THE GOES-R PROVING GROUND

Accelerating User Readiness for the Next-Generation Geostationary Environmental Satellite System

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By demonstrating the advanced capabilities of the next generation of geostationary satellites, the proving ground addresses user readiness and the research-to-operations-to-research loop.

The Geostationary Operational Environmental Satellite R series (GOES-R) Proving Ground (PG) is an initiative to accelerate user readiness for the next generation of U.S. geostationary environmental satellites. The GOES-R system is a joint development between the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA), with NASA responsible for the space segment (spacecraft and instruments) and NOAA responsible for the overall program and ground segment. The GOES-R PG is a collaborative effort between the GOES-R Program Office (GPO); NOAA Cooperative Institutes; NASA's Short-Term Prediction Research and Transition Center (SPoRT); National Weather Service (NWS) Weather Forecast Offices (WFOs); NWS National Centers for Environmental Prediction (NCEP); National Environmental Satellite, Data, and Information Service (NESDIS) Office of Satellite and Product Operations (OSPO) and the Center for Satellite Applications and Research (STAR); and NOAA test beds to conduct demonstration activities to gain early experience with GOES-R capabilities in an operational environment. Improved spacecraft and instrument technology will support expanded detection of environmental phenomena, resulting in more timely and accurate forecasts and warnings. The Advanced Baseline Imager (ABI), described by Schmit et al. (2005), is a 16-channel imager with 2 visible channels, 4 near-infrared channels, and 10

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infrared (IR) channels that will provide 3 times more spectral information, 4 times the spatial coverage, and an increase in temporal resolution that is more than 5 times the current imager. Other advancements over current GOES capabilities include total lightning detection and mapping of in-cloud and cloud-to-ground (CG) flashes never before available to forecasters from the Geostationary Lightning Mapper (GLM; Goodman et al. 2010) and increased dynamic range, resolution, and sensitivity in monitoring solar X-ray flux with the Solar UV Imager (SUVI). Figure 1 provides a listing of the GOES-R baseline products, those that are funded for operational implementation as part of the ground segment base contract, and potential GOES-R future capabilities, by sensor. The GOES-R is scheduled for launch in October 2015, followed by an on-orbit postlaunch test that will consist of both engineering and science phases. Additional information on the GOES-R program can be found online (at www.goes-r.gov).

Preparing the user communities for the GOES-R series addresses key recommendations from the National Research Council (2000) and the challenge to transition research into operations that "NOAA should form a team at the start of sensor development … to plan the full scope of the data research and utilization effort as part of sensor design with a budget to support the activity" (National Research Council 2000, p. 51). It is critical for mission success to start early with product demonstrations, assessment, and feedback on product utility with added attention to the situational awareness element of GOES-R products, especially as they contribute to the NWS warning decision support services.

PG DESCRIPTION. The GOES-R PG program enables the transition from research to operations with the principal emphasis on NOAA's operational forecast office environment. This focus is accomplished by utilizing existing capabilities to simulate GOES-R products and techniques, which are then demonstrated and evaluated at NWS WFOs, NCEP, and NOAA test beds. Those users provide valuable feedback on the use of decision aids, training, and products to the development teams who make up the GOES-R Algorithm Working Group (AWG). The AWG manages and coordinates development of GOES-R products and validation activities. Research activities in satellite algorithm design and development are transferred to operations through such programs as the NOAA Hazardous Weather Testbed (HWT) and Joint Hurricane Testbed (JHT). GOES-R Risk Reduction (GOES-R3) and AWG activities provide a solid basis for development of GOES-R proxy datasets and other user-relevant applications in synergy with other satellite, radar, in situ, or model information. A

Baseline Products

Advanced Baseline Imager (ABI)

Aerosol Detection (Including Smoke and Dust)
Aerosol Optical Depth (AOD)
Clear Sky Masks
Cloud and Moisture Imagery
Cloud Optical Depth
Cloud Particle Size Distribution
Cloud Top Height
Cloud Top Phase
Cloud Top Pressure
Cloud Top Temperature
Derived Motion Winds
Derived Stability Indices
Downward Shortwave Radiation: Surface
Fire/Hot Spot Characterization
Hurricane Intensity Estimation
Land Surface Temperature (Skin)
Legacy Vertical Moisture Profile
Legacy Vertical Temperature Profile
Radiances
Rainfall Rate/QPE
Reflected Shortwave Radiation: TOA
Sea Surface Temperature (Skin)
Snow Cover
Total Precipitable Water
Volcanic Ash: Detection and Height

Geostationary Lightning Mapper (GLM)

Lightning Detection: Events, Groups & Flashes

Space Environment In-Situ Suite (SEISS)

Energetic Heavy Ions
Magnetospheric Electrons & Protons: Low Energy
Magnetospheric Electrons: Med & High Energy
Magnetospheric Protons: Med & High Energy
Solar and Galactic Protons

Magnetometer (MAG)

Geomagnetic Field

Extreme Ultraviolet and X-ray Irradiance Suite (EXIS)

Solar Flux: EUV
Solar Flux: X-ray Irradiance

Solar Ultraviolet Imager (SUVI)

Solar EUV Imagery

Future Capabilities

Advanced Baseline Imager (ABI)

