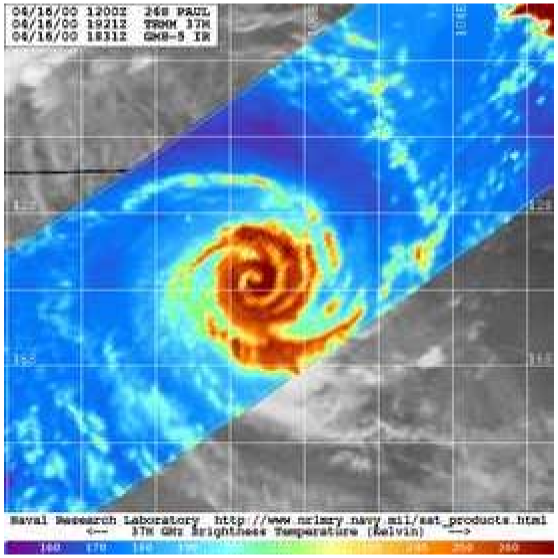
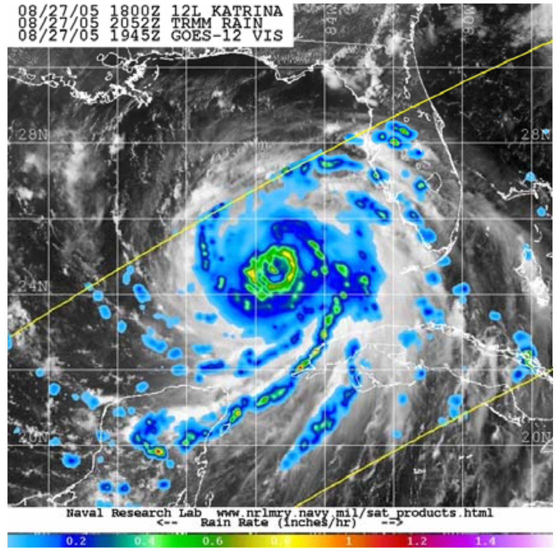
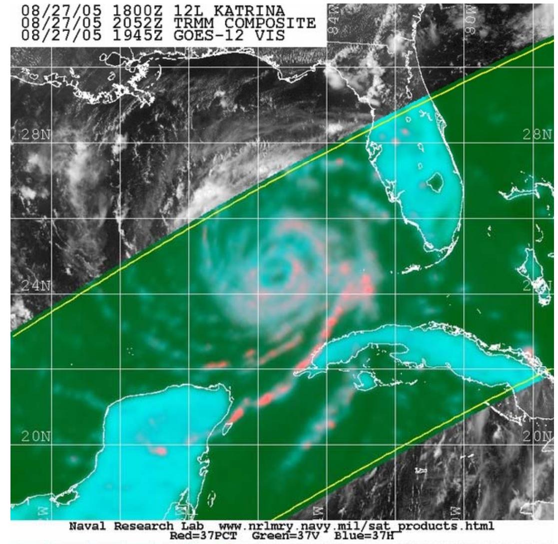






Advanced Satellite Remote Sensing: Microwave Remote Sensing

FIU HRSSERP Internship

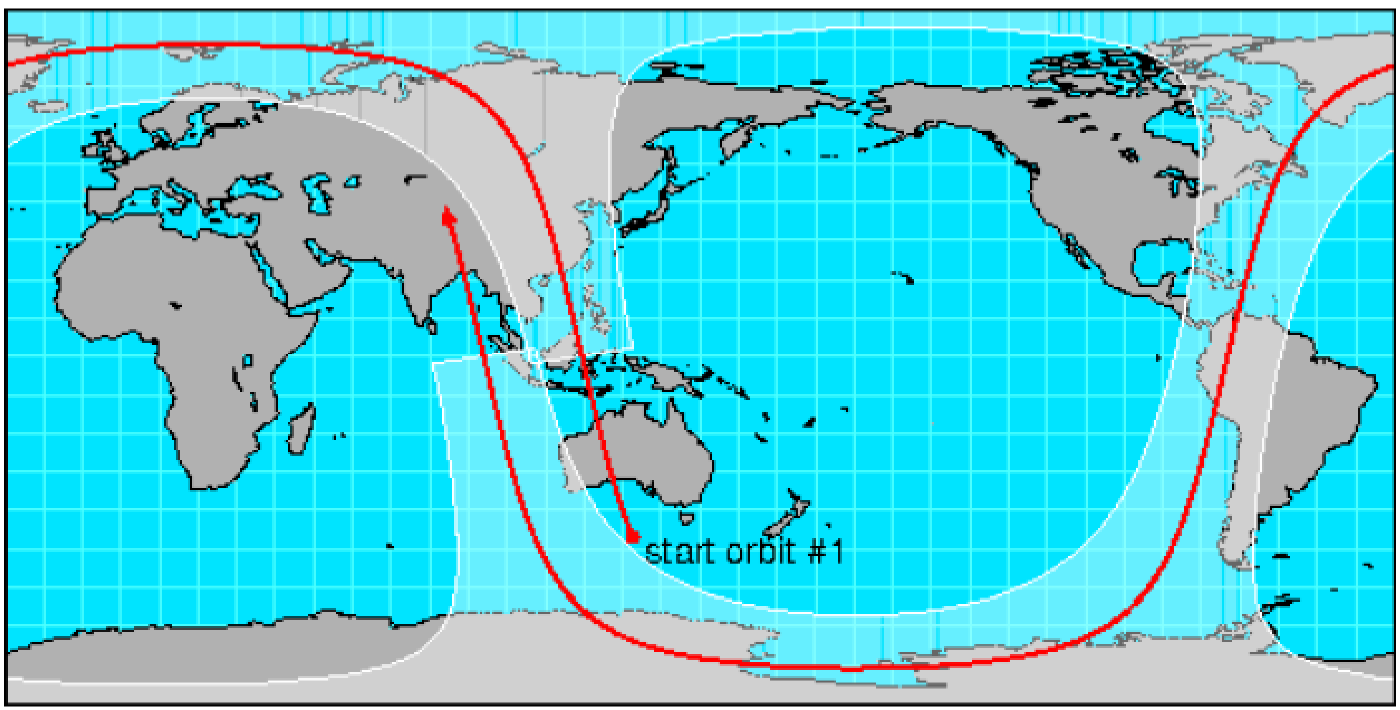
August 11, 2011

What can Microwave Satellites Measure?

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

Polar Orbiting Satellites

- Polar orbiters are only 800-900 km above the surface and continuously view a different part of the surface, following a path called a “swath”



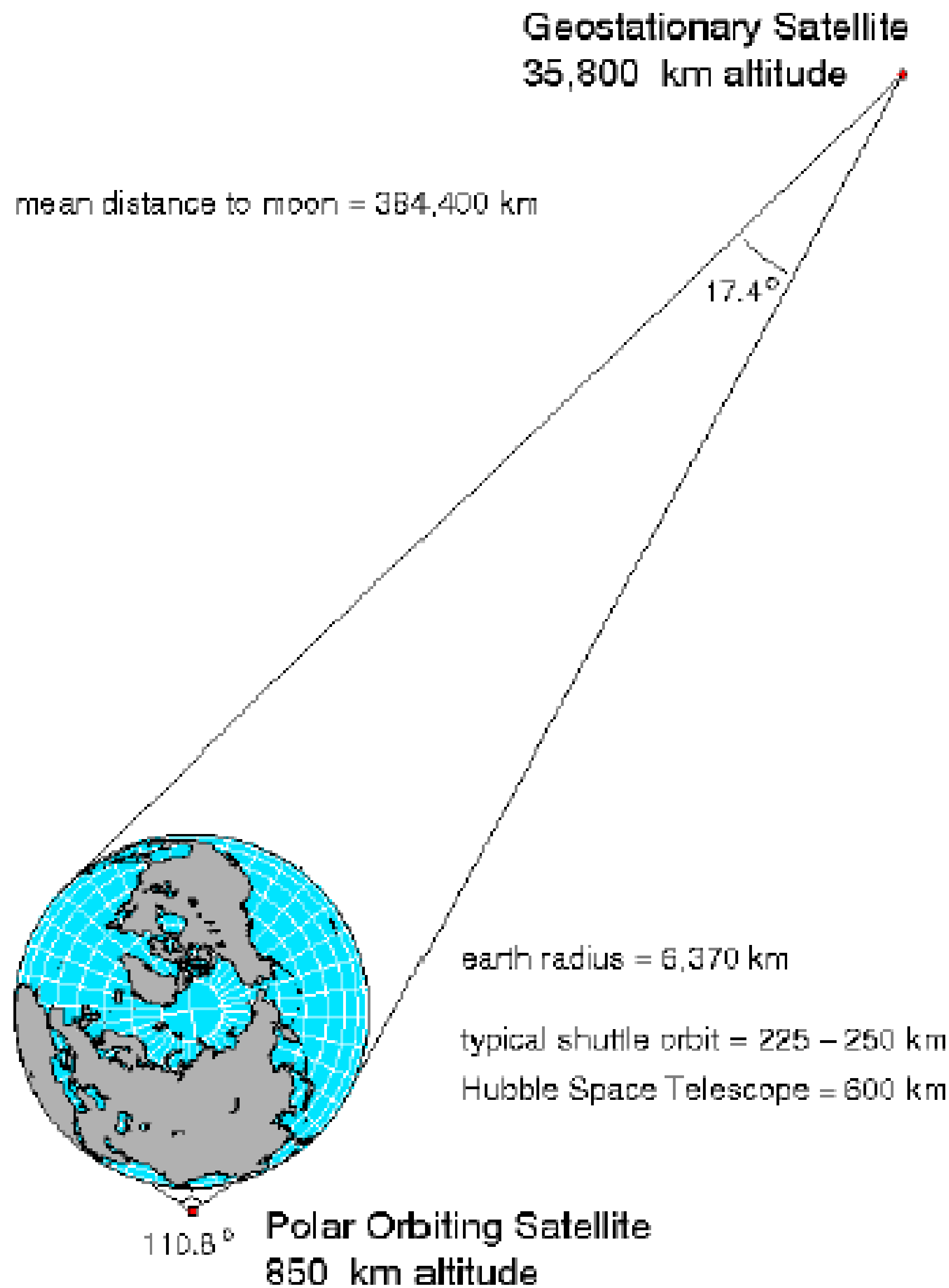
Polar Orbit

<u>Advantages:</u>

- High ground resolution
- Covers most of earth's surface

<u>Disadvantages:</u>

- Only passes over each location 1-2 times/day
- Swath is narrow and can miss important features (like TC center)

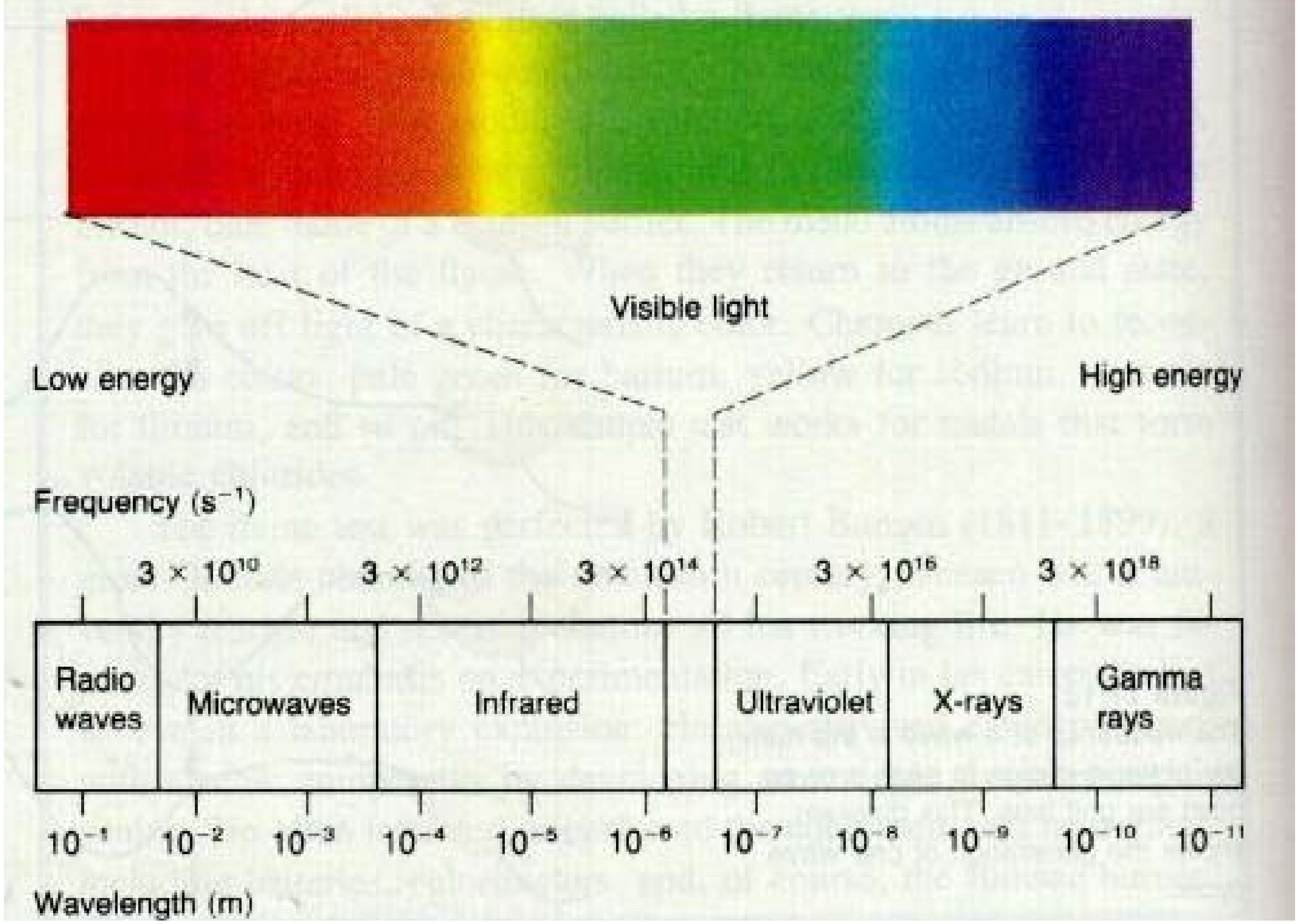


Polar-Orbiting Environmental Satellite Microwave Instruments

Instrument	Full Name	Satellite(s)
SSM/I *	Special Sensor Microwave Imager	DMSP F-8 to -15
SSMIS *	Special Sensor Microwave Imager/Sounder	DMSP F-16 to -20
TMI *	TRMM Microwave Imager	TRMM
PR *	TRMM Precipitation Radar	TRMM
GMI *	GPM Microwave Imager	future GPM
DPR *	Dual-frequency Precipitation Radar	future GPM
SeaWinds	SeaWinds	QuikSCAT
ASCAT	Advanced SCATterometer	MetOp-A, -B, -C
AMSU *	Advance Microwave Sounding Unit	NOAA-15 to -18, MetOp
MHS	Microwave Humidity Sounder	NOAA-18, MetOp
AMSR-E *	Advanced Microwave Scanning Radiometer for EOS	EOS Aqua
MWR	Microwave Radiometer	Envisat
MIS *	Microwave Imager/Sounder	future NPOESS

