VIIRS and MODIS Multi-Spectral Imagery Assessment for Aviation Weather and Cloud Analysis at High Latitude – Winter 2013-14

Introduction

This report describes the 2013/14 assessment of multi-spectral, false color composites produced by the NASA Short-term Prediction Research and Transition (SPoRT) Center, similar to other products developed previously by the Naval Research Laboratory (NRL) and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT). Products herein are generated from the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard NASA's Terra and Aqua satellites, and the Visible Infrared Imaging Radiometer Suite (VIIRS) aboard the Suomi National Polar-Orbiting Partnership (S-NPP)as an extension of previous capabilities developed from the geostationary capabilities of the Spinning Enhanced Visible Infrared Imager (SEVIRI) operated by EUMETSAT as part of the Meteosat series, or higher resolution applications of traditional Geostationary Operational Environmental Satellite (GOES) series operated by NOAA. Applications described herein highlight future capabilities of the Advanced Baseline Imager (ABI) aboard NOAA's upcoming GOES-R satellite series and focus on use by NOAA/NWS Weather Forecast Office (WFO) collaborators at high latitude within the NWS Western and Alaska Regions. The report is intended for NOAA and NASA program managers, operational forecasters, product developers, other institutions participating in JPSS and GOES-R Proving Ground and research-to-operations activities, and the general satellite remote sensing community.

Products evaluated include the Day-Night Band (DNB) Red, Green, Blue (RGB) composite imagery, the Nighttime Microphysics (NtMicro) RGB, and the SPoRT Hybrid GEO/LEO 11-3.9µm product. The DNB RGB imagery is only available from VIIRS. The product combines the DNB channel with the 11 µm infrared (IR) channel, similar to a daytime RGB product developed by NESDIS that combines GOES visible and infrared channels to differentiate high and low cloud features while providing high-resolution detail of the cloud structure. The NtMicro RGB is created using a combination of short and longwave IR channels and channel differences, based "RGB Best Practices" developed by EUMESTAT and applied to the SEVIRI instrument (EUMETSAT 2012). The NtMicro RGB imagery from MODIS and VIIRS provide a near real-time product similar to future applications from GOES-R. The SPoRT GEO/LEO Hybrid 11-3.9µm difference imagery uses 4 km GOES imagery and then replaces portions of this base image with the same spectral difference from 1 km MODIS or VIIRS. Several of SPoRT's WFO collaborators have used the Hybrid 11-3.9µm previously, but it was included in this assessment for comparison to the NtMicro RGB which uses a similar channel difference (11-3.7µm) as a component of the final RGB composite. The DNB and NtMicro RGBs provide enhanced capabilities to the analysis of clouds at night through their ability to depict the structure, thickness, and thermal characteristics of cloud features within a single image.

Low clouds and fog can present significant ceiling and visibility hazards to aircraft operations. NWS WFOs are responsible for short-term Terminal Aerodrome Forecasts (TAFs) at specific airports within their warning area and rely upon accurate information concerning both the spatial extent and timing of hazards that may affect aviation operations at these locations. GOES 11-3.9µm difference imagery has traditionally been used to analyze and track low clouds and fog at night to support the preparation and amendment of TAFs. The DNB and NtMicro RGB products provide additional information within a single image to increase the forecaster's awareness of cloud characteristics relevant to aviation hazards. In particular, the NtMicro RGB contains additional channels and channel differences in order to help differentiate low clouds from fog which is not readily apparent using the traditional 11-3.9µm imagery. Although the polar orbit of Terra, Aqua, and S-NPP provide MODIS and VIIRS products with greater temporal frequency at high latitudes, their frequency is still much less than the 15-min updates from existing GOES imagery. However, the increase in spatial resolution versus standard GOES IR imagery provides unique value despite a reduced number of observations per night for a given location.

The assessment sought to determine the value added to the short-term forecast of ceiling and visibility, particularly as they apply to TAFs issued by high-latitude WFOs. In addition, the assessment exposed forecasters to the application of complex multi-spectral imagery (i.e. RGB composite), and hence, the future paradigm of satellite imagery that will become available in the JPSS and GOES-R eras. The assessment also provides important pre-launch feedback to GOES-R and JPSS product developers regarding optimal production and delivery of RGB imagery to meet aviation forecast needs. The assessment was conducted in two periods. The WFO at Great Falls, MT assessed the products from 15 September to 31 October 2013 to coincide with their regional climatology of high frequency IFR and LIFR events. The second period of the assessment ran from 1 December 2013 to 15 February 2014. This period aligned with the climatological peak of marine fog and stratus cloud development at the WFO in Medford, OR. Partnering WFOs in Alaska (Juneau and Anchorage) also participated in the second assessment period. During the second period, use of DNB and NtMicro products were particularly advantageous, as daylight in Alaska is minimal during the winter months. The participating WFOs and the number of feedback submissions via an online "2-minute survey" of 10 questions (mostly multiple choice) is shown in Figure 1.

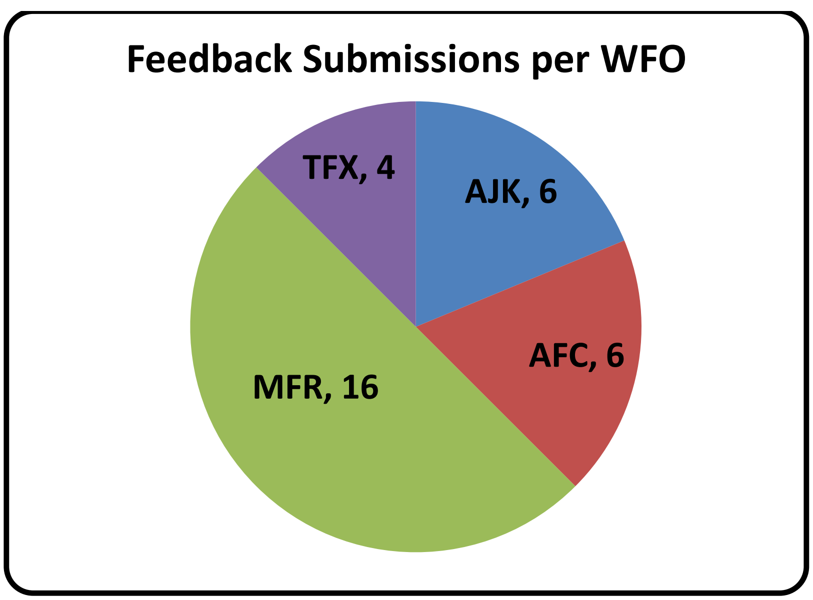


Figure 1. A total of 32 submissions via online user feedback form were provided by forecasters during the assessment. Participating WFOs are listed via 3-letter abbreviation and the number of submissions per office is shown next to the WFO within the chart. Abbreviations include Anchorage, AFC; Great Falls, TFX; Juneau, AJK; Medford, MFR

NWS forecasters provided feedback via the online survey or blog posts after viewing data within their AWIPS or AWIPS II display system for a relevant event where products were used to support aviation hazards and cloud analysis. This report includes a product description, the methodology used for this assessment work, a discussion of results from user feedback, and a summary with recommendations.

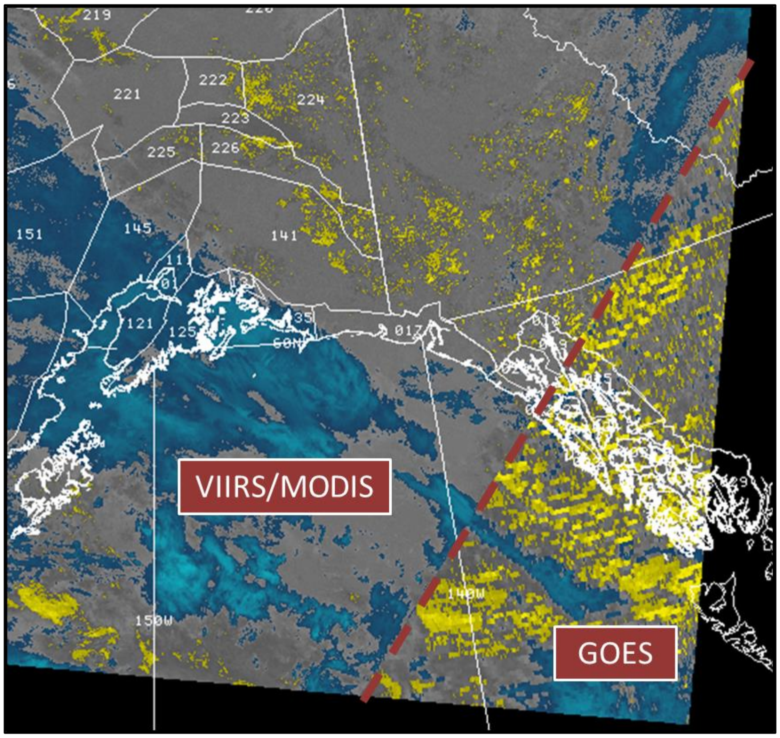
Product Description

All of the products used during this assessment period were derived from the MODIS aboard the NASA Terra and Aqua satellites, and VIIRS aboard the Suomi National Polar-orbiting Partnership (S-NPP) satellite. MODIS observes the Earth's surface and atmosphere using 36 spectral bands ranging from the visible to the thermal infrared. Terra and Aqua each provide a daytime and a nighttime set of passes across the CONUS domain in a 24 hour period. (For more information, please visit http://modis.gsfc.nasa.gov/ or http://weather.msfc.nasa.gov/sport/modis/). Similar to MODIS, VIIRS observes the Earth and the atmosphere at 22 visible and infrared wavelengths and follows an orbital track and equatorial crossing time similar to Aqua (For more information, please visit http://www.raytheon.com/capabilities/products/viirs/ or http://weather.msfc.nasa.gov/sport/jpsspg/viirs.html). A short description of products used during the assessment is as follows.

