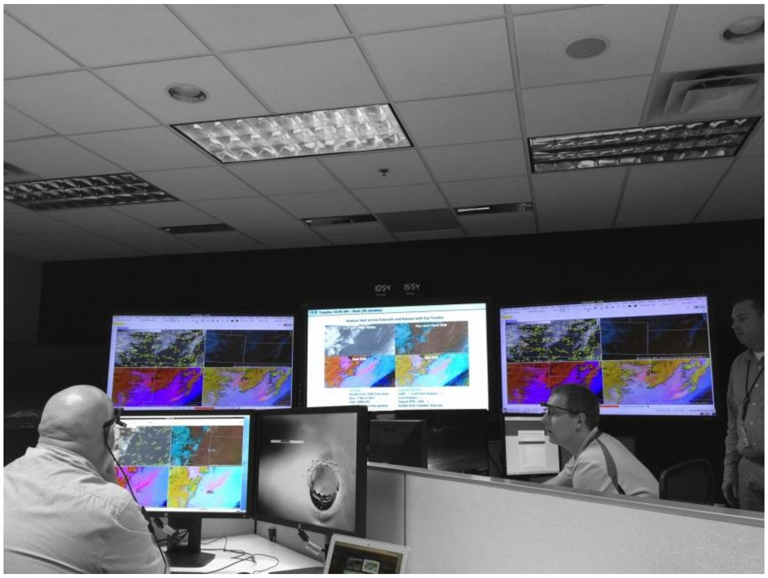
NWS Operations Proving Ground
Operational Impact Evaluation Report

Evaluating Multiple Spectral Bands and RGB Imagery for the GOES-R Era by NWS Forecasters with Color Vision Deficiency



NWS Operations Proving Ground

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Table of Contents

Executive Summary

In April of 2017, the National Weather Service (NWS) Operations Proving Ground (OPG) hosted and facilitated an evaluation to document particular challenges that forecasters with color vision deficiency (CVD) have in properly interpreting RGBs, to identify which RGB composites posed the biggest problems, and to determine whether there are technological or procedural aids that might help to mitigate their difficulty in using these data.

Three male NWS forecasters with red-green CVD participated in this evaluation. Central, Southern, and Eastern Regions each provided one forecaster for the evaluation. Two of the forecasters were Leads and one was a General at the time. Two of the three forecasters wore some type of corrective eye wear.

The evaluation began on Tuesday with an introduction to the OPG. After the introduction, participants were assigned to an Advanced Weather Interactive Processing System II (AWIPS II) workstation. Participants were instructed on how to use eye tracker technology while they analyzed specific meteorological phenomena using archived RGB composite imagery during four archived data exercises. During these exercises, the forecasters analyzed fog and low stratus during the day and night, wildfire activity, and lofted dust using various RGBs. After the participants were finished with the exercises, OPG staff and each of the participants watched the video that was created by their personal eye tracker. While watching the video, OPG staff took notes on observations and thoughts the participants relayed to them. This process is similar to a process that was applied by Heinselman et al. (2015) in the Phased Array Radar (PAR) Innovative Sensing Experiments and Gravelle et al. 2016 in the GOES-R 1-Minute Imagery Evaluations. It is called a Recent Case Walkthrough (RCW). After the RCW was completed, there was a group discussion between the forecasters and OPG staff.

On Tuesday afternoon participants went through the same four exercises they completed in the morning, but while wearing Enchroma glasses instead of the eye tracker head gear. Enchroma glasses are specialty glasses designed to improve color vision for individuals with CVD. The forecasters completed survey questions while wearing the glasses and another group discussion was conducted after the analysis. Wednesday has the same assessment methodology as Tuesday, but with a different set of RGBs and exercises.

On Thursday, participants were given access to live GOES-R data through their AWIPS II workstations. They were able to view any of the RGBs they analyzed the previous day in real-time. At this point they were taught how to use the Composite Options Tool in AWIPS II to change the gamma settings on the RGBs. By changing the gamma settings of a RGB channel, a participant can bring out contrast in each band within the component. Doing this allows the participant to make their own color table for the RGB. Participants were also introduced to a mobile application called Color Blind Pal that has been designed to aid individuals with CVD. The application works with a mobile phone or tablet’s camera to manipulate what is viewed on the screen. The application can identify a color and provide the name, display a single color while making all other colors gray-scale in the image, and add stripes to certain colors for visual identification. The application can also be put into a mode that is designed to augment colors viewed in the camera to enhance vision for a person with red-green CVD. At the end of the day, the participants filled out an overall survey for the evaluation and a final group discussion was conducted.

After three days of evaluation, participants ranked the usefulness of the RGB composites and the ease of interpretation of those RGB composites. Out of the 14 RGB composites evaluated, the most useful RGB composites were the Fire Temperature, Nighttime Microphysics, Air Mass, Day land Cloud, Daytime Composite #1, and Daytime Convection. The only RGB that all the forecasters deemed not useful was the Simple Water Vapor. One forecaster also deemed the Day Snow-Fog RGB as not useful.

Out of the 14 RGB composites evaluated, the easiest RGB composites to interpret were the Day Land Cloud, Day Land Cloud Convection, Daytime Convection, Fire Temperature, and Nighttime Microphysics. The most difficult RGB composites to interpret were the Air Mass and Simple Water Vapor.

