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Attempting to Turn Night into Day; Development of Visible Like Nighttime Satellite Images

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1.0 Introduction

Aviation interests are frequently concerned with low clouds, fog, and thunderstorms. Satellite images can provide an overview of these weather conditions. However, traditional satellite images do not always provide adequate depiction of these adverse weather phenomena. During the day the visible satellite images can be used to identify low clouds, fog, as well as identifying thunderstorms by their overshooting towers. Infrared images can be used to identify thunderstorms, but the low clouds and fog are difficult or impossible to identify on infrared images. While the visible images are useful, they are only available during daylight hours. Since aviation operates at night as well as the day, the daylight only is a serious limitation for visible images. To illustrate the point, figure 1a is a visible image obtained from the Aviation Weather Center (AWC) web page at 13Z on Dec. 9, 2012 over the south central US. The sun is just coming up with the left side of the image still in the dark. Figure 1b shows the same location with infrared data which has been colorized to show the temperature ranges. At the time of the images there were extensive low clouds and fog along with thunderstorm activity in the eastern Tennessee region.

The "fog" technique of using the difference between the 3.9 micron and 11 micron infrared channels for monitoring low clouds at night was developed by Ellrod (1995), and applied to AWC operations using a

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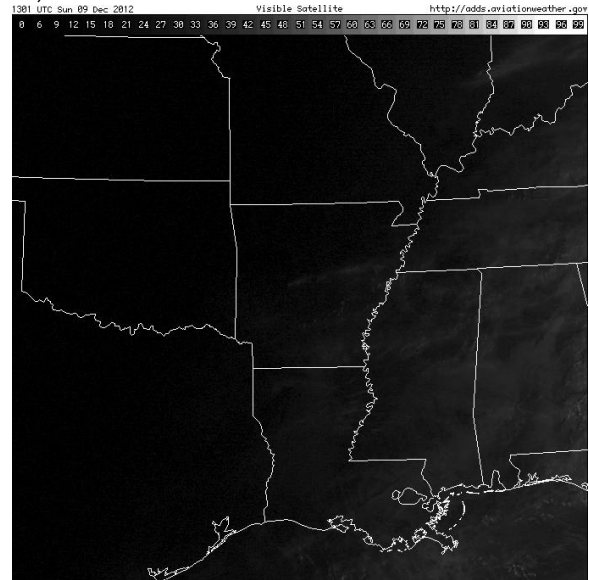


Figure 1a. Visible image from 13Z, Dec. 9, 2012. The right side of the image is in daylight, but the left side is still dark.

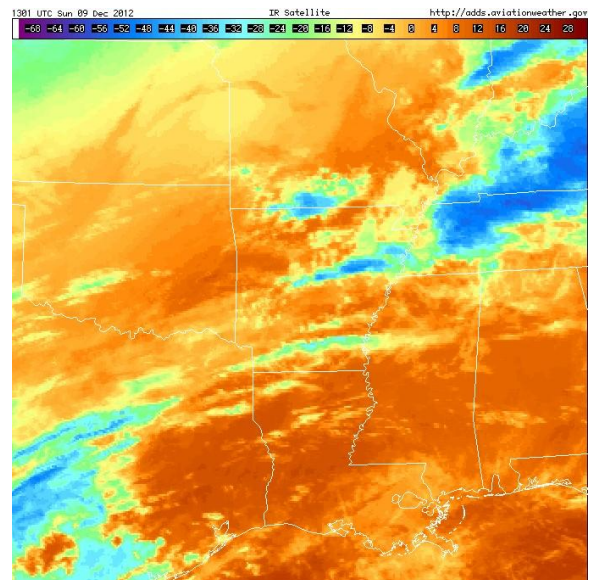


Figure 1b. Infrared image at the same time and location as figure 1a. The infrared image has been color enhanced to show the various temperature ranges. (from AWC)

"vis/fog" technique. The visible image was used during the daylight hours, and the "fog" image was inserted into the dark regions of the visible. Figure 2 shows the AWC "vis/fog" image for 13:15Z on Dec. 9, 2012. The overlay cloud cover symbols are for low IFR (magenta), IFR (red), MVFR (blue), and VFR (white) flying conditions obtained from surface observations. The visible image is on the right while the "fog" image is on the left.

