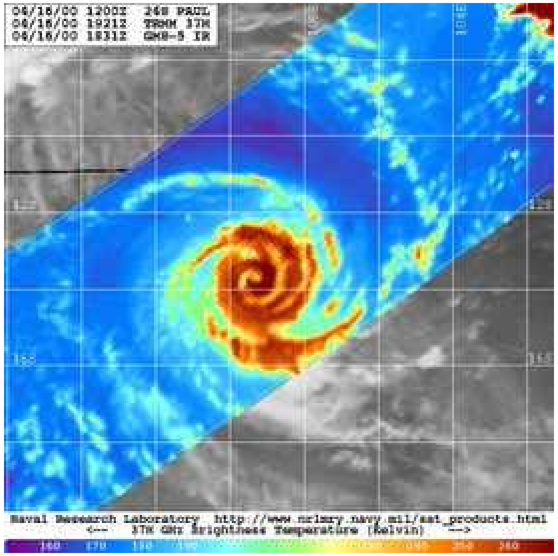
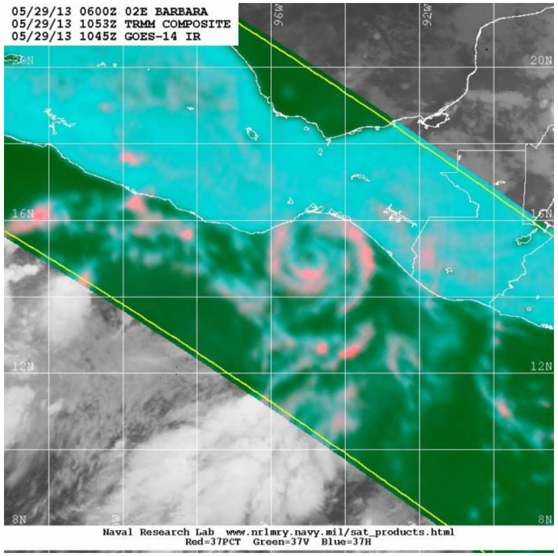
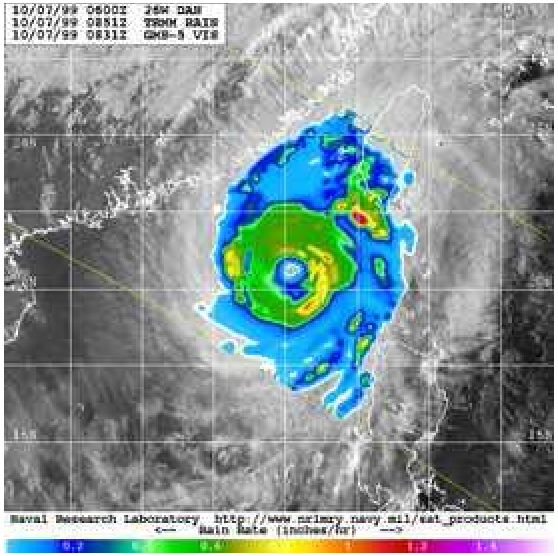




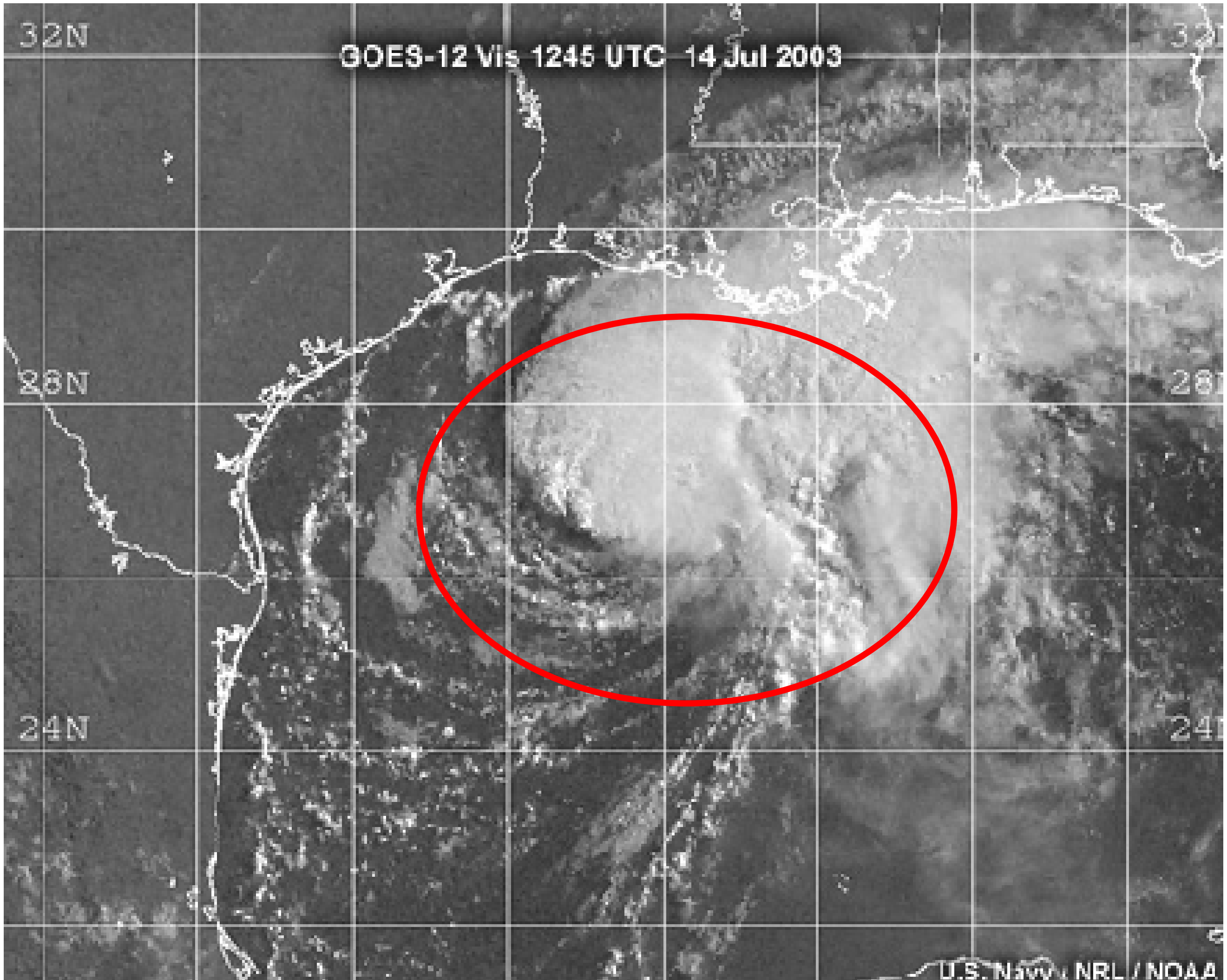


Advanced Satellite Remote Sensing: Microwave Remote Sensing

FIU HRSSERP Internship

August 15, 2013

Where is the eye?



- Visible Image of Tropical Storm Claudette
- The maximum wind speed is 55 knots
- Cirrus covers the storm

Global Operational Satellite Observation System

Satellite Orbits

- Geostationary: at about 35,800 km above the equator, move with the earth

  - For example: GOES-EAST, GOES-WEST

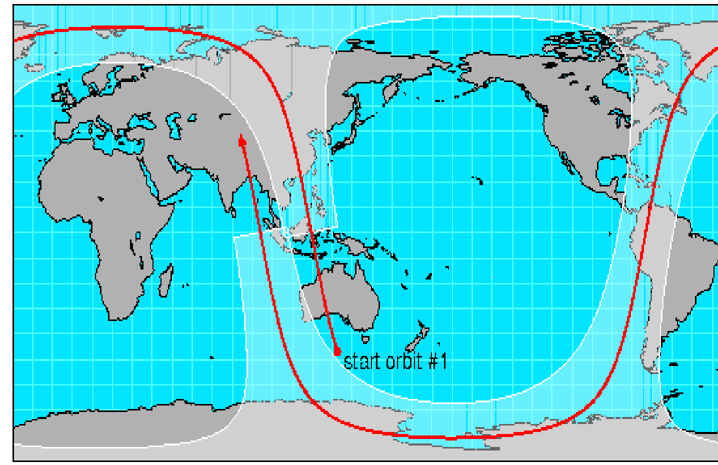
- Polar-orbiting: at about 850 km above the surface

  - For example: POES, GPM (early 2014)

- Research and Development: between certain latitudes a few hundred km above the surface

  - For example: TRMM

Polar Orbiting Satellites



- Only 800-900 km above the surface
- Observe most areas twice daily
- Continuously view a different part of the surface, following a path called a “swath”

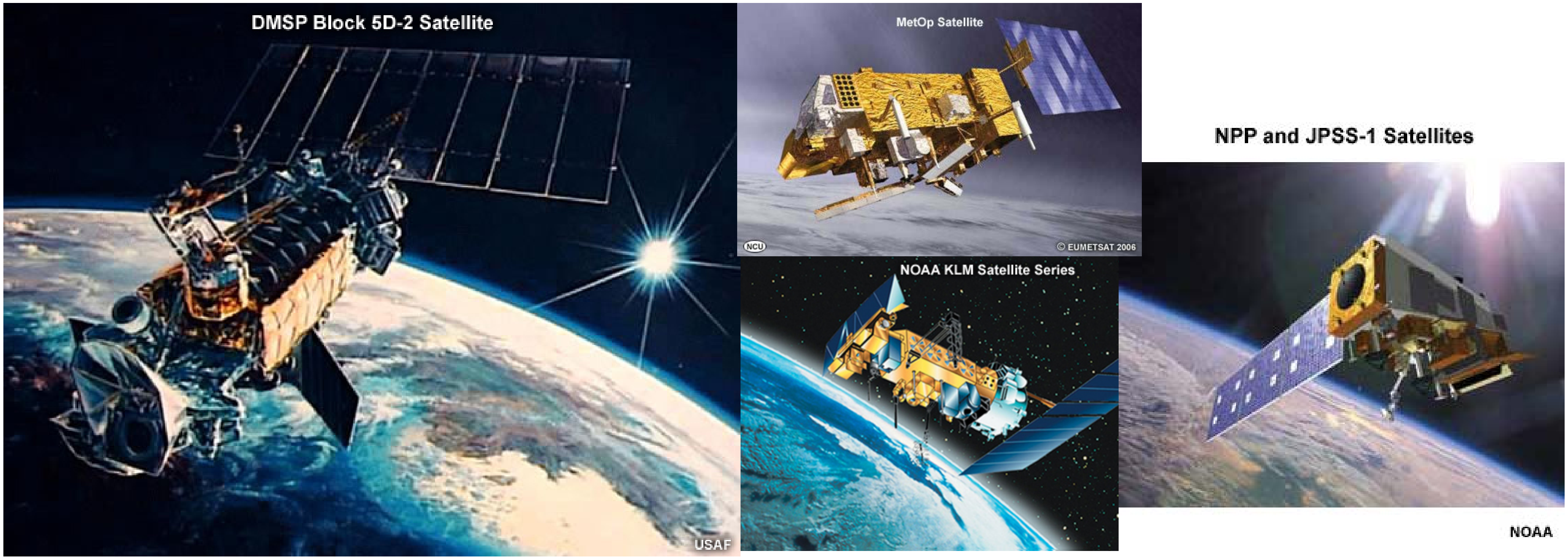
Geostationary vs. Polar orbits

	Geostationary	Polar
Advantages	• Higher temporal coverage • Observe and collect information continuously over specific regions	• Typically higher spatial resolution than geostationary • Covers most of earth's surface • Microwave imaging instruments can be used • Launch costs much cheaper than GEO
Disadvantages	• Low spatial resolution • Cannot see poles very well	• Poor temporal coverage • Can miss some important features

Geostationary vs. Polar Applications

- For real-time operational forecasting, the visible, IR, and water vapor satellite images are most commonly.
- There are several exceptions: environmental conditions, the life cycle of a tropical cyclone, at night, the eye of a developing hurricane.
- However, for analysis purposes and especially for scientific research, the polar orbiters are very advantageous.

Microwave Remote Sensing



- Be deployed on polar-orbiting satellites
- Penetrate clouds

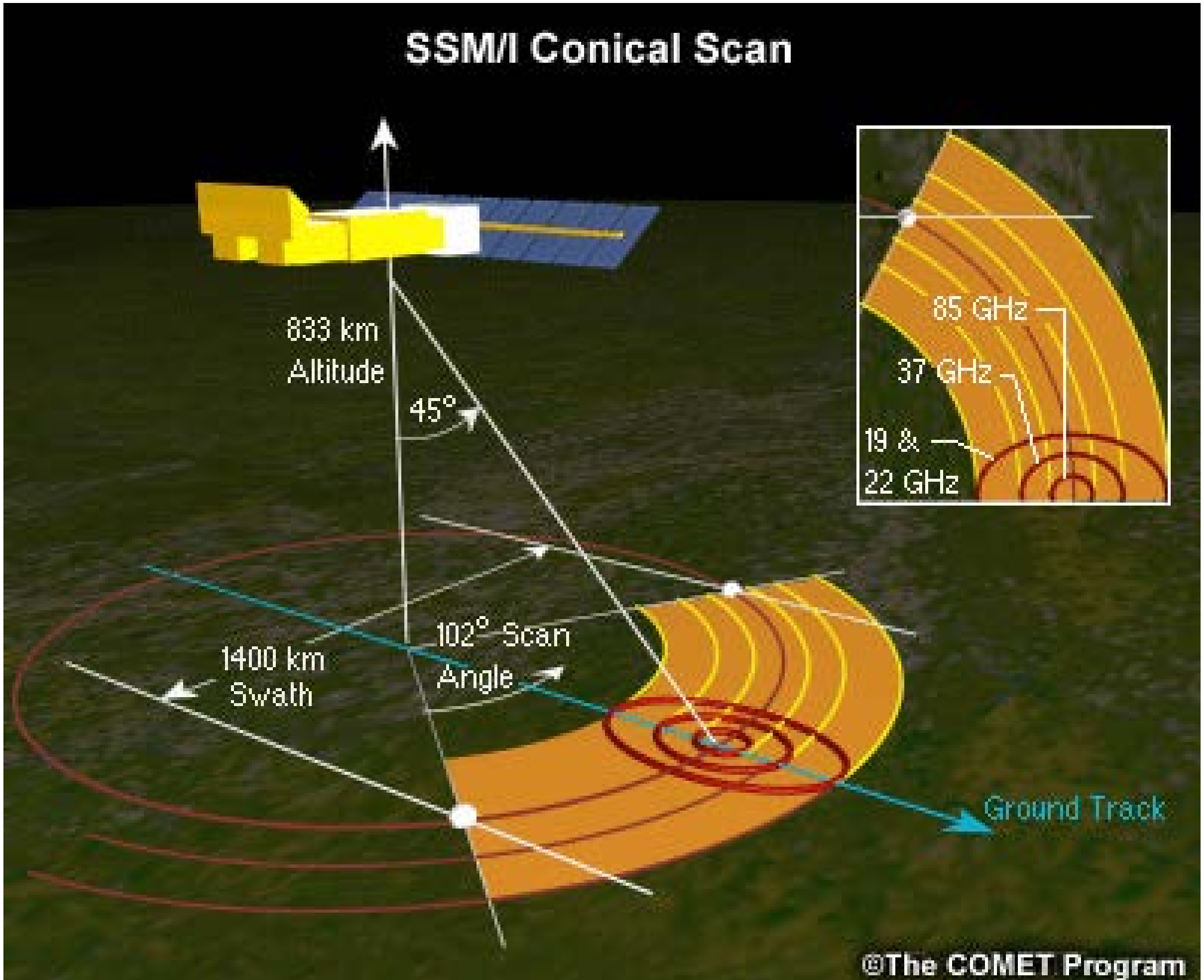
  - provide view of the atmosphere, the interior of clouds, and surface below
- Operate day and night
- Observe the entire planet

Active vs. Passive Microwave Remote Sensing

- Active Microwave Remote Sensing: send and receive pulses of energy similar to weather radar
- Passive Microwave Remote Sensing: sense microwave radiation emitted naturally by the earth-atmosphere system

