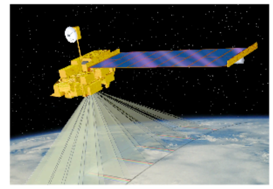
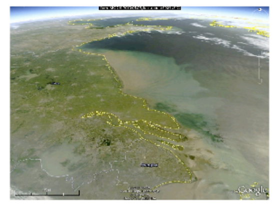
# Introduction to the MODIS sensor and products

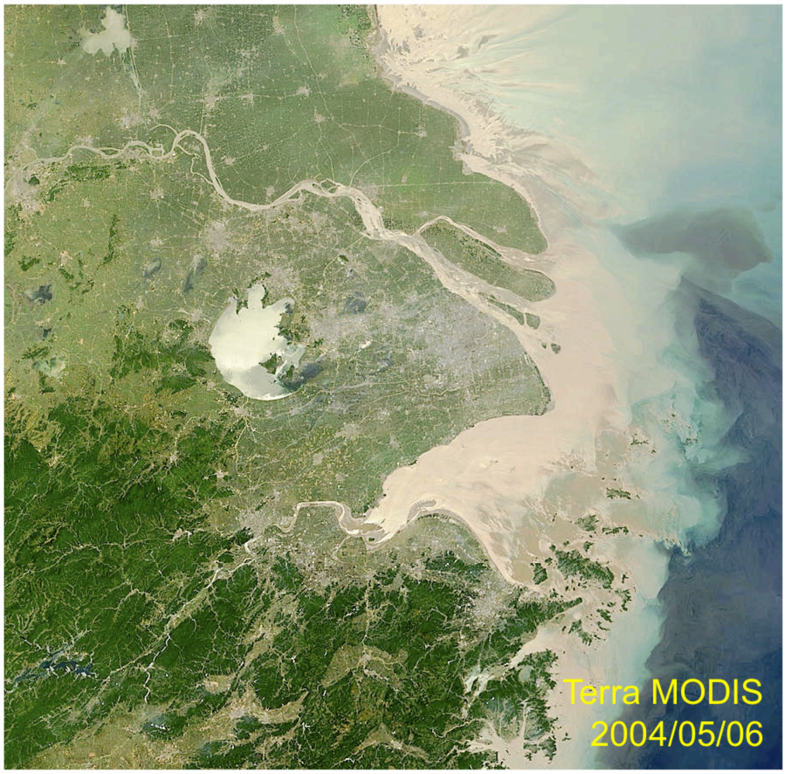


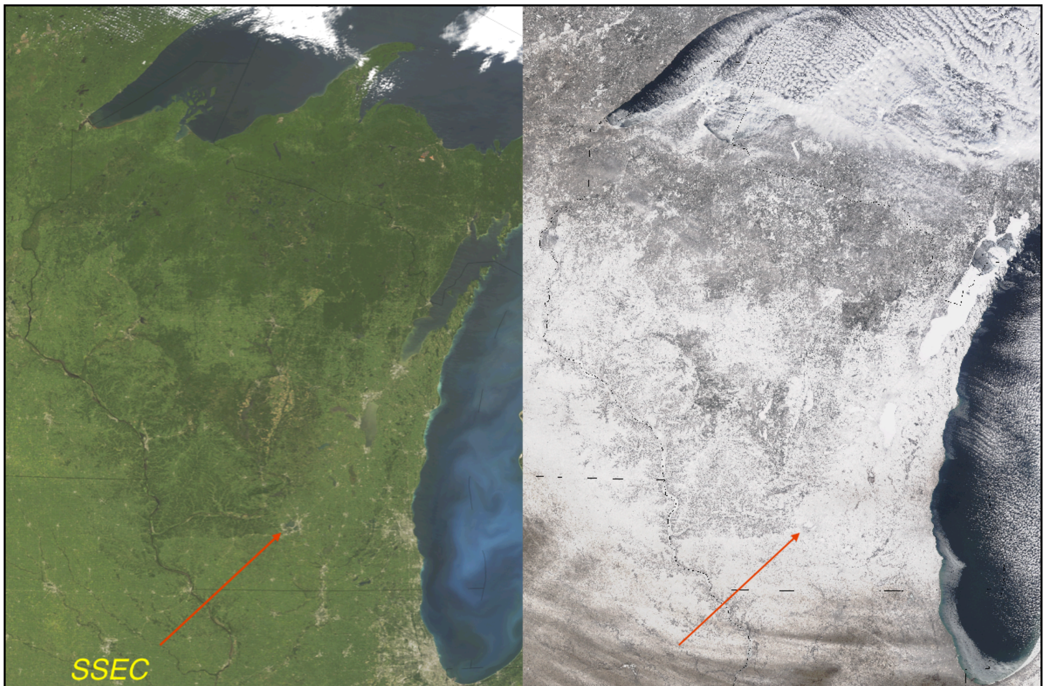


**ECNU IMAPP Workshop**
**Shanghai, China**
**June 1-5, 2011**

Liam Gumley
Space Science and Engineering Center
University of Wisconsin-Madison

Title slide


Terra MODIS
2004/05/06




*Visit Wisconsin: Beautiful in Summer and Winter*

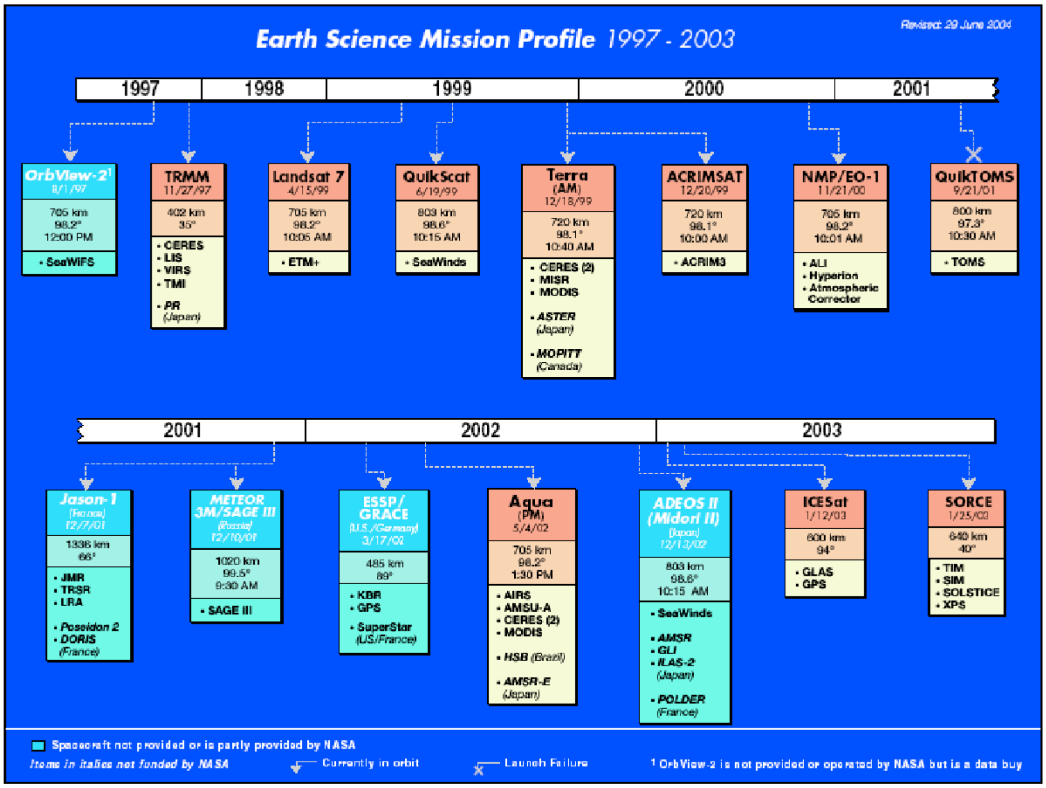
# Earth Observing System (EOS)

The Earth Observing System is a constellation of NASA satellites for observing and quantifying global change processes

*The Earth Observing System (EOS) is intended to measure the impact of human activities and other phenomena on the world's climate over a period spanning nearly two decades …*

*It is the biggest single science program in the world ...*

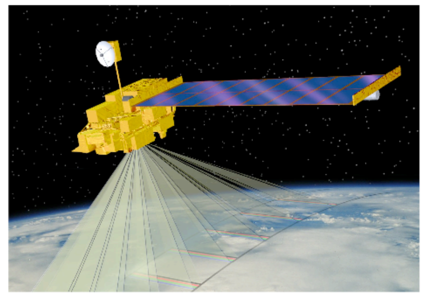
*- Charles F. Kennel*




The constellation of NASA Earth Observing Satellites provides a comprehensive suite of instrumentation for observing the Earth. Of particular note for this presentation are Terra and Aqua.

## Terra

Launched: Dec. 18, 1999
10:30 am descending node
ASTER: Hi-res imager
CERES: Broadband scanner
MISR: Multi-view imager
MODIS: Multispectral imager
MOPITT: Limb sounder



Expected lifetime about 15 years

Despite a design lifetime of only 5 years, the Terra spacecraft is expected to operate for up to 15 years.

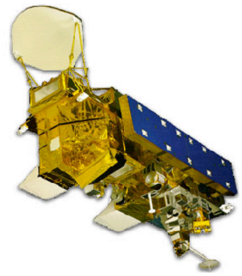
## Terra MODIS first light image, 24 Feb. 2000

Birdfoot Delta
Mississippi River
USA

The first daytime imagery from Terra MODIS was acquired on 24 February 2000.

## Aqua

Launched: May 4, 2002
1:30 pm ascending
AIRS: Infrared sounder
AMSR-E: Microwave scanner
AMSU: Microwave scanner
CERES: Broadband scanner
MODIS: Multispectral imager



Expected lifetime about 15 years

## Moderate Resolution Imaging Spectroradiometer (MODIS)

Heritage: AVHRR (land), SeaWIFS (ocean), HIRS (atmosphere)

Spectral coverage: 36 bands from 0.4 to 14.2 microns

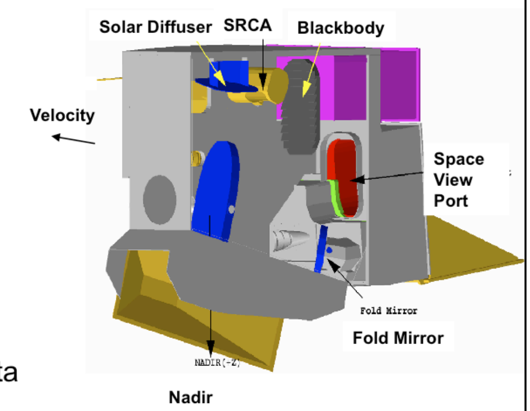
Spatial resolution: 2 bands @ 250 m; 5 @ 500 m; 29 @ 1000 m

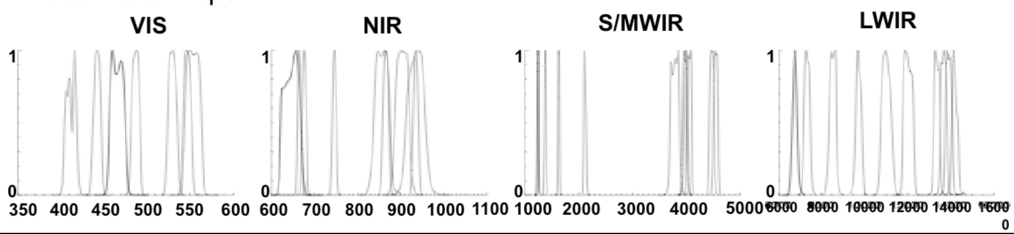
Major differences:

- Many spectral bands (490 detectors)
- Multiple samples along track on each earth scan
- Higher spatial resolution
- On-orbit radiometric, spatial, and spectral calibration
- Improved radiometric accuracy and precision (12-bit)
- Improved geolocation accuracy
- Higher data rate requiring X-band direct broadcast

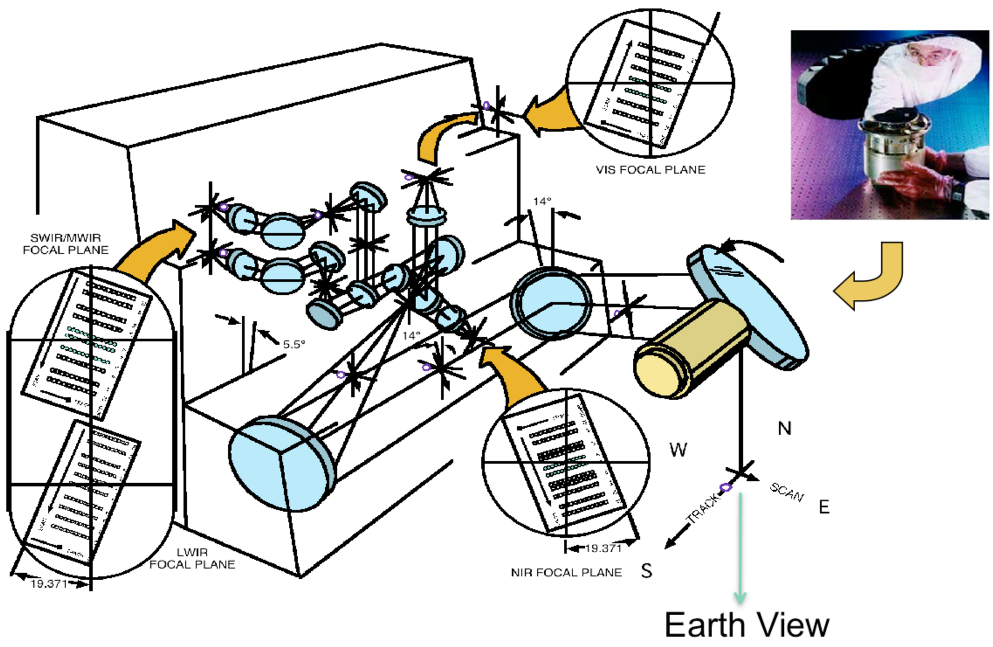
# MODIS Instrument Overview

- 36 spectral bands (490 detectors) covering 0.4 to 14.5 μm
- 4 Focal Plane Arrays: Visible, Near Infrared, Shortwave Infrared, Longwave Infrared
- On-Board Calibrators: SD/SDSM, SRCA, and BB (plus space view)
- 12 bit (0-4095) dynamic range
- 2-sided Paddle Wheel Scan Mirror scans 2330 km swath in 1.47 sec
- Day data rate = 10.6 Mbps; night data rate = 3.3 Mbps



# MODIS Optics System




Starting with the double-sided scan mirror, the MODIS optical system is a complex arrangement of beam splitters, fold mirrors, and focal plane arrays. The complexity of the optical system introduces the possibility of artifacts including polarization and striping.

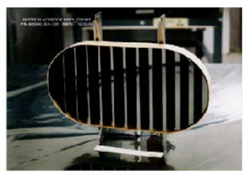
# MODIS On-board Calibrators

SD

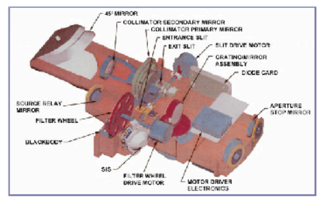
SDSM

- **SD** – Solar Diffuser for RSB calibration, SD BRDF determined from pre-launch, referenced to a transfer standard calibrated at NIST
- **SDSM** – Solar Diffuser Stability Monitor for tracking SD degradation
- **BB** – Blackbody (12 thermistors reference to NIST standard) for TEB calibration. Emissivity determined from pre-launch calibration using a blackbody calibration source.
- **SRCA** – Spectroradiometric Calibration Assembly for spectral and spatial characterization

BB



SRCA




A special feature of the MODIS instrument is the presence of onboard calibration sources for both the infrared and visible channels. The Solar Diffuser and Solar Diffuser Stability Monitor allow accurate calibration and monitoring of the reflectaed solar channels. The Black Body and Space View allow precise calibration of the infrared channels on every Earth scan. The SRCA allows the long term stabiity of the reflected solar channel spectral responses to be monitored.

