10B.4 COLOR DAY/NIGHT VISIBLE GOES SATELLITE IMAGES

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1.0 INTRODUCTION

Visible satellite images have a wide variety of uses among many different user groups. For pilots, visible satellite data is very useful for identification of areas with clouds or fog. Beginning pilots must obey Visible Flight Rules (VFR) which forbid them from flying in clouds. The VFR pilot must be able to see the ground and see other aircraft around. Hence, visible satellite pictures are very useful for flight planning for VFR pilots. However, the traditional visible satellite image does not show anything at night. Aircraft fly both day and night, so a cloud/fog satellite product suite is needed round the clock. The day/night GOES visible satellite images available at http://wx.erau.edu are full color images constructed so as to provide easily interpreted information on clouds. The goal of this product is to generate satellite images which appear similar both day and night at the highest possible spatial and time resolution. During the daytime a three channel color image is generated. The clouds above 21,000 feet are tinted light blue to distinguish the high clouds from the lower clouds. At night an image is derived from multiple infrared channels to generate an image similar to the daytime visible image. Figure 1 is an example of the product showing the sunrise transition from the night (left side of image) to daylight (right side of image) over Florida.

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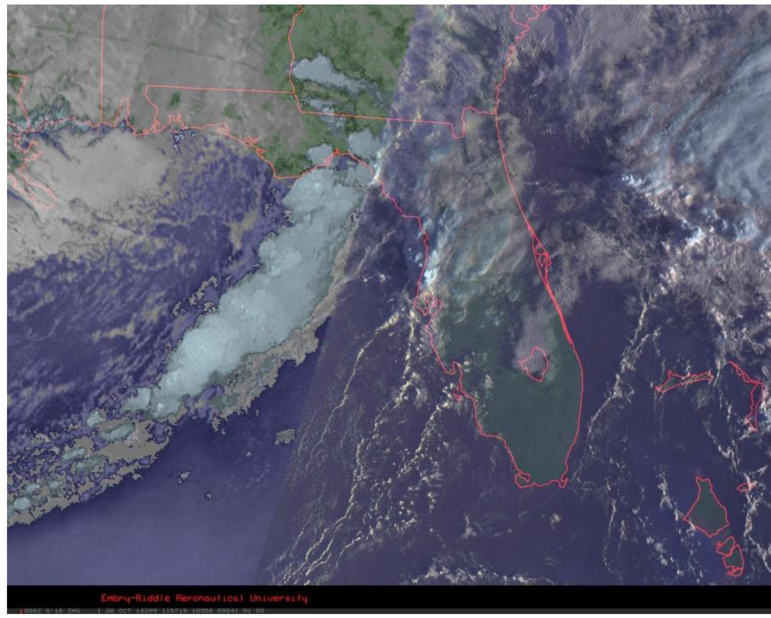

Figure 1. Day/night visible image from Oct. 26, at 11:57 UTC. The diagonal line near the center of the image is the sunrise terminator line. The portions of the image to the left are still in darkness, while the portions to the right are in daylight.

2.0 DAYTIME VISIBLE FULL COLOR

During the day the color images are generated from bands 1 (blue), 2 (red), and 3 (vegetation) on the GOES-east satellite. The GOES satellite does not have a true green channel, so the .8 micron vegetation channel is used as a substitute green channel. Chlorophyll in green plants causes a weak reflectance (about 5%) in the green visible region of the spectrum, and a strong reflectance (about 30%) in the .8 micron near infrared spectrum. To tone down the vegetation channel into a green channel, a weighted average of the blue, red, and vegetation channels is performed. Weights of .29, .29, and .33 are utilized for the blue, red, and vegetation channels respectively to generate a “green” channel. The three bands without enhancements are then combined into a color image.