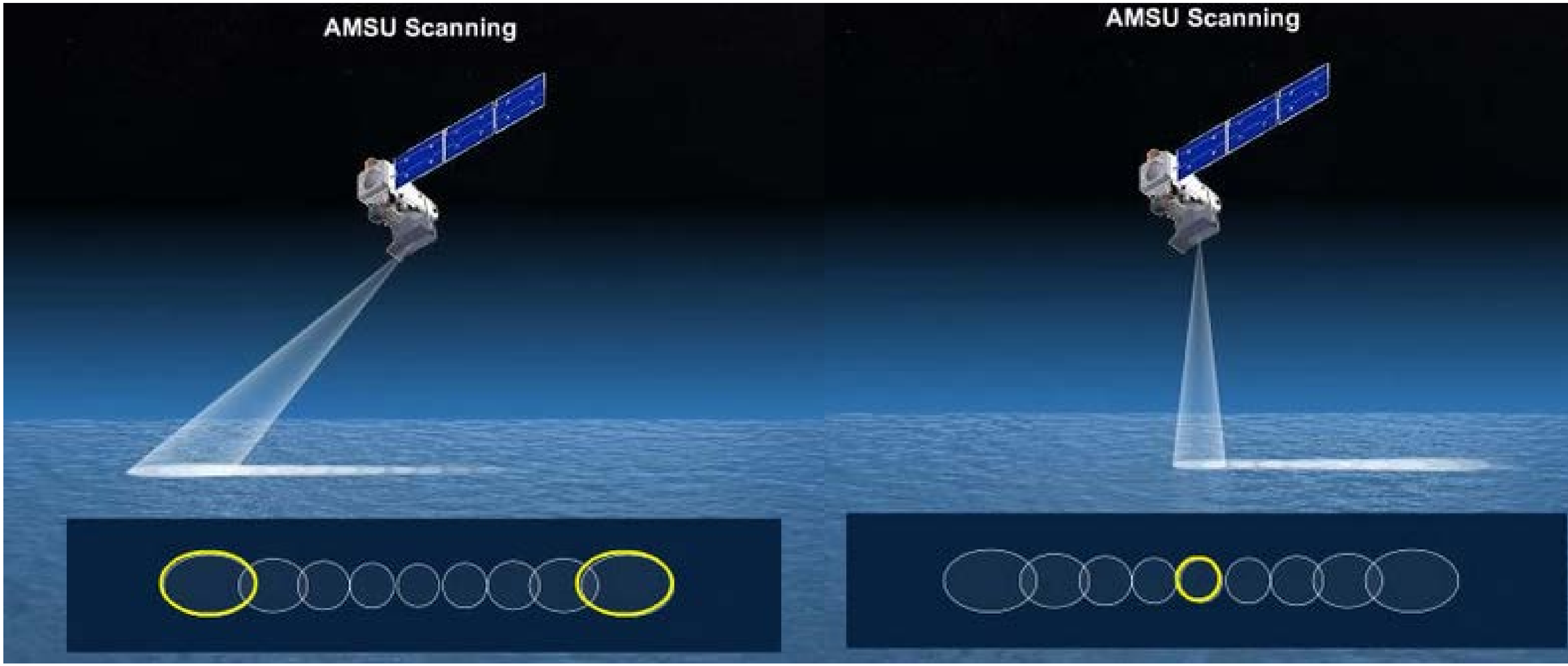
  - Require much less power

Scanning Geometry: Conical Scanning Instruments



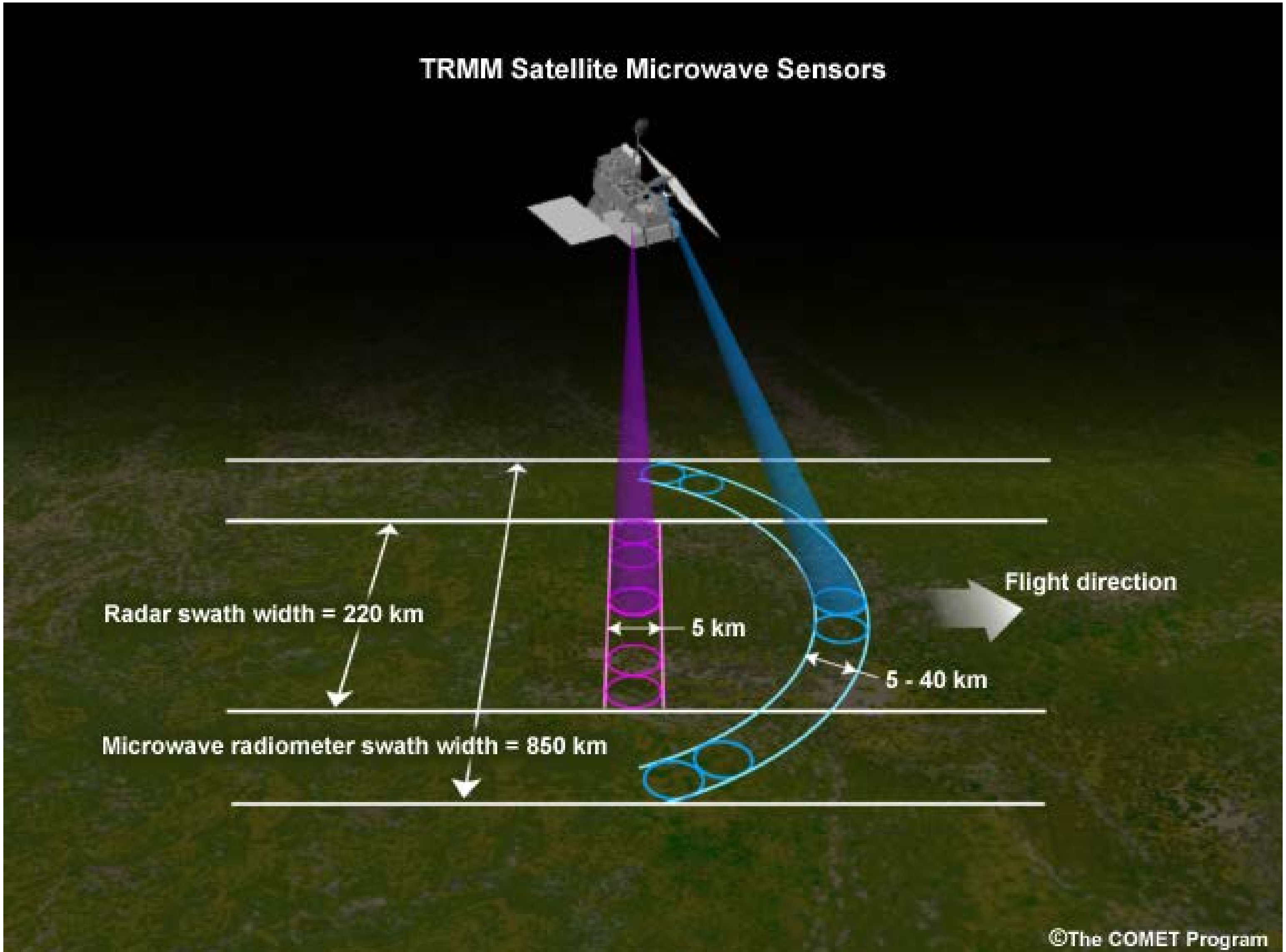
- Footprint size remains the same across the scan
- Example: SSM/I, SSMIS, AMSR-E, TMI, WindSat

Scanning Geometry: cross-track scanning instruments



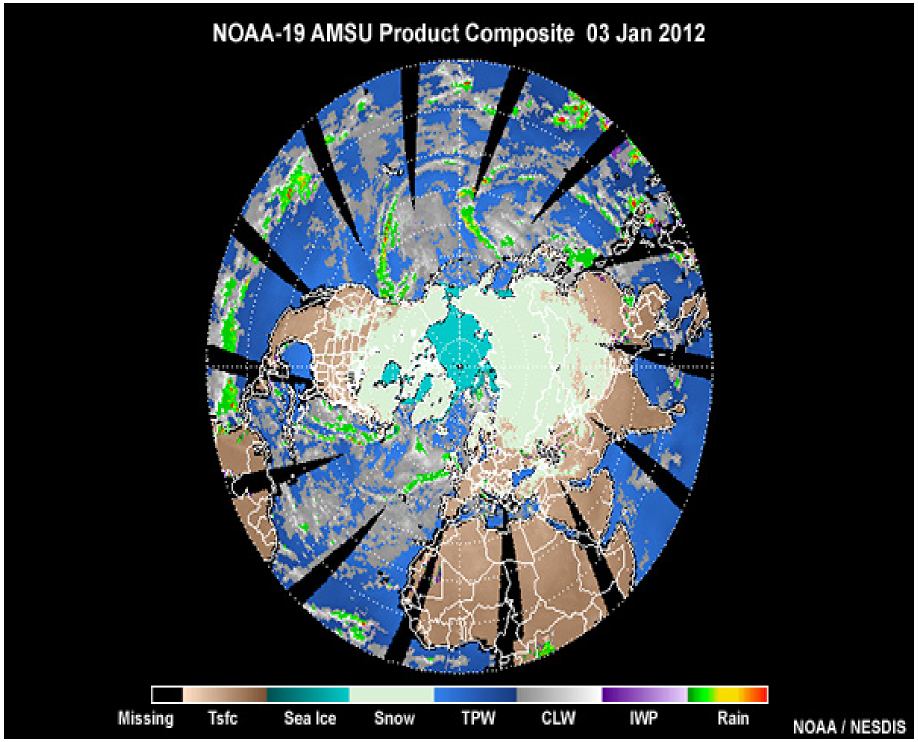
- Footprints get bigger at the edge of an orbit swath

TRMM Instruments

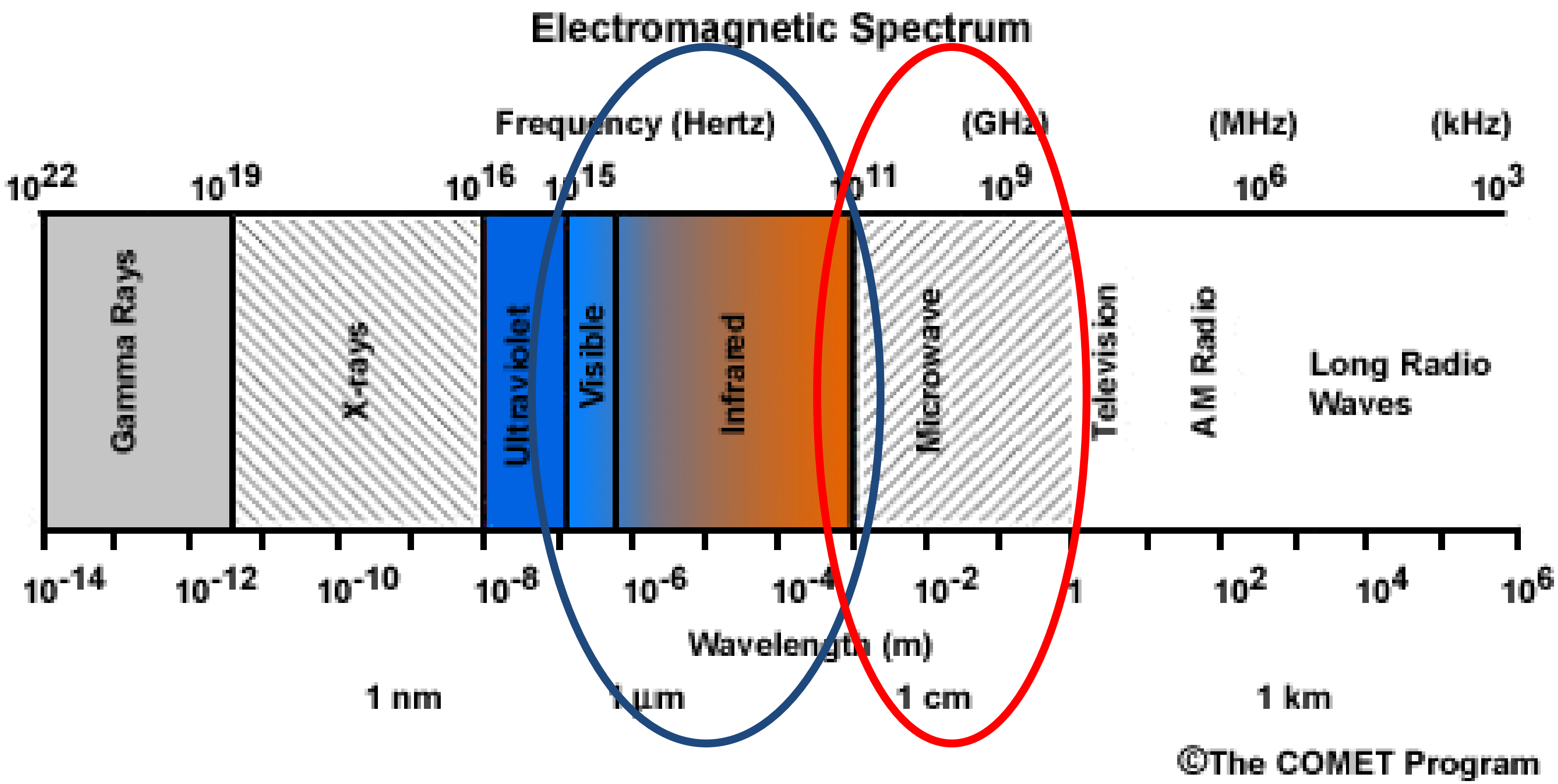


What can Microwave Satellites Measure?

- Ocean Surface Wind Speed
- Sea Ice Concentration, Edge, and age
- Precipitation Rate (Land & ocean)
- Liquid Water Content (Ocean & Land)
- Cloud Water Content (Ocean, land, ice, & snow)
- Atmospheric Vapor Content (Ocean)
- Surface Moisture over land (except heavy vegetation)
- Surface Temperature (many surfaces)
- Snow Water Content, Edge
- Cloud amount (Land & snow)
- Surface Characteristics (type)
- And MORE!



Electromagnetic Spectrum

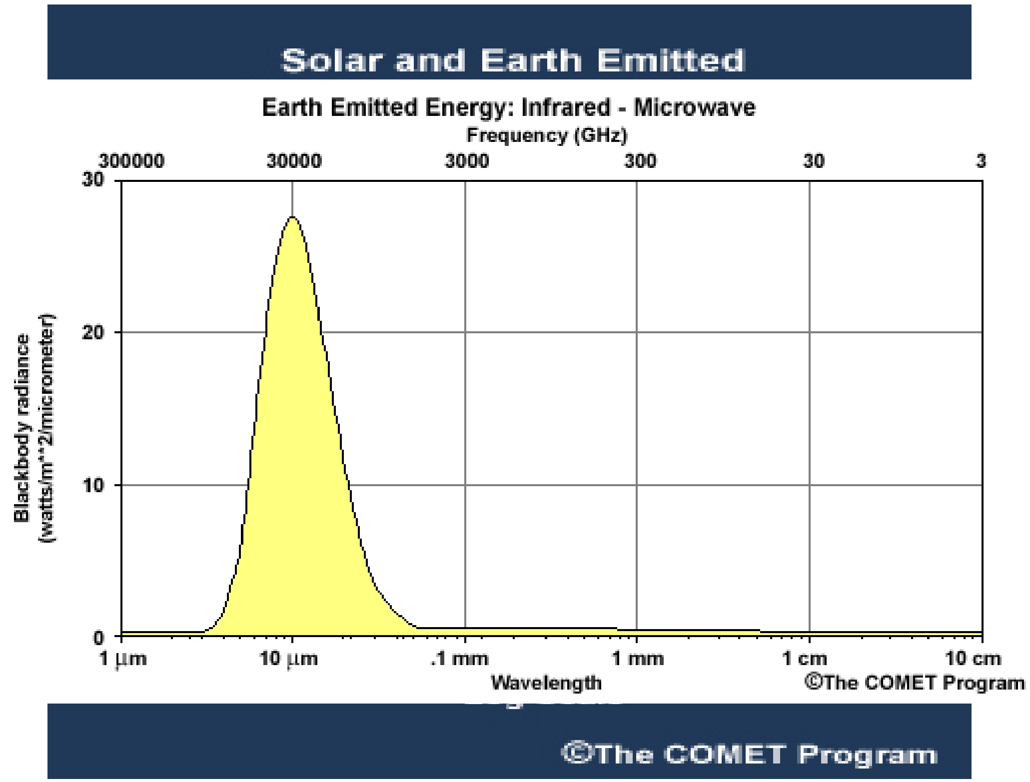


- Microwave instruments sense much longer wavelengths
- Expressed in units of frequency called gigahertz (GHz)

Planck Curve

- Two theoretical limitations to Microwave Imagery:

1) Earth does not emit very much MW radiation, especially at high λ (low freq.)
2) E = hf, so at low frequencies, microwave radiation is harder to detect with from satellites



What do MW satellites detect?

