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# Day/Night Visible Satellite Images

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## Introduction

Visible satellite images are very useful for a wide variety of users. In particular, they are helpful in identifying areas of clouds and fog for general aviation pilots who must fly within sight of ground. However visible satellite images have several major drawbacks, such as at night the visible pictures are black. Another problem is that it is sometimes difficult to distinguish between high clouds and low clouds. While the infrared channel can be used at night, frequently the low clouds and fog are near the temperature of the ground, so low clouds do not show up well on infrared images.

## Nighttime Low Cloud Detection

Starting with the GOES-8 geostationary satellite series, the 3.9 micron channel has been available. At night the difference between the 3.9 and 11 micron channels detects emissivity differences rather than absolute temperature (Ellrod, 1995). The temperature difference between the channels is on the order of a few degrees. 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. Ellrod (1995 ) has developed a difference product (available at http://www.orbit.nesdis.noaa.gov/smcd/opdb/aviation/fog.html) which can be used at night for low cloud detection. However this product is only available at night, and processing is terminated when the sun rises on the east coast of the US. Figure 1 shows an example of the NESDIS fog image product at night.

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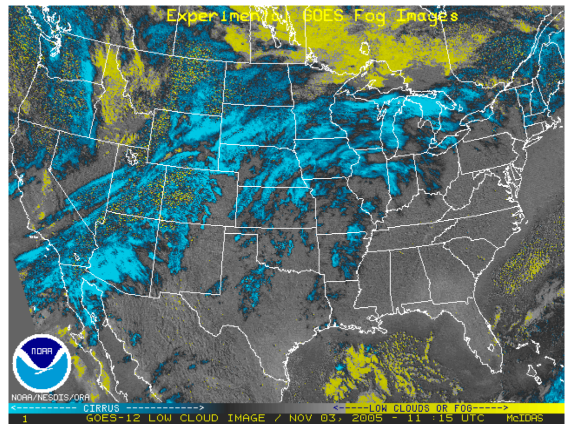


Figure 1. Nighttime fog product from NESDIS with yellow clouds being low clouds and blue being high clouds.

A similar band difference product is available from NCAR-RAP which is just the band 2 minus band 4 without screening for day/night transitions. This difference product is available at http://www.rap.ucar.edu/weather/satellite A similar difference product is available on the AWIPS workstations used by NWS forecasters. However, during the day the sun has some radiance at the 3.9 micron frequency, so during the day there is a blend of the emissivity differences and the reflected solar energy. Hence there is a marked change in appearance of the clouds between the day and night which make interpretation of the 3.9-11 micron images difference images difficult, especially for users not trained in satellite image interpretation. Figure 2 shows an example of the 3.9-11 micron difference product with the sun rise going extending from the Northern Wisconsin to Texas. In this product the low clouds are dark during the night and white during the day. The cirrus clouds are white both day and night.

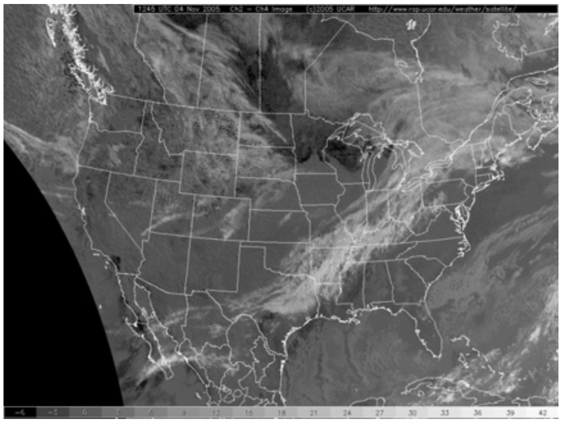

Figure 2. 3.9-11 micron difference from NCAR-RAP. The western and central US is still dark while the eastern US are in daylight. The low clouds at night are dark and white during the day. The high clouds are white both day and night.

**Day-Night Cloud Detection**

To try to improve the interpretation problem, the Aviation Weather Center (AWC) has developed a vis/fog product (available at [aviationweather.gov](aviationweather.gov) that inserts the visible image into the daytime portion of the image, and uses the 3.9-11 micron fog image in the nighttime portion of the image.