SPoRT Hybrid GEO/LEO 11-3.9µm:

The spectral difference product, also known as the thermal difference or "fog product", is produced by differencing the brightness temperatures in the 11µm and 3.9µm channels. Based upon the technique of Elrod (1995), the product leverages differences in the thermal emissivity between clouds comprised of liquid water droplets and their cloud-top temperature (11µm). Using a predefined temperature difference threshold of 2.5K and a corresponding color curve, the resultant imagery produces shades of blue for smaller 11-3.9 µm brightness temperature differences representing high, ice-crystal clouds, and shades of yellow for larger differences corresponding to fog and low clouds. Although color enhancements vary among users, many forecasters are familiar with this product and concept in working with imagery from the current GOES imager, with 4 km spatial resolution, however, imagery from polar-orbiting instruments better discerns mesoscale cloud features due to their improved spatial resolutions of 1 km (MODIS, bands 31, 22) or 750 m (VIIRS bands M15, M12). While forecasters recognize the value of the improved spatial resolution, the infrequent passes of LEO instruments make it difficult to view a time series (i.e. loop) of the imagery. To improve the spatial and temporal continuity of the polar-orbiting imagery, NASA SPoRT has developed a technique to embed VIIRS and MODIS imagery within standard GOES imagery, referred to as the SPoRT Hybrid 11-3.9µm Product (Figure 2 and Figure 3). This allows infrequent polar-orbiting imagery to be viewed in a loop that provides context via standard GOES imagery both at the time of the LEO pass (in areas not covered by the MODIS and VIIRS instruments) as well as in between LEO passes (when no MODIS or VIIRS data exists).

Insertion of polar-orbiting imagery within a corresponding geostationary image provides context of cloud features with which forecasters have familiarity, helping with the application process and easing the burden of identifying features in single frame imagery. Further, by fusing LEO data into the GEO imagery, there is no requirement for the forecaster to remember when a particular LEO pass will be available. There are two items to keep in mind when using this product. First, this 11-3.9 μm band differenced is only valid at night for fog detection, as the channel differencing technique requires thermal radiance only, and during the day, the 3.9 μm band receives solar reflectance and thermal emission. Second, regions of low stratus clouds could be indicated as fog, when fog may not actually be present.



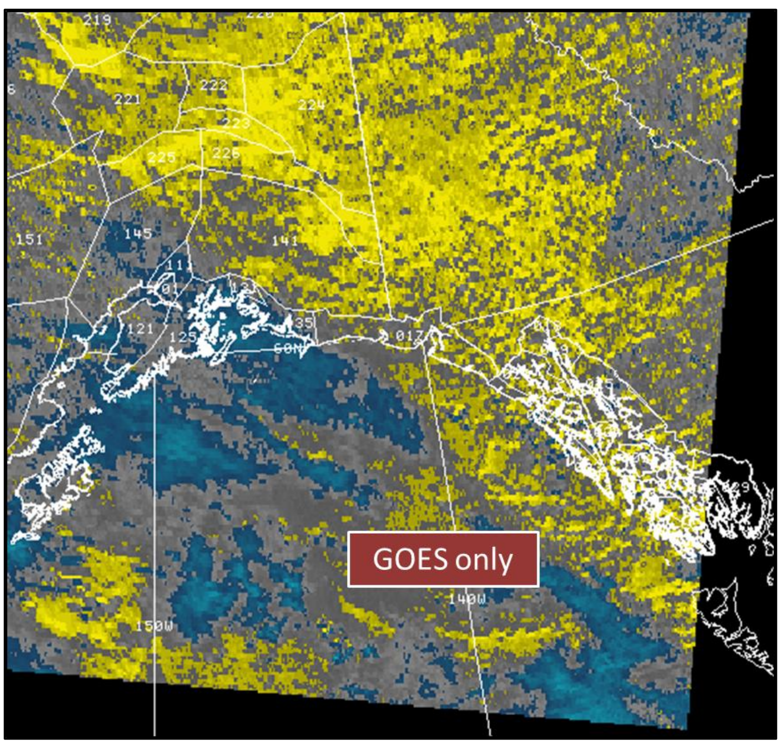


Figure 2. SPoRT Hybrid GEO/LEO 11-3.9µ imagery within AWIPS/D-2d for 1330 UTC on 15 November 2013. VIIRS data is in the middle and on the left side of the image while GOES fills in the rest of the scene on the lower right. Details in high and low cloud features are more readily apparent within the VIIRS swath area compared to GOES data near this same time (see Figure 3). Note the reduced positive difference in the 11-3.9µ product compared to the same GOES product in the bottom right portion of the image .

Figure 3. SPoRT Hybrid GEO/LEO 11-3.9µ imagery within AWIPS/D-2d for 1400 UTC on 15 November 2013. Only GOES data is available at this time, and the low viewing (i.e. zenith) angle results in false indications of low cloud features in yellow (see Figure 2.).

VIIRS Day-Night Band Radiance and Reflectance RGBs:

The VIIRS Day-Night Band (DNB) provides a night-time image of reflected moonlight and other light sources emitted from the surface with a spatial resolution (750 m) comparable to day-time visible imagery from GOES (1 km). Analogous to how visible imagery derived from reflected sunlight, the DNB senses reflected moonlight and can be used to detect small-scale features at night that are not as readily seen in standard IR channels. The DNB radiance is the basic product from the VIIRS sensor of emitted and reflected light. Because the cities lights are far brighter than reflected moonlight, clouds can appear very faint while ground sources appear very bright. The DNB radiance is normalized by the available amount of moonlight (phase and angle) in order to focus on the reflected portion of the imagery and create a “DNB Reflectance” product (Figure 4). This provides a more consistent brightness of features in the final image during different moon phases. The RGB products that incorporate the DNB radiance and reflectance were developed by the Naval Research Lab (NRL) and used by Navy meteorologist via the NRL NexSat online data portal. The DNB radiance and reflectance RGB products assign the DNB channel (0.7 µm) to the red and green components of the composite while the IR M15 channel (11 µm) is assigned to the blue component of the RGB. The resultant image shows warm, reflective clouds and city lights in yellow shades (i.e. equal amounts of red and green, but lack of blue), while cold, reflective clouds will appear blue (i.e. equal amounts of red and green, but large amount of blue).

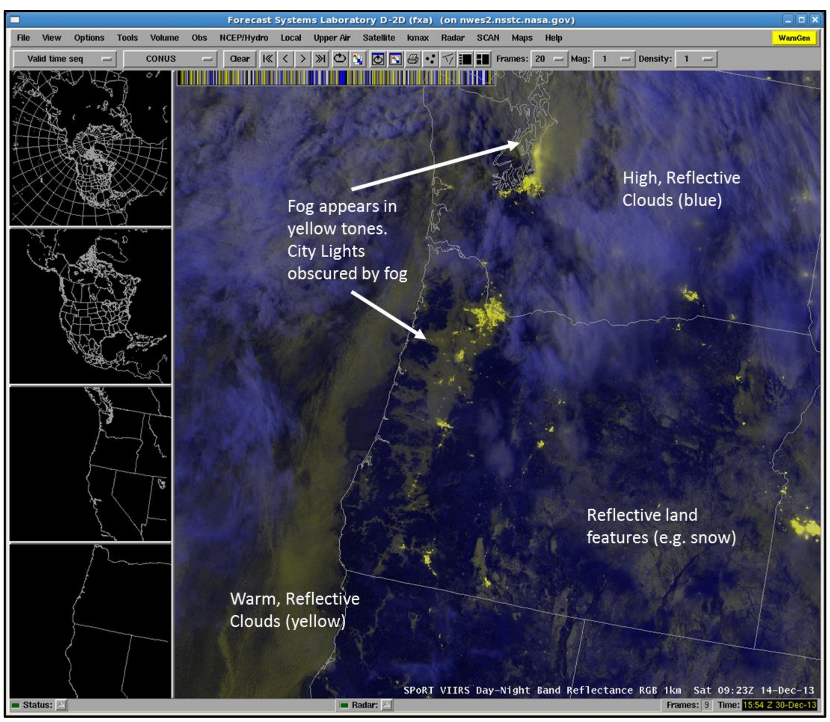


Figure 4. VIIRS DNB Reflectance RGB imagery for 0923 UTC on 12 December 2013 centered on west Oregon displayed within the AWIPS/D-2d software. City light emissions saturate pixels with bright yellow and the metro city area of Portland is easily seen in the image upper center. Fog can be seen in faint yellow near the center portion of the image along the Interstate 5 corridor as well as in the river valleys near southwest OR. Reflective, low (i.e. warm) clouds are evident off the coast in yellow tones while reflective, high (i.e. cold) clouds are further off the coast as well as covering much of Washington State. Yellow tones in southeast Oregon include reflective land features such as snow cover at this time.

