable feedback was received on the GLD-360 Lightning Density contours during the 2014 NHC PG. The main focus of the 2014 evaluation of Lightning Density was to compare it with the GLD-360 Lightning Strike data (e.g., Fig 10) as we work towards finalizing the NHC GOES-R/JPSS operational suite. Most feedback was submitted via online forms from the HSU desks, suggesting forecasters were routinely looking at lightning data. Feedback was submitted regarding observed relationships between 1) increases in inner-core lightning and increases in vertical shear and 2) increases in inner-core lightning and a halting of intensification or a delay in rapid intensification. These relationships have been documented in DeMaria et al. 2012. A more in-depth discussion of NHC PG feedback regarding lightning activity and RII can be found in section 4.2.2 on the Lightning-based RII.

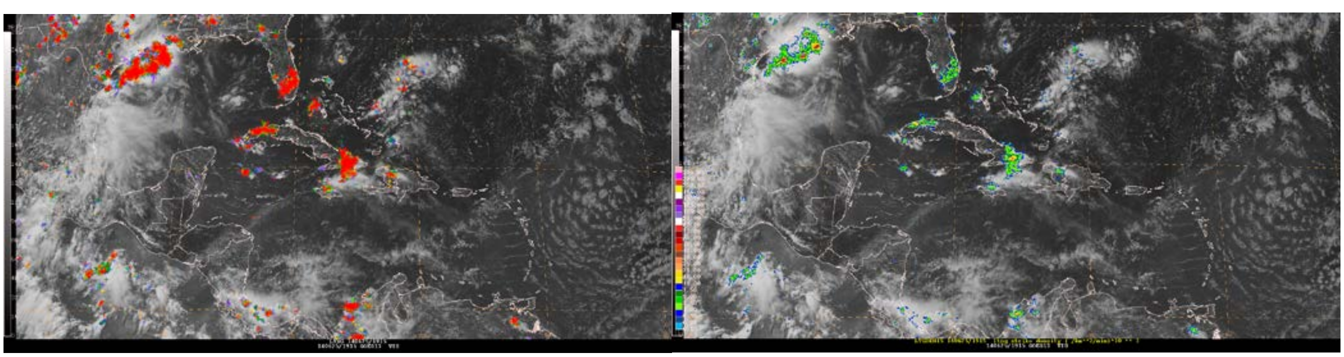


Figure 10. Comparison of strike locations color coded by age (left) and GLD-360 Lightning Density contours (right).

Several forms referencing the lightning density product and comparing it to the lightning strike product were submitted. A form submitted regarding the use of lightning data during TS Odile and TD 16E stated, “The lightning density provided a better depiction of the time changes in the lightning strike locations." Similarly, a form submitted referencing the use of lightning data during Hurricane Norbert suggested that "contours better depict tendencies." Some feedback was received regarding how the lightning density product could be improved and/or adapted for optimal use, including a recommendation that the lightning density contours be adjusted to highlight activity on the mesoscale (e.g., strikes min^{-1} 10 km^{-2}), particularly for TCs that have average to below-average lightning activity (e.g., Norbert, Fig. 11). Along the same lines, a form submitted referencing the use of lightning data during Hurricane Rachel stated that "the lightning density data (30-min interval) seemed a bit noisy. Perhaps a longer time interval for the composite could be used in cases like Rachel that currently has a bursting-type convective pattern (as is common for TCs in a high-shear environment)." An example of the lightning density in Hurricane Rachel around this time is shown in Figure 12. Generally, it was suggested that lightning density contours and strikes provided complementary information, with the form submitted during Hurricane Norbert suggesting that "contour data should optimally be overlaid on strike data."

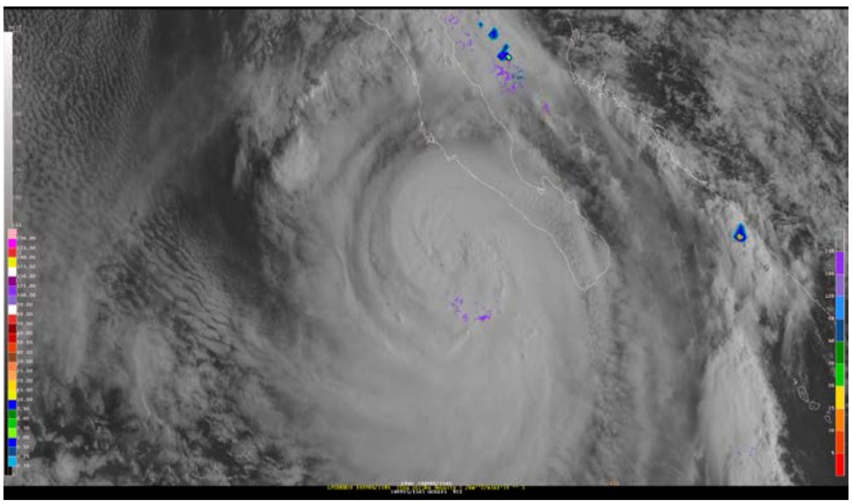


Figure 11. Hurricane Norbert GLD-360 Lightning Density contours, showing how little lightning activity was being captured using the current contour levels.

