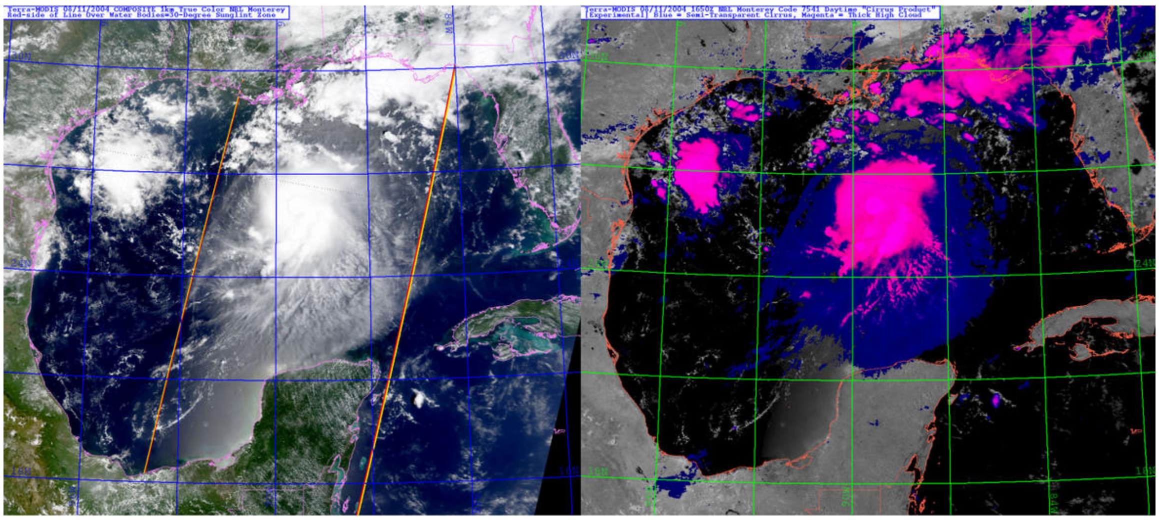
Satellite Product Tutorials:

Cirrus Cloud Detection



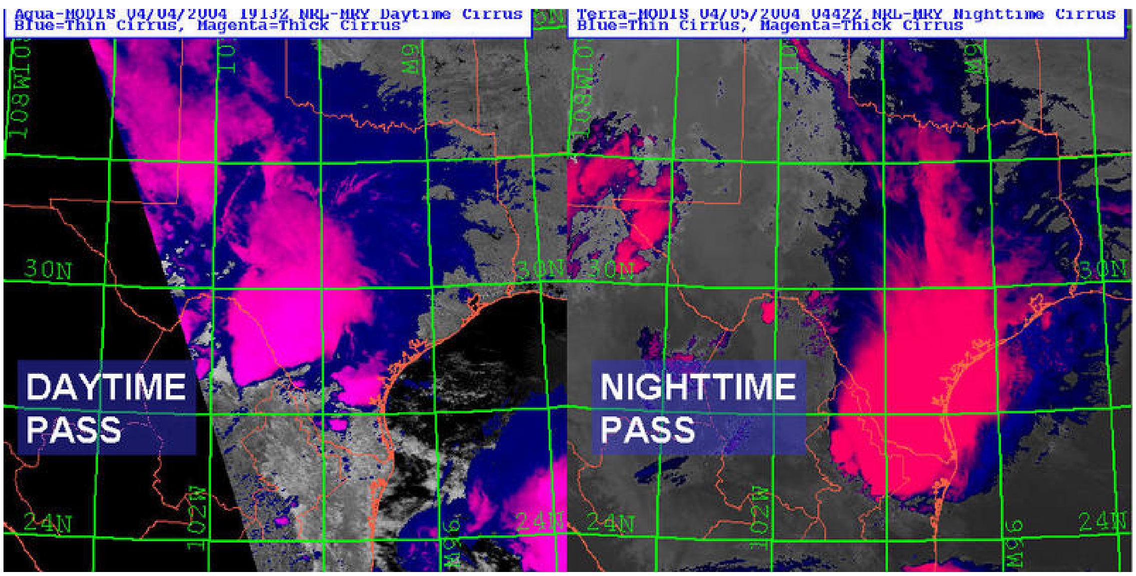
Above: The thin/thick cirrus detection product portrays transparent (optically thin) cirrus as blue and opaque (optically thick) cirrus and areas of deep convection as magenta. A natural color (left) rendition of Hurricane Bonnie (August 2004) shows the storm centered in the Gulf of Mexico, and the cirrus product (right) shows the full extent of the cirrus fan (dark blue) spiraling off the top of this system. Thick clouds associated with convective rainfall bands near the storm's center are highlighted in magenta. Lower atmosphere clouds and the Earth's surface are depicted as black & white scale visible imagery.

