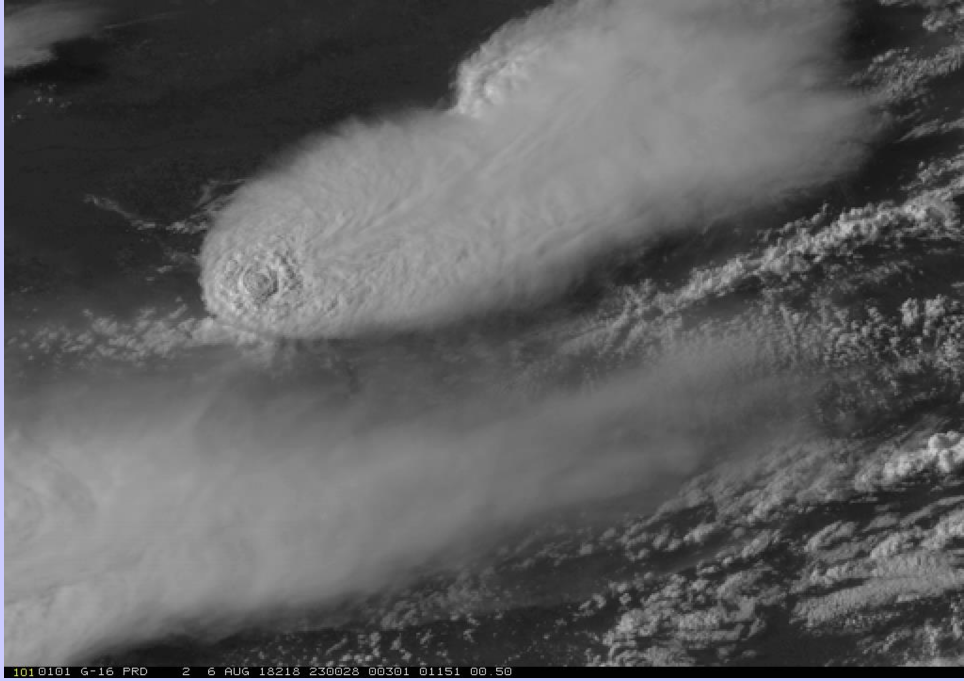


Spectral Bands And Their Applications

James F.W. Purdom, PhD

Chair AOMSUC, International Conference Steering Committee

Focus

- Major focus of this presentation is visible, near infrared and infrared data since those are the types data most NMHSs receive on a routine basis
- Near end there is a short 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 use the resources of the Satellite Virtual Laboratory

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

Before we dig into spectral bands

- A brief look into today's WMO space based observing systems
- A glimpse at the four basic Resolutions
  - Spatial – Temporal – Spectral – Radiometric (~Signal to Noise)
- Many of the slides have notes in the notes section, and there are a number of hidden slides for your inspection at a later time
- There are many (PowerPoint display) "hidden slides" with different examples

Orbits

- The mainstay orbits for meteorological and environmental applications
  - **Sun synchronous Polar orbits**
  - **Geostationary orbits**
- Other orbits and specialized applications
  - **Pro-grade orbits**
  - **Constellations and formation flying**

A Brief Reminder: Comparison of geostationary (Geo) and low earth orbiting (Leo) satellite capabilities

Geo	Leo
observes process itself (motion and targets of opportunity)	observes effects of process
repeat coverage in minutes ($\Delta t \leq 10$ minutes)	repeat coverage twice daily ($\Delta t = 12$ hours)
near full earth disk	global coverage
best viewing of tropics & mid-latitudes	best viewing of poles
same viewing angle	varying viewing angle
differing solar illumination	same solar illumination
multispectral imager	multispectral imager (generally higher resolution)
IR only sounder (8 km resolution)	IR and microwave sounder (1, 17, 50 km resolution)
filter radiometer	filter radiometer, interferometer, and grating spectrometer
diffraction more than leo	diffraction less than geo

Orbit configuration (both Geostationary and Polar)

https://www.wmo-sat.info/oscar/instruments/view/3

OSCAR

Observing Systems Capability Analysis and Review Tool

To learn more about a particular satellite

Home | Observation Requirements | Space-based Capabilities | Surface-based Capabilities | Analysis

Overview | Programmes | Satellites | **Instruments** | Frequencies | Agencies | Gap Analyses

Instrument: ABI

Instrument details

Acronym	ABI				
Full name	Advanced Baseline Imager				
Purpose	Multi-purpose VIS/IR imagery and wind derivation by tracking clouds and water vapour features				
Short description	16 channels, balanced VIS, NIR, SWIR, MWIR and TIR [see detailed characteristics below]				
Background	Replacing IMAGER flown on GOES 8 to 15				
Scanning Technique	Mechanical, 3-axis stabilised satellite, E-W continuous, S-N stepping				
Resolution	Changing with channel (see table)				
Coverage / Cycle	Full disk every 15 min, 3000 x 5000 km2 ("CONUS", Continental U.S.) in 5 min, 1000 x 1000 km2 in 30 s				
Mass	338 kg	**Power**	450 W	**Data Rate**	66 Mbps

Satellites this instrument is flying on

Note: a red tag indicates satellites no longer operation blue tag indicates future satellites

- Geostationary Operational Environmental Satellite
  - GOES-16 (see instrument status) Nov 2016
  - GOES-17 (see instrument status) Mar 2018
  - GOES-T (see instrument status) 2020 - 203
  - GOES-U (see instrument status) 2025 - 203

Instrument classification

- Earth observation instrument
  - Passive optical radiometer or spectrometer
    - Moderate resolution optical imager

Mission objectives

Providing Agency	NOAA
Instrument Maturity	Backed by strong heritage
Utilization Period:	2017-12-18 to ≥2036
Last update:	2017-03-26

Detailed characteristics

Central wavelength	Bandwidth	SNR or NEΔT @ specified input	Resolution (s.s.p.)
470 nm	40 nm	300 @ 100 % albedo	1.0 km
640 nm	100 nm	300 @ 100 % albedo	0.5 km
860 nm	40 nm	300 @ 100 % albedo	1.0 km
1380 nm	30 nm	300 @ 100 % albedo	2.0 km
1610 nm	60 nm	300 @ 100 % albedo	1.0 km
2260 nm	50 nm	300 @ 100 % albedo	2.0 km
3.90 μm	0.20 μm	0.1 K @ 300 K	2.0 km
6.15 μm	0.90 μm	0.1 K @ 300 K	2.0 km
7.00 μm	0.40 μm	0.1 K @ 300 K	2.0 km
7.40 μm	0.20 μm	0.1 K @ 300 K	2.0 km
8.50 μm	0.40 μm	0.1 K @ 300 K	2.0 km
9.70 μm	0.20 μm	0.1 K @ 300 K	2.0 km
10.3 μm	0.50 μm	0.1 K @ 300 K	2.0 km
11.2 μm	0.80 μm	0.1 K @ 300 K	2.0 km
12.3 μm	1.00 μm	0.1 K @ 300 K	2.0 km
13.3 μm	0.60 μm	0.3 K @ 300 K	2.0 km

Mission objectives

Primary mission objectives

- Cloud cover
- Cloud optical depth
- Cloud top height
- Cloud top temperature
- Cloud type

Show all

It's not quiet that simple

Tentative Evaluation of Measurements

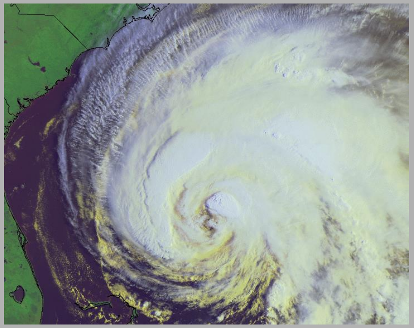
The following list indicates which measurements can **typically** be retrieved from this category of instrument. To see a full Gap Analysis by Variable, click on the respective variable.

Note: table can be sorted by clicking on the column headers

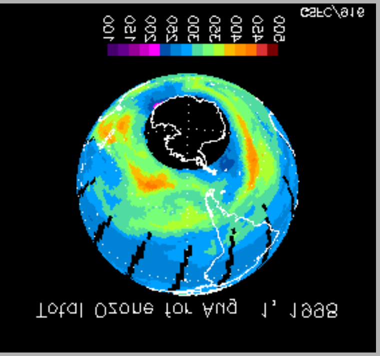
Search:

Variable	Relevance for measuring this variable	Operational limitations	Explanation
Cloud cover	1 - primary	No specific limitation.	VIS, NIR, SWIR, MWIR and TIR channels
Cloud type	1 - primary	No specific limitation.	VIS, NIR, SWIR, MWIR and TIR channels
Aerosol volcanic ash Total Column	1 - primary	Cloud sensitive.	TIR channel(s). Frequent sampling (GEO) enables early detection of ash plumes
Cloud top height	2 - very high	No specific limitation.	TIR channels in window and water vapour band (for emissivity) for temperature; and in CO2 band for atmospheric column above cloud top
Cloud top temperature	2 - very high	No specific limitation.	TIR channels in window and water vapour band (for emissivity)
Fire radiative power	2 - very high	Cloud sensitive.. Coarse spatial resolution.	MWIR and TIR channels. Frequent sampling (GEO) enables early detection
Fire temperature	2 - very high	Cloud sensitive.. Coarse spatial resolution.	MWIR and TIR channels. Frequent sampling (GEO) enables early detection

Meteorological

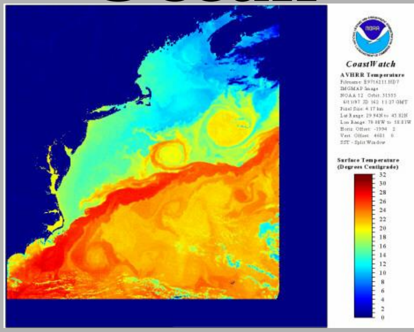


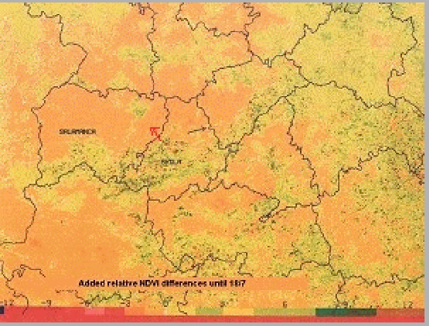
Climate



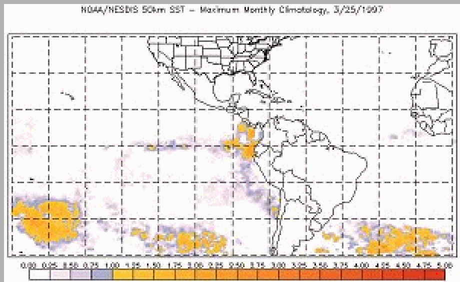
The spatial and temporal domains of the phenomena being investigated drive the satellite's observing requirements as a function of space, time, spectra, and signal to noise: <u>and here the trade off begins.</u>

Ocean





Ecological



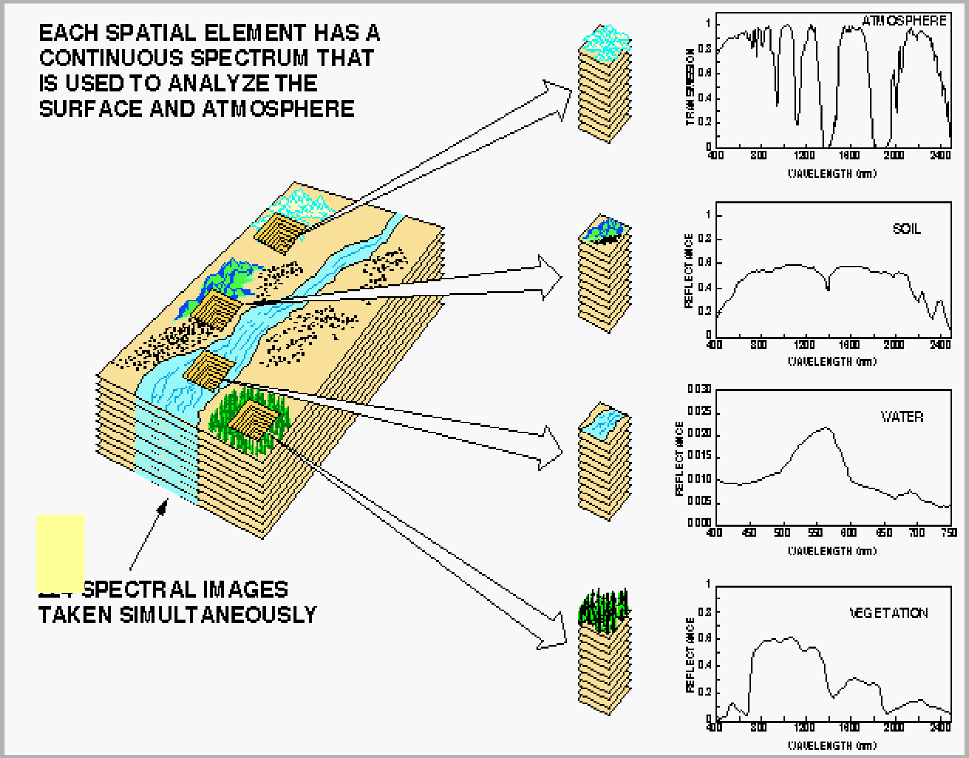
Land

Recall that in satellite remote sensing, four basic parameters need to be addressed: all deal with resolution. The new generation satellites are a giant step forward in all four!!!

- **temporal (how often)**
- **spatial (what size)**
- **spectral (what wavelengths and their width)**
- **radiometric (signal-to-noise)**

They all must be addressed together in context.

The spatial and temporal domains of the phenomena being observed drive the satellite systems' spectral needs as a function of space, time, and signal to noise.



Each spatial element has a continuous spectrum that may be used to analyze the surface and atmosphere

With satellite remote sensing, there are four basic questions that need to be addressed

- They all deal with resolution:
  - temporal (how often)
  - spatial (what size)
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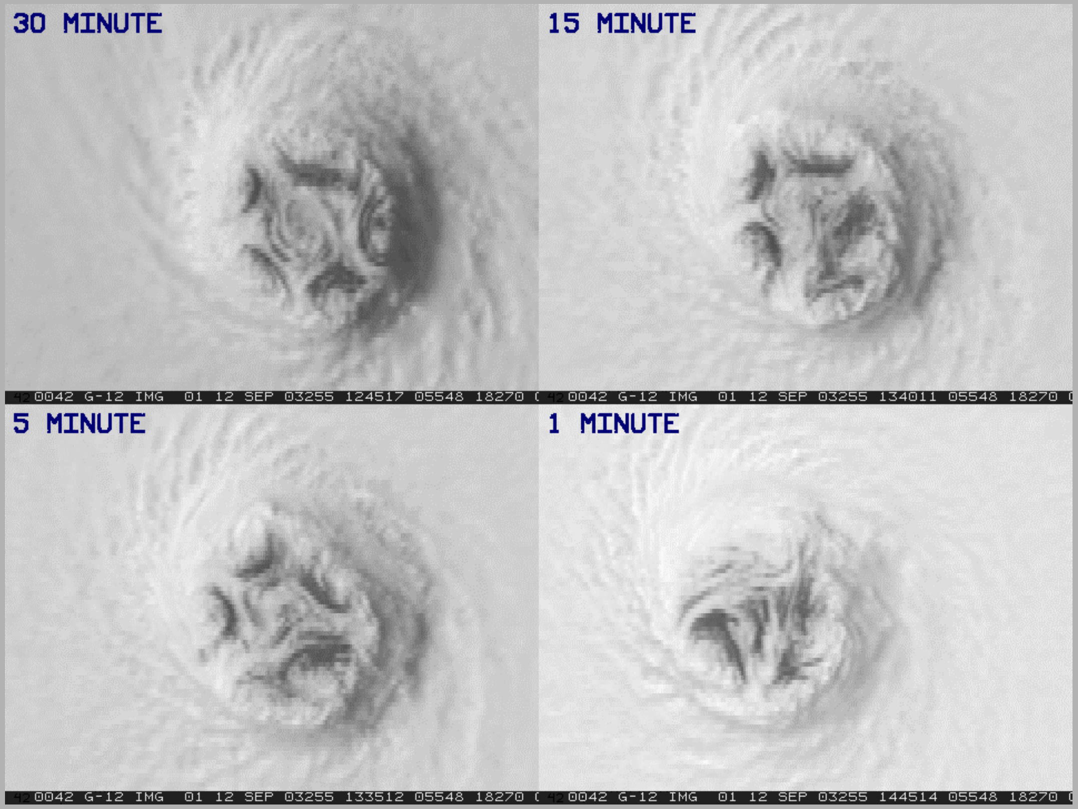
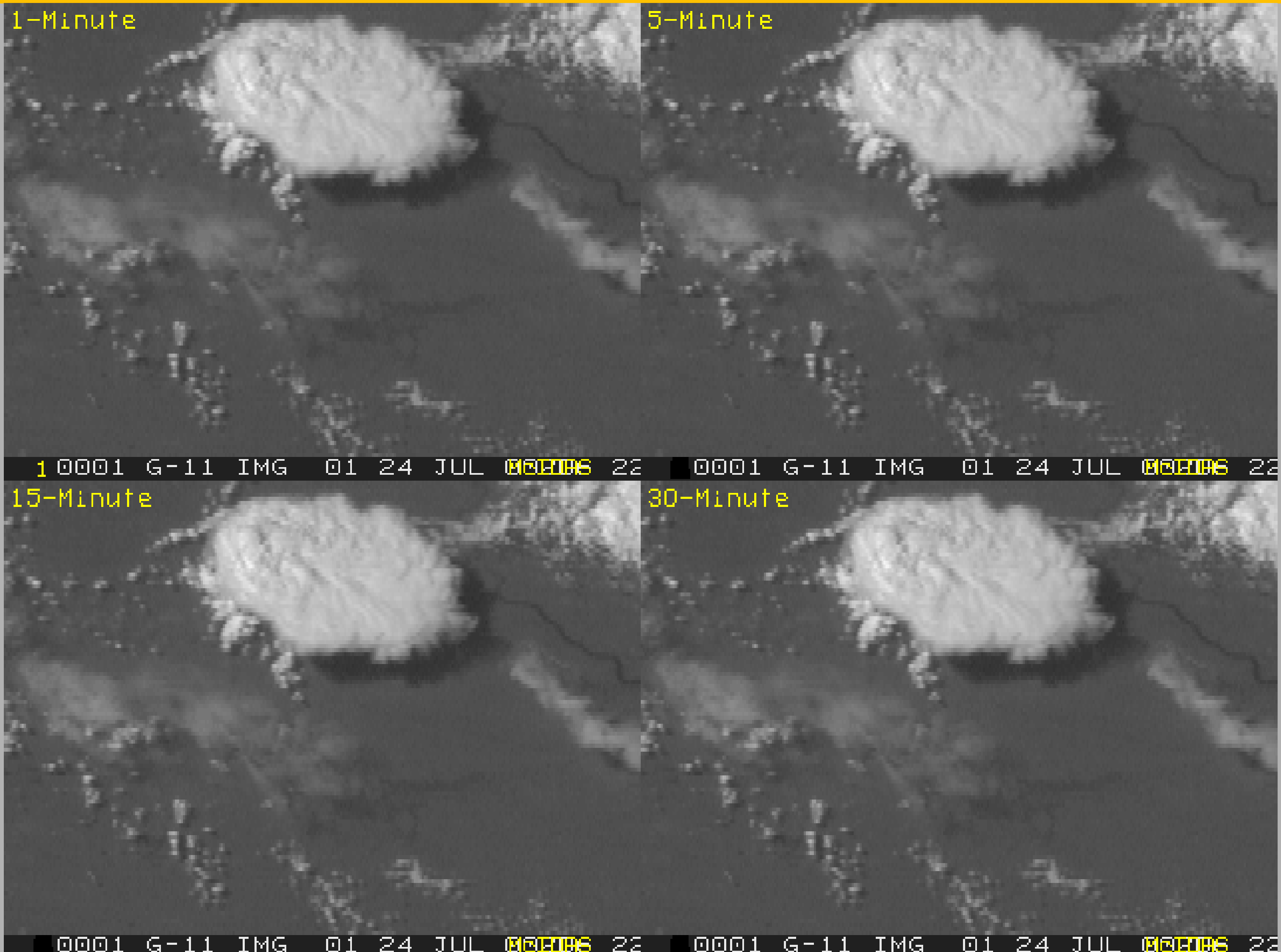
  - radiometric (signal-to-noise)

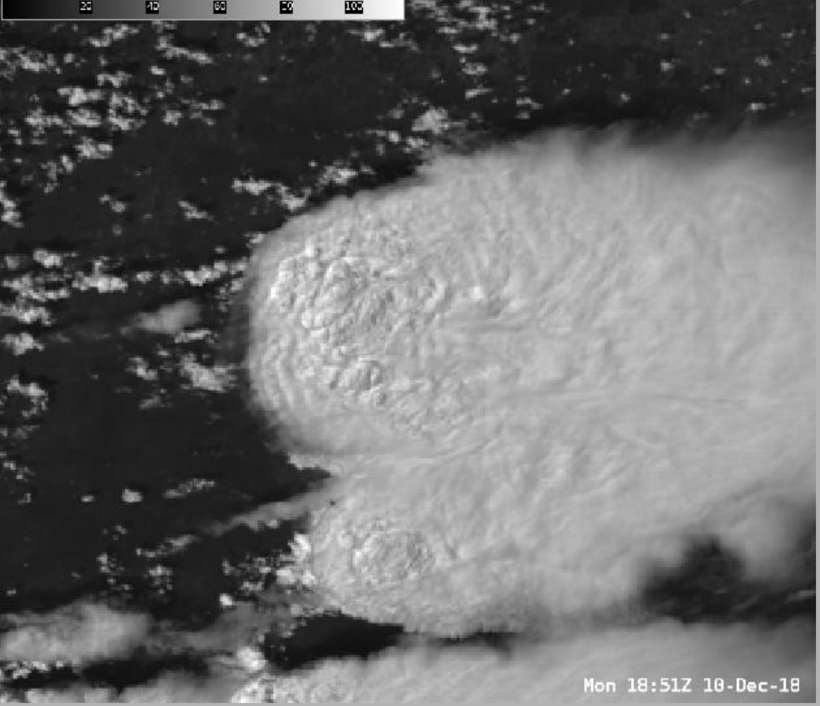


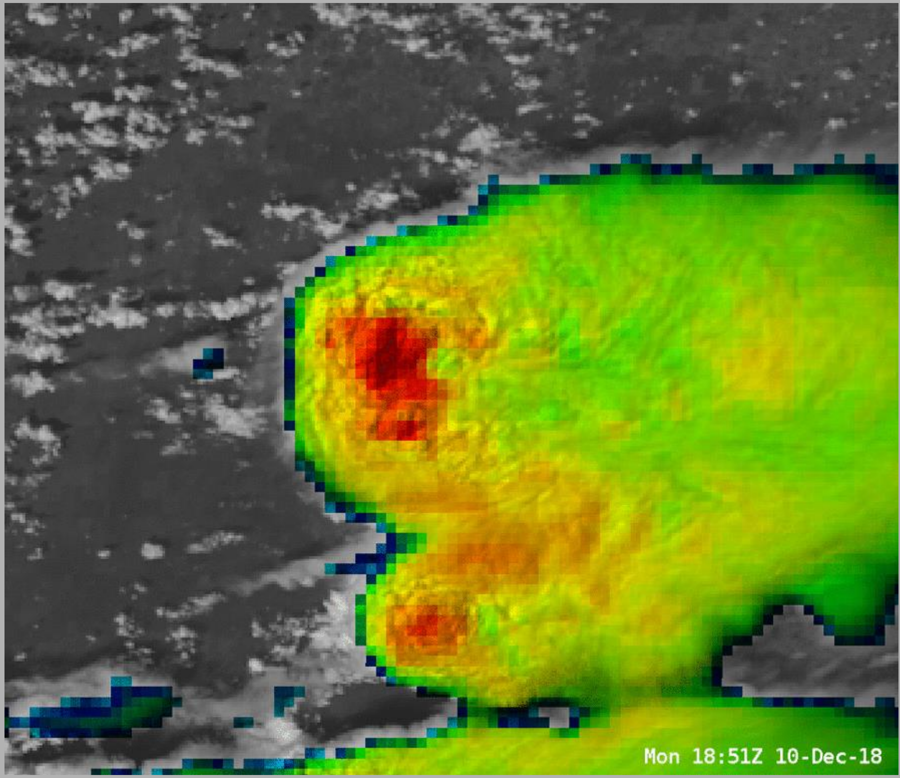
Eye Region Hurricane Isabel on 12 September 2003

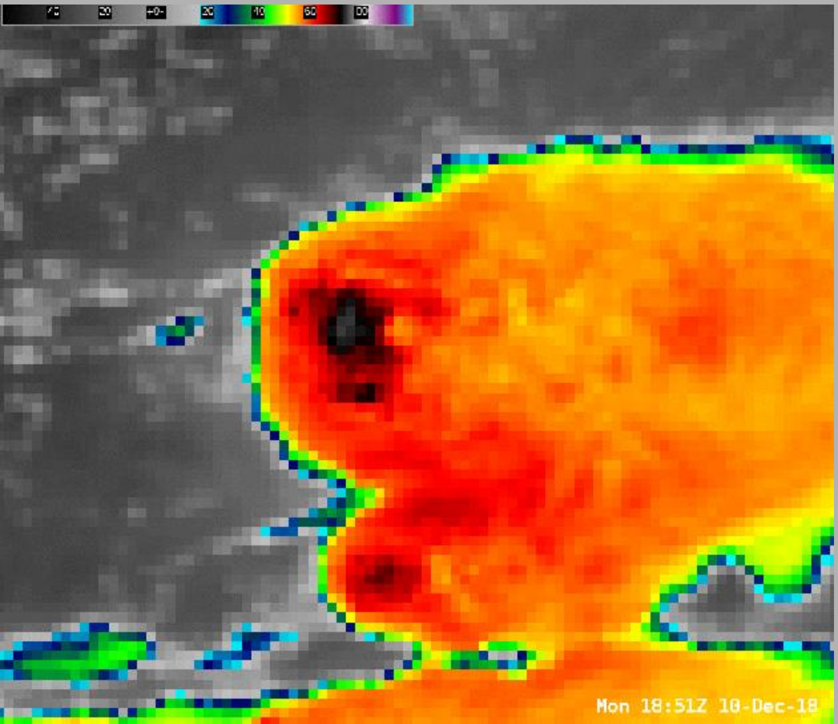
Temporal (2010 era)

Comparison of animation sequences of severe thunderstorm over western Kansas. Movies at 30, 15, 5 and 1 minute intervals. While 5 minute interval imaging is routine for 2015s, special imaging like this is possible at 1 minute intervals or less.







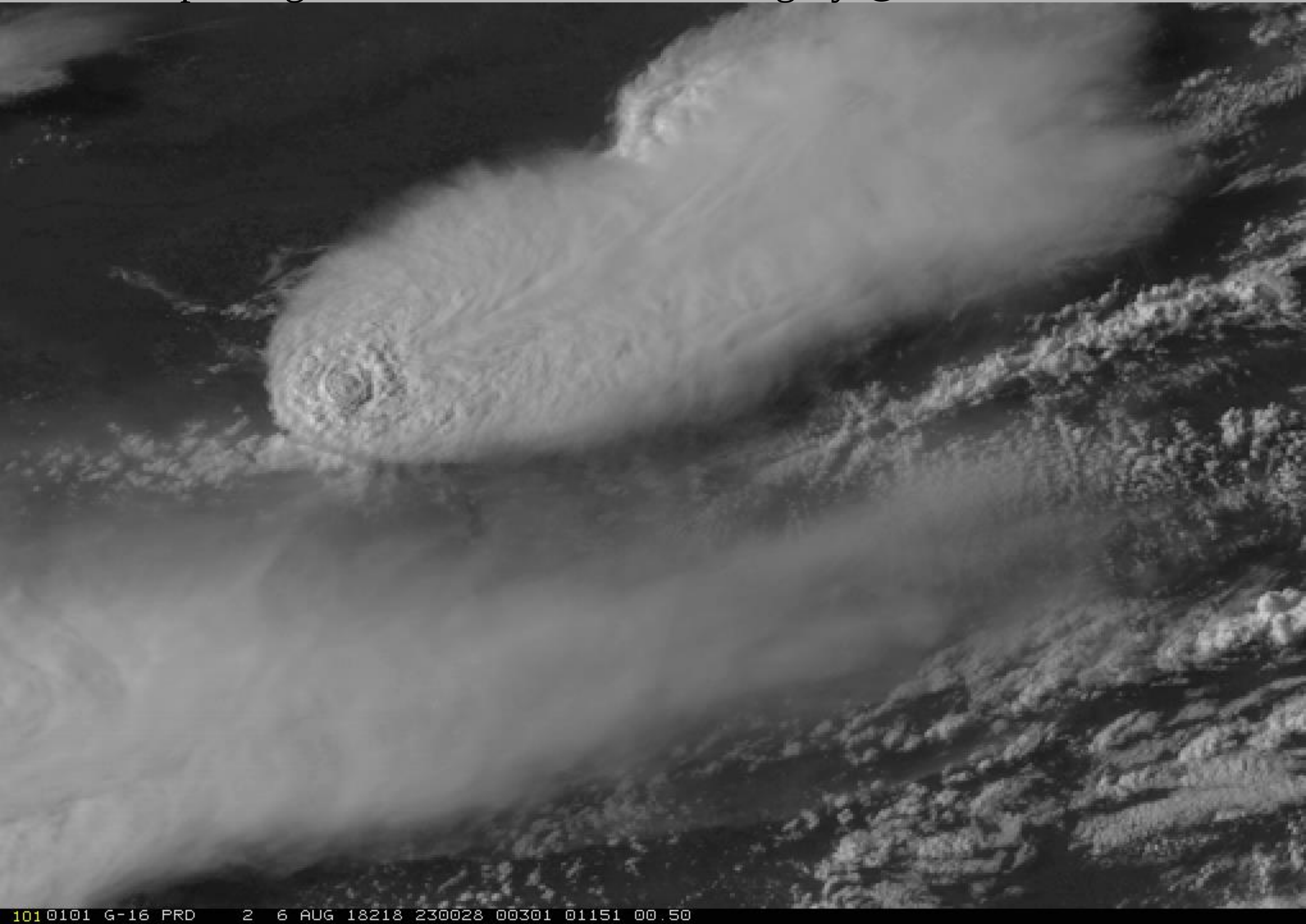


The spatial and temporal domains of the phenomena being investigated drive the satellite's observing requirements as a function of space, time, spectra, and signal to noise.

These animations are storm overshooting top relative at one minute interval

Upper left: 0.5 km visible (500 meters)
Lower left: 2 km IR window (2000 meters)
Above: IR transparency over visible image

Exploring the limits with 0.5 km imagery @ 6 sec. intervals



At least two things to note in this one minute interval 500 meter visible imagers animation

The cloud streets moving Northward in the loop appear to be almost rolling, which actually is a reflection of shear across that stably capped cloud street layer (water clouds).

Inspection of the two prominent storms as they evolve: the cloud streets can be seen being “tilted” upward into the storm due to increasing vertical motion and buoyancy.

GEO observes the process: A visual representation of the “tilting term” in the vorticity equation

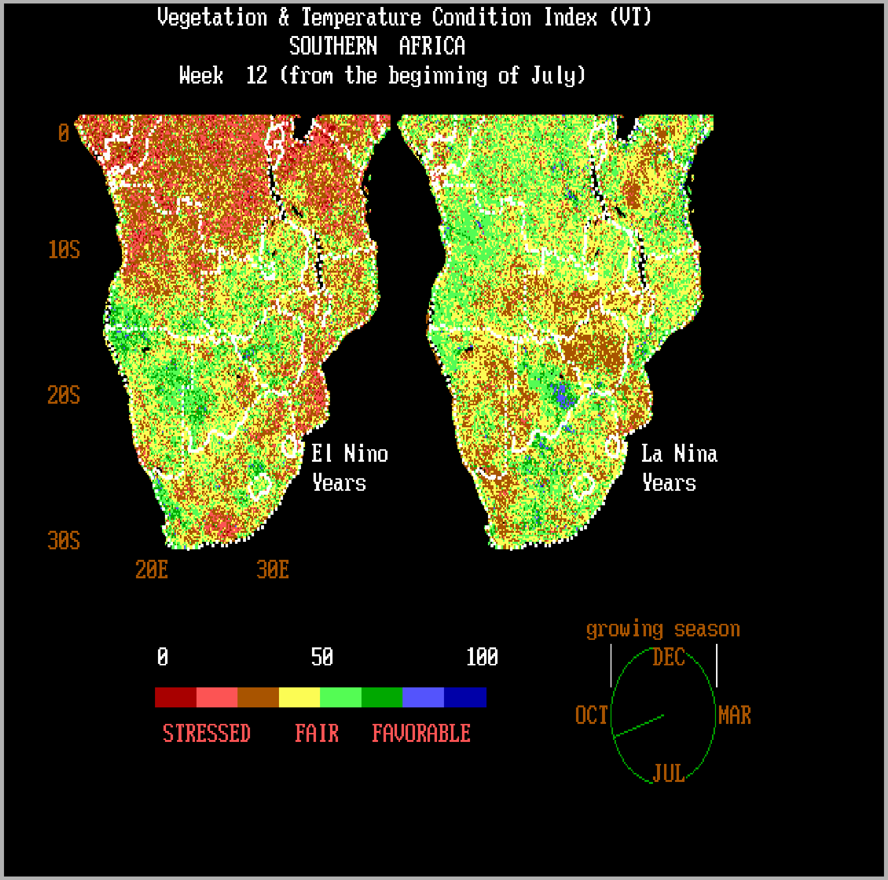
$$\left(\frac{\partial w}{\partial y}\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}\frac{\partial v}{\partial z}\right)$$

For severe storms spatial and temporal synergy!

With satellite remote sensing, there are four basic questions that need to be addressed

- They all deal with resolution:
  - temporal (how often)

Vegetation related products which change on slow time frames may be best observed using weekly data; such as this vegetation and temperature condition index above (derived from AVHRR vegetation index data and thermal infrared data).



Polar product animation

With satellite remote sensing, there are four basic questions that need to be addressed

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  - spatial (what size)
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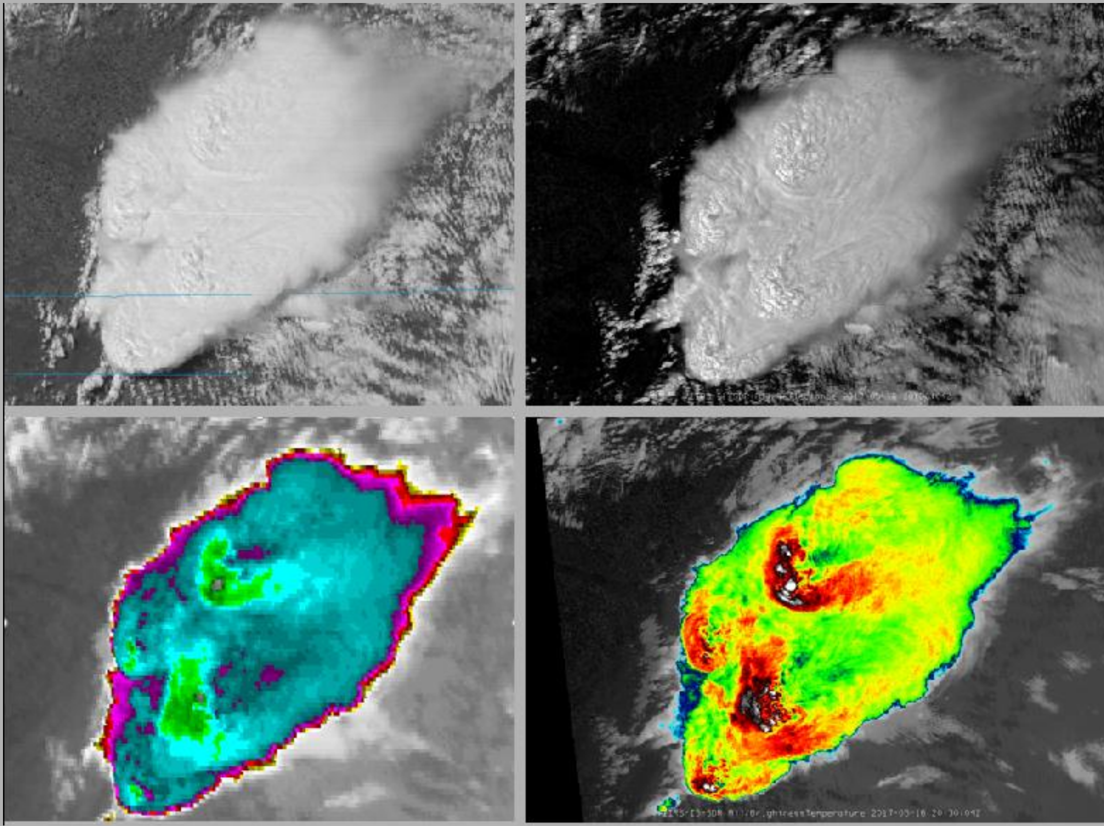
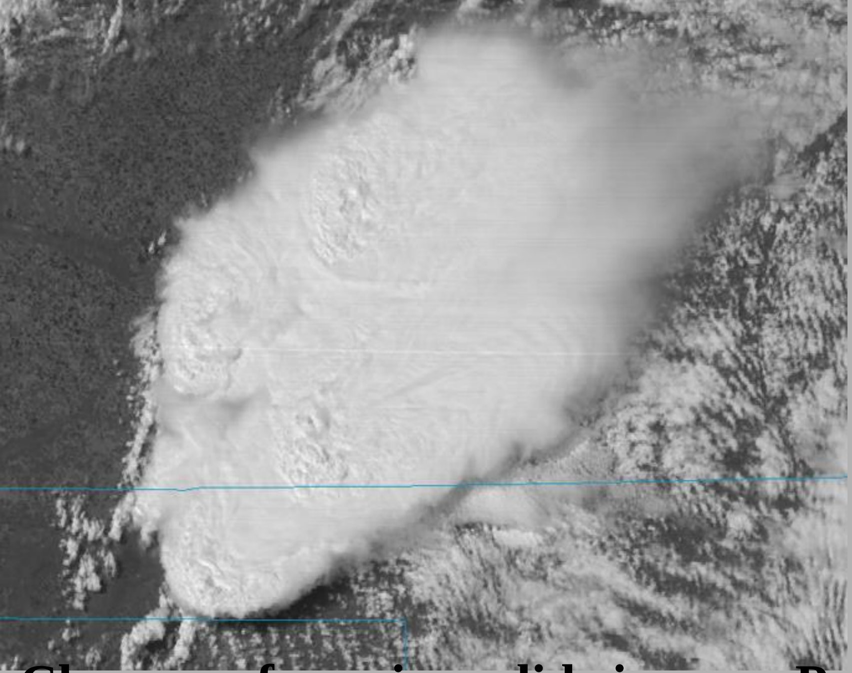
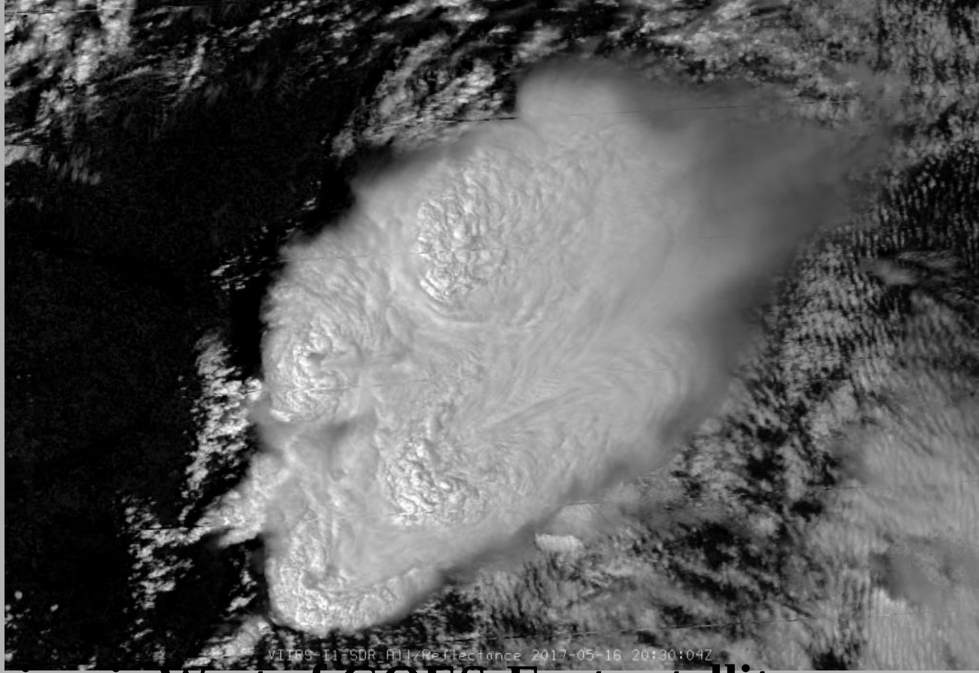
  - radiometric (signal-to-noise)

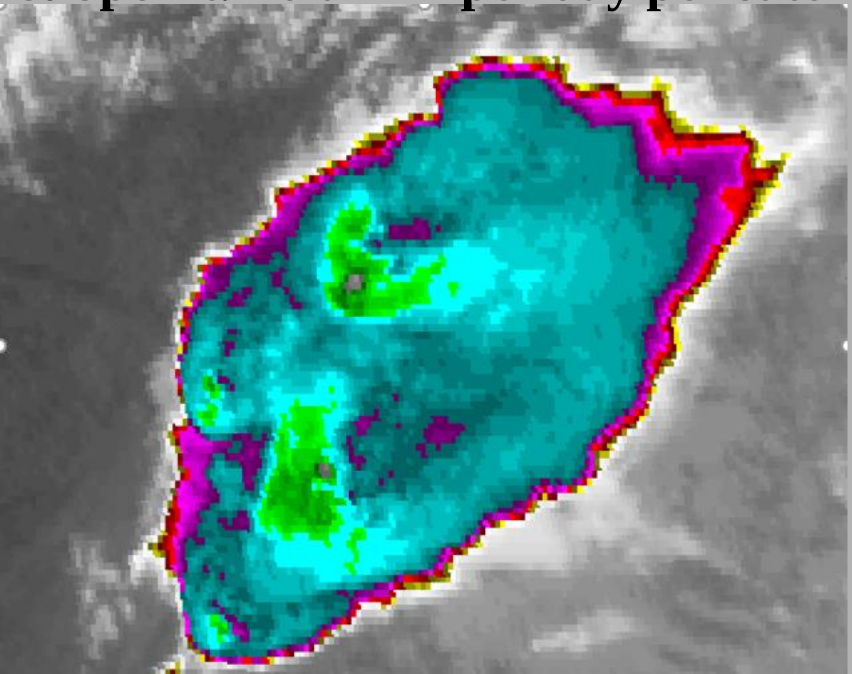


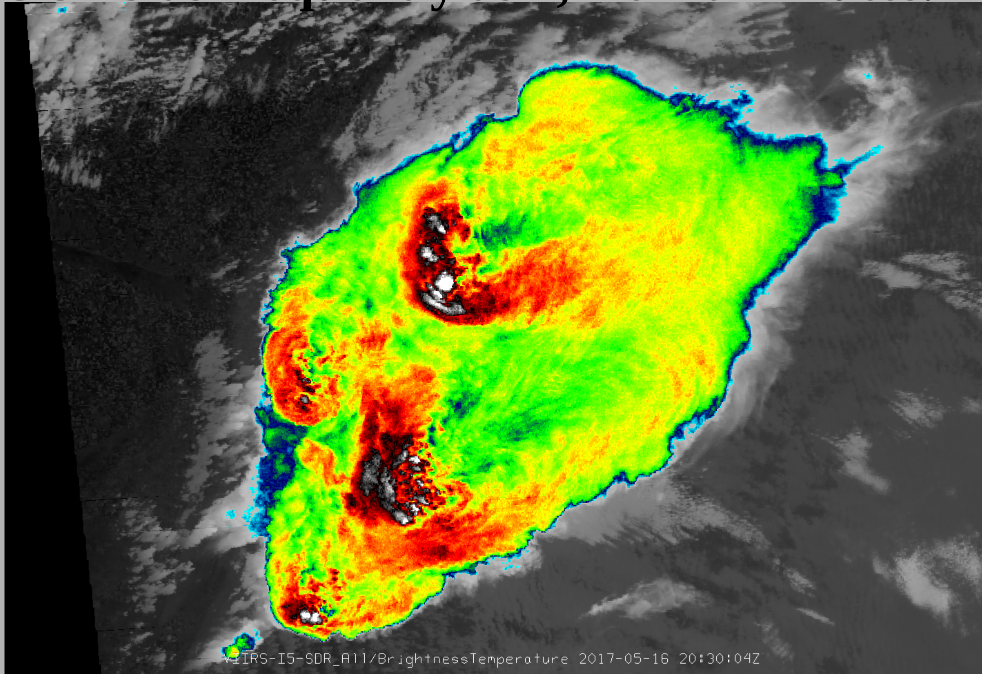
GOES and VIIRS Vis (top) 500 vs 375 meters
GOES and VIIRS IR (bottom) 2 km vs 375 meters
Images taken within 30 seconds of each other, and remapped to same projection





Close up of pervious slide images, Polar view is West of GOES-East satellite subpoint. Polar 2 x per day per satellite, GOES as frequently as 1, 2 or10 minutes.





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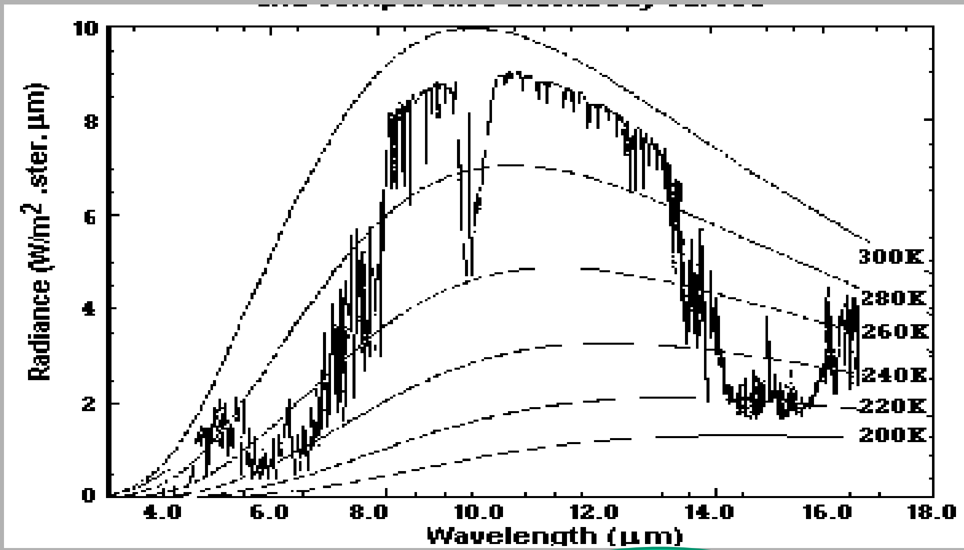
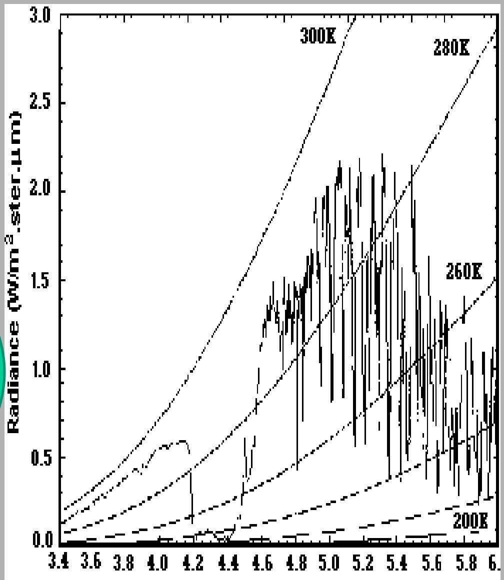


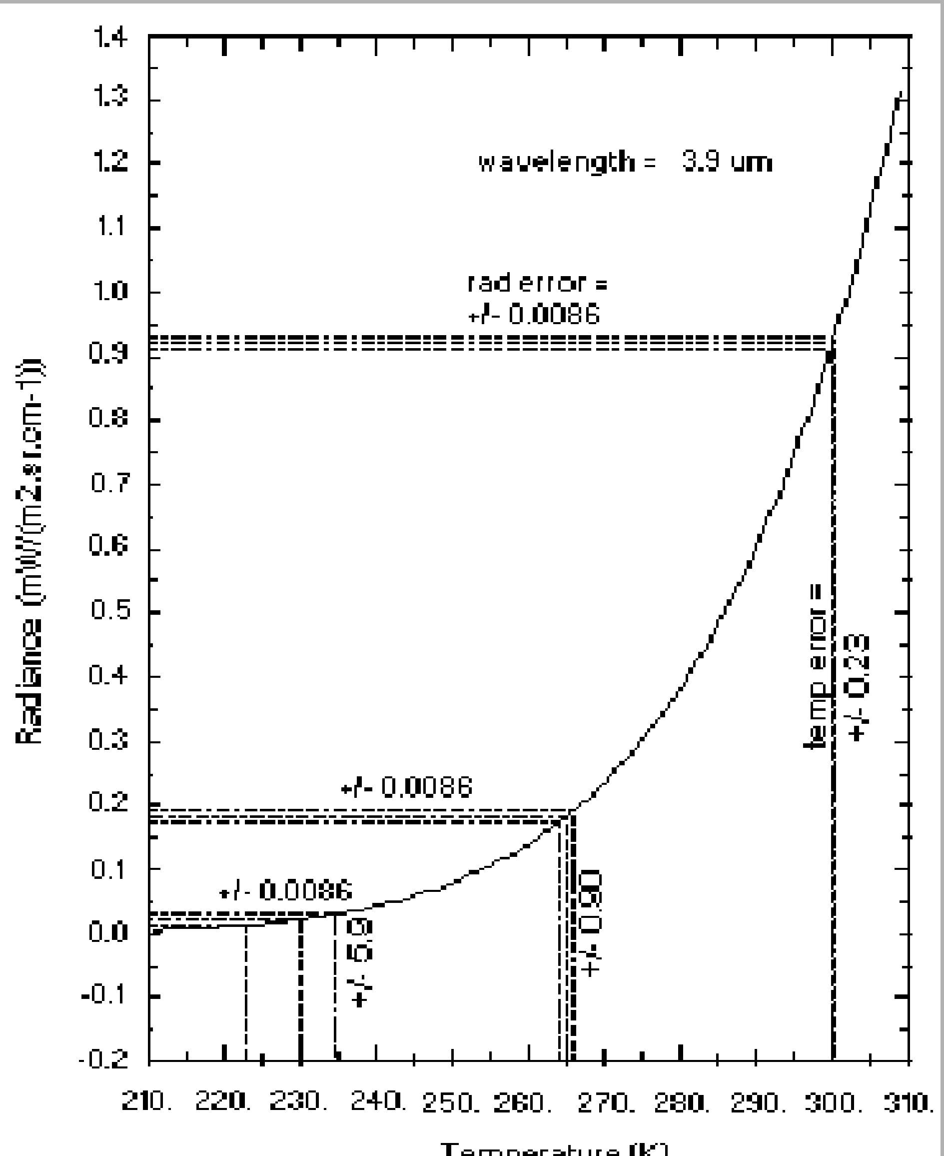
Planck blackbody curves (highly non-linear) and IRIS instrument observed spectrum



Planck bb temperature vs wavelength curves very steep at 3.9 microns but relatively flat at 10 microns

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}$$

Notice the difference in signal to noise at the cold end for 3.9 vs 10.7 (from GOES I/M series)



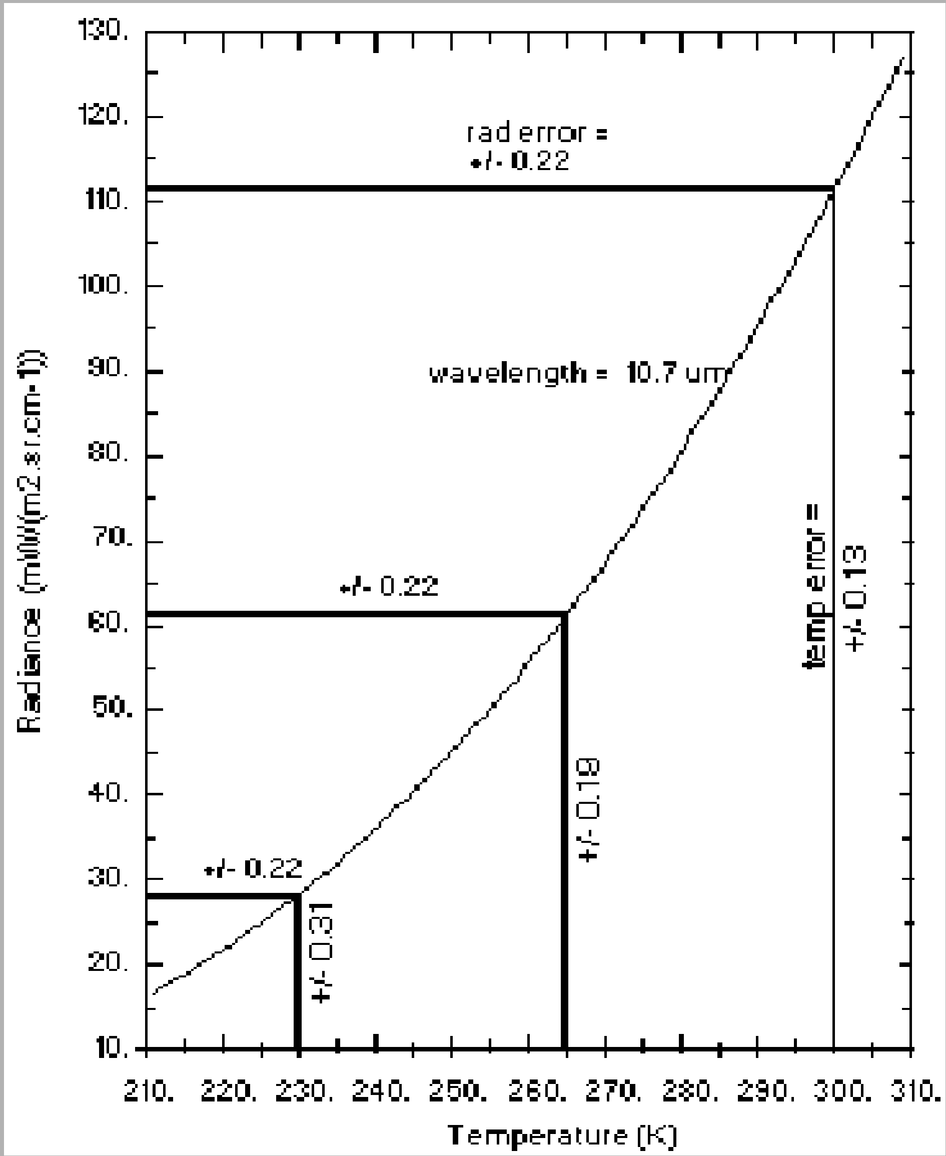
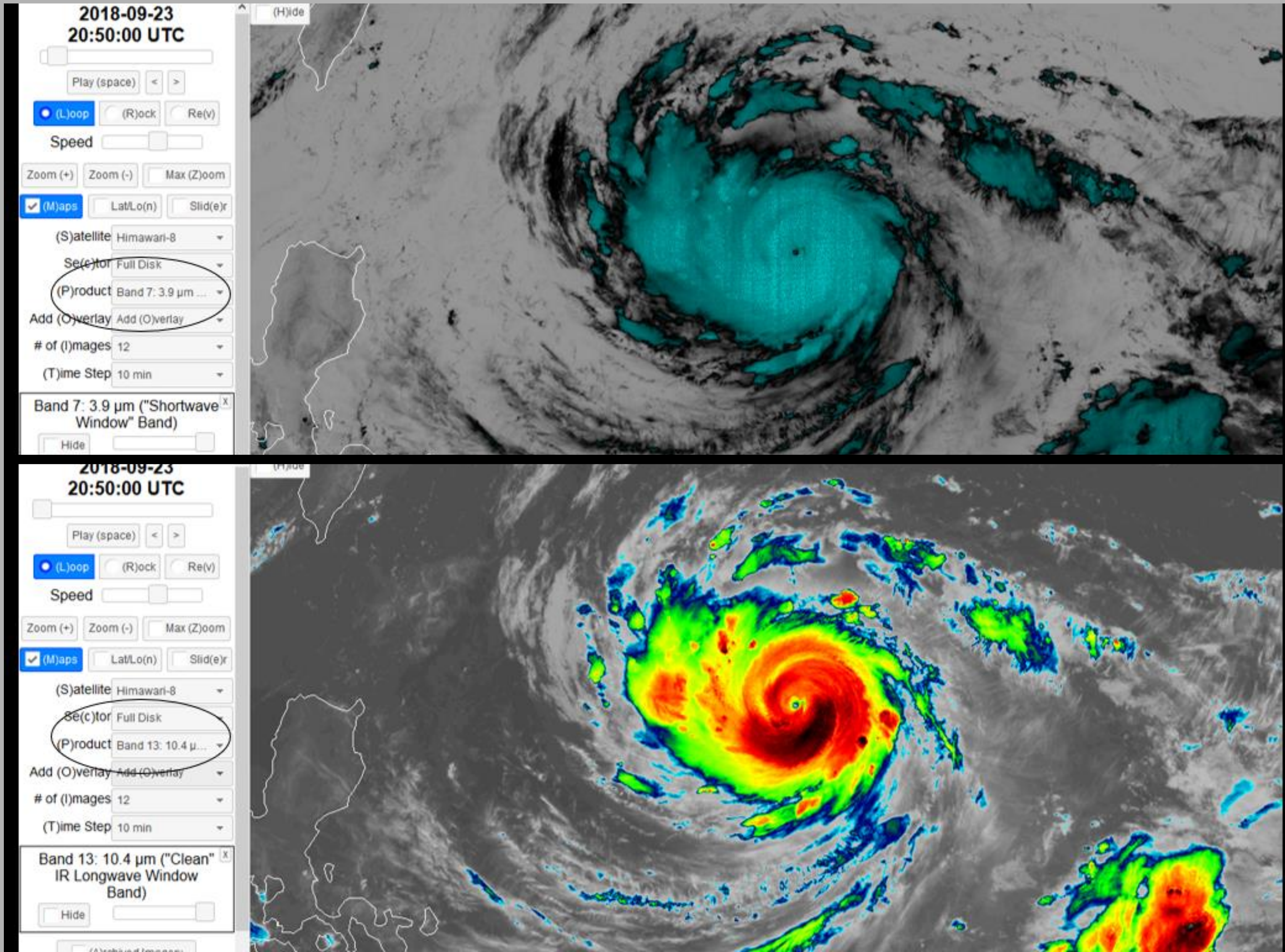
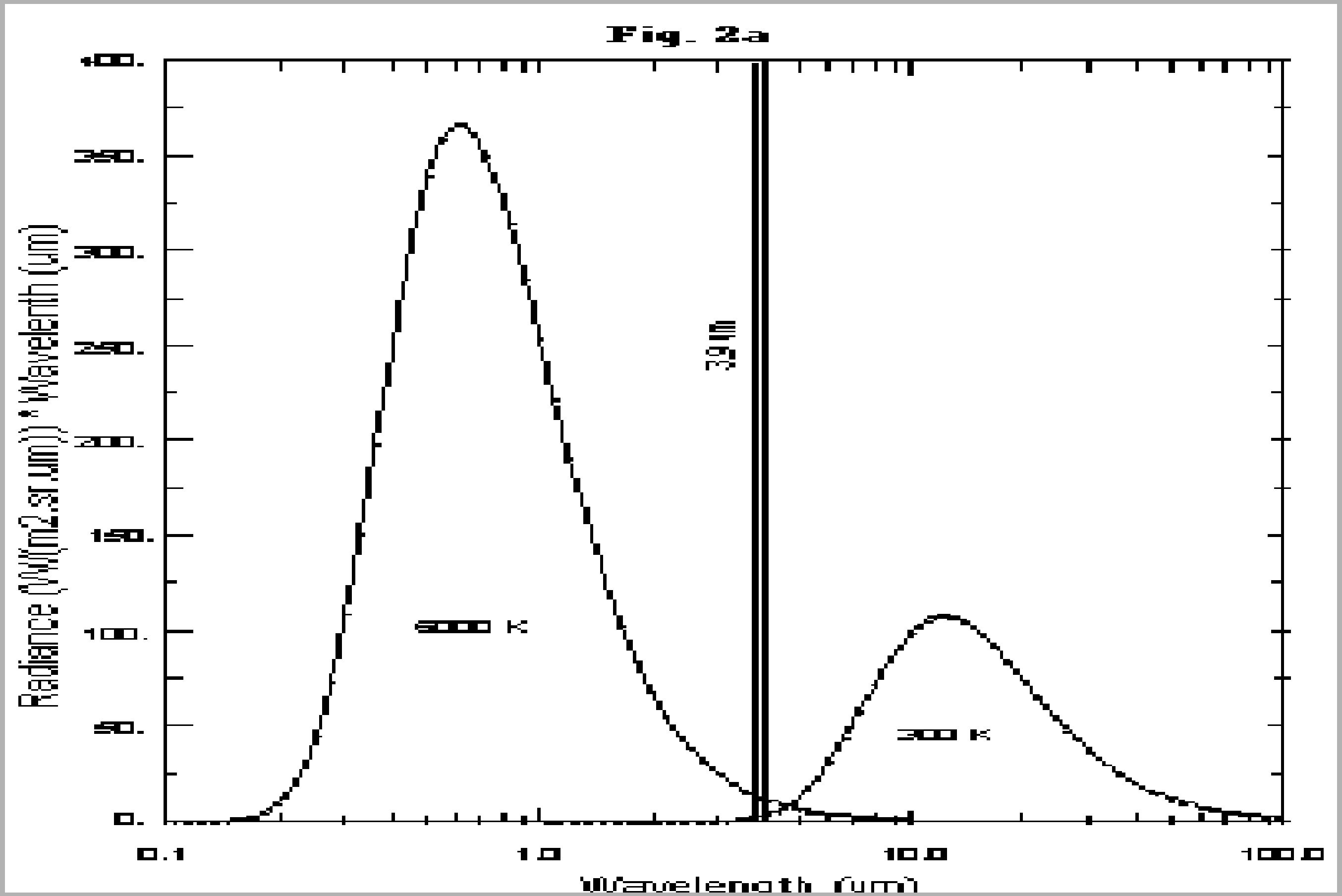


Illustration of the difference in signal to noise between 10.7 (bottom) and 3.9 (top) micron channels



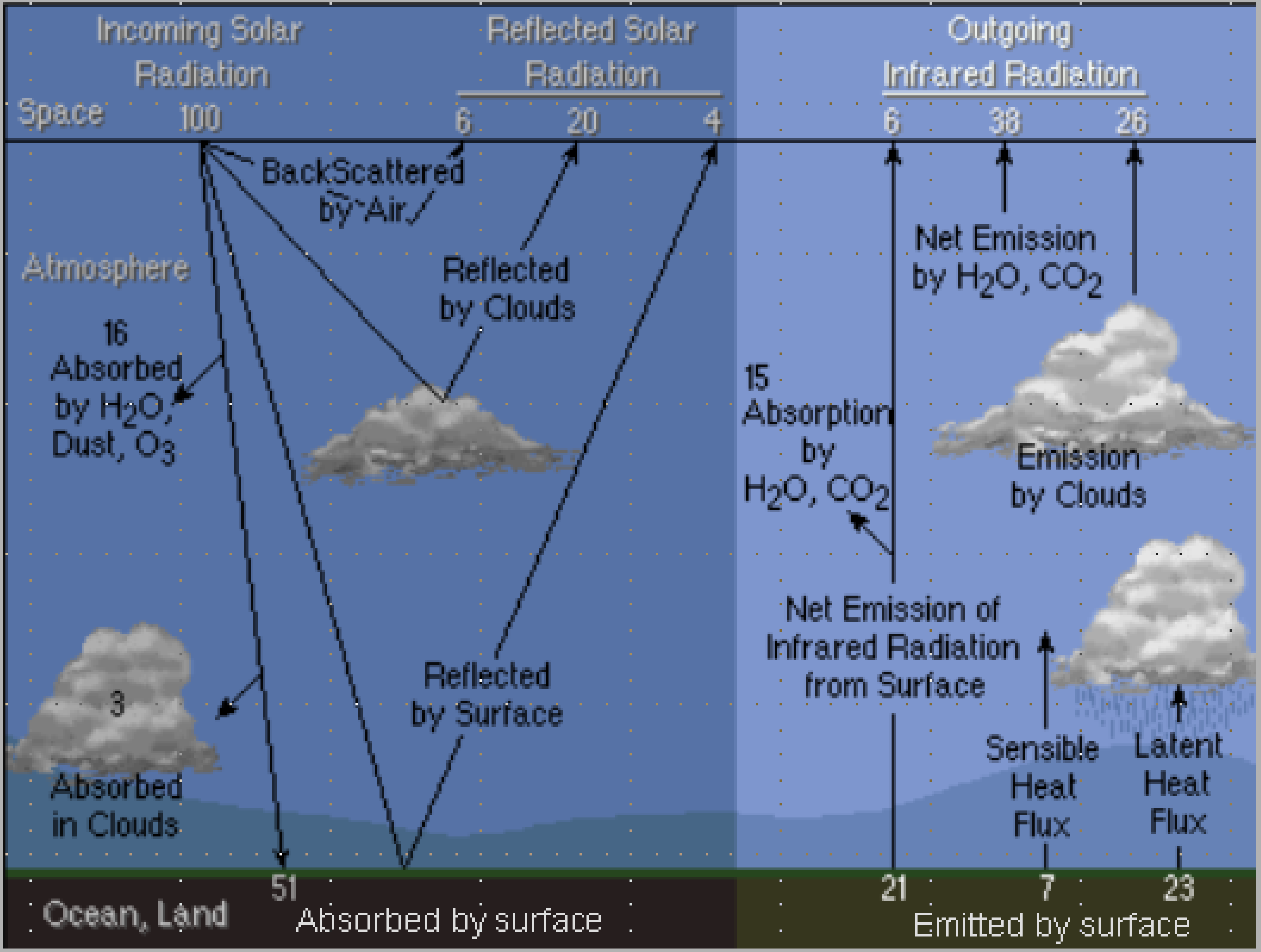
Radiance versus wavelength for blackbodies at 6000 K (sun) and 300 K (earth), notice 3.9 μm region



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)



Recall that in satellite remote sensing, four basic parameters need to be addressed: all deal with resolution. The new generation geostationary satellites are a giant step forward in all four!!!