Absorbed Shortwave Radiation: Surface
Aerosol Particle Size
Aircraft Icing Threat
Cloud Ice Water Path
Cloud Layers/Heights
Cloud Liquid Water
Cloud Type
Convective Initiation
Currents
Currents: Offshore
Downward Longwave Radiation: Surface
Enhanced "V"/Overshooting Top Detection
Flood/Standing Water
Ice Cover
Low Cloud and Fog
Ozone Total
Probability of Rainfall
Rainfall Potential
Sea and Lake Ice: Age
Sea and Lake Ice: Concentration
Sea and Lake Ice: Motion
Snow Depth (Over Plains)
SO_2 Detection
Surface Albedo
Surface Emissivity
Tropopause Folding Turbulence Prediction
Upward Longwave Radiation: Surface
Upward Longwave Radiation: TOA
Vegetation Fraction: Green
Vegetation Index
Visibility

FIG. 1. GOES-R baseline products and future capabilities, by sensor. TOA = top of atmosphere; EUV = extreme ultraviolet.

key component in user readiness is the training and demonstration that builds the forecaster's knowledge base as part of NOAA's evolving operations.

PG PARTICIPANTS. The PG participants can be categorized as either developers or users. Developers are satellite algorithm scientists who develop and deliver the demonstration product(s) and related training materials to the end users. The Cooperative Institute for Meteorological Satellite Studies (CIMSS) and the Advanced Satellite Products Branch (ASPB) of the NESDIS STAR located at the University of Wisconsin—Madison; the Cooperative Institute for Research in the Atmosphere (CIRA) and the Regional and Mesoscale Modeling Branch (RAMMB) at Colorado State University; and NASA SPoRT in Huntsville, Alabama, are the three main developers within the GOES-R PG program. The users (e.g., test bed operators and forecasters) are those users who work with the providers to integrate the product(s) for demonstration into an operational setting for forecaster interaction and provide the product assessments. At select NCEP offices, there are also onsite long-term visiting scientist technical liaisons (i.e., subject matter satellite application experts, or "satellite champions") that aid in the transition from research to operations by actively participating in the product demonstrations, interpreting the added value of the satellite-derived information, and conducting training. The developers work with the satellite champions to build capacity within the forecast office or national center.

DEMONSTRATION ACTIVITIES. Activities at the HWT, National Hurricane Center (NHC), and those involving the Air Quality PG (AQPG) customers are described in detail below to illustrate the wide variety of products demonstrated at various facilities.

> *"We saw several instances where the total lightning was picking up on storms before the AWIPS lightning [NLDN CG] program picked up on them. One could see the utility of this in the future, bringing with it a potential for lightning statements and potentially lightning-based warnings."*
>
> —PAT SPODEN
> (SOO, NWSFO, PADUCAH, KENTUCKY)

Hazardous weather test bed spring experiment demonstration. The GOES-R PG principal collaboration for severe convective weather occurs within NOAA's HWT and Storm Prediction Center (SPC) in Norman, Oklahoma. Since 2009, the GOES-R PG has participated in the annual SPC/National Severe Storms Laboratory (NSSL)/WFO Spring Experiment (www.nssl.noaa.gov/projects/hwt/). Between 17 May and 18 June 2010, a total of 20 visiting scientists and 15 NWS forecasters, invited by the GOES-R PG, participated in real-time forecasting and warning exercises using a variety of experimental GOES-R products within the Spring Experiment's Experimental Forecast Program (EFP) (www.nssl.noaa.gov/projects/hwt/efp/) and Experimental Warning Program (EWP) (http://ewp.nssl.noaa.gov/). In 2011, the campaign ran from 9 May to 10 June 2011, with 24 NWS forecasters participating.

Products generated from current satellite-, land-, and numerical model–based datasets such as convective initiation (CI) nowcasting (Mecikalski and Bedka 2006; Mecikalksi et. al. 2010; Sieglaff et al. 2011), overshooting top (OT) and thermal couplet detection (Bedka et al. 2010), pseudo-geostationary lightning mapper (PGLM) (Fig. 2), and simulated satellite imagery (Fig. 3) helped demonstrate GOES-R products to operational forecasters and the broader scientific community. Other future capability products demonstrated included a 1–9-h GOES sounder-based precipitable water/θ_e nearcast model, a 0–3-h severe hail probability product, and a NSSL Weather Research and Forecasting model (WRF) simulated lightning threat forecast (McCaul et al. 2009). Weather Event Simulator (WES) cases were developed to demonstrate GOES-R PG products within the EWP for training purposes during periods of inactive weather. The products included in the Spring Experiment are described in greater detail below.