Why We're Interested…

Cirrus clouds are the most widespread class of cloudiness in the Earth's atmosphere. Researchers have long recognized the complex role cirrus plays in balancing the "energy budget" of our planet's climate. Whether cirrus serves to warm or cool the planet is strongly dependent on physical properties like ice crystal size, shape, and concentration. To short-term weather forecasters, cirrus cloud formations help identify midlatitude "jet streams" (currents of rapidly moving air in the upper atmosphere). In other applications, thin clouds are not the feature of interest but rather a source of contamination (for example, land characterization, rainfall estimation, estimation of temperature/moisture profiles from satellite, and pilot visibility). In these latter cases, detection of cirrus can be used to flag areas of uncertainty or even account for their presence.

How This Product is Created…

The cirrus product is based on measurements from the NASA Moderate-resolution Imaging Spectroradiometer (MODIS). It is actually composed of two algorithms—one for day and the other for night. We can take advantage of additional information from solar reflection channels during the daytime orbits to produce a superior product. At night we resort to other channels for cirrus detection, but must be more conservative in order to avoid false alarms in the enhanced imagery.



Example of the differences in appearance between the daytime (left) and nighttime (right) cirrus product for the same thunderstorm complex viewed roughly 9.5 hours apart.

Day:

The daytime algorithm hinges on the measurement of reflected sunlight in the 1.38 micron shortwave infrared channel. This channel is special because the abundant water vapor of our planet's atmosphere is strongly absorbing in this region, meaning that sunlight that travels too deep into the atmosphere has no chance of reflecting back to the satellite. Cirrus clouds, which reside high in the atmosphere and above most of the water vapor, reflect this 1.38 micron radiation with minimal effect of water vapor absorption, and are therefore sensed by MODIS. Low-level clouds and the surface, on the other hand, are "buried in the vapor" and effectively filtered from the scene. Reflection detected in the 1.38 micron channel above a certain threshold is considered "cirrus" and color-coded as blue.

To separate thin from thick cirrus, we use two more MODIS channels (6.7 and 11.0 micron) situated in the infrared part of the spectrum. The 6.7 micron channel corresponds to another one of those "water vapor absorption bands" just like the 1.38 micron channel, but since it's in the infrared part of the spectrum (where sunlight has minimal contribution) here we are dealing with Earth/atmosphere emissions only. The 11.0 micron channel is in a so-called "clean window" region, in the sense that water vapor and other gases are mostly transparent to radiation having this wavelength (so from a satellite vantage point w could in principle see all the way down through the intervening atmosphere to the surface in this band, if a cloud is not in the way). Measurements from these two channels are expressed in units of temperature (Celsius or kelvins (=Celsius+273.15)), and we are interested in the difference between these two measurements as a way to find thick, deep clouds in the scene.

The idea is that low clouds will again be "buried" in the water vapor, and since the 6.7 channel sees the temperature of the cooler water vapor present above the cloud (since temperature decreases with height), the satellite-measured temperature will be lower than the actual cloud top temperature. The same cloud observed at 11.0 micron (the window channel) will yield a temperature much closer to the true cloud top temperature. So, the difference between the two measurements (6.7 vs 11.0) will be large. Conversely, for a high and thick cloud, there is not much water vapor above it to depress the relative difference between 6.7 and 11.0, so the values in this case are small. Essentially we look for small differences between these two channels as a proxy for where the high and thick clouds are. We color code these areas as red. In terms of color composites, anywhere where we have both cirrus (blue) and "thick high cloud" (red) forms a magenta color.

Night:

While the 6.7-11.0 micron difference technique described above also applies to night imagery, we no longer have access to the 1.38 micron information to identify any thin cirrus component. Fortunately, another channel difference between 3.7 micron and 11.0 micron works fairly well for this purpose. 3.7 micron is a special channel because it is sensitive to both sunlight and earth/atmosphere radiation. At night, the sun-component is removed and this channel is very useful for detecting warm surface emissions (this channel is the cornerstone of fire detection). Because it is so sensitive to heat, any small amount that transmits through thin cirrus to reach the satellite creates a strong signal. This is in contrast to the 11.0 micron measurement, which will report a cooler temperature. In this way, we look for large differences between 3.7 and 11.0 micron as a way to highlight thin cirrus, which gets color coded as blue just like in the daytime enhancement.

