Final Report
2011 GOES-R Proving Ground Demonstration at the National Hurricane Center (NHC)

1. Project Overview

The purpose of the GOES-R Proving Ground (PG) demonstration at the National Hurricane Center (NHC) is to provide forecasters with an advanced look at tropical cyclone analysis and forecast products for evaluation and feedback. The 2011 PG was held from August 1 to November 30. Nine GOES-R products (baseline, future capabilities, decision aids and Risk Reduction) were provided by NESDIS/STAR, CIRA, CIMSS, NASA/SPoRT and OAR/HRD as summarized in Table 1. The Advanced Baseline Imager (ABI) products were produced using proxy data from Meteosat, GOES, and MODIS, and the Geostationary Lightning Mapper (GLM) product was produced from ground-based lightning network data. The list of primary participants is provided in Appendix A and a list of acronyms is in Appendix B.

This final report provides forecaster feedback on each of the products. The feedback was gathered through a variety of means, including email exchanges between the NHC forecasters and product providers, the mid-project review held at NHC on Sept. 13th, 2011, a de-briefing conference call between product providers and NHC forecasters on Feb. 9th, 2012, a meeting at the Interdepartmental Hurricane Conference on March 7, 2012 and informal discussion at the GOES-R Science Week meeting April 30-May 4, 2012.

This 2011 PG was primarily focused on the Hurricane Specialist Unit (HSU) of NHC, but the Tropical Analysis and Forecast Branch (TAFB) also provided some input. The participation by TAFB will be expanded in 2012 through collaboration with the NCEP OPC/HPC/SAB PG, and will likely include some demonstrations outside of the hurricane season. The TAFB portion of the PG outside of the hurricane season will include its own operations plan and final report.

2. 2011 Hurricane Season Tropical Cyclone Summary

The 2011 Atlantic Hurricane Season had 19 named storms, which was much above the long term average of 10. Fifteen of these tropical cyclones occurred during the PG experiment period (Fig. 1). Seven of those became hurricanes and three became major hurricanes, which was somewhat low given the above average number of named storms. The 2011 Atlantic season included a large number of storms interacting with vertical shear, and there were very few cases of rapid intensification (30 kt or greater increase in the maximum winds in 24 hr). Most of the stronger storms were in the western side of the basin, and so were not in the region where SEVIRI data were available.

The 2011 East Pacific season had only 11 named storms (Fig. 2), which was below the long term average of 15. However, 10 of the storms became hurricanes, and 6 became major hurricanes. Seven of these storms occurred within the PG experiment period. A larger fraction than normal of the east Pacific forecast cases underwent rapid intensification.

Table 1. The nine products demonstrated in the 2011 NHC Proving Ground

Product	Type	Provider	Proxy Data
1. Hurricane Intensity Imager Estimate (HIE)	Baseline	CIMSS	MSG SEVIRI and GOES
2. Super Rapid Scan Imagery	Baseline	CIRA	GOES Imager
3. Tropical Overshooting Top (TOT) Detection Algorithm	Future Capabilities	CIMSS	MSG SEVIRI and GOES Imager
4. Red-Green-Blue (RGB) Air Mass Product	Decision Aid	NASA/SPoRT and CIRA	MSG SEVIRI and GOES Imager
5. RGB Dust Product	Decision Aid	NASA/SPoRT	MSG SEVIRI
6. Saharan Air Layer (SAL) Product	Decision Aid	CIMSS and OAR/HRD	MSG SEVIRI
7. GOES-R Natural Color Imagery	Decision Aid	CIRA	MODIS
8. Pseudo Natural Color Imagery	Decision Aid	CIMSS and OAR/HRD	MSG SEVIRI
9. Rapid Intensification Index (RII)	GOES-R Risk Reduction	CIRA	WWLLN and GOES Imager