While analyzing weather phenomena on different RGB composites during the evaluation, participants used different technology meant to improve color vision for individuals with CVD. The first technology evaluated was Enchroma Glasses. Two participants found improvement to their color vision with the Enchroma glasses. One participant found no improvement to their color vision with the Enchroma glasses. The participants that found improvement in their color vision indicated that it was dependent of the RGB composites that were being viewed. The glasses added the most improvement in the ability to identify Fog/Low stratus on the Nighttime Microphysics RGB, wildfires on the Day Land Cloud RGB, convection on the Day Convection RGB, and synoptic scale attributes on the Air Mass RGB.

The second technology evaluated was the Color Blind Pal application. There are four main tools in the application. The most useful tools for the participants were the Filter Tool which is designed to take the image being viewed in the tablet or mobile phone’s camera and only show you areas that are a certain color with everything else is in grayscale; and the Inspecting Color Tool which uses a tablet or mobile phone’s camera to identify the color of anything in the center of the crosshair on the screen.

The third technology evaluated is native to AWIPS II. This was the Composite Options Tool. This tool allows a user to change the gamma setting of a RGB composite. Forecasters felt that this functionality was moderately to extremely useful in aiding in the interpretation of RGB composites.

From the findings of this evaluation, the OPG has the following recommendations.

Recommendation 1: Explore the possibility of incorporating the Filter Tool and Inspecting Color Tool functionality from the Color Blind Pal application into AWIPS II.

Recommendation 2: Develop forecaster training on how to use the Composite Options Tool to adjust the gamma setting of RGB composites.

With only three forecasters participating in this evaluation, statistically significant results cannot be discerned from the data. However, this evaluation can be seen as a starting point for future research. As a result of this evaluation, the OPG plans to help foster development of training materials on the Composites Options Tool in AWIPS II, so that NWS forecasters with CVD have the ability to adjust RGBs to fit their needs. Currently, the functionality of the Color Blind Pal application is not available in AWIPS II. However, at the time of writing this report, the application is free to download onto mobile devices with iOS and Android operating systems. NWS forecasters with CVD can put this application on their own devices and experiment with the functionality while viewing RGBs on their AWIPS II workstations.

1. Evaluation Purpose and Goals

In November of 2016, Geostationary Operational Environmental Satellite-R Series (GOES-R) was launched into orbit. GOES-R or more specifically GOES-16 is the first satellite with the Advanced Baseline Imager (ABI). This imager provides three times more spectral information, four times the spacial resolution, and five times the temporal resolution compared to the previous GOES imager (Schmit et al. 2005). With data from the new ABI channels on GOES-16, Red-Green-Blue (RGB) imagery has been developed to help meteorologists identify different atmospheric phenomena. The RGB imagery aids with atmospheric phenomena identification because specific colors relate to specific atmospheric features. However, it has been theorized that National Weather Service (NWS) forecasters with color vision deficiency (CVD) may have problems interpreting some of the RGB imagery.

Deuteranomaly, the most common form of CVD (NEI 2017) involves red-green color vision defects and occurs in about 1 in 12 males and 1 in 200 females with Northern European ancestry. Color vision defects are inherited from genes on the X chromosome. Men have one X chromosome and one Y chromosome. Women have two X chromosomes. Men inherit CVD in greater numbers because genetic changes only have to occur on one X chromosome. For women to have CVD there would have to be a genetic change on both X chromosomes (GHR 2017). As of April 2017, the NWS has 4,365 permanent employees via data from the NWS Equal Opportunity and Diversity Management Division via the National Finance Center. 3,142 of those employees are Caucasian men and 672 are Caucasian women. Using those statistics, there could be around 262 Caucasian men and 3 Caucasian women with CVD in the NWS. Thus, it is important to make sure that new RGB imagery from GOES-16 can be interpreted by individuals with CVD, so that they can benefit from this new technology.
In April of 2017, three NWS forecasters with red-green CVD were brought to the NWS Operations Proving Ground (OPG) to document particular challenges that forecasters with CVD have in properly interpreting RGBs, to identify which RGB composites posed the biggest problems, and to determine whether there are technological or procedural aids that might help to mitigate their difficulty in using these data.

2. Participant Selection

NWS forecasters were selected to participate in the CVD evaluation by the four continental United States (CONUS) NWS Regional Offices. This resulted in a group of three male forecasters from NWS Weather Forecast Offices (WFOs) located in Central (1 forecaster), Southern (1 forecaster), and Western (1 forecaster) Regions. Two of the participants are Lead Forecasters and one participant is a General Forecaster in the NWS. There were no other prerequisites for the evaluation besides being a NWS forecaster with CVD.

The three selected participants were given a pre-evaluation survey before coming to the OPG. From the survey, it was found that all three participants had been formally diagnosed as having CVD by an Ophthalmologist or Optometrist. One participant indicated that they had Deuteranomaly; one participant indicated that they had red-green CVD; and one participant didn't know exactly which CVD they possessed. An online Ishihara color vision test available from the creators of Enchroma CVD glasses (Enchroma 2017) indicated that each participant likely has red-green CVD or more specifically Deuteranomaly. It should be noted that there was not time before the evaluation to have the participants visit their Ophthalmologist or Optometrist for clarification on the type of CVD they possess. The background survey also indicated that one participant wears prescription glasses, one participant wears contact lenses, and one participant requires no prescription eyewear.