## MODIS Challenges

***Multiple detectors:***

•Detector differences are noticeable

•Dead or out-of-family detectors must be handled

•Multiple samples along track introduce bowtie distortion

***Spectral information:***

•Many interdependent bands

•How to use the spectral information? (algorithm design challenge)

***Data rate:***

•Orders of magnitude larger than heritage sensors

MODIS added several challenges compared to heritage instruments.

## MODIS Reflected Solar Bands

| Primary Use | Band | Bandwidth[1] | Spectral Radiance[2] | Required SNR[3] | |
|---|---|---|---|---|---|
| Land/Cloud/Aerosols Boundaries | 1 | 620 - 670 | 21.8 | 128 | 250 meters |
| | 2 | 841 - 876 | 24.7 | 201 | |
| Land/Cloud/Aerosols Properties | 3 | 459 - 479 | 35.3 | 243 | 500 meters |
| | 4 | 545 - 565 | 29.0 | 228 | |
| | 5 | 1230 - 1250 | 5.4 | 74 | |
| | 6 | 1628 - 1652 | 7.3 | 275 | |
| | 7 | 2105 - 2155 | 1.0 | 110 | |
| Ocean Color/ Phytoplankton/ Biogeochemistry | 8 | 405 - 420 | 44.9 | 880 | 1000 meters |
| | 9 | 438 - 448 | 41.9 | 838 | |
| | 10 | 483 - 493 | 32.1 | 802 | |
| | 11 | 526 - 536 | 27.9 | 754 | |
| | 12 | 546 - 556 | 21.0 | 750 | |
| | 13 | 662 - 672 | 9.5 | 910 | |
| | 14 | 673 - 683 | 8.7 | 1087 | |
| | 15 | 743 - 753 | 10.2 | 586 | |
| | 16 | 862 - 877 | 6.2 | 516 | |
| Atmospheric Water Vapor | 17 | 890 - 920 | 10.0 | 167 | |
| | 18 | 931 - 941 | 3.6 | 57 | |
| | 19 | 915 - 965 | 15.0 | 250 | |
| Cirrus Clouds | 26 | 1380 | | | |

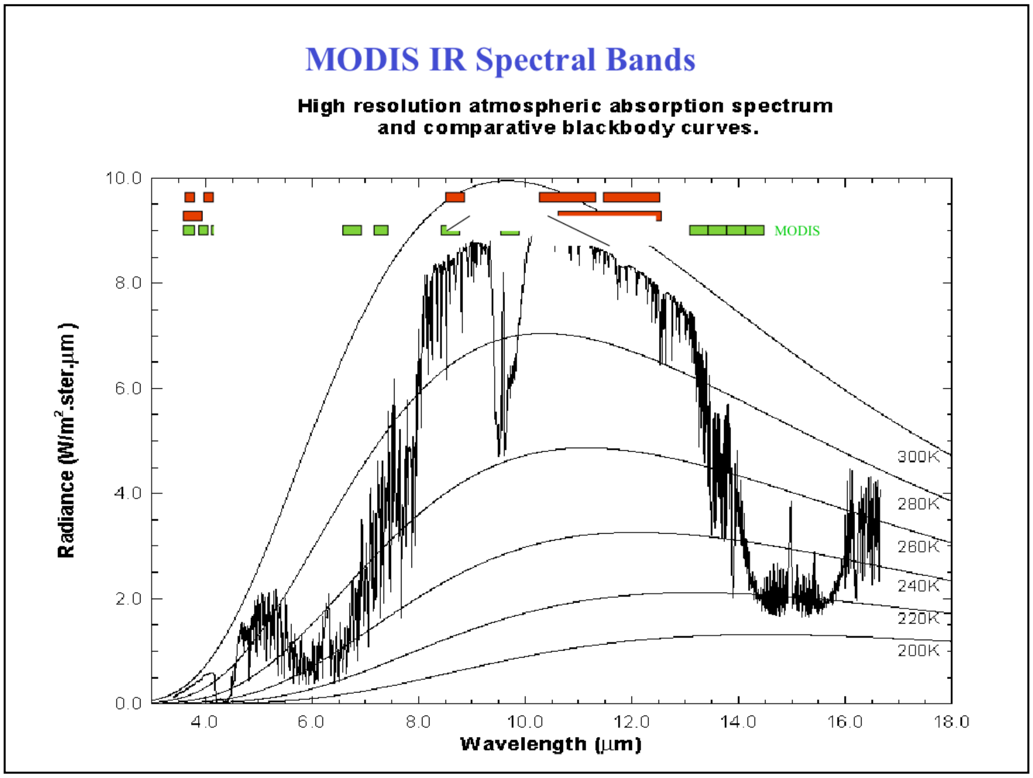
MODIS reflected solar channels measure the intensity of solar photons that have been reflected or scattered into the sensor field of view by the atmosphere, land, or ocean. These bands only operate when the sun is above the horizon. Bands 1 and 2 are 250 meter resolution at nadir; Bands 3-7 are 500 meter resolution; Bands 8-19 and 26 are 1000 meter resolution.

## MODIS Thermal Emissive Bands

| Primary Atmospheric Application | Band | Bandwidth[1] | $T_{typical}$ (K) | Radiance[2] at $T_{typical}$ | NEΔT (K) Specification | NEΔT (K) Predicted |
|---|---|---|---|---|---|---|
| Surface Temperature | 20 | 3.660-3.840 | 300 | 0.45 | 0.05 | 0.05 |
| | 22 | 3.929-3.989 | 300 | 0.67 | 0.07 | 0.05 |
| | 23 | 4.020-4.080 | 300 | 0.79 | 0.07 | 0.05 |
| Temperature profile | 24 | 4.433-4.498 | 250 | 0.17 | 0.25 | 0.15 |
| | 25 | 4.482-4.549 | 275 | 0.59 | 0.25 | 0.10 |
| Moisture profile | 27 | 6.535-6.895 | 240 | 1.16 | 0.25 | 0.05 |
| | 28 | 7.175-7.475 | 250 | 2.18 | 0.25 | 0.05 |
| | 29 | 8.400-8.700 | 300 | 9.58 | 0.05 | 0.05 |
| Ozone | 30 | 9.580-9.880 | 250 | 3.69 | 0.25 | 0.05 |
| Surface Temperature | 31 | 10.780-11.280 | 300 | 9.55 | 0.05 | 0.05 |
| | 32 | 11.770-12.270 | 300 | 8.94 | 0.05 | 0.05 |
| Temperature profile | 33 | 13.185-13.485 | 260 | 4.52 | 0.25 | 0.15 |
| | 34 | 13.485-13.785 | 250 | 3.76 | 0.25 | 0.20 |
| | 35 | 13.785-14.085 | 240 | 3.11 | 0.25 | 0.25 |
| | 36 | 14.085-14.385 | 220 | 2.08 | 0.35 | 0.35 |

MODIS Thermal Infrared bands sense the energy of photons which are emitted by the atmosphere, land, and ocean. These bands operate day and night. The shortwave infrared bands (3-7 to 4.0 microns) do contain a small but significant reflected solar contribution during daytime.

The transmittance of the atmosphere from 0.4 to 2.5 microns is dominated by oxygen, ozone, water vapor, and carbon dioxide absorption. Remote sensing of cloud, land surface, and ocean features is accomplished within the transparent window regions of the spectrum. Remote sensinr of water vapor is achieved using the absoprtion bands around 0.9 microns. High cirrus clouds may be detected at 1.38 microns because very few photons can reach the surface in this water vapor absopriton band, and the only photons reaching the sensor are those that have reflected or scattered from high clouds.




This slide shows an observed infrared spectrum of the earth thermal emission of radiance to space. The earth surface Planck blackbody - like radiation at 295 K is severely attenuated in some spectral regions. Around the absorbing bands of the constituent gases of the atmosphere (CO2 at 4.3 and 15.0 um, H20 at 6.3 um, and O3 at 9.7 um), vertical profiles of atmospheric parameters can be derived. Sampling in the spectral region at the center of the absorption band yields radiation from the upper levels of the atmosphere (e.g. radiation from below has already been absorbed by the atmospheric gas); sampling in spectral regions away from the center of the absorption band yields radiation from successively lower levels of the atmosphere. Away from the absorption band are the windows to the bottom of the atmosphere. Surface temperatures of 296 K are evident in the 11 micron window region of the spectrum and tropopause emissions of 220 K in the 15 micron absorption band. As the spectral region moves toward the center of the $CO_2$ absorption band, the radiation temperature decreases due to the decrease of temperature with altitude in the lower atmosphere.

## MODIS Orbit and Scan Geometry

Terra: 10:30 am local descending

Aqua: 1:30 pm local ascending

Orbit period: 99 minutes

Repeat cycle: 16 days (same as Landsat; precisely controlled)

Scan mirror: Double sided, 20.3 revolutions/minute

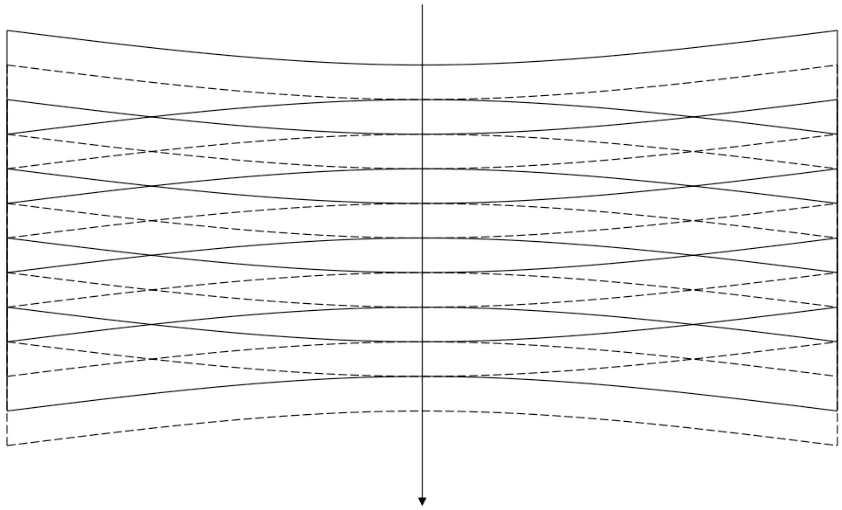
Scan rate: 1.477 scans/sec

Scan angle: +/- 55 degrees

Swath width: 2330 km across track, 10 km along track

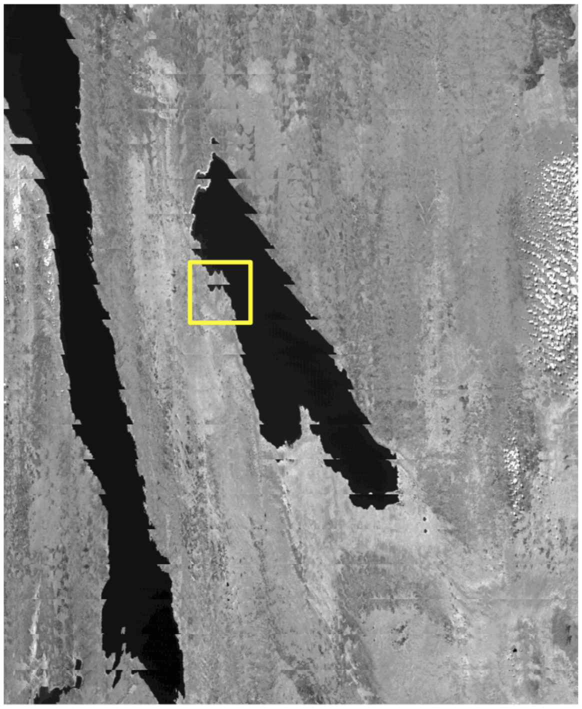
## MODIS Bowtie

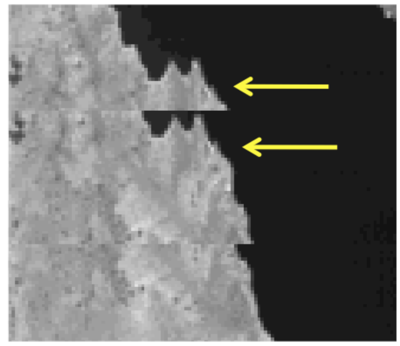
Consecutive "bowtie" shaped scans are contiguous at nadir, and overlap as scan angle increases…



Each MODIS earth scan paints a bowtie-shaped outline on the surface of the Earth. As the spacecraft moves forward in time, each successive scan paints a new bowtie on the Earth, thus building up a continuous image. Ten 1000-meter samples are acquired along the ground track for each scan.

## MODIS bowtie artifacts at edge of swath





Band 2 (0.87 micron)

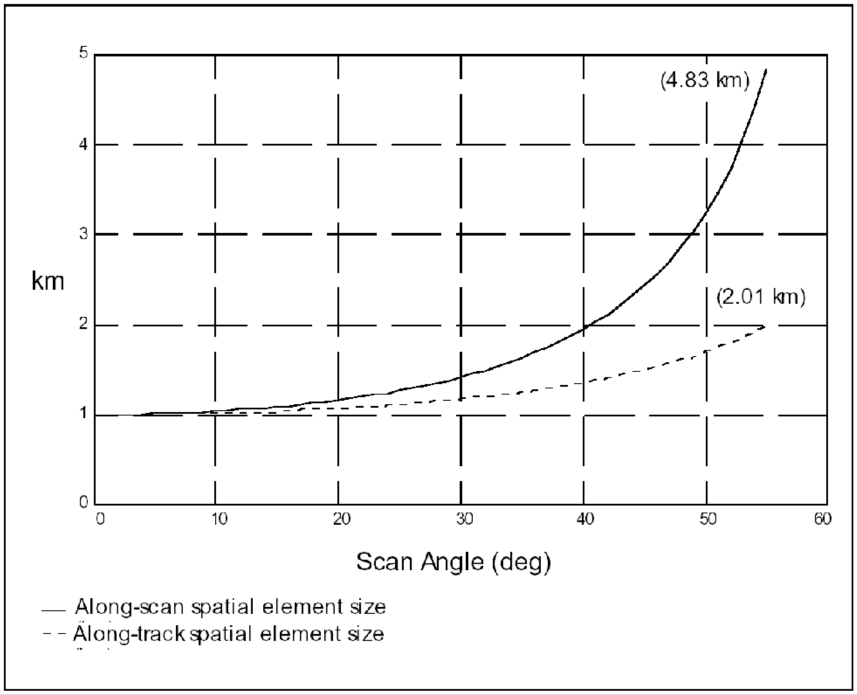
250 meter resolution

However a consequence of the bowtie scan is that the same region of the Earth is sensed on consecutive scans.