Electromagnetic Spectrum

Wavelength = Speed of light / Frequency $\lambda = c/f$



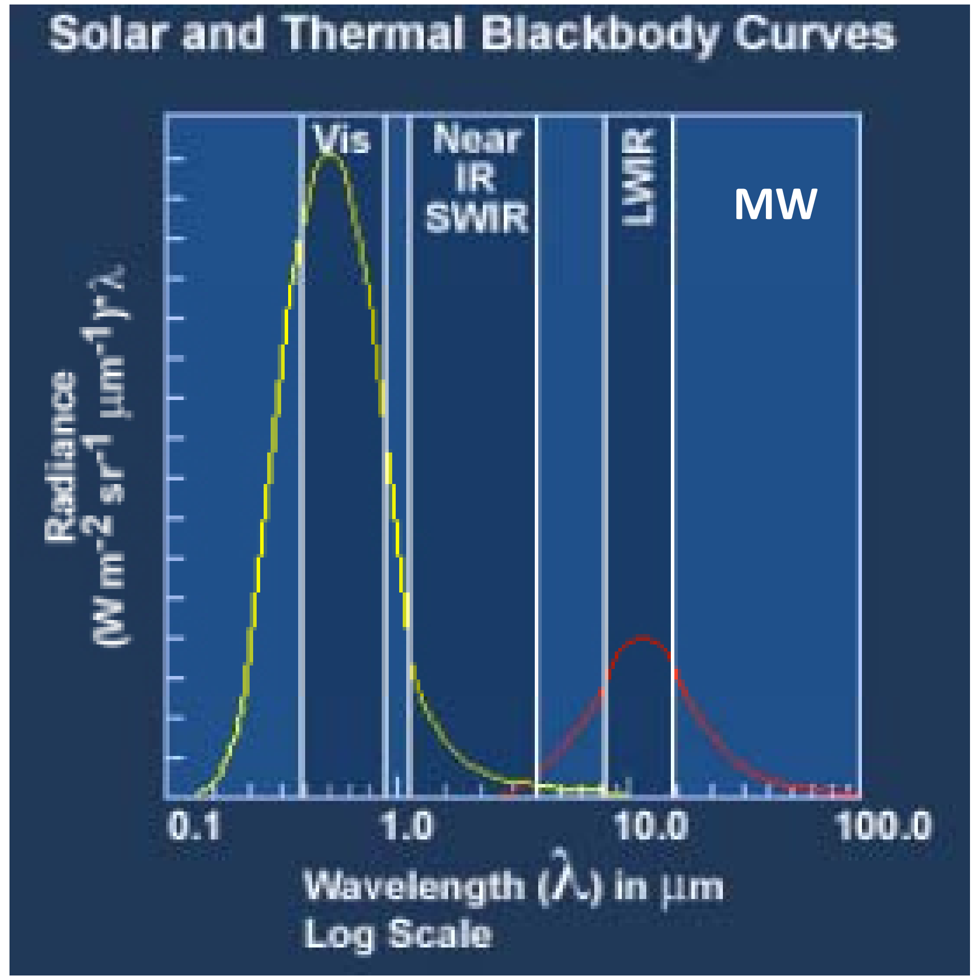
Long wavelength
Low Frequency

Short Wavelength
High Frequency

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?

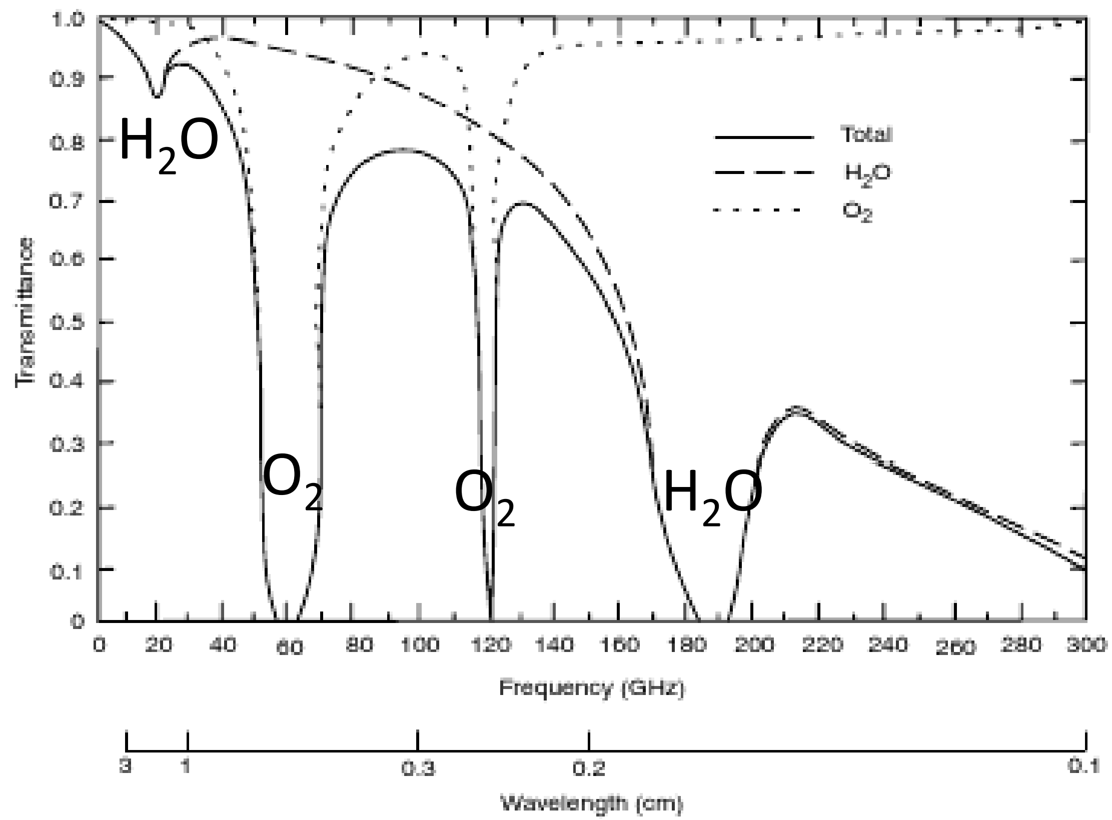
- MW satellites detect Brightness Temperature, just like IR Satellites
- The difference is that instead of measuring the temperature of the cloud tops (10.7 μm IR) or water vapor (6.7 μm WV), the MW satellites usually measure
  - Cloud droplets
  - Rain droplets
  - Ice/Snow/Hail

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: Magnetic dipole moment causes absorption centered at 60, 118 GHz—not useful for meteorology
- 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



Liou 2002, p.415

37 and 85 GHz Channels

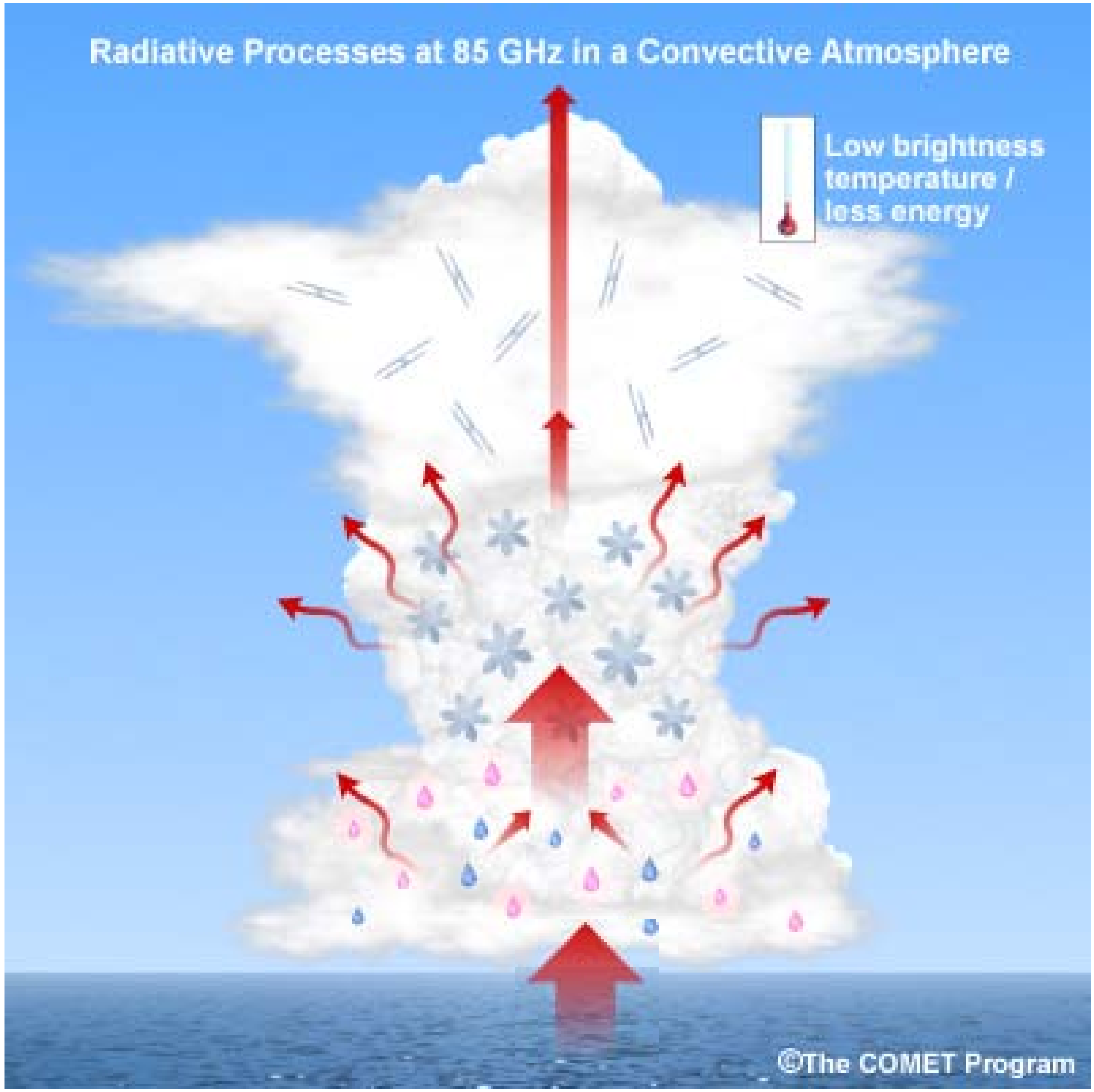
- 37/85 GHz frequencies chosen to avoid atmospheric gas absorption bands
- **Can not see clouds at all**, cloud droplets are too small and do not interact with EM-radiation at these frequencies
- Both channels can see difference between land and ocean
- **37 GHz** mostly sees emission from rain particles, also sees some scattering from ice particles
- **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

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 **emission from low level clouds and water vapor**
  - 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.



