Spectral Bands And Their Applications

Lecture B of HPTE

Focus

- Major focus of Lecture B is visible, near infrared and infrared data since those are the types data most NMHSs receive on a routine basis
- At the end there is a section on microwave data and products as well as active sensors
  - For in depth information concerning the microwave portion of the spectrum and its applications see the lectures in the tutorials portion of the Virtual Resource Library

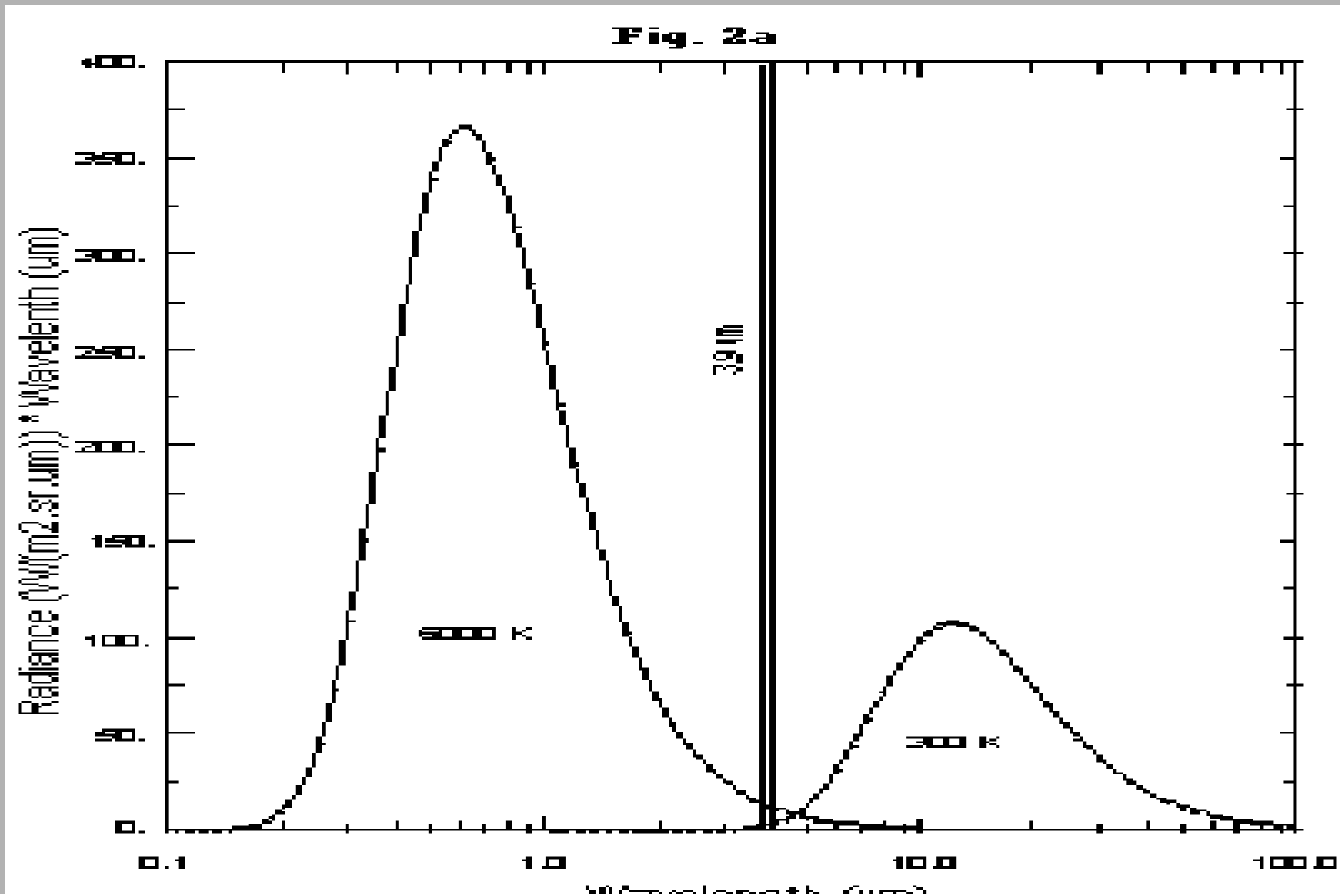
Goals

- Understand the difference between visible, near infrared and infrared radiation (channels)
  - Understand the influence of surface and atmospheric properties on what we view with a satellite sensor
- Understand the basic underlying principals behind channel selection and the factors that influence channel selection
- Understand what information can be obtained using the various satellite channels available from operational and research satellites
- Understand how to interpret data from various channels individually and in combination with other channels
- Understand the difference between multi-spectral and hyper-spectral data

Resources

- Information from Virtual Resource Library
  - Text, several tutorials and PowerPoint lectures that together cover this topic in detail
  - Links to imagery and products from the VRL as well as Sponsor and Center of Excellence sites
- Lecture notes accompanying presentation
- Hydra lab for inspection and manipulation of multispectral data

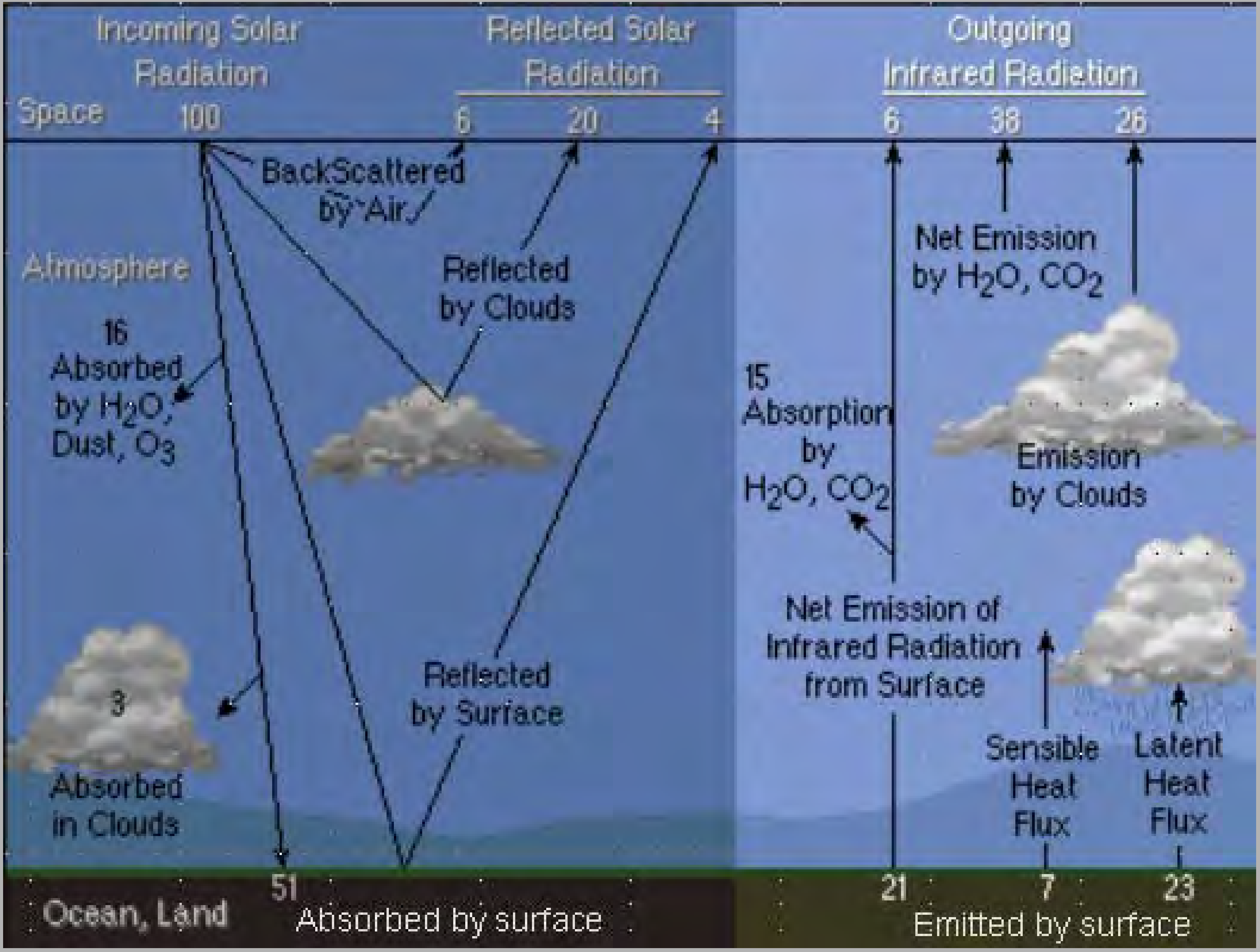
Radiance versus wavelength for blackbodies at 6000 K (sun) and 300 K (earth), notice 3.9 µm region



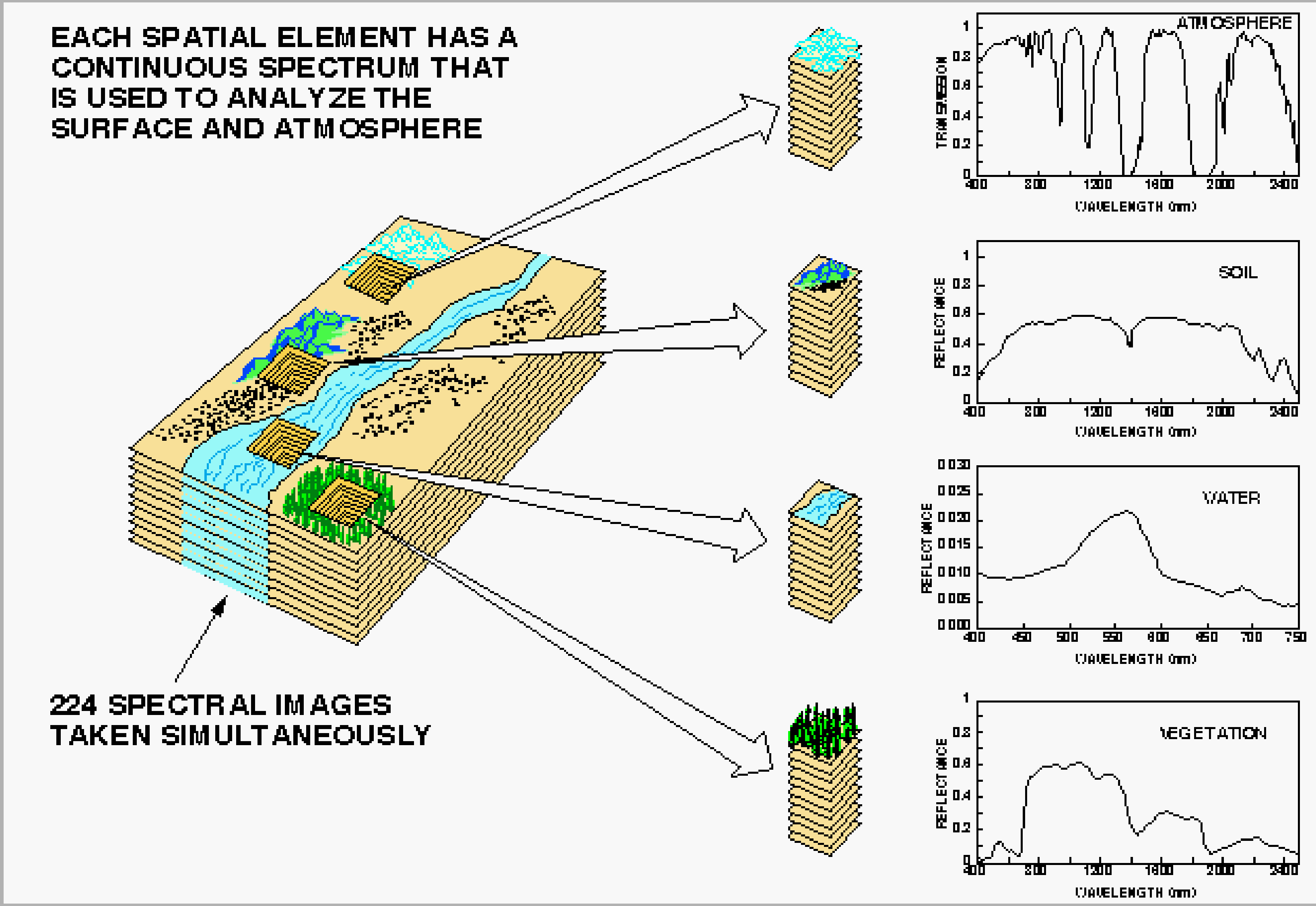
Today's satellites measure energy in spectral regions ranging from the visible portion of the electromagnetic spectrum to the far infrared and into the microwave region

At visible wavelengths, that energy is only reflected solar radiation; at far infrared wavelengths, that energy is only emitted terrestrial radiation. However for short wavelength infrared channels near 3.9 um energy measured by the satellite can be a mixture of reflected solar and earth emitted radiation during daytime.

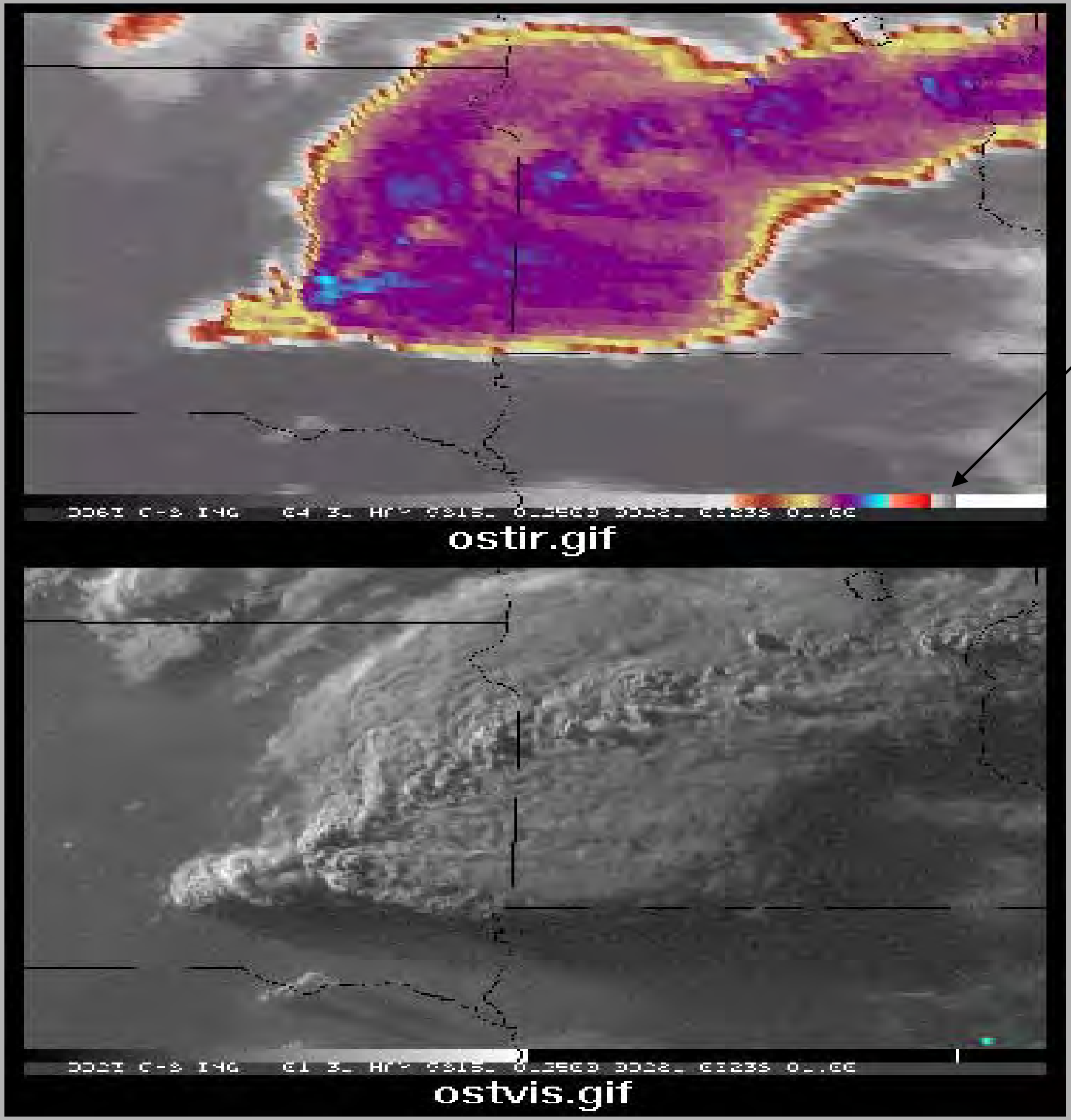
Surface and atmospheric properties effect what we view with a satellite sensor (solar left, emitted IR right)



Today we're digital (brought forth in Lecture A) AND MULTISPECTRAL



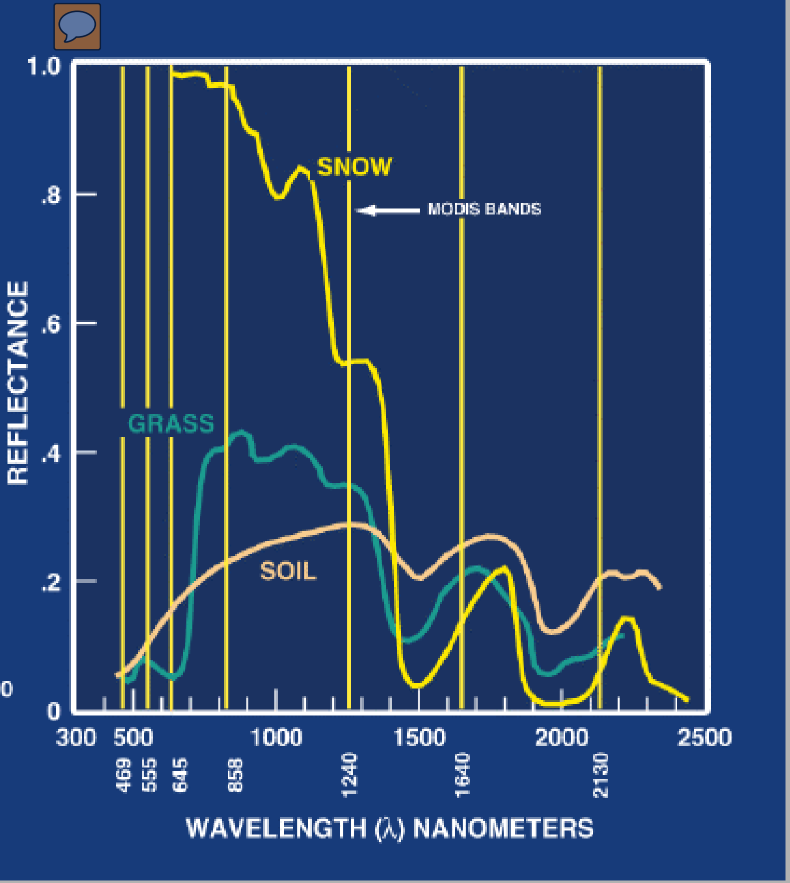
One advantage of digital data: Image Enhancement: Helping the eye detect



Color bar with warm on left and cold on right

Overshooting thunderstorm tops and cloud top temperature

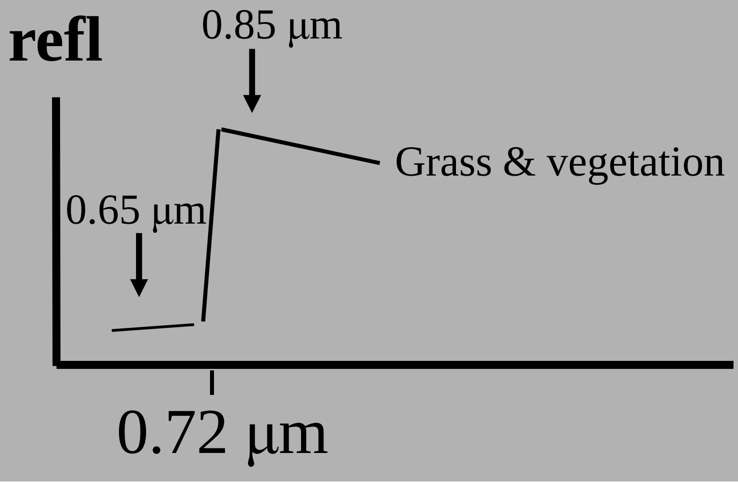
Investigating with Multi-spectral Combinations



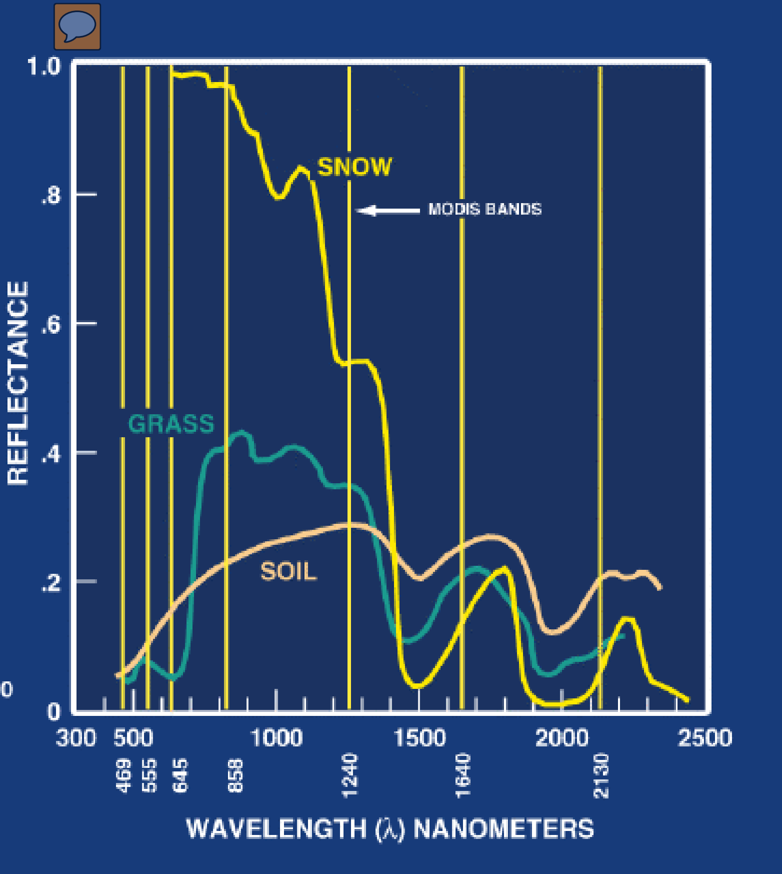
Being digital and multispectral allows for identification of features by taking advantage of their spectral signatures

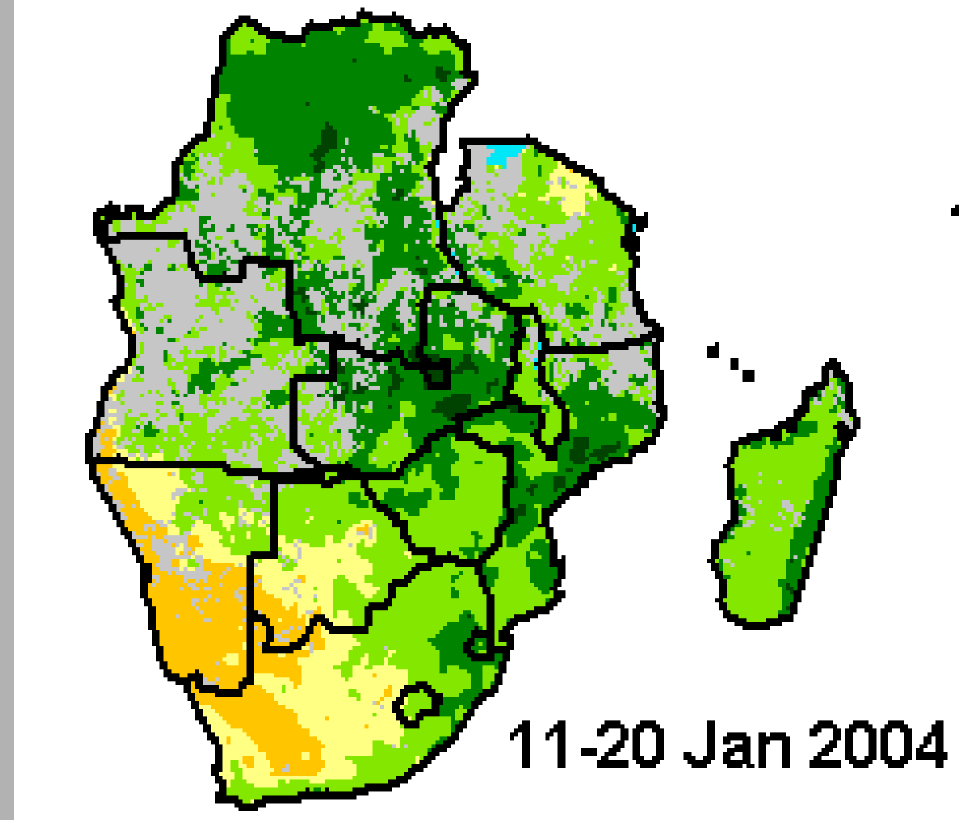
Given the spectral response of a surface or atmospheric feature select a part of the spectrum where the reflectance or absorption changes with wavelength

e.g. reflection from grass and vegetation



If 0.65 µm and 0.85 µm channels see the same reflectance then surface viewed is not vegetation;
if 0.85 µm sees considerably higher reflectance than 0.65 µm then surface might be vegetation





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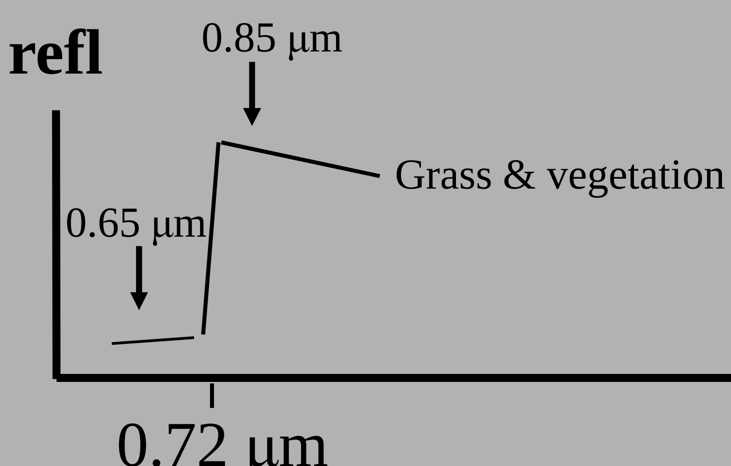

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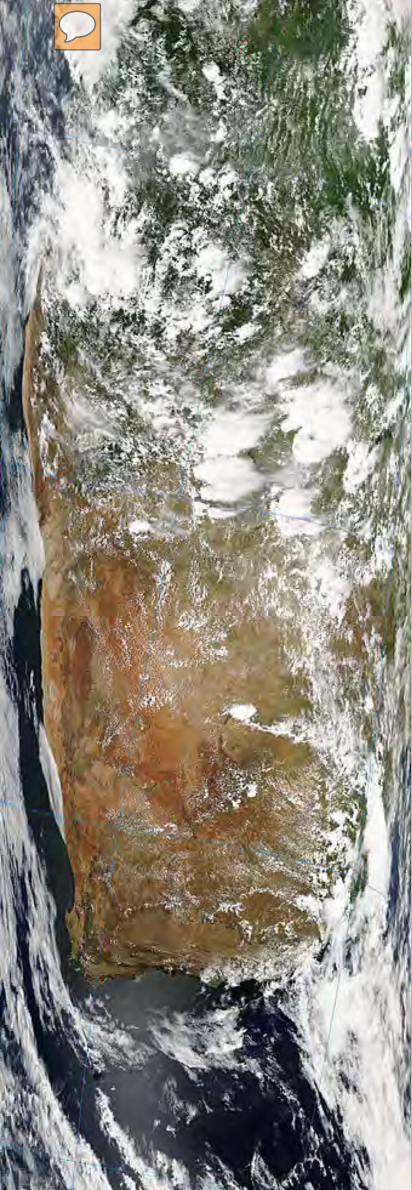
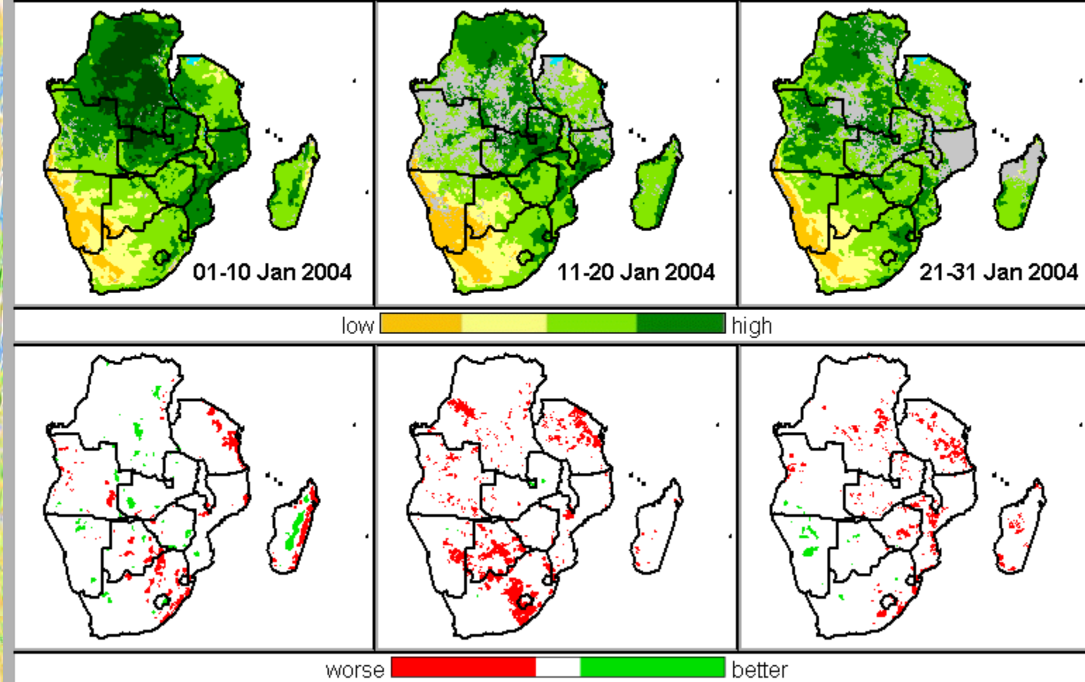
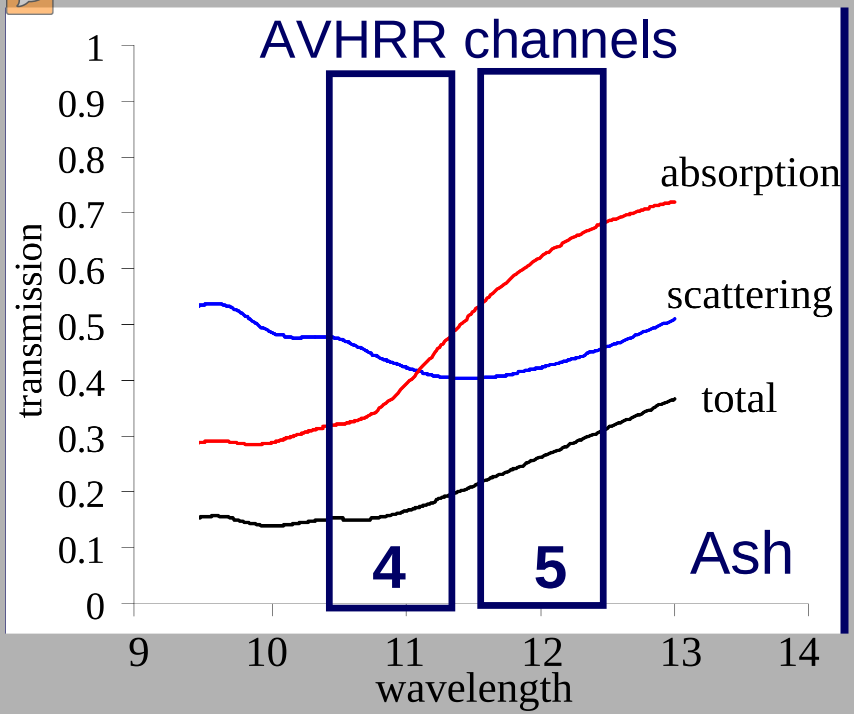




Many satellites have channels to derive vegetation information as well as land surface characteristics. Well known are SPOT and LANDSAT. Above are shown vegetation and change maps for the area in the previous slide. To the left is a 1 km resolution vegetation map (right) and true color image (left) of the same region, taken from 12:10-12:25 UTC by Aqua's MODIS. Note that the AVHRR and MODIS examples are not the same scale or map projection.

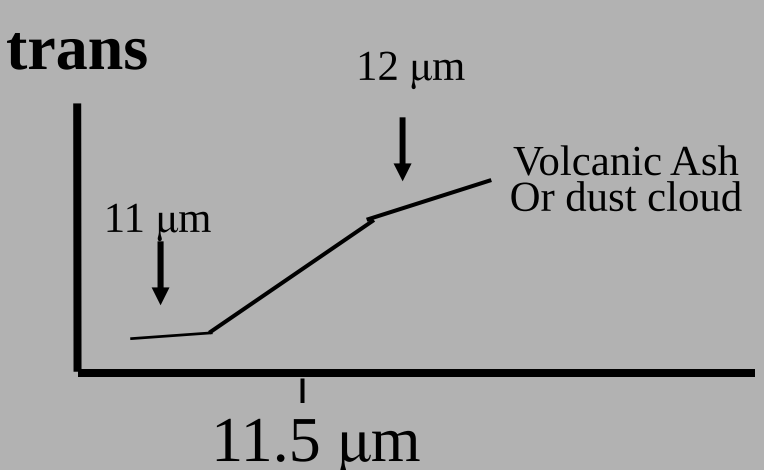


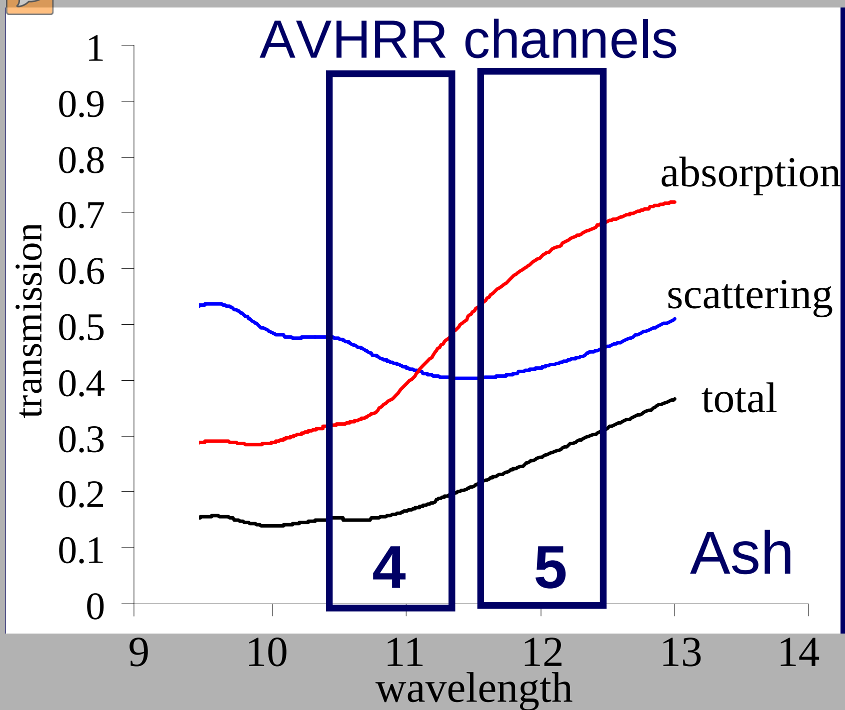
Investigating with Multi-spectral Infrared Combinations

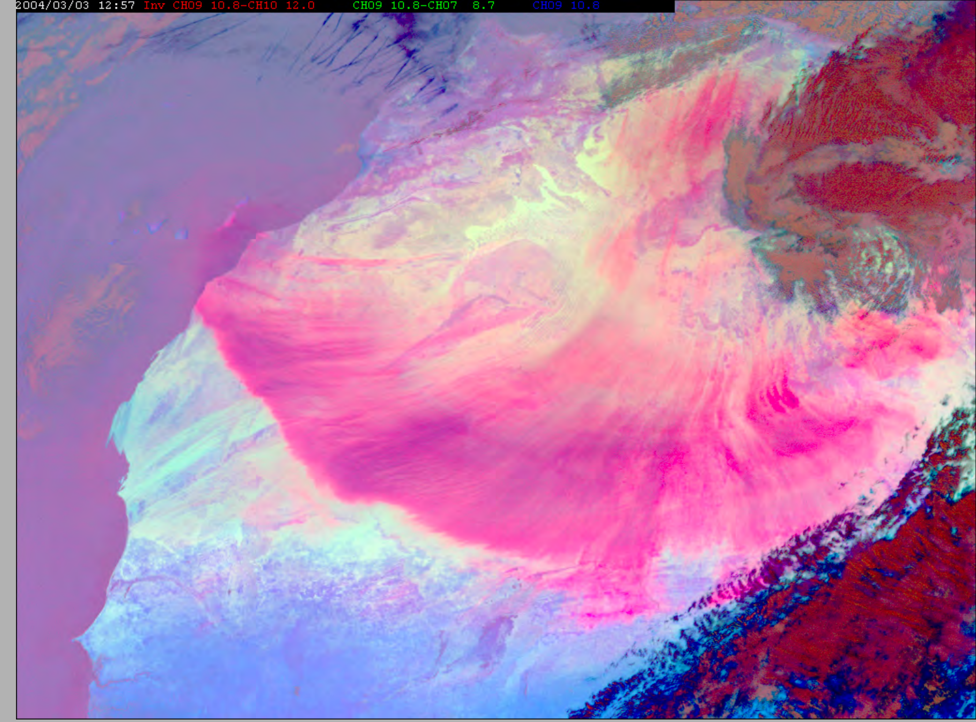
Given the spectral response of a surface or atmospheric feature select a part of the spectrum where the absorption changes with wavelength

e.g. transmission through dust cloud or volcanic ash

If 12 μm sees considerably higher BT than 11 μm then the atmosphere probably contains dust or volcanic ash; if 11 μm sees the same or higher BT than 12 μm the atmosphere viewed does not contain dust cloud or volcanic ash.