Features with high reflectance in the DNB and very cold temperatures in the M15 IR channel retrievals will appear white. The combination of the DNB and IR channels in an RGB is useful in the determination of cloud height and thickness. A particular strength of the DNB RGB over the standalone infrared or DNB images is the ability to discern areas of low cloud and fog, especially around cities and low lying areas. Thin clouds and fog will cause scattering of city lights, with sources of light appearing more diffuse or "blooming" to adjacent areas. Thus, the RGB product can lend context as to whether the thin clouds are high level cirrus which would appear blue, or low clouds and fog which would have a yellow cast. Additionally, since this product contains a visible component, optically thin cirrus clouds do not fully block the reflectance by lower sources to be seen by the sensor and hence detection of low to mid cloud features beneath the cirrus. This is especially significant since cirrus cloud radiance emissions can saturate the IR thermal channel and thus mask lower cloud emissions from being detected by the IR sensor.

RGB Night-Time Microphysics:

False color (RGB) composite products allow for multi-channel information to be shown simultaneously and in such a way as to help highlight a particular weather or atmospheric phenomenon. Several RGB composite products have been developed by EUMETSAT that can be applied to current MODIS and VIIRS instruments to demonstrate new applications of multispectral data and to prepare forecasters for the GOES-R era (http://oiswww.eumetsat.int/~idds/html/product_description.html). The Night-Time Microphysics RGB composite combines three channels and their differences to build a composite image that helps to better delineate cloud types. The 12-10.8µm channel difference is applied to the red component of the RGB. This channel difference is physically related to optical depth and is typically used as a proxy to cloud thickness. The green component of the RGB is the aforementioned "fog product", or difference between the 10.8µm and 3.7µm channels. This physically relates to the particle size and phase of the cloud and is used to diagnose if clouds are water- or ice-based. The blue component is assigned to the 10.8µm infrared channel which gives the temperature of an emitting surface, and often it is used to diagnose cloud top temperature. However, in the absence of clouds the 10.8µm infrared channel represents the surface temperature. This composite was originally designed to help delineate all variety of cloud features by utilizing a physical (optical depth, red), microphysical (phase and particle size, green), and thermal component (cloud-top temperature, blue) within a single image. As an IR-based product, the highest-altitude cloud features will be depicted in the image, and any clouds below will be obstructed from view. As described in the Hybrid GEO/LEO Spectral Difference section, the reflective component of the short-wave IR 3.7µm band will limit the product to only use at night.

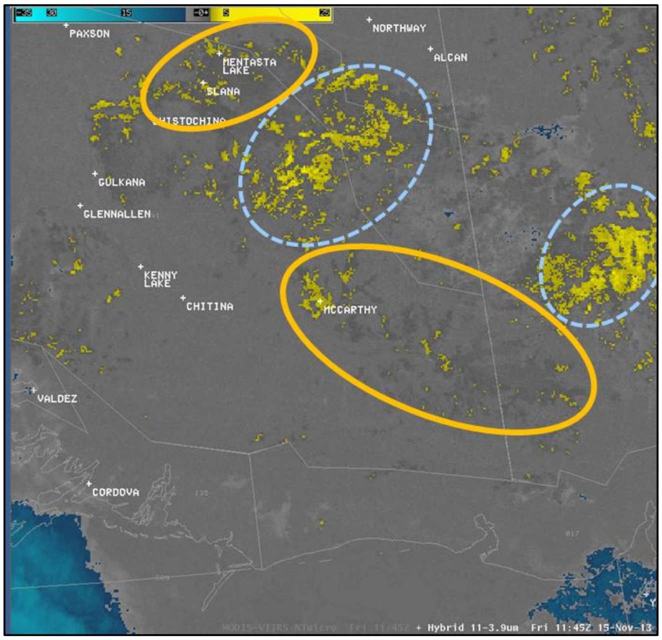


Figure 5. SPoRT Hybrid GEO/LEO 11-3.9µ product at 1145UTC on 15 November 2013 centered on McCarthy AK where MODIS imagery has replaced the GOES imagery at this time. Annotations to image depict similar yellow cloud objects representing low clouds (dotted blue oval) or fog (solid orange ovals). In the absence of surface observations, a user may not be able to distinguish whether the yellow shades represent low clouds or if they indicate fog.

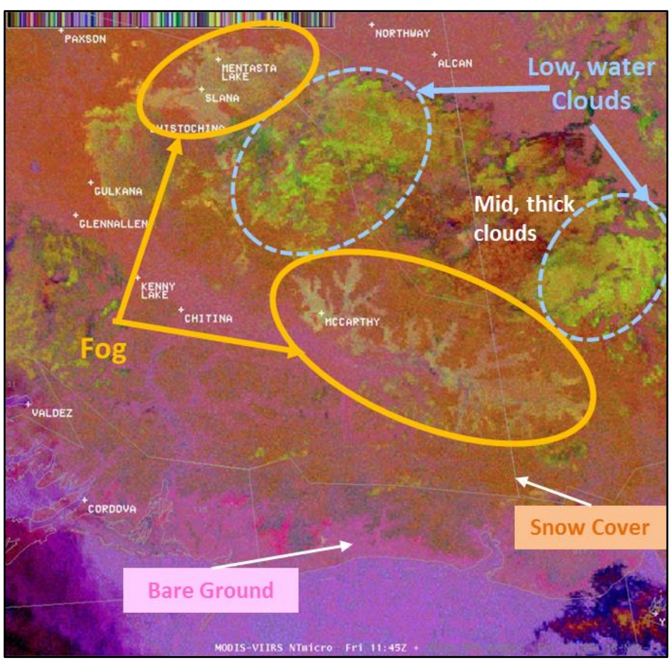


Figure 6. MODIS NtMicro RGB at same time and domain as Figure 5. Color differences in RGB for the "low cloud and fog" objects from Figure 5 allow the differentiation of fog from low clouds as annotated on image as well as identification of mid and high clouds. Bare ground and snow covered areas are also noted and not obvious in the hybrid imagery.

An advantage of the NtMicro RGB is an ability to differentiating between low clouds and fog in the overnight period, through the added use of the red component to see thick vs thin cloud features, as well as the blue component to provide the relative temperature of the cloud objects with positive 10.8-3.9µm differences. Fog is often comprised of smaller water droplets and is relatively warm compared to low-level stratus clouds. Also, in the case of thin fog, some of the surface emissions can be apparent with emissions from the small water droplets that make up the relatively thin fog. These factors change the resulting value of the channels and channel differences, and hence, the amount of color contributed from the various R-G-B components for fog verses low clouds (Figure 6). At high latitudes in winter, fog tends to be a dull green to nearly gray shades while thick, warm low level stratus with slightly bigger water droplets tends to be a bright yellow-green color shades at higher latitudes.

Methodology

SPoRT has steadily transitioned a new RGB imagery suite of products to its WFO partners as part of efforts to demonstrate and test future GOES-R capabilities and new Suomi NPP products. SPoRT has conducted previous assessments regarding GOES and MODIS products that were applied to low cloud and fog analysis, and this assessment of new RGB imagery was the next phase in the evolution of products to address the short-term forecast challenges of aviation hazards during the nighttime period. However, this assessment was also an opportunity for users to become familiar with future geostationary imagery capabilities using current, real-time data (i.e. MODIS & VIIRS), and it allowed product developers to better understand the strengths and limitations of how RGB imagery products are able to be applied for the given forecast issue. The NtMicro and DNB RGBs were provided to address analysis of cloud features for possible hazards to aviation and to determine how their application impacts the TAF product, particularly regarding low clouds and fog. The SPoRT Hybrid 11-3.9µ product was included for comparison to the RGB imagery as this is the current primary product used by SPoRT collaborators to address low cloud and fog issues at night. Future comparison of the NtMicro and DNB RGBs to the new Fog and Low Stratus (FLS) product (baselined for GOES-R ABI) could better articulate the role for each product in identifying possible aviation hazards.

Prior to the start of the assessment period, each office was contacted to determine their interest in participation, product familiarity and training needs. Training was provided by SPoRT in several ways. Although a basic level of training was recommended via COMET modules (e.g. “Multispectral Satellite Applications: RGB Products Explained”) through the NWS Learning Management System (LMS), SPoRT also developed training specific to the Alaska and high latitude U.S. regions where products were to be evaluated for use in operational aviation forecasts. A teletraining session was held shortly before the start of each assessment period in order to deliver these training materials and provide an opportunity for a direct question and answer session between users and product developers. The focus of the training session was to provide users with and understanding of how the RGB products are created, their strengths and weaknesses, and a case example of their application to aviation forecasts. The product information and case example were used to create a “micro lesson” of eight minutes in audio length. This lesson is a self-paced, web-based training module that can be used by those unable to attend the teletraining. Additional examples detailing how each of the products could be used in the operations were provided by the WFO Huntsville (HUN) Applications Integration Meteorologist (AIM). Additionally, single-page, double-sided “Quick Guides” were created that briefly describe and illustrate what the products are, what to look for in the imagery, and the caveats one should keep in mind. Essentially, the Quick Guides provide a reminder of the important points covered in the more robust teletraining and micro lesson. These Quick Guides were laminated and sent to each WFO for easy reference, directly within the operations area. Both the micro lesson and the PDF version of the Quick Guide were made available from the Transition tab on the SPoRT website (http://weather.msfc.nasa.gov/sport/training/) for the WFOs to review and make available to forecasters via their local intranet.