3. Description of Exercises and Assessment Methodology

The evaluation was developed using guidance from a previous operational readiness evaluation administered in the OPG which investigated the usefulness of RGB imagery from Japan's Himawari-8 satellite (https://www.weather.gov/media/opg/ABI-RGB-Report-FINAL.pdf) and from the NWS GOES-R Science and Operations Officer Preparation Course. The evaluation was completed over three days (Tuesday through Thursday) in April of 2017. On Tuesday morning participants attended an introductory session that covered the evaluations goals, technology training, and background on the OPG. After the introduction, participants were assigned to an Advanced Weather Interactive Processing System II (AWIPS II) workstation. Participants were instructed on how to use eye tracker technology while they analyzed specific meteorological phenomena using archived RGB composite imagery during four archived data exercises. The eye tracker technology was developed by Pupil Labs. It is worn as a headset, and allows recording of an individual's complete field of view and eye movements (Kassner et al. 2014). For this evaluation, the eye tracker headgear's primary goal was to film the viewing environment of the participant and not track eye gaze. This was due to the fact that one of the participants wears corrective eye glasses which can have impacts on eye tracker accuracy (Gwon et al. 2014). Participants also answered survey questions while performing analysis using the RGB composites.

Exercise 1 had participants analyze fog and low stratus at night across Texas and Oklahoma on 27 February 2017 at 1300 UTC. The RGB composite they analyzed was the Nighttime Microphysics (Fig 1). Exercise 2 had forecasters analyze fog and low stratus during the day across Missouri and Iowa on 27 February 2017 at 1700 UTC. The RGB composites they analyzed were the Day Land Cloud, Day Snow Fog, and the Daytime Composite #1 (Fig 2). Exercise 3 had forecasters analyze wildfire detection and evolution across Kansas, Oklahoma, and Texas on 7 March 2017 at 0300 UTC. The RGB composites they analyzed were the Day Fire Detection, Day Land Cloud (Fire Variant), and Fire Temperature (Fig 3). Exercise 4 had forecasters analyze dust across Colorado and Kansas for 7 March 2017 at 0000 UTC. The RGBs they analyzed were the Day Land Cloud, Dust, and Ash (Fig 4). After the participants were finished with Exercise 4, OPG staff and each of the participants watched the video that was created by their personal eye tracker. While watching the video, OPG staff took notes on observations and thoughts the participants relayed to them. This process is similar to a process that was applied by Heinselman et al. (2015) in the Phased Array Radar (PAR) Innovative Sensing Experiments and Gravelle et al. 2016 in the GOES-R 1-Minute Imagery Evaluations. It is called a Recent Case Walkthrough (RCW). The goal of the RCW during this evaluation was to record any useful insights and observations by forecasters that might have been missed in the survey questions completed during the analysis exercises. The RCW in this evaluation is slightly augmented from Heinselman et al. (2015) and Gravelle et al. 2016, as the participants answered survey questions while conducting analyses instead of writing thoughts and decision points in a decision log. After the RCW was completed, there was a group discussion between the forecasters and OPG staff.

On Tuesday afternoon, participants went through the same four exercises they completed in the morning, but while wearing Enchroma glasses instead of the eye tracker head gear. Enchroma glasses were developed by co-inventors Andrew Schmeder and Don McPherson. The glasses are designed to enhanced color vision for individuals with red-green CVD. With red-green CVD, the red and green photopigments in the eye overlap more than normal. The glasses use a patent pending optimal filter that targets those red and green photopigments and helps separate the overlapping (Enchroma 2017). The forecasters completed survey questions while wearing the glasses and another group discussion was conducted after the analysis.

Wednesday has the same assessment methodology as Tuesday, but with a different set of RGBs and exercises. Exercise 5 had participants analyze convection across Iowa and Illinois for 28 February 2017 at 2230 UTC. The RGBs they analyzed were Day Land Cloud Convection, Day Convection, and Daytime Composite #1 (Fig 5). Exercise 6 had forecasters analyze meteorological features on the synoptic scale for 1 March 2017 at 0000 UTC. The RGBs they analyzed were Simple Water Vapor, Air Mass, and Differential Water Vapor (Fig 6). Exercise 7 had forecasters analyze snow and ice across California for 28 February 2017 at 2230 UTC. The RGBs they analyzed were Day Land Cloud, Day Snow Fog, and Daytime Composite #1 (Fig 7).

On Thursday, participants were given access to live GOES-R data through their AWIPS II workstations. They were able to view any of the RGBs they analyzed the previous day in real-time. At this point they were taught how to use the Composite Options Tool in AWIPS II to change the gamma settings on the RGBs. By changing the gamma settings of a RGB channel, a participant can bring out contrast in each band within the component. Doing this allows the participant to make their own color table for the RGB. It should be noted that a forecaster should understand the science behind a particular RGB before changing the gamma settings. Participants were also introduced to a mobile application called Color Blind Pal created by Vincent Fiorentini that has been designed to aid individuals with CVD (Color Blind Pal 2017). The application works with a mobile phone or tablet's camera to manipulate what is viewed on the screen. The application can identify a color and provide the name, display a single color while making all other colors gray-scale in the image, and add stripes to certain colors for visual identification. The application can also be put into a mode that is designed to augment colors viewed in the camera to enhance vision for a person with red-green CVD. At the end of the day, the participants filled out an overall survey for the evaluation and a final group discussion was conducted.

4. Overall Results

After three days of evaluation, participants ranked the usefulness of the RGB composites and the ease of interpretation of those RGB composites. Out of the 14 RGB composites evaluated, the most useful RGB composites were the Fire Temperature, Nighttime Microphysics, Air Mass, Day land Cloud, Daytime Composite #1, and Daytime Convection. The only RGB that all the forecasters deemed not useful was the Simple Water Vapor. One forecaster also deemed the Day Snow-Fog RGB as not useful.