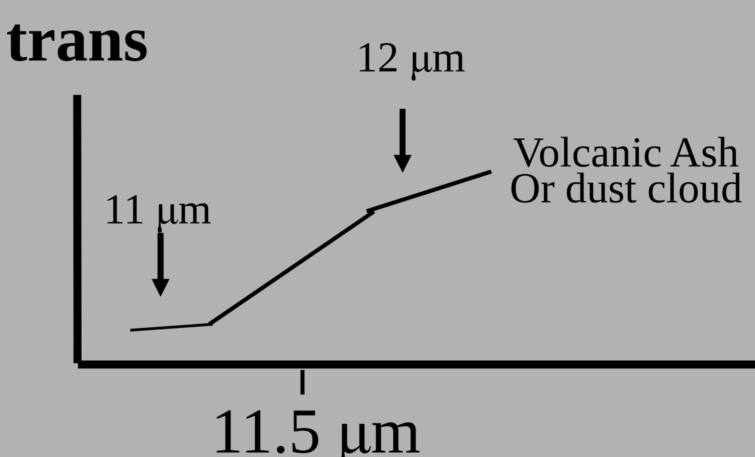






METEOSAT movie of large dust storm over Africa

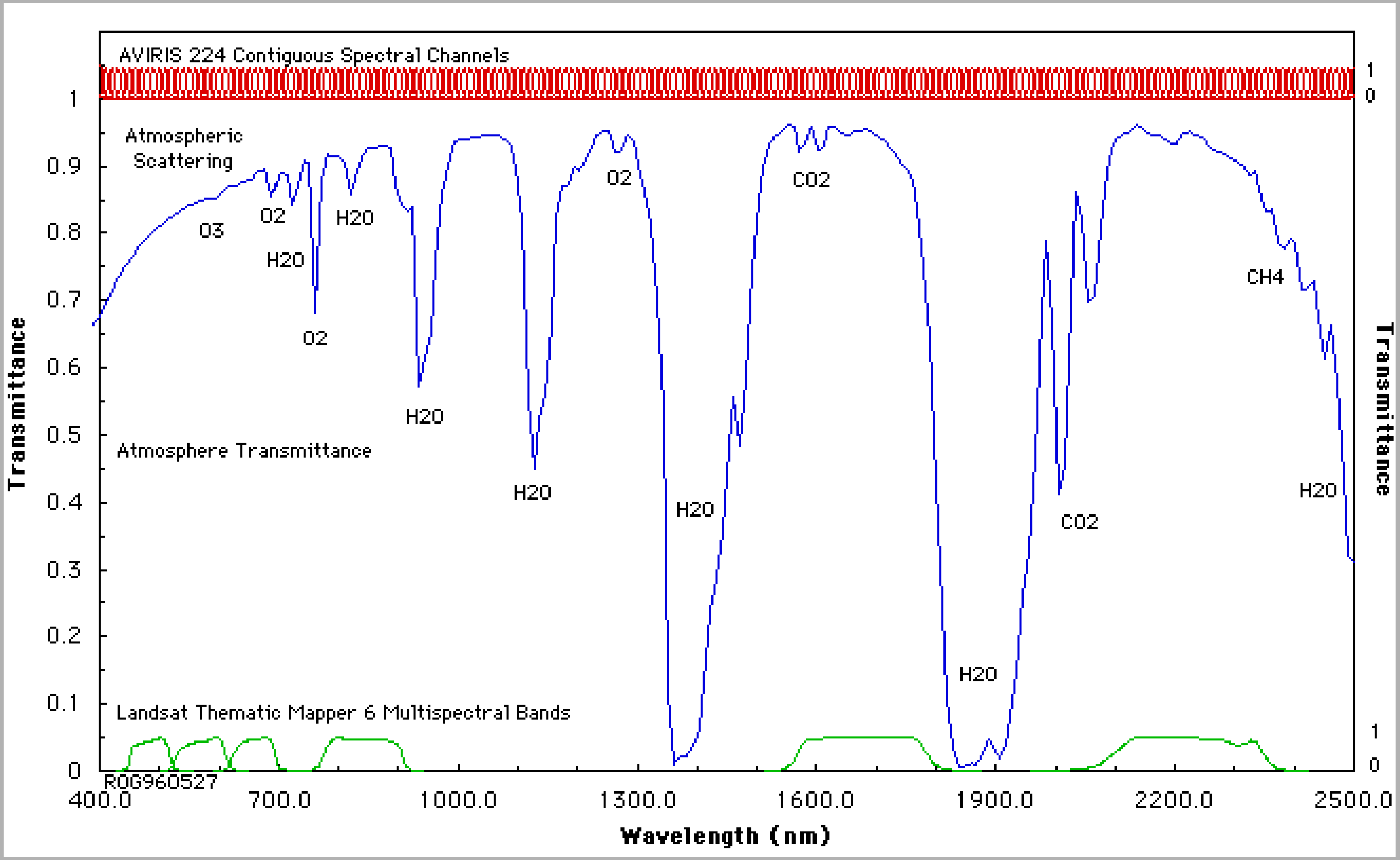
If 12 μm sees considerably higher BT than 11 μm then the atmosphere probably contains dust (as above) or volcanic ash; if 11 μm sees the same or higher BT than 12 μm the atmosphere viewed does not contain dust cloud or volcanic ash;

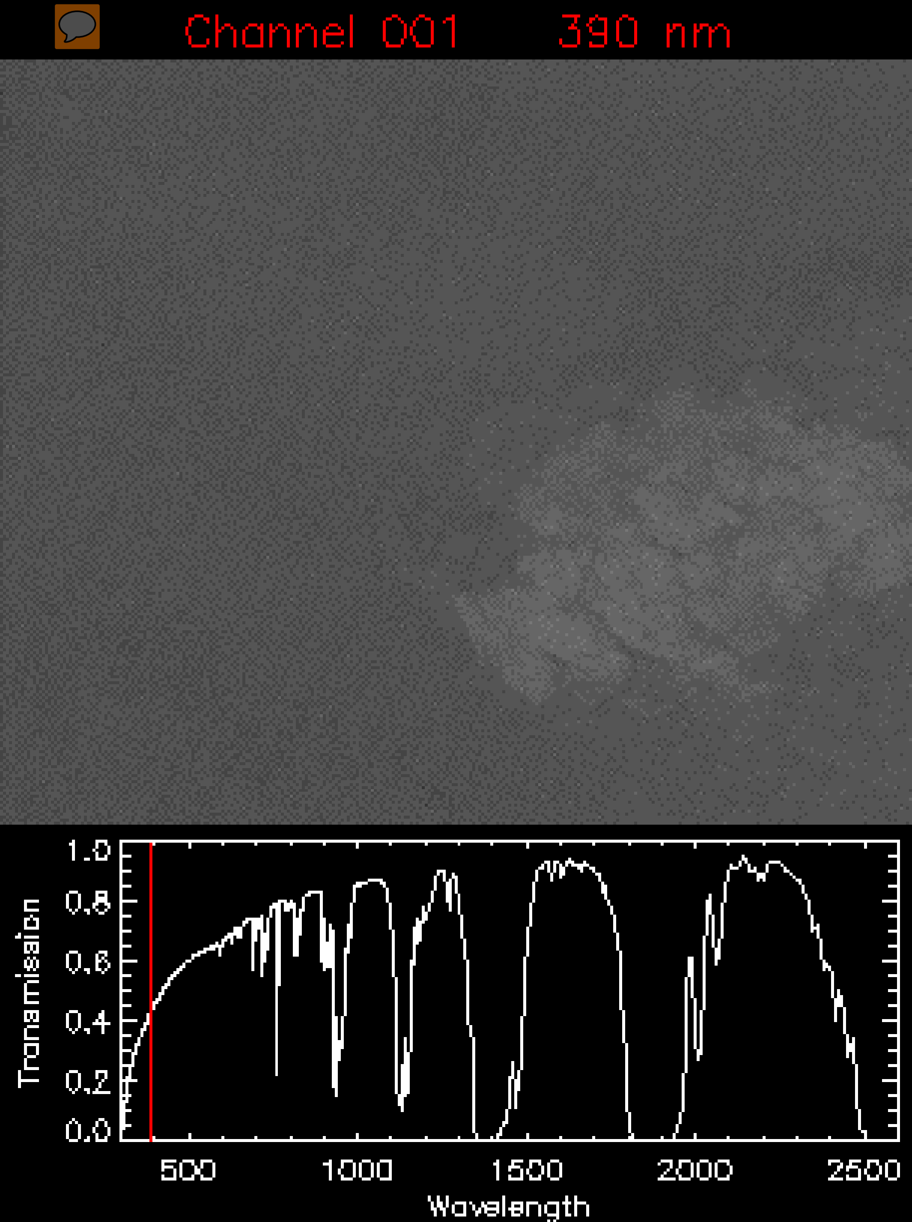


Spectral Information

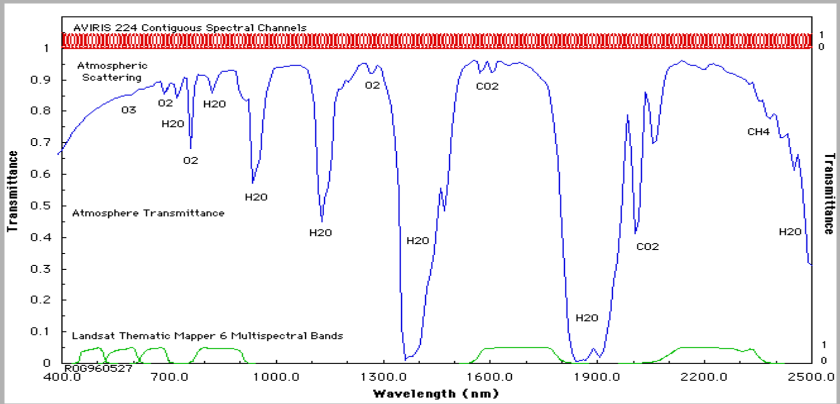
- Now let’s look in more detail at the visible, near infrared and infrared portions of the spectrum. Our objective is to get a better understanding of their unique characteristics and how that information may be used to analyze the land, ocean and atmosphere.

The visible to near infrared portion of the spectrum



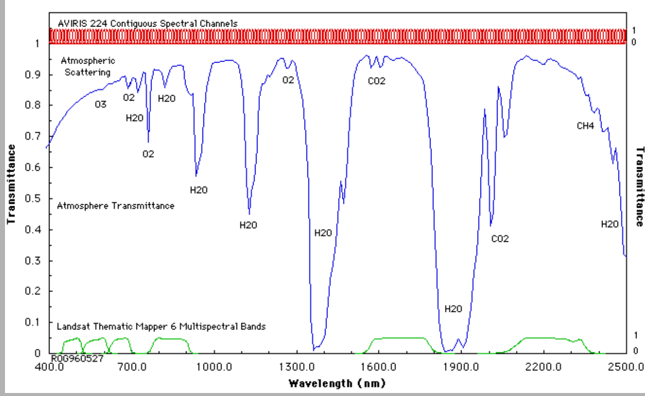


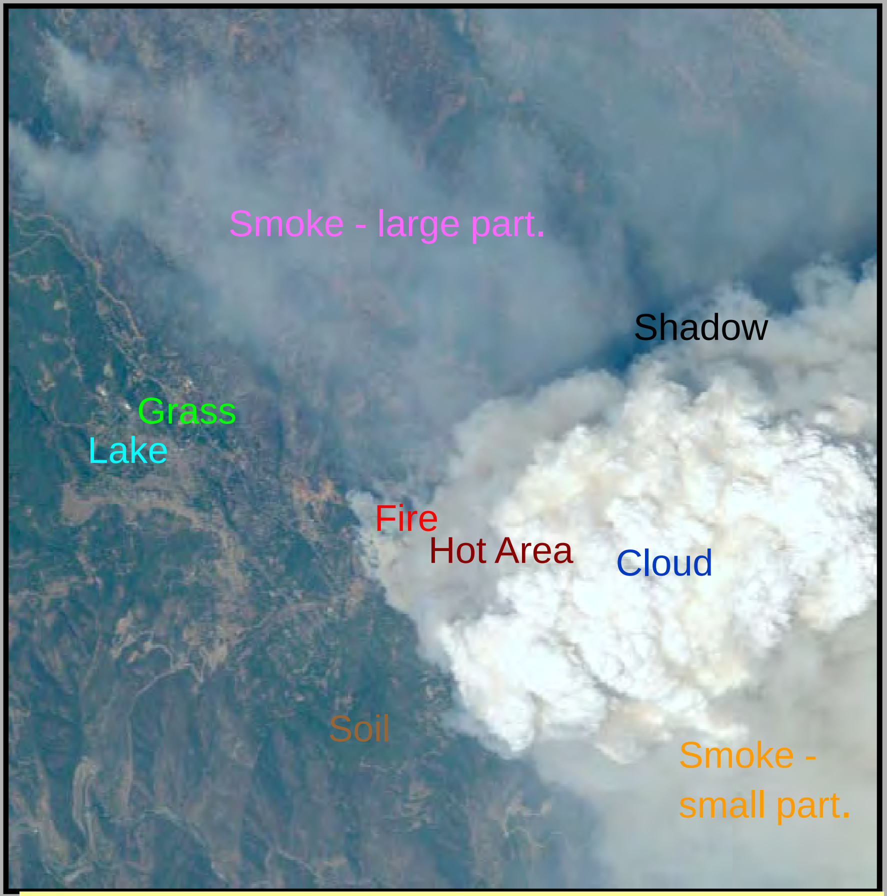
Spectral animation of a single AVIRIS scene reveals the power of being able to observe with high spectral resolution. Beginning at 400 nanometers ground features are difficult to discern, mainly due to molecular scattering which decreases at longer wavelengths. As we observe the scene at longer wavelengths, some features become distinct (land), while others become obscure (apparent decrease in smoke). Note the effect of the water vapor absorption regions on scene brightness. See also next slide.



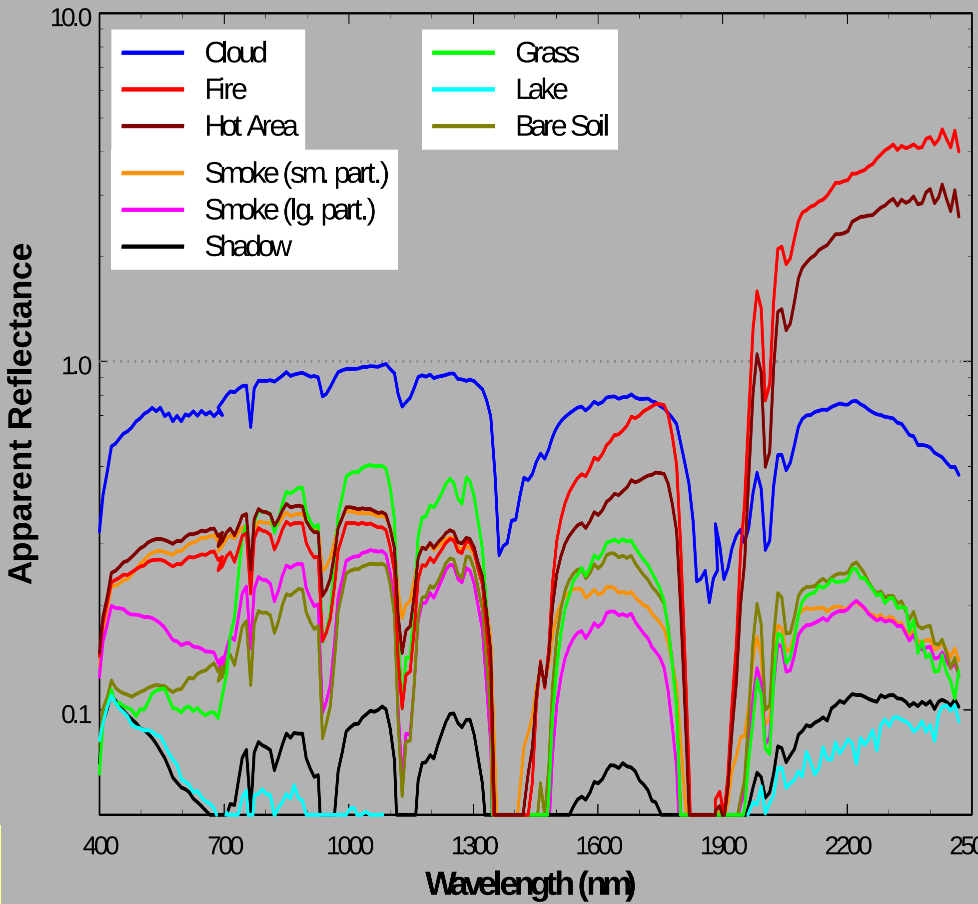
Click on picture to start and stop animation.

AVIRIS Spectral Information from the Scene Depicting Cloud, Smoke and Active Burn Areas



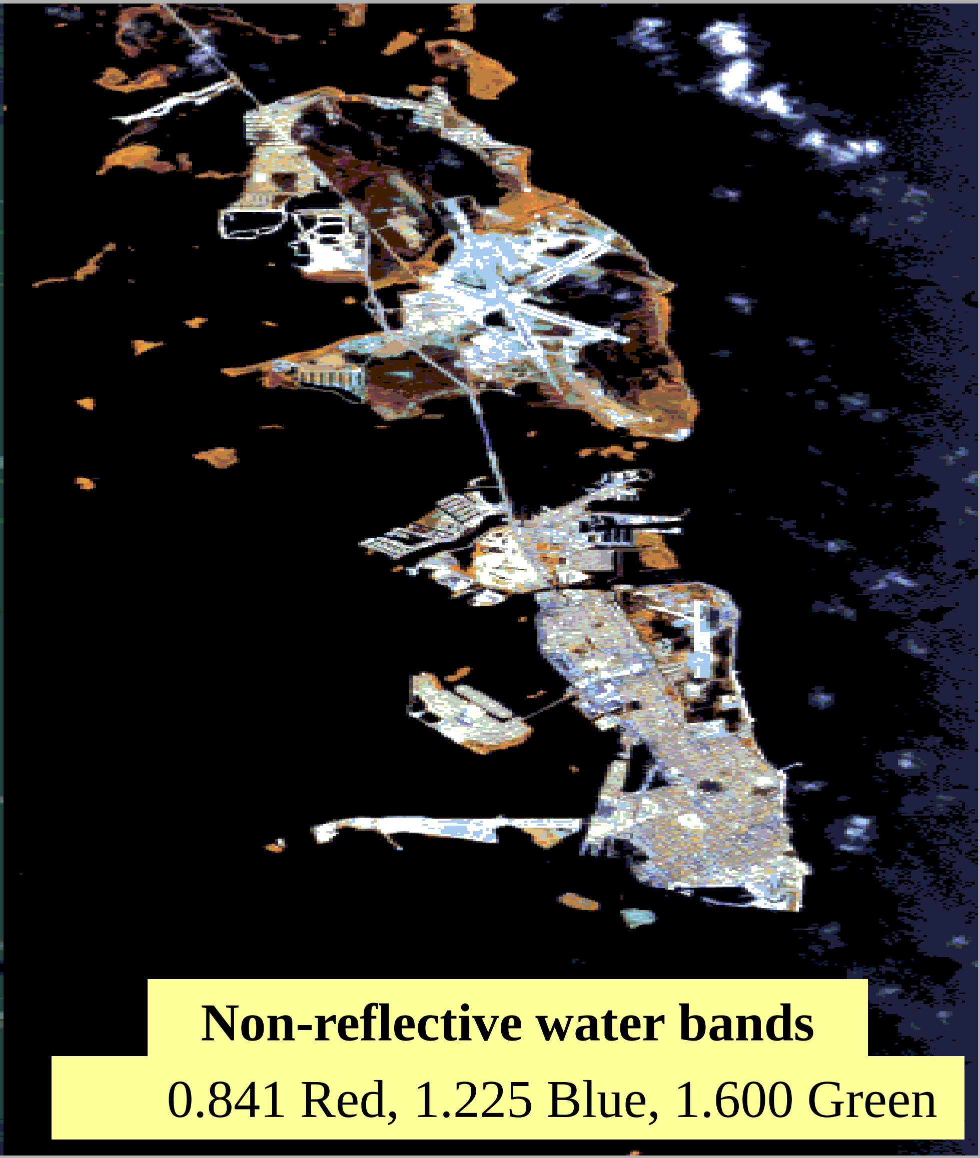


AVIRIS Image - Linden CA 20-Aug-1992
224 Spectral Bands: 0.4 - 2.5 μm
Pixel: 20m x 20m Scene: 10km x 10km

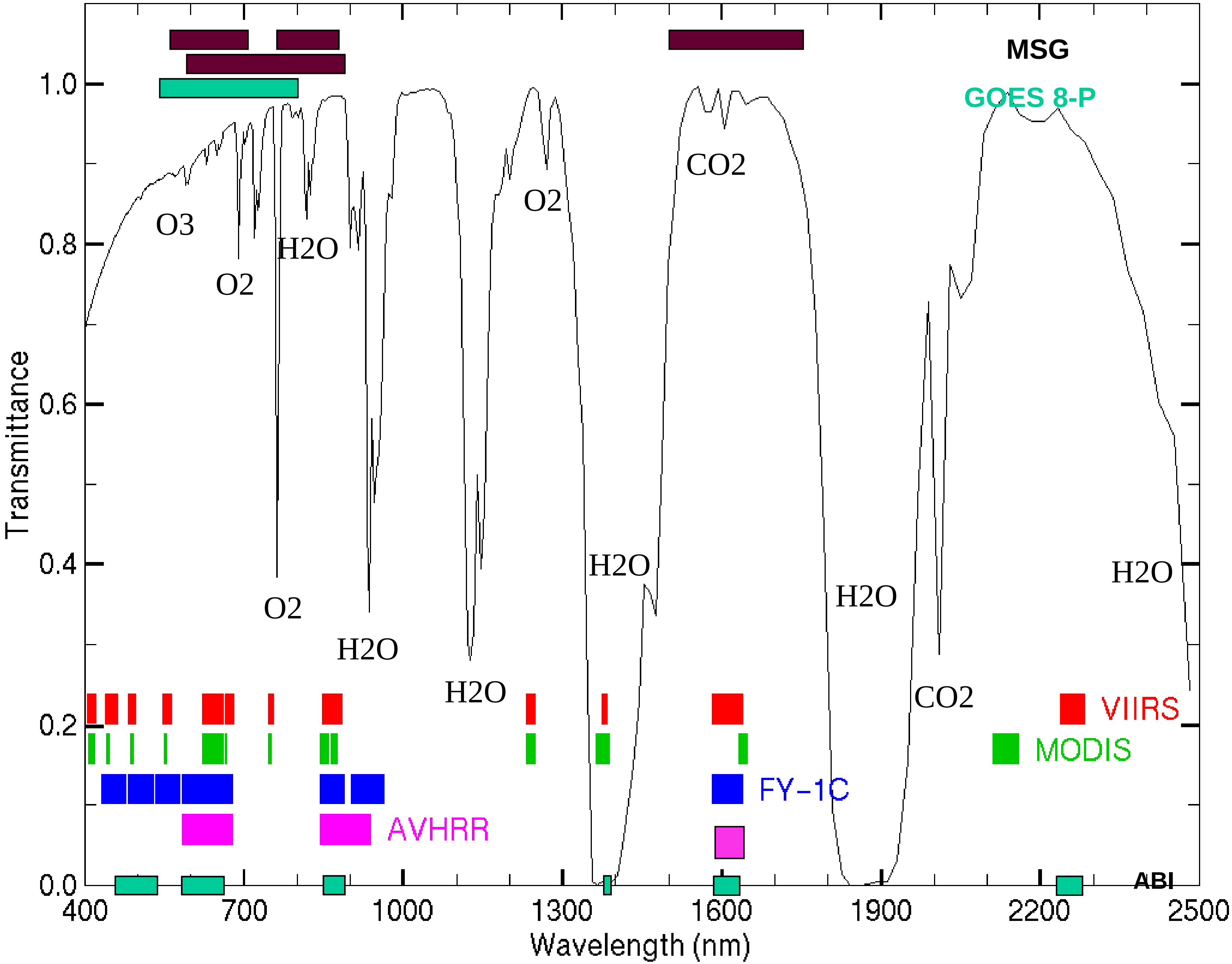


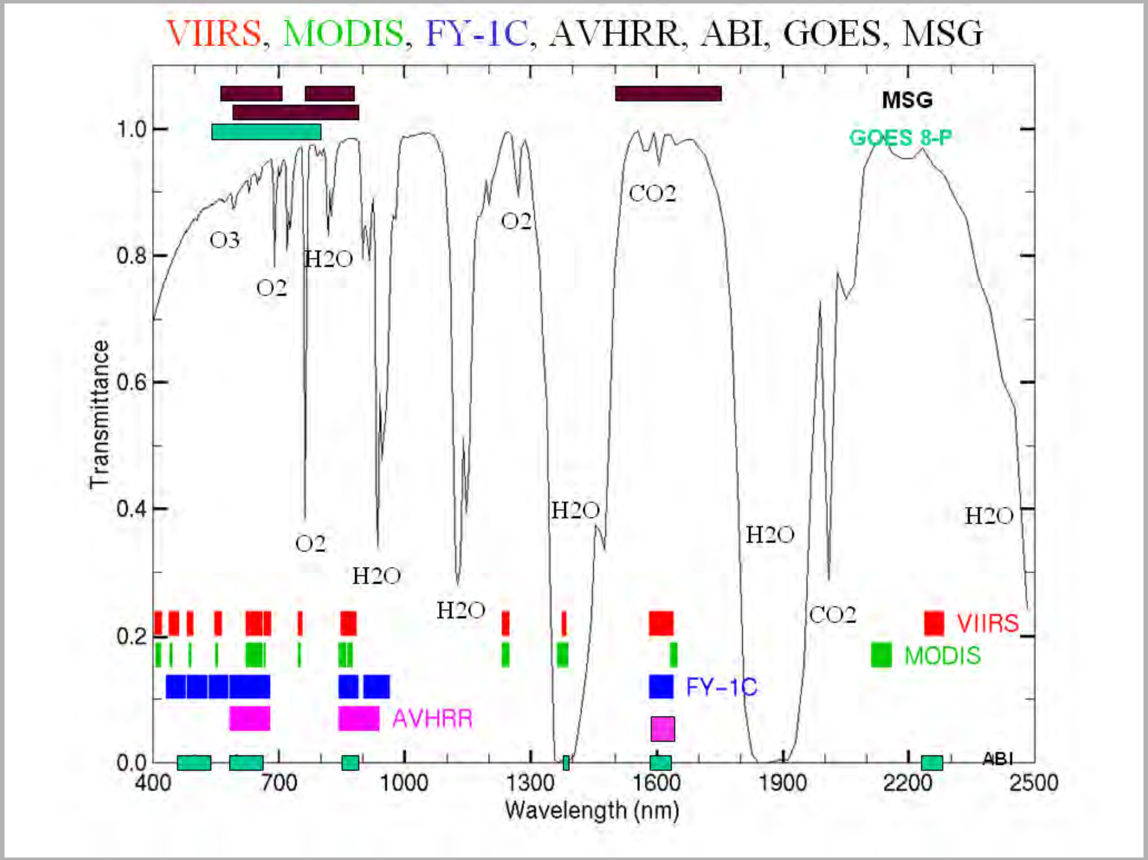
Spectral Signatures of Selected Pixels

Below, the same scene viewed with different visible to near infrared wavelength combinations

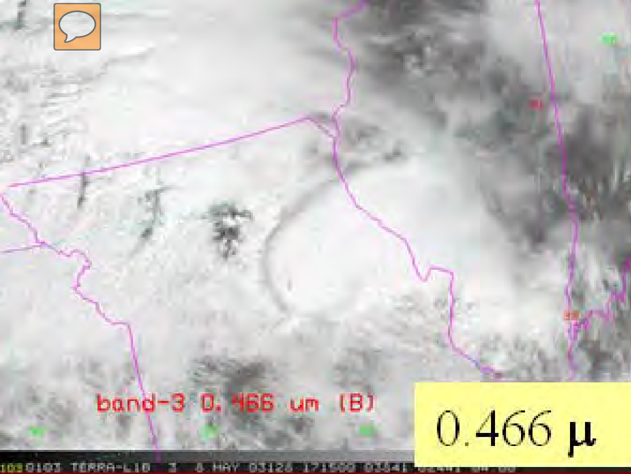


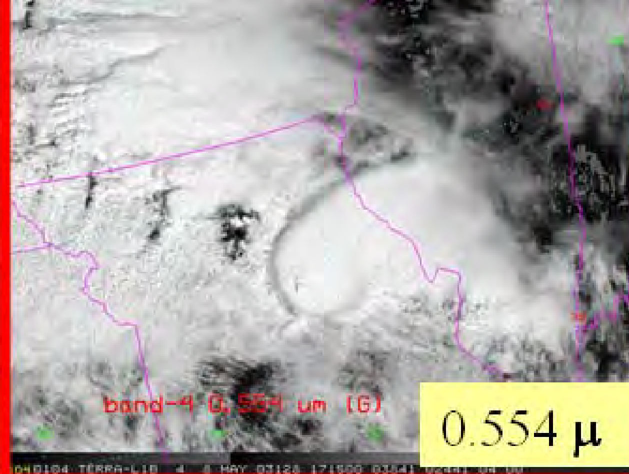
VIIRS, MODIS, FY-1C, AVHRR, ABI, GOES, MSG

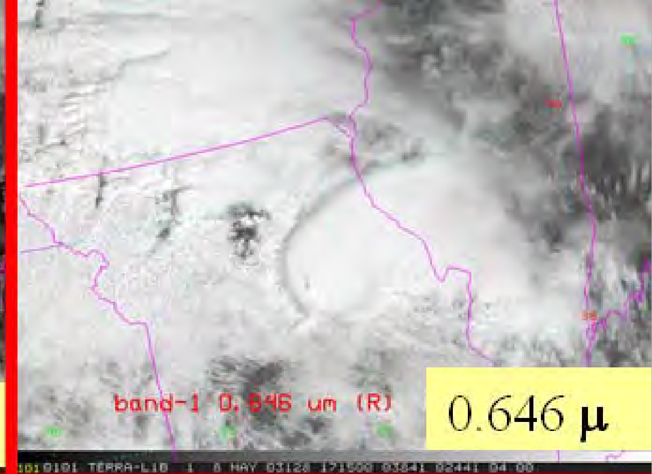


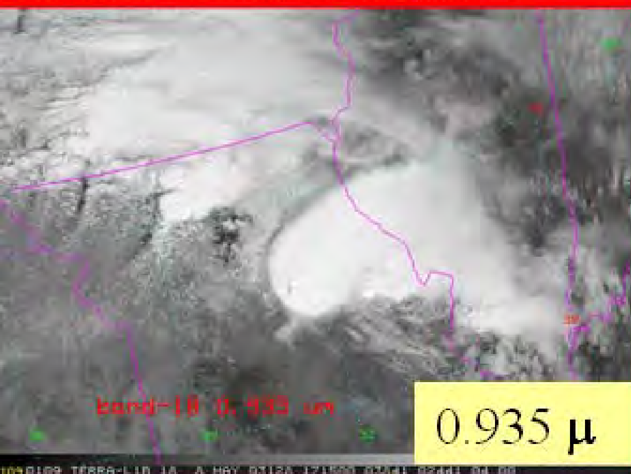


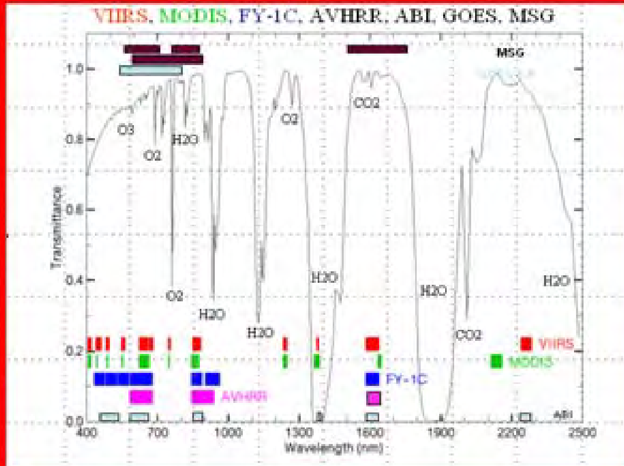
One might ask "why the various satellite imager channel widths and spectral locations?" The answers are complex, but basically relate back to the resolutions described earlier (Lecture A) and specifically the tradeoff between desired spectral resolutions versus the practicality of spatial resolution versus obtaining a high enough signal to noise ratio so that the instrument's data may be used to describe the feature of interest to a desired accuracy level