For a SPoRT assessment to be successful, it is crucial that our partners provide feedback on their experiences with the products. To strike a proper balance between the needs of the assessment and the operational forecast environment, SPoRT has developed the “2-minute feedback” form, which can be accessed at any time on the SPoRT website. Forecaster respondents answered questions using easily clickable radio buttons corresponding to their choice of 3-6 predetermined answers. Comment boxes were also provided if a question and predefined answer did not adequately capture the information they were trying to convey, but also allowed for a more detailed feedback in paragraph form. For this assessment, questions were designed to rate the products impact on assessing fog and low clouds for aviation forecasts (i.e. TAF) in the overnight periods. Initially, users were asked if they used or referenced any of the training materials (i.e. micro lesson, Quick Guide), sought help from a fellow forecaster, relied on their previous experience, or had not seen any training at all. An additional choice allowed users to indicate that they had seen the training materials, but that they still were not able to interpret the RGB imagery and would need additional help. Users were also asked which of the three products they preferred for the given event. These responses help to frame user feedback regarding impact rankings of these products on aviation. For example, someone who has not yet seen the training or consulted a peer with more experience may tend to answer differently from users who have benefited from those resources. Several questions asked users to rank the impact on aviation forecasts, in general, and one question specifically addresses the issue of whether or not the NtMicro RGB helped differentiate areas of fog from areas of low clouds. The survey went a bit further and asked users to provide the product that gives them more confidence when analyzing low clouds and fog if it is not the NtMicro RGB. At the end of each survey, a comment box was provided for any additional information the forecaster felt necessary or had the time to provide. Communication was conducted via email with users to acknowledge their submitted feedback, respond to their comments, or ask for clarification. These conversations led to improved understanding of the product’s impact and uses that can then be shared with other forecasters during and after the assessment is completed. At the end of the assessment all of the responses were analyzed by SPoRT to gain an understanding of how the products may or may not have met the aviation forecast needs of users, and any problems that might need to be addressed moving forward. Results are presented in the next section.

In addition to the evaluation form, SPoRT also hosts The Wide World of SPoRT blog, and provides WFO partners with access to write content and share images describing their experiences. The Proving Ground Satellite Champion for the Alaska Region made two blog posts. One was related to the weakness of the NtMicro RGB in extreme cold temperatures of interior Alaska, and the second showed the benefit of the NtMicro RGB to highlight fog and the variations in thickness compared to the VIIRS Day-Night Band Reflectance, longwave IR, and traditional “fog” (11-3.9µ) imagery (Figure 7). The blog post highlighted the greater detail and efficiency in analysis of fog in the low-lying areas via the NtMicro RGB imagery.

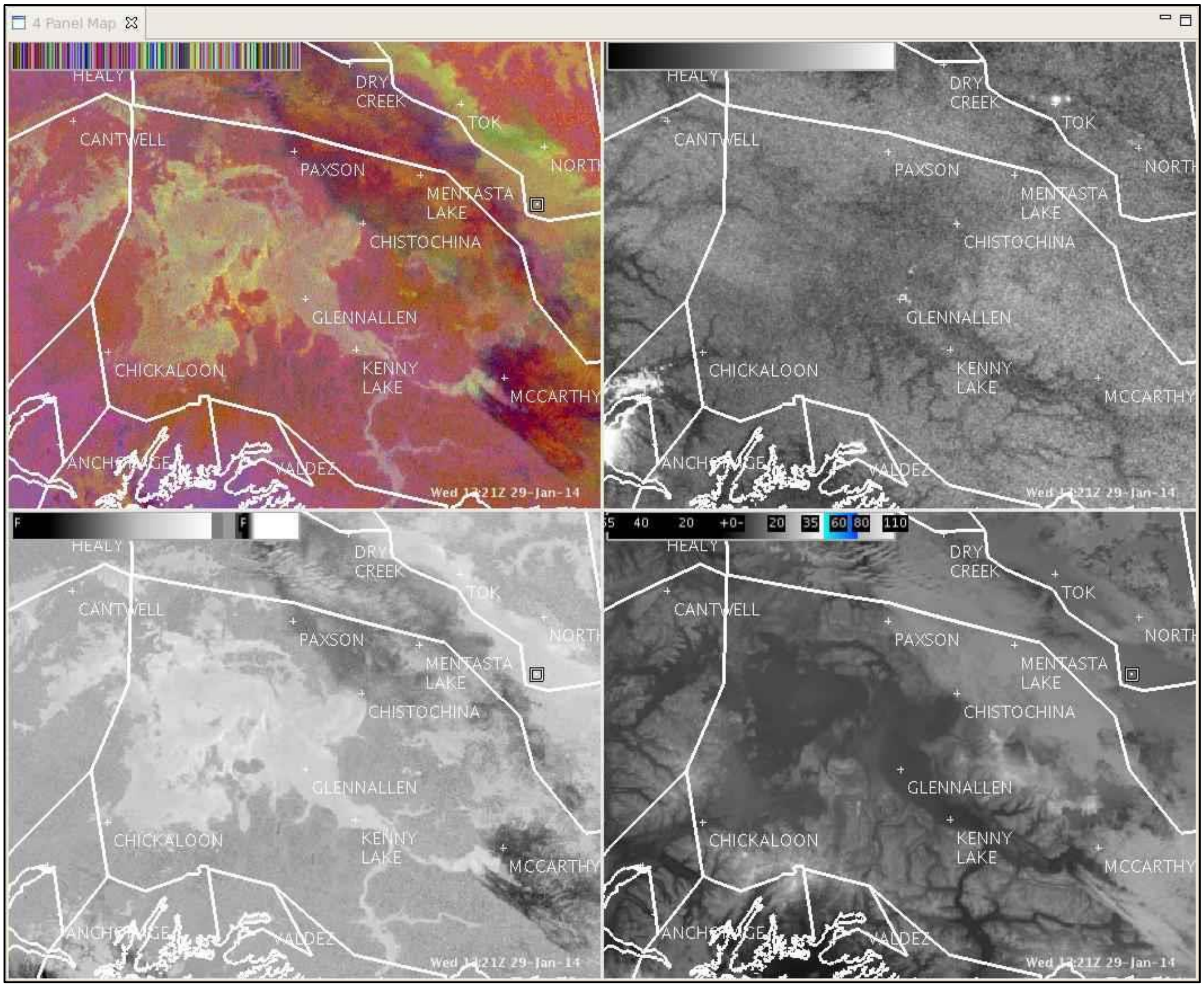


Figure 7. Four-panel screen capture from AWIPS/D-2d in Fairbanks, AK WFO of the NtMicro RGB (top left), Day-Night Band Reflectance (top right), 11.45µ long wave IR imagery (bottom right), and traditional "fog" or 11-3.9µ difference imagery (bottom left), centered over the Copper River Basin to the northeast of Anchorage, Alaska.

Lastly, the SPoRT NWS chat room (address nasa_sport) was also provided to all forecasters at each participating NWSFO as a forum for feedback during the evaluation. The chat room was created to enable efficient communication between SPoRT and collaborators in an open forum setting. In addition, the chat room has proven to be valuable for communicating information about specific products and any related technical issues.

Results

At the close of the assessment period, personnel at the participating NWS WFOs had submitted 32 surveys and three blog posts.

There were at least four surveys completed by each of the participating NWS WFOs with the majority of those occurring in December 2013 and/or during the midnight shifts. Of the 32 surveys, there were 13 individuals who participated, as well as 4 anonymous submissions. Overall, users said that the NtMicro

RGB was the most preferred product of the three products in this evaluation. In 81% of events the NtMicro RGB had “some” to “very large” impact on aviation forecasts, and in 84% of events it had “some” to “very large” impact on differentiating between fog and low clouds. While the total number of surveys means the results are not statistically significant due to the sample size, insightful information can still be gleaned from the forecaster feedback.

User Feedback to Assessment Questions

A set of nine questions were posed to operational forecasters to assess the value of unique RGB imagery related to aviation hazards and cloud structure analysis. Two components go into the operational utility of the products, timeliness and user confidence of the products for application to specific forecast challenges. MODIS and VIIRS imagery is available 4-6 times a night in Alaska, and GOES imagery supplements the polar imagery coarse frequency as part of the Hybrid concept, in order to provide continuity between passes of high-resolution polar imagery. Despite having three products, there were 7 different events where users noted that the imagery they preferred to assess was not available. The missing data in these cases could have been due to either large latency or a short gap in production.

The NtMicro RGB was the most preferred of the three products 81% of the time, followed by the DNB RGB at 10%, the Hybrid 11-3.9 μm at 3%, and no preference at 3%. One user described an advantaged of the NtMicro, stating,

“Same story as the night before. This product is most useful in helping see areas of low clouds and fog where the other (GOES) imagery is often more difficult to see the distinct features with less resolution.”

The NtMicro RGB most often had “large” or “some” impact on aviation forecast issues in general, and was rated positively (“some”, “large”, or “very large”) in 81% of cases (Figure 8). The NtMicro RGB was rated as having “some” or “large” impact on the specific forecast challenge of differentiating low clouds and fog in 22 of 33 events, and rated positively in 84% of cases (Figure 9). Both of these results indicate that the majority of users were confident in the RGB products and found value in operations.