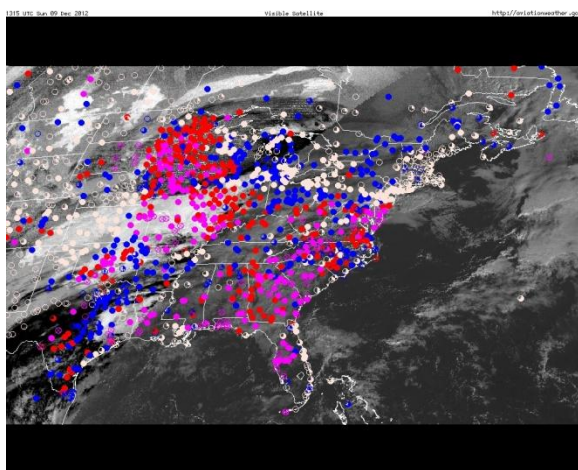


Figure 2. "Vis/Fog" image from the AWC showing the visible image on the right and the "fog" image on the left. The fog image is generated from the difference between the 3.9 micron and 11 micron images. The overlay shows LIFR (magenta), IFR (red), MVFR (blue) and VFR (white) obtained from surface observations.

2.0 Problems with Previous Satellite Images Products

Visible satellite images have long been used in aviation flight planning. The visible satellite images show a variety of phenomena of interest to aviation, including fog, low clouds, thunderstorms, etc. Since one's eyes detect visible light, the visible satellite image is easier for untrained personnel to interpret than other bands. The biggest problem with the visible images is that they are not available at night. While the 11 micron IR is available both day and night, the low clouds and fog are very

difficult to detect on IR images. The original nighttime derived product was the "fog" images (Ellrod, 1995) generated from the difference between the 3.9 micron channel and the 11 micron infrared channel on the GOES satellites. At night the difference between the 3.9 and 11 micron channels detects emissivity differences rather than absolute temperature (Ellrod, 1995). These emissivity differences are related to the size of the cloud particles, so small droplets (such as occur in fog) can be readily distinguished from larger ice crystal clouds or the ground. Hence low clouds can be detected at night even if they are at the same temperature as the ground. Taking the difference between the two channels will generate a low nighttime cloud image which appears white, but the cirrus clouds will appear black, with the ground being gray. While the "fog" images were useful at night, during the day there is some solar radiation in the 3.9 micron band, so low clouds will change from white to black as the sun comes up.

Mosher (2006) developed a "vis/fog" product which used the "fog" images for the nighttime portion of the image, and the visible image for the daytime portion of the image. Figure 2 shows an early version of the "vis/fog" technique. However the high clouds look black at night and white during the day. To overcome this problem, Mosher (2006) modified the "vis/fog" technique to use IR pixels for the sections of the nighttime image which were above 18,000 feet. The sections of the image above 18,000 feet were also tinted light blue to identify those clouds as high. While this helped make a more visible like nighttime product, there were still problems. High thin cirrus with low emissivity would appear warmer and lower, so black cirrus clouds would still show up at night in the low cloud section. Another problem with using the infrared image for the portion of the image above 18,000 feet is that active thunderstorms are difficult to detect relative to inactive cirrus clouds. Active thunderstorms have overshooting tops.

Towers do not have much temperature variation because of the nearly isothermal vertical temperature structure near the tropopause. Hence thunderstorms are difficult to detect without enhancements.

3.0 Making the Nighttime Portion of the Image More Visible Like

Currently, users need different types of images to see different weather hazards. A single type of visible like image which can be used by aviation users for all types of weather would be a useful overview product. An enhanced version of the day/night visible satellite images has been developed to make the product even more visible like both day and night. Figures 3 a, b, and c show the "day/night" visible product for the same times as figures 1 and 2. Figure 3a is at 11:45Z when the area was totally dark before sunrise. Figure 3b is at 13:15 during sunrise, and figure 3c is at 14:00Z when the sector is fully in daylight.