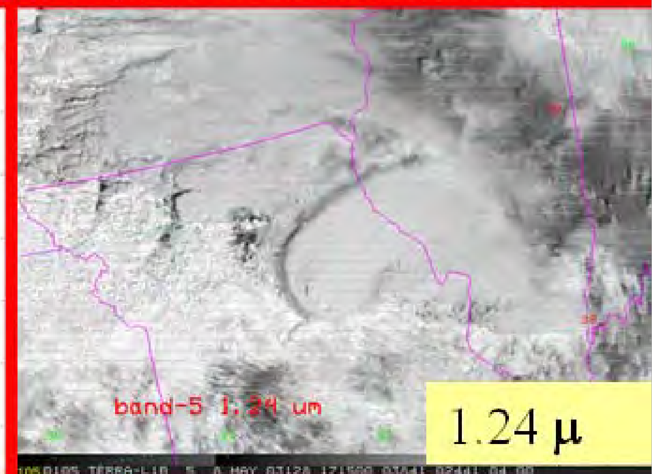




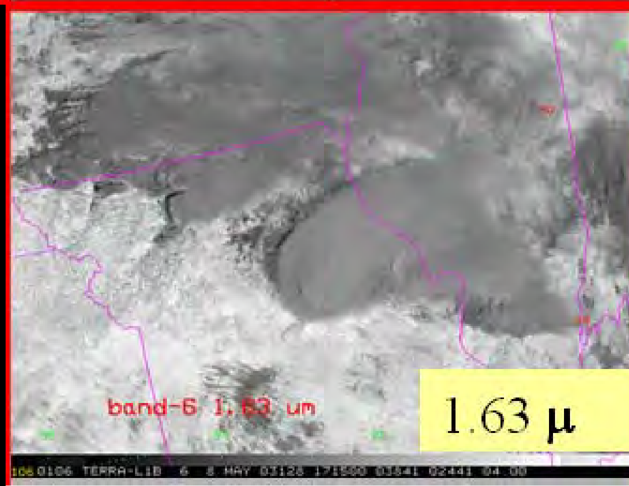


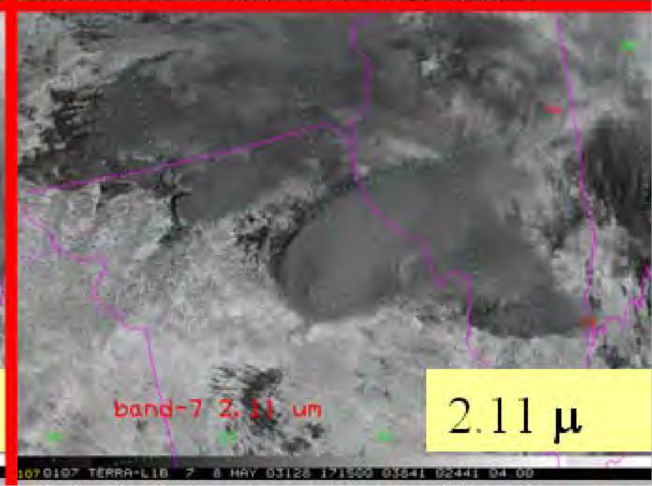


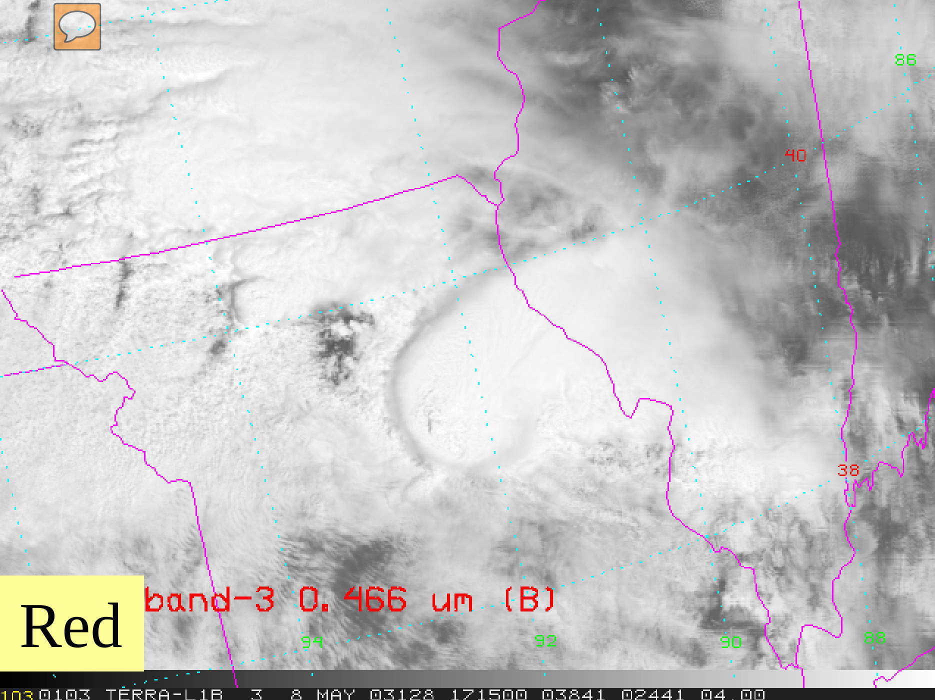


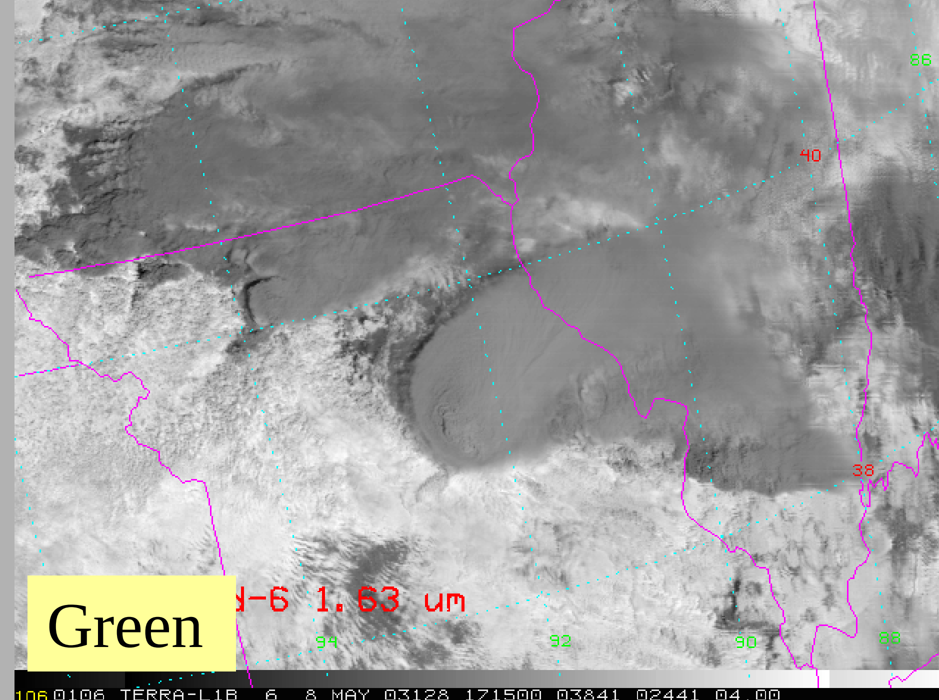


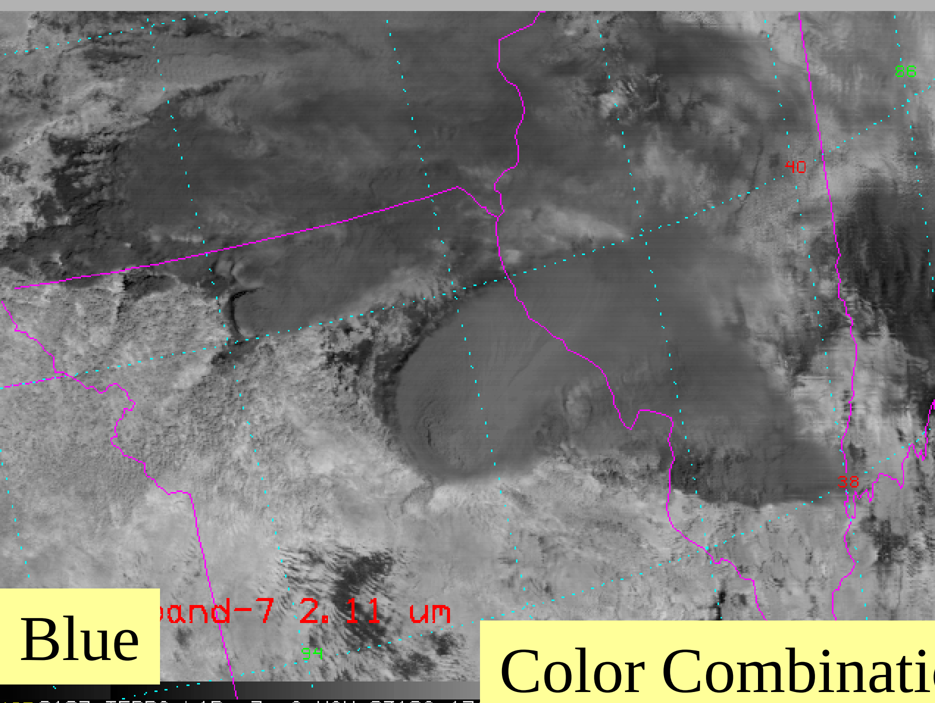
Daytime view of low cloud (water) and a thunderstorm anvil (ice) in different MODIS reflective channels



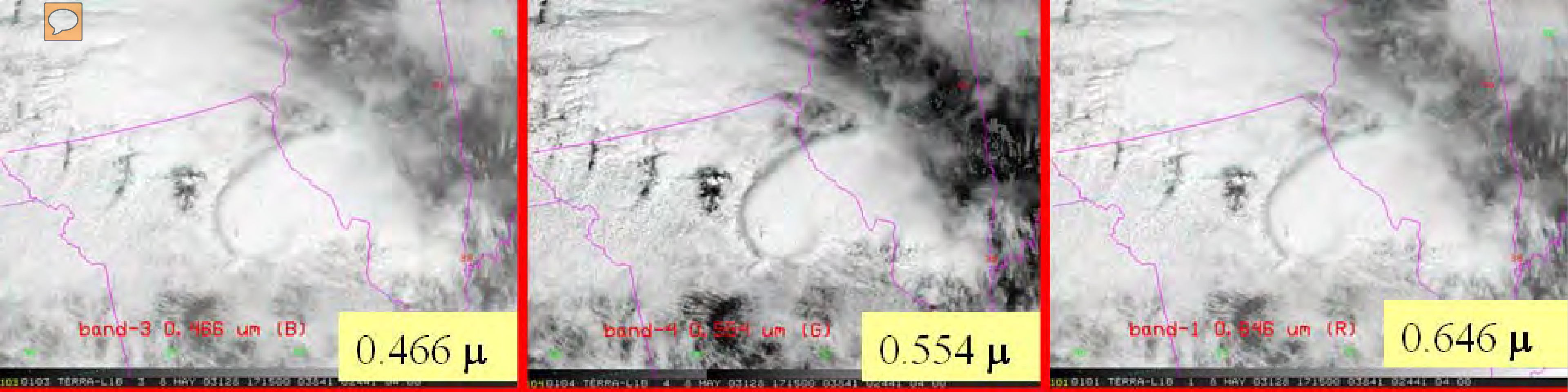


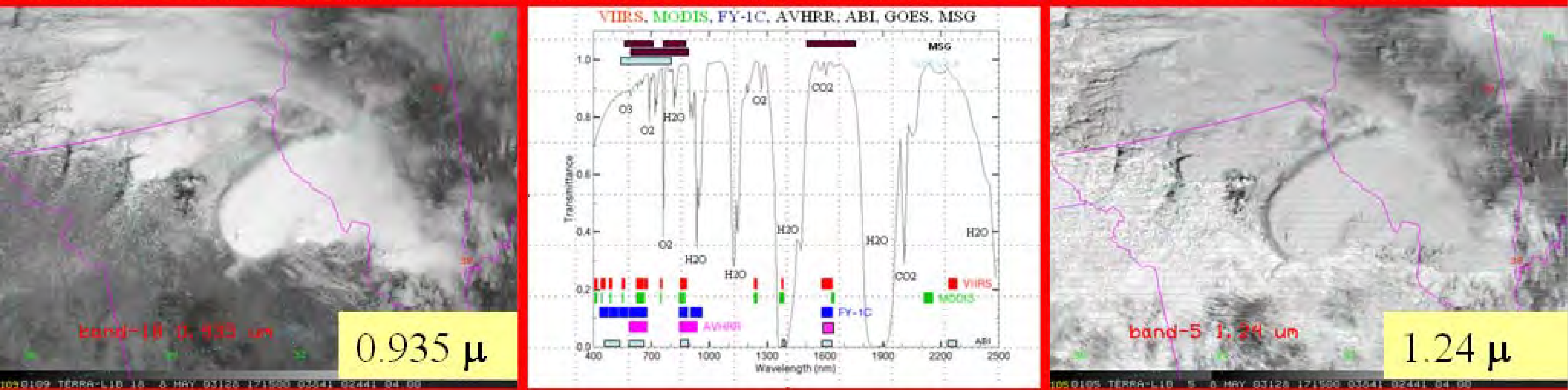


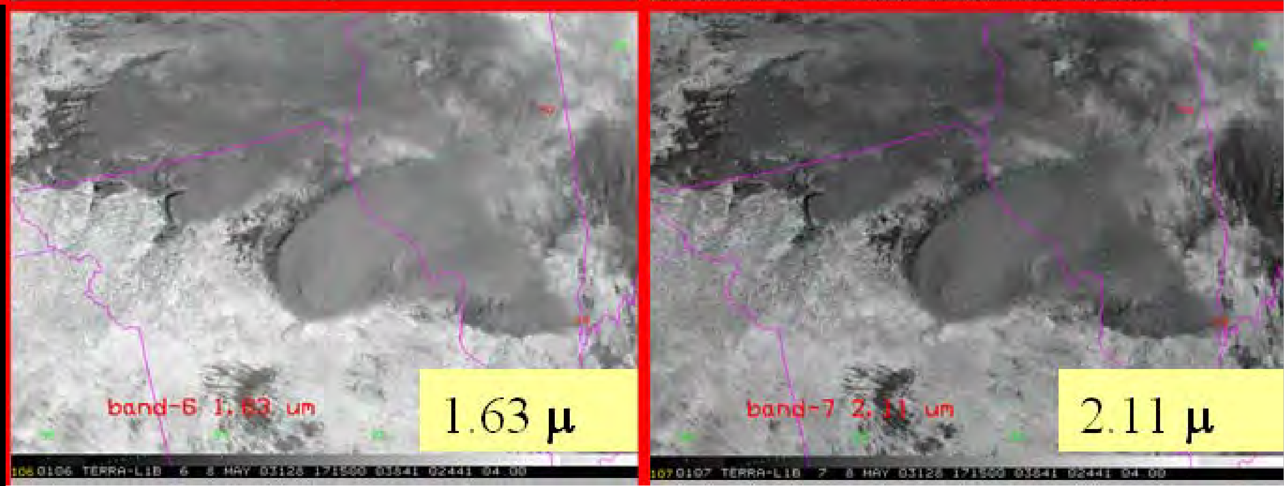




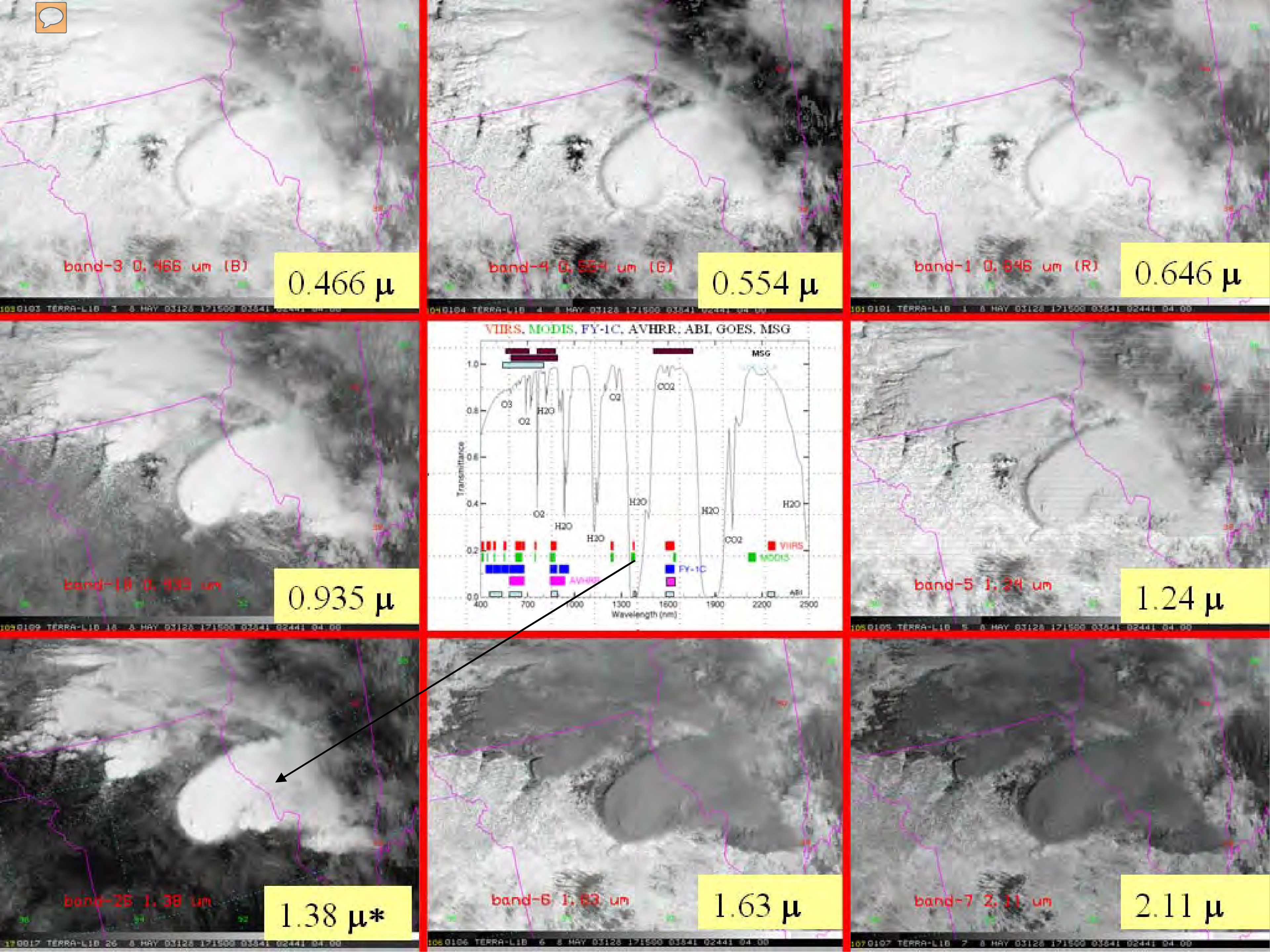
Color Combinations Aid In Cloud Type Interpretation



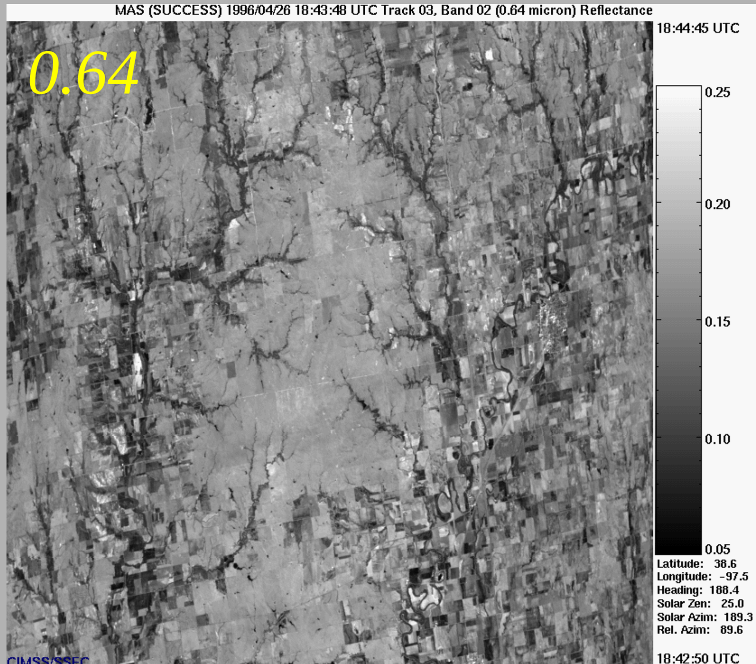


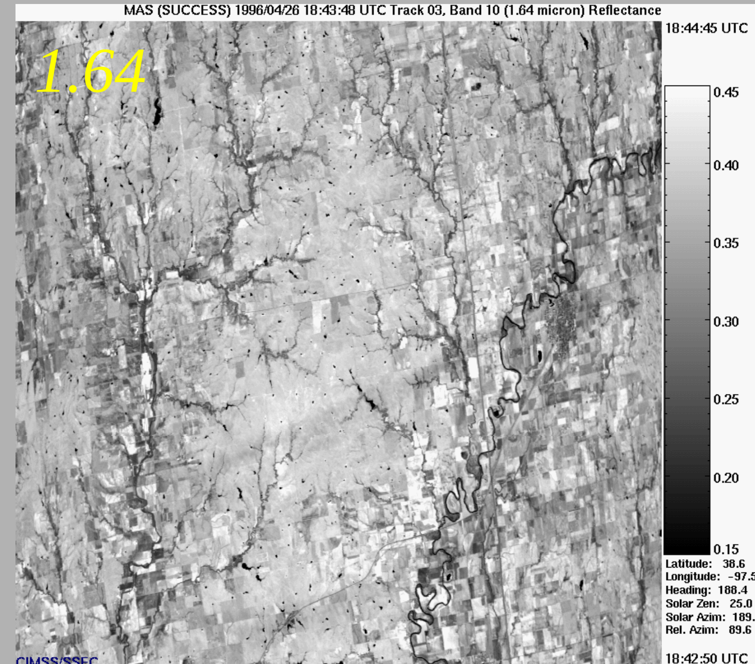


Now for a look at the reflection from the 1.38 micron MODIS channel in the center of a water vapor absorption region



band-3 0.466 um (B)
0.466 μ
0.554 μ
band-1 0.646 um (R)
0.646 μ
0.935 μ
VIIRS, MODIS, FY-1C, AVHRR, ABI, GOES, MSG
Transmittance
Wavelength (nm)
O3
O2
H2O
CO2
VIIRS
MODIS
FY-1C
AVHRR
ABI
MSG
1.24 μ
band-26 1.38 um
1.38 μ*
1.63 μ
2.11 μ


MAS (SUCCESS) 1996/04/26 18:43:48 UTC Track 03, Band 02 (0.64 micron) Reflectance
0.64
18:44:45 UTC
0.25
0.20
0.15
0.10
0.05
Latitude: 38.6
Longitude: -97.5
Heading: 188.4
Solar Zen: 25.0
Solar Azim: 189.3
Rel. Azim: 89.6
18:42:50 UTC
CIMSS/SSEC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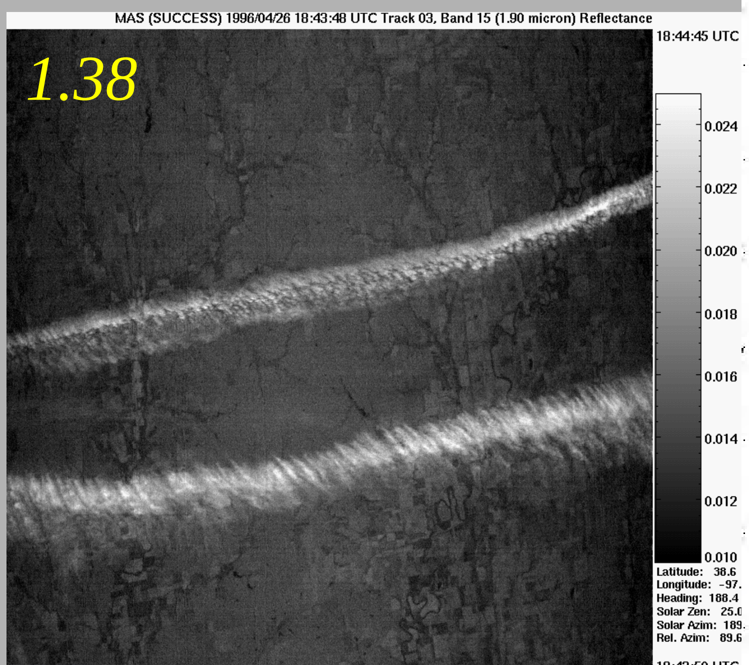
1.64
18:44:45 UTC
0.45
0.40
0.35
0.30
0.25
0.20
0.15
Latitude: 38.6
Longitude: -97.5
Heading: 188.4
Solar Zen: 25.0
Solar Azim: 189.3
Rel. Azim: 89.6
18:42:50 UTC
CIMSS/SSEC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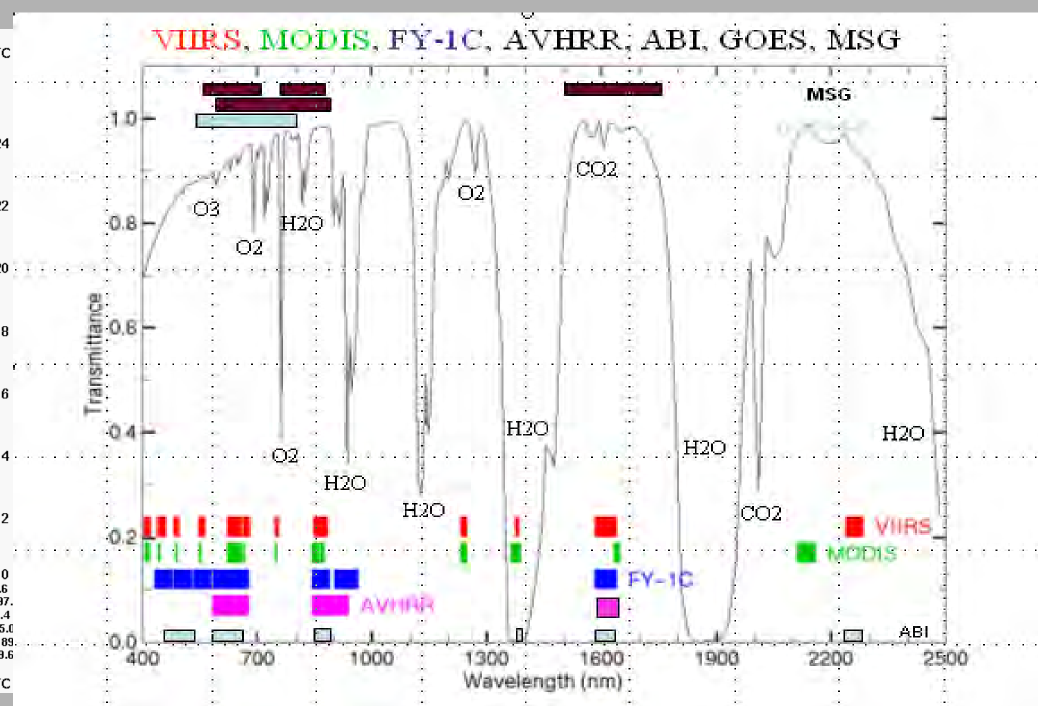
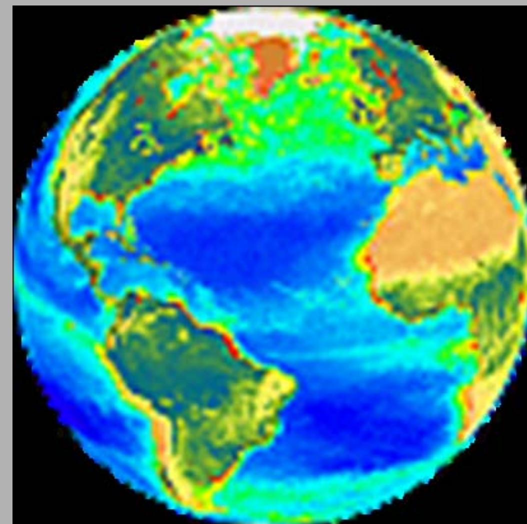
1.38
18:44:45 UTC
0.024
0.022
0.020
0.018
0.016
0.014
0.012
0.010
Latitude: 38.6
Heading: 188.4
Rel. Azim: 89.6
18:42:50 UTC
CIMSS/SSEC

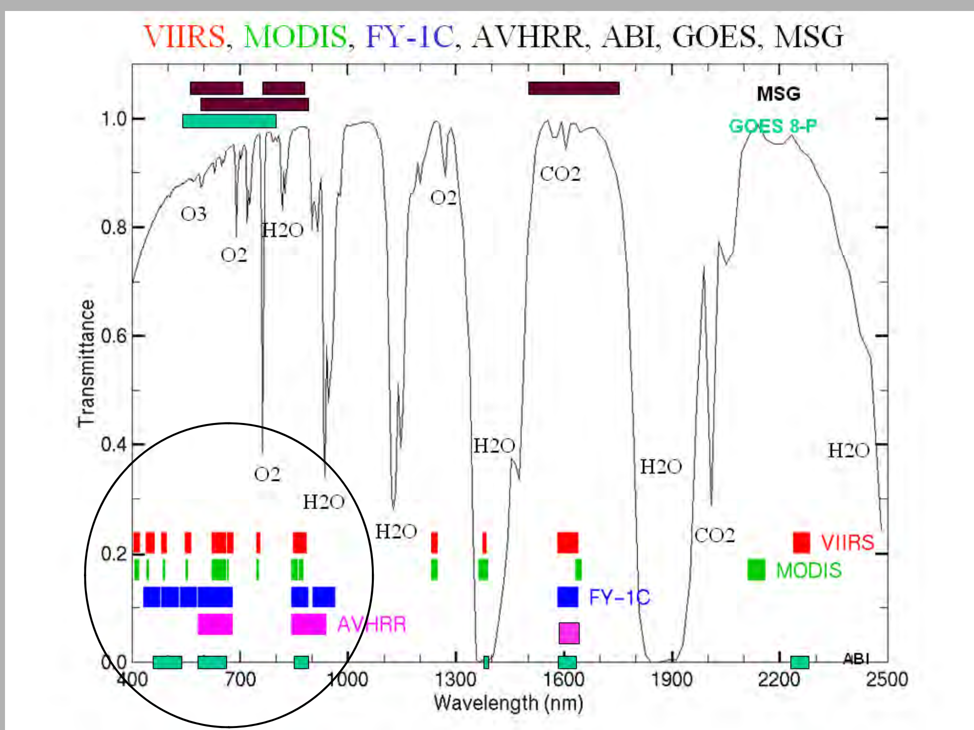

VIIRS, MODIS, FY-1C, AVHRR, ABI, GOES, MSG
MSG
O3
O2
H2O
O2
O2
H2O
H2O
H2O
CO2
H2O
CO2
H2O
VIIRS
MODIS
FY-1C
AVHRR
ABI
Transmittance
1.0
0.8
0.6
0.4
0.2
0.0
400
700
1000
1300
1600
1900
2200
2500
Wavelength (nm)

Ocean Color: As illustrated by SeaWifs



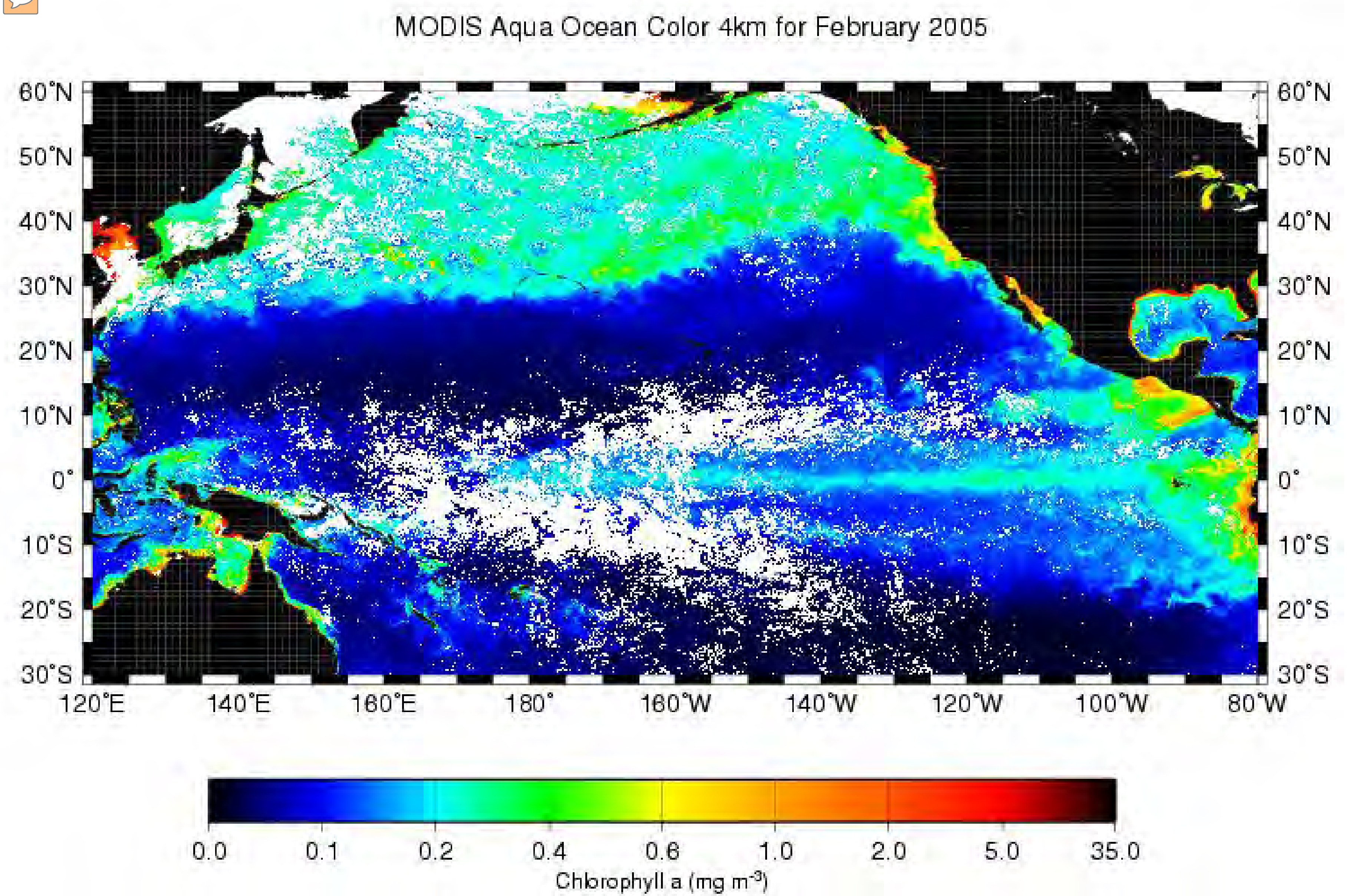
Instrument Bands

402-422 nm
433-453 nm
480-500 nm
500-520 nm
545-565 nm
660-680 nm
745-785 nm
845-885 nm



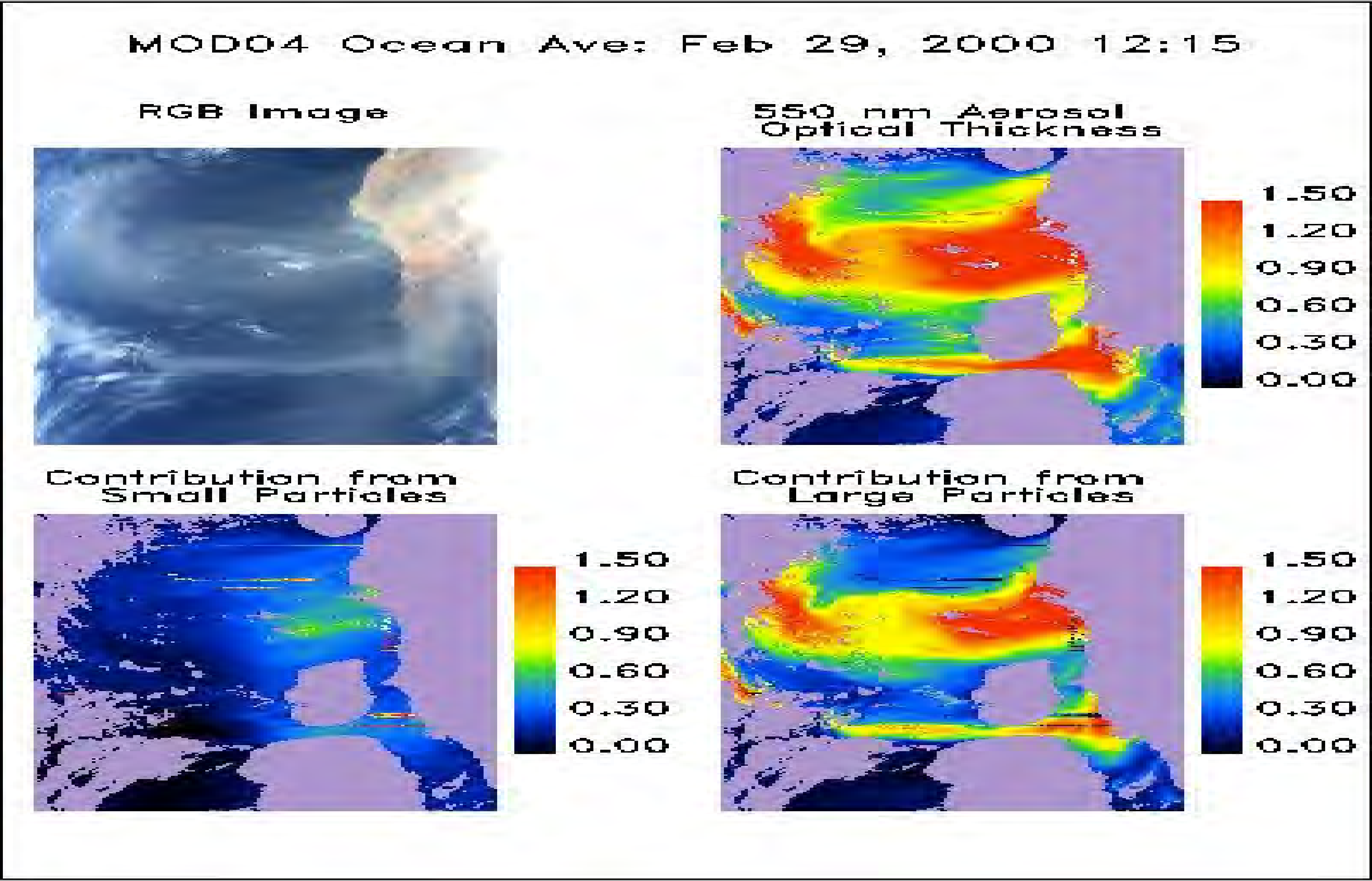
Mission Characteristics

Sun Synchronous Orbit 705 km
Equator Crossing 12:20 PM descending
Orbital Period 99 minutes
Swath Width 2,801 km
Spatial Resolution1.1 km
Revisit Time1 day
Digitization10 bits

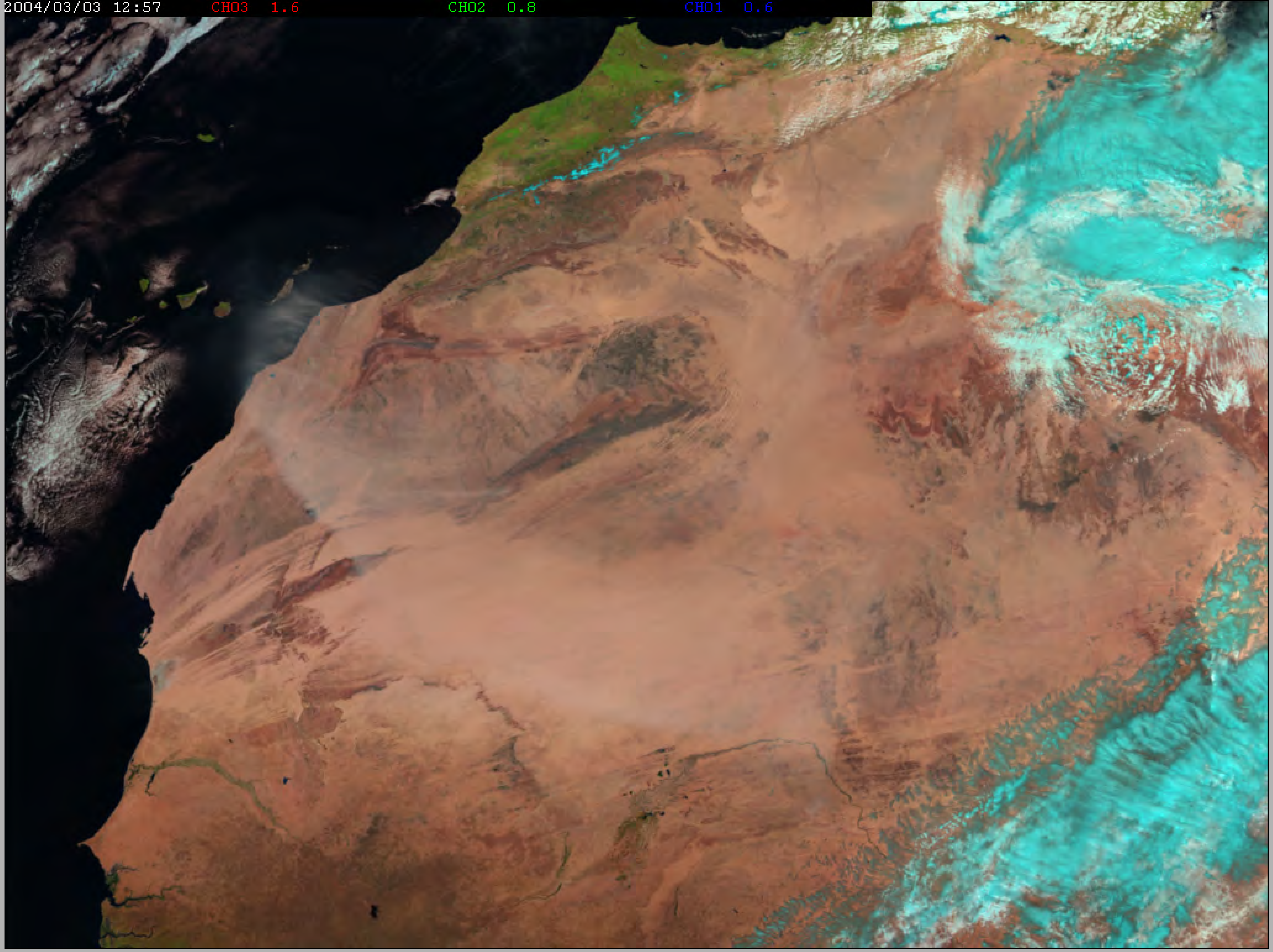


Ocean color product from MODIS showing the abundance of chlorophyll a across part of the Pacific Ocean.