- temporal (how often)
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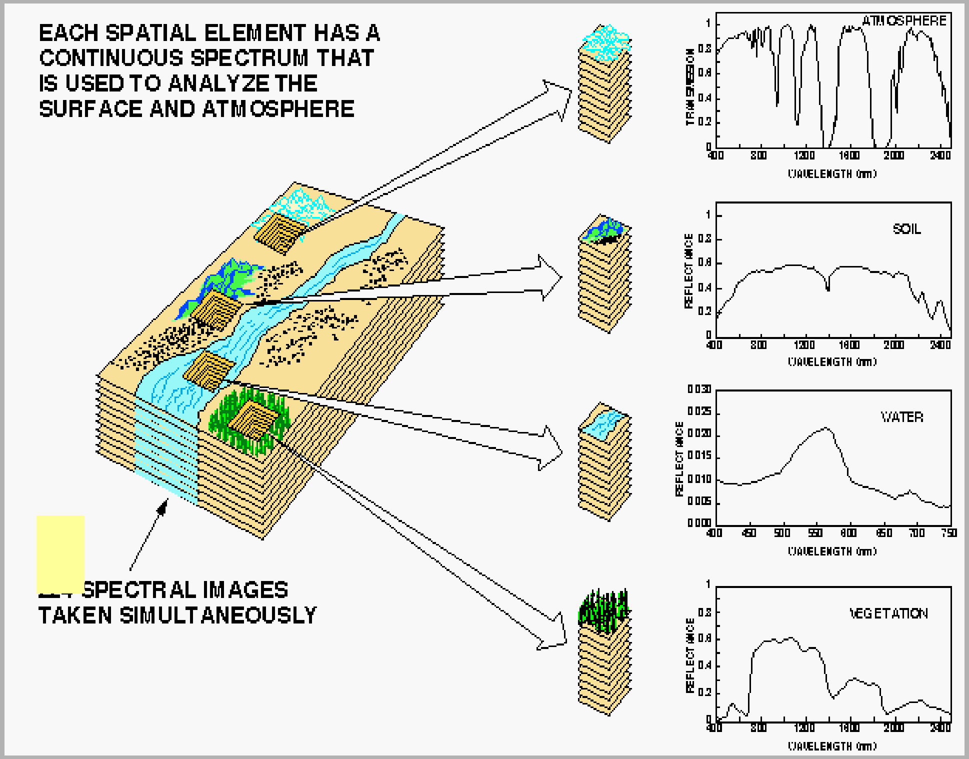
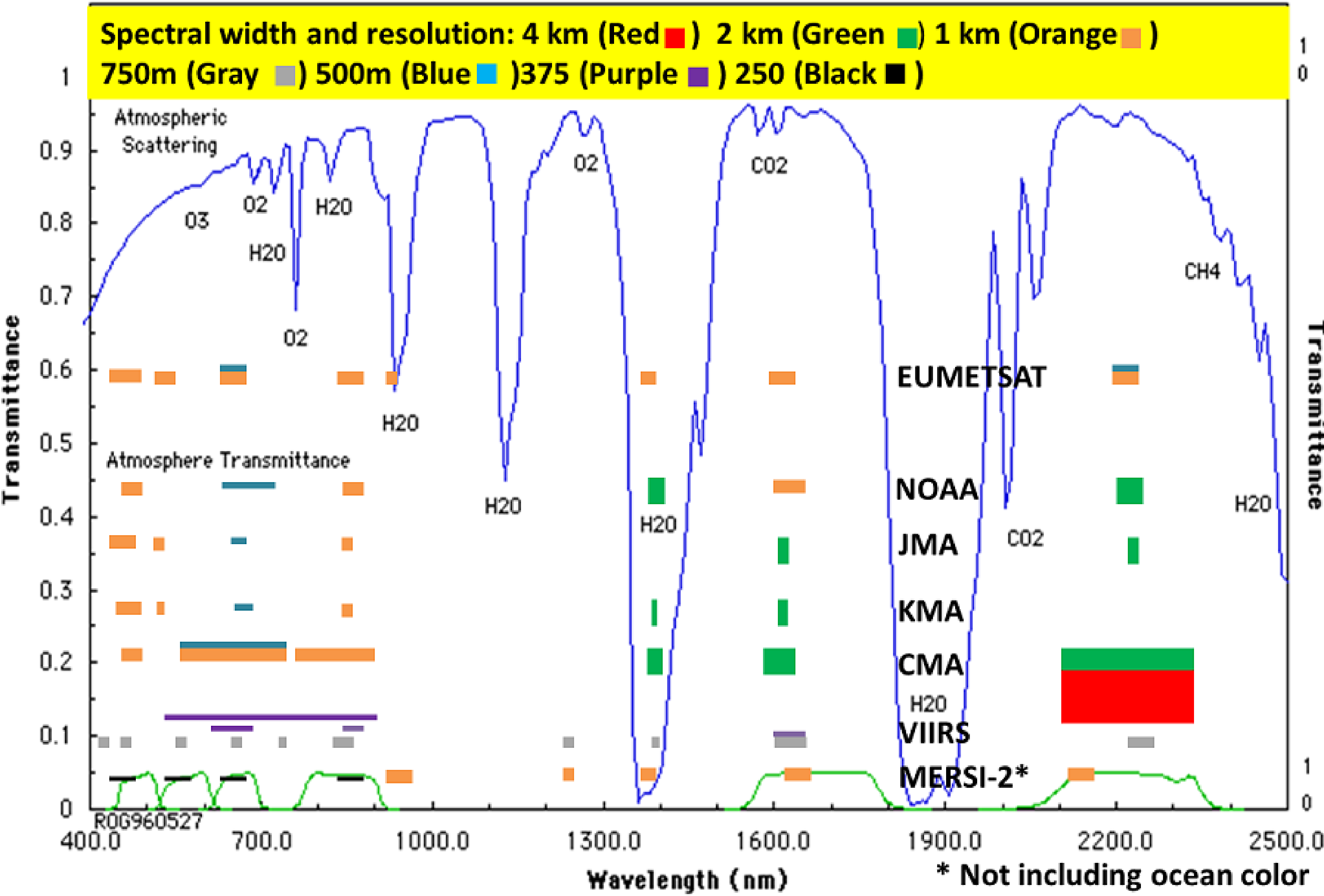
The spatial and temporal domains of the phenomena being observed drive the satellite systems' spectral needs as a function of space, time, and signal to noise.



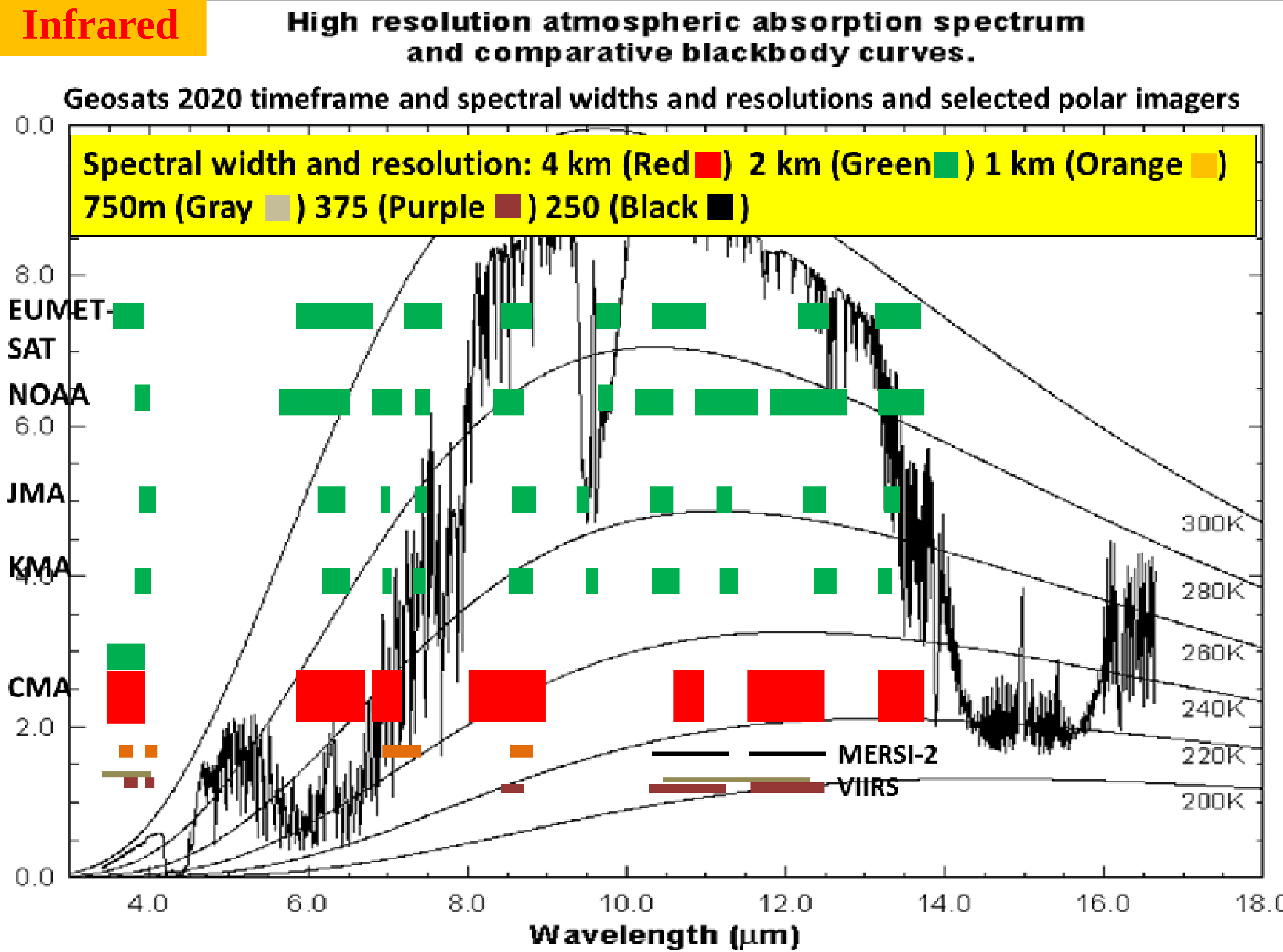
Each spatial element has a continuous spectrum that may be used to analyze the surface and atmosphere

Geosats 2020 timeframe and spectral widths and resolutions and selected polar imagers



* Not including ocean color

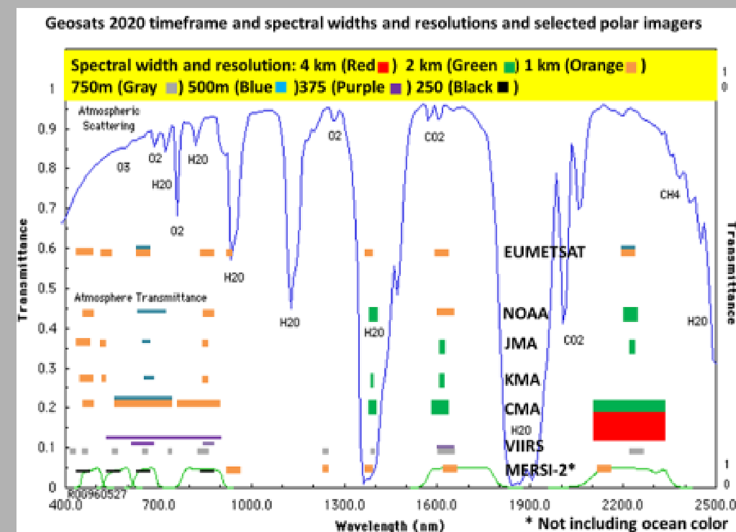
Infrared

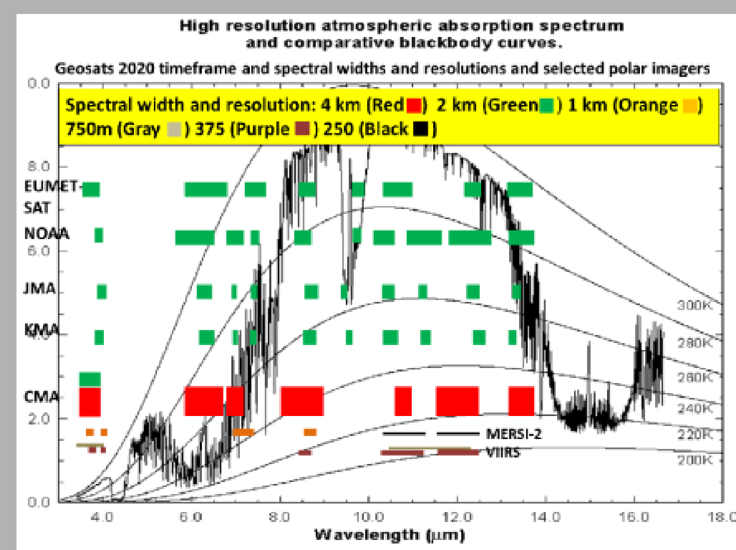

High resolution atmospheric absorption spectrum
and comparative blackbody curves.
Geosats 2020 timeframe and spectral widths and resolutions and selected polar imagers
Spectral width and resolution: 4 km (Red) 2 km (Green) 1 km (Orange)
750m (Gray) 375 (Purple) 250 (Black)
EUMET-SAT
NOAA
JMA
KMA
CMA
MERSI-2
VIIRS
300K
280K
260K
240K
220K
200K
0.0
8.0
6.0
4.0
2.0
0.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
Wavelength (µm)

FULL UTILIZATION = BIG CHALLENGE

65,535 ways to "combine" 16 channels

- Single channel 16
- 2 channels per image 120
- 3 channels per image 560
- 4 channels per image 1820
- 5 channels per image 4368
- 6 channels per image 8008
- 7 channels per image 11440
- 8 channels per image 12870
- 9 channels per image 11440
- **********
- 15 channels per image 16
- 16 channels 1

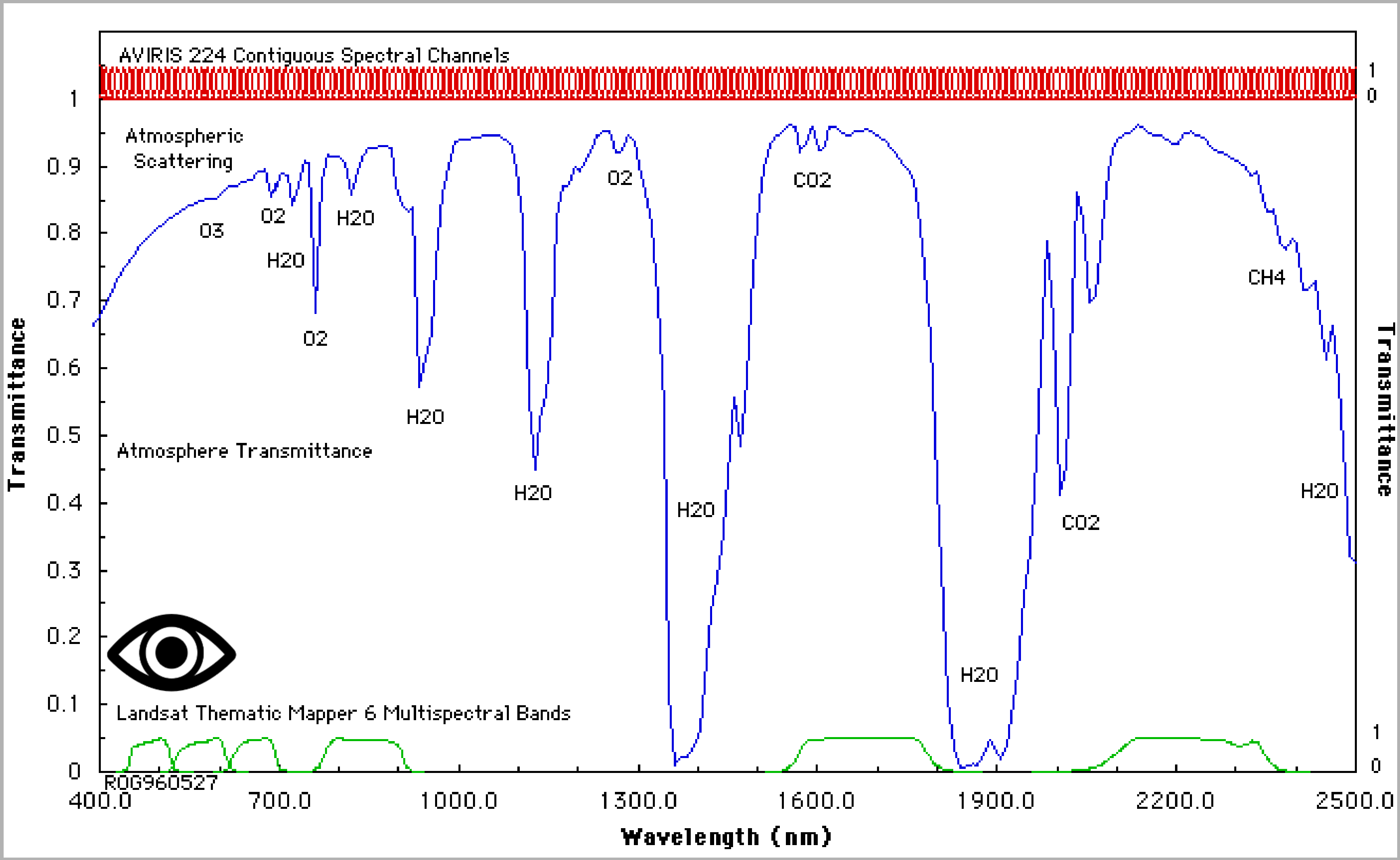


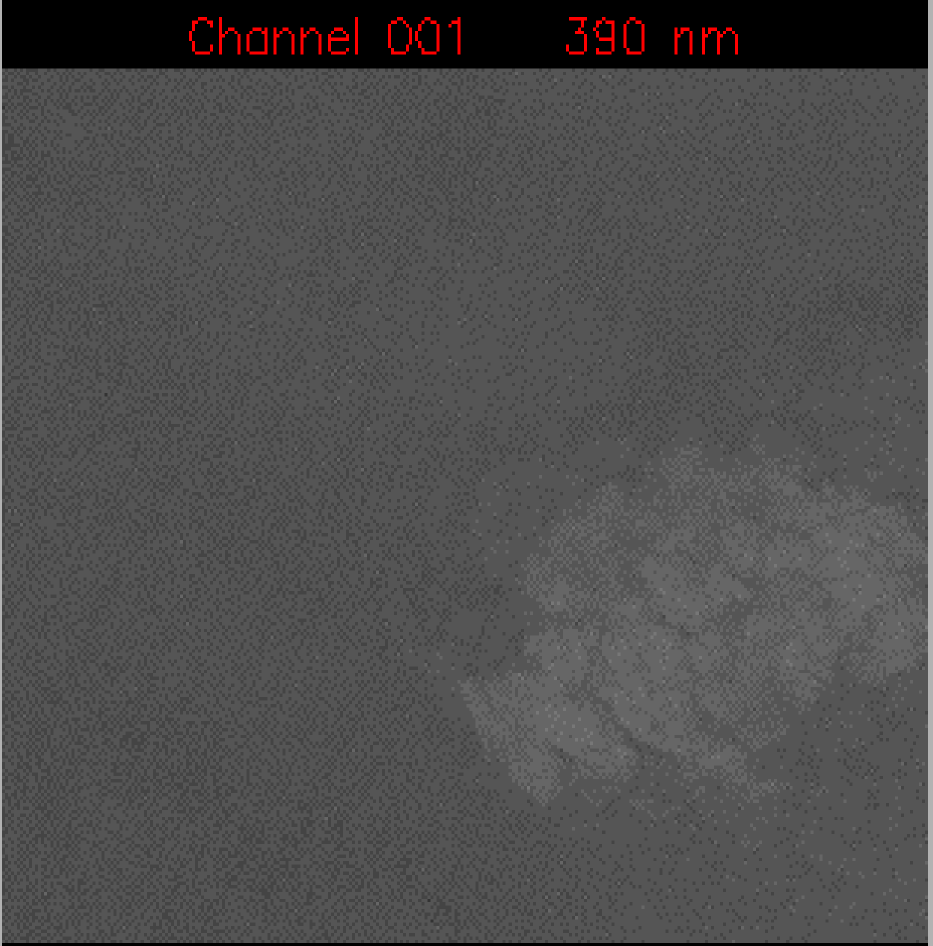


Spectral Information

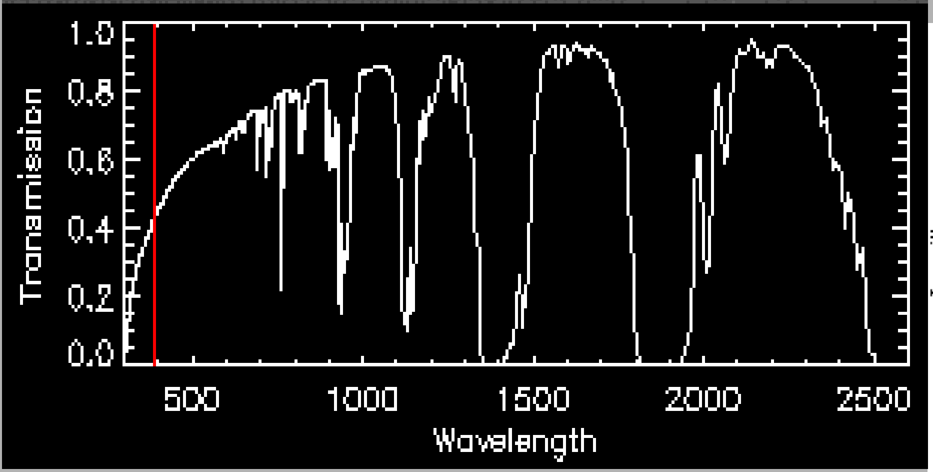
- Now let’s look in more detail at the visible, near infrared and infrared portions of the spectrum. Our objective is to get a better understanding of their unique characteristics and how that information may be used to analyze the land, ocean and atmosphere.

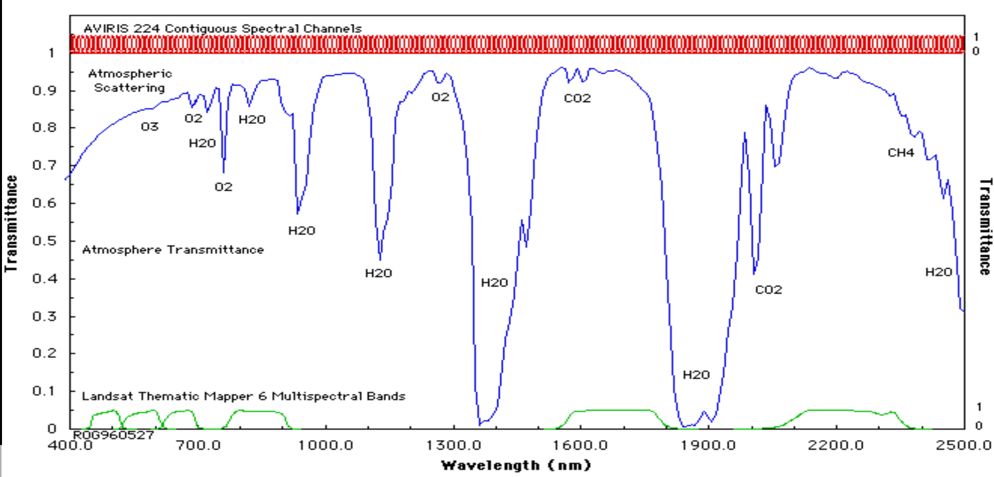
The visible to near infrared portion of the spectrum

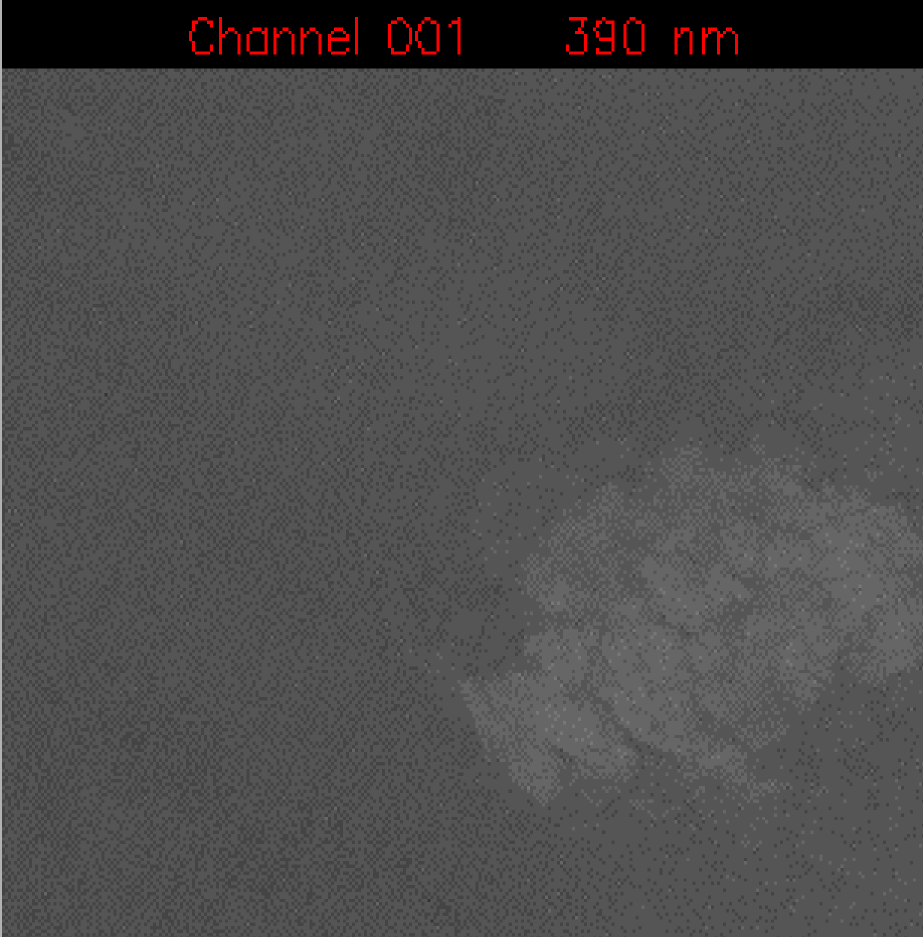




Spectral animation of a single AVIRIS scene reveals the power of being able to observe with high spectral resolution. Beginning at 400 nanometers ground features are difficult to discern, mainly due to molecular scattering which decreases at longer wavelengths. As we observe the scene at longer wavelengths, 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.







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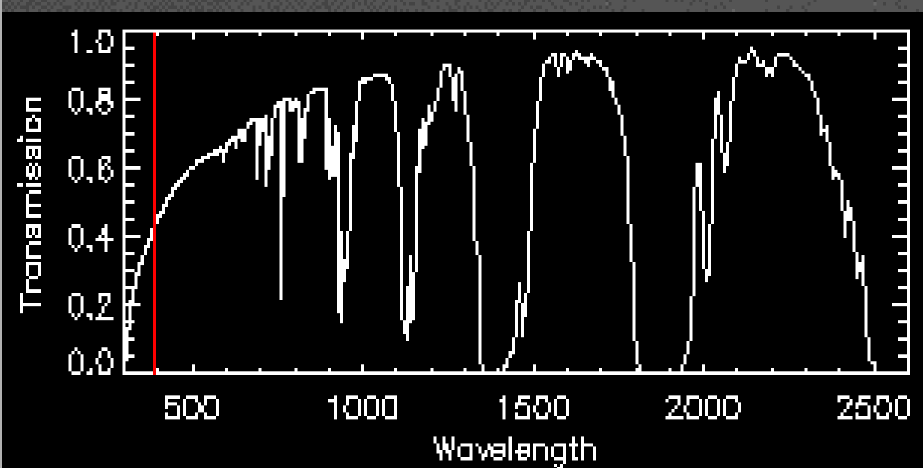
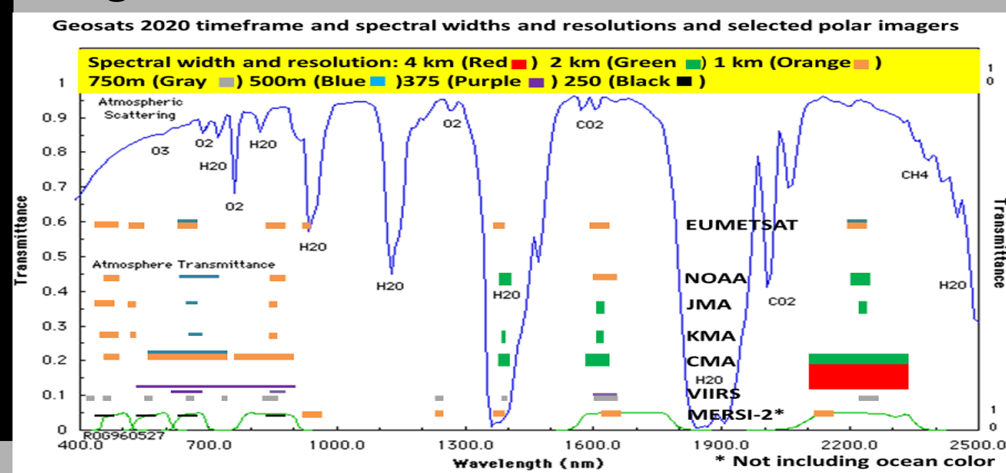
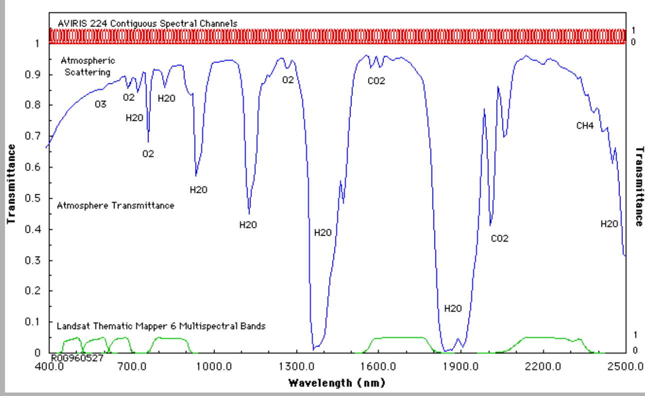
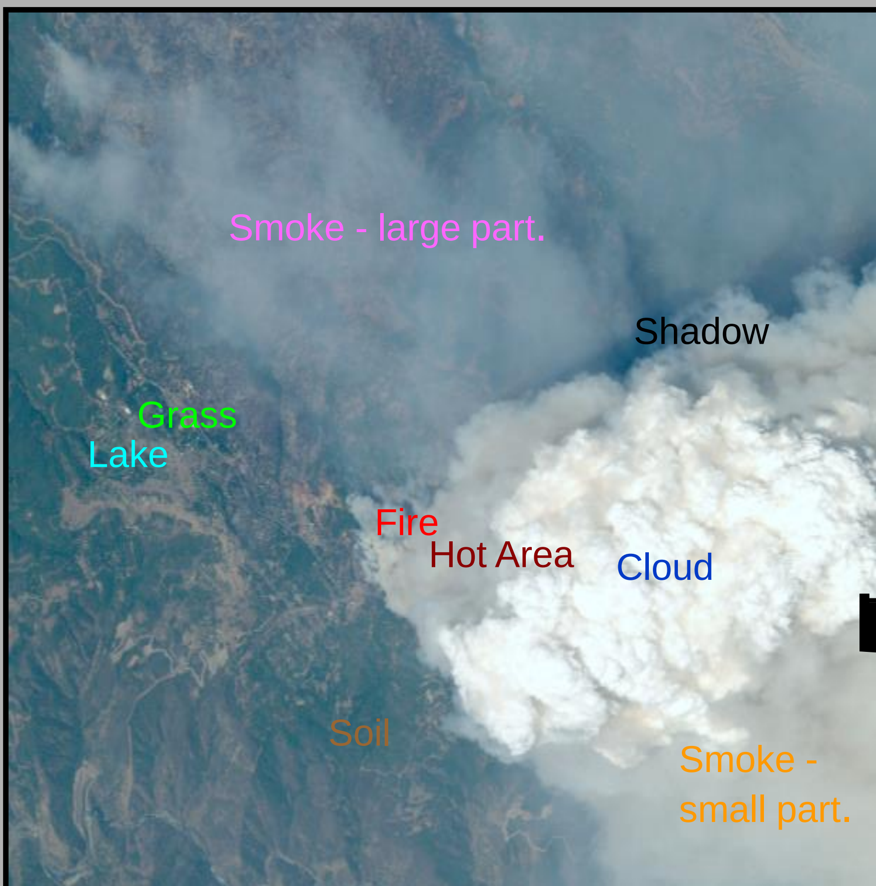


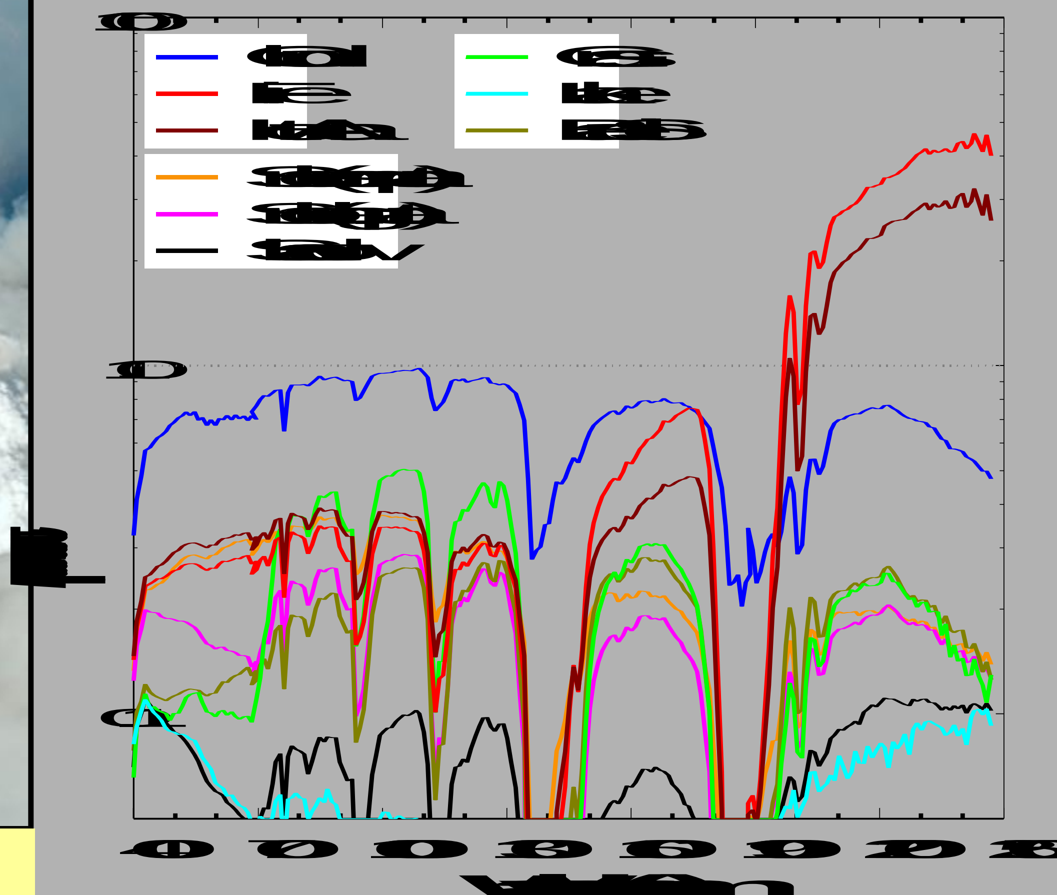


AVIRIS Spectral Information from the Scene Depicting Cloud, Smoke and Active Burn Areas

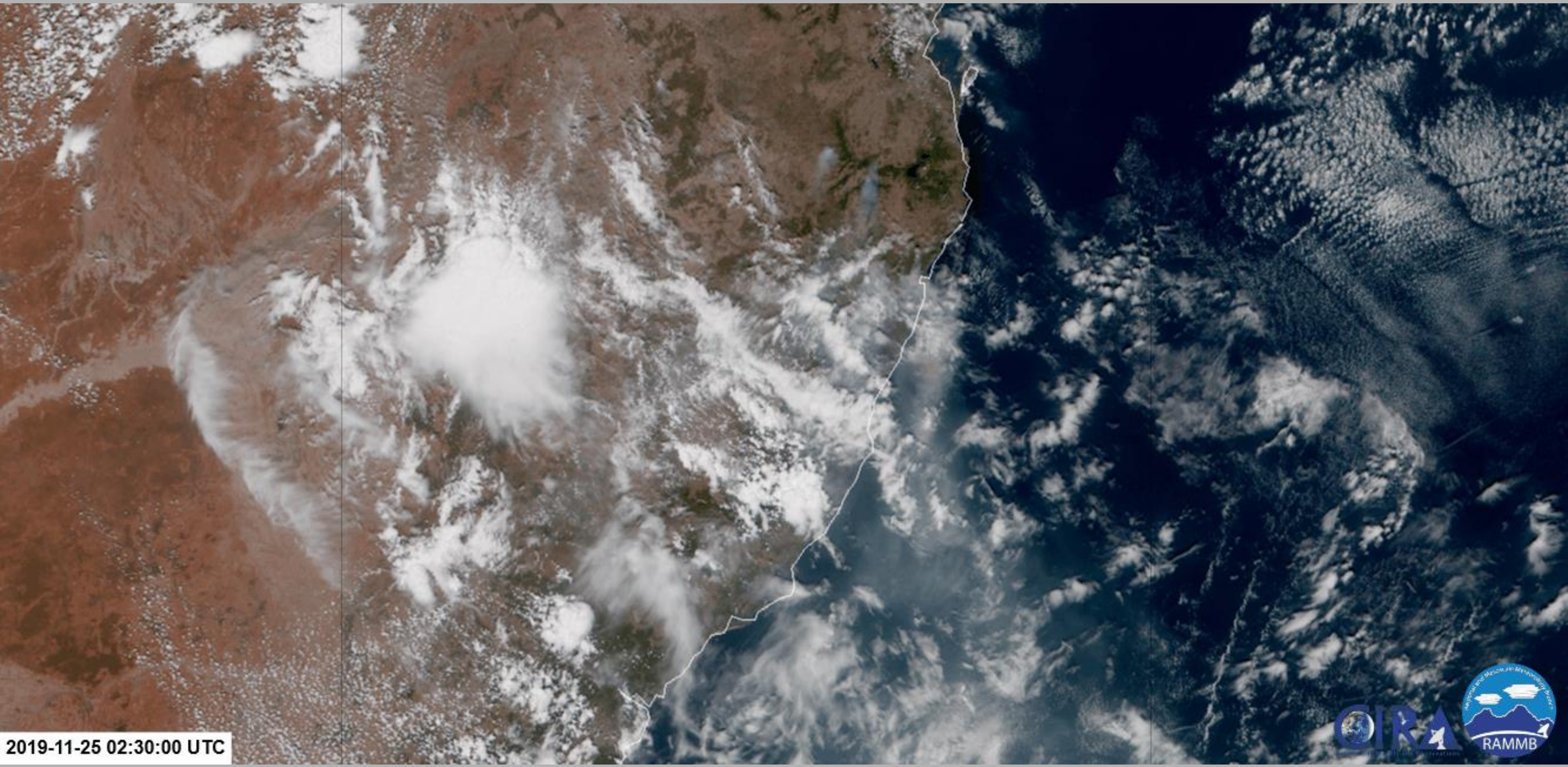




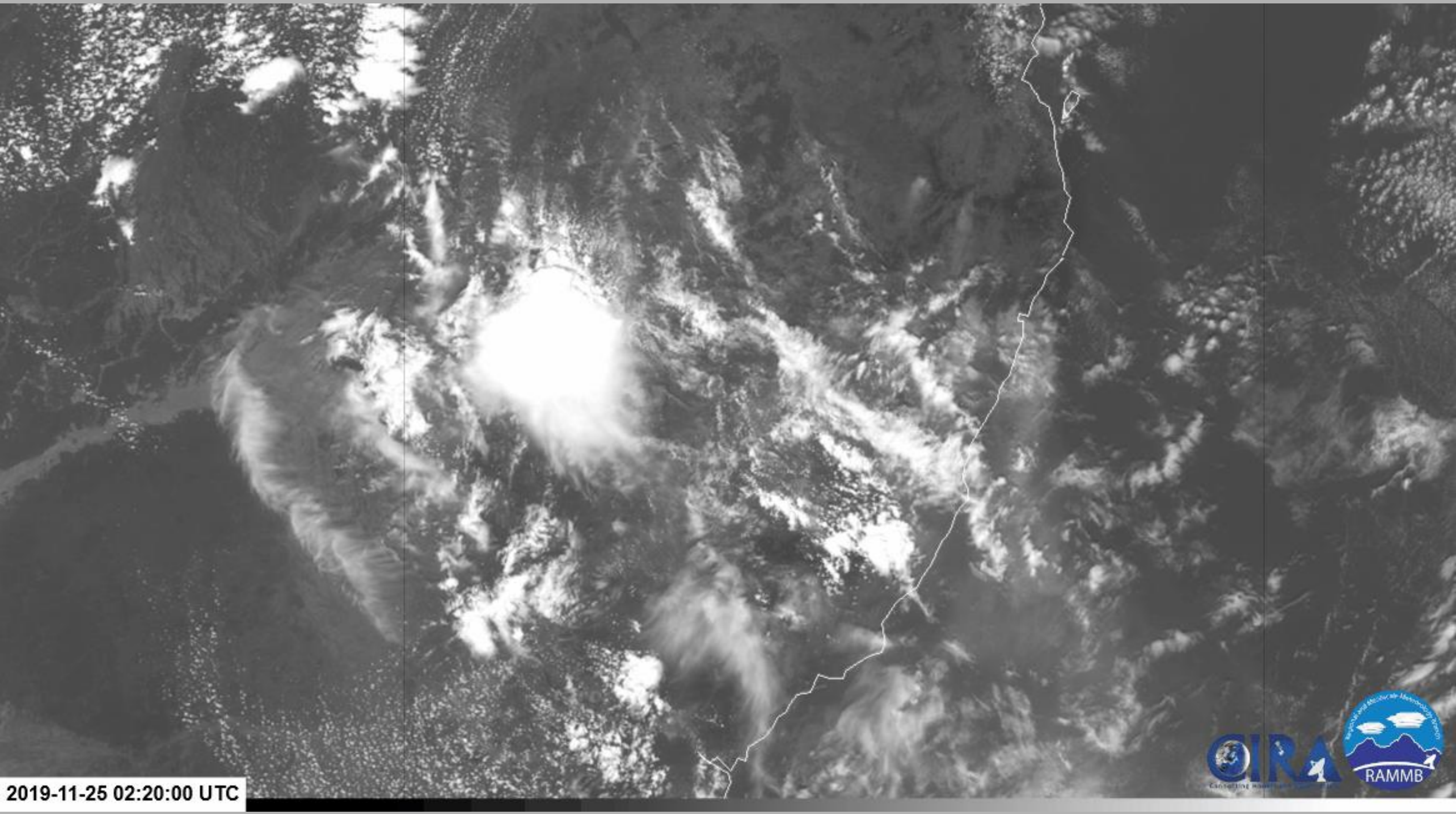
AVIRIS Image - Linden CA 20-Aug-1992
224 Spectral Bands: 0.4 - 2.5 μm
Pixel: 20m x 20m Scene: 10km x 10km



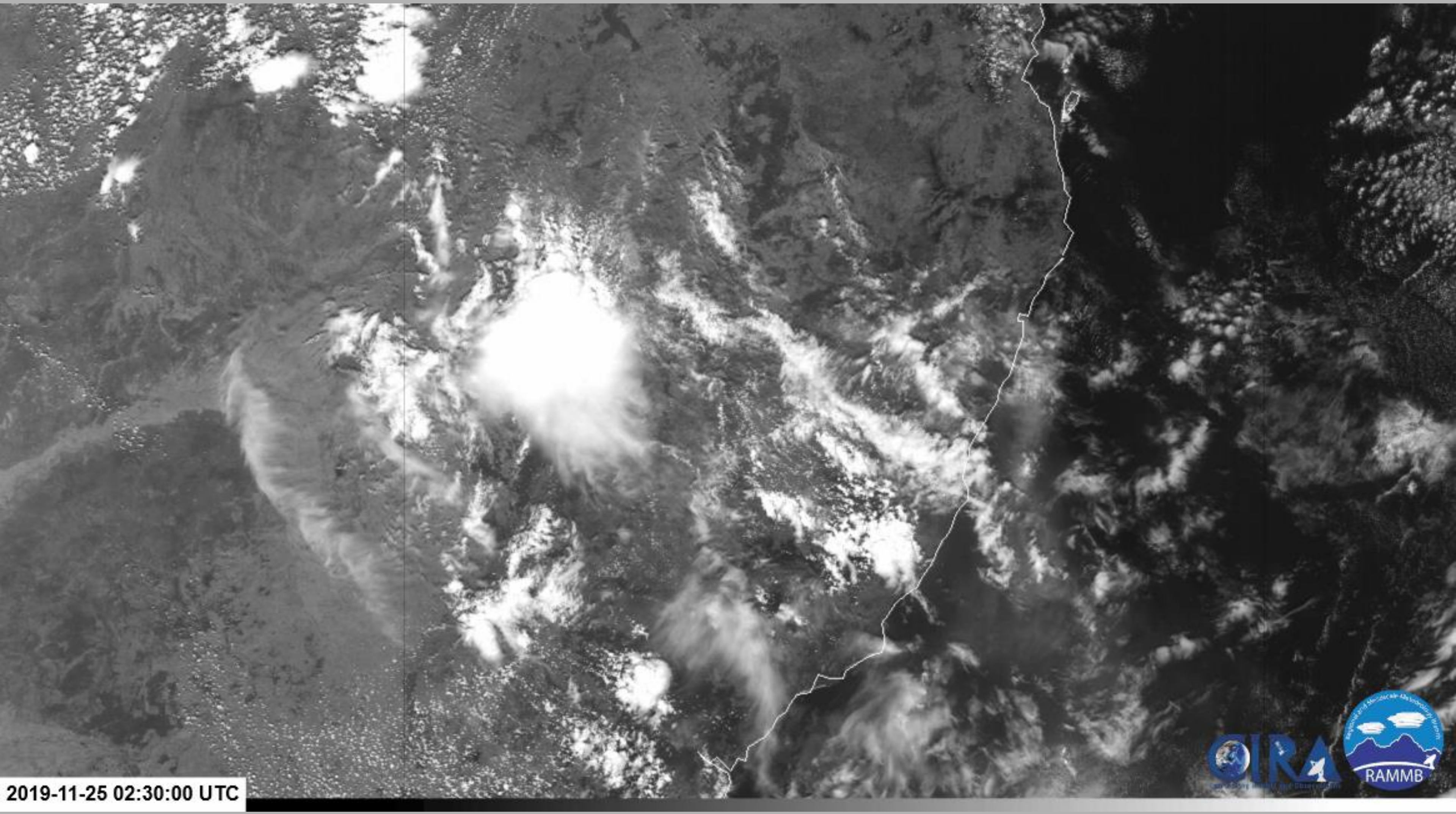
Spectral Signatures of Selected Pixels



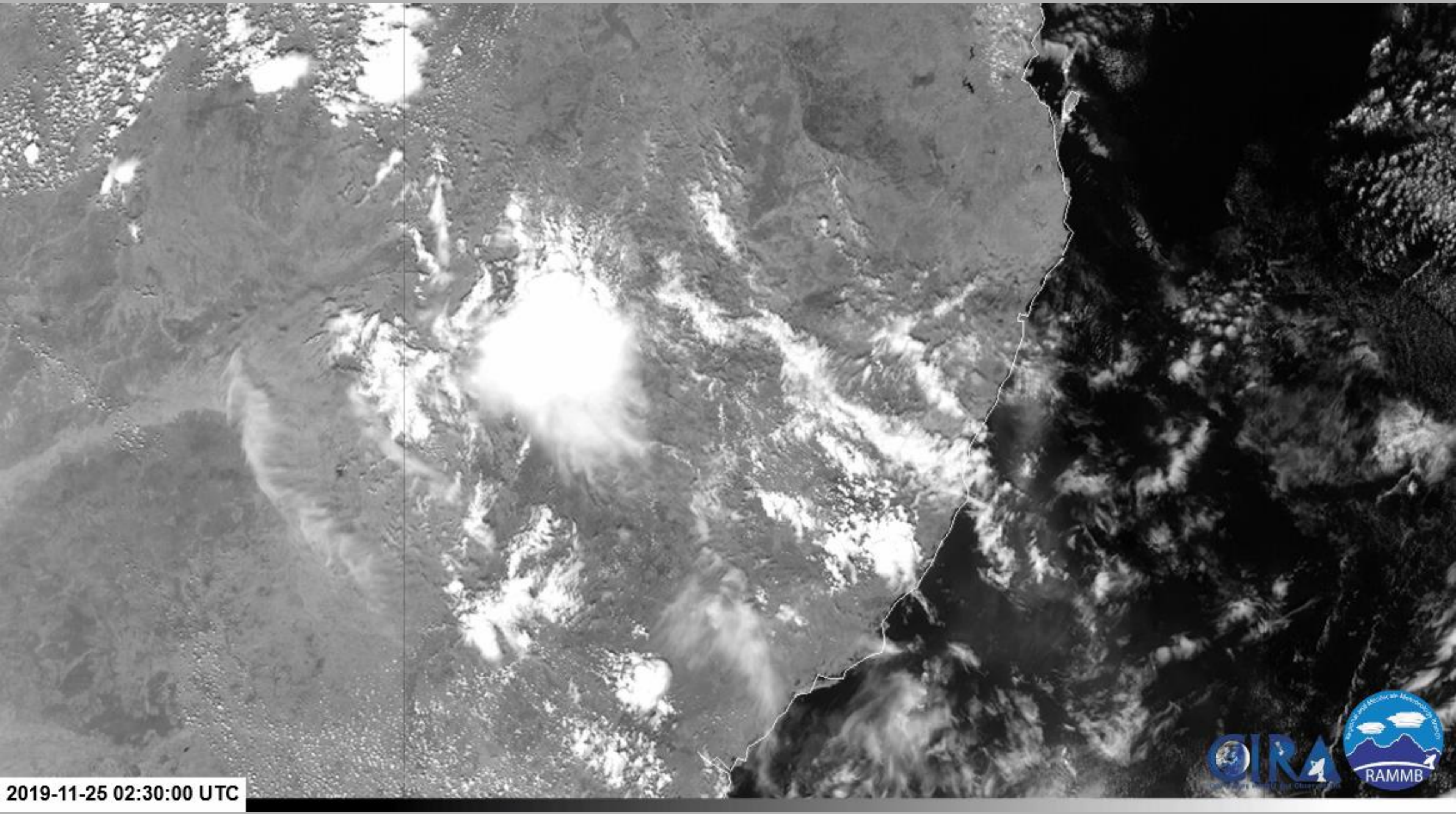
Slider: CIRA GeoColor showing smoke and clouds over SE Australia



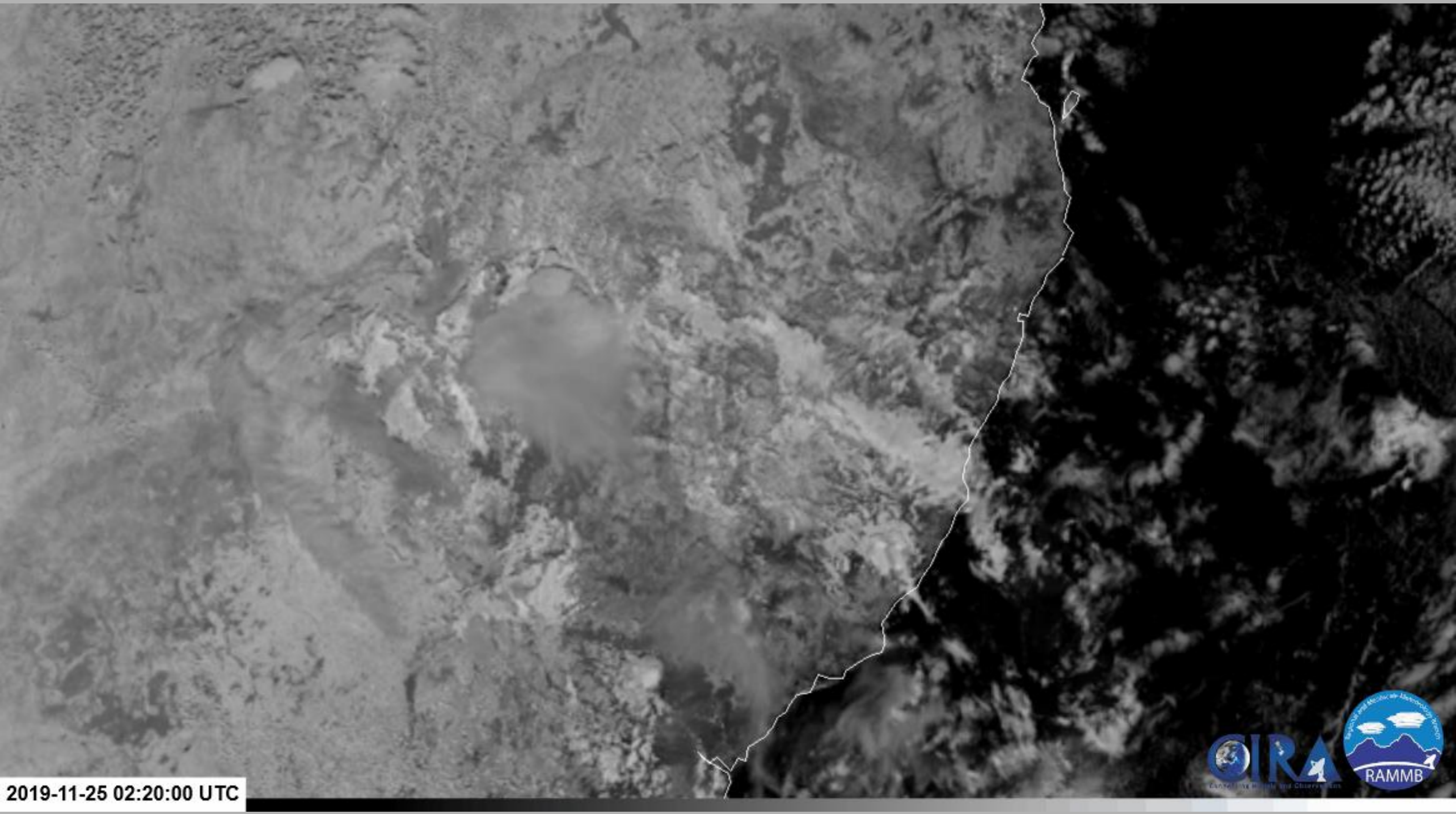
Slider: CIRA 0.47 micron showing smoke and clouds over SE Australia



Slider: CIRA 0.64 microns showing smoke and clouds over SE Australia



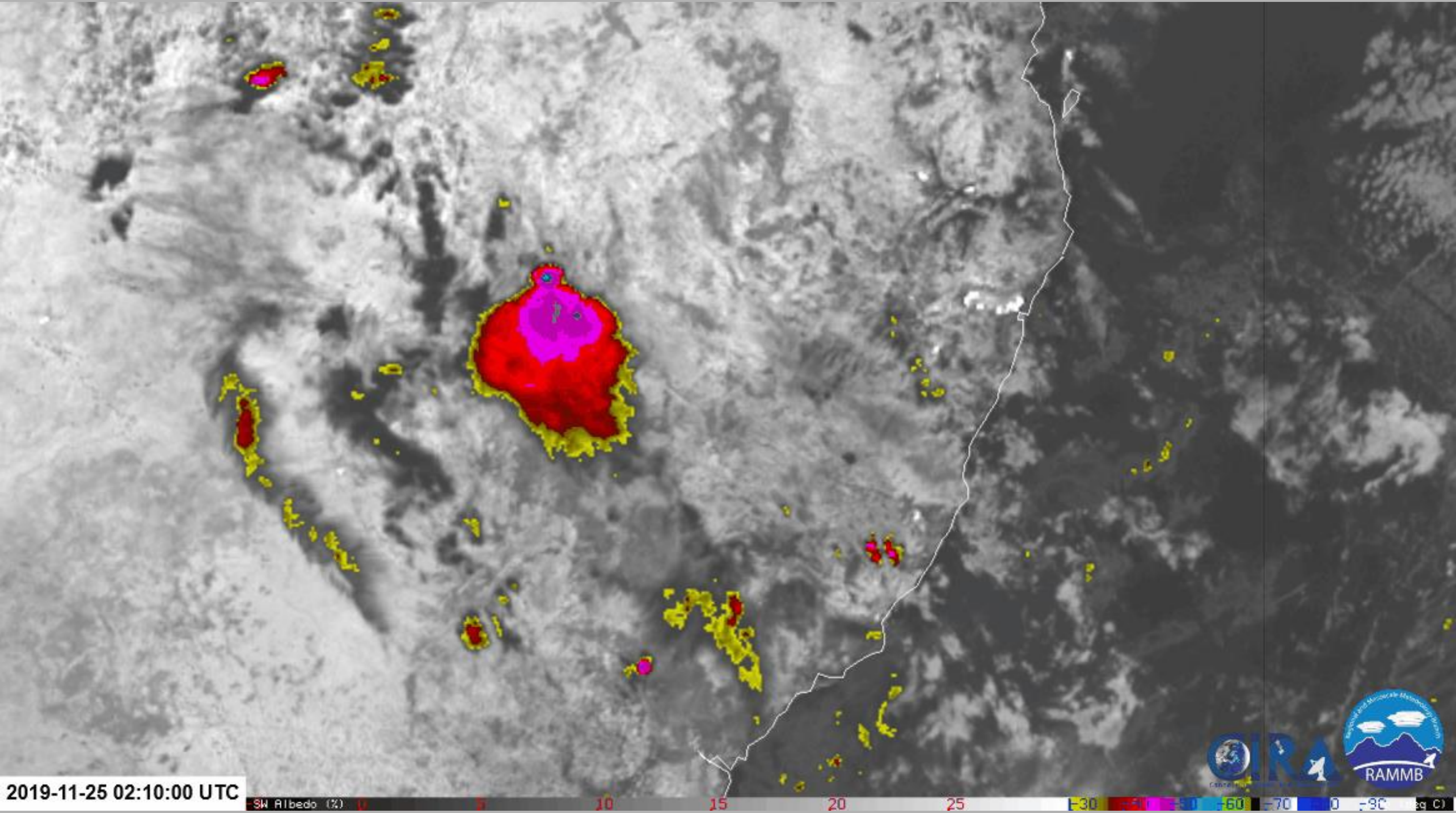
Slider: CIRA 0.86 showing clouds over SE Australia



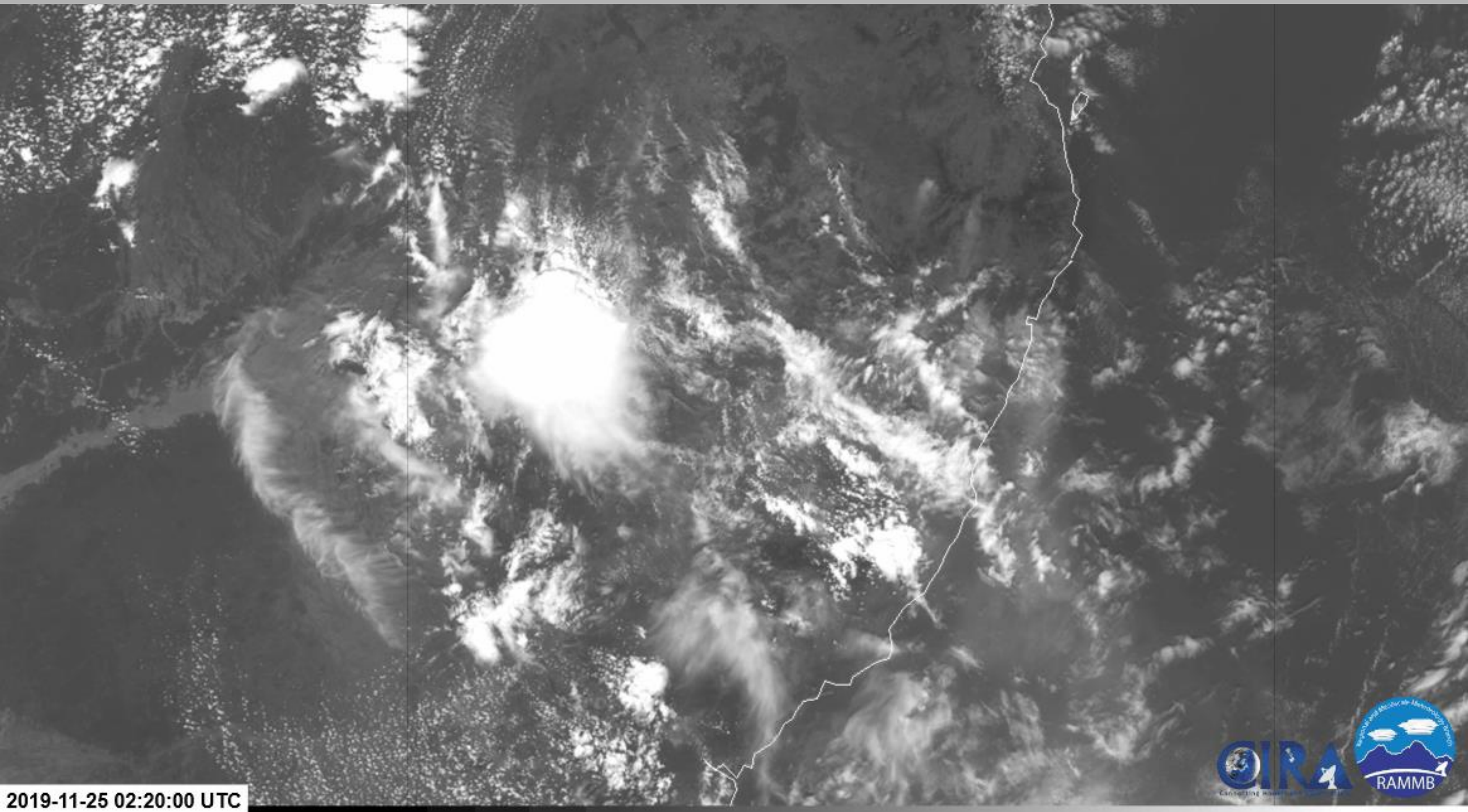
Slider: CIRA 1.6 microns microns showing clouds over SE Australia

Slider: CIRA 2.3 microns showing fires and clouds over SE Australia

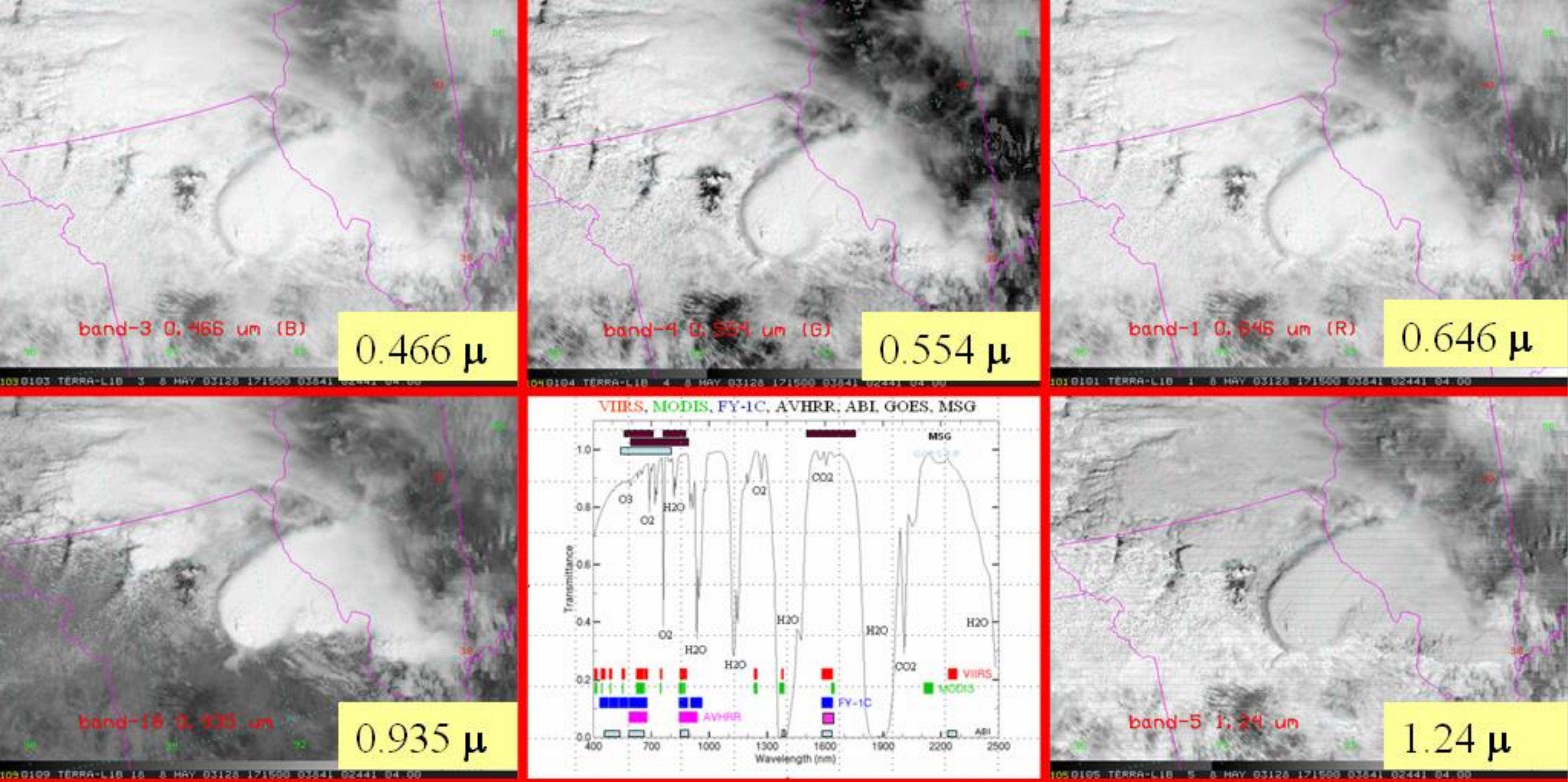
We'll look at how this product is made from 3.9 and 10.7 micron infrared data a little later. For now the bright spots are fire areas.