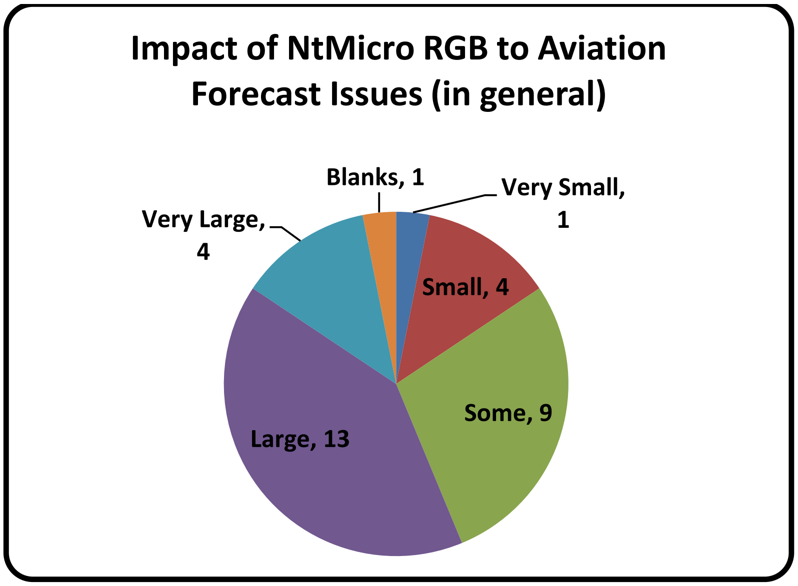


Figure 8. Distribution of WFO feedback when asked to rank the impact of the NtMicro RGB imagery for general support of aviation forecast issues.

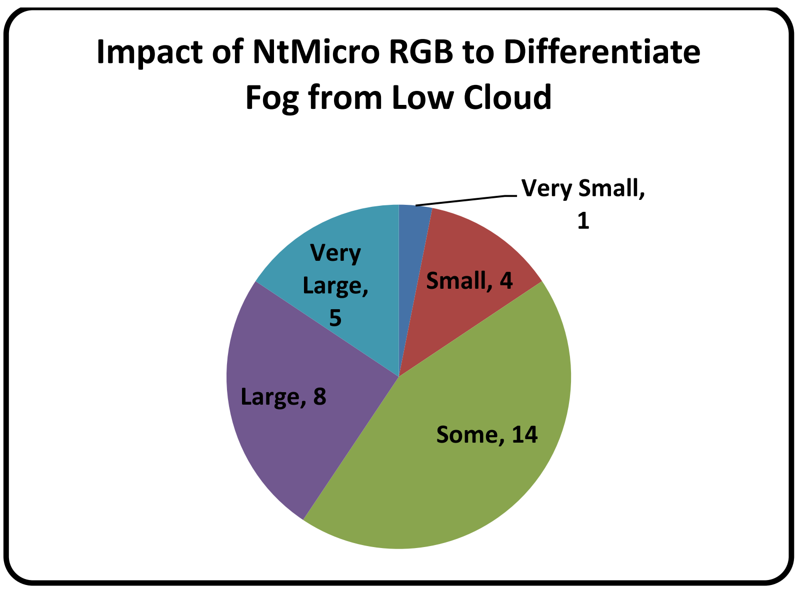


Figure 9. Distribution of WFO feedback when asked to rank the impact of the NtMicro RGB imagery to help differentiate fog objects from other low cloud features in the imagery.

However, users in nine events indicated that a different product provided more confidence or better utility to differentiate low clouds from fog than the NtMicro. Among the products listed were the GOES 11-3.9µ difference product, hybrid 11-3.9µm, Day-Night band RGB, GOES visible, surface observations of ceiling visibility, and "WR fog product" (i.e. spectral difference). A forecaster in WFO-AFC stated,

"[…]Using the [NtMicro] RGB in conjunction with the Hybrid 11-3.9 µm imagery provided a clearer picture on which was fog/stratus and which was mid-level."

According to forecaster feedback, the VIIRS DNB RGB also had "some" impact on TAFs for about half the events (Figure 10), and it was rated positively in 63% of events. However, in 11 cases, the impact of the

Day-Night Band RGB was ”small” or “very small”, and in only 6 events did forecasters regard the impact as “large” or “very large”, distinguishing its impact as less than that of the NTmicro RGB. The DNB RGB was used mainly for differentiating between high and low clouds and less frequently to observe city light pattern changes.

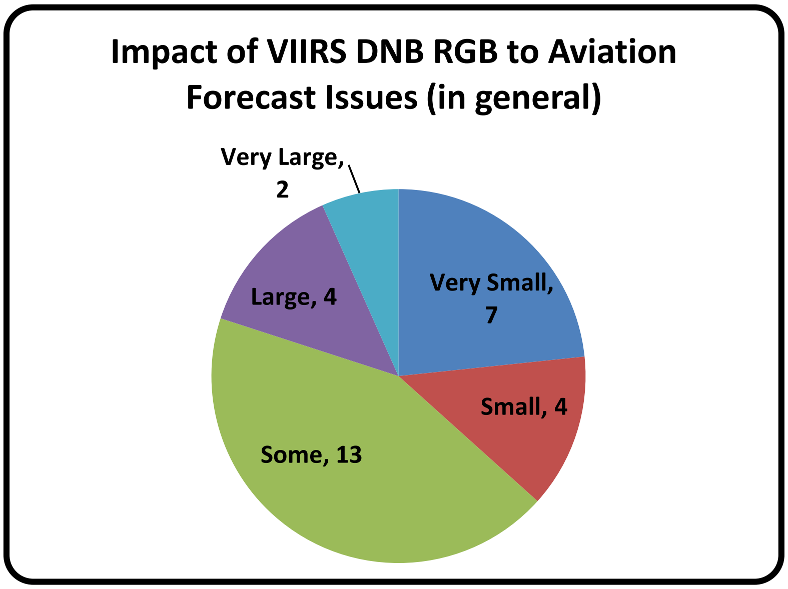


Figure 10 User feedback regarding impact of VIIRS DNB RGB on operational aviation forecast responsibilities.

A number of forecasters indicated in their comments that they used the RGBs and hybrid imagery collectively during the event and their comments often encompassed those products as a suite. For example, a forecaster from Medford, OR (MFR) noted on 14 December 2013 that,

“Valley low cloud and fog simply jumps off the screen in all of these products tonight. […] Was able to discern that low cloud/fog was more widespread in the valleys than with any other products.”

This fog event was seen by VIIRS during a period with large amounts of moonlight and hence both the NtMicro and DNB Reflectance RGBs were examined (Figure 11).The NtMicro RGB image is labeled in Figure 11 to identify various cloud types and areas of snow cover. These same labels are applied to the DNB RGB to compare the imagery characteristics. Note that the DNB RGB shows the high, thin clouds in a grayish blue color, corresponding to the areas of dark blues and reds in the NtMicro RGB. Medford comments are illustrated in Figure 11 as the fog along coastal Oregon and California is clearly evident where the view is not blocked by mid-level cloud features. The mid-level clouds are not well highlighted in the DNB Reflectance RGB. Both the high and mid-level clouds are relatively thin, but the high clouds may contain a greater concentration of ice particles which are more reflective than the super-cooled water droplets of some mid-level clouds. Thus, the current enhancement of the DNB RGB and resulting composite do not highlight the mid-level cloud details as well as the NtMicro RGB. Fog can also be seen in various valleys and low lying regions in southwest Oregon and northern California (center of image).

This region also has orange colored objects in the NtMicro RGB and wide spread areas of reflectance that correspond to snow cover.