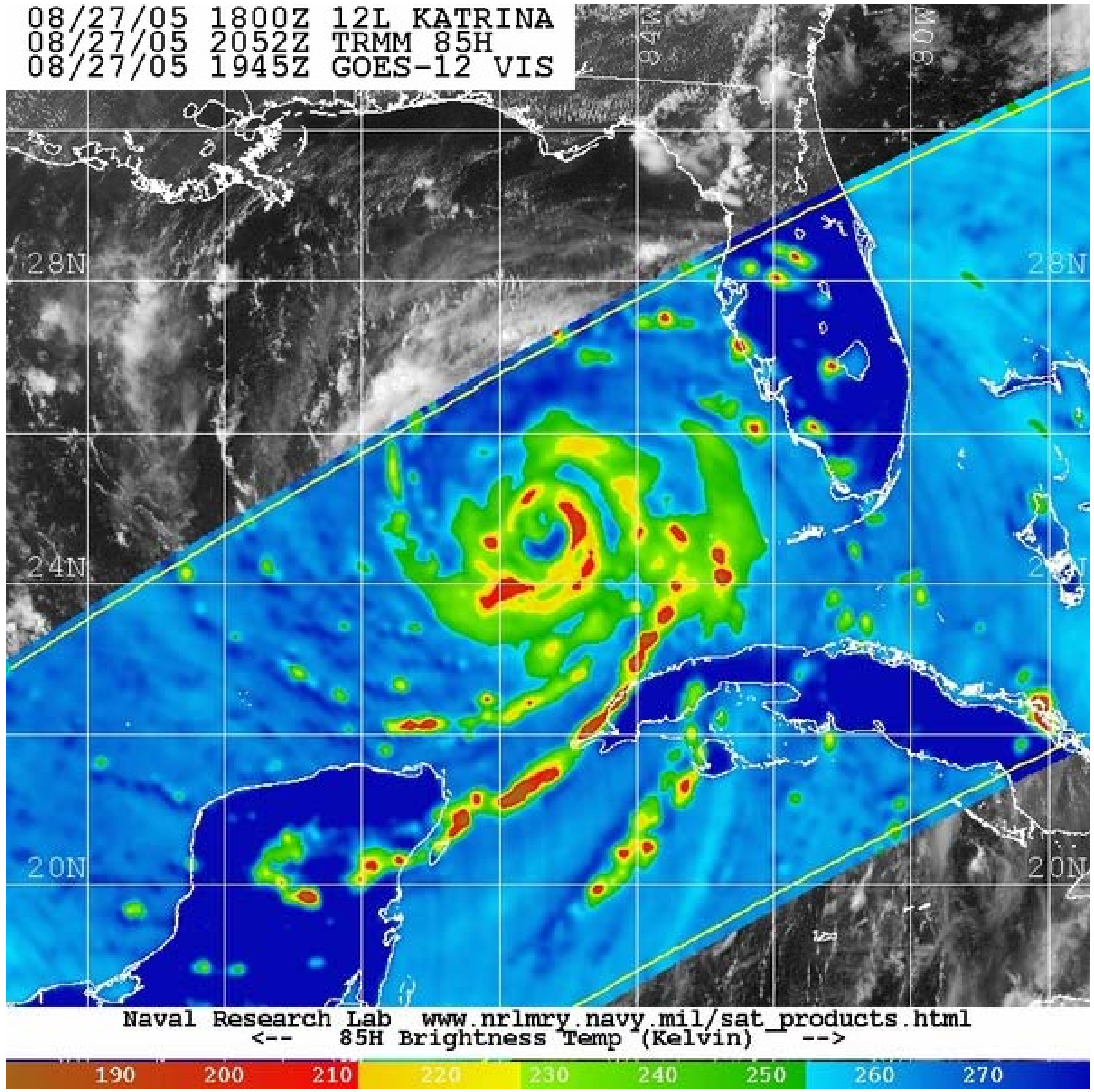
TRMM 85 GHz T_B (Horizontal Polarization)

-Land = Warm

-Ocean = Slightly cooler

-Low clouds and moisture = Warm

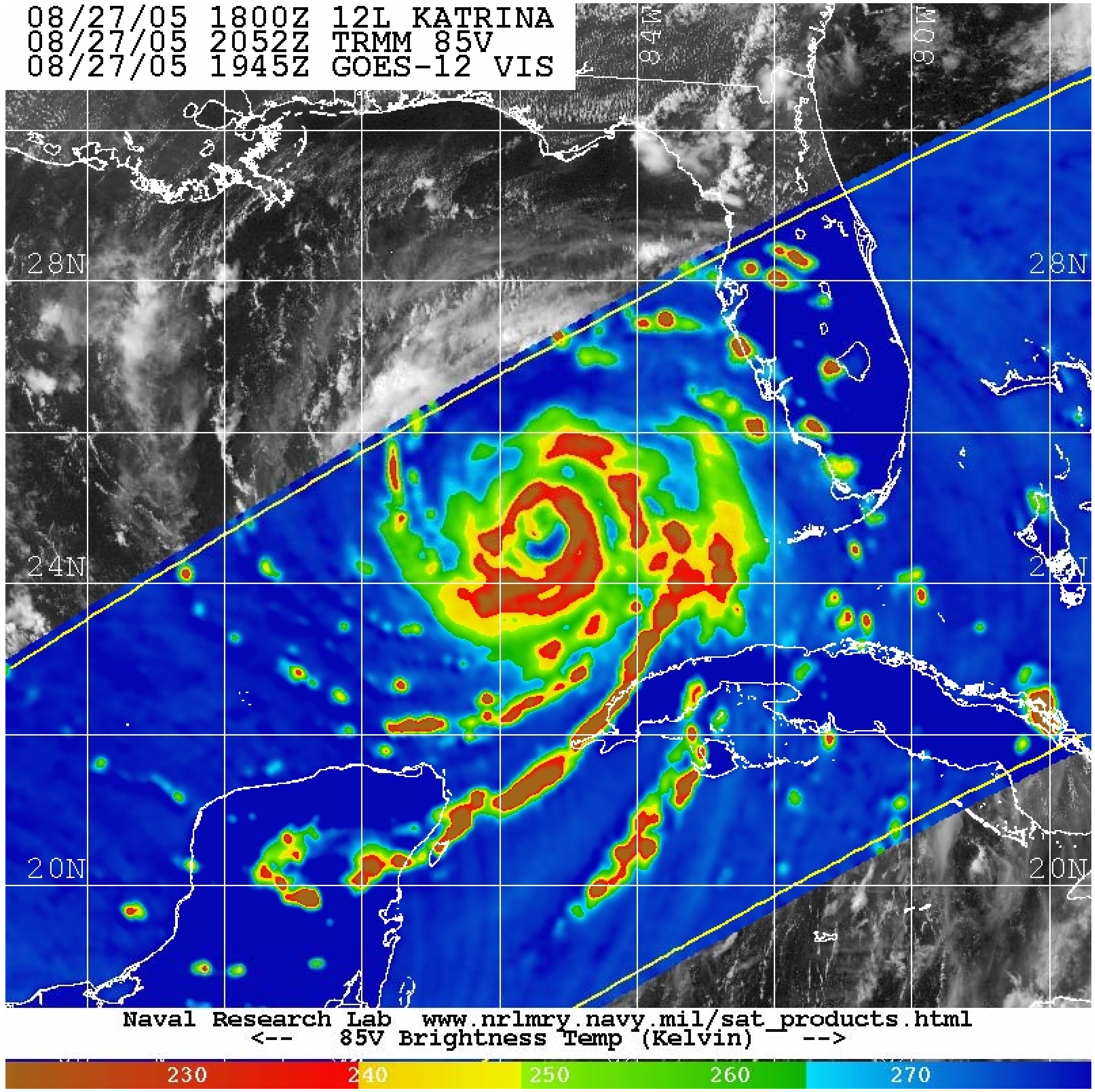
-Ice/Snow = Very cold



Note inverse scale!!!

TRMM 85 GHz T_B (Vertical Polarization)

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



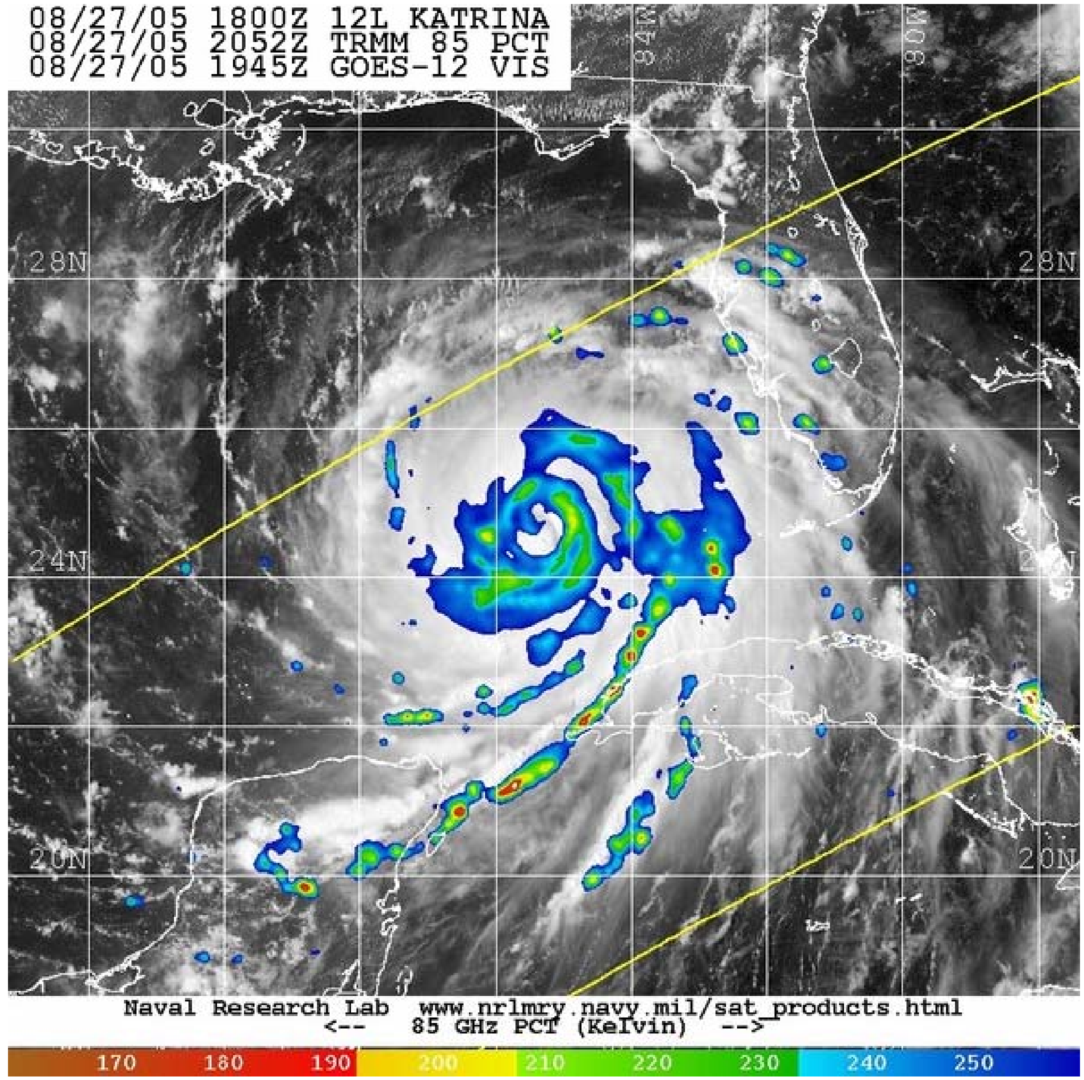
Different scale than 85-H

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

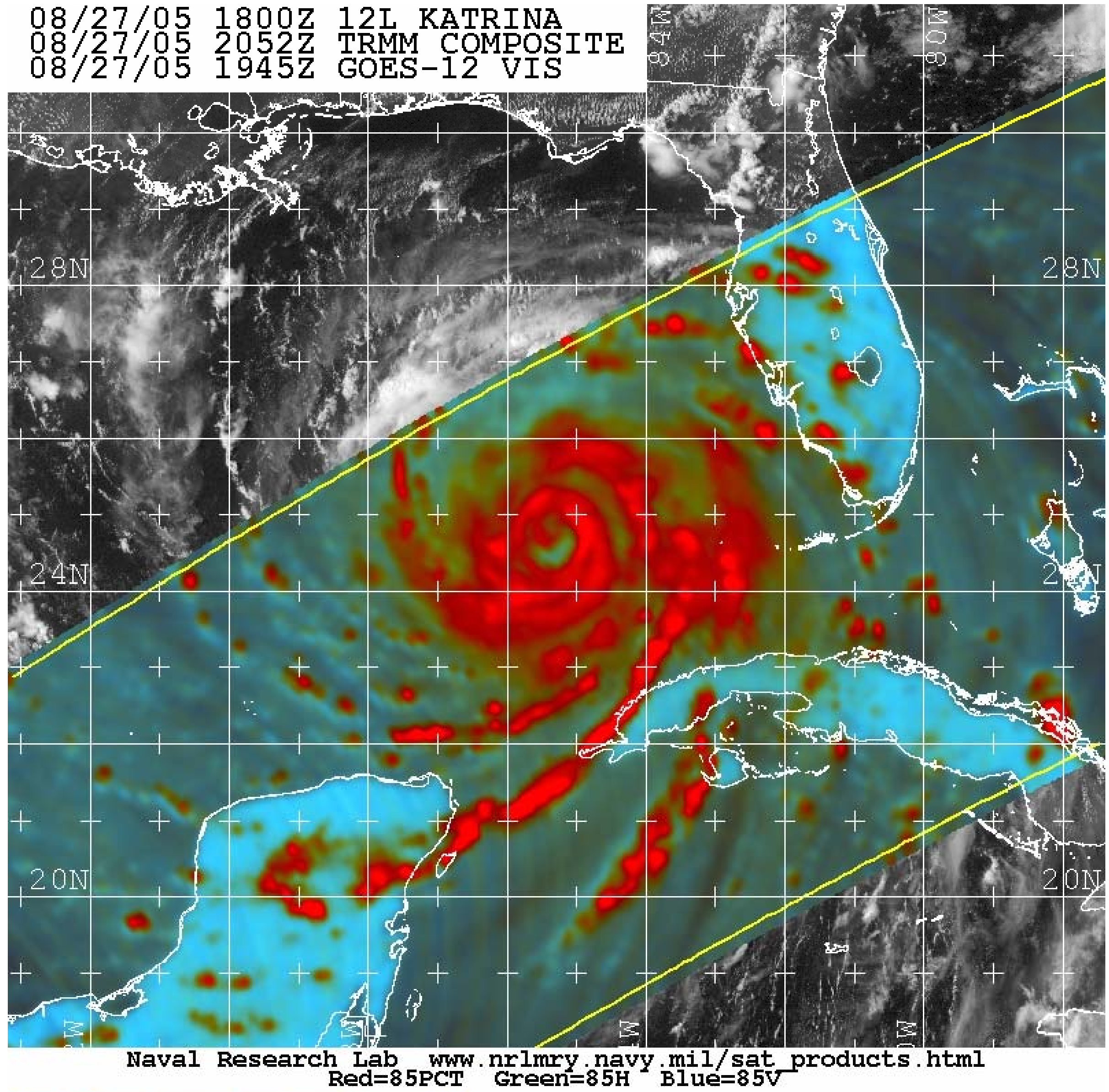
85 GHz Polarization Corrected Temperature (PCT)