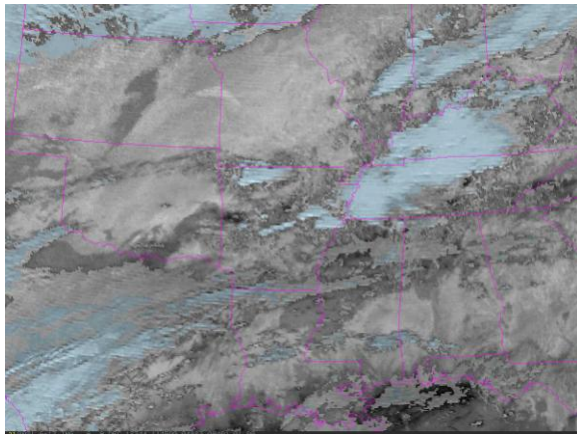


Figure 3a. Image at 11:45Z when the area was totally dark before sunrise.

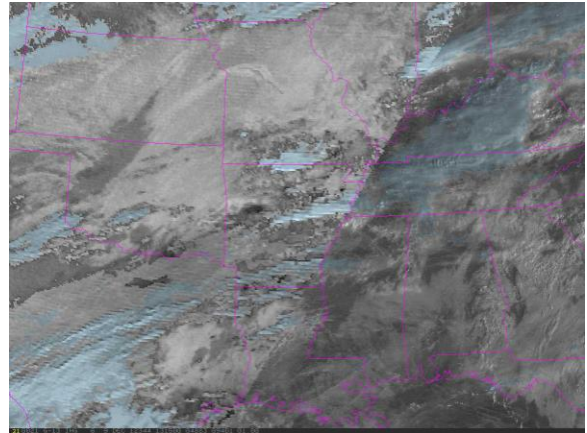


Figure 3b. Image at 13:15Z during the sunrise transition. The sections of the image on the right are in daylight while the sections to the left are still dark.

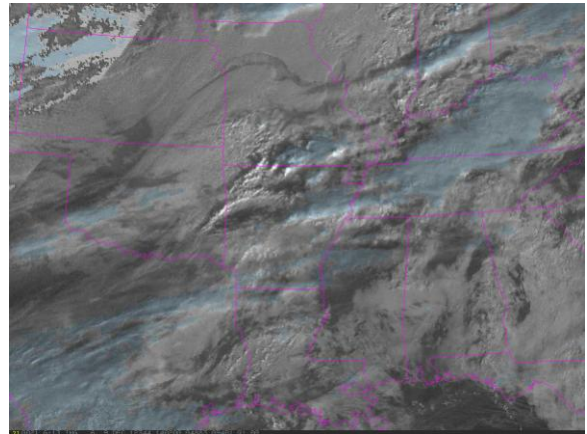


Figure 3c. Image at 14:00 when the sector was fully illuminated with sunlight.

The images in figures 3 are reasonably similar to one another so they can be useful to aviation interests for monitoring aviation weather both day and night.

4.0 Processing Steps

To derive the images in figures 3, all the GOES channels were used for the image processing.

4.1 Correct Cirrus IR temperatures Using Water Vapor Data

Thin cirrus clouds have low emissivity which allows for radiation from lower in the

atmosphere to be transmitted through the cirrus cloud. The sum of the emitted radiation from the cloud and the transmitted radiation from lower in the atmosphere has the effect of the cirrus cloud appearing warmer and lower than it actually is. When the image is split between below and above 18,000 feet, frequently the high cirrus clouds will be misplaced as a lower cloud. To correct for this problem, the water vapor image is used in conjunction with the infrared. While the water vapor image of the cirrus has radiation coming from below, the lower radiation is coming from the water vapor in the atmosphere, which is typically higher (and colder) than the IR radiation coming from the surface or low clouds. Hence the water vapor cirrus temperature should be more correct than the IR cirrus temperature.

A correlation between IR and WV clouds is performed. Pixels which show cloud correlations utilize the WV temperature to replace IR temperature. All other pixels remain the IR temperature. Figure 4a shows the IR image, while figure 4b shows the water vapor image. Figure 4c shows the IR image with the thin cirrus pixels being replaced with the water vapor pixels.