How to Interpret…

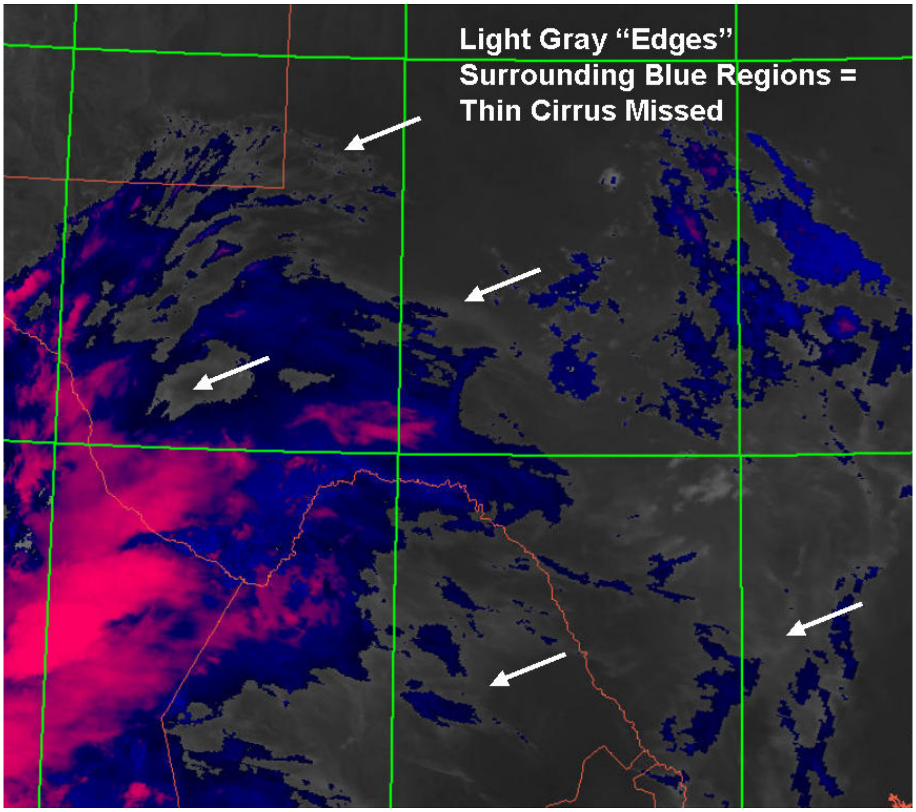
In both day and night imagery, thin cirrus clouds appear dark blue while thick cirrus/t-storm tops appear magenta. Areas devoid of cirrus are substituted with visible-channel imagery during the daytime, or infrared imagery at night. These regions are represented in black & white to provide context of the cirrus formations in the scene.

What to Look For:

Mature thunderstorms typically appear as oval shapes with bright magenta cores and potentially large fans of blue (thin) cirrus, depending on the strength of the upper level wind field. Cirrus associated with large, organized storm systems often appear as extensive shields ahead of the storm front. Jet stream cirrus, also commonly observed during the winter time months and associated with storm systems, typically appear as elongated chords following an undulating path along the upper level flow.

Caveats to Watch Out For:

Since the 1.38 micron channel only applies to daytime scenes, the nighttime cirrus product lacks the same high sensitivity to thin cirrus as the daytime product. Variable surface properties (especially over land) and lower atmospheric water vapor make the problem even more challenging. At night the product sometimes fails to pick up all the thin cirrus. Occasionally there



will be "gray rims" surrounding enhanced cloud structures; the product has failed to discern these clouds as cirrus. The example above illustrates an example of these missed thin cirrus regions (some pointed out with white arrows) associated with the remnants of thunderstorm anvils over southern Texas and northern Mexico.

Looking Toward the NPOESS Era…

The National Polar-orbiting Operation Environmental Satellite System (NPOESS) Visible/Infrared Imaging Spectrometer (VIIRS) will feature the 1.38 micron shortwave water vapor channel found on present-day MODIS sensors, enabling a wealth of new cirrus applications. Many of the cirrus region depicted in the current daytime products are completely indiscernible to the contemporary operational sensors (AVHRR, GOES, DMSP/OLS).

Did You Know…?

Cirrus clouds can obscure the eye of a hurricane (fanning away from deep convection in the surrounding eye wall and feeder bands to produce "central dense overcast"), making it more difficult to locate and track the center of the storm. These conditions necessitate the use of microwave imagery that can "see through" these clouds.

Want to Learn More?

Learn about studies done on cirrus at NASA's CRYSTAL-FACE website.

Turk, F. J., and S. D. Miller, 2004: Towards Improved Characterization of Remotely-Sensed Precipitation Regimes With MODIS/AMSR-E Blended Data Techniques, Submitted to IEEE Trans. Geosci. Rem. Sens.

Technical P.O.C.: Steve Miller (miller@nrlmry.navy.mil)