- Combines 85 GHz V and H channels to remove the interference from the surface
- Disadvantage: also removes light rain—only heavy rain left

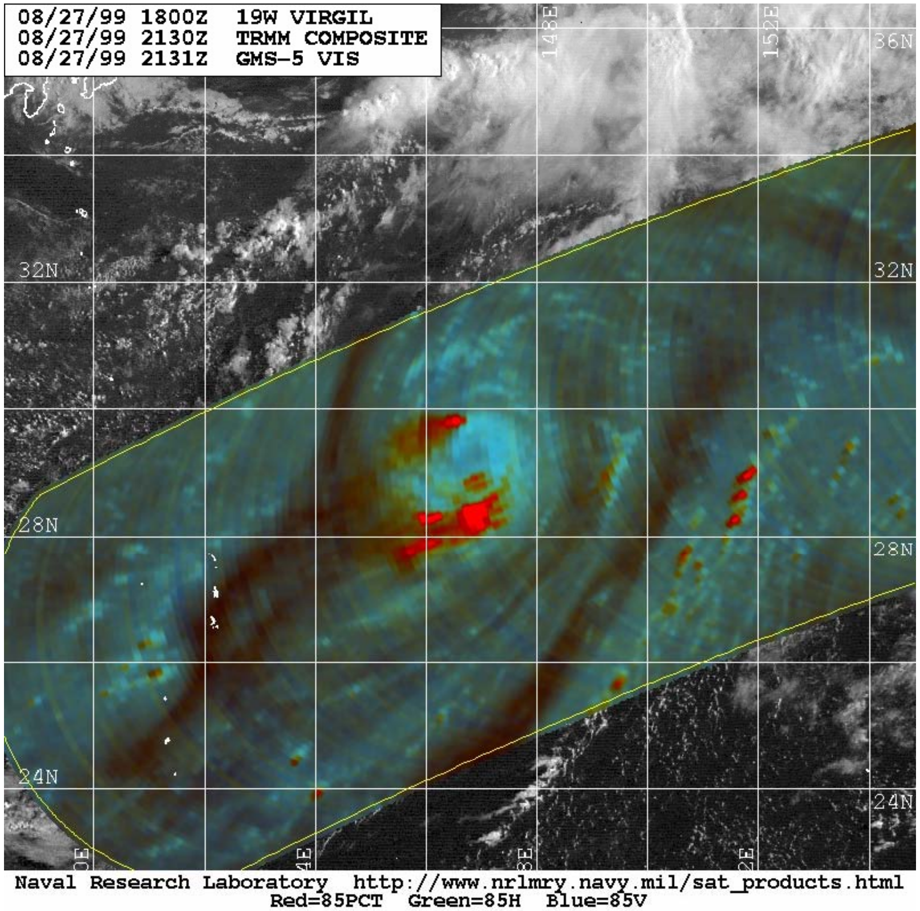


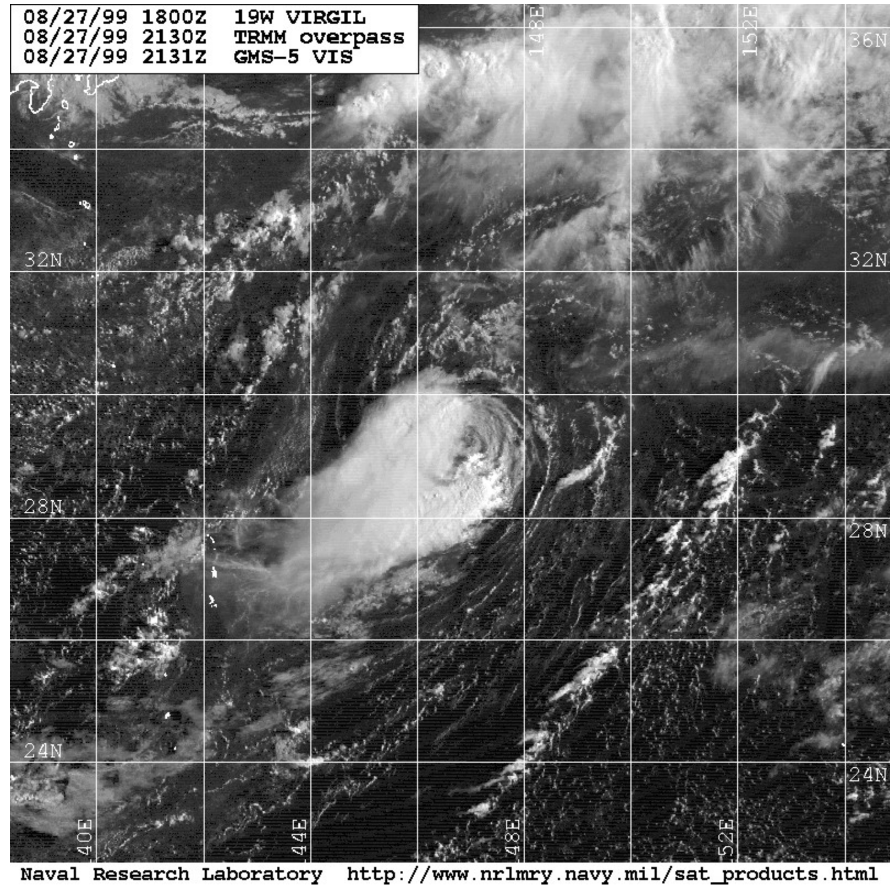
85 GHz Color Enhancement

- Best choice for 85 GHz
- Red = deep convection
- Blue-green = low-level clouds, water vapor, and warm precpitation
- Gray = dry
- No color scale!