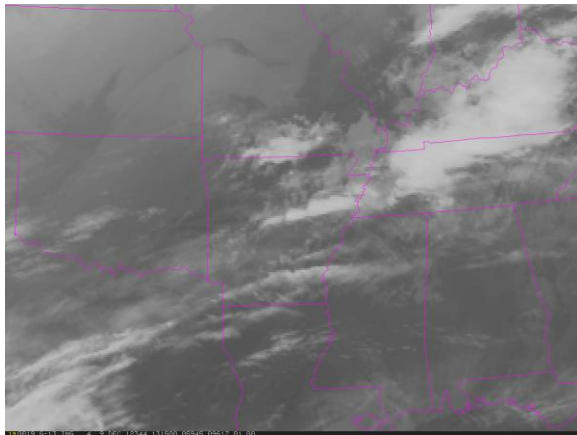


Figure 4a. Infrared image on Dec. 9, 2012 at 13:15.

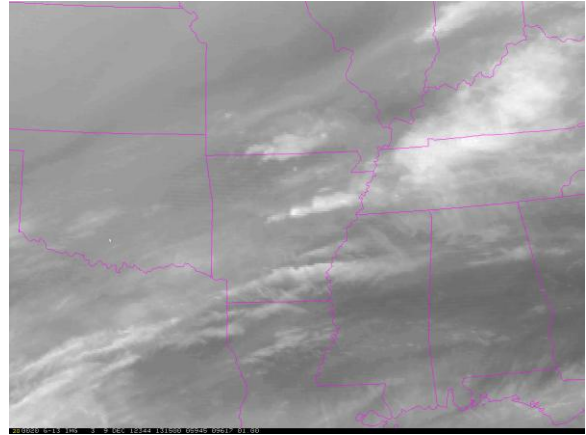


Figure 4b. Water Vapor Image at the same time as figure 4a.

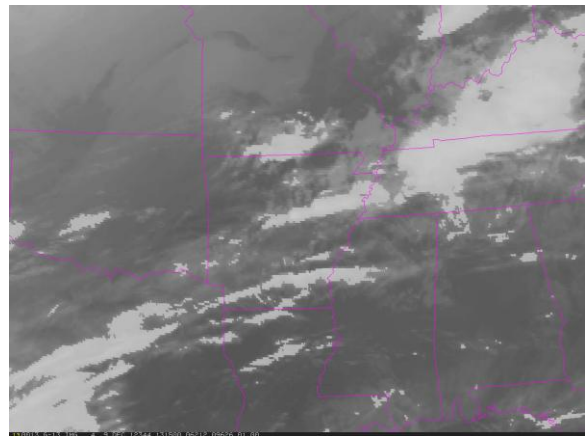


Figure 4c. Modified Infrared image where the cirrus cloud pixels which correlate between the infrared and the water vapor have been replaced with the water vapor temperature value. The water vapor temperature of the cirrus cloud should be more representative of the true temperature of the cirrus cloud.

4.2 Convert Corrected IR Temperature into Cloud Height

Once the IR temperatures have been corrected for the thin cirrus, the IR temperatures are converted to cloud heights. Currently the temperature to height conversion is done using seasonally adjusted standard atmospheres. The January and July standard atmospheres for every 15 degrees of latitude are used. A

linear interpolation between latitudes is used along with a cosine interpolation between dates. The resultant sounding is then used to convert the temperatures to heights. Figure 5 shows the resultant image of the cloud heights. This climatologically derived heights is generally satisfactory for the subsequent processing. The only problems observed have been for very cold winter situations and for high mountain areas. Consideration is being given to adjusting the temperature to height routine to use current model soundings.