MODIS estimation of aerosol optical thickness

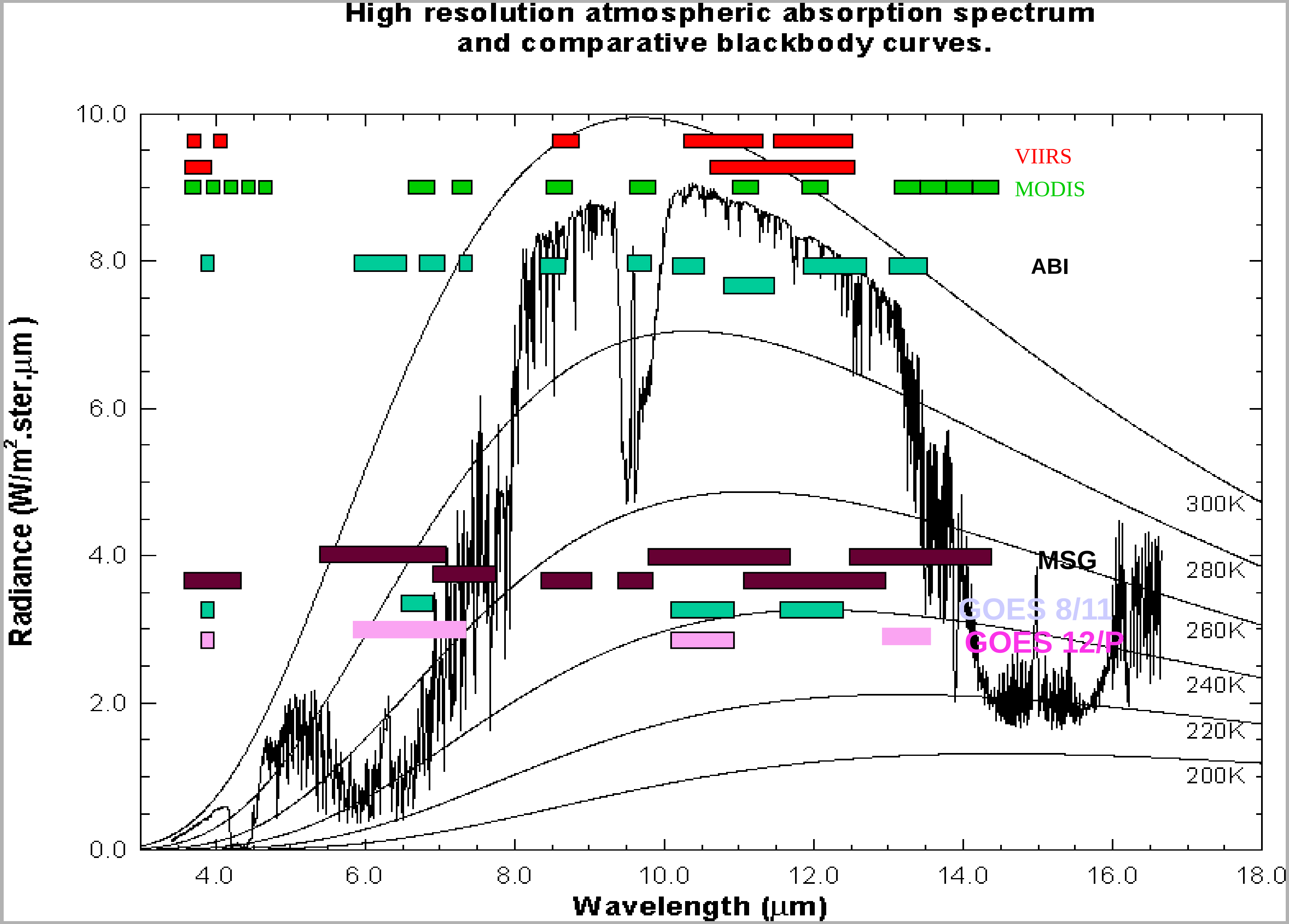


Kaufman et al.

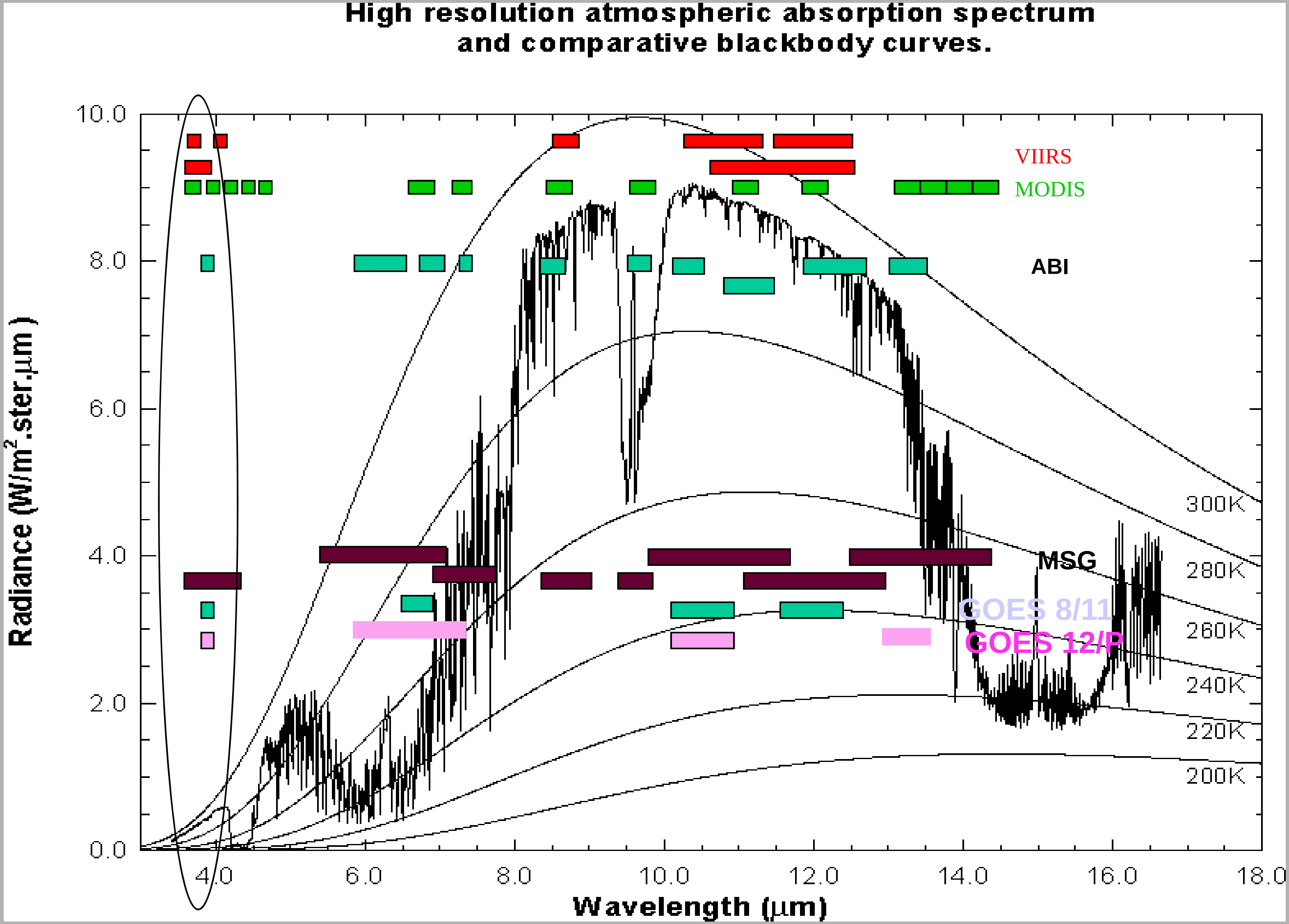


Daytime multispectral METEOSAT-8 image of large dust storm over Africa. This is made using a combination of images from the 0.6, 0.8 and 1.6 micron channels. Click on the image to view animation.

Earth emitted spectra overlaid on Planck function envelopes



Earth emitted spectra overlaid on Planck function envelopes

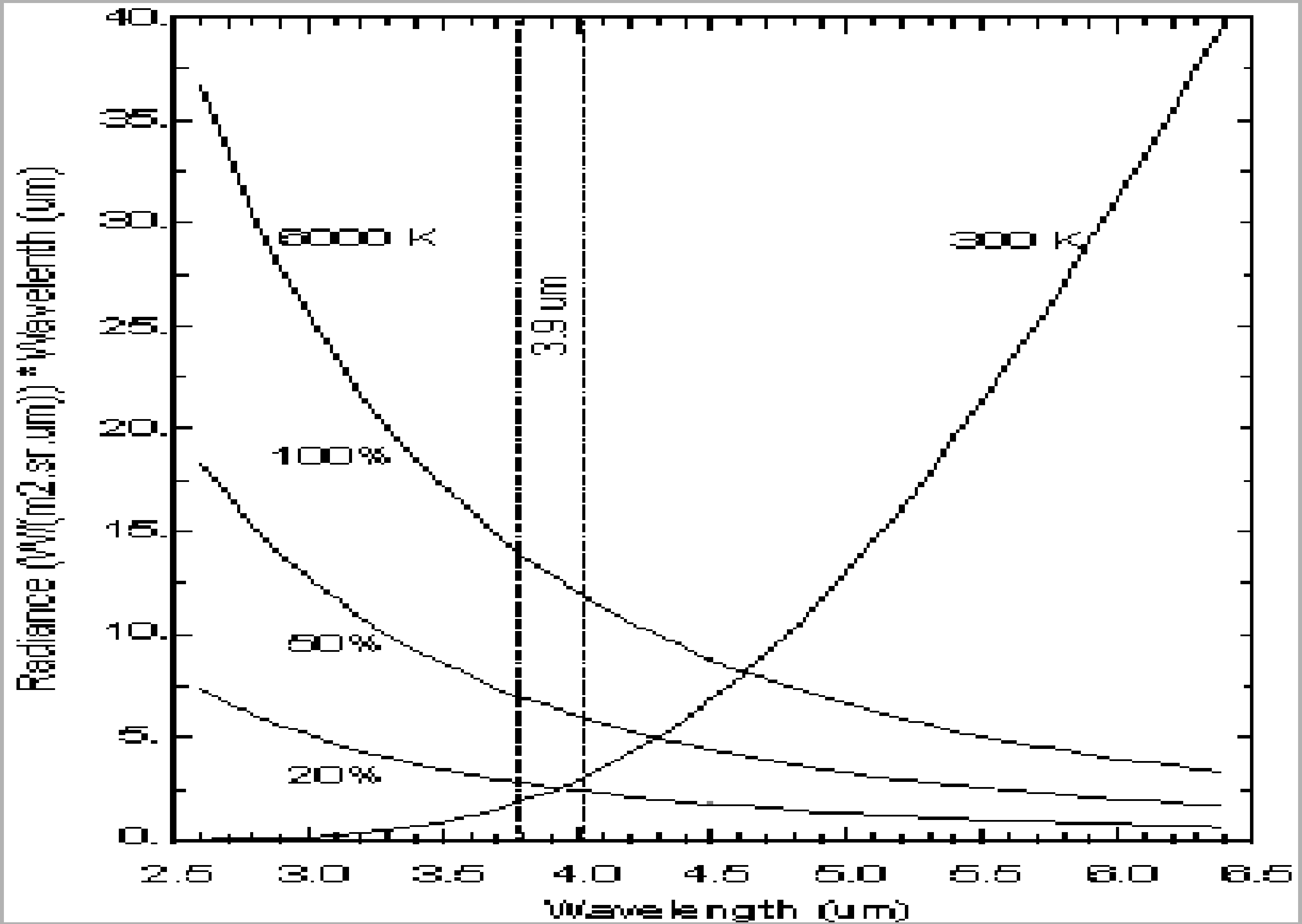


The special area in the vicinity of 3 and 4 microns

3.7 - 3.9 um Channel Imagery Applications

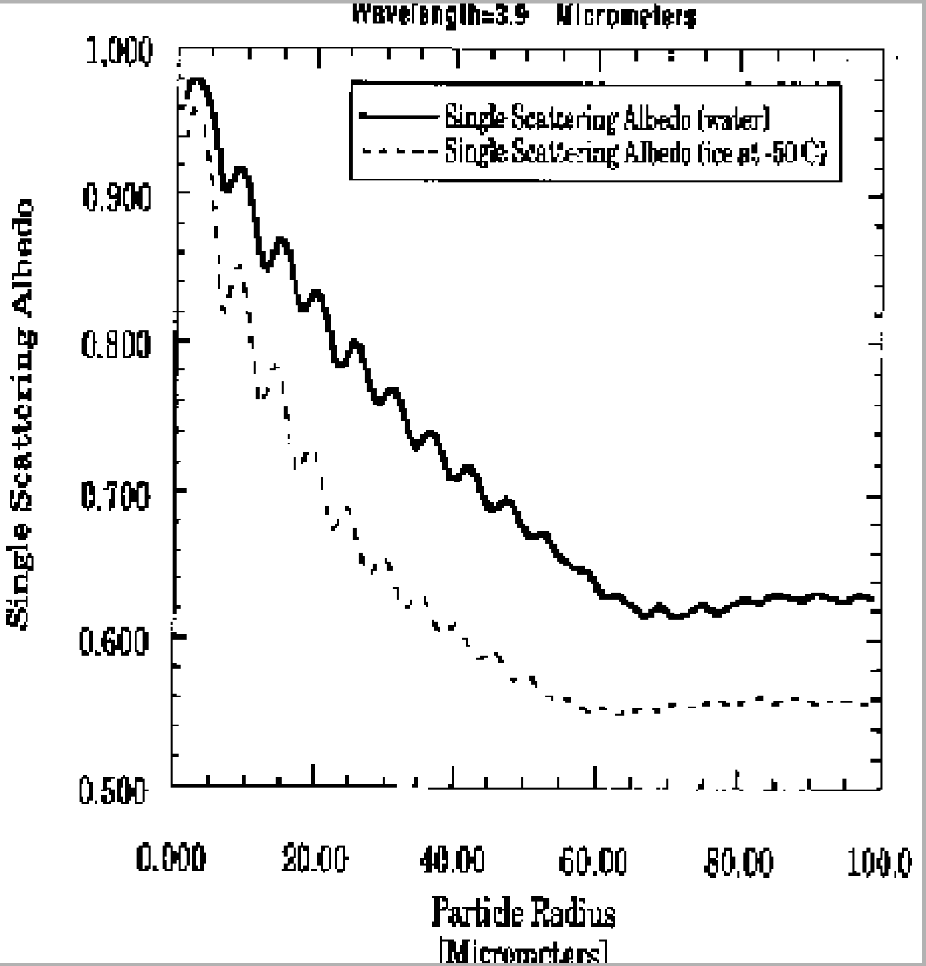
- Night-time Fog, Stratus & Cirrus
- Super-cooled Clouds
- Fog, Ice & Water Clouds Over Snow
- Winter Storms
- Land- and Sea-surface Temperatures
- Thin Cirrus & Multi-layered Clouds
- Urban Heat "Islands"
- Fire Detection
- Sun Glint
- Cumulus Bands at Night
- Convective Cloud Phases
- Volcanic Ash Cloud Monitoring

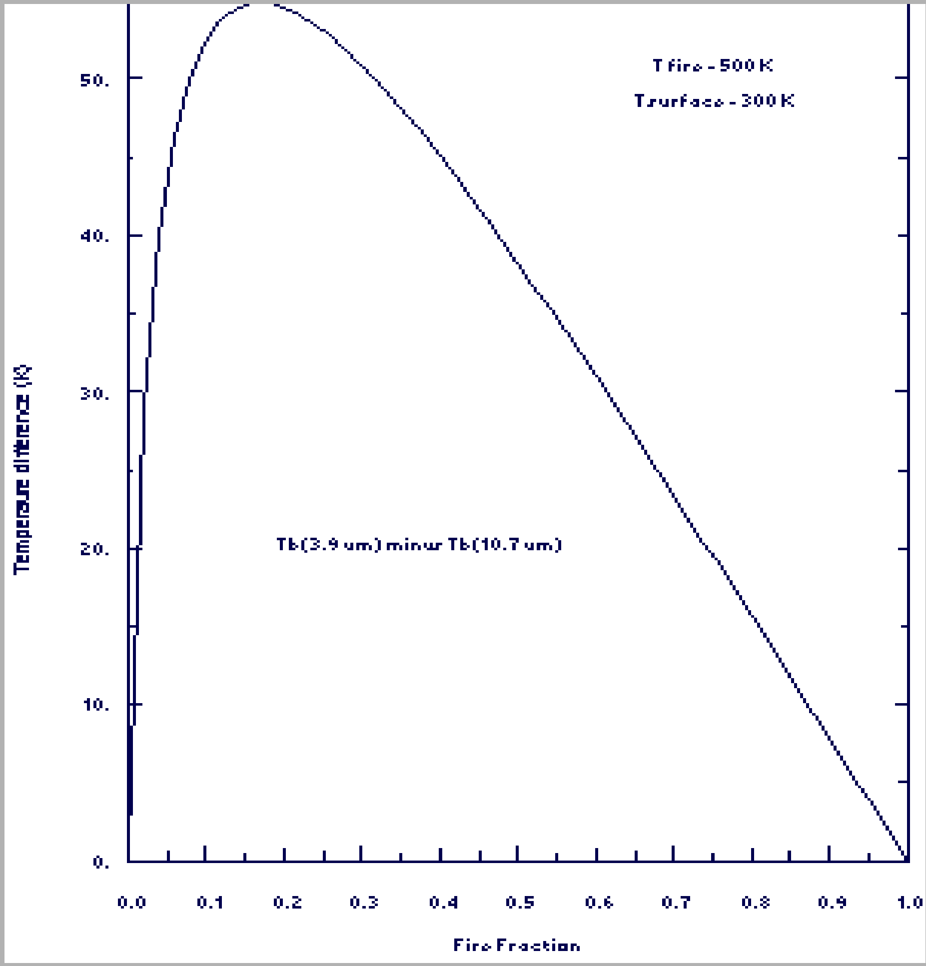
A close-up view around 3.9 mm, with radiance at 100%, 50% and 20% for the 6000 K source



The special area between 3 and 4 microns

Spectral Awareness, cloud phase and non-linear aspects of thermal response

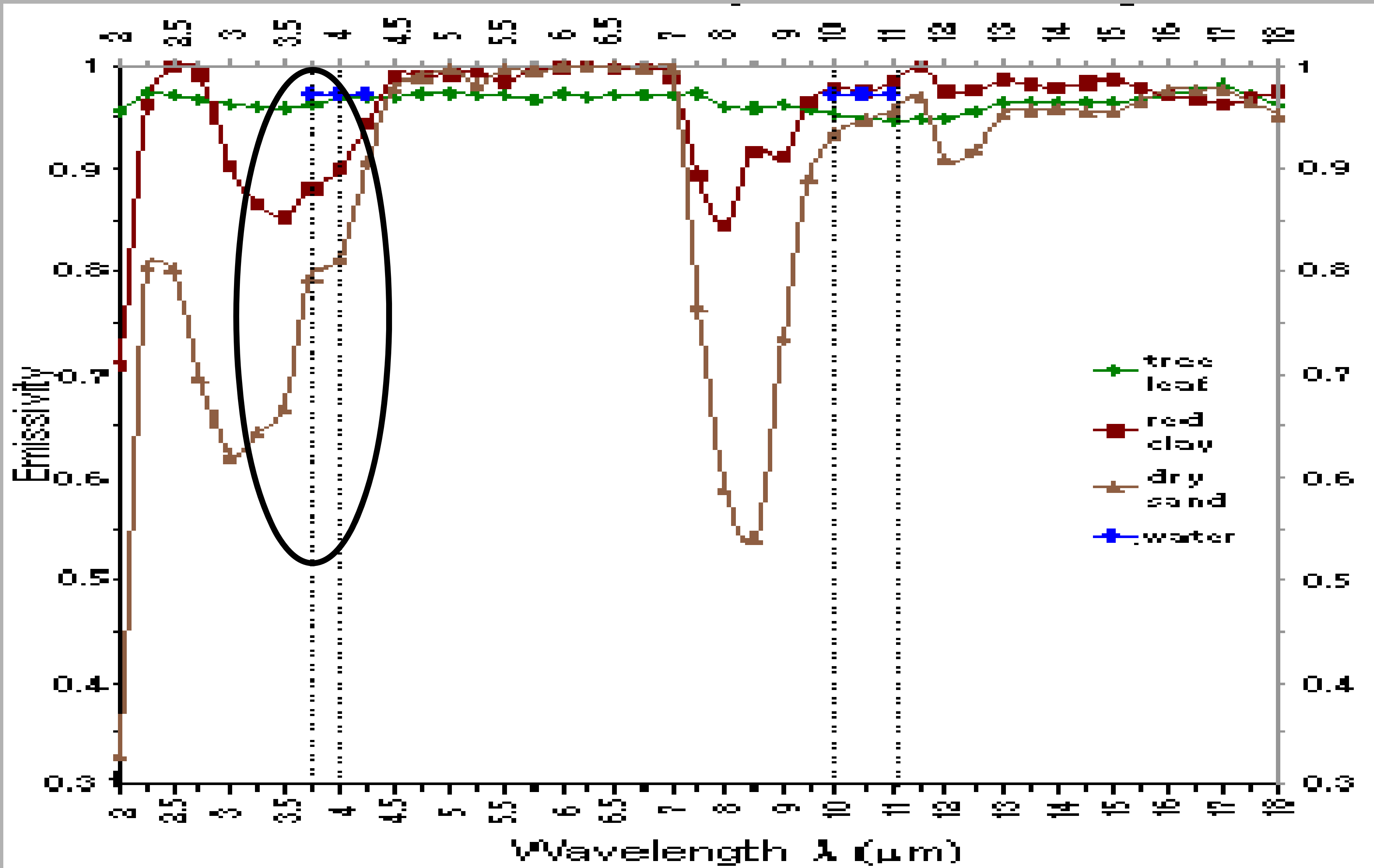




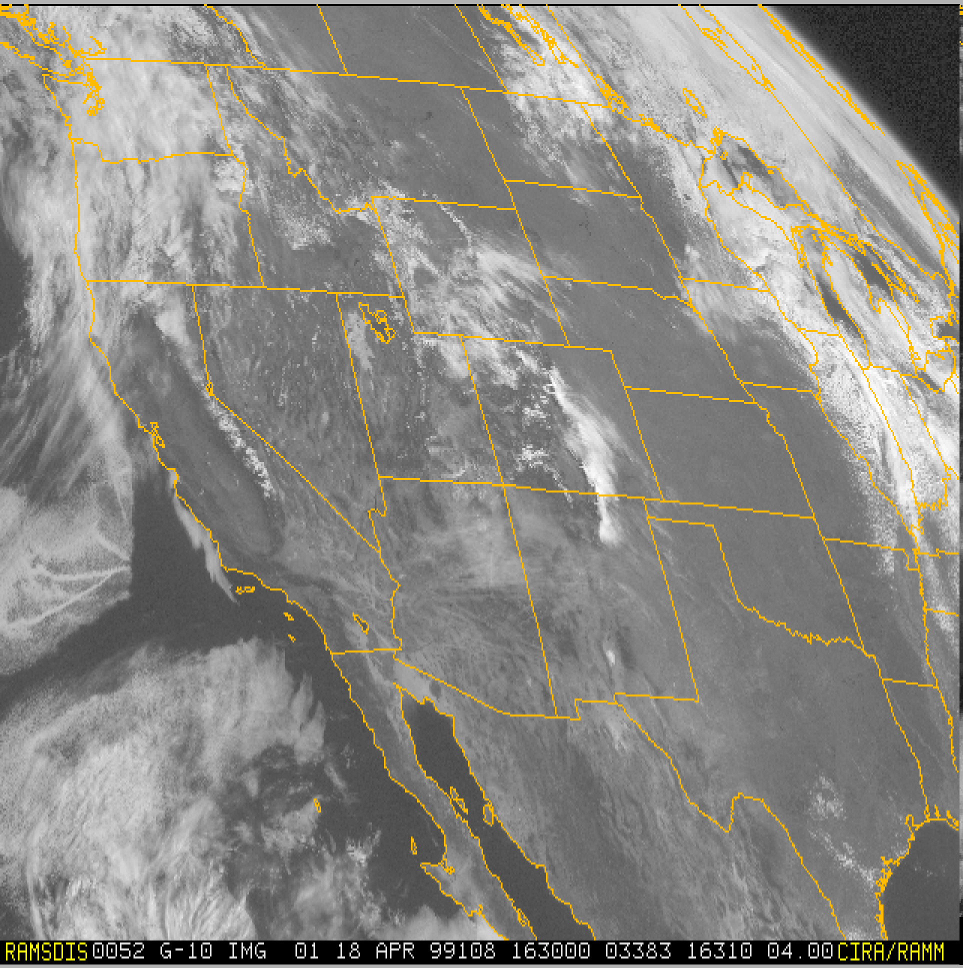
Scattering from water versus ice particles at 3.9 microns

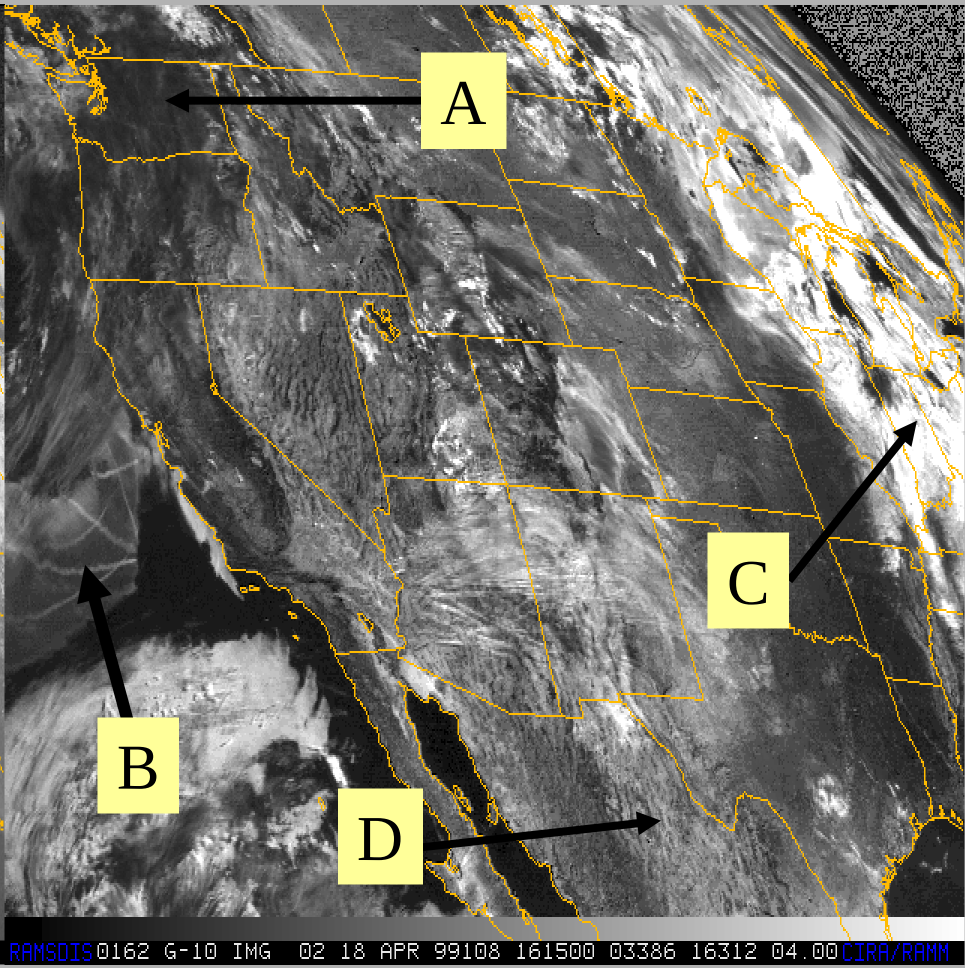
Response of 3.9 vs. 10.7 microns to Temperature variability in a FOV

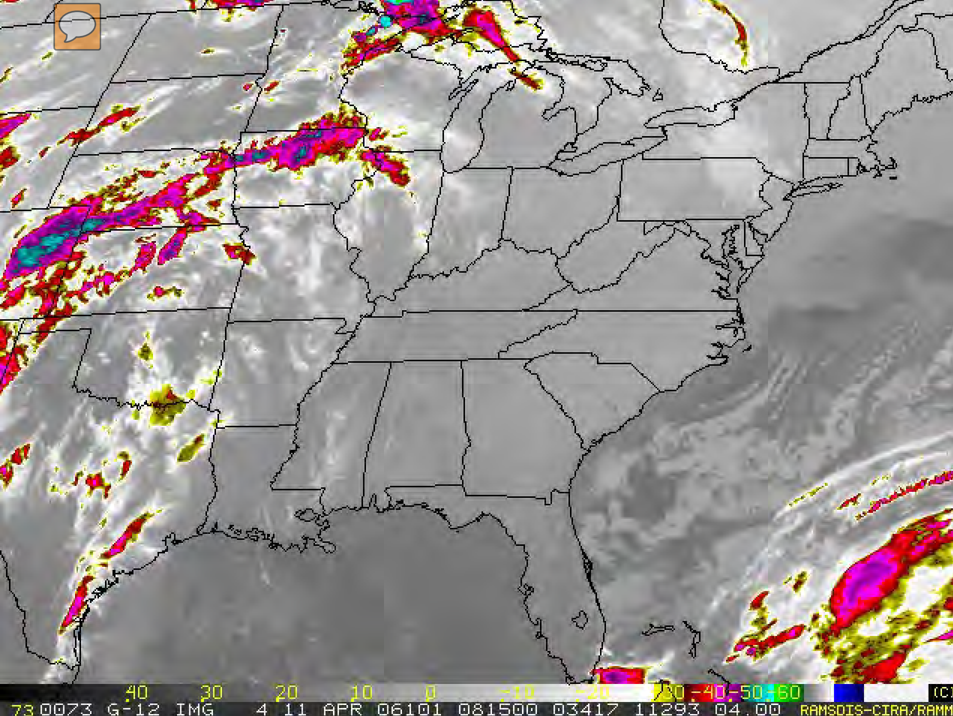
Spectral Awareness, surface characteristics

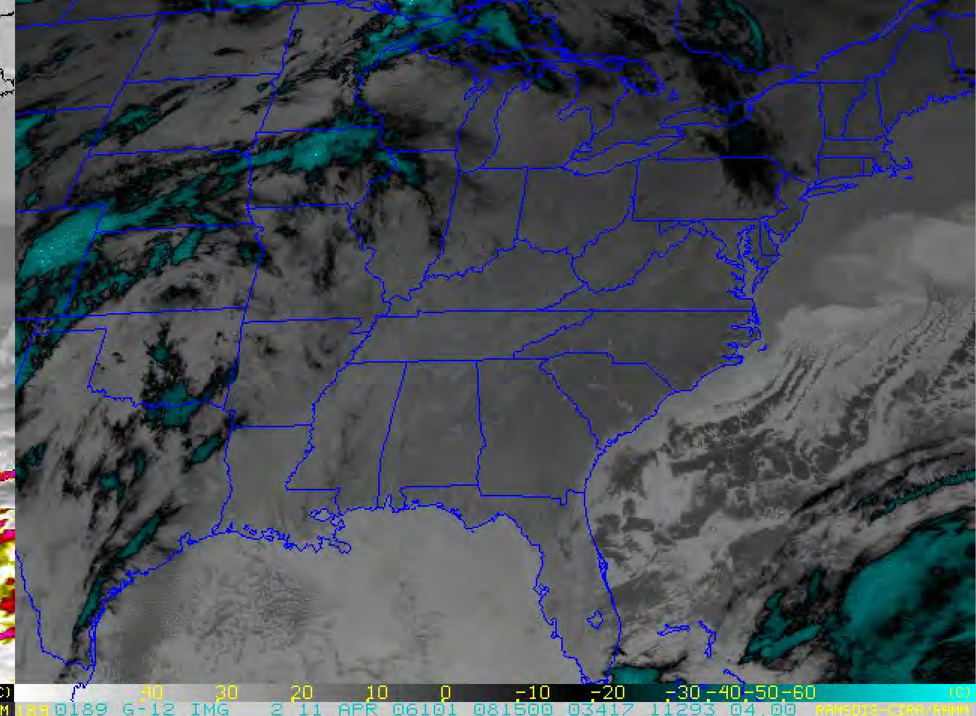


Display and analysis of imagery at short 3.9 microns.
Visible loop (left) and 3.9 micron reflective component loop (right) from GOES-West (aspect ratio not 1:1)
Click on images to start and stop animations.