In order to distinguish the high clouds (above 21,000 feet) from the low clouds a corrected infrared temperature is converted to cloud top height. Thin cirrus clouds have an emissivity less than one, so there is a mixture of radiation coming from the cloud and radiation going through the cloud from below. This causes the thin clouds to have an infrared temperature that is warmer than the true cloud temperature. To correct for this warm cirrus cloud bias, a correlation analysis is performed between the infrared temperature (band 13) and the water vapor temperature (band 9). Pixels which show clouds in both the water vapor and infrared channels have the water vapor temperature inserted into the infrared image. This corrected IR temperature is then used to determine the cloud height. The conversion of temperature to height is done using the 1966 US Standard Atmosphere Supplement soundings (available at https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19670028571.pdf) for January and July at latitudes 15, 30, 45, 60 and 75. A cosine interpolation for date and a linear interpolation for latitude is performed to obtain a sounding for the pixel being converted from temperature to height. To generate the high/low cloud image, the original images are separated into two images; one with pixels above 21,000 feet and another with pixels below 21,000 feet. The higher cloud image brightness values (0-255) are compressed into the 191-255 brightness range. The lower cloud image bright values are compressed into the 0-190 brightness range and then merged back with the high cloud image. The two high/low brightness ranges are expanded back into the full brightness ranges using an enhancement table on the display, with the high cloud range having a little blue added to the enhancement.

The three channels are each brightness normalized by dividing the pixel brightness by the cosine of the solar zenith angle. The brightness normalization corrects for the changing brightness caused by the changing sun angle. The basic correction is to divide the brightness by the cosine of the solar zenith angle (the angle from the overhead at a spot to the sun). However, this breaks down at sunrise/sunset when the cosine of the solar zenith angle is zero. The routine limits this effect in two ways. First, if the sun is within 3 degrees of the horizon, the processing is terminated. The second modification to the divide by the cosine is a correction term based on multiple scattering in clouds. The correction is to multiple the normalized brightness by 1/(1+ (sun's zenith angle in radians)/pi). This reduces the cloud brightness near the terminator zone to better approximate the cloud brightness at higher sun angles.

For the blue channel, in addition to the brightness normalization, a simplified Rayleigh scattering correction is applied. The term 27*(1-cos(sun angle)*(1-cos(sat angle)) is subtracted from the normalized brightness value. The value 27 was obtained from looking at the difference in the sea brightness value near the equator over the Pacific ocean between local noon and local sunset for GOES-16 channel 1 normalized images. Both the normalization and Rayleigh Scattering corrections assume isotropic scattering (i.e. scattering equally in all directions). No phase function has been incorporated into the calculations. This isotropic scattering assumption is a reasonable assumption for most situations. However, for forward scattering situations (such as the eastern Atlantic early in the morning where the sun is to the east of the cloud and the satellite is to the west of the cloud (forward scattering)) the brightness normalized clouds can be too bright.

3.0 SINGLE CHANNEL VISIBLE

For the GOES-15 satellite, there is only one visible channel in the red band. It is processed the same as the red channel for the east satellite with brightness normalization and high/low stripping. Then pseudo blue and green channels are constructed utilizing a land/sea mask. For locations over water, the pseudo blue channel has 30 brightness counts added to the darker values (less than 80 counts) where there are no clouds. For locations over land, a pseudo green channel is generated by adding 15 counts to the darker values with normalized brightness counts of 80 or less. This pseudo color image is used for all the GOES-15 displays and other satellites with only one visible channel.. When a newer GOES-17 is put into operations, the west images will be treated the same as the east. The following is a “colorized” GOES-15 image of Hawaii just after sunrise, with the left portion of the image being in the dark

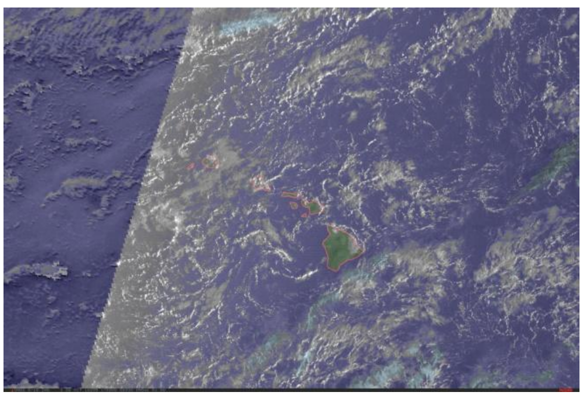

Figure 2. GOES-15 colorized image from Oct. 26, 2018 at 17:00 UTC with the daylight section of the image being on the right. A land sea mask is applied, and land areas have increased brightness added to the "green" channel, and water areas having increased brightness added to the "blue" channel. The red channel is the original visible.