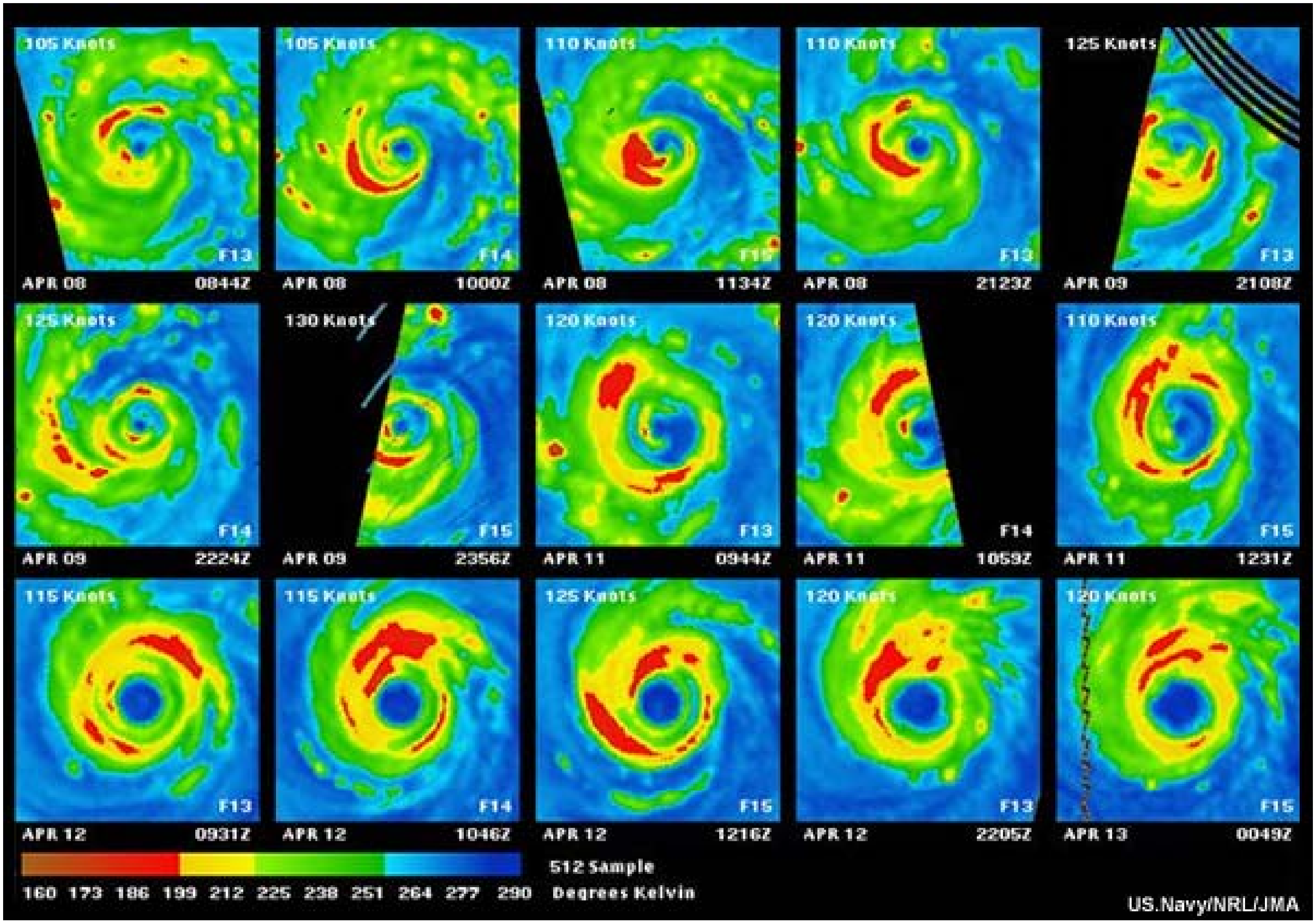
85 GHz color vs. Visible



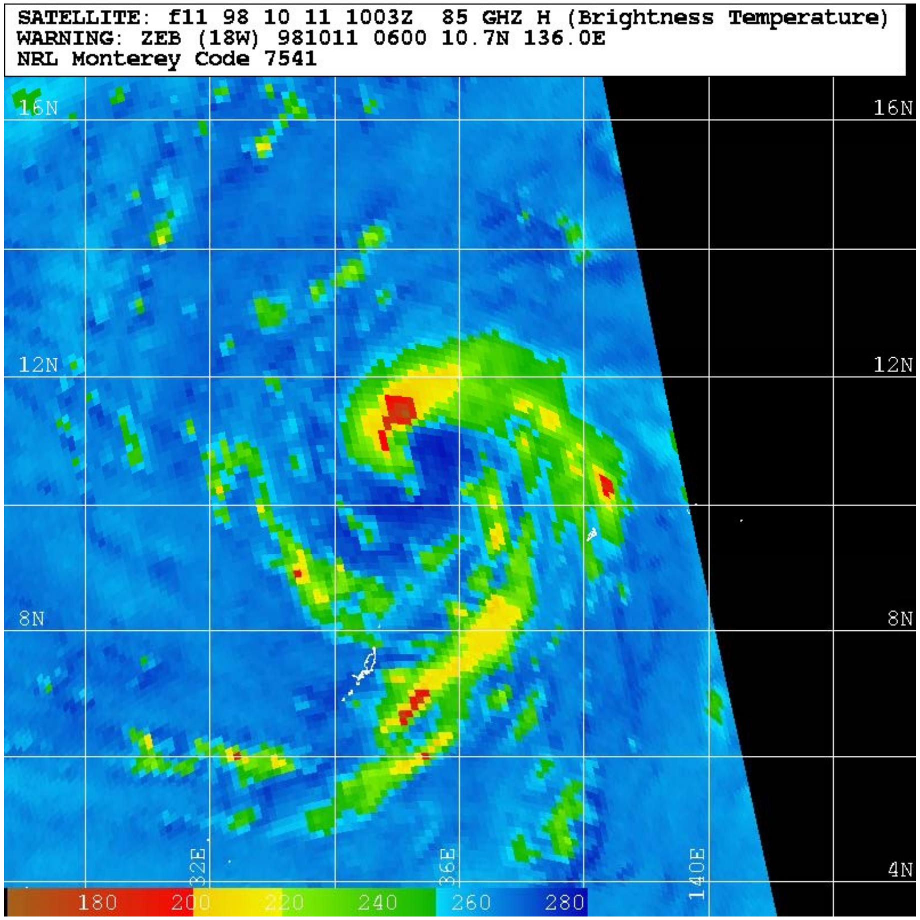


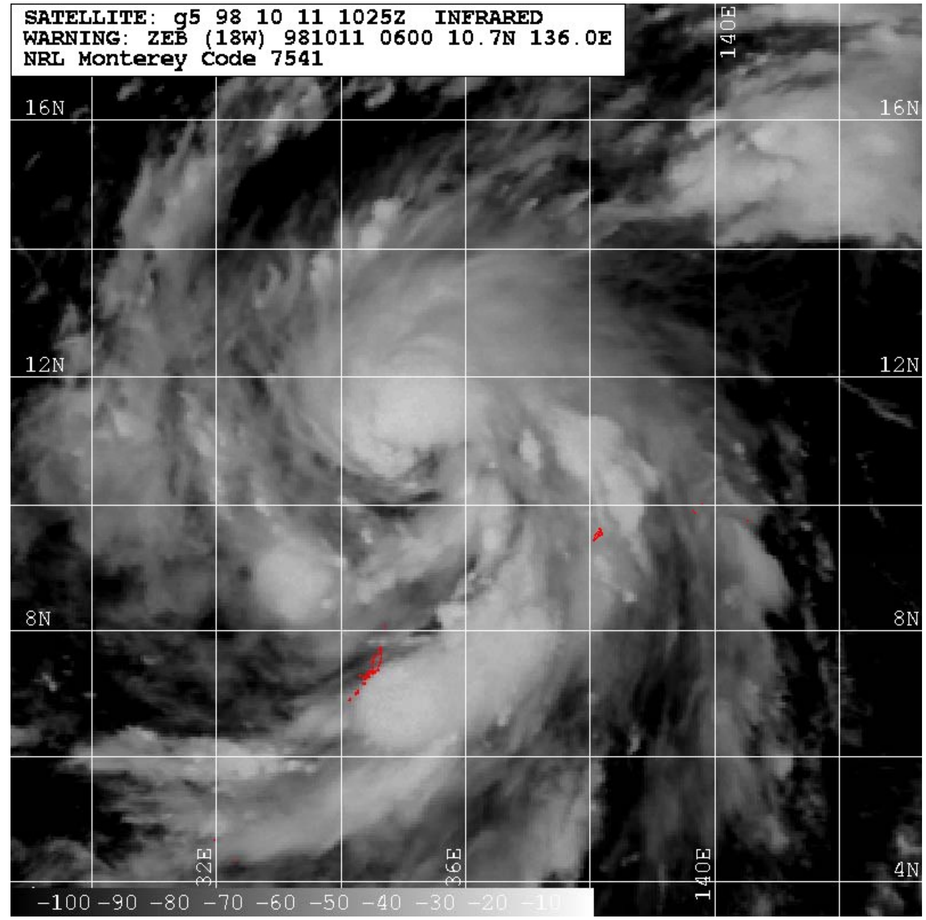
- Deep convection = Red
- Low-level swirl = Blue-Green

Eyewall Replacement Cycle (85 GHz H)



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 Applications

- You want to know…
  1. Whether or not a storm has partial/concentric eyewalls:
     - Use 85 GHz H
  2. If a TC or TC region has deep convection or shallow convection:
     - Use 85 GHz Color
  3. The details of the structure of the rain bands below the freezing level
     - Use 37 GHz instead, warm rain looks too much like the ocean surface in the 85 GHz imagery

37 GHz Channel

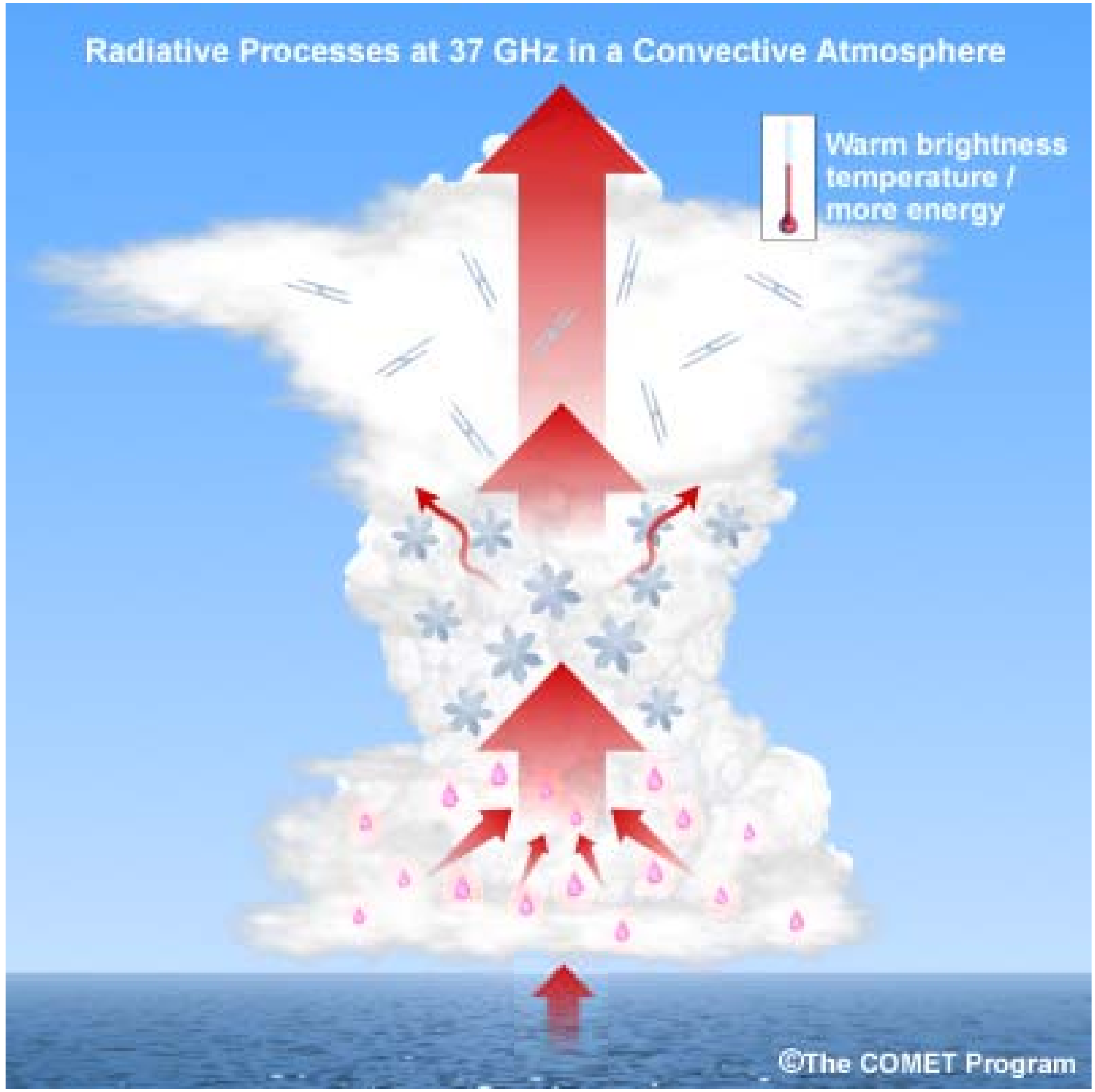
- Most noticeably detects **liquid rain** in the lower levels of the atmosphere
  - T_B ranges from 210-270 K in rain bands
  - Heavier rain= **warmer** T_B compared to ocean surface
- In regions with no rain, detects emission of land or ocean
  - Ocean surface T_B = 150-170 K for H, 220-230 K for V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

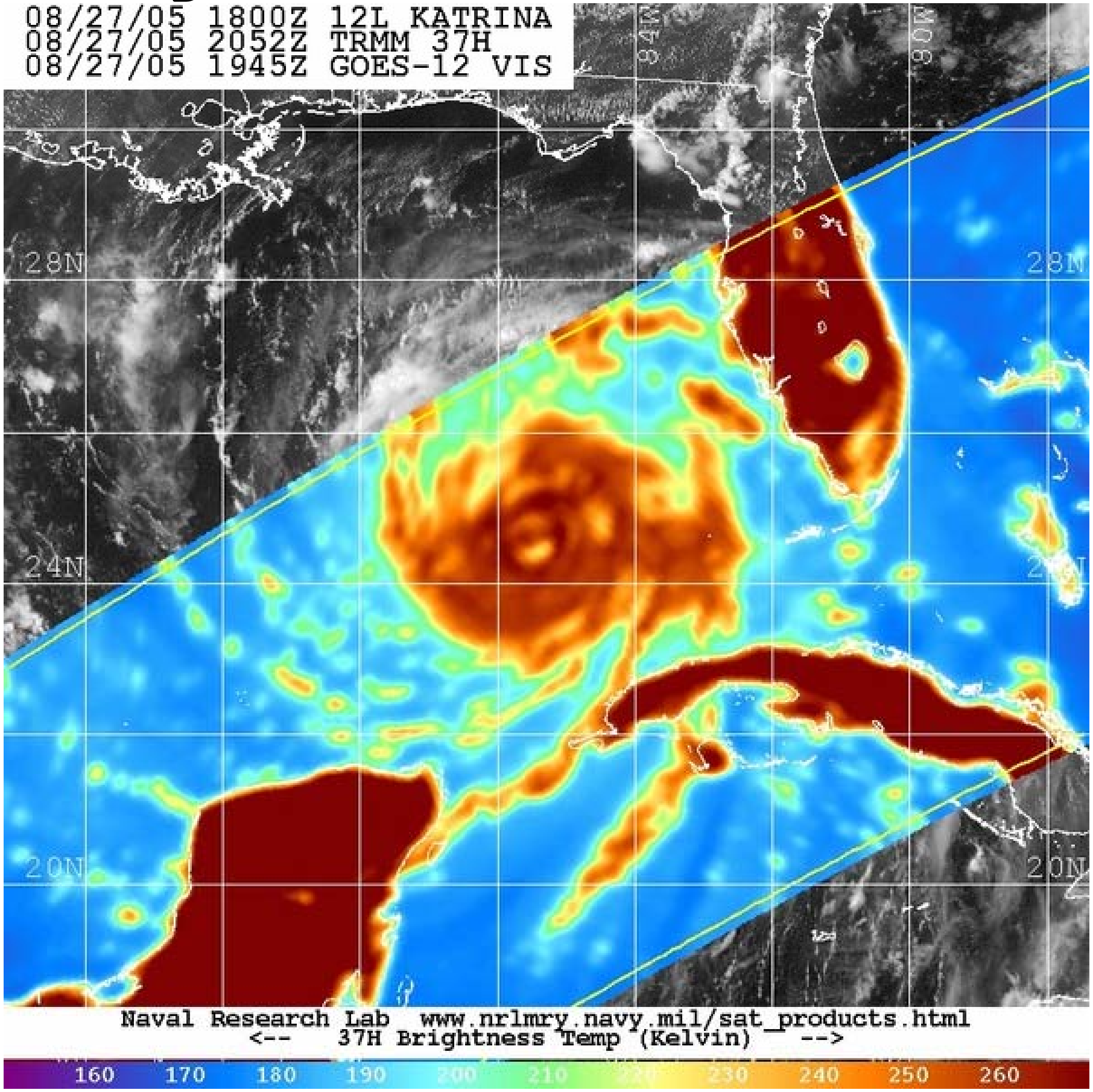
Unlike 85 GHz, only very large ice crystals cause measurable scattering

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



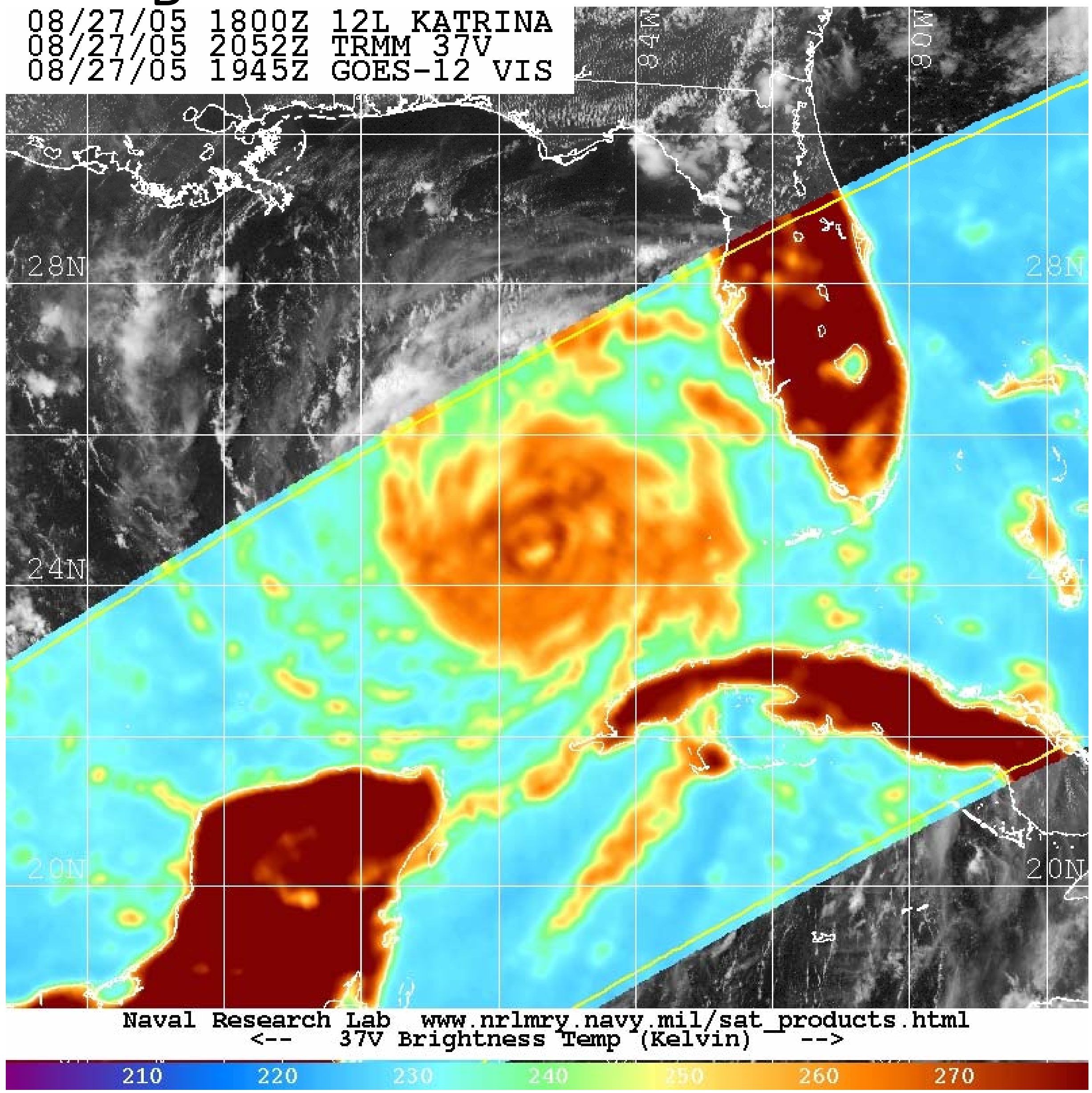
TRMM 37 GHz T_B (Horiz. Polarization)