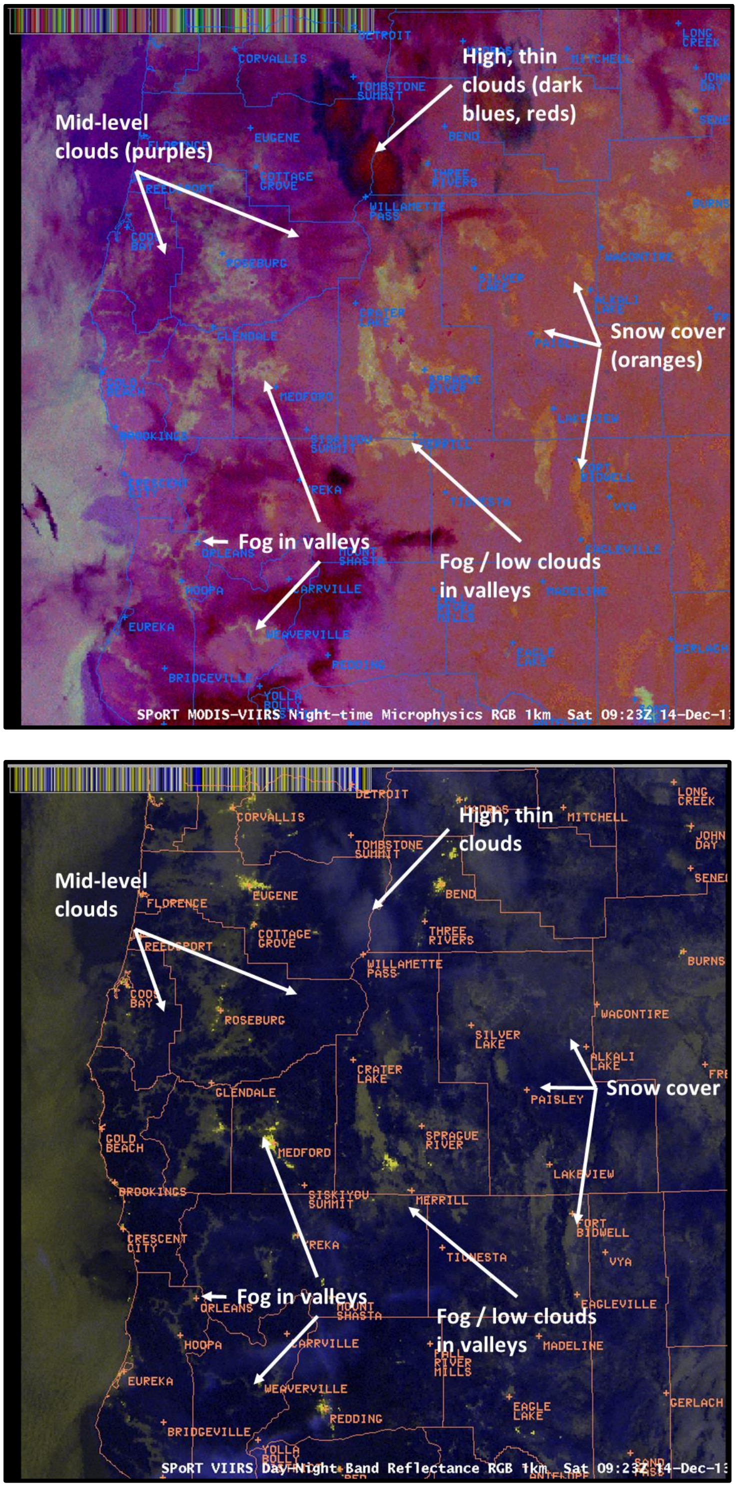


Figure 11. The NtMicro (upper) and DNB Reflectance (lower) RGBs for 14 December 2013 at 0923 UTC as displayed via AWIPS/D-2d. Feedback for this event came from MFR. The image is centered near the Oregon/California border and the city of Medford is in the left, center of the image.

Forecasters favorably viewed the higher resolution of the MODIS and VIIRS data within the Hybrid GEO/LEO 11-3.9μ imagery (“hybrid”), stating mostly that it had “some”, “large”, or “very large” utility. Although it was *not* the most preferred product for fog and low cloud analysis, the positive feedback from users indicates the value of a hybrid product over standard lower resolution GOES imagery or polar-orbiter imagery alone. About 66% of participants noticed the higher resolution MODIS or VIIRS imagery inserted to GOES imagery when looping the hybrid product; however, 12% did not notice the higher resolution data, and 16% did not loop the product. A forecaster from Anchorage AK (AFC) evaluated the impact of the hybrid imagery inserted in the GOES background as “very large” on 10 December 2013 (Figure 12) and evaluated the impact of the NtMicro as “very large” for differentiating between fog and low clouds. The high resolution hybrid imagery clearly shows areas of fog/low cloud throughout portions of the image (yellow shades), and the NtMicro RGB helps distinguish the fog in low lying areas and in the valleys from the low, thick clouds.

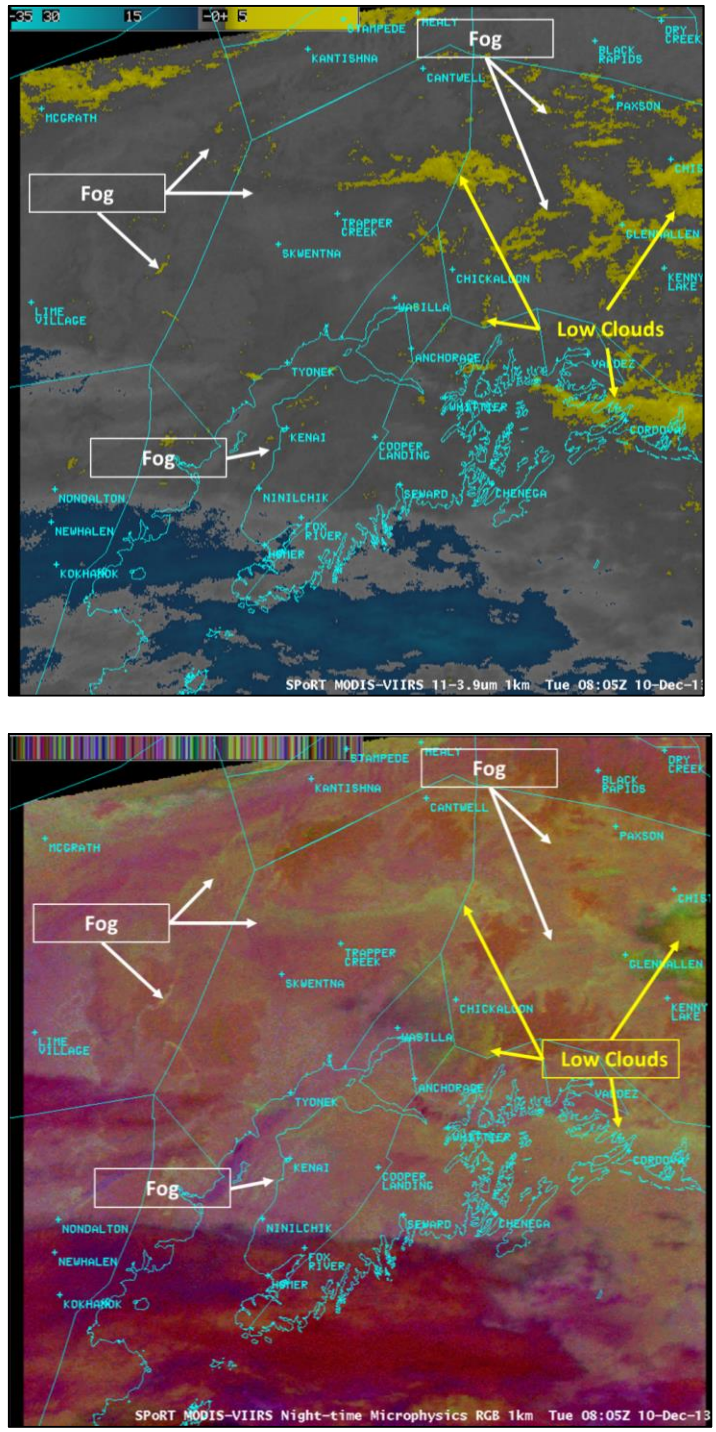


Figure 12 MODIS imagery from 10 December 2013 centered near Anchorage AK, SPoRT Hybrid 11-3.9μ imagery (upper) and NtMicro RGB (lower) with annotations for some areas of “Low Clouds” (yellow) and “Fog” (white). Not all low clouds or fog areas are labeled. Annotated areas serve as examples and other similar coloring in the imagery correspond to other fog and low cloud features.

Forecasters were also asked what training resources were used during operations in order to gauge user's training needs for this new paradigm of imagery. The training question provided the option to choose multiple training items per event. More than 50% of the total training resources used were forecaster's own "Previous Training or Experience" (Figure 13).

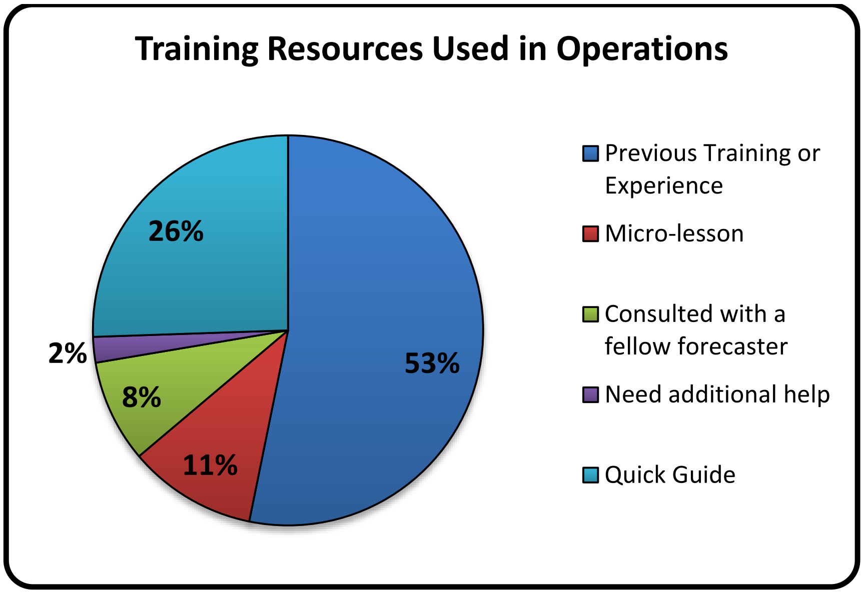


Figure 13. Percentage of time that a "training resource" was indicated by users for the events during the assessment period. Users were able to choose more than one resource per event, so the total number of choices (47) was greater than the total number of submitted surveys (32). Note that while user experience was often sited, the Quick Guides were the next most used resource, at least in terms of information used during an operational shift.

Consulting the quick guides, micro-lesson modules, and colleague assistance were the other primary sources of in-operations training on these products. Only one individual cited needing additional help in interpreting the products, which likely indicates that training was not an overt influence on forecasters' assessment of RBG products. However, one particular forecaster who submitted multiple assessments, without citing training inadequacies, later visited NASA-SPoRT to collaborate on a publication regarding operational use of RGB imagery. After preparing for the visit and receiving additional information on the development and application of RGBs, he indicated that he would in hindsight have evaluated the products more favorably than he did during this assessment period and he would be better prepared to apply this new knowledge of RGBs to forecast problems in his WFO. This anecdotal evidence could suggest a subtle training or experience deficit that, if more endemic in the forecaster community, would impact their perception and use of RGBs unless sufficiently addressed through additional training and learning opportunities.

