AN OVERVIEW OF CIRA'S CONTRIBUTION TO THE GOES-R PROVING GROUND

Edward J. Szoke[1,2,3], Renate Brummer[1], Hiro Gosden[1], Steve Miller[1], Mark DeMaria[4], and Deb Molenar[4]

[1]Cooperative Institute for Research in the Atmosphere (CIRA), Fort Collins, Colorado
[2]NOAA Earth System Research Laboratory (ESRL), Boulder, Colorado
[4]National Environmental Satellite, Data, and Information Services, Center for Satellite Applications and Research (NESDIS/STAR)

1. INTRODUCTION

The Geostationary Operational Environmental Satellite (GOES)-R is the first member of a next generation series of satellites that will replace the current GOES-I/M and GOES-N/O/P series. Scheduled for launch in 2015, its Advanced Baseline Imager (ABI) radiometer will provide marked improvements over the current GOES imager in terms of its spectral, radiometric, spatial, and temporal resolution. A description of GOES-R can be found online at http://www.goes-r.gov/. In addition, GOES-R will carry the first Geostationary Lightning Mapper (GLM). The National Oceanic and Atmospheric Administration (NOAA) conceived the GOES-R Proving Ground as a means to providing day-1 readiness to this new satellite era that will allow operational forecasters to achieve the maximum utility from the new data and products that will be provided.

The concept of the GOES-R Proving Ground was developed in part because of lessons learned from the success of a similar effort in the development of the National Weather Service (NWS) NEXRAD Program. A key goal of the GOES-R Proving Ground is to bridge the gap between the developers and end users for the purposes of training, product evaluation, and solicitation of user feedback. The concept of the Proving Ground is that this type of interaction will enable the most effective products to be developed that will be useful to operational forecasters as soon as GOES-R data is available.It is important to establish this dialogue early to allow time for development of useful products for operations, based on GOES-R simulated and proxy datasets.

Proving Ground efforts are spread across NOAA/NESDIS/GPO, NOAA/NWS, NOAA/OSD, NOAA/OSDPD, NOAA/NESDIS/STAR, NASA's Short-term Prediction Research and Transition (SPoRT) Program, and two NOAA Cooperative Institutes: the Cooperative Institute for Meteorological Satellite Studies (CIMSS), and the Cooperative Institute for Research in the Atmosphere (CIRA) with Colorado State University. The Proving Ground provides simulated GOES-R products for operational testing to NWS Weather Forecast Offices (WFOs) and other operational centers, using a variety of means including combining current GOES channels with other satellite channels, making use of analogous MODIS satellite imagery, and using synthetic, model-generated imagery to simulate GOES-R products. A map showing the various interactions by the different groups is presented in Figure 1.

CIRA is an active member of the GOES-R Proving Ground, as seen in Figure 1. CIRA's initial Proving Ground interaction with NWS forecasters focused on the two closest NWS WFOs, at Boulder, Colorado and Cheyenne, Wyoming. Over the last couple of years we have expanded our interactions to other WFOs as opportunities have arisen, as well as National Centers (the National Hurricane Center (NHC), Aviation Weather Center (AWC), and Storm Prediction Center (SPC). In this paper we will detail these interactions and describe our Proving Ground products. We will also address the challenges we have encountered, especially in the area of forecaster feedback. Plans will be outlined for future products and interactions, incorporating ideas from the most recent GOES-R Proving Ground Annual Meeting in Boulder in May 2010

2. WHAT IS THE GOES-R PROVING GROUND?

The concept of the GOES-R Proving Ground project is to engage the NWS forecast and warning community in pre-operational demonstrations of selected capabilities anticipated from the next generation of NOAA geostationary Earth observing systems.

[3]*Corresponding author address:* Ed Szoke, NOAA/ESRL/GSD,R/GSD, 325 Broadway, Boulder, CO 80305; e-mail: Edward.J.Szoke@noaa.gov

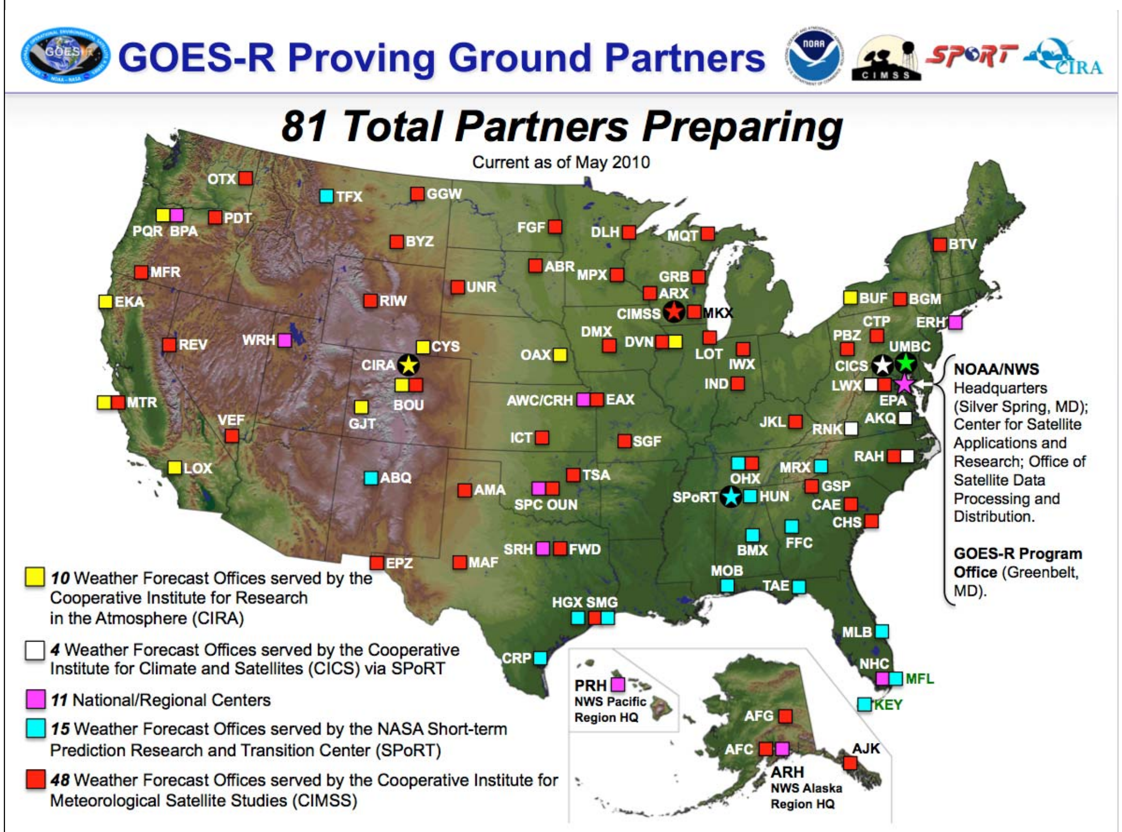

Fig. 1. Overview of the current (May 2010) interactions between the principal GOES-R product developers and main end users. As noted, this figure shows the main interactions taking place; other WFOs also receive GOES-R Proving Ground products, as discussed in the text.

The Proving Ground project objective is to bridge the gap between research to operations by:

- Utilizing current systems (satellite, terrestrial, or model/synthetic) to emulate various aspects of future GOES-R capabilities
- Infusing GOES-R products and techniques into the NWS operational environment, with emphasis on the Advanced Weather Information Processing System (AWIPS) and transitioning from AWIPS-I ("AWIPS Legacy") to AWIPS-II ("AWIPS Migration").
- Engaging in a two-way dialogue to provide feedback to the developers from the users.

A key element of this activity is a sustained interaction between the developers and end users for the purposes of training, product evaluation, and solicitation of user feedback. The Proving Ground relies on close coordination with the GOES-R Algorithm Working Group (AWG) and Risk Reduction programs as sources of demonstration products, and will enhance the operational transition pathway for those programs.

The intended outcomes of this project are Day-1 readiness and maximum utilization for both developers and users of the GOES-R observing system, and an effective transition of GOES-R research products to the operational weather community. Details on the GOES-R Proving Ground can be found online at http://cimss.ssec.wisc.edu/goes_r/proving-ground.html.

