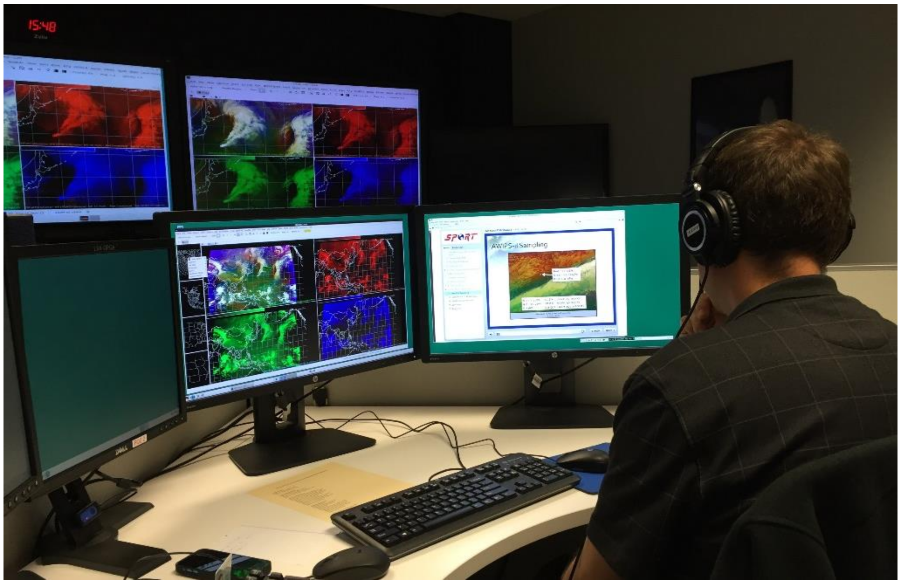
NWS Operations Proving Ground
Operational Impact Evaluation Report

Evaluating Applications and Visualizations of Multiple Spectral Bands for the GOES-R Era



NWS Operations Proving Ground
7220 NW 101st Terrace
Kansas City, MO 64153

Table of Contents

Executive Summary

In March and April of 2016, the National Weather Service (NWS) Operations Proving Ground (OPG) hosted and facilitated three week-long Operational Impact Evaluation (OIE) sessions where NWS forecasters evaluated applications of multiple spectral bands for the Geostationary Operational Environmental Satellite (GOES) R-series era. These evaluations focused on forecasters' ability to accomplish various analysis and forecasting tasks by correctly using and interpreting imagery from fifteen spectral bands and several red-green-blue (RGB) composites, all of which will be available when GOES-R becomes operational.

A total of nine NWS forecasters, representing five of the six NWS Regions, participated in this evaluation. In addition to the three forecasters at each session, a Subject Matter Expert from NASA's Short-term Prediction Research and Transition Center (SPoRT) was invited to observe the evaluation sessions while offering expertise with interpreting the satellite imagery. Data from the Himawari-8 (H8) Advanced Himawari Imager (AHI) were used as a proxy for GOES-R, since the latter is not scheduled for launch until November 2016.

Evaluation exercises were designed around four objectives:

1. Using H8 imagery and a phenomenon-based approach, gain insight into which spectral bands, channel differences, and/or RGB composites offer the most operational value in the opinions of participating forecasters.

2. Assess forecasters' ability to interpret and understand RGB imagery for various diagnostic tasks.

3. Assess and document any Advanced Weather Interactive Processing System (AWIPS) performance issues experienced while interrogating high-resolution satellite imagery.

4. Obtain feedback on the usefulness of the AWIPS Integrated Training Plugin, developed by NASA SPoRT and the NWS Experimental Plugin Development Team (EPDT), and document forecaster insights regarding needs for GOES-R multispectral application-based training.

Participating forecasters were guided through six different exercises, during which they were instructed to use AHI spectral bands and RGB composites to analyze targeted atmospheric and land-based phenomena. These phenomena that included fog and stratus (4 exercises), wildfire detection (3 exercises), smoke (3 exercises), convection (3 exercises), mid-latitude cyclones (3 exercises), and melting snowpack (2 exercises). All H8 data used in this evaluation was provided to the OPG by Dan Lindsey (NOAA Center for Satellite Applications and Research; Cooperative Institute for Research in the Atmosphere) and converted into Network Common Data Form (NetCDF) for AWIPS by Kevin McGrath (NASA SPoRT).

During each exercise, participants used real-time web-based observation logs to answer questions about how they used the imagery, and to document their observations as they analyzed different phenomena. At the conclusion of each exercise, OPG staff facilitated a group discussion with the participants. These discussions were invaluable as they allowed participants to raise questions about the process, the satellite imagery, or their interpretations; and to share insights they did not document in their observation logs. From the facilitators' perspective, these interactions also created an opportunity to deepen their understanding of the forecasters' knowledge, analysis methods, and ability to interpret the data correctly.

A significant majority of participants shared the opinion that a subset of spectral band imagery available on GOES-R will be valued and readily embraced by forecasters for a variety of practical applications, while others will likely be used for more limited and specific purposes. They also concluded that the complexity of some RGB composite imagery (e.g., Air Mass and Nighttime Microphysics) will require the development of in-depth training and operationally-relevant examples in order for many NWS forecasters to achieve the level of understanding needed to apply them for decision making.

The AWIPS Integrated Training (AIT) Plugin received extremely favorable ratings from all nine forecasters. This is not surprising since the capability to immediately acquire product resources through an AWIPS workstation meets a need that has been expressed by numerous field forecasters in multiple forums (e.g., 2014 WR Region SOO Conference, 2015 National SOO Meeting, and 2014-2015 OPG Operational Readiness Evaluations). The benefits of having refresher information available at the moment the forecaster needs it, within his/her decision support system, are self-evident. In addition, the AIT framework represents an excellent structure for hosting a library of locally developed application/use cases. Many forecasters were impressed by the quality of the training resources as well. In fact, several commented that these materials (one-page quick guides and short, focused micro-lessons) would serve as a valuable supplement to GOES-R foundational training, and should be required for all NWS forecasters to complete as pre-launch training.

During the evaluations, qualitative feedback and quantitative statistics were gathered on AWIPS workstation performance. After different iterations of AWIPS configurations, feedback from participating forecasters revealed that Java Virtual Machine heap size of 6 GB and Common AWIPS Visualization Environment (CAVE) texture cache set to 2 GB provided the level of workstation performance forecasters needed to complete all tasks without experiencing unwanted slowdowns and errors. These settings also were sufficient for the AWIPS workstation to generate client-side RGB composites on demand. The evaluation led to seven findings and eleven recommendations that focused on preparing NWS forecasters to use high-spectral satellite imagery and RGB composites in the GOES-R era.