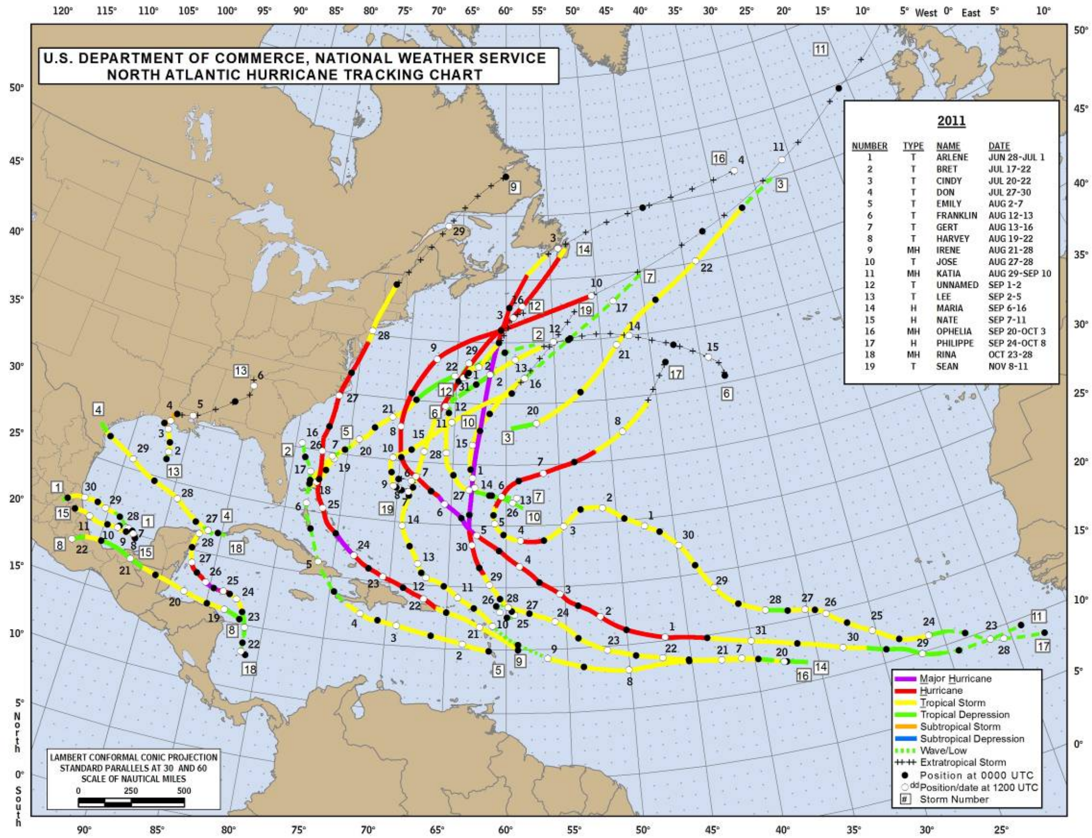
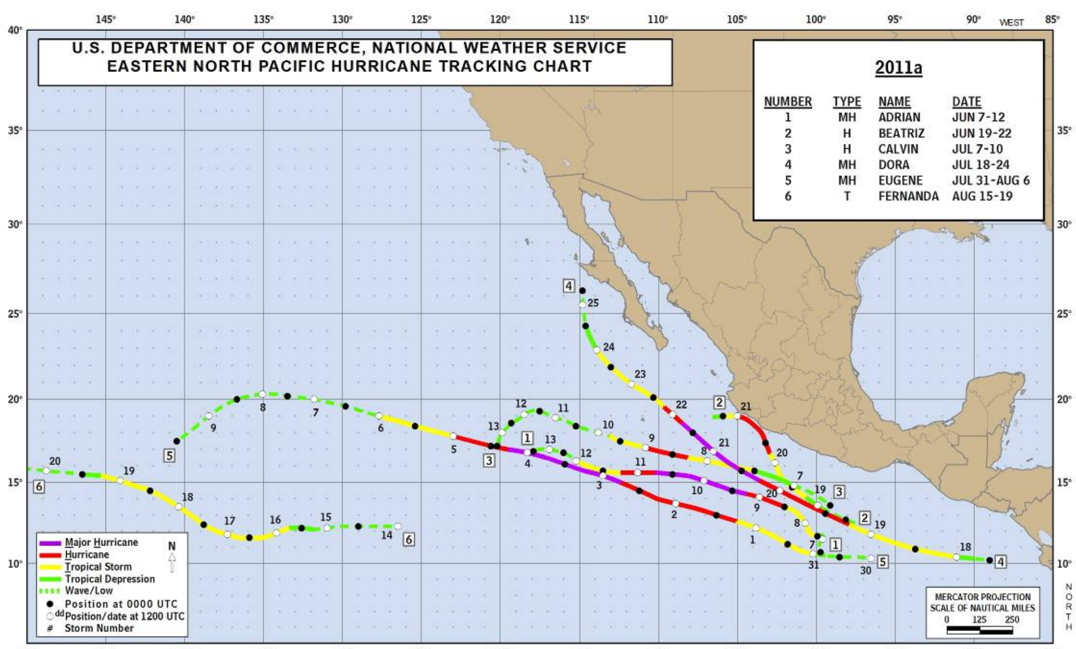