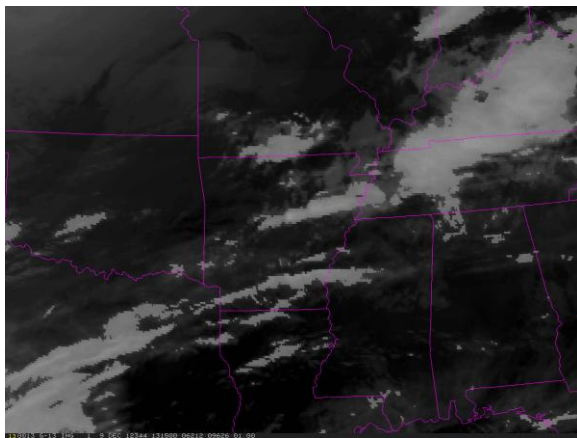


Figure 5. Cloud height image where the corrected IR temperatures have been converted to heights using a seasonally adjusted standard atmosphere.

4.3 Visible Brightness Normalization

The visible image is brightness normalized by dividing the visible brightness by the cosine of the solar zenith angle. Solar angles within 3 degrees of the horizon are considered dark, which avoids the problem of trying to divide by zero for pixels where the sun is setting. Figure 6a shows the visible image at 13:15Z. Figure 6b shows the brightness normalized visible image. Pixels for solar angles below 3 degrees of sunset are set to zero.

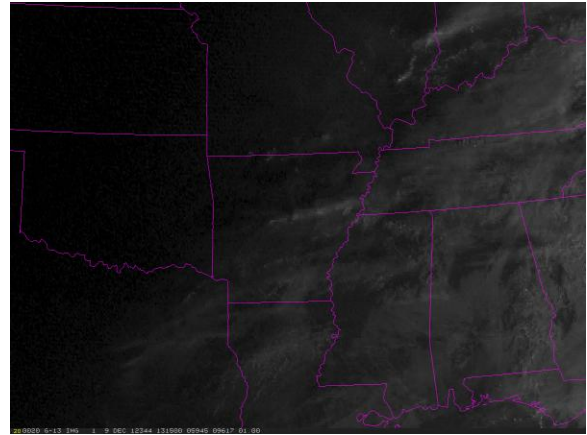


Figure 6a. Visible image at 13:15Z

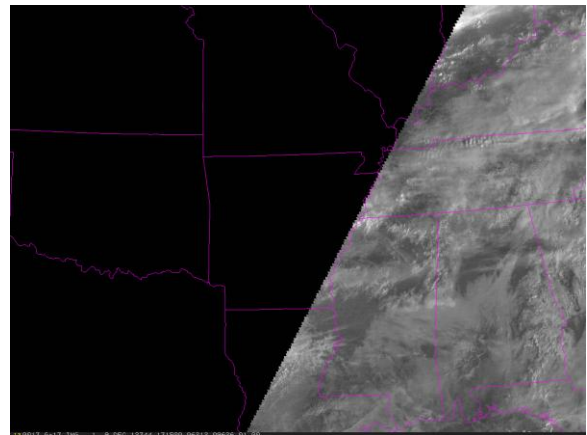


Figure 6b. Brightness normalized visible image. Brightness normalization is generated by dividing each pixel by the cosine of the solar zenith angle. Pixels with the sun below 3 degrees of sunrise/sunset are set to zero.

4.4 Split Visible Image into High and Low Images

The visible image is split into a high and a low image. The high image will be given a blue tint to aid untrained users in determining relative cloud heights. The brightness normalized visible image is divided into two different images. The visible pixels which are higher than 18,000 feet (using the heights from section 4.2) are assigned a brightness range of 191-255. The human eye can distinguish 30-40 gray levels in an image. By assigning 64 gray

levels to an image section, the original brightness information can be maintained. The current technique then assigns 1-190 to the image section with pixels below 18,000 feet. While the current technique splits the image into two height ranges, the technique could be expanded to four different height sections. Figure 7a shows the section of the visible image with heights above 18,000 feet. Figure 7b shows the section of the visible image with heights below 18,000 feet.