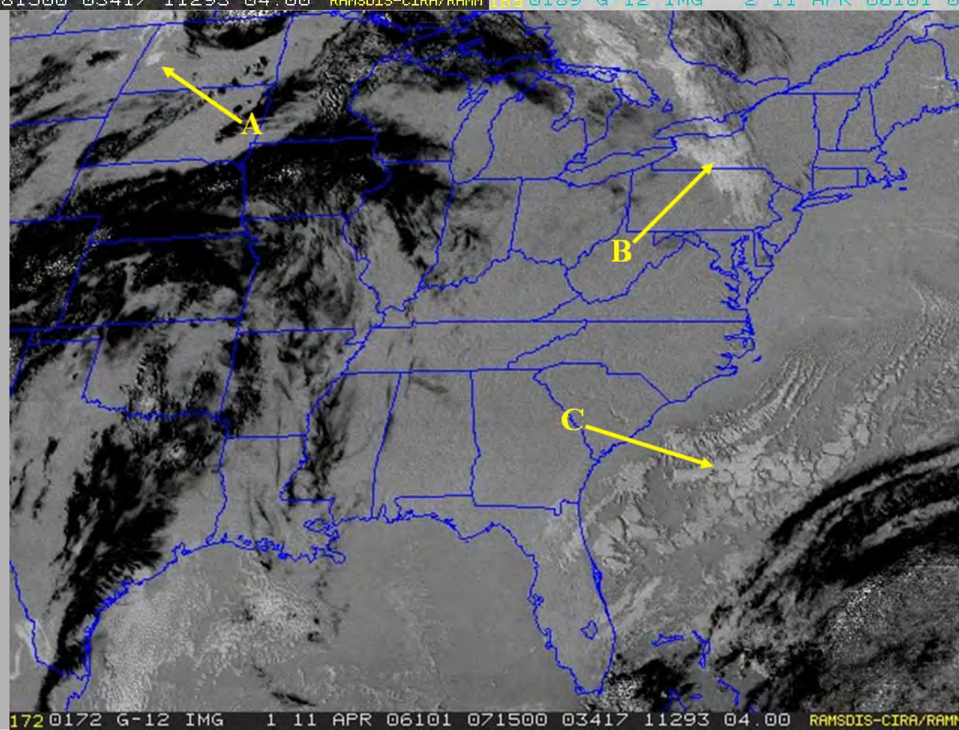


Top left: 10.7 enhanced infrared

Top right: 3.9 enhanced infrared

Bottom: fog product for same time

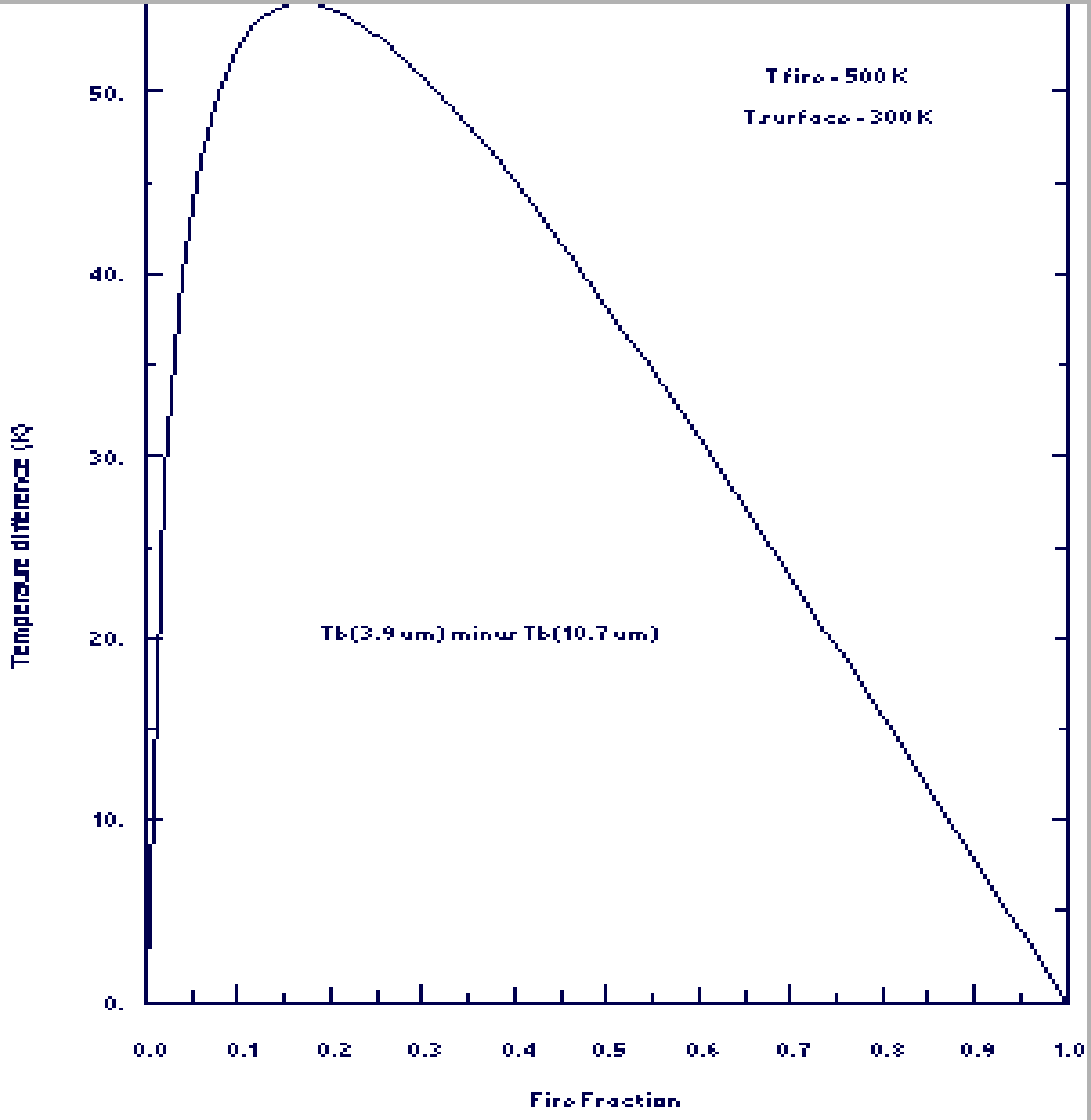
These are nighttime images. White is water cloud and black is ice cloud



B: water cloud with cloud top temperature (CTT) between -12 and – 15C

C: water cloud over ocean with CTT between 5 and 0 C

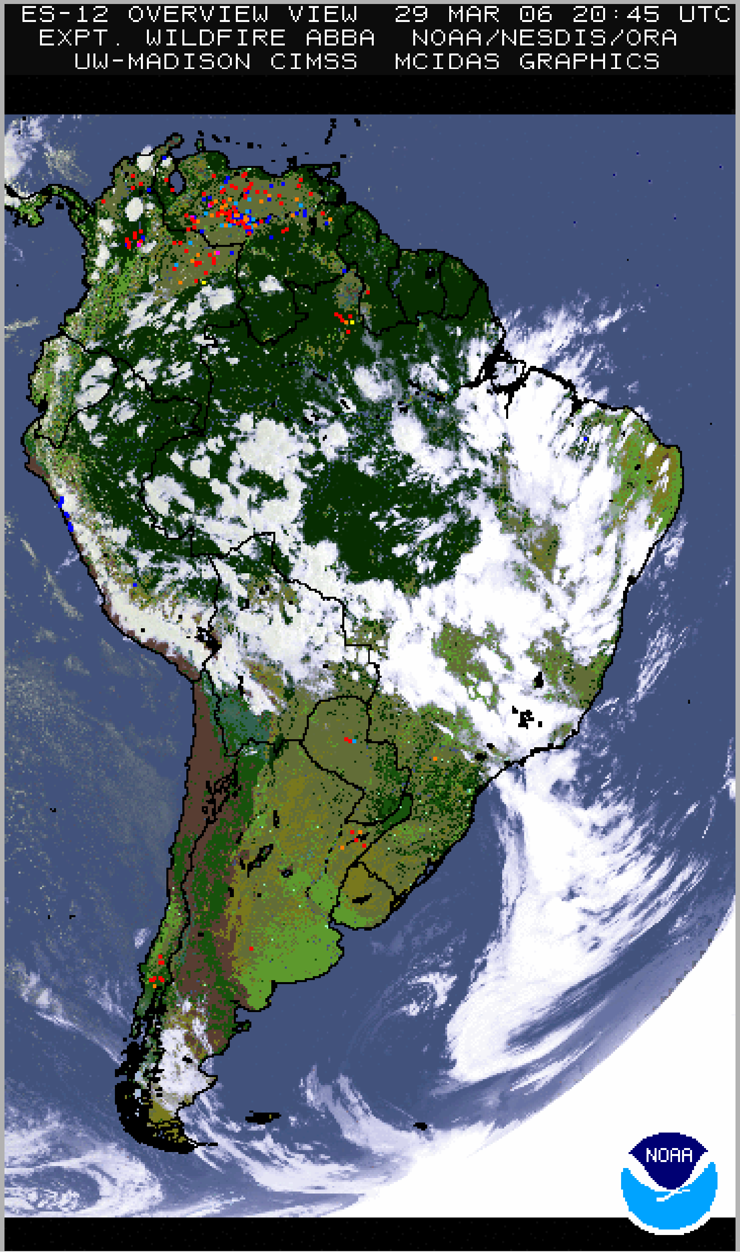
A: fog or stratus with CTT of 4 C

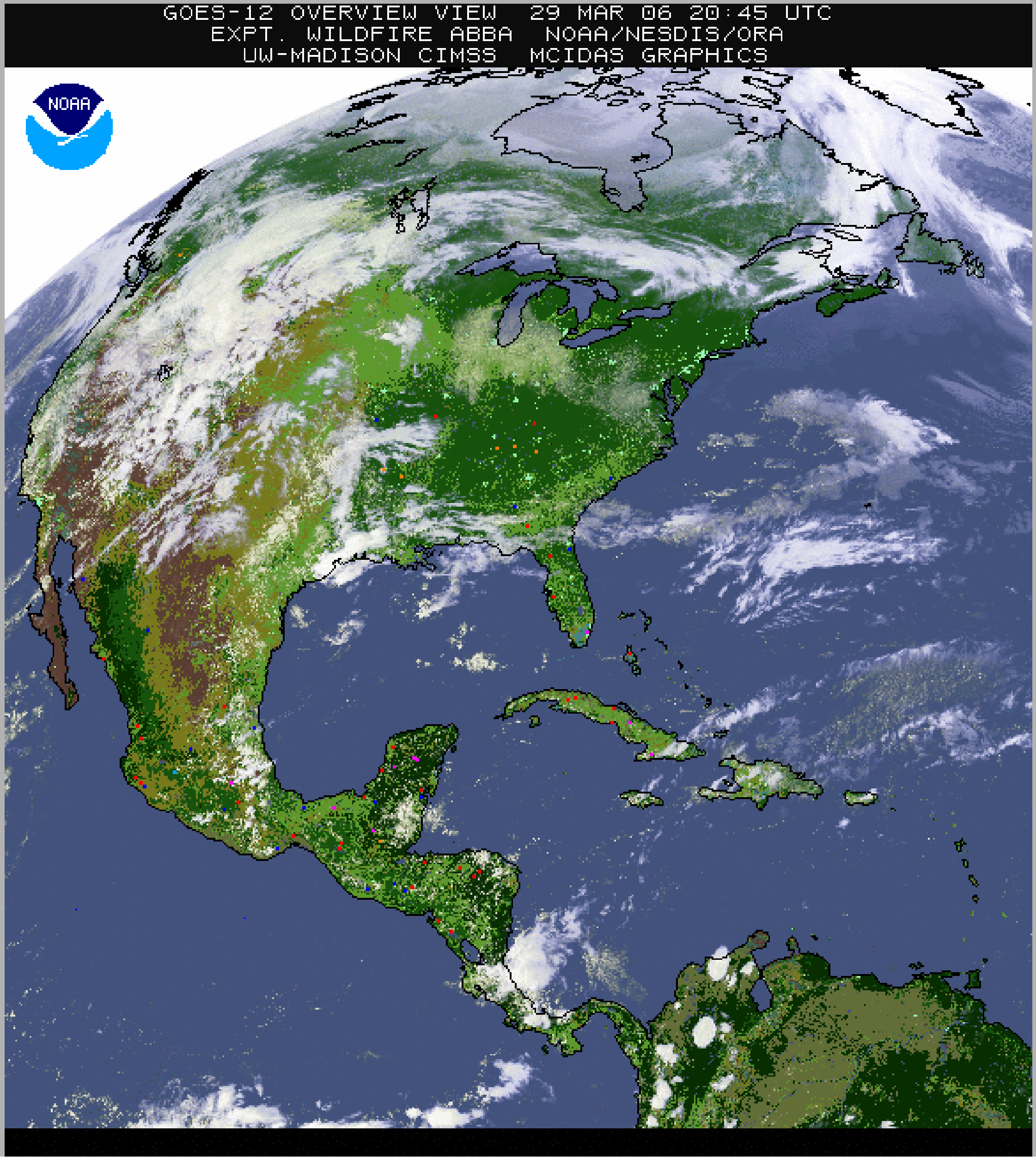


On the left is an example of the difference in temperature measured at 3.9 and 10.7 microns for a partially filled field of view (FOV) for nighttime when there is no solar reflection. In this example, the hot-area is at 500 K and the remainder of the pixel is at 300 K.

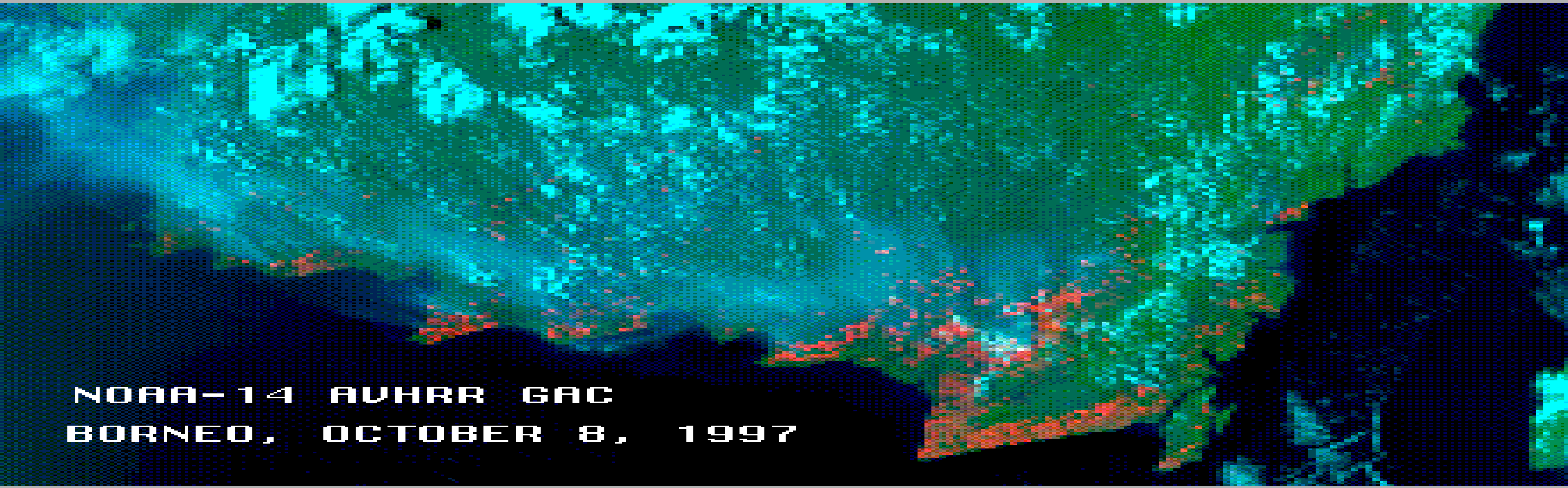
Geostationary fire coverage at frequent intervals

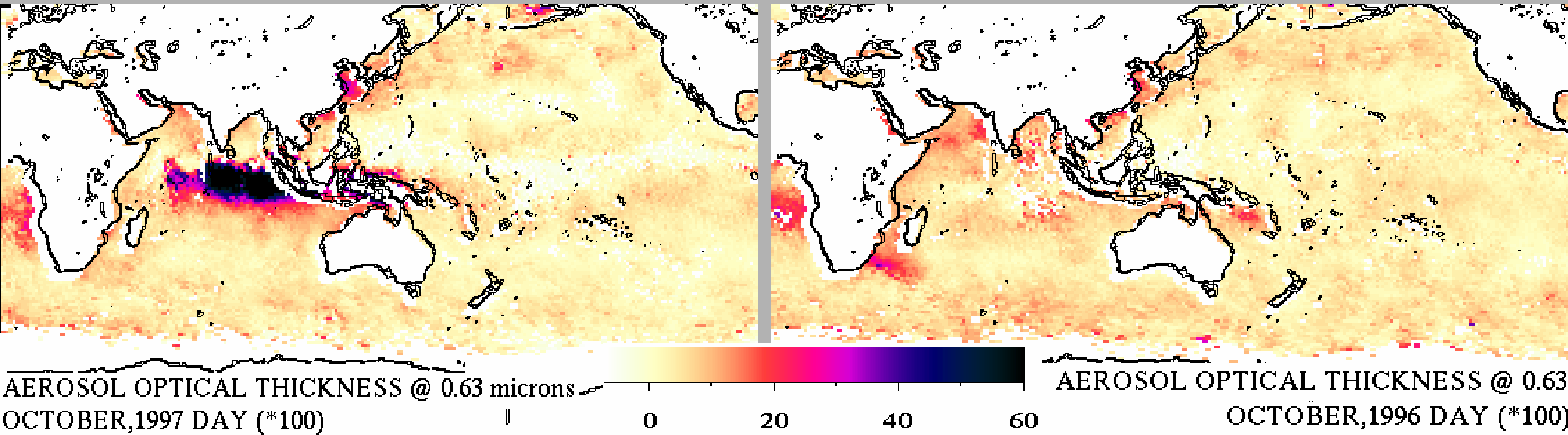
Pixels with fires within the field of view are red



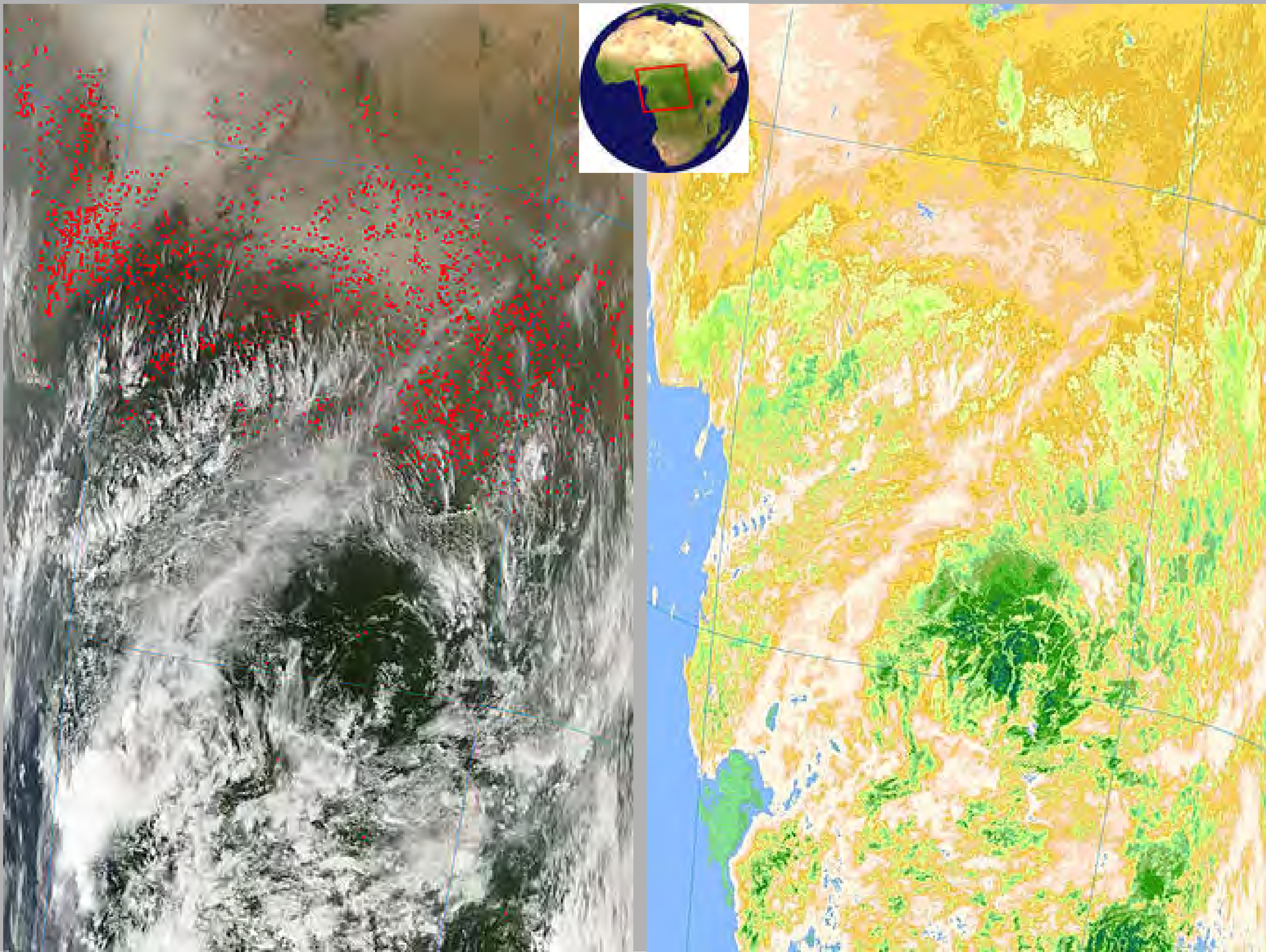


Fires detected on October 8, 1997, using AVHRR over Borneo, and aerosols over region in mid-October 1996 versus mid-October 1997

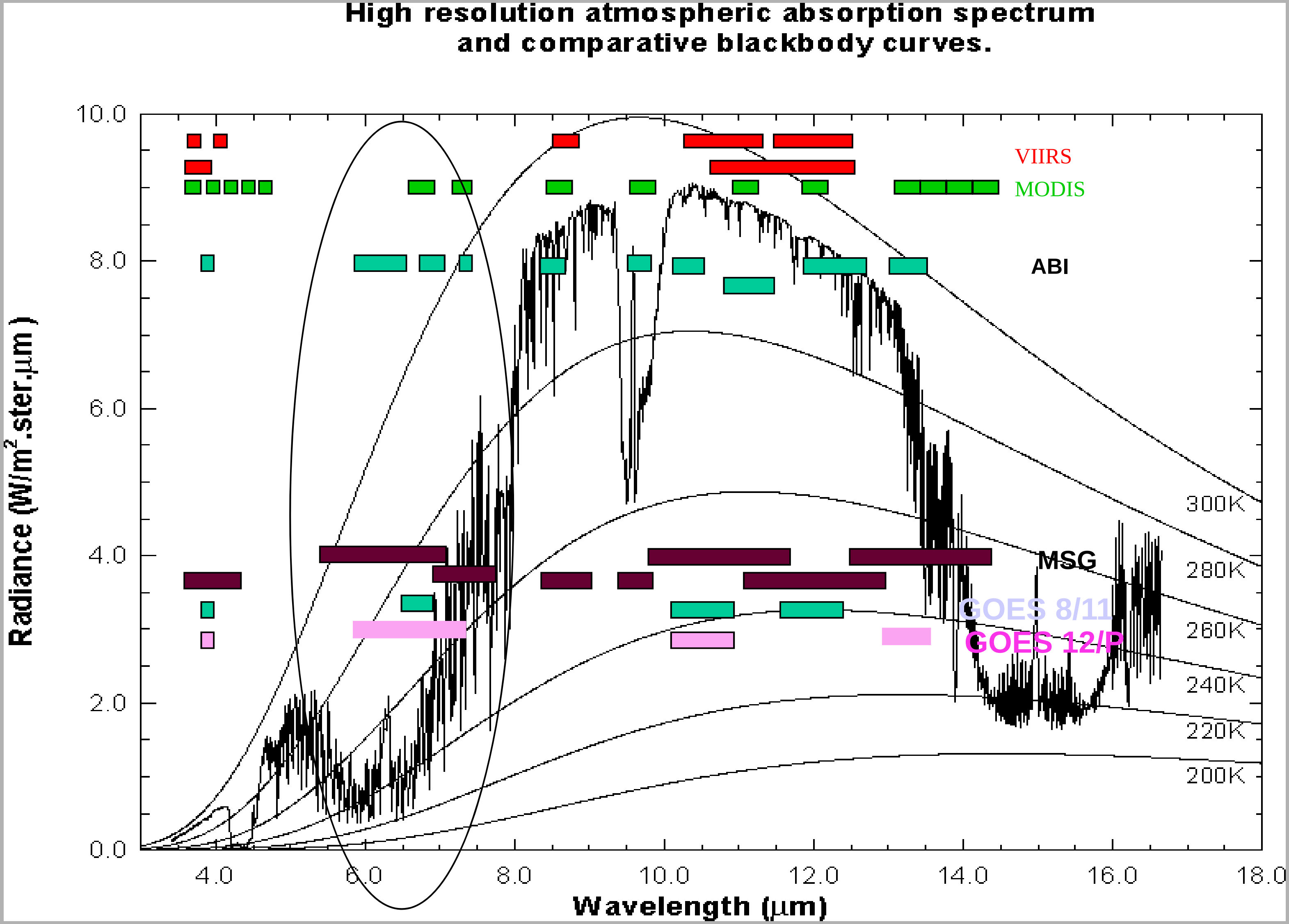




Fires detected by MODIS over Africa (left) and NDVI (right)

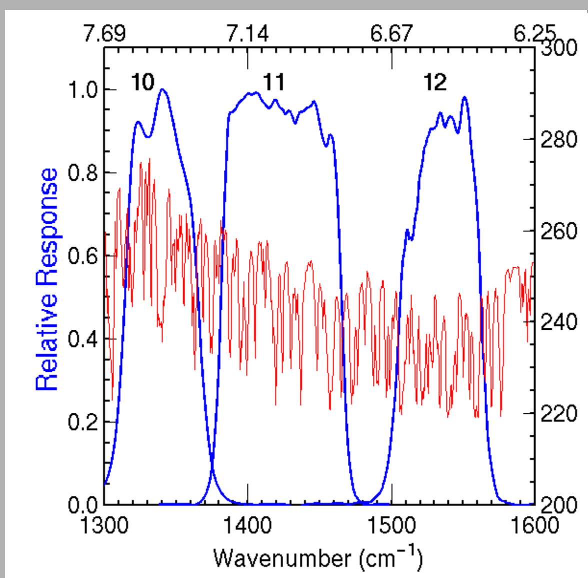


Earth emitted spectra overlaid on Planck function envelopes

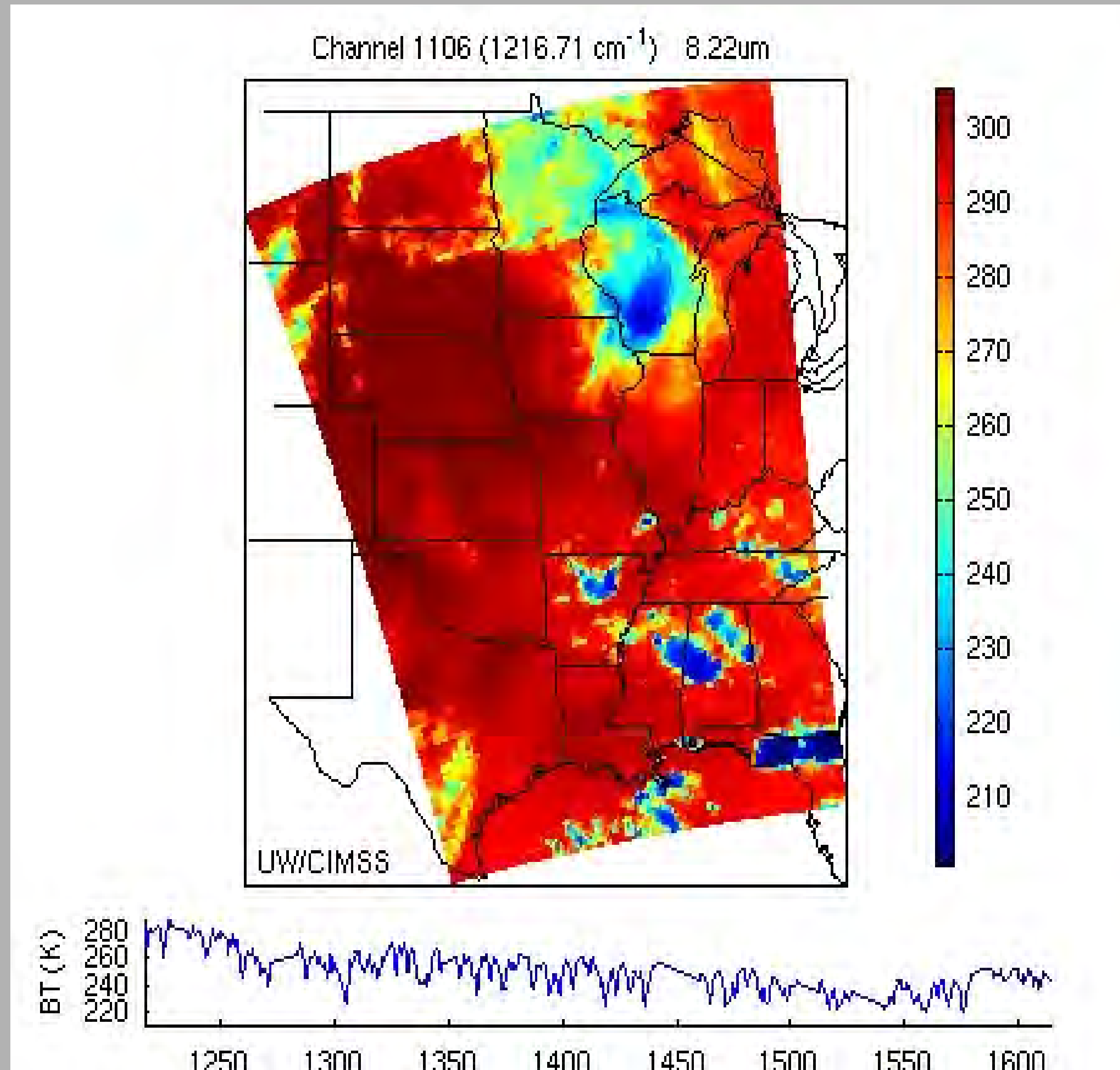


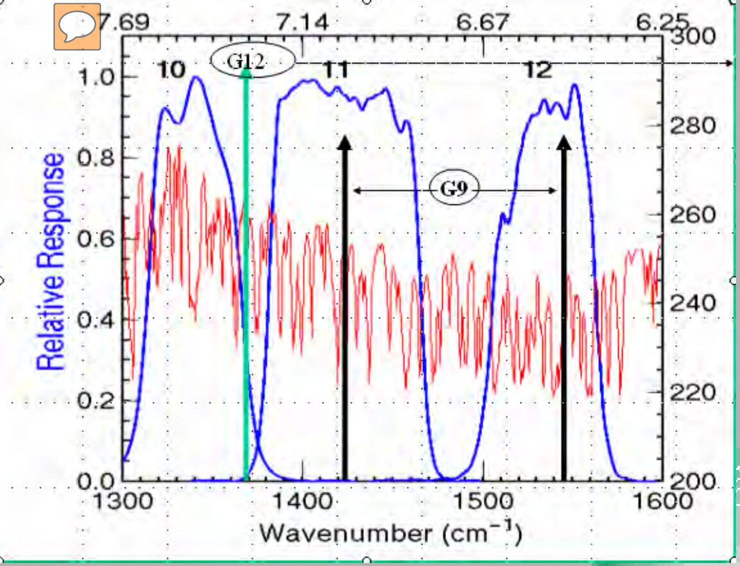
The strong water vapor absorption region

High Spectral Resolution ($AIRS$) resolves H_2O Spectral Features (right). Click image to animate. This animation immediately illustrates the advantage for many applications of very high spectral resolution versus broad channels.



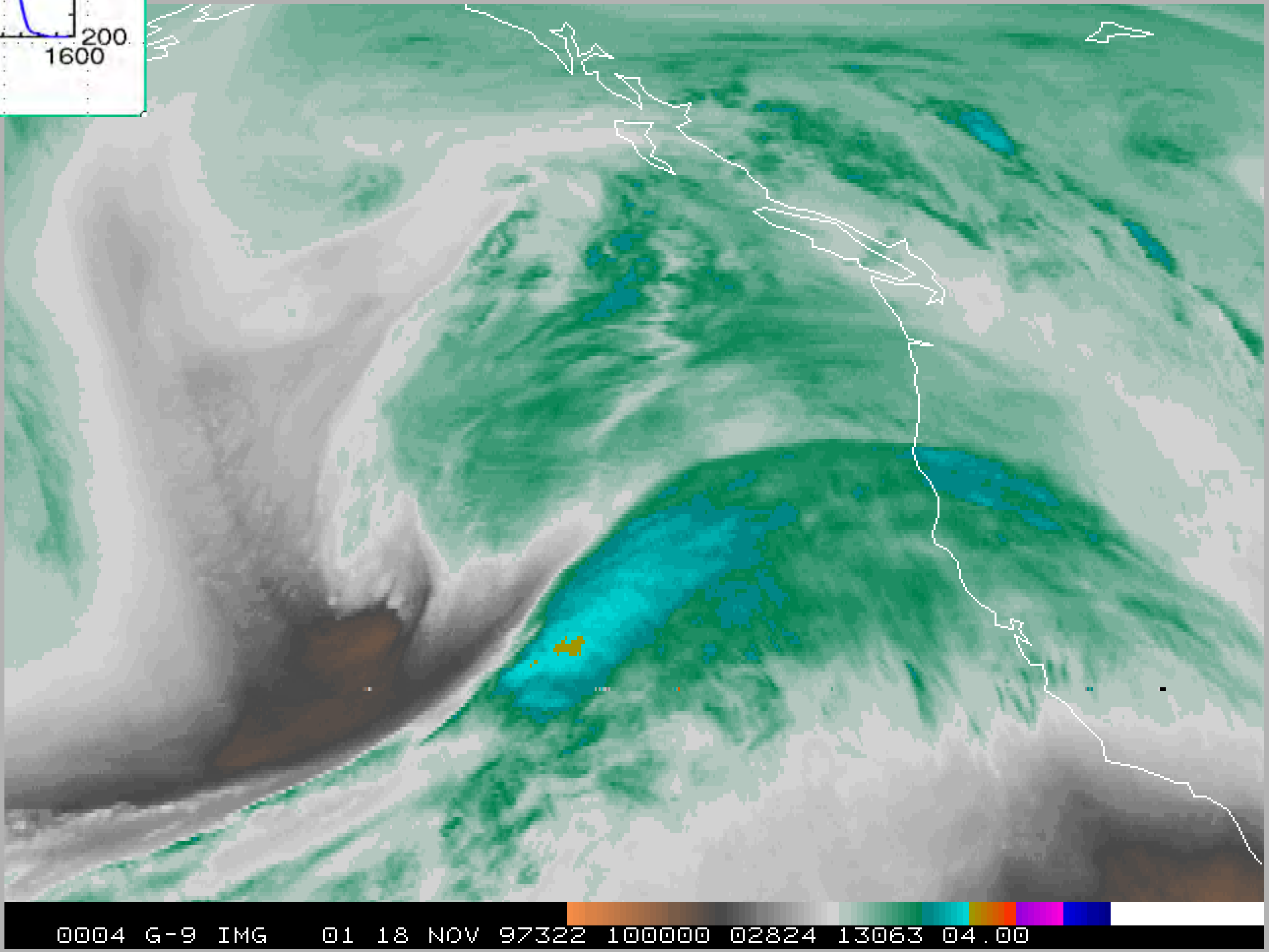
GOES-I/M era sounder H_2O Channels (above)



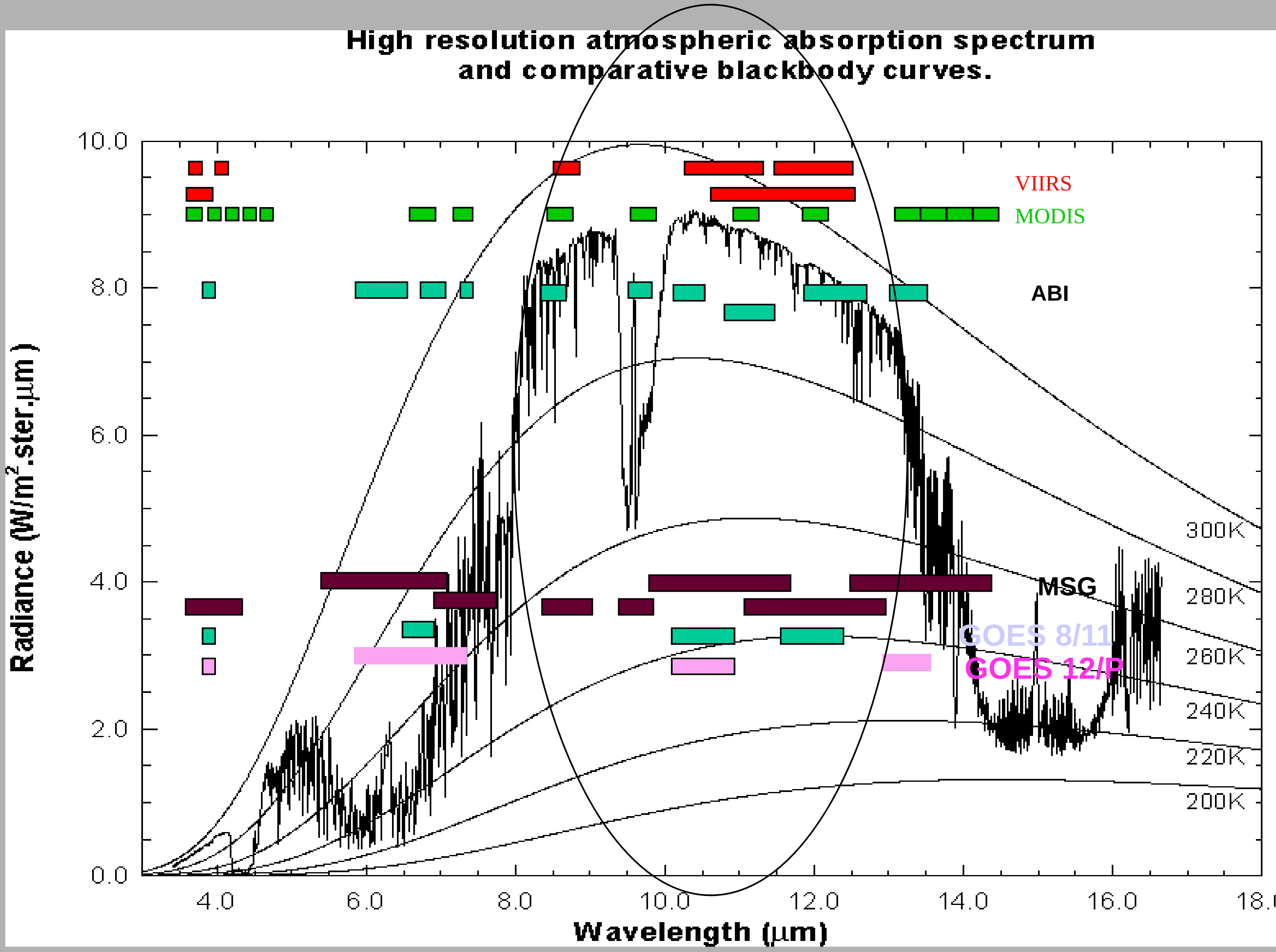


GOES-9 6.7 micron infrared (water vapor channel) movie loop: a broadband channel that extends from 6.47 to 7.02 microns