Figure 1. The 2011 Atlantic Tropical Cyclones (from www.nhc.noaa.gov)



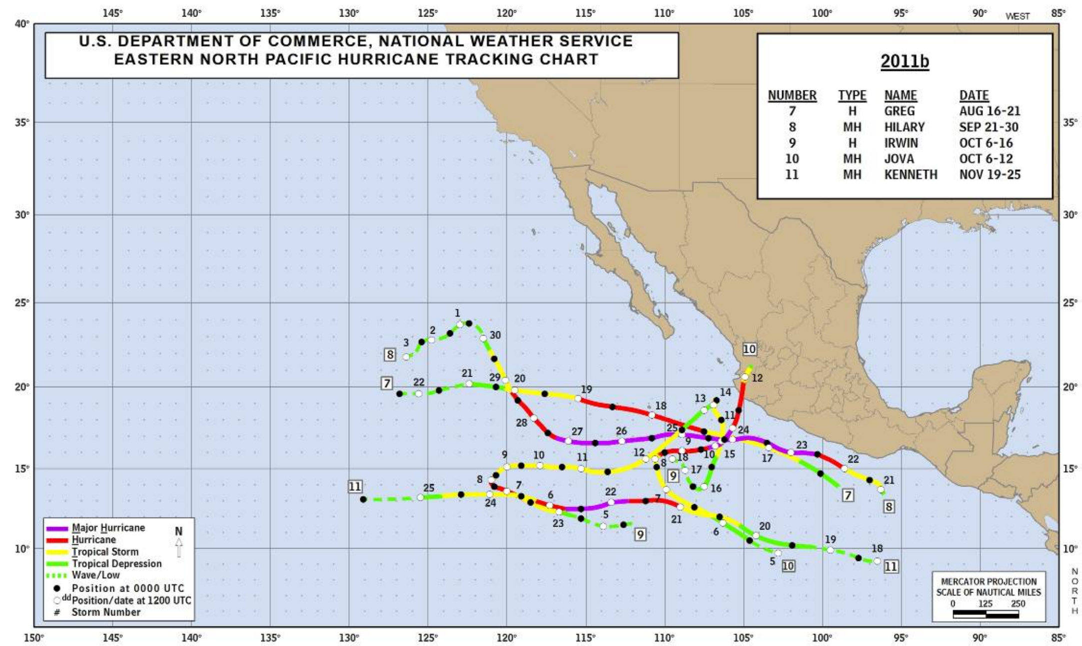


Figure 2. The 2011 East Pacific Tropical Cyclones (from www.nhc.noaa.gov)

3. 2011 NHC Demonstration Product Evaluation

Feedback on each of the PG products is provided below. This information was based on the feedback collected during the season and the meetings summarized in section 1.

3.1 Hurricane Intensity Estimate (HIE)

The HIE product was generated from Meteosat Second Generation (MSG) and GOES-East imagery and made available to the NHC forecasters via a web page. Although there were few strong storms in the eastern Atlantic this season, the forecasters were able to use the HIE product during Katia when deciding to upgrade the storm. Mike Brennan, Hurricane Specialist, said, "I found the GOES-R Proving Ground HIE product useful on my midnight shift on August 30 when I made the decision to upgrade TD 12 to Katia. The HIE was more responsive in showing intensification compared to the operational ADT, and reached a 2.5 by the time I put out the 09Z advisory in agreement with the 06Z classifications from SAB and TAFB." It was also mentioned that the addition of GOES-East HIE estimates in 2011 provided a much larger sample for evaluation.

A few days of the HIE values from Hurricane Katia were missed but were provided by CIMSS for the post-season evaluation. Jack Beven (Hurricane Specialist) preformed an evaluation of the HIE and noted that the large number of weaker and less organized Atlantic cyclones might increase the errors from the method, and some emphasis should be placed on algorithm improvements for sheared storms. Despite that limitation, Jack found that the HIE estimates were close to the final NHC best track values in most cases. He also found that the higher temporal sampling (15-min) makes the HIE somewhat more responsive to short term intensity changes than the operational ADT with 30-min sampling. Jack also noted that the HIE does not employ the new wind-pressure relationship, which sometimes leads to minimum pressure biases. CIMSS is continuing to improve the HIE "parent" algorithm, the ADT, partially based on user feedback from the PG, but there is currently no mechanism to add these to the HIE code. This problem should be addressed before the final operational deployment of the HIE for use by the NWS. Further details on Jack's evaluation of the HIE during 2011 can be found in C. Velden's presentation from the Satellite Science Week Meeting in May of 2012, available from http://www.goes-r.gov/downloads/2012-Science-Week/pres/tues/Velden.ppt.