The OPG recognizes that it is important to convey these findings with care and restraint. There are inherent limitations, discussed in detail within the body of the report, when completing evaluations of new tools and capabilities. Nevertheless, we believe the observations, findings, and recommendations of these forecasters have merit. Furthermore, some generalizable conclusions can be drawn from the collective group experience, which can be used both to guide GOES-R initial operating capability decisions, and to inform future activities aimed at evaluating the data, testing new operating concepts, determining training gaps, and developing resources to address those needs.

1. Evaluation Purpose and Goals

The next generation of the Geostationary Operational Environmental Satellite (GOES) series, GOES-R, is scheduled to launch on 4 November 2016 and will offer improved spacecraft and instrument technology to provide more accurate, detailed, and timely detection of environmental phenomena. However, the increase in temporal, spatial, and spectral resolution presents both opportunities and challenges to the operational forecaster. For example, when compared to the current GOES imager, the GOES-R Advanced Baseline Imager (ABI) will provide forecasters the opportunity to analyze spectral imagery at four times the spatial resolution. This will not only increase forecaster confidence when analyzing weather-related hazards, but also to visualize and understand phenomena not possible with the current GOES imager. In contrast, an increase in temporal, spatial, and spectral information does pose challenges. For example, National Weather Service (NWS) forecasters currently receive five spectral channels from the current GOES series. However, most forecasters only use three of those channels (0.64, 6.5, and 10.7 µm) regularly for decision making. With 16 spectral bands on GOES-R, it is important to gather feedback on how NWS forecasters can effectively exploit the additional spectral capability. In addition, the vast amount of information that will be received from GOES-R will create new demands on system storage and performance.

In 2014, the Japanese Meteorological Agency (JMA) launched its Himawari-8 (H8; Bessho et al. 2016) geostationary satellite. The H8 spacecraft features fifteen of the sixteen spectral bands that will be on the GOES-R ABI (Fig. 1). Since these data are available now, the H8 Advanced Himawari Imager (AHI) offers an excellent opportunity to investigate which spectral bands and red-green-blue (RGB) composite imagery will be most useful for NWS forecasters. Therefore, the Operations Proving Ground (OPG) was enlisted to develop a series of exercises where NWS forecasters evaluate applications of multiple spectral bands for the GOES-R era, using H8 AHI data as a proxy for GOES-R ABI. Approval and funding to plan and execute this evaluation was granted by the NWS Science and Technology Integration (STI) portfolio, to be completed over three weeks in March and April of 2016.

This was the second evaluation of the GOES-R baseline cloud and moisture imagery organized by the OPG. The first, conducted in 2015, focused on using of high-temporal resolution satellite imagery in NWS Weather Forecast Office (WFO) operations (Gravelle et al. 2016).

In conjunction with the NWS Operational Advisory Team (NOAT) and the GOES-R Program, four evaluation goals were identified for this operational impact evaluation (OIE), as follows:

1. Using H8 imagery and a phenomenon-based approach, gain insight into which spectral bands, channel differences, and/or RGB imagery offers the most operational value in the opinions of participating forecasters.

2. Assess forecasters' ability to understand and interpret RGB imagery for various diagnostic tasks.

3. Assess and document any Advanced Weather Interactive Processing System (AWIPS) performance issues experienced while interrogating the high-resolution satellite imagery, emphasizing three specific target areas:

(a) Assess if dynamic generation of pre-defined RGB recipes on the AWIPS workstation has negative impacts on forecaster workflow and/or system performance;

(b) Assess whether normal actions taken by forecasters in manipulating satellite imagery have notable adverse effects on workstation performance (e.g., zooming, panning, roaming, merging images, superimposing other datasets, etc.); and

(c) Identify any shortcomings that could impact data retention needs in the GOES-R era.

4. Obtain feedback on the usefulness of the AWIPS Integrated Training Plugin, developed by the NWS Experimental Plugin Development Team (EPDT) and NASA's Short-term Prediction Research and Transition Center (SPoRT), and document forecaster insights regarding needs for GOES-R multispectral application-based training.

2. Participant Selection

NWS forecasters were selected to participate in the evaluation by NWS Regional Scientific Services Divisions. Since only nine NWS forecasters were participating in this evaluation, emphasis was placed on diversity in both geography and experience. The roster included five General Forecasters, three Lead Forecasters, and one Science and Operations Officer from NWS WFOs located in Eastern (2), Central (2), Southern (2), Western (2), and Alaska (1) Regions. Prior to arriving for the evaluations, participants were instructed to complete three COMET™ modules as foundational pre-requisite training: *GOES-R ABI: Next Generation Satellite Imaging*, *Advanced Himawari Imager*, and *Multispectral Satellite Applications: RGB Products Explained*. This material was intended to ensure baseline knowledge necessary to use the H8 imagery and accomplish the evaluation goals.

During each of the three week-long sessions, exercises were facilitated by OPG staff and one RGB composite subject matter expert (SME) from NASA SPoRT who assisted with technical and interpretive questions from the evaluation participants.

3. Description of Exercises and Assessment Methodology

During the evaluation exercises, forecasters received the fifteen spectral bands from H8 that will be included on GOES-R, and the RGB composite imagery shown in Fig. 1. Forecasters were not provided data from the AHI 0.51 µm band, whose central wavelength is in the green portion of the visible spectrum. Since there is no corresponding "green band" on GOES-R, this band was excluded. Each RGB composite was dynamically generated on the local AWIPS workstations using Python derived parameter code developed by a NWS EPDT, and refined by NASA SPoRT. Five of the six RGB composites analyzed during the evaluation used recipes developed by the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT; Fig. 2). These same recipes have been adopted by the JMA for use with H8. The one exception is the GeoColor RGB, which was developed by the Cooperative Institute for Research in the Atmosphere (CIRA). The True Color RGB composite was generated using the green component approximation developed by Steve Miller (CIRA) for the GOES-R era. In addition to the H8 satellite imagery and RGB composites, participants received Meteorological Terminal Aviation Routine (METAR) surface weather reports for each exercise and Global Forecast Systems model output for the mid-latitude cyclones exercises. Finally, the AWIPS Integrated Training Plugin was available for participants to access relevant training resources (Fig. 3) during the evaluation. Resources included ABI Fact Sheets for each individual spectral band. For each RGB composite, Articulate Modules and Interactive Quick Guides provided by NASA SPoRT were made available. All H8 data used in this evaluation was provided to the OPG by Dan Lindsey (CIRA) and converted into Network Common Data Form (NetCDF) for AWIPS by Kevin McGrath (NASA SPoRT).