The University of Wisconsin Convective Initiation (UWCI) algorithm utilizes a box-averaged approach for monitoring cloud-top cooling rates of immature, vertically growing convective clouds. The box-averaged approach is computationally inexpensive, uses a physically based IR-only cloud-type algorithm allowing day/night independence, and is portable from one geostationary imager platform to another. The UWCI algorithm separates false cloud-top cooling associated with horizontal cloud advection from true cloud-top cooling associated with vertical cloud growth through a series of tests (Sieglaff et al. 2011). After the true cloud-top cooling signal is isolated, the cooling pixels are assigned convective

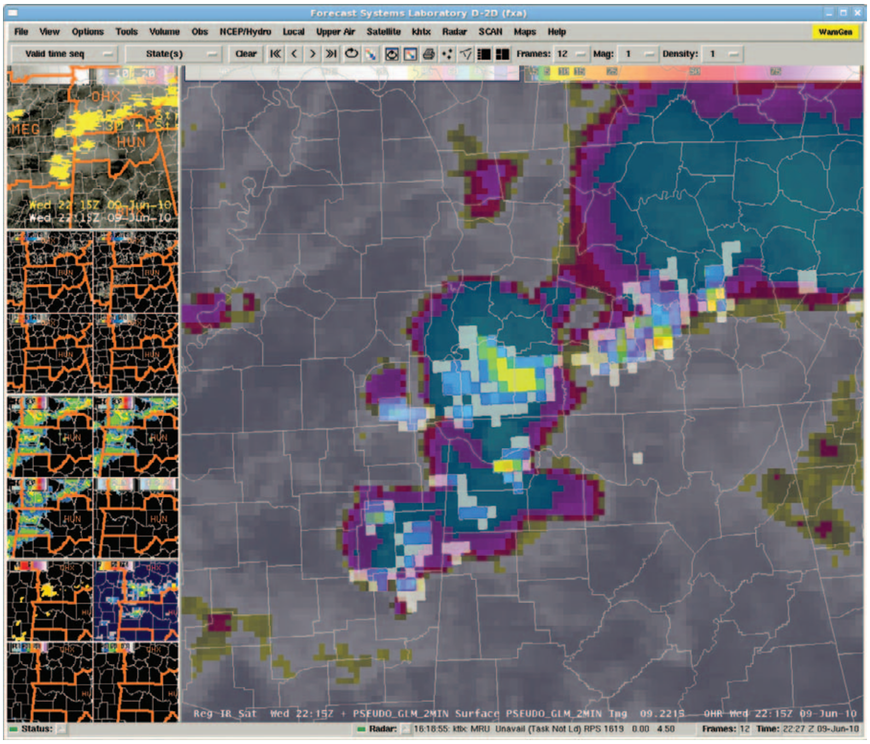

Fig. 2. Forecaster AWIPS display of PGLM flash extent density product and IR image over central Tennessee and northern Alabama at 2215 UTC 9 Jun 2010. The overlay of PGLM on IR allowed the forecaster to focus on the most active convective cores.

initiation nowcast categories based upon cloud-type classification and trends. Three nowcast categories exist, pre-CI cloud growth, CI likely, and CI occurring, which represent vertically growing water cloud, vertically growing supercooled/mixed phase cloud, and vertically growing and recently glaciated cloud, respectively.

The Satellite-Based Convection Analysis and Tracking (SATCAST) is a proxy for the AWG version of the GOES-R CI algorithm. The algorithm uses a daytime statistically based convective cloud mask (Berendes et al. 2008) and performs multiple spectral differencing of IR fields (Mecikalski and Bedka 2006). SATCAST then quantifies and monitors cumulus cloud objects (Goodman et al. 2011) while applying object-based atmospheric motion vectors (AMV) to track cloud objects being monitored for future CI (Zinner et al. 2008). SATCAST is also available at nighttime using an identification approach to identify cumulus clouds (Jedlovec et al. 2008). SATCAST output has provided additional insight when implemented in well-established decision support systems, such as Consolidated Storm Prediction for Aviation (CoSPA; Wolfson et al. 2008). The CoSPA integrates radar observations, numerical weather prediction (NWP) winds and stability fields, and other data to assist in developing CI nowcasts and convective storm evolution forecasts over the 0–8-h period. NWP data also help remove spurious false alarms in SATCAST by requiring convective available potential energy (CAPE) indications of instability in the near-storm environment. False alarms may also be caused by mesoscale AMV tracking errors, view-angle-related problems that affect interest field thresholds and the inherent difficulties associated with tracking growing cumulus in 4-km IR data. Separately, the NESDIS Office of System Development (OSD) is evaluating the two CI products in support of validating them for possible operational implementation. Forecaster comments from the HWT were provided to OSD in support of the validation activities.

The overshooting top detection (OTD) product identifies those deep convective storm updraft cores of sufficient strength to rise above the storms' general equilibrium level near the tropopause region and penetrate into the lower stratosphere. Thunderstorms with overshooting tops that penetrate the tropopause frequently produce hazardous weather at Earth's surface such as heavy rainfall, damaging winds, large hail, and tornadoes (Adler et al. 1985; Brunner et al. 2007; Dworak et al. 2012). Turbulence and CG lightning are found to occur most frequently near the OT region (Bedka et al. 2010), indicating that OTs represent significant hazards to ground-based and in-flight aviation operations. This algorithm will also help better detect areas of potential turbulence, giving pilots ample warning of potentially dangerous flying conditions. In addition, the OTD product identifies features in the IR cloud tops associated with the enhanced-V signatures that have been shown to be associated with severe weather at the ground (Brunner et al. 2007).