## Bowtie Artifacts

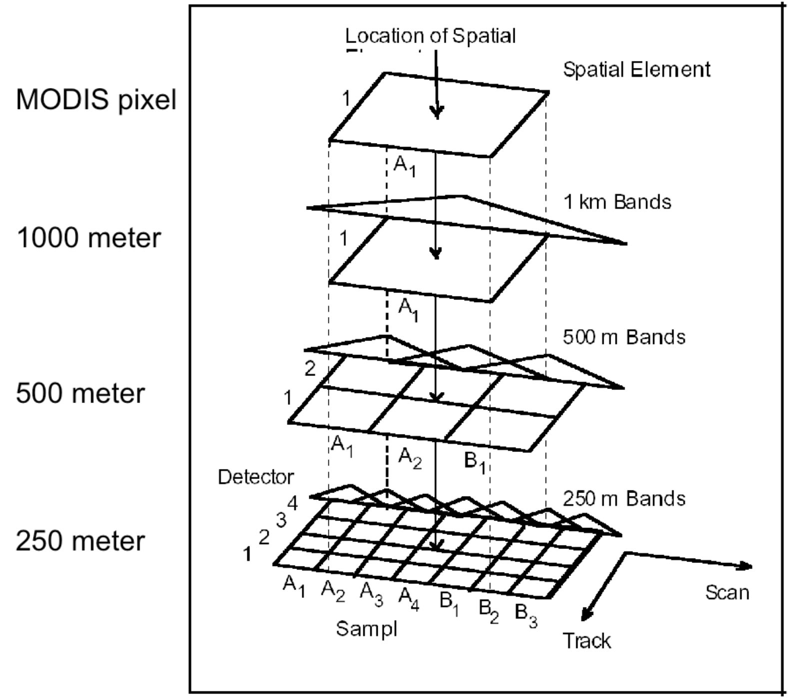
1. Are not a ‘problem’: they are a consequence of the sensor design
2. Can be removed for visualization purposes by reprojecting the image onto a map
3. Do not affect science algorithms that run on a pixel-by-pixel basis or within one earth scan
4. Will be present on next generation of operational polar orbiting imagers (VIIRS on NPP/JPSS-1)

## Growth of MODIS 1 km pixel with scan angle

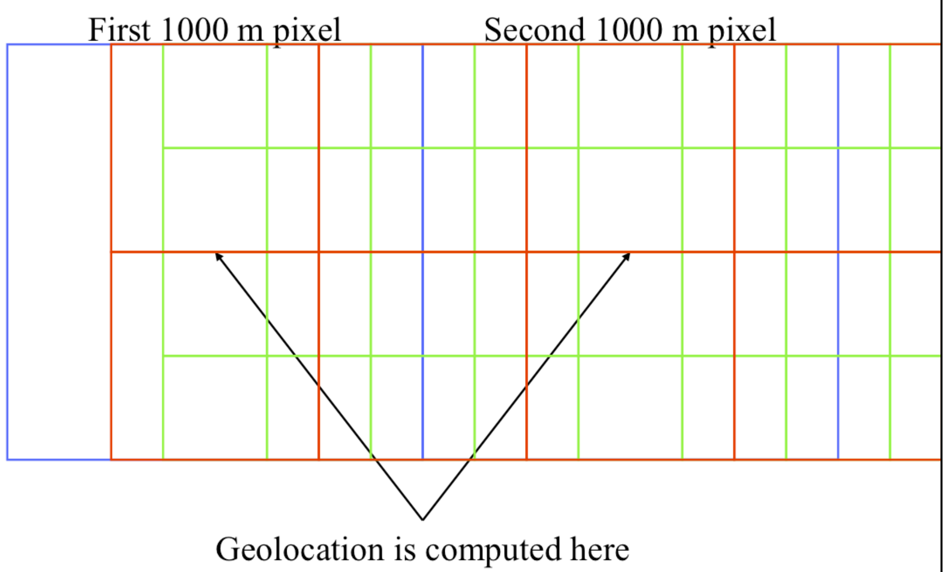



The area sensed by a MODIS field of view (i.e., a pixel) grows as a function of scan angle.

# Inter-band Registration



## Nominal MODIS inter-band registration

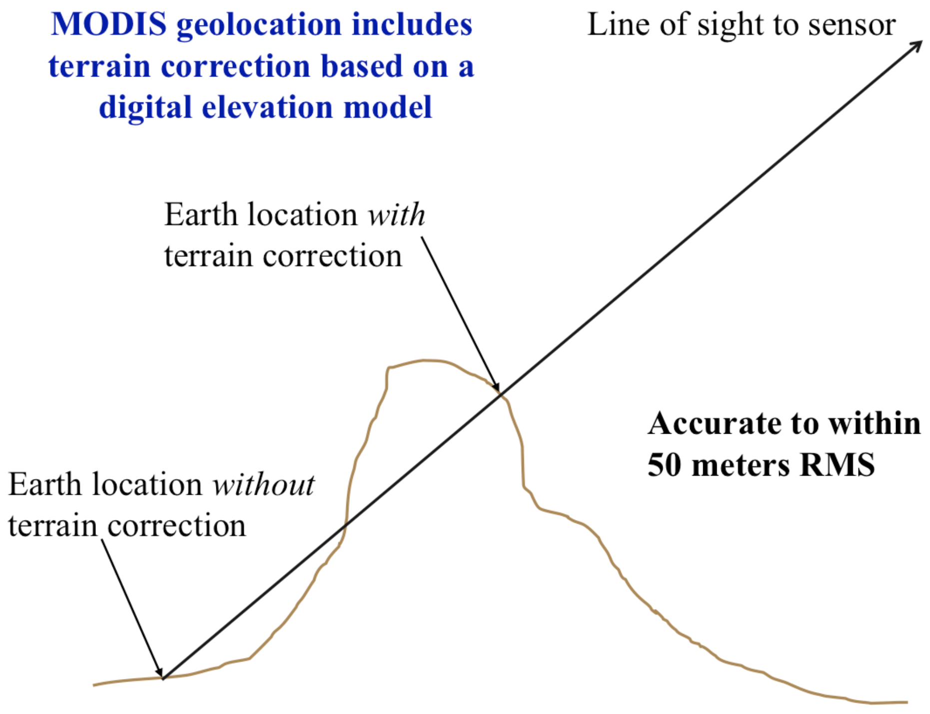


## MODIS Geolocation

Earth locations computed for every 1000 meter pixel (WGS84):

- Geodetic latitude (degrees, -90S to +90N)
- Geodetic longitude (degrees, -180W to +180E)
- Sensor zenith and azimuth (degrees, pixel to sensor)
- Solar zenith and azimuth (degrees, pixel to sun)
- Terrain height above geoid (meters)
- Land/Sea mask
  - 0: Shallow Ocean
  - 1: Land
  - 2: Ocean Coastlines and Lake Shorelines
  - 3: Shallow Inland Water
  - 4: Ephemeral (intermittent) Water
  - 5: Deep Inland Water
  - 6: Moderate or Continental Ocean
  - 7: Deep Ocean

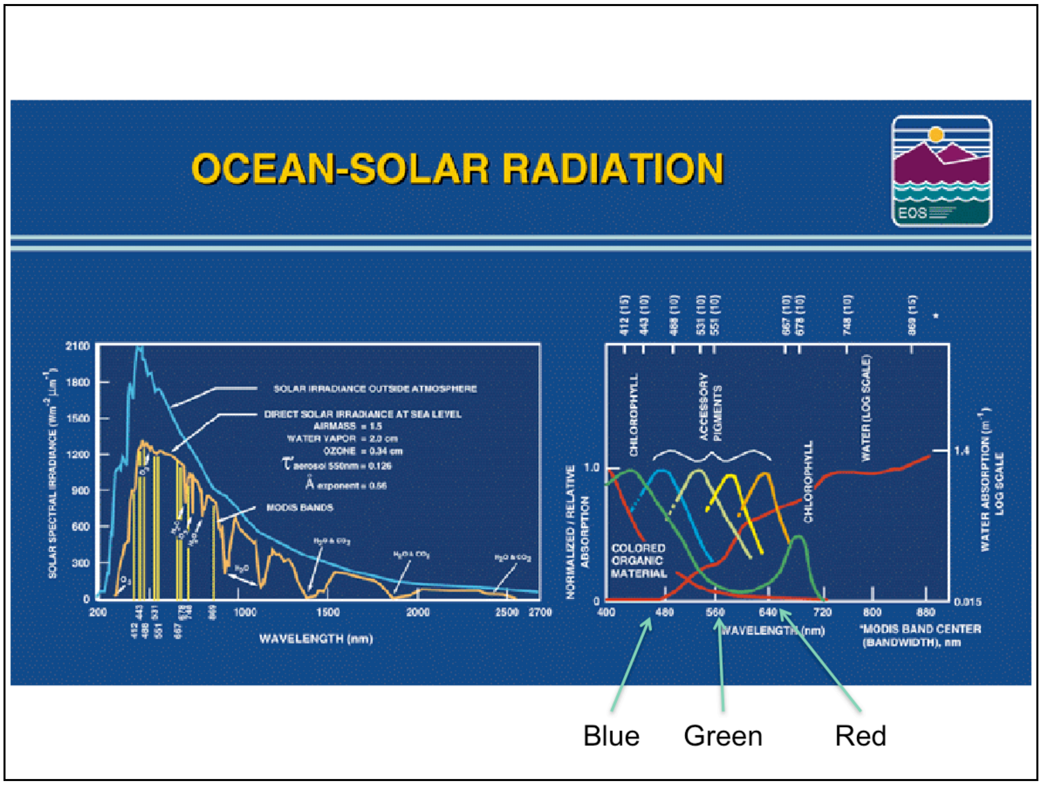
**MODIS geolocation includes terrain correction based on a digital elevation model**



# MODIS Ocean Applications

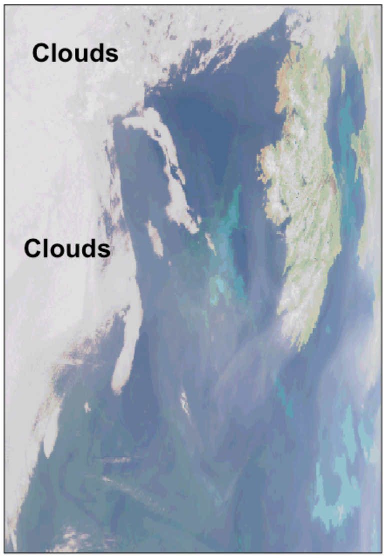
## MODIS Ocean Products

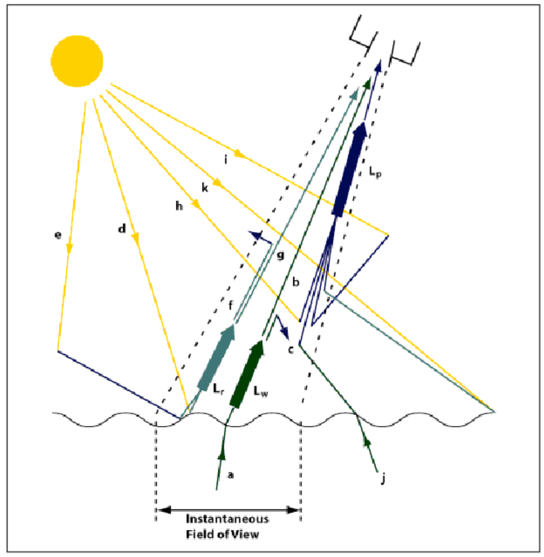
| Geophysical Parameter Name | Description |
|---|---|
| nLw_412 | Normalized water-leaving radiance at 412 nm |
| nLw 443 | Normalized water-leaving radiance at 443 nm |
| nLw_488 | Normalized water-leaving radiance at 488 nm |
| nLw_531 | Normalized water-leaving radiance at 531 nm |
| nLw_551 | Normalized water-leaving radiance at 551 nm |
| nLw_667 | Normalized water-leaving radiance at 667 nm |
| Tau_869 | Aerosol optical thickness at 869 nm |
| Eps_78 | Epsilon of aerosol correction at 748 and 869 nm |
| Chlor_a | OC3 Chlorophyll a concentration |
| K490 | Diffuse attenuation coefficient at 490nm |
| Angstrom_531 | Angstrom coefficient, 531-869 nm |
| SST | Sea Surface Temperature: 11 micron |
| SST4 | Sea Surface Temperature: 4 micron (night only) |




For ocean applications, the MODIS team has selected several spectral bands that are on line and off line absorption features associated with chlorophyll and accessory pigments. The multispectral data will be used to reveal their respective concentrations in the ocean waters.

*Atmospheric correction is critical for ocean color*

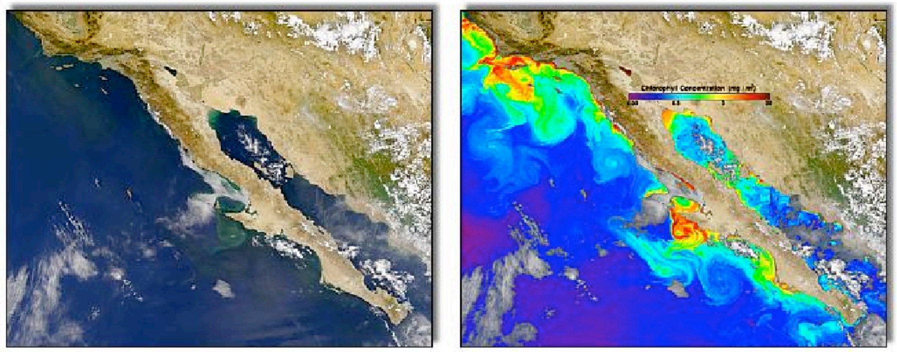



- cloud masking – less rigorous on sensors with no IR bands
- $L_w$ – only 5% of signal reaching satellite: rest due to $L_p$
- $L_p$ components: molecular (Rayleigh) & aerosols

There are many pathwys via which a photon can reach the sensor. In a typical case, less than 5% of the signal received at the sensor is from the water itself. The remainder is due to scattering in the atmosphere and reflection from the ocean surface. These atmospheric conltributions to the measured radiance must be removed in order to determine the optical properties of the water.

# Chlorophyll



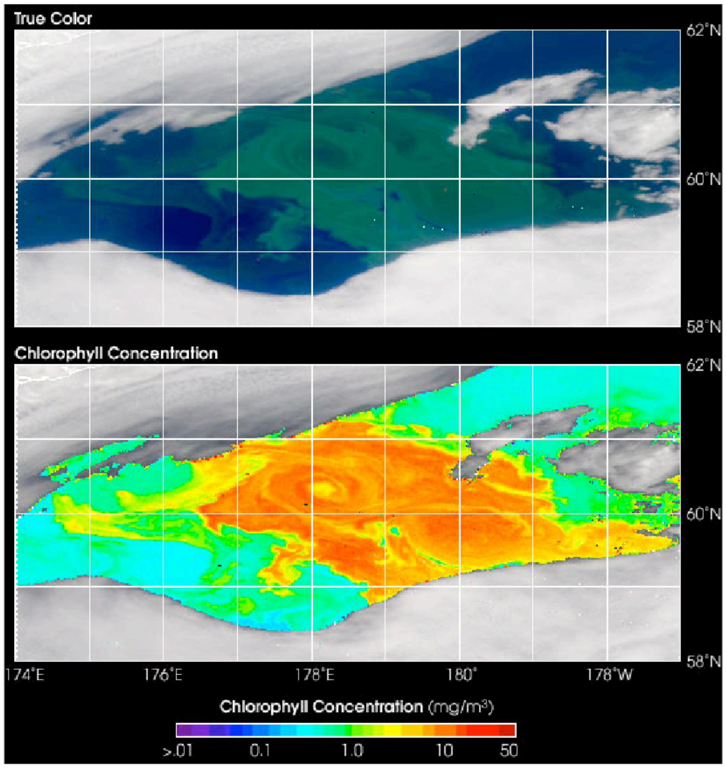
August 10, 2003

Strong absorption of the blue light by phytoplankton in chlorophyll-rich waters results in low water-leaving radiance in the blue bands.

Dominant band shifts from blue to green with increasing chlorophyll concentration.

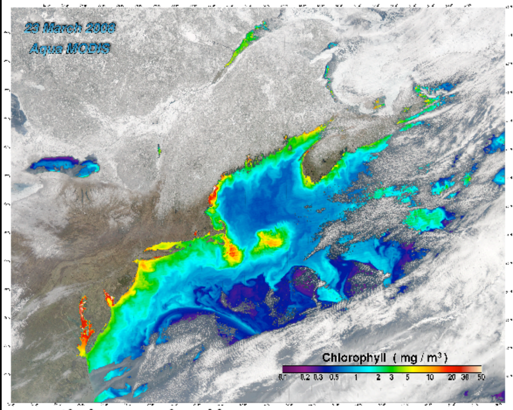
Index of the change in spectral shape ⇒ chlorophyll

Retrieval of chlorophyll-A relies on the change in absorption at blue and green wavelengths as a function of increasing chlorophyll.

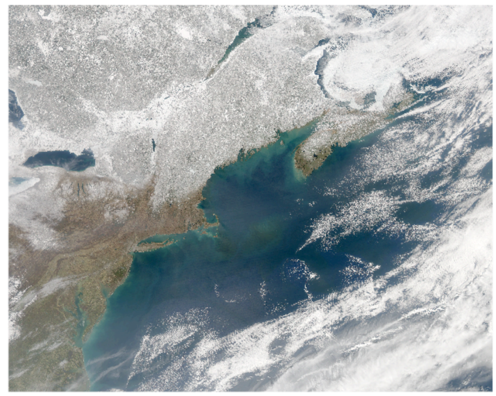



Strong chlorophyll features may be visible in true color imagery.