In each exercise, the satellite imagery was systematically provided to the participants in an effort for them to achieve a level of comfort when assessing the satellite imagery's usefulness for analyzing the atmospheric and land-based phenomena. For example, while interrogating wildfires across southwestern Australia in Exercise 1 (Table 1), participants analyzed a single panel of the 0.64 µm band, followed by a series of two-panel displays (0.64 and 3.9 µm; 0.64 µm and True Color RGB; 0.64 µm and Natural Color RGB); concluding with a four-panel of the 0.64 µm and 0.47 µm bands, the True Color RGB, and the Natural Color RGB (fire variant; Fig. 4). After each panel of satellite imagery, participants answered questions that ranged from the usability of the satellite imagery to which spectral band and/or RGB composite was easiest to interrogate the phenomena. See Table 1 for a complete outline of Exercise 1. Variations of this approach, single band analysis followed by the inclusion of RGB composites, was used throughout each guided exercise participants completed during the evaluation.

Due to the varying complexity of RGB composite imagery, these composites were also systematically introduced to participants throughout the week-long evaluation. In Exercises 1 and 2 (occurring each Tuesday), the three simple (i.e., one spectral band in each RGB component) RGB composites (i.e., True Color, Natural Color, and Natural Color Fire Variant) were introduced to participants. Simple RGB composites are generally easier to interpret since they usually have atmospheric and land-based features that are similar to how the human eye may view the scene. In Exercises 3 and 5 (occurring on Wednesday and Thursday Mornings), the two complex (i.e., more than one spectral band in at least one RGB component) RGB composites, Air Mass (Fig. 2; EUMETSAT 2016a) and Nighttime Microphysics (Fig. 2; EUMETSAT 2016b), were introduced to participants. Here, participants initially analyzed phenomena using single band imagery which was followed by completing a RGB composite training module within the AWIPS workstation using the Integrated Training Plugin. These training modules gave participants a solid, baseline knowledge of how the RGB composite was created while providing several interpretation examples. One advantage to this approach is that participants can pause the module and integrate the displaced real-time imagery to deepen the understanding of the material. Once the RGB module was complete, participants used an Interactive Quick Guide for the remainder of the exercise to quickly access RGB composite background information or interpretation information.

Since the primary objective of this evaluation was to assess operational impact of GOES-R spectral imagery on operations, the exercises were distinctly different in character than those typically conducted at the OPG, where participants are asked to reproduce normal WFO routines. For this evaluation, forecasters were presented with selected satellite imagery, challenged to analyze and interpret the scene for specific phenomena, and then asked to hypothesize how the data might be incorporated into various operational tasks for NWS decision making. Participants were invited to interrogate scenarios featuring the following phenomena:

- fog and stratus (4 exercises)
- wildfire detection (3 exercises)
- smoke plumes and aerosols (3 exercises)
- deep moist convection (3 exercises)
- mid-latitude cyclones (3 exercises)
- melting snowpack (2 exercises)

Participants were guided through Exercise 1 and completed self-directed discovery in Exercise 2, using the fifteen H8 spectral bands, True Color, and Natural Color RGB composites while analyzing the phenomena listed above. In Exercise 3, occurring on each Wednesday morning, participants were guided through analyzing a developing mid-latitude cyclone, using the imagery discussed in Exercises 1 and 2, but with the addition of the Air Mass RGB composite. The focus on using the new spectral capabilities with a mid-latitude cyclone continued in Exercise 4 as participants completed a self-guided discovery exercise where they used the AWIPS Product Generation tool to perform a subjective analysis on the satellite imagery. Analyzing nighttime fog and stratus was the focus of Exercises 5 and 6 as participants were introduced to the Nighttime Microphysics RGB composite. Finally, in Exercise 7, participants were assigned to apply what they had learned from previous exercises, and create four-panel AWIPS displays that they felt would be useful for diagnosing each of the weather hazards that had been showcased earlier in the week. More details about these exercises can be found in Table 2.

During each exercise, participants used real-time web-based observation logs to answer questions about how they used the satellite imagery, and to document their observations as they analyzed the different phenomena. At the conclusion of each exercise, OPG staff facilitated a group discussion with the participants. These discussions were invaluable as they allowed participants to raise any questions about the process, the satellite imagery, or their interpretations; and to share or enhance insights they did not document in their observation logs. On each Friday morning, participants completed an anonymous comprehensive survey that allowed them to rate and discuss their experiences using the satellite imagery. The results presented in section 4 are a combination of the methods discussed here.

4. Overall Results

Before the results of this evaluation are presented, it is important to discuss potential limitations. First, evaluation participants were analyzing atmospheric and land-based phenomena over geographic areas in which they had no familiarity or experience. Although none of the participating forecasters raised this point as an issue of concern during the evaluation, it is worth noting.

Second, GOES-R baseline products that will be accessible to NWS forecasters along with satellite imagery (e.g., Total Precipitable Water, Derived Motion Winds) were unavailable during these exercises, as were most supplemental datasets that NWS forecasters routinely use for decision making (e.g., WSR-88D, High Resolution Rapid Refresh model output). Having all the datasets forecasters are accustomed to using would have provided a more realistic assessment of how the added spectral information from GOES-R enhanced their analysis and forecasting decisions. This option was largely precluded by the H8 West Pacific domain.

Third, during the evaluation exercises, participants used full-disk H8 imagery at native resolution (2 km at nadir). While this did not affect how forecasters analyzed the satellite imagery, it may have affected AWIPS performance. In the GOES-R era, full disk imagery will be processed with a spatial resolution of 6 km. The process of zooming in and roaming scenes derived from 2 km full disk imagery in order to interrogate a specific phenomenon is far more demanding on system resources than displaying the targeted subsector at 6 km resolution. Similarly, the process of dynamically generating RGB composites at the AWIPS workstation from a 2 km full disk is significantly more memory intensive than running the same procedure on a 6 km full disk or a 1-2 km subdomain.

Finally, the conclusions here are derived from a small sample size; based on the expertise of nine NWS forecasters who shared observations and suggestions during a single, three-day experience.

Despite these limitations, the observations, findings, and recommendations of these forecasters have merit. Furthermore, some generalizable conclusions can be drawn from the collective group experience, which can be used both to guide GOES-R initial operating capability decisions, and to inform future activities aimed at evaluating the data, testing new operating concepts, determining training gaps, and developing resources to address those needs.

4a. General Forecaster Feedback on Practical Utility of Imagery

To conclude each evaluation week, forecasters completed a 90-min anonymous online survey, which asked them to rate and discuss topics including, but not limited to, the utility of the individual spectral bands and RGB composites, applications of that imagery, and the exercises completed during the evaluation week. Following completion of the online survey, forecasters participated in a final group discussion with OPG facilitators.

There is some concern that forecasters may be overwhelmed with the challenge of incorporating three times more spectral information into their decision making routines. This concern drove the objective to ascertain whether OPG forecasters had a sense for which individual spectral bands offer the most direct and intuitive value for a variety of operational tasks. To determine their collective opinion, participants were presented with this question: *"From the perspective of your operational analysis and forecasting needs, rank imagery from the 15 spectral bands used during the evaluation in order of importance to you; with 1 being the most important and 15 being the least important."* The results from this question are summarized in Table 3.