3.2 Super Rapid Scan Operations (SRSO) Imagery

The SRSO was called for GOES-West for one day during Tropical Storm Don and four days during Tropical Storm Nate in the western Gulf of Mexico, and one day during Hurricane Hillary in the east Pacific, and made available on a CIRA web page. NHC forecaster feedback indicated that the Nate case on Sept. 11th, 2011 was the most useful since it enabled them and the satellite analysts at the NESDIS Satellite Analysis Branch (SAB) to get several supplemental visible images just after sunrise. These helped to improve the accuracy of Nate's center position, which was farther north than originally suggested by the multi-channel IR imagery. Currently, the multi-channel IR imagery used at night are only displayed at NHC every 30 minutes, so the SRSO visible imagery provided a much higher temporal refresh rate to help support NHC operations. For later analysis and training, a web site was created at CIRA to archive all of the SRSO cases (see http://rammb.cira.colostate.edu/products/srso/).

Based on these results, the hurricane specialists suggested the design of a special "sunrise" SRSO for 2012 to help support (1) center finding and (2) aircraft reconnaissance go/no go decisions. The period of the SRSO would be relatively short, so it would not interfere with the scanning required by the atmospheric motion vector wind algorithms.

3.3 Tropical Overshooting Top Detection

The Tropical Overshooting Top (TOT) Detection product was new in 2012 and was not heavily used by the NHC forecasters. For tropical cyclones, there are multiple overshooting tops, so it is not yet clear what information this product provides. It was suggested that there might be some relationship between the TOTs and lightning, which the product developers should investigate in more detail. A comparison of the daily TOT counts and lightning density over 10^{o} latitude-longitude areas was performed by CIRA and CIMSS for the main part of two hurricane seasons (July-Oct of 2010 and 2011) for the tropical Atlantic, from the equator to 40^{o}N. The lightning locations were obtained from the World Wide Lightning Location Network (WWLLN), which is being used as a proxy for the GLM. The correlation between the two time series only explained about 17% of the variance, which suggests that the TOTs are mostly independent of the lightning, and might provide additional forecast information. TAFB forecasters indicated that the TOT product might be useful for narrowing down the most active areas of convection and said they would make an effort to look at the TOT product more in 2012. TAFB and HSU forecasters both indicated that it would be helpful if the product was also available from GOES-East. That capability was added to the CIMSS web page. HSU and TAFB forecasters also indicated that the product would be more useful if it could be made available in N-AWIPS format.

3.4 RGB Air Mass Product

The RGB Air Mass product was generated from MSG and the GOES sounder data and was initially provided to NHC via a CIRA web page in Google Earth format. Shortly after the start of the project, SPoRT began to supply the products in an N-AWIPS format in collaboration with CIRA (Fig. 3). The availability in N-AWIPS has greatly increased the use of the product compared with 2010, and was one of the major successes of the 2011 PG. The RGB Air Mass product has been a very popular aid at the NHC and was utilized during the extratropical transition of Lee, Irene, Katia and Philippe, and the extratropical to tropical transition of Sean. Mike Brennan mentioned the RGB Air Mass Product in his forecast discussion product for Tropical Storm Lee. For Tropical Storm Irene, the RGB Air Mass Product clearly showed a polar front intersecting the storm when it was near the North Carolina coast, which suggested an earlier than normal beginning of extratropical transition and may be something to look for in future systems. Jack Beven commented that the contrast between the blues and the greens are more subtle in the sounder version of the product and these subtle variations get lost because the colors are not as distinct as in the MSG version. This is a limitation of the horizontal resolution of the sounder, which is almost an order of magnitude lower, in terms of pixel size, than SEVIRI. Sometimes there are also limb effects in the SEVIRI product and the developers might consider adding a limb correction.

Michael Folmer (the satellite champion for the OPC/HPC/SAB PG) in collaboration with CIRA, began collecting the RGB Air Mass products for extratropical transition cases to look for common features. A web page is being developed at CIRA to assist with this effort (see http://rammb.cira.colostate.edu/research/tropical_cyclones/air_mass/).