The PGLM product utilizes total lightning data from three ground-based Lightning Mapping Array (LMA) networks (central Oklahoma; northern

> *"The band difference has a lot of potential . . . you can get a head start by looking at the trends in the data that help you anticipate what's going to happen."*
>
> —HWT Forecaster on WRF Band Difference (KPPs)

Alabama; and Washington, D.C.) and the Lightning Detection and Ranging (LDAR) network (Kennedy Space Center, Florida) that detect very high-frequency (VHF) radiation from lightning discharges. The real-time lightning data are resampled to the GLM nadir pixel resolution of 8 km and summed into 1- or 2-min intervals, depending on the network, and sorted into flashes using spatiotemporal clustering algorithms available through the Warning Decision Support System–Integrated Information (WDSS-II). Following flash sorting, a flash extent density product, which can be looped in the Advanced Weather Interactive Processing System (AWIPS) and trended with time, is created at 8-km resolution to match the GOES-R GLM lightning detection event product. The PGLM product is a nowcasting and warning tool that aids forecaster situational awareness by identifying rapidly developing and intensifying thunderstorms with the potential to produce severe or high-impact (e.g., microbursts) convective weather (Goodman et al. 2005; Gatlin and Goodman 2010; Schultz et al. 2009).

The WRF lightning threat forecast is a model-based method for making quantitative forecasts of lightning threat. The algorithm uses microphysical and dynamical output from high-resolution, explicit convection runs of the WRF (Skamarock et al. 2005) conducted daily during the Spring Experiment time period. The algorithm uses two separate proxy fields to assess lightning flash rate density and areal coverage, based on storms simulated by the WRF. One field, based on the flux of large precipitating ice (graupel) in the mixed-phase layer near −15°C, has been shown to be proportional to lightning flash peak rate densities while accurately representing the temporal variability of flash rates during updraft pulses (McCaul et al. 2009). The second field, based on vertically integrated ice hydrometeor content in the simulated storms, is proportional to peak flash rate densities while also providing information on the spatial coverage of the lightning threat, including lightning in storm anvils. A composite gridded threat field is created by blending the two aforementioned ice and graupel fields, after making adjustments to account for differing sensitivities to specific configurations of the WRF used in the forecast simulations. One chief advantage of a physically based lightning threat forecast is that it predicts a much smaller region for strong–severe thunderstorm activity than would be suggested by more general indicators of potential instability such as CAPE. The regional LMA networks are used to support the validation of the lightning threat forecasts.

Simulated GOES-R ABI imagery and band differences generated from the NSSL WRF 0000 UTC 4-km model run are provided by CIMSS and CIRA for display within the HWT National Advanced Weather Information Processing System (NAWIPS). One of the most useful aspects of simulated satellite imagery from a model is the ability to compare the output directly to observed satellite imagery to determine model performance, as well as having a one-stop 3D representation of the model atmosphere.

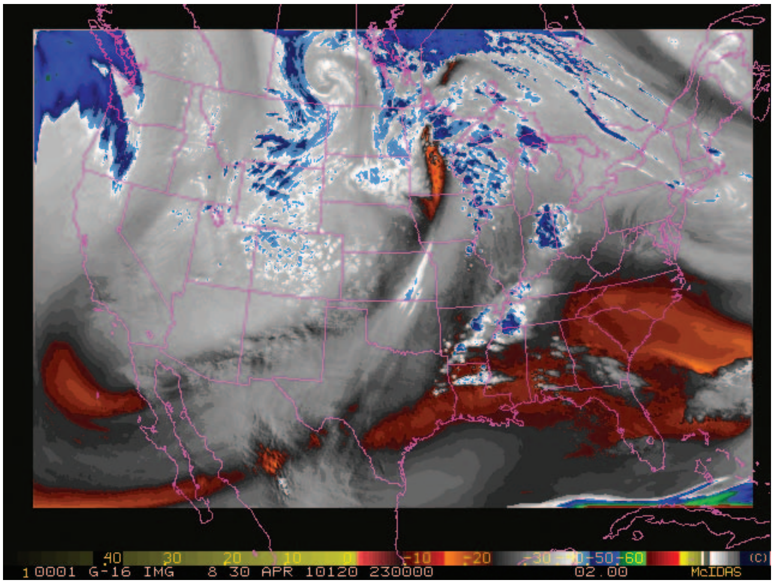

Fig. 3. Example of a synthetic 6.185-m image at 2300 UTC 30 Apr 2010. The image is based on a 23-h forecast from NSSL's 4-km Advanced Research WRF (ARW-WRF), run through a forward radiative transfer model to produce ABI brightness temperatures.

> *"A lot of the time to increase my lead time in the morning, I like to take a look at PW* [precipitable water] *and WV* [water vapor] *... so I found that this was a nice utility because it was indicative of finding areas of greatly deep instability, or moisture source regions."*
>
> —HWT Forecaster
> on Nearcast (Legacy Atmospheric Profiles)

CIMSS provides simulated satellite data for one visible and all nine nonsolar GOES-R ABI IR bands from the NSSL WRF for 12–36-h forecast periods. The three ABI water vapor channels, each peaking at a different level in the atmosphere, provide three layers of water vapor information unavailable from the current series of operational GOES satellites. In addition, CIRA provides the HWT with three GOES-R specific band differences not available from the current GOES satellites. Features such as low-level moisture pooling and boundary identification are useful in the forecast of convective initiation. Data from both CIMSS and CIRA arrived at SPC by 1415 UTC to produce the imagery, with the band differences available an hour later.