The GOES-R Proving Ground will facilitate the testing and validation of new ideas, technologies and products before they become integrated into operational use. This proving ground is an essential component of GOES-R risk reduction, which will help to ensure that users are ready for the new types of satellite imagery and products that will be available in the upcoming GOES-R era.

The potential for a number of new products and types of imagery in the GOES-R era is possible in part because of the increased number of bands that will be available in the Advanced Baseline Imager (ABI) on GOES-R. As seen in Table 1, 16 bands will be available, compared to 5 useable bands in the current operational GOES. In addition to the greater number of channels, there will be an increase in both time and spatial resolution of products over the current GOES. IR image resolution will be 2 km, compared to the current 4 km with GOES, and for visible imagery will be 0.5 to 1 km (depending on the band), compared to the current 1 km. The time resolution will increase to a full-disk image every 5 min, versus 15 min today, with rapid scan at 1-min resolution.

Table 1. Summary of the wavelengths, resolution, and sample use and heritage instrument(s) of the ABI bands. The minimum and maximum wavelength range represent the full width at half maximum (FWHM or 50%) points. [The Instantaneous Geometric Field Of View (IGFOV).]

Future GOES imager (ABI) band	Wavelength range (μm)	Central wavelength (μm)	Nominal subsatellite IGFOV (km)	Sample use	Heritage instrument(s)
1	0.45–0.49	0.47	1	Daytime aerosol over land, coastal water mapping	MODIS
2	0.59–0.69	0.64	0.5	Daytime clouds fog, insolation, winds	Current GOES imager/sounder
3	0.846–0.885	0.865	1	Daytime vegetation/burn scar and aerosol over water, winds	VIIRS, spectrally modified AVHRR
4	1.371–1.386	1.378	2	Daytime cirrus cloud	VIIRS, MODIS
5	1.58–1.64	1.61	1	Daytime cloud-top phase and particle size, snow	VIIRS, spectrally modified AVHRR
6	2.225–2.275	2.25	2	Daytime land/cloud properties, particle size, vegetation, snow	VIIRS, similar to MODIS
7	3.80–4.00	3.90	2	Surface and cloud, fog at night, fire, winds	Current GOES imager
8	5.77–6.6	6.19	2	High-level atmospheric water vapor, winds, rainfall	Current GOES imager
9	6.75–7.15	6.95	2	Midlevel atmospheric water vapor, winds, rainfall	Current GOES sounder
10	7.24–7.44	7.34	2	Lower-level water vapor, winds, and SO_2	Spectrally modified current GOES sounder
11	8.3–8.7	8.5	2	Total water for stability, cloud phase, dust, SO_2 rainfall	MAS
12	9.42–9.8	9.61	2	Total ozone, turbulence, and winds	Spectrally modified current sounder
13	10.1–10.6	10.35	2	Surface and cloud	MAS
14	10.8–11.6	11.2	2	Imagery, SST, clouds, rainfall	Current GOES sounder
15	11.8–12.8	12.3	2	Total water, ash, and SST	Current GOES sounder
16	13.0–13.6	13.3	2	Air temperature, cloud heights and amounts	Current GOES sounder/ *GOES-12+* imager

Table 1: ABI bands on GOES-R.

There are a number of ways in which test products representative of GOES-R era products can be demonstrated to forecasters now in order to get feedback that will greatly help to improve the operational utility of satellite products available to forecasters once GOES-R is launched. One method involves using the Terra and Aqua polar orbiting satellites that have 36 bands from the Moderate Resolution Imaging Spectroradiometer (MODIS), as well as higher spatial resolution than the current GOES. Test products can be created by either sending some of the MODIS satellite images directly, making new products from the MODIS channels, or combining some of the imagery with current GOES imagery, as will be demonstrated later for a product developed by the CIRA group. A major downside to using the MODIS imagery directly is that the time resolution is quite poor, generally only a usable image or two per day at a given location, since the Aqua and Terra are polar orbiting satellites.

One way to overcome the time resolution issue and still demonstrate some of the new bands is to use "synthetic" imagery. CIRA genrates synthetic imagery by using a high-resolution version of the WRF numerical model to generate output that resembles the images that could be displayed from the GOES-R satellite. Another method of generating Proving Ground products is to use new combinations of existing GOES bands. The advantage of using GOES is that the products would have much higher time resolution than MODIS-based products.

In the next sections we will discuss in more detail the various CIRA products and where they are being distributed. In this paper we will concentrate on products being tested at NWS WFOs. CIRA National Center (NHC) products are discussed in a separate paper at this conference by DeMaria et al. (2011).

3. CIRA GOES-R PROVING GROUND PARTNERS

The CIRA NWS WFO GOES-R Proving Ground partners are listed in Table 2. The WFOs listed in Table 2 are also displayed on the map in Figure 1 except for Pueblo (PUB), our newest partner. Our two oldest partners are the nearest WFOs to the CIRA group (located at Fort Collins and Boulder, Colorado), the WFOs at Cheyenne, Wyoming and Boulder. There are a number of obvious advantages to having a close WFO to partner with, including ease of more frequent visits, training opportunities, and general interaction. In the case of Boulder, the WFO is actually co-located with the research facility, and so it is easy to simply drop by and chat with forecasters when there is weather that is more appropriate for a particular product, or even to participate in forecast shift opportunities.

We have come to partner with the other WFOs in a number of different ways. Sometimes it is simply previous contacts with one of the forecasters (as in GJT, DVN, MKE, LAX and OAX) or a WFO (MTR), or through contact at a scientific meeting (BUF). Once a product is up and running at a WFO, other WFOs within the same region may want to try it (such as with RIW and PUB for the Synthetic Imagery product, or EKA and PQR for the Orographic Rain Index (ORI) product.

A number of the products are labeled as "pending" in Table 2. For many of these we are still working out final installation instructions, for some initial contacts and interest has been established, but other more pressing items at the WFO level have pushed back further progress at this time (in LAX, for example). At BUF the products are still

	WFO	Products	Server	Status
	PRODUCT IS GOING TO REGIONAL SERVER AND WFO			
	PRODUCT IS GOING TO REGIONAL SERVER BUT NOT WFO			
	PRODUCT IS NOT YET GOING TO REGIONAL SERVER			
	BOU (Boulder, CO)	GeoColor	CRHQ	Since April 2009
		Low Cloud/Fog	CRHQ	Since *October* 2009
		Synthetic NSSL WRF-ARW Imagery	CRHQ	Since October 2010
		MODIS Snow	CRHQ	Pending
	CYS (Cheyenne, WY)	GeoColor	CRHQ	Since April 2009
		Low Cloud/Fog	CRHQ	Since November 2009
		Synthetic NSSL WRF-ARW Imagery	CRHQ	Pending
	RIW (Riverton, WY)	Synthetic NSSL WRF-ARW Imagery	CRHQ	Since November 2010
	PUB (Pueblo, CO)	Synthetic NSSL WRF-ARW Imagery	CRHQ	Since November 2010
	OAX (Omaha, NE)	GeoColor	CRHQ	Since March 2010
		Low Cloud/Fog	CRHQ	Since March 2010
	BUF (Buffalo, NY)	GeoColor	CRHQ	Pending
		Low Cloud/Fog	CRHQ	Pending
		MODIS Snow	CRHQ	Pending
		GOES Snow		Pending
	DVN (Davenport, IA)	GeoColor	CRHQ	Since May 2010
		Low Cloud/Fog	CRHQ	Since May 2010
	MKE (Milwaukee, WI)	GeoColor	CRHQ	Pending
	GJT (Grand Junction, CO)	GeoColor	CRHQ	Since October 2010
		Low Cloud/Fog	CRHQ	Pending
		Dust	CRHQ	Pending
		MODIS Snow	CRHQ	Pending
	EKA (Eureka, CA)	ORI	WRHQ	Since February 2010
	PQR (Portland, OR)	ORI	WRHQ	Since May 2010
	MTR (Monterrey, CA)	ORI	WRHQ	Pending
	LAX (Los Angeles, CA)	ORI	WRHQ	Pending

Table 2. CIRA NWS WFO Partners.

being extensively tested first at the Eastern Regional Headquarters. While at times progress can be slow, it is important to be careful with installation so that the product delivery can be as dependable as possible. The forecasters certainly understand that the GOES-R Proving Ground products are experimental, but it is still important for them to be as reliable as possible. Otherwise, forecasters may soon lose interest in looking at a product if it is not available during interesting weather events when it may be particularly useful. In addition, we have found that it is quite important to have the products available on AWIPS and not just online, as the forecasters are far more likely to look at products that are easily available in a familiar format and setting.