March 23, 2008 MODIS Aqua
Northeast USA and Canada

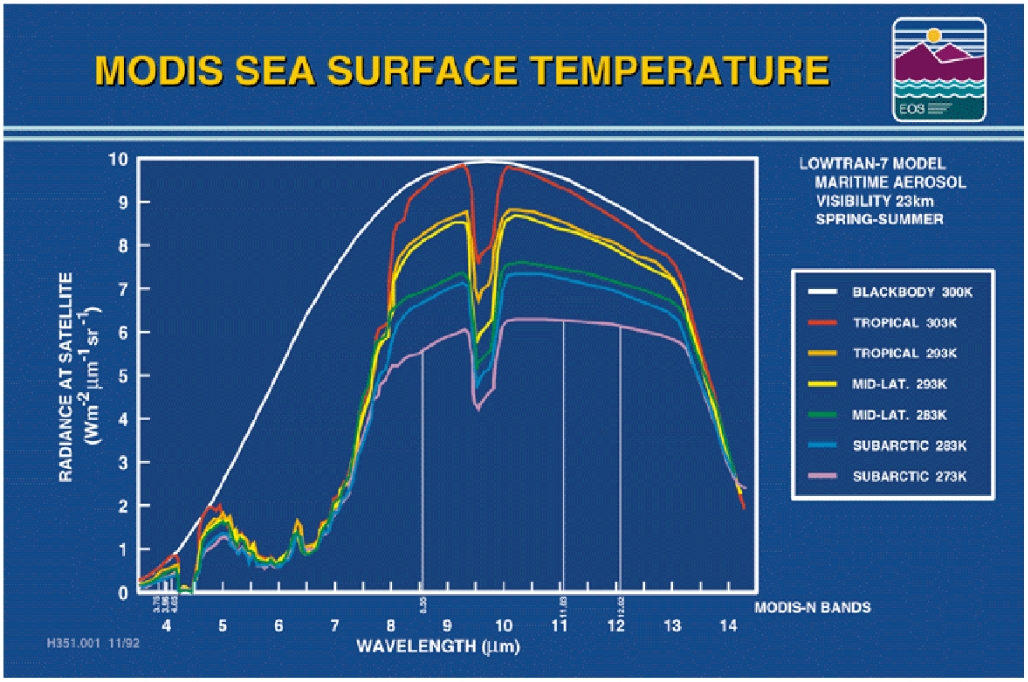



Chlorophyll concentration



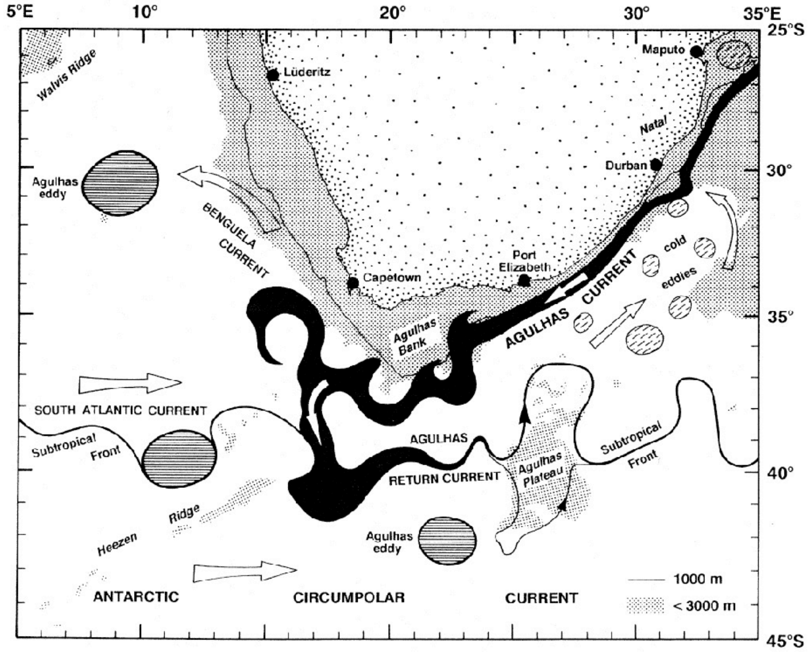
True color

But fine structure in chlorophyll concentration will only be revealed following atmospheric correction.




The infrared radiance received at the satellite depends of the ocean surface temperature and emissivity, and the amount of water vapor in the atmosphere. The height of the curve indicates the surface temperature, while the difference between the 11 and 12 micron radiances indicates the amount of water vapor absoprtion (more at 12 microns than 11 microns).

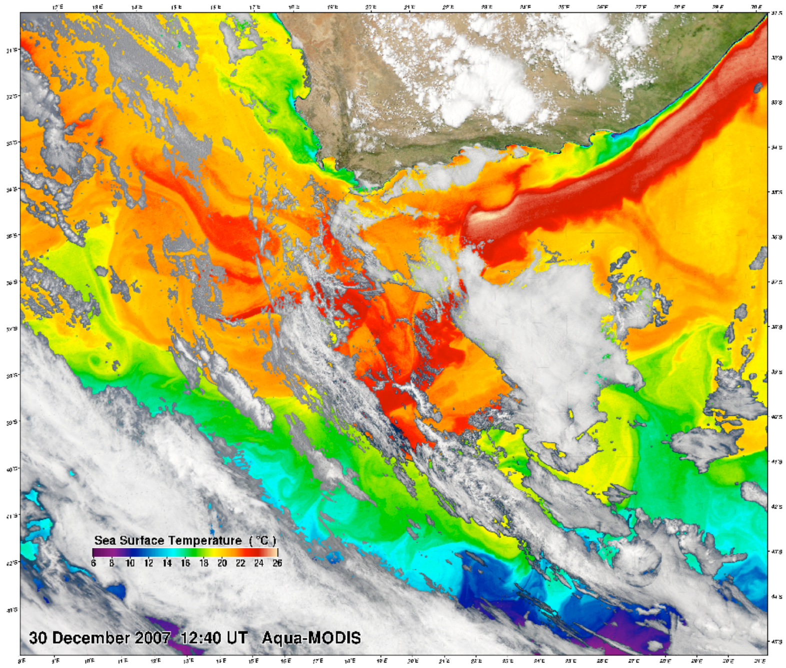
## Ocean currents near Southern Africa




Peterson and Stramma, 1991

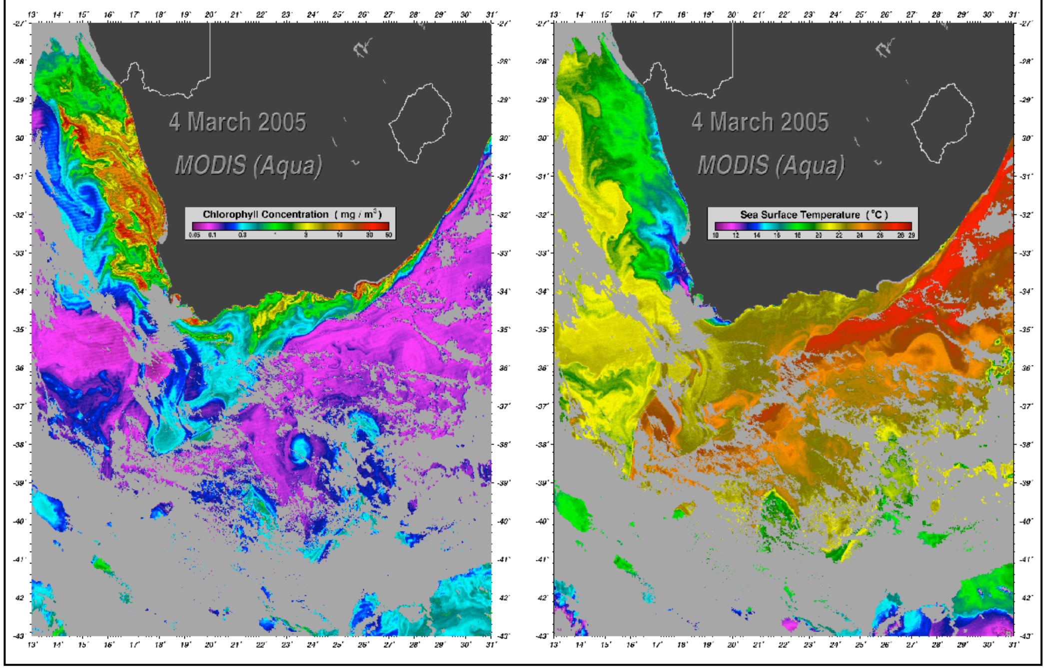
Agulhas Current and Agulhas Retroflection (south of Africa) and associated currents and eddies (from Peterson and Stramma, 1991; after Lutjeharms and van Ballegooyen, 1988).

# Agulhas & Benguela Currents

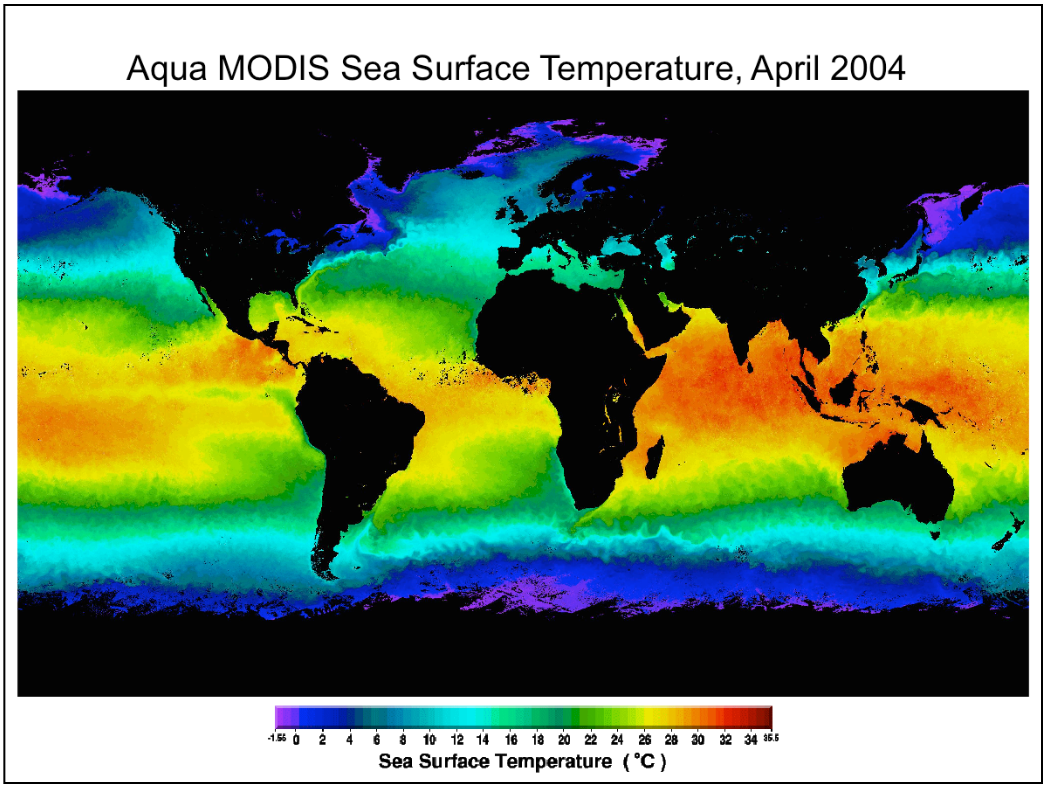



In this SST example from Aqua MODIS, the warm Agulhas current can be seen streaming down the southeast coast of the African continent, bringing warm water from lower latitudes.

# Agulhas & Benguela Currents

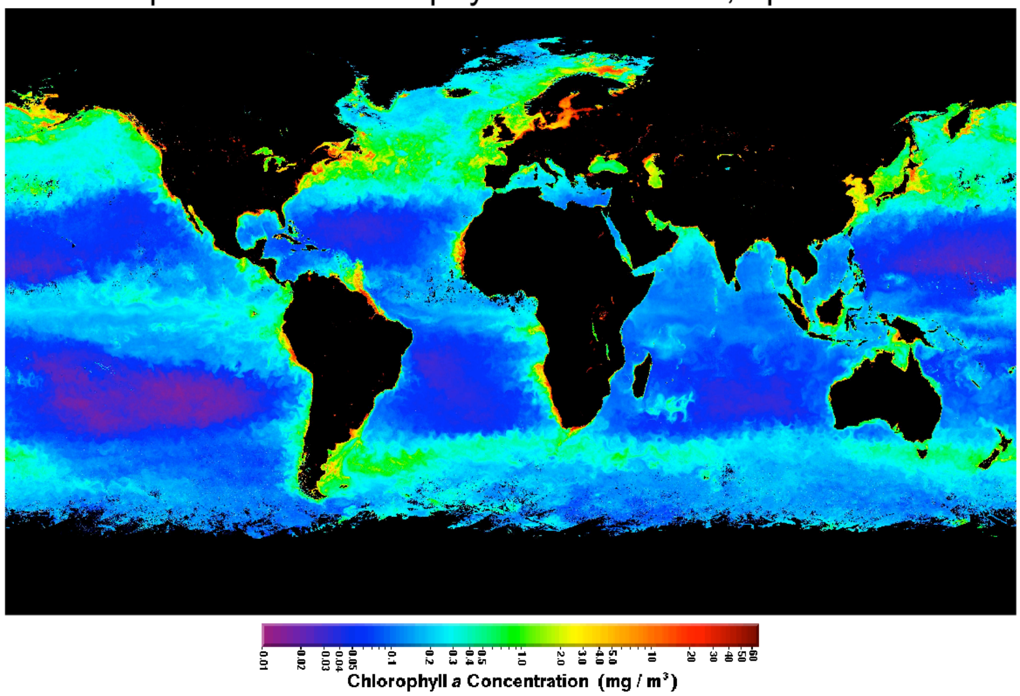



In this sea surface temperature image, the Agulhas Current shows up as a tongue of warm water flowing southwest from the Indian toward the Southern Ocean. The northward flowing Benguela Current appears as a band of lower temperature along the west coast of South Africa.A corresponding chlorophyll image shows that the nutrient-poor, subtropical water in the Agulhas Current supports relatively meager populations of phytoplankton while the coastal upwelling associated with the Benguela Current supports one of the most productive phytoplankton assemblages in the world.




Global composites of sea surface temperature and chlorophyll reveal the relationship between temperature and ocean productivity.

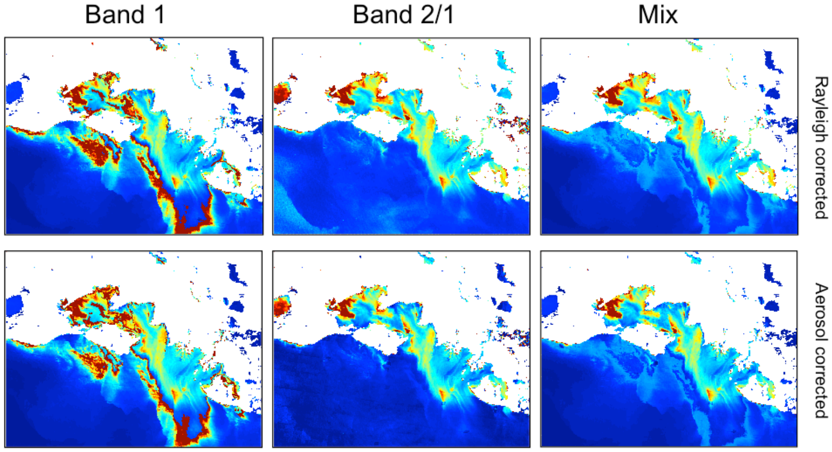
## Aqua MODIS Chlorophyll Concentration, April 2004

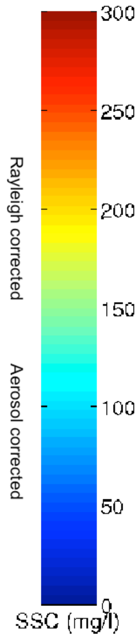


MODIS Terra true color image of the Atchafalaya Bay region of the Gulf Coast for 21st March, 2001.

Suspended sediments cause changes in absoprtion at red wavelengths.