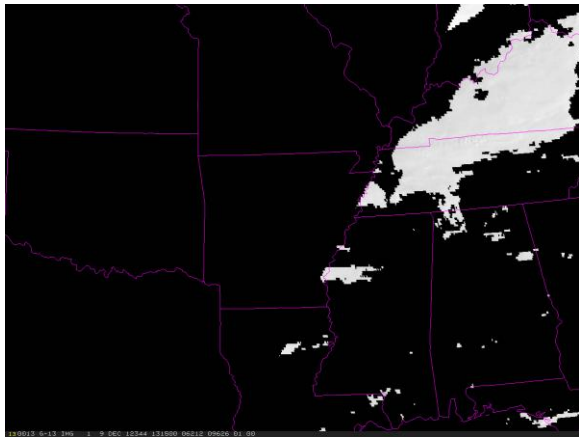


Figure 7a. Section of the visible image with pixels above 18,000 feet. The visible brightness is compressed into digital values of 191-255 counts for the high clouds

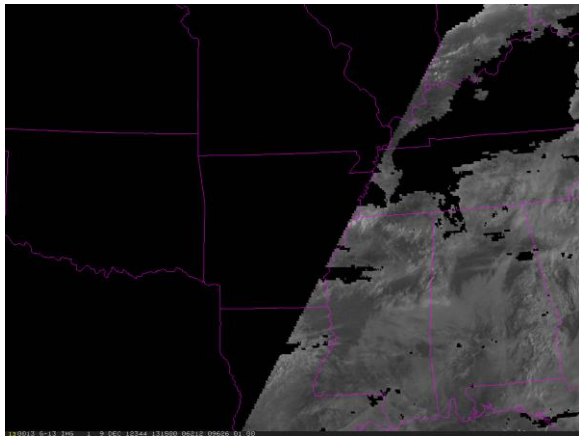


Figure 7b. Section of the visible image with pixels below 18,000 feet. the visible brightness is compressed into digital values of 1-190 for the low clouds.

The two sections of high and low clouds are then combined into a single image. An enhancement table is then used to restore the original brightness values. The high clouds use an enhancement to expand the 191-255 into a brightness range of 1-255 with a blue tint. The low clouds use an enhancement to expand the 1-190 into a 1-255 brightness range without any tint. Figure 7c shows the resultant combined visible image with the enhancement table applied.

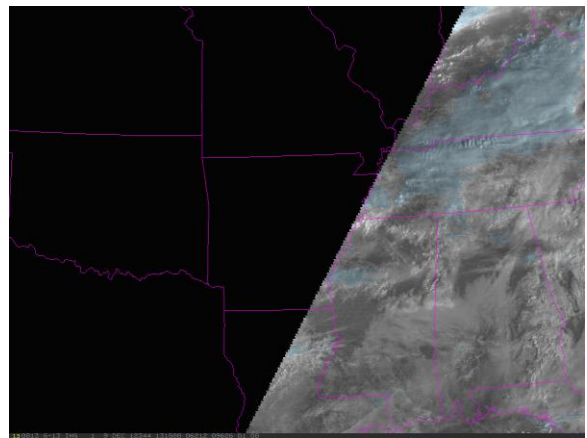


Figure 7c. Combined visible image with high cloud brightness range expanded back to 1-255 with a blue tint and low clouds expanded back to 1-255 retaining the black and white character of the image.

4.5 Generate Low Cloud "Fog" Image

The low cloud "fog" image is generated by taking the difference between the 3.9 micron and 11 micron channels. The difference of -4 to +10 degrees K is stretched into image count 1-255 count range. The channel differences are caused by emissivity differences. The resultant image shows low clouds with droplets as white, ground as gray, and ice crystal clouds as black (for nighttime sections of the image). Figure 8 shows the resultant "fog" image generated by the channel difference algorithm.

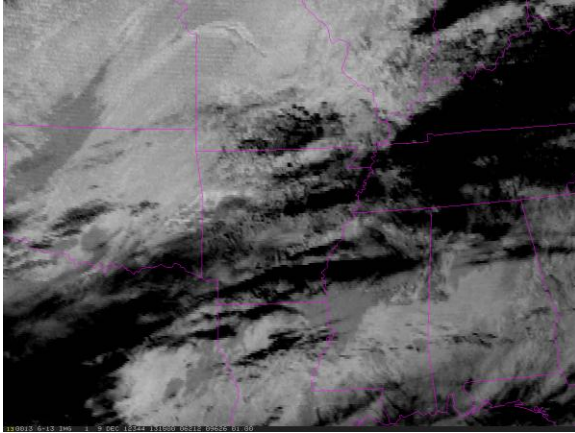


Figure 8. "Fog" image generated by channel difference between the 3.9 and 11 micron channels. The low clouds with water droplets show up as white, the ground as gray, and the cirrus ice crystals as black.