The CIMSS/ASPB nearcast model applies a Lagrangian framework to advect temperature and moisture retrievals from the 18-channel GOES sounder (Schmit et al. 2002) to generate forecasts of conditional instability out to 9 h from the initialization time. A nearcast model of vertical moisture and θ_e gradients shows skill at identifying regions of rapidly developing, convective destabilization up to 6 h in advance. The nearcast model thus addresses the information gap between extrapolating observations for nowcasting to longer-range NWP. The nearcast model must be able to detect and retain substantial gradients in the atmosphere (especially moisture fields) and incorporate large volumes of high-resolution synoptic data while remaining computationally efficient. A Lagrangian approach uses hourly, full-resolution (10–12 km) multilayer retrieved parameters from the GOES sounder to optimize the impact and retention of information. Forecasters find the model enhances current operational NWP forecasts by capturing and retaining details of atmospheric structure that are key to the development of convective instability several hours in advance, even after subsequent IR satellite observations become cloud contaminated.

Statistical hail probability provides forecasters with a product created by fusing satellite and numerical forecast model information. The product is based on a statistical model built by using observed severe hail reports over three years, along with the corresponding (in space and time) GOES observations and analyses and forecasts from the SPC's surface mesoanalysis and the Rapid Update Cycle (RUC) model. GOES data include the 10.7-μm brightness temperatures and the locations of overshooting tops derived from the OTD product discussed above. Additional inputs include convective instability information, surface dewpoint, and severe hail (greater than or equal to 1 in. in diameter) climatology. Output from the real-time product provides the probability of severe hail within the 0–3-h time window on a 0.5° × 0.5° latitude/longitude grid across the eastern two-thirds of the United States, roughly within the GOES-East domain. The product was designed to provide additional guidance to SPC forecasters who generate hail probability forecasts several times per day as part of their convective outlooks. It may also assist in the issuance of mesoscale discussions and severe thunderstorm watches.

Forecasters and participants of the Spring Experiment at the HWT provided feedback via real-time blogging (http://goesrhwt.blogspot.com), online postevent surveys, and daily postmortem discussions throughout the 5-week experiment. The feedback gathered was essential in identifying training needs and potential uses of the GOES-R products prior to their operational deployment. Forecasters identified specific information that they would like to see within training modules, as well as additional WES case types, to help better demonstrate the utility of GOES-R products. Feedback from NWS forecasters has also been essential in developing effective situational awareness display techniques within their current AWIPS/NAWIPS and future AWIPS II systems for next-generation satellite products.

National Hurricane Center hurricane season demonstration. A set of GOES-R products was tested at the NHC during the most active part of the 2010 hurricane season. The official GOES-R baseline product set includes one product specifically designed for tropical cyclones, the hurricane intensity estimate (HIE). However, data and products from the ABI and GLM have many potential applications to tropical cyclone analysis and forecasting, and a subset was chosen for evaluation within the NHC demonstration. Products evaluated at the NHC included the HIE; three red, green, and blue (RGB) imagery products (Miller et al. 2006, 2012); and an experimental rapid intensification index (RII) that used lightning data as one of the inputs. Super-Rapid Scan Operations (SRSO) 1-min imagery was also collected. The initial products and decision aids were chosen through early planning coordination with NHC forecasters, which began several months in advance of the experiment that ran from 1 August to 30 November 2010.

The experimental products were evaluated directly by forecasters from the NHC Hurricane Specialist Unit and the Tropical Analysis and Forecast Branch. Onsite training was provided prior to the start of the demonstration and associated documentation on the GOES-R products was also available online (http://rammb.cira.colostate.edu/research/goes-r/proving_ground/cira_product_list). A midterm project review was held at the NHC in early September 2010, and a postdemonstration meeting was held in January 2011 to obtain forecaster feedback on the utility of the GOES-R products.

The HIE is a state-of-the-art algorithm that provides an objective estimate of the maximum sustained surface wind of tropical cyclones using IR window channel input. The algorithm is based on the advanced Dvorak technique (ADT) (Olander and Velden 2007), which is now used operationally at the NHC and other global tropical cyclone (TC) analysis centers to complement the subjective Dvorak technique (SDT) intensity estimates. The ADT has been shown to be competitive in skill with the SDT and has the distinct advantage of rapid refresh (30-min estimates vs typical 6-hourly SDT estimates). The HIE algorithm was adapted by CIMSS to use the increased horizontal and temporal resolution that will be available from the ABI and tested using Spinning Enhanced Visible and Infrared Imager (SEVIRI) data as a proxy for the ABI. Real-time demonstrations have been provided to the NHC via a dedicated web page for product evaluation.

