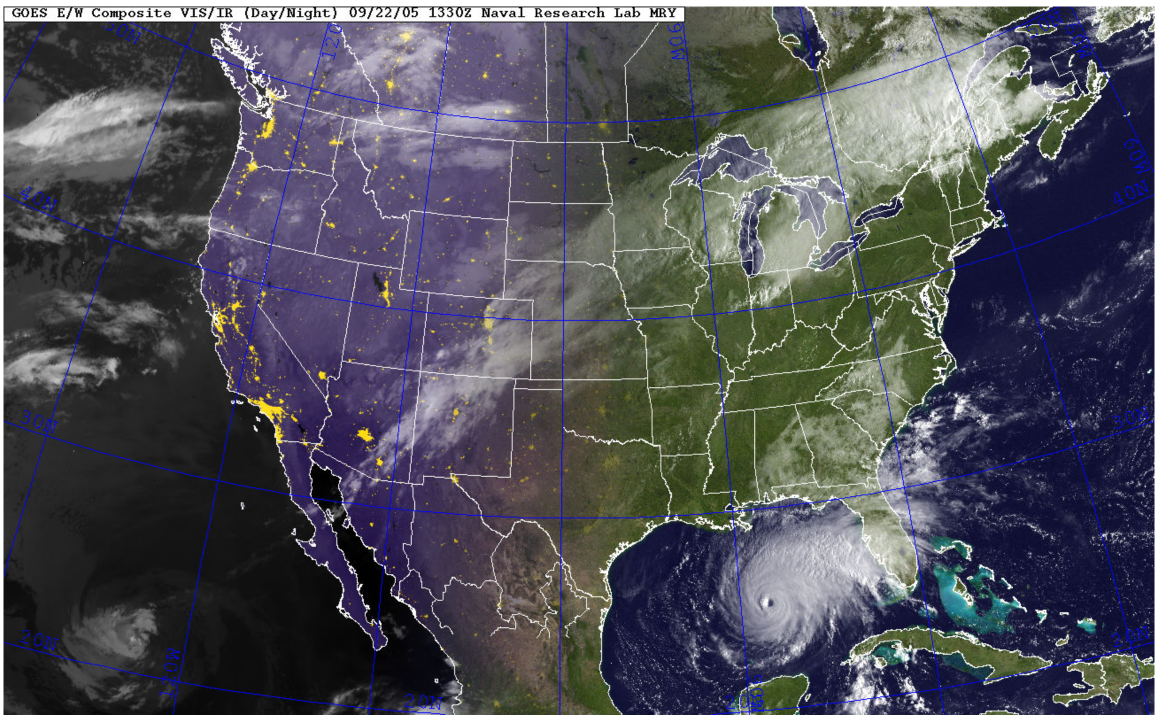
Satellite Product Tutorials:

Geo-Color Blended Imagery



Above: This view over the continental United States, depicting clouds and snow cover (when present) in white, moonlit nighttime terrain in purple, city lights from major metropolitan areas in yellow, and daytime land and shallow-water features in natural color, is not available from any single satellite observing system currently in orbit. Rather, the image is the result of blending between real-time visible and infrared channel data from geostationary satellites and static backgrounds produced from a constellation of polar orbiting satellites. The natural day/night transitions and dynamic transparency factors specified according to cloud opacity offer an intuitive, realistic, and value-added tool for visualizing the weather.

Why We're Interested…

Geostationary satellites are defined by equatorial orbits at altitudes (~35,786 km above mean sea level) resulting in orbital periods that approximately match the rotation rate of the Earth (~24 hr). As a result, these satellites appear to "hover" over a fixed location on the ground. This contrasts with polar orbiting satellites, whose orbital mechanics provide global coverage and improved spatial resolution but at the cost of reduced revisit frequency to a particular location (resulting in "snap shots" of the weather situation at the particular moment of a satellite overpass. Just like the communication satellites that offer us such wonders as Satellite television and radio broadcasting, geostationary weather satellites offer meteorologists a capability that is unique and essential to monitoring the changing weather—the ability to "stare". For example, the United States Geostationary Operational Environmental Satellite (GOES) program operates a western satellite at 135 W longitude and an eastern one at 75 W longitude. Almost every television weather broadcast animation showing the clouds in motion makes use of these two geostationary satellites. The "Geo-Color" application demonstrated here on *NexSat* can be thought of as just another innovation on this fundamental geostationary satellite dataset.