- MW satellites detect Brightness Temperature, just like IR Satellites
- The difference is that instead of measuring the temperature of the cloud tops (10.7 μm IR) or water vapor (6.7 μm WV), the MW satellites usually measure

  - Cloud droplets

  - Rain droplets

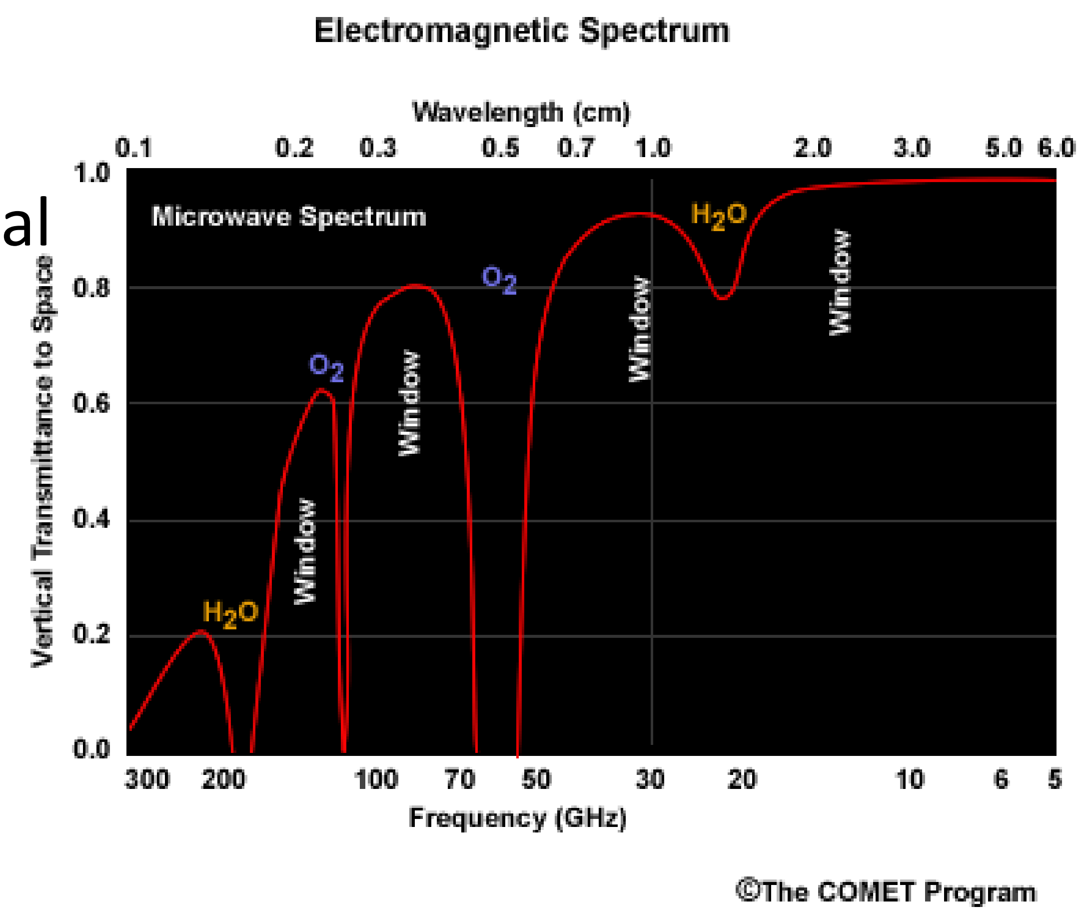
  - Ice/Snow/Hail

Emission vs Scattering

- Upward emission increases the Brightness Temperature measured by the satellite
- Good emitters:
  - Ocean and land surface
  - Rain droplets
- Scattering reduces the Brightness Temperature measured by the satellite
- Particles that scatter strongly:
  - Snowflakes
  - Hail
  - Graupel
- The exact interaction depends on both the frequency/wavelength and the size of the rain drop/ice particle.

Transmittance in MW Spectrum

- O_2: Ideally suited for atmospheric temperature sounding ----not useful for tropical cyclones
- H_2O: Rotational spin widened by pressure broadening at 22 GHz-useful for WV
- High transmittance "Windows" at 37 and 85 GHz-useful for precipitation



37 and 85 GHz Channels

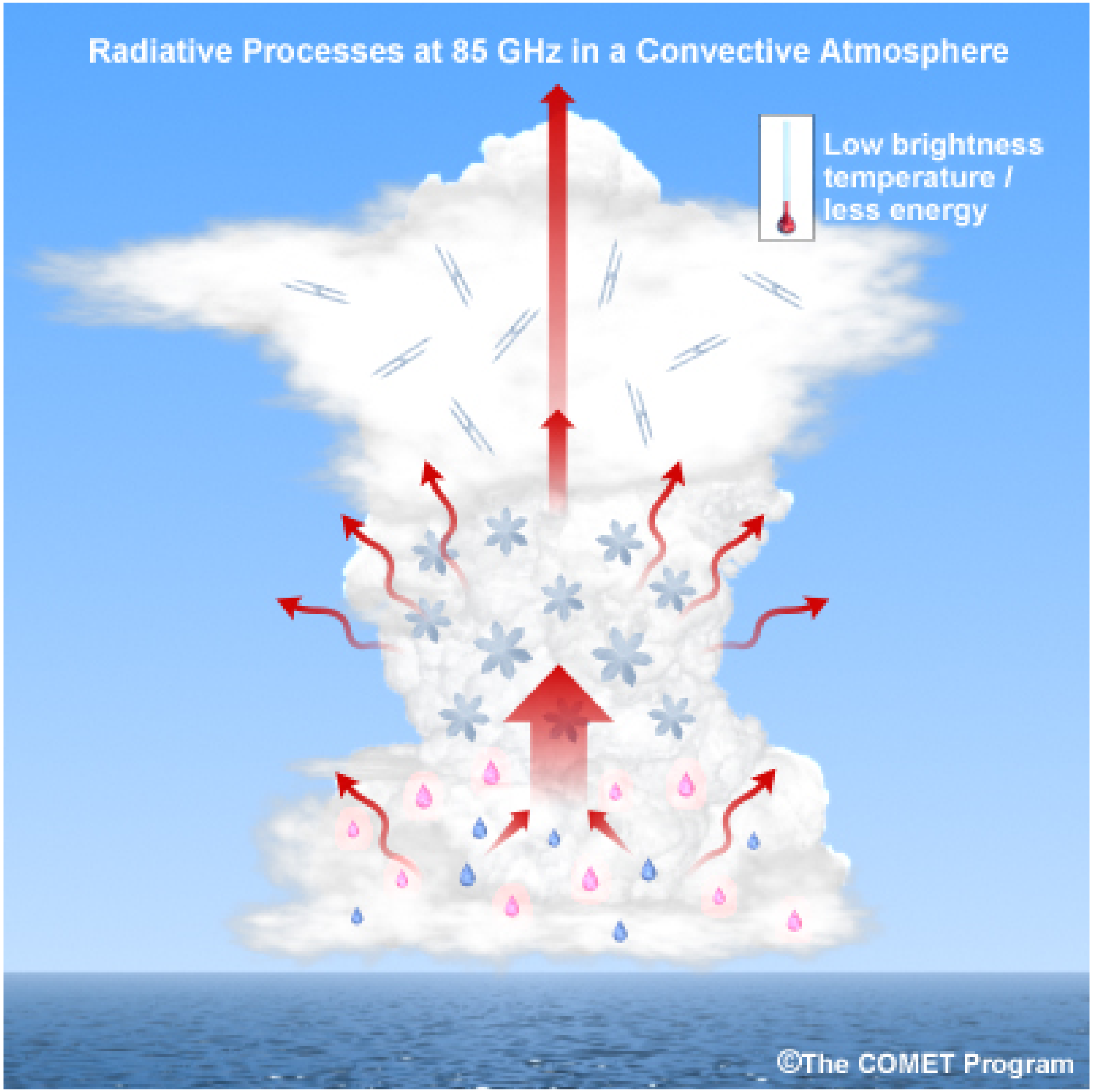
- 37/85 GHz frequencies chosen to avoid atmospheric gas absorption bands
- Both channels can see difference between land and ocean
- 37 GHz sees both emission from rain and cloud droplets and scattering from large ice particles (hail/graupel)
- 85 GHz mostly sees scattering from ice particles, also sees some emission from low level water vapor
- Channels with lower frequencies (7,10,19 GHz) are useful for other applications, but they have too low of a resolution to be used independently for Tropical Cyclone applications

85 GHz Channel

- Most noticeably detects scattering from **ice crystals** high in convective clouds
  - T_B as low as 150-200 Kelvin in thunderstorms
  - More ice = colder T_B = stronger convection
- In regions with no ice clouds, detects a very weak emission signal from liquid rain
  - T_B as warm as 280 K in rain showers without ice
- In clear sky regions, detects temperature of Earth's surface
  - Ocean surface T_B = 250 K for H, 280 K for V
  - Land surface T_B = 280 K or so

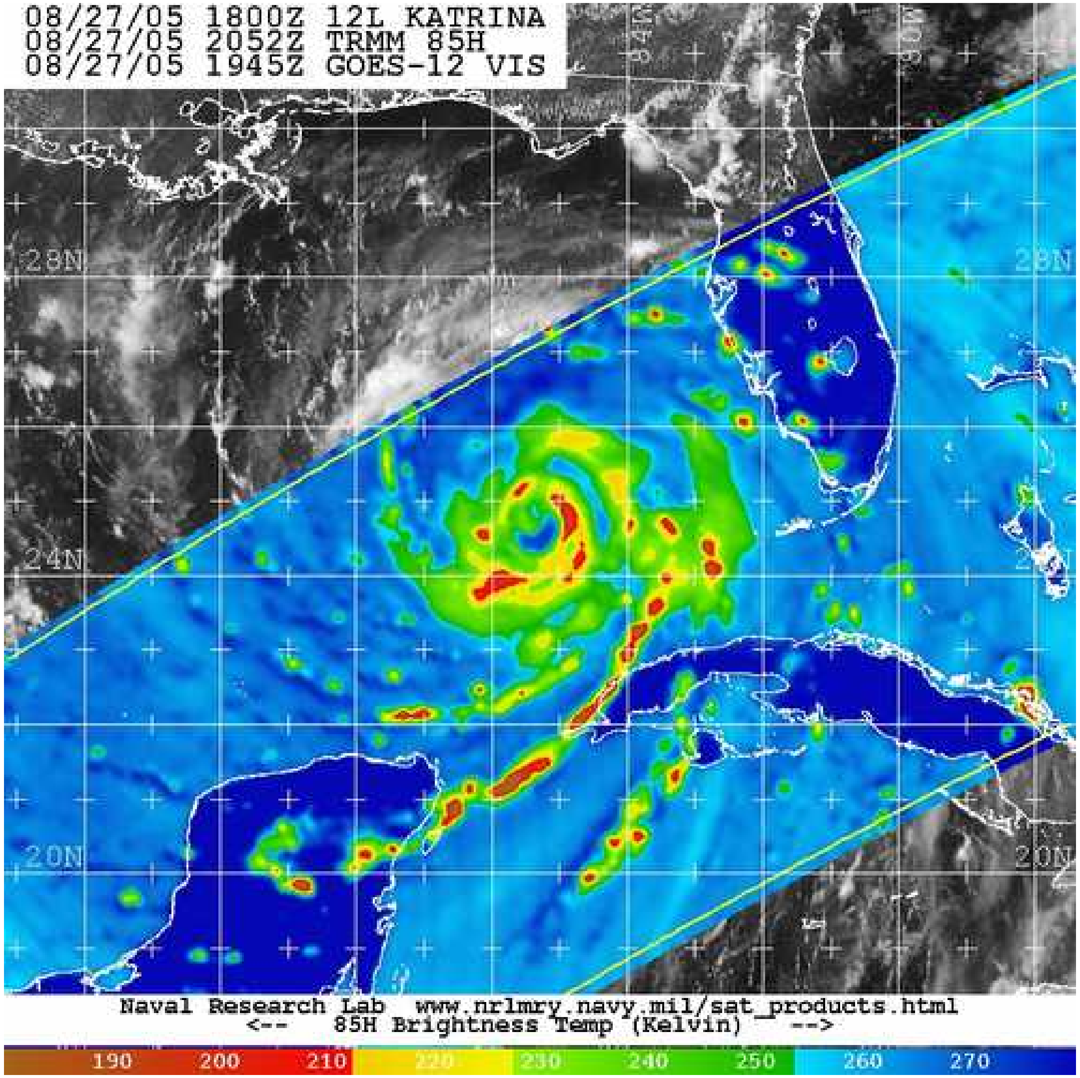
If there are ice particles in the cloud, the upwelling radiation is scattered away in all directions and does not reach the satellite.

Liquid cloud water, water vapor, and ocean surface all emit radiation upward.



TRMM 85 GHz T_B (Horizontal Polarization)

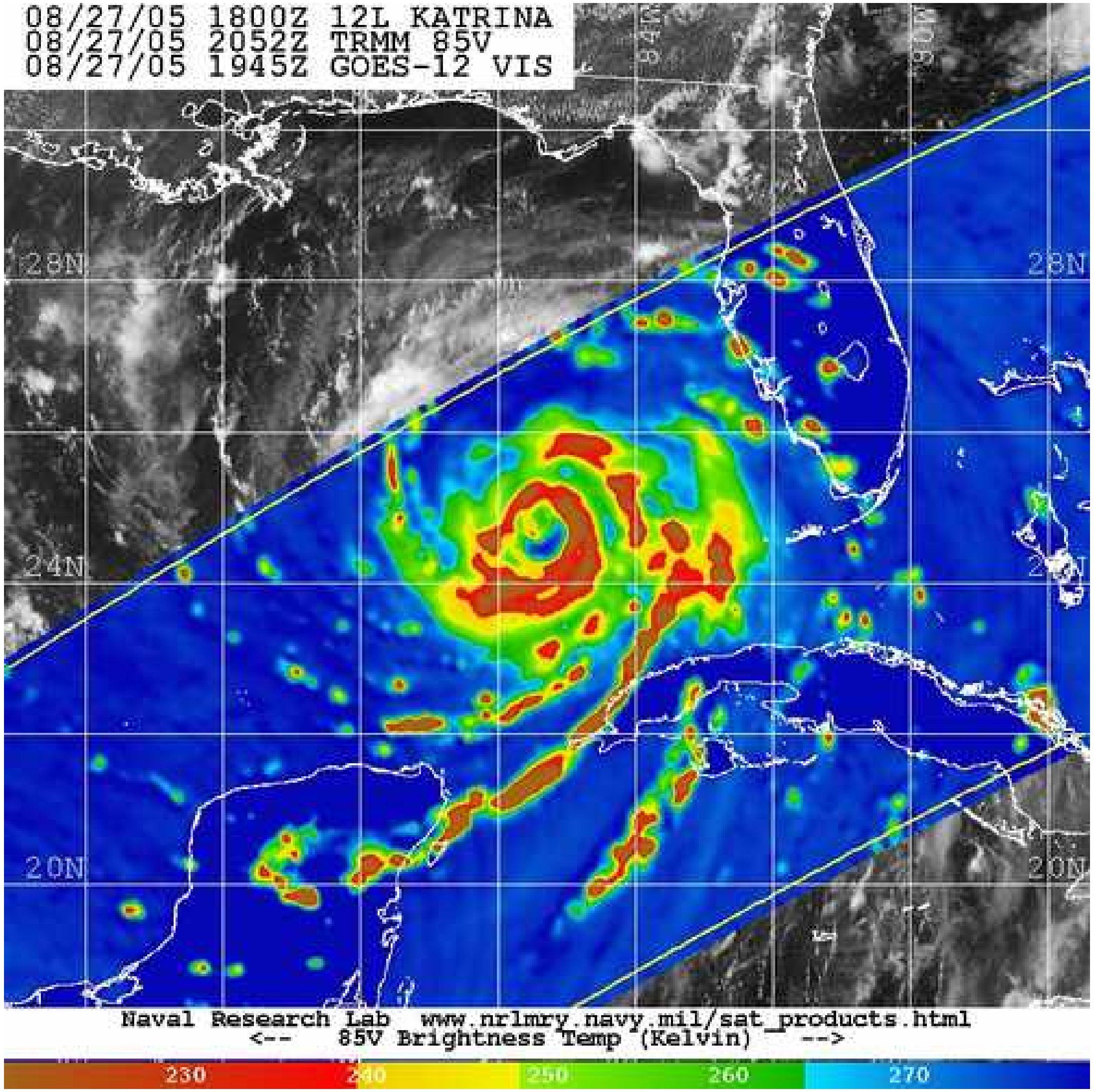
- Land = Warm
- Ocean = Slightly cooler
- Low clouds and moisture = Warm
- Ice/Snow = Very cold



* Note inverse scale!!!