# Suspended Sediment Concentration



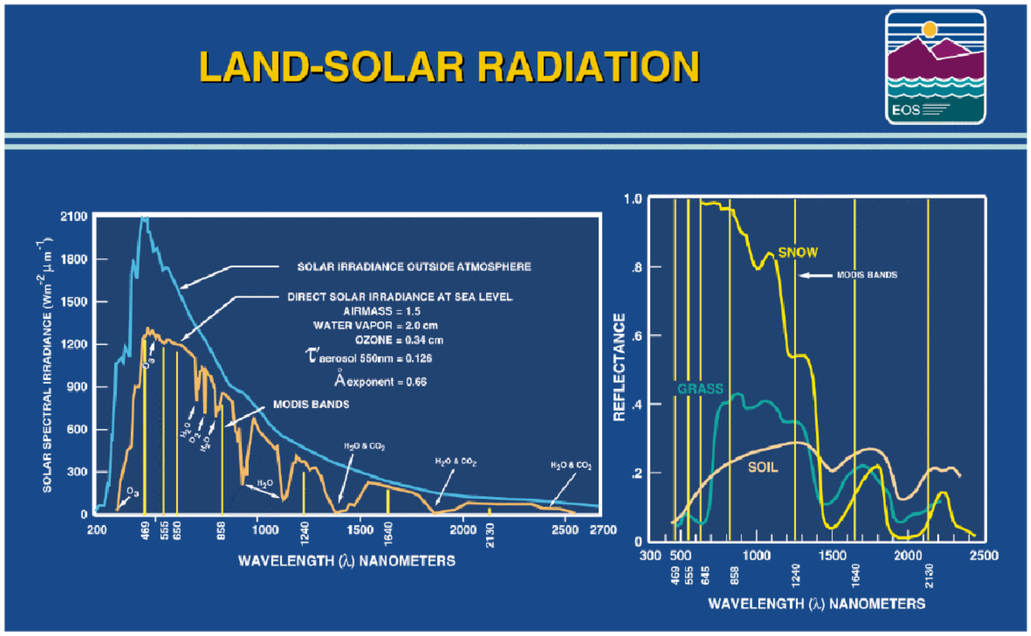

Suspended sediment concentration from $R_{rs}(1)$, from $R_{rs}(2)/R_{rs}(1)$ and from a weighted mix of these. The upper panels give the retrieved SSC for a Rayleigh only atmospheric correction, the lower panels are for an Aerosol + Rayleigh correction. The Band 2/1 ratio method is less sensitive to the atmospheric correction and is applied where high sediment concentrations cause the band 1 method to lose precision. The weighted mix is one approach to fix this.

Suspended sediment is retrieved here using 3 different near-infrared bands, both with and without atmospheric correction. Sediment optical properties are highly variable depending on the river discharge source.

# MODIS Land/Surface Applications

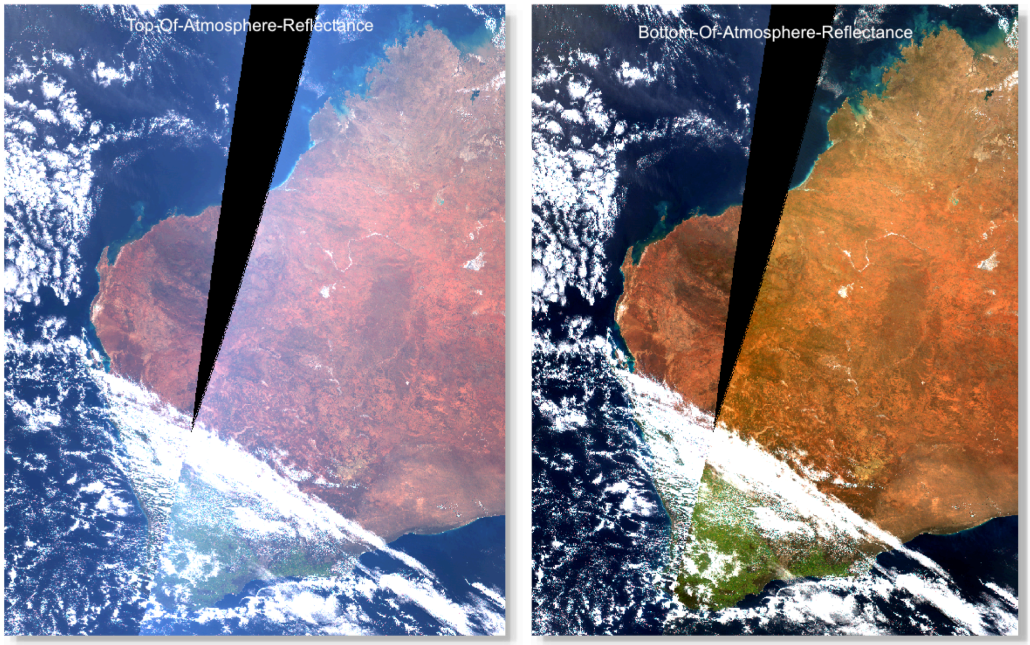
# MODIS Land Products

MOD 09 - Land Surface Reflectance
MOD 10 - Snow Cover
MOD 11 - Land Surface Temperature & Emissivity
MOD 12 - Land Cover/Land Cover Change
MOD 13 - Gridded Vegetation Indices (NDVI & EVI)
MOD 14 - Thermal Anomalies (Fires)
MOD 15 - Leaf Area Index & FPAR
MOD 16 - Evapotranspiration
MOD 17 - Net Photosynthesis and Primary Productivity
MOD 29 - Sea Ice Cover
MOD 43 - Nadir BRDF Adjusted Reflectance
MOD 44 - Vegetation Cover Conversion




At visible and near infrared wavelengths, surface type has a large impact on the sensed radiance and reflectance. Vegetation reflectance is low for wavelengths below 0.7 microns, and then sharply increases. Likewise, snow reflectance is high for wavelengths less than 0.9 microns, but sharply reduced at 1.6 and 2.1 microns. These reflectance changes with wavelength can be used to infer the properties of the land surface.

Atmospheric scattering is removed to retrieve surface properties

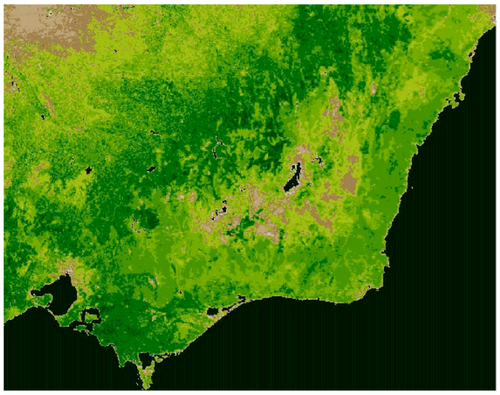



Terra MODIS 09/09/2003 01:27UTC 03:04UTC

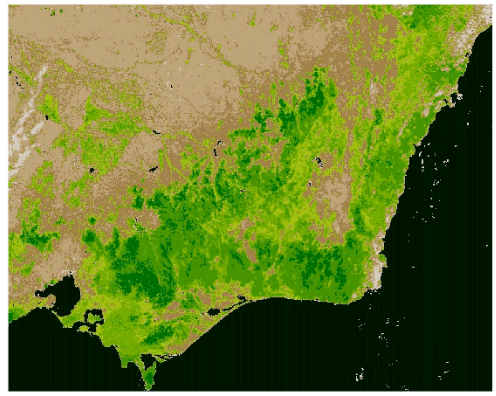
Even though surface features contribute a large part of the signal sensed over land, the contribution of the atmosphere must be removed to provide accurate characterization of the land surface, particularly when trying to detect changes (e.g., in vegetation cover).

Normalized Difference
Vegetation Index

South East Australia

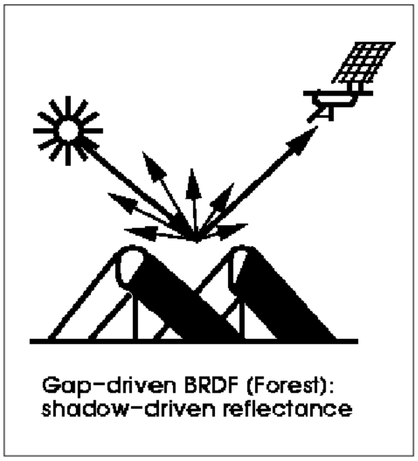


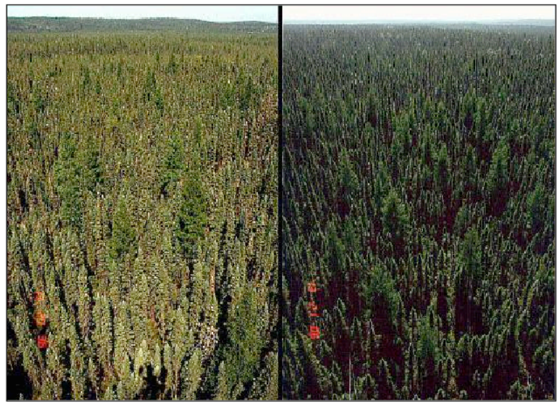
Nov 2003
Spring



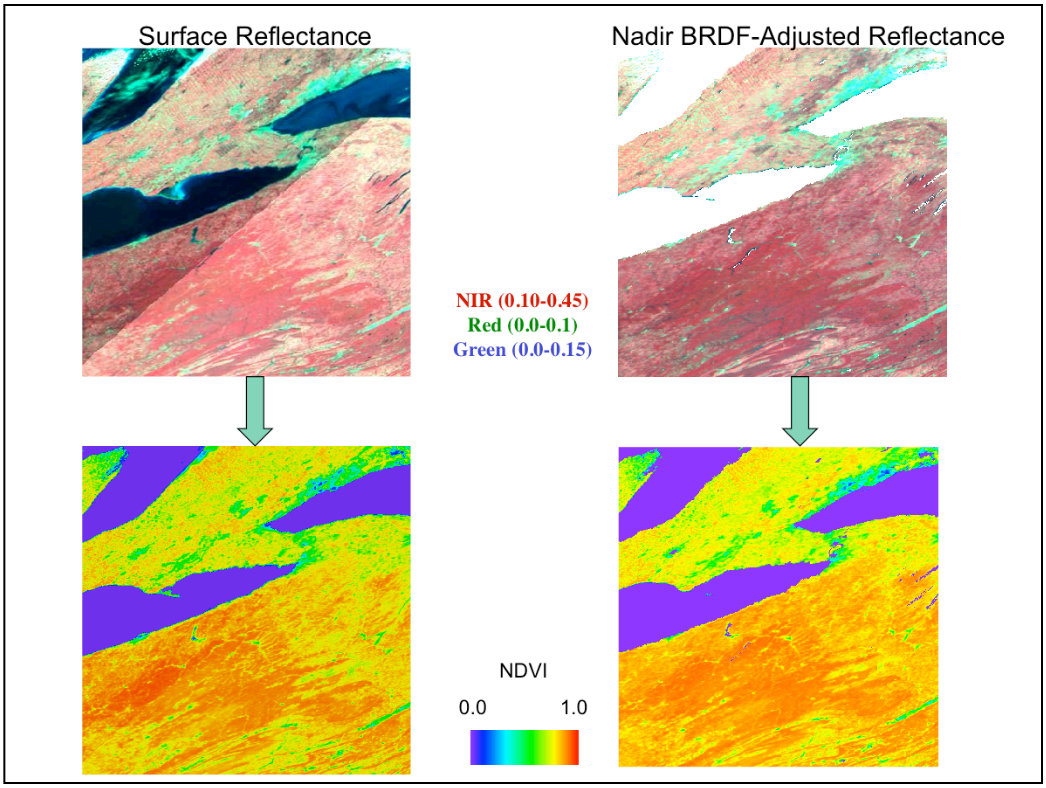
Apr 2004
Fall

# BRDF Example



Black spruce forest in Canada.
Left, looking away from the sun
Right, looking towards the sun




In addition, reflectance changes as a function of viewing angle must be removed for accurate change detection. In the left hand images. This is done by adjusting the reflectance to a nadir view.

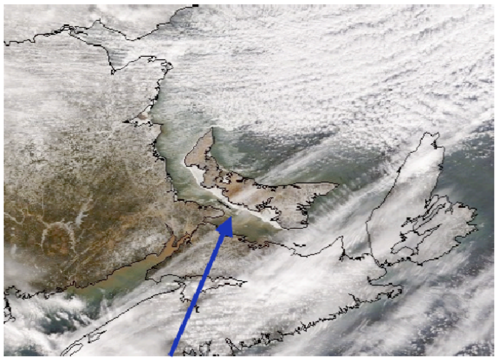
## Canadian Ice Service integrates MODIS into operational data stream for ice monitoring

CIS data suite includes RadarSat and Envisat (SAR); AMSR, QuikScat and SSM/I (microwave); MODIS, OLS, NOAA and GOES (visible images).

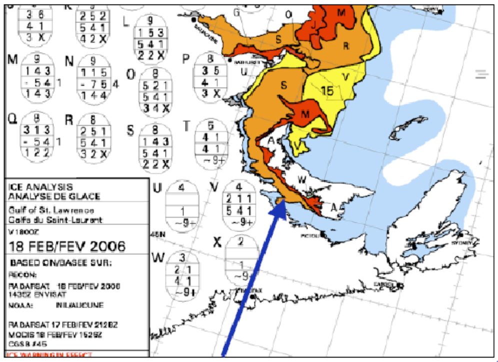
•MODIS supplements SAR data in clear sky conditions.

• 250 meter resolution true color GeoTIFF images are obtained daily from SSEC for Great Lakes, Hudson Bay, Labrador coast, and Gulf of St. Lawrence.