While very subjective, and based on limited exposure, the results are interesting and instructive. First, after using the H8 imagery for seven exercises, the cumulative rank of the fifteen spectral bands shows a clear break point between the bands rated as seventh (cumulative rank of 56) and eighth (cumulative rank of 71) most important. This break is interpreted to infer that, based on their 3-day experience at the OPG, participating forecasters held the opinion that a few spectral bands (those ranked seventh and higher) will show themselves more valuable for operational forecasting tasks, at least initially. The fact that they identified a subset of bands as being most important does not imply that the others have no value; only that the utility of some bands can be recognized and applied more readily than others. During discussions, participants revealed that they recognized the potential for many of the spectral bands to provide useful information, yet it was their opinion that the operational value of some spectral bands will be in the form of contributions to algorithm-generated products or RGB composites. In contrast, there are some spectral bands for which the imagery provides valuable intelligence for analysis, interpretation, and situational awareness – in a way that is direct, immediate and intuitive.

A few general observations can be made from the top seven bands. First, eight of the nine participating forecasters ranked the 0.64 µm 500-m spectral band as most important. This is not surprising since the 0.64 µm band has the greatest spatial resolution of all fifteen spectral bands evaluated. Second, all three water vapor channels (7.3, 6.9, and 6.2 µm) were ranked among the top seven bands. It is clear that participating forecasters saw the value in being able to visualize four-dimensional atmospheric flow while being able to monitor large-scale regions of moist and dry air. In contrast, the only longwave infrared spectral band that ranked among the top seven was the 10.4 µm band (Clean Infrared Longwave). Participating forecasters stated, in both written surveys and group discussions, that the primary reason for ranking the 10.4 µm band higher was because it is less sensitive to water vapor absorption and, in turn, improves surface temperature retrievals. While forecasters shared a clear preference for the 10.4 µm longwave band when their intent is to analyze an individual longwave infrared band, most also expressed an understanding of the importance and value the 10.4-12.4 split window difference provides (Lindsey et al. 2014).

Finally, it is important to point out that forecasters did recognize some spectral bands ranked eighth and lower will offer significant value for specific applications. For example, the 0.47 µm (Blue Visible) and 0.86 µm (Veggie) bands will be useful for monitoring thin smoke or aerosols and to identify burn scars from wild fires, respectively.

Participating forecasters were also asked to identify the spectral bands and/or RGBs that were the most useful for diagnosing atmospheric and land-based phenomena. The spectral bands and/or RGBs that are listed below were identified by at least seven of nine participants.

Identify the spectral band(s) and/or RGB imagery you found most valuable for diagnosing the…

…formation, extent, and/or dissipation of fog and low stratus during the day.
1. 0.64 µm (Red Visible)

…formation, extent, and/or dissipation of fog and low stratus during the night.
1. Nighttime Microphysics RGB
2. GeoColor RGB (i.e., 10.4 µm - 3.9 µm Spectral Difference)

…development and decay of mid-latitude cyclones.
1. 0.64 µm (Red Visible)
2. Air Mass RGB
3. 10.4 µm (Clean Infrared Longwave)

…location, extent, and growth of wildfires and smoke.
1. 0.64 µm (Red Visible)
2. 3.9 µm (Shortwave Window)
3. True Color RGB
4. Natural Color RGB (Fire Variant)

…difference between ice clouds and liquid water clouds.
1. Nighttime Microphysics RGB

…initiation and evolution of deep convection.
1. 0.64 µm (Red Visible)
2. 10.4 µm (Clean IR Longwave)

Not surprisingly, there is an emphasis on the 500-m resolution 0.64 µm spectral band in daytime scenes with a secondary emphasis on the 10.4 µm longwave band. However, it is clear that forecasters found utility in using the individual spectral channels and RGB composites together. The four RGB composites introduced during the exercises were identified as being useful for diagnosing four of the six phenomena analyzed during the evaluation. All nine forecasters listed the Nighttime Microphysics RGB valuable for diagnosing the formation, spatial extent, and/or dissipation of fog or low clouds. In addition, participating forecasters identified the True Color, which is not scheduled to be a baseline GOES-R capability in AWIPS, and Natural Color (Fire Variant) RGB composites useful for diagnosing the location, extent, and growth of wildfires.

4b. Specific Quotes and Observations from Phenomena-Based Exercises

(1) River Valley Fog and Stratus Detection
"FLS is easily identified in the 0.64 µm channel. The [increase in] spatial resolution could lead the way to polygon Non-Precipitation Warnings by increasing confidence in areal extent and exact locations of the hazards."

"The [spatial] resolution in the 0.64 µm channel is so good that I can resolve many of the smaller river basins as well as the surrounding terrain, where cumulus clouds are already developing."

"The Natural Color RGB imagery adds new and relevant information to the scene. The valley fog appears tan/brown around the edges or where it is eroding quickly. Thus, with experience, this RGB would allow forecasters to acquire a sense of where the fog is eroding first and where it may linger longest. Operationally, this could influence decisions on dense fog advisories. These additional details seen in the Natural Color RGB are not available from the 0.64 µm channel image alone."

(2) Monitoring Wildfires
"Complexities in the fire behavior are more detailed in the Natural Color RGB. The Natural Color RGB clearly shows the difference in the vegetation types between the fires along the west coast and those in the area south of YPKG. The smoke plumes are clearly different colors, likely from the difference in fuel types."

(3) Frontal Convection and Dissipating Snow Cover
"There is impressive resolution of overshooting tops in all channels, but especially in the 0.64 µm and 11.2 µm imagery."

"The low/mid-level water vapor (7.3 µm) and the single 11.2 µm channels show development of new convective cells before the 0.64 µm channel or the 0.64-11.2 µm combined images."

"The spatial detail in the 0.64 µm 0.5 km image is striking. Variations in the contrast of the snow cover delineate topographic details including cities, valleys, and ridgetops. The snow cover is thin and eroding along the southeast edge, presumably at lower elevation. Overall contrast of the scene varies with sun angle through the day and there is a hint of cirrus coming into the scene from the southwest. Widespread stratocumulus forms downwind of the snow cover."

4c. AWIPS Integrated Training Plugin

One of the secondary objectives of this evaluation involved soliciting feedback on a prototype AWIPS Integrated Training Delivery plugin developed by NASA SPoRT. This plugin provides a framework for forecasters to access relevant training resources within their AWIPS CAVE session. The resources made available for this evaluation included GOES-R ABI Fact Sheets, Interactive Quick Guides, and Articulate micro-lesson modules. This "just in time" capability does not currently exist in the NWS operational environment. OPG management proposed this feature to the NWS Scientific Services Division Chiefs in 2015 as an enhancement to operational forecasters' expressed need for accessing short, focused, job-relevant training resources within their operational decision support system. Opinions were overwhelmingly favorable about these resources, both as a convenient training delivery concept, and for the quality of the content. Credit goes to NASA SPoRT, UW-CIMSS, and CIRA for the latter.