Once a product is flowing reliably to a WFO, the next major issue is to solicit feedback from the forecasters. This can be one of the most challenging aspects of the interaction. Often a fine line must be tred between not asking the busy forecasters to spend extra time on formal feedback, as this can produce a negative reaction amongst the forecasters, and staying too much in the background, which can result in little if any feedback. We continue to explore the best and most effective ways to gather feedback from the different WFOs. For more remote WFO partners, the SOO and/or MIC (Meteorologist In Charge) can be the critical factor in interacting with the forecasters and gathering forecaster reaction. For closer WFOs (such as BOU and CYS) often the feedback may come through talking with the forecasters both at formal WFO Workshops as well as informally during a shift when interesting weather is occurring.

Forecasters will often use a product but it may become routine enough that they do not necessarily remember to record any formal feedback. With this in mind it is important for the forecaster to be able to enter commentary in as easy a manner as possible. We have found some success with the use of the forecaster shift log. In the case of WFO BOU, this is an online entry (formerly simply a written log) of comments on issues that come up during a shift. Recently we implemented changes to an online blog that has been used for some time by the Virtual Institute for Satellite Integration Training (VISIT) to make it easier for both forecasters and developers to enter comments related to the various GOES-R Proving Ground products. At this point it is too early to determine how effective this will be in soliciting more comments from forecasters, but it is an interesting platform for easily updating training type information by including case study entries in the blog.

4. CIRA GOES-R PROVING GROUND PRODUCTS

In this section we will give examples of some of the current CIRA GOES-R Proving Ground products. The complete list of products can be found at http://rammb.cira.colostate.edu/research/goes-r/proving_ground/cira_product_list/, and the list is also shown in Table 3. The product list appears online at the above link exactly how it looks in in Table 3. However, on the web each of the product names is also an active link to detailed information about each product, called "Product Descriptions". The Product Descriptions have a set format that includes (1) basic information about the product, including who is developing and receiving the productt and the product size; (2) a Product Description section that describes the purpose of the product, why the product is a GOES-R Proving Ground product, and how the product can be created now (before GOES-R is launched); (3) a section that gives examples and describes how to interpret the imagery; and finally (4) a section describing advantages and limitations of the product. The Product Descriptions contain a lot of information, but they are kept relatively brief, typically fitting onto a few web pages. Additionally, there is a basic version of each Product Description that is more concise, but can be easily expanded into the full Product Description.

The Product Descriptions provide a good introduction as well as a basic level of training. One of the ideas of the GOES-R Proving Ground blog is to provide a means of easily adding additional examples, both from product developers and forecasters.

4.1 *GeoColor and Low cloud/fog imagery*

We have grouped these first two products that were introduced to the WFOs together as aspects of the GeoColor imagery make it useful for highlighting low clouds and fog. In Figure 2 an example of both products is displayed for a case of

CIRA Product List:

Product Name	Product Input	Demonstration Type	Demonstration Resolution	GOES-R Resolution	Product Status/Availability	Product Source
GeoColor Imagery	GOES/MODIS/DMSP	New Imagery/Visualization Technique	GOES 4 km/30 min	2 km/5 min	Since Spring 2009	CIRA
True Color Imagery	MODIS	New Product	0.5 - 1 km/3 hour	1 km/5 min	Since Spring 2010	CIRA
Low Cloud / Fog Imagery	GOES	Product Variant	GOES 4 km/15 min	2 km/5 min	Since Fall 2009	CIRA
Cirrus Detection	MODIS	New Product	1 km/3 hour	1 km/5 min	Since Spring 2010	CIRA
Orographic Rain Index (ORI)	GOES/Radar/GFS	New Product	1 km/1 hour	2 km/1 hour	Since Winter 2009	CIRA
Marine Stratus Cloud Climatology	GOES	New Product	GOES 4 km/1 hour	2 km/30 min	Summer 2010	CIRA
Blowing Dust Detection (Split-window technique)	GOES	Product Variant	GOES 4 km/30 min	2 km/5 min	Since Fall 2009	CIRA
Blowing Dust (Blue-light absorption technique)	MODIS	Product Variant	1 km/3 hour	2 km/5 min	Since Spring 2010	CIRA
Cloud / Snow Discriminator	MODIS	Product Variant	1 km/3 hour	2 km/5 min	Since Fall 2009	CIRA
Cloud Layers & Snow Cover Discriminator	MODIS	Product Variant	1 km/3 hour	2 km/5 min	Since Fall 2009	CIRA
Snow / Cloud Discriminator (3-color technique)	GOES	Product Variant	GOES 4 km/30 min	2 km /5 min	Summer 2010	CIRA
Volcanic Ash (PCI)	GOES	Product Variant	GOES 4 km /30 min	2 km /5 min	Summer 2010	CIRA
Volcanic Ash (Blue-light absorption technique)	MODIS	Product Variant	1 km/3 hour	2 km/5 min	Summer 2010	CIRA
Land Surface Temperature (LST)	GOES	AWG Baseline Product	GOES 4 km/30 min	2 km/5 min	Summer 2010	CIRA
Vegetation (NDVI)	MODIS	New Product	1 km/3 hour	1 km/5 min	Since Spring 2010	CIRA
SPC Hail Probability	GOES / RUC	New Product	Probability forecast every 1 hour	Hourly	Since Spring 2010	CIRA
Synthetic NSSL WRF-ARW Imagery	NSSL WRF-ARW	New Product	4 km/ 1 hour	2 km/5 min	Since Spring 2010	CIRA
NHC Lightning-based TC Intensity Prediction	Ground-based lightning network/GFS/GOES	New Product	Probability forecast every 6 hours	6 hourly	Summer 2010	CIRA
MSG-based RGB Air Mass Product	MSG	New Product	MSG 3 km/30 min	2 km/5 min	Summer 2010	CIRA
MSG-based RGB Dust Product	MSG	New Product	MSG 3 km/30 min	2 km/5 min	Summer 2010	CIRA
Super Rapid Scan Imagery	GOES	Product Variant	4 km/7 min	2 km/5 min	Summer 2010	CIRA

Table 3. CIRA WFO Product List.