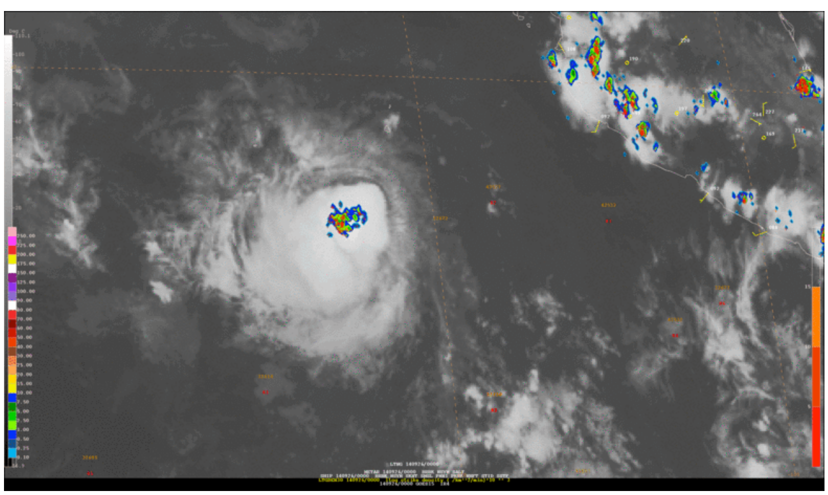


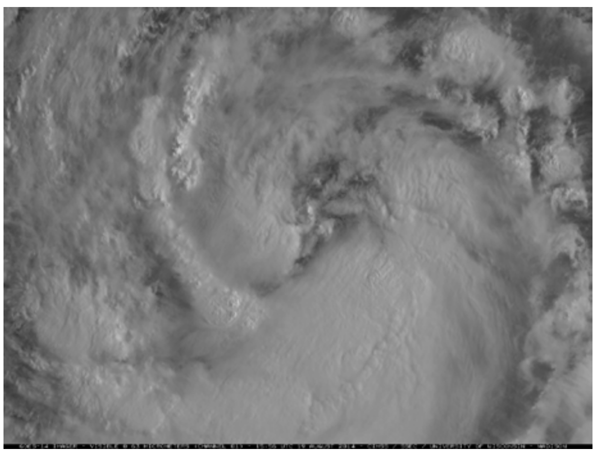
Figure 12. Hurricane Rachel GLD-360 Lightning Density contours, showing an inner core lightning burst during a time of enhanced environmental vertical shear.

4.14 GOES-R SRSO Imagery

Evaluation Strategy = Underutilized

There were several periods of GOES-14 SRSOR centered on tropical systems, many of which were called to support HS3 missions. These periods included Cristobal at the TD and hurricane stages in the Atlantic and Lowell and Marie in the eastern North Pacific. A full list of SRSOR periods can be found at http://cimss.ssec.wisc.edu/goes/srsor2014/GOES-14_SRSOR.html).

General HSU feedback suggests the underutilization of the SRSO imagery is at least partly due to the fact that it wasn't available in NAWIPS. HSU feedback was submitted (via online form) regarding the utility of SRSOR imagery early in life of then-TD Lowell. HSU forecasters suggested SRSOR imagery should be most useful for center-fixing systems that are weak (e.g., TD Lowell, Fig. 13, left), particularly near sunrise. SRSOR imagery will also be useful for public outreach. However, the 1-minute data will not replace the 15-minute data for monitoring of mesoscale storm behavior unless technology can accommodate the loading the displaying of very long and fast loops.



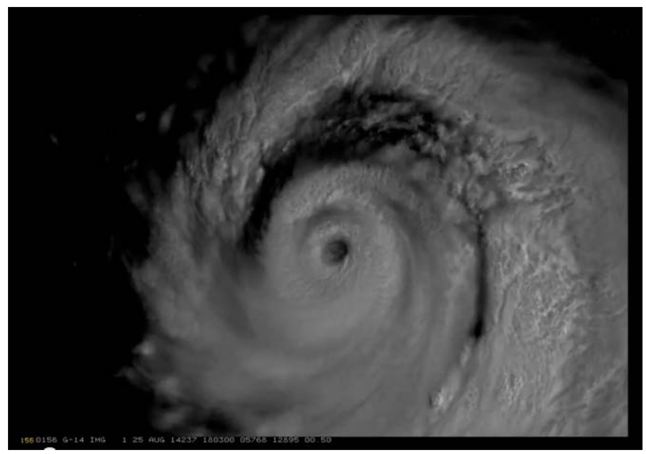


Figure 13. Snapshots from GOES-14 SRSO loops for Tropical Storm Lowell (left) and Hurricane Marie (right).