4.0 NIGHTTIME "COLOR VISIBLE"

The nighttime portion of the image is constructed from several infrared bands attempting to replicate features of the daytime visible as closely as is possible using the available infrared bands. The low and high cloud portion of the derived image are generated separately and then combined. The low cloud portions are constructed using the 3.9 micron (GOES-16 band 7) subtracted from the 10.3 micron (GOES-16 IR band 13). The temperature difference between -4 and +10 degrees C are then stretched into the brightness values of 30 to 255 counts. Figure 3a shows the original IR (GOES-16 band 13), figure 3b. shows the 3.9 micron (GOES-16 band 7) and figure 3c shows the difference product showing the low clouds over Texas.

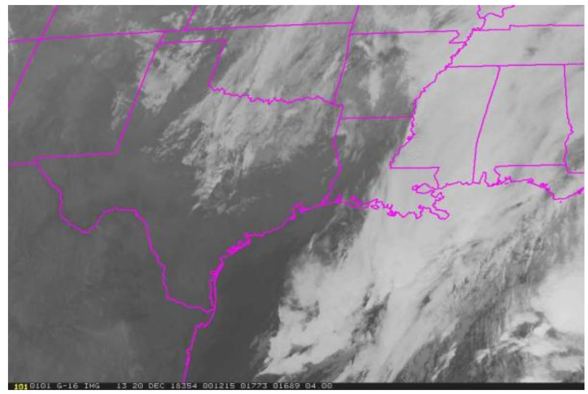

Figure 3a. IR (GOES-16 band 13) for December 20, 00:12 UTC.

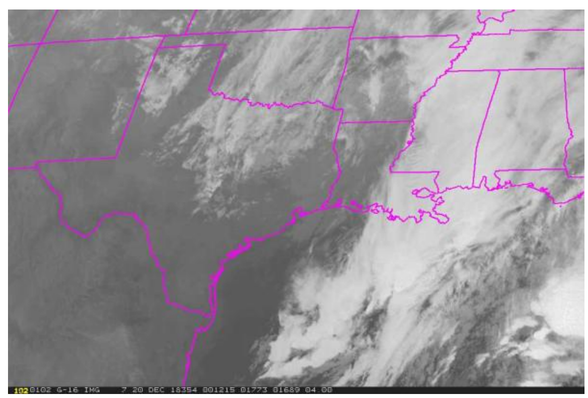

Figure 3b. 3.9 micron (GOES-16 channel 7) for Dec. 20, 00:12 UTC. The sun has set in the area.

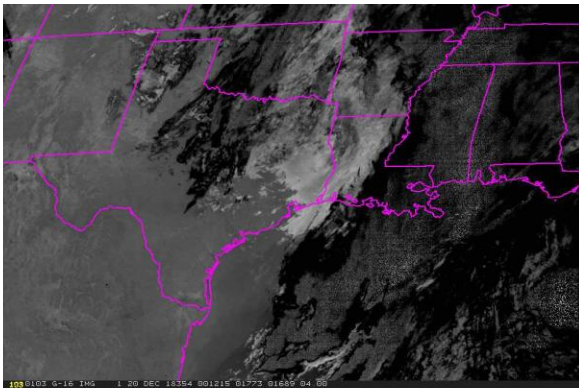

Figure 3c. Difference image of previous two images. The low clouds show up as white and the high clouds show up as black.

The temperature differences between the two channels is caused by slight differences in emissivity resulting from particle size differences. The difference image shows the low clouds with small droplets as white, the ground gray, and the high clouds with large ice particles as black. This is used for the low cloud portion of the nighttime image. This difference technique for monitoring low clouds and fog at night was first utilized for geostationary satellites by Ellrod (1995) and is used by many different producers of nighttime satellite images.

The 9.6-10.3 micron difference (GOES-16 band 12- band 13) is used to generate the high cloud part of the image. The 9.6 micron channel is normally used to detect ozone (O3) in stratospheric intrusions into the troposphere. There also is a slight difference in the emissivity of clouds between the two channels. The difference in the temperature (caused by the differences in emissivity) between the two channels is related to the thickness of the clouds. Since only the difference in cloudy areas is used, the variability of ozone in the clear areas does not impact the use of the difference for cloud thickness determination. Figure 4a shows the 9.6 micron channel for the same area as figures 3, while figure 4b shows the derived high cloud image.