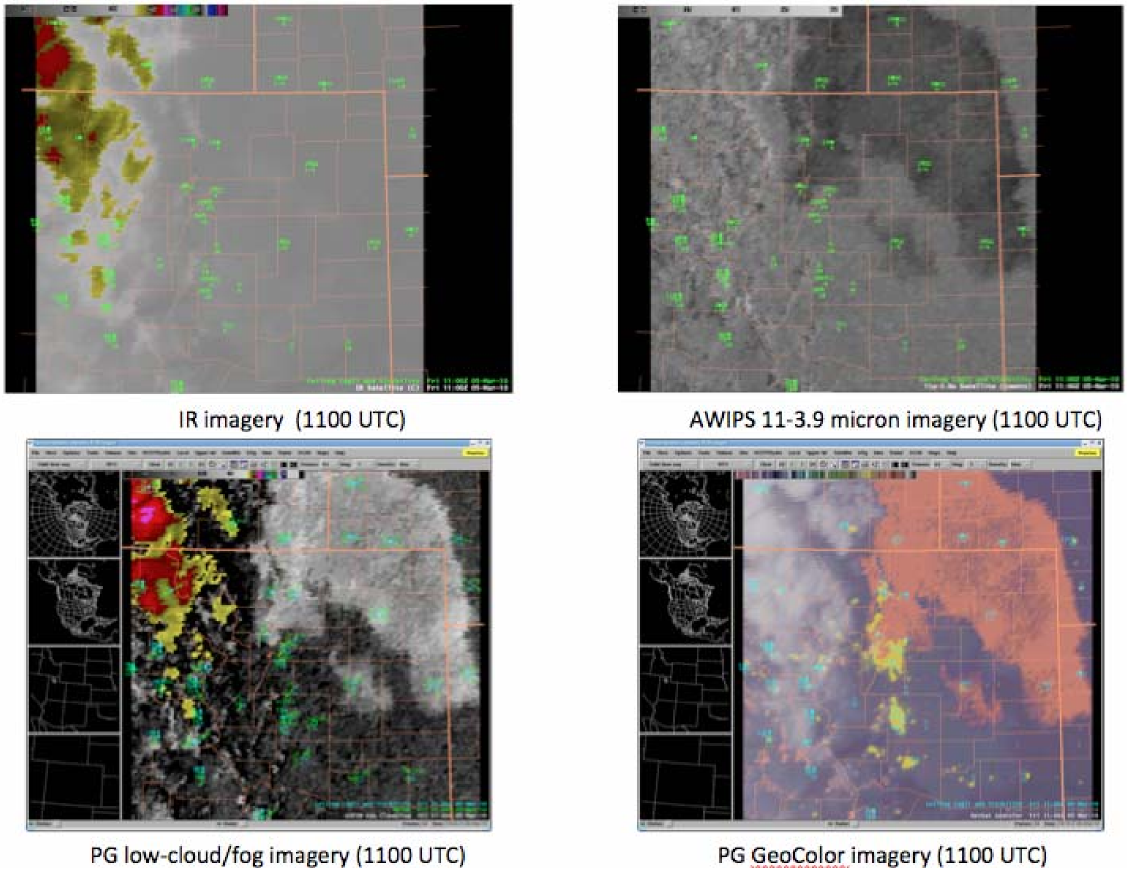

Fig. 2. Example of screenshots from AWIPS for 1100 UTC on 5 March 2010 of a standard IR image (top left), operational fog/low cloud product (top right), CIRA Proving Ground Low cloud/fog imagery (lower left), and CIRA Proving Ground GeoColor imagery (lower right).

early morning (1100 UTC) low clouds and fog in Northeastern Colorado on 5 March 2010. The GOES-R Proving Ground imagery is compared to a basic standard IR image and the main fog product used by forecasters and available on AWIPS (11 minus 3.9 µm imagery). Clear differences are seen in how the area of low clouds and fog is displayed in each of the images.

There is a lot more to the GeoColor Imagery than a different presentation of low clouds and fog. The product is a nice representation of the capabilities that will be available in the GOES-R era, and was initially developed several years ago for use by forecasters at the Naval Research Laboratory in Monterey, California. The image combines IR and visible imagery to make a single image that smoothly transitions from day to night, uses true color and city lights as background, and makes use of the difference between GOES channels 2 and 4 (3.9 and 11 µm, identical to the difference used for the standard low cloud/fog imagery now available to forecasters) to distinguish low clouds and fog at night, which are colored pinkish/red. The daytime image resembles the current GOES visible image except that a natural color background is used.

The GeoColor product is created with blending techniques in the vertical and horizontal that are used to combine the images. The current GOES visible and IR images provide the basic satellite imagery for the product, with a horizontal blending at the day/night interface done by employing a solar zenith weighting factor. The true color image used for the daytime background comes from the NASA Blue Marble dataset, while the nighttime lights comes from an NGDC dataset. Both images are static images in the current product, but in the GOES-R era they will be frequently updated using imagery from the new "Joint Polar Satellite System" (JPSS). Vertical blending is used when compiling the imagery, with the GOES images scaled to define a transparency factor that allows the background to penetrate through the cloud layer, depending on its thickness and properties. The 11 – 3.9 µm imagery is introduced as a separate layer in the vertical blending of the GeoColor imagery. In this way a special color table is applied to the low cloud/fog layer to make it distinct from the other clouds.

Initial reaction to the GeoColor imagery by forecasters at the BOU WFO was mixed. Some forecasters found the city lights to be a distraction. It is interesting though that over time the imagery has become accepted and even preferred by a growing number of forecasters, and there has generally been a positive reaction to the imagery when introduced at other WFOs.

The CIRA low cloud/fog imagery, described in detail by Kidder et al. (2000), uses a simple algorithm to compute the reflected (only) component of the shortwave (3.9 µm) infrared window band, which normally consists of both emitted and reflected energies. The emitted component is removed through the use of the longwave (10.7 µm) infrared window band, by computing the shortwave-equivalent radiance from the longwave radiance through simple Planck function relationships. The behind-the-scenes name for the Low-Cloud/Fog product is the "Shortwave Albedo" product, indicating that the image is really the reflected component or albedo that remains after the emitted component has been subtracted.

The reflected component of the shortwave infrared window band is the key to the product. In the shortwave portion of the spectrum, ice clouds and snow are not very reflective, unlike water-droplet clouds, which are highly reflective. This characteristic leads to an easy way to distinguish between ice and water clouds. Although this distinction is seen in the shortwave infrared window band alone, subtracting the emitted component of the shortwave highlights/enhances the reflected component for the user of this product.

This product has heritage in the "fog" product that was developed after the first appearances of the shortwave infrared window band on geostationary satellites in the 1980s. The fog product however has its best application at night. Another "reflectivity" product for daytime use has also been used to distinguish between ice and water clouds. But the Low-Cloud/Fog product is a more general form of both products, generated by a single formula both day and night, unlike the distinct fog and reflectivity products, which are generated differently. Reaction to this product has varied among WFOs, but so far it has not been used quite as much as the GeoColor imagery.

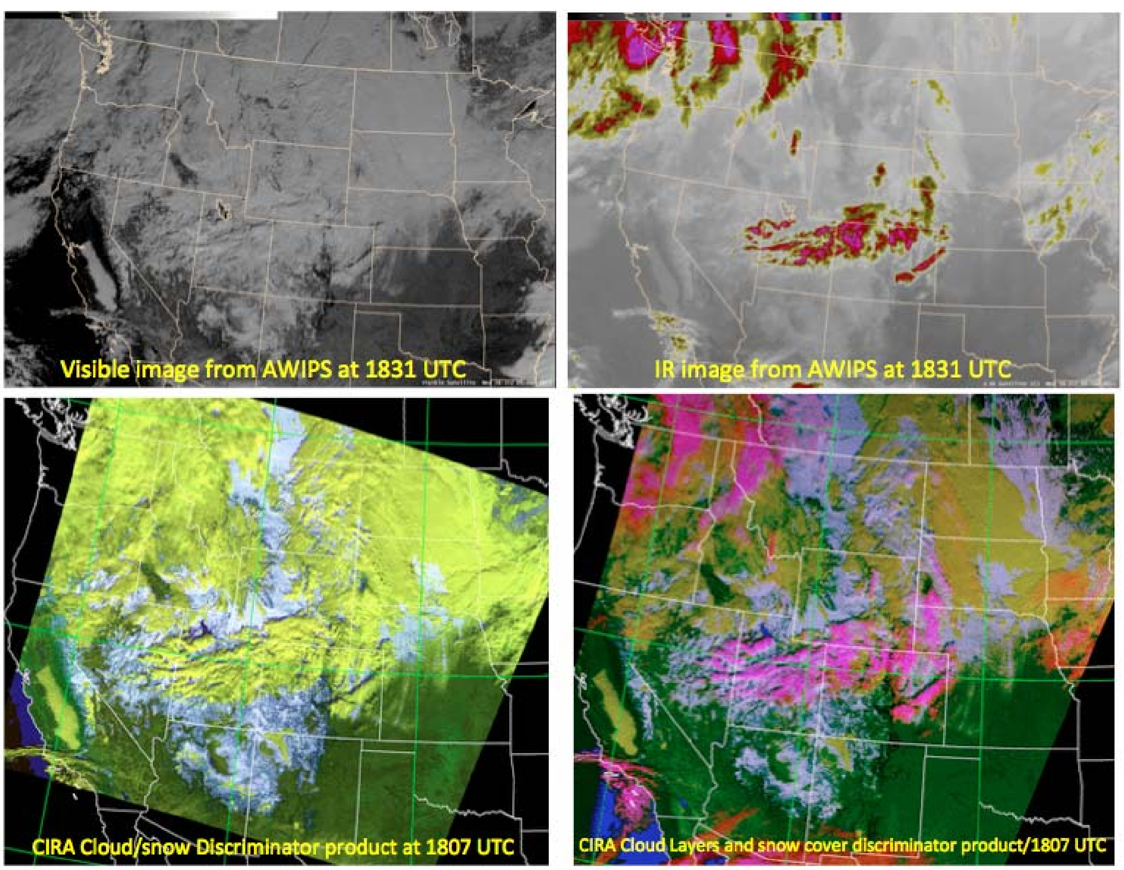

Fig. 3. Example of the CIRA cloud/snow discrimitor products compared to standard visible and IR imagery for 5 January 2011.