Out of the 14 RGB composites evaluated, the easiest RGB composites to interpret were the Day Land Cloud, Day Land Cloud Convection, Daytime Convection, Fire Temperature, and Nighttime Microphysics. The most difficult RGB composites to interpret were the Air Mass and Simple Water Vapor.

While analyzing weather phenomena on different RGB composites during the evaluation, participants used different technology meant to improve color vision for individuals with CVD. The first technology evaluated was Enchroma Glasses. Two participants found improvement to their color vision with the Enchroma glasses. One participant found no improvement to their color vision with the Enchroma glasses. The participants that found improvement in their color vision indicated that it was dependent of the RGB composites that were being viewed. The glasses added the most improvement in the ability to identify Fog/Low stratus on the Nighttime Microphysics RGB, wildfires on the Day Land Cloud RGB, convection on the Day Convection RGB, and synoptic scale attributes on the Air Mass RGB. It should be noted that the usefulness of the Enchroma glasses appears to be a very individual. A person with CVD must experiment for themselves to determine the usefulness of the glasses.

The second technology evaluated was the Color Blind Pal application. There are four main tools in the application. The most useful tools for the participants were the Filter Tool (Fig 8), which is designed to take the image being viewed in the tablet or mobile phone's camera and only show you areas that are a certain color with everything else is in grayscale; and the Inspecting Color Tool which uses a tablet or mobile phone's camera to identify the color of anything in the center of the crosshair on the screen (Fig 9).

The third technology evaluated is native to AWIPS II. This was the Composite Options Tool. This tool allows a user to change the gamma setting of a RGB composite. Forecasters felt that this functionality was moderately to extremely useful in aiding in the interpretation of RGB composites. The following are quotes from the participating forecasters on the usefulness of the composite options tool in AWIPS II.

"If there was an answer between moderate and extreme I would choose that. It was quite useful for certain RGB's in certain situations. In some respects, I think it will change the way we view certain features/parameters. For example, I believe I will be able to see low stratus/fog in most situations better than I ever have before."

"This was one of the most helpful tools for improving my perception of forecast graphics. Being able to customize it allowed me to improve the contrast enough to identify key features with ease. I will likely continue exploring this feature at the WFO to continue developing color combinations that work best for me."

"This functionality is critical to add contrast and better view the differences in the color bands."

5. Findings and Recommendations

From the findings of this evaluation, the OPG has the following recommendations.

Recommendation 1: Explore the possibility of incorporating the Filter Tool and Inspecting Color Tool functionality from the Color Blind Pal application into AWIPS II.

Recommendation 2: Develop forecaster training on how to use the Composite Options Tool to adjust the gamma setting of RGB composites.

With only three forecasters participating in this evaluation, statistically significant results cannot be discerned from the data. However, this evaluation can be seen as a starting point for future research. As a result of this evaluation, the OPG plans to help foster development of training materials on the Composites Options Tool in AWIPS II, so that NWS forecasters with CVD have the ability to adjust RGBs to fit their needs. Currently, the functionality of the Color Blind Pal application is not available in AWIPS II. However, at the time of writing this report, the application is free to download onto mobile devices with iOS and Android operating systems. NWS forecasters with CVD can put this application on their own devices and experiment with the functionality while viewing RGBs on their AWIPS II workstations. The following quotes are final takeaways from the participating forecasters:

"I can also say that I feel like I have a few more tools to help me combat my vision deficiency. It hasn't been a big problem for me in my career, but it is nice to have some options. Hopefully some of our work here this week can help others in the future."

"While most features are identifiable using the default color schemes, it is still challenging since color-blind forecasters don't perceive gradients/brightness as well. The ability to modify the color schemes to better suit color-blind forecasters helps alleviate this problem quite a bit."

"A large portion of the difficulties in seeing certain RGBs could be mitigated by the composite options techniques and using the Color Blind Pal tool. Adding the Color Blind Pal functionality to AWIPS would go even further toward completely mitigating the difficulty."

6. References

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7. Tables and Figures

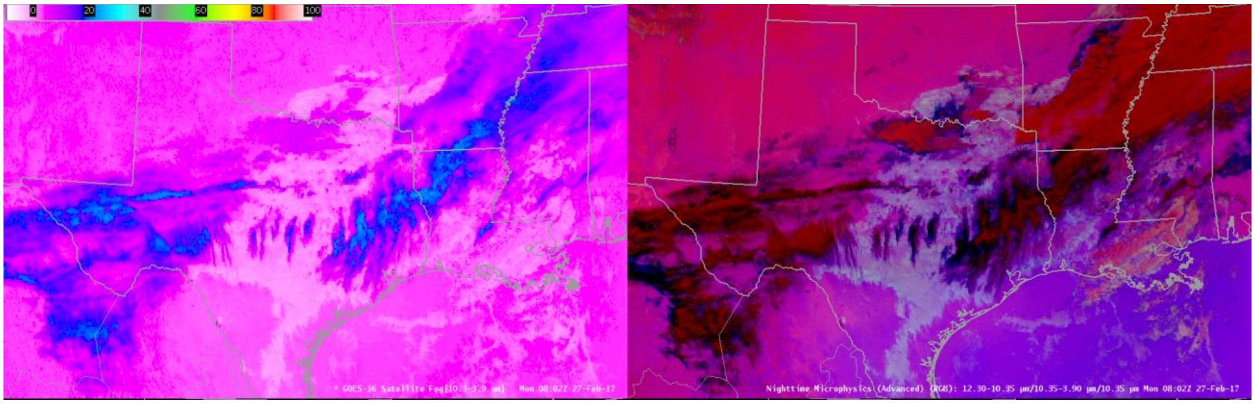

Figure 1. GOES-16 Satellite Imagery 2-Panel from 27 February 2017 at 08:02 UTC. Left panel is the Satellite Fog Product and right panel is the Nighttime Microphysics RGB.