TAFB forecasters commented that the RGB Air Mass product may be useful for identifying oceanic frontal boundaries for the tropical surface analysis product. They also indicated that it has application to some of their marine products.

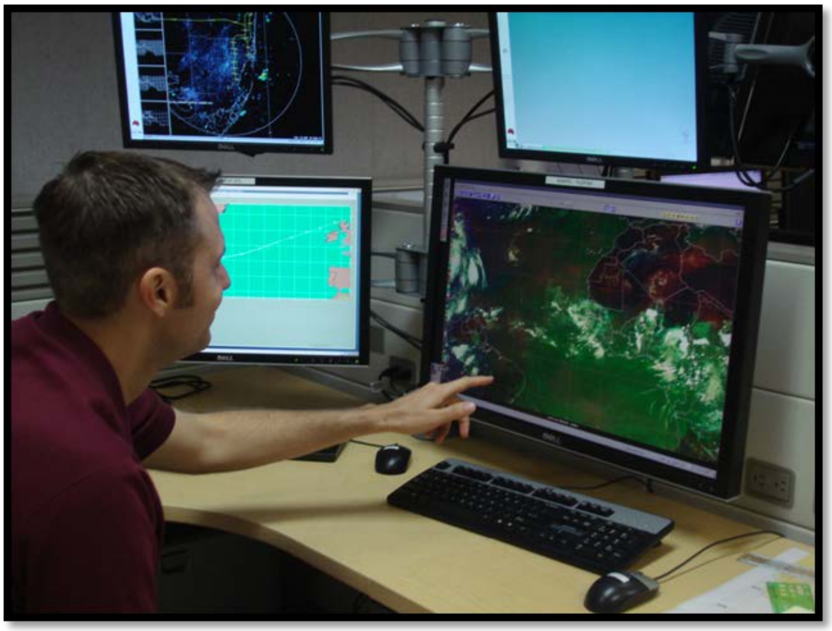


Figure 3. Eric Blake pointing out features in the RGB Air Mass Product displayed in N-AWIPS at NHC

3.5 RGB Dust Product

Similar to the Air Mass product, SPoRT began providing the RGB dust product in N-AWIPS format and its utilization has increased. Jack Beven noted that the "RGB Air Mass and Dust products were very useful in showing that the pre-Irene disturbance was going to have dry air issues initially. I think this helped us give the system a low chance of development in the early tropical weather outlooks." Another comment about the Dust product was that some of the big dust outbreaks could be identified all the way to the edge of the SEVIRI image and it was clearly evident that the dust and dry air sometimes got trapped within high pressure systems. The product was also useful during Tropical Storm Gert. It has received favorable reviews within the HSU and they look forward to using it more frequently as a decision aid. One item to note is that stratocumulus sometimes shows up as dust in the RGB dust product and the Saharan Air Layer product, and forecasters need help in distinguishing the two. Steve Miller from CIRA is developing a refined version of the Dust Product that might be used next year.

TAFB forecasters are also finding the RGB Dust Product useful for their tropical weather discussions and marine products. The product is useful for identifying large scale dust outbreaks and regions with limited visibility. They also mentioned that this product may be useful for the San Juan WFO.

3.6 Saharan Air Layer (SAL) Product

The SEVIRI-based SAL product was provided to NHC forecasters via a web page at CIMSS. The evaluation of this product was fairly limited due to the lack of an N-AWIPS version, but was sometimes used in combination with the Dust product. CIMSS, CIRA and SPoRT should coordinate in the off season to see if an N-AWIPS version of this product can be provided in 2012.

3. 7 GOES-R Natural Color Imagery

The GOES-R Natural Color Imagery Product is generated from the MODIS instrument and provides an idea as to what the Natural Color Imagery product from GOES-R will look like. This product is available on the CIRA web page. In the future, forecasters would like to be able to make the same product from the National Polar Partnership Visible/Infrared Imagery Radiometer Suite (NPP VIIRS). HSU forecasters indicated that the utility of the product is limited because it is based on low-earth orbiting (LEO) data, with low time resolution and some latency issues. However, it has some utility in identification of dust in the storm environment. The geostationary version after the launch of GOES-R will have greater utility for HSU forecasters and for public outreach.

The PG demonstrations in 2011 have proven useful to the developers at STAR and CIRA. The routine generation of the product revealed a problem with the algorithm, where the image is too green in areas with large zenith angles. This problem was fixed in October of 2011. Figure 4 shows an example of the product before and after the adjustment to the algorithm.