4.6. Generate High Cloud "Height" Image

The current GOES satellites have a 13.5 micron channel which is influenced by carbon dioxide absorption. The difference between the 13.5 micron channel and the 11 micron channel is a measure of the height of the cloud in the atmosphere. High clouds will have very little difference, while lower clouds will have more of a difference between the two channels. Figure 9 shows the "Height" image generated by the 13.5-11 micron channel differences. The high clouds are white while the low clouds are gray. Note that this difference is a direct measure of the pressure height of the cloud and is not impacted by the temperature sounding. Hence thunderstorm overshooting turrets will show up nicely in the "height" image since they protrude above the thunderstorm anvil, even if they don't show much temperature variation.

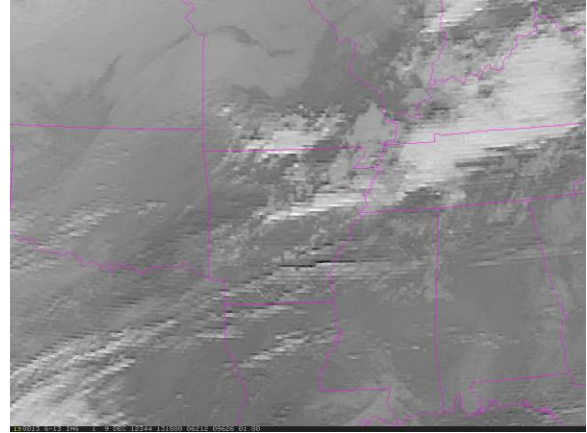


Figure 9. "Height" image generated by the difference between the 13.5 and 11 micron channels. The 13.5 micron channel is influenced by CO₂ absorption. High clouds (white) have very little difference while low clouds (gray) have more difference. The difference is related to the depth of the atmosphere above the cloud.

The 13.5-11 micron difference is used to generate the "height" image for the GOES satellites. For the other satellites without the 13.5 micron channel, the 11 micron IR image is used for the "height" image.

4.7 Merge "Fog" and "Height" images

The "fog" and "height" images are then merged together. Any "fog" pixels which are dark (less than value 80) are replaced with "height" pixels. While the dark pixels are generally caused by cirrus ice crystals, the 3.9-11 micron difference is also influenced by low level water vapor absorption, especially in the tropics. Dark "fog" pixels below 6,000 feet (using the cloud height image of section 4.2) are retained in the image. Figure 10 shows the merged "fog" and "height" images.

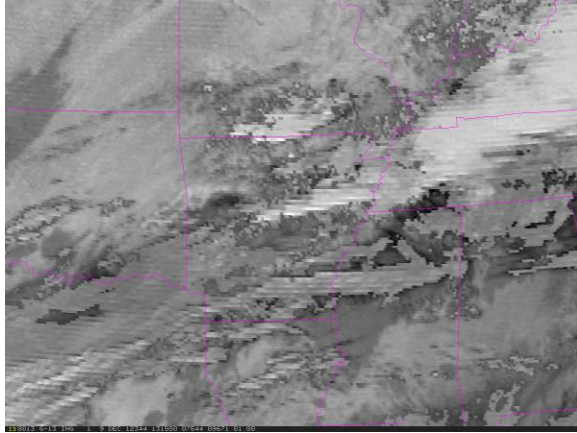


Figure 10. Merged "fog" and "height" images. Dark "fog" pixels (less than 80 counts brightness) are replaced with "height" pixels unless the "fog" pixel is below 6,000 feet. This allows for the dark appearing water vapor absorption of the tropics to be retained in the image.

4.8 Merge with Visible

The merged "fog/height" image is then split into high and low sections in the same manner as the visible in section 4.4. Then the "fog/height" image is merged with the visible. Sections of the visible image which had been set to zero during the normalization of section 4.3 are replaced with the "fog/height" image. Then the enhancement table stretching the high clouds into the full dynamic range with the blue tint is applied to the resultant image. Figure 11 shows the resultant image.