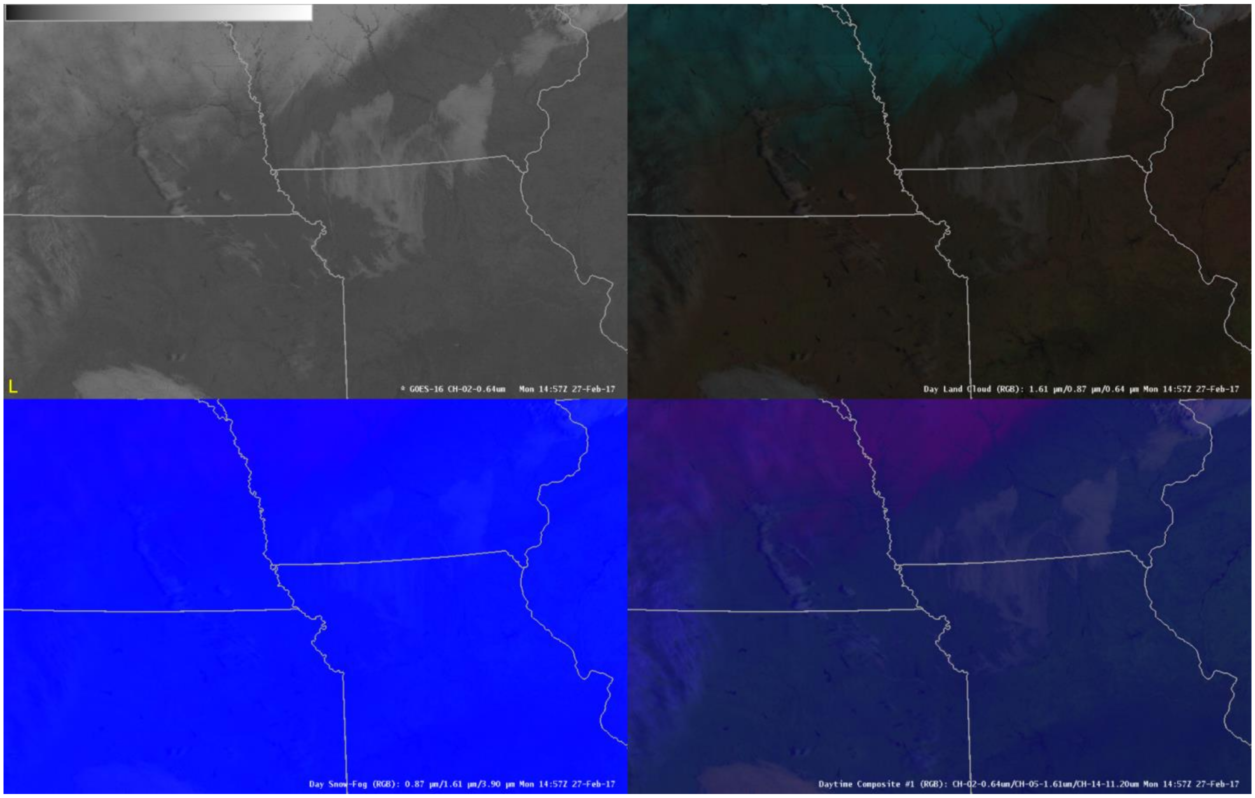

Figure 2. GOES-16 Satellite Imagery 4-Panel from 27 February 2017 at 14:57 UTC. Top left panel is the "Red" Band Visible, top right panel is the Day Land Cloud RGB, bottom left panel is the Day Snow-Fog RGB, and the bottom right panel is the Daytime Composite #1 RGB.