4.2 *Snow/Cloud Discriminator Products*

The next set of imagery described can be used to help forecasters address the issue of diagnosing clouds over snow cover during the daytime. An example of the two MODIS-based CIRA products is shown in Figure 3, along with a standard visible and IR image for 5 January 2011. Widespread snow cover was present across the western half of the nation, including much of the white area in the visible satellite image. There are different layers and amounts of cloudiness over the snow cover, some of which can be discerned with the IR image. But some of the areas of clouds are difficult to detect either with the IR or visible image, or even when looping the visible imagery. Two different CIRA products to help discriminate clouds from snow are presented in Figure 3. Both of the products use bands available on the MODIS Terra and Aqua satellites and not available on the current GOES to demonstrate products that will be possible using the same or similar bands with GOES-R. The advantage of using the MODIS imagery is that the images created will look very much like what will be possible with GOES-R. The main disadvantage is that the time resolution for satellite coverage in a particular area outside Polar regions is poor, with only two images available per day by using both satellites. Of course in the GOES-R era the frequency of the data will be much improved.

The poor time resolution can be a significant hindrance to how useful MODIS-based Proving Ground products can be. However, because they can represent bands that will closely match those in the GOES-R era, the general feeling is that they are valuable to the Proving Ground effort. One additional limitation that can be a hindrance to their use is that a number of images per day can be ingested that might partially cover an area near a WFO, but will for the most part be blank over the WFO area and of limited, if any, use. However, ingesting these images can use valuable bandwidth, which is often limited at a WFO. With this in mind, CIRA developed software to pre-select only those images (two per day) that would be most applicable to a given WFO. This will also allow a partner WFO to use the saved bandwidth to possibly ingest other products that may be developed.

The CIRA Cloud/Snow Discriminator product (lower left image in Figure 3) is created by combining information from several channels into a single visual aid. The image combines visible (VIS), shortwave infrared (SIR), thermal infrared (TIR), and 1.38 µm cirrus-band (CIR) channels, then using a special color coding. In the image, clouds are color-coded as yellow/light-green, snow cover appears white, and clear-sky surfaces appear darker green. This results in a much easier distinction of clouds from snow than is possible with either IR or visible imagery.

The second product shown in the lower right image of Figure 3 is called the CIRA Cloud Layer and Snow Discriminator product. This is similar to the other product, but goes a step further by using the 1.6 and 3.9 µm channels to determine cloud type, either ice or liquid phase, instead of simply clouds. The color coding is therefore more complex, as seen in the image in Figure 3, with green = land (clear sky, devoid of snow cover), white/bluish-white = snow cover, yellow = low-level liquid-phase clouds, and orange/magenta = mid/high level ice phase clouds.

Both of the products have only recently been introduced, so we do not have any definitive feedback at this point. However, already we have had additional WFOs express an interest in receiving the imagery. An additional GOES-based snow discriminator product is under development, listed in Table 3, that should be ready for distribution fairly soon.

4.3 *Cirrus Detection Product*

Another MODIS-based product recently introduced (but not yet being ingested at any WFOs) is the CIRA Cirrus Detection Product. An example of this product for the same time as our example in Figure 3 (1807 UTC on 5 January 2011) is shown in Figure 4. The Cirrus Detection product is actually composed of two algorithms - one that works for day and the other for night. We can take advantage of additional information from solar reflection channels during the daytime orbits to produce a superior product. At night we resort to other channels for cirrus detection, but must be more conservative in order to avoid false alarms in the enhanced imagery.

The daytime algorithm hinges on the measurement of reflected sunlight in the 1.38 µm shortwave infrared channel mentioned above. This channel is special because the abundant water vapor of our planet's atmosphere is strongly absorbing in this region, meaning that sunlight that travels too deep into the atmosphere has no chance of reflecting back to the satellite. Cirrus clouds, which reside high in the atmosphere and above most of the water vapor, reflect this 1.38 µm radiation with minimal effect of water vapor absorption, and are therefore sensed by MODIS. Low-level clouds and the surface, on the other hand, are "buried in the vapor" and effectively filtered from the scene. Reflection detected in the 1.38 µm channel above a certain threshold is considered "cirrus" and color-coded as blue.

To separate thin from thick cirrus, we use two more MODIS channels (6.7 and 11.0 µm) situated

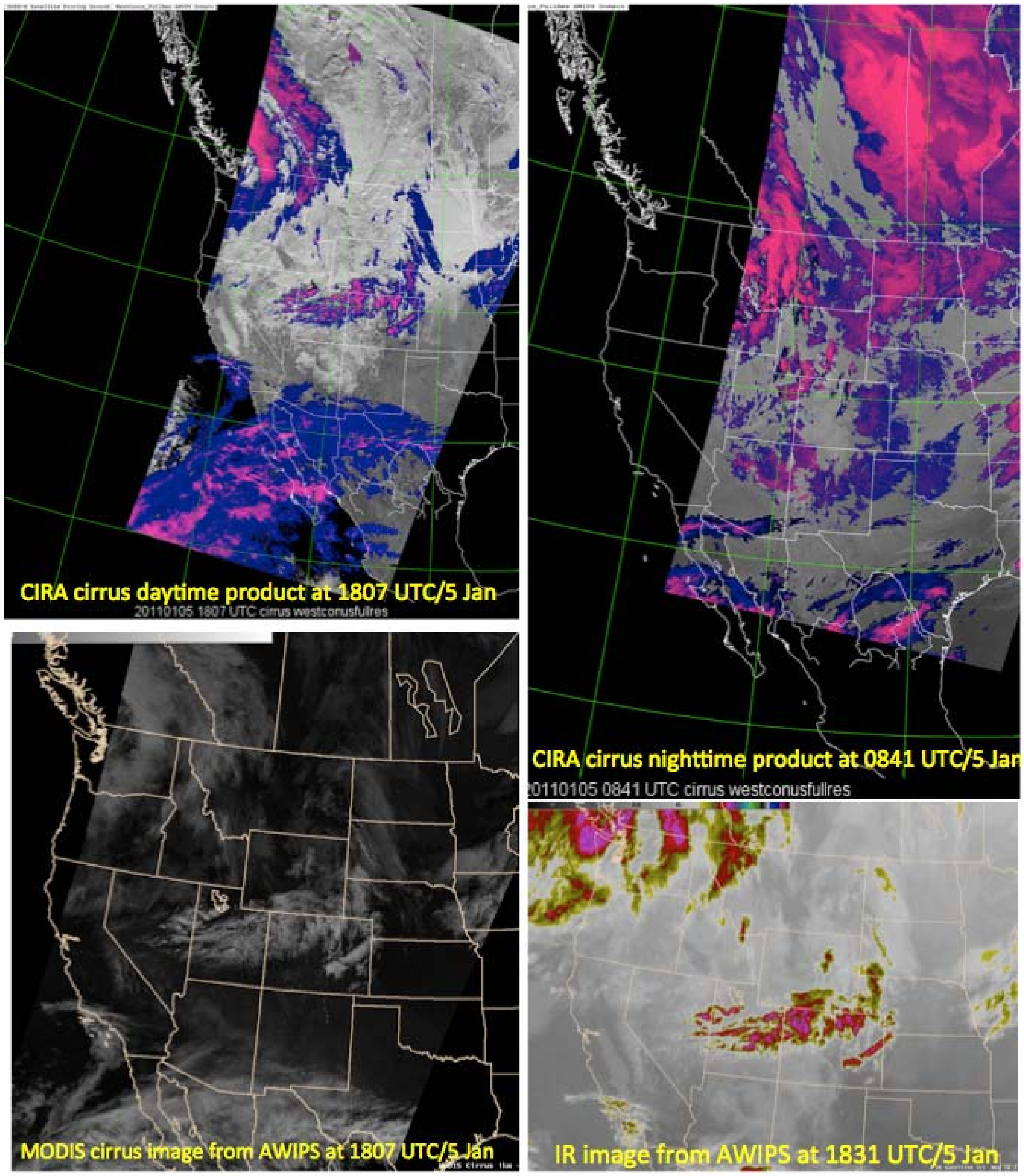

Fig. 4. Example of the CIRA cirrus products (day and night version) compared to a MODIS cirrus image and IR imagery from AWIPS for 5 January 2011. Note that the cirrus nighttime image is about 12 h earlier than the others.