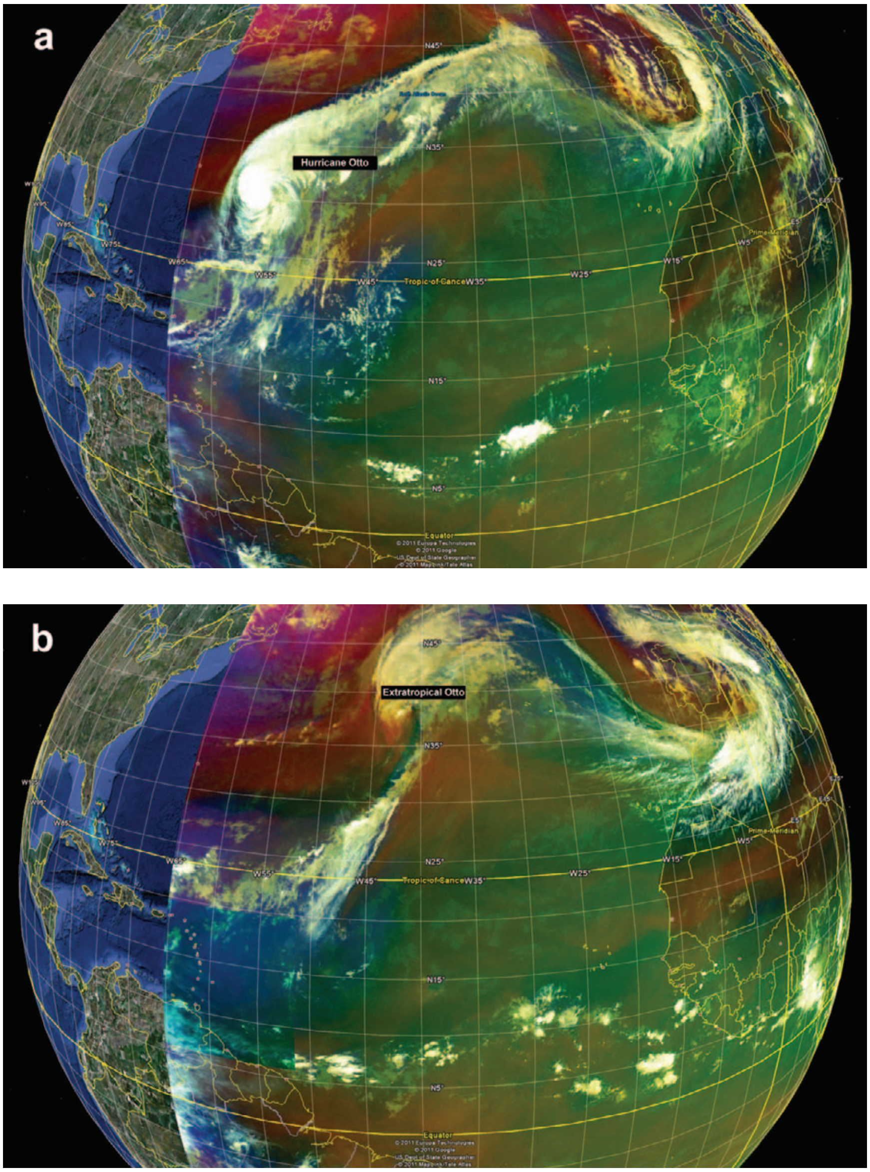

Fig. 4. An example of the RGB airmass product in Google Earth format for Hurricane Otto at (a) 0500 UTC 9 Oct and (b) 0500 UTC 10 Oct 2010. On 9 Oct, the airmass product showed that the cyclone was near an airmass boundary, as indicated by the color contrast to the west of the storm, with the red colors indicating much drier and higher ozone content typical of polar air. By 10 Oct in (b), Otto had transitioned to an extratropical cyclone, where the polar air mass surrounded the cyclone by that time.

> *"The RGB airmass 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."*
>
> —Jack Beven
> NHC

With 16 ABI channels, it will be more difficult and time consuming for forecasters to extract all the information directly from that data. For this reason, the use of image combinations designed to highlight features of interest will be of greater importance in the GOES-R era. To prepare for these applications, three RGB image products were demonstrated at the NHC. The first of these was the RGB airmass product (Fig. 4). Originally designed by scientists at the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), it has been adapted for tropical applications to highlight differences between dry, tropical, and midlatitude air masses (EUMETSAT User Service Division 2010). The second product demonstrated was the RGB dust product, which works in a similar fashion. The dust product is designed to monitor the evolution of dust storms during both day and night. Dust plumes in the tropical Atlantic have been hypothesized to slow tropical storm development and to affect sea surface temperatures directly where tropical cyclones form (Evan et al. 2006). The third RGB product was the Saharan air layer (SAL) product, which is another example of an enhanced image product potentially related to tropical cyclone evolution by tracking dry, dusty air in the lower to middle levels of the atmosphere (Dunion and Velden 2004). The RGB products were provided by CIRA and CIMSS in a Google Earth format via a web page. SEVIRI data were used as a proxy for the ABI, and the domain covered most of the northeastern tropical Atlantic east of the Lesser Antilles. The Google Earth format was used previously because of the color display limitations of the NAWIPS systems, but in future demonstrations the RGB products will transition from Internet based to AWIPS II access.