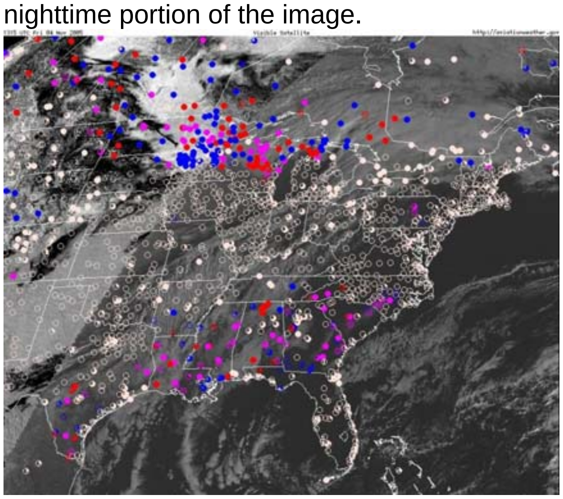

Figure 3. AWC GOES-east vis/fog product with 3.9-11 micron difference product inserted into the nighttime (left) sections of the visible image. At night the high clouds are dark and the low clouds are white with the ground being gray. The colored dots show observed IFR (red), MVFR (blue), and VFR (white) flying conditions at airports.

While this is an improvement for low cloud surveillance (they remain white both day and night), there still is a major discontinuity in appearance of the high clouds between day (white) and night (black). Figure 3 shows the same time as figure 2 above but with the AWC vis/fog product from the GOES-east satellite.

Another approach to continuous day-night satellite visible image continuity has been developed for the National Hurricane Center (NHC) by NESDIS which utilizes a brightness normalized visible image for the daytime portion of the image and inserts an infrared image into the nighttime portion. These data are available at http://www.nhc.noaa.gov/satellite.shtml and are illustrated by figure 4 for the east Pacific sector. These data show the day-night continuity of high clouds, such as hurricanes, but limit the monitoring of low clouds that are near the ground temperature.

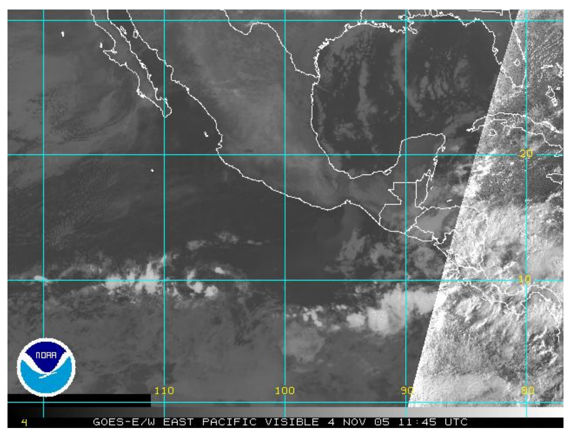


Figure 4. NHC visible-infrared composite product with the visible being on the right and the infrared image inserted on the left where the sun is still below the horizon.

This problem of day/night differences in appearance also limits the potential to make visible global mosaics. A number of groups make global infrared and water vapor composites (such as SSEC at http://www.ssec.wisc.edu/data/composites.html), but no one makes a visible global composite. Not all of the satellites scan at the same time or at the same rate, so there are time differences between sections of the mosaic. For infrared and water vapor, the cloud displacements are relatively minor, but for the visible the sun is moving at 1000 mi/hr, so minor time differences between images make large appearance differences. To solve this problem, one needs the nighttime section of the images to have the same approximate appearance as the daytime. This requires a synthetic nighttime “visible” image and a brightness normalized visible image during the day. This purpose of this day/night visible effort has been to develop such a product.

**Day-Night “Visible” Images**

In order to make the day-night “visible” type images, one needs to generate a derived product that has properties of both visible and infrared types of data. The brightness of the 11 micron infrared image is primarily determined by the cloud temperature, so high, cold clouds are white. For the visible the brightness is primarily determined by the sun angle and the optical thickness of the cloud so all thick clouds are white during the day. The intent of the day-night image is to separate the information in the image into two classes; a high cloud class and a low cloud class. The high clouds will use a blue color to identify them while the low clouds will be white. This allows for separate processing in both day and night regions of the image so that the net result looks similar to each other for both day and night.