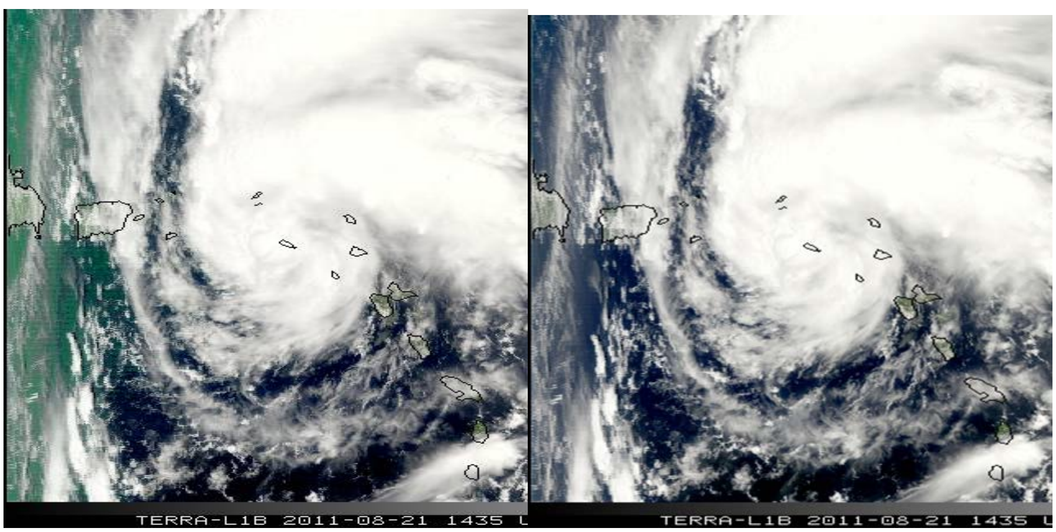


*Figure 4. An example of the GOES-R natural color product using MODIS input that includes the simulated green before (left) and after (right) the algorithm correction for Hurricane Irene on 21 Aug 2011***.**

3.8 Pseudo Natural Color Imagery

This product is a qualitative image combination of SEVIRI bands available from a CIMSS web page that illustrates some of the natural color capabilities that will be available from GOES-R. This product complements the Natural Color Imagery from MODIS in that it can provide looping, even though it does not use a quantitative color algorithm. HSU forecasters indicated that dust shows up very well and the cyan color helps differentiate upper-level moisture from low-level moisture. They also indicated that in the GOES-R era, this product or the natural color version might serve as the default image loop instead of a standard gray-scale visible image used now. Again, this product would be more useful to the NHC forecasters if it was available in N-AWIPS.

3.9 Rapid Intensification Index (RII)

An experimental version of the operational Rapid Intensification Index (RII) was developed that includes lightning input from the WWLLN as a proxy for the GLM. The experimental algorithm includes the same basic predictors as the operational RII, although it was developed from a smaller sample (2005-2010 versus 1989-2010) since reliable WWLLN data are only available back to 2005. Similar to the operational product, the probability of rapid intensification (RI; maximum wind increase of 30 kt or greater in the following 24 h) is estimated every 6 h. Separate versions of the experimental RII were developed with and without the WWLLN input, and both were run in real time and made available via an ftp site at CIRA. The experimental RII also estimates the probability of rapid weakening (RW; maximum wind decrease of 20 kt or greater in the following 24 h), which is not available from the operational algorithm. Results from the dependent data showed that above-average lightning in the rain band region of the storm (200-300 km) increases the probability of RI, but above-average inner core lightning (0-100 km) reduces the probability of RI and increases the probability of RW. The experimental RII also provides a time series of the rain band and inner core lightning through the life cycle of each storm.

Through exposure to the lightning based RII and direct display of lighting locations on their N-AWIPS systems, the HSU forecasters have gained the experience to recognize that an inner core lighting outbreak is often associated with an increase in vertical shear, and prevents intensification. Jack Beven provided an example from the eastern Pacific, which is shown below in Fig. 5. The eastern cyclone (Jova) was interacting with vertical shear and had considerably more inner core lightning than the western cyclone (Irwin). Consistent with the RII, the western cyclone intensified while the eastern storm weakened in the next few days.