4.15 GOES-R Tropical Overshooting Top Detection

Evaluation Strategy = Underutilized

General HSU feedback suggests the underutilization of the GOES-R TOT detection product is due to a lack of a consistent, observable relationship between TOTs and TC intensity change in real time. No obvious signal was observed by HSU forecasters during the 2013 or 2014 seasons. However, HSU feedback did note that the TOT detection product seems to be working better since the algorithm was adjusted mid-season in 2013 (TOT threshold reduced from 9K to 5K in the cold CDO region as defined by IR brightness temperatures).

4.16 Plans for 2015

The NOAA Satellite Proving Ground at the National Hurricane Center will continue in 2015. This will be the last NHC PG before the launch of GOES-R in spring of 2016. During this time, the final selection of initial GOES-R products, future capabilities, and decision aids to be displayed at NHC will be made. Initial development of AWIPS displays of PG products will be conducted in 2015. Several product adjustments and improvements will be made based on validation and feedback from 2013 and 2014. The radial intervals used to compute azimuthal average lightning density for the RII will be scaled by storm size based on verification results from 2014. In response to direct requests by HSU and TAFB forecasters for increased VIIRS DNB coverage, additional direct readout sites will be used to expand the VIIRS domain.

Since the NHC PG is relatively saturated with products at this time only one new product, Derived Motion Winds (DMV's, GOES-R Baseline), will be introduced in 2015. Obtaining feedback on new cloud-top RGBs and the DMVs will be a high priority in the 2015 NHC PG, as will continuing to gather feedback that will help refine NHC GOES-R initial product suite. The use of ATMS/CrIS soundings to obtain storm environment temperature and moisture profiles will also be investigated.

5. References

Braun, S., 2010: Reevaluating the Role of the Saharan Air Layer in Atlantic Tropical Cyclogenesis and Evolution. *Mon. Wea. Rev*., **138**, 2007-2037.

DeMaria, M., R.T. DeMaria, J.A. Knaff and D. Molenar, 2012: Tropical cyclone lighting and rapid intensity change. *Mon. Wea. Rev*., **140**, 1828-1842.

Dunion, J. P., and C. S. Velden (2004): The impact of the Saharan air layer on Atlantic tropical cyclone activity, *Bull. Amer. Meteor. Soc.*, **85,** 353–365.

Evan, A. T., R. Bennartz, V. Bennington, H. Corrada-Bravo, A. K. Heidinger, N. M. Mahowald, C. S. Velden, G. Myhre & J. P. Kossin (2008): Ocean temperature forcing by aerosols across the Atlantic tropical cyclone development region. *Geochem. Geophys. Geosyst.*, **9,** Q05V04, doi:10.1029/2007GC001790.

Guimond, S.R., G.M. Heymsfield, and F.J. Turk (2010): Multiscale observations of Hurricane Dennis (2005): The effects of hot towers on rapid intensification. *J. Atmos. Sci*., **67**, 633-654.

Hillger, D.W., L.D. Grasso, S. Miller, R. Brummer, and R. DeMaria, 2011: Synthetic advanced baseline imager true-color imagery. *J. Appl. Remote Sens*. (JARS) **5**, 053520 (2011), DOI:10.1117/1.3576112

Kerkmann, J., cited 2010: Applications of Meteosat Second Generation (Meteosat-8), AIRMASS. [available on-line at http://oiswww.eumetsat.org/IPPS/html/bin/guides/msg_rgb_airmass.ppt]

Kerkmann, J., HP. Roesli, G. Bridge and M. König, cited 2010: Applications of Meteosat Second Generation (MSG), RGB Composites with Channels 01-11 and their interpretation. [Available on-line at http://oiswww.eumetsat.org/IPPS/html/bin/guides/msg_rgb_dust.ppt]

Knaff, J.A., S.P. Longmore, D.A. Molenar, 2014: An Objective Satellite-Based Tropical Cyclone Size Climatology. *J. Climate*, **27,** 455-476. doi: http://dx.doi.org/10.1175/JCLI-D-13-00096.1

Monette, S., 2011: Tropical Applications of a Satellite-Based Objective Overshooting Top Detection Algorithm. MS thesis, Univ. Wisconsin-Madison, Dept. Atmos. Sci. 112 pp.

Montgomery, M.T., M.E. Nicholls, T.A. Cram, and A.B. Saunders (2006): A vertical hot tower route to tropical cyclogenesis. *J. Atmos. Sci*., **63**, 356-386.

Rosenfeld, D, I.M. Lensky, 2008: Clouds-Aerosols-Precipitation Satellite Analysis Tool (CAPSAT), *Atmos. Chem. Phys.,* **8,** 6739-6753. http://www.atmos-chem-phys.net/8/6739/2008/acp-8-6739-2008.pdf

Rosenfeld, D, I.M. Lensky, 1998: Satellite-Based Insights into Precipitation Formation Processes in Continental and Maritime Clouds, *Bull. Amer. Meteor. Soc.,* **79,** 2457-2476.