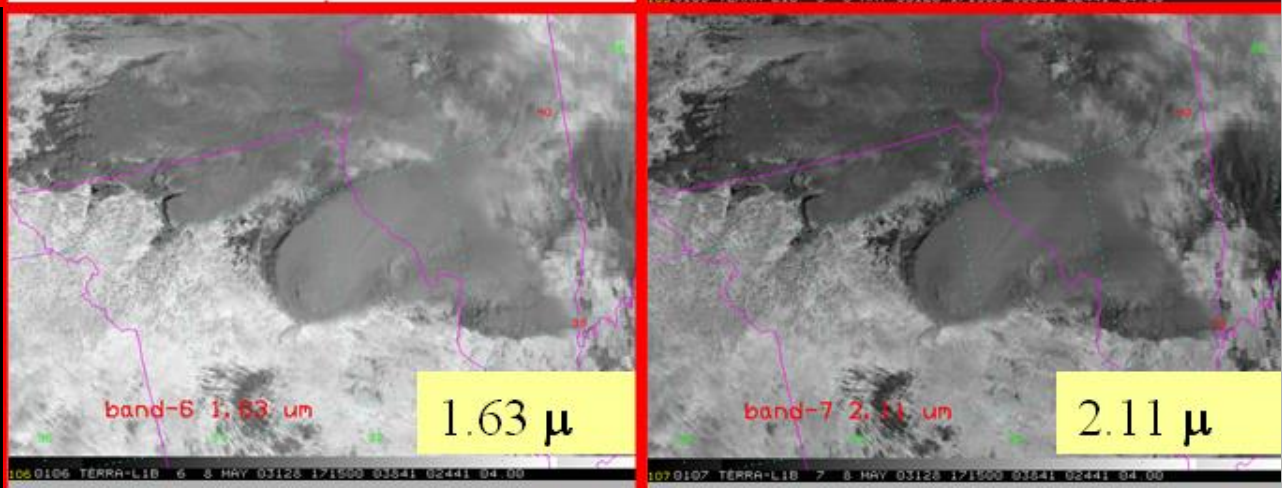
Slider: CIRA Shortwave albedo showing fires and clouds over SE Australia

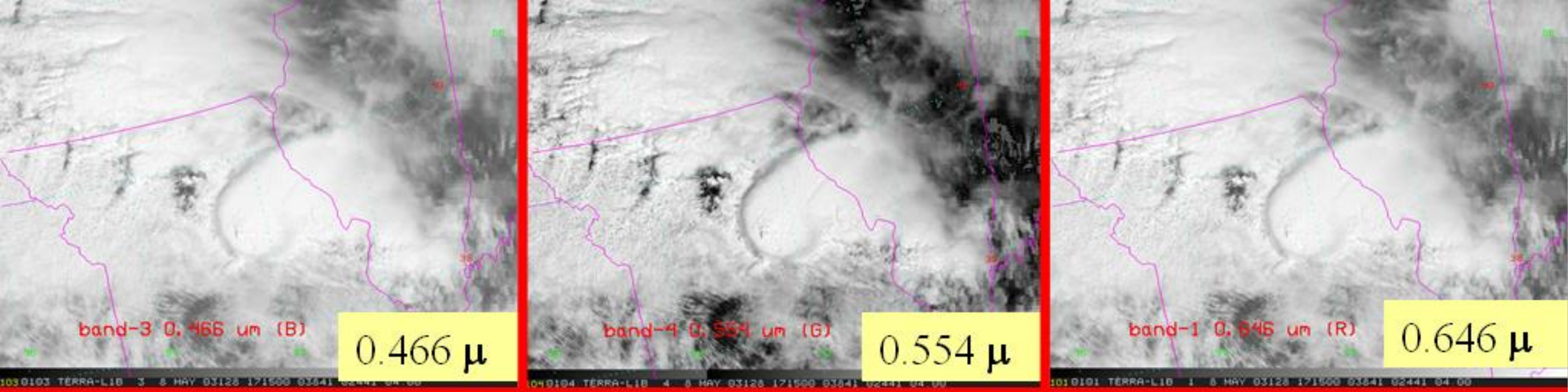


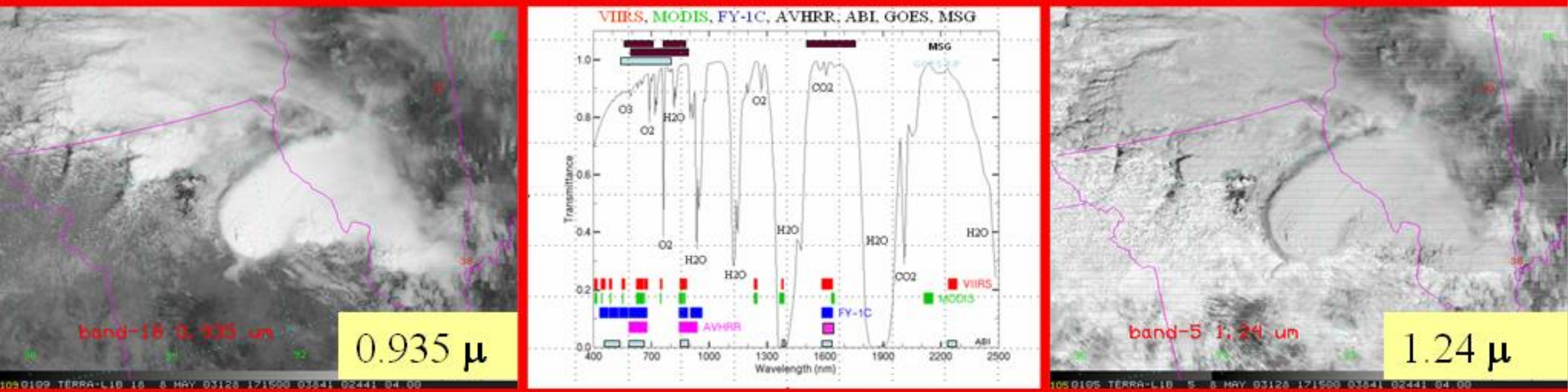
Slider: CIRA 0.47 microns showing smoke and clouds over SE Australia



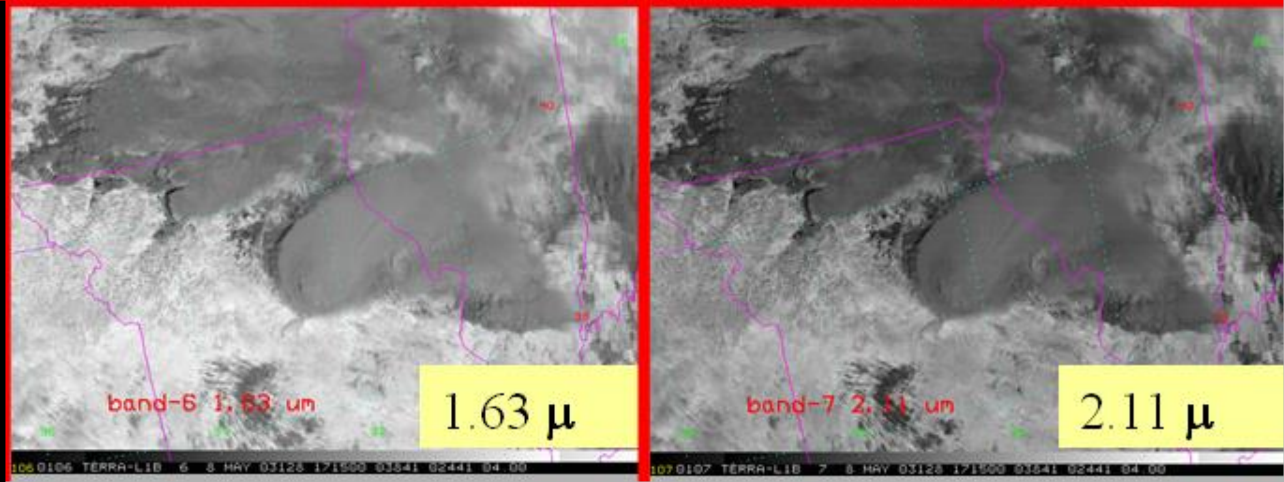
Daytime view of low cloud (water) and a thunderstorm anvil (ice) in different MODIS reflective channels

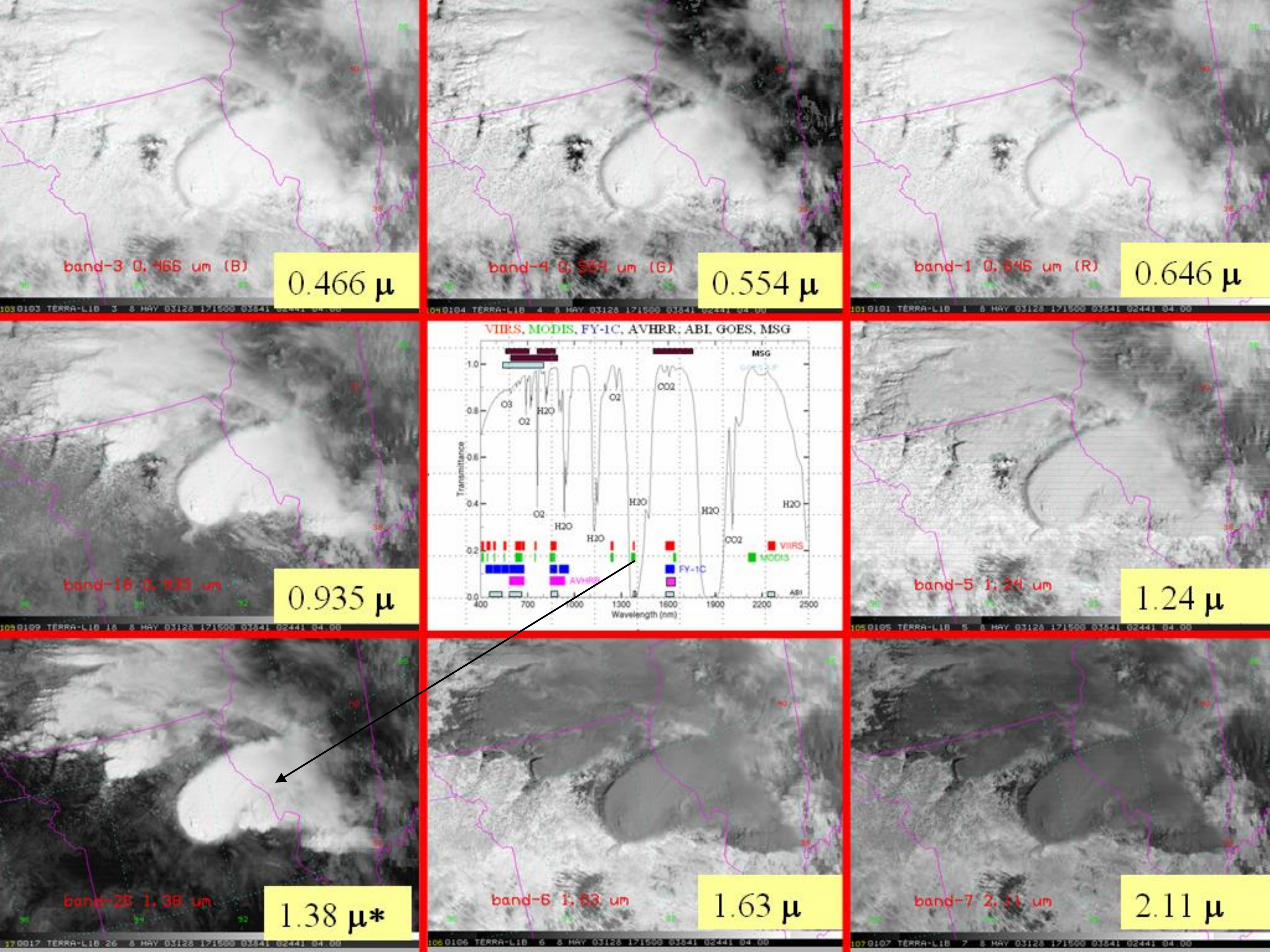






Now for a look at the reflection from the 1.38 micron MODIS channel in the center of a water vapor absorption region





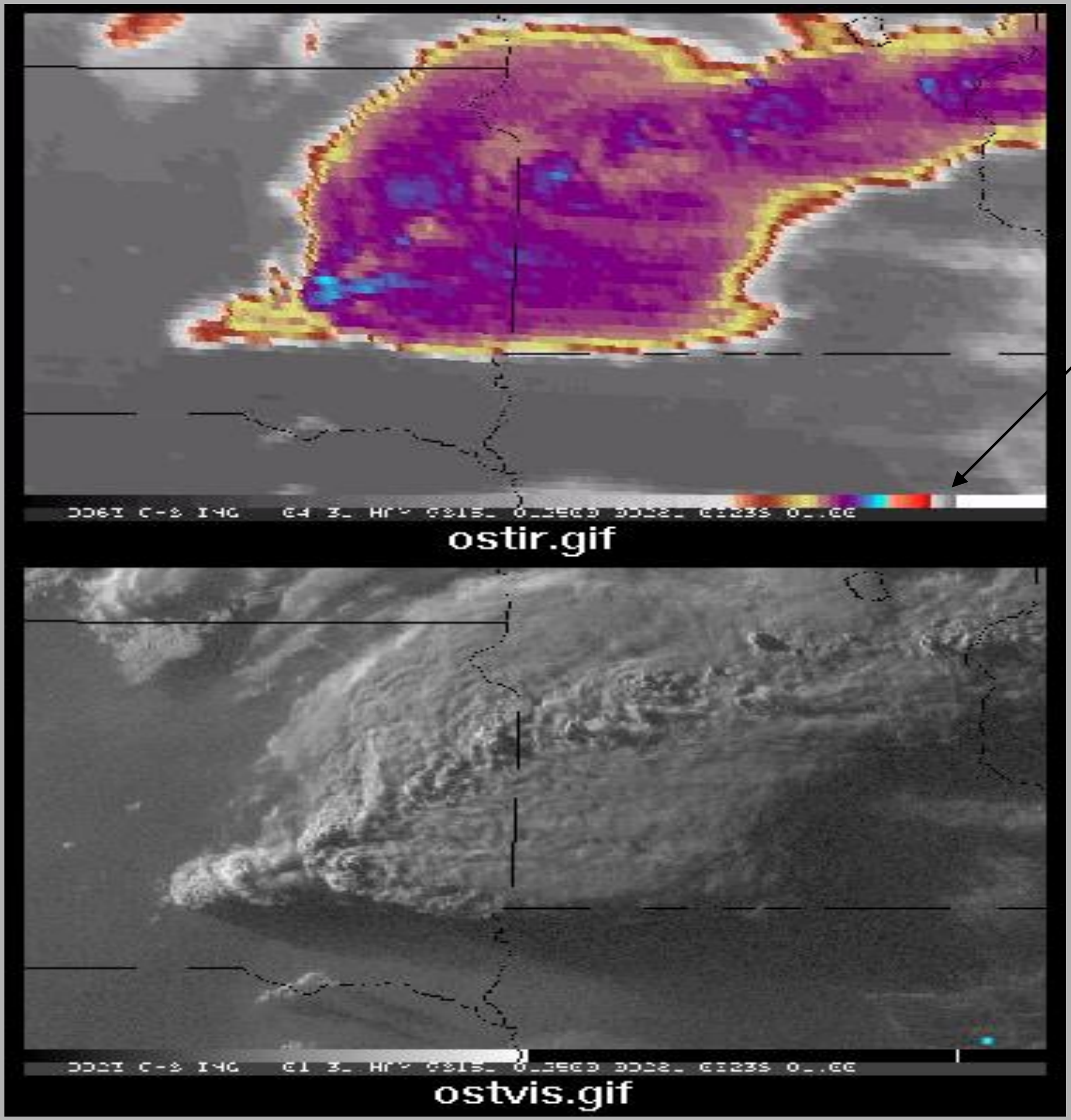
0.466 μ
0.554 μ
0.646 μ
0.935 μ
1.24 μ
1.38 μ*
1.63 μ
2.11 μ
VIIRS, MODIS, FY-1C, AVHRR, ABI, GOES, MSG
MSG
Transmittance
Wavelength (nm)
O3
O2
H2O
CO2
VIIRS
MODIS
FY-1C
AVHRR
ABI

Let’s look at a few simple examples

- Enhancing single imagery channels

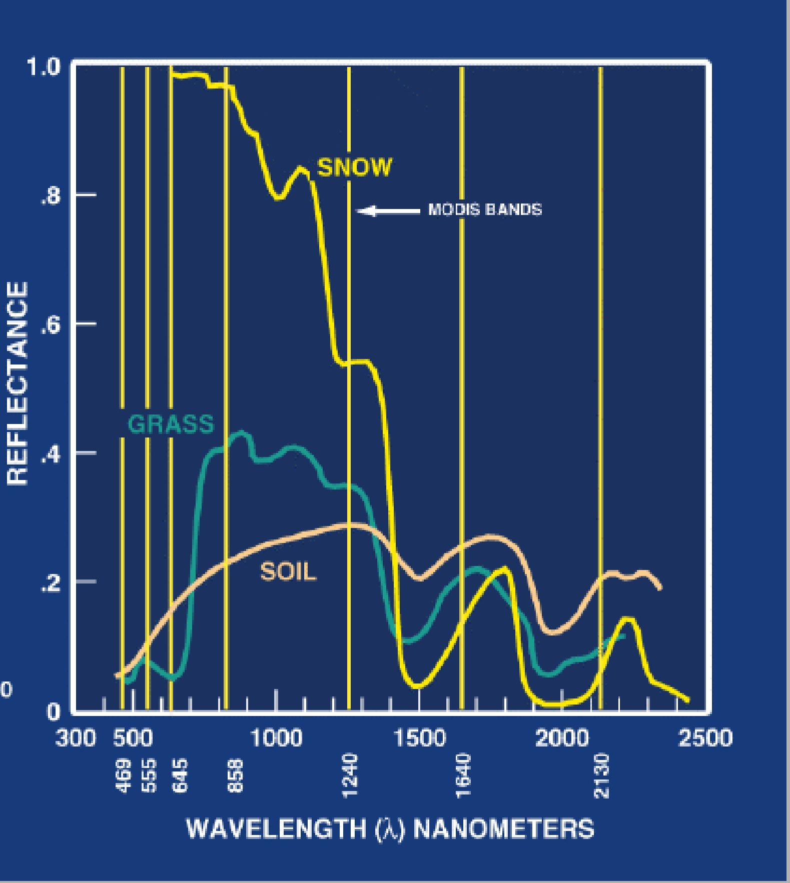
- Using two or three channels to look for a specific information

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



Color bar with warm on left and cold on right

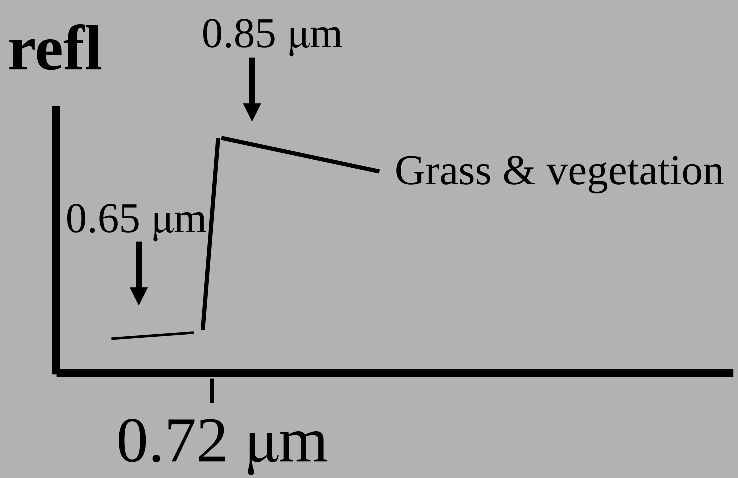
Overshooting thunderstorm tops and cloud top temperature



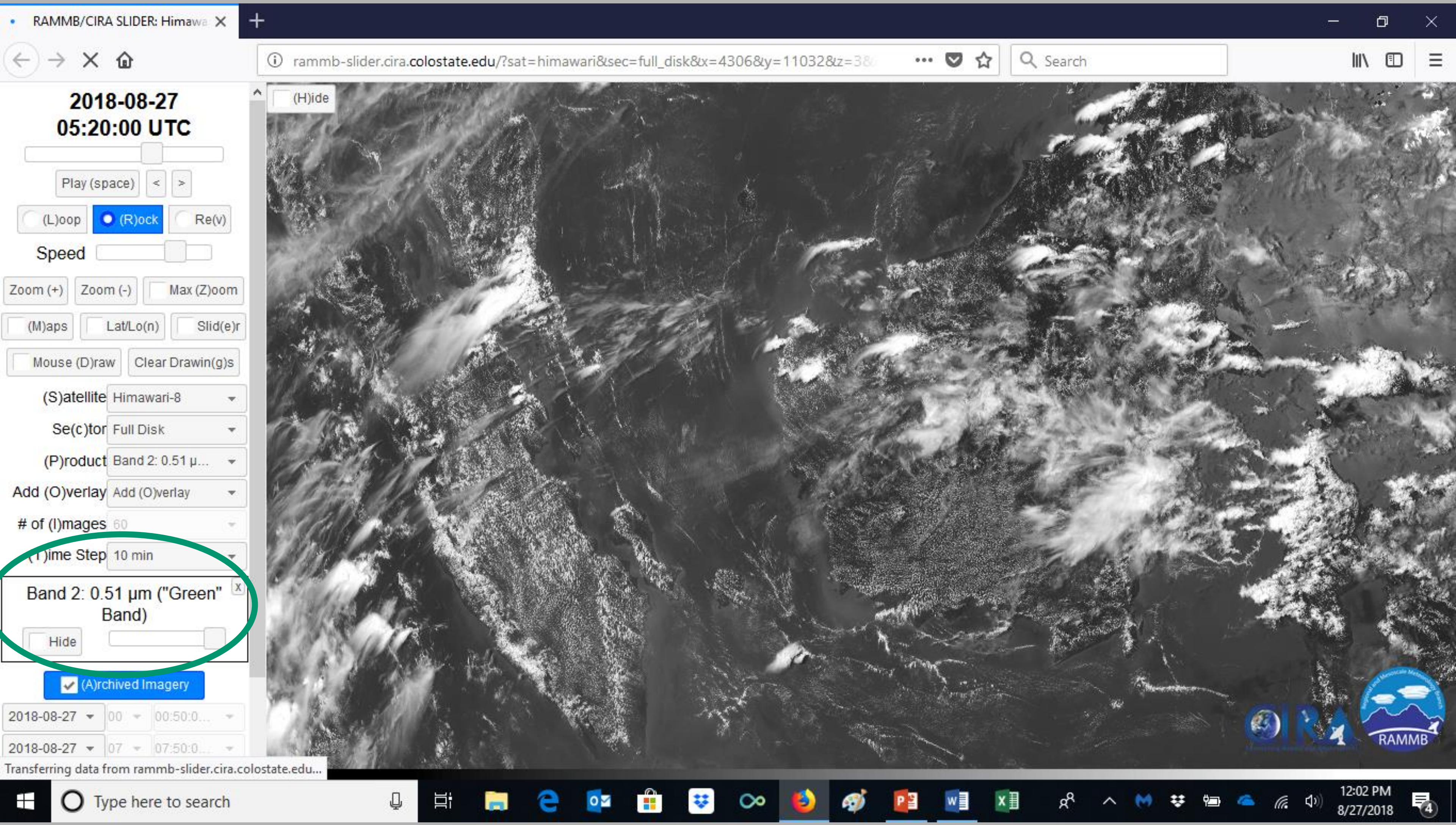
Investigating with Multi-spectral Combinations

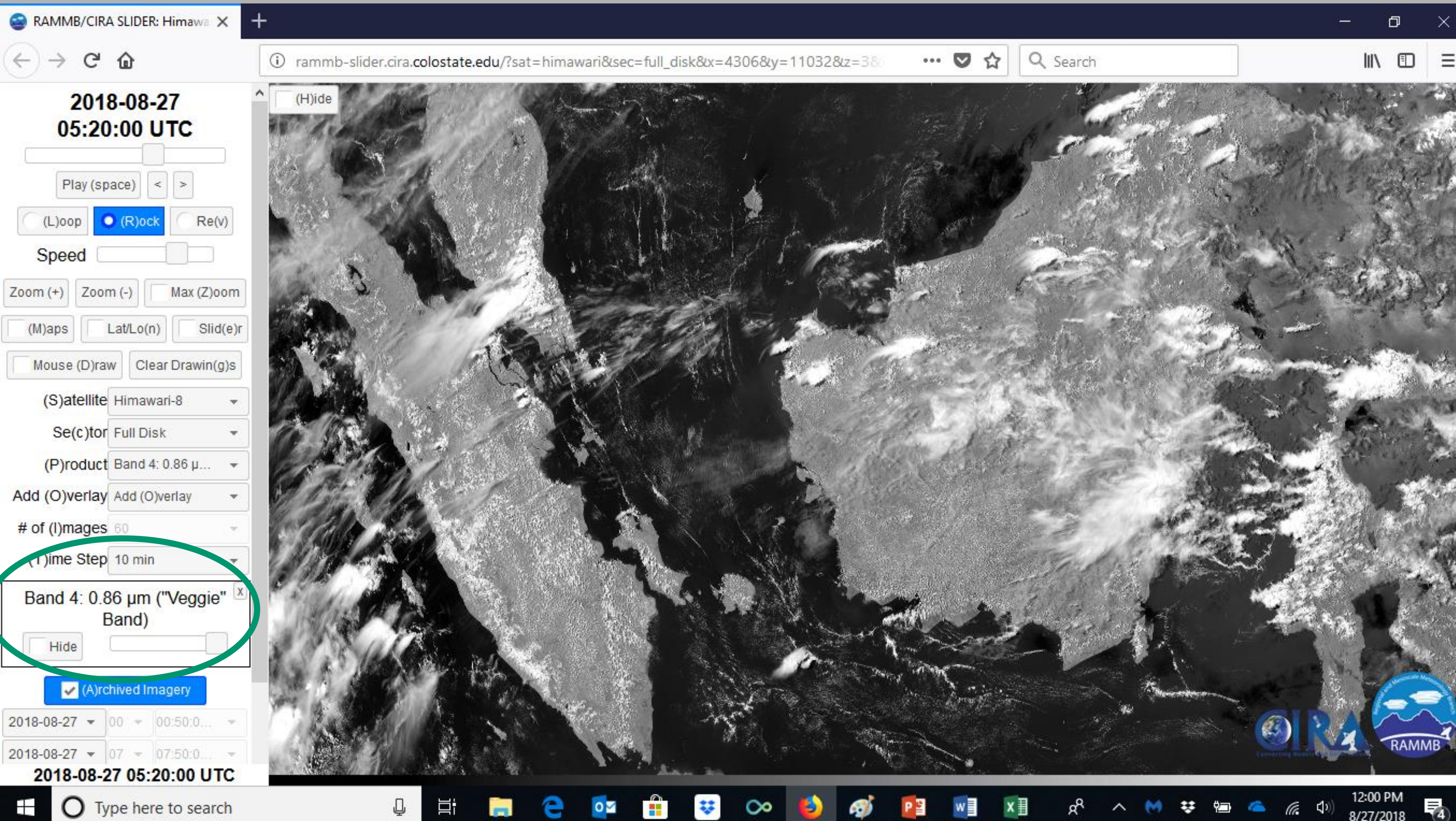
Being digital and multispectral allows for identification of features by taking advantage of their spectral signatures

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



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


RAMMB/CIRA SLIDER: Himawa
rammb-slider.cira.colostate.edu/?sat=himawari&sec=full_disk&x=4306&y=11032&z=3
Search
(H)ide
2018-08-27
05:20:00 UTC
Play (space)
<
>
(L)oop
(R)ock
Re(v)
Speed
Zoom (+)
Zoom (-)
Max (Z)oom
(M)aps
Lat/Lo(n)
Slid(e)r
Mouse (D)raw
Clear Drawin(g)s
(S)atellite
Himawari-8
Se(c)tor
Full Disk
(P)roduct
Band 2: 0.51 µ...
Add (O)verlay
Add (O)verlay
of (I)mages
60
(T)ime Step
10 min
Band 2: 0.51 µm ("Green" Band)
Hide
(A)rchived Imagery
2018-08-27
00
00:50:0...
2018-08-27
07
07:50:0...
Transferring data from rammb-slider.cira.colostate.edu...
CIRA
RAMMB
Type here to search
12:02 PM
8/27/2018


RAMMB/CIRA SLIDER: Himawa
rammb-slider.cira.colostate.edu/?sat=himawari&sec=full_disk&x=4306&y=11032&z=3&
Search
(H)ide
2018-08-27
05:20:00 UTC
Play (space)
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>
(L)oop
(R)ock
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Speed
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Zoom (-)
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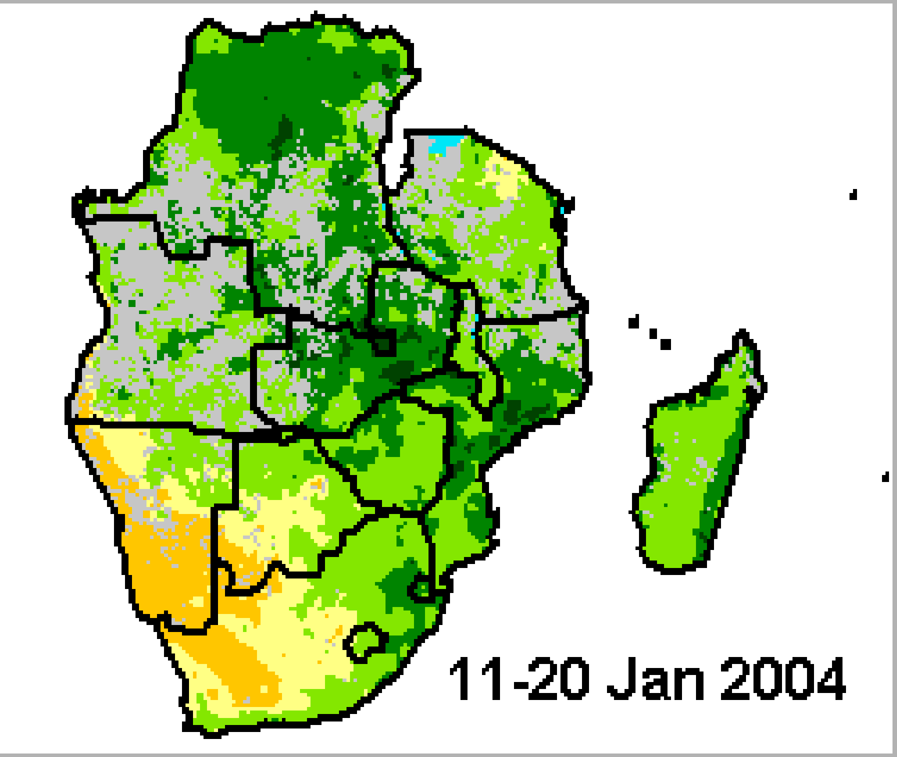
Mouse (D)raw
Clear Drawin(g)s
(S)atellite
Himawari-8
Se(c)tor
Full Disk
(P)roduct
Band 4: 0.86 μ...
Add (O)verlay
Add (O)verlay
of (I)mages
60
(T)ime Step
10 min
Band 4: 0.86 µm ("Veggie" Band)
Hide
(A)rchived Imagery
2018-08-27
00
00:50:0...
2018-08-27
07
07:50:0...
2018-08-27 05:20:00 UTC
CIRA
RAMMB
Type here to search
12:00 PM
8/27/2018



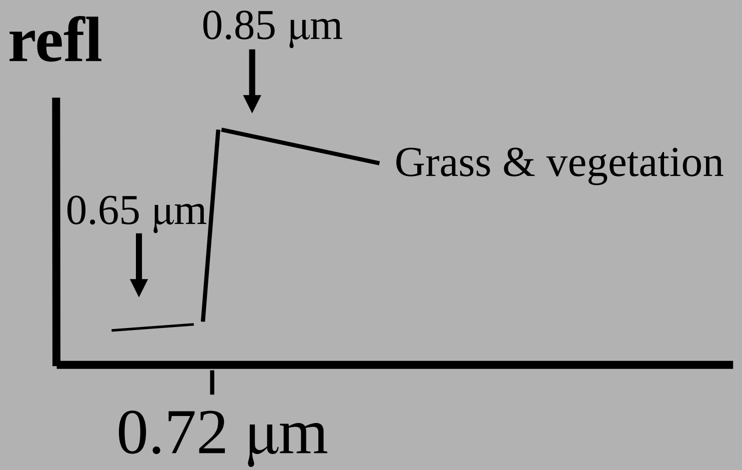
Being digital and multispectral allows for identification of features by taking advantage of their spectral signatures

Investigating with Multi-spectral Combinations

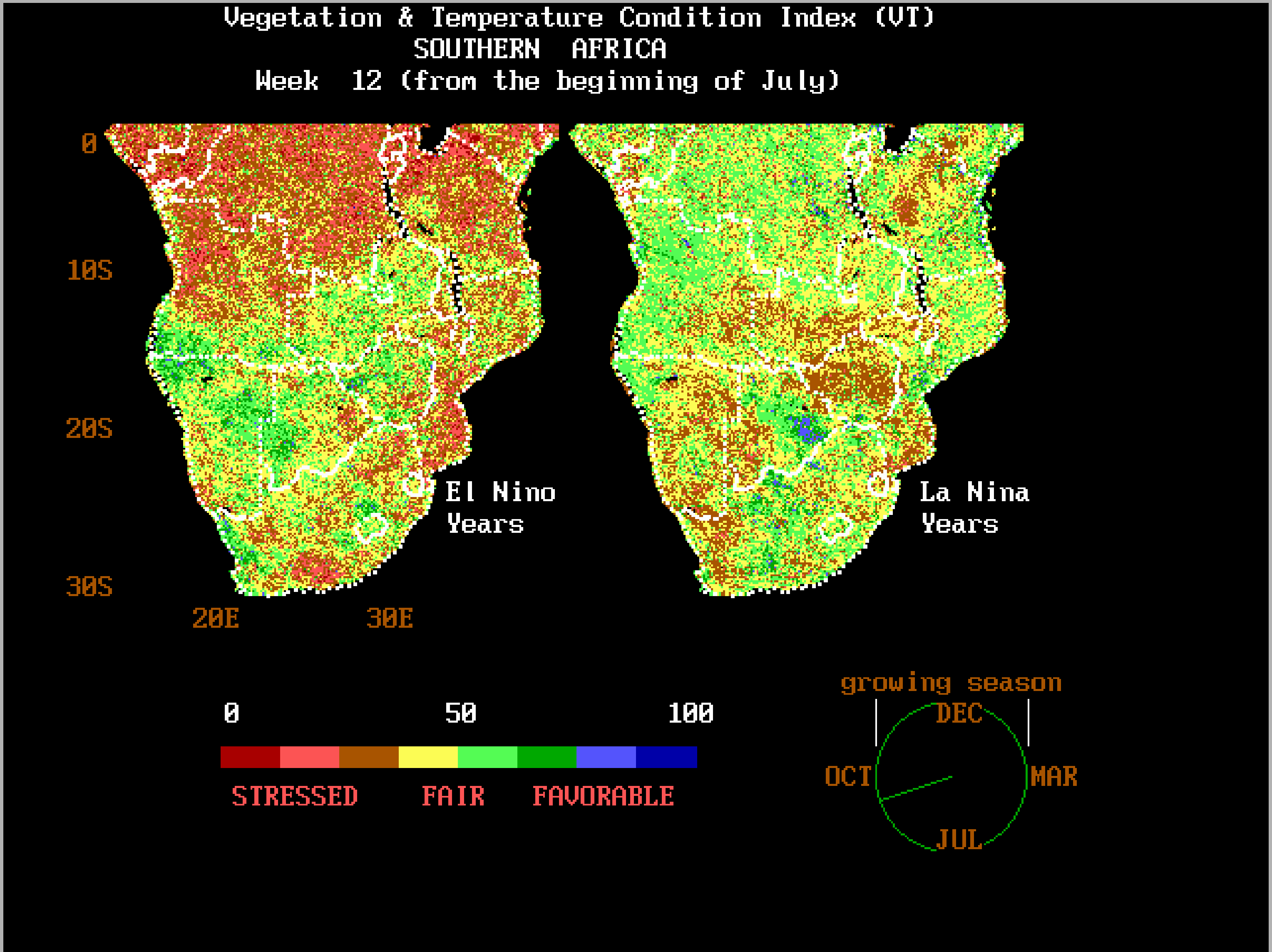
Given the spectral response of a surface or atmospheric feature

Select a part of the spectrum where the reflectance or absorption changes with wavelength

e.g. reflection from grass and vegetation



Animation of vegetation health (stressed to favorable) based on temperature and vegetation index information

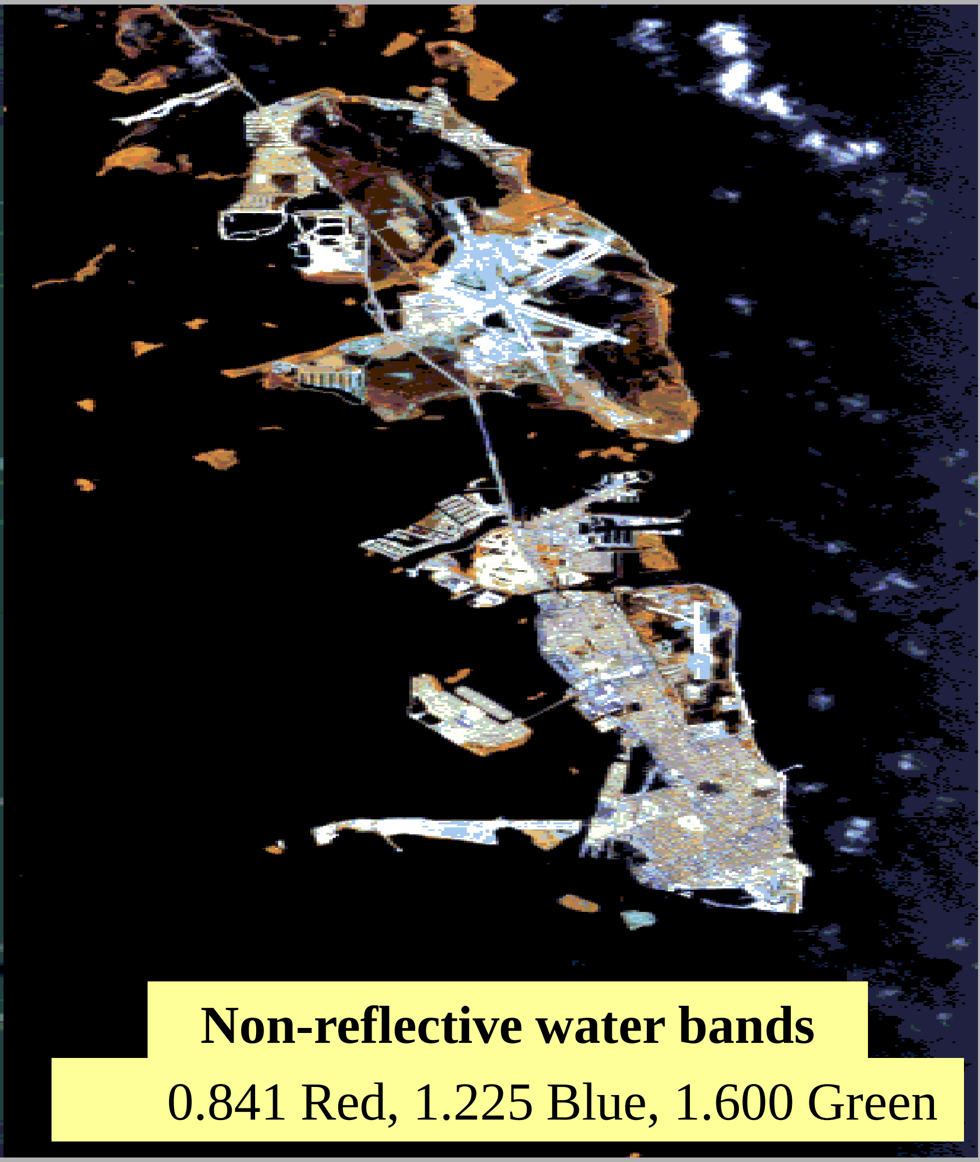


Below is a “true color” image from combinations or blue, green and red channels

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

“true color”

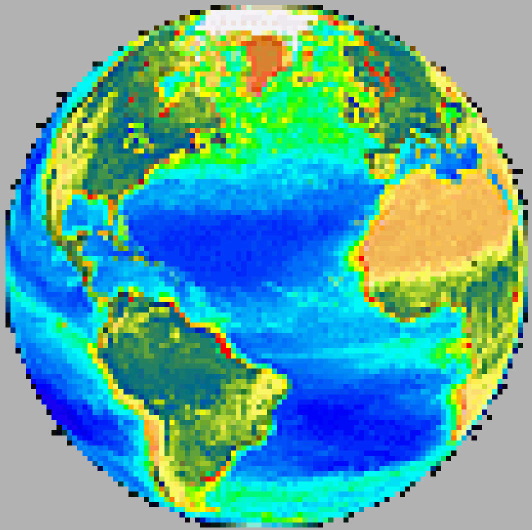
0.646 Red, 0.547 Blue, 0.449 Green



Non-reflective water bands

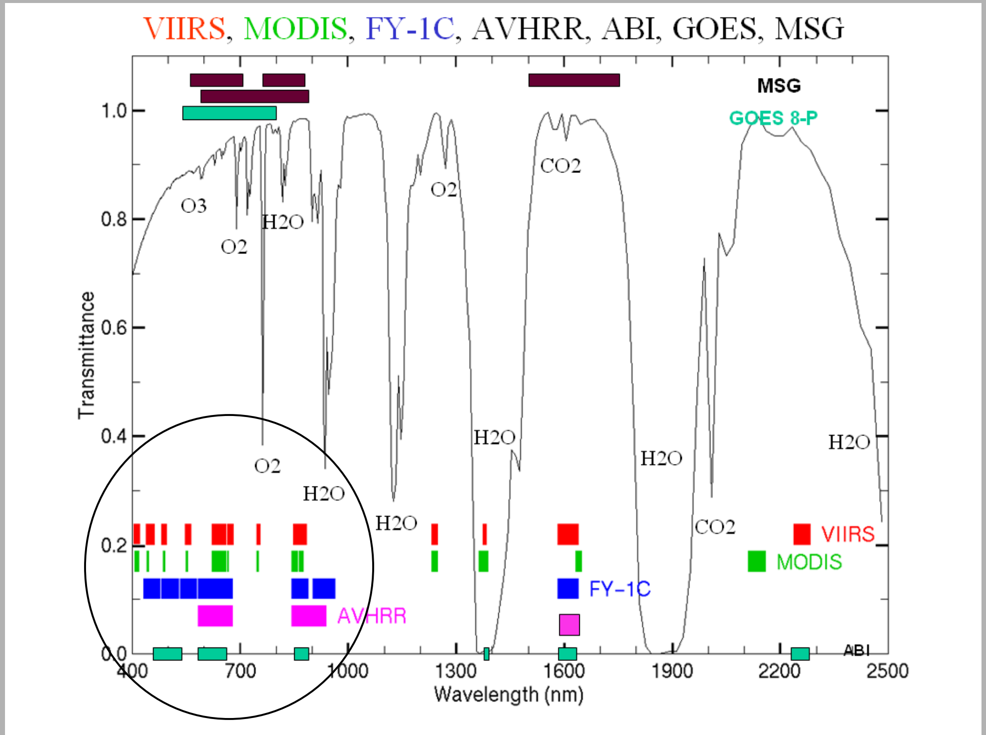
0.841 Red, 1.225 Blue, 1.600 Green

Ocean Color: As illustrated by SeaWifs



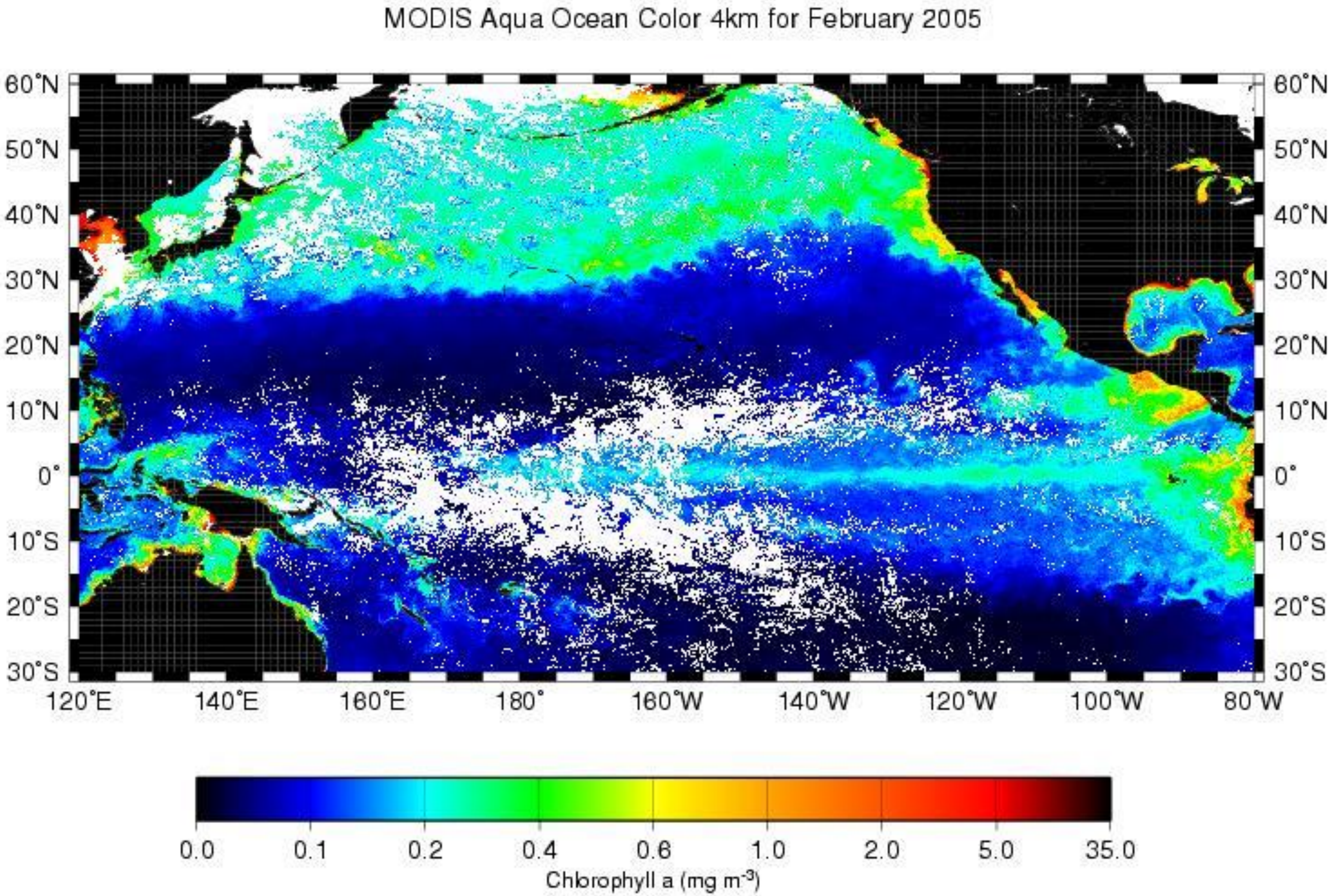
Instrument Bands

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

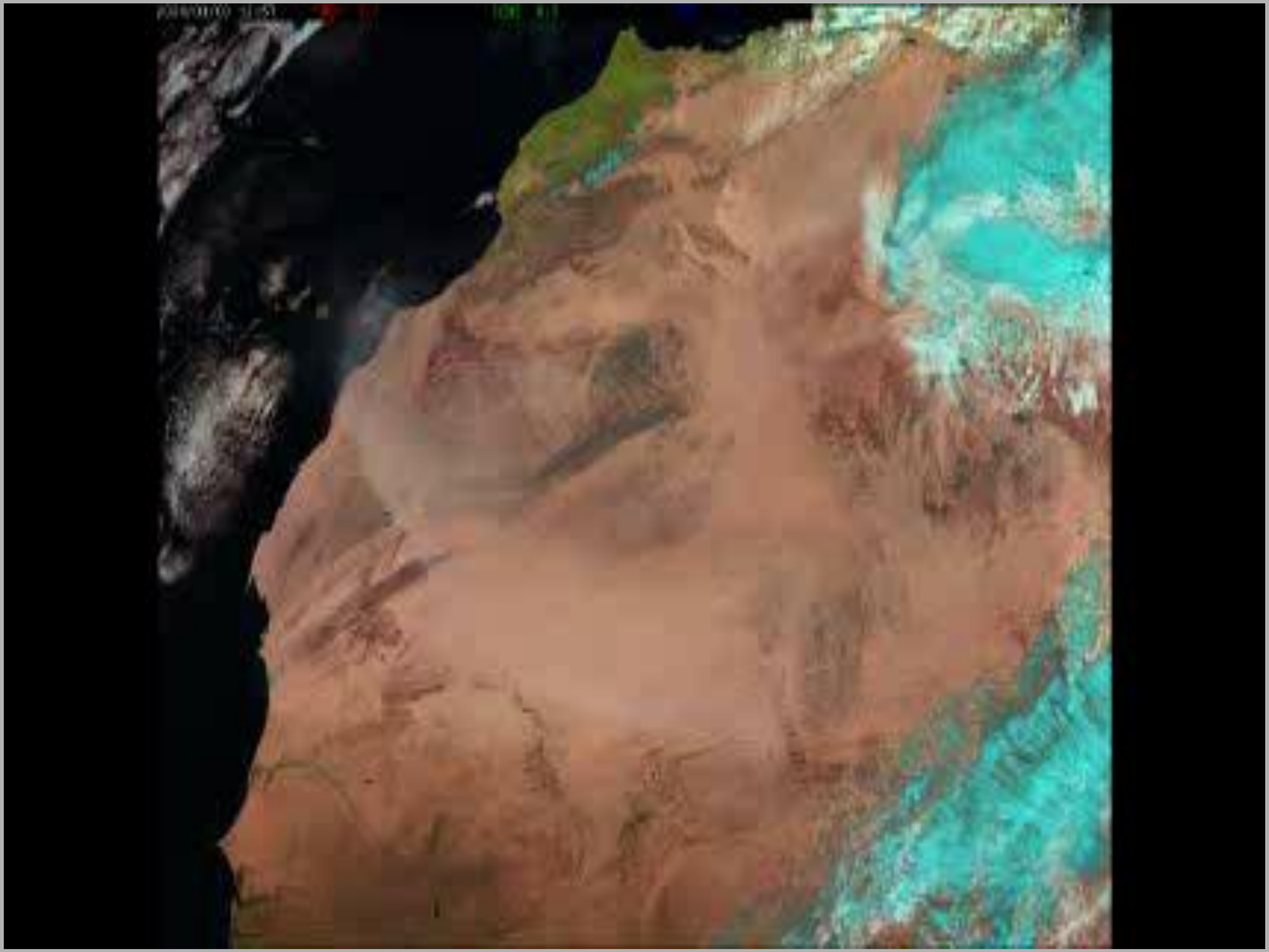


Mission Characteristics

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



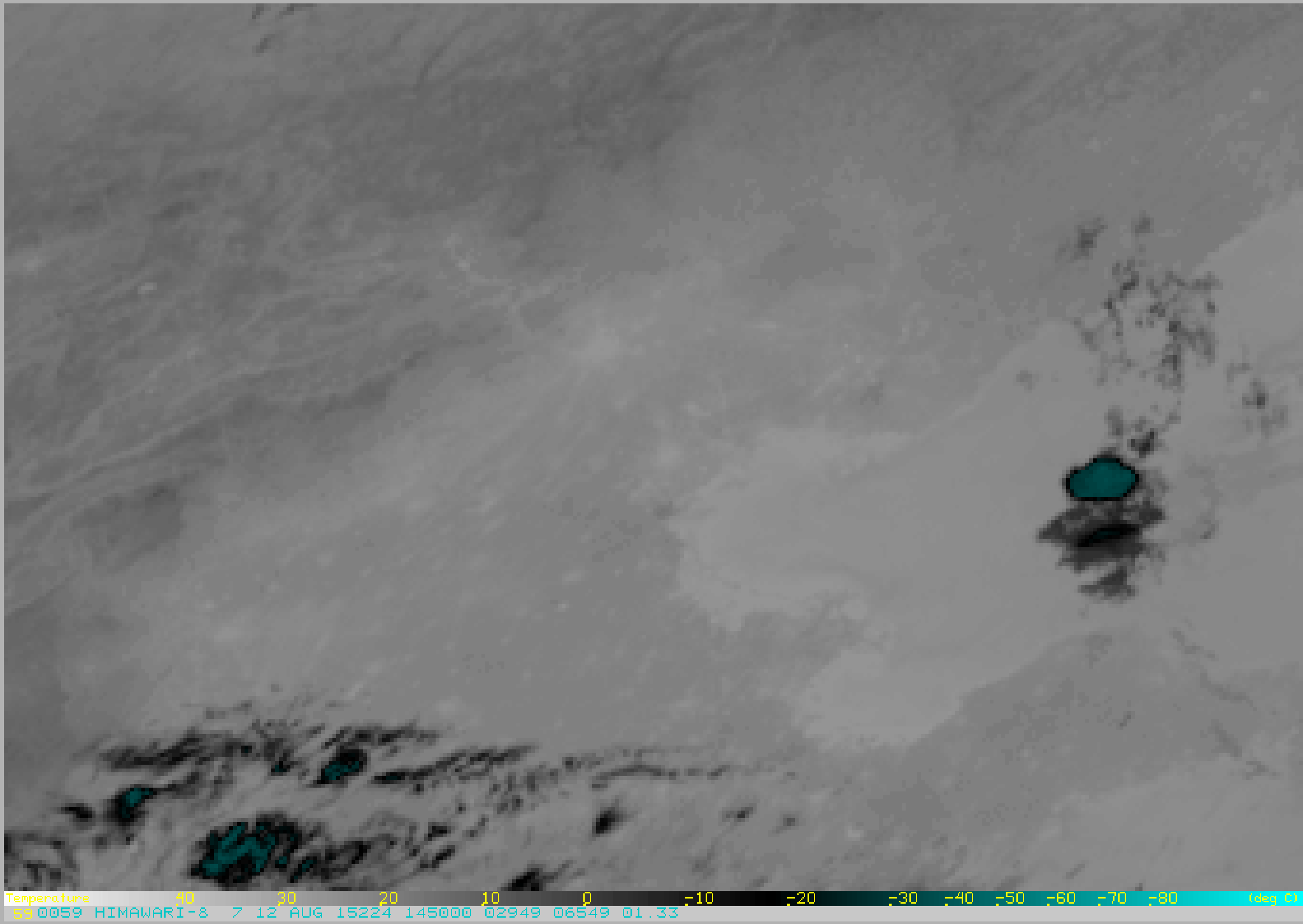
Ocean color product from MODIS showing the abundance of chlorophyll a across part of the Pacific Ocean.

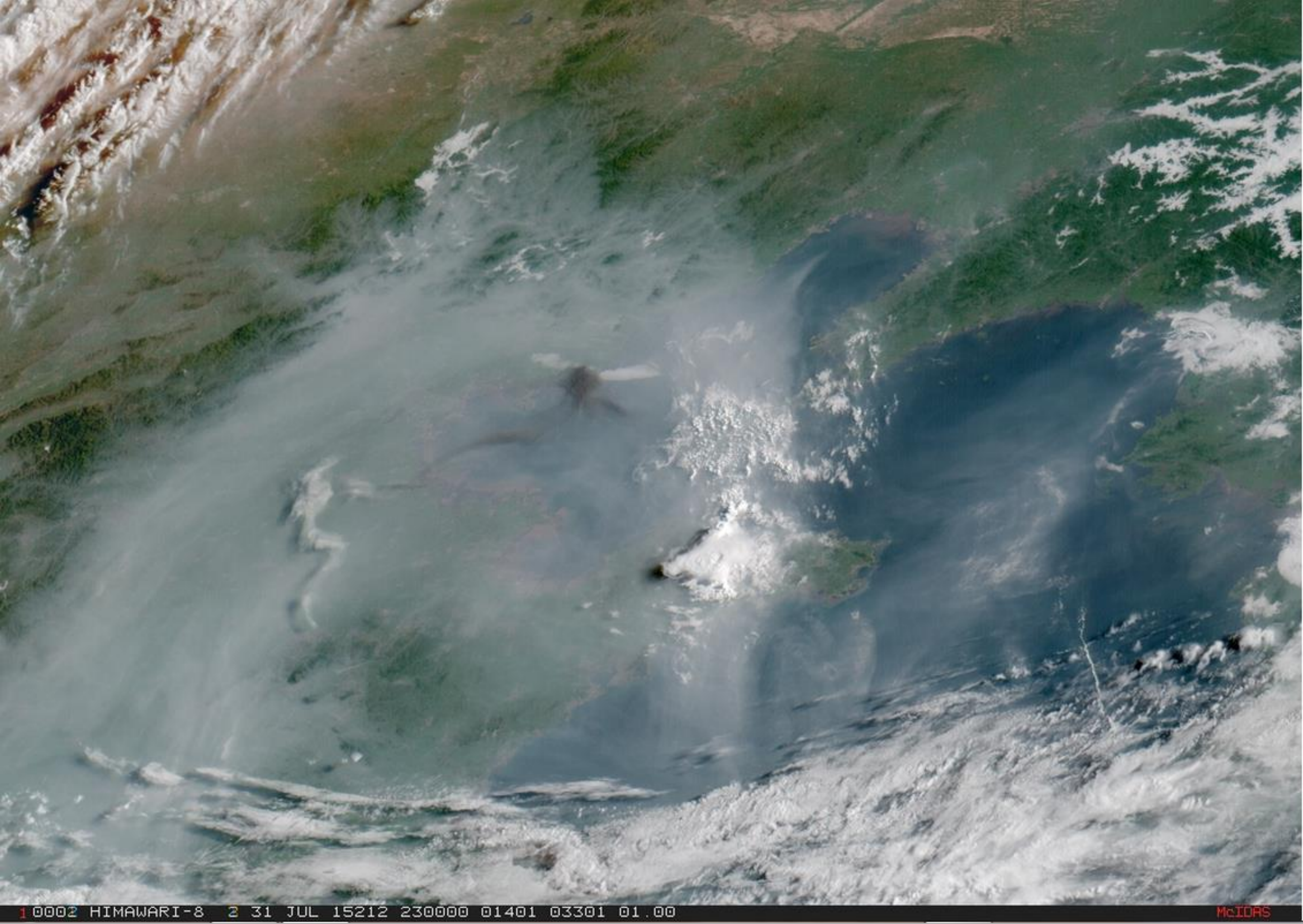


Daytime multispectral METEOSAT-8 image of large dust storm over Africa. This is made using a combination of images from the 0.6 (Blue), 0.8 (Green) and 1.6 (red) micron channels. Click on the image to view animation. Recall 0.6 and 0.8 are used for vegetation index and 1.6 is used for ice vs water cloud.