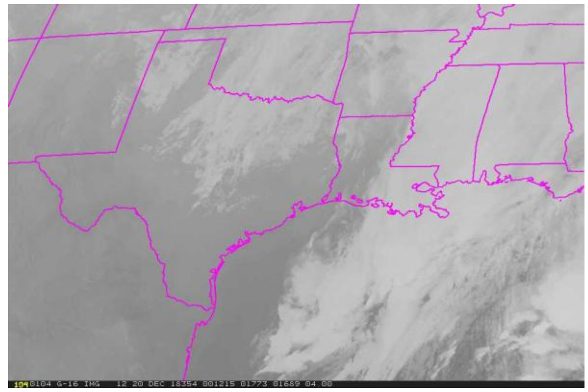

Figure 4a. 9.6 micron (GOES-16 channel 12) for the same area as the previous figure.

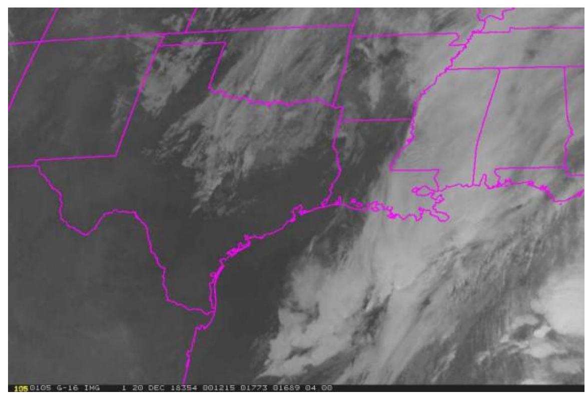

Figure 4b. Difference between the 9.6 and 10.3 (GOES-16 channel 12-channel 13) showing the high clouds.

This difference image allows for thin cirrus to be depicted as dim clouds and thick thunderstorms to be depicted as bright clouds. This difference allows overshooting tops of thunderstorms to be more noticeable than a simple IR temperature image. This O3-IR difference is used for all the high cloud portion of the image as well as for the dark portions of the lower cloud image. The low and high cloud images are merged to form the nighttime portion of the image product. Figure 4c. shows the resultant merged nighttime image.

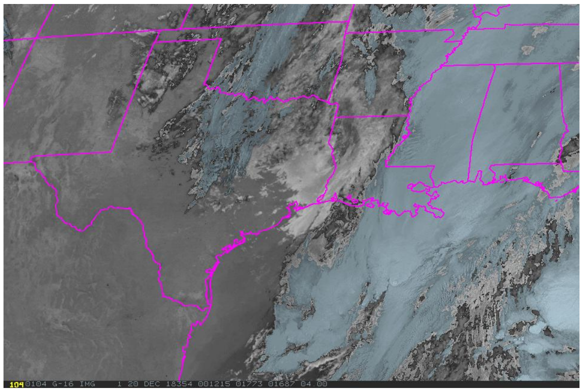

Figure 4c. Merged nighttime cloud product showing the low clouds as white, and the higher clouds with a blue tint.

Since the daytime visible image is a color image generated from red, green, and blue channels, for consistency the nighttime image is also "colorized". During the initial days of processing GOES-16 data, the same single channel colorizing technique described in section 3.0 was used. However as the seasons changed, it became apparent that the nighttime green differed significantly from the daytime green. To better follow the seasons, a new nighttime green technique was developed. During the day, a month long cloud free image was generated for the three visible channels at 16, 17, and 18 UTC. The month long minimum brightness composite for each time period eliminated the clouds, but retained the shadows. To eliminate the shadows, the maximum brightness for the three times are combined into a composite. A "green" cloud free image was generated. The difference between the red and "green" cloud free images is used to colorize the nighttime green channel.

The nighttime merged image is utilized as the red channel image. The nighttime green channel is generated using the merged image plus the daytime red green difference for each pixel. The "blue" channel is generated by adding 30 counts to the clear water areas. The nighttime portion of the images is then mapped into the daytime resolution merged with the daytime portion for the final products. Figure 5a shows the resultant "color" nighttime image for the same time and location as the figures 3 and 4. Figure 5b shows daytime visible image for the same location, but two hours prior when the sun was still up.