in the infrared part of the spectrum. The 6.7 µm channel corresponds to another one of those "water vapor absorption bands" just like the 1.38 µm channel, but since it's in the infrared part of the spectrum (where sunlight has minimal contribution) here we are dealing with Earth/atmosphere emissions only. The 11.0 µm channel is in a so-called "clean window" region, in the sense that water vapor and other gases are mostly transparent to radiation having this wavelength (so from a satellite vantage point we could in principle see all the way down through the intervening atmosphere to the surface in this band, if a cloud is not in the way). Measurements from these channels are expressed in units of temperature and we are interested in the difference between these two measurements (6.7 vs 11.0 µm) as a way to find thick, deep clouds in the scene. The idea is that low clouds will again be "buried" in the water vapor, and since the 6.7 channel sees the temperature of the cooler water vapor present above the cloud (since temperature decreases with height), the satellite-measured temperature will be lower than the actual cloud top temperature. The same cloud observed at 11.0 µm (the window channel) will yield a temperature much closer to the true cloud top temperature. So, the difference between the two measurements (6.7 vs 11.0 µm) will be large. Conversely, for a high and thick cloud, there is not much water vapor above it to depress the relative difference between 6.7 and 11 µm. Essentially we look for small differences between these two channels as a proxy for where the high and thick clouds are. We color code these areas as Red. In terms of color composites, anywhere both cirrus (blue) and "thick high cloud" (red) are present, a magenta color is formed.

While the 6.7-11.0 µm difference technique described above also applies to night imagery, we no longer have access to the 1.38 µm information to identify any thin cirrus component. Fortunately, another channel difference between 3.7 µm and 11.0 µm works fairly well for this purpose. 3.7 µm is a special channel because it is sensitive to both sunlight and earth/atmosphere radiation. At night, the sun-component is removed and this channel is very useful for detecting warm surface emissions (this channel is the cornerstone of fire detection). Because it is so sensitive to heat, any small amount that transmits through thin cirrus to reach the satellite creates a strong signal. This is in contrast to the 11.0 µm measurement, which will report a cooler temperature. In this way, we look for large differences between 3.7 and 11.0 µm as a way to highlight thin cirrus, which gets color coded as blue just like in the daytime enhancement.

4.4 *Dust Detection Product*

Another new product that is close to being distributed to WFOs is the Dust Detection Product. There are actually two products that CIRA has developed to highlight areas of blowing dust, one using MODIS channels and the other channels that are on GOES-West, and which will be available again in the GOES-R era. An example of the GOES-based product is shown in Figure 5.

The GOES-derived product displays standard GOES Imager data in a unique way using simple image differencing and color enhancement. It uses a split-window technique, and the inputs are the 10.7 um (more-transparent longwave) and 12.0 um (less-transparent longwave) infrared window bands from the GOES Imager. Simple image differencing is used to compute the longwave infrared window band difference in temperature units. Since the brightness temperatures in two longwave window

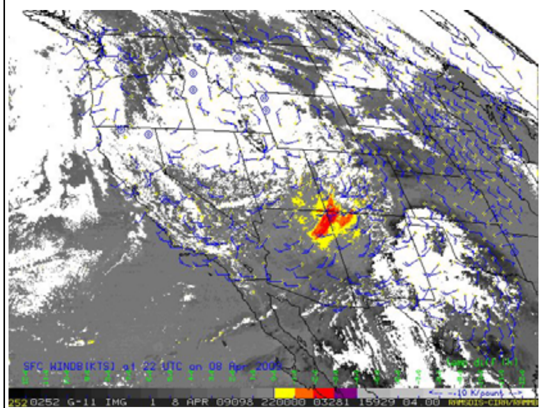

Fig. 5. Example of the CIRA GOES-based Dust Detection product. Dust is shown by the yellow and red colors near the Four-Corners region for this example at 2200 UTC on 8 April 2009.

bands (10.7 minus 12.0 µm) are only slightly different, that temperature difference has an average near zero and a range from at most about -10°C to +10°C, and much less for most image features. That difference is then stretched to fill the full range of available image counts (0-255) and is color-enhanced to emphasize the negative temperature differences (as yellow and red) that are indicative of blowing dust (with the more intense dust as red). The product is then improved by applying a cloud mask that eliminates the larger positive temperature differences and clouds (shown as the white areas in Figure 5).

The other CIRA Dust Detection product uses MODIS and a blue-light absorbtion technique. The current approach combines several of the more reliable discriminators, which take advantage of the spectral bands that will be available to GOES-R. An example of the imagery derived from this technique is shown in Figure 6.

Three considerations were used in developing the enhancement for this product:

1) Color: to some extent we can distinguish dust from meteorological clouds with our own eyes through color differences (mineral dust clouds often have earth tones, owing to their strong absorption of blue light). Since most meteorological clouds appear gray/white, the color information provides a useful discriminator. This is why true color imagery can also be useful for dust detection. A satellite sensor that has the ability to distinguish color (e.g., via multiple narrow-band channels in the visible part of the spectrum) can combine this information in an analogous way to color vision for dust detection. This approach works well over dark surface backgrounds, like water, but

becomes problematic over bright surfaces like deserts (and particularly, when the dust is over a surface background that has similar coloration to the dust itself). In this case, we need to appeal to other discriminators, and these are described below.

2) Temperature: When dust is lofted into the atmosphere, its temperature rapidly adjusts to whatever the air temperature of the environment is. The dust layer will have a radiative influence on its environmental temperature (via absorption of upwelling thermal radiation from below, and reflection of incoming solar radiation from above) but these effects occur on longer time scales and are of secondary importance here, so we ignore them. Since temperatures in the lower atmosphere generally decrease with height (especially during the daytime hours), the dust layer cools as it rises, and soon produces a nice "thermal contrast" against the warmer surface. A satellite sensor that is sensitive to heat (infrared radiation) can therefore assist us in detecting an elevated dust plume based on the temperature contrast it produces against the warm background surface. If we combine this temperature contrast information with the color distinction information, now we have a more robust way of distinguishing between meteorological clouds (which are gray/white and cool) and dust plumes (which are earth-tones and cool) over both water and land surfaces than either test can provide on its own.

3) Spectral Differences in Transparency: The chemical and physical properties of mineral dust layers give rise to different optical properties (scattering and absorption behavior) depending on what part of the infrared spectrum we view them in. In the same way that these properties result in preferred blue-light absorption in the visible part of the spectrum, differences occur in the middle and thermal infrared parts of the spectrum which gives rise to dust plumes appearing "thinner" (more transparent) or "thicker" (more opaque). As a result, measurements of a mid-level dust plume in a part of the infrared spectrum that corresponds to the more absorbing behavior may appear cooler than measurements of that

In the example shown in Figure 6 the dust is clearly same dust plume in a part of the infrared