- -Land = Warm
- -Ocean = Cold
- -Rain = Warm
- -Light rain = Cool (Green)
- -Can not see details of heavy rain or ice scattering



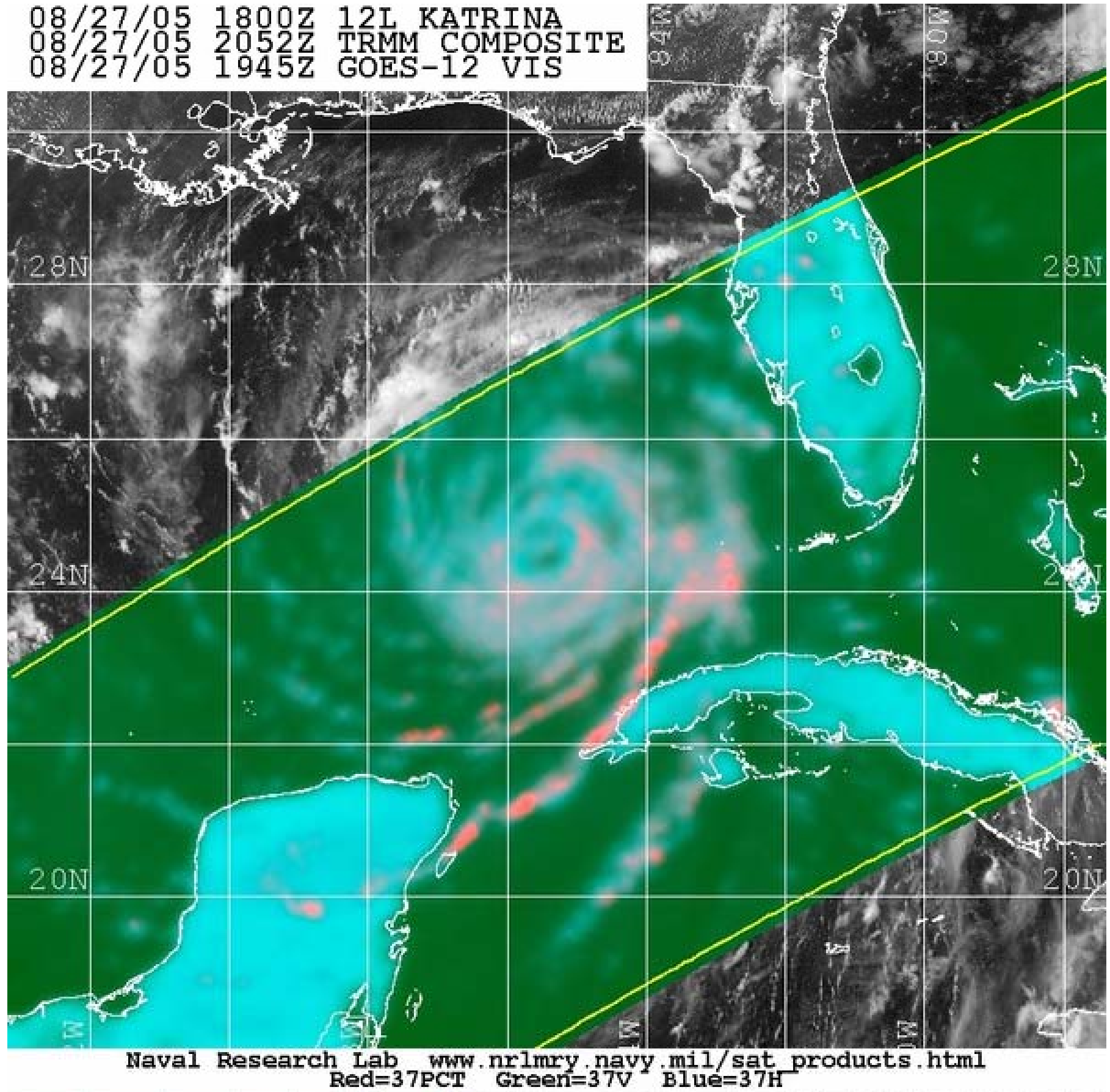
TRMM 37 GHz T_B (Vertical Polarization)

- -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:

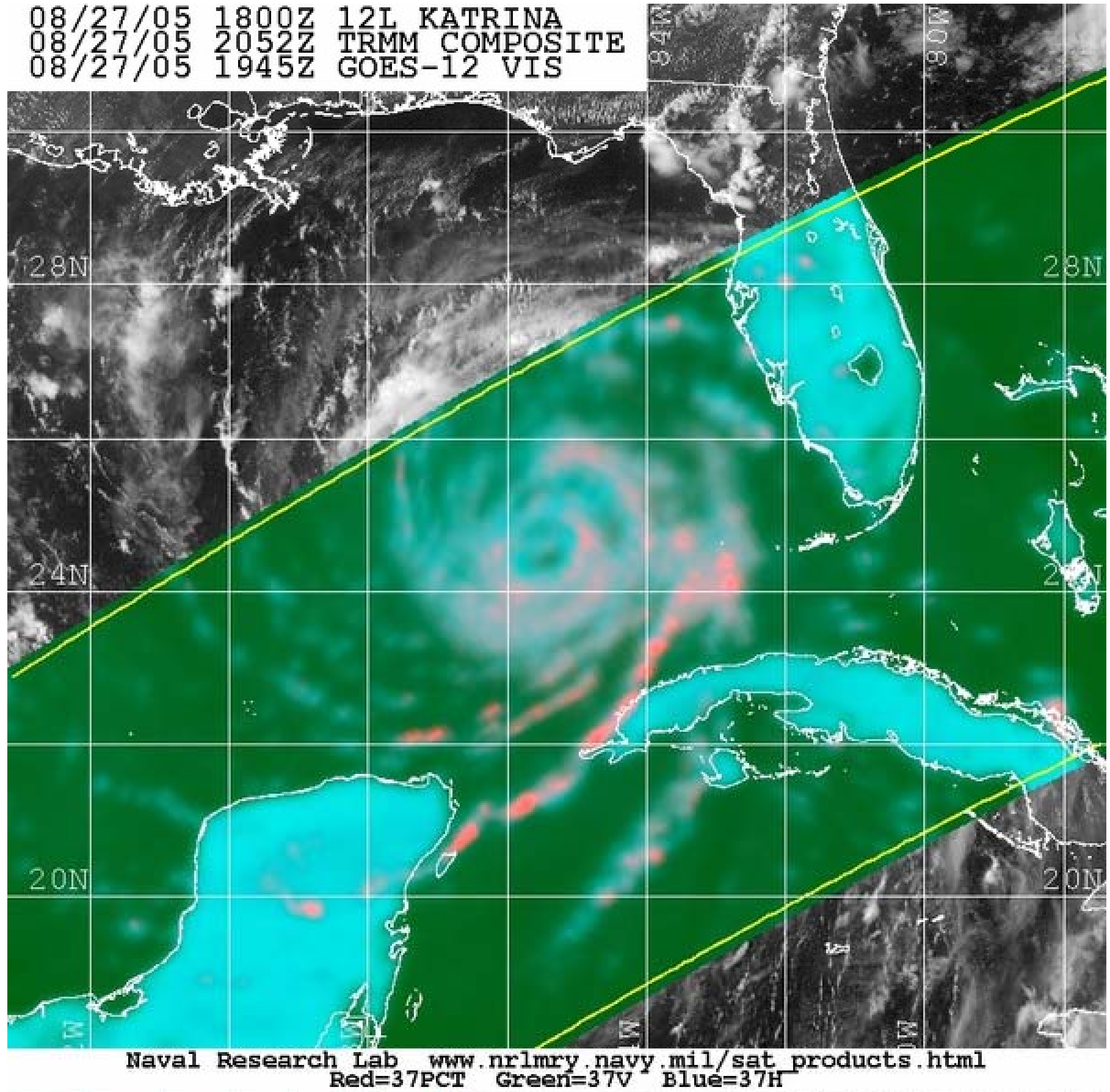
-Shows good contrast between light and heavy rain

-Can see eyewall forming earlier than other methods

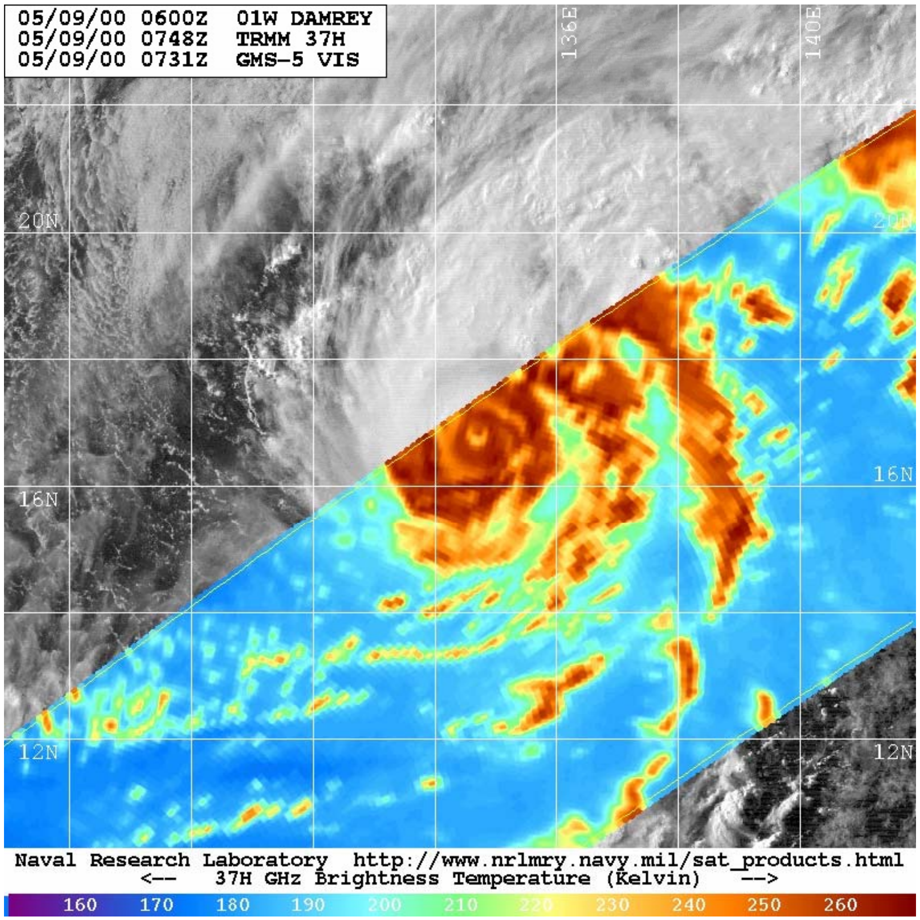
- Disadvantages:

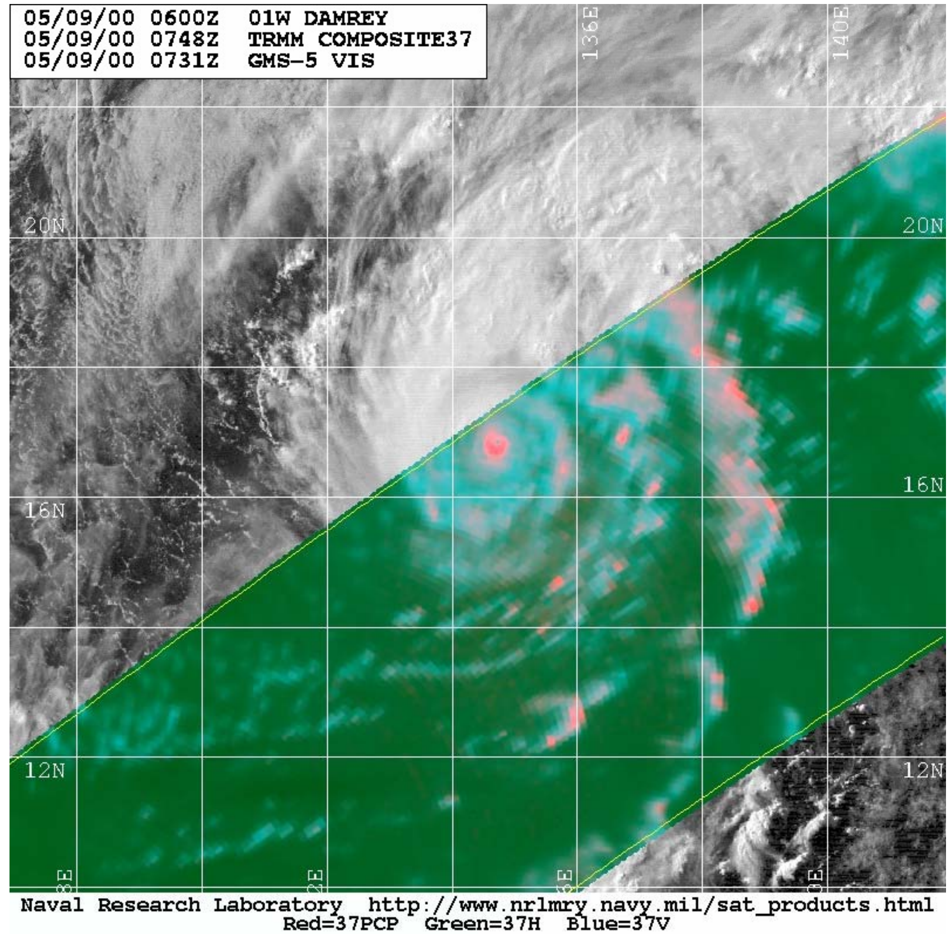
-37 H is better for very light rain

-Does not work over land



37 GHz H vs. 37 GHz Color



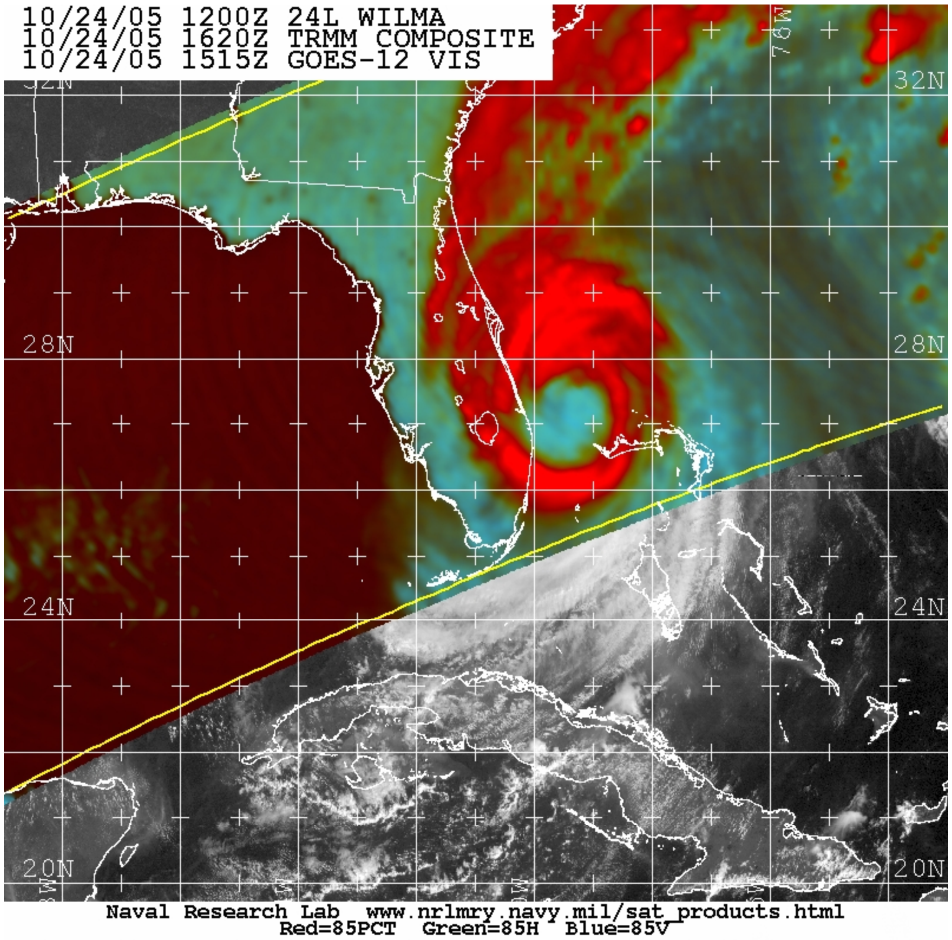


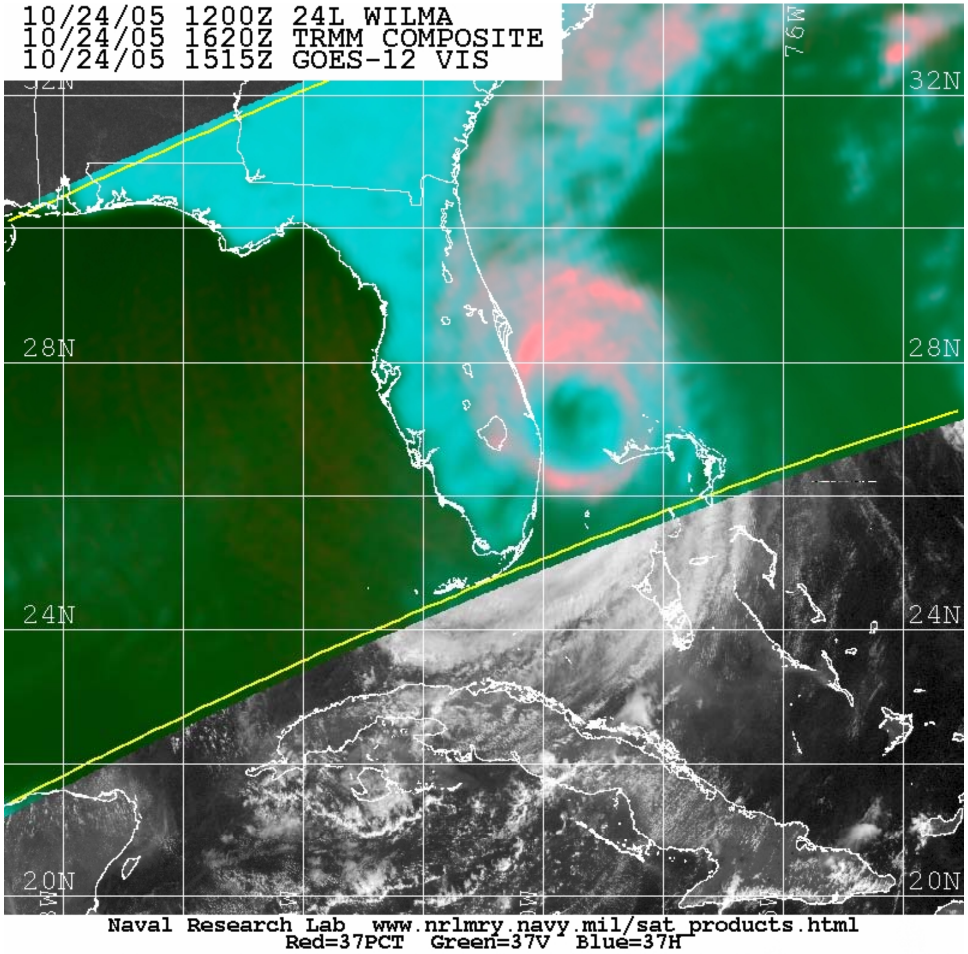
-All rain looks brown in 37-H, but it is easy to distinguish convective eyewall in 37 Color

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

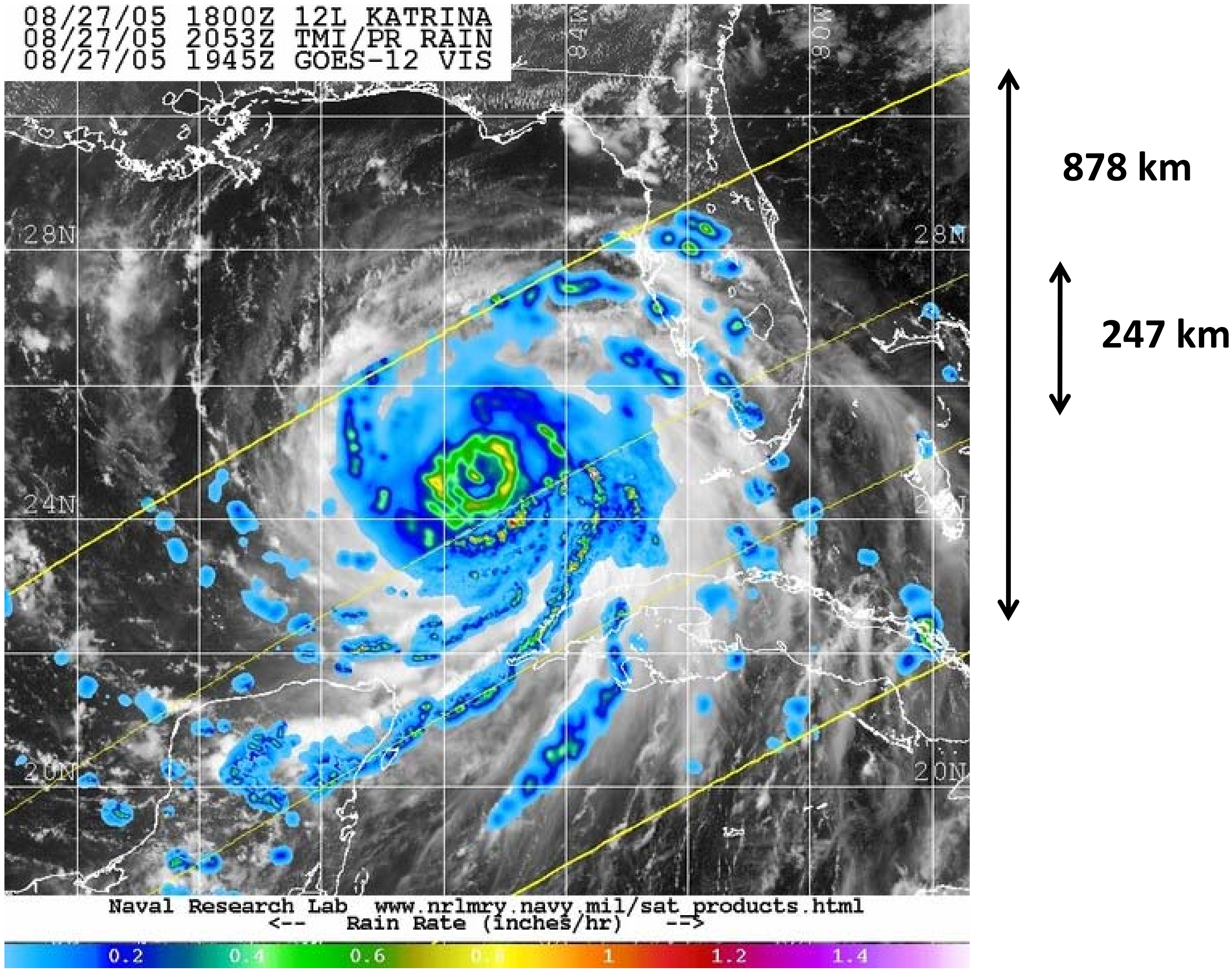
85 Color vs. 37 Color





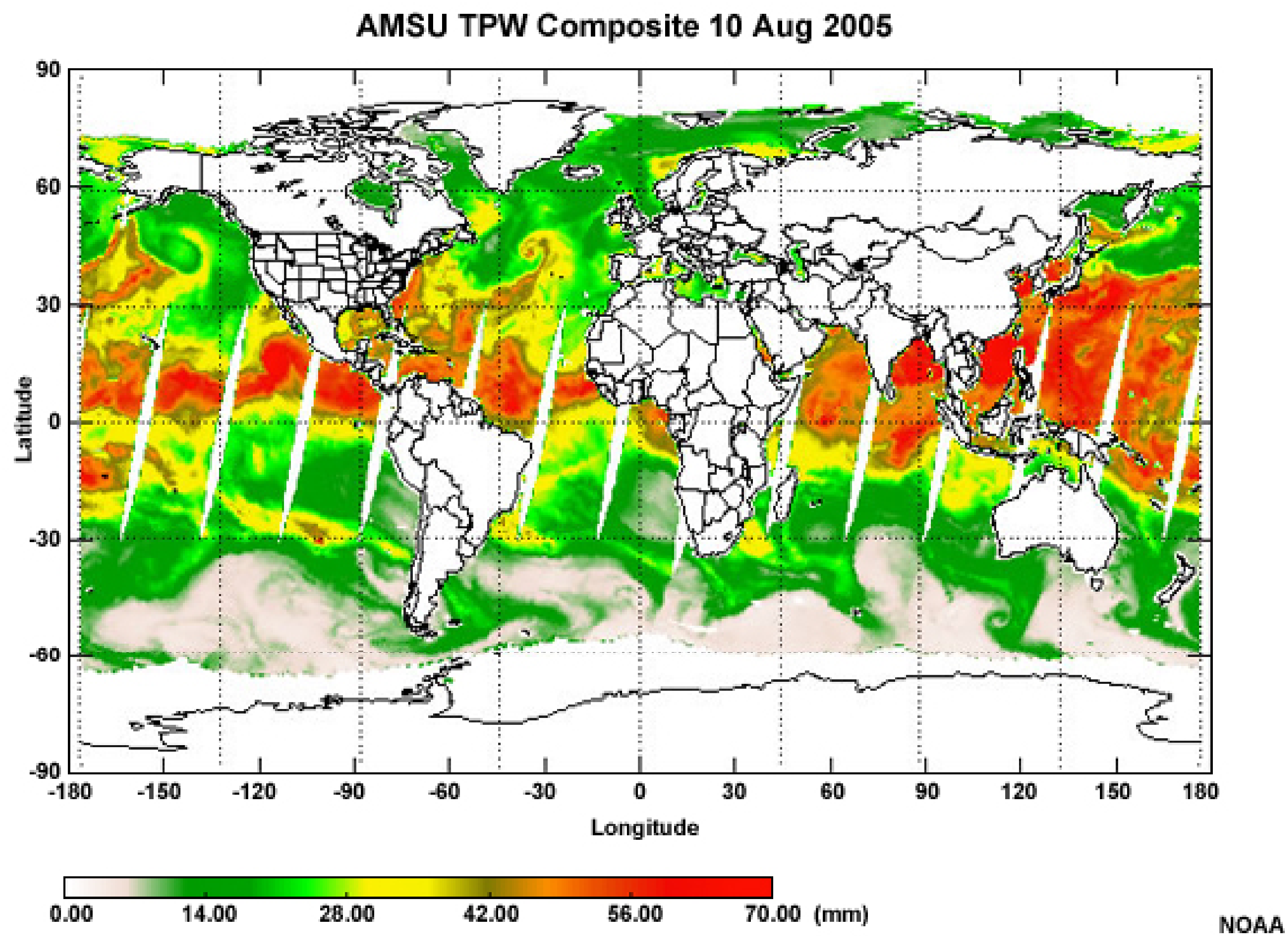
- 37 Color ineffective over land
- Besides that, they are quite similar