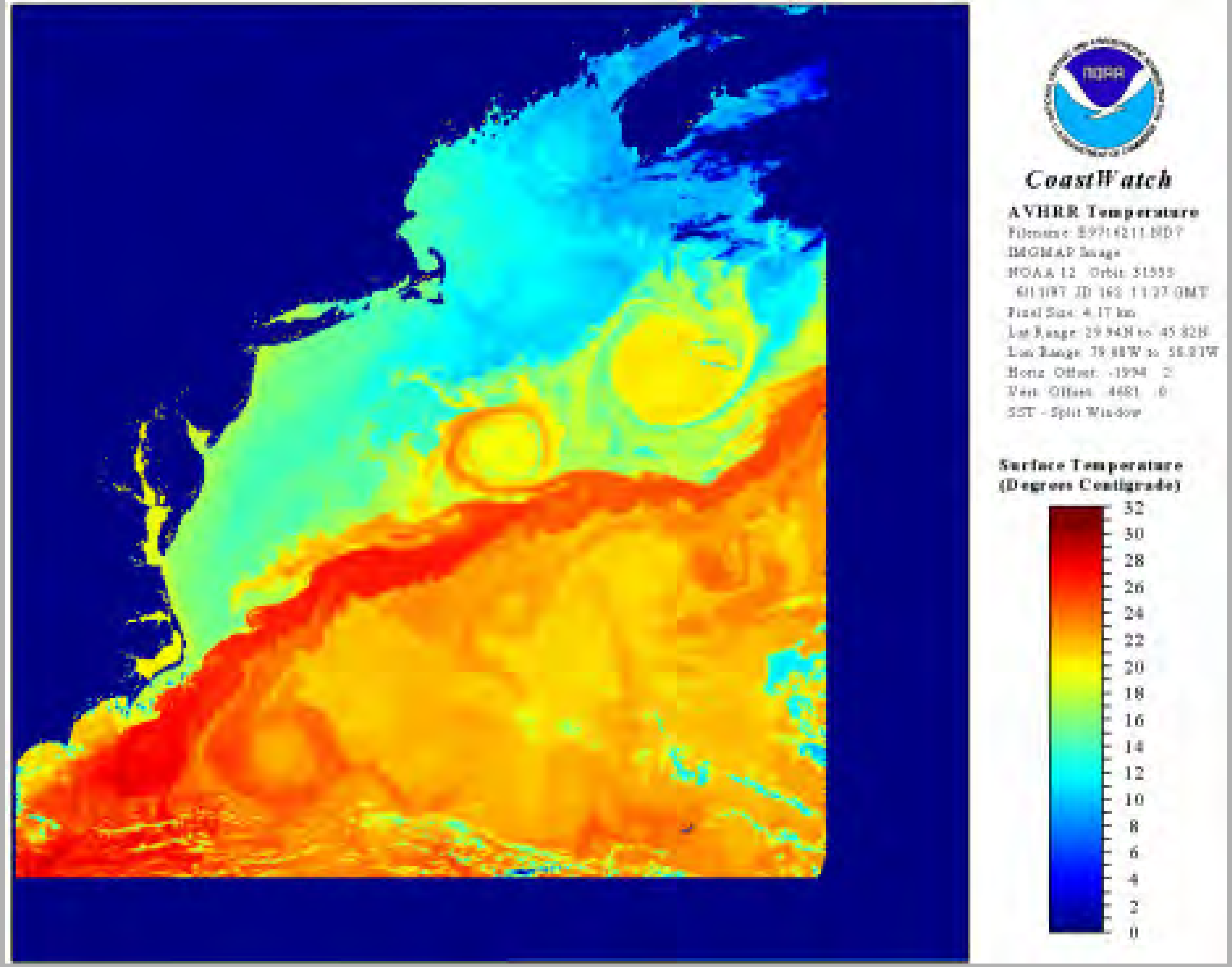
With GOES-12 the broadband water vapor channel spectral rage was increased to span the interval 5.8 to 7.3 microns



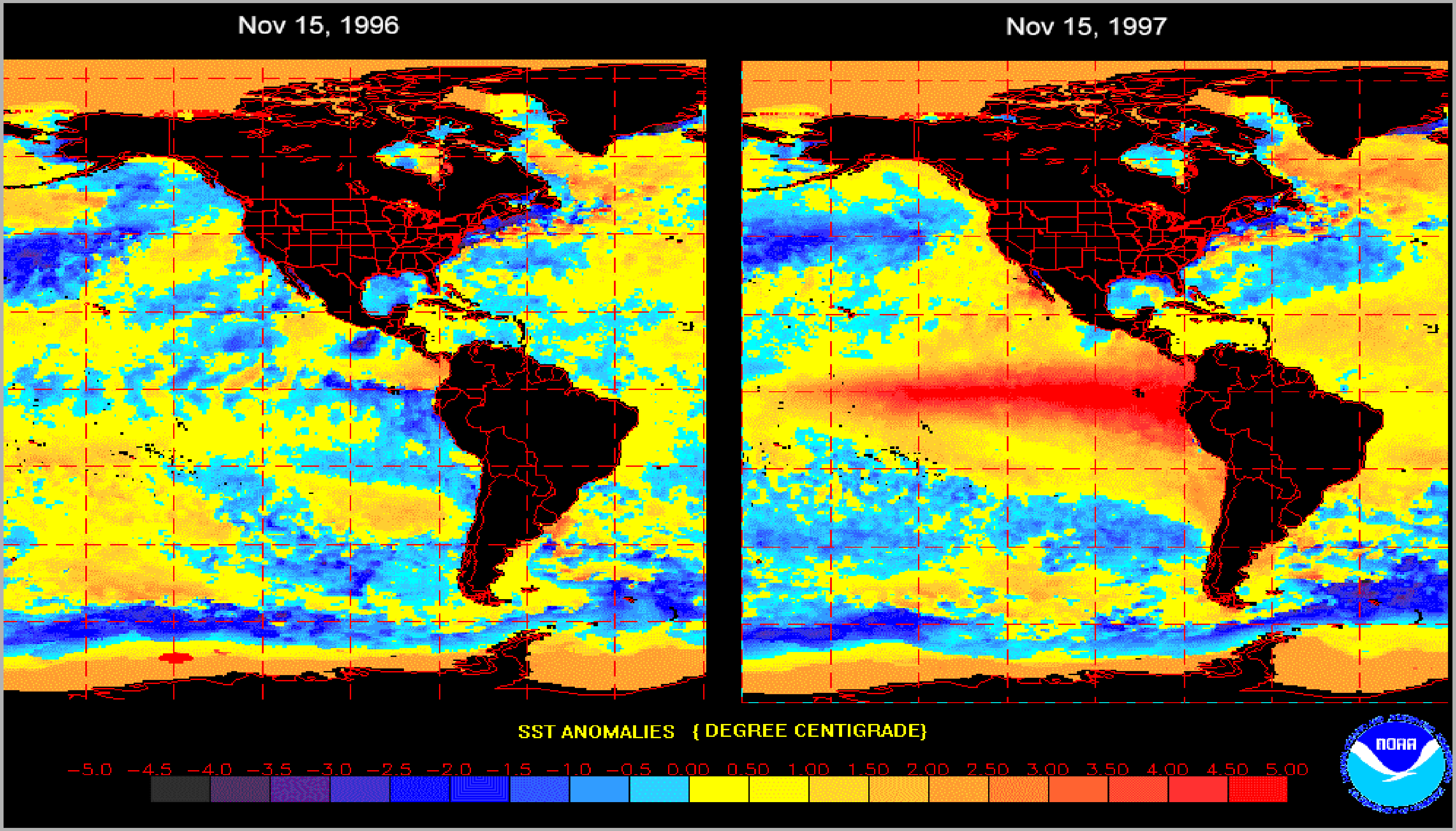
Earth emitted spectra overlaid on Planck function envelopes



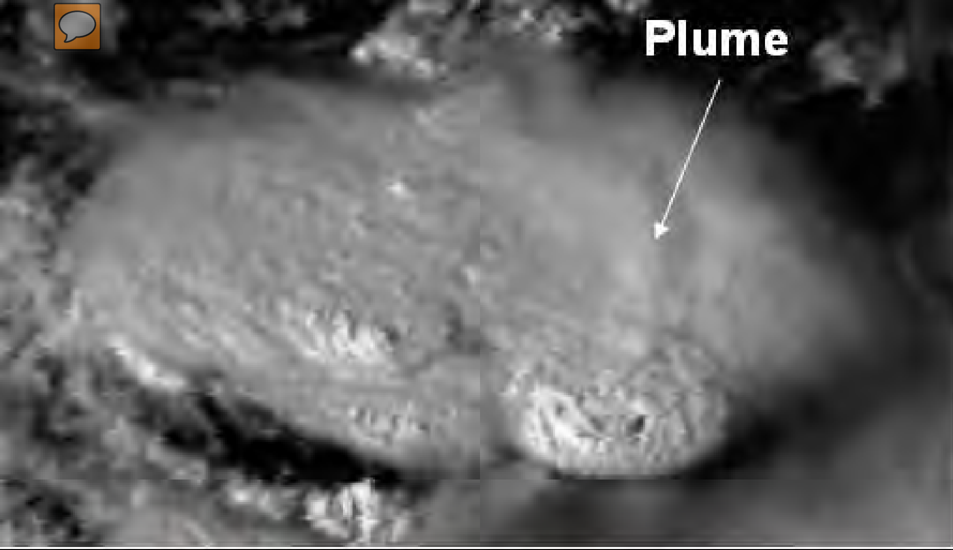
The infrared window regions and ozone absorption area



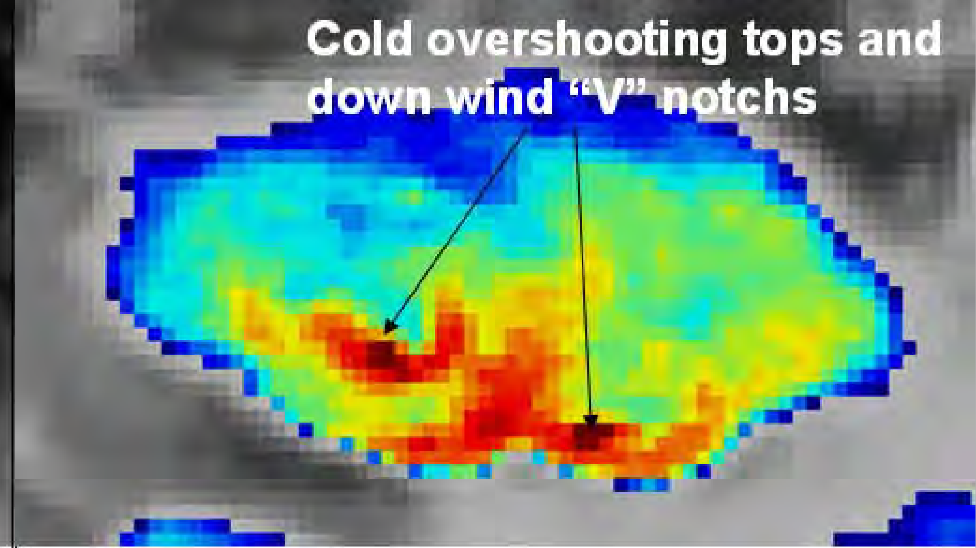
AVHRR Sea surface Temperature product produced by CoastWatch. This picture is over he Atlantic Ocean off of the East Coast of the United States. Notice the strong temperature gradient across the boundary of the Gulf Stream and warm eddies that have broken off and migrated into the colder waters.



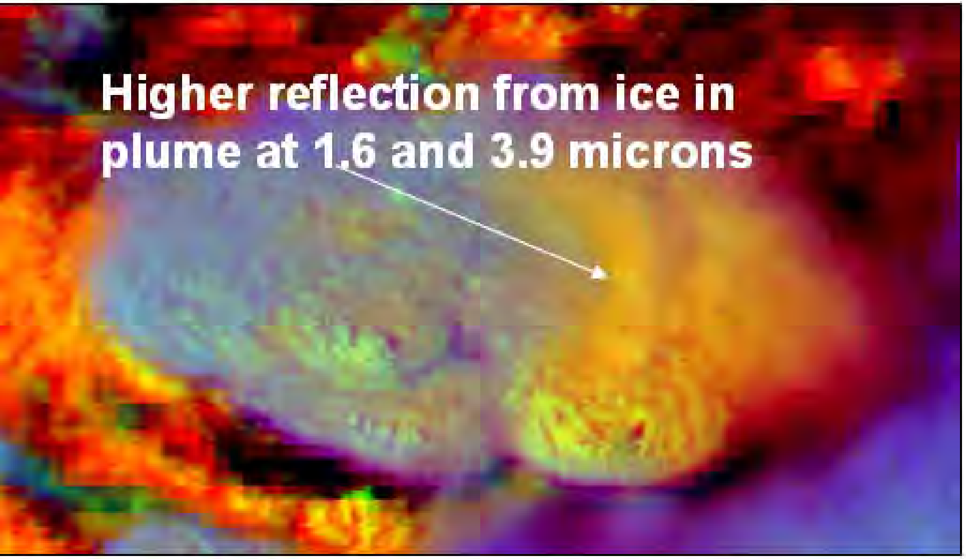
AVHRR Sea Surface temperature Anomalies (Deg. C)
November 1996 vs November 1997



MSG High Resolution Visible (HRV)



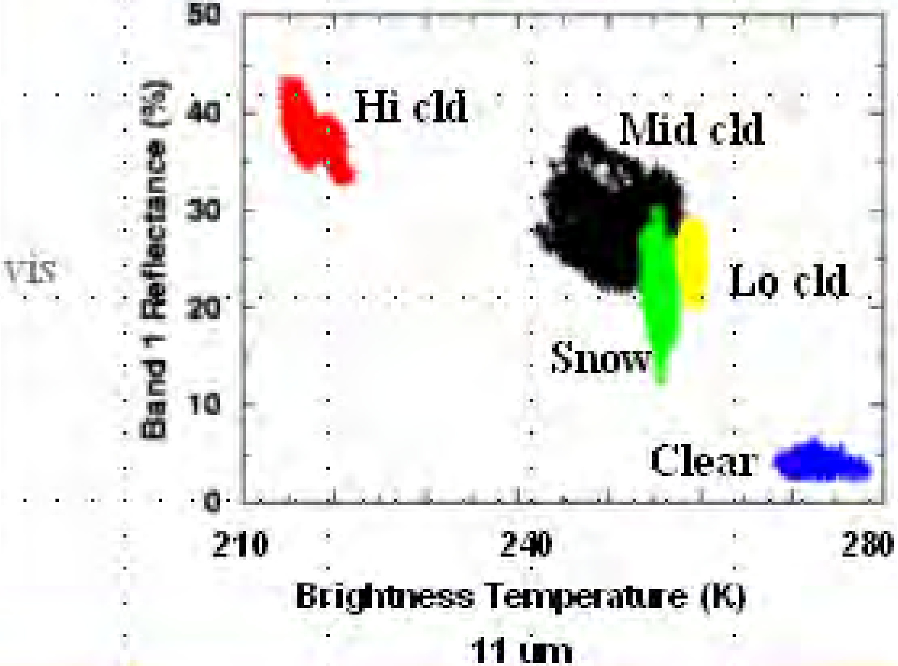
MSG Enhanced 10.7 micron IR

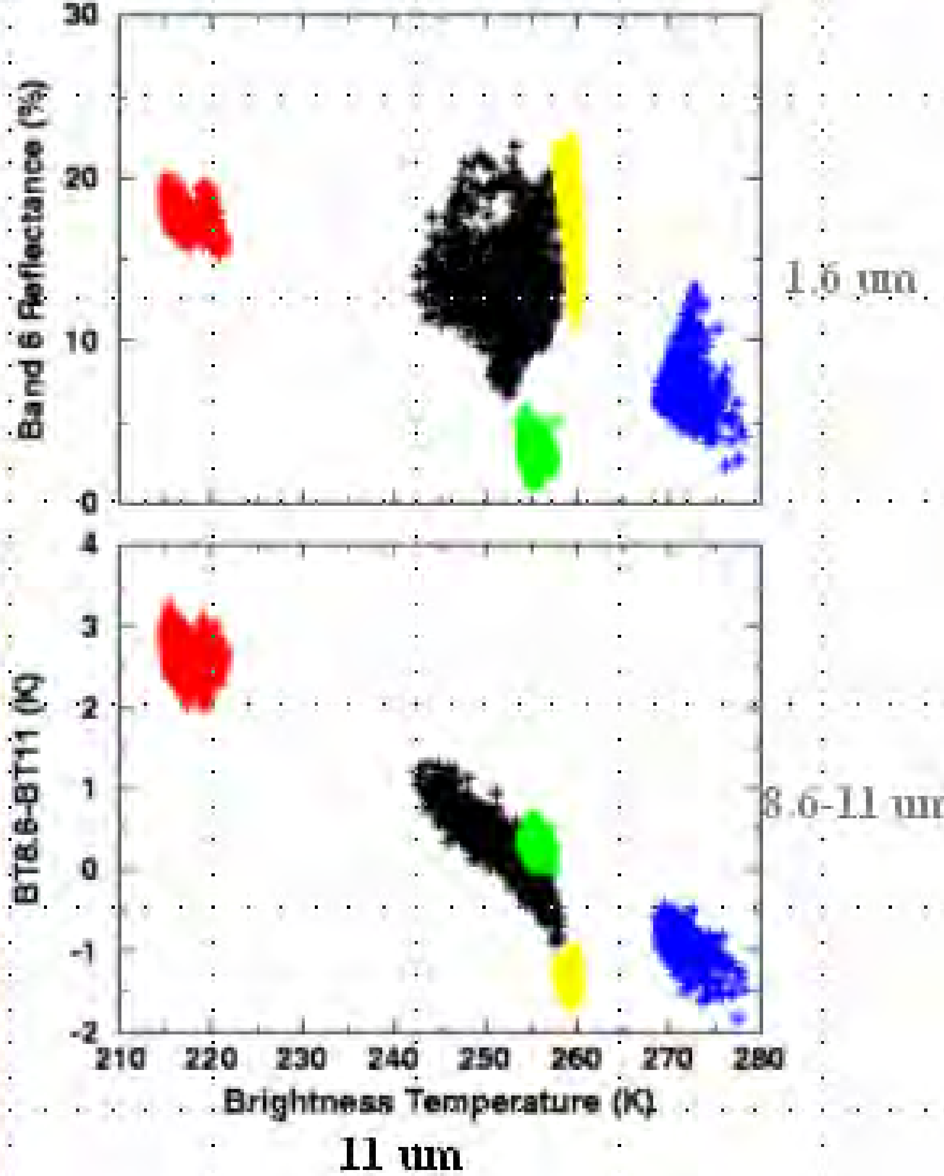


MSG 3 channel color image using HRV, 1.6 and 3.9 micron channel data

Figure 27: Thunderstorm tops over Europe from MSG on 29 July 2005 at 14:30 UTC. This case, presented by Martin Sevtak at the EUMETSAT Users' Conference showed higher reflection from ice in the plume at thunderstorm top in 1.6 and 3.9 microns, likely due to smaller cloud particle size and related to updraft characteristics. Cold over-shooting top and "V" notches are clearly shown in the 10.7 channel image, as are the plume brighter reflection from the right-most storm.

Clouds separate into classes when multispectral radiance information is viewed

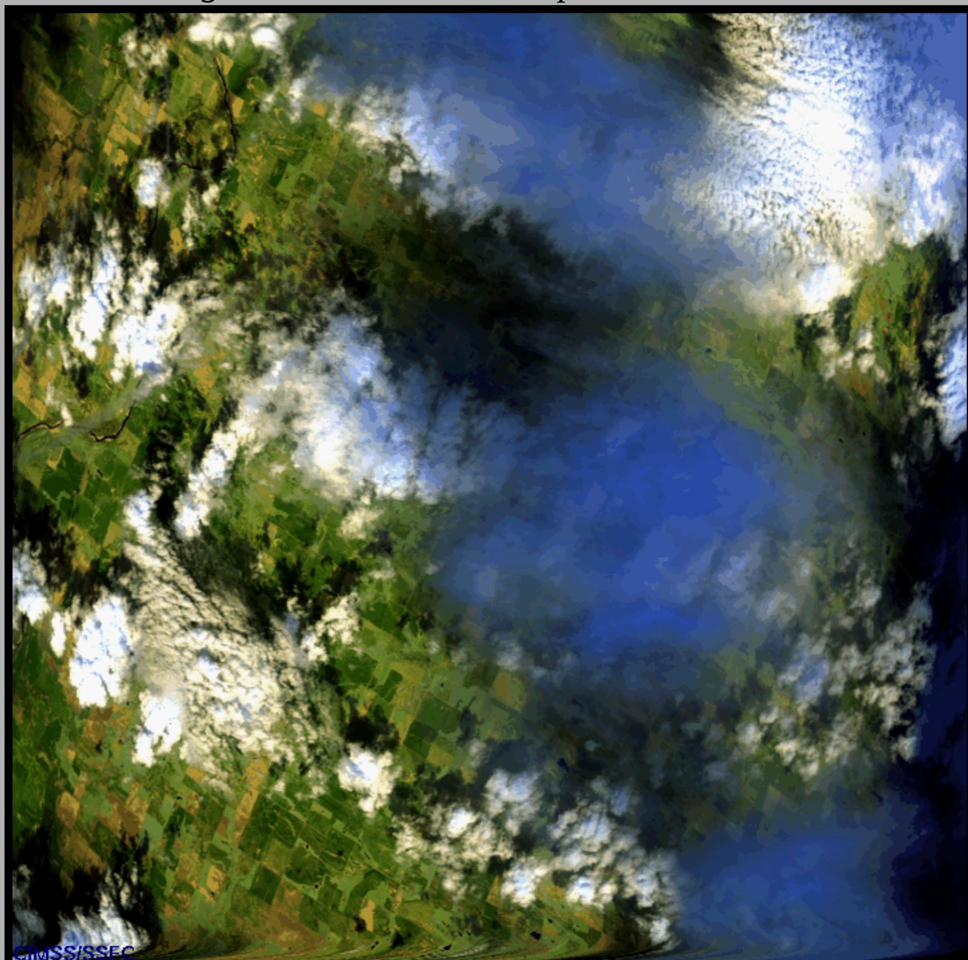


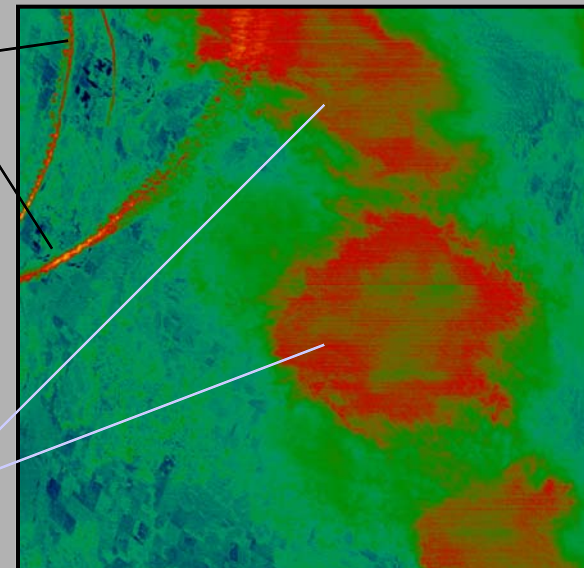


These three scatter plots illustrate how different types of clouds, snow and clear ground have different spectral signatures when plotted against 11 µ brightness temperature.

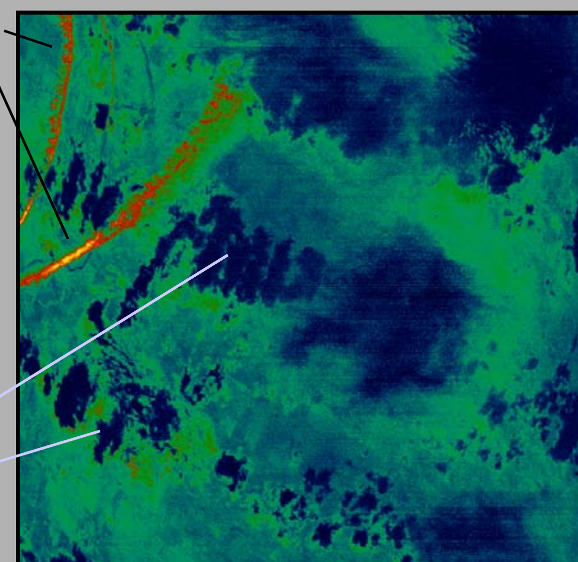
Cloud Composition

Image Over Kansas - 21 April 1996

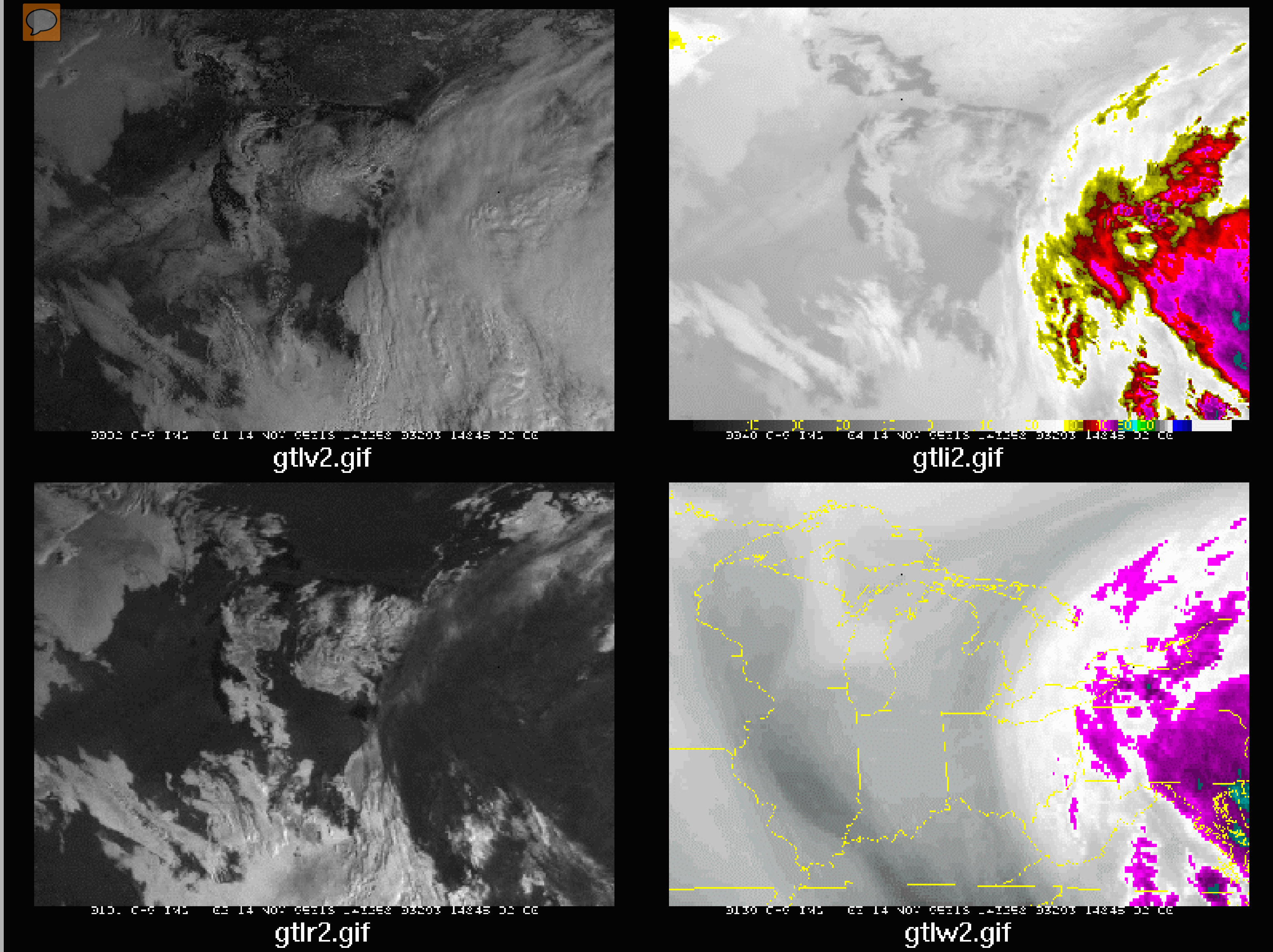




Infrared Temperature Difference - 8.6 μm (Band 29) - 11.0 μm (Band 31)



Infrared Temperature Difference - 11.0 μm (Band 31) - 12.0 μm (Band 32)

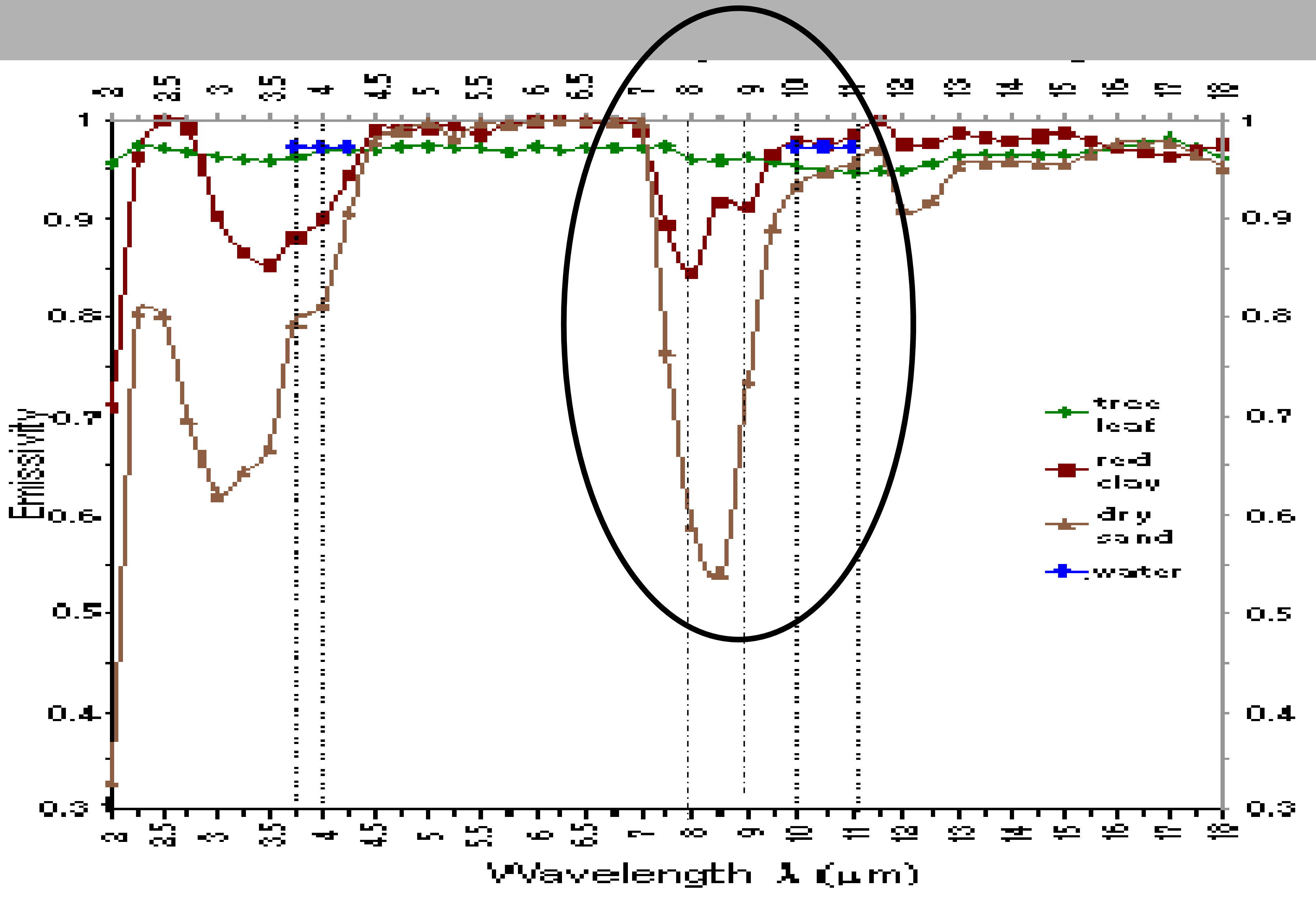


Four panel GOES image over the middle United States.

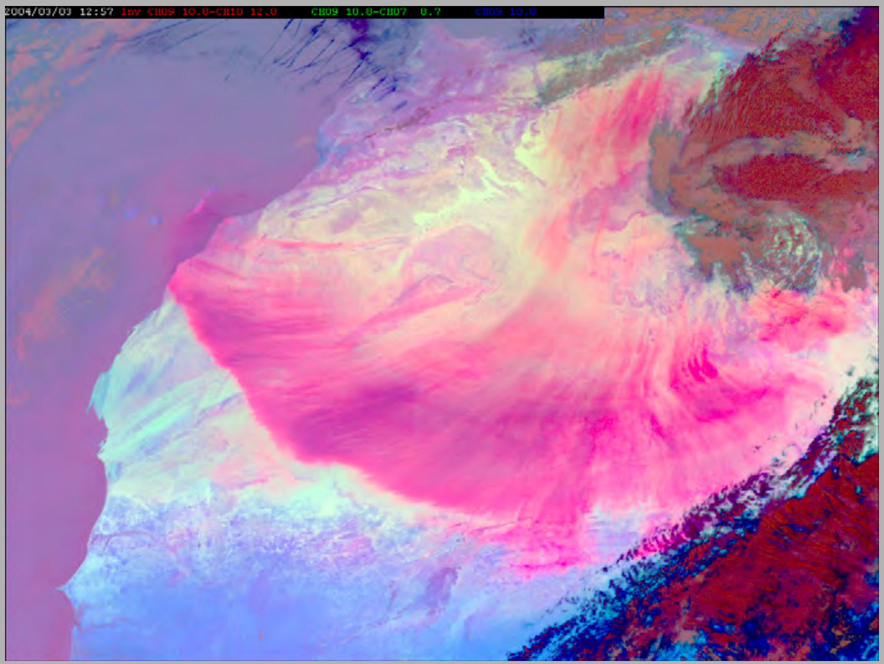
Click on image to animate.

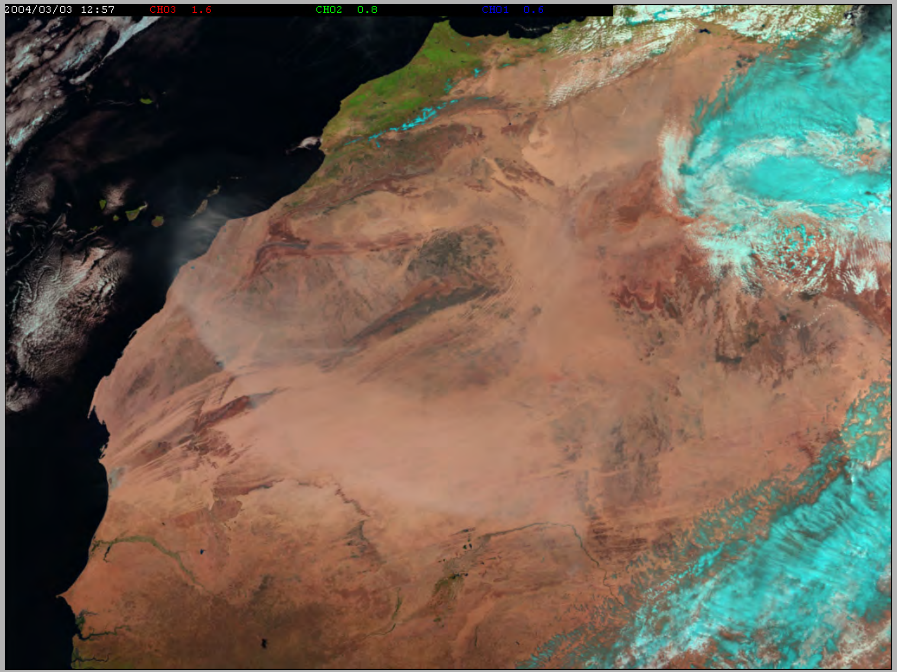
Visible is upper left; enhanced 10.7 micron infrared is upper right; reflective portion of 3.9 micron channel is lower left; enhanced 6.7 micron infrared water vapor is lower right.