**MODIS helps to define ice boundary along southern Prince Edward Island**

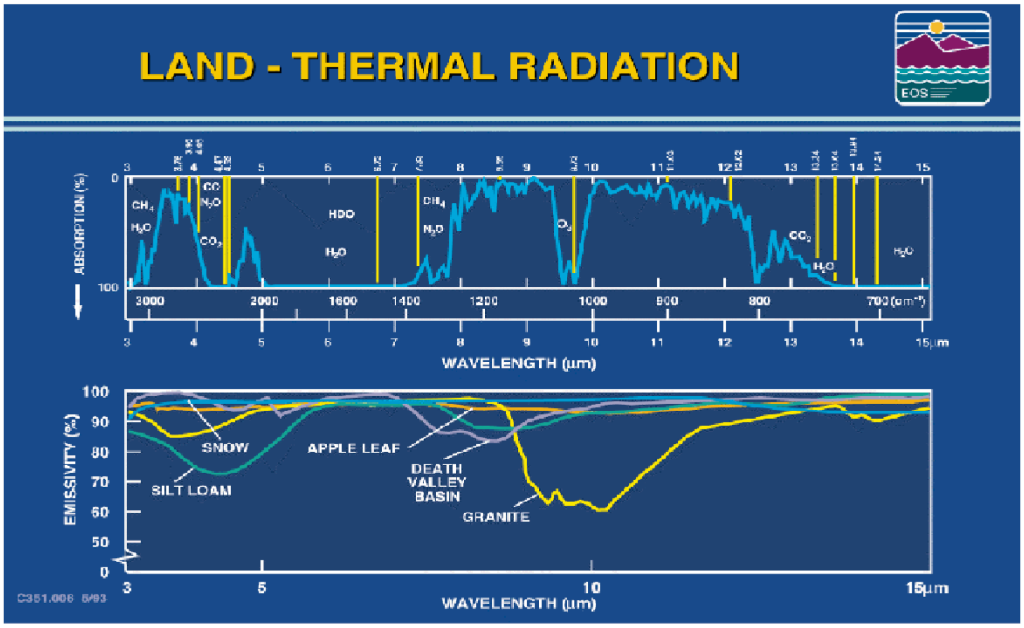


**MODIS DB image 2006/02/18 15:26 UTC**

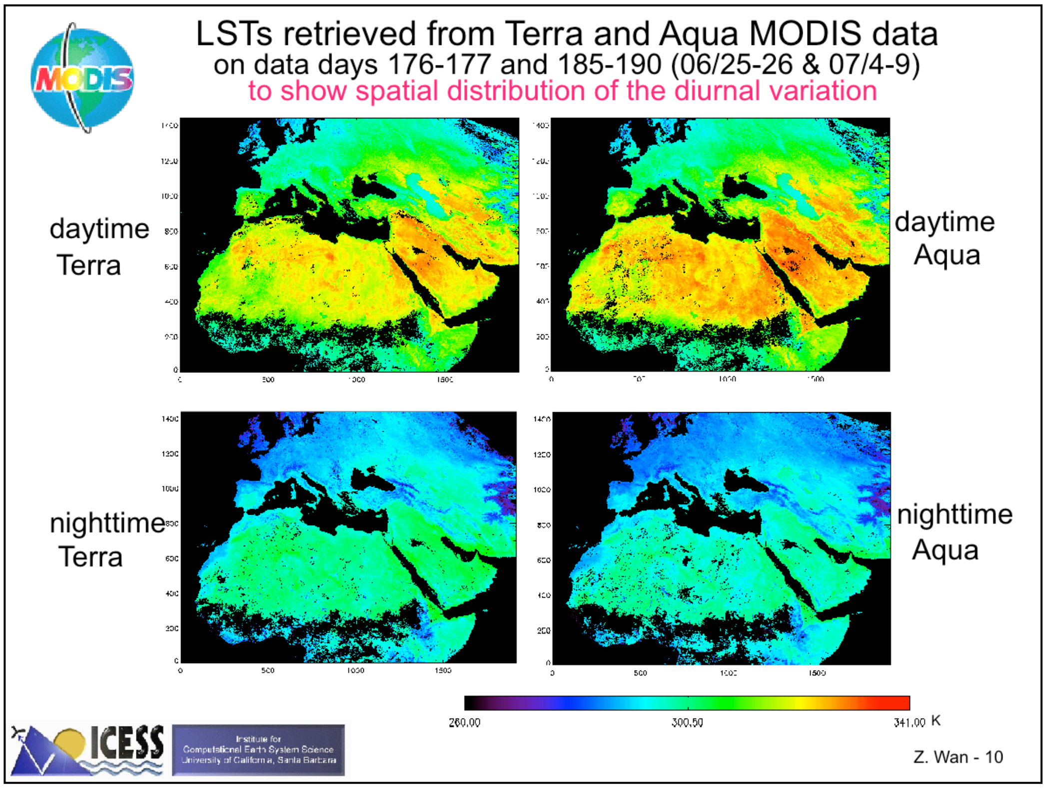



**CIS Ice Analysis 2006/02/18**

he Canadian Ice Service. The operational MODIS algorithm for snow detection uses a normalized difference snow i

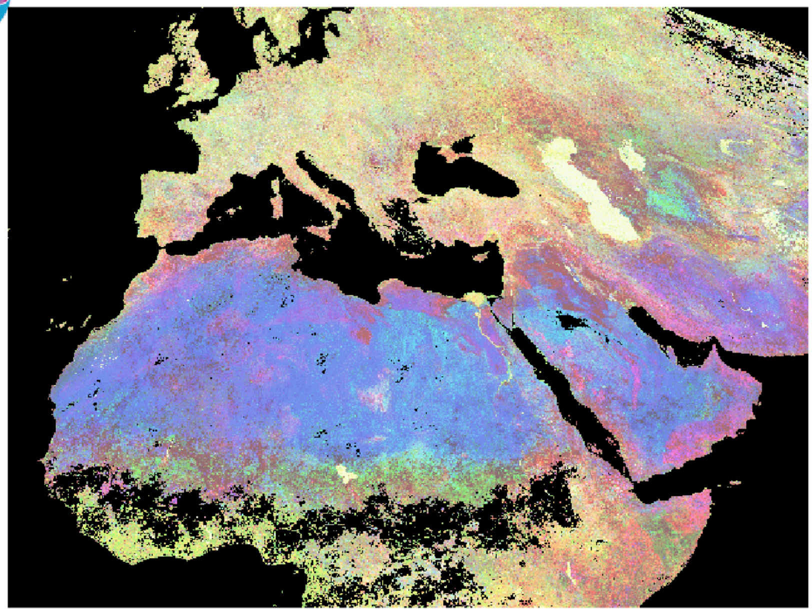



It is important to note that the atmospheric windows are not transparent (there is some moisture absorption of radiation in the 8 to 12 um region) and that the earth surface does not exhibit blackbody behavior. These characteristics must be accounted for when using remote sensing data over land to infer temperature and moisture profiles. They are also important for mapping land surface properties. However the sensed radiance is dominated by surface temperature and emissivity over the land.




In these composites from Terra and Aqua, the diurnal change in land surface temperature can be clearly seen. Note how the LST warms up in the afternoon overpasses from Aqua, and then cools down in the night passes.

## Surface emissivities retrieved by Terra and Aqua MODIS



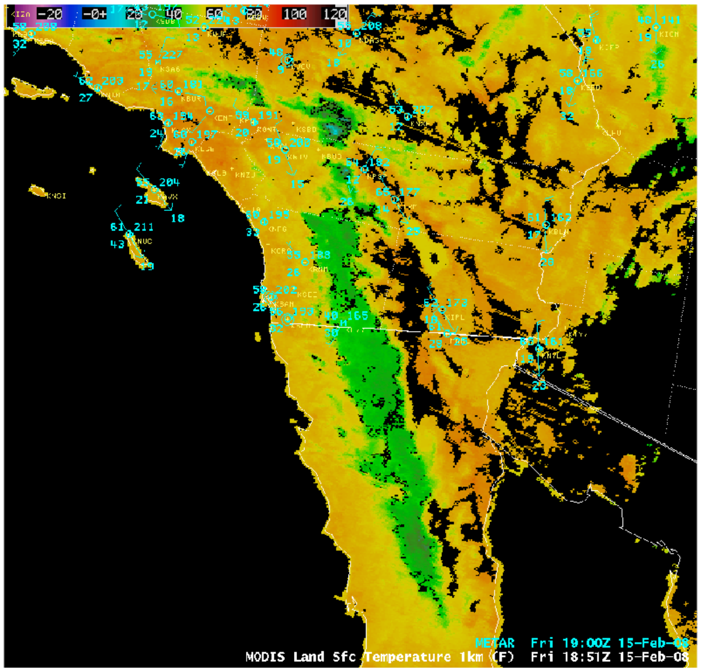
Color composite image with emissivities in bands 29, 31, and 32 as RGB components.

Z. Wan - 11

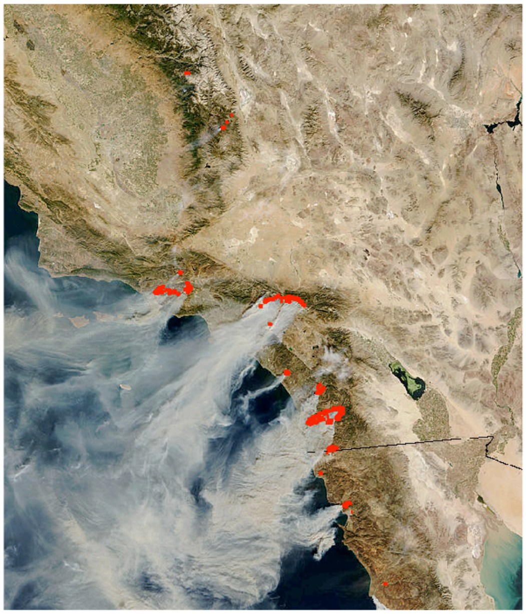
In this RGB image combination of MODIS derived emissivities, the drastic difference in emissivity over North Africa can easily be seen.

# MODIS True Color

# MODIS Land Surface Temperature



# MODIS Active Fire Detection

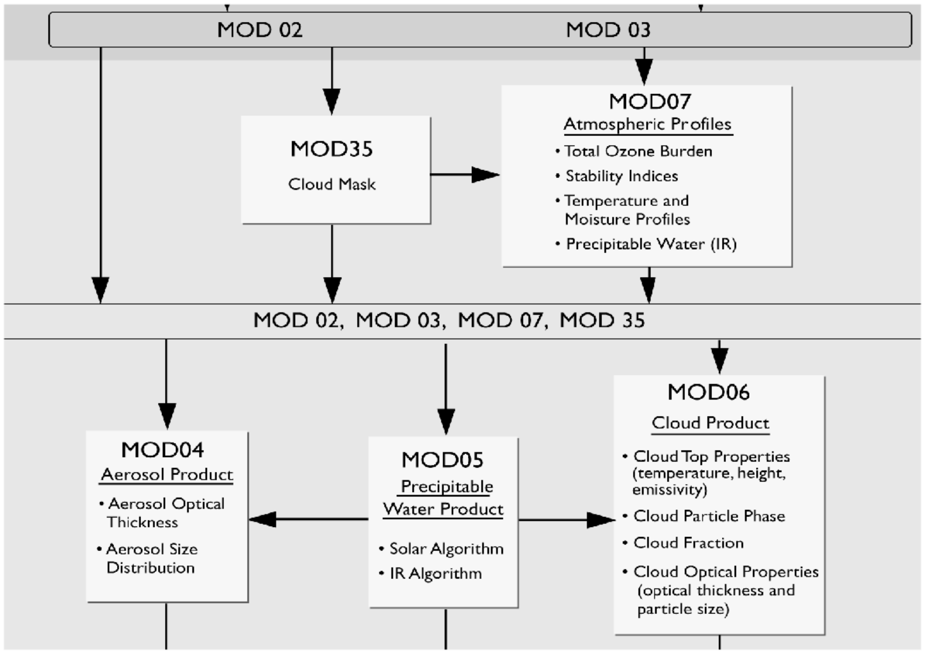


California – 10/26/03

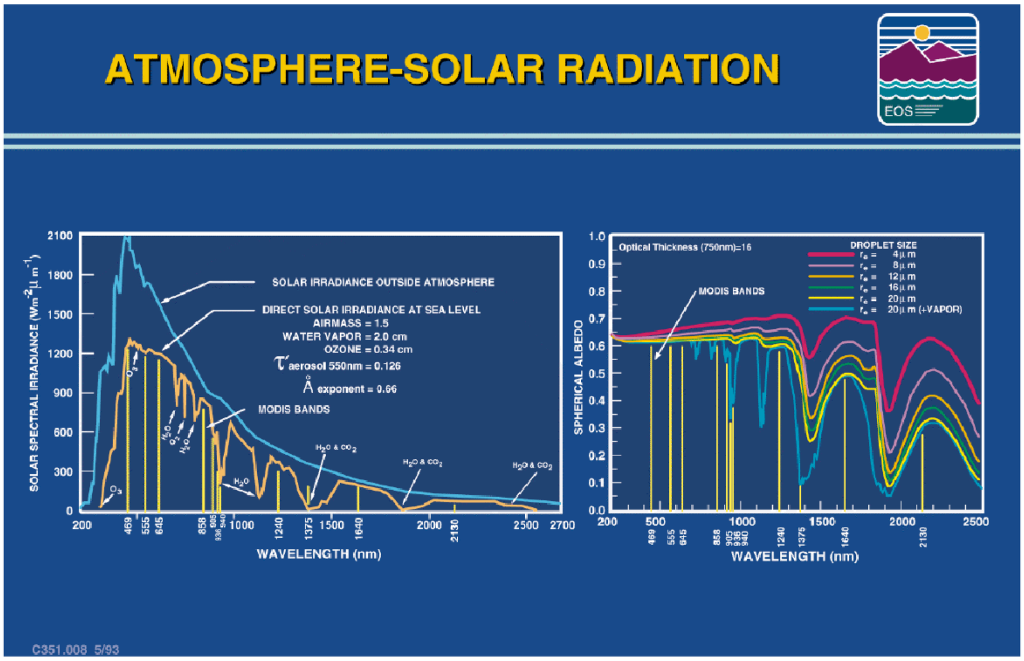
- The algorithm considers the spectral signature (in middle and thermal infrared) of each pixel and compares it to the non-burning surrounding pixels
- The natural variability of the surrounding background is taken into account
- Fewer false detections than traditional threshold-based algorithms
- Sensitive enough to detect small fires

# MODIS Atmosphere Applications

## MODIS Atmosphere Product Flowchart




This flowchart shows the relationships between the MODIS atmosphere products. Note that all of the products depend on the MODIS cloud mask.



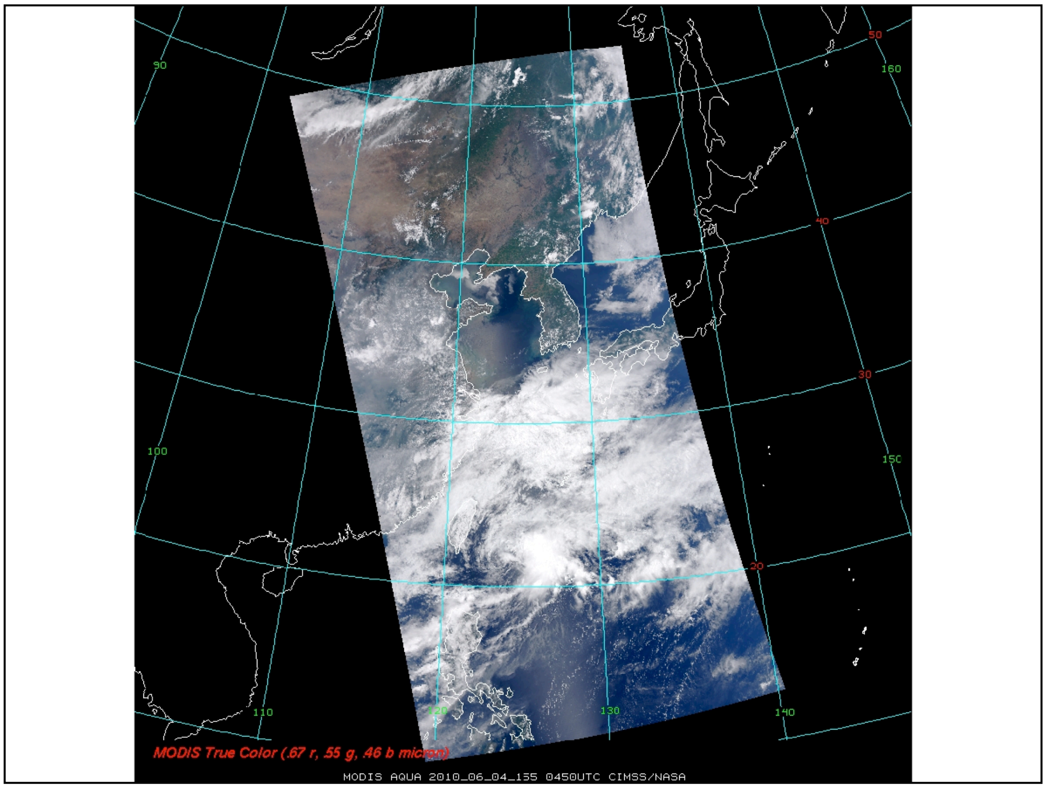

For atmospheric applications, MODIS reflective bands can indicate particle size in clouds. Notice how the spectrum opens with increasing wavelength so that measurements at 2.1 and 0.75 um can be used to discriminate 5 to 30 um particles. Again this is a multispectral application of the MODIS data to reveal cloud and clear sky properties.