Forecaster feedback on the RII indicated that the lightning input only modified the RI probabilities by a few percent. This makes it very difficult to evaluate the impact of the lightning input in just one season. This was especially difficult in the 2011 Atlantic season, where there were very few RI cases. A systematic evaluation of the impact of the lighting on the RII will be performed at the end of the 2012 season, after three years of independent data (2010-2012) have been obtained. The forecasters also indicated that they did not have much time to evaluate the new RW part of the algorithm. This will be run again in 2012 to provide additional experience.

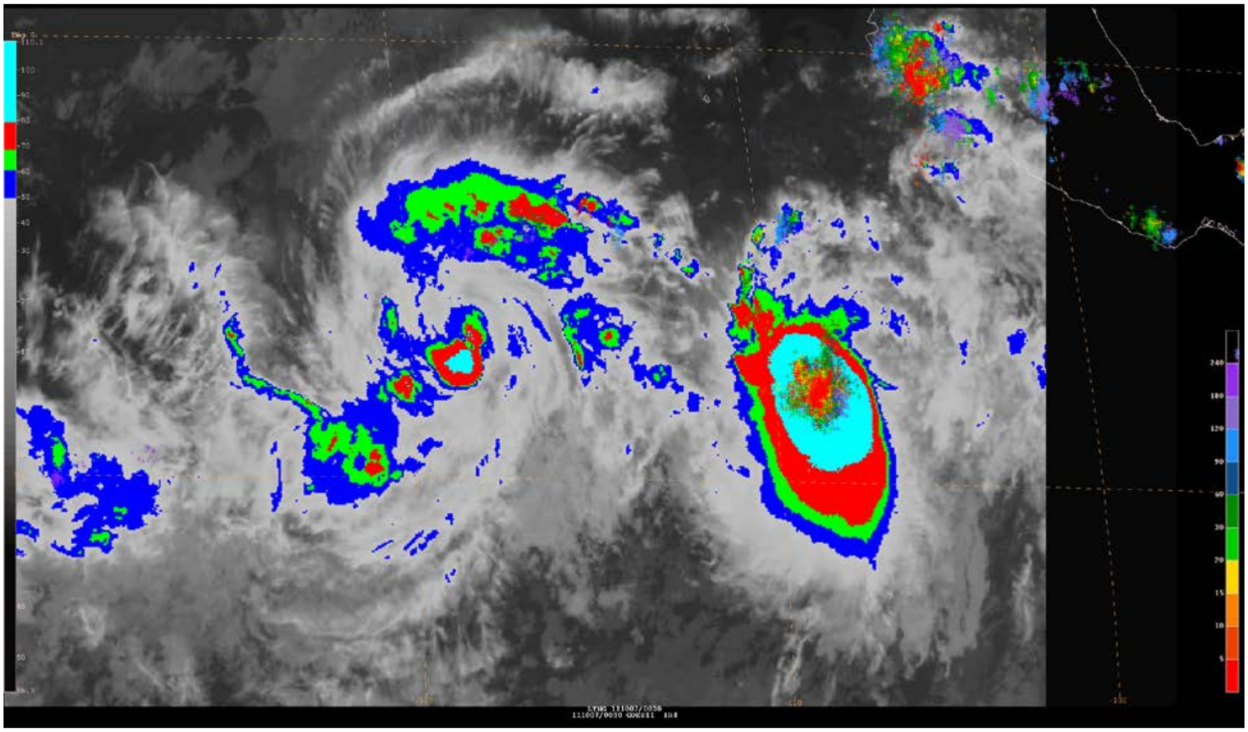


Figure 5. Lightning locations (small points) from the Vaisala GLD360 ground based network on a color enhanced infrared satellite image from NHC's N-AWIPS system. This example is from 7 October 2011 during tropical storms Irwin (left) and Jova (right).Tropical storm Jova had considerably more lightning near the storm center due to interaction with vertical shear and did not intensify much after this time. Irwin had less lightning activity near the center but had some in the outer bands and intensified to hurricane intensity shortly after this time.

4. Recommendations for 2012

Based on a planning meeting at the Interdepartmental Hurricane Conference, more experience is needed with the products that were demonstrated during 2011. Thus, the recommendation is to demonstrate the same set of products listed in Table 1 during 2012. If possible, the SAL, pseudo natural color, and TOT products should be provided in N-AWIPS format. Another recommendation is to increase the participation by TAFB, which will be coordinated with the OPC/HPC/SAB/TAFB satellite champion (Michael Folmer). Additional training on the HIE and the differences between the HIE and ADT products should also be provided before the 2012 NHC PG. A more formal mechanism for documenting forecaster feedback through the use of an online electronic feedback form was also suggested. The 2012 operations plan should be finalized by June 30, 2012.