Additional Comments from User Feedback

A few of the user comments from the assessment form have been included as support to the quantitative user survey results previously discussed, but this section will be used to discuss the user comments in detail. The quantitative assessment results indicated there was both large and small impact of the RGBs and user feedback reflected this with both positive and negative comments. While several large impact examples were highlighted in the previous results, a few comments suggested that the RGBs were hard to interpret without more experience and that *"people see colors differently"*. This same type of comment was provided by several individuals from other user groups who previously assessed the RGB imagery. It is also recognized that the human eye can vary to the point where individuals physically do not “see” the same color and/or physical deficiencies result in “blindness” within part of the color spectrum. The use of RGB imagery by those with color blindness was outside the scope of this assessment but there was a pre-existing awareness that the issue needs to be addressed at some point.

There was a comment that the NtMicro RGB colors for fog and low clouds were very similar, and this could be the result of the extreme cold temperatures that occurred during the event.

*“The one image (NtMicro) was far superior to any traditional GOES based products, which were basically useless in identifying the location and areal extent of the fog and stratus. Both areas of interest appeared the same shade of light green. … There have been multiple examples over the past week of similar appearance of fog vs. stratus in this very cold environment.” (*Figure 14*)*

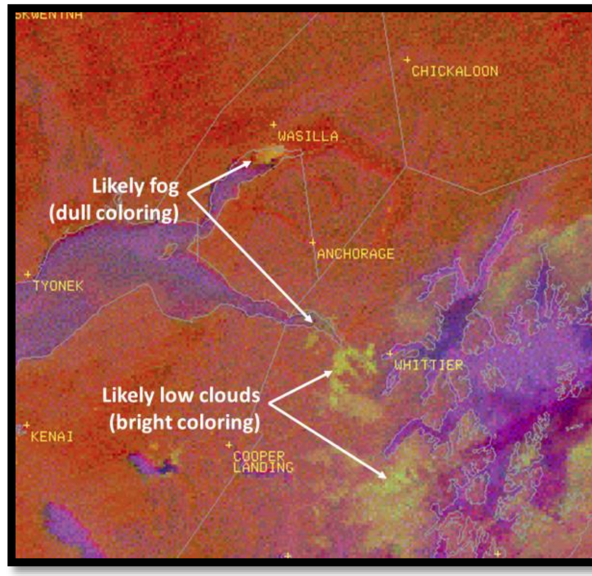


Figure 14. NtMicro RGB at 0725UTC, 25 December 2014 centered on Anchorage AK. Arrows in center of image annotate likely fog areas due to dull coloring at the ends of Knik and Turn Again Arms. Brighter coloring to the west of Whittier and east of Coopers Landing are likely low clouds due to greater contribution of all colors suggesting thicker clouds. Color of fog and low clouds are similar due to temperatures at or below -20 Celcius.

The 3.7µm brightness temperature used in the green component of the NtMicro RGB has a short-term noise (i.e. error) that increases exponentially as the temperature of the objects become less than -20 Celcius. This cold bias can also often be seen at mid-latitudes during retrievals of brightness temperatures at the tops of strong, convective thunderstorms.

The resulting image enhancement will have a speckled or “noisy” appearance as some pixels will have much colder temperatures than a neighboring pixel. Similarly, at high latitudes in winter, a cold air mass and associated cloud features at less than -20 Celcius can limit the effectiveness of the green component of the NtMicro RGB to differentiate cloud objects.

Other negative comments revolved around missing or latent data or the blocked view of lower level clouds by the mid and high clouds. Very few issues occurred where hardware or software problems interrupted production. Data was processed on local, virtual machines at the University of Alaska Fairbanks (UAF) Geographical Information Network of Alaska (GINA) in order to reduce the latency for most VIIRS imagery. The blocked view of fog and low clouds by other mid to high clouds was noted as a limitation, but in separate comments users noted that the low clouds could be seen through the *"holes"* in higher cloud layers and in another case that ….

*"The RGB nighttime microphysics imagery show low clouds/fog underneath thin layers of high clouds, which is something we haven't been able to see with traditional fog imagery products. It's a great tool for situational awareness and knowing where low clouds/fog are offshore"(*Figure 15*).*

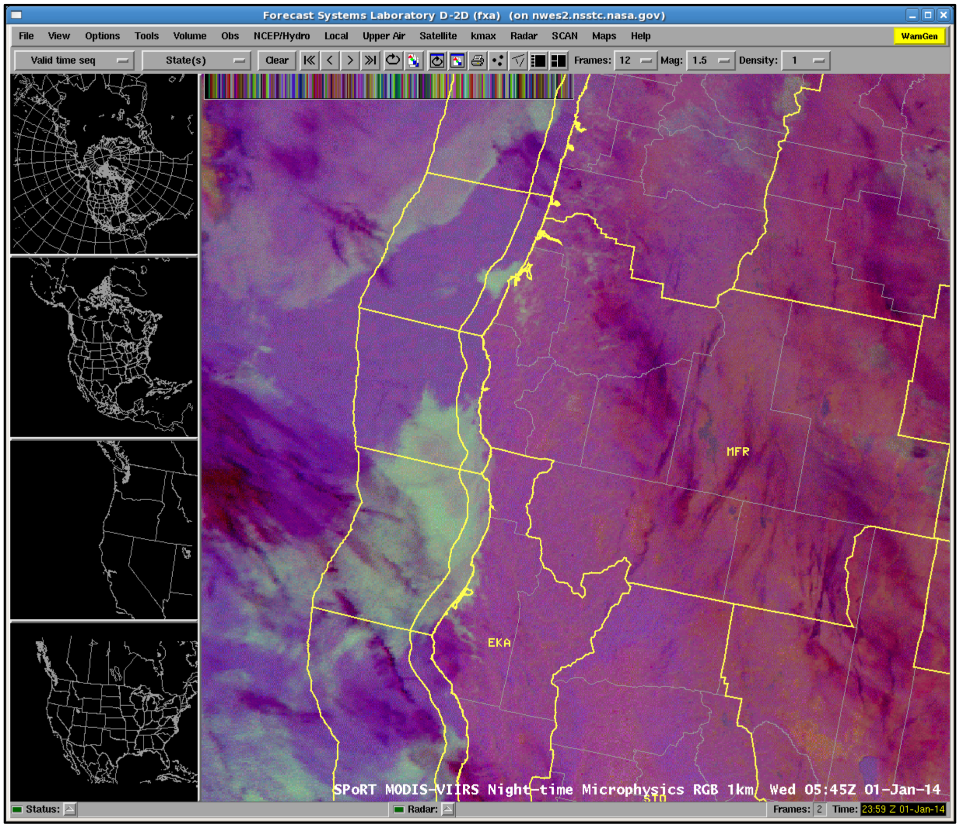


Figure 15. NtMicro RGB imagery at 0545UTC 01 January 2014 centered on western Medford OR CWA (outlined in yellow) with the coastal and marine zones also outlined (yellow). Dull gray to aqua coloring representing fog and low clouds respectively are evident in the coastal and marine areas even with some mid-level clouds above.

In addition to the quantitative results showing noticeable impact to aviation forecasts and the differentiation of fog from low clouds, several user comments also expressed these values. At least two specific comments revolved around the use of the NtMicro RGB to aid in the differentiation of fog from low stratus, and there were many comments suggesting the NtMicro RGB was an improvement over traditional imagery used for analysis of fog and low clouds. The improved capability was specifically noted by two separate forecasters. The first stated that *"the microphysics image was very helpful in picking out where the fog and low clouds were in the complex terrain"* and *"the microphysics image was very helpful with figuring out fog for zone and marine forecasts."* A second user stated, *"Tonight, was able to discern the low clouds from the fog using the RGB imagery. This also allowed me to narrow my area for the dense fog advisory for this morning" (*Figure 16*).* Many other comments revolved around the use of both RGB imagery products to quickly identify mid- and high-level clouds verses low cloud features.

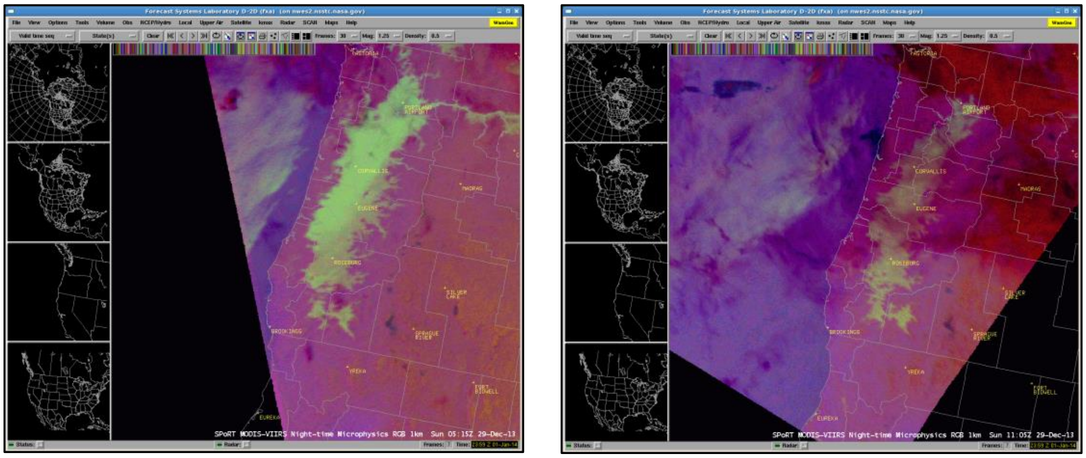


Figure 16. NtMicro RGB centered on Medford OR CWA for 28 December 2014 at 0515UTC (left, MODIS) and 1105UTC (right, VIIRS). Medford forecaster applied the imagery to limit the area of a Dense Fog Advisory. Note decrease in area of aqua coloring between times and the ability to see the fog feature even with thin, mid-level clouds (purple shades) in the area. Image at 0930UTC was also available (not shown).