The nighttime portion of the derived image is generated from a combination of the 11-3.9 micron “fog” image and the raw infrared image. The “fog” portion of the image is constructed from the temperature difference of the 11 and 3.9 micron channels. The 11-3.9 micron temperature difference is relatively small. In order to see significant effects, this difference is stretched into the dynamic range of the display device. The stretch used has a -8 degree C difference mapped to a count of 1 and a +6 degree C difference mapped to a count of 223. The difference values from -8 to +6 were linearly mapped to the interval between 1 and 223. This difference enhancement leaves the low clouds with small droplets white, the ground gray, and the high cirrus clouds with large ice particles black. The dark, cirrus cloud pixels (less than 66 counts of the stretched difference) are then replaced with infrared image pixels as are any other “fog” pixels higher than 18,000 ft. The 18,000 ft. temperature threshold is determined from a modified standard atmosphere. This derived product has the “fog” difference product where ever there are small droplet clouds along with the ground pixels, and infrared pixels inserted into all other locations. For the higher clouds the infrared pixels are bright, so most of these inserted pixels are bright.

In order to provide separate color enhancements for high and low pixels that may have similar brightness values, the image is subdivided into two images with different dynamic ranges. The image is divided into those pixels above 18,000 ft. and those below. The brightness of the pixels above 18,000 ft are stretched into the gray scales between 1 and 64. The brightness of the pixels below 18,000 ft are stretched into the gray scales between 65 and 255. The lower clouds are given a larger dynamic range than the high clouds in order to allow for future enhancement of dim features near the ground, such as would be used to detect volcanic ash or haze. The two images are then recombined into one image. Figure 5 shows this image with the two brightness ranges. The left side of the image is the nighttime portion of the image.

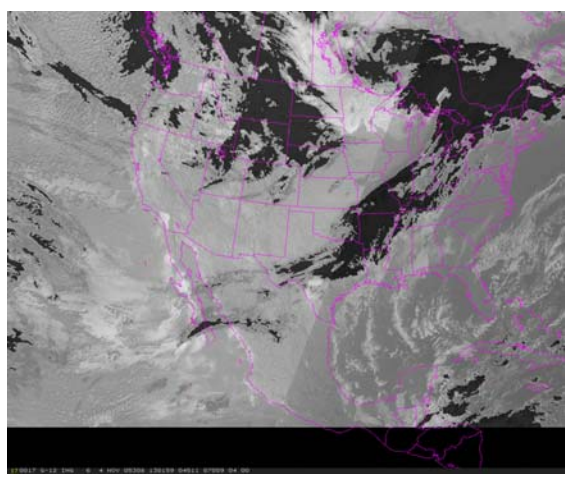

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Figure 5. Derived product where pixels above 18,000 ft are given a brightness range of 1-64 and the pixels below are given a range of 65-255. The nighttime portion of the image is on the left.

For operational use, however, the dark high portion of the image is given an enhancement that stretches the 1-64 gray scales into a 0-255 blue scale with the 65-255 being stretched into a 0-255 black and white scale. The net result is an image with the higher clouds having a blue tint, and the lower cloud looking white. Figure 6 shows the same image with the blue tint for the high clouds. The blue tint was chosen to conform to the general convention of NESDIS of having high clouds colored blue, such as shown in figure 1.

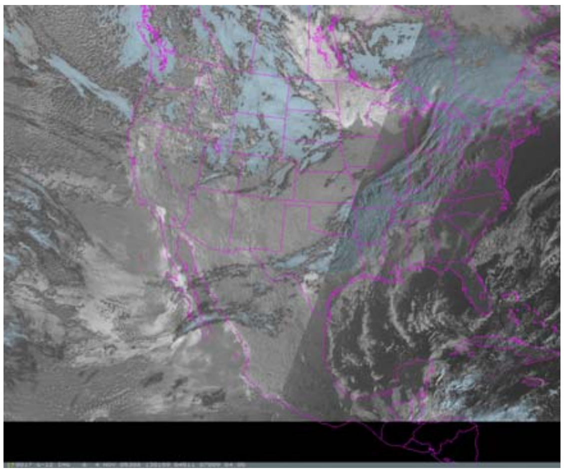

Figure 6. Same image as figure 5, but with a blue tint given to the clouds above 18,000 feet. The night portion of the image is on the left. The night portion low clouds are derived from the 11-3.9 micron "fog" difference while the higher nighttime clouds utilize 11 micron infrared image pixels.