5. Summary and Conclusions

The 2011 Proving Ground at NHC was very successful. Nine GOES-R products were demonstrated, and hurricane forecasters continued to gain experience with multi-spectral RGB applications. The availability of the RGB air mass and dust products in N-AWIPS format in 2011 through coordination between NHC, SPoRT, and CIRA greatly increased their utilization compared with 2010. The forecaster feedback on the HIE and natural color products is helping the developers improve these algorithms, and the experience with the super rapid scan imagery during Hurricane Nate is suggesting ways to optimize the use of this data. Partially because of the heavy workload of the hurricane specialists during tropical cyclone events, it takes several years to gain familiarity with new guidance products, especially those that provide guidance for rare events such as rapid intensification. For that reason, the NHC Proving Ground should continue for the next several years to prepare NHC forecasters for the GOES-R data and products, and expand the participation by TAFB.

Appendix A

2011 NHC Proving Ground Primary Participants and Their Roles

NOAA/National Hurricane Center
- Michael Brennan, Hurricane Specialist, Primary NHC PG Focal Point
- Jack Beven, Hurricane Specialist, Primary NHC PG Focal Point
- Eric Blake, Hurricane Specialist
- Dan Brown, Hurricane Specialist
- Jiann-Gwo Jiing, Technical Support Branch chief
- Chris Sisko, Technical Support Branch
- Jessica Schauer, Tropical Analysis and Forecast Branch forecaster
- Dan Mundell, Tropical Analysis and Forecast Branch forecaster

NOAA/NESDIS/STAR Regional and Mesoscale Meteorology Branch
- Mark DeMaria, project management, lightning products
- John Knaff, lightning products, RGB products, training
- Debra Molenar, technical support

NASA/Short-term Prediction Research and Transition (SPoRT) Center
- Gary Jedlovec, project management
- Andrew Molthan, RGB products and technical support
- Kevin Fuell, RGB products and technical support

Cooperative Institute for Meteorological Satellite Studies/University of Wisconsin
- Tim Olander, Hurricane Intensity Estimate product, training
- Chris Velden, Hurricane Intensity Estimate product, RGB products, training

Cooperative Institute for Research in the Atmosphere/Colorado State University
- Renate Brummer, project coordination, training
- Kevin Micke, technical support, Google Earth products

Cooperative Institute for Marine and Atmospheric Studies/University of Miami
- Jason Dunion, Saharan Air Layer product, RGB products, training

Cooperative Institute for Climate Studies (CICS)/University of Maryland
- Michael Folmer, GOES-R Satellite Champion for OHC/HPC/SAB/TAFB

GOES-R Program Office
- Bonnie Reed, Project Coordination

Appendix B List of Acronyms

Acronym	**Meaning**
ABI	Advanced Baseline Imager
ADT	Advanced Dvorak Technique
CIMSS	Cooperative Institute for Meteorological Satellite Studies
CIRA	Cooperative Institute for Research in the Atmosphere
GLM	Geostationary Lightning Mapper
GOES	Geostationary Operational Environmental Satellites
HIE	Hurricane Intensity Estimate
HPC	Hydrometeorological Prediction Center
HRD	Hurricane Research Division
HSU	Hurricane Specialist Unit
IR	Infrared
LEO	Low Earth Orbit
Meteosat	Meteorological satellite
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
N-AWIPS	NCEP- Advanced Weather Interactive Processing System
NCEP	National Centers for Environmental Prediction
NESDIS	National Environmental Satellite, Data, and Information Service
NHC	National Hurricane Center
NPP	National Polar Orbiting Partnership
NWS	National Weather Service
OAR	Oceanic and Atmospheric Research
OPC	Ocean Prediction Center
PG	Proving Ground
RGB	Red Green Blue
RII	Rapid Intensification Index
RW	Rapid Weakening
SAB	Satellite Analysis Branch
SAL	Saharan Air Layer
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SPoRT	Short-term Prediction Research and Transition Center
SRSO	Super Rapid Scan Operation
STAR	Center for Satellite Applications and Research
TAFB	Tropical Analysis and Forecast Branch
TD	Tropical Depression
TOT	Tropical Overshooting Top
VIIRS	Visible Infrared Imaging Radiometer Suite
WWLLN	World Wide Lightning Location Network