TRMM 85 GHz T_B (Vertical Polarization)

- Land = Warm
- Ocean = Warm
- Ice = Very cold
- Can not see low clouds or moisture

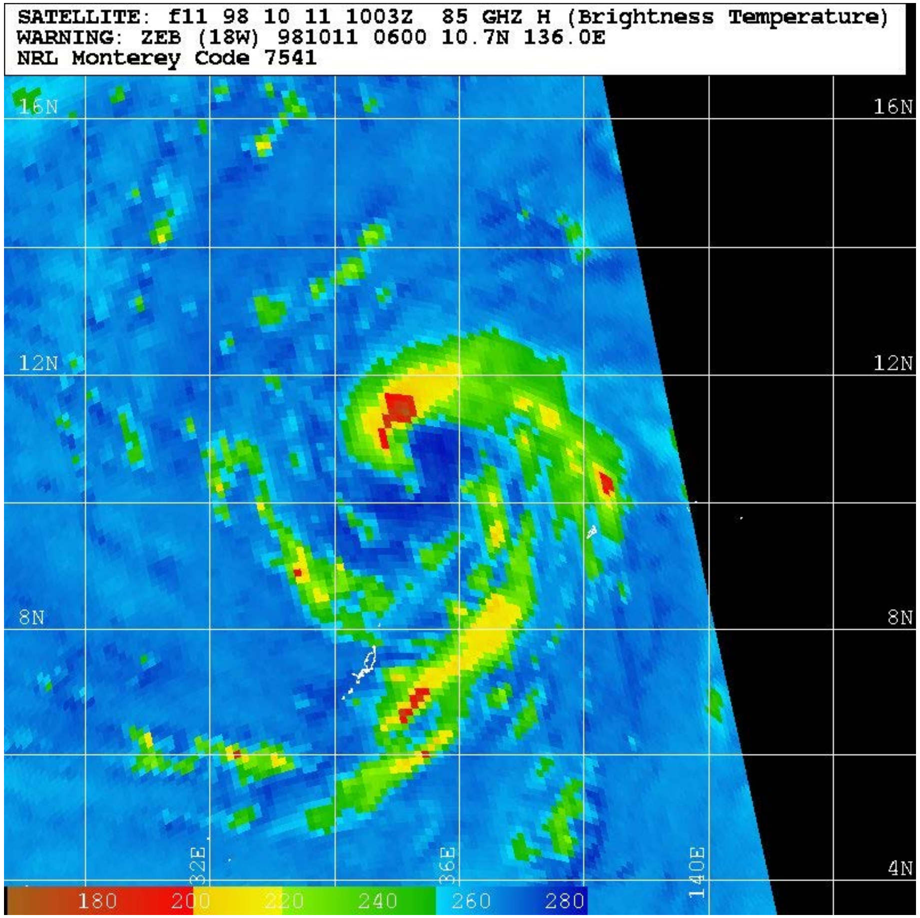


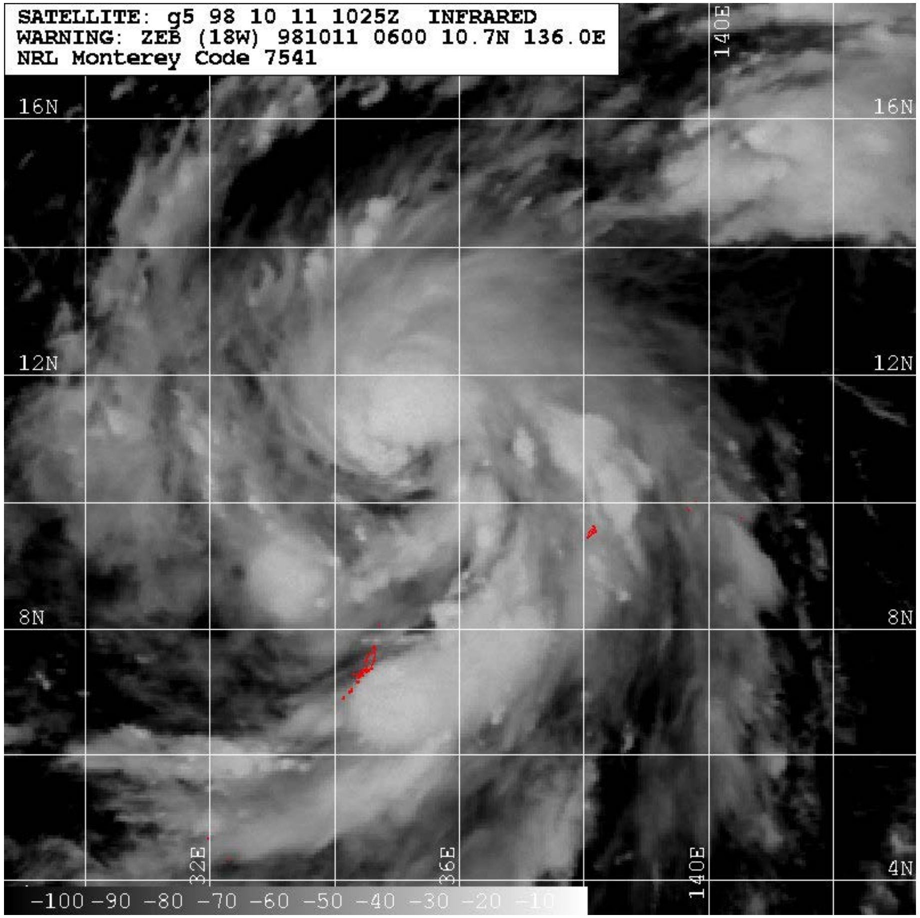
* Different scale than 85-H

Polarization

- Definition: an object is polarized if its EM-Waves have a preferred direction of orientation
- Land surface not polarized, appears uniformly warm on both Vertical & Horizontal channels
- Ocean surface highly polarized, emits more radiation in Vertical direction
  - Vertical emissivity = 0.6, Horizontal emissivity = 0.4
  - Result: ocean appears colder in H channel than V
- Ice crystals are not polarized at all, appear uniformly cold in V and H channels
  - Note: the NRL TC page has different color tables for the V and H channels

85 GHz H vs. 10.7 µm IR

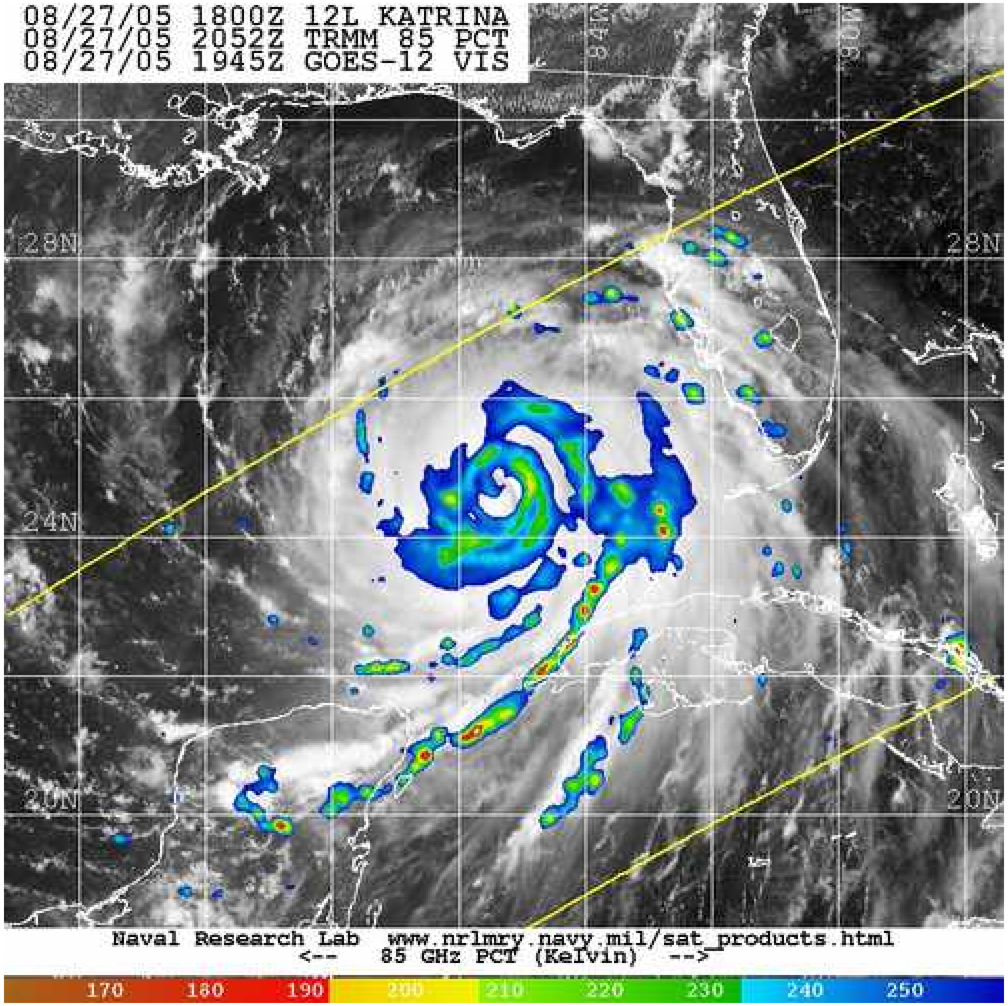




- Lower-level moisture = dark blue
- Partial eyewall= yellow/red curved band to the N of center

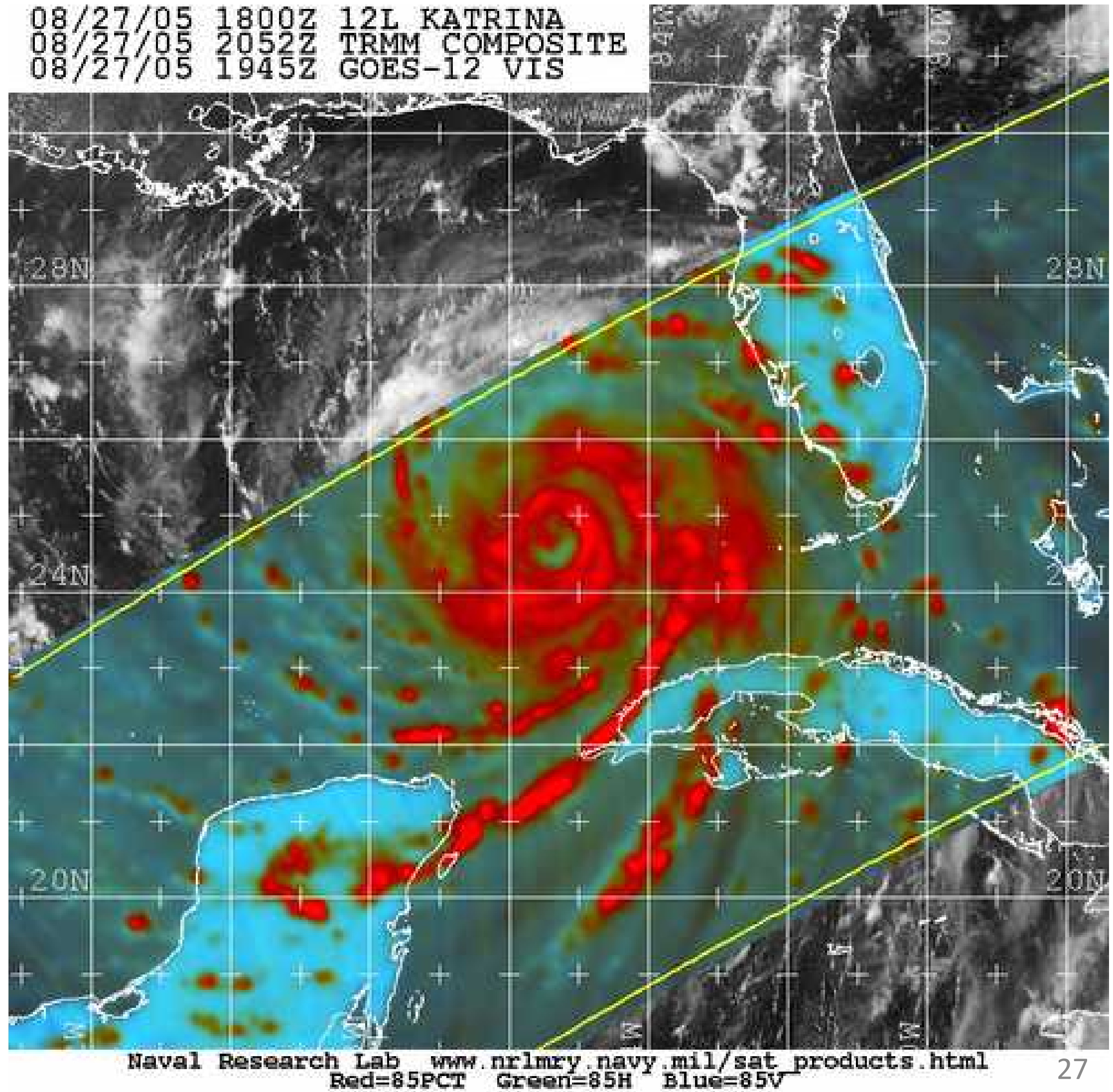
85 GHz Polarization Corrected Temperature (PCT)

- Combines 85 GHz V and H channels to remove the interference from the surface
- Disadvantages: also removes light rain – only areas with strong ice scattering remain

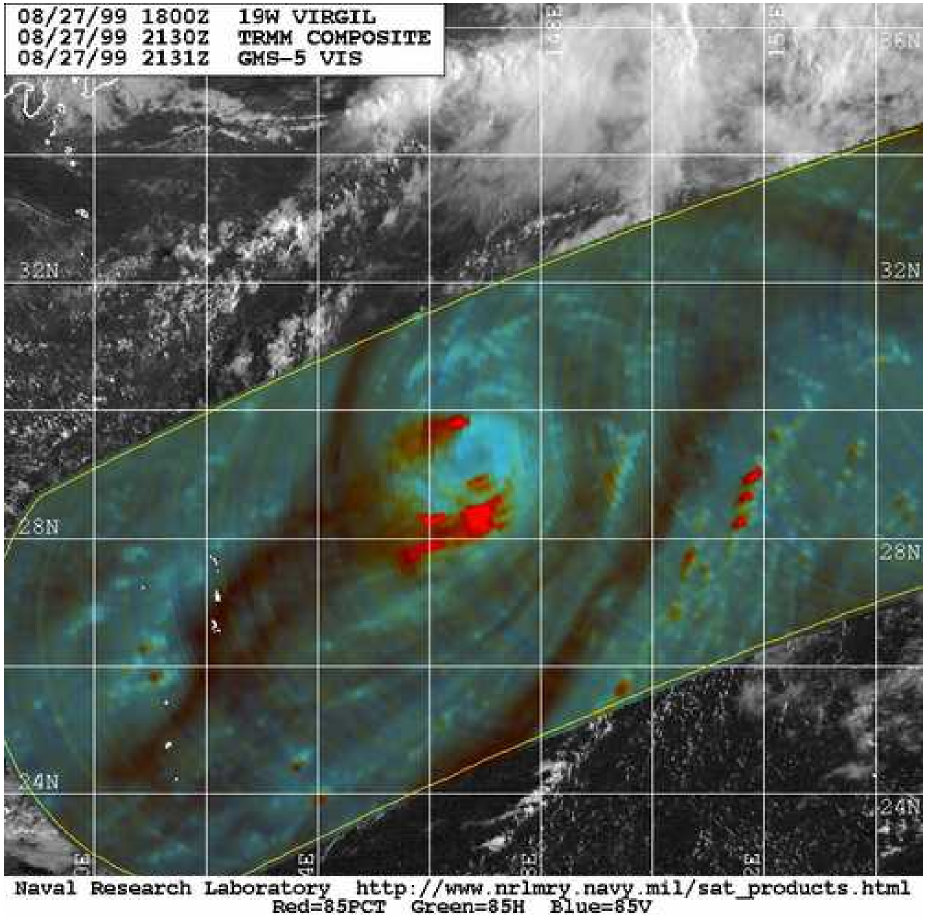


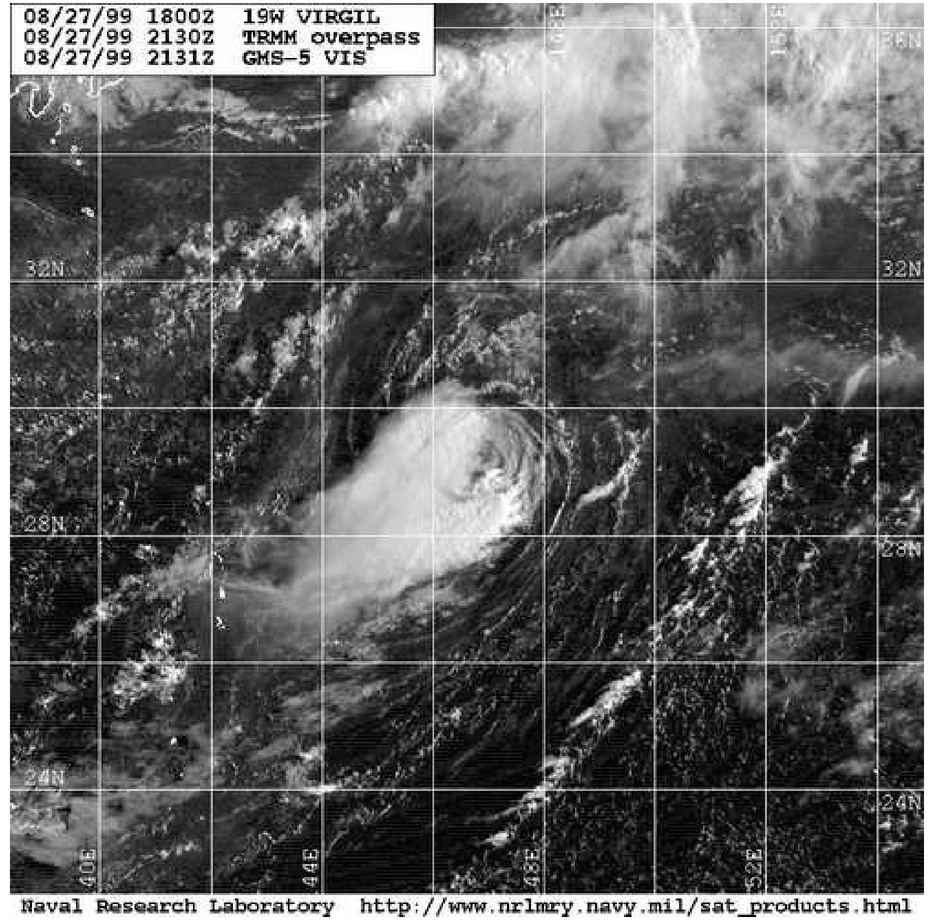
85 GHz Color Enhancement

- Red = deep convection
- Blue-green = low-level clouds, water vapor, and warm precipitation
- Gray = dry
- No color scale, uses and RGB combination