A number of studies have suggested a relationship between lightning activity and tropical cyclone intensity changes (e.g., Abarca et al. 2011). To evaluate the predictive capability of the lightning information, an experimental version of the operational RII product described by Kaplan et al. (2010) was developed. The ground-based World Wide Lightning Location Network (WWLLN) data from 2005 to 2009 were used as a proxy for the GLM for the algorithm development (Rodger et al. 2004). Although the WWLLN detects cloud-to-ground and not total lightning activity, the reported spatial accuracy of 10–15 km over the oceans provides a good approximation to the spatial resolution of the GLM. These data combined with multichannel imagery can be used to explore the added utility of lightning observations to monitor high-impact convective weather over data-sparse regions. The lightning-based RII was run in real time and provided to NHC forecasters for evaluation. The Vaisala Global Lightning Dataset 360 (GLD-360) was used for the real-time evaluation (Demetriades and Holle 2009). Figure 5 shows an example of a 6-h composite of lightning locations from the GLD-360 network. Correction factors developed from a period of overlap in 2009 were applied to the GLD-360 data to account for differences from the WWLLN data. The experimental RII, provided to the NHC via an FTP site in a text format similar to the operational version, uses lightning data input from the inner core and rainband regions.

To gain experience with high-temporal-resolution imagery of tropical cyclones, several periods of 1-min GOES SRSO data were collected (Hillger and Schmit 2009). Fortunately, the recently launched *GOES-15* was in checkout mode during the most active part of the 2010 season (http://rammb.cira.colostate.edu/projects/goes-p/), which allowed for much more SRSO data to be collected than is normally possible after the satellites become operational. Extended periods of SRSO were obtained from Hurricanes Danielle, Earl, Igor, and Karl. These were available to the NHC forecasters in real time via a web page and will be used for later research and training on the use of high time resolution for hurricane analysis.

Forecaster feedback provided valuable information regarding the prototype GOES-R products. A possible bias in the HIE minimum pressure estimates was identified, which is being investigated by the product developers. The RGB products were found to be a useful way to identify features of interest, but they also have some shortcomings, including false alarms. To further exploit the advanced capabilities of GOES-R, there will be a range of automated, quantitative products describing aerosols, dust, ash, moisture, ozone, etc. The "recipes" for the RGB products are being adapted and address these issues. Preliminary results with the RII showed that the lightning data reduced the bias by a few percent in both the Atlantic and eastern Pacific. Additional tests in the postseason showed that larger reductions (up to 16% in the Atlantic) in the bias were obtained when the RII was run with lightning data input from the WWLLN instead of the GLD-360. In addition, other measures of probabilistic forecasts such as the Brier skill score improved with the WWLLN data. The improvement with the WWLLN data is primarily because those are the same data from which the statistical algorithm was developed. Time series of the lightning activity in radial bands around tropical cyclones, which were provided as part of the RII, were found to have some value in monitoring storm evolution. More research is needed to determine the value of the SRSO data. Efforts to collect SRSO data for a U.S. land-falling hurricane will continue, because this was not obtained in 2010. The feedback from forecasters will be used to improve the NHC PG activities, which will likely continue up until the launch of GOES-R. Additional products will also be tested as they become available using proxy data.

Air Quality Proving Ground demonstration. The goal of the AQPG is to demonstrate emulative GOES-R air quality–related products in near–real time so the air quality user community can use, get familiar with, test, and evaluate the products. A user advisory group provides constructive feedback to algorithm/product developers on the value and needed changes to products for increased utility. The GOES-R ABI air quality products to be demonstrated include suspended matter/aerosol optical depth (AOD), aerosol type, aerosol detection (smoke/dust), and fire detection. These proxy retrievals are derived or simulated from existing Moderate Resolution Imaging Spectroradiometer (MODIS) radiances or from the Community Multiscale Air Quality (CMAQ) model, the WRF with Chemistry (WRF-Chem), and the Community Radiative Transfer Model (CRTM).

The GOES-R ABI suspended matter/aerosol optical depth and aerosol detection products have applicability within the NWS for visibility assessment and direct comparison to the NWS prototype aerosol forecast product. PM2.5, denoting particulate matter with particles smaller than 2.5 μm in diameter, has harmful health consequences with important economic impacts and is monitored by the Environmental Protection Agency (EPA) for federal air quality standard compliance. Satellite-derived AODs have been shown to be a good proxy for surface PM2.5 (e.g., Wang and Christopher 2003; Engel-Cox et al. 2004; Hoff and Christopher 2009). The currently operational GOES and MODIS AOD products are widely used by the EPA and other agencies in assessing PM2.5 spatial distributions.

Aerosol detection (including smoke and dust) is a qualitative imagery product that provides presence/absence information of smoke or dust in a GOES-R ABI pixel. This information, combined with location of fires detected by the GOES-R ABI, helps the forecasters with the identification of the nonanthropogenic pollution sources and the spatial distribution patterns of the smoke and dust. The NWS/NCEP is currently testing the MODIS dust mask product to use in verifying the operational Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) forecast. The air quality (AQ) demonstration has evaluated the MODIS dust mask product and, based on the NWS feedback, modified the algorithm to avoid classifying thin dust as cloud.