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



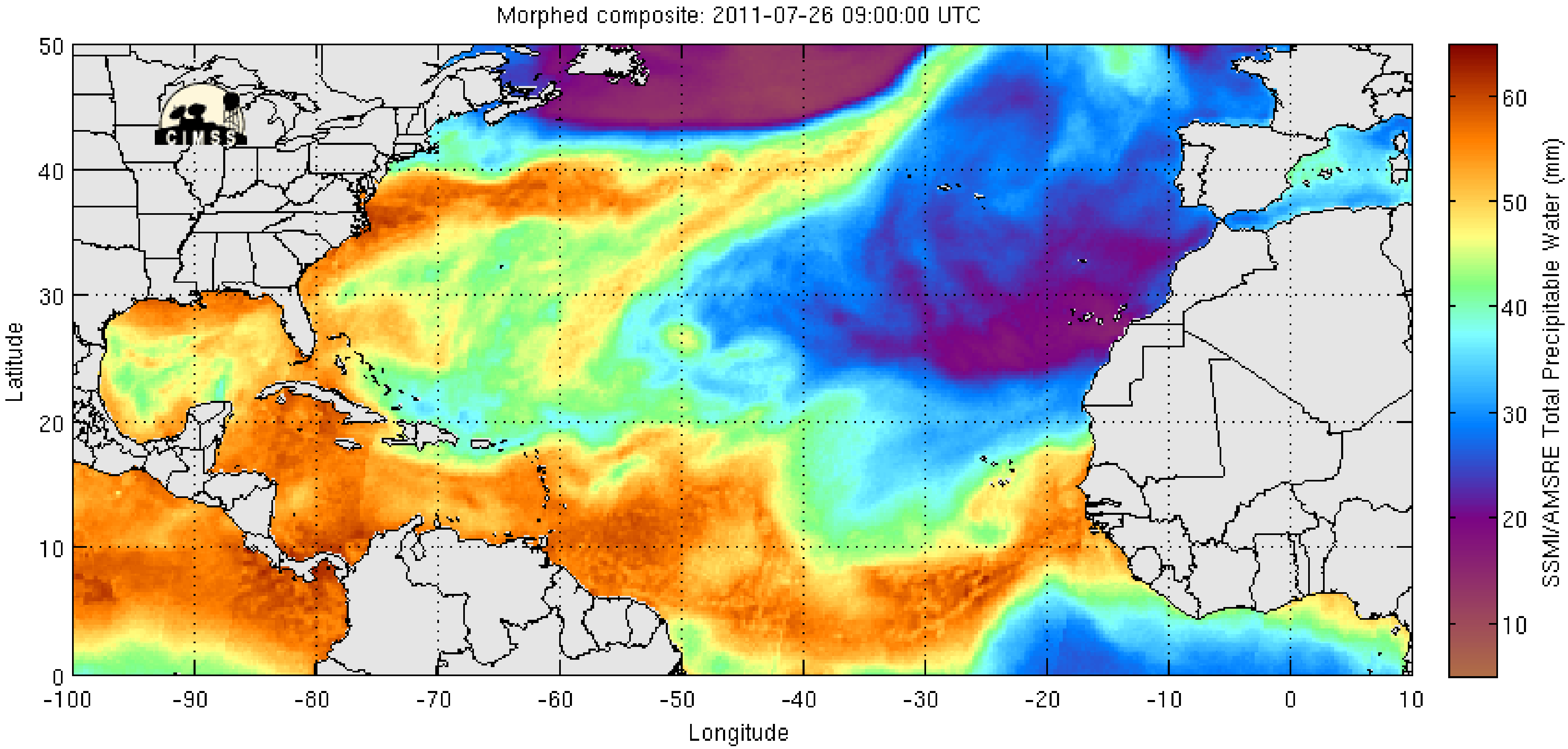
Total Precipitable Water

- 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

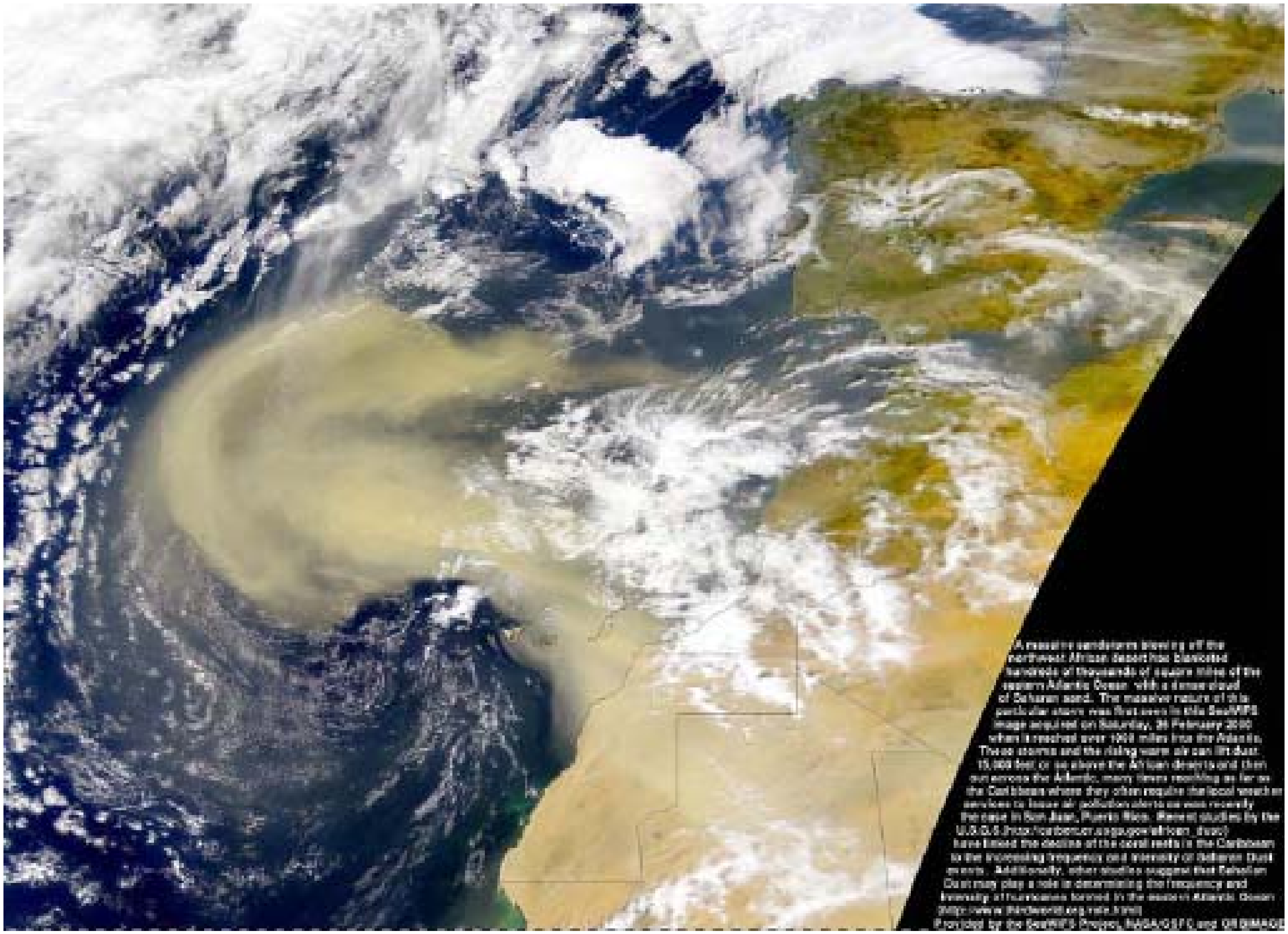


- Which regions are favorable for TC development?
- What is that giant mass of dry air to the west of Africa?

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 from Visible Satellite



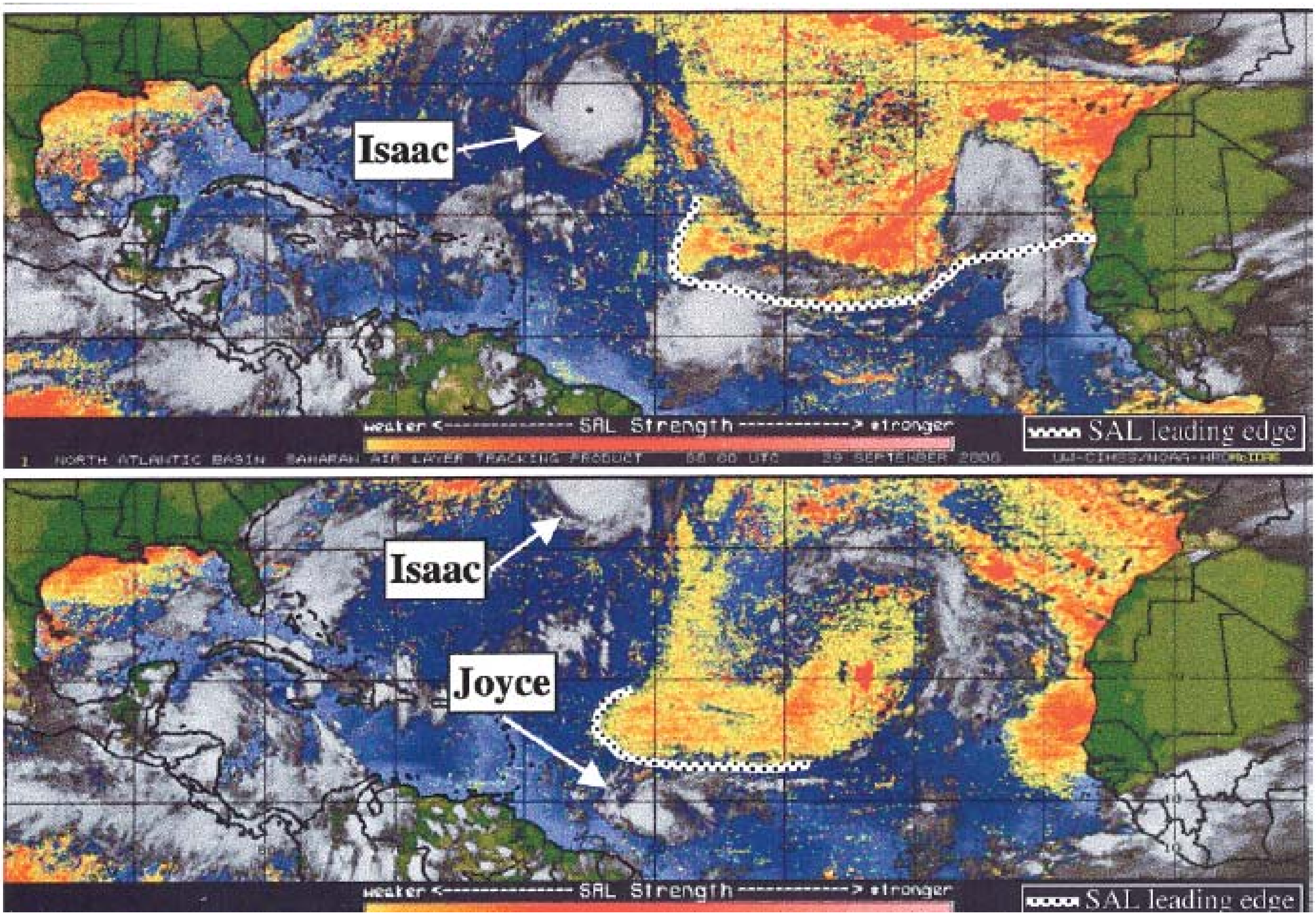
SAL Impact on TCs

- 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