Spectral Awareness, surface characteristics



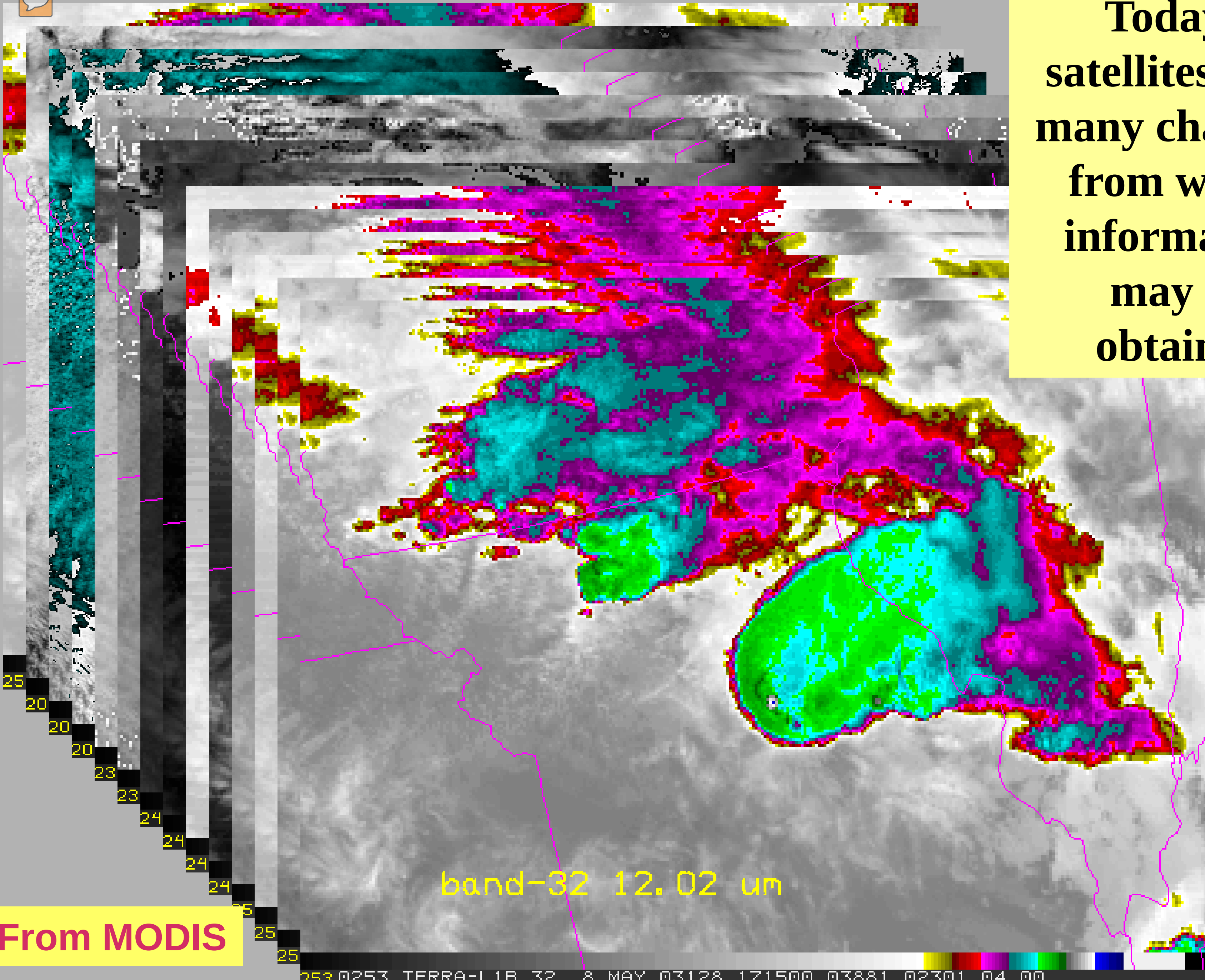
METEOSAT-8 (MSG) detection of large dust storm over Africa using visible to near IR (right) and IR (left) channel combinations



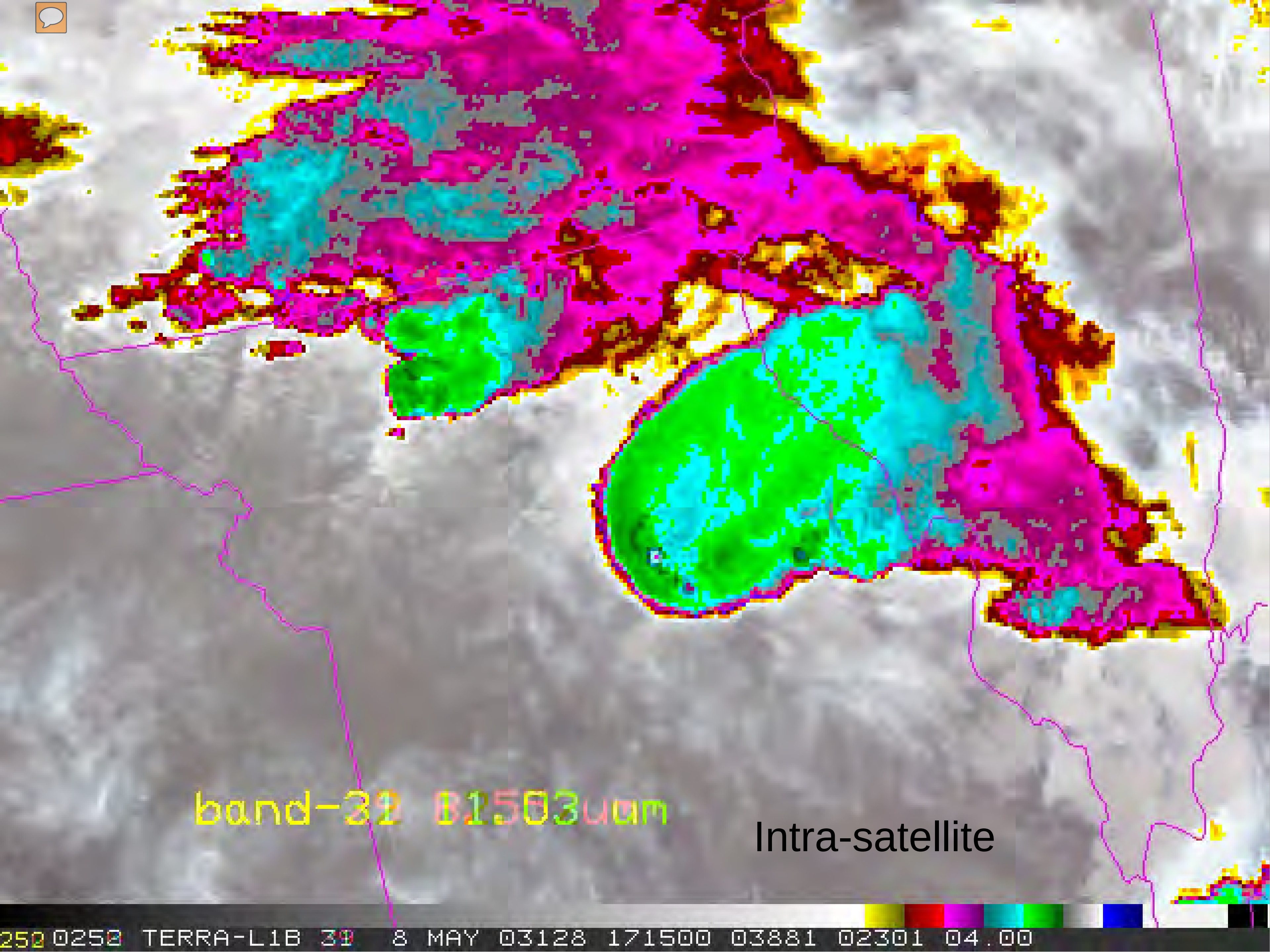


False color images from MSG channels. Left: 12.0-10.8 (R), 10.8-8.7 (G), 10.7 (B). Right: 1.6 (R), 0.8 (G), 0.6 (B). Click on either image to view animation.

Today’s satellites have many channels from which information may be obtained

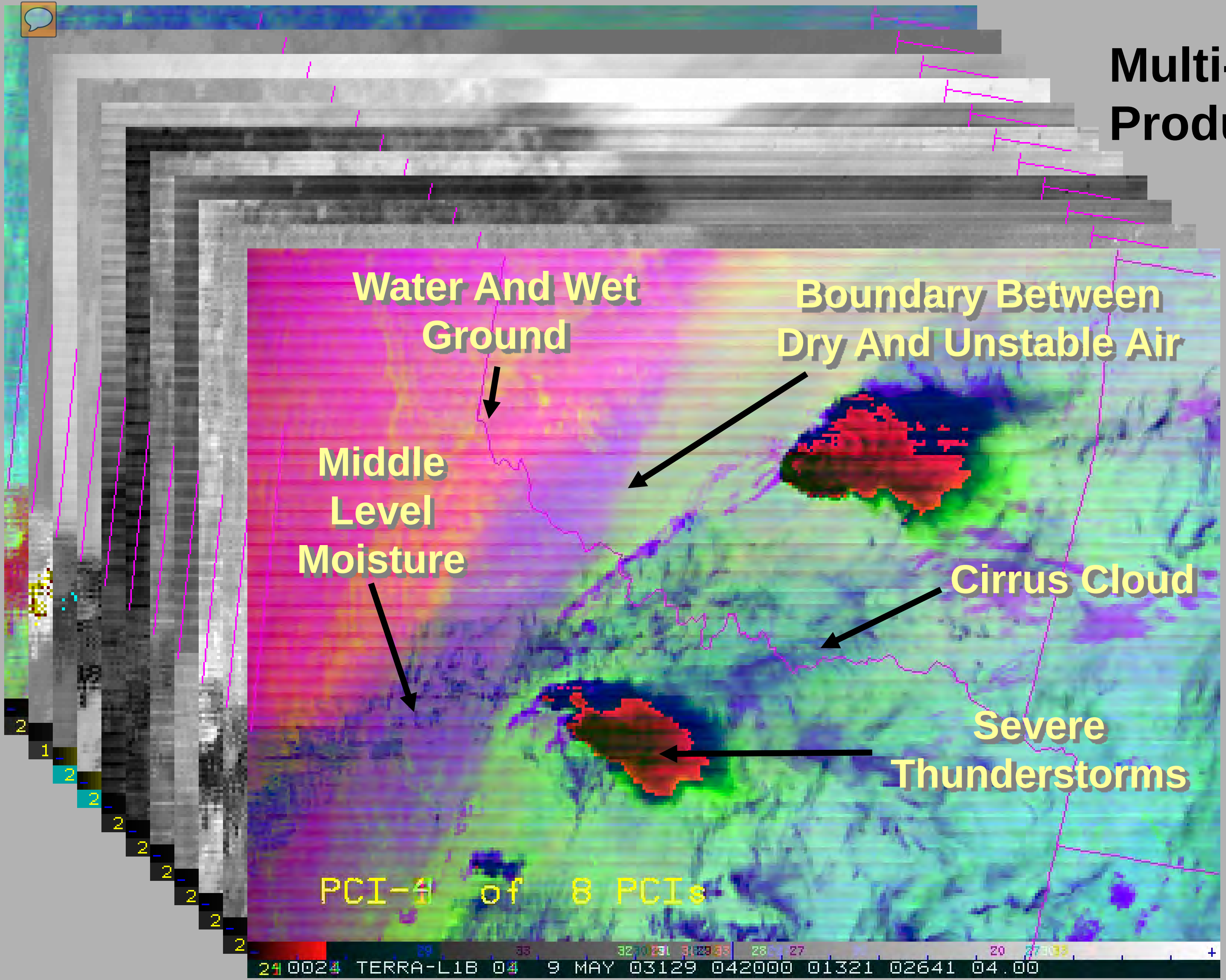


From MODIS



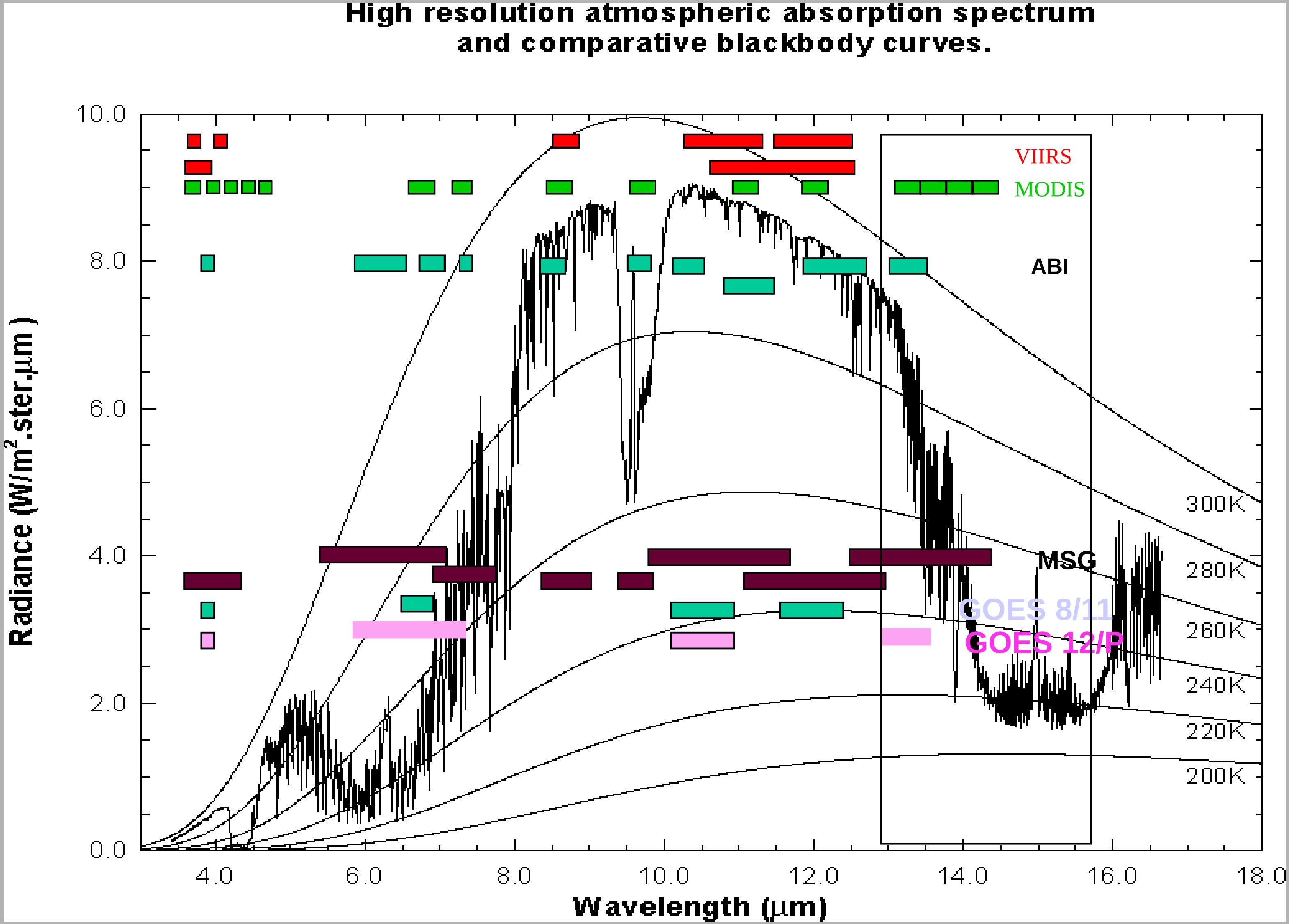
Intra-satellite
TERRA-L1B
8 MAY 03128 171500 03881 02301 04.00

Multi-channel Product

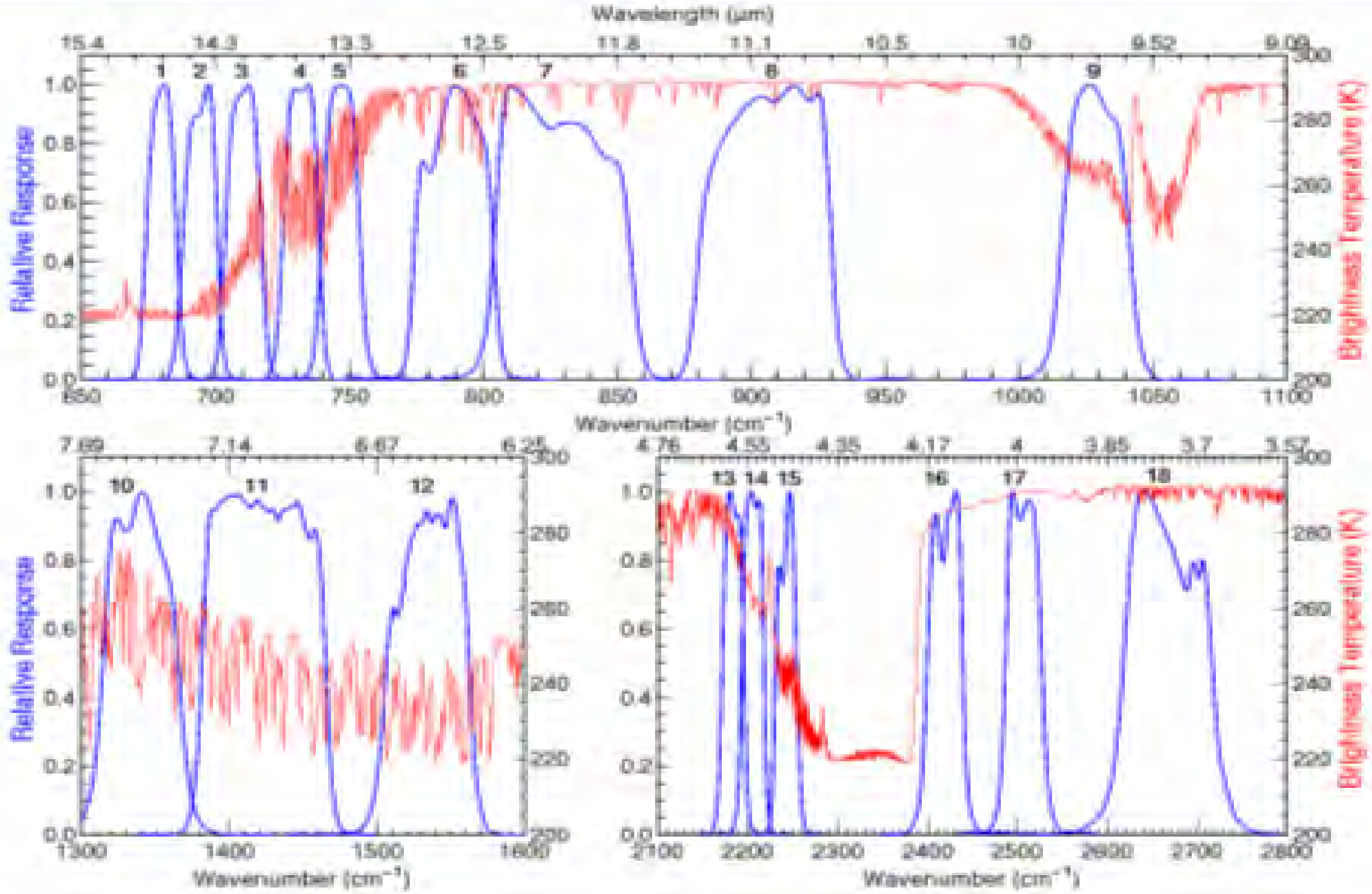


Products based on mathematical analysis of multi-channel images – we can do now with MODIS and MSG!

Earth emitted spectra overlaid on Planck function envelopes

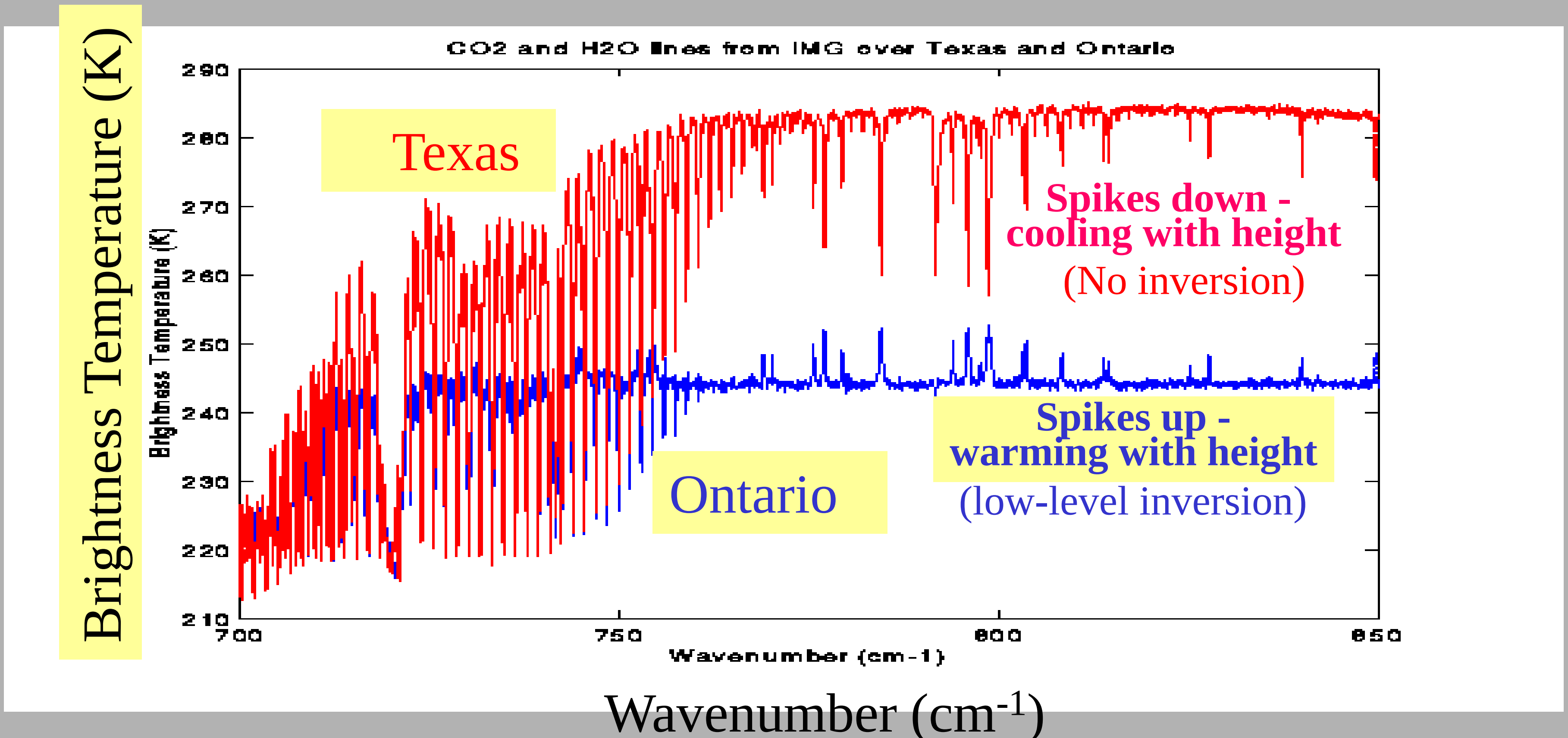


The longwave CO_2 absorption region



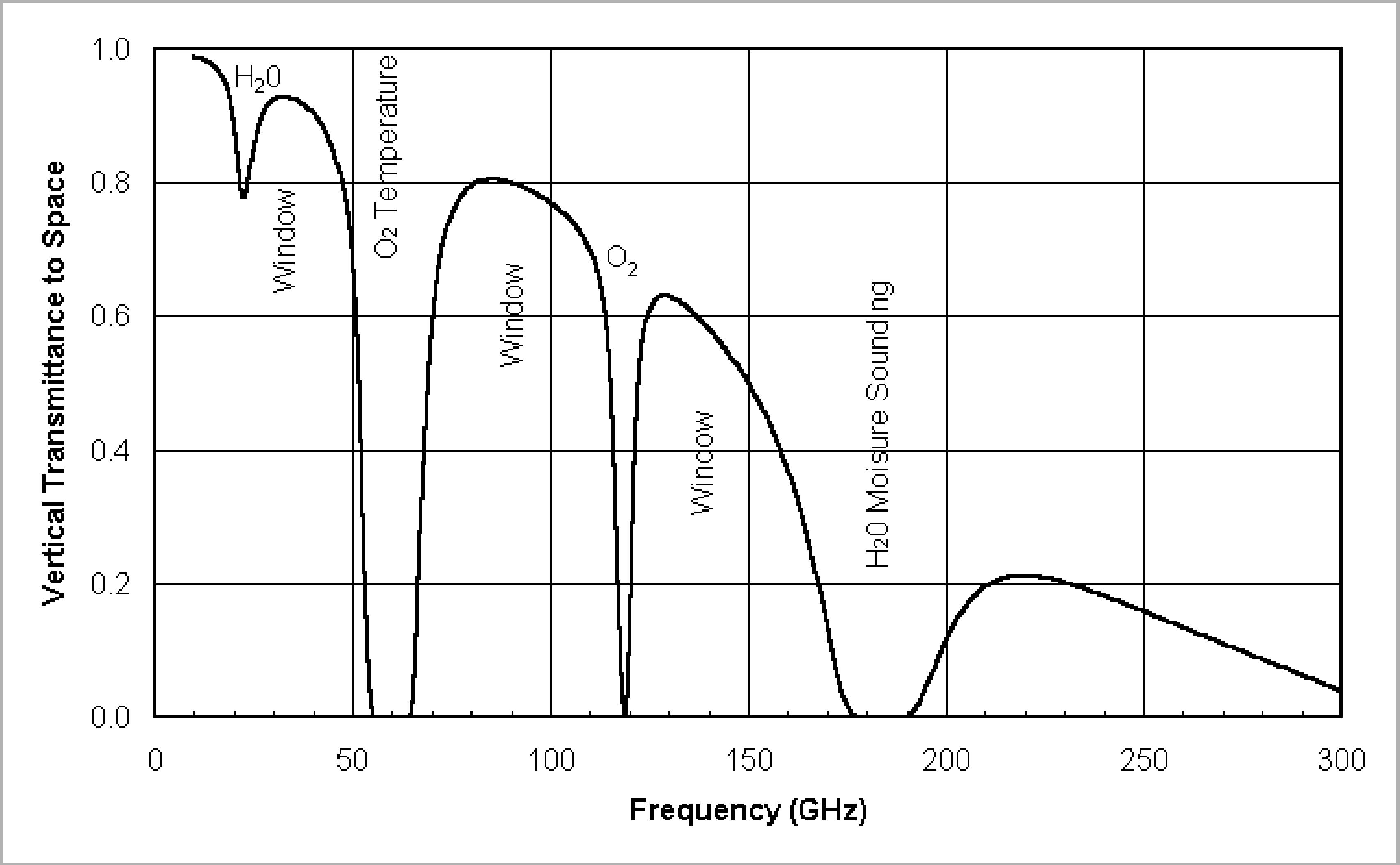
The red curve shows the thermal terrestrial spectrum between 4 µm and 15 µm in terms of brightness temperatures at the top of the atmosphere calculated for a standard mid-latitude summer atmosphere and nadir view. The blue curves depict the relative spectral response functions of the GOES I-M series sounder instrument.

Detection of Temperature Inversions Possible with Hyperspectral IR



Detection of inversions is critical for severe weather forecasting. Combined with improved low-level moisture depiction, key ingredients for night-time severe storm development can be monitored.

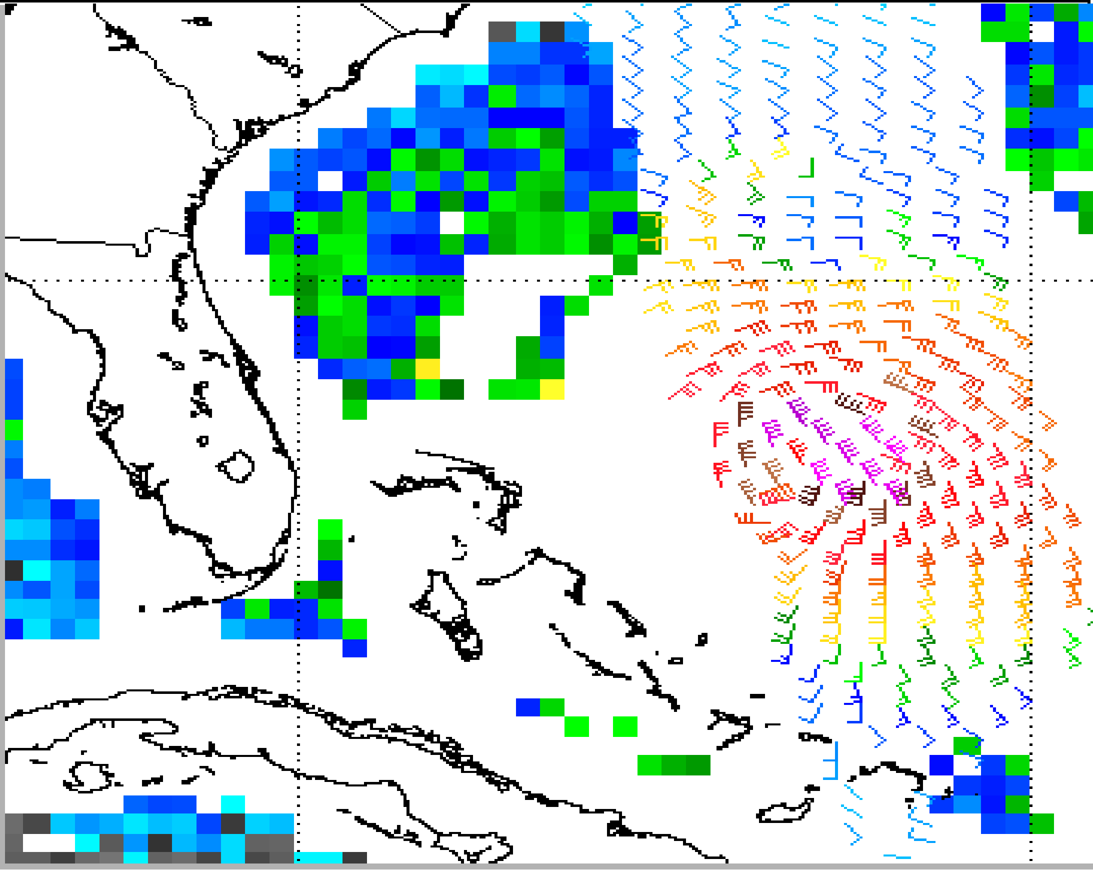
The microwave portion of the spectrum



Earth's microwave spectrum at the top of the atmosphere.

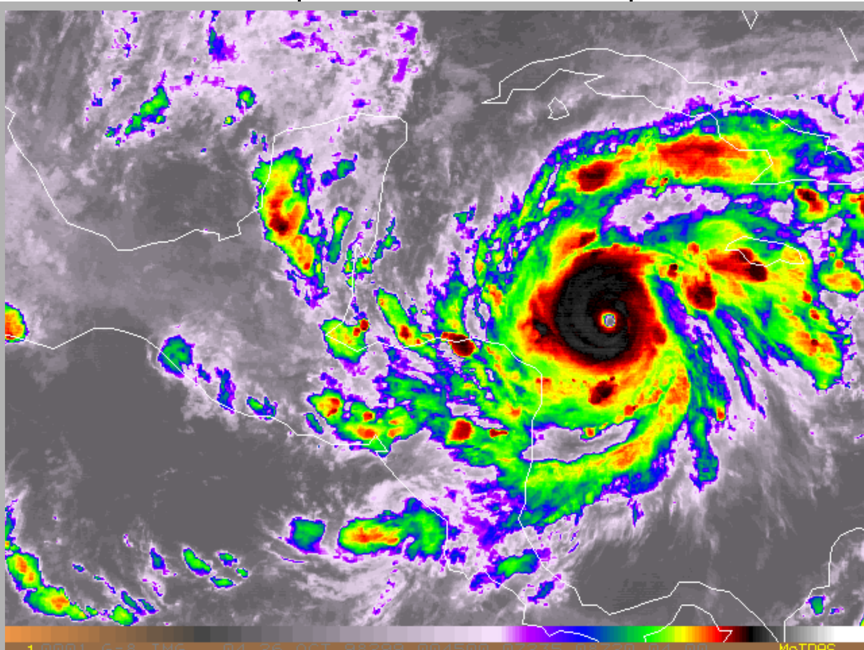
Land vs. Ocean
(Key Interactions and Potential Uses)

Frequencies AMSU	Frequencies SSM/I	Microwave Processes	Potential Uses
31, 50, 89 GHz	19, 37, 85 GHz	• Large land vs. water emissivity contrast • Variable land emissivity • Variable ocean emissivity - smooth vs. rough - ice vs. water • Scattering by snow and ice	• Land/water boundaries • Land surface temperature • Soil moisture/wetness • Surface vegetation • Ocean surface wind speed • Sea ice cover • Snow and ice cover

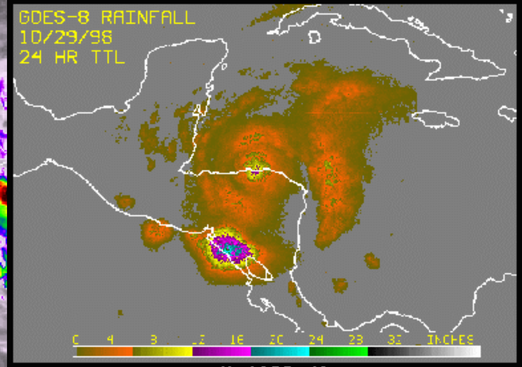


Precipitation – Cloud Water and Ice
(Key Interactions and Potential Uses)

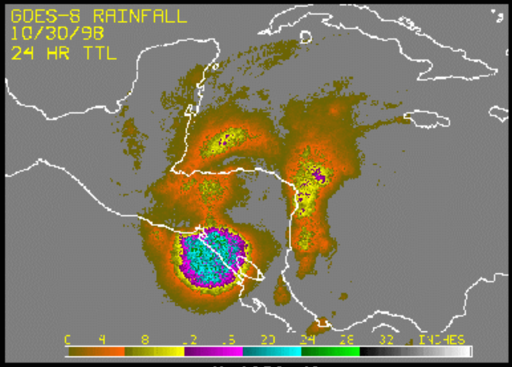
Frequencies		Microwave Processes	Potential Uses
AMSU	SSM/I		
31 GHZ 50 GHz 89 GHz	19 GHZ 37 GHz 85 GHz	• Absorption and emission by cloud water: o Large drops/high water content o Medium drops/moderate water content o Small drops/ low water content	• Oceanic cloud water and rainfall • Oceanic cloud water and rainfall • Non-raining clouds over ocean
89 GHz	85 GHz	• Scattering by cloud ice	• Land and ocean rainfall



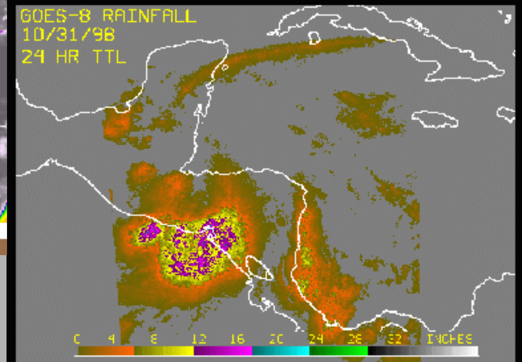
Click movie to stop animation



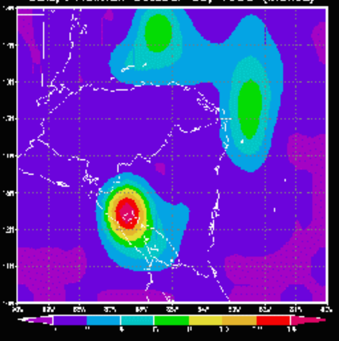
mitc1029.gif



mitc1030.gif



mitc1031.gif



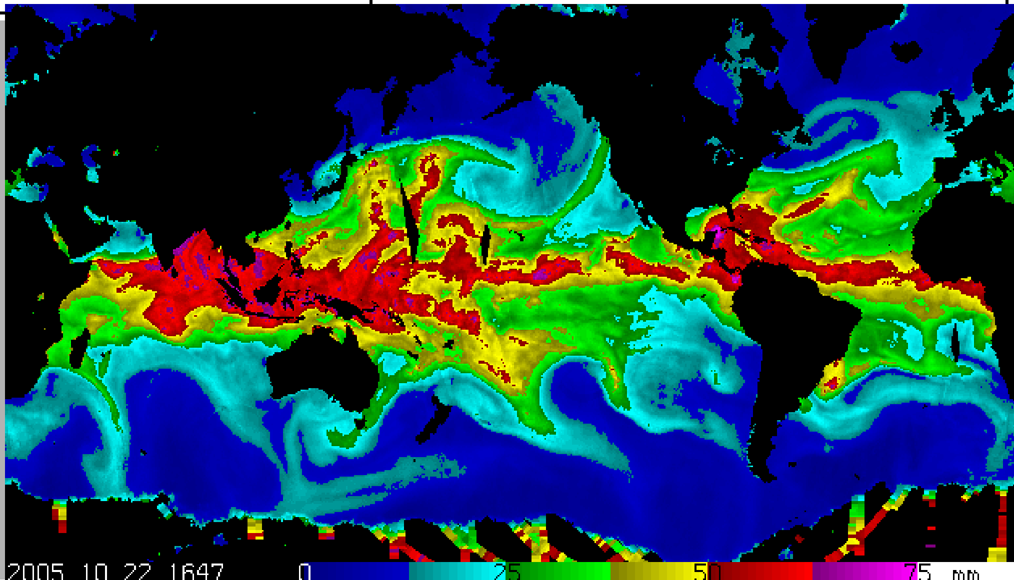
mitch3.gif

Meteorlogical Parameters

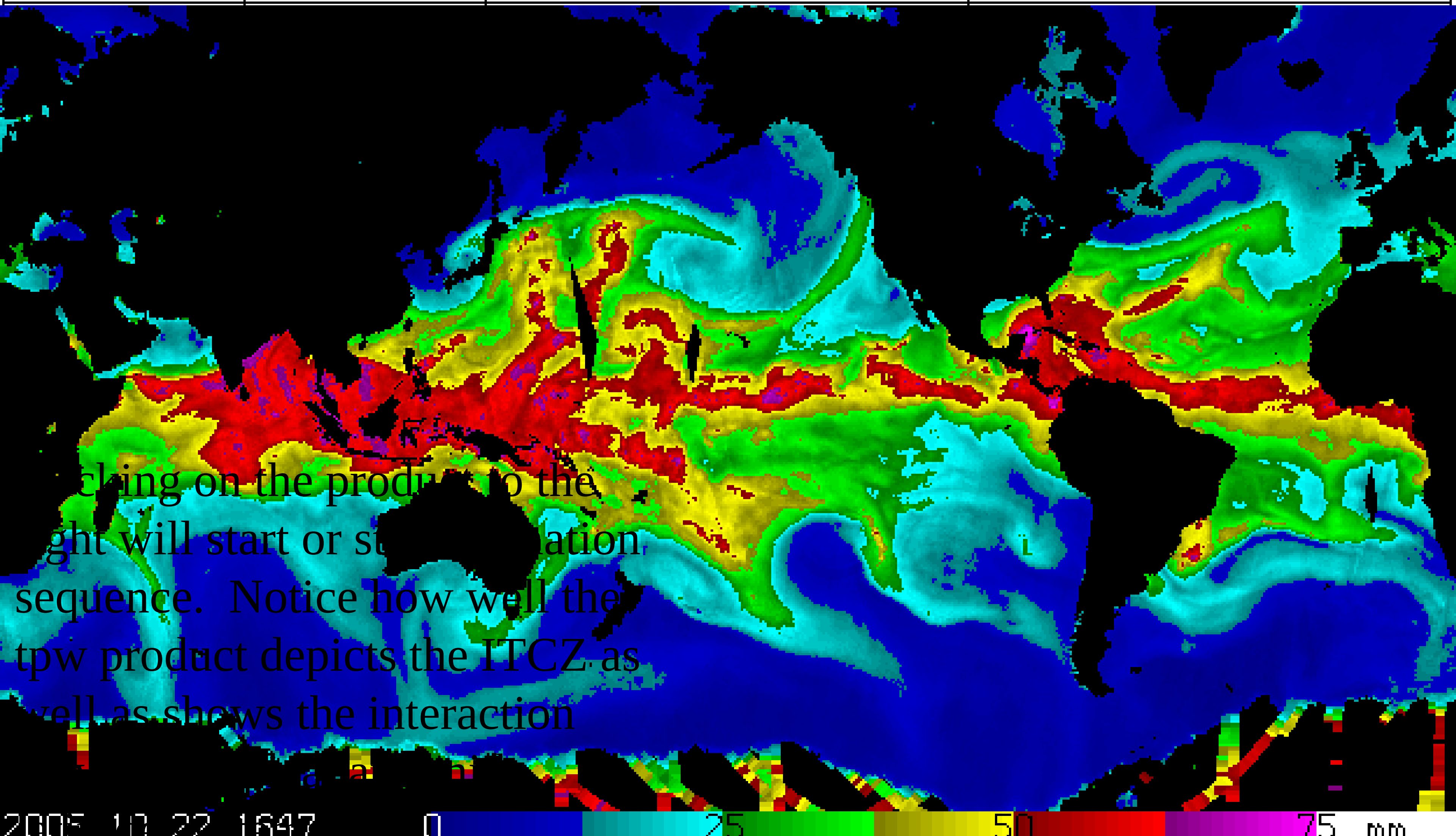
(Summary of Key Interactions and Potential Uses)

Frequencies AMSU	Frequencies SSM/I	Microwave Processes	Potential Users
23 GHz	22 GHz	• Absorption and emission by water vapor	• Oceanic precipitable water
31, 50 89 GHz	19, 37 85 GHz	• Absorption and emission by cloud water	• Oceanic cloud water and rainfall
89 GHz	85 GHz	• Scattering by cloud ice	• Land and ocean rainfall
31, 50 89 GHz	19, 37, 85 GHz	• Variations in surface emissivity: o Land vs. water o Difference land types o Different ocean surfaces • Scattering by snow and ice	• Land/water boundaries • Soil moisture/wetness • Surface vegetation • Ocean surface wind speed • Snow and ice cover

Clicking on the movie will start or stop animation. Notice how well the tpw product depicts the ITCZ as well as shows the interaction between tropical and mid-latitude systems. (larger version on next slide)



Meteorlogical Parameters (Summary of Key Interactions and Potential Uses)			
Frequencies		**Microwave Processes**	**Potential Users**
AMSU	**SSM/I**		
23 GHz	22 GHz	• Absorption and emission by water vapor	• Oceanic precipitable water



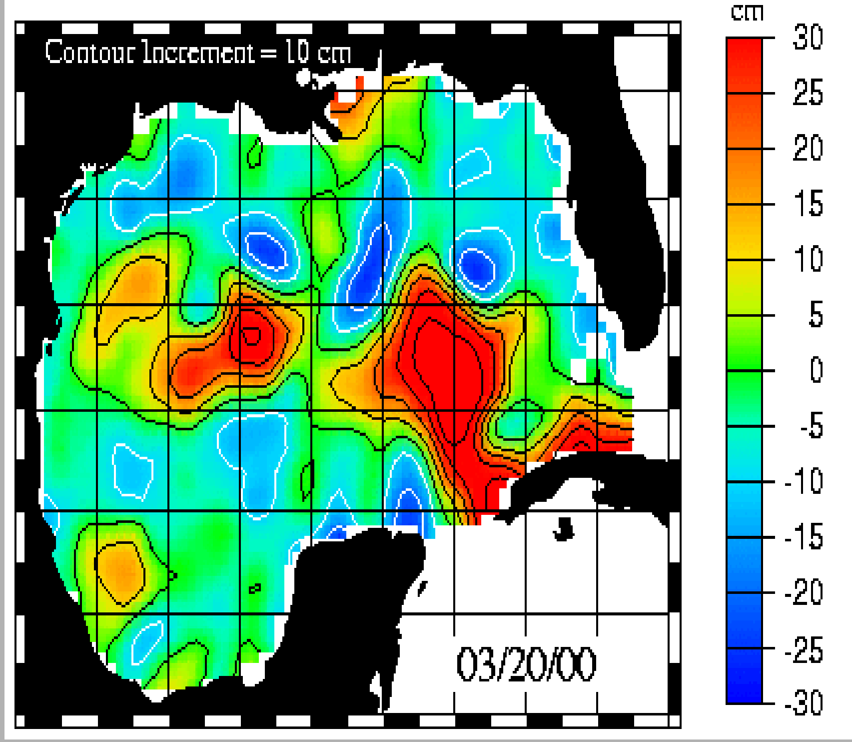
...cking on the produ... to the ...ght will start or st... ...ation sequence. Notice how well the tpw product depicts the ITCZ as ...ell as shows the interaction ... latitude systems.