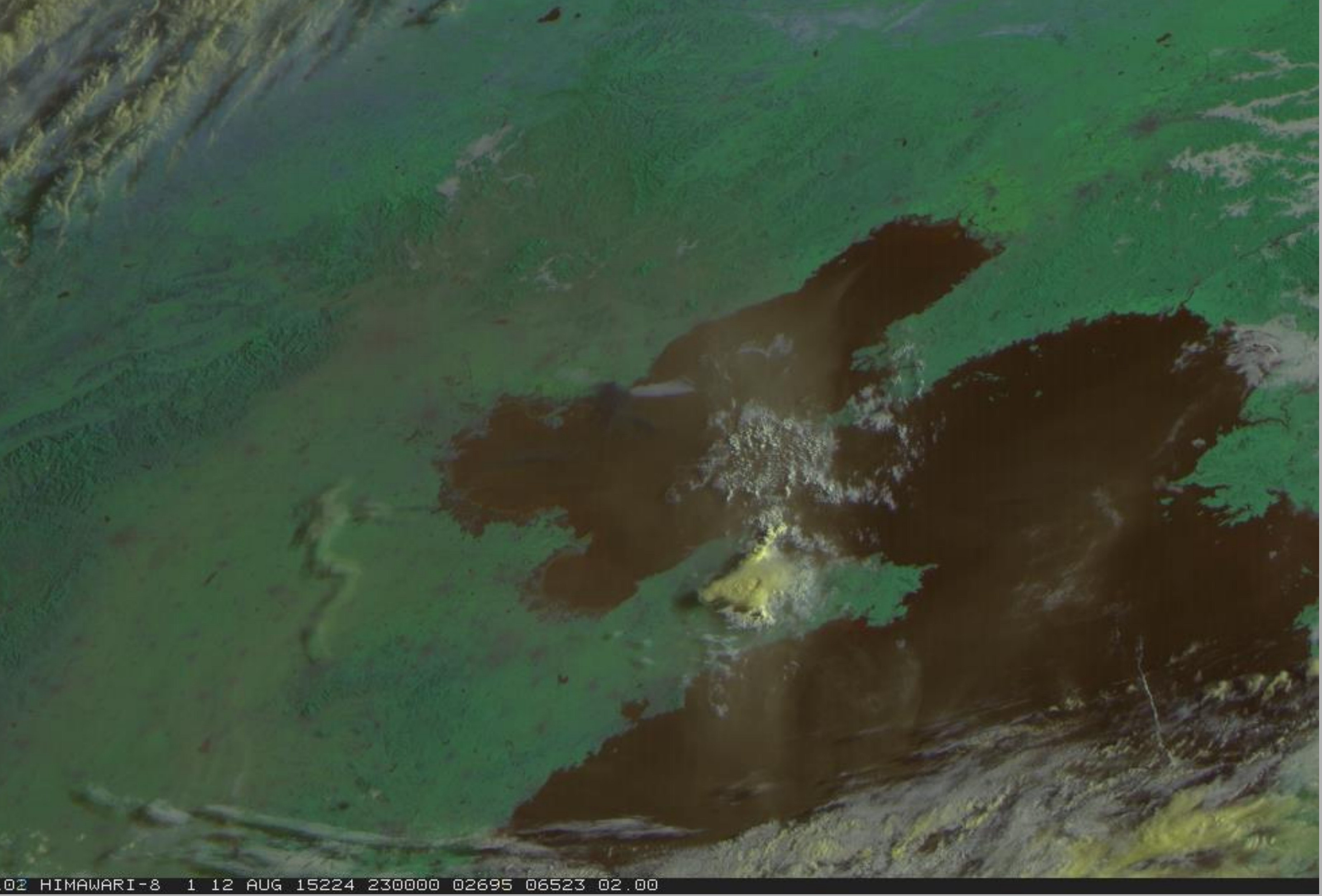
Tianjin China: An example of some satellite data analysis capabilities

A single channel animation (3.9 micron channel satellite images) reveals the heat generated by the explosion which occurred at night, as well as various cloud and land features. We've been doing this type activity for decades.





True color image over Bohai Bay, Tianjin, Beijing and North East China



Three channel composite (.74, .86, 1.2) image over Bohai Bay area

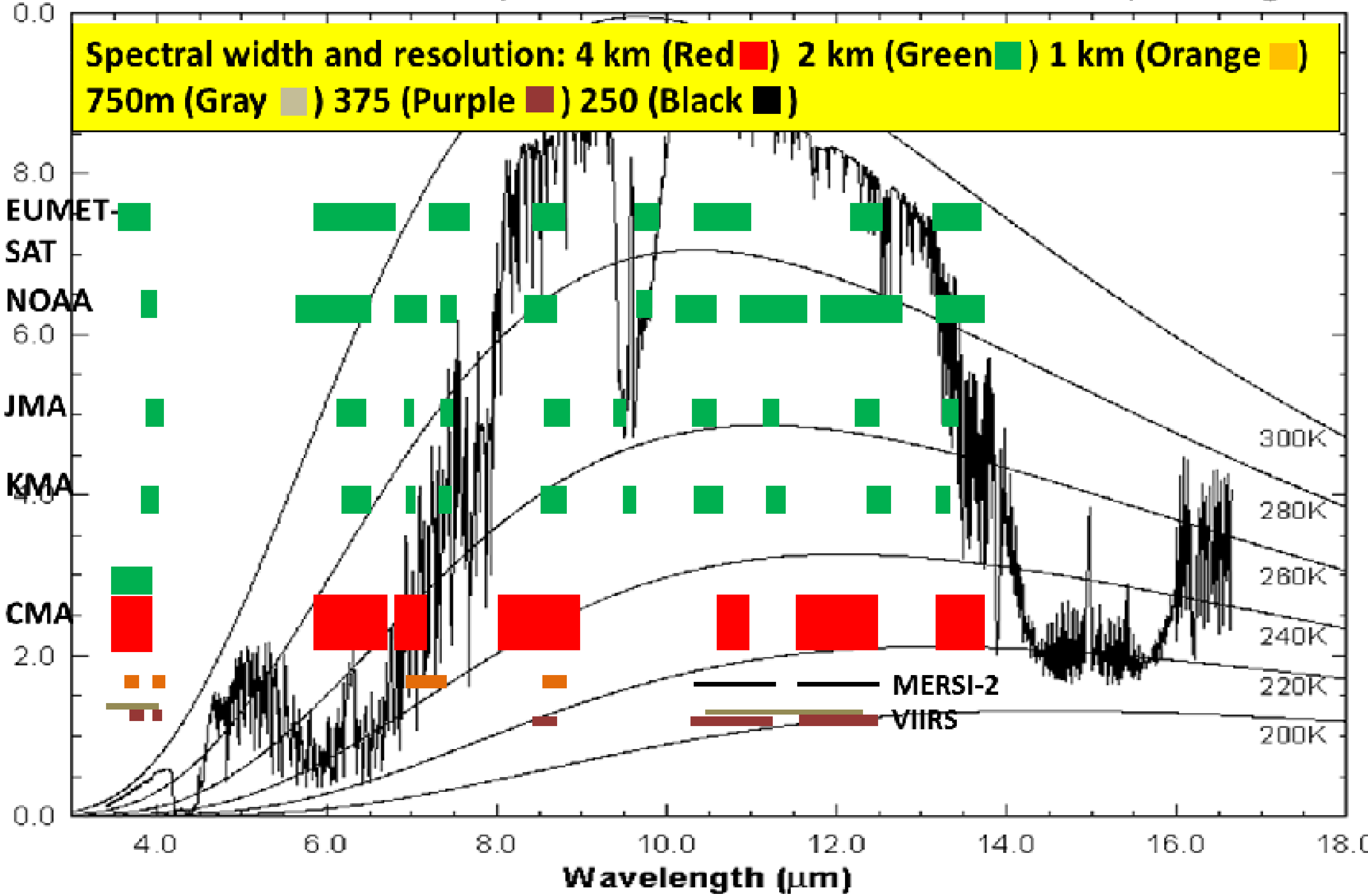
Spectral Information

- Now let's look in more detail at the 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.

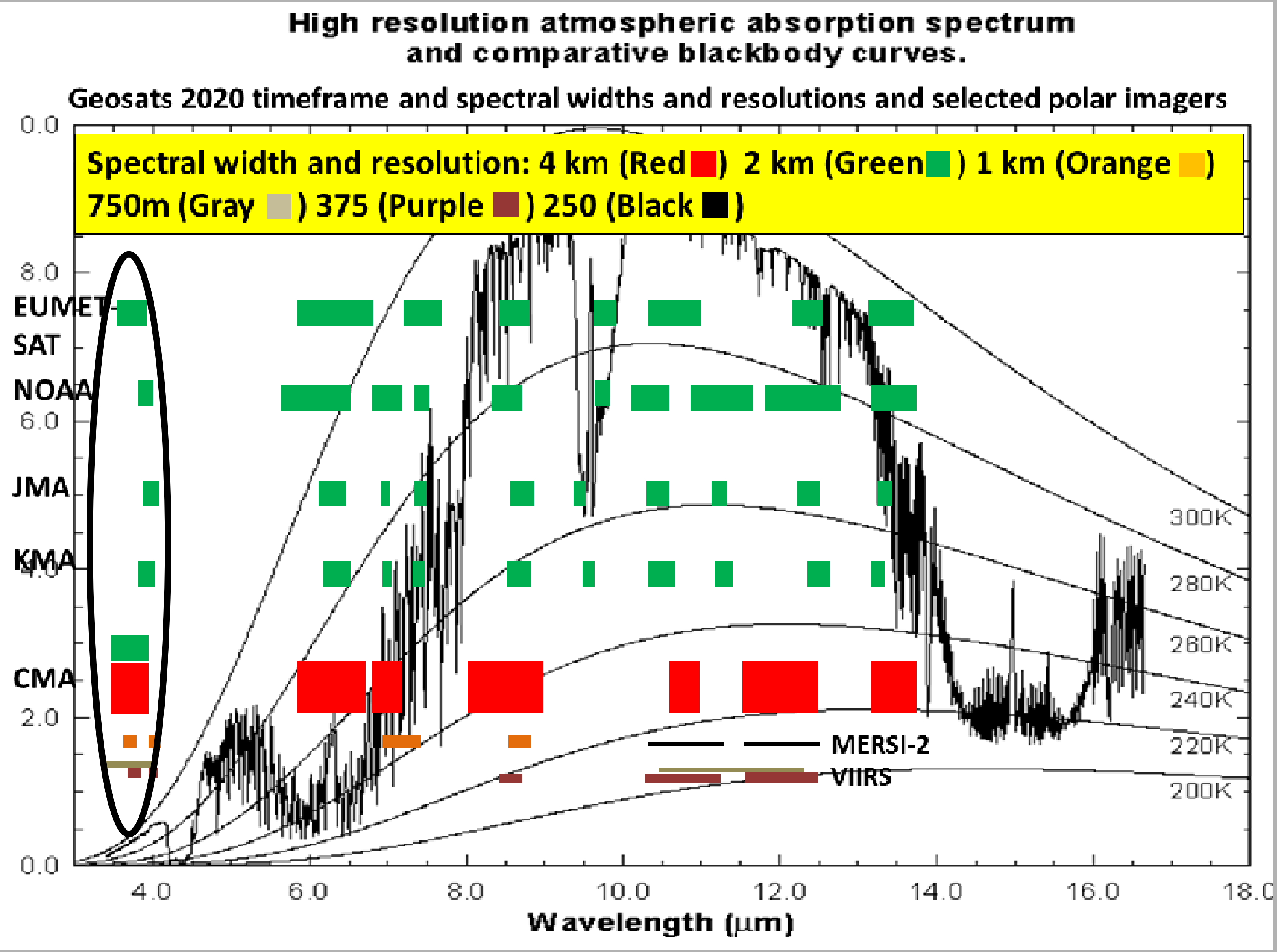
Infrared

High resolution atmospheric absorption spectrum and comparative blackbody curves.

Geosats 2020 timeframe and spectral widths and resolutions and selected polar imagers

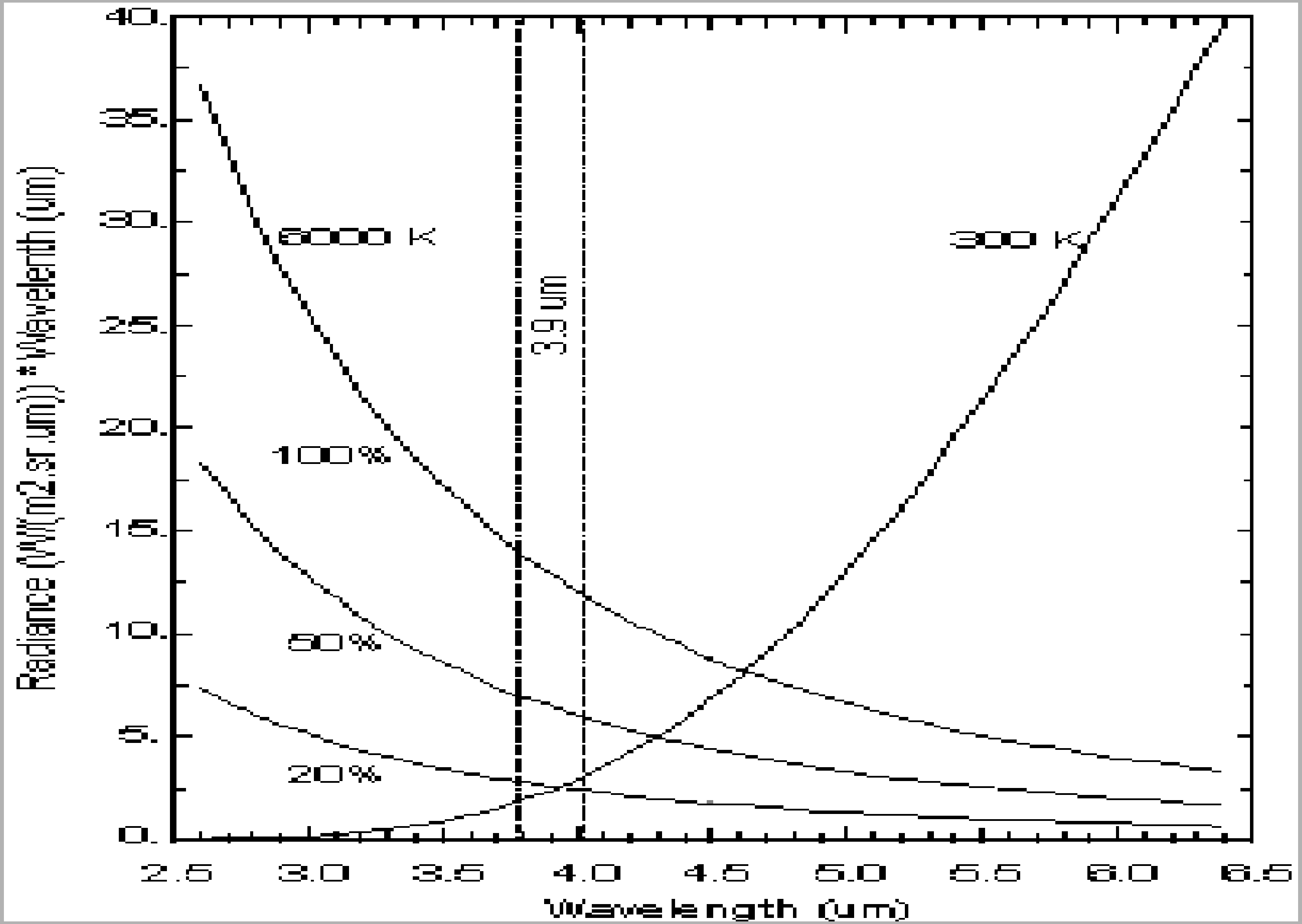


Earth emitted spectra overlaid on Planck function envelopes



The special area in the vicinity of 3 and 4 microns

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

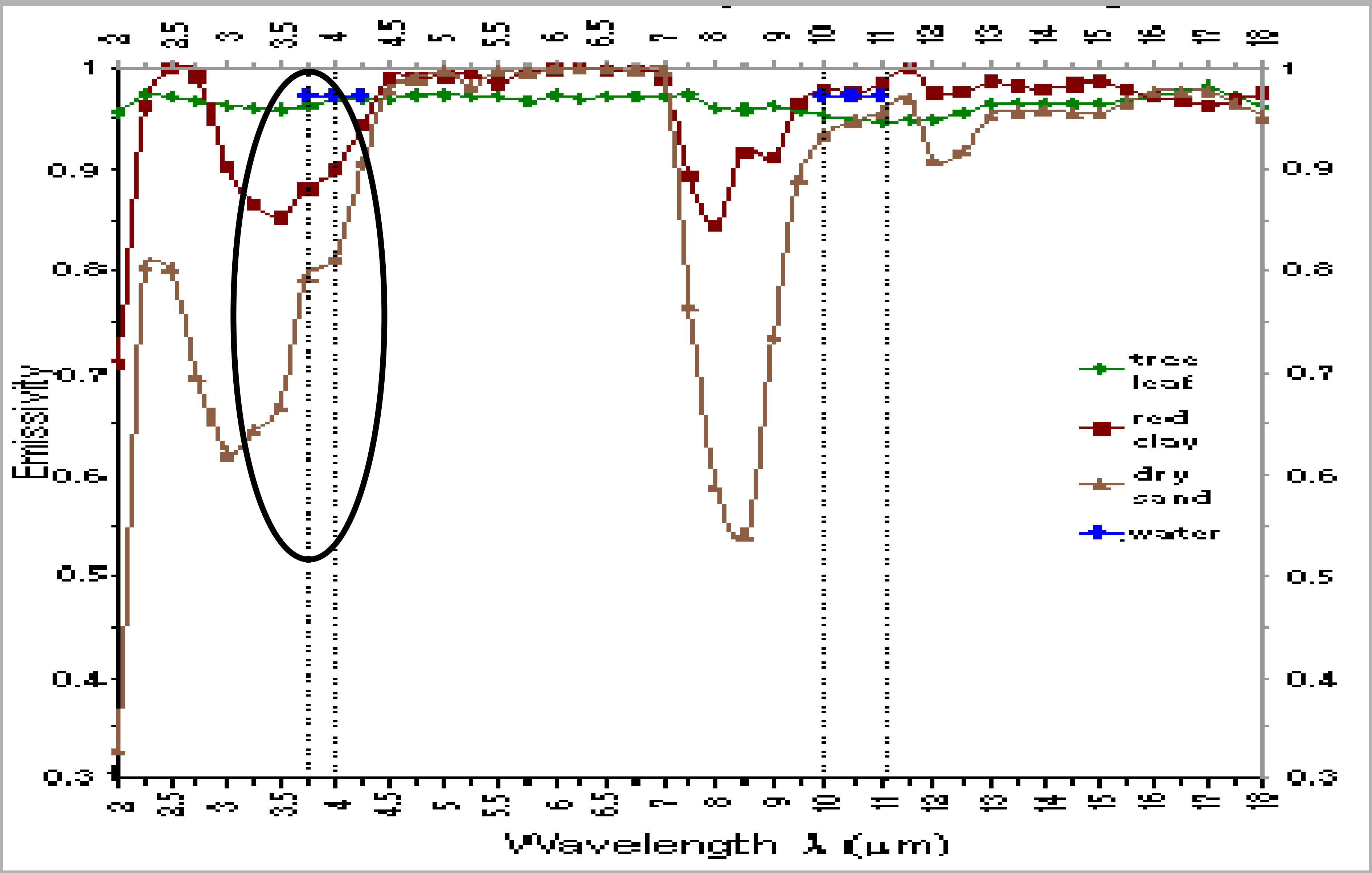


The special area between 3 and 4 microns

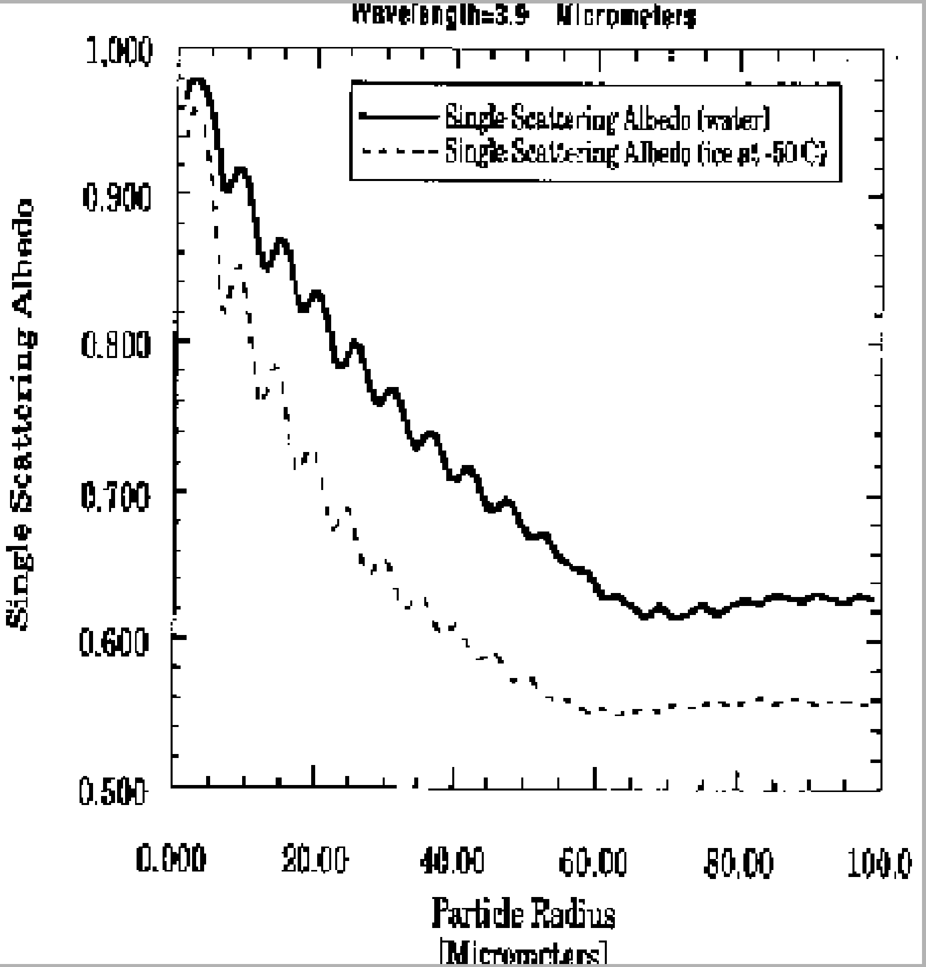
3.7 - 3.9 um Channel Imagery Applications (often with other channels as products)

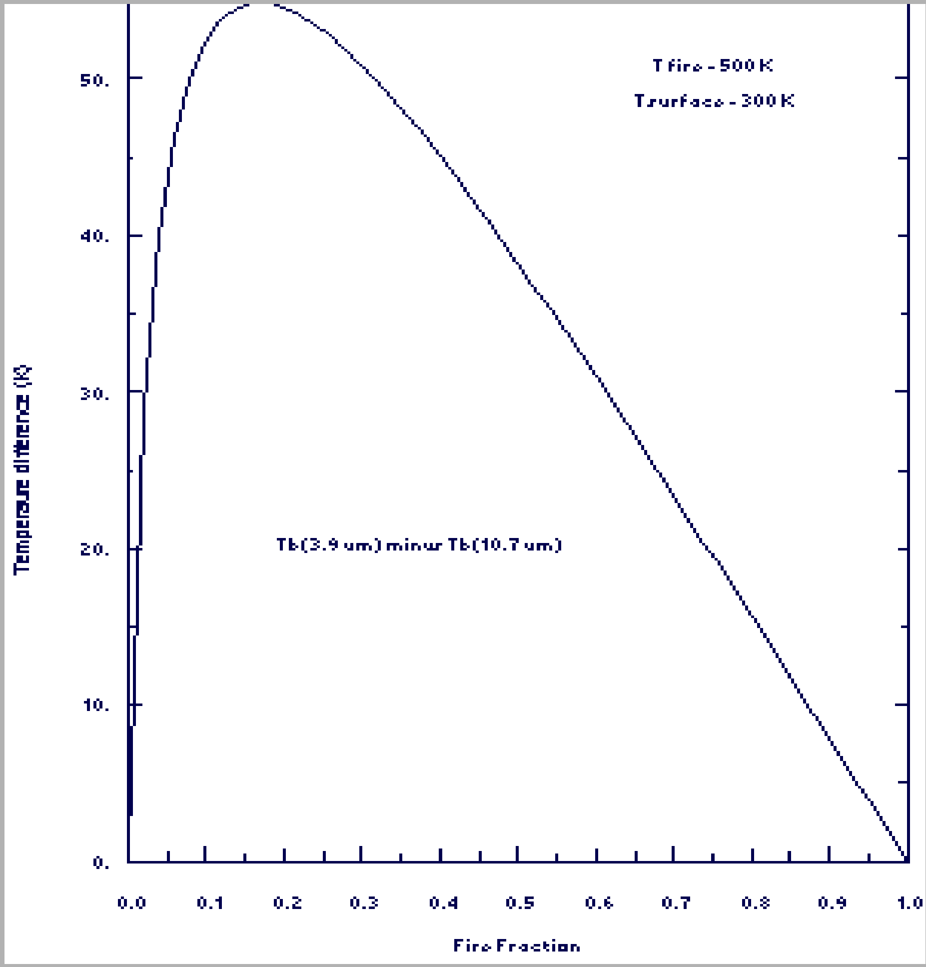
- Night-time Fog, Stratus & Cirrus
- Super-cooled Clouds
- Fog, Ice & Water Clouds Over Snow
- Winter Storms
- Land- and Sea-surface Temperatures
- Thin Cirrus & Multi-layered Clouds
- Urban Heat "Islands"
- Fire Detection
- Sun Glint
- Cumulus Bands at Night
- Convective Cloud Phases
- Volcanic Ash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

Spectral Awareness, surface characteristics



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

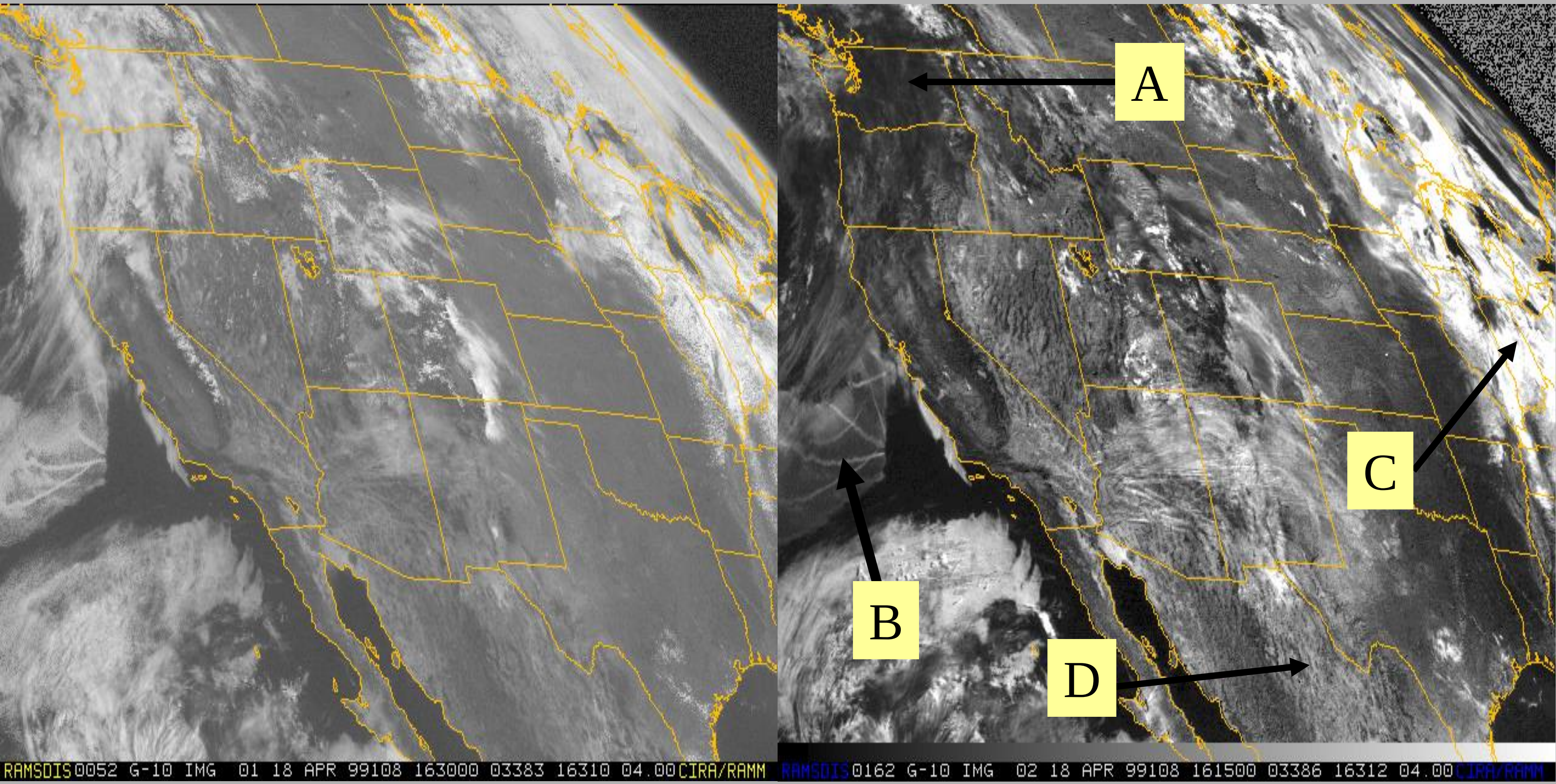


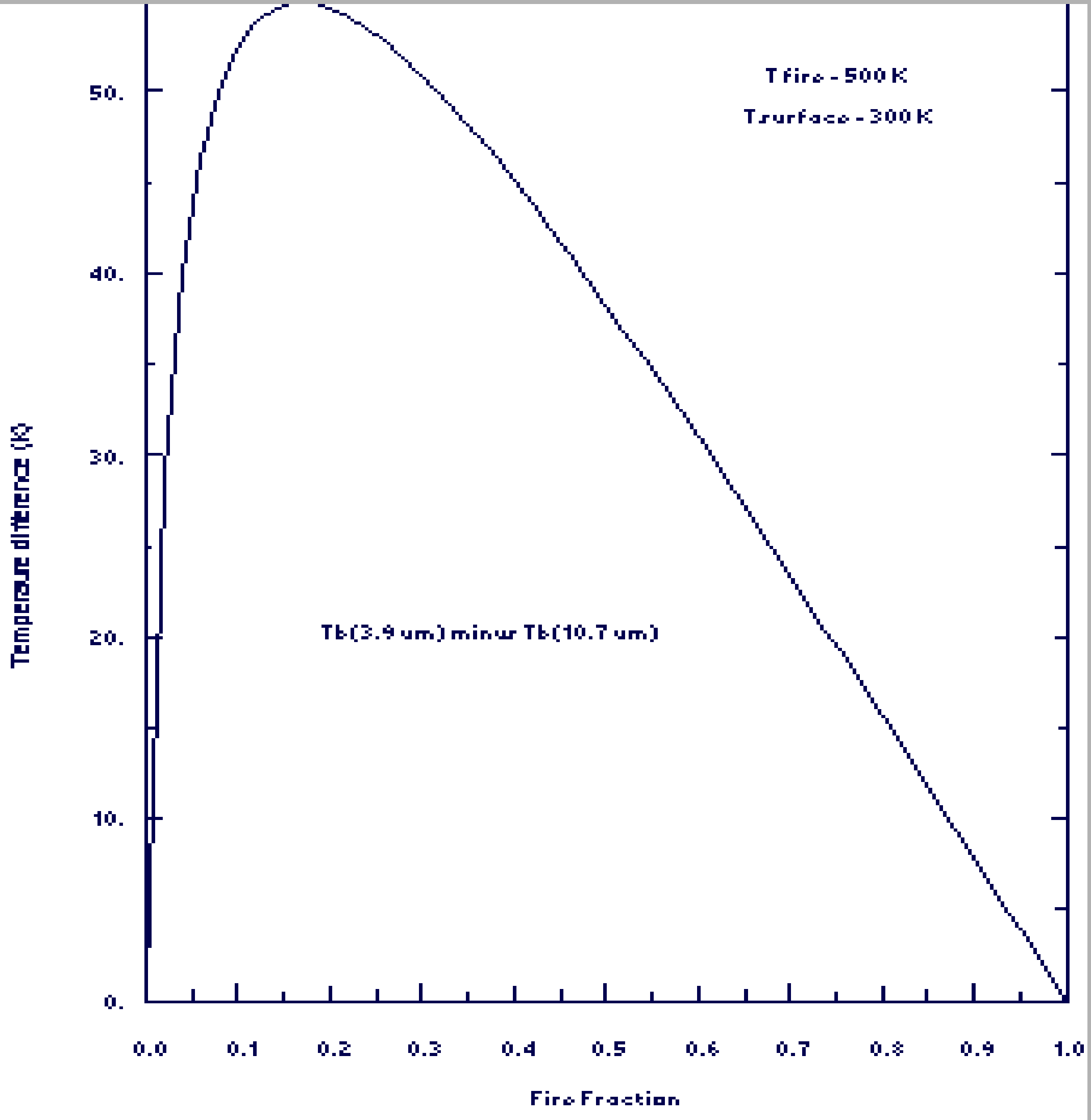


Scattering from water versus ice particles at 3.9 microns

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

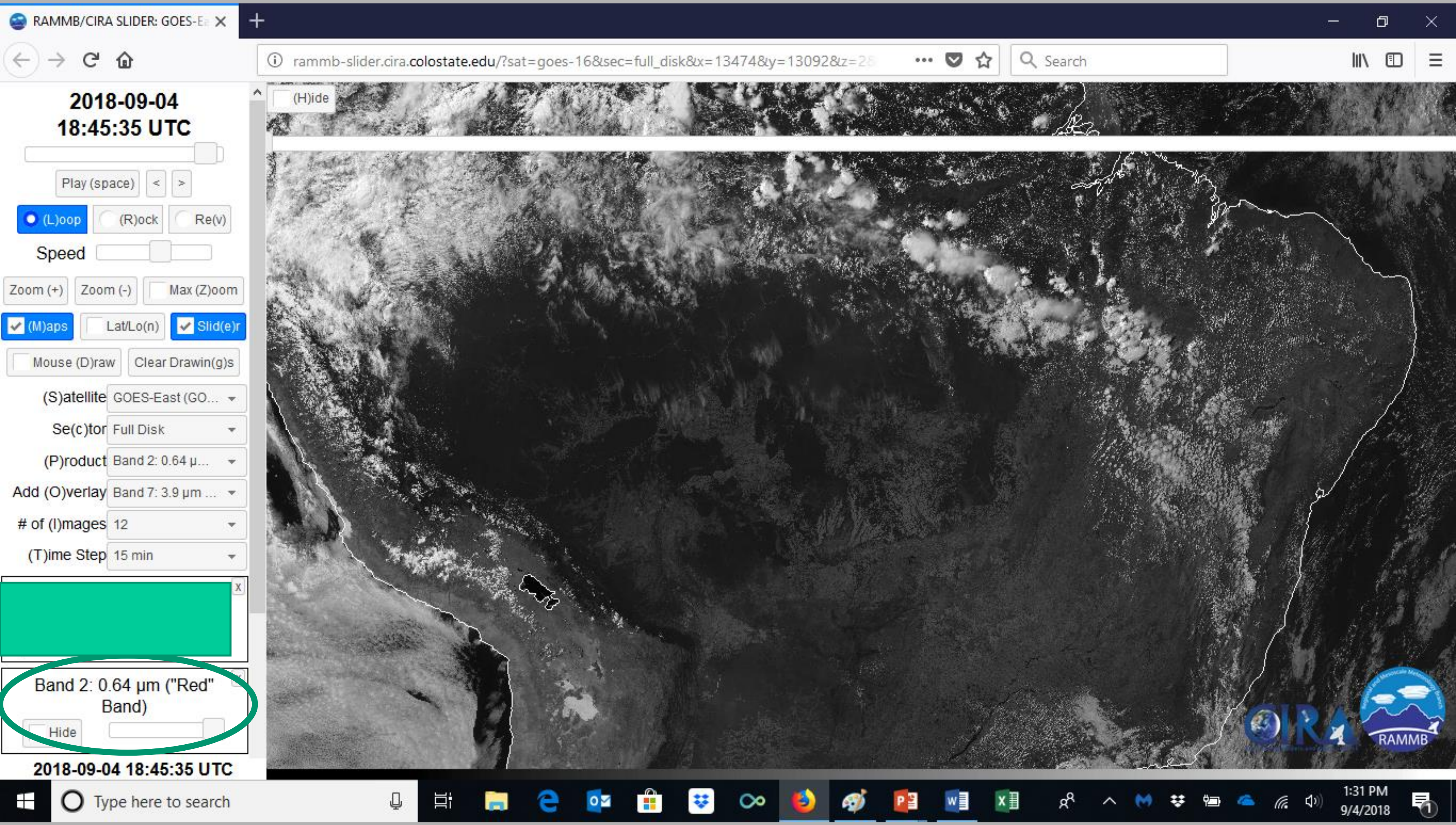
Display and analysis of imagery at short 3.9 microns.
Visible loop (left) and 3.9 micron reflective component loop (right) from GOES-West (aspect ratio not 1:1)
Click on images to start and stop animations.





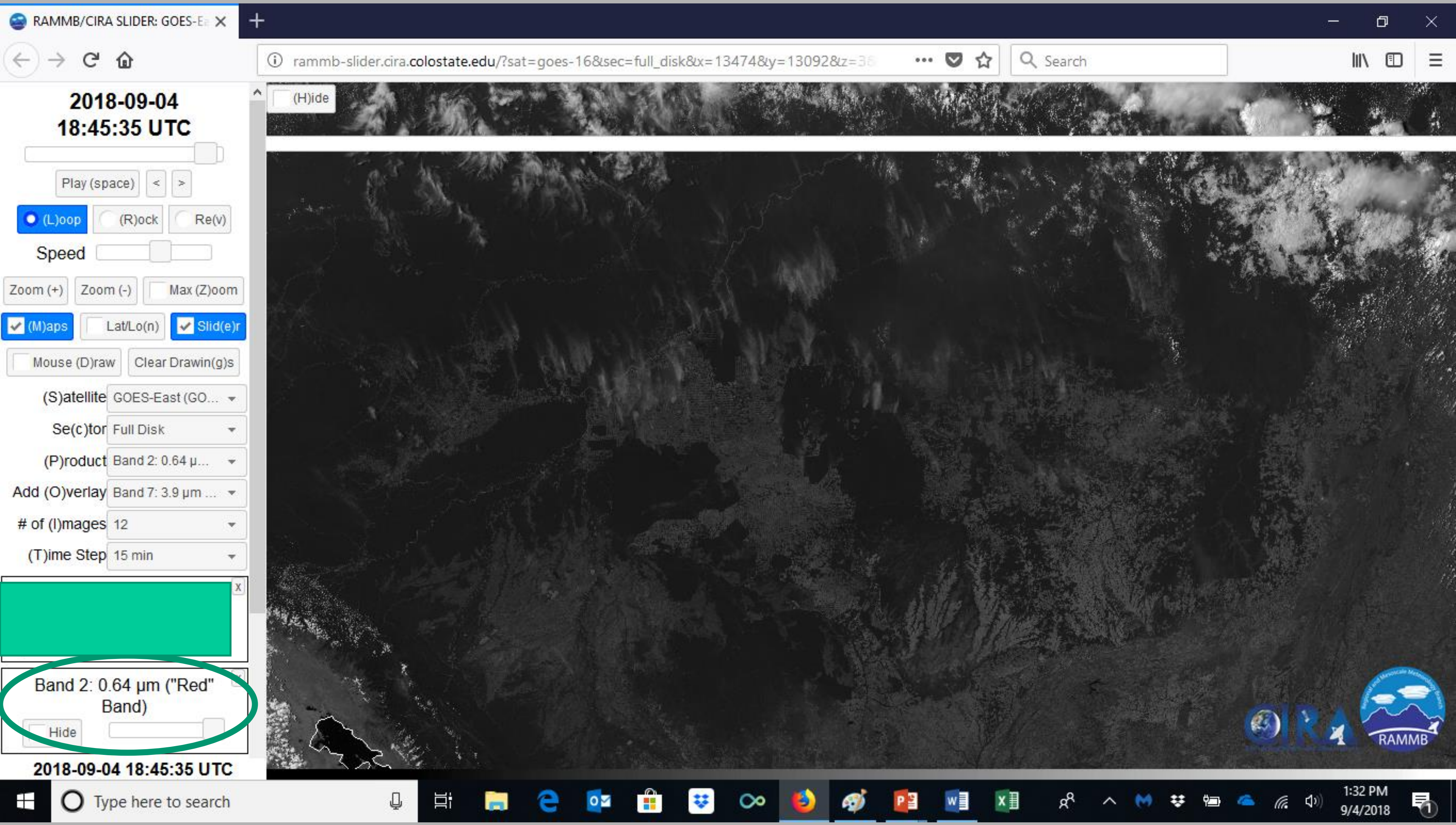
On the left is an example of the difference in temperature measured at 3.9 and 10.7 microns for a partially filled field of view (FOV) for nighttime when there is no solar reflection. In this example, the hot-area is at 500 K and the remainder of the pixel is at 300 K.

A look at fires over Brazil

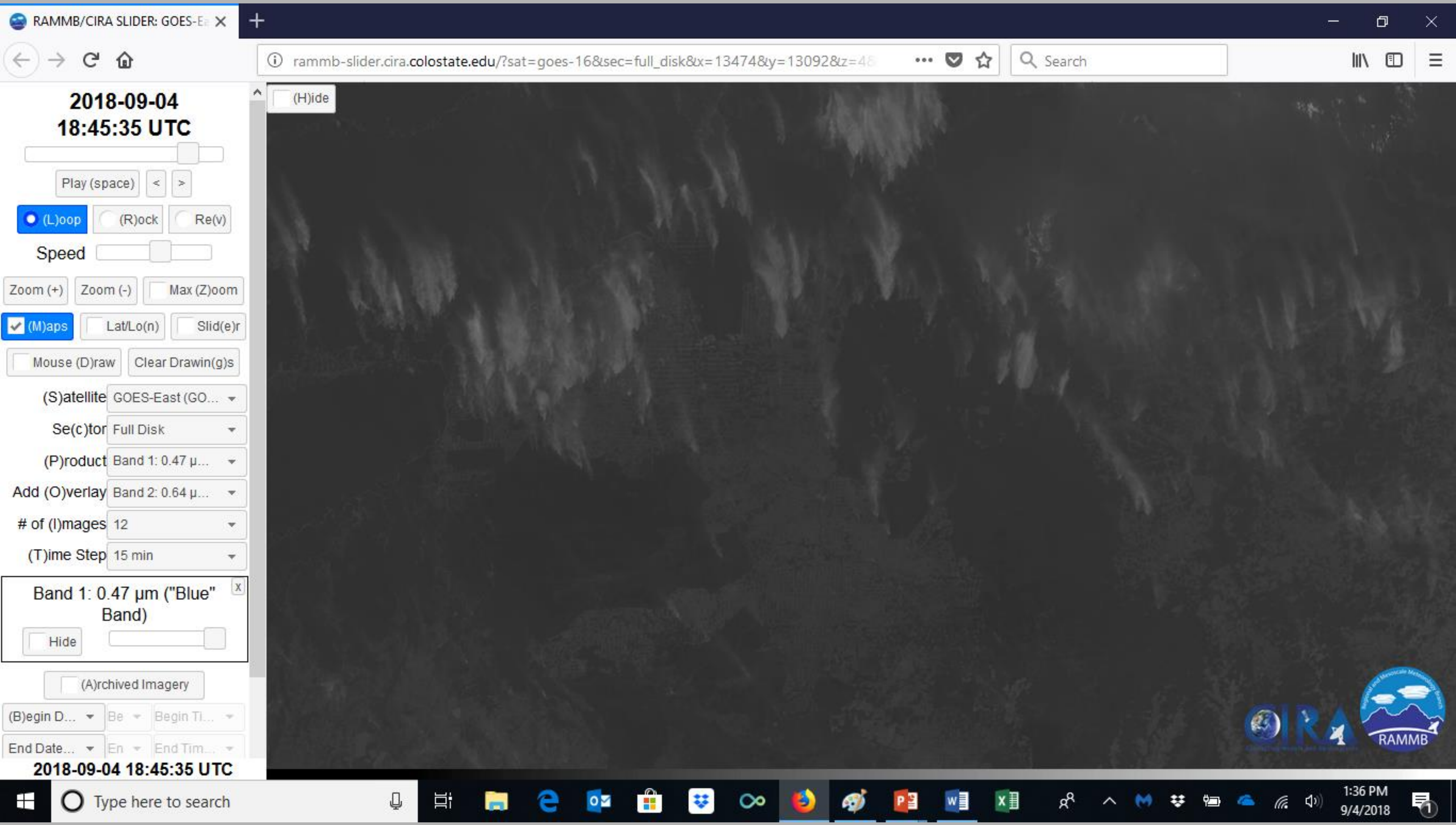


This image and the next two are from GOES-16 and are the 0.64 micron channel

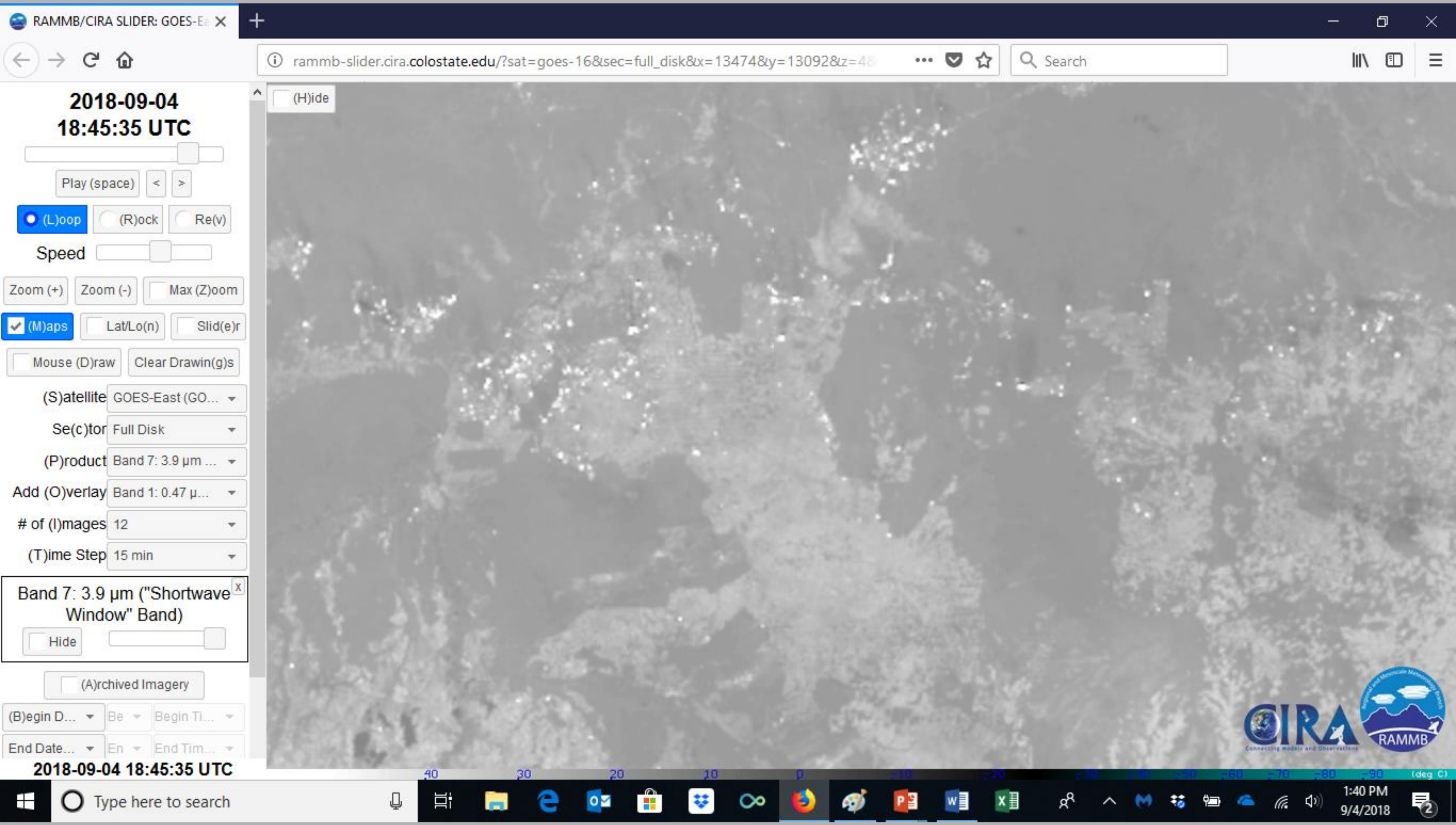
Zooming in on the scene



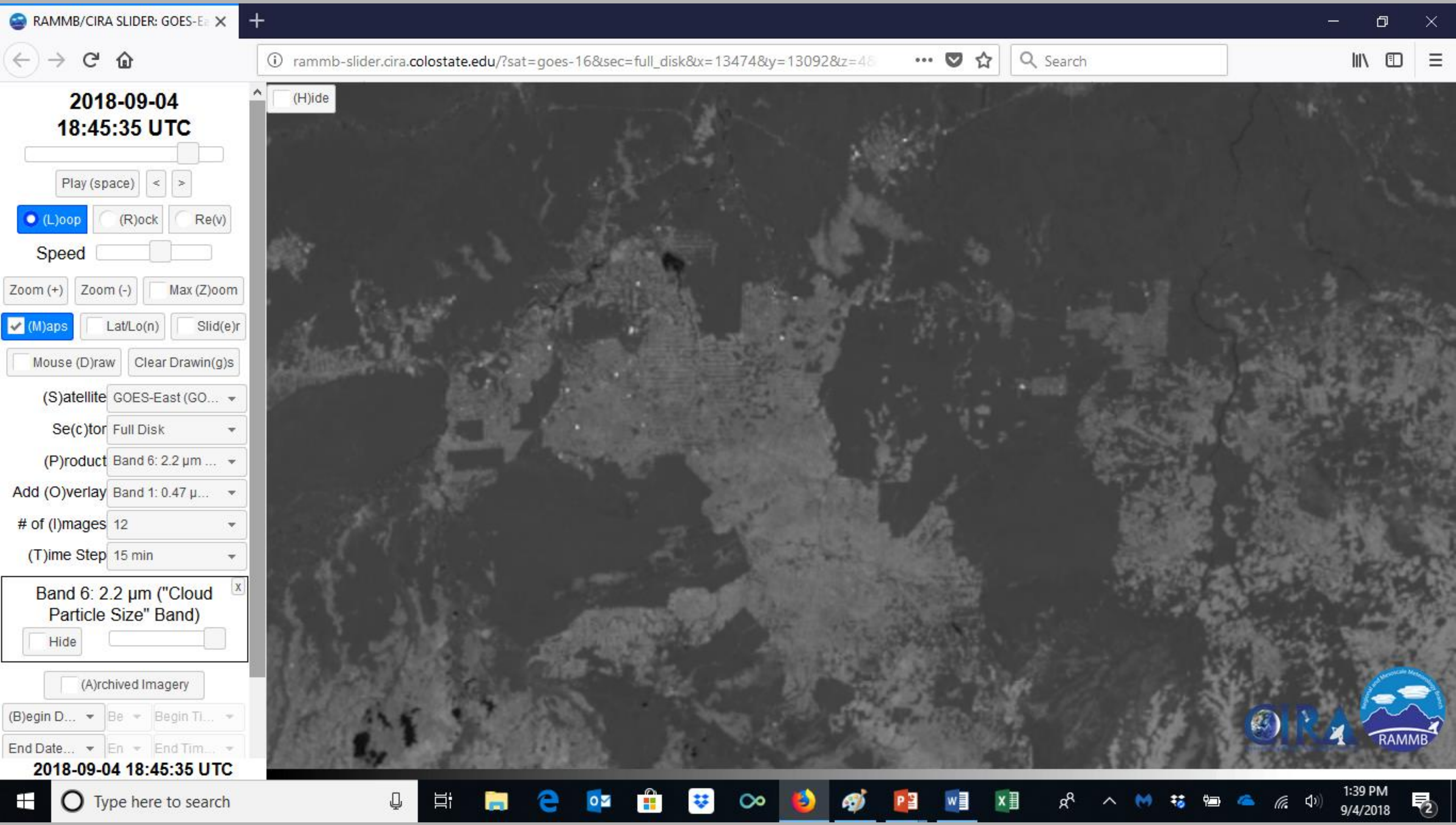
Zooming in even more



Fires show up as bright in this 3.9 micron channel image. This is because it is displayed in a reflective mode, not an emissive mode.



This image is from the 2.2 micron channel. While you see no smoke, there are some thermal signatures from some of the more intense fires.

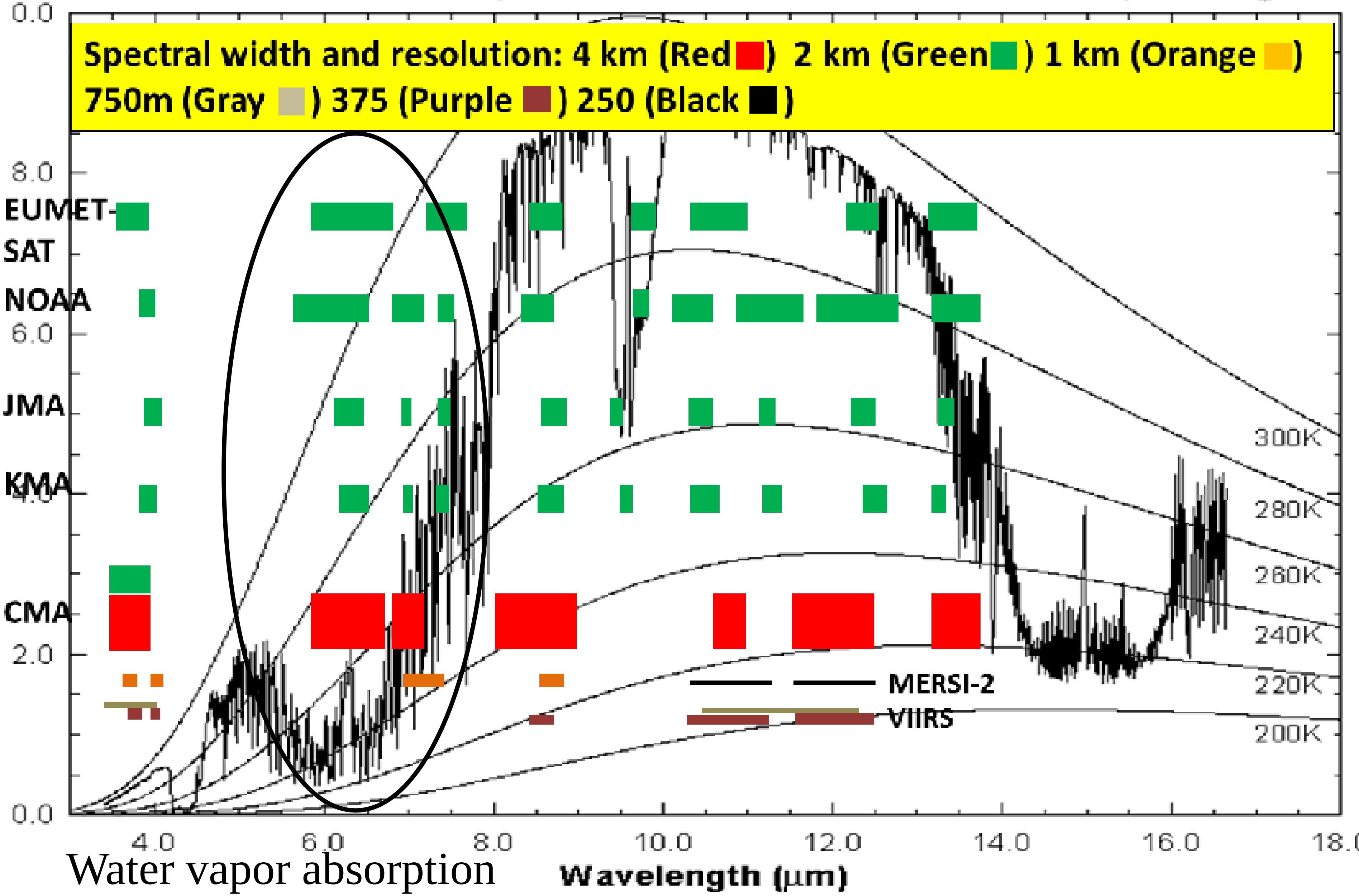


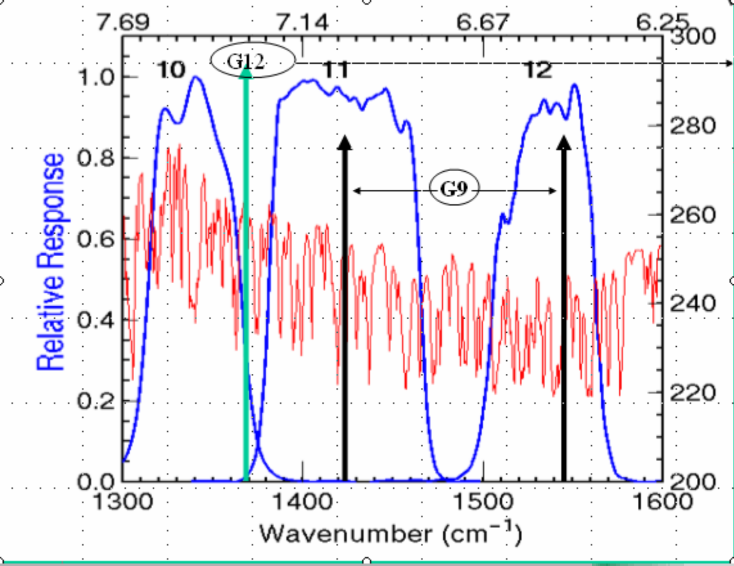

13 0013 G-16 IMG 2 4 SEP 18247 180035 12623 13001 01.00

61 0061 G-16 IMG 7 4 SEP 18247 180035 12453 12789 01.33

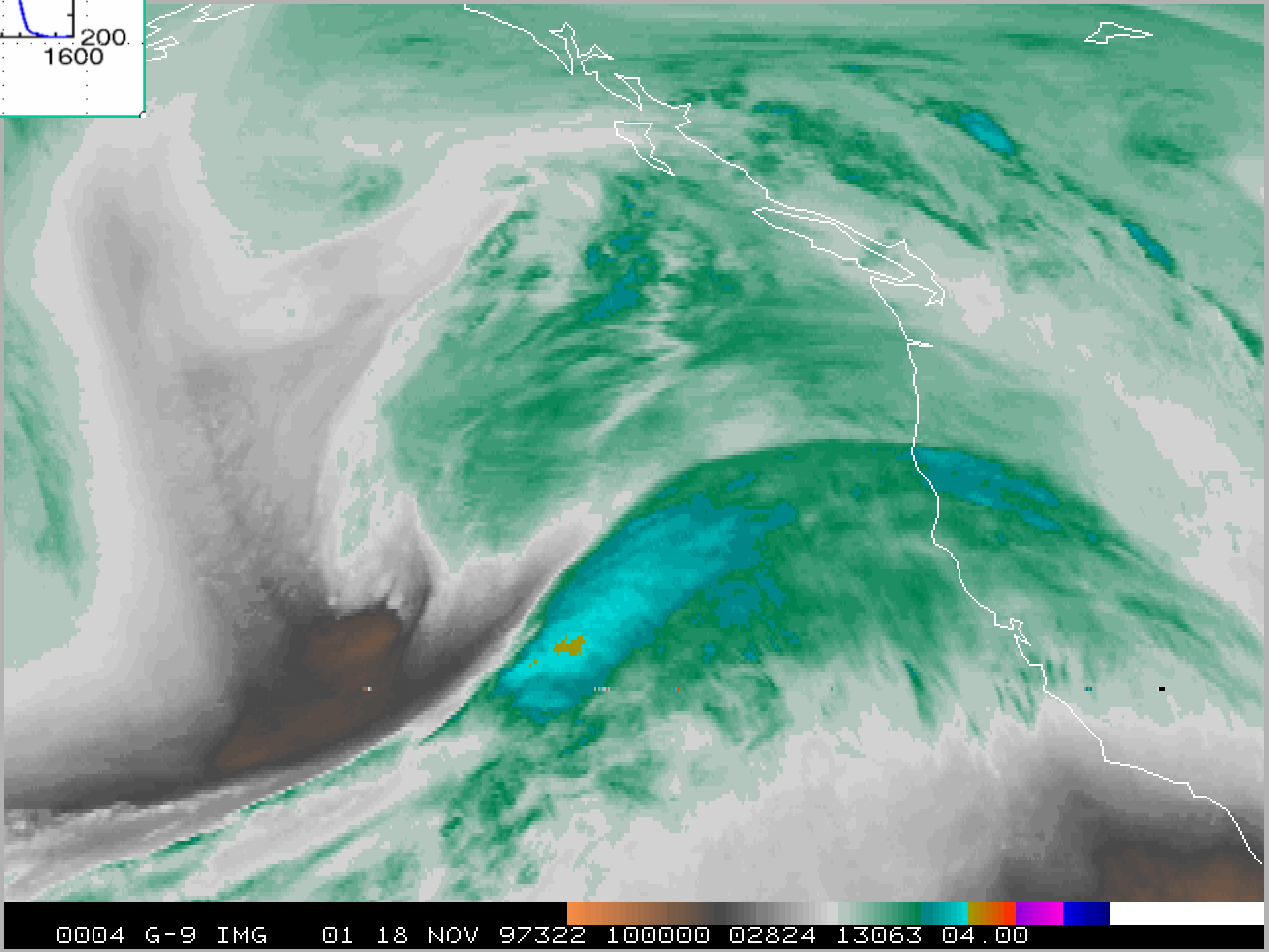
High resolution atmospheric absorption spectrum and comparative blackbody curves.