Some more advanced users from the Great Falls WFO used the NtMicro RGB imagery to analyze the color characteristics of low-level clouds coincident with a surface observation on 25 September 2013 of heavy precipitation but lacking an analogous radar reflectivity signature (Figure 17). This observation site was at Havre, MT where the lowest radar scan is at 14,400 feet. At the time of the event, users were unsure of the source of the precipitation, but later via discussion with developers, forecasters were better able to understand the cloud microphysical characteristics depicted by the RGB colors and were more prepared to analyze future precipitation events.

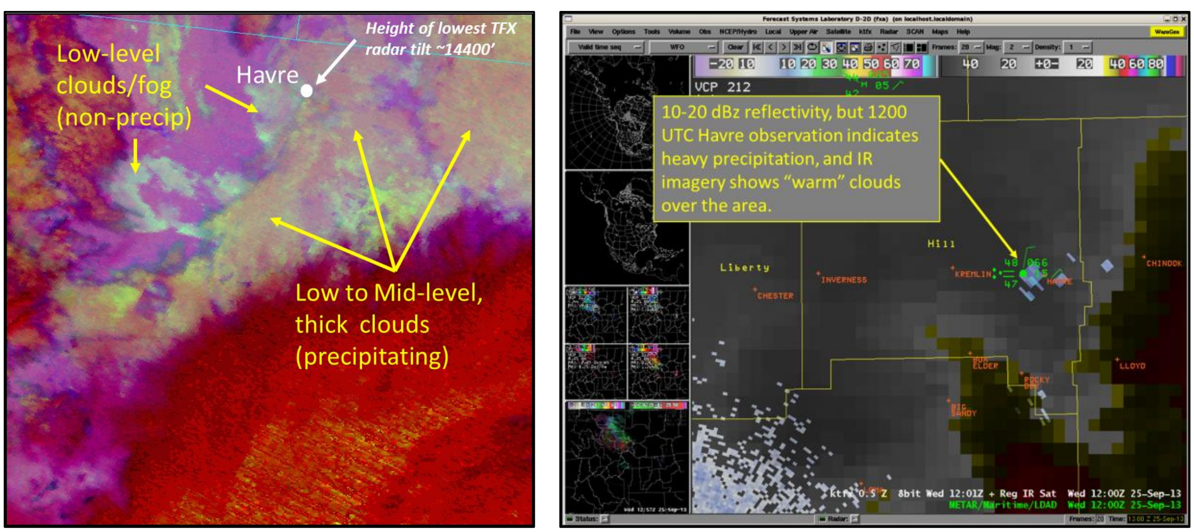


Figure 17. NtMicro RGB (left) from Aqua-MODIS centered on north central MT for 25 September 2014 at 1010 UTC. City of Havre is labeled in upper center of image. Low-level clouds and fog (aqua to gray) were just to the west and southwest of Havre, but low to mid-level clouds (olive to light tan) associated with cyclone to the southeast (reds, yellows) were rotating from the east and produced heavy precipitation 2 hours after this time as shown by METAR, TFX Radar and GOES IR imagery combination plot (right) at 1200 UTC captured from AWIPS/D-2d via TFX forecaster.

A short time later on 9 October 2013, VIIRS assisted in the analysis of a multi-layer cloud scene where cloud seeding from ice particles was theorized to be a cause of showers occurring along higher elevations of the Rocky Mountain Front Range. Forecaster comments showed that the imagery provided insight to the dynamic and microphysical processes taking place for this precipitation event …

"Weak upslope generated low clouds along Rocky Mtn Front. Radar indicates scattered rain or snow showers in this area. Aloft, southwest flow carried scattered mid-level clouds over the area. Area ceilings were approx 1000 ft AGL. GOES IR and 11-3.9 showed a fuzzy depiction of the low and mid clouds. VIIRS nighttime Microphysics provided remarkable resolution of these two cloud layers (10:02 & 10:19 UTC), but no particular distinction between fog and/or low cloud. A small area of red on the Nt Microphysics corresponded directly with radar indicated showers along the Rocky Mtn. Front. Large green contribution suggests supercooled water here... but is it rain or snow? Depends of whether surface elevation is above the freezing level, such that snow would be possible where ice crystals from higher clouds (red in Microphysics) would seed super cooled droplets in lower saturated, supercooled water layer."

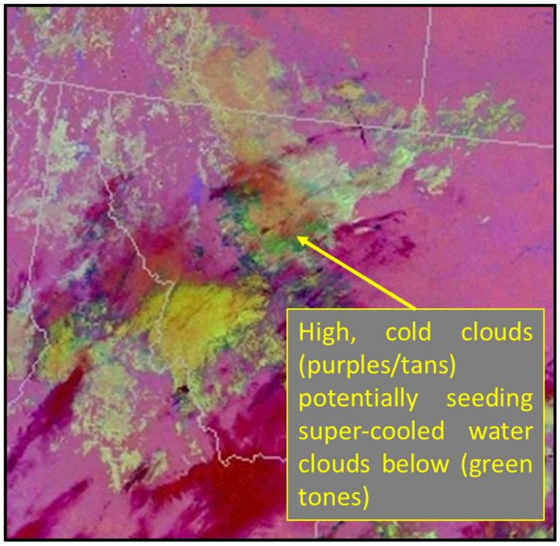


Figure 18. NtMicro RGB from VIIRS centered on west central MT for 9 October 2014 at 1002 UTC. User feedback from application of this image indicated advanced interpretation of cloud dynamic and microphysics related to observed precipitation.

Summary and Recommendations

The analysis of clouds for aviation issues of low ceilings and visibility at high latitudes can be difficult with geostationary imagery due to the larger viewing angle of the instrument and hence the lower resolution and object displacement (i.e. parallax), especially at locations within Alaska. Even some CONUS locations at higher latitude have issues with geostationary imagery but to a lesser degree. The use of polar-orbiting satellites is more common at high latitudes due to the improved resolution and viewing angle, and many of the western CONUS regions with data void areas find polar-orbiting satellites useful in operations as well. Hence, SPoRT combined GOES and polar-orbiting satellite imagery into a Hybrid product where users are able to view the imagery in an animated sequence just as is done for GOES-only imagery. Users had prior experience with the SPoRT Hybrid imagery and found value in the high-resolution, inserted imagery. Using the polar-orbiting satellites to create the 11-3.9µ difference imagery, the areas with low clouds and fog become more apparent, but it's often difficult to discern which of these is occurring at any given time. The NtMicro and DNB RGB imagery was transitioned to several WFOs at high latitude (both AK and CONUS) to evaluate their use to differentiate between fog and cloud features in order to improve forecast products directed at aviation users. The assessment showed that 72% of users preferred the NtMicro RGB imagery over any other product to analyze low clouds and fog while the other 28% tended toward traditional satellite or surface observations. Between 40-50% of responses indicated that the NtMicro RGB imagery had large to very large impact on general aviation and the differentiation of fog from other cloud features. However, the same impact in these two categories from the VIIRS DNB RGB imagery was roughly 20%. The DNB RGB imagery was not available as often due to its availability from only VIIRS and the dependency of the moon phase. These issues limited the effectiveness in the DNB RGB product in its current state.

While some users found the NtMicro RGB imagery to be a large advance in satellite imagery applications, others were unsure of the imagery interpretation and did not find the resulting colors intuitive to identify various features. The level of comfort with RGB imagery seemed to be a factor of the experience level of the user. While training was provided on these products, it was those users who had prior training on the basics of RGB imagery and who had already established some experience that found large value in the NtMicro RGB imagery to analyze and differentiate cloud features. In some cases the extreme cold of high-latitude winter did limit the NtMicro RGB imagery effectiveness, but overall a notable impact was seen in operations with several user feedback submissions indicating that decisions regarding aviation responsibilities were influenced by the RGB imagery.

Some specific recommendations include:

- A product modification or alternate method that would mitigate the “noise” that occurs in the 3.9 µm channel of the NtMicro and 11-3.9 µm products in very cold (<20ºF) temperatures, which most often occur within high-latitude, over-land locations.
- Development of products and/ or tools to better “quantify” the qualitative NtMicro RGB to help users more easily interpret resulting colors. For example, a tool could be created to allow sampling of imagery with a “mouse roll-over” that would display individual RGB components that went into making the resulting composite color.
- Increase availability of RGB imagery by including other polar-orbiting instruments via both domestic and international satellites. High-latitude locations have more frequent passes of polar-orbiting instruments and are better viewed by these satellites compared to geostationary imagers.
- Development of specific VIIRS DNB imagery to better utilize wide range of radiance values for unique situations (e.g. changes in city lights, smoke and fire events)
- Development of RGB case library for operational user reference in order to both gain experience with RGB color interpretation and expand knowledge of product applications. Non-intuitive nature of RGB color interpretation (due to interchange of channels used) requires more user experience per product and easy-to-find cases of similar events.

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