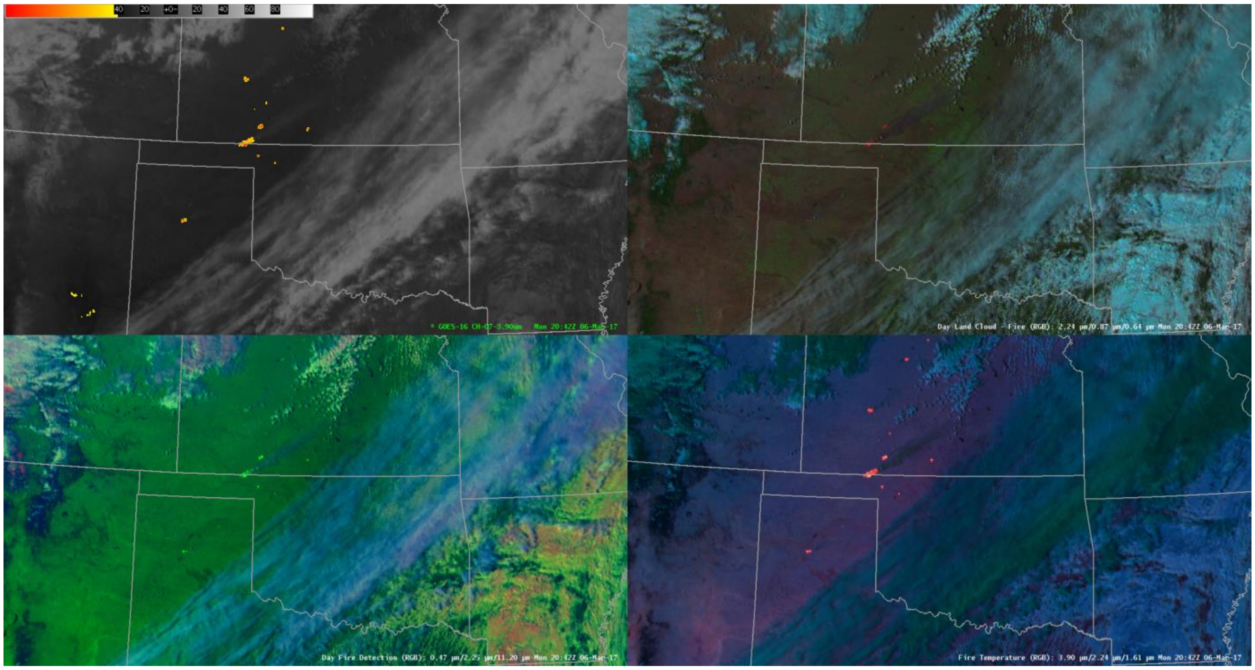

Figure 3. GOES-16 Satellite Imagery 4-Panel from 06 March 2017 at 20:42 UTC. Top left panel is the "Shortwave" Window Band IR, top right panel is the Day Land Cloud-Fire RGB, bottom left panel is the Day Fire Detection RGB, and the bottom right panel is the Fire Temperature RGB.

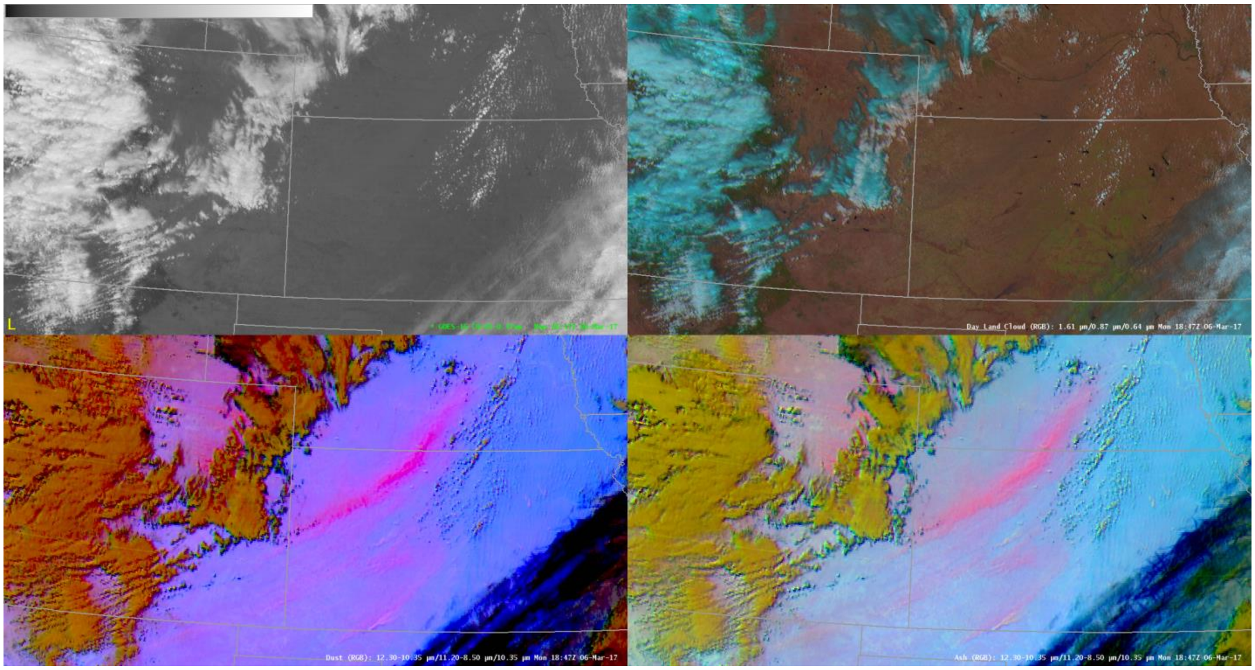

Figure 4. GOES-16 Satellite Imagery 4-Panel from 06 March 2017 at 18:47 UTC. Top left panel is the "Blue" Band Visible, top right panel is the Day Land Cloud RGB, bottom left panel is the Dust RGB, and the bottom right panel is the Ash RGB.