Geosats 2020 timeframe and spectral widths and resolutions and selected polar imagers



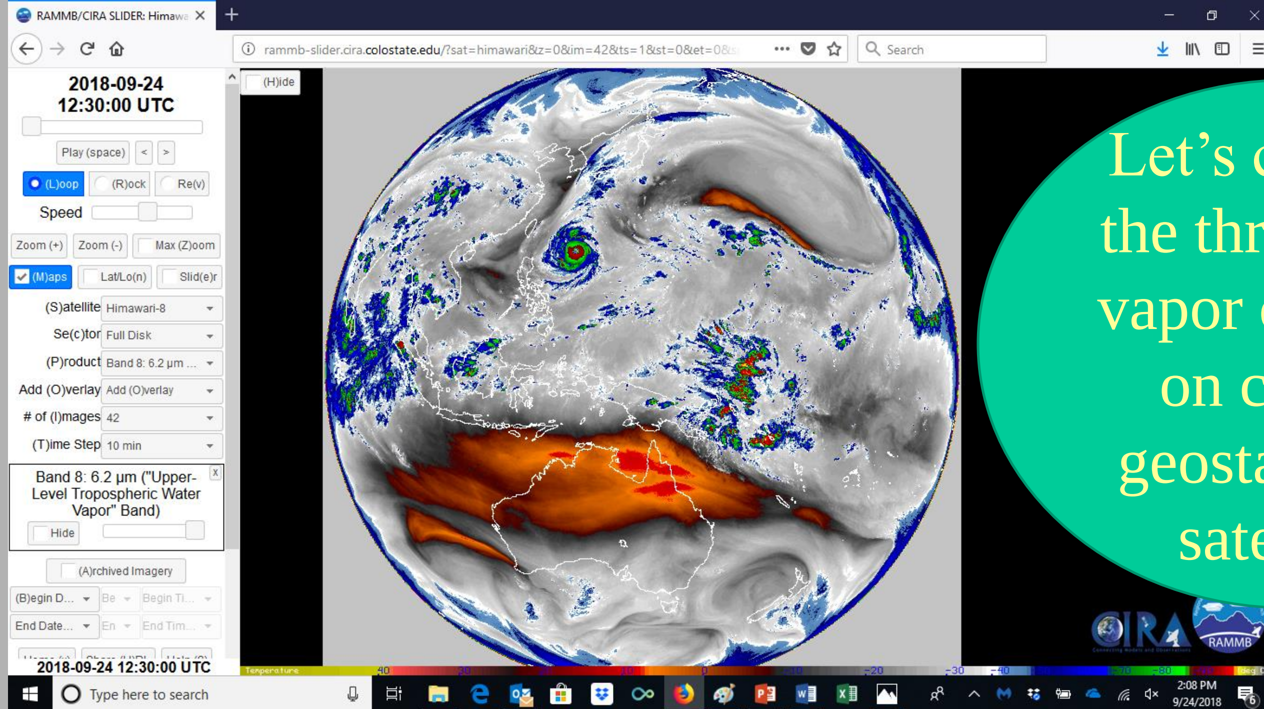


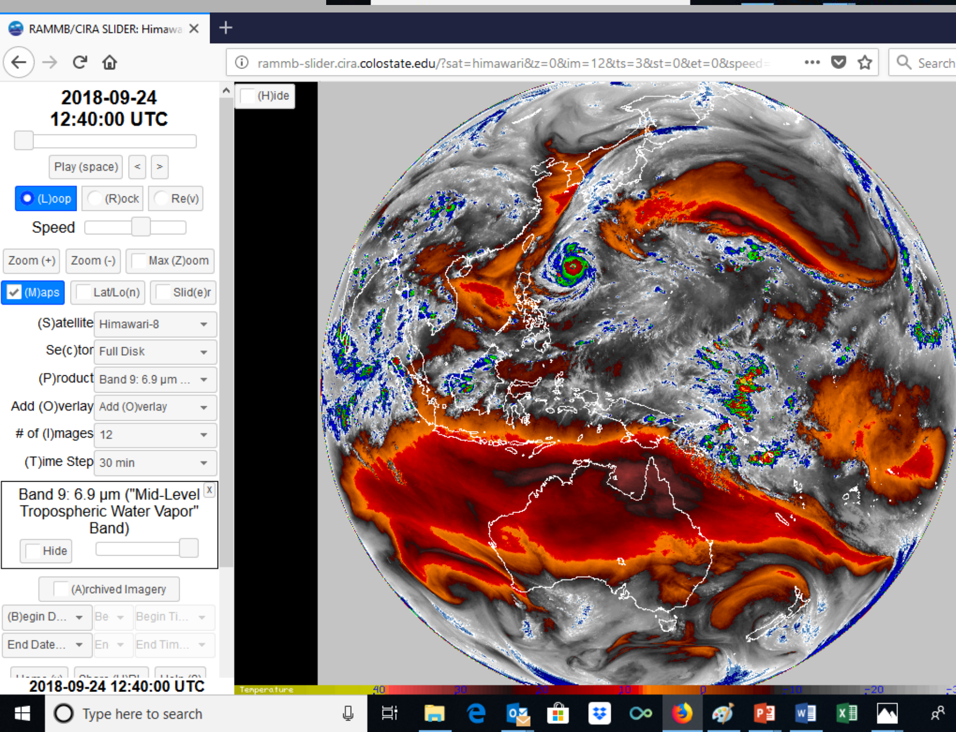
GOES-9 6.7 micron infrared (water vapor channel) movie loop: a broadband channel that extends from 6.47 to 7.02 microns

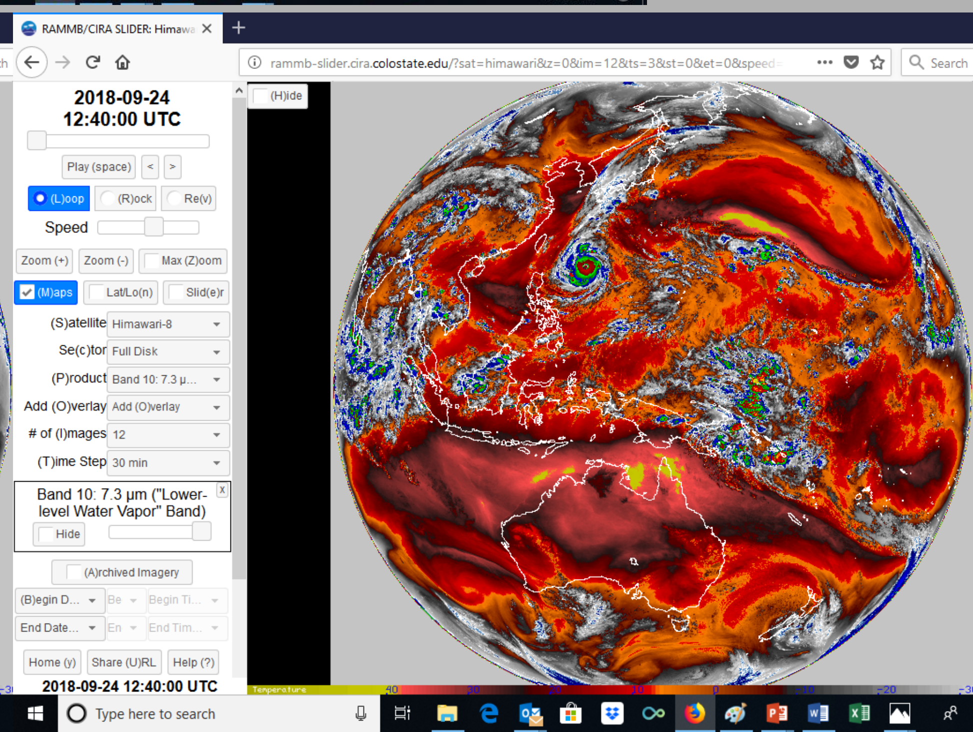


With GOES-12 the broadband water vapor channel spectral rage was increased to span the interval 5.8 to 7.3 microns

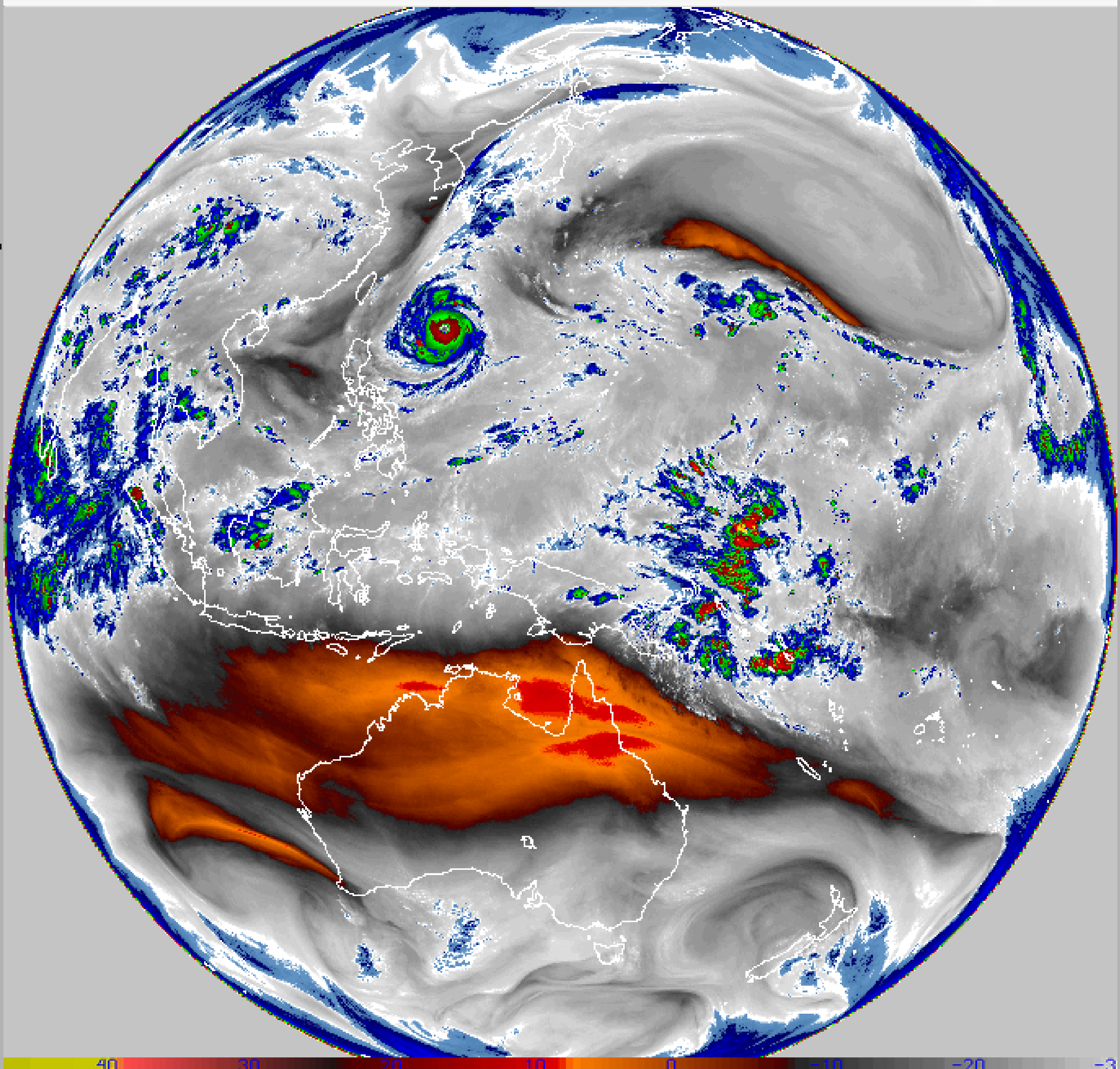
Let’s compare the three water vapor channels on current geostationary satellites



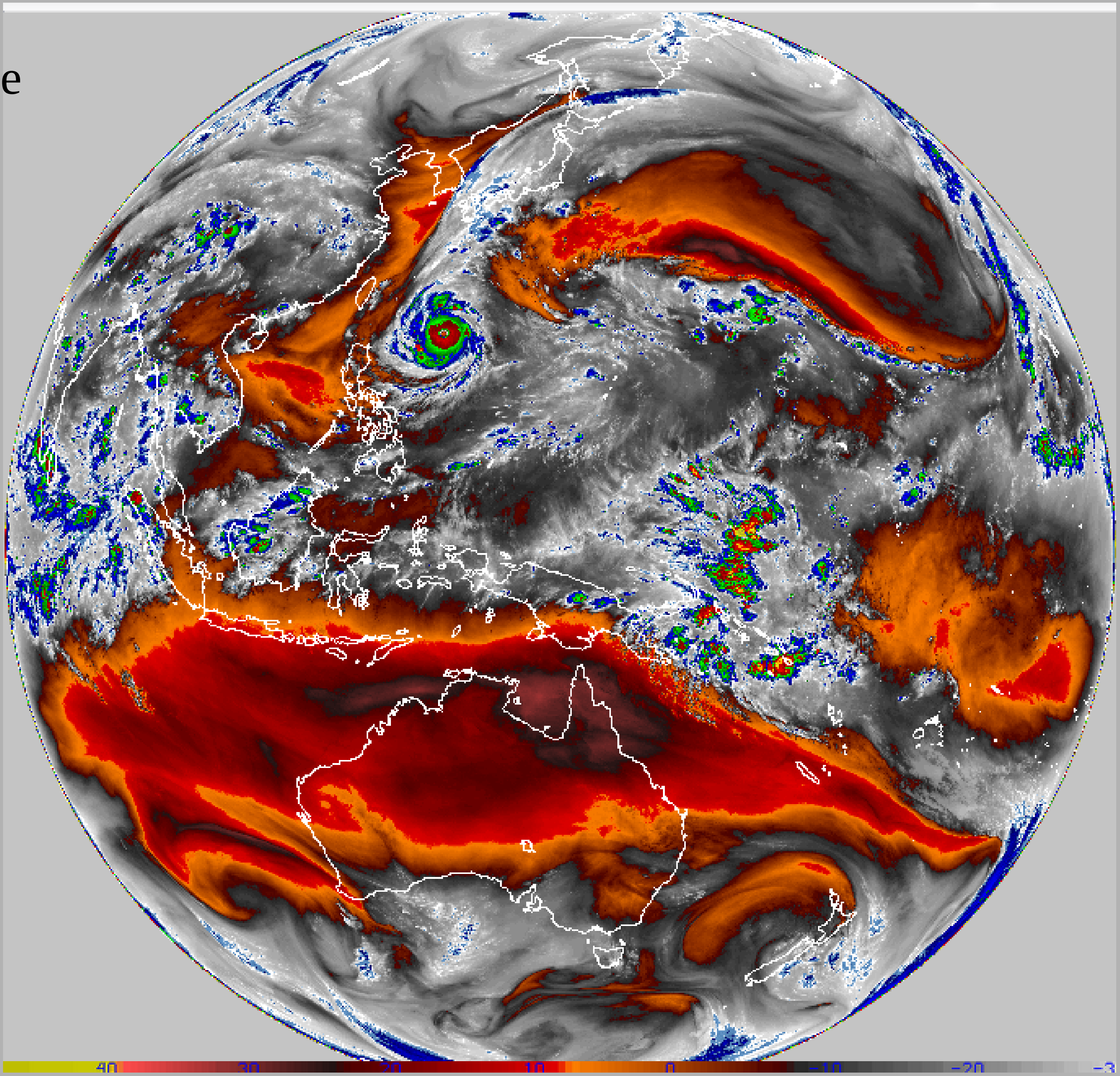




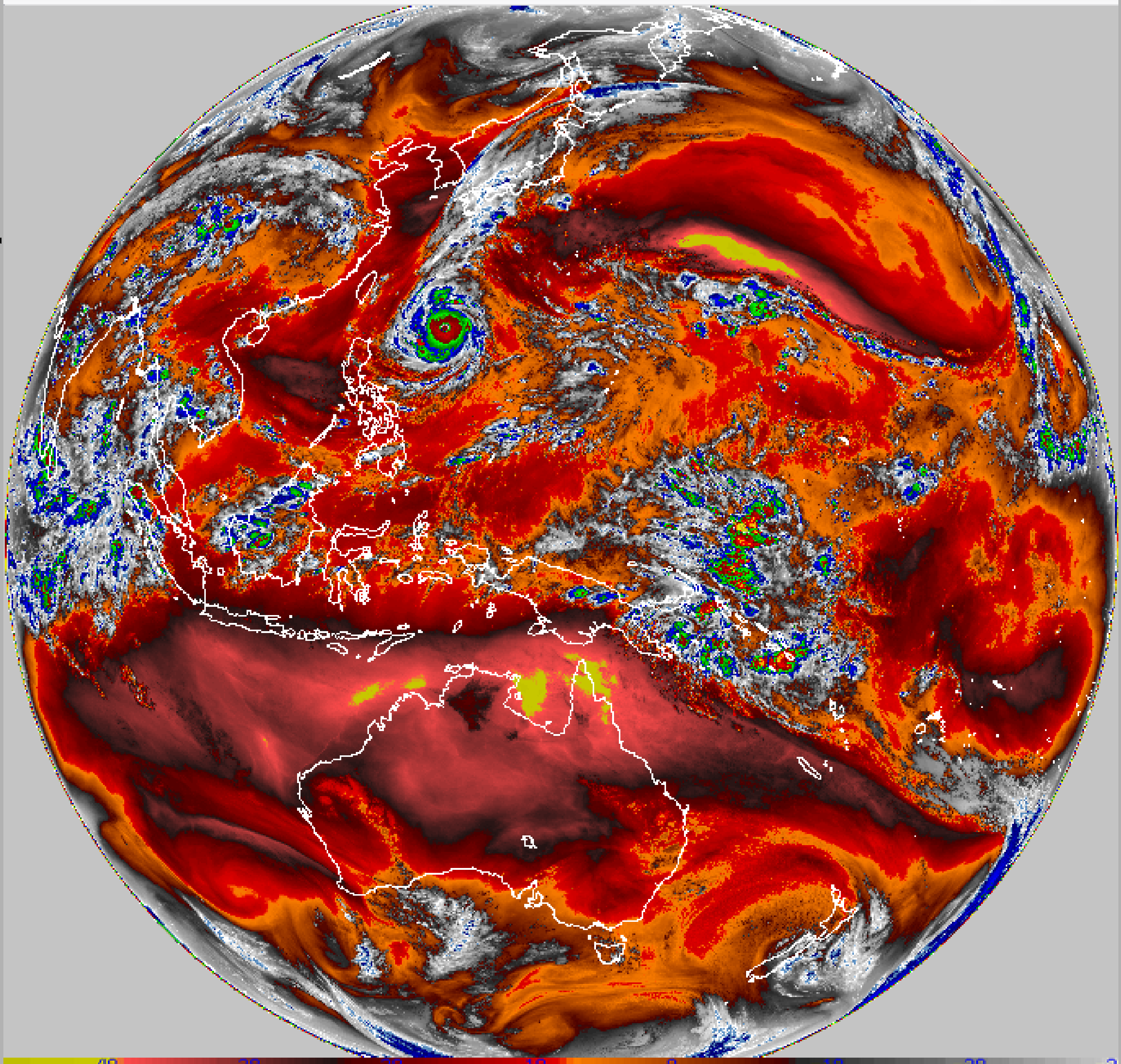
High
level
H20
vapor



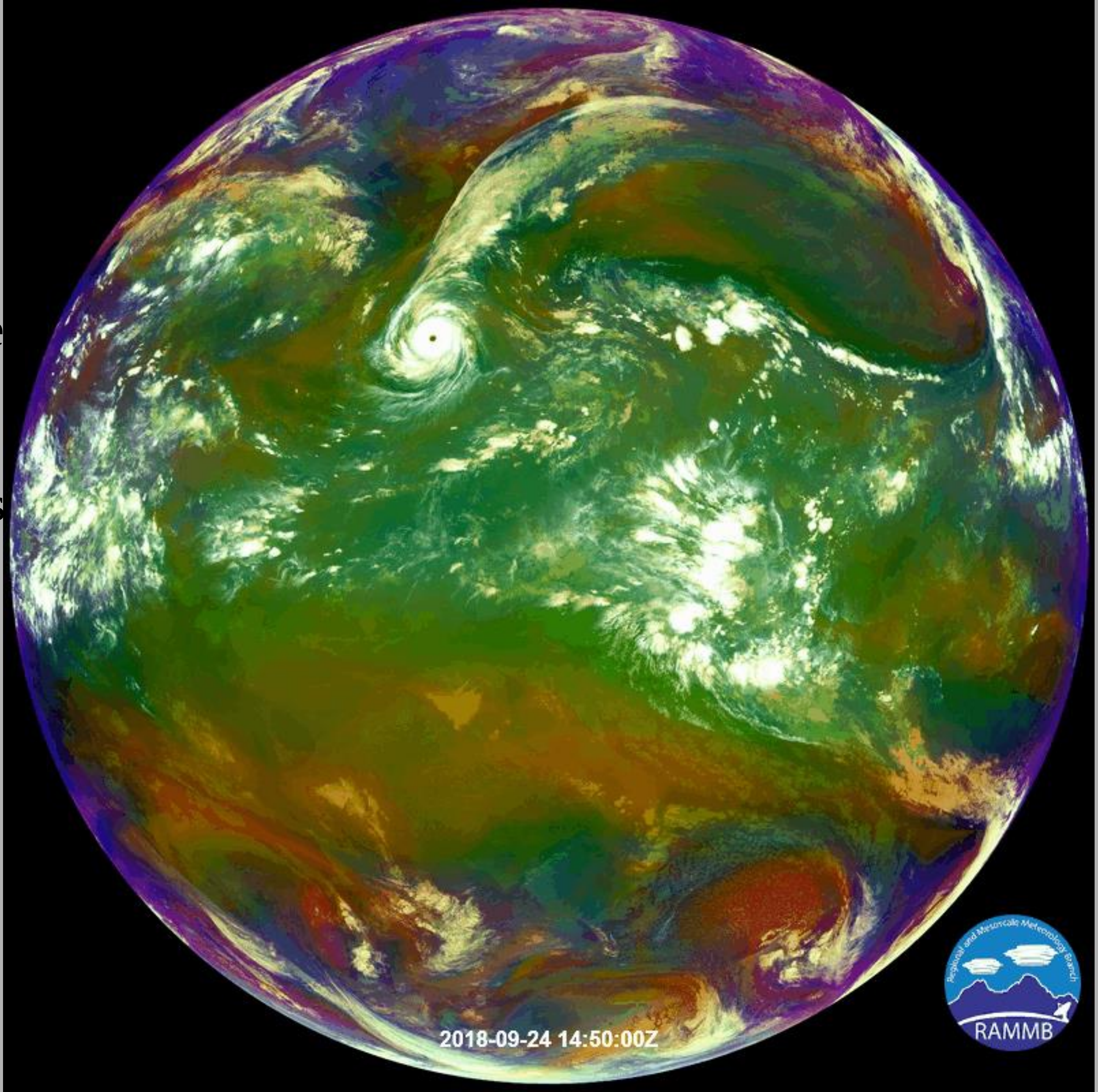
Middle
level
H20
vapor

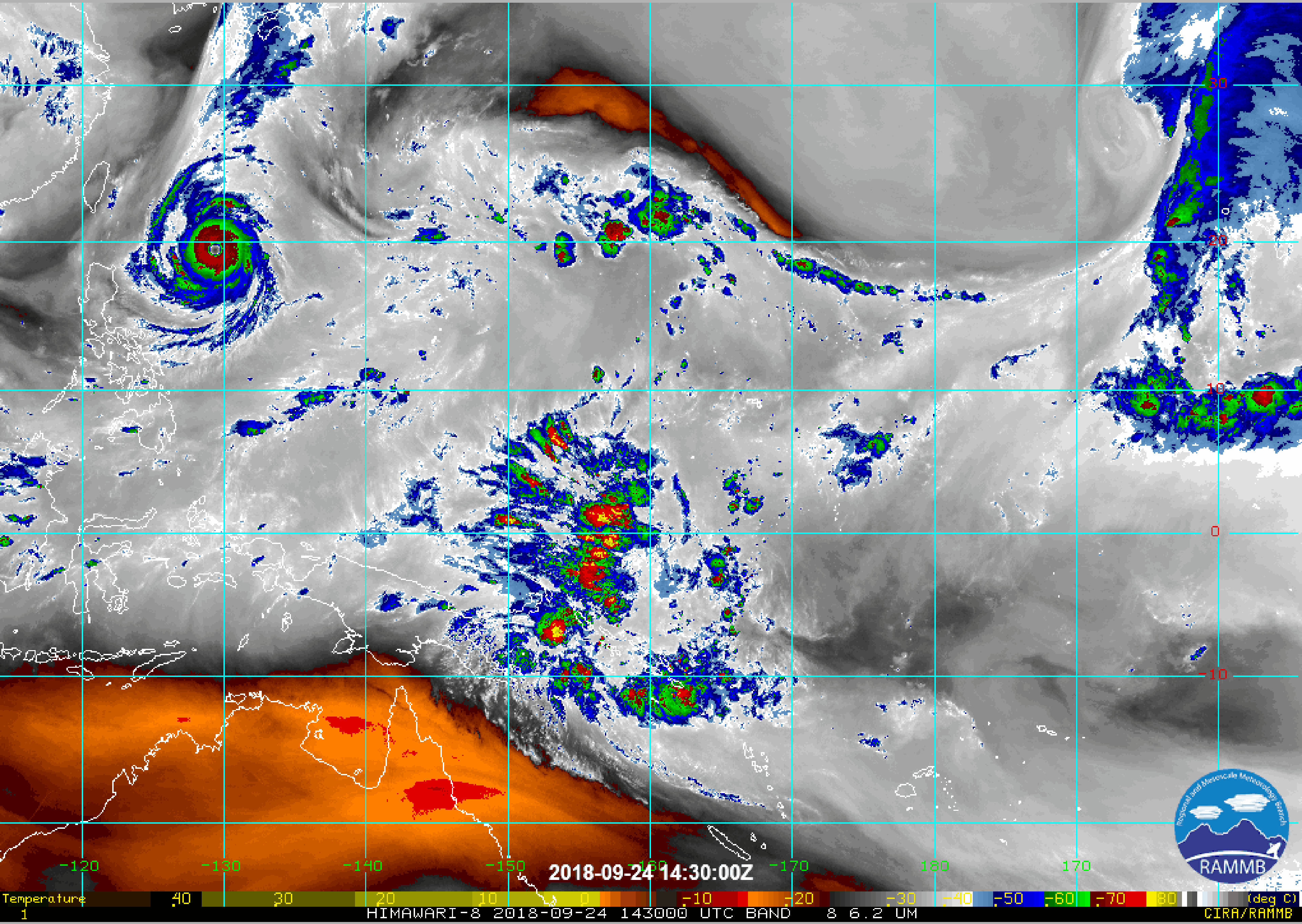


Low level H20 vapor

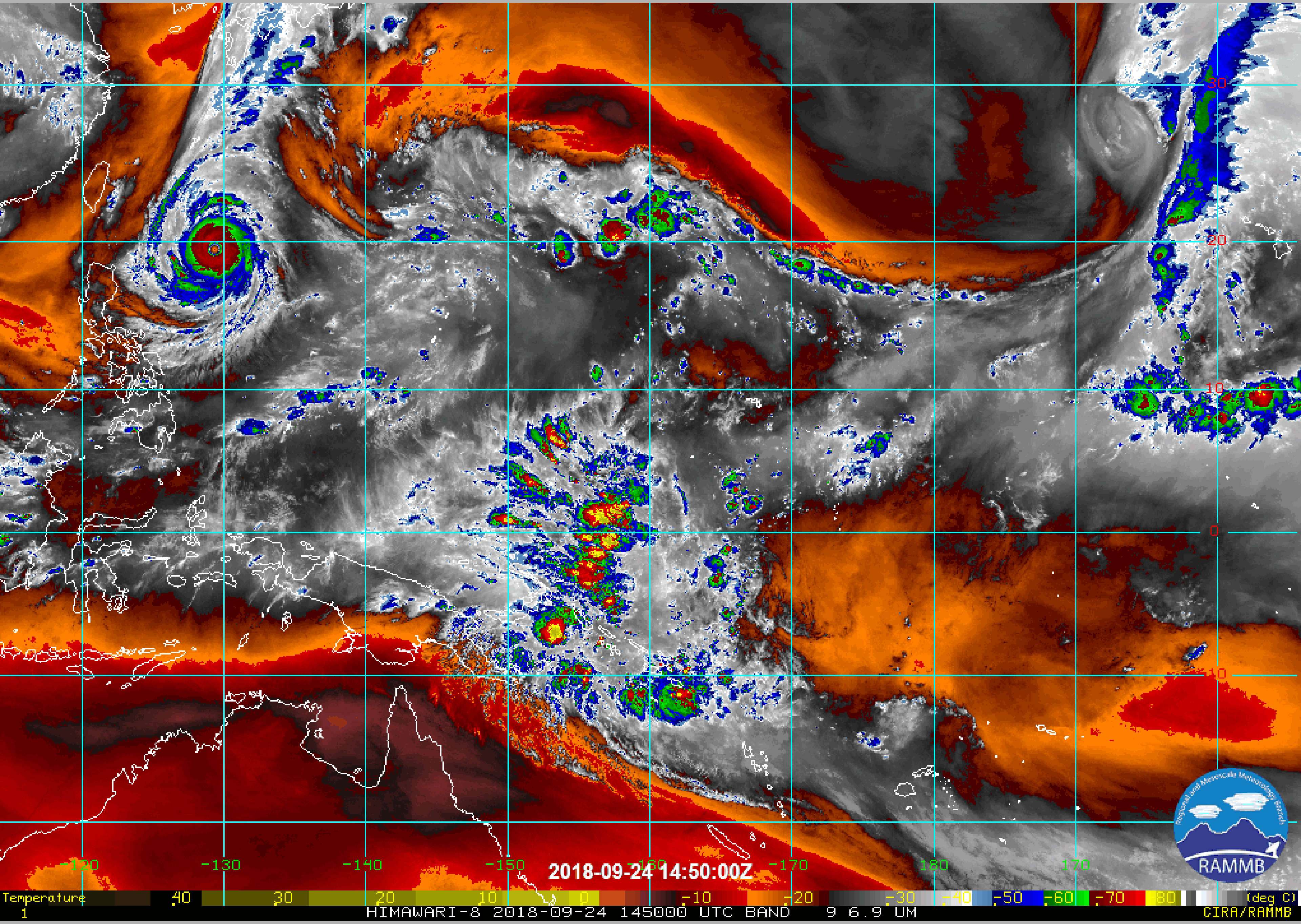


Air-mass product made using the three water vapor channels





30
20
10
0
-10
-120
-130
-140
-150
-160
-170
180
170
2018-09-24 14:30:00Z
RAMMB
Temperature
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
(deg C)
1
HIMAWARI-8 2018-09-24 143000 UTC BAND 8 6.2 UM
CIRA/RAMMB


30
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-120
-130
-140
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-160
-170
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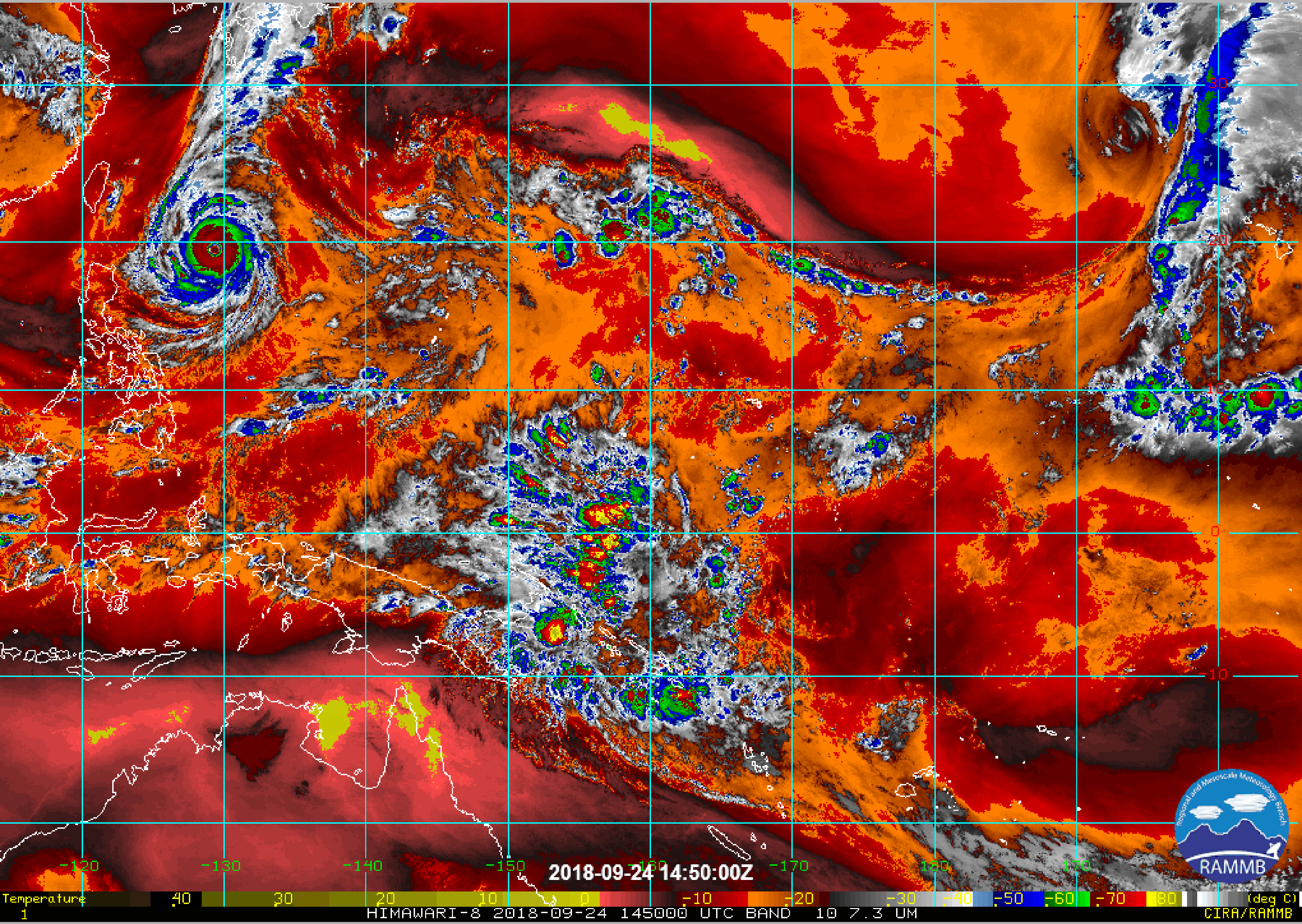
170
2018-09-24 14:50:00Z
RAMMB
Temperature 40 30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 (deg C)
1 HIMAWARI-8 2018-09-24 145000 UTC BAND 9 6.9 UM
CIRA/RAMMB



30
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2018-09-24 14:50:00Z
RAMMB
Temperature
40
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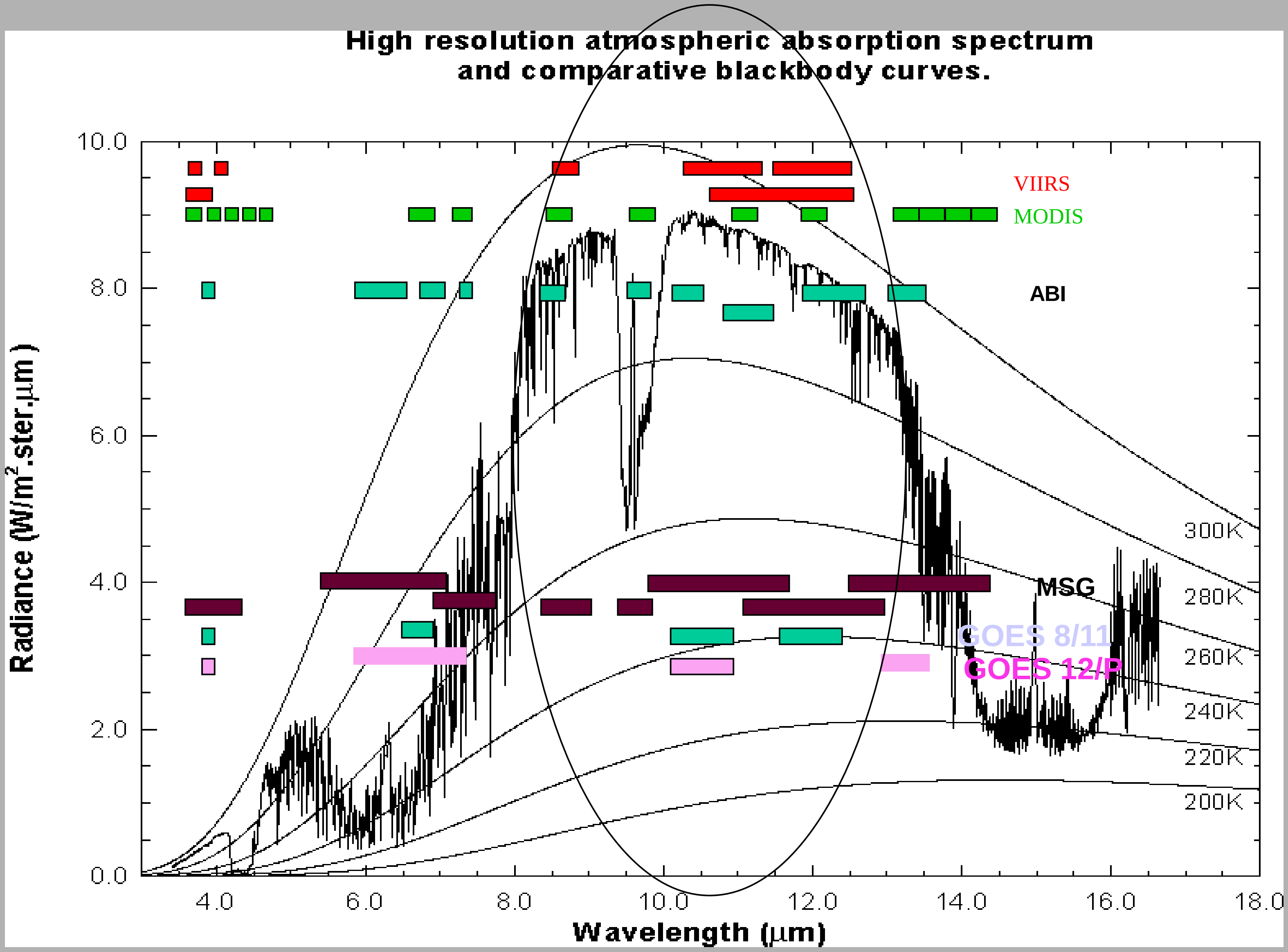
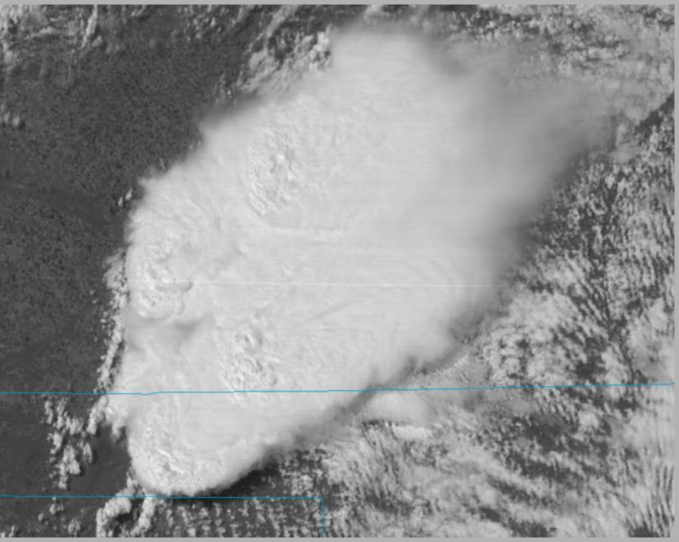
10
0
-10
-20
-30
-40
-50
-60
-70
-80
(deg C)
1
HIMAWARI-8 2018-09-24 145000 UTC BAND 10 7.3 UM
CIRA/RAMMB

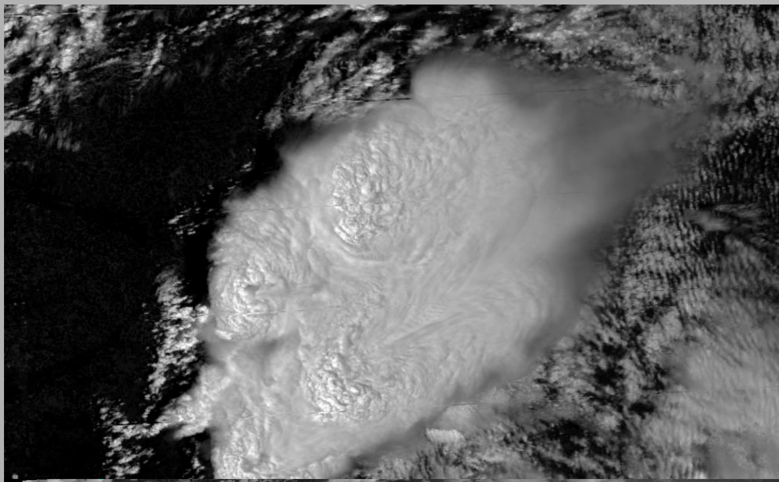
Earth emitted spectra overlaid on Planck function envelopes

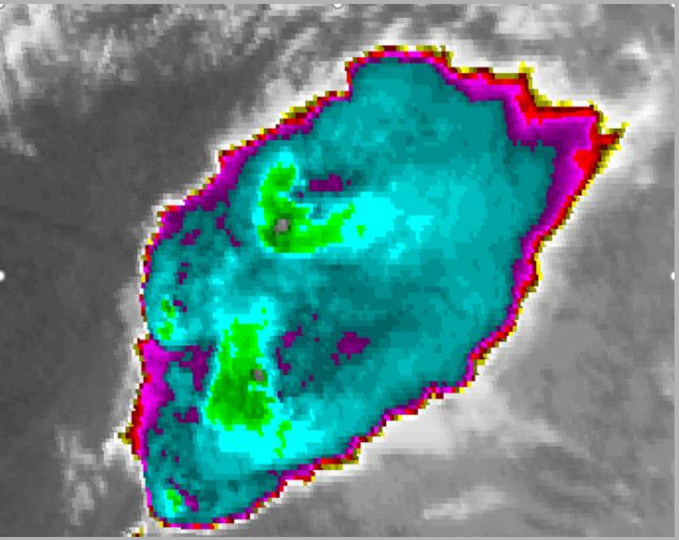


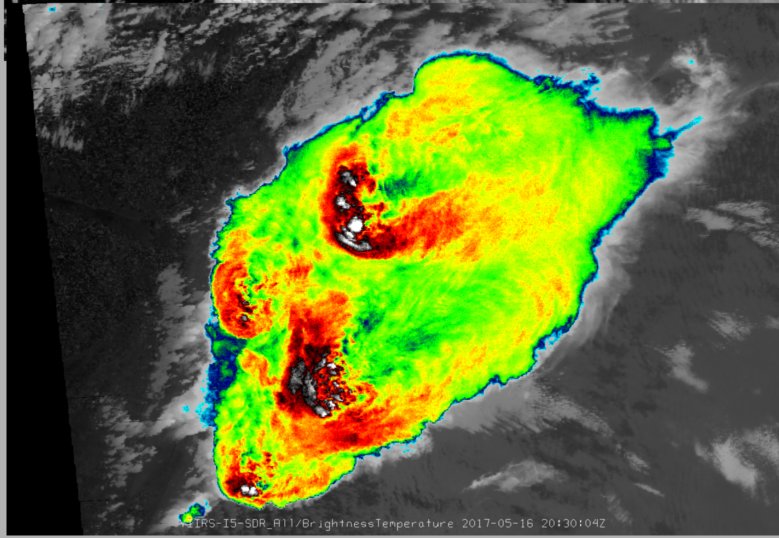
The infrared window regions and ozone absorption area



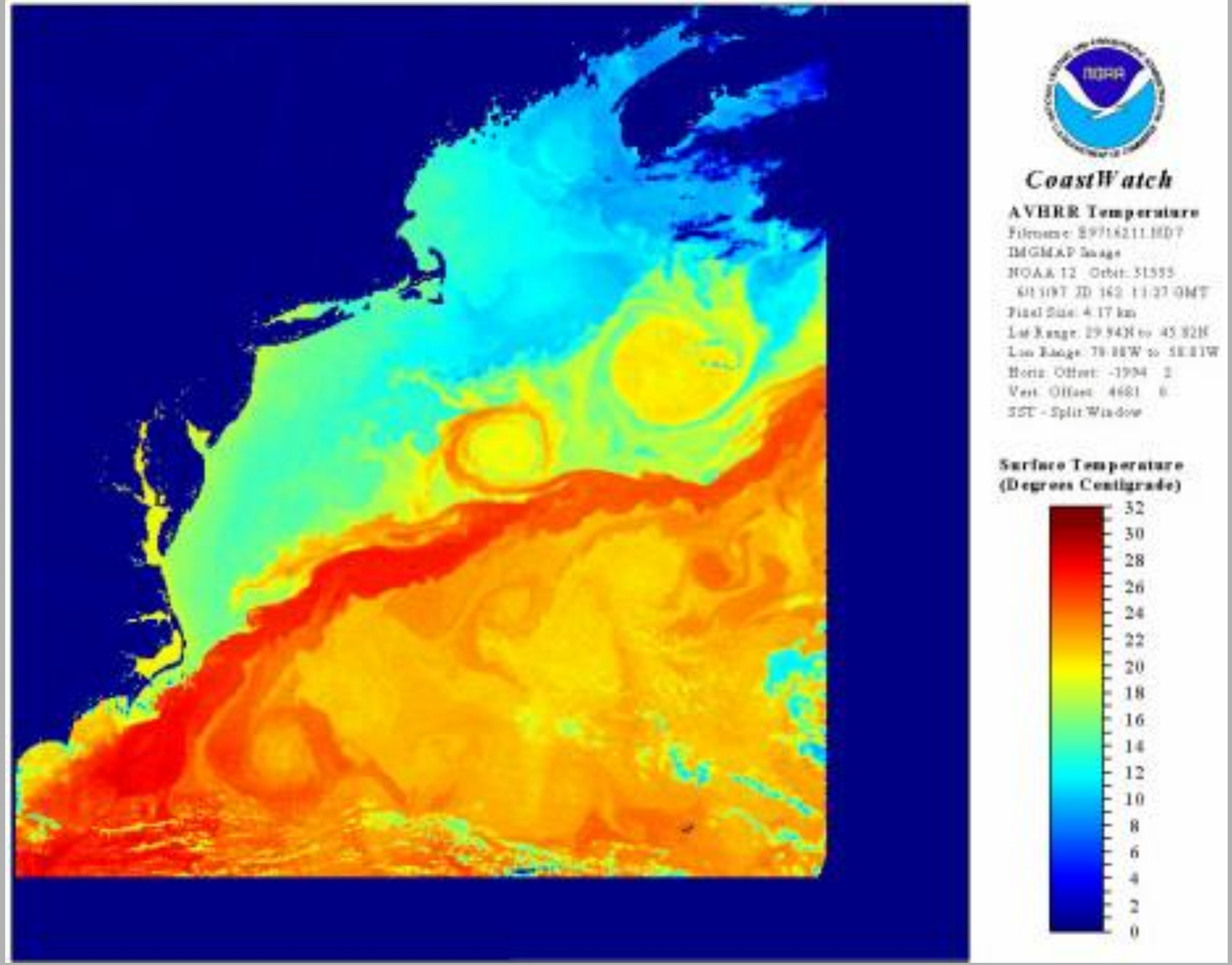
Comparison of visible and infrared imagery from GOES-15 and JPSS Polar satellite. GOES IR is 2 km resolution while Polar is 375 meters. Visible is 500 vs 375 (JPSS) meters



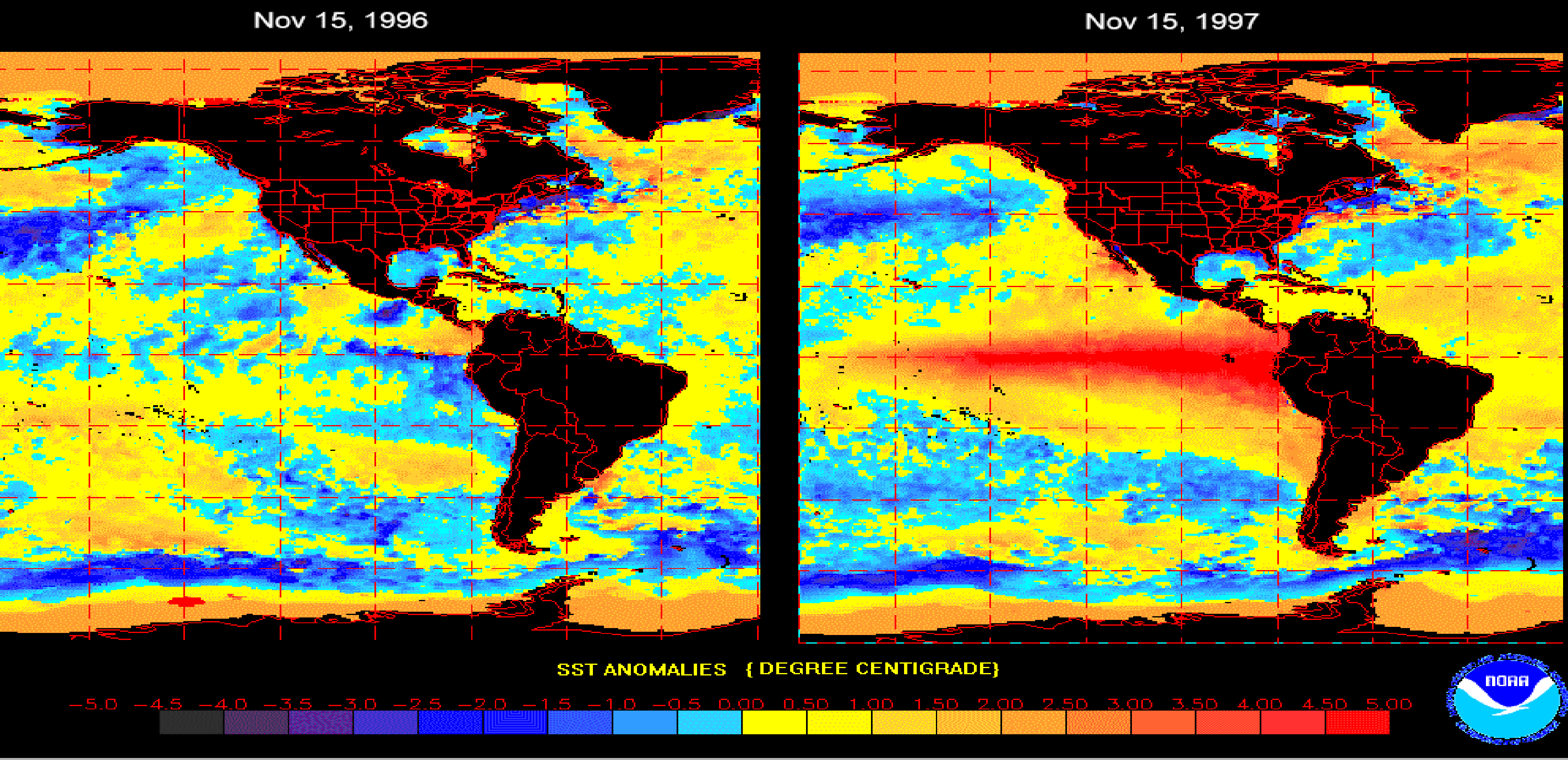




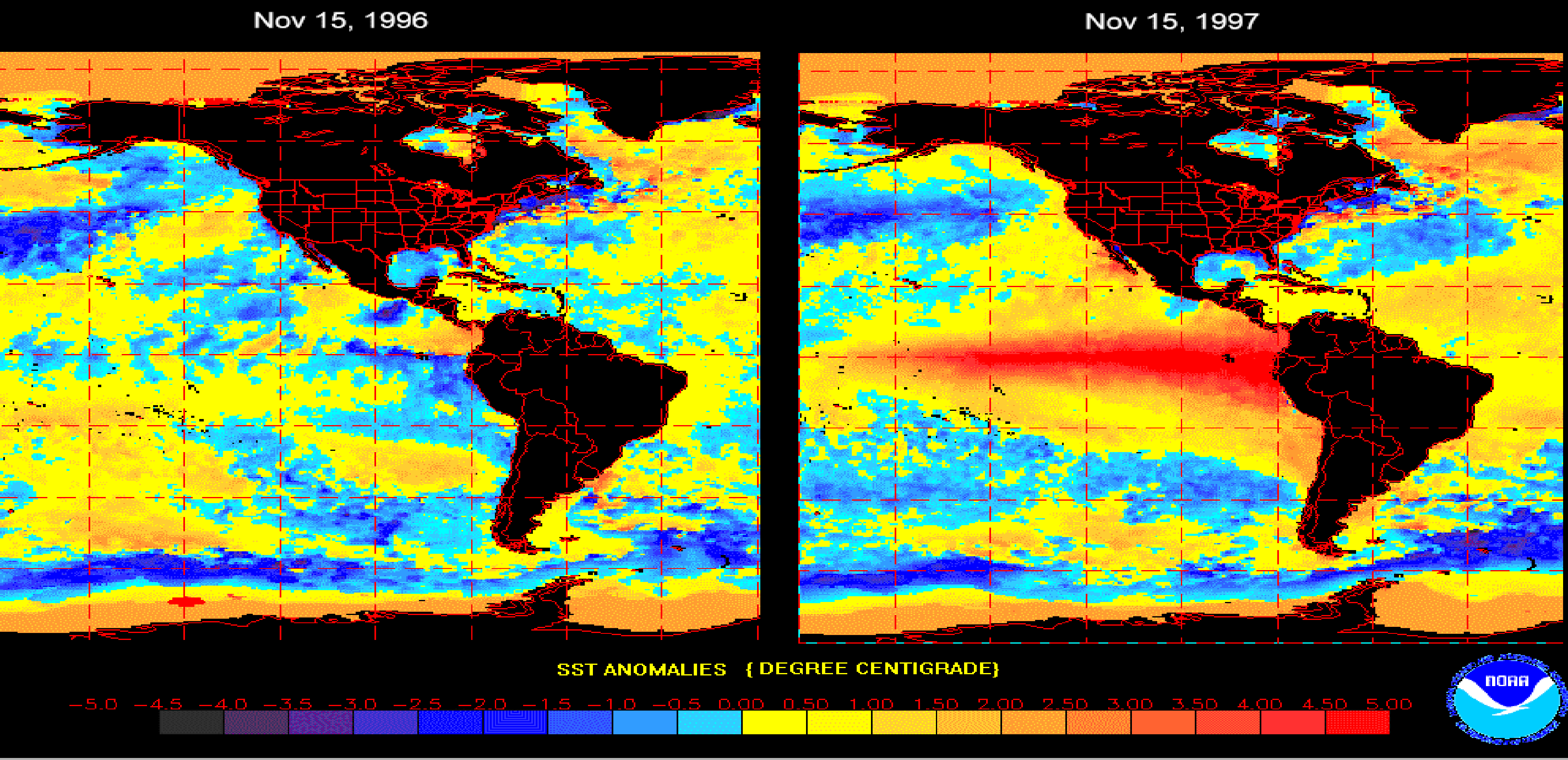
These images are of large severe thunderstorms and were taken within 30 seconds of one another.



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.

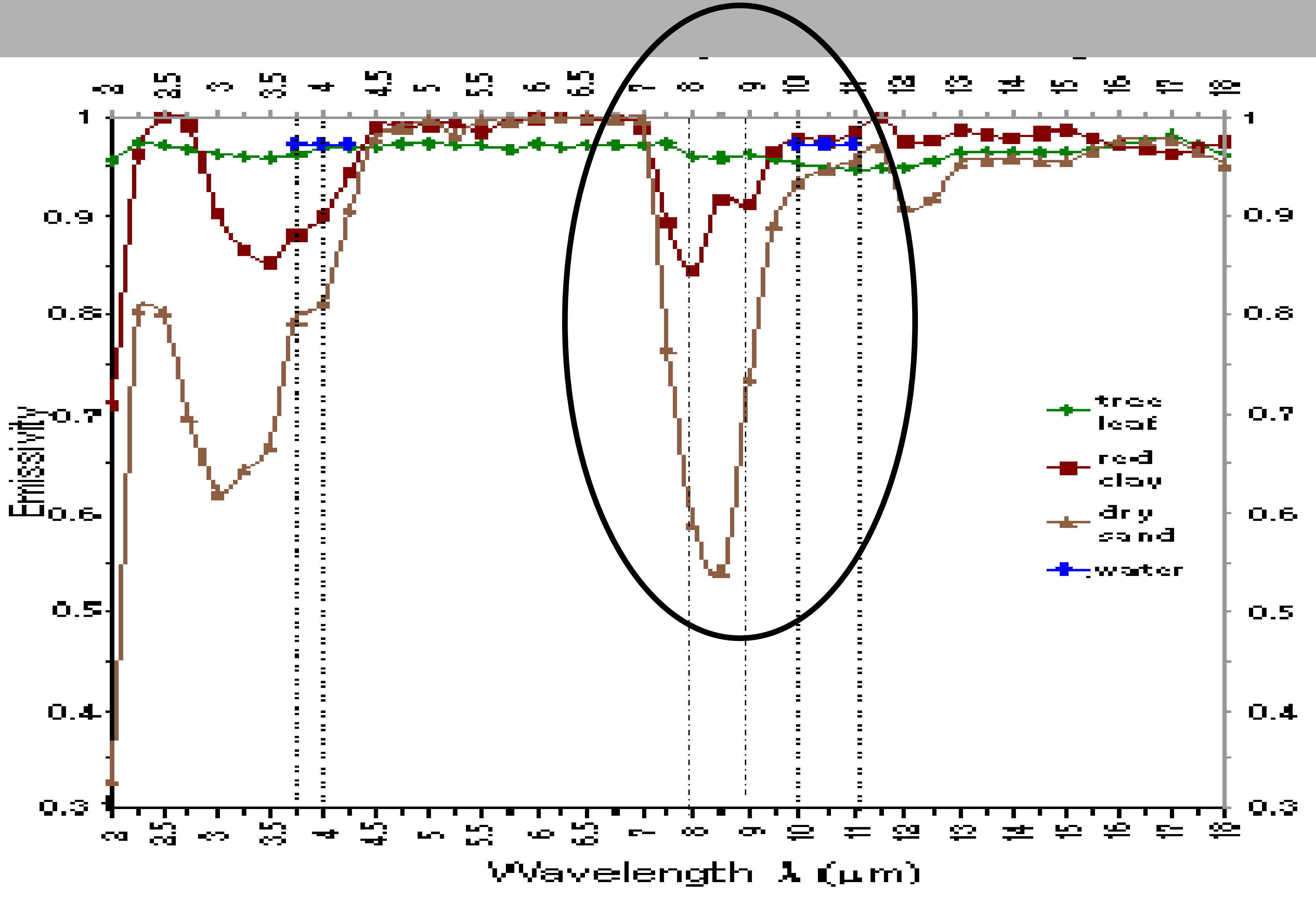


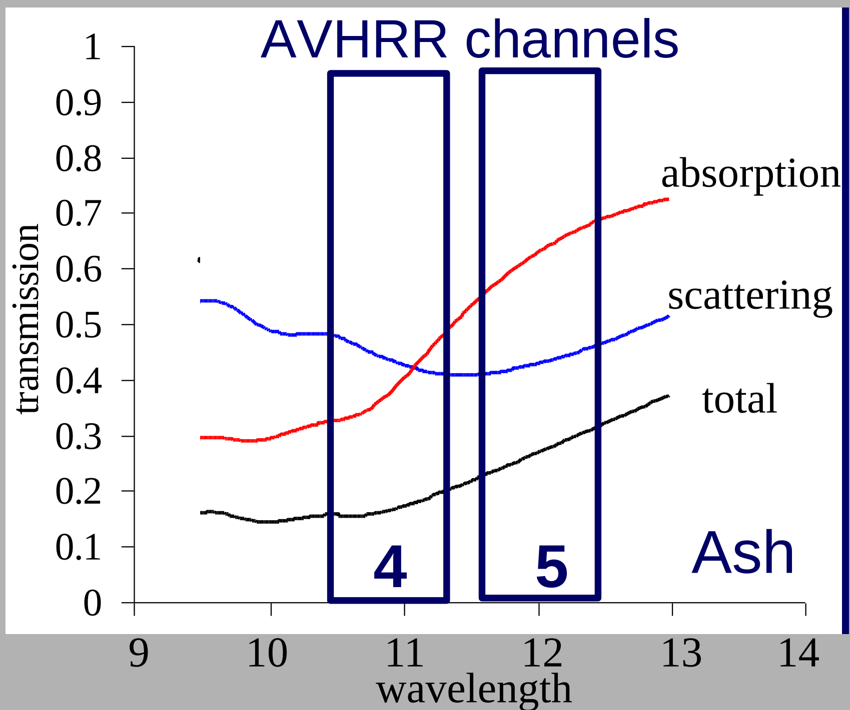
AVHRR Sea Surface temperature Anomalies (Deg. C)
November 1996 vs November 1997

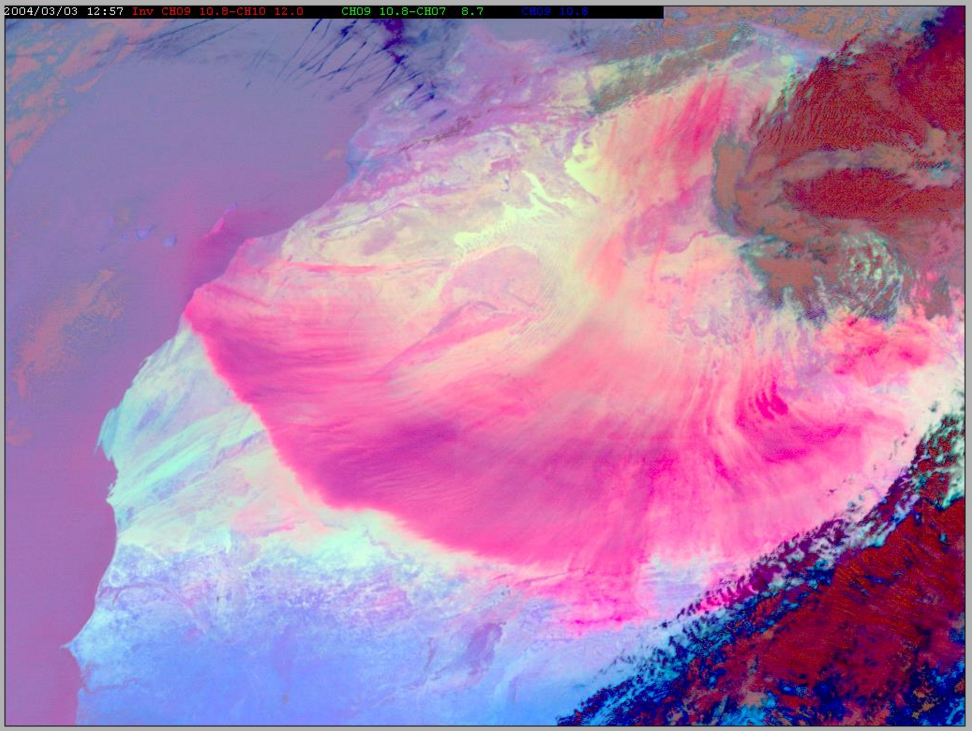


AVHRR Sea Surface temperature Anomalies (Deg. C)
November 1996 vs November 1997

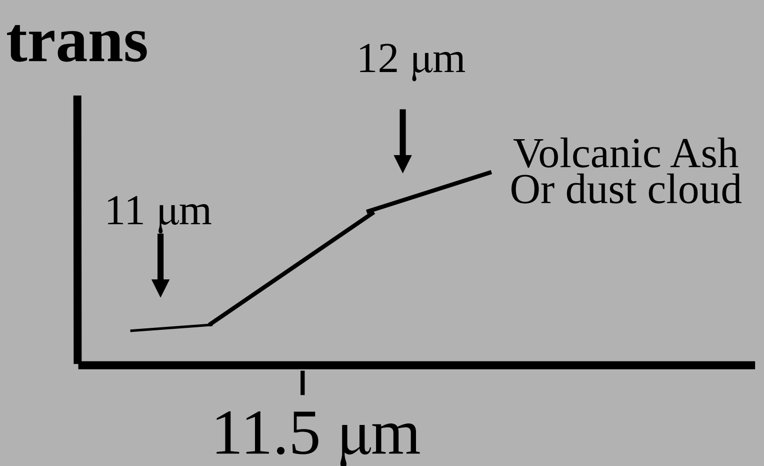
Spectral Awareness, surface characteristics





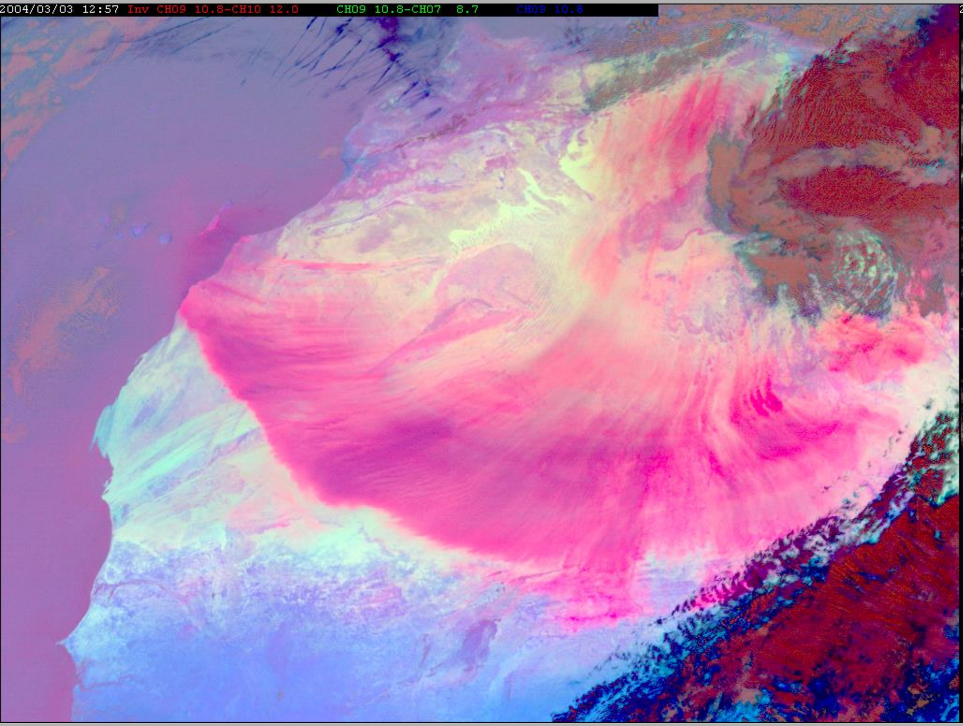


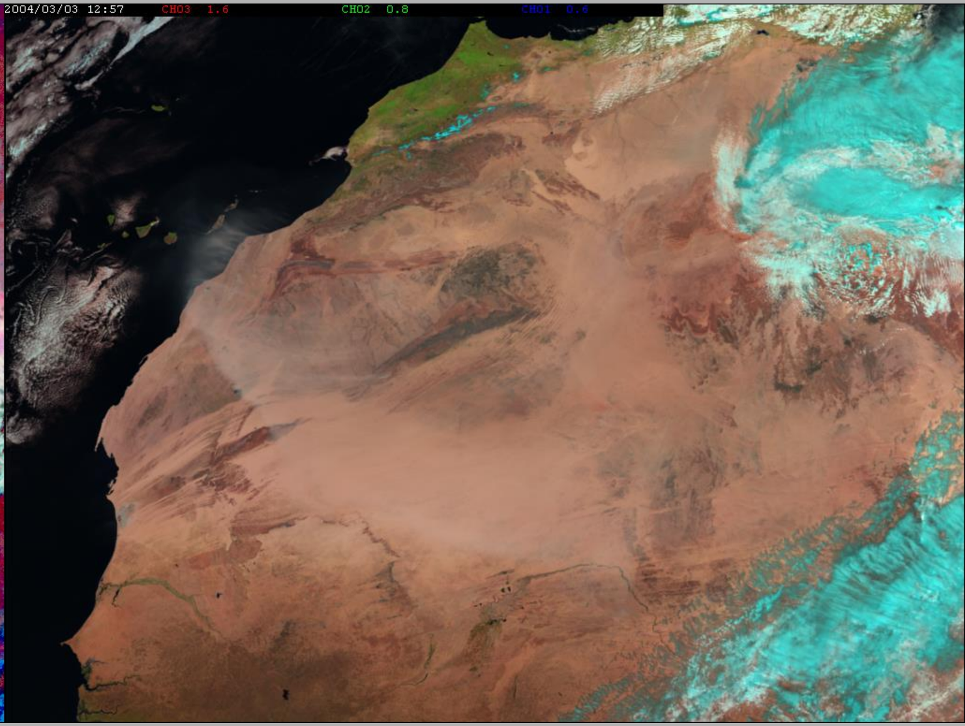
METEOSAT movie of large dust storm over Africa



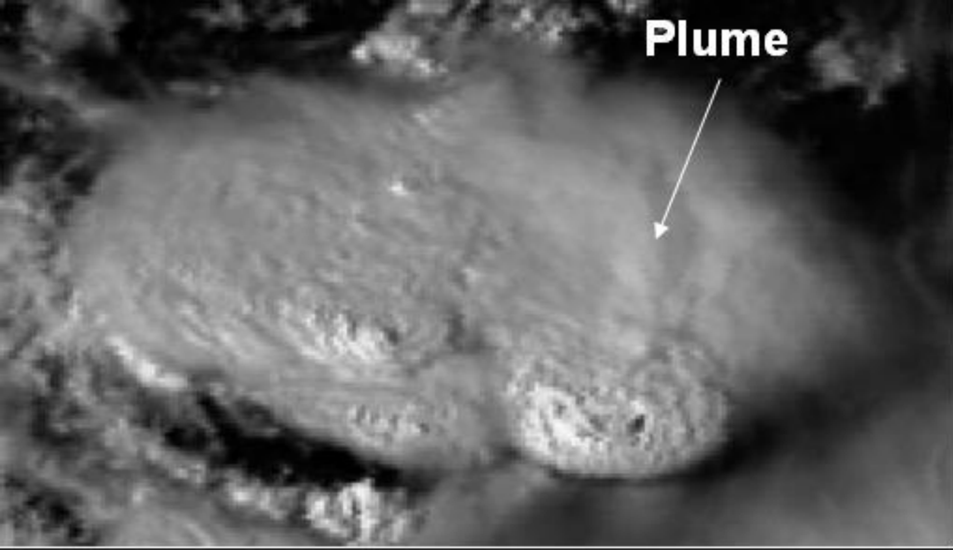
If 12 μm sees considerably higher BT than 11 μm then the atmosphere probably contains dust (as above) or volcanic ash; if 11 μm sees the same or higher BT than 12 μm the atmosphere viewed does not contain dust cloud or volcanic ash;

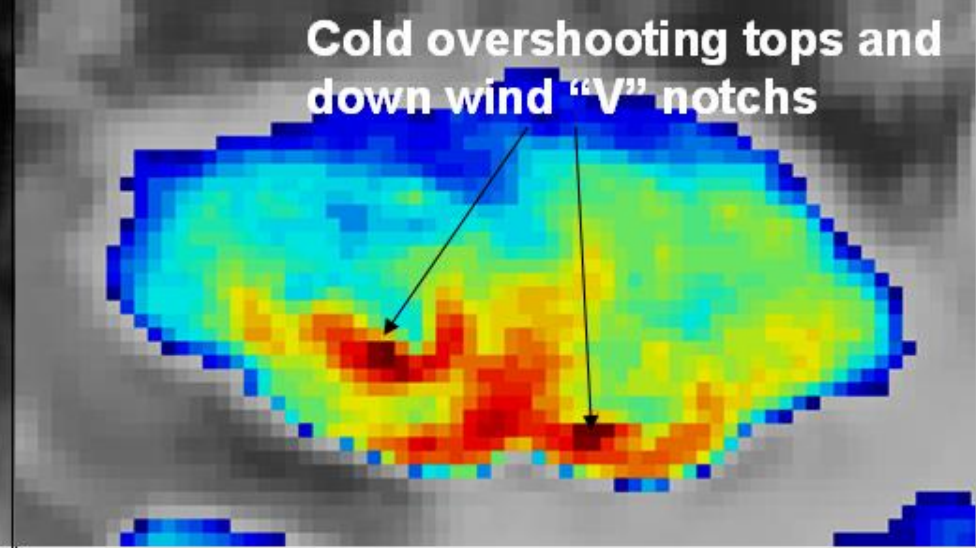
METEOSAT-8 (MSG) detection of large dust storm over Africa using visible to near IR (right) and IR (left) channel combinations





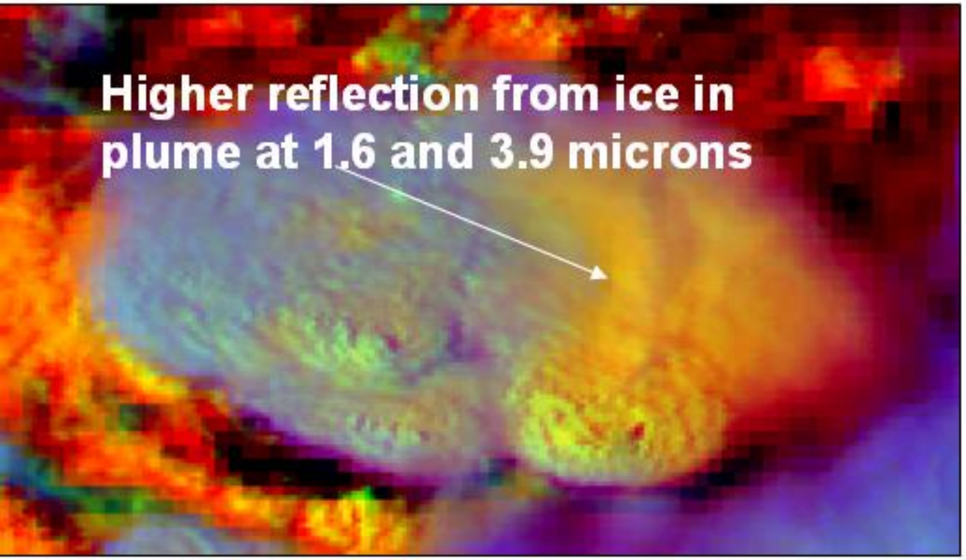
False color images from MSG channels. Left: 12.0-10.8 (R), 10.8-8.7 (G), 10.7 (B). Right: 1.6 (R), 0.8 (G), 0.6 (B). Click on either image to view animation.