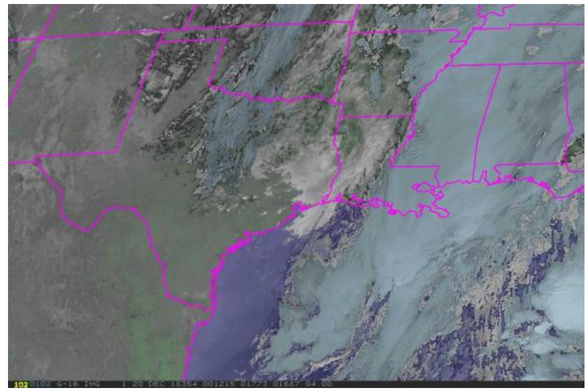

Figure 5a. Resultant colorized nighttime image. The red channel is the nighttime image of figure 4c. The "green" channel is generated from the nighttime image plus the difference between daytime cloud-free red and green channels The "blue" channel has 30 counts added to the water areas of the clear nighttime image with counts less than 80.

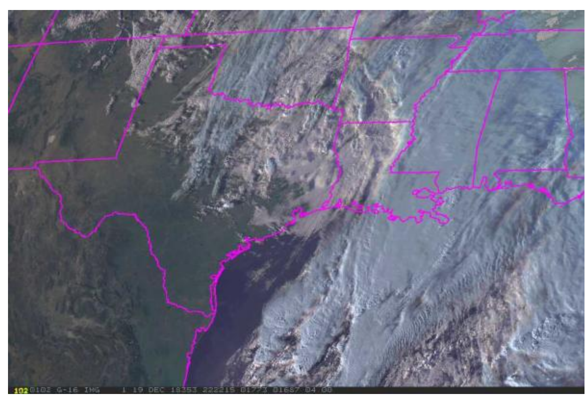

Figure 5b. The daylight visible image from two hours prior to figure 5a for comparison purposes.

The resultant 3 channel images are combined to make color images for display on the web. Over the US, sectors are defined which are remapped into Lambert conformal projections (so north is always up in the center of each sector). The various US sectors are at a 0.8 km pixel resolution and are 1280x1920 size images. The full resolution red channel is .5 km at the satellite subpoint, and decreases as one moves away from the subpoint. The blue and green channels are 1 km and the various infrared channels are 2 km. Hence at night, the .8 km sectors are a blowup of the raw satellite data. For the hemisphere sectors, the sectors are 1500x2050 in size and generally 2-4 km resolution per pixel. The sectors are available at the web site wx.erau.edu. Figure 6 shows the web product generated for sector for the time of the images in figures 3 to 5.

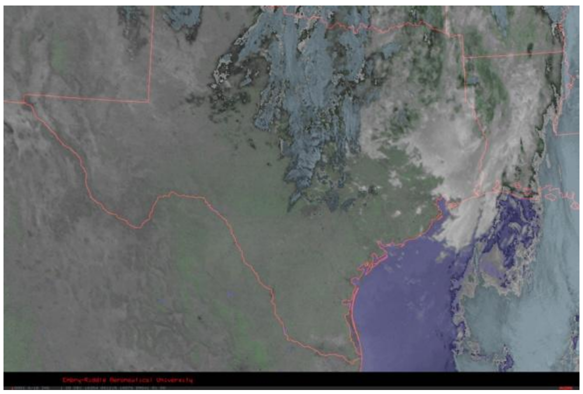

Figure 6. Web night visible product for Dec. 20 00:12 UTC generated for the Austin, TX sector.

5.0 STRENGTHS AND WEAKNESSES OF THE DAY/NIGHT VISIBLE IMAGES

The day/night visible images generally fulfill the design goal of a product to see clouds (especially low clouds) both day and night for use by VFR pilots. Since the night time portions are generated from 2 km pixel size infrared channels, some of the very smallest clouds are not depicted as well at night as during the day. One aesthetic problem with the night time images is that they do not show snow on the ground. An attempt was made to insert a cloud free daytime ground image into the clear areas of the nighttime image, but the ground image removed some of the smaller clouds from the nighttime images. The problem is that the 3.9 micron image used in the low cloud/fog image generation at night also has a weak water vapor absorption band within its spectral response. Low level moisture will cause the clear ground portions of the nighttime low clouds to be slightly darker for high dewpoint areas and slightly lighter for dry areas. Hence some of the small low clouds may have a green or blue tint. I was not able to establish a reliable "clear sky" threshold for inserting the ground image without losing some of the small clouds.