The GOES-R AQPG held its kickoff users and advisory group workshop at the University of Maryland, Baltimore County, in September 2010. To help the AQPG team understand user needs, state and local AQ forecasters gave a series of presentations about air quality forecasting and analysis across the country. The talks highlighted how satellite observations fit into the forecasting process. Users described their current and planned use of GOES

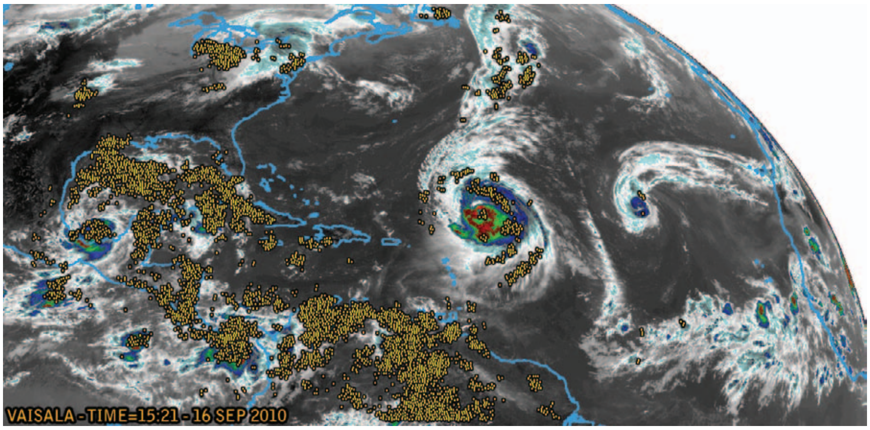

Fig. 5. Lighting locations (gold points) within 3 h of 1500 UTC 16 Sep on a color-enhanced GOES IR image. Three hurricanes (Igor in the center, Julia to the east of Igor, and Karl in the southwestern Gulf of Mexico) were in the Atlantic basin at this time.

> *"Total lightning data preceded the CG network anywhere from 10–40 minutes. I was able to quickly determine when flash rate was significantly increasing, and then compare with satellite and updraft/downdraft parameters for a nice big picture."*
>
> —HWT FORECASTER ON LIGHTNING DETECTION

products and imagery in the preparation of real-time forecasts and in retrospective analysis to address the exceptional event rule when smoke/dust/ozone/PM2.5 levels resulted in air quality nonattainment. Users are looking forward to the increased spatial and temporal resolution of the ABI instrument and more accurate air quality products. Future EPA air quality rules for ozone and PM2.5 particulates are expected to increase the demand for archived satellite data in retrospective analysis.

TRAINING. The GOES-R PG is both a user and developer of satellite-related training. The participants in the PG activities need to be cognizant of the characteristics of the proxy GOES-R products and their utility within NOAA's complex operational environment. The knowledge users gain in applying these products is then passed back to product developers, GOES-R, other NOAA program managers, and the broader user communities outside of NOAA.

There are numerous sources of training for PG participants, including the GOES-R PG website, the Cooperative Program for Meteorology Education and Training (COMET), the Virtual Institute for Satellite Integration Training (VISIT), Satellite Hydrometeorology Course (SHyMet) courses, the Environmental Satellite Resources Center (ESRC), SPoRT, and WES cases. More training and information are available at CIMSS and VISIT satellite blogs. The PG website provides a list of available proxy GOES-R products and descriptions of the products, how they are developed, and their strengths and limitations. Training website addresses are listed in Table 1.

TABLE 1. Training links.

COMET	www.comet.ucar.edu/
VISIT	http://rammb.cira.colostate.edu/training/visit/
SHyMet	http://rammb.cira.colostate.edu/training/shymet/
ESRC	www.meted.ucar.edu/
SPoRT	http://wwwghcc.msfc.nasa.gov/sport/
WES	www.wdtb.noaa.gov/tools/wes/index.htm

WES cases are developed as part of the PG concept to prepare forecasters for the dramatic increase in spatial, spectral, and temporal resolution from the ABI and new lightning detection capabilities from the GLM. The PG partners are developing WES scenarios for a variety of operational high-impact weather situations, including convective outbreaks over the midwestern United States, land-falling hurricane events and other tropical systems, and severe weather outbreaks. Forecasters are provided simulated ABI images and products to learn how to integrate them into their operations.

FUTURE PLANS. There is a good deal of additional work to be done within the PG framework to ensure user readiness. Demonstration plans have been completed for activities at NWS's Ocean Prediction Center and the Hydrometeorological Prediction Center. Plans for aviation-related products have been developed and were initiated in early 2011 for the Aviation Weather Center (AWC) and the Alaska Aviation Weather Unit (AAWU). The aviation products include volcanic ash, cloud-top height, turbulence, lightning detection, precipitation, icing, and low clouds and fog. A plan for a Space Weather Prediction Center PG demonstration includes many of the products that will become available from the SUVI on GOES-R and will be derived from the NASA Solar Dynamics Observatory's Atmospheric Imaging Assembly (AIA). Within the HWT, additional experiments are being planned to utilize additional GOES-R products outside of the severe weather spectrum that are directly applicable to SPC operations, including fire weather, heavy precipitation, and winter weather forecasting. The next-generation GOES will continue providing valuable data to support high-impact weather warnings as well as key inputs for global and regional NWP models. The large quantities of GOES-R data will present new challenges and opportunities that require more intelligent integration of information derived from blended satellite products (e.g., geostationary and polar satellite observations); multidimensional classification of severe storm potential by combining satellite, radar, in situ data, and models; and new ways of visualizing GOES-R data within the AWIPS II forecaster workstation (e.g., RGB imagery-derived products akin to those generated by EUMETSAT from the Meteosat Second Generation SEVIRI; Roesli et al. 2006; Hillger et. al.

2011). Indeed, the GOES-R satellite series will usher in a revolutionary change in the utility of geostationary satellite information.

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