Conventional display of visible and infrared channel geostationary satellite imagery typically involves no blending of different pieces of information. In most cases, infrared imagery is presented since this can be looped in 24-hr mode to track clouds. Traditionally, these data have been presented to the public as gray-scale (clouds light gray to white, land/ocean surfaces in black) imagery. More advanced displays, seldom presented to the public due to the additional interpretation required, involved simple "stitched" composites of daytime visible and nighttime infrared data employing a discrete cut-off between the two kinds of data (e.g., at a specified sun zenith angle). This technique provides continual coverage across a given region while taking advantage of the approximately 16-times (1 km vs. 4 km pixels) higher spatial resolution and superior depiction of low cloud structures offered by daytime visible imagery. However, the stitch line (i.e., the seam between visible and infrared data) in this method is readily apparent, and it is difficult to optimize contrast scaling to account for the large dynamic range of values present in the scene.

An ideal display product would incorporate both visible and infrared datasets in a seamless way—optimizing cloud cover detection and adding value to the cloud-free regions. The Geo-Color product is an attempt to do this via "three dimensional blending", that is, a composite of rapidly updating (30 min refresh) geostationary satellite visible and infrared "foreground" imagery highlighting clouds and static land/ocean surface "background" imagery for the clear regions. Specifics of the approach are provided below.