Another aesthetic problem is the thin mid level clouds at night. During the day, the visible light is not scattered well by these thin clouds. Because of the high resolution of the visible channels, one can generally see through the thin cirrus to see the lower cloud beneath. However at night, these thin clouds are shown on the high level portion of the image. The lower resolution of the IR channels tends to smear the cirrus pixels resulting in a perceived increase in mid cloud extent. At night, one cannot see through the thin cirrus to see the low clouds below.

6.0 DAY/NIGHT VISIBLE VS. GEOCOLOR IMAGES

While several web sites offer daytime color visible GOES satellite images, the NWS/NOAA web site https://www.weather.gov/satellite offers the GeoColor satellite images which has color images during the day and derived images during the night. While the GeoColor and the Day/Night visible images are similar, there are some noticeable differences. The GeoColor images are available for 10 US regions with an image size of 600x600 lines and elements in the native satellite projection with a pixel size of 2 km. The Day/Night images have 19 regional locations with 1280x1920 size images which have been remapped into 0.8 km resolution Lambert Conformal images. Hence the Day/Night images have higher spatial resolution than the GeoColor images. Both the GeoColor and Day/Night images utilize the band 3 "veggie" for a green. The GeoColor utilizes a smaller fraction of the band 3 image than the Day/Night resulting in the Day/Night images having more of a green tint in areas of vegetation.

At night the GeoColor images are generated as separate high and low cloud images which are then combined. The GeoColor low clouds are generated from the difference of band 13 and 7, the same process that is used for the Day/Night nighttime low cloud images. The GeoColor low clouds are displayed as blue, while the Day/Night low clouds are displayed as white. The GeoColor high clouds are infrared images displayed as white, while the Day/Night high cloud images are derived from the band 12-13 difference and displayed as blue. The GeoColor image defines a clear sky threshold for the low clouds and inserts a static nighttime city lights image as a background image. Figure 7a shows the GeoColor image while figure 7b shows the Day/Night image for the same time in the Gulf of Mexico region.

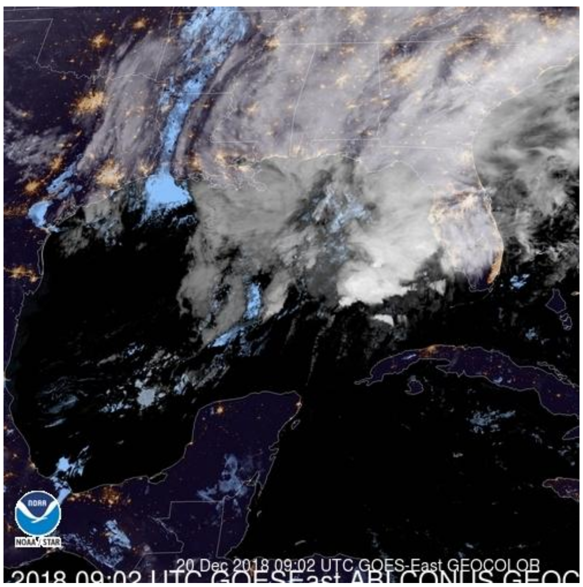

Figure 7a. GeoColor image for 9:02 UTC on Dec. 20, 2018. Blue clouds are low clouds, white are high clouds, and a static image of city lights has been added in clear areas.

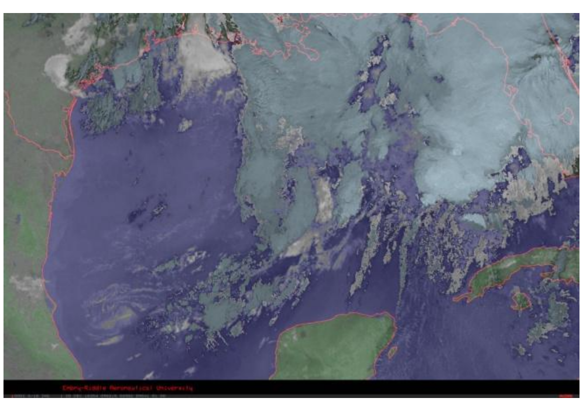

Figure 7b. Day/Night image for the same time as 7a. The high clouds are blue, the low clouds white, and clear areas are shown in green and blue.