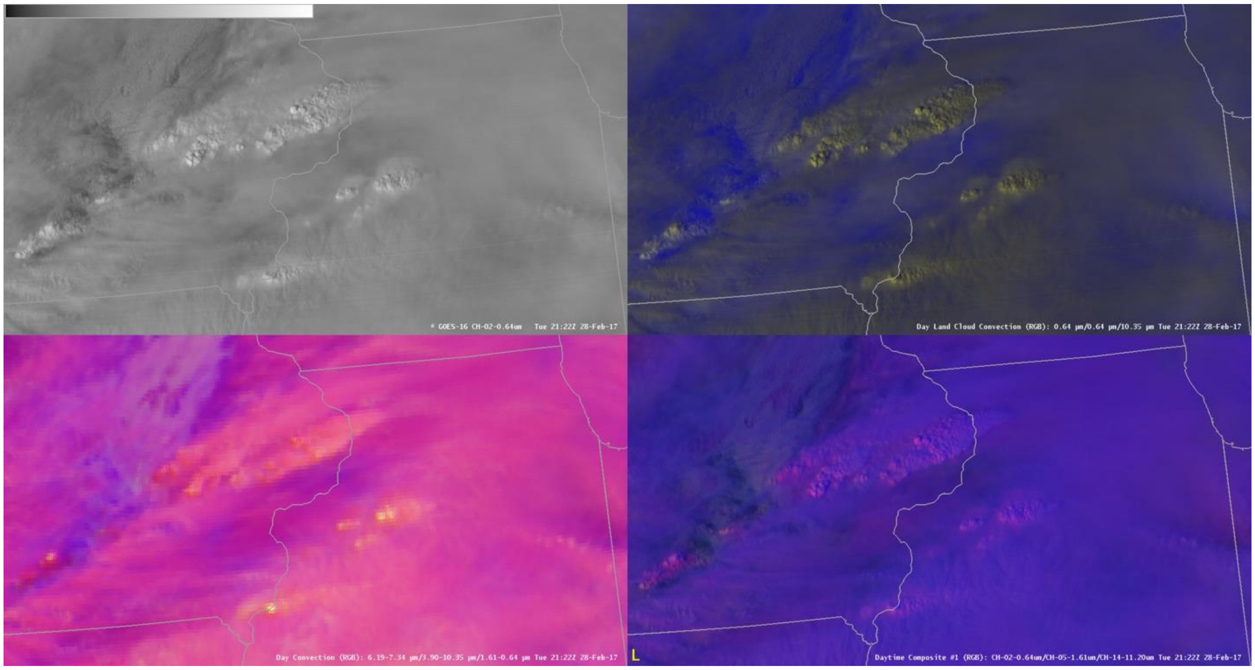

Figure 5. GOES-16 Satellite Imagery 4-Panel from 28 February 2017 at 21:22 UTC. Top left panel is the "Red" Band Visible, top right panel is the Day Land Cloud Convection RGB, bottom left panel is the Day Convection RGB, and the bottom right panel is the Daytime Composite #1 RGB.

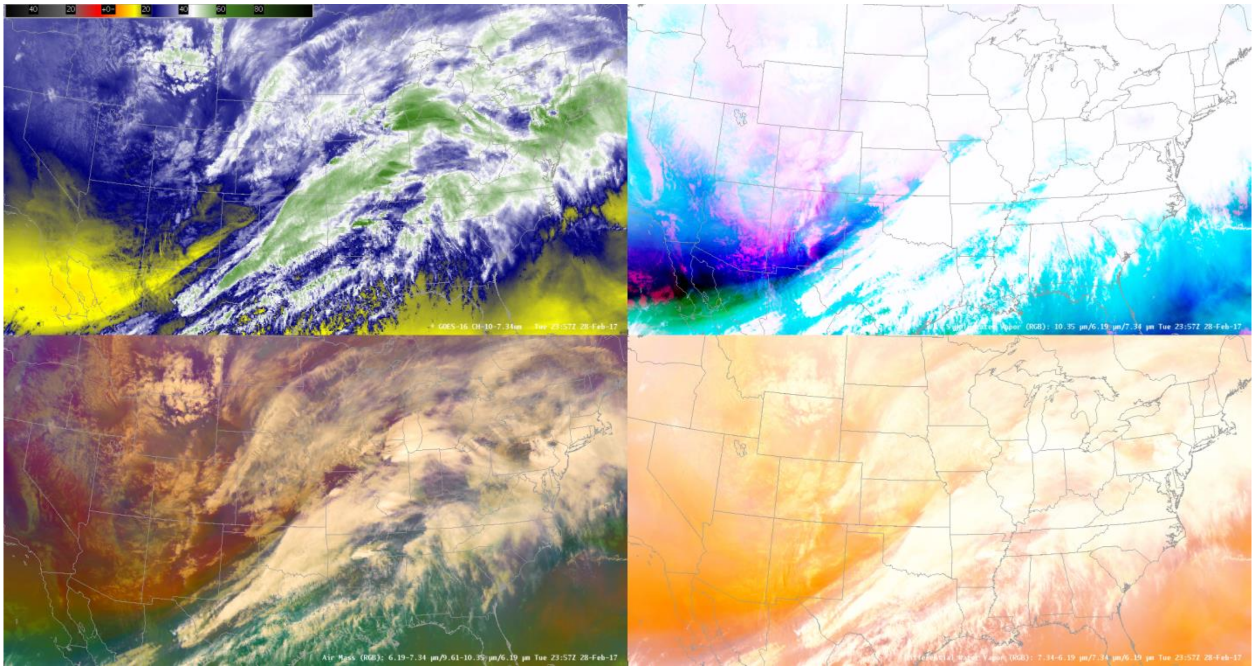

Figure 6. GOES-16 Satellite Imagery 4-Panel from 28 February 2017 at 23:57 UTC. Top left panel is the "Lower-Level Water Vapor" Band IR, top right panel is the Simple Water Vapor RGB, bottom left panel is the Air Mass RGB, and the bottom right panel is the Differential Water Vapor RGB.