MSG High Resolution Visible (HRV)

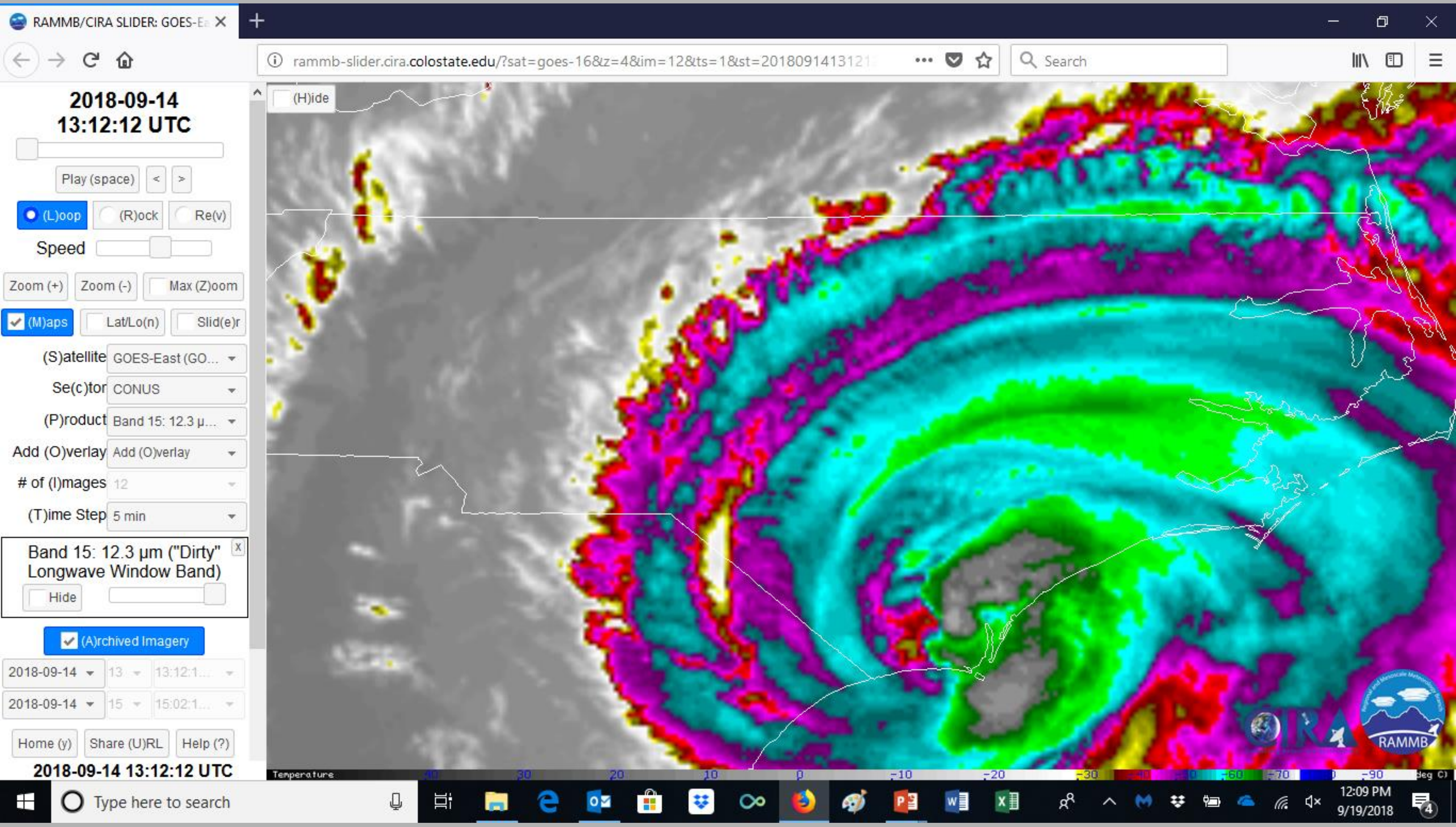
MSG Enhanced 10.7 micron IR



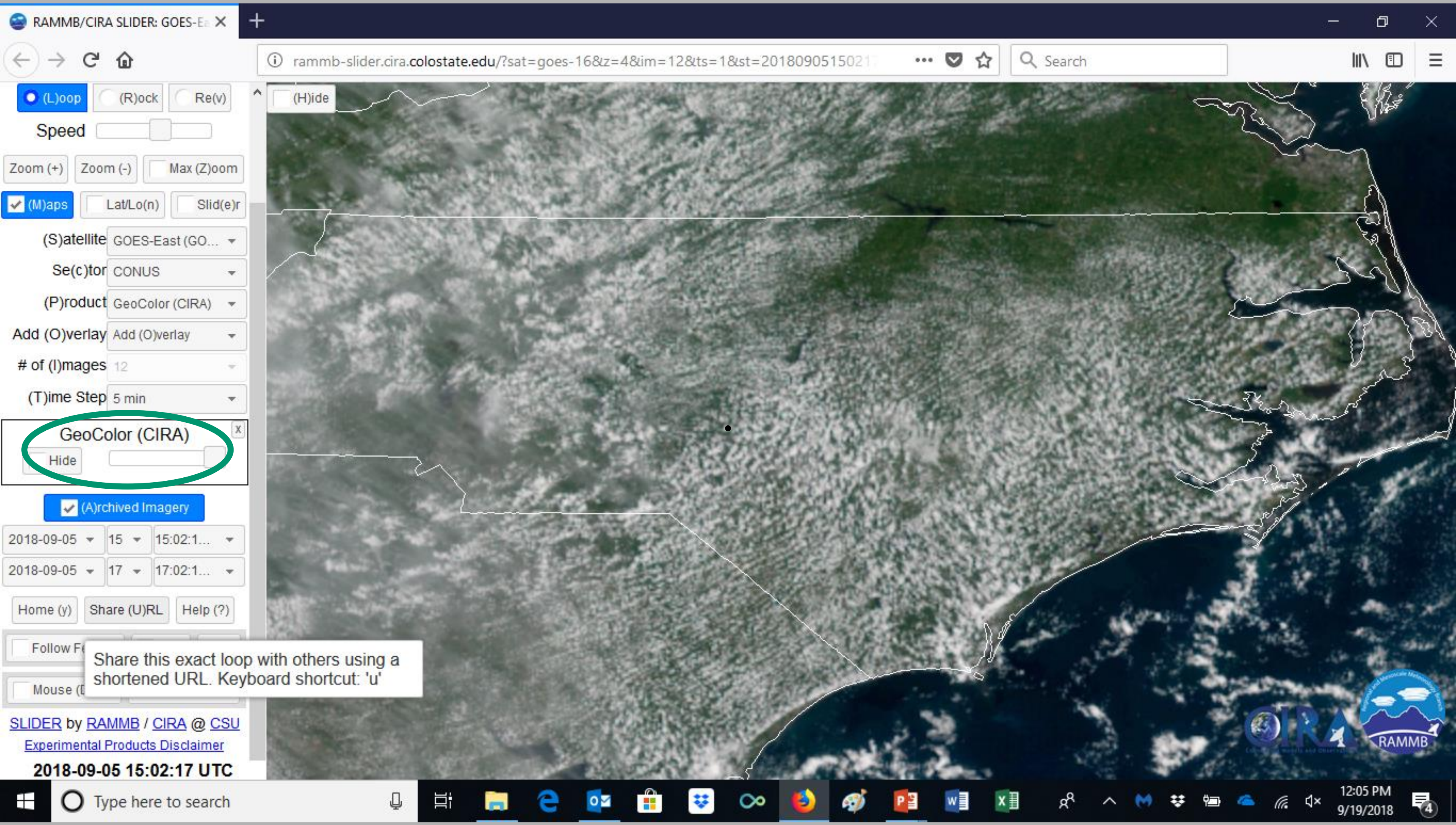
MSG 3 channel color image using HRV, 1.6 and 3.9 micron channel data

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.

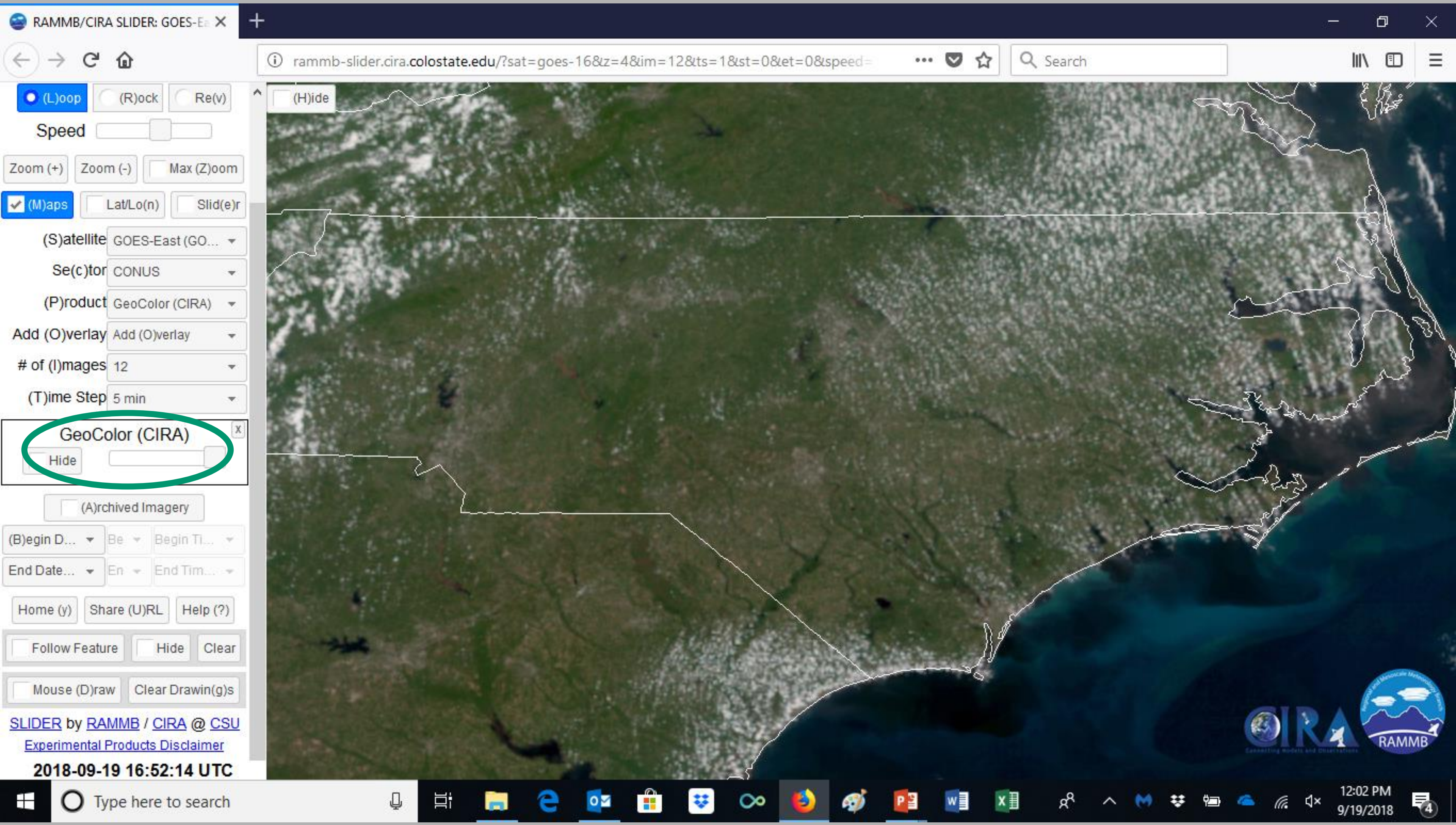
Image of hurricane Florence which produced massive flooding along the USA East Coast State of North Carolina



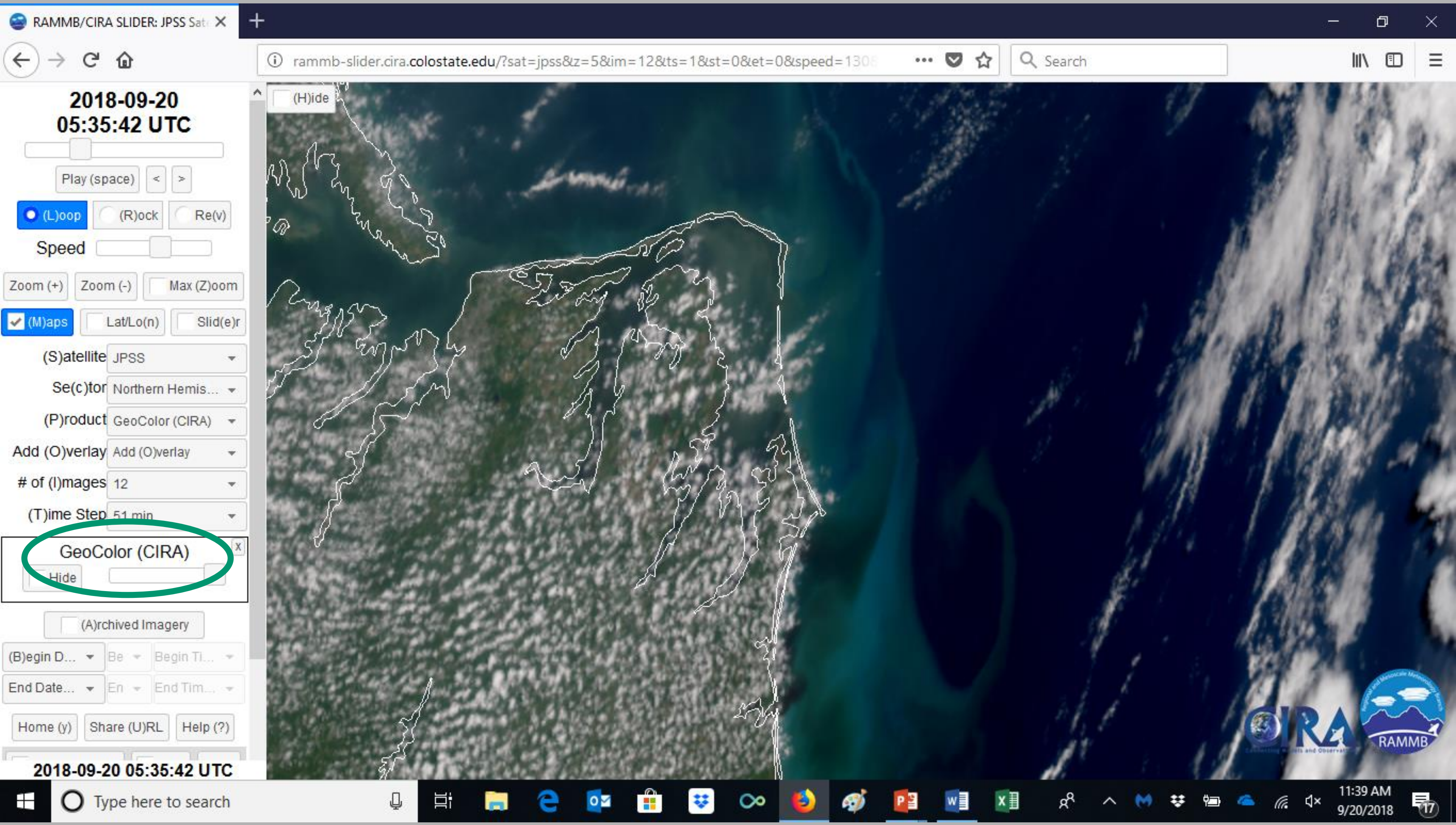
This is before Florence arrival. Note no ocean sediment.



This is after Florence arrival. Note ocean sediment.

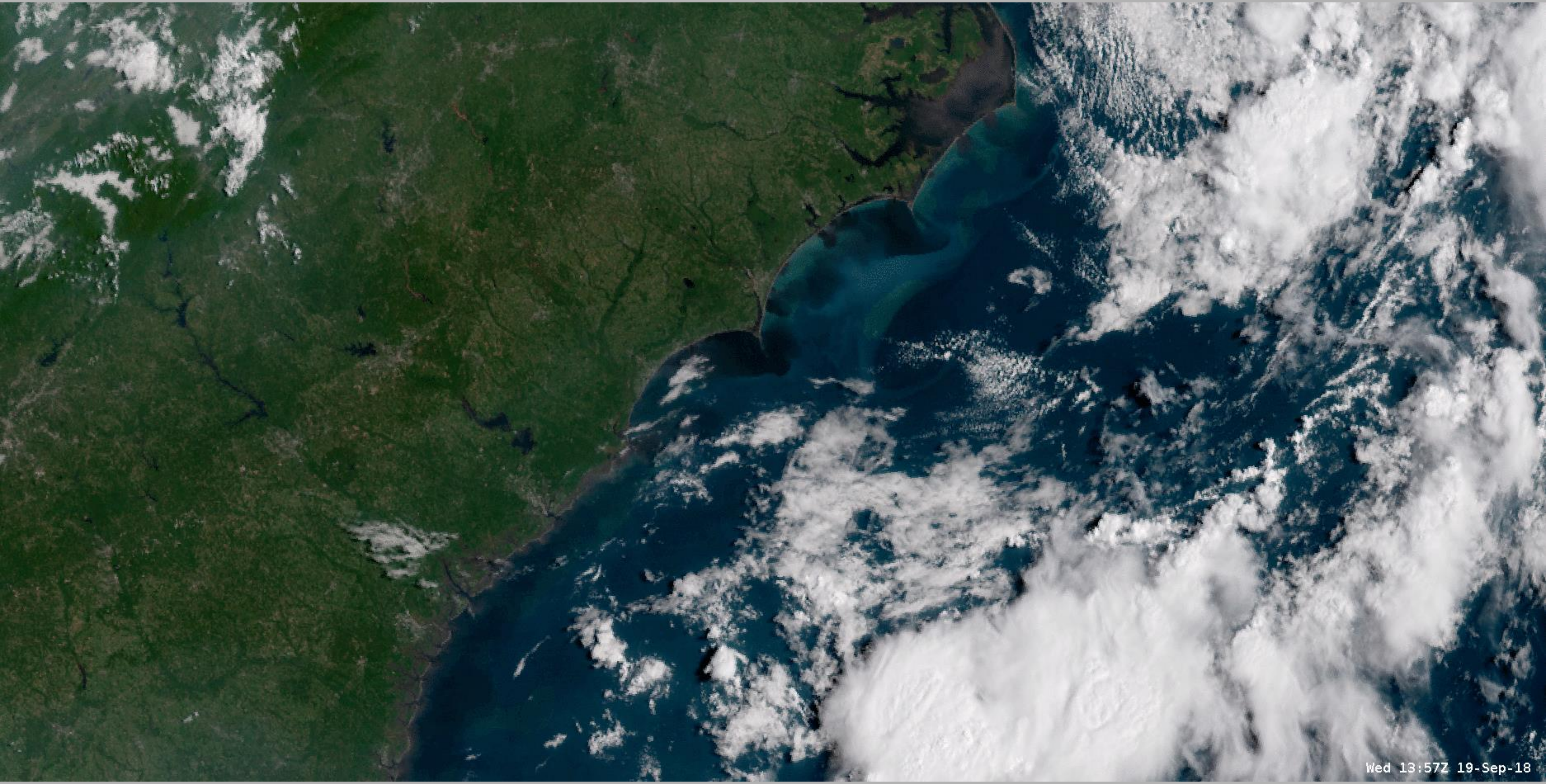


VIIRS composite image from 11:39 AM, September 19, 2018



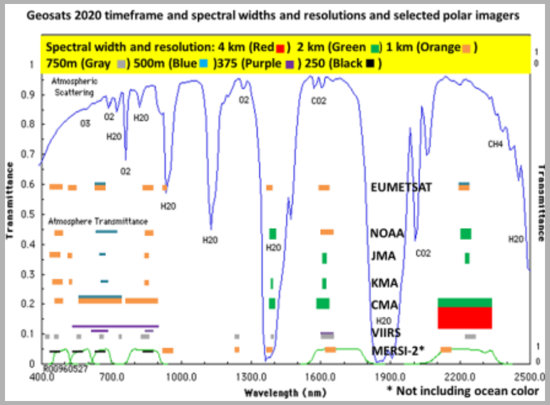
Ocean sediment very apparent.

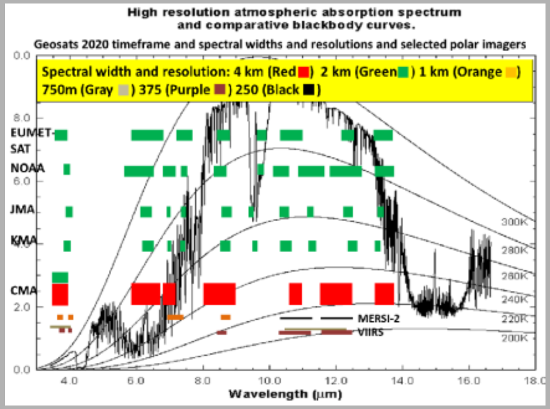
Animation of GOES-16 from September 19, 2018 using CIRA Geo-color product.



65,535 ways to “combine” 16 channels

- Single channel 16
- 2 channels per image 120
- 3 channels per image 560
- 4 channels per image 1820
- 5 channels per image 4368
- 6 channels per image 8008
- 7 channels per image 11440
- 8 channels per image 12870
- 9 channels per image 11440
- **********
- 15 channels per image 16
- 16 channels





A Glimpse to the Future

16 channel imagers offer the possibility of 65,535 ways to combine those channels (number includes using each independently). From Geostationary Orbit possibilities exist every 5 to 10 minutes with full disc imagery and at times over limited areas with imagery as frequently as one to two minutes (special events).

Numerous product areas, such as precipitation estimation, cloud motion vector derivation, feature tracking, severe storm identification and nowcasting will benefit from this new generation of geostationary satellite data, but only with a strong emphasis on advanced analysis methods, and in many cases in synergy with other types of satellite data

The Problem and a Solution

- **Multi-spectral (satellite) imagery has spectral bands that contain more <u>redundant</u> information, than <u>difference</u> information, about the scene being viewed**.
- It would be nice if each spectral band/image contained information <u>separate</u> from the other spectral bands/images. But this is <u>not</u> the case in the real world.
- There is a transformation technique for multi-spectral imagery that can separate the variables and help interpret the imagery.

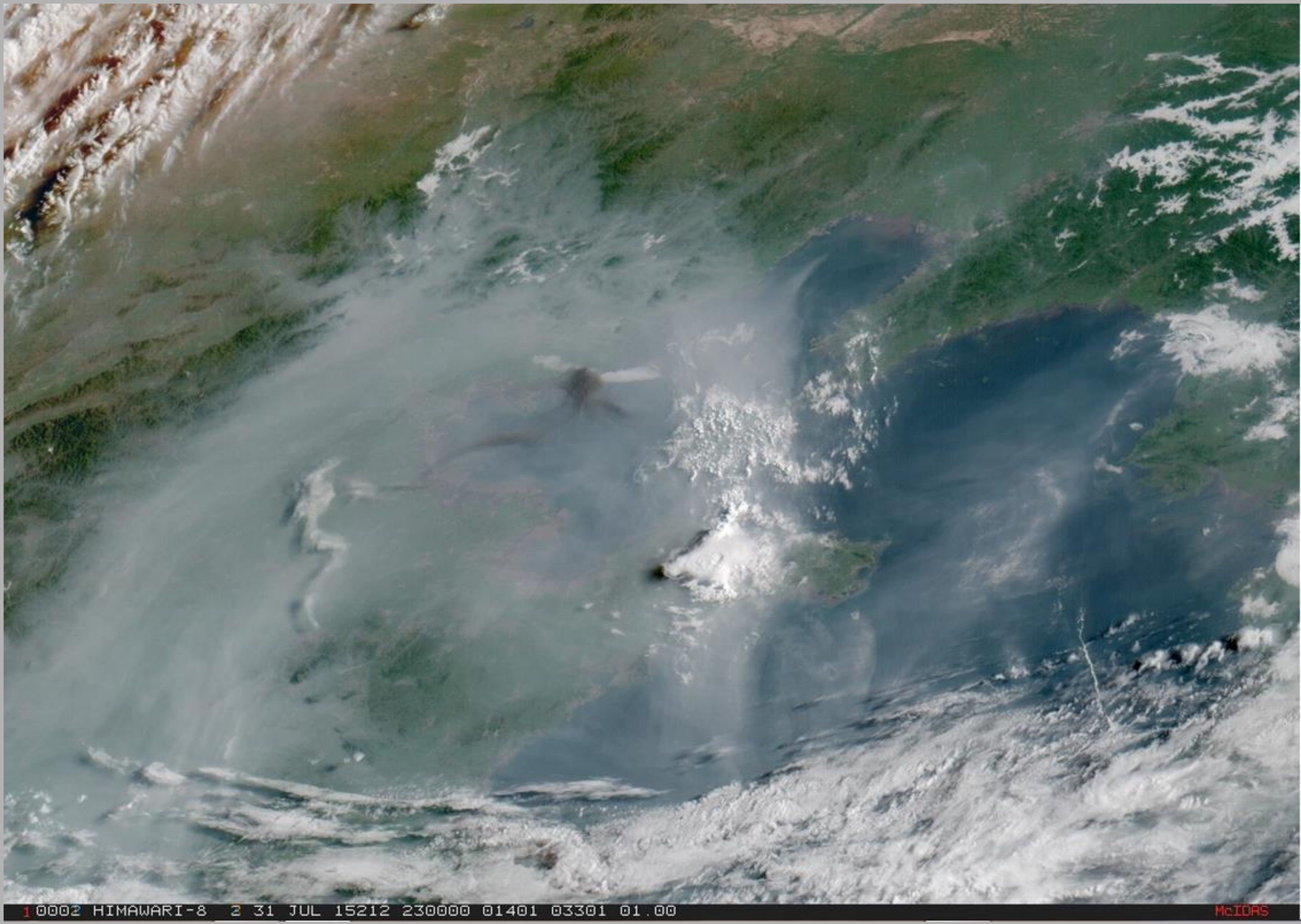
Features of
Principal Component Imagery (PCI)

(this work based on research of Don Hillger, RAMM team, NOAA/NESDIS, CIRA, Colorado State University)

- Puts common/redundant information into first PCIs
- Puts difference information into higher-ordered PCIs.
- Reduces the number of independent variables to a minimum.
- Can reduce noise by relegating noise to highest-order PCIs.

We’ll analyze this case with VIIRS imagery.

We’ll look at a Himawari example after this.

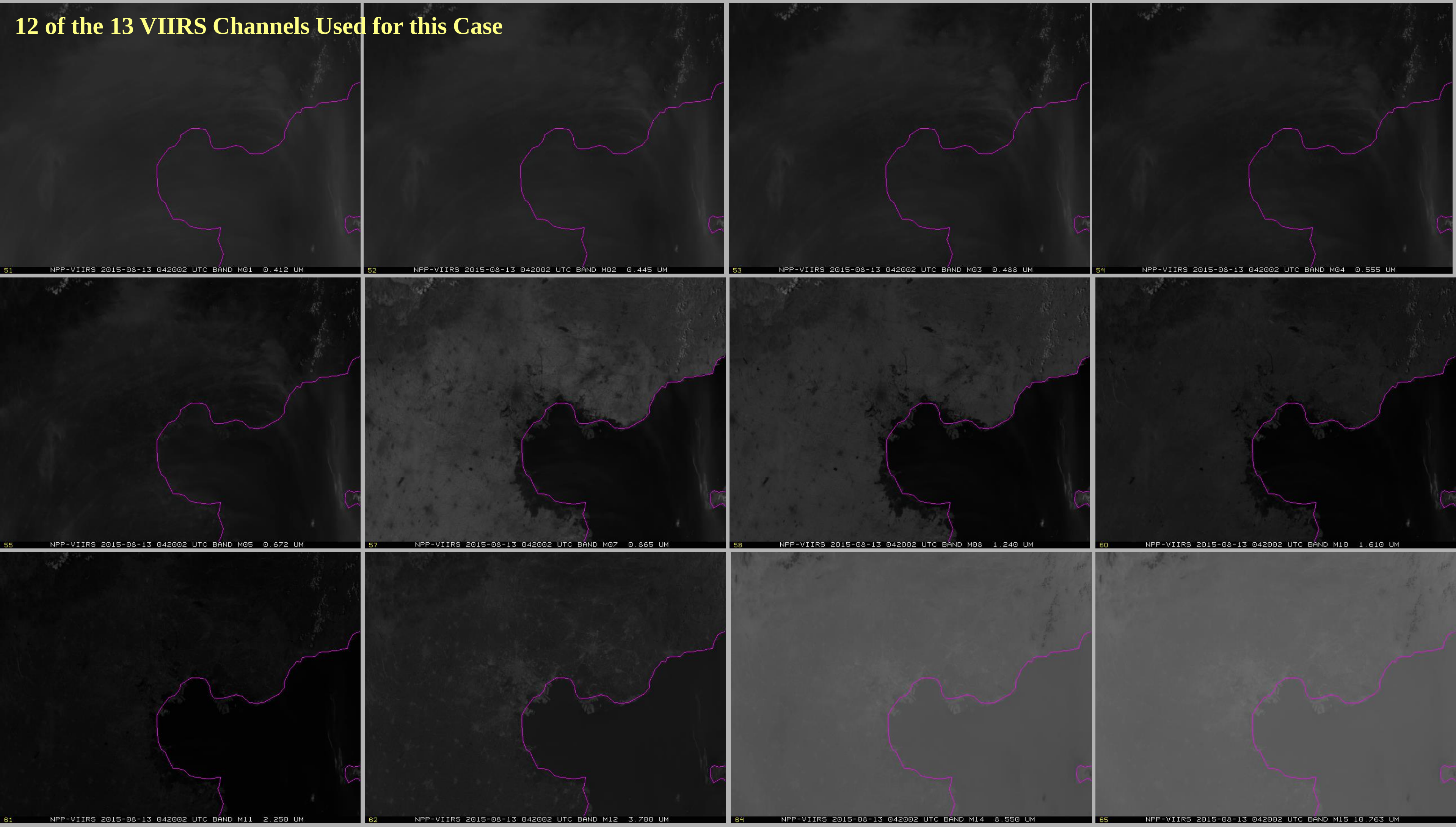


True color image over Bohai Bay, Tianjin, Beijing and North East China – n

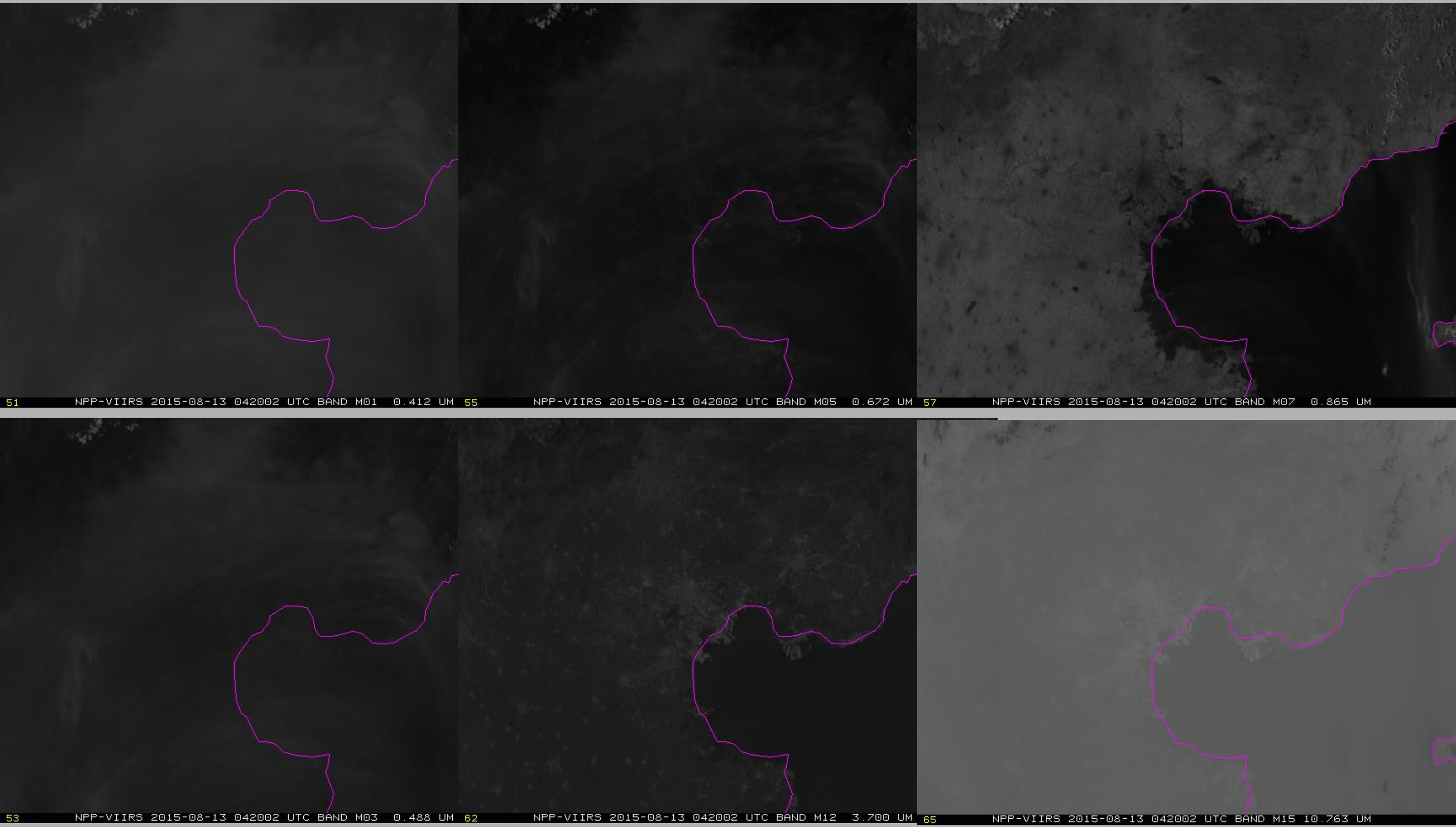
13 VIIRS Channels Used in 12 August 2015 Tianjin Analysis

VIIRS Band	McIDAS Band	Central Wavelength	
6	M01	0.412 um	
7	M02	0.445 um	
8	M03	0.488 um	
9	M04	0.555 um	
10	M05	0.672 um	
~~11~~	~~M06~~	~~0.746 um~~	not used bad striping
12	M07	0.865 um	
13	M08	1.240 um	
~~14~~	~~M09~~	~~1.378 um~~	not used very noisy
15	M10	1.610 um	
16	M11	2.250 um	
17	M12	3.700 um	
~~18~~	~~M13~~	~~4.050 um~~	not used no data
19	M14	8.550 um	
20	M15	10.763 um	
21	M16	12.013 um	

12 of the 13 VIIRS Channels Used for this Case



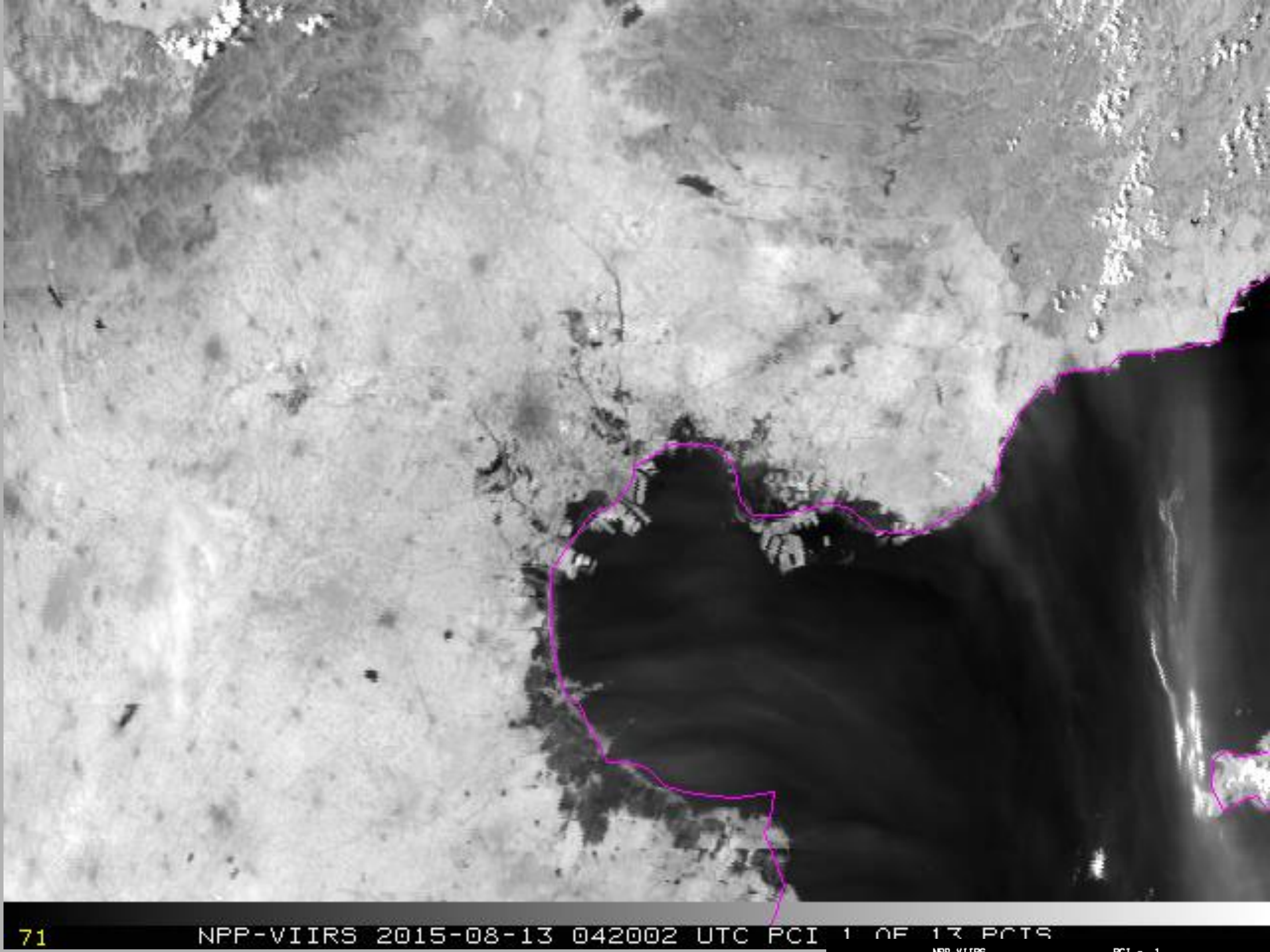
Closer View of 6 of the 13 VIIRS Channels Used for this Case: illustrates scattering at shorter wavelengths and some properties of 0.67 vs 0.86 (water and vegetation and scattering) and of 3.7 vs 10.7 (distinct heat islands)

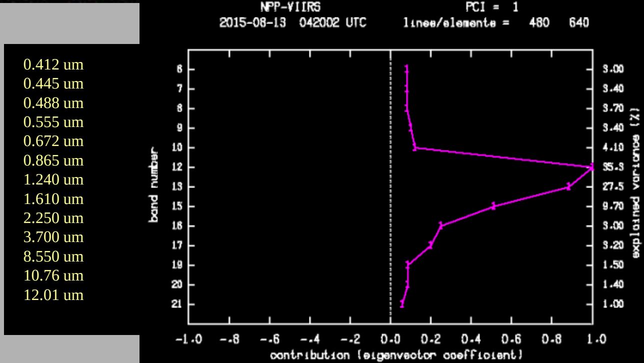


First Principal Component Image from the 13 Channels of VIIRS imagery.

Common and redundant information into lower order PCIs

Note land and water darkness dominate

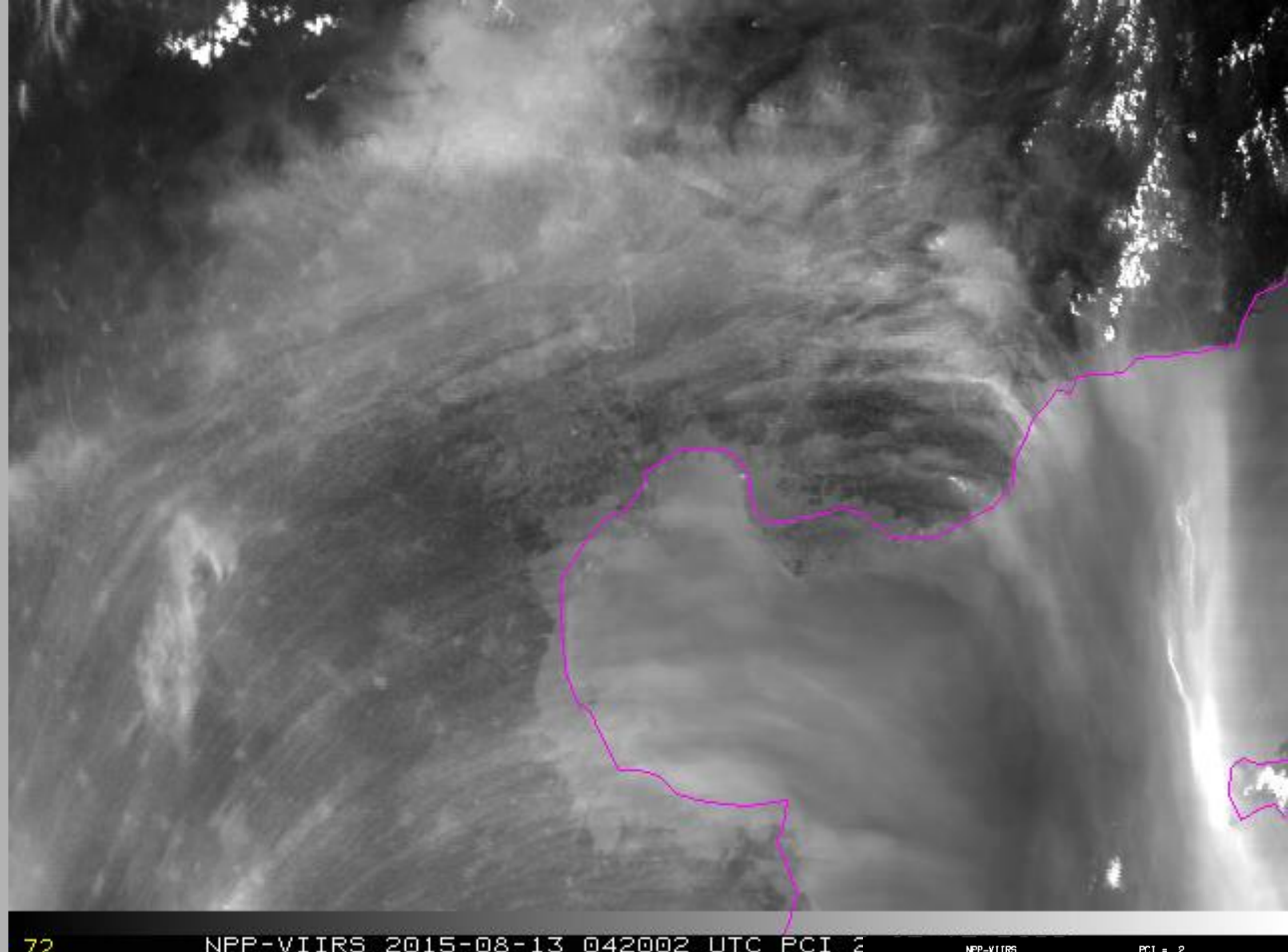


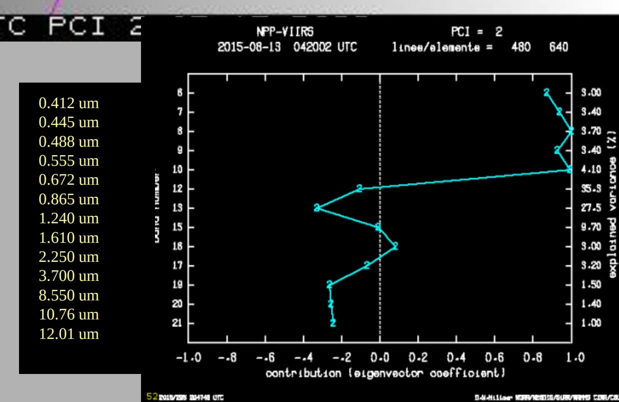


Second Principal Component Image from the 13 Channels of VIIRS imagery.

Common and redundant information into lower order PCIs

Note haze and cloud features dominate

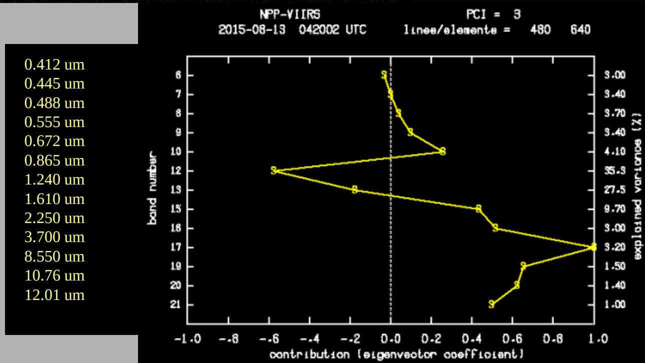




Third Principal Component Image from the 13 Channels of VIIRS imagery.

Common and redundant information into lower order PCIs

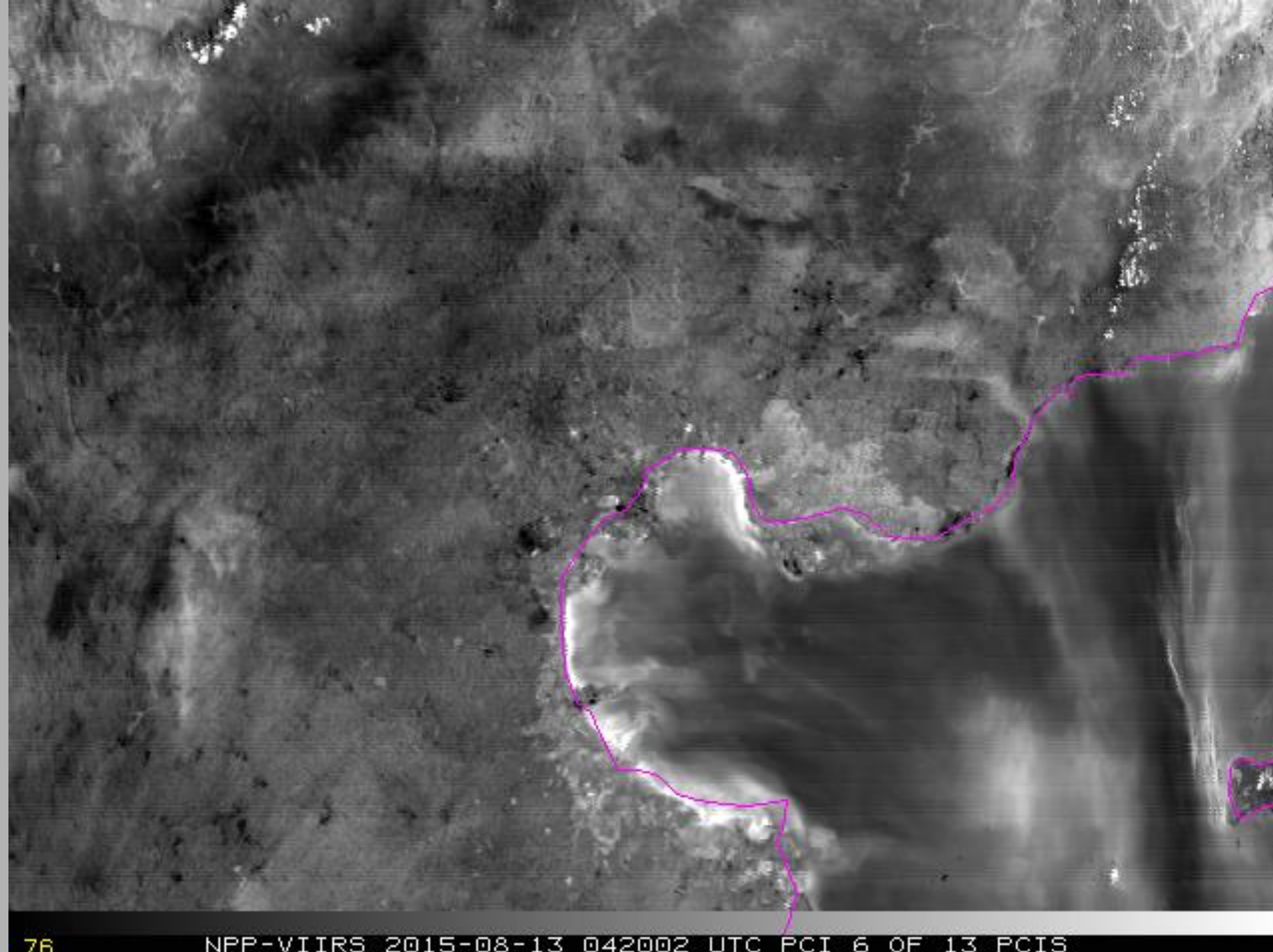
Note contribution from 0.86 and IR, particularly 3.7

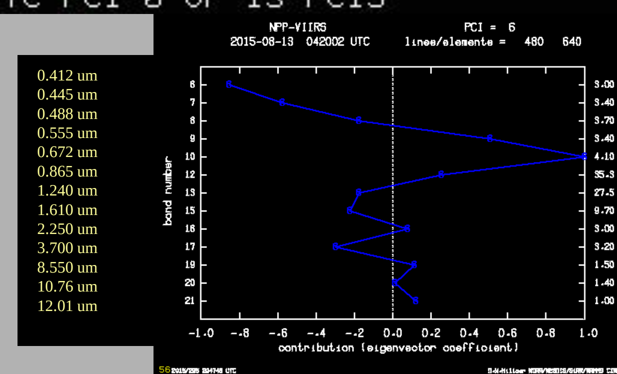


Sixth Principal Component Image from the 13 Channels of VIIRS imagery.

Common and redundant information into lower order PCIs, difference information into higher order PCIs

Note the coastal waters

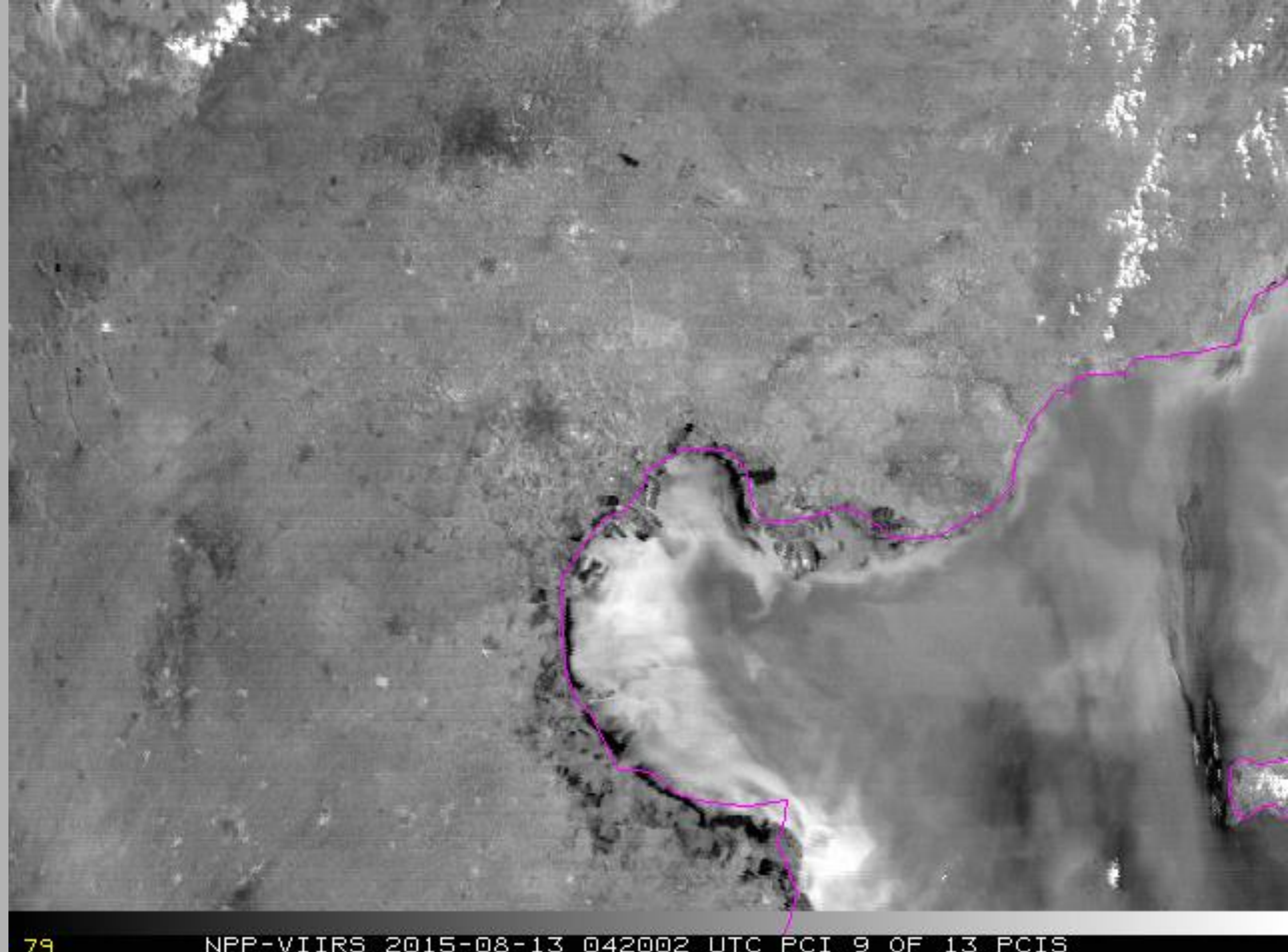


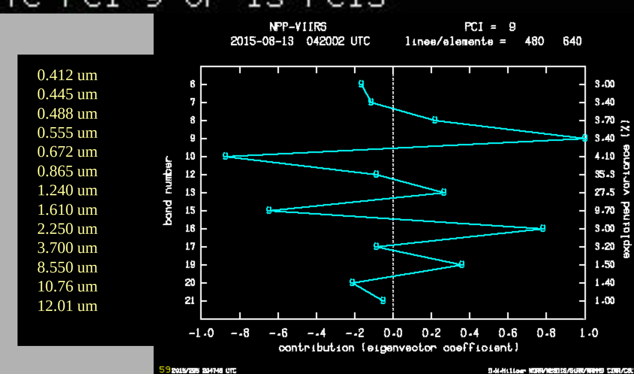


Ninth Principal Component Image from the 13 Channels of VIIRS imagery.