How This Product is Created…

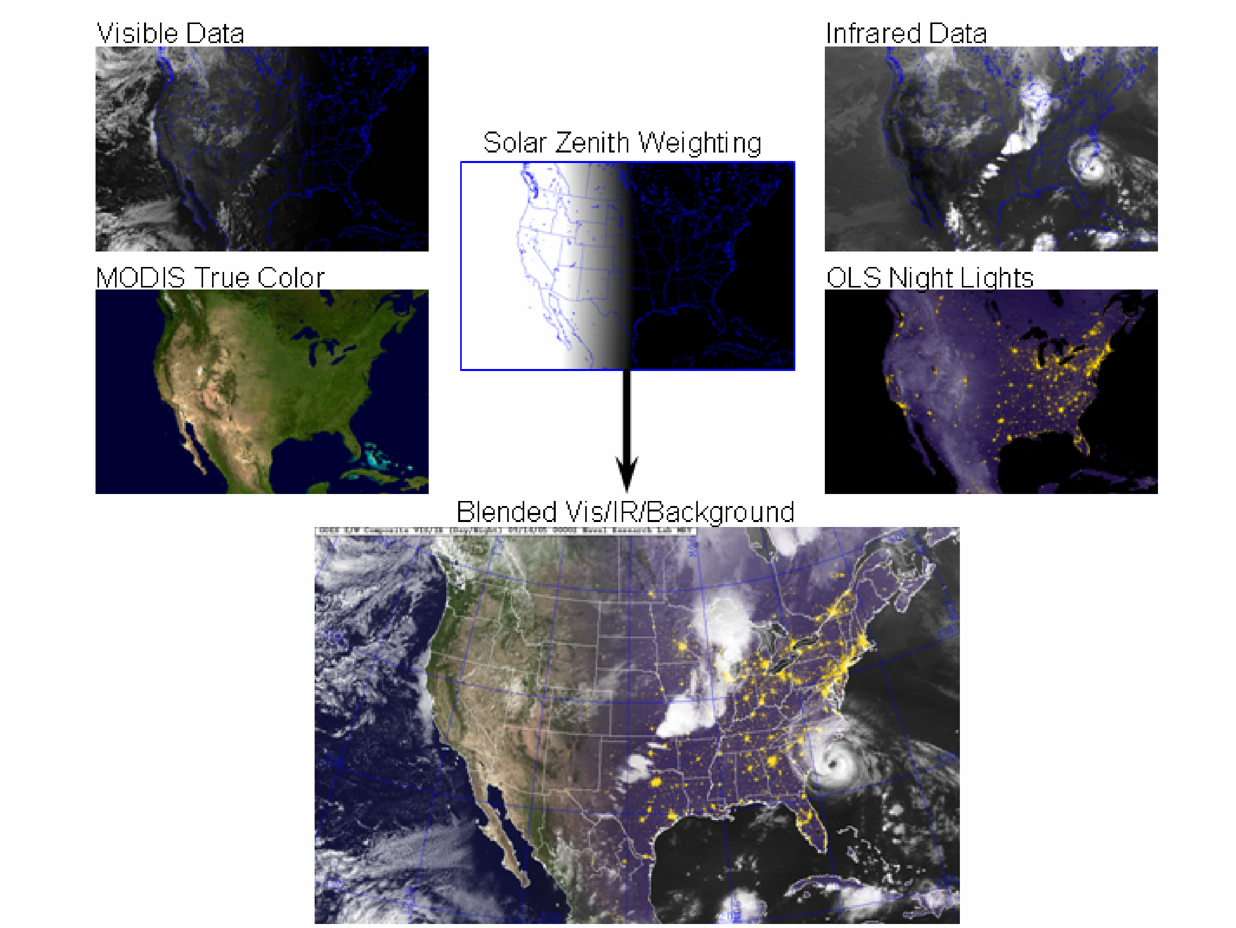


Fig. 1 Illustration of the five primary components contributing to the visible/infrared/background composite imagery.

Figure 1 illustrates the various components of the Geo-Color imagery blending technique. Time-matched Geostationary Operational Environmental Satellite (GOES), East (75°W) and West (135°W) have been stitched together at the 100°W meridian. For this example, collected at 0000

Greenwich Mean Time (GMT) on 14 September 2005, the eastern half of the United States lies in total darkness, while the western half is still illuminated by late afternoon sun. City lights are not apparent on the nighttime side of the GOES visible scene because this satellite detector lacks adequate sensitivity to these relatively weak light emissions (several orders of magnitude fainter than the minimum detectable signal). Color backgrounds are not available from GOES because this sensor lacks the red/green/blue channels required to render true color imagery.

In the foreground are the GOES E/W satellite visible and infrared datasets (divided at the 100°W meridian). The daytime background to the GOES visible imagery is the NASA Blue Marble (based on a composite of cloud-cleared imagery from the Moderate Resolution Imaging Spectroradiometer (MODIS)). On the nighttime side, a customized scene that incorporates the National Geophysical Data Center's (NGDC) 2003 Nighttime Lights of the World database (based on the Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) satellite sensors) is used beneath infrared imagery.

These data are first blended vertically (one dataset serving as the foreground, and the other as the background) using scaled and normalized versions of the satellite data to determine the transparency factor. For example, for visible imagery (daytime side), the transparency factor is smallest for the brightest GOES visible channel (channel 1; 0.65 μm)pixels (which are presumably highly reflective cloud or snow cover)—effectively blocking out the Blue Marble background. The transparency factor is largest for the darker GOES visible channel pixels (e.g., clear sky scenes over land and ocean)—allowing more of the Blue Marble background to "bleed through" the satellite imagery foreground. Here, special accommodations for desert scenes (whose reflectances are high even for clear sky conditions) must be made. Similarly for the nighttime side, transparency factors are specified according to the brightness temperatures of the GOES infrared window channel (channel 4; 11.0 μm) pixels (e.g., cold pixels indicative of high/thick clouds are given low transparency, and warmer pixels indicative of clear sky scenes are given higher transparency).

After this "vertical blending" is done for the visible (daytime) and infrared (nighttime) data independently, the merged datasets are blended *horizontally* using the solar zenith angle as a weighting term. This technique results in a gradual fade between the daytime and nighttime blended products, and represents one of the unique elements of this *NexSat* geo-color product.