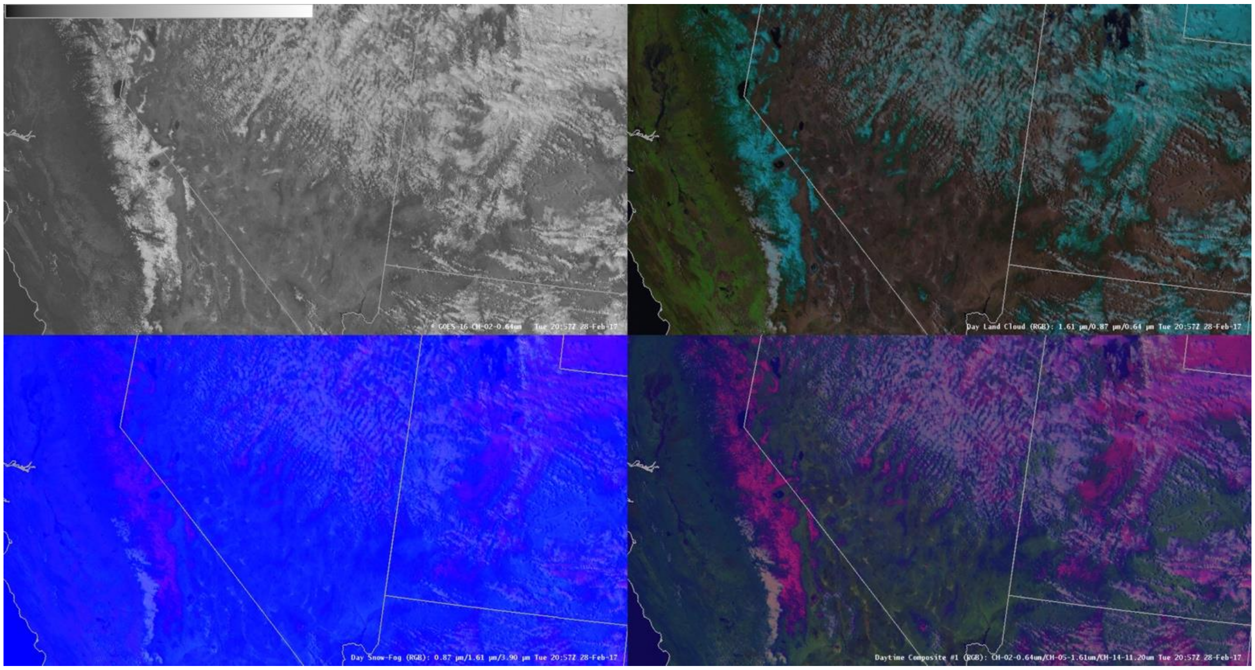

Figure 7. GOES-16 Satellite Imagery 4-Panel from 28 February 2017 at 23:57 UTC. Top left panel is the "Red" Band Visible, top right panel is the Day Land Cloud RGB, bottom left panel is the Day Snow-Fog RGB, and the bottom right panel is the Daytime Composite #1 RGB.

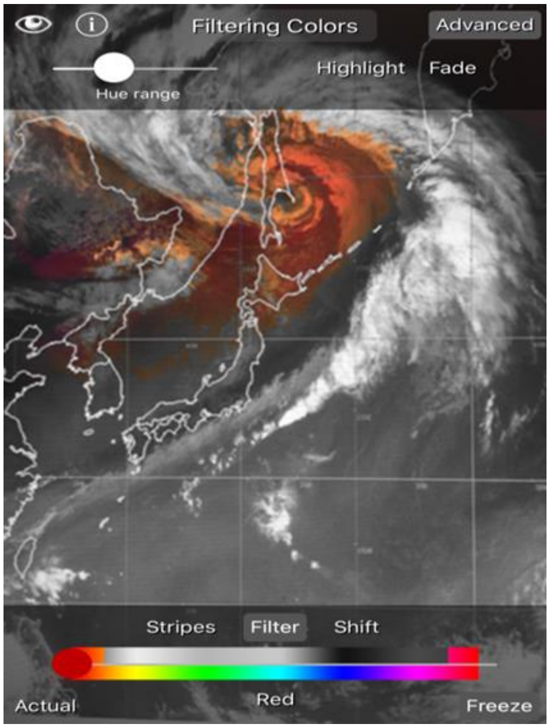

Figure 8. Color Blind Pal Application Filter Tool. In this image only shades of red are colorized. Everything else is shaded in greyscale.

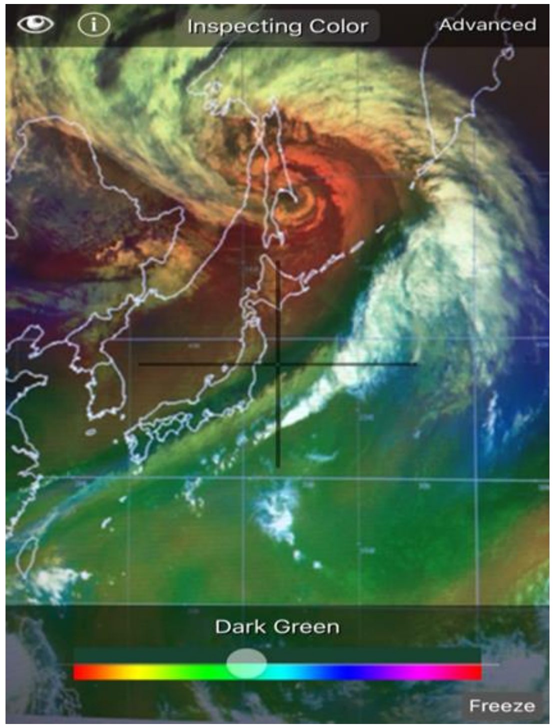

Figure 9. Color Blind Pal Application Inspecting Color Tool. In this image the color of the object in the center of the crosshair is labeled. The center color is dark green.