After completing the Mid-Latitude Cyclone exercise where the Air Mass RGB composite was introduced to participating forecasters, they were asked the following question: *On a scale of 1-10, where 1 is not valuable and 10 is extremely valuable, when learning how to interpret the Air Mass RGB imagery, how valuable was it to view the Airmass RGB Articulate Module and Interactive Quick Guide in AWIPS during this exercise to reinforce foundational RGB concepts learned before arriving at the evaluation?* Six of nine forecasters rated the value of the Integrated Training Plugin as extremely valuable with the other three forecasters rating its value at a nine, eight, and six, respectively. After using the Integrated Training Resources to introduce the new, complex RGB composite, two participating forecasters said the following:

"Being able to introduce a new product or new concept in AWIPS through a module like that, but also being able to look at real-time data to go along with that module, is a step in the right direction."

"I thought it was good. It was useful. I think the model of learning something and then immediately using it, is a model we don't use enough."

The following are overall forecaster comments about the Integrated Training Plugin capability:

"On a scale of 1-10....a 100. Integrated training ensures that training does not fall on the floor once foundational training is completed. It's a way for forecasters to continually be able to reference the building blocks and apply those building blocks to applications and the forecast process…continue to build on the knowledge they've gained!"

"Very valuable - a must have. I explained before that I have found myself fumbling around with papers/binders/laminations on shift just looking for a quick reference that I would not have to do if the Fact Sheets or Interactive Quick Guides were available to me with a click of a button."

"I like it having it there. It would be nice to have this type of training built into AWIPS for all the radar products too. There are so many, so it's hard to remember a lot of the nitty gritty detail [with the radar products]."

"Having to sift through hundreds of pages on our internal wiki/Google sites page at my office can get time consuming, so having this option to quickly pull up training right within AWIPS and have it right next to what you are viewing is something very valuable and beneficial in my opinion."

4d. AWIPS Performance

Another secondary objective was to assess and document AWIPS performance issues that were experienced while interrogating the high-resolution satellite imagery. Statistics were collected on three performance categories:

1) workstation responsiveness to various display commands (i.e., initial image display, zooming, panning, roaming, creating multiple-pane procedures and perspectives, manipulating color curves, and merging satellite imagery with other data sets);

2) dynamic, client-side generation of RGBs (as opposed to creating images on a central server and disseminating them across the SBN); and

3) adequacy of data retention for the GOES-R era (available space on current baseline AWIPS Direct Attached Storage (DAS) is very limited, and requirements for GOES-R storage will exceed current system capacity.

During the 3-week evaluation, a variety of workstation memory configurations were tested in an effort to optimize the performance of AWIPS under the increased workload of processing and displaying high-resolution satellite imagery.

The first evaluation week was used to document performance of the AWIPS Build 16.1.1 baseline configuration. Workstations were configured with texture cache set at 512 MB and Java Virtual Machine (JVM) heap size at 1024 MB. This AWIPS configuration was quickly identified as being inefficient; forecasters experienced frequent and persistent messages regarding low memory resources. By the end of the first week, over 370 errors were documented.

Prior to the second evaluation, the OPG AWIPS was reconfigured to texture cache to 512 MB and JVM heap size to 4 GB. These adjustments resulted in improvement, but slow performance and recurring memory resource errors were still common enough to be disruptive. On Day 3, the texture cache was increased to 1 GB and the JVM heap size to 6 GB. While this decreased the number of recorded errors on the third day to 35, with a total number of errors for the week at 240, participating forecasters said they were still too frequent when compared to AWIPS performance they are accustomed to.

Finally, at the beginning of the third evaluation week, texture cache was increased to 2 GB with JVM heap size set at 6 GB. With this configuration, only 19 errors were recorded for the week and all occurred with a single forecaster during the first exercise. The final six exercises were completed with no performance slow-downs or memory issues. All three forecasters identified workstation performance as being similar to what they are accustomed to experiencing.

Memory usage patterns were similar throughout the three evaluation sessions. Resident memory for Java would start at approximately 1 GB and increase over the course of the 4-hour exercises to approximately 5 GB. This is considered an accurate representation of how much actual physical memory the processes are consuming. That memory would only be released upon closing the CAVE session. The baseline Nvidia GeForce GTX 760 graphics card has 4 GB of total memory available. Thus, setting maximum video texture cache to 2 GB limits the user to two CAVE sessions. Additional testing will be required to assess the impact of modifying this parameter on multiple CAVE sessions and the optimal baseline setting or recommendations if simultaneous CAVE sessions are desired or expected. It is likely that this testing can be accomplished at the Silver Spring AWIPS Testbed but, if additional testing at OPG would be deemed useful, that can be accommodated.

The OPG uses considerable amounts of archived data over extended periods of time to support its research-to-operations mission. Simulations using these historical cases must be available to support operational readiness evaluations, and exempt from purging routines. When preparing for these AHI/RGB evaluations, OPG technical staff discovered our on-board storage would not be adequate to support all seven exercises. As a short term solution, an OPG Request for Change was approved to utilize 2 TB of unallocated space on the OPG AWIPS Network Attached Storage. Ensuing discussions with various stakeholders revealed that the AWIPS Program Office and Raytheon acknowledged a shortcoming in existing storage capacity for supporting GOES-R at the WFO level. Since those discussions, a temporary local data storage requirement of 1 TB has been established for GOES-R operations. All these findings were reported to the Office of Planning and Programming for Service Delivery, to ensure appropriate Central Processing portfolio managers are engaged to develop an enterprise solution to these issues.

5. Findings and Recommendations

Presented below is the list of findings and associated recommendations, which emerged from the evaluation. Context and rationale for these findings are contained within Section 4 of the report.

FINDING 1: While some spectral band imagery available on GOES-R will have numerous applications, others, if at all, will only be valuable for analyzing certain atmospheric phenomena.

RECOMMENDATION 1a: In order to fully appreciate the full value of some new spectral bands, forecasters need more illustrative cases demonstrating how to apply them for specific forecast challenges, in particular:
- 10.4 µm vs. 11.2 µm vs. 12.4
- 6.2 µm, 6.9 µm, 7.3 µm for the best 4-D representation of atmospheric flow
- 0.47 µm and 0.86 µm for Impact-based Decision Support Services
- Spectral Differencing

RECOMMENDATION 1b: The NWS Central Processing portfolio, in coordination with the NWS Office of the Chief Learning Officer (OCLO) and the GOES-R Program, should investigate if all sixteen GOES-R spectral bands should be distributed to WFOs for every sector and timestamp.

FINDING 2: The complexity of some RGB composite imagery (e.g., Air Mass and Nighttime Microphysics) will require in-depth training and operationally-relevant examples that are devoted to assisting NWS forecasters in understanding and applying the RGBs for decision making.