How to Interpret…

Figures 2 and 3 (below) demonstrate the performance of the Geo-Color product for daytime and nighttime scenes. During the day (Figure 2), the Blue Marble true color background depicts blue ocean water in the Gulf of Mexico as well as light green shallow-water features (highly reflective sand/shoals) near Key West, Florida, and Key Largo (south of Cuba). Green vegetation dominates the background scene. Close inspection reveals transparency of thin cirrus over Cuba, in contrast to the opaque clouds associated with Katrina's rain bands over southern Louisiana. At night (Figure 3), the Blue Marble is replaced by nighttime city lights, shown as yellow/orange patches (to simulate the appearance of sodium lighting which dominates most urban lighting), corresponding to the major metropolitan areas. Again, note the transparency (city lights shining through cirrus) to the north of Katrina in contrast to the opacity (coastal cities obscured by deep, cold clouds) closer to the storm's rain bands.

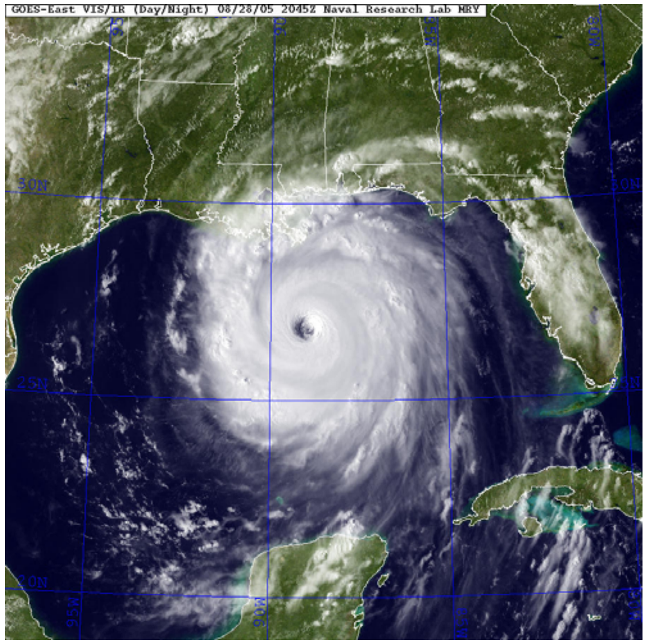


Fig. 2 Daytime composite of Hurricane Katrina advancing on the city of New Orleans, LA. Note cirrus transparency near Cuba, in contrast to the relative opacity of the primary hurricane cloud formations (e.g., feeder bands).

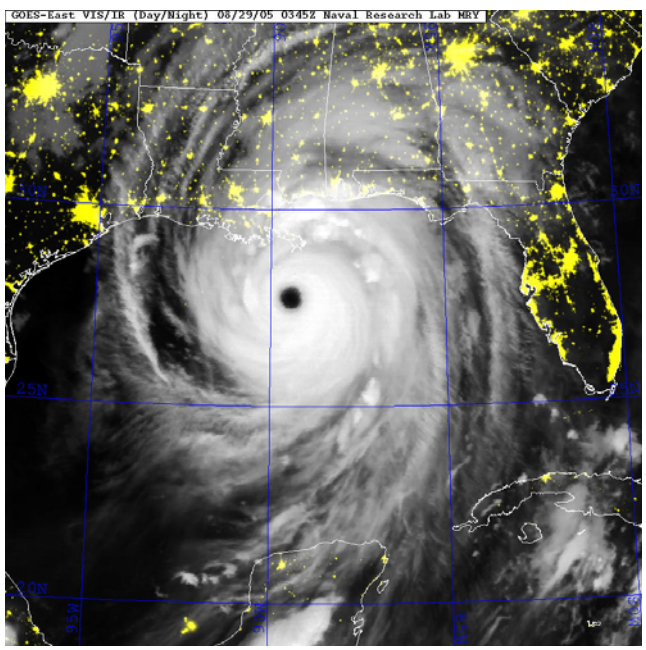


Fig. 3 Hurricane Katrina moves closer to shore in this nighttime-only composite. Purple terrain has been turned off in the background of this example. City lights offer additional information on the proximity of storm features to major metropolitan areas.