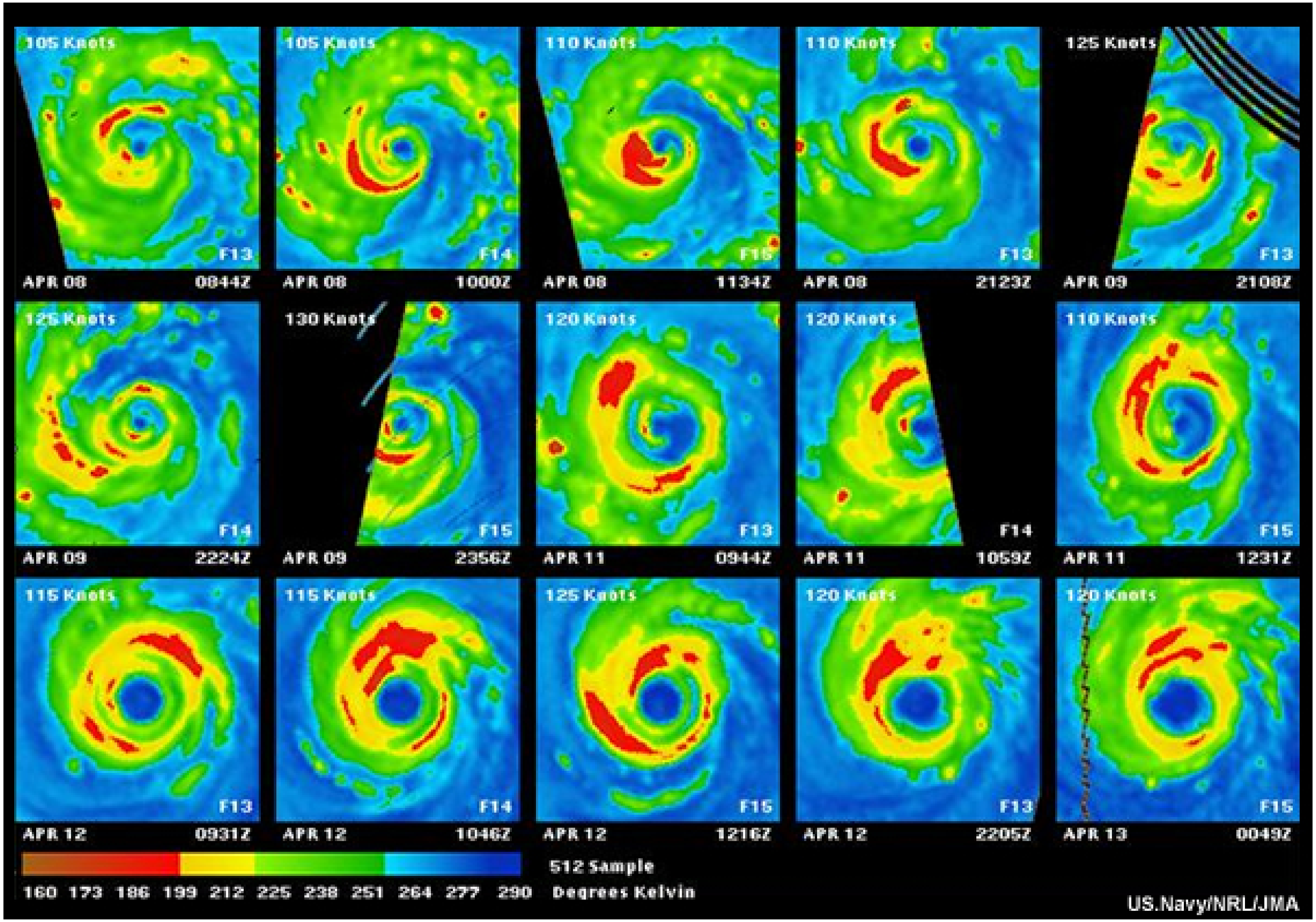
85 GHz color vs. Visible





- Deep convection = Red
- Low-level swirl = Blue-Green

Eyewall Replacement Cycle (85 GHz H)



85 GHz Limitations

- 85 GHz sees mostly ice, which is located high up in the troposphere, not near the surface

  - If there is ice above, there is not necessarily rain below, especially if there is strong wind shear or if the convection is decaying

- 85 GHz can't see warm rain

  - This is a big limitation in weaker storms, sometimes it is much easier to see the structure in 37 GHz

85 GHz Applications

- You want to know…

<u>1. Whether or not a storm has partial/concentric eyewalls:</u>

- Use 85 GHz H

<u>2. The details of the structure of the rain bands</u>

- Depends, usually 85 H is better for stronger storms (hurricanes), 37 color is almost always better for weaker storms

<u>3. What about the 85 GHz color (red) images?</u>

- Although they look cool, the color imagery sacrifices quantitative information and usually doesn't show anything that you can't find on the 85 GHz H (although there are a few exceptions)

37 GHz Channel

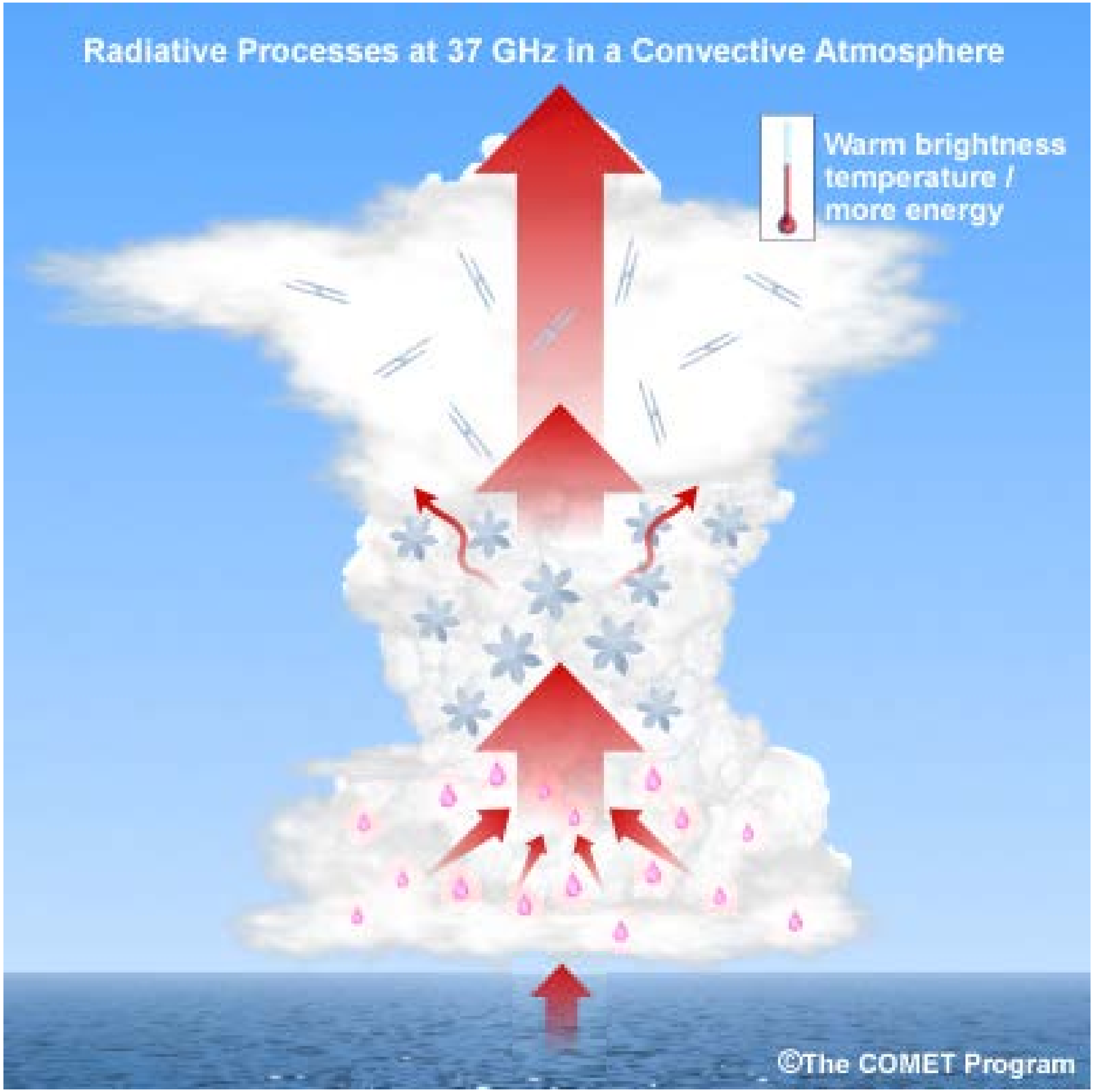
- Most noticeably detects **liquid rain** in the lower levels of the atmosphere
  - T_B ranges from 210-270 K in rain bands
  - Heavier rain= **warmer** T_B compared to ocean surface
- In regions with no rain, detects emission of land or ocean
  - Ocean surface T_B = 150-170 K for H, 220-230 K for V
  - Land surface T_B = 270-280 K or so
- Opposite of 85 GHz channel—**rain bands are warmer than the ocean surface**.

But wait…how can the rain drops appear warmer than the ocean surface?

- Remember, Brightness Temperature is not always equal to actual Temperature
- **T_B = Emissivity * T**
- At 37 GHz:
  - Emissivity of Ocean = 0.4
  - Emissivity of rain= close to 1.0
- So while the **actual temperature** of rain is colder than the ocean, the satellite measured **brightness temperature** of rain is warmer than the ocean at 37 GHz.

Unlike 85 GHz, only very large ice crystals cause measurable scattering

Warm raindrops in cloud emit MW radiation upward, more so than the ocean by itself



TRMM 37 GHz T_B (Horiz. Polarization)

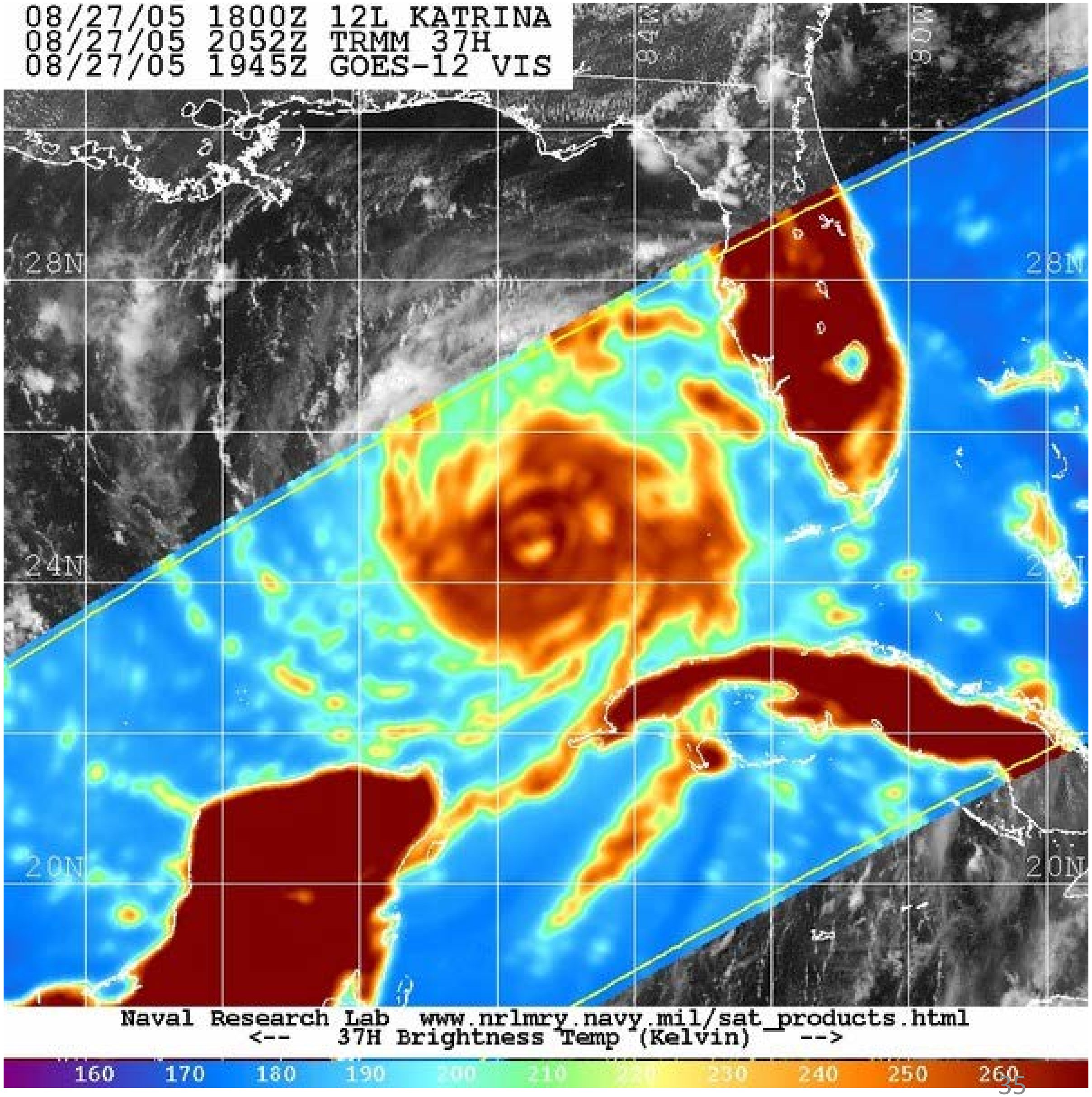
-Land = Warm

-Ocean = Cold

-Rain = Warm (red)

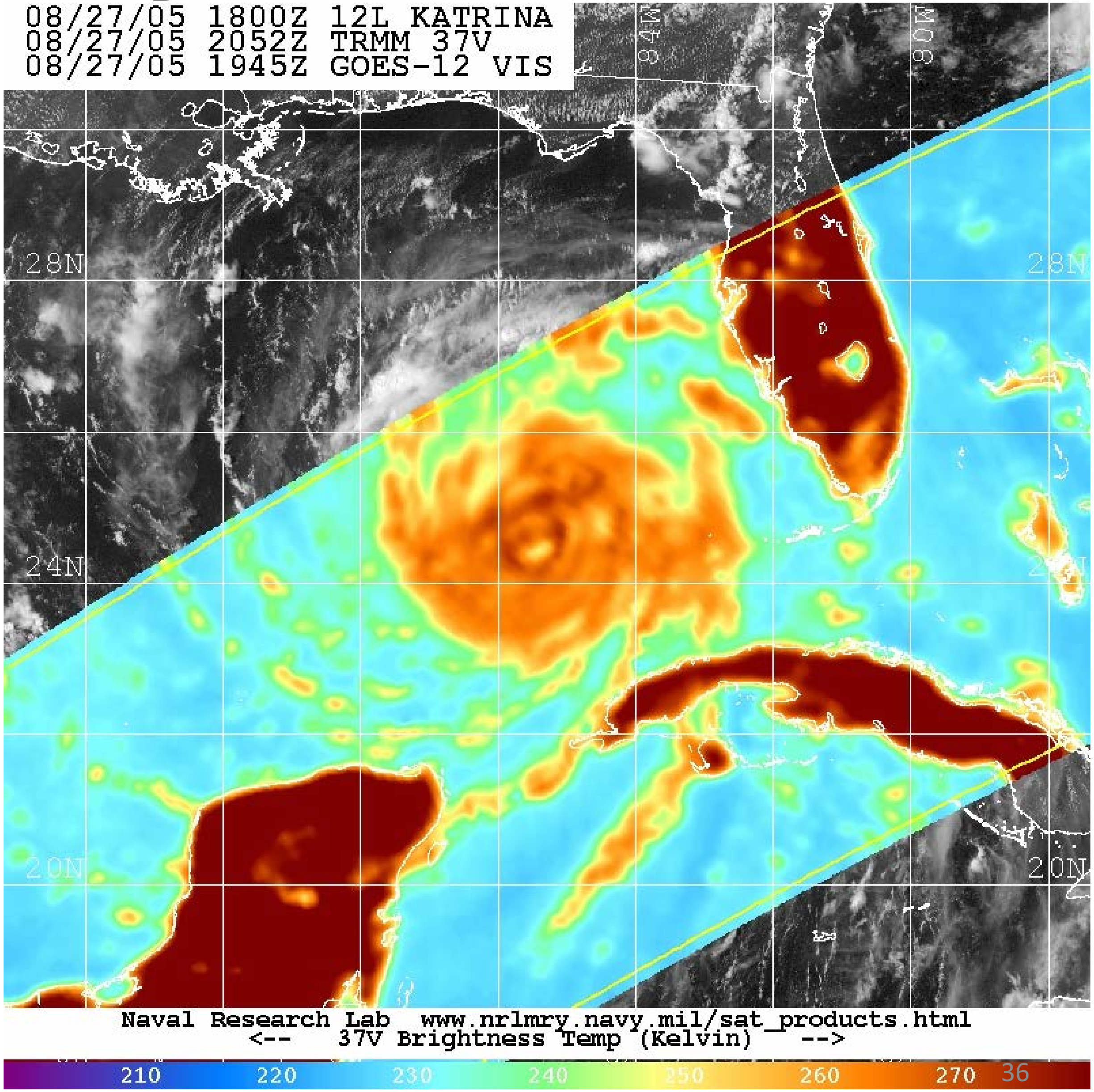
-Light rain = Cool (Green)