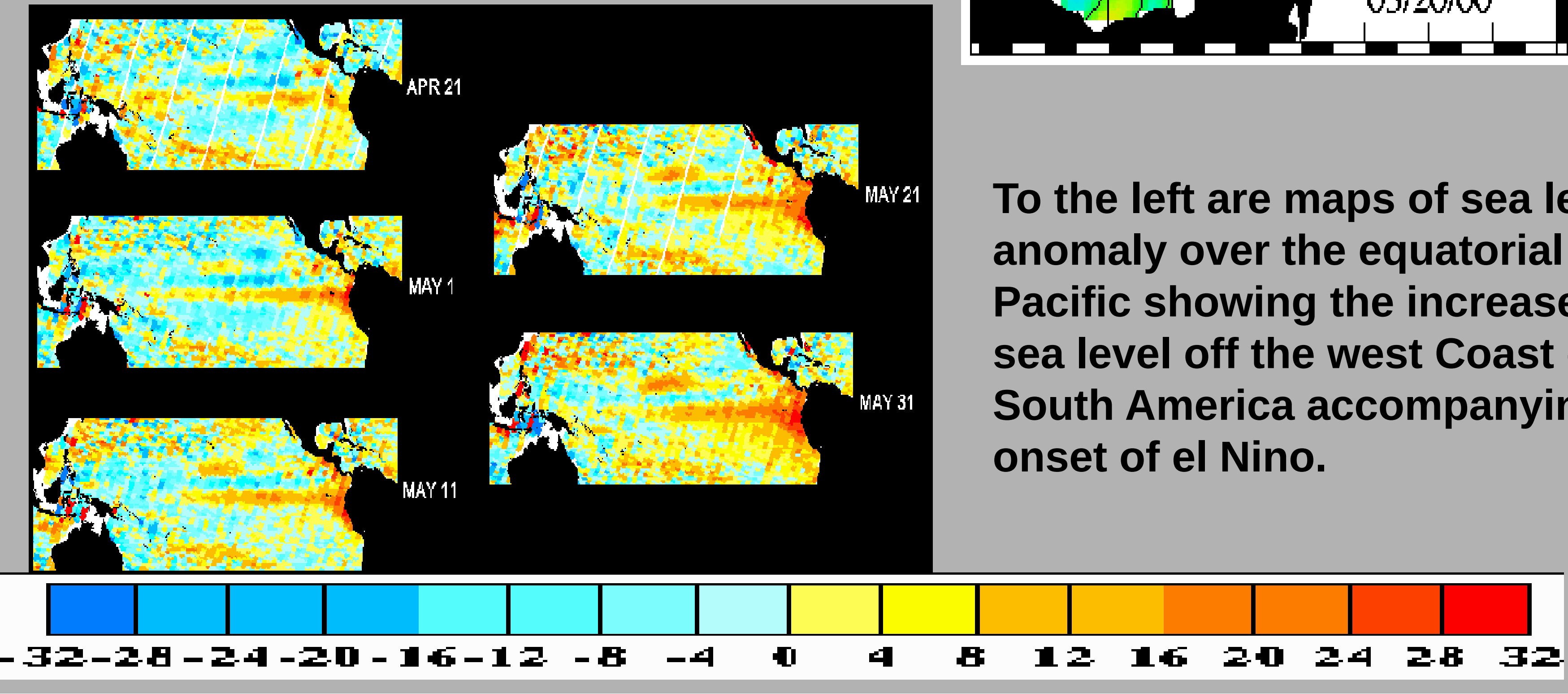
Active sensors

- Active sensors from research satellites are used to measure various sea surface properties (altimetry, wind speed and direction, ice field characteristics as well as ice berg tracking). The are also used to measure rainfall over water or land. Many of those products are available for use by NMHS'.

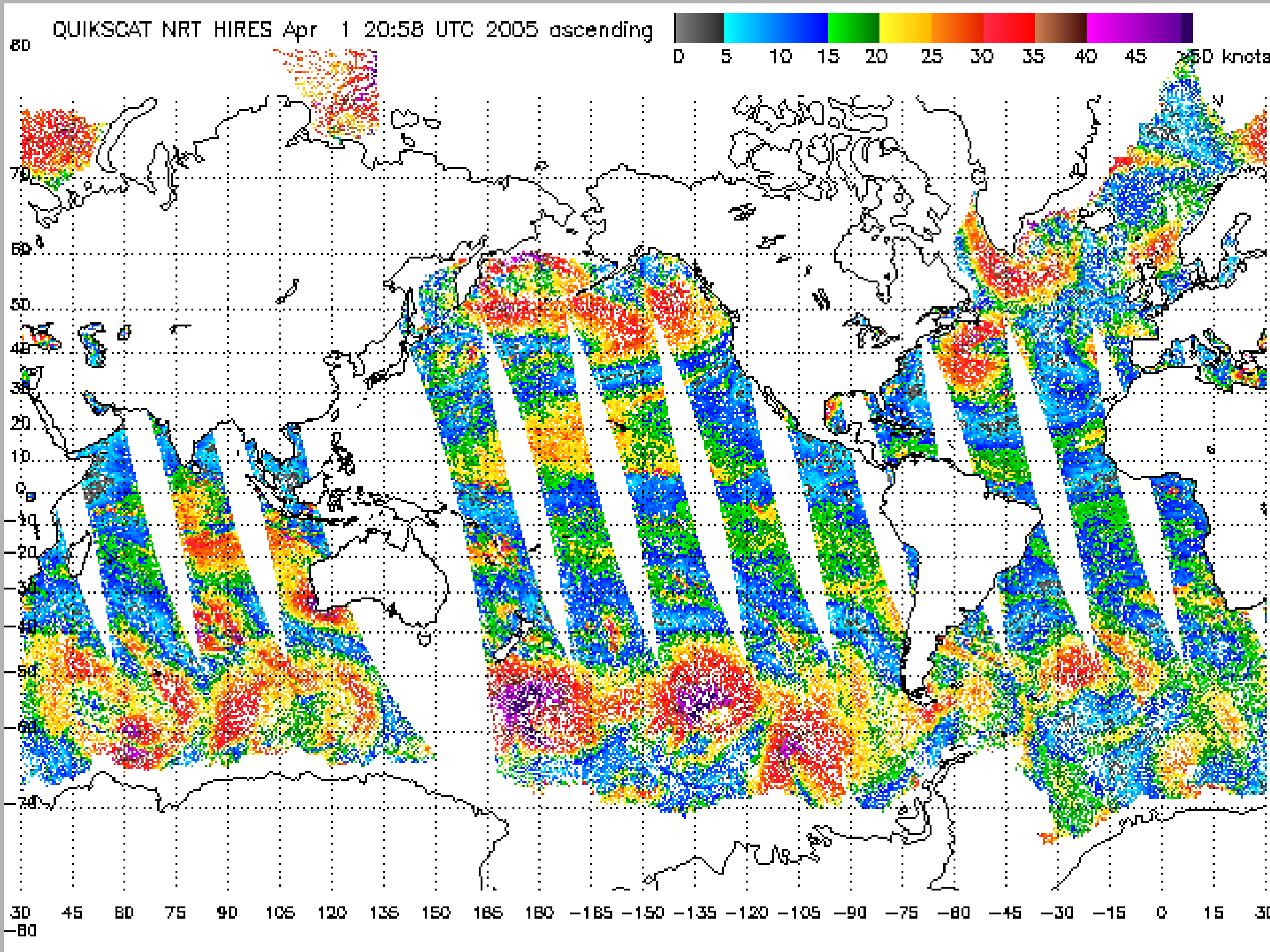
Altimetry

Right: Sea level anomaly over Gulf of Mexico from satellite altimetry.



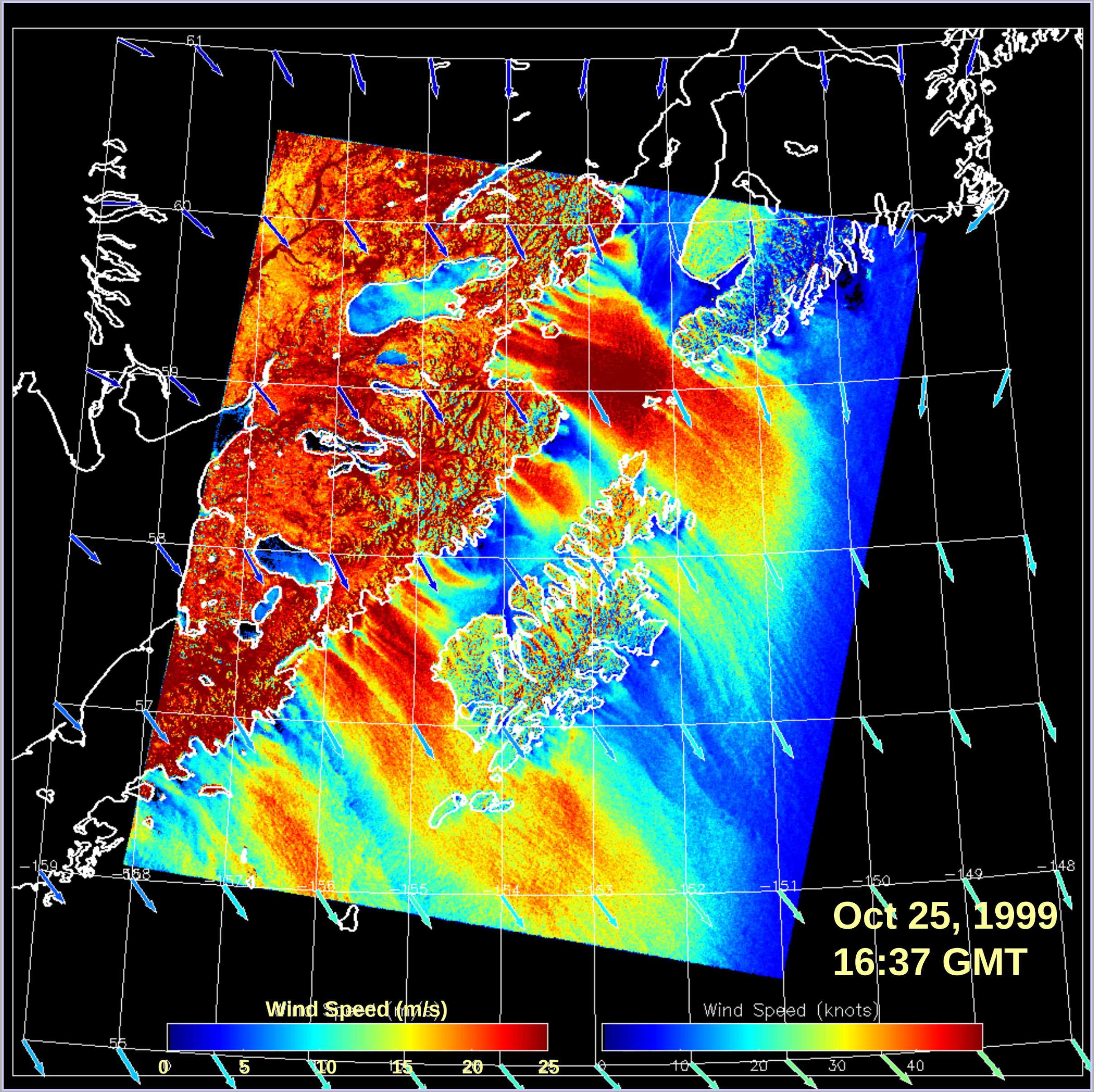


To the left are maps of sea level anomaly over the equatorial Pacific showing the increase in sea level off the west Coast of South America accompanying the onset of el Nino.

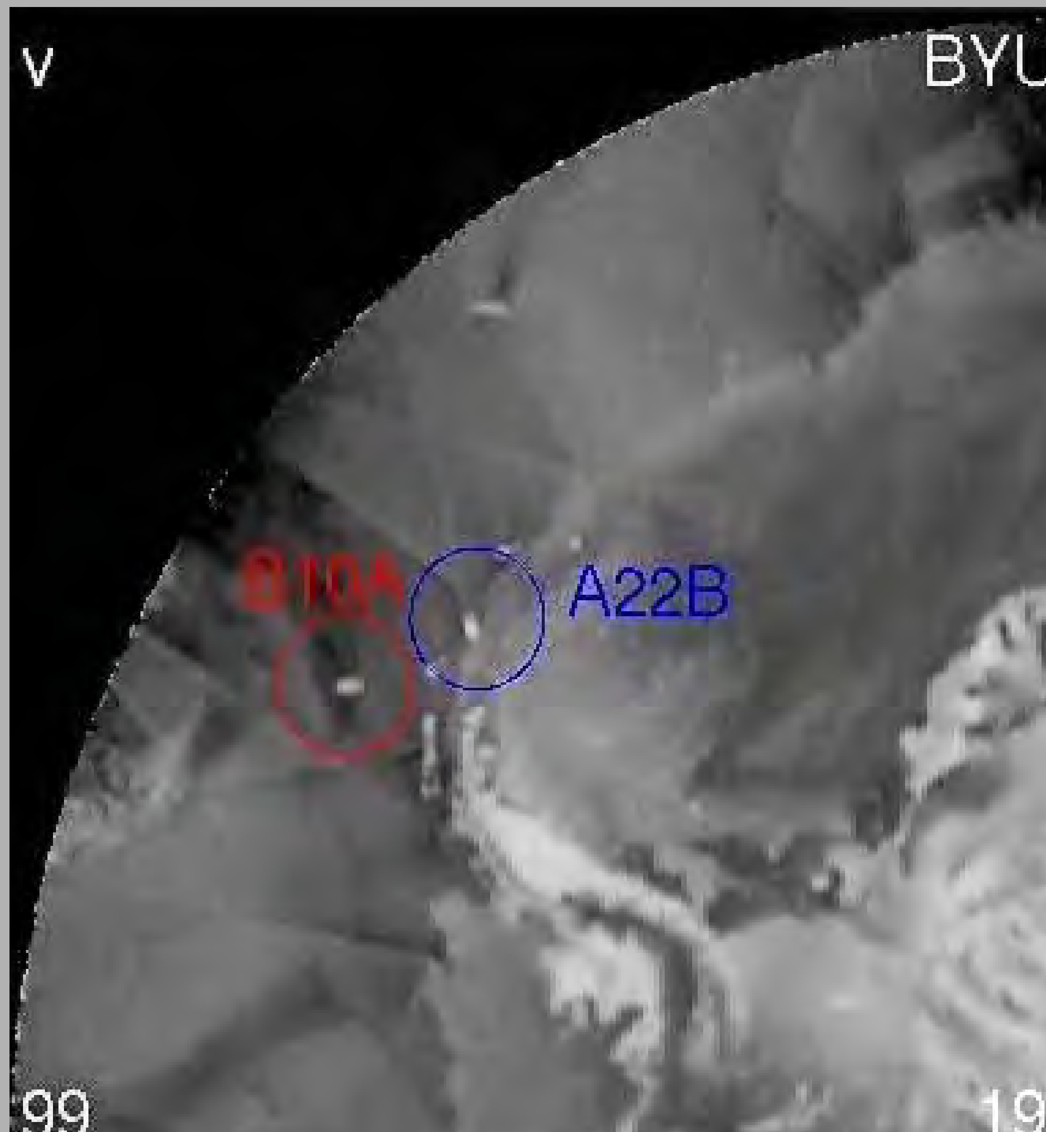


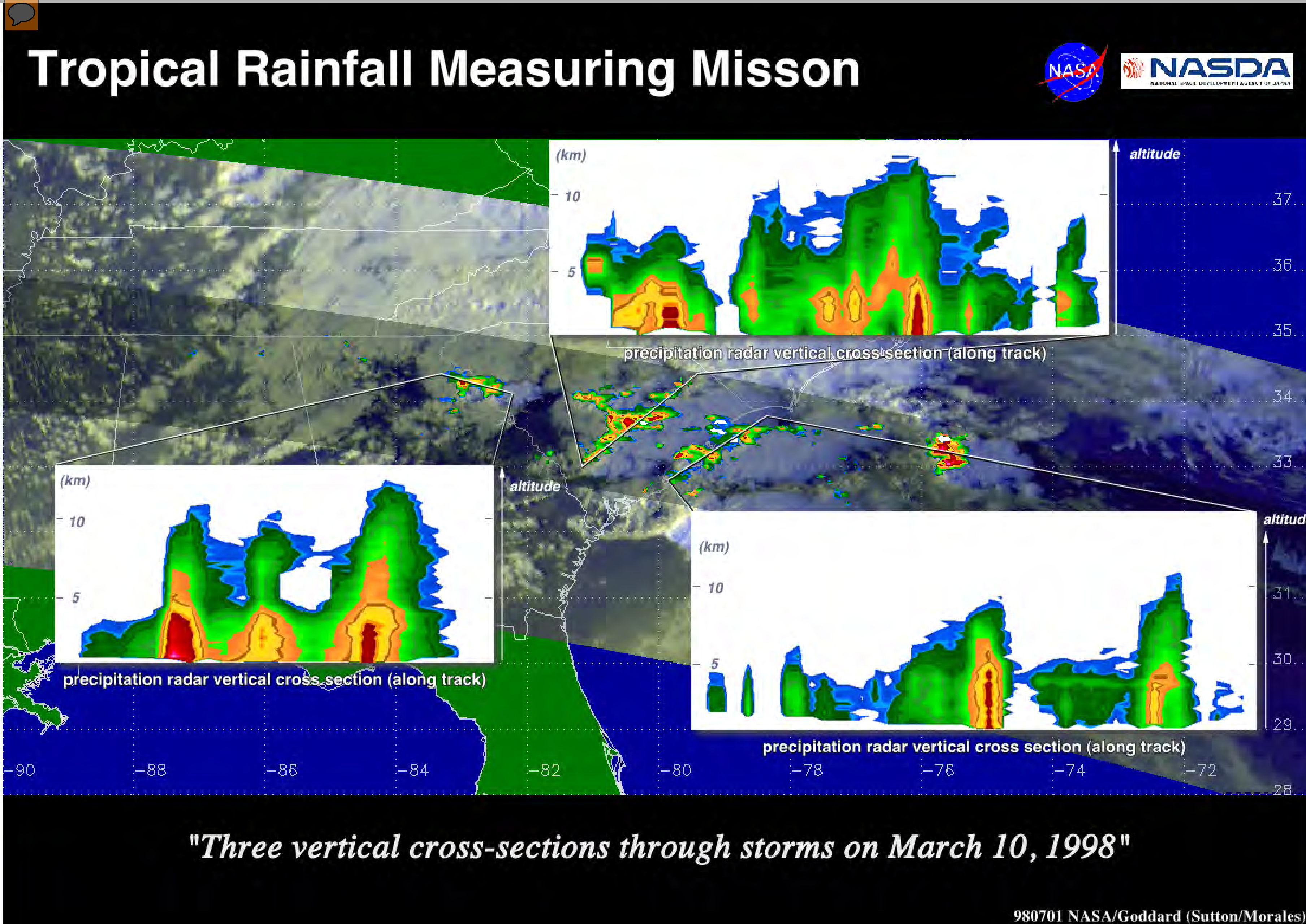
Example of global wind coverage from QuikSCAT for April 1 2005. The time 20:58 UTC in the top legend indicates the most current pass in the product.

SAR Wind Speed Product

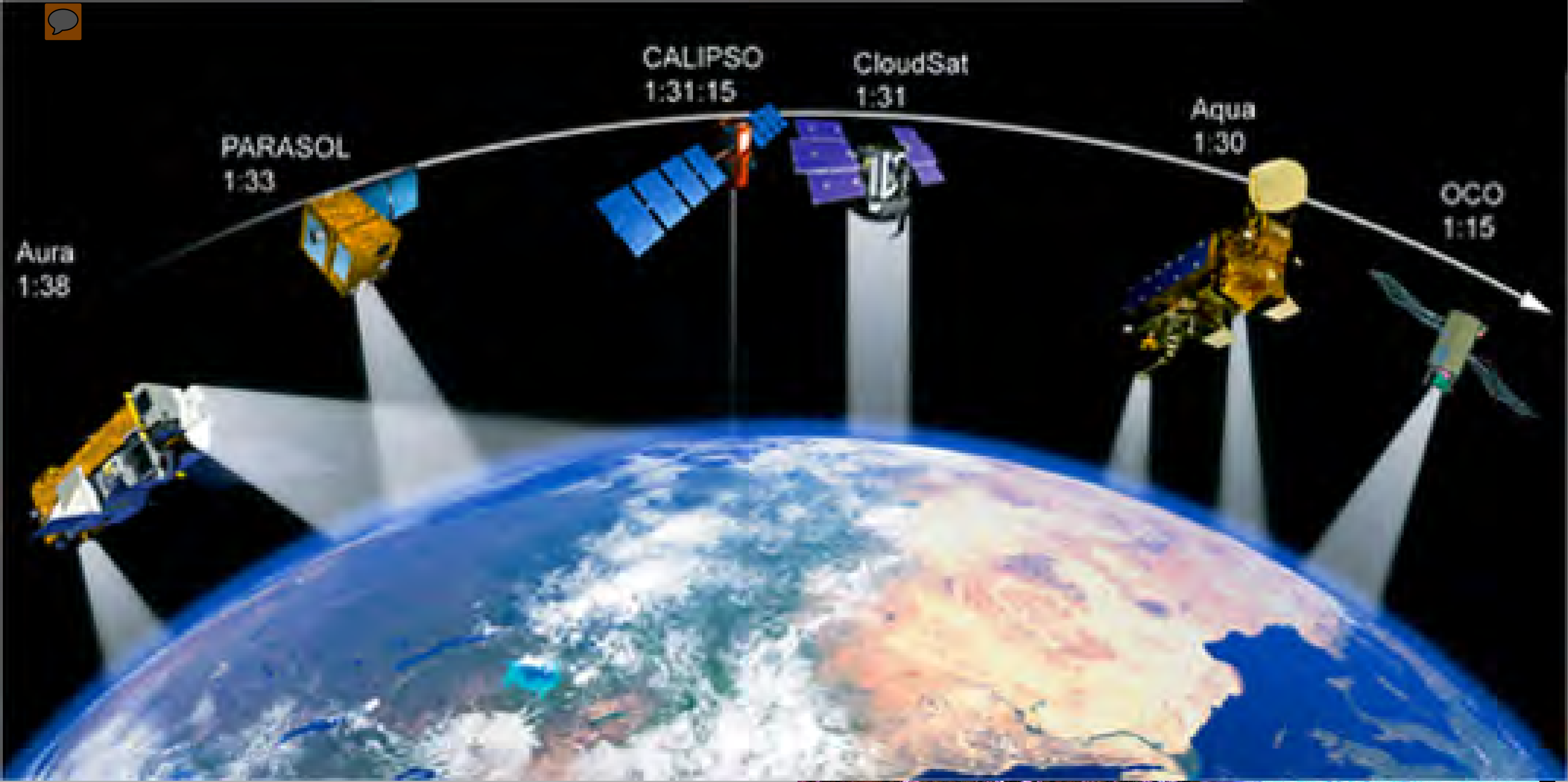


SAR Iceberg Tracking and monitoring of ice shelf edge and sea ice

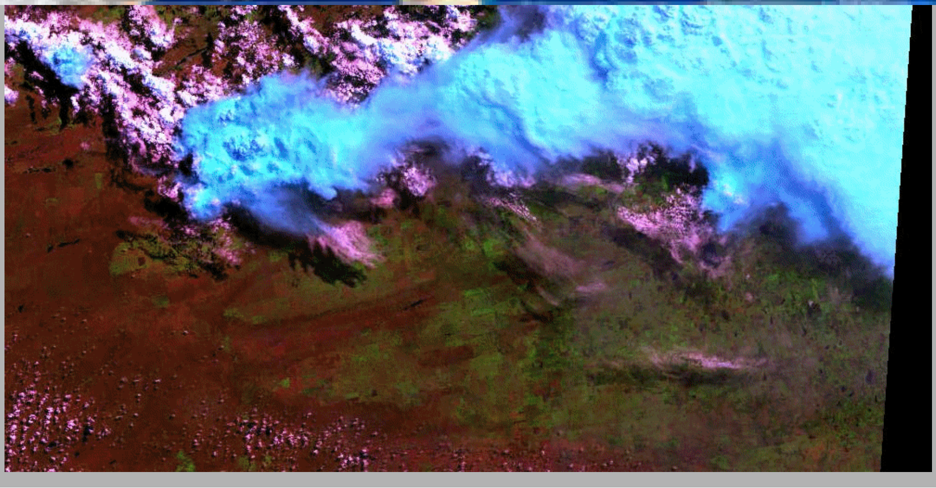




TRMM radar cross sections, from NASA/GSFC web site.

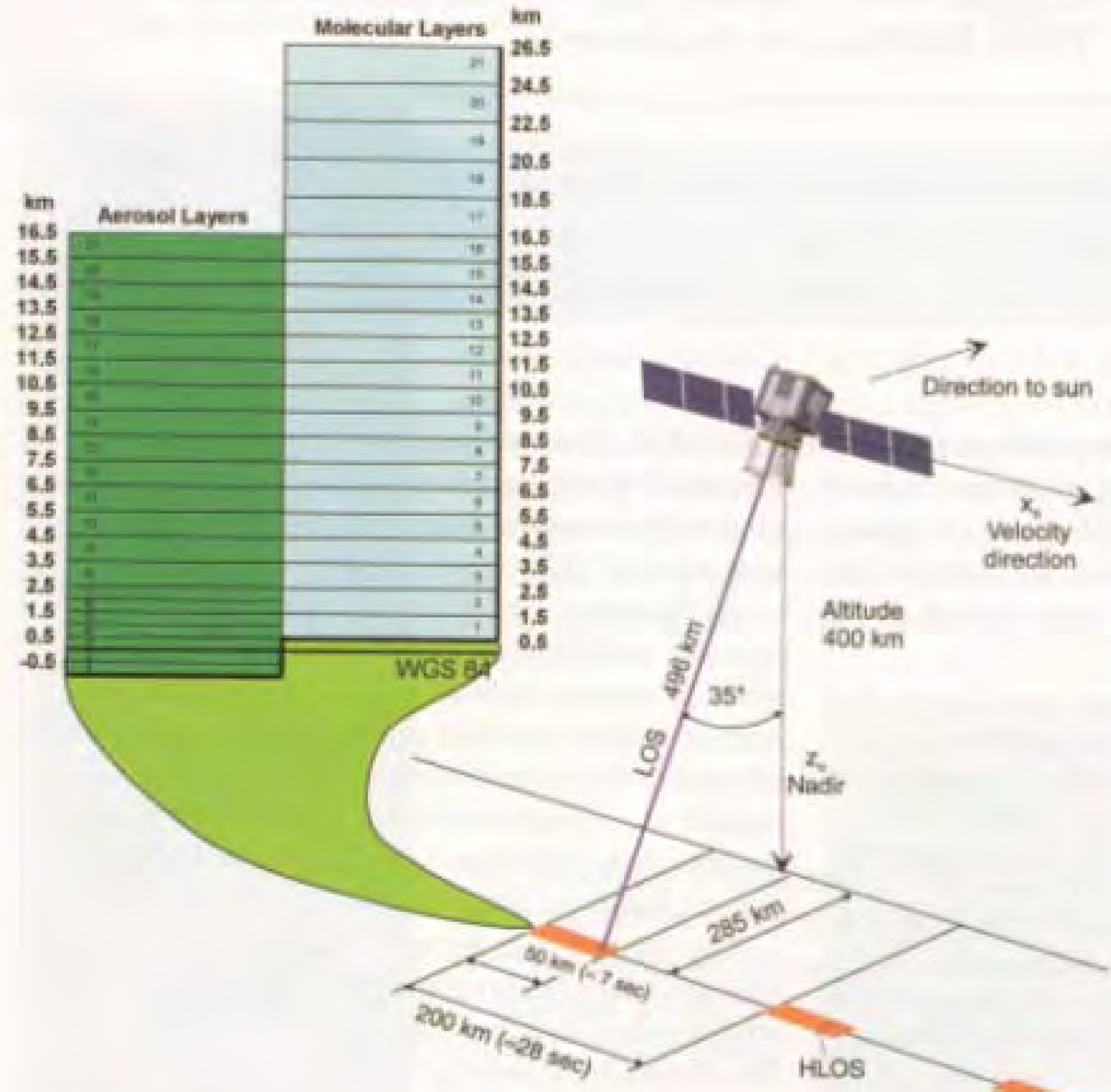


The “A Train” formation with equator crossing times. In the formation, the satellites nominally all trace out the same ground track. Click on the bottom right to see an animation of clouds made from the formation of Terra, SAC-C and LandSat-7 (an total interval of about 40 minutes from first to last).

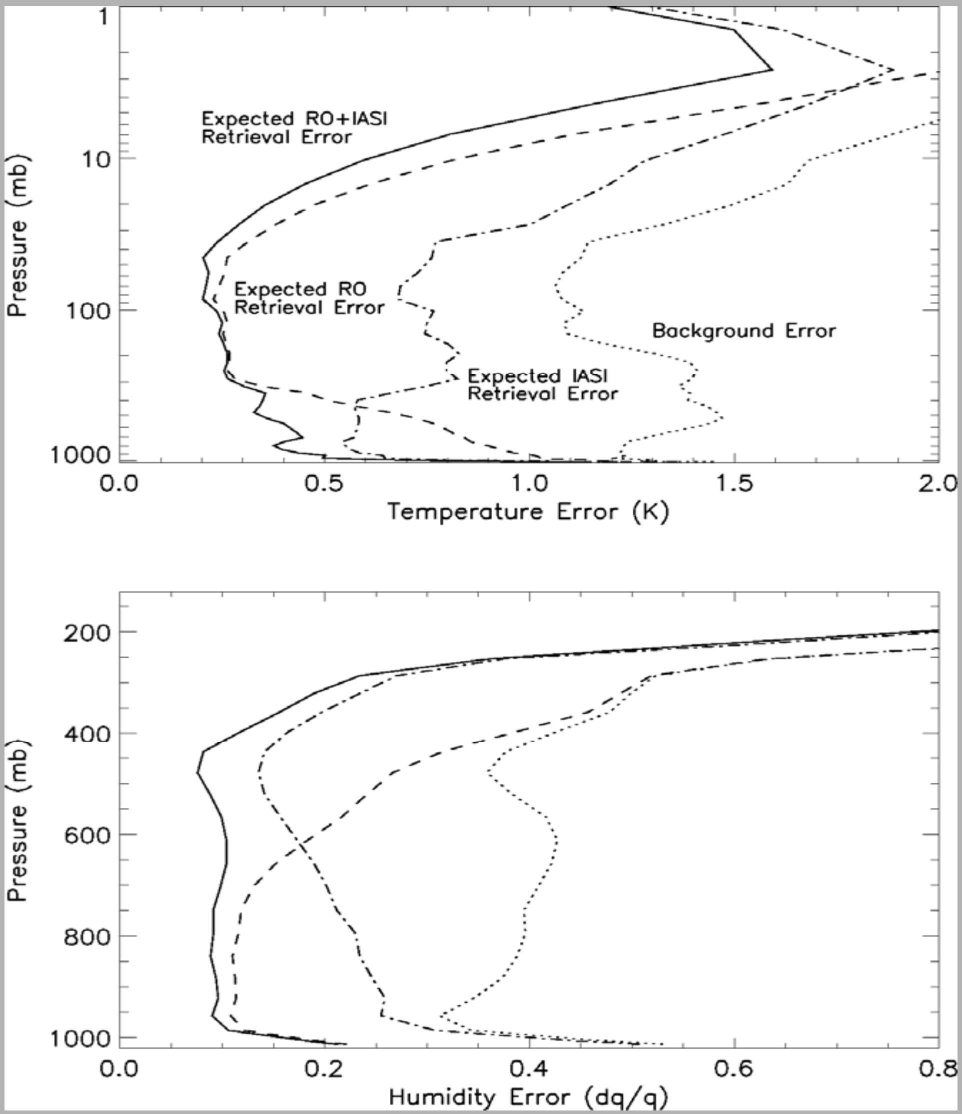


Atmospheric Dynamics Mission (ADM)

Active Doppler wind lidar for determination of atmospheric winds (also aerosols). Flies in a dawn/dusk orbit



Polar and/or Geo with GPS RO



Collard and Healy, QJRMS, 129, p.2741, 2003

The figure at the left is From Collard and Healy (2003) showing the anticipated accuracy when GPS and hyperspectral sounding data are combined. Notice that by utilizing the two together that the answer is better than either separately.

This concludes Lecture B

- More information on spectral bands and their applications may be found by accessing the Virtual Resource Library (VRL). If you do not have a CD that contains the VRL information, using Internet go to the WMO web site and access the WMO Satellite Program to link to the Virtual Laboratory.