# MODIS Cloud Mask

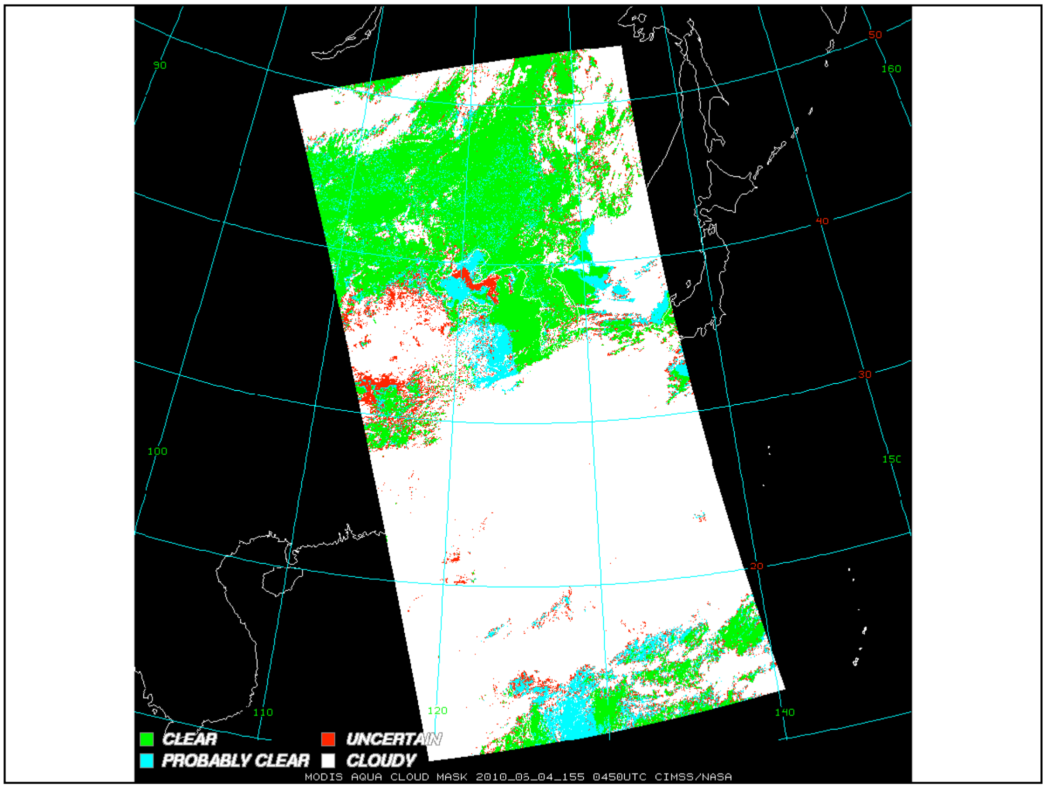
- **1 km** spatial resolution **day & night**, (250 m day)
  - **19 spectral bands (0.55-13.93 µm, incl. 1.38 µm)**
  - 11 individual spectral tests (function of 5 processing paths) combined for initial pixel confidence of clear
  - temporal consistency test over ocean, desert (nighttime); spatial variability test over ocean
- **48 bits per pixel** including individual test results and processing path
- **Result classes are**

  **Confident Clear, Probably Clear, Uncertain, Cloudy**

The MODIS Cloud Mask detects the presence of cloud in each field of view (pixel). Reflected solar (daytime) and thermal emissive bands (day/night) are used in combination, depending on the surface type, to indicate the likelihood of cloud. Note that there are four result classes, not just a binary clear/cloudy decision.


MODIS True Color (.67 r, .55 g, .46 b micron)
MODIS AQUA 2010_06_04_155 0450UTC CIMSS/NASA

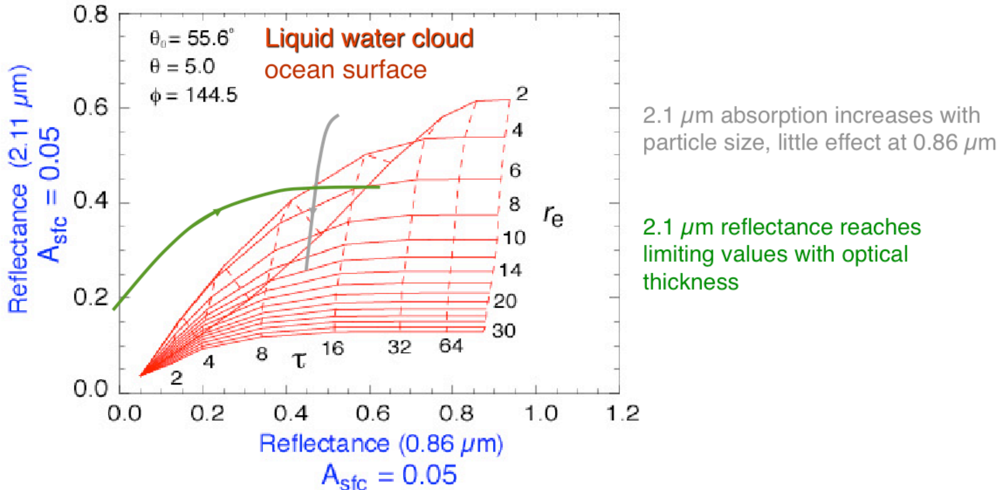
This is



CLEAR
UNCERTAIN
PROBABLY CLEAR
CLOUDY
MODIS AQUA CLOUD MASK 2010_05_04_155 0450UTC CIMSS/NASA

## MODIS Cloud Optical Properties

MODIS observations at 0.66, 0.86, 1.6, 2.1, and 3.7 microns contain information about the cloud droplet size and optical properties.

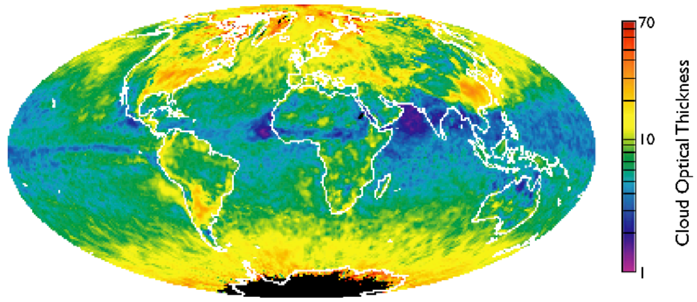



S. Platnick, ISSAOS '02

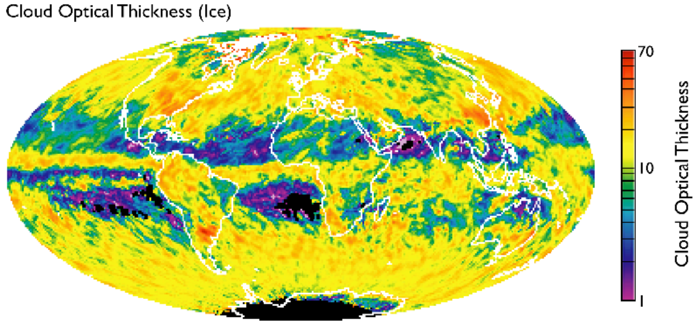
In this example, a liquid water cloud over and ocean surface is simulated, and the reflectance at 1.6 microns vs. the reflectance at 0.86 microns is plotted for a range of cloud droplet sizes (effective radius). It can be seen that for small droplets, there is good sensitivity at 2.1 microns for a range of optical depths. However as the cloud droplet size increases, there is less sensitivity to changes in optical depth.

# Monthly Mean Cloud Optical Thickness

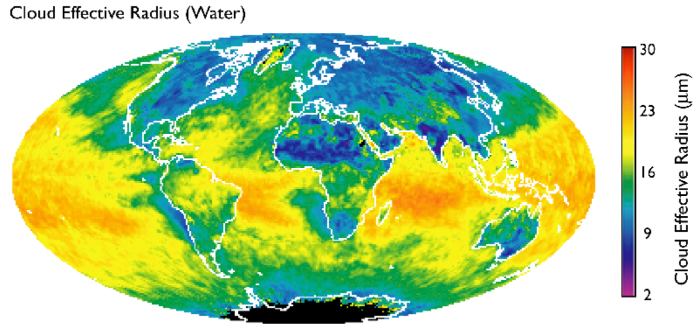
Cloud Optical Thickness (Water)

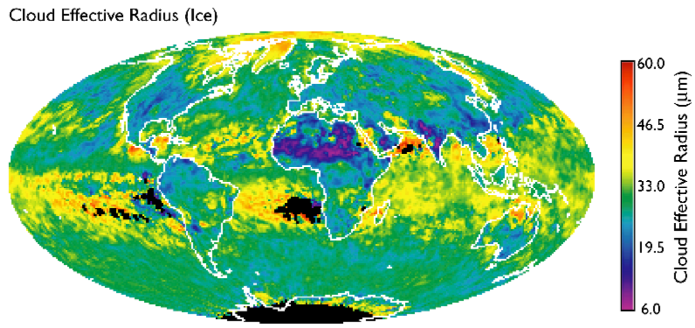



Cloud Optical Thickness (Ice)



# Monthly Mean Cloud Effective Radius

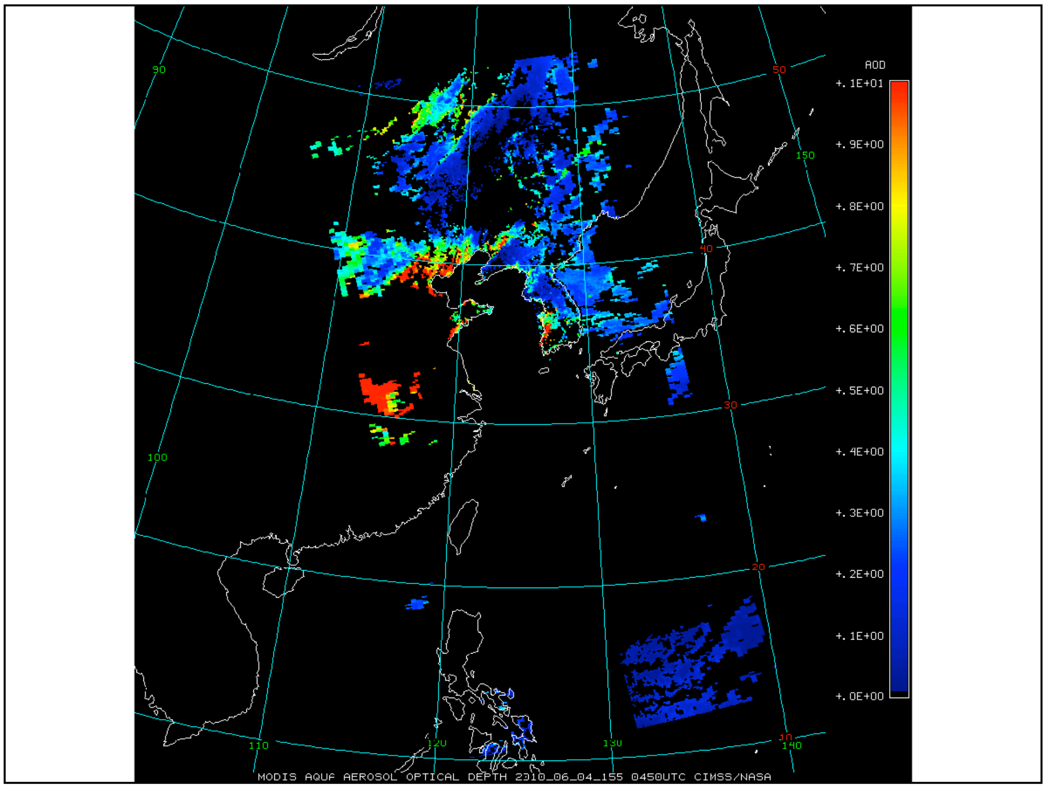


# MODIS Aerosol Product

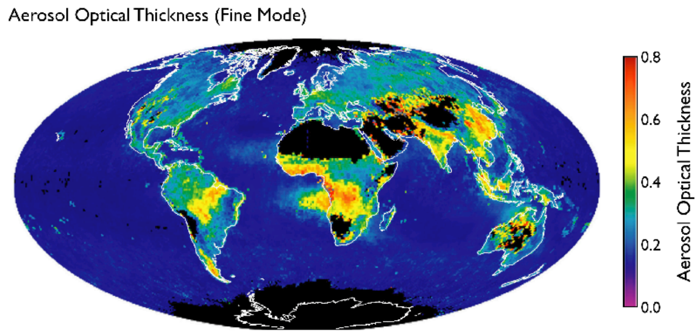
## Y. Kaufman, L. Remer, D. Tanre NASA/GSFC

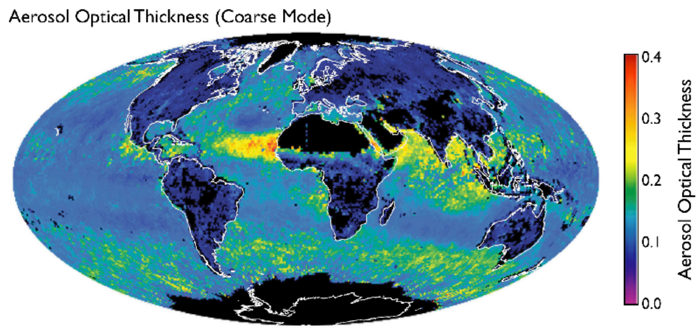
- Separate aerosol retrieval algorithms for land and water
- Algorithm matches observed reflectances to a lookup table of precomputed reflectances for a wide variety of aerosol conditions
- Over land, atmospheric and land surface reflectance are separated by estimating the surface contribution from the measured reflectance at 2.13 microns for dark targets
- Final land products include aerosol optical thickness at 0.47, 0.56, and 0.65 microns at 10-km spatial resolution, and the fine mode (radius 0.6 micron) fraction of the aerosol optical thickness at 0.56 microns
- Over ocean the surface contribution to the total reflectance is small and can be calculated
- Retrieved aerosol products are represented by the best fits between observed reflectance and the lookup table
- Ocean products include aerosol optical thickness at 0.47, 0.56, 0.65, 0.86, 1.24, 1.64, and 2.13 microns at 10-km spatial resolution, effective radius of the particle population, and fine mode fraction



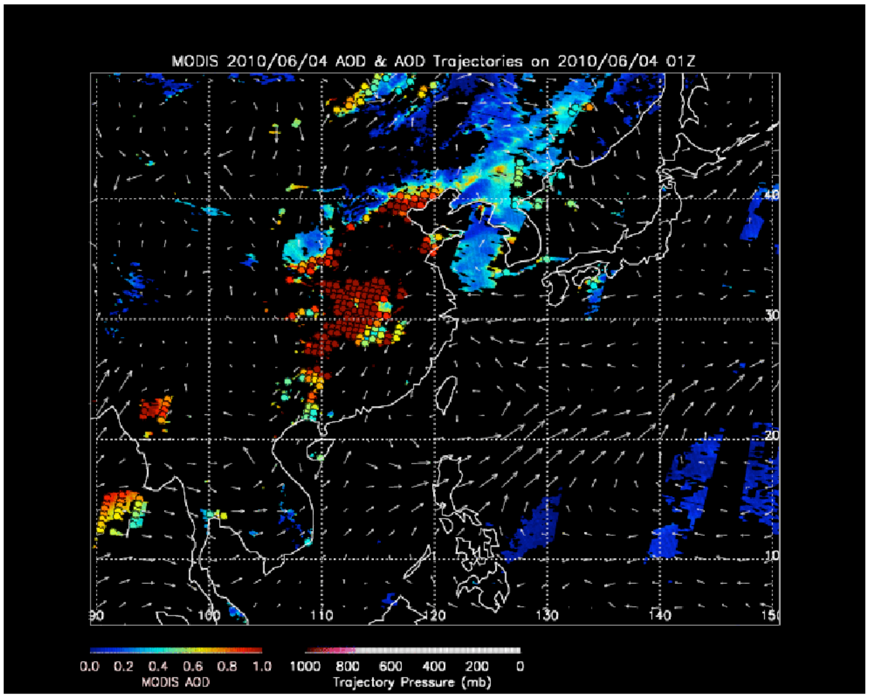

Aqua MODIS Aerosol Optical Depth from ECNU DB station on June 4, 2010

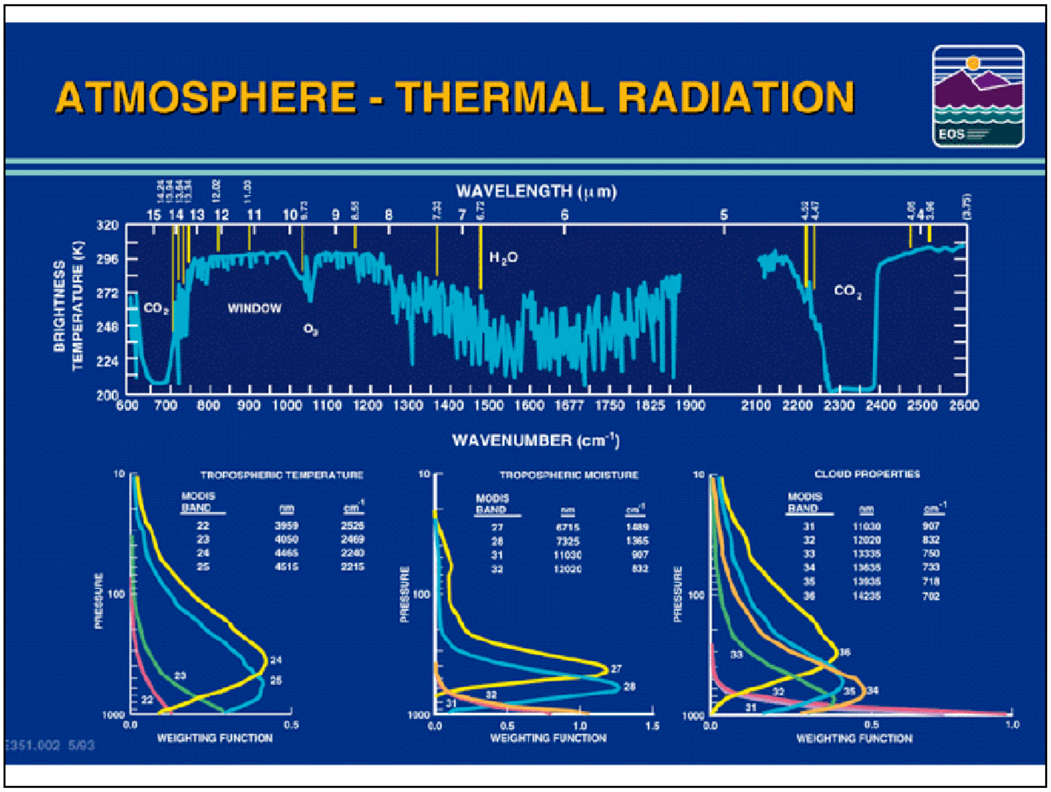
# Monthly Mean Aerosol Optical Thickness