-Can not see details of heavy rain or ice scattering



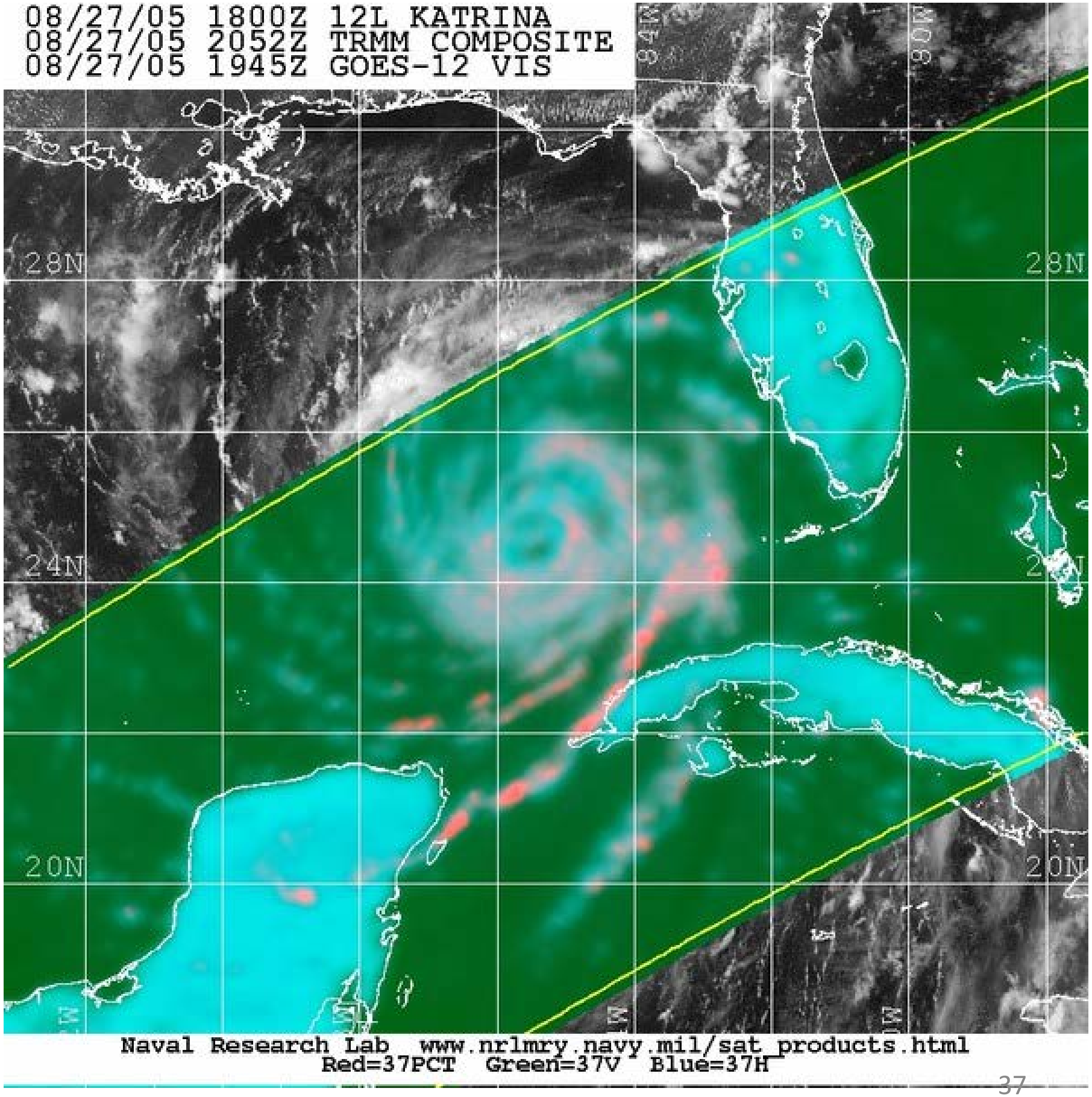
TRMM 37 GHz T_B (Vertical Polarization)

- -Land = Warm
- -Ocean = Not as Cold
- -Rain = Warm
- -Light rain = Hard to see
- -Can not see details of heavy rain or ice scattering



37 GHz Color Enhancement

- Solves problem with differentiating between light and heavy rain in 37 H image
- Green = sea surface
- Cyan = land and light rain
- Pink = heavy rain/deep convection



37 GHz Color (continued)

- Advantages:

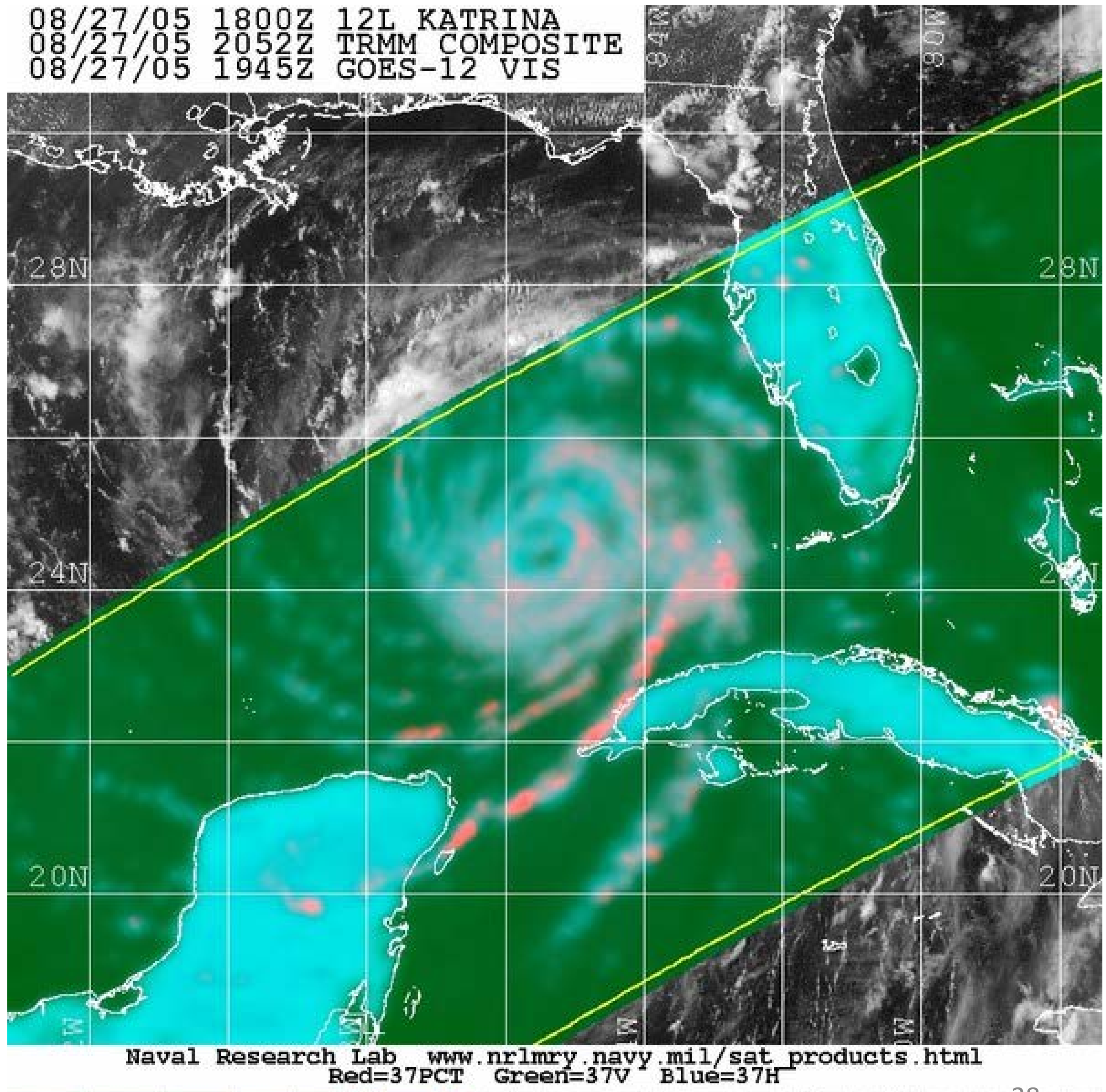
-Shows good contrast between light and heavy rain

-Can see eyewall forming earlier than other methods

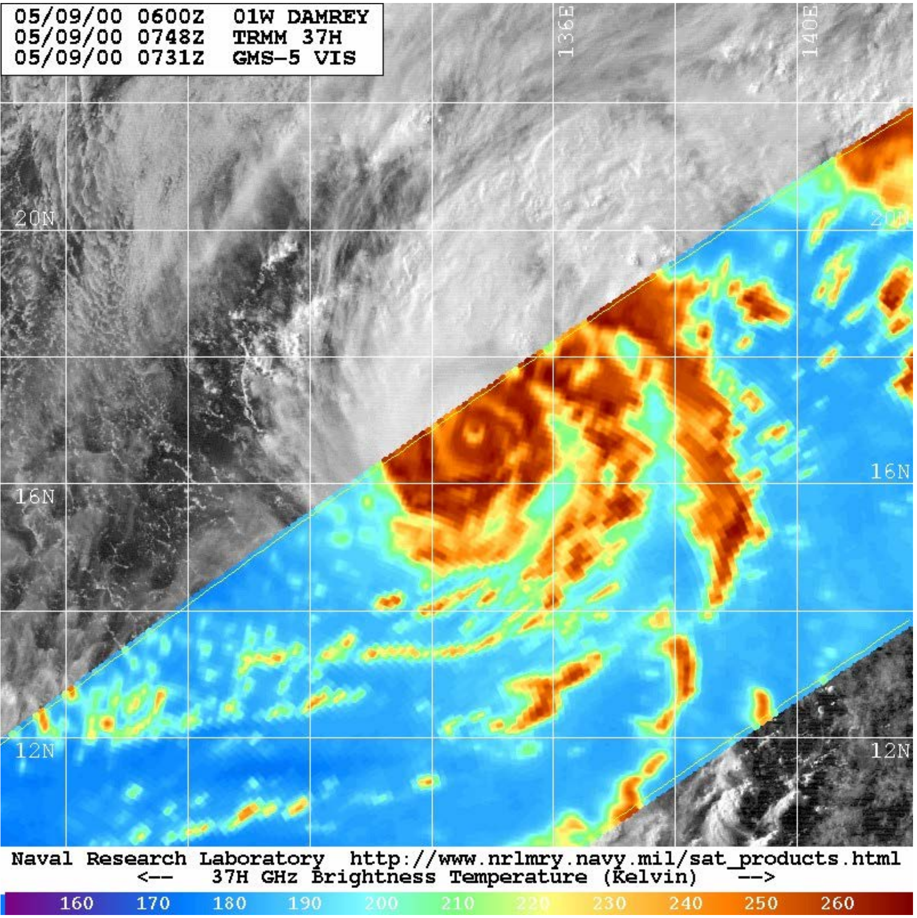
- Disadvantages:

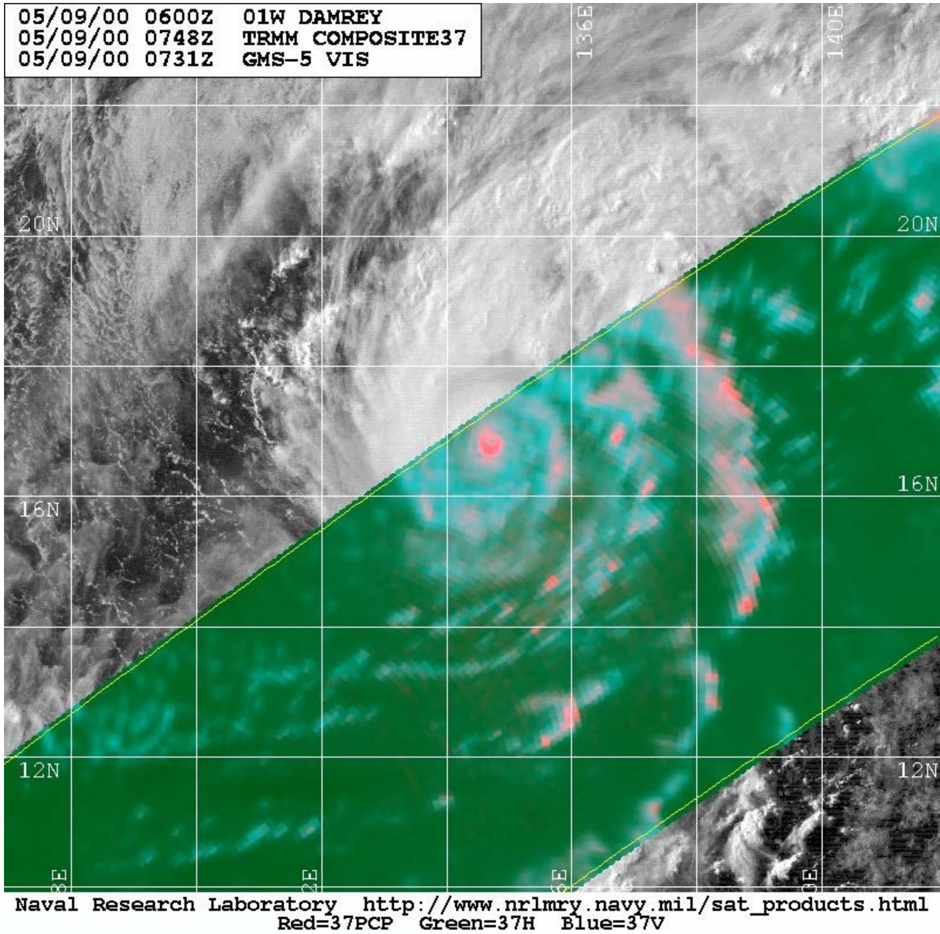
-37 H is better for very light rain

-Does not work over land



37 GHz H vs. 37 GHz Color



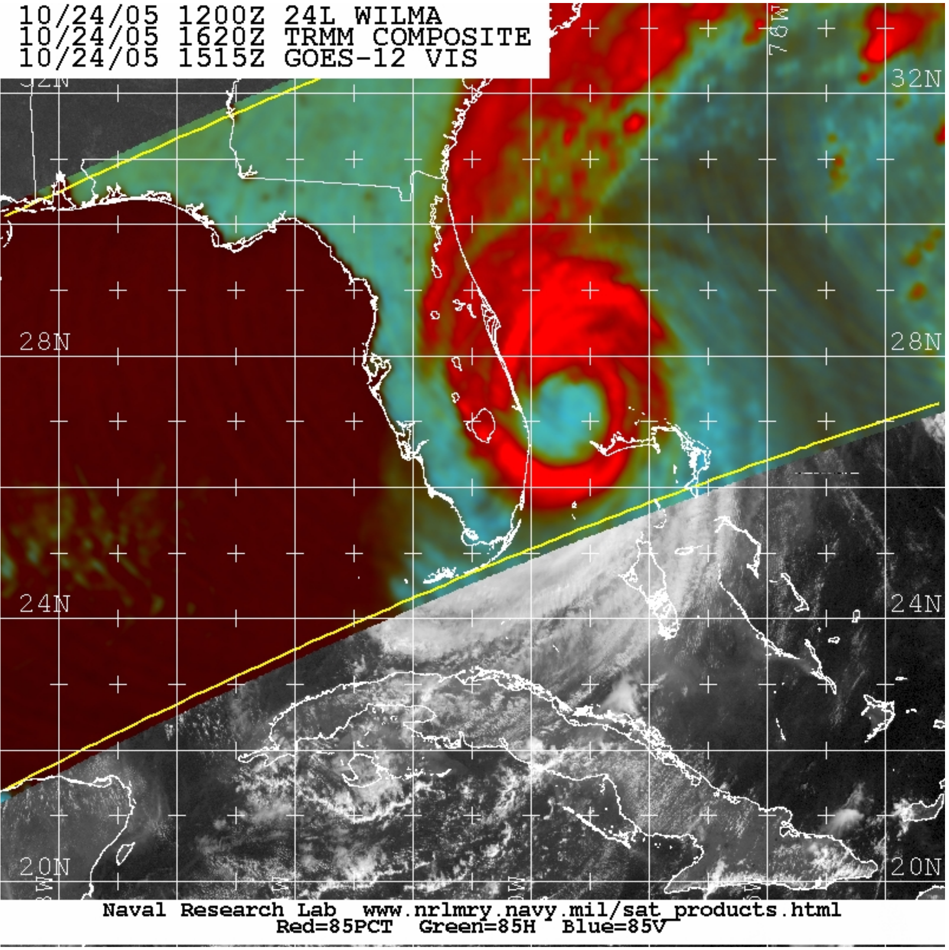


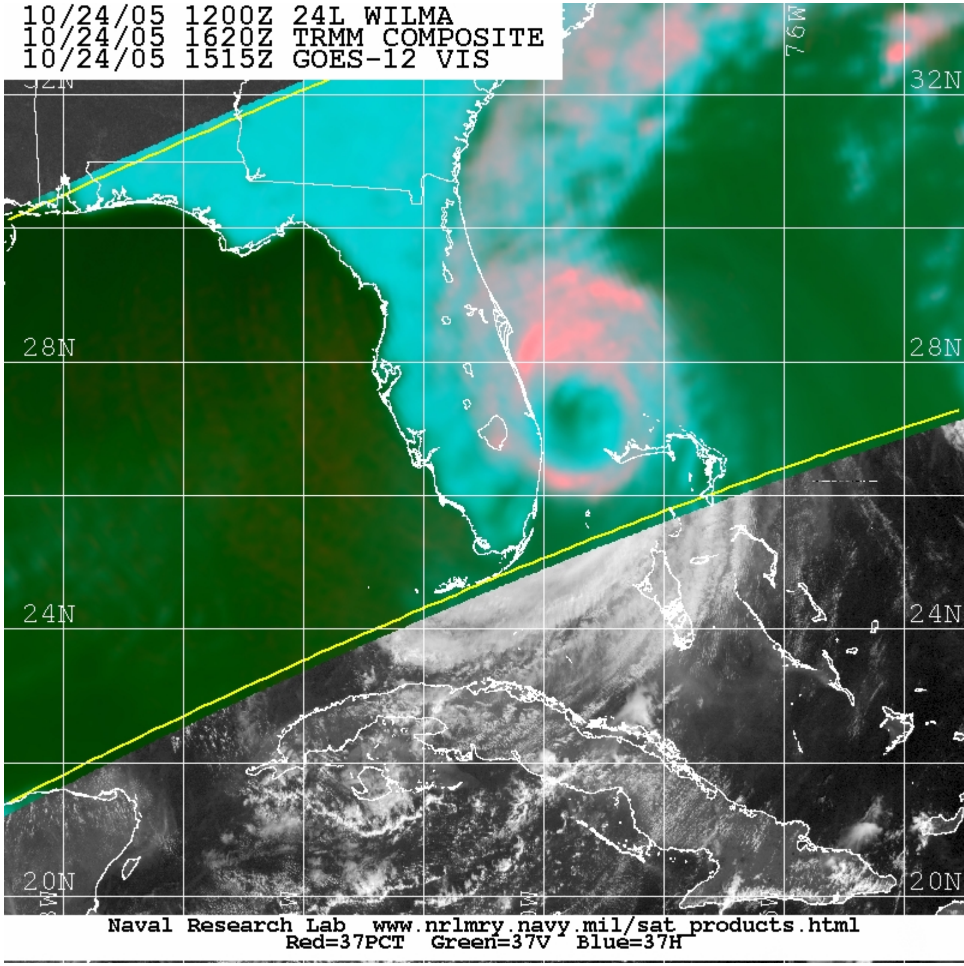
-All rain looks brown in 37-H, but it is easy to distinguish convective eyewall in 37 Color

37 GHz Applications

- You want to know…
  1. Whether a storm is beginning to develop an eye or banding/eyewall features:
     - Usually use 85-H
     - If wind shear or too much ice scattering, use 37-Color
  2. If a TC or TC region has deep convection or shallow convection:
     - Use 85 GHz Color or 37 GHz Color
  3. The details of the structure of the rain bands below the freezing level:
     - Use 37 GHz Color
     - Use 37 GHz-H for light rain, such as a weakening TC

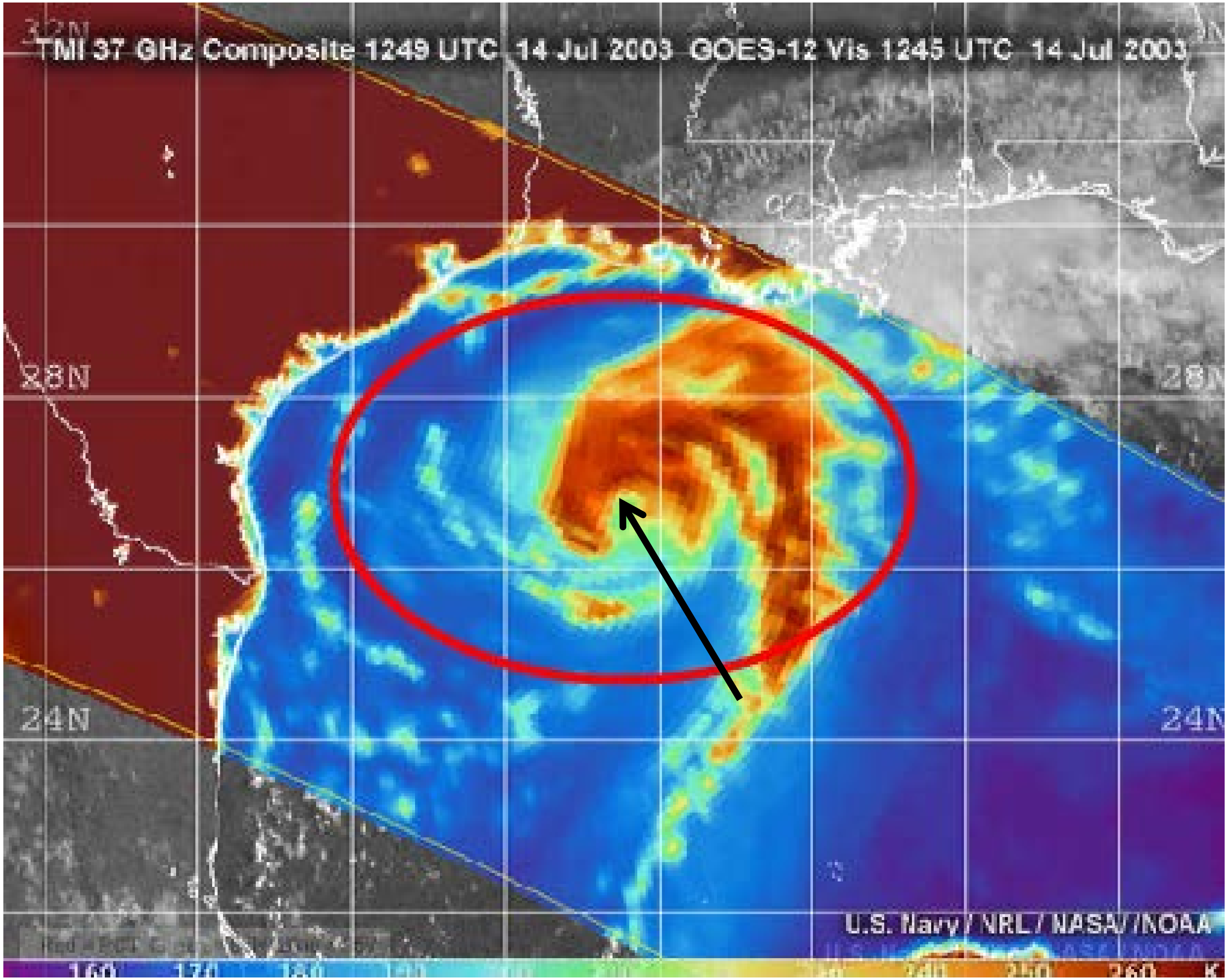
85 Color vs. 37 Color



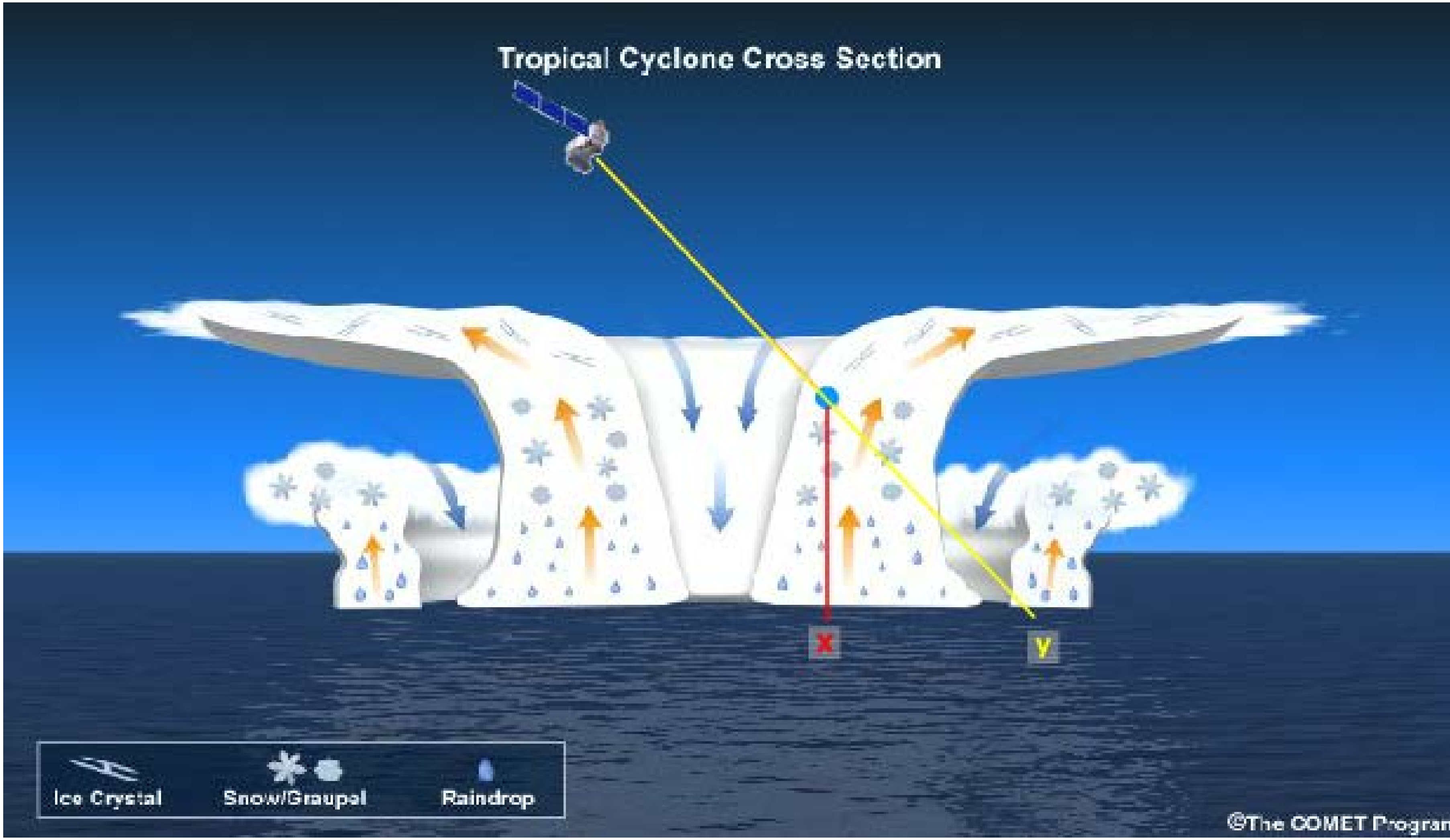


- 37 Color ineffective over land
- Besides that, they are quite similar

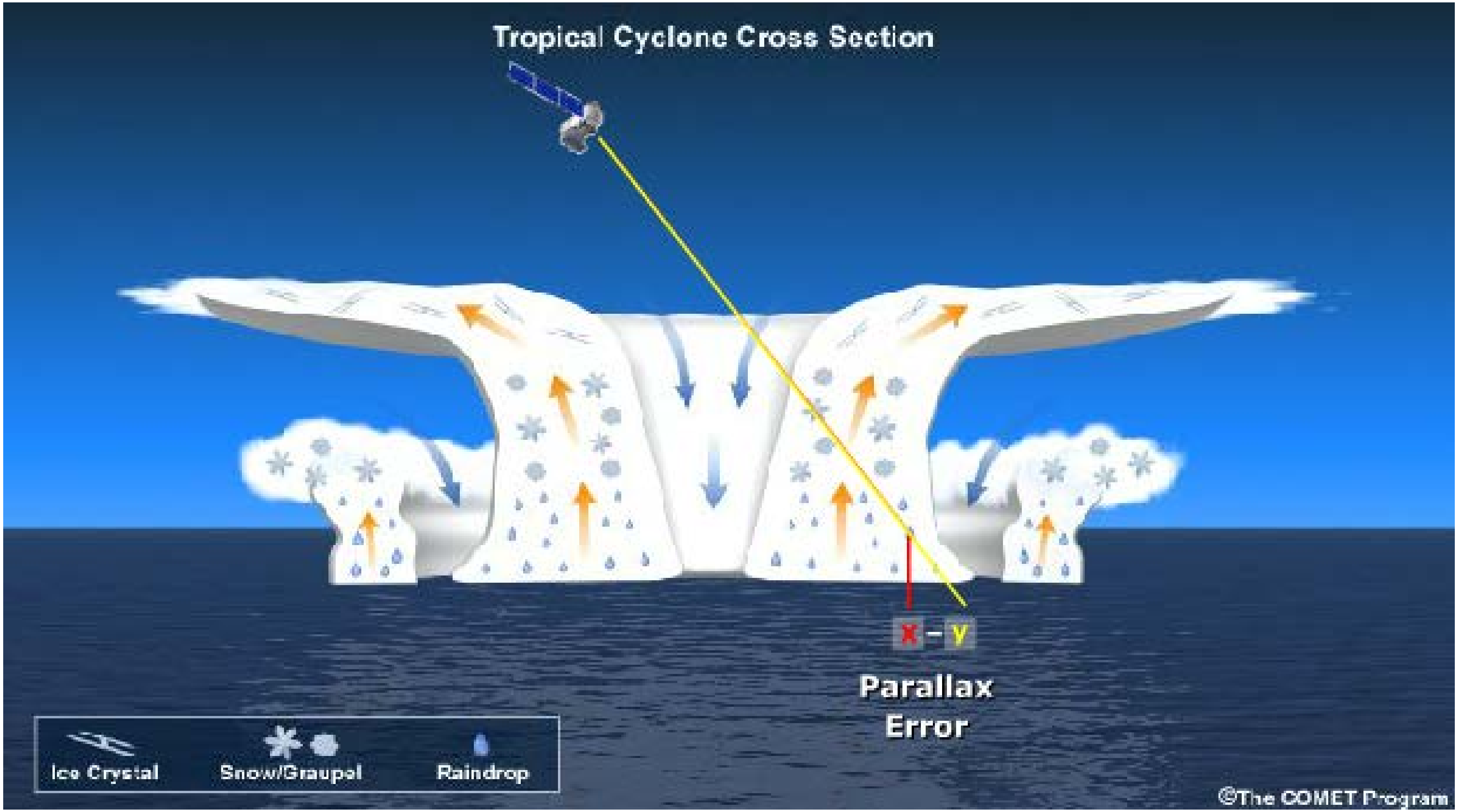
Where is the eye?