**Daytime Brightness normalization**

The daytime portion of the image is generated from the visible pixels and then height separated by the 11 micron infrared channel. The visible pixels first require a brightness normalization to remove the effects of the varying sun angle. The solar energy hitting the top of the atmosphere has an intensity variation determined by the cosine of the solar zenith angle (the angle from overhead to the sun). Figure 7 shows a raw visible image (obtained from the SSEC web site at http://www.ssec.wisc.edu/data/east/latest_eastvis.jpg) that shows the clouds getting dimmer as they approach the terminator zone, and then the dark areas to the west where the sun is below the horizon. A first order brightness normalization is to divide the measured visible brightness by the cosine of the solar zenith angle. If the normalized brightness is linearly scaled from 0 to 100, this is termed the albedo of the cloud.

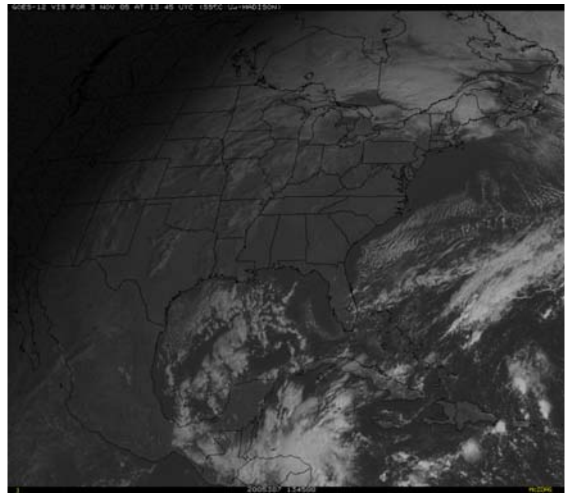

Figure 7. Visible GOES-east image of the US showing decrease in brightness of the clouds as the sun is lower in the sky. The dark area on the left is where the sun is below the horizon.

Several groups provide visible satellite images that have been divided by the cosine of the solar zenith angle. Figure 8 shows the same time as figure 7, but having the visible brightness converted to albedo. These data were obtained from the NCAR-RAP web site at http://www.rap.ucar.edu/weather/satellite

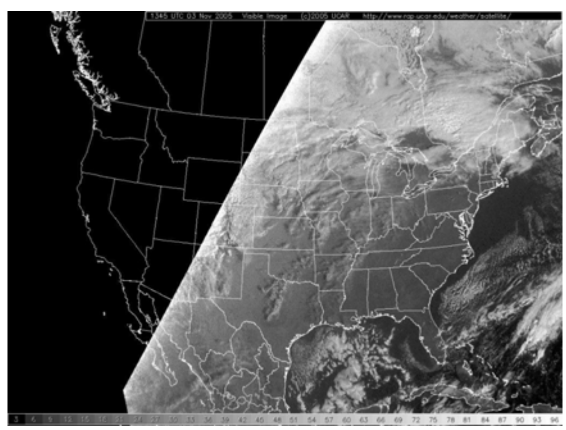

Figure 8. Visible GOES-east data at the same time as figure 7. The visible brightness has been divided by the cosine of the solar zenith angle.

However one can note that the clouds near the terminator zone are overly brightened. Clouds are not perfect Lambertian reflectors and do not maintain a constant albedo as a function of sun angle. The relationship of albedo to sun angle is a complex function dependent upon cloud particle size distribution, cloud thickness, total scattering angle, and cloud geometry. Generally the cloud's albedo increases with sun angles near the horizon. This then has the adverse effect of having normalized visible clouds near the sunrise or sunset line being too bright. For this effort an empirically derived correction factor was used to adjust the albedo. The cosine of the solar zenith angle was adjusted by a factor of $1/(1+ \theta/\pi)$ where $\theta$ is the solar zenith angle in radians and $\pi$=3.14. This helped, but did not totally eliminate the over brightening near the terminator.