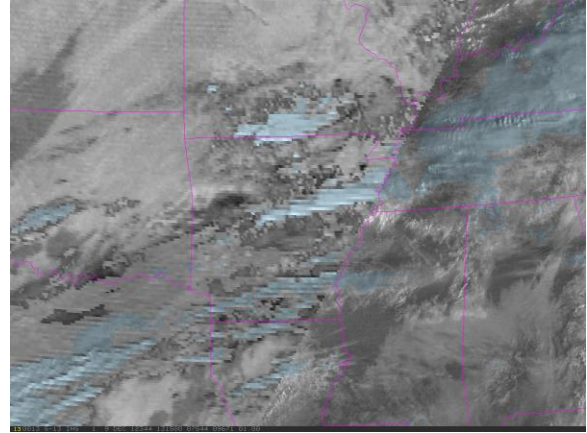


Figure 11. Resultant merged image. Visible is on the right with the "fog/height" on the left.

5.0 Availability

The derived images are routinely available in jpg format at http://wx.erau.edu/erau_sat/. The GOES images over the CONUS are generated every 15 minutes, while the Hemisphere image are generated every 30 minutes. Figure 12a shows the locations for which images are available in the CONUS and figure 12b shows the hemisphere sectors.

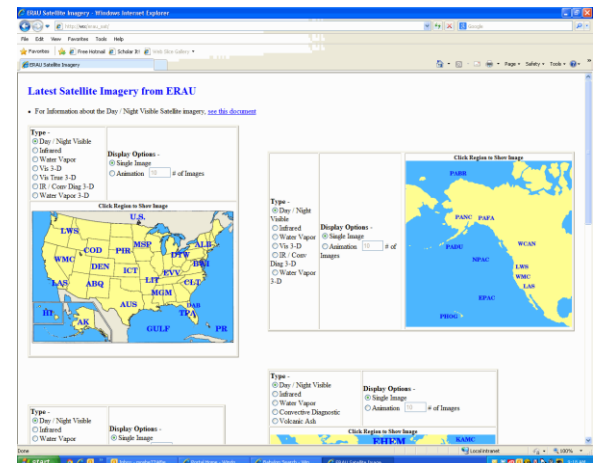


Figure 12a. Sectors available over the CONUS at http://wx.erau.edu/erau_sat/ for the day/night images. The CONUS sectors are generated every 15 minutes.

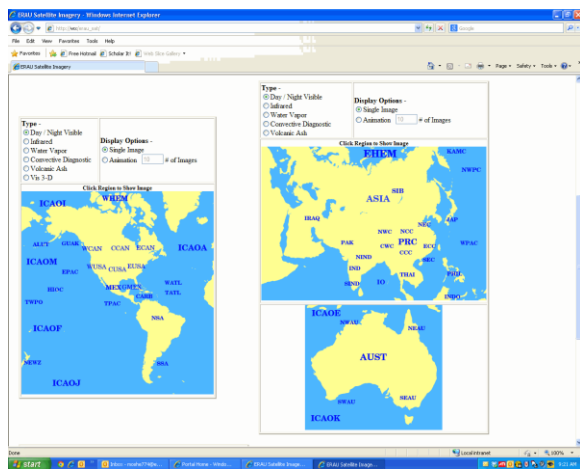


Figure 12b. Sectors available over the hemisphere at http://wx.erau.edu/erau_sat/. The western hemisphere has the "height" portion of the image as the 13.5-11micron difference, while the eastern hemisphere use the 11 micron image for the high clouds at night. The hemispheric images are generated every 30 minutes.

6.0 References

- Ellrod, G. P., 1995: Advances in the detection and analysis of fog at night using GOES multispectral infrared imagery. *Wea. Forecasting*, 10, 606-619
- Mosher, Frederick R.: "Day/Night Visible Satellite Images", Preprints, 14th Conference on Satellite Meteorology and Oceanography, Atlanta, Georgia, Feb. 2006.