Difference information into higher order PCIs

Note the coastal waters

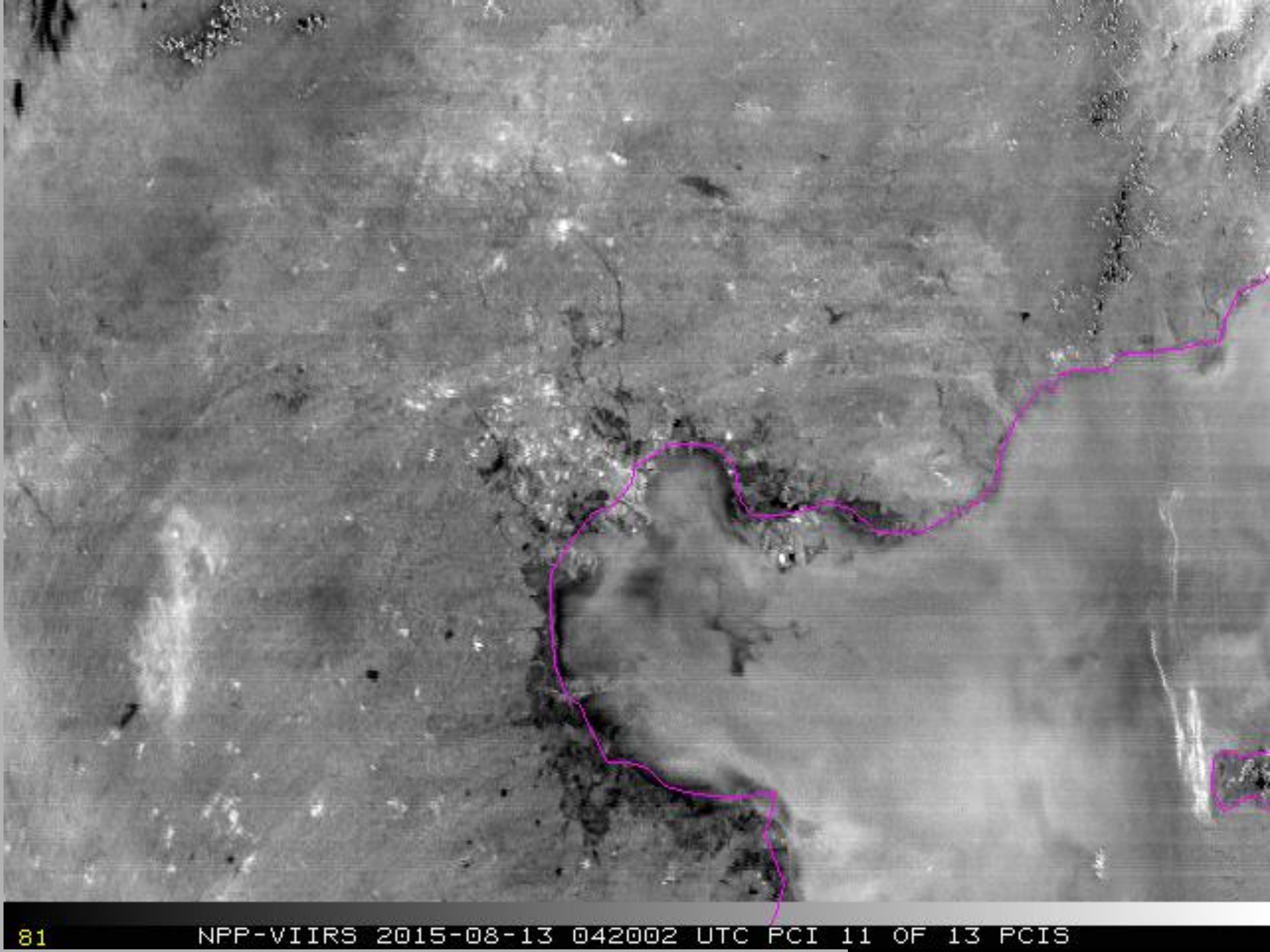


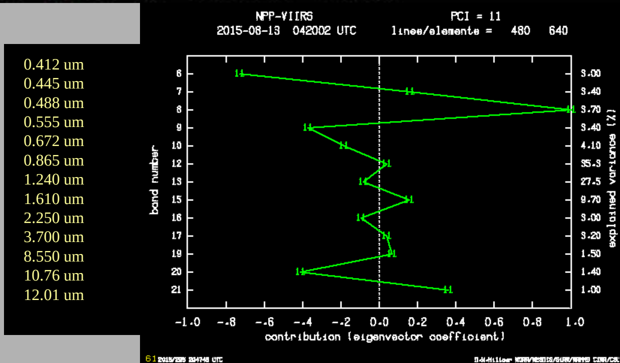


Eleventh Principal Component Image from the 13 Channels of VIIRS imagery.

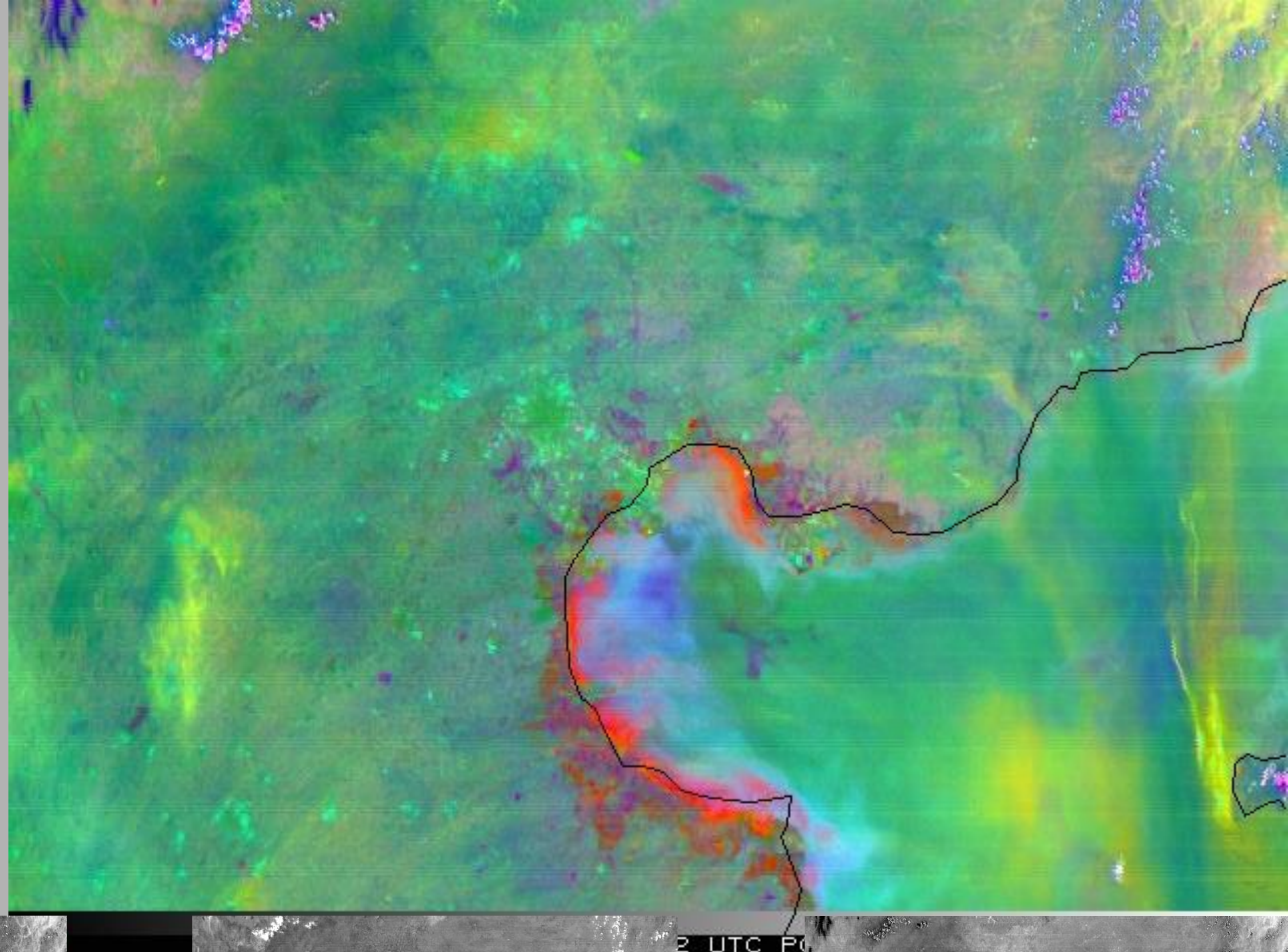
Common and redundant information into lower order PCIs, difference information into higher order PCIs

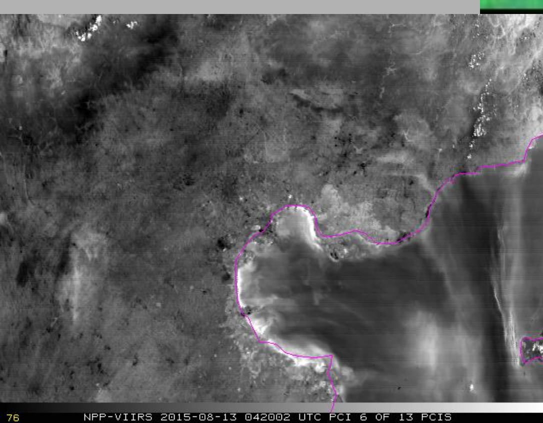
Note the near coastal region

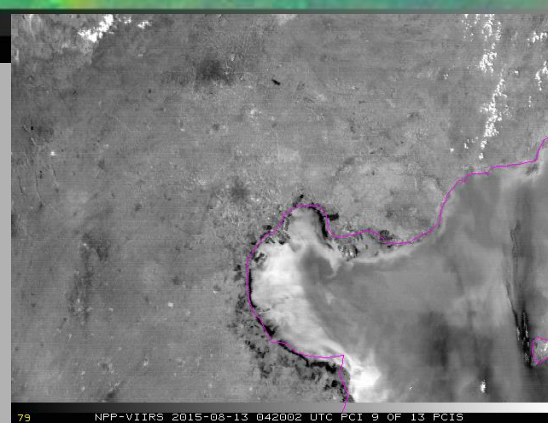


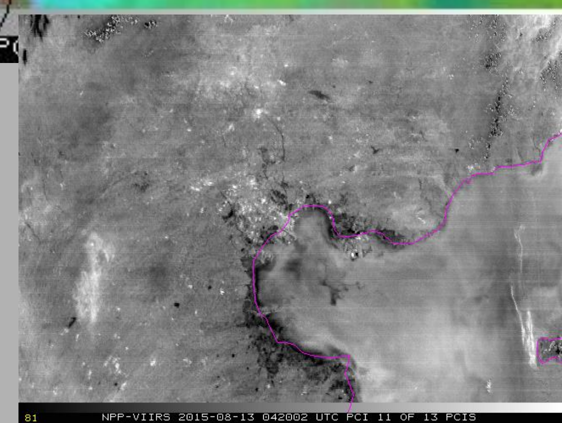


RGB image made from PCI’s 6 (lower left), 9 (lower center) 11 (bottom right) made to emphasize coastal land and water areas



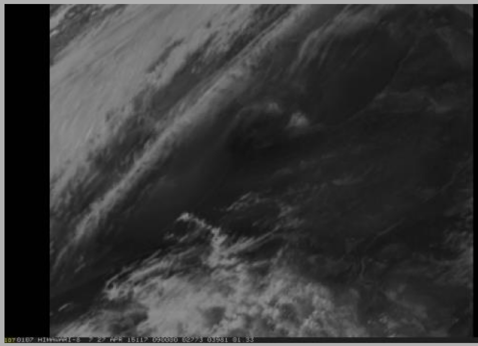




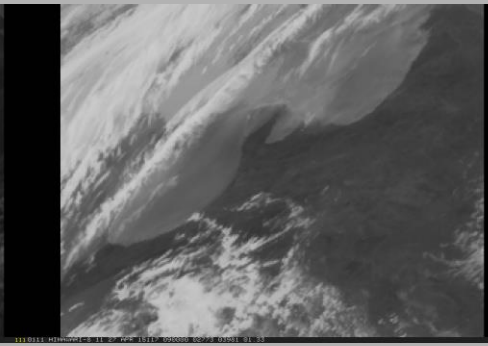


Dust storm observed by Himawari-8 at 10 minute intervals;

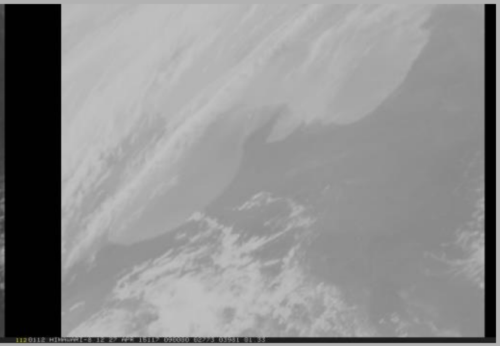
Himawari - 8



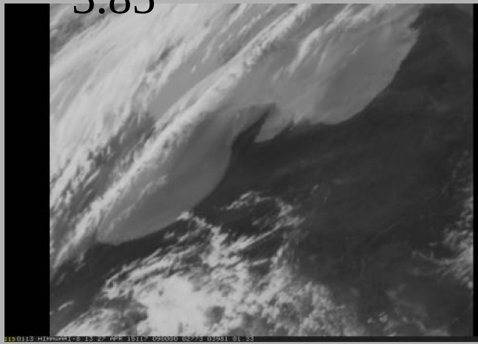
3.85



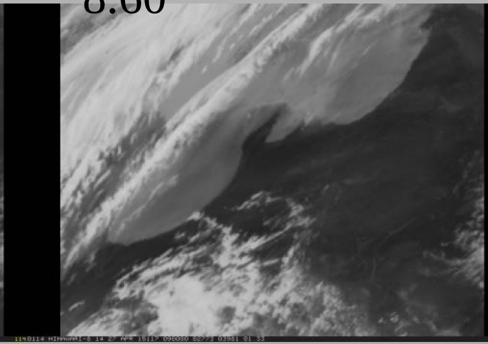
8.60



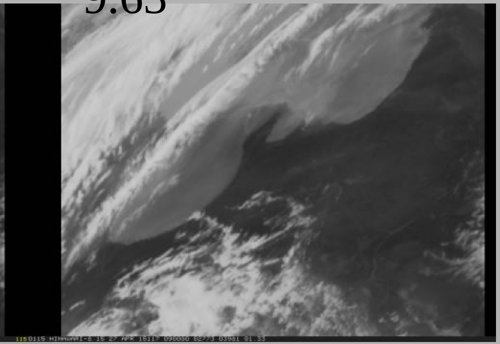
9.63



10.45

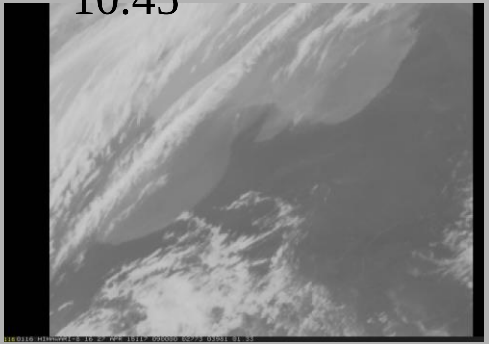


11.2

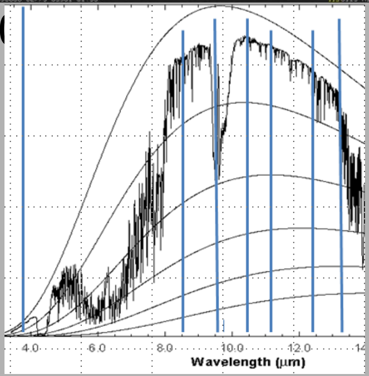


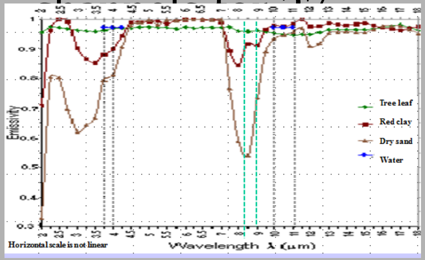
12.35

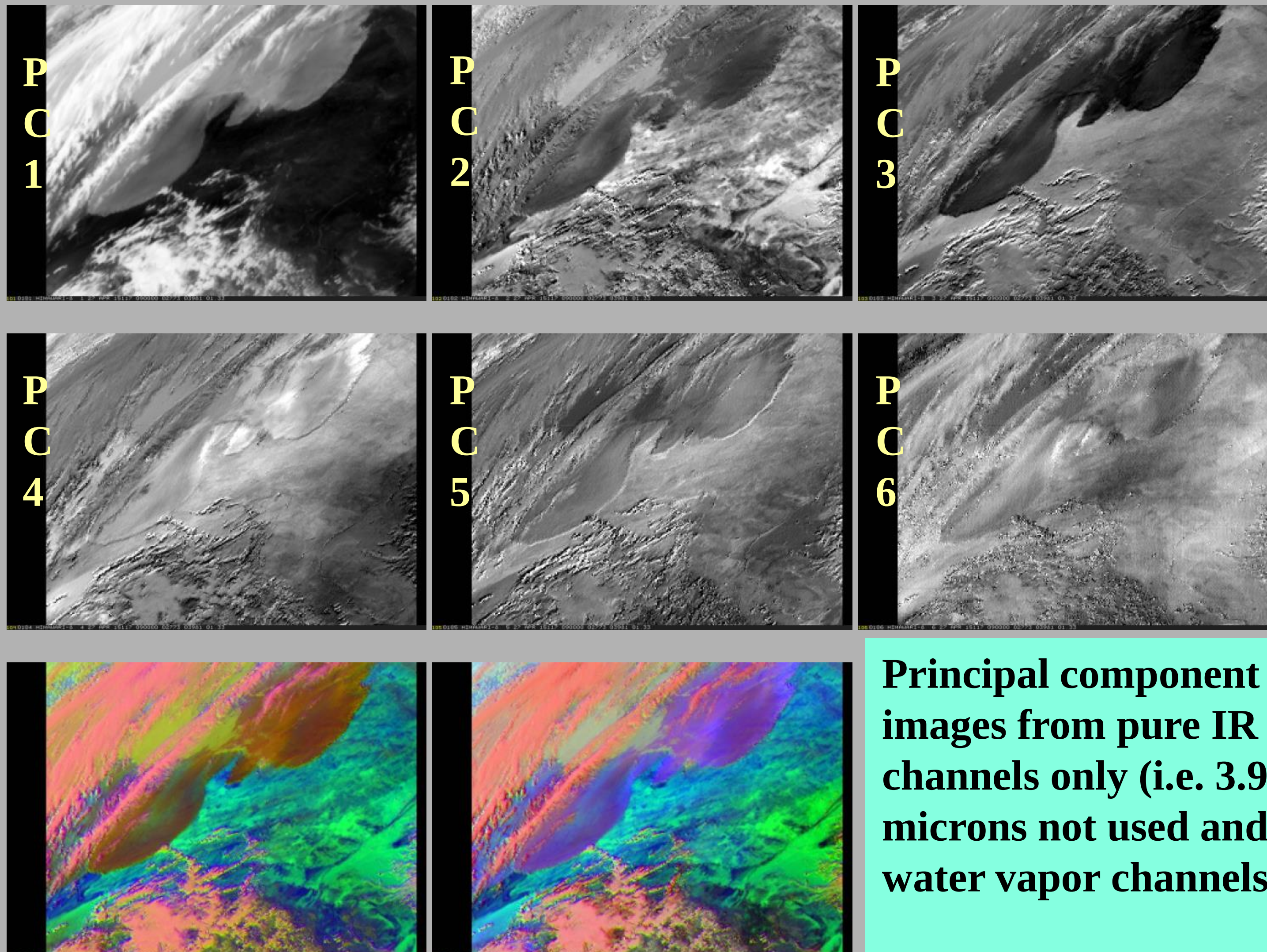
Himawari IR



13.30

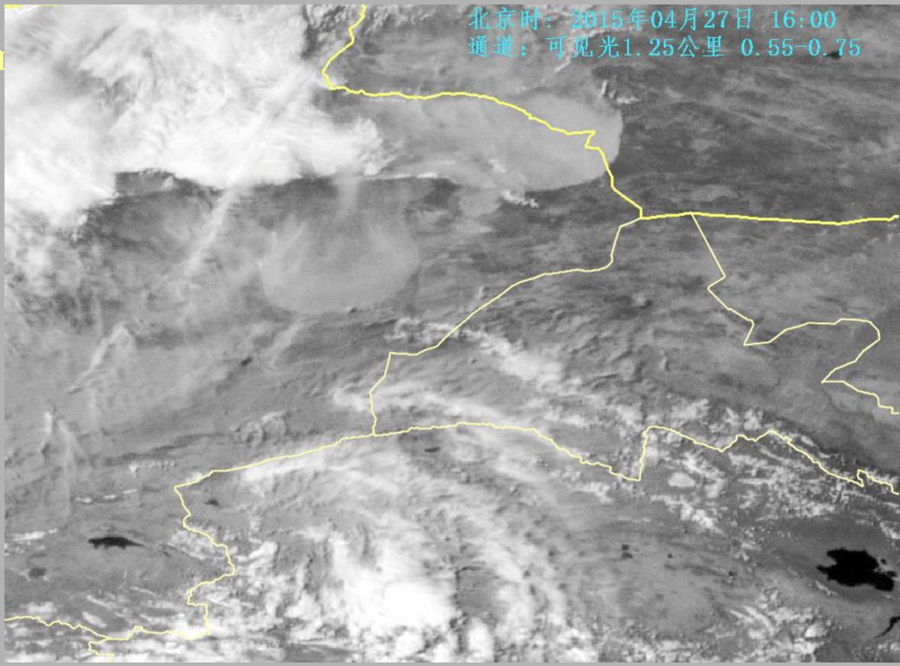






Principal component (PC) images from pure IR channels only (i.e. 3.9 microns not used and no water vapor channels).

Upper left to lower right: PC images 1-6 and RGB of PC 1,2,3 then PC 1,2,4

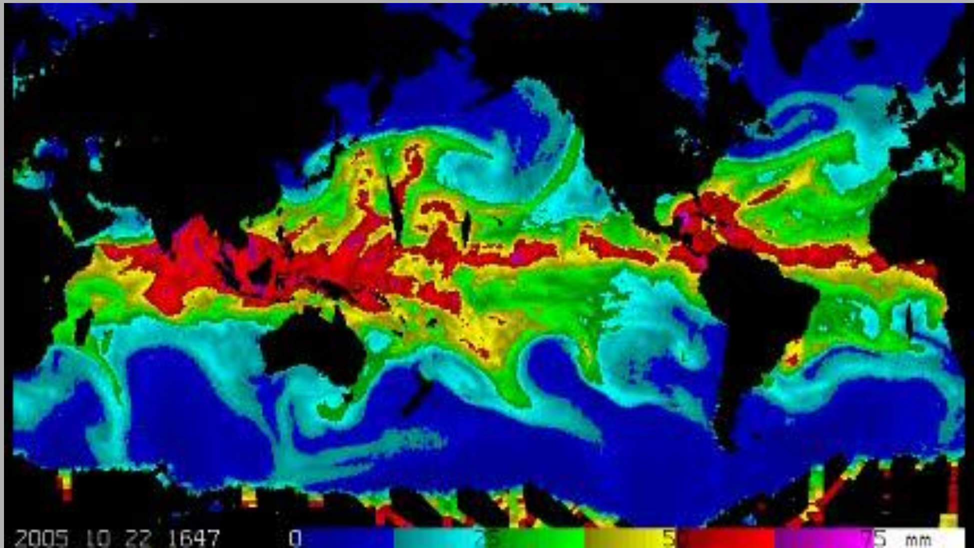


Animations of the dust case just presented, but from two different viewing perspectives, with Himawari-8 imagery at 10 minute intervals on the left and FY-4 with three minute intervals on the right. While the animations overlap in time, they do not cover the same time period (himawari-8 covers a longer time period). The image sizes also differ, with FY-4 covering a larger area than Himawari-8.

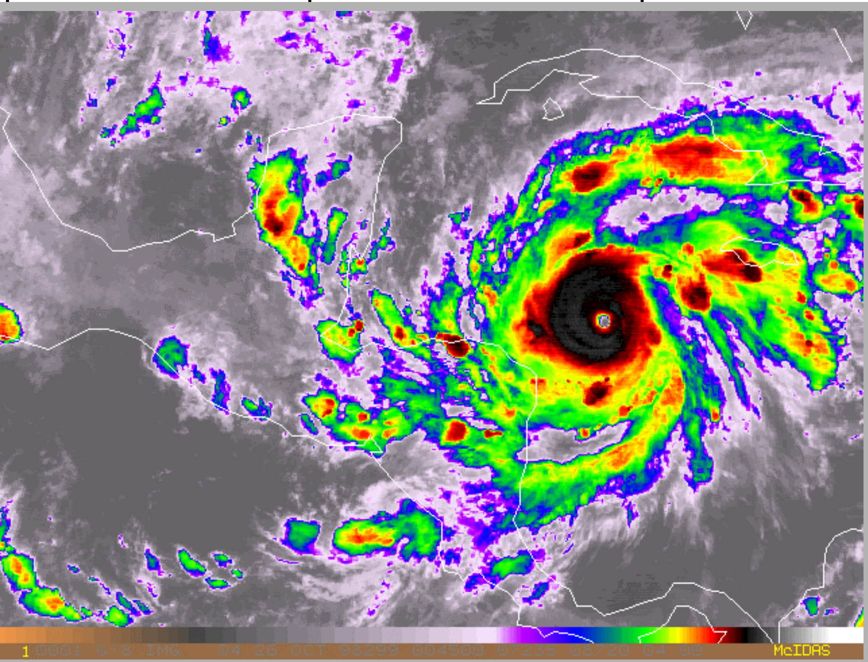
Meteorlogical Parameters
(Summary of Key Interactions and Potential Uses)

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

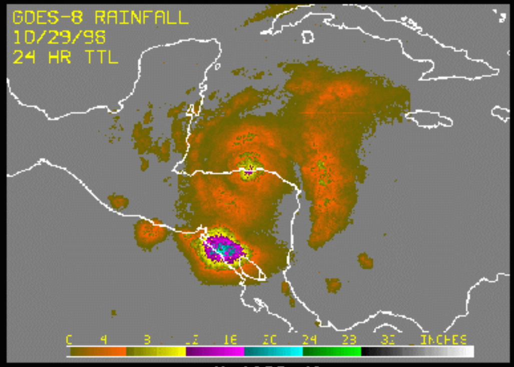
Clicking on the total precipitable water (tpw) movie will start or stop animation. Notice how well the tpw product depicts the ITCZ as well as shows the interaction between tropical and mid-latitude systems.



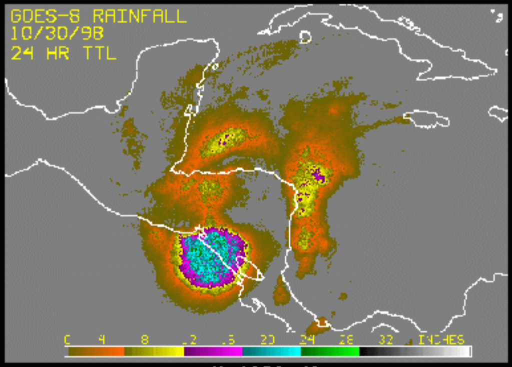
Precipitation – Cloud Water and Ice (Key Interactions and Potential Uses)			
Frequencies		**Microwave Processes**	**Potential Uses**
AMSU	**SSM/I**		
31 GHZ 50 GHz 89 GHz	19 GHZ 37 GHz 85 GHz	• Absorption and emission by cloud water: o Large drops/high water content o Medium drops/moderate water content 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



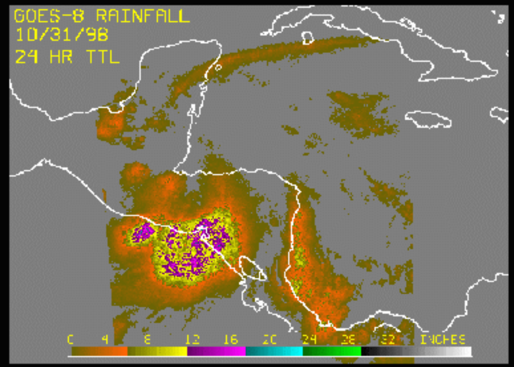
Click to stop animate



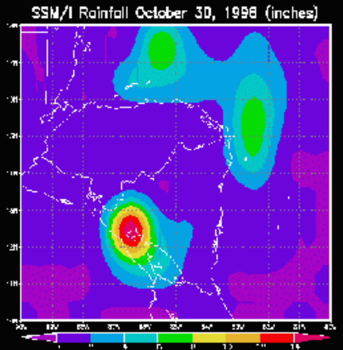
mitc1029.gif



mitc1030.gif

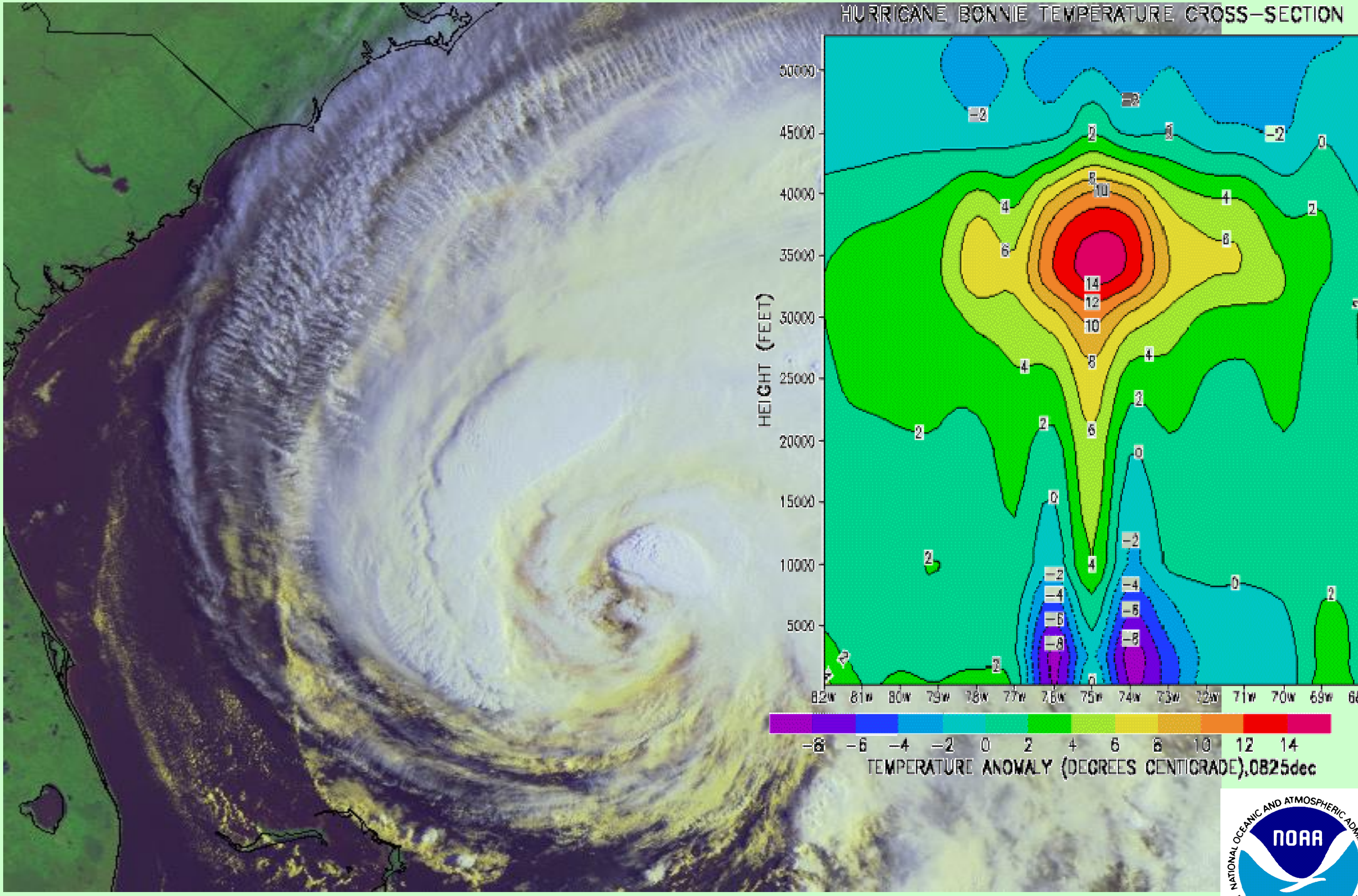


mitc1031.gif

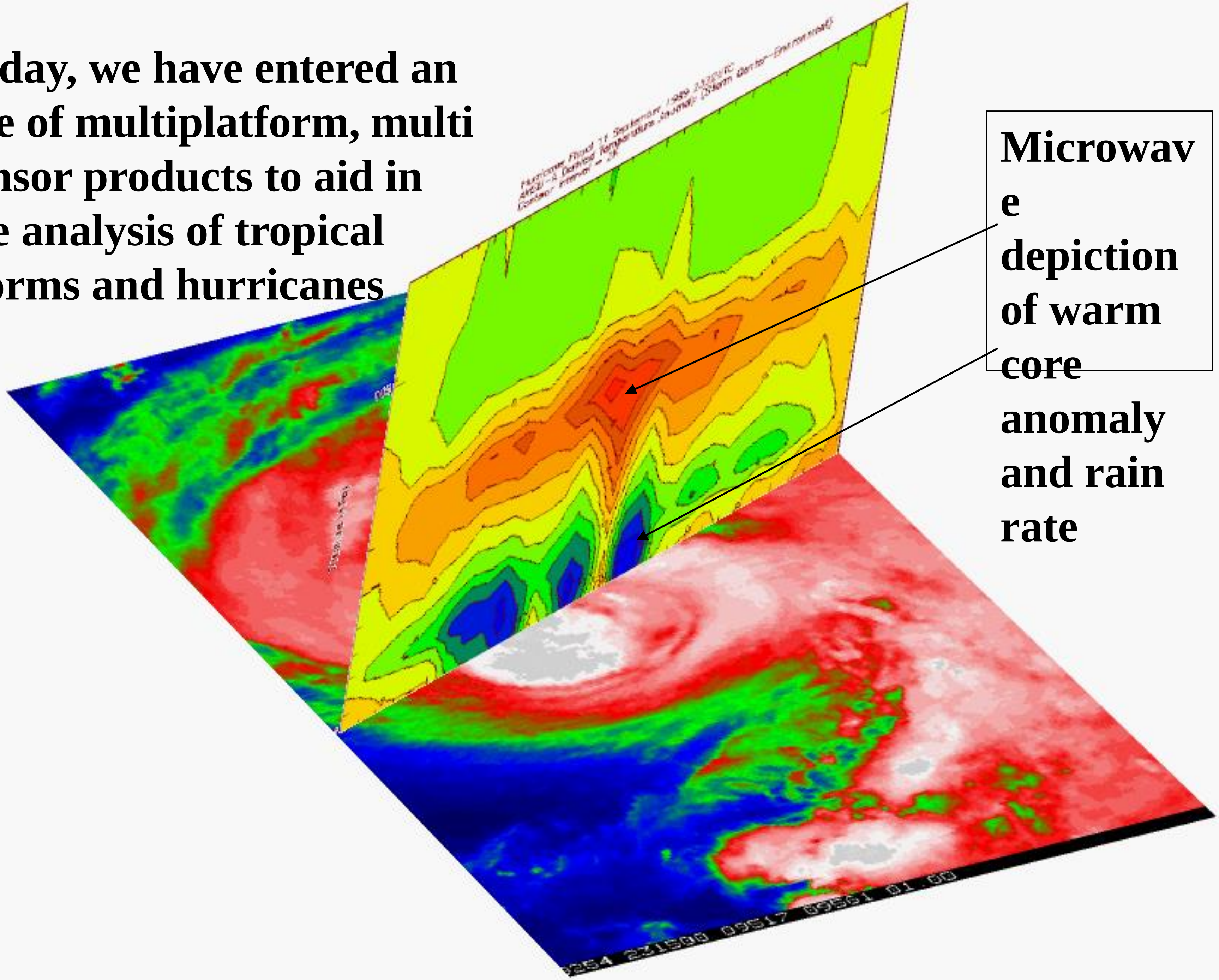


mitch3.gif

Hurricane Bonnie’s warm core revealed in temperature anomaly cross section derived using NOAA-15 Advanced Microwave Sounding Unit (AMSU) data

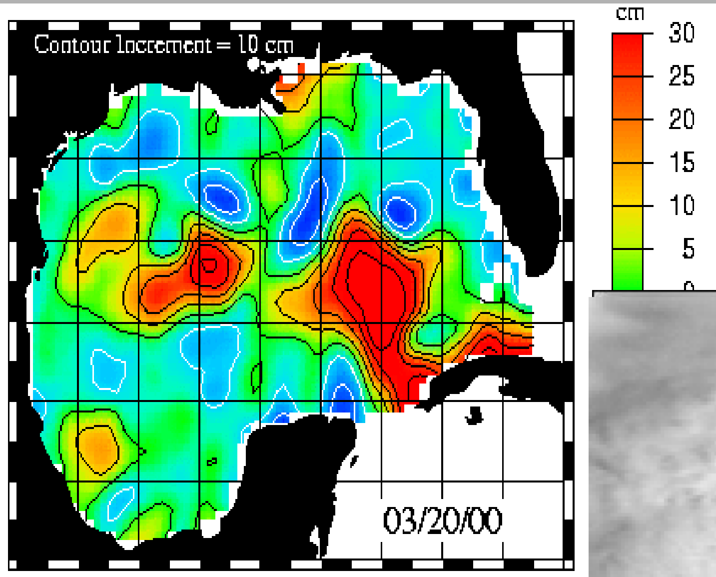


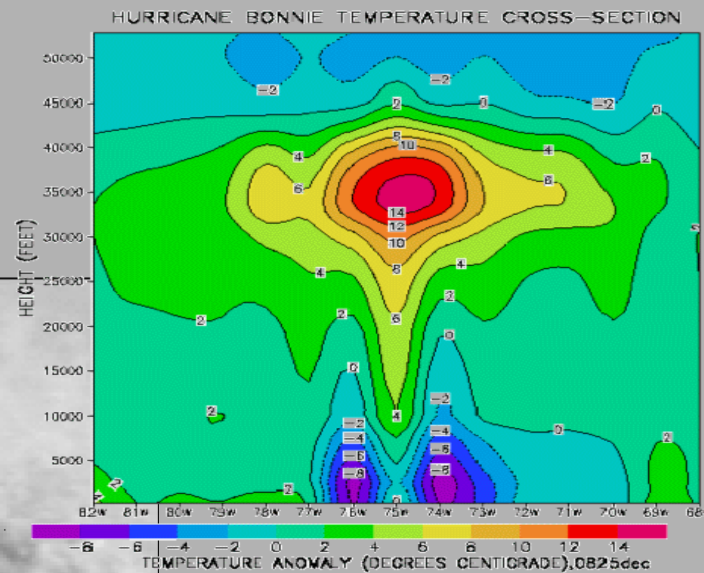
Today, we have entered an age of multiplatform, multi sensor products to aid in the analysis of tropical storms and hurricanes

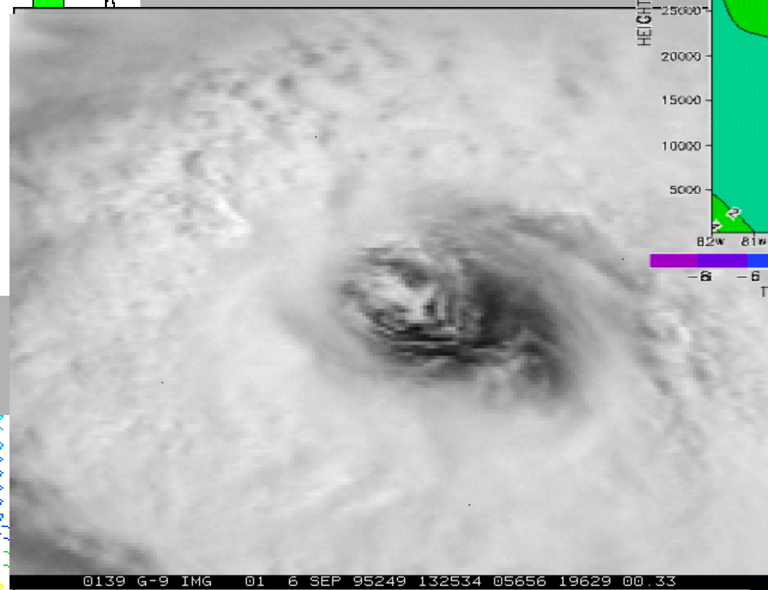


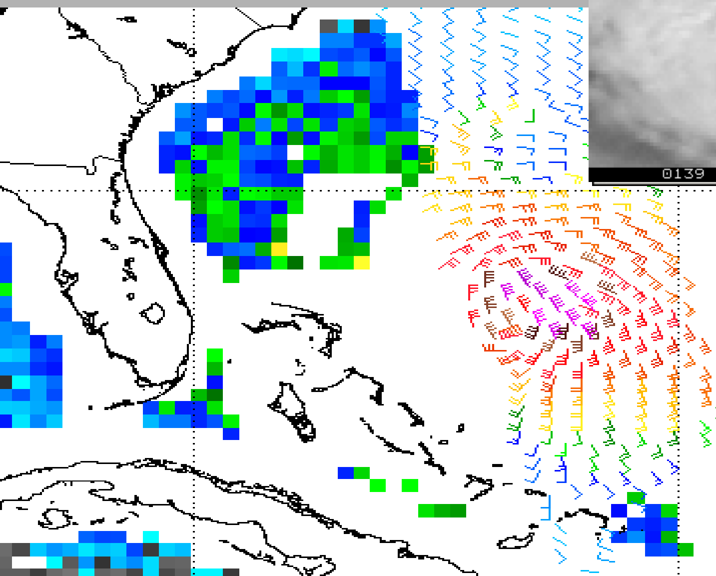
Microwave depiction of warm core anomaly and rain rate

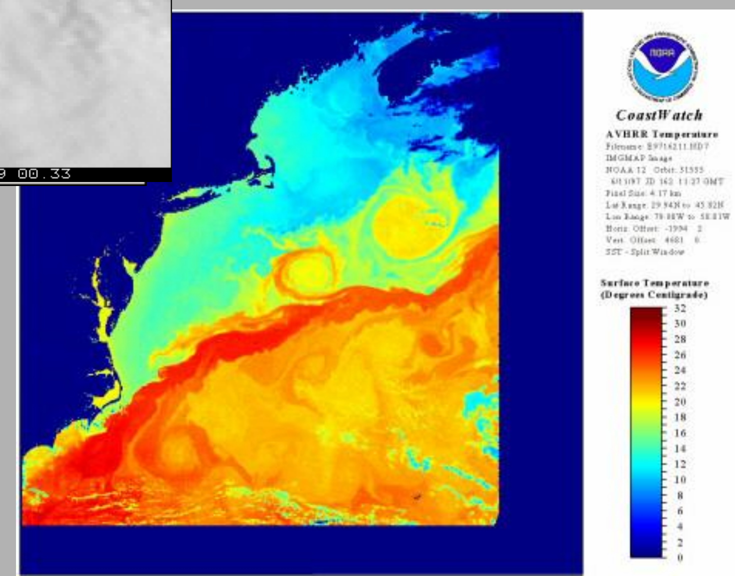
Winds, SST, Microwave anomaly and Altimetry
GOES Rapid Scan







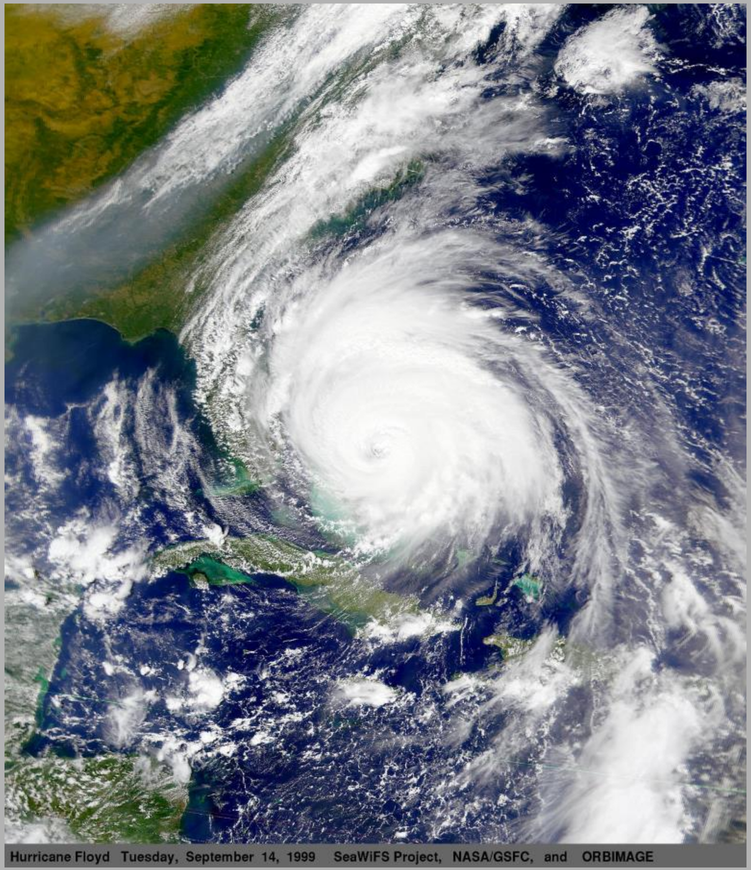


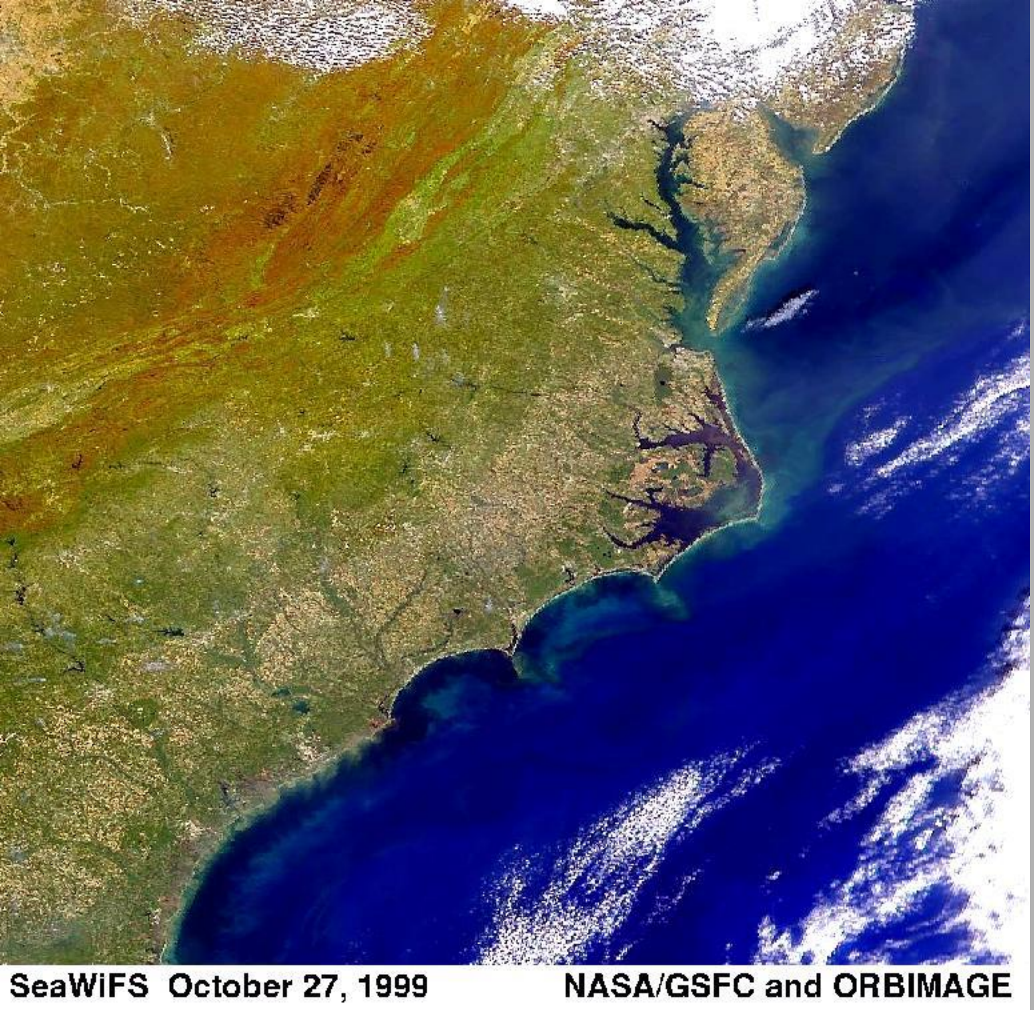


Then along came Floyd

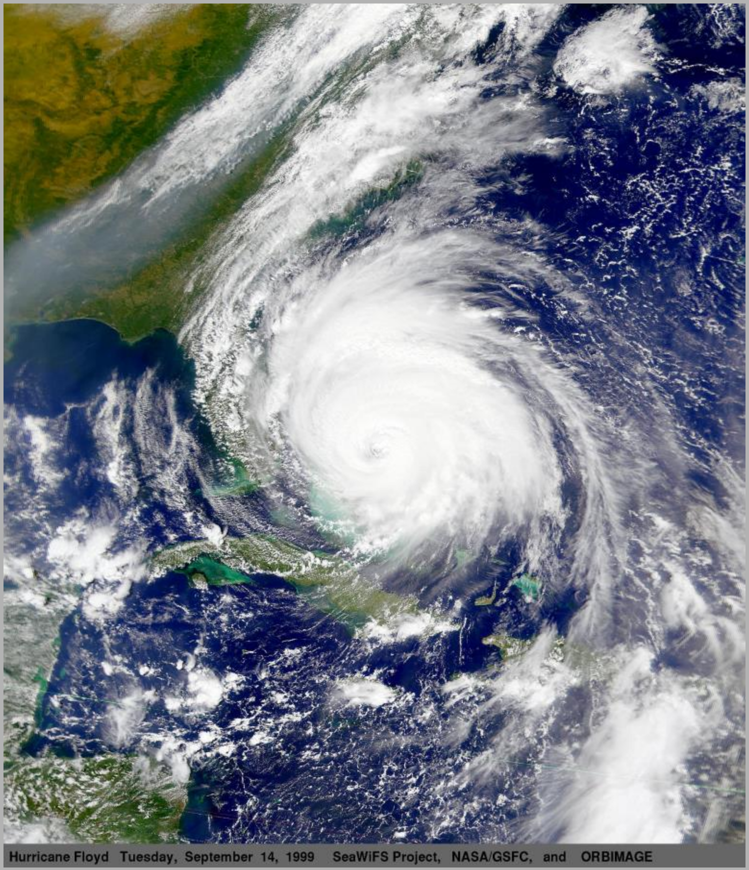
It will be important to monitor such disasters at very high resolution to follow ocean pollution

Ocean color showing result of flooding interacting with pig farms. You want to be able to make daily cloud free images of this consequence of a natural disaster immediately and blend with SST, ocean currents and other information.





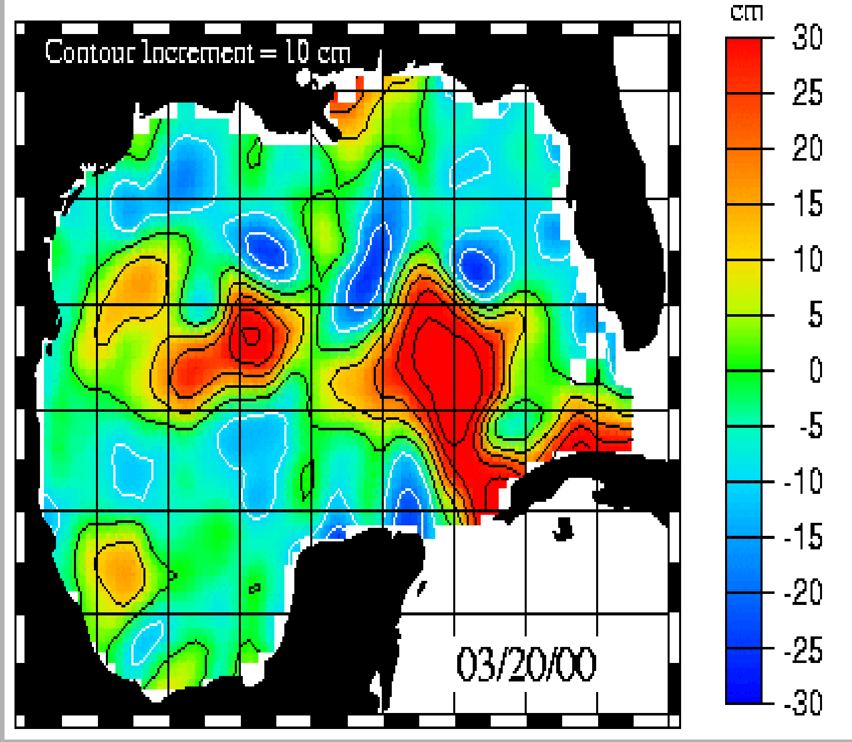
One month later the ocean water is much clearer



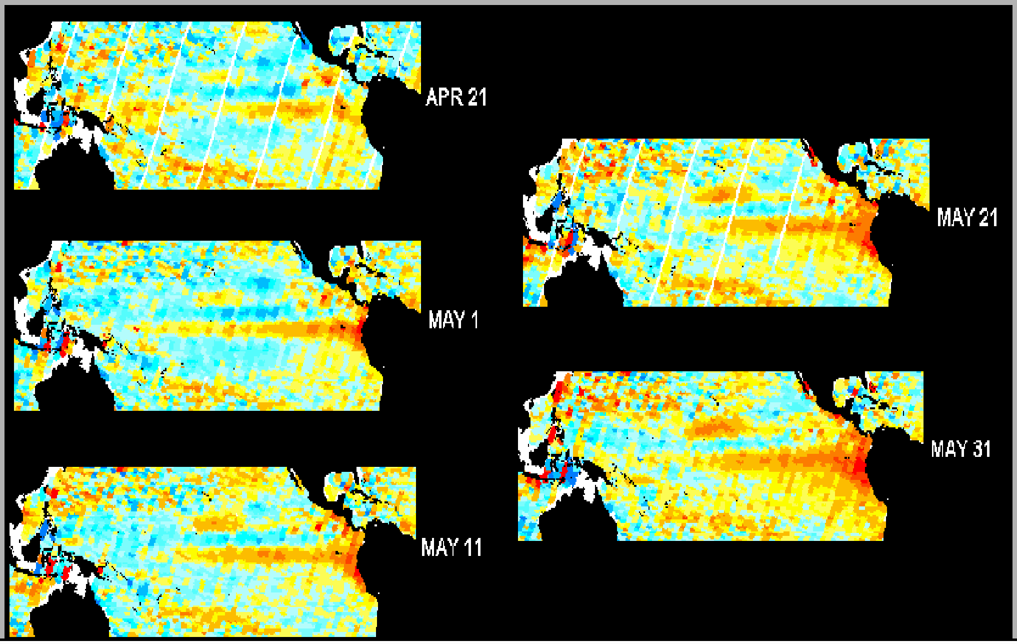
Active sensors

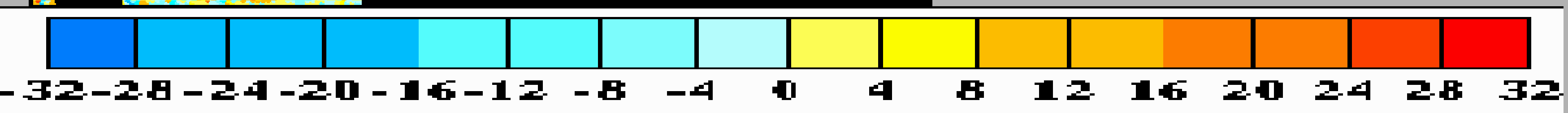
- Active sensors from research satellites are used to measure various sea surface properties (altimetry, wind speed and direction, ice field characteristics as well as ice berg tracking). The are also used to measure rainfall over water or land. Many of those products are available for use by NMHS'.

Altimetry

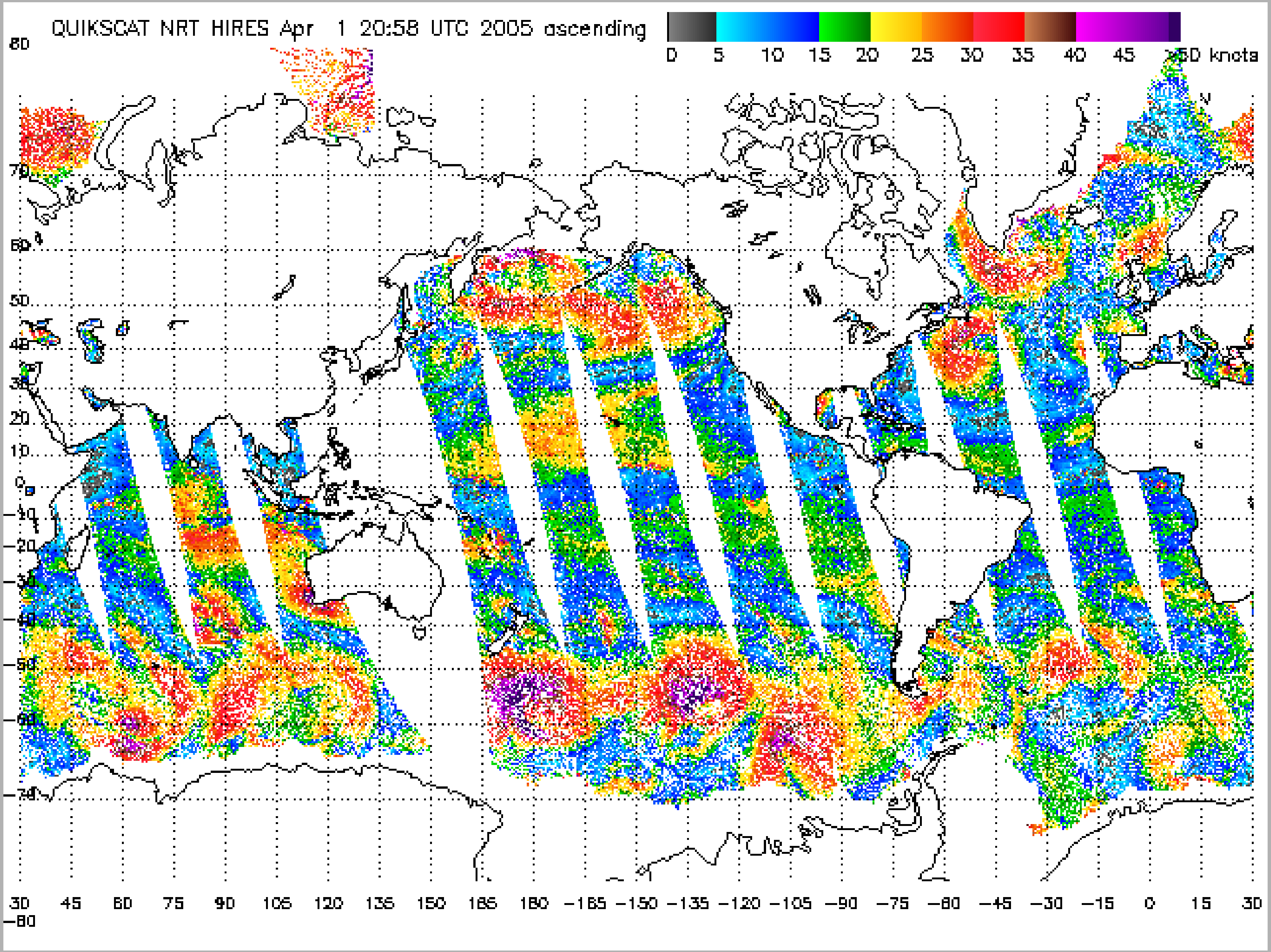


Right: Sea level anomaly over Gulf of Mexico from satellite altimetry.



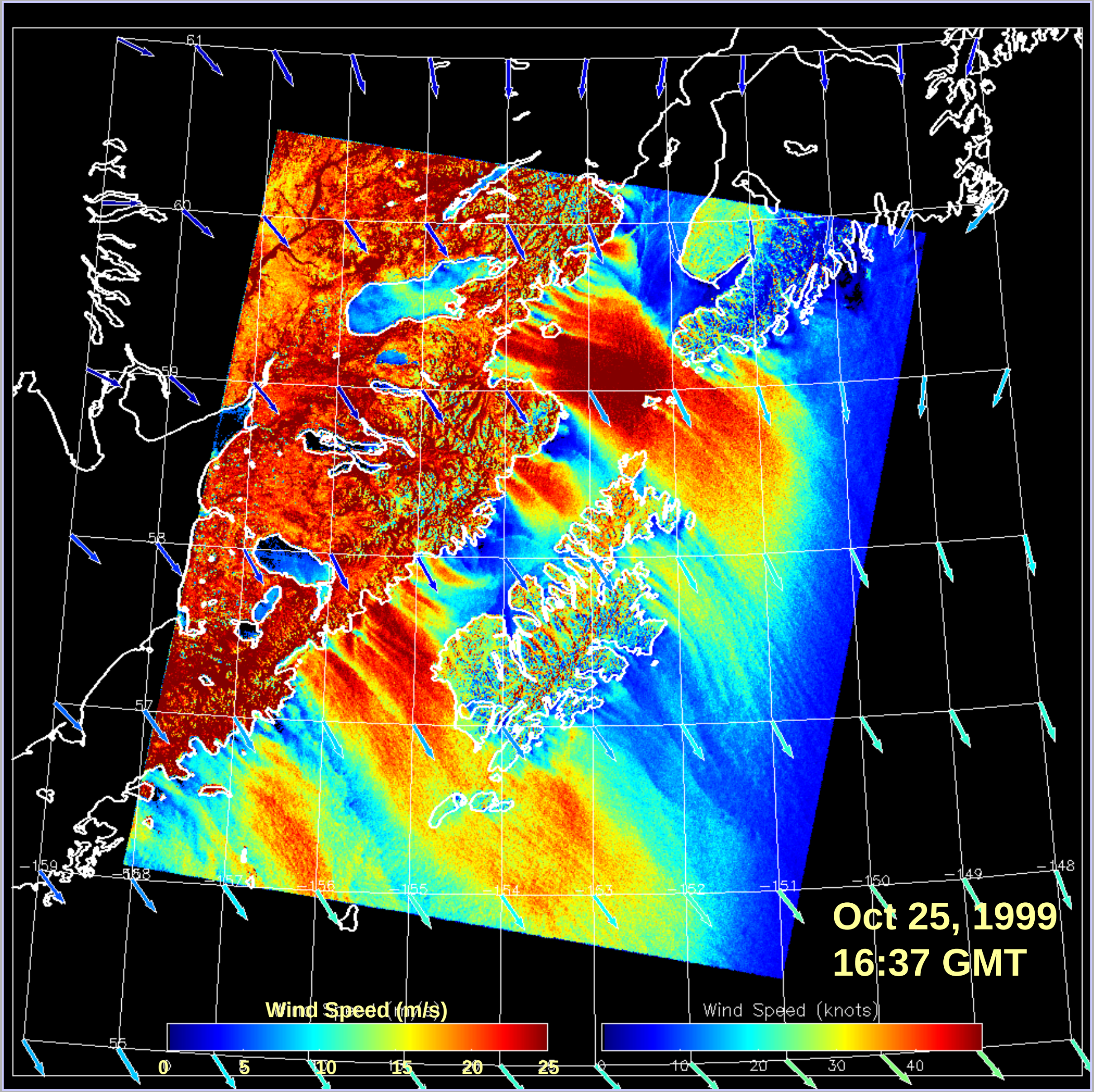


To the left are maps of sea level anomaly over the equatorial Pacific showing the increase in sea level off the west Coast of South America accompanying the onset of el Nino.