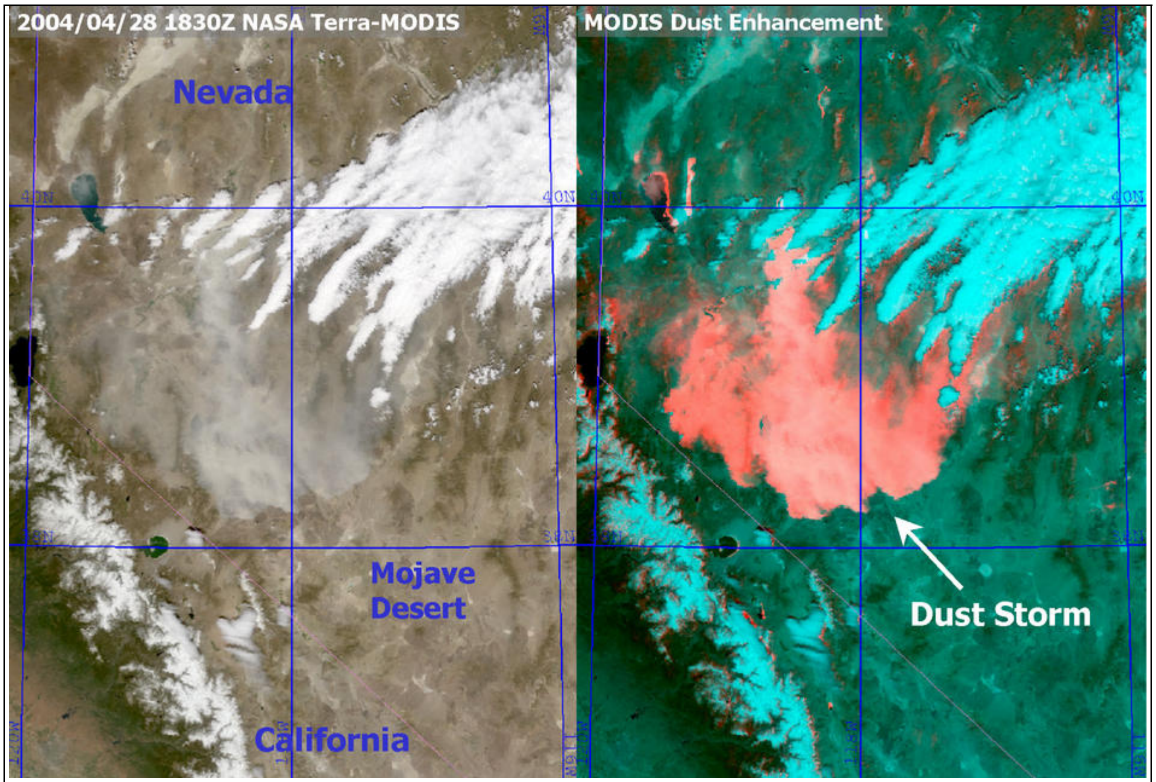

Fig. 6. Example of the CIRA MODIS Dust Detection product (right image) for the case of a dust storm centered over Nevada, compared to visible imagery from the same Terra-MODIS satellite for a storm on 28 April 2004.

spectrum where dust appears more transparent. In the case of more absorbing behavior, we're seeing more of the cool emissions of the dust layer's environmental temperature, while in the case of more transparent behavior we're seeing warmer contributions from the underlying surface that are able to transmit through the dust. Computing a difference between two such measurements, chosen carefully, provides an effective way to identify dust. The two channels used here are the 11 and 12 micrometer thermal infrared bands, which provide a dust detection signal that is opposite in sign to most meteorological clouds.more visible in the Dust Detection Product compared to the visible imagery. The Grand Junction, Colorado (GJT) WFO is most interested at this time in testing the dust products, especially after a recent late March dust storm that ended up influencing snow melt later in the spring with a change in the snow albedo.

4.5 *CIRA Synthetic Imagery Products*

As noted earlier, another approach for introducing potential satellite products is through "synthetic imagery", where one uses the sophisticated cloud microphysics scheme available with a high-resolution model to output cloud imagery that simulates what the satellite would produce for different bands. In this way, one can show the forecaster what a particular GOES-R band will look like. At this time, CIRA produces synthetic imagery for four bands that will be available on GOES-R; 6.95 µm (band 9, similar to the current GOES 6.7 µm water vapor band on AWIPS), 7.34 µm (band 10), 8.50 µm (band 11), and 10.35 µm (band 13, similar to the GOES IR band on AWIPS). An example comparing these bands is shown in Figure 7. The imagery is generated from the NSSL ARW version of the WRF model, run at a 4-km horizontal grid resolution once per day at 0000 UTC out to 36 h. The model output is processed at CIRA in Fort Collins and the products sent to the NWS Central Region server for distribution to the WFOs. The process occurs quickly enough for most of the imagery to be available to the forecasters by ~0900 UTC, which is early enough to use in preparation for the early morning forecast package.

We introduced synthetic imagery to the BOU WFO early in the fall of 2010, and more recently to the WFOs at RIW and PUB. Initial reaction has been quite positive (with more feedback so far, of

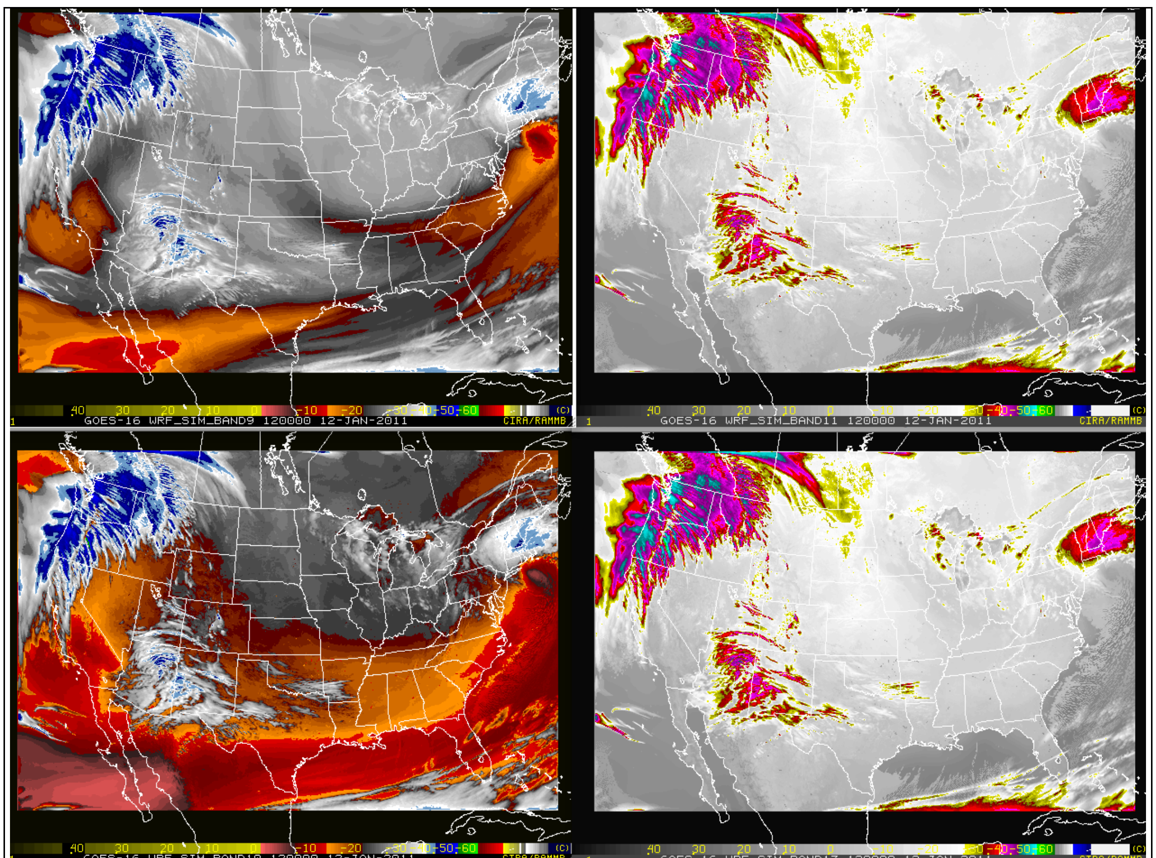

Fig. 7. Example of the CIRA Synthetic Imagery products, generated for a 12-h forecast valid at 1200 UTC on 12 January 2011. Bands shown are 9 (upper-left), 11 (upper-right), 10 (lower left) and 13 (lower right).

course, from BOU). In part this may be because the imagery represents a new way to view output from a high-resolution model. Naturally forecasters might be suspicious of how well a model can simulate clouds, since this is a new type of model output. With this in mind, the first two bands introduced were similar to the GOES IR and water vapor bands that are familiar to forecasters. This provides a way for the forecaster to gauge model reliability by comparison to imagery that they are accustomed to examining. A common forecast problem along the Front Range of Colorado is the prediction of wave clouds, which can change a temperature forecast (both low and high temperature). We received very early positive feedback early on from the BOU WFO when the forecast successfully showed the development of a wave cloud along the Front Range.

Of course the real goal of using the synthetic imagery is to introduce the forecasters to new bands that will be available on GOES-R and new products that will be possible. In this regard two new bands have recently been added, band 10, another water vapor type band, and band 11, a different IR band. Other and more complex imagery will also be possible in the future.