**Day-Night "Visible" Reconstructed Images**

The brightness normalized visible image pixels are then divided into two images, above and below 18,000 ft. using the same procedures as the nighttime pixels. The visible pixels above 18,000 ft. are stretched into the 1-64 brightness scale while the lower pixels are given the 65-255 gray scales. The images are then reconstructed into a single daytime image. The nighttime and daytime images are then reconstructed into a single image that is then displayed with an enhancement table that gives the clouds above 18,000 ft a blue tint. Figure 6 shows an example of this reconstructed day-night "visible" image. The day light portion of the image is on the right, and the night time portion of the image is on the left. Figure 9 shows the full resolution portion of the image for the Texas region showing the transition of the daylight portion on the right and the night time portion on the left.

This same processing can be used on multiple satellites and the results pieced into a global mosaic. Figure 10 shows an example of a Western Hemisphere mosaic generated from day-night "visible" images from GOES-east, GOES-west, Meteosat-8 (MSG), and GAC polar satellite data for the polar regions. The sunrise extends from western Greenland down the east coast of the US, across Central America and out into the eastern South Pacific.

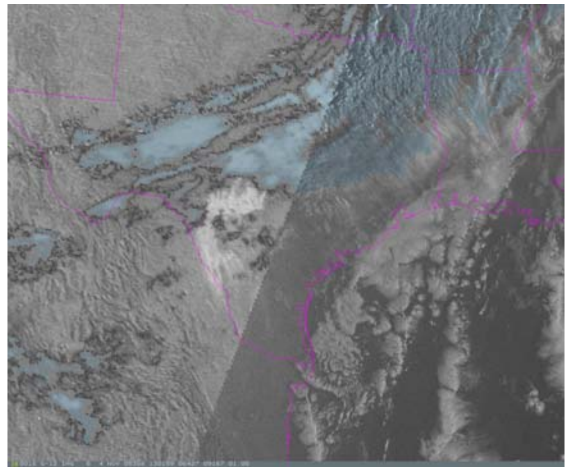

Figure 9. Same data as figure 6, but showing the full resolution details over Texas. The day light region is on the right and the nighttime region is on the left.

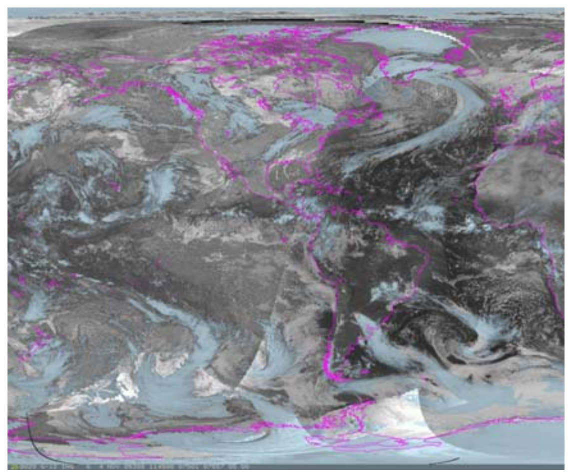

Figure 10. Western Hemisphere day-night "visible" mosaic of GOES-east, GOES-west, Meteosat-8 (MSG), and polar orbiter GAC data in the polar regions. The sunrise is from western Greenland down the east coast of the US down into the eastern South Pacific.

**Future Development**

While the empirically derived brightness normalization described above greatly helps in having a uniform visible brightness from sunrise to sunset, it still is not perfect. When there is forward scattering (the scattering angle between the sun, cloud and satellite approaching 180 degrees) the cloud is still over brightened. A normalization technique that takes into the total scattering angle between the sun, the cloud, and the satellite needs to be developed. This forward scattering problem is most pronounced in the polar regions.

Another factor that has been ignored in this effort is the differing visible channel calibrations. None of the visible channels are calibrated. For the GOES satellites, there is a noticeable brightness difference as the satellite ages. Since GOES-west (GOES-10) is older than the GOES-east (GOES-12), the west data is dimmer than the east. This visible calibration needs to be done for all the geostationary and polar weather satellites.

These day-night "visible" data will posted on the web starting early in 2006 at http://wx.erau.edu/data

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