The Geo-Color technique provides a simple yet visually powerful mechanism for transitioning seamlessly between multiple sources of information both in the vertical *and* horizontal dimensions. Behind the scenes in the Geo-Color algorithm itself, tunable scaling factors provide operators flexibility in determining the relative strength of transparency in both dimensions (i.e., control over the amount of information retained/lost during the blending operation). This technique results in dramatic improvement to the presentation quality of standard visible and infrared satellite imagery, and is therefore well-suited as a briefing tool. The smooth transition from visible to infrared detected clouds across the day/night terminator supplants previous methods which either use infrared exclusively (to avoid the terminator problem) or invoke discrete cutoffs. Noteworthy in this regard is the cover image of this tutorial, which demonstrates a transition from infrared to visible imagery for frontal clouds extending from Arizona through Wisconsin (for clouds over the terminator, a blend of visible/infrared is used according to the product creation discussion above). For best viewing results, it is recommended that this product be displayed in the "Animate" mode on *NexSat*, with mode set to back/forth (rocking) and speed tuned to obtain a fluid cloud motion.

The main caveat users must always be aware of when using this product is that the backgrounds (ie, the Blue Marble and NGDC nighttime city lights) are indeed *static*. As such, almost all dynamics pertaining to the background will not be captured in this product. Unless some aspect of the change is captured in the real-time GOES visible/infrared observations, it will not be represented. For example, seasonal changes in vegetation, power outages, river plumes, variation of nighttime land brightness with lunar phase, etc, or impacts from a natural disaster, may not be represented in real-time imagery produced from this method. Examples of backgrounds that *will* be detected are snow cover and sea ice. Although technically part of the "background" since they are not atmospheric features, they will be revealed in the Geo-Color imagery due to their high reflectance in the GOES daytime visible channel imagery. For an example of poor performance due to static backgrounds, the city lights of New Orleans appeared to shine brightly the night after Hurricane Katrina's passage over the city. Other products available on *NexSat* (e.g., the "Night Visible" product, which uses real-time

DMSP/OLS nighttime visible data) can be used reveal the current nighttime lights situation.

Looking Toward the NPOESS Era…

It may not be immediately clear why Geo-Color, a primarily *geostationary* satellite system application, would be featured on *NexSat*—a website dedicated to previewing capabilities of the future NPOESS *polar-orbiting* satellite system. The reason lies in the backgrounds, which are produced now from the NPOESS heritage sensors (MODIS and OLS). In the NPOESS era, these backgrounds will be produced more often and at higher fidelity by the Visible/Infrared Imaging Spectrometer (VIIRS) sensors (which include the Day/Night Band for nighttime lights). More frequent updates will enable the capture of some of the dynamic background components that were mentioned previously—improving its representation of all components of the scene.

NPOESS/VIIRS will likely play an important supplementary role to the U.S. national geostationary program as well as any international programs (e.g., Meteosat Third Generation) that opts to follow suit with the current ABI band selection. As for the nighttime side of Geo-Color, the ABI provides "low light" sensitivity, but the light levels in this case refer to twilight conditions as opposed to natural/artificial terrestrial light emissions and lunar reflection light levels—several orders of magnitude fainter.

The global coverage of NPOESS means that these day/night backgrounds can be applied to any geostationary satellite around the world—dramatically improving the display quality of standard visible/infrared platforms. Similar products based on the current global background datasets have been produced using Meteosat-8 (Europe/Africa), Meteosat-5 (Middle East), and MTSAT (Western Pacific). The current application also hints at quantitative utility of backgrounds. For example, cloud-cleared datasets play an integral role in cloud mask algorithms that form a basis for several other environmental applications (cloud properties, surface radiation budget, temperature and moisture profiles, sea surface temperature retrievals, etc.). The improved environmental data records lead in turn to improved weather forecasts, climate data records, and general comprehension of the earth/atmosphere system. This equips policy makers and planners with the tools to make better informed decisions in the interest of life and property.

Did You Know…?

We haven't had true color capability on geostationary satellites since 1967, when the ATS provided all three red, green, and blue narrow-band channels.

Want to Learn More?

Rick Kohrs, of the Space, Science, and Engineering Center (SSEC; University of Wisconsin, Madison) has developed a similar Geo-Color approach that features a more sophisticated (use of sea and land surface temperature information) and robust way of specifying transparency factors.

Read more details about the VIIRS DNB.

Learn more about implications of the GOES-R ABI "green band" omission.

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