MODIS IDEA-I Product for 2010/06/04

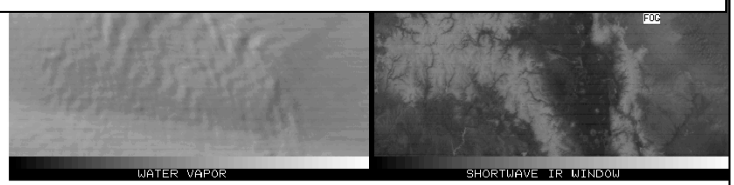





The brightness temperatures of the outgoing radiance observed by an airborne interferometer are shown along with the MODIS infrared spectral bands. The brightness temperatures generally decrease as the center of an absorption band is approached. This decrease is associated with the decrease of tropospheric temperature with altitude. Near about 690 $cm^{-1}$, the temperature shows a minimum which is related to the colder tropopause. On the basis of the sounding principle already discussed, the MODIS team selected a set of sounding wave numbers such that a temperature layers in the troposphere can be described. The arrows indicate the selection. The associated weighting functions are also shown revealing that the radiation is coming from broad overlapping layers, helping to confound the inversion problem from multispectral radiance measurements to temperature profile.

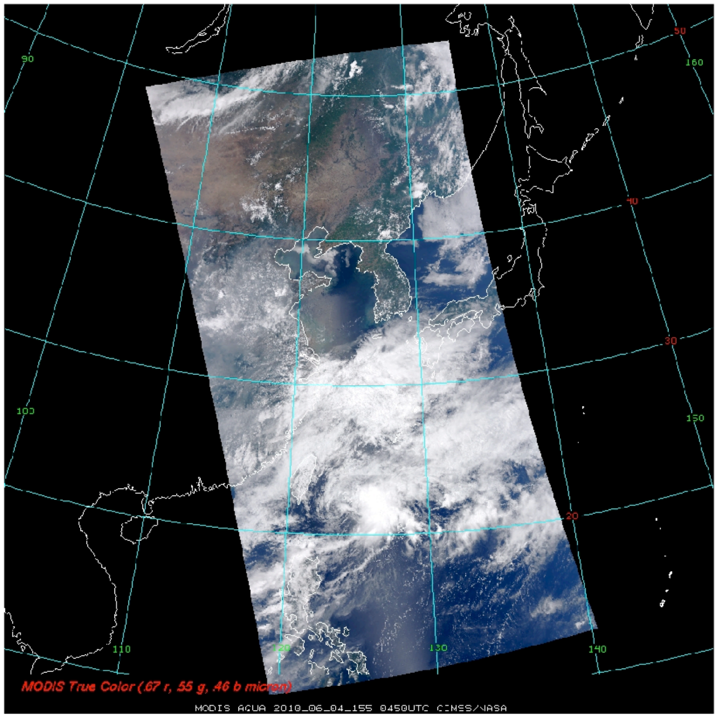
# Four Panel Zoom of Cloud-Free Orographic Waves revealed in Water Vapor Imagery

These events (mountain waves and gravity waves were detected in clear skies.



## Aqua MODIS True Color Image: 2010/06/04

Note land, ocean, and sunglint surfaces, and mix of high clouds, low clouds, and fog.




The MODIS Cloud Top Pressure product is generated by a physical algorithm based on ratios of radiance observations in the longwave infrared, where the atmosphere becomes more opaque at longer wavelengths due to $CO_2$ absorption.

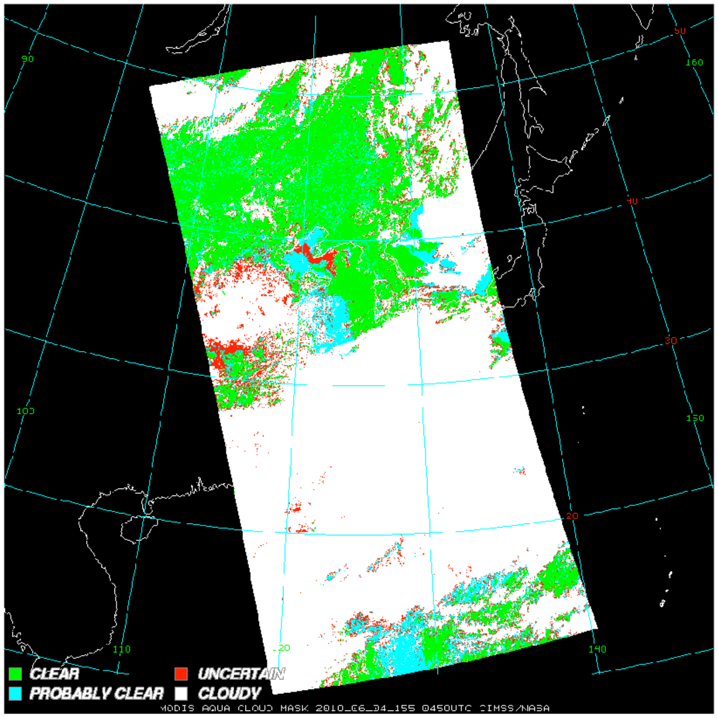
## MODIS Cloud Mask Product (MOD35)

Clear and Cloudy Sky (everywhere)

Day/Night

1 km resolution

Fuzzy logic spectral tests




The MODIS Cloud Top Pressure product is generated by a physical algorithm based on ratios of radiance observations in the longwave infrared, where the atmosphere becomes more opaque at longer wavelengths due to $CO_2$ absorption.

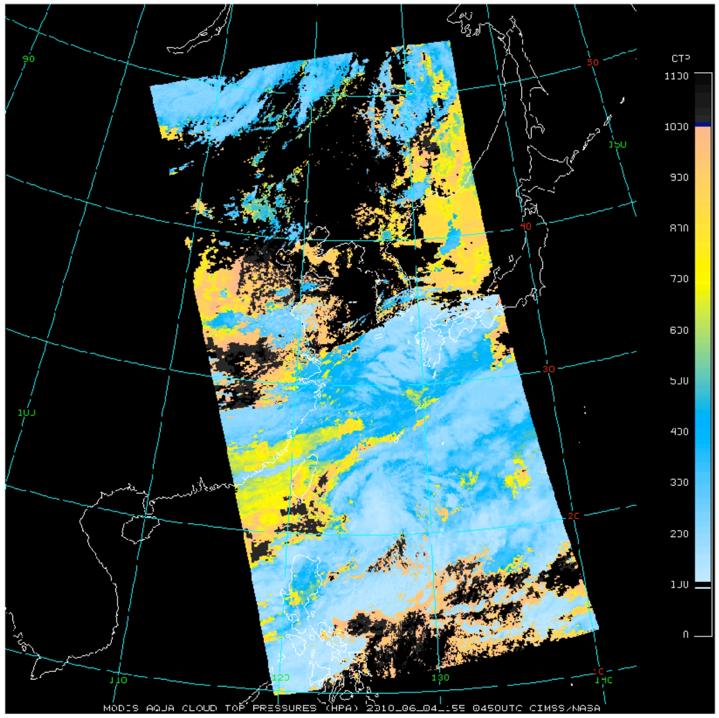
# MODIS Cloud Top Pressure Product (MOD06)

Cloudy Sky Only

Day/Night

5 x 5 km resolution

$CO_2$ slicing algorithm




The MODIS Cloud Top Pressure product is generated by a physical algorithm based on ratios of radiance observations in the longwave infrared, where the atmosphere becomes more opaque at longer wavelengths due to CO2 absorption.

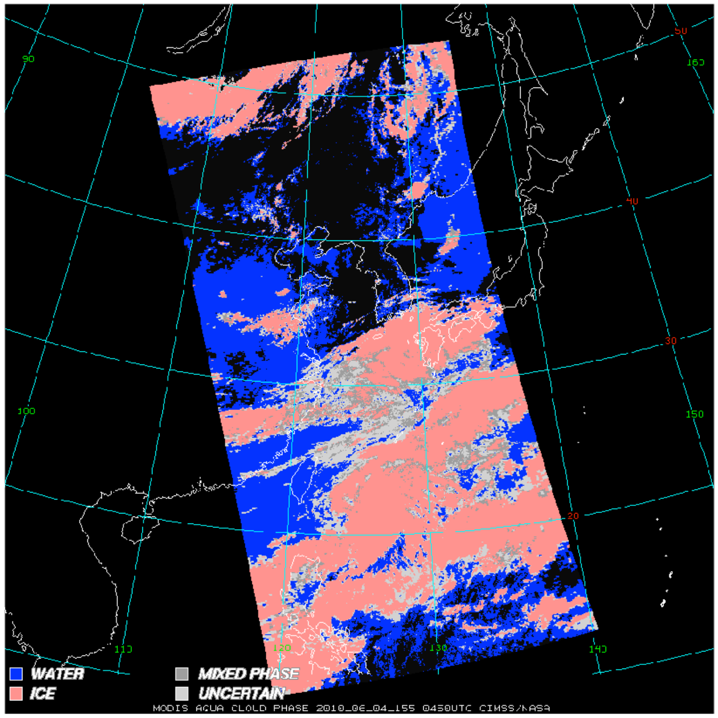
## MODIS Cloud Phase Product (MOD06)

Cloudy Sky Only

Day/Night

5 x 5 km resolution

Threshold Algorithm




The MODIS Cloud Phase product is generated by a threshold algorithm based on modeled effects of cloud phase on 8.5, 11, and 12 micron brightness temperatures, where the change in refractive index of ice vs. water creates larger brightness temperature differences.

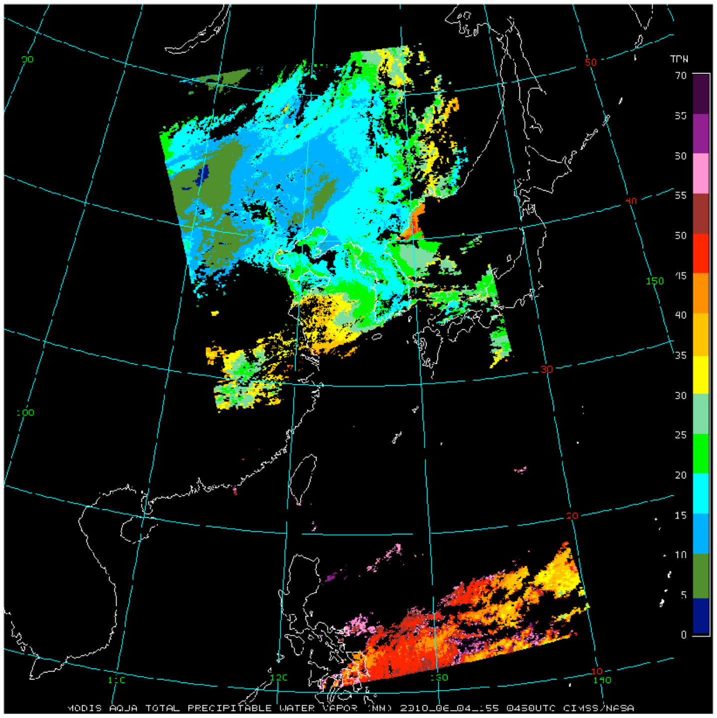
# MODIS Water Vapor Product (MOD07)

Clear Sky Only

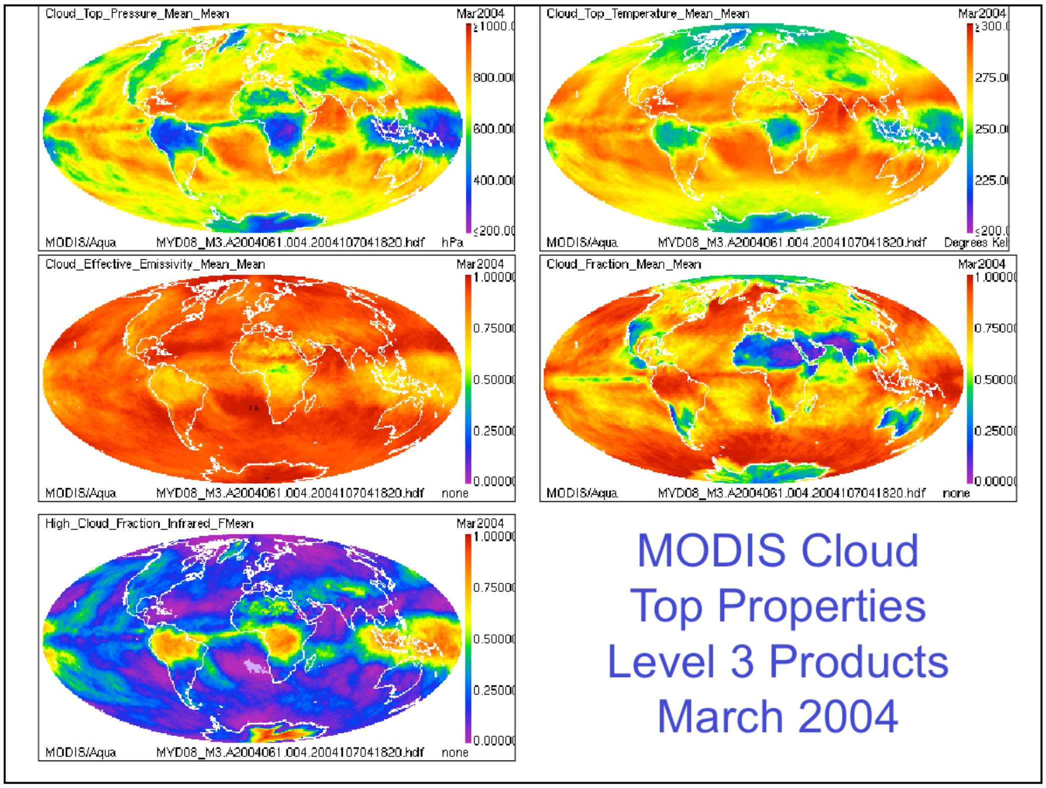
Day/Night

5 x 5 km
resolution

Statistical
Algorithm




The MODIS infrared total water vapor retrieval is done by a statistical algorithm that has been trained by a global database of quality controlled radiosondes.




Global statistics of MODIS cloud properties help to reveal information about the presence of optically thick high and low clouds, and also the presence of optically thin high clouds, both of which may be important indicators of climate change. The scientific community is still debating whether there are long term changes in cloudiness.

# End of Part One