RECOMMENDATION 2a: The development of training dedicated to assisting NWS forecasters with integrating complex RGB composite imagery, individual spectral bands, and other forecaster resources needs to both, utilize the expertise of NWS forecasters and be a priority for the OCLO and GOES-R applications training.

RECOMMENDATION 2b: Initial widespread NWS exposure to RGB composites should focus on recipes and best practices developed by EUMETSAT, adopted by the World Meteorological Organization, and that have been demonstrated by the Satellite Proving Ground.

FINDING 3: NWS forecasters with color vision deficiency may have difficulty using RGB composites due to their wide spectrum of colors.

RECOMMENDATION 3: Efforts should be undertaken to explore mitigation strategies that counter the problem RGBs pose to forecasters with color vision deficiency.

The OPG was awarded a grant through the University of Oklahoma's Cooperative Institute for Mesoscale Meteorological Studies to support evaluation of new technology by EnChroma, Inc. that separates light into its primary spectral components before reaching the eye. This OPG evaluation is planned for FY17.

FINDING 4: The AWIPS Integrated Training Plugin supplements foundational training by providing immediate access to product resources through the NWS forecaster workstation.

RECOMMENDATION 4a: Leveraging NASA SPoRT's successful prototype design, the Integrated Training Plugin should be implemented into a future AWIPS baseline build.

RECOMMENDATION 4b: Supplemental resources (e.g., quick guides, short videos) that can be incorporated into the Integrated Training Plugin should be required for all NWS forecaster training.

RECOMMENDATION 4c: An applications library accessible via the NWS Virtual Laboratory (VLab) and AWIPS Integrated Training Plugin needs to be developed that includes short, focused regional and local examples illustrating how GOES-R imagery, RGB composites, and baseline products can have a direct, positive impact on operational decision making.

FINDING 5: In order to circumvent a significant degradation in performance when analyzing GOES-R imagery, adjustments to the baseline AWIPS configuration will be required.

RECOMMENDATION 5: After the 2016 WFO hardware refresh is complete, the default JVM heap size will increase to 6 GB and CAVE texture cache will be set to 1 GB. However, the OPG technical staff recommends increasing default CAVE texture cache to 2 GB for better workstation performance.

FINDING 6: The AWIPS workstation is capable of generating RGB composites on demand without compromising workstation performance.

RECOMMENDATION 6: The NWS Central Processing portfolio should continue to invest resources in optimizing the dynamic generation of RGB composites at the AWIPS workstation. Avoiding the centralized creation and dissemination of RGB composites will save resources, bandwidth, and WFO storage.

FINDING 7: Baseline AWIPS storage capacity at the WFO is insufficient to support operations in the GOES-R era.

RECOMMENDATION 7: An enterprise solution to replace and upgrade the AWIPS Direct Attached Storage capacity needs to be developed in order to meet the needs of NWS forecasters in the GOES-R era.

6. References

Bessho, K., and Coauthors, 2016: An introduction to Himawari-540 8/9 - Japan's new-generation geostationary meteorological satellites. *J. Meteor. Soc. Japan*, http://doi.org/10.2151/jmsj.2016-009.

EUMETSAT, 2016a: Airmass RGB. 17 pp. [Available online at oiswww.eumetsat.int/~idds/html/doc/airmass_interpretation.pdf.]

EUMETSAT, 2016b: Nighttime Microphysical RGB. 12 pp. [Available online at http://oiswww.eumetsat.int/~idds/html/doc/fog_interpretation.pdf.]

Gravelle, C. M., K. J. Runk, K. L. Crandall, and D. W. Snyder, 2016: Forecaster evaluations of high temporal satellite imagery for the GOES-R era at the NWS Operations Proving Ground. *Wea. Forecasting*, **31**, 1157–1177.

Lindsey, D. T., L. Grasso, J. F. Dostalek, and J. Kerkmann, 2014: Use of the GOES-R split-window difference to diagnose deepening low-level water vapor. *J. Appl. Meteor. Climatol.*, **53**, 2005–2016.

7. Figures and Tables

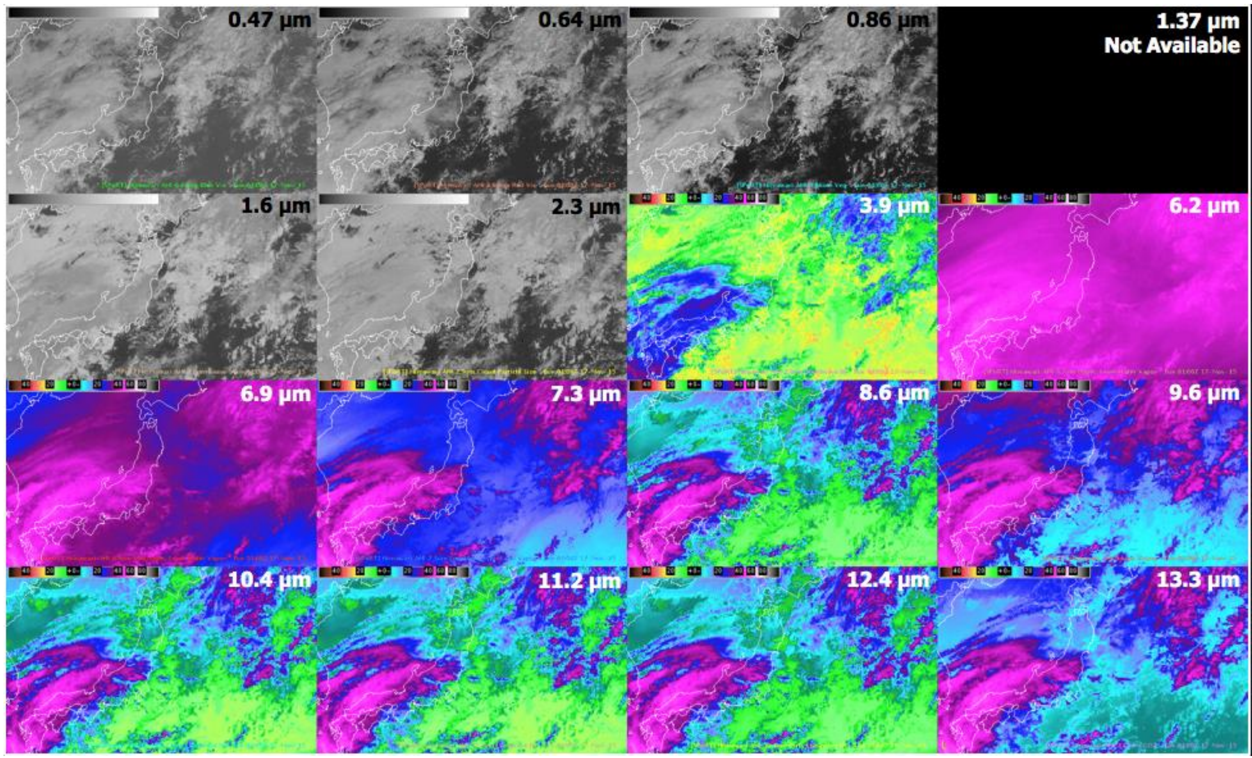


Figure 1. Japanese Meteorological Agency Himawari-8 imagery from the fifteen spectral bands that will be available on the GOES-R Advanced Baseline Imager and the individual spectral imagery participating forecasters analyzed during the evaluation.