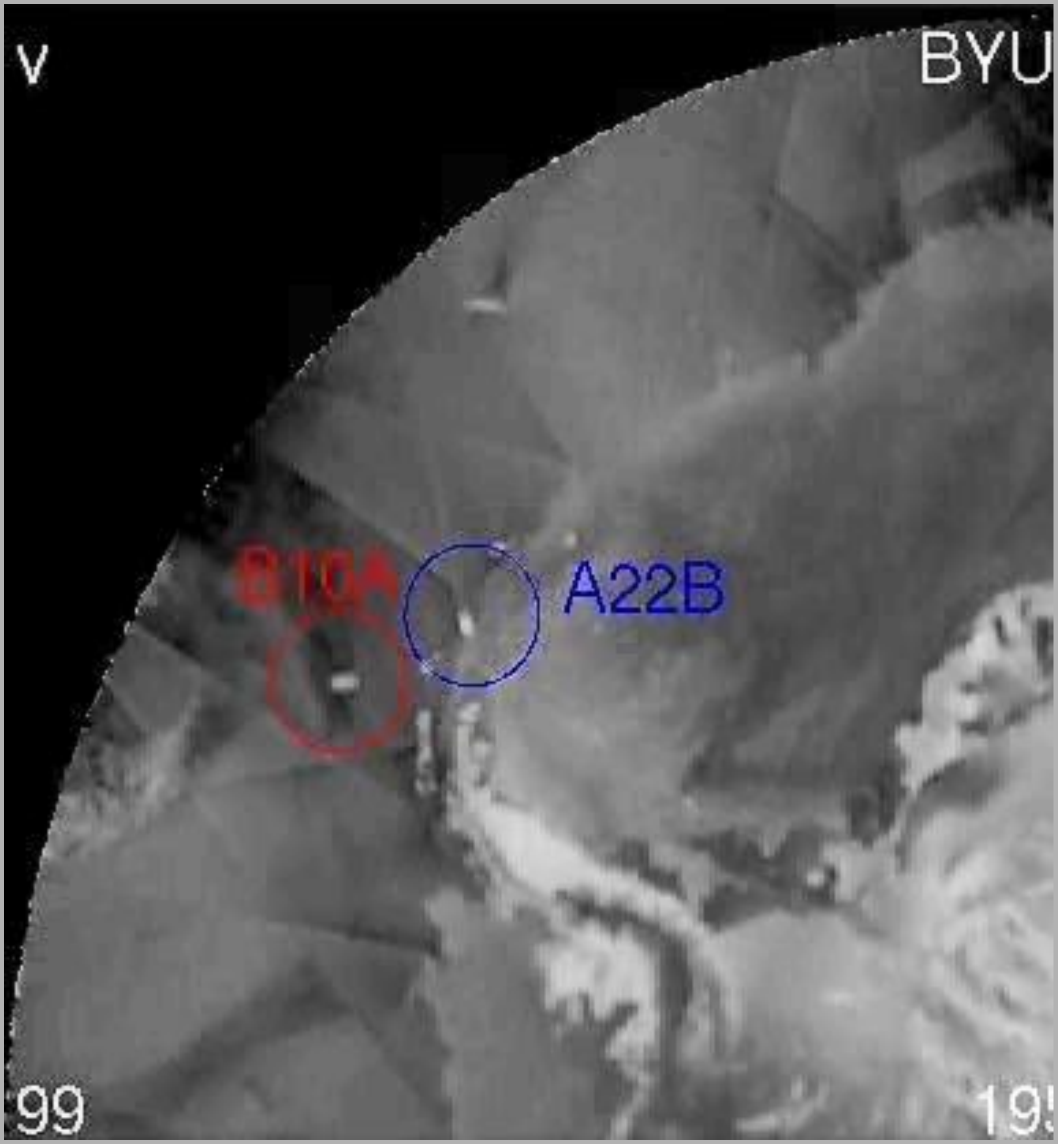


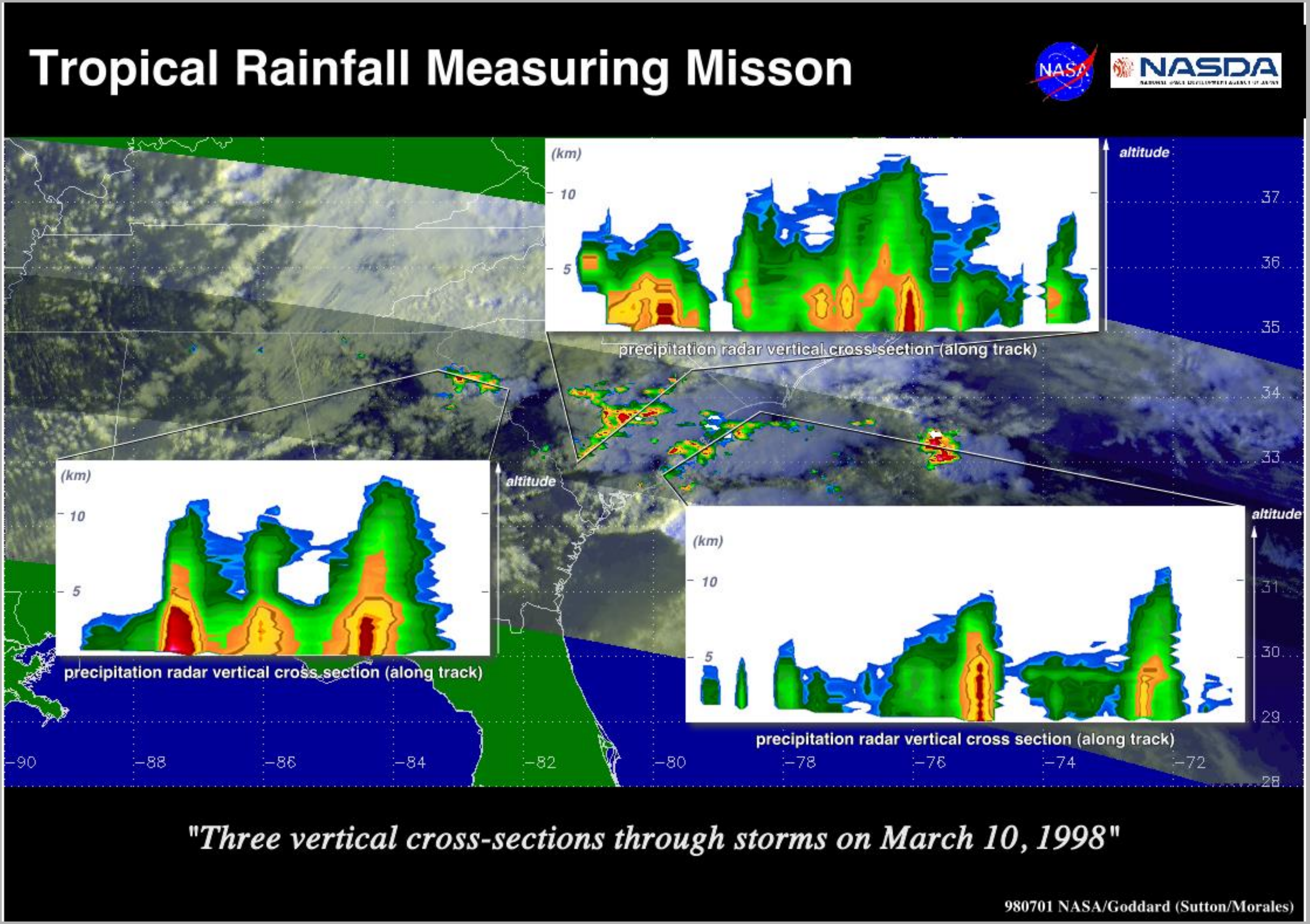
Example of global wind coverage from QuikSCAT for April 1 2005. The time 20:58 UTC in the top legend indicates the most current pass in the product.

SAR Wind Speed Product



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

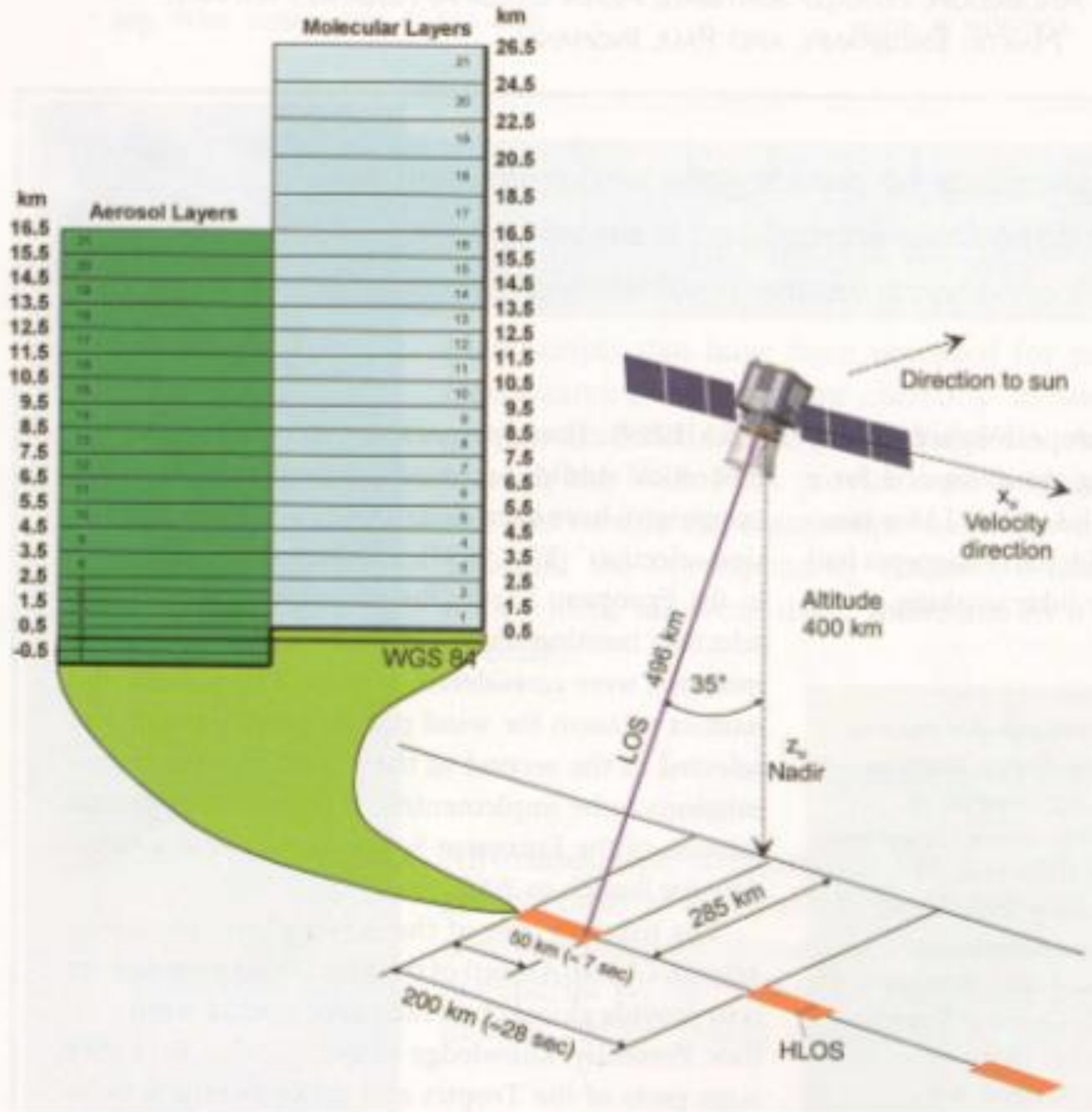




TRMM radar cross sections, from NASA/GSFC web site.

Atmospheric Dynamics Mission (ADM)

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



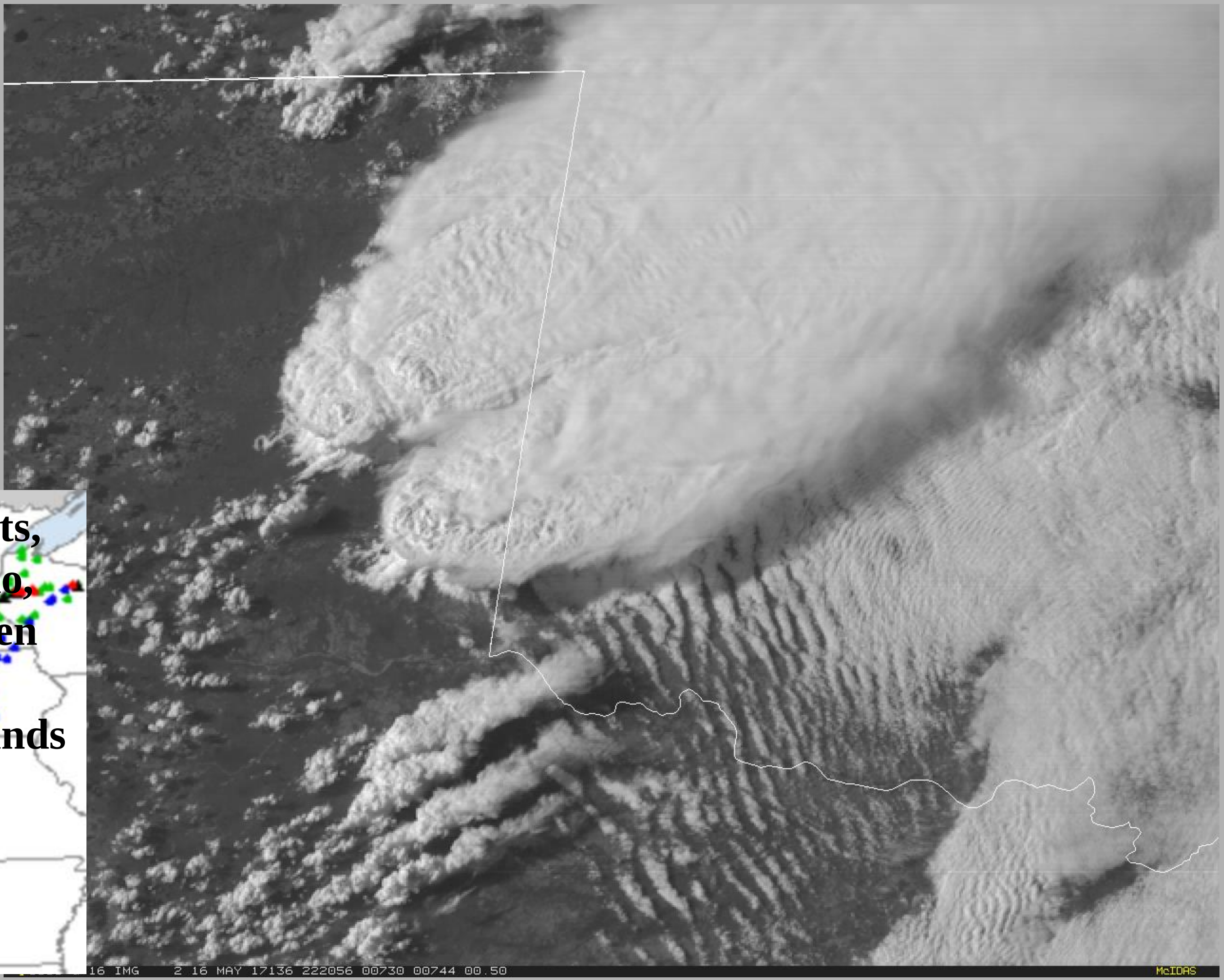
This concludes the lecture on Spectral Bands and their Applications

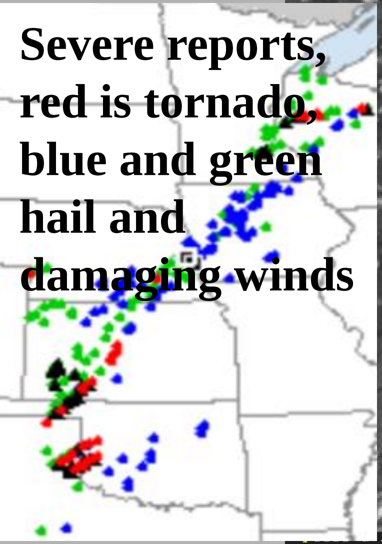
- More information on spectral bands and their applications may be found by using Internet go to the WMO web site and access the WMO Space Program to link to the Virtual Laboratory.

How we display the data (imagery) becomes exceptionally important since the spatial and temporal domains of the atmospheric phenomena being observed (or oceanographic and terrestrial) should dictate the spatial, spectral and temporal domains of the satellite imagery used to view and analyze that phenomena.

Among the topics to be addressed are using stereo, feature relative motion and image averaging to extract meaningful information.

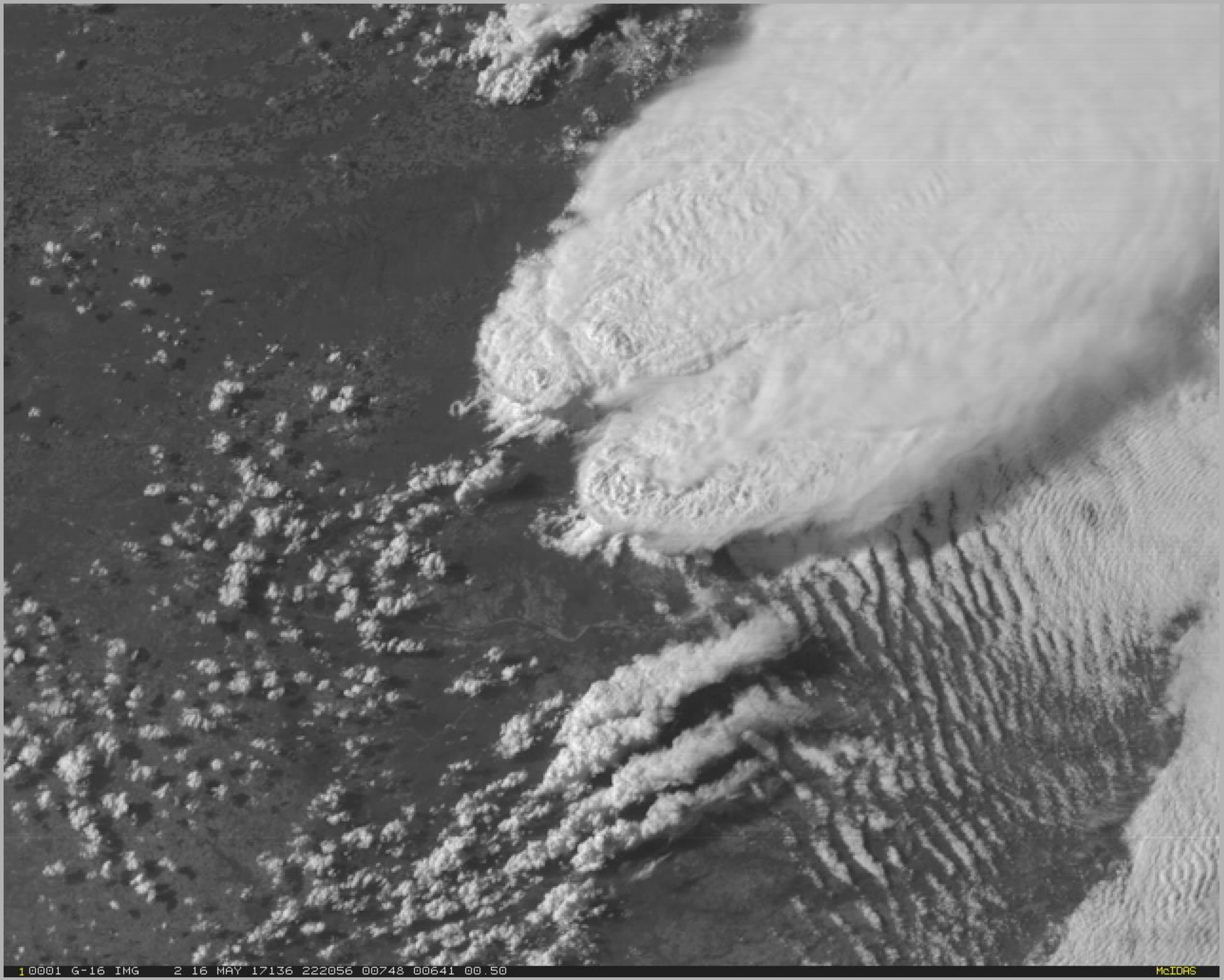
Earth relative animation of one minute interval visible data





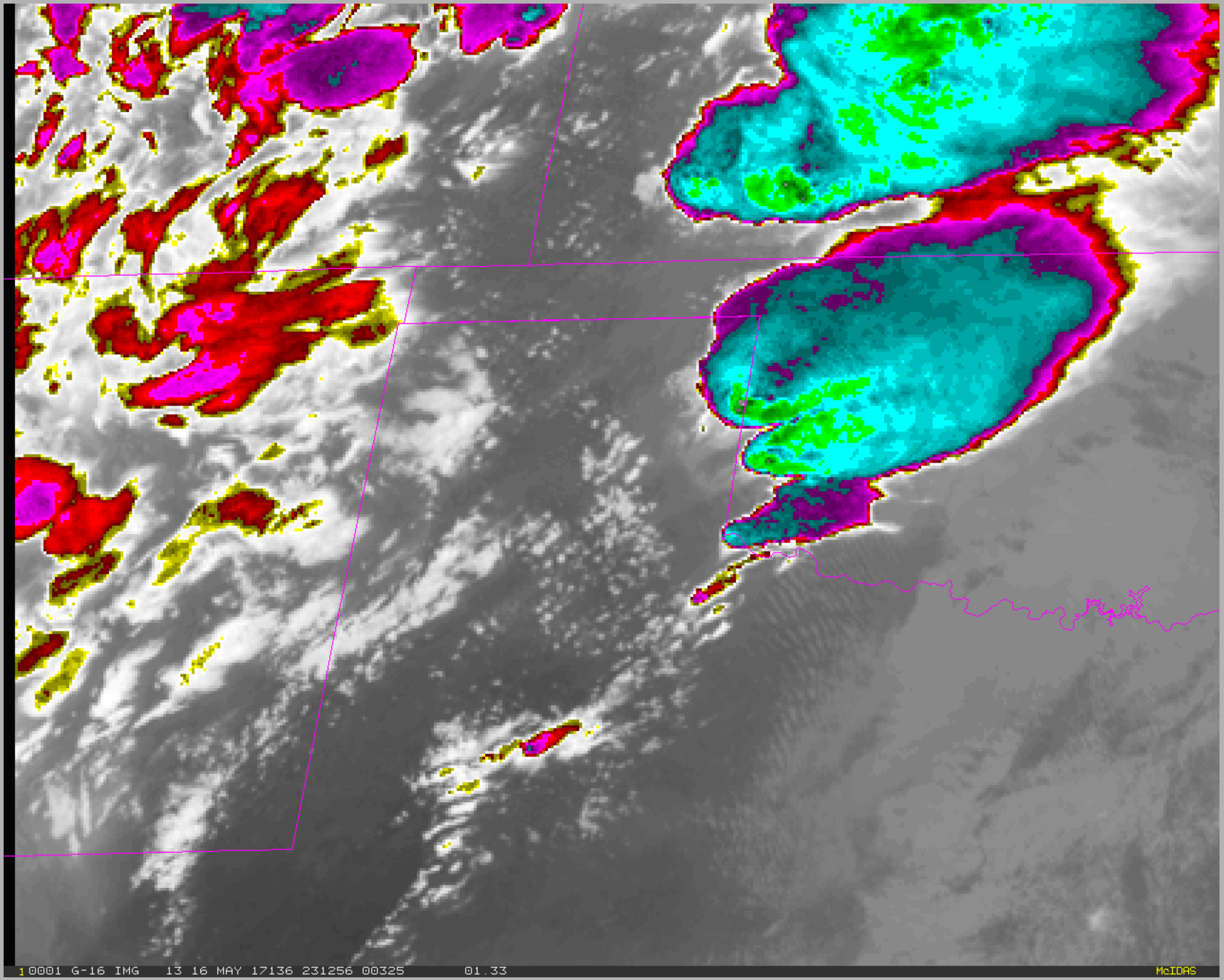
Severe reports, red is tornado, blue and green hail and damaging winds

Storm relative animation of one minute interval visible data

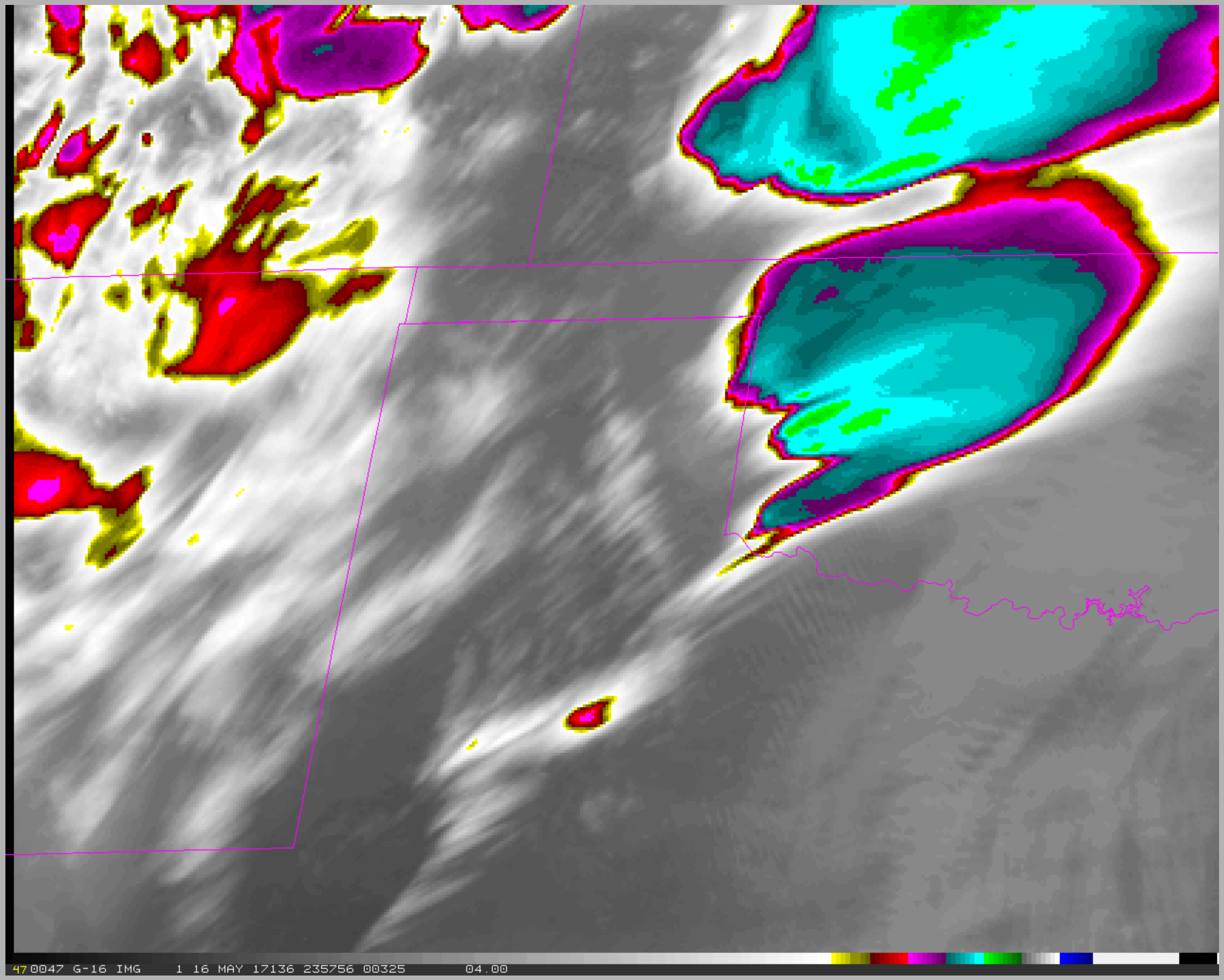


Earth relative animation of one minute interval infrared data

33 minutes in length

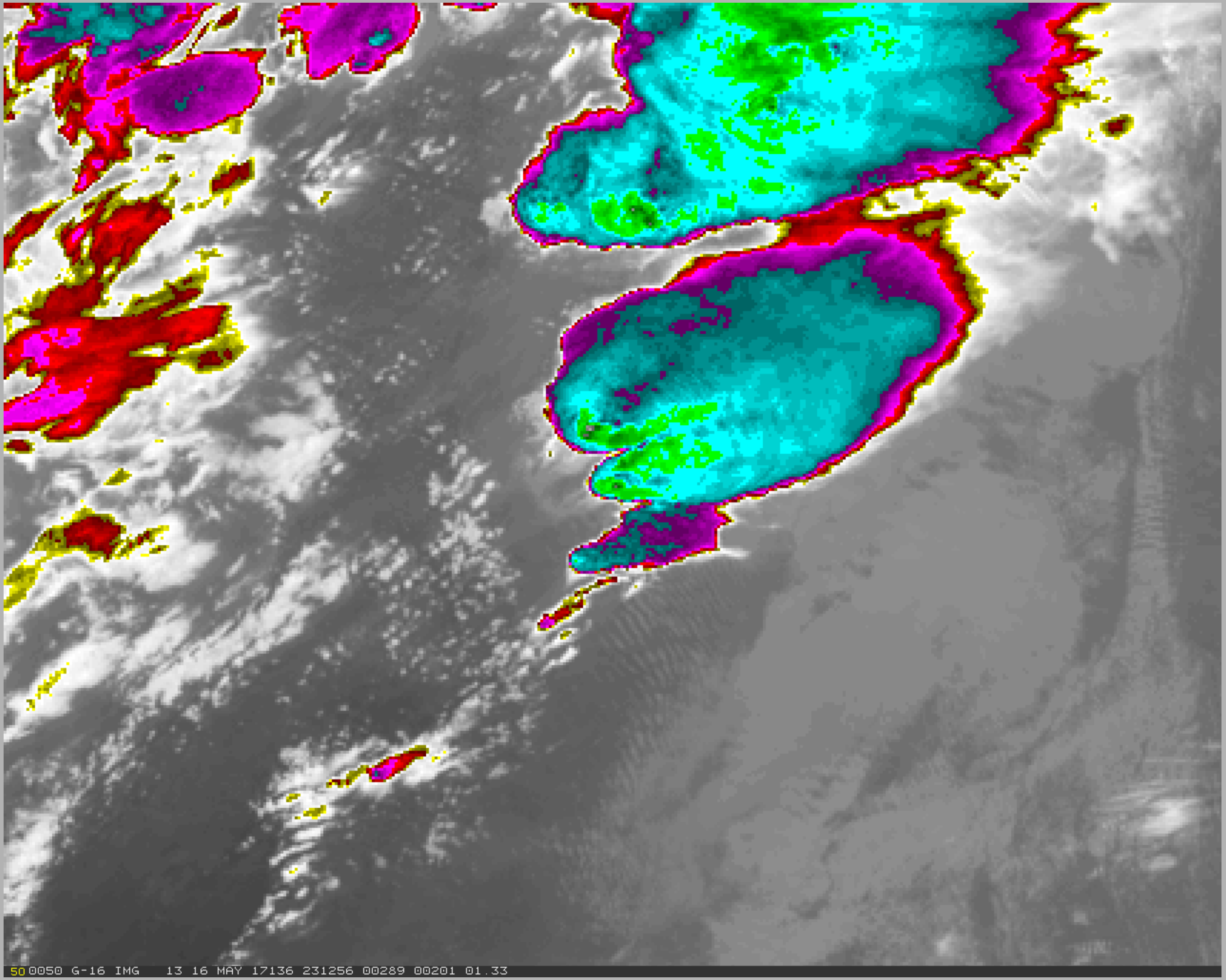


Average of 33 minutes of Earth relative infrared imagery from animation just shown

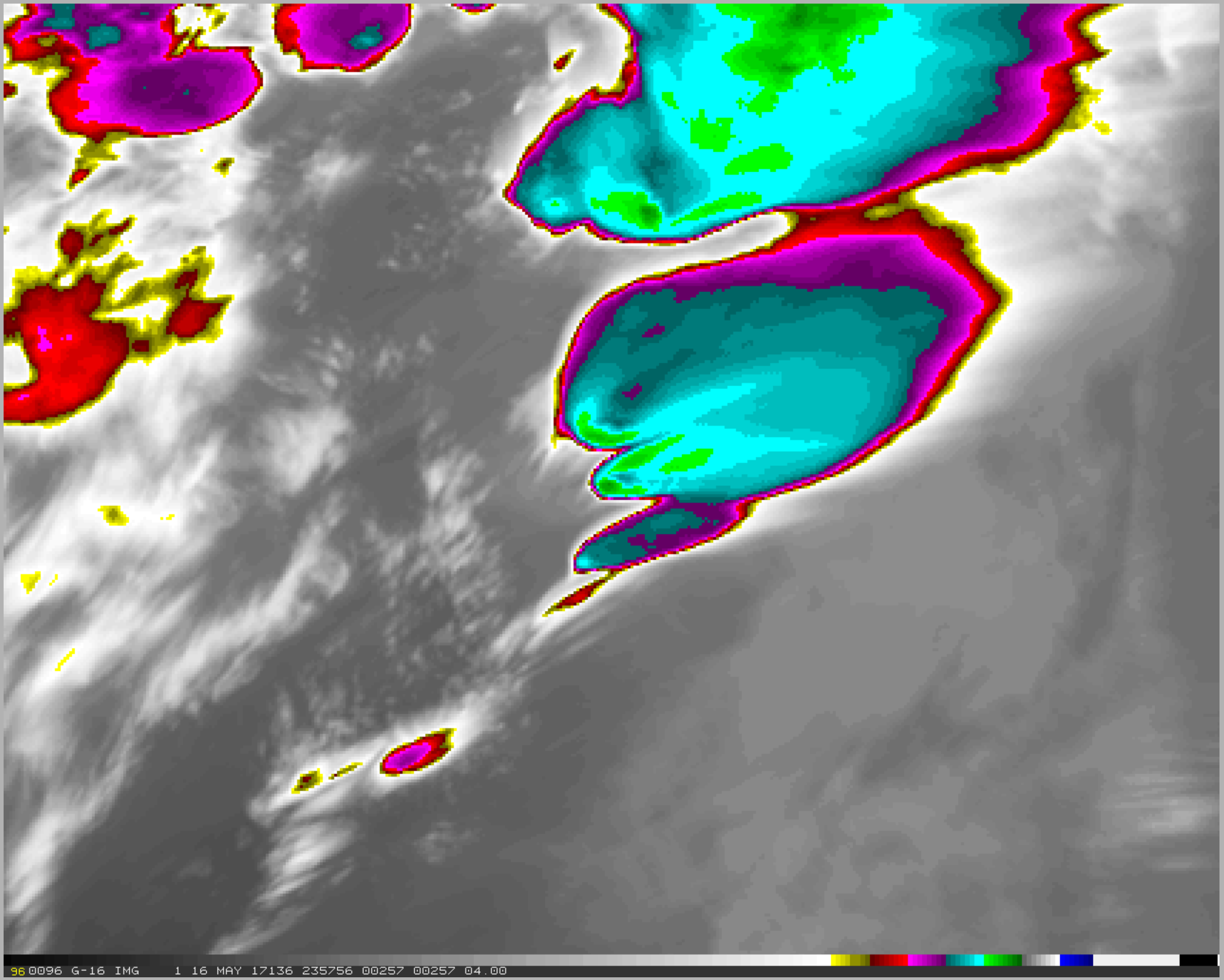


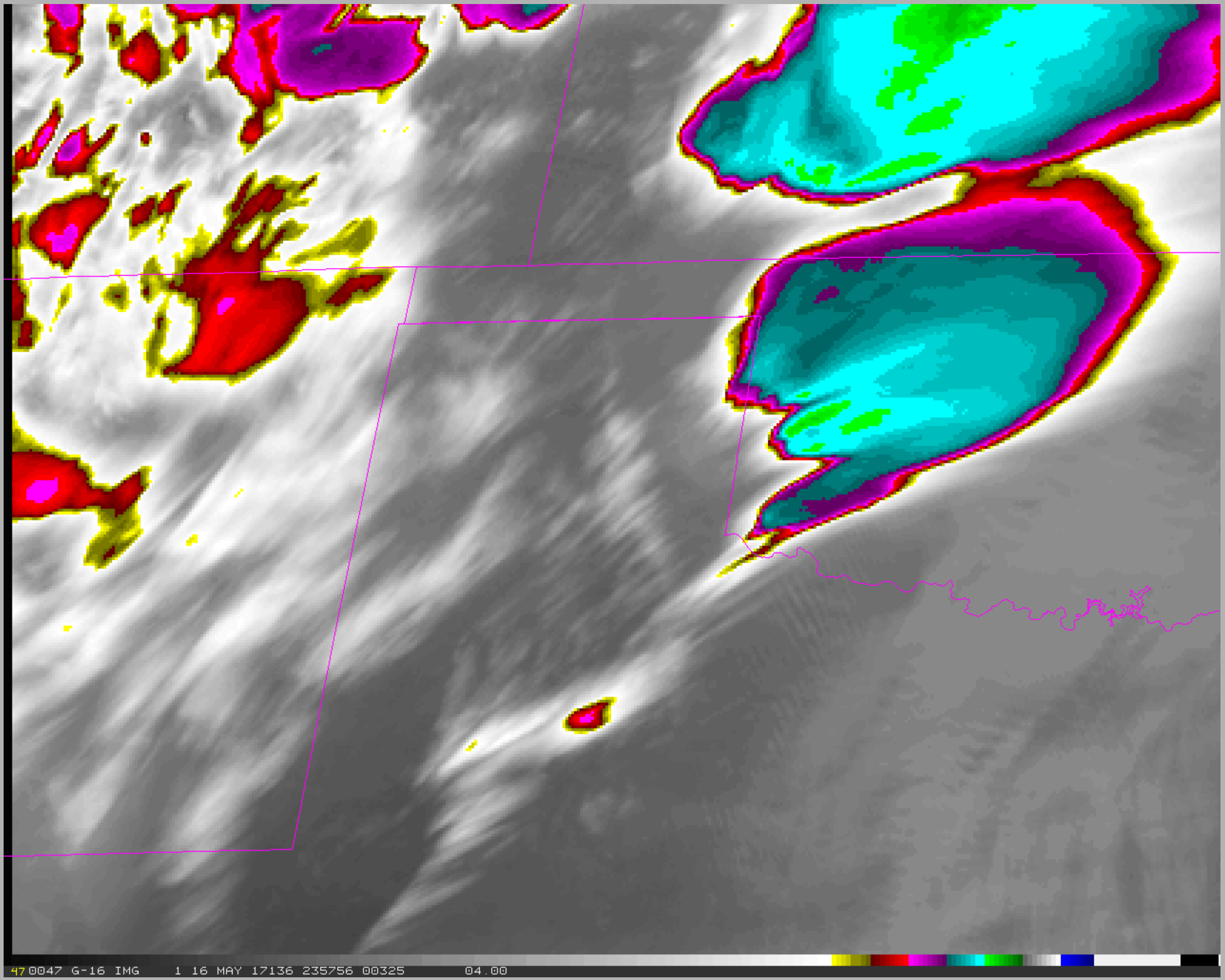
Storm relative animation of one minute infrared data

33 minutes in length



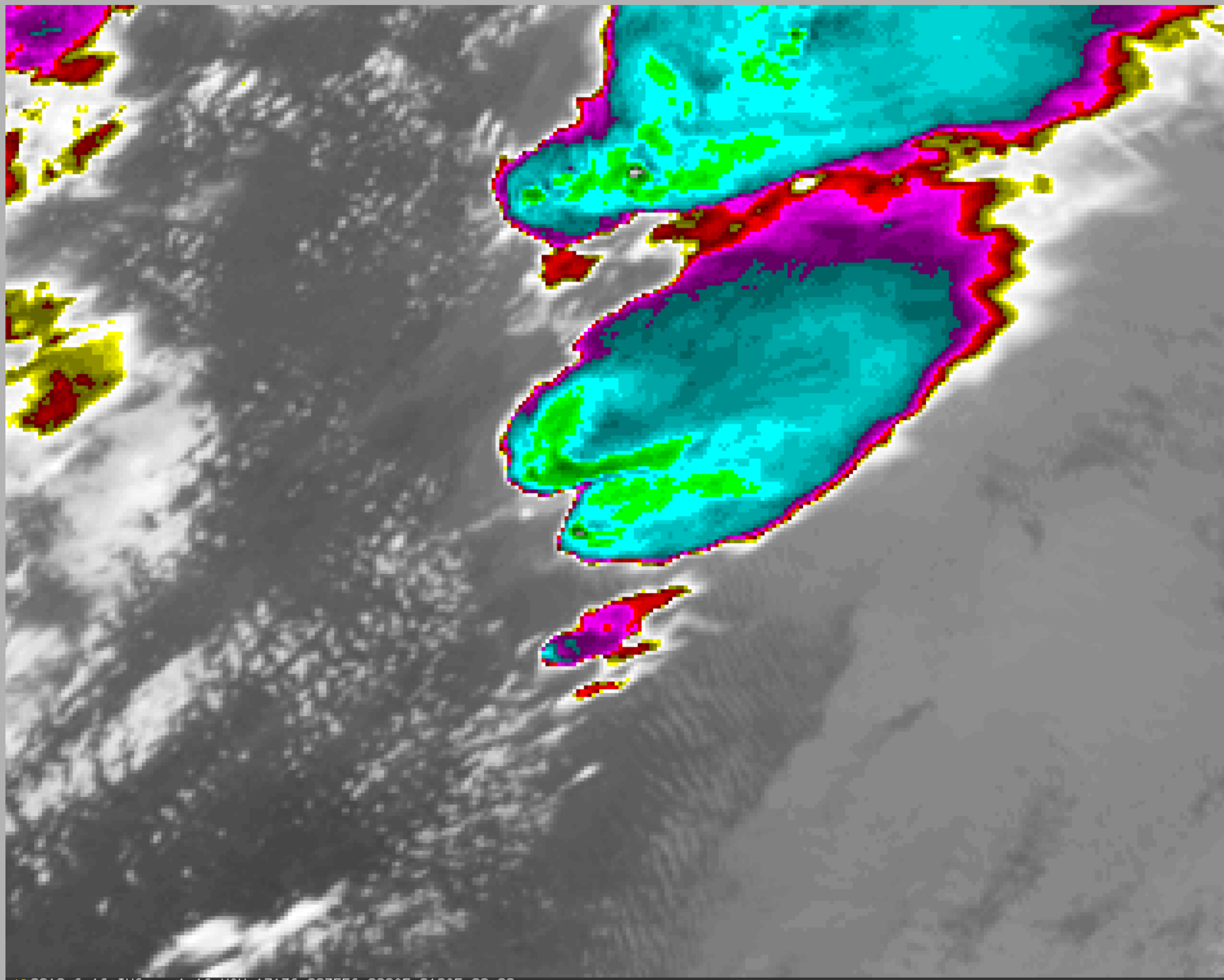
Average of 33 minutes of storm relative infrared imagery from animation just shown

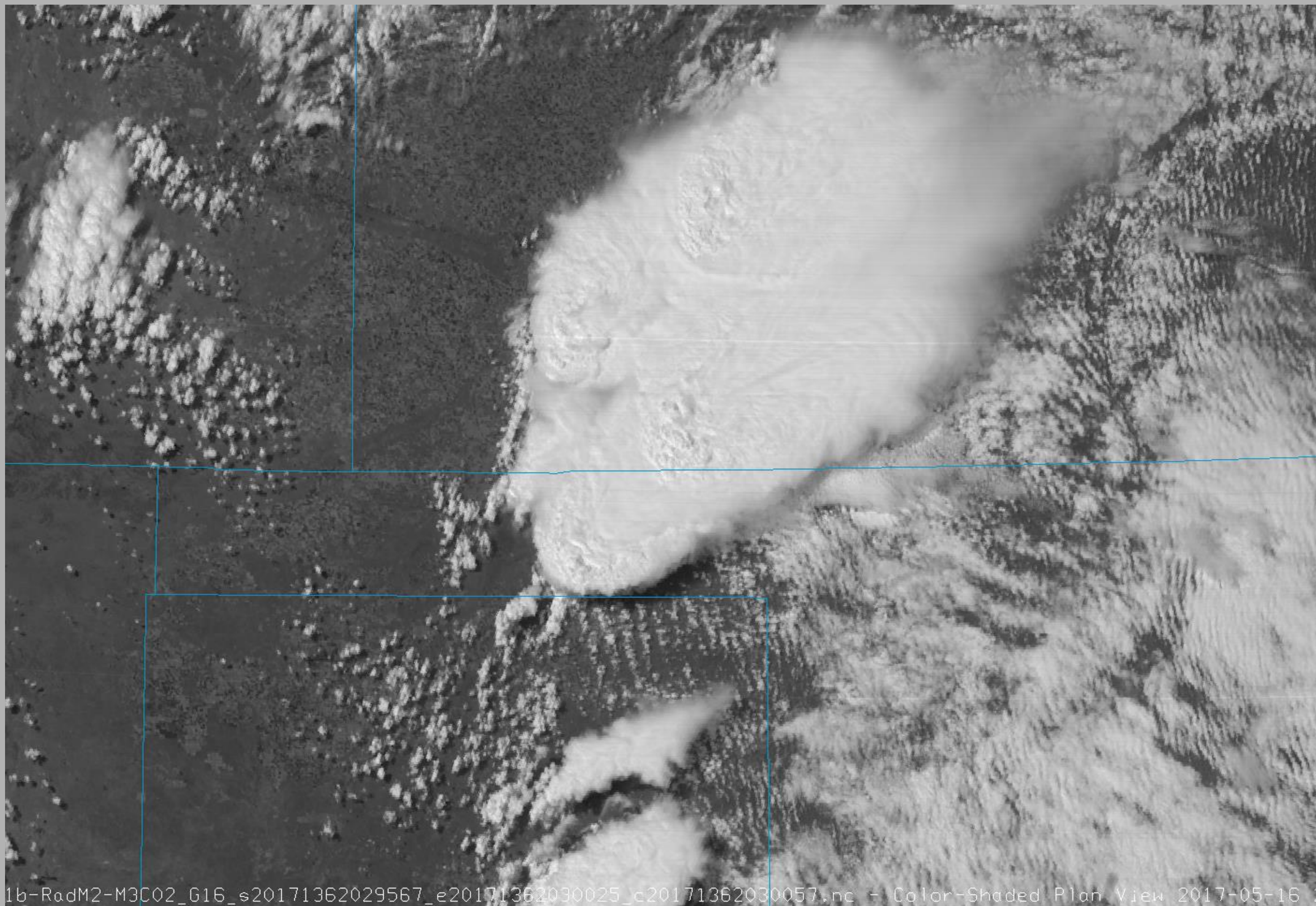




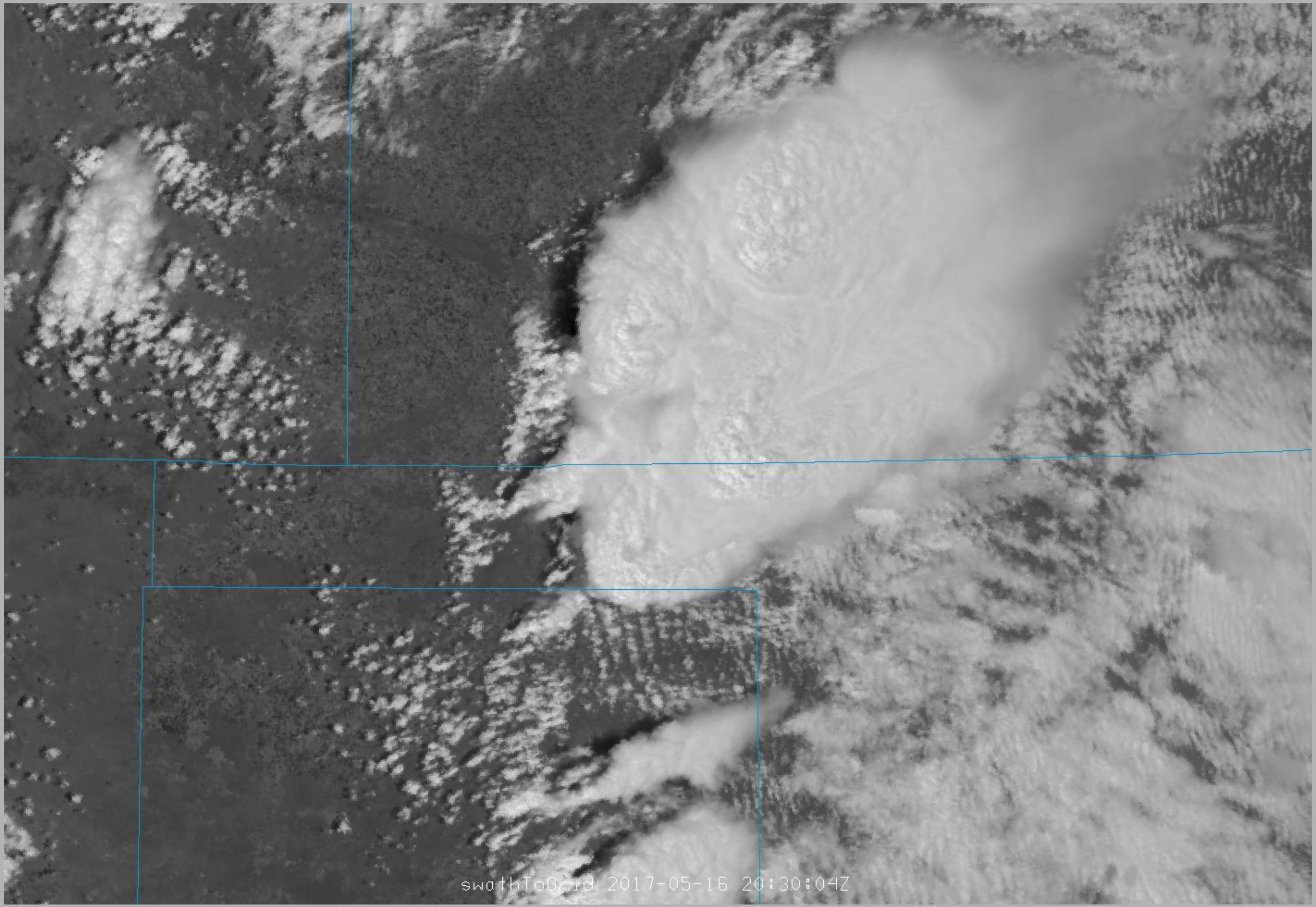
Earth relative average of 33 minutes of infrared imagery for comparison with storm relative average just shown

3 minute running mean loop made from infrared storm relative imagery



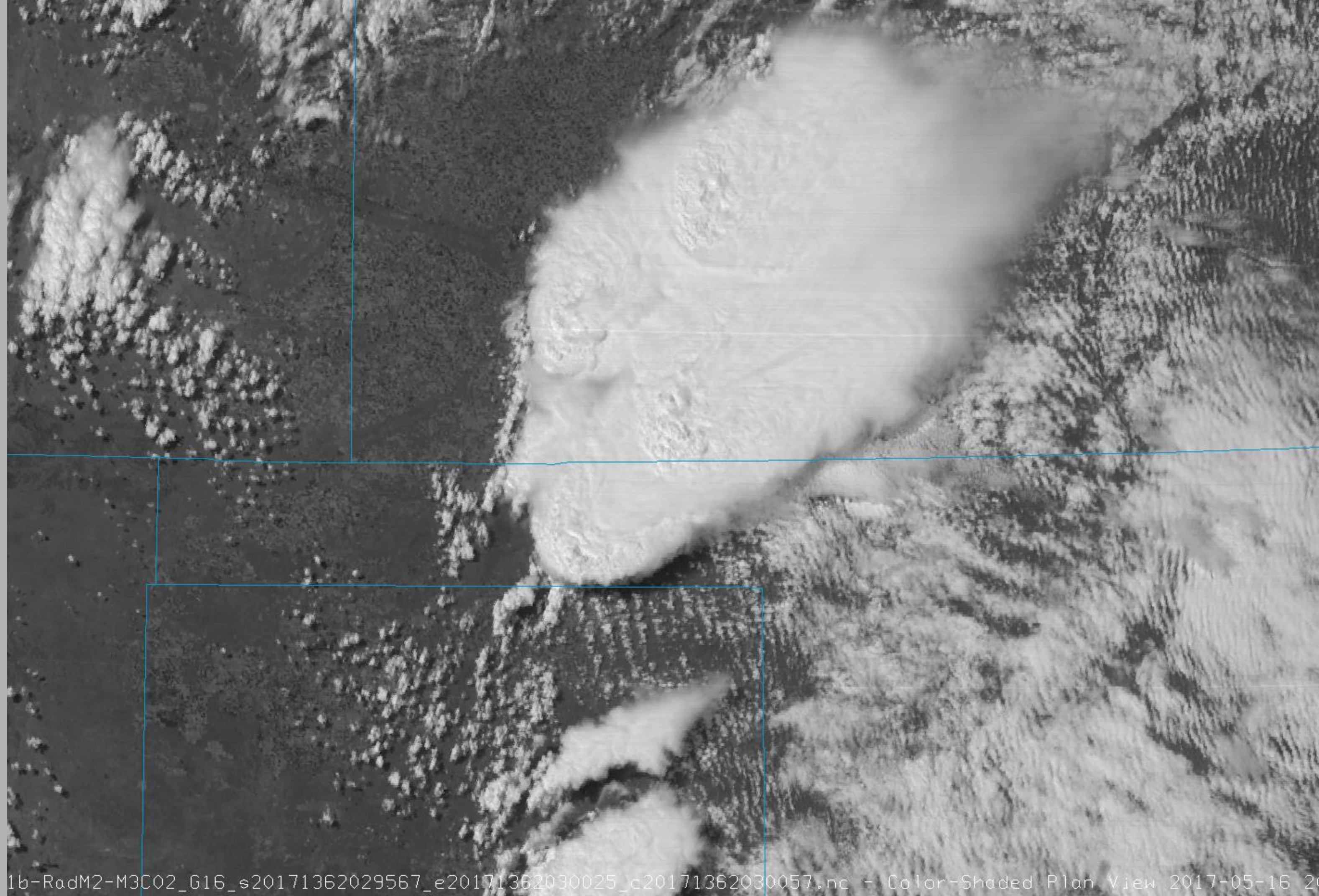


Stereo example remapped GOES-16 image

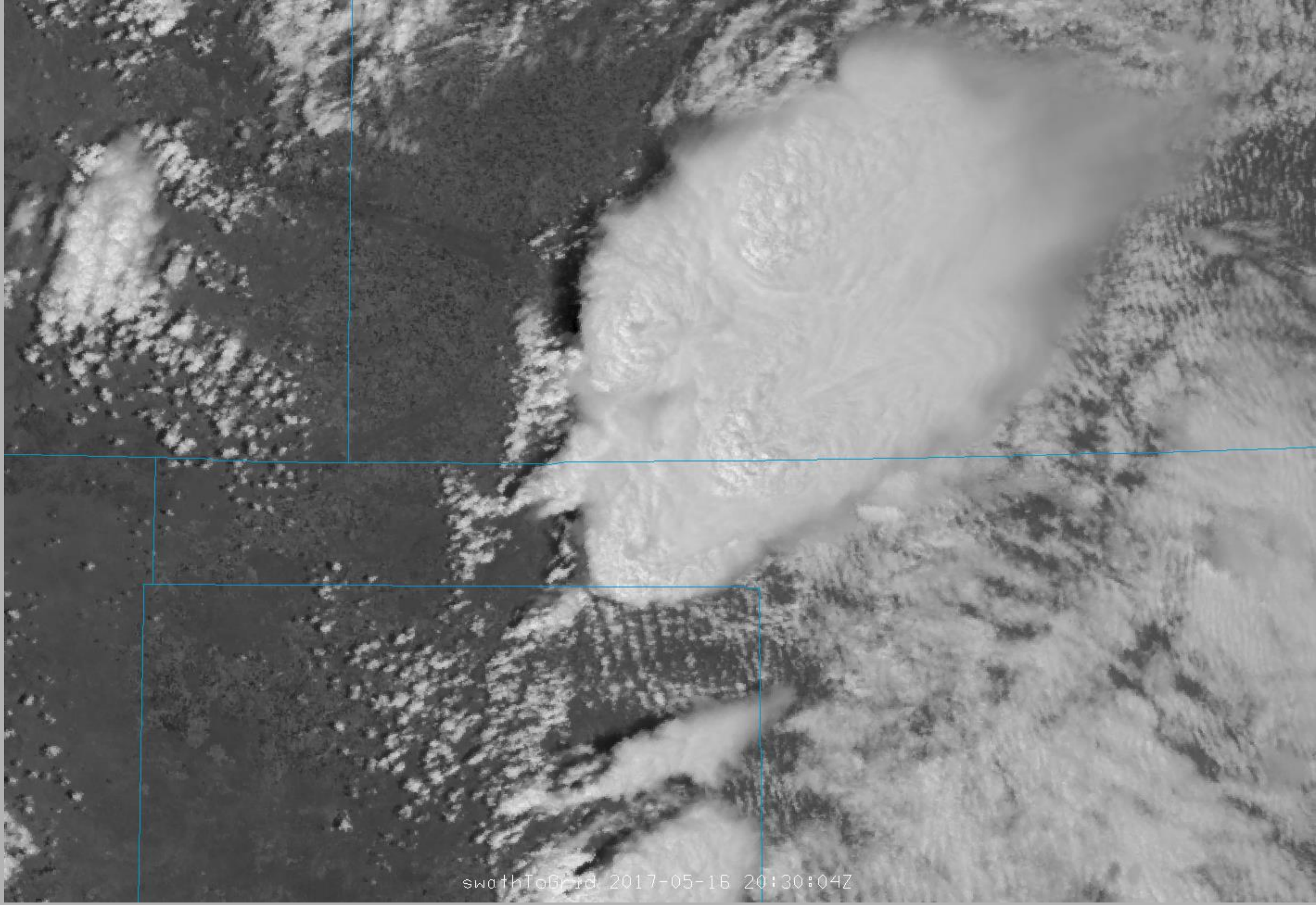


Stereo example remapped VIIRS image

Holding cloud streets south of storm system stationary reveals that they are lower than high based cumulus to the west of the storm

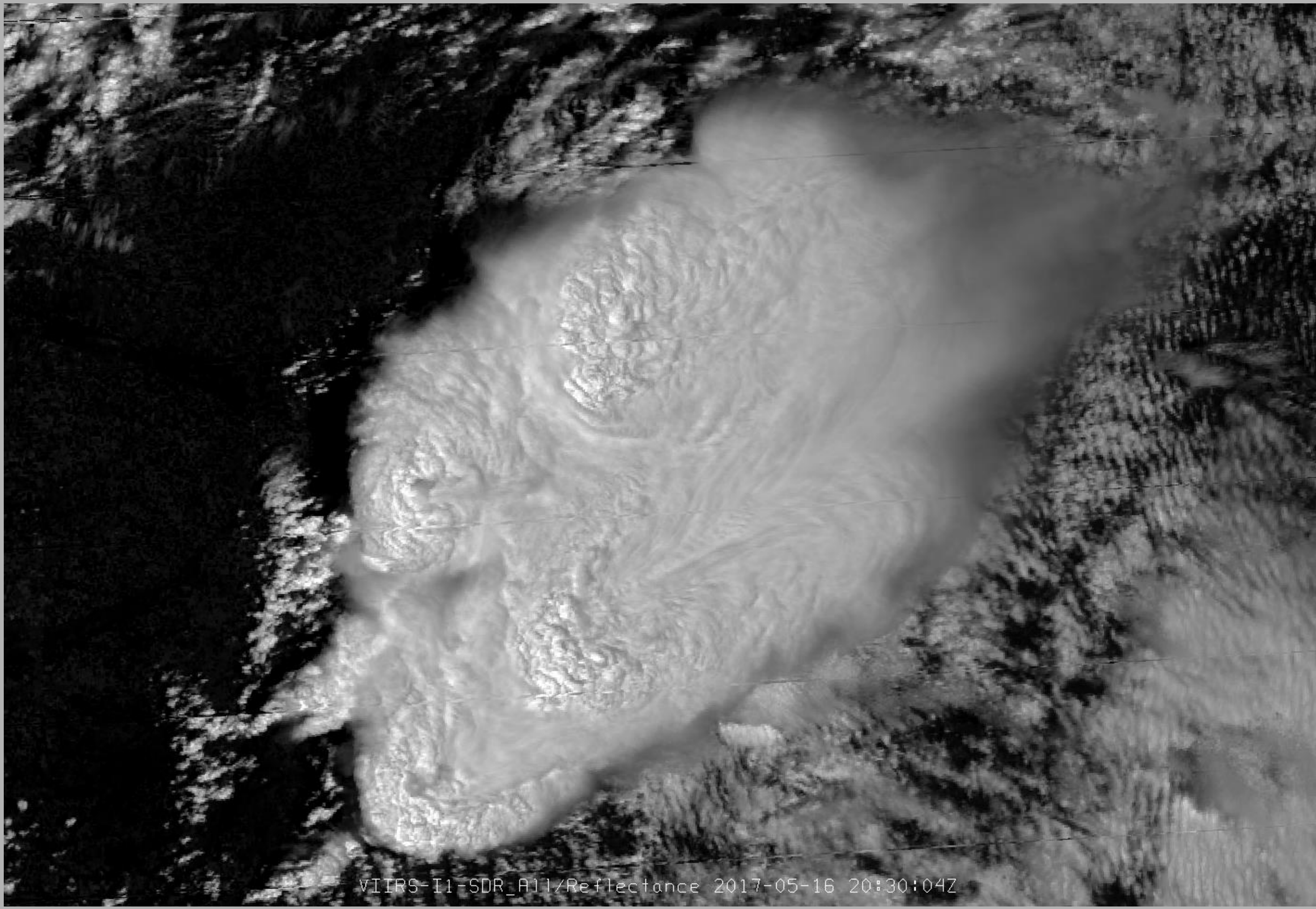


Holding cloud streets south of storm system stationary reveals that they are lower than high based cumulus to the west of the storm



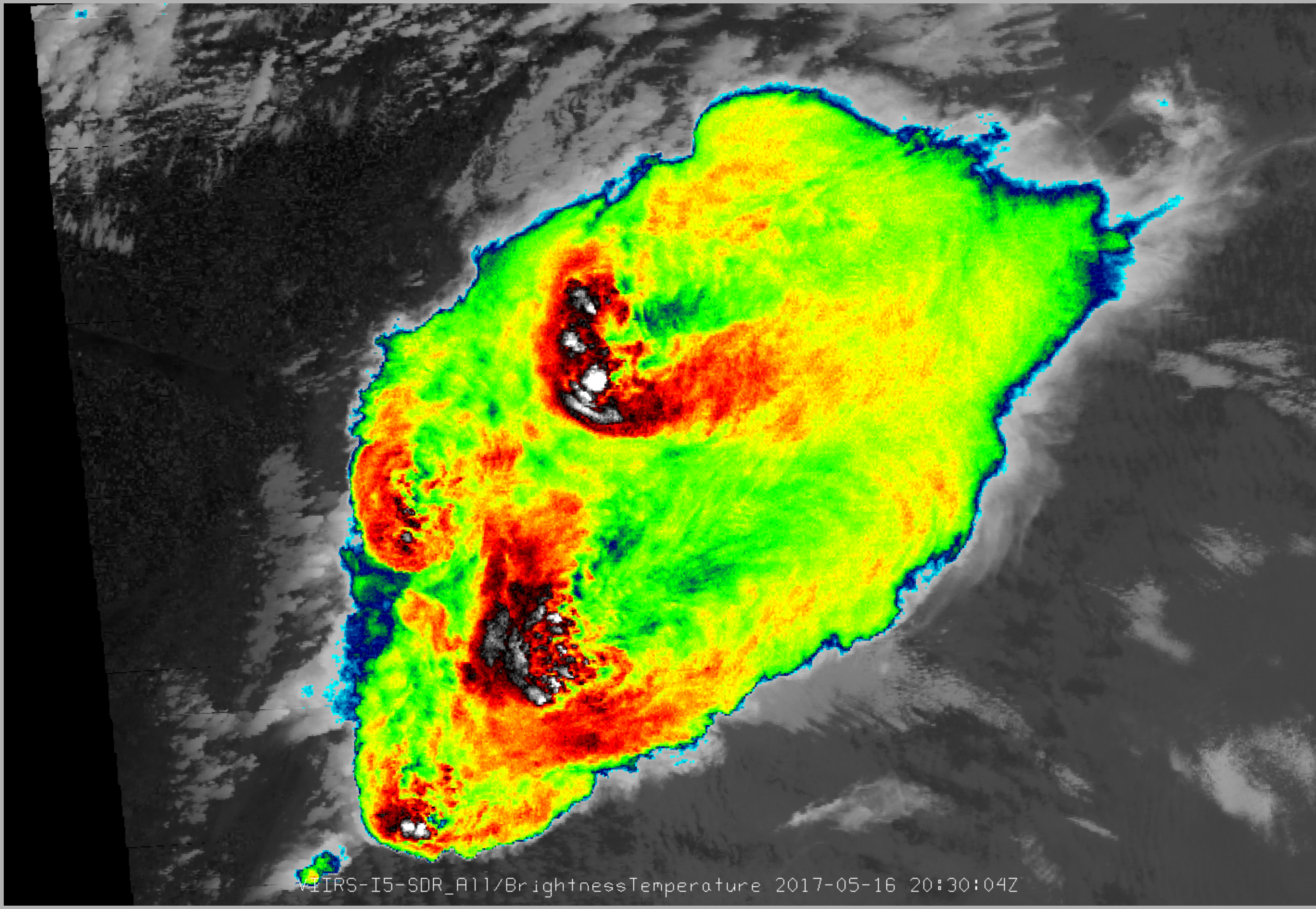
375 meter resolution VIIRS visible image

Let’s go <u>beyond here</u> next with our geostationary systems



375 meter resolution VIIRS infrared image

Let’s go here next with our geostationary systems



We have briefly addressed Principal Component Analysis, viewing rapid scan imagery in an Earth Relative and Storm, or Cloud Relative Mode, and Averaging Image Sequences to Help Diagnose Storm System Characteristics.

- These effect the way we approach data handling, science, product development, training and utilization.
- We must now think in terms (investigate and develop) of new multi-channel products, derived from mathematical analysis, at frequent intervals to be used in specific application areas.
- Numerous product areas, such as precipitation estimation, cloud motion vector derivation, feature tracking, severe storm identification and nowcasting in general will benefit from these advanced analysis methods.
- How we display the data (imagery) becomes exceptionally important since the spatial and temporal domains of the atmospheric phenomena being observed (or oceanographic and terrestrial) dictate the spatial, spectral and temporal domains of the satellite imagery used to view and analyze that phenomena.