4.6 *CIRA Orographic Rain Index (ORI) Products.*

A different type of product is the CIRA Orographic Rain Index (ORI) product. This is another different type of Proving Ground product in that it is derived from the CIRA blended Total Precipitable Water (TPW) product, which uses measurements from various satellites and sensors. These measurements will improve in the GOES-R era, so this product represents an application of the improved sensing ability of the GOES-R satellite to a derived product intended to aid in the nowcasting of orographically enhanced precipitation. The TPW imagery is combined with short-range forecasts of the 850 mb horizontal wind from the NCEP GFS model (needed to advect the TPW out to 3 h) and high-resolution topography to produce a product that consists on an index that can be related to rainfall rate (the origins of the development of this product were from precipitation experiments along the West Coast, see Nieman et al 2008).

An example of an ORI image for the first big impulse of rain during the big mid-December 2010 West Coast rain event is shown in Figure 8. This is compared to a low-level reflectivity scan from the Monterey, California NWS radar. The two images are quite different, but one feature that stands out is that the coverage of the ORI product is uniform up and down the coastal mountain range, while the radar, of course, will suffer from obstruction by topography and change with distance from the radar. The detail is also very impressive in the ORI image, and this comes from the use of the high-resolution topography in the calculation of the ORI product.

A closeup of the ORI image as it would appear on the AWIPS localized for the Monterey WFO is shown in Figure 9. We have used the AWIPS "combine image" feature to blend an image of topography as a background. In this way we can clearly see how the ORI product identifies areas where orographically-forced precipitation is maximized. Such precipitation can be important to short-term flooding concerns, and certainly the ORI product can have value in identifying flooding

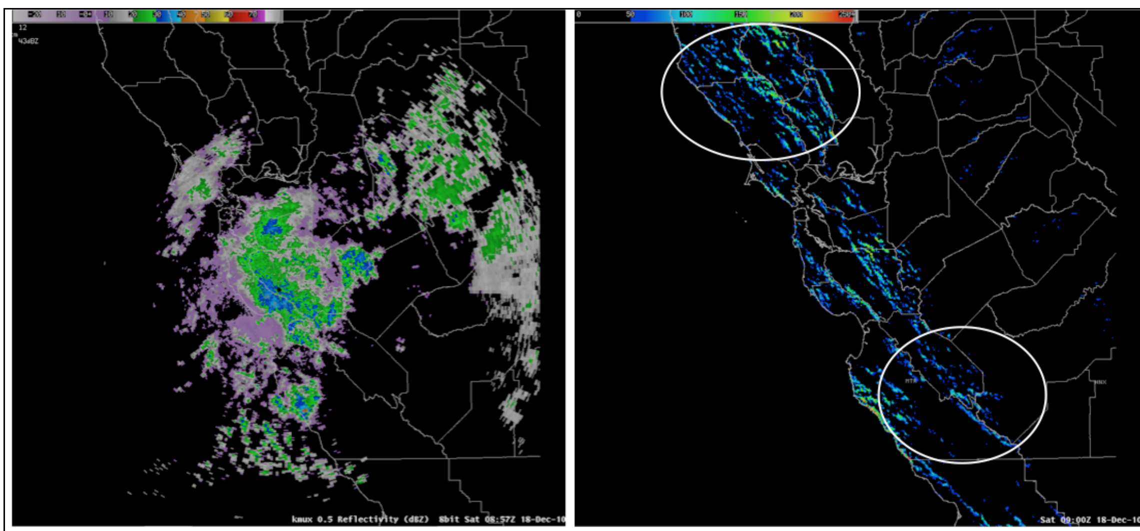

Fig. 8. Comparison a low-level radar scan (left) from KMUX (Monterey, California) compared to the CIRA ORI product (right) for 0900 UTC on 18 Dec 2010, the start of a big rain event in California. Areas outlined by the ovals demonstrate how ORI can "see" areas outside the local radar range.

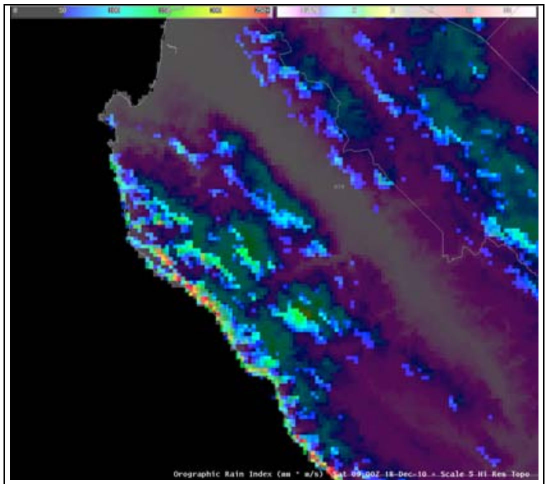

Fig. 9. The same ORI image as in Fig. 8 but here combined with a high-resolution topography image from AWIPS.

potential for nowcasting and warning concerns.

The ORI product has been used for several years at the Heavy Precipitation Branch of the NWS Hydrometeorological Prediction Center (HPC), and is referenced in some of their discussions. At the WFO level it is still fairly new to the forecasters (at Eureka, California and Portland, Oregon). Because it is an index and not a forecast of an actual precipitation amount, there is still some uncertainty as to how to interpret and use the ORI product. Clearly further training and direct interaction will be needed with the forecasters before it can become potentially more useful to them.

5. FUTURE DIRECTIONS

We have given an overview of the current CIRA GOES-R Proving Ground products and the WFO partners that we are interacting with. While the list of WFOs has grown, we are still in the process of bringing a number of the WFOs into real-time product delivery. It is important to have any new products delivered to the forecasters via AWIPS, but this must be done carefully so as to prevent any interference with operations. Close communication with the NWS Regional Directors was also emphasized in the May 2010 GOES-R Proving Ground annual meeting in Boulder.

In addition to interaction at the WFO level, continued interactions with the national centers are planned, including the National Hurricane Center and the Aviation Weather Center. Planning is underway for participation once again in the Storm Prediction Center (SPC) 2011 Spring Program.

An important challenge in our interactions continues to be determining the best way to get forecaster feedback. Online forms remain a possibility, but the forms must be carefully designed so as to not be overly long, and yet still be able to capture quantitative as well as free-form feedback from the forecasters. We have had some success with more informal methods (emails, shift logs at the WFO), but it is clear that feedback will be more frequent if the WFO management (MIC and SOO, for example) is firmly on board and the forecasters find the products interesting and potentially useful to their operations. Forecaster feedback from two of the WFOs is given in another paper at this conference by Niefeld et al (2011).

The CIRA GOES-R Proving Ground products cover a wide range of methods of introducing GOES-R like products to the forecast community. This includes use of current GOES, MODIS, derived products (such as ORI), and synthetic imagery. This will give us a lot of potential to pursue additional products in the future.

6. ACKNOWLEDGMENTS

We thank Brian Jamison of GSD for an internal scientific review and Annie Reiser of GSD for a technical review.

6. REFERENCES

DeMaria, M., J. Knaff, M. Brennan, J. Beven, N. Demetriades, R. DeMaria, A Schumacher, and J. Kaplan, 2011: Tropical cyclone rapid intensity change forecasting using lightning ddata during the 2010 GOES-R Proving Ground at the National Hurricane Center. *Fifth Conference on the Meteorological Applications of Lightning Data.* Seattle, WA, Amer. Meteor. Soc., Paper 3.4.

Kidder, S.Q., D.W. Hillger, A.J. Mostek, and K.J. Schrab, 2000: Two simple GOES Imager products for improved weather analysis and forecasting. Nat. Wea. Dig., 24(4).

Nieman, P.J., F.M. Ralph, G.A. Wick, J.D. Lundquist, and M.D. Dettinger, 2008: Meteorological characteristics and overland precipitation impacts of atmospheric rivers affecting the West Coast of North America based on eight years of SSM/I satellite observations. *J. Hyrometeorology*, **9**, 22-47.

Nietfeld, D., J. Gerth and J. Craven, 2011: Use and evaluation of GOES-R Proving Ground Products at WFO Omaha and WFO Milwaukee. *Seventh Annual Symposium on Future Operational Satellite Systems.* Seattle, WA, Amer. Meteor. Soc., Paper 580.