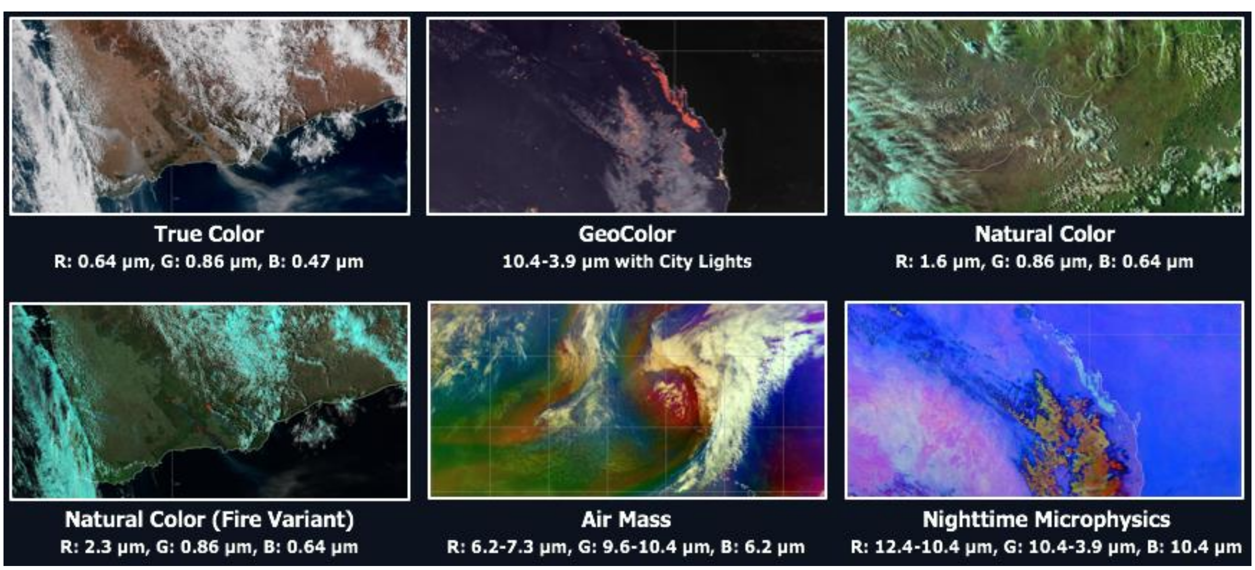


Figure 2. Red-Green-Blue composite imagery participating forecasters analyzed during the evaluation.

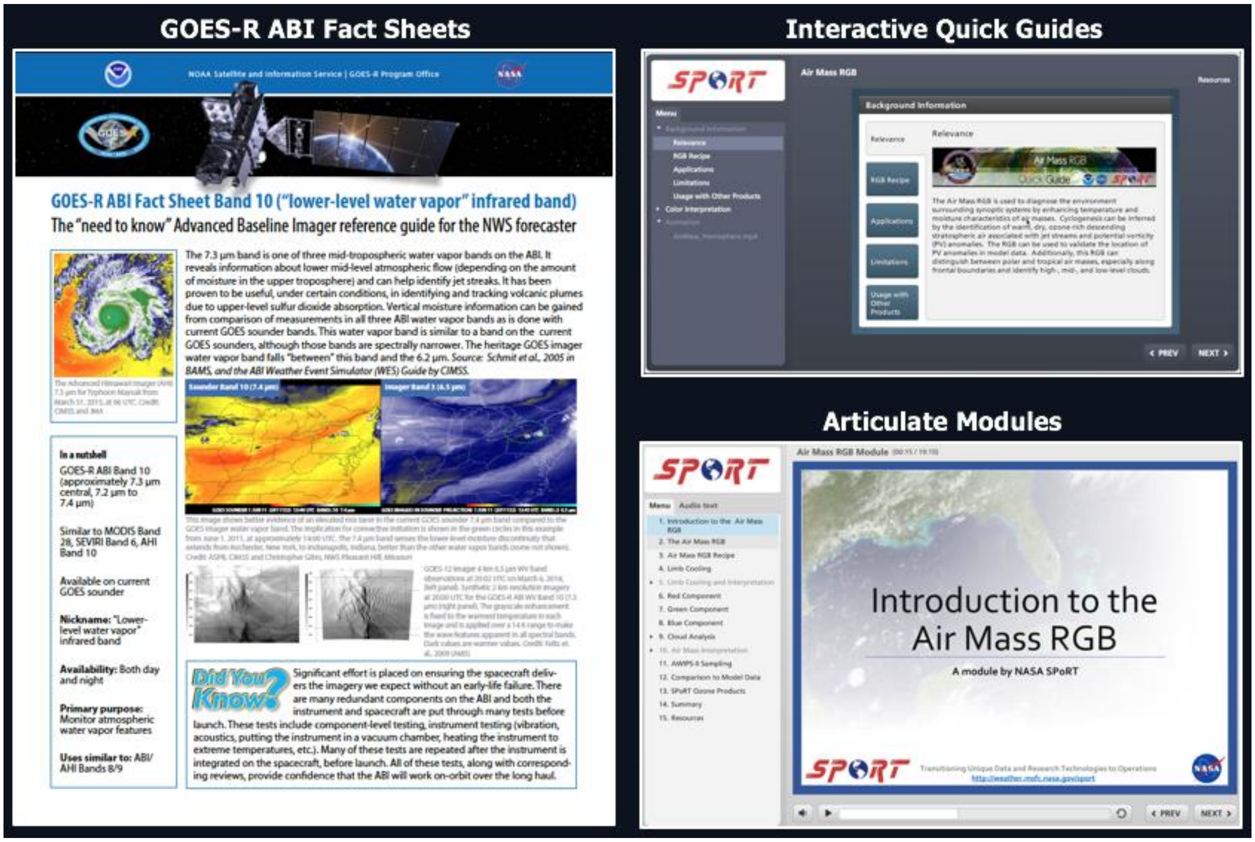


Figure 3. Training resources (ABI Fact Sheets, RGB Composite Interactive Quick Guides, and RGB Composite Articulate Modules) participating forecasters had access to through the AWIPS Integrated Training Plugin during each exercise.