Smaller clouds which do not fill up the IR sensors fields of view will appear dimmer than the larger cloud fields. Because the Geocolor images utilize a threshold brightness to define clear sky areas for inserting the city lights, some of the smaller, dimmer clouds will be eliminated in the nighttime images. Figure 8a shows the GeoColor image and figure 8b show the Day/Night image around Puerto Rico in the afternoon of Dec. 20, 20:07 UTC. Note the large number of small trade wind cumulus clouds over the water.

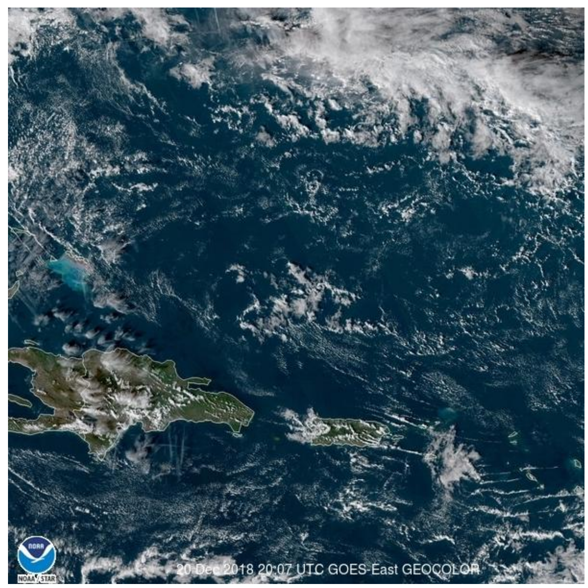

Figure 8a. GeoColor image of Puerto Rico on the afternoon of December 20, 2018 at 20:07 UTC showing the large number of small clouds over the water.

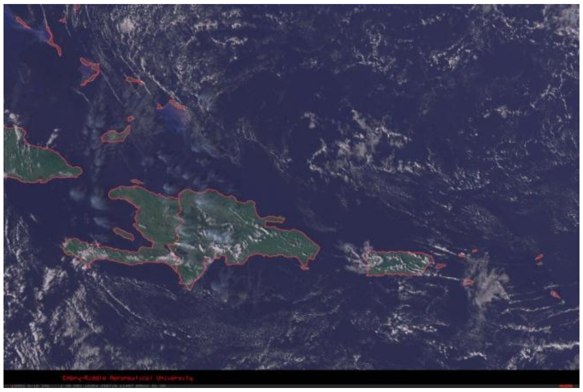

Figure 8b. Day/Night image showing the same time and approximate location as figure 8a.

Over land, small cumulus clouds will typically dissipate after sunset, but over water the trade wind cumulus will typically persist all night long. Because of their small size, they do not show up well in the images generated at night. Figure 8c shows the enlarged GeoColor image around the island of Puerto Rico. Figure 8d shows the same approximate location for the Day/Night image.

Figure 8c. GeoColor image enlargement around the island of Puerto Rico two hours later from figure 8a. Note the loss of most of the small clouds in the image.

Figure 8d. Day/Night image for the same time as figure 8c. Note that some of the small clouds have been detected, but have been tinted blue like the water.

Another difference between the Day/Night and the GeoColor images is the transition between day and night. The GeoColor does a slow fade from daytime visible to nighttime. The fade takes place over a two hour period. During the fade period, one can lose track of a feature as it fades away and then comes back in the nighttime mode. The Day/Night images use a visible brightness normalization during the day with an abrupt transition between day and night modes. Features are easily tracked between day and night modes for the Day/Night images.

7.0 REFERENCES

Ellrod, G.P, 1995: Advances in the Detection and Analysis of Fog at Night Using GOES Multispectral Infrared Imagery. *Weather and Forecasting,* ***10,*** 606-619.