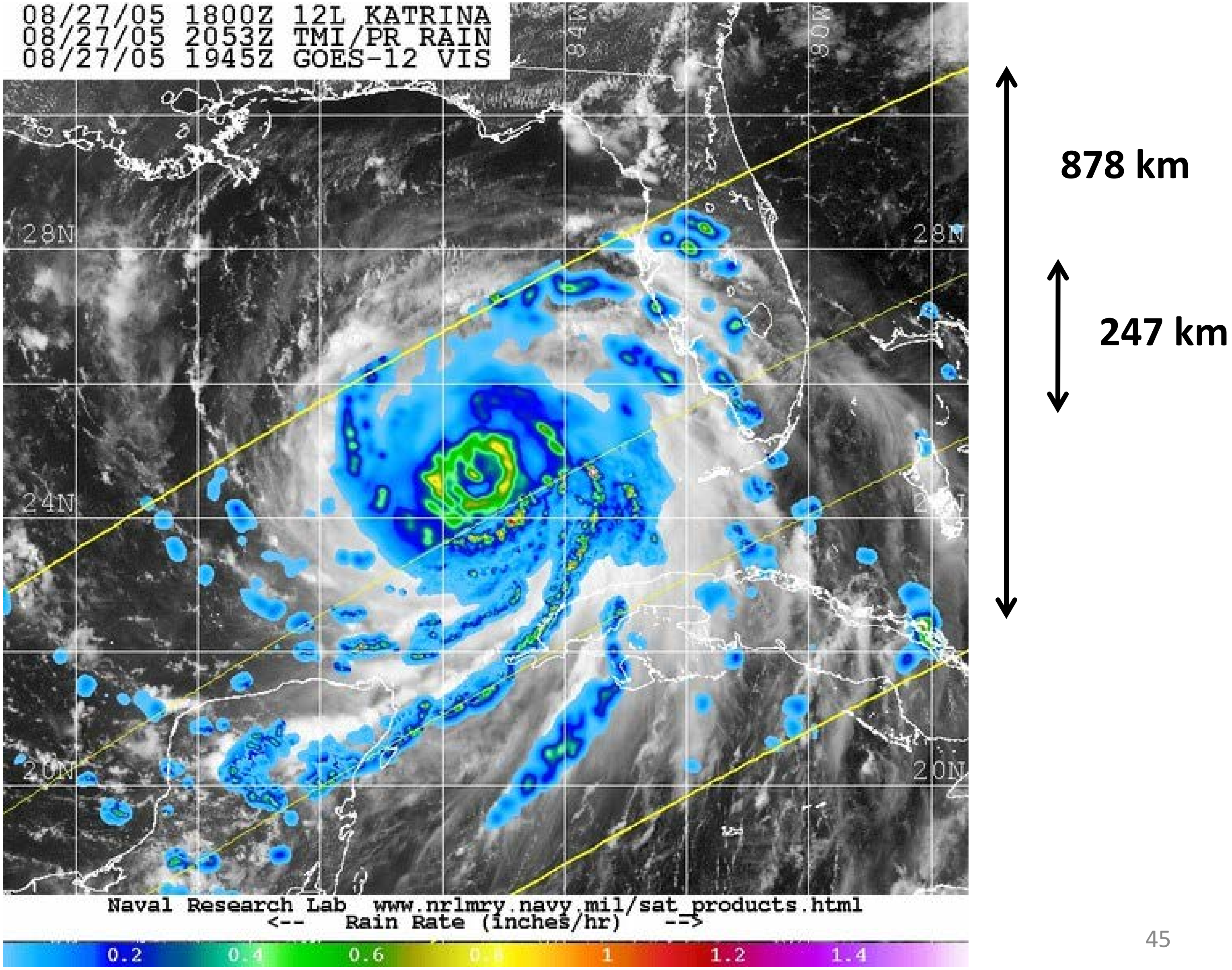
Parallax Error in 85 GHz Channel



Parallax Error in 37 GHz Channel

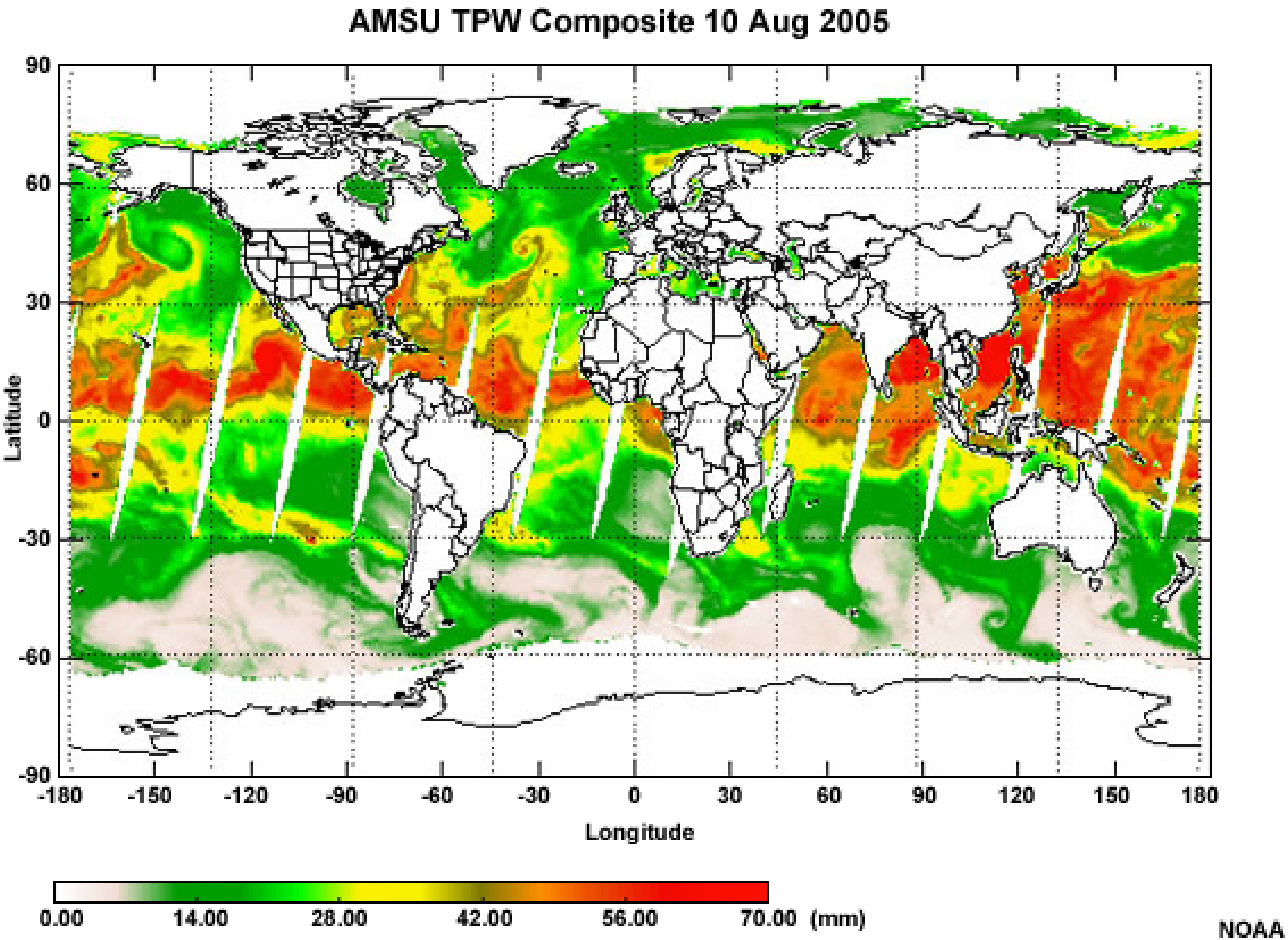


Rain Rate: PR (center) and TMI (outer)



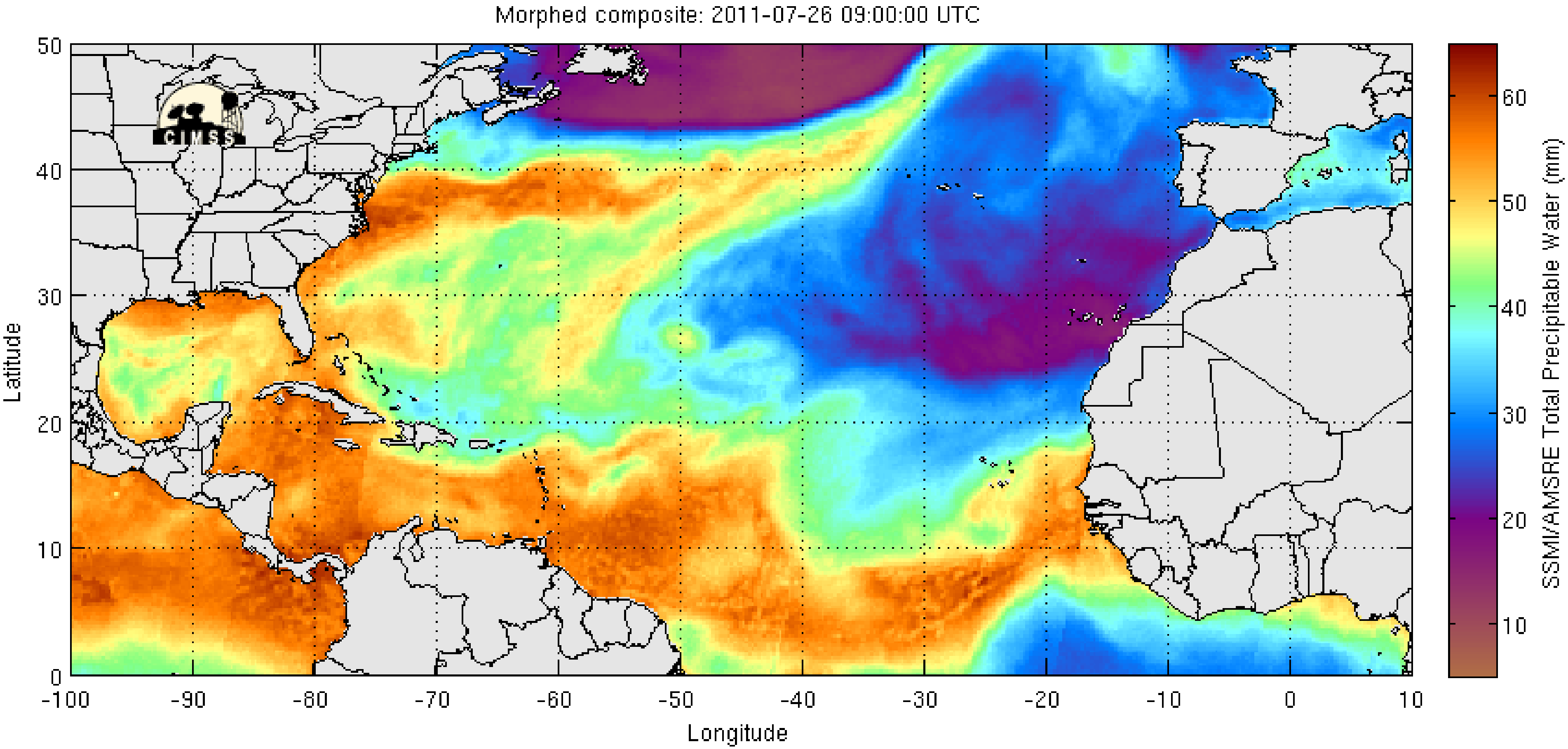
Total Precipitable Water

- Definition: a microwave product that represents the depth of liquid water that would be accumulated if all the water vapor in a hypothetical cylinder above a location on the earth were condensed into an equivalent amount of liquid water.
- Most water vapor is concentrated in the lower atmosphere
  - 6.7 μm Water Vapor channel only sees upper atm.



- Considered to be as accurate as a weather balloon

TPW Multi-Satellite Composite



- Which regions are favorable for TC development?
- What is that giant mass of dry air to the west of Africa?

Saharan Air Layer (SAL)

- Very deep pool of dry and dusty air, extends from the surface up to mid-levels (500 mb)
- Advected to the west over the Atlantic by Easterly Waves
- Lower levels are moistened by ocean, mid-levels maintain warm, dry, stable structure across entire Atlantic
- Size: sometimes as large as the continental US
- Responsible for periods of colorful sunsets in Miami and a surprising portion of our topsoil

SAL Impact on TCs

- Extremely unfavorable due to dry air, convection is suppressed or quickly dissipated
- Can completely prevent tropical cyclogenesis
- Can wrap into a mature hurricane and cause significant weakening
- SAL is often accompanied by an easterly jet stream moving 20-45 knots.
  - Causes significant wind shear in addition to suppressing convection
  - Moves fast enough to catch TCs that may otherwise be unaffected

GOES Detection of the SAL

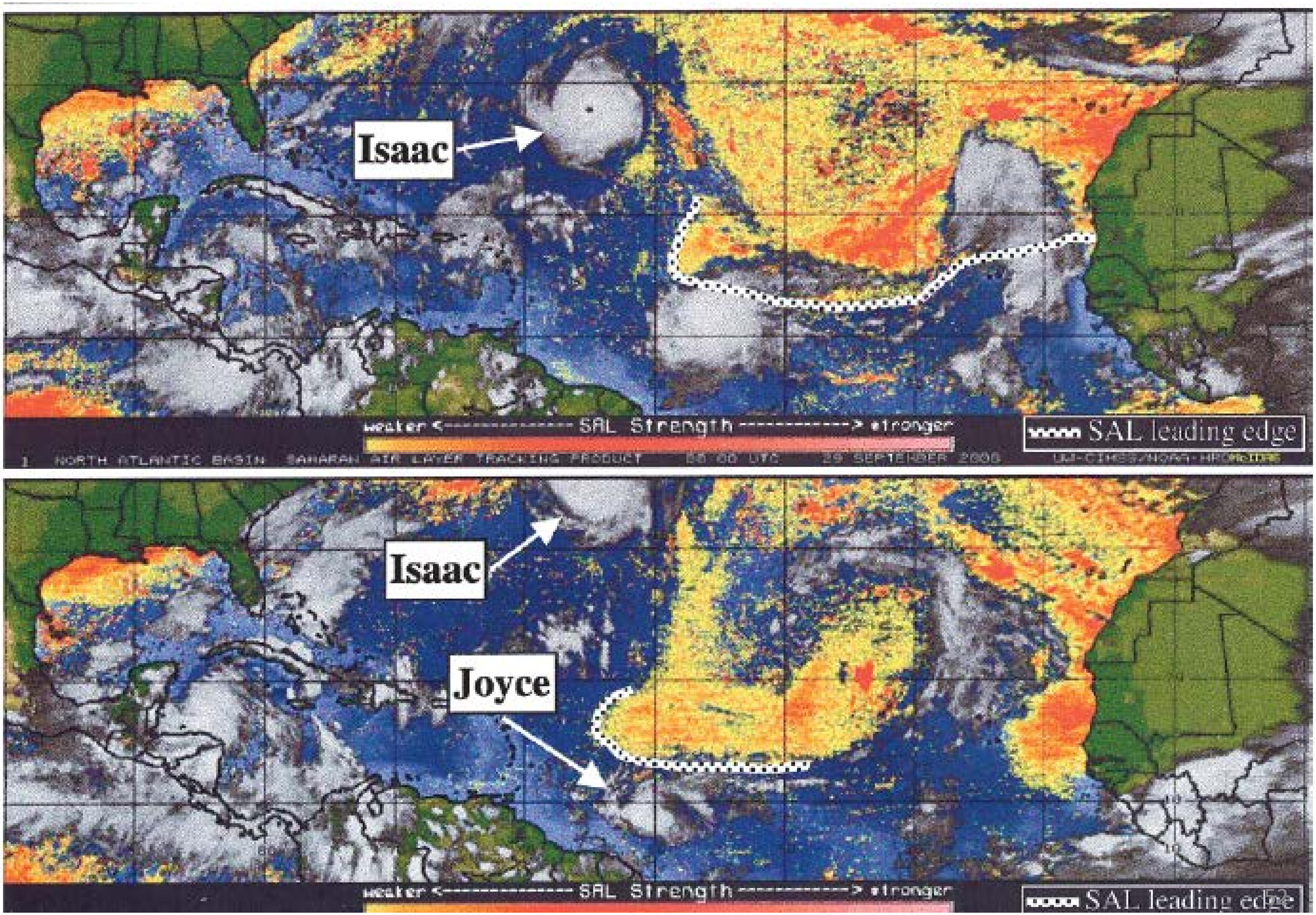
- First thought: Use the water vapor channel?

  No, SAL only extends up to about 500 mb, too low to be seen by 6.7 µm channel if there is upper-level moisture

- Use difference between 10.7 µm and 3.9 µm IR channels
  - 10.7 µm is nearly completely transparent to water vapor
  - 3.9 µm picks up some lower-level water vapor
  - Usually, the 3.9 µm channel is colder than 10.7
  - However, the dry and dusty SAL reduces the difference or even reverses it in extreme dusty cases

- For more info, see *Dunion and Velden (2004)*

CIMSS SAL Product



Review: Fill in the blanks

	85 GHz	37GHz	SAL Product
Satellite measures	Brightness Temperature	Brightness Temperature	10.7-3.9 μm difference in IR Brightness Temp.
Coldest regions	Thunderstorms with lots of ice scattering	Ocean Surface	N/A
Warmest regions	-Land surface -Shallow rain showers	Land surface Rain	N/A

Simplest guide to MW imagery:

- Eyewall Replacement Cycle
  - Use 85 GHz-H, look for concentric eyewalls
- Rapid Intensification
  - Use 37 GHz Color, look for spiral banding and a cyan-colored eyewall to start forming
- Weaker storms or Tropical Storms
  - Use 85-GHz-H and 37 GHz-H, look for curved/spiral bands and symmetry
- Hurricanes
  - Use 85 GHz color, the bright red around the eye is a good measure of the strength/size of the eyewall