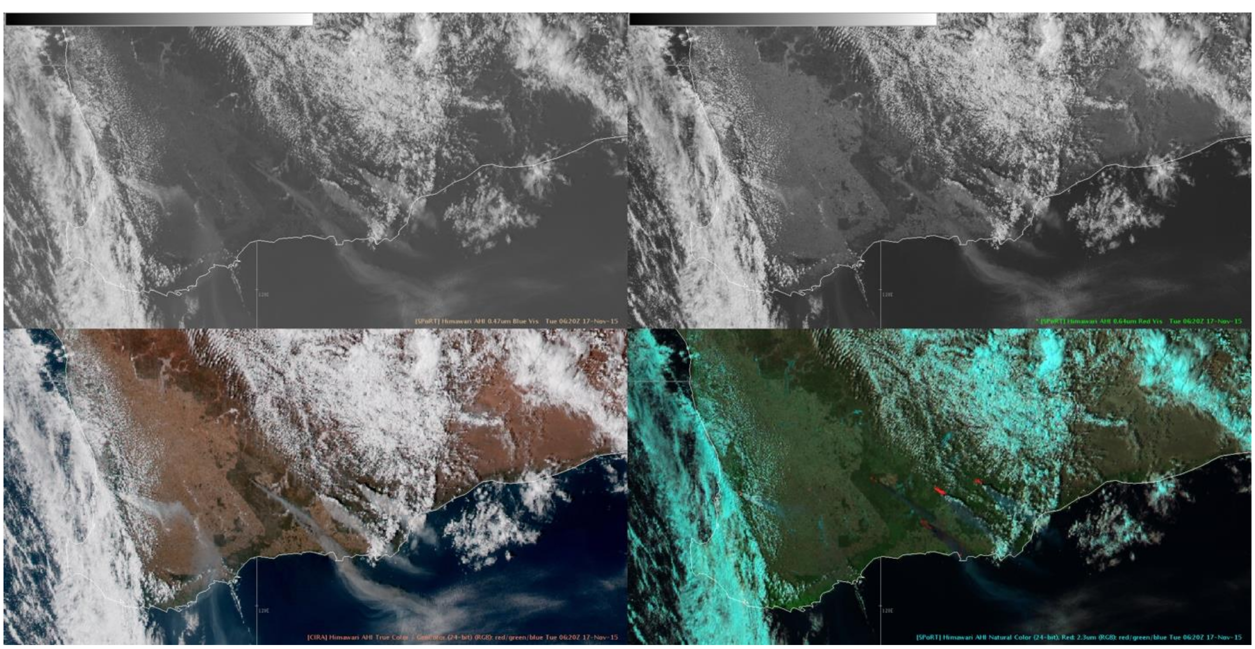


Figure 4. Japanese Meteorological Agency Himawari-8 imagery four-panel of the 0.47 µm (top left), 0.64 µm (top right), the True Color RGB (bottom left), and the Natural Color Fire Variant RGB (bottom right) participating forecasters used to analyze wildfires across Southwestern Australia during Exercise 1.

17 November 2015
Fog and Stratus (Southeast Asia River Valleys) - 0300 UTC
8:30 AM - 0.64 µm 8:40 AM - 0.47 µm, 0.64 µm, 0.86 µm, and 11.2 µm 8:50 AM - True Color RGB Interactive Quick Guide 8:55 AM - 0.64 µm and True Color RGB 9:05 AM - Natural Color RGB Interactive Quick Guide 9:10 AM - 0.64 µm and Natural Color RGB 9:20 AM - 0.47 µm, 0.64 µm, True Color RGB, and Natural Color RGB 9:35 AM - Break
Wildfires (Southwestern Australia) - 0420 UTC
9:50 AM - 0.64 µm 10:00 AM - 0.64 µm and 3.9 µm 10:10 AM - 0.64 µm and True Color RGB 10:20 AM - 0.64 µm and Natural Color Fire Variant RGB 10:30 AM - 0.64 µm, 3.9 µm, True Color RGB, and Natural Color Fire Variant RGB
Frontal Convection (Japan) and Sea Breeze (Taiwan) - 0515 UTC
10:45 AM - 0.64 µm, 0.64-11.2 µm Merge, 7.3 µm, and 11.2 µm 10:55 AM - 0.64 µm and True Color RGB 11:05 AM - 0.64 µm and Natural Color RGB (1.6 µm Red Component) 11:15 AM - 0.64 µm, 0.64-11.2 µm Merge, True Color RGB, and Natural Color RGB 11:30 AM - Break
Snow Cover (Northeast China and Mongolia) - 0600 UTC
11:50 AM - 0.47 µm, 0.64 µm, 1.6 µm, and 2.3 µm 12:00 PM - 0.64 µm, 1.6 µm, True Color RGB, and Natural Color RGB

Table 1. Outline of facilitator guided Exercise 1.

No.	Exercise	Date	Time (UTC)	Geographic Area
1	Phenomena Based (Guided)	17 November 2015	0100-0600	Various
2	Phenomena Based (Self Guided)	29 September 2015	0100-0600	Various
3	Mid-Latitude Cyclone (Guided)	14-16 November 2015	2200-0300	North Pacific Ocean
4	Mid-Latitude Cyclone Analysis (Self Guided)	17 August 2015	1800	North Pacific Ocean
5	Nighttime Fog and Low Stratus 1 (Guided)	2 September 2015	0900-1400	Eastern Australia
6	Nighttime Fog and Low Stratus 2 (Guided)	20 September 2015	2000-0300	Eastern China
7	Phenomena Based 4-Panel Displays (Self Guided)	2 October 2015	0200-0700	Various

Table 2. List of exercises participating forecasters completed during each of the three evaluation weeks.

H8 Band; Central Wavelength	Nickname	Cumulative Rank	Overall Rank
Band 3; 0.64 µm	Red Visible	10	1
Band 13; 10.4 µm	Clean IR Longwave	25	2
Band 9; 6.9 µm	Mid-Level Water Vapor	33	3
Band 10; 7.3 µm	Low-Level Water Vapor	40	4
Band 7; 3.9 µm	Shortwave Window	47	5
Band 8; 6.2 µm	Upper-Level Water Vapor	51	6
Band 4; 0.86 µm	Veggie	56	7
Band 14; 11.2 µm	Traditional IR Longwave	71	8
Band 5; 1.6 µm	Snow/Ice	76	9
Band 1; 0.47 µm	Blue Visible	79	10
Band 6; 2.3 µm	Cloud Particle Size	83	11
Band 11; 8.6 µm	Cloud Top Phase	87	12
Band 15; 12.4 µm	Dirty IR Longwave	88	13
Band 12; 9.6 µm	Ozone	96	14
Band 16; 13.3 µm	CO2	108	15

Table 3. Cumulative rank of the fifteen Himawari-8 spectral bands participating forecasters said were most important from the perspective of their operational analysis and forecasting needs. Double line indicates statistical break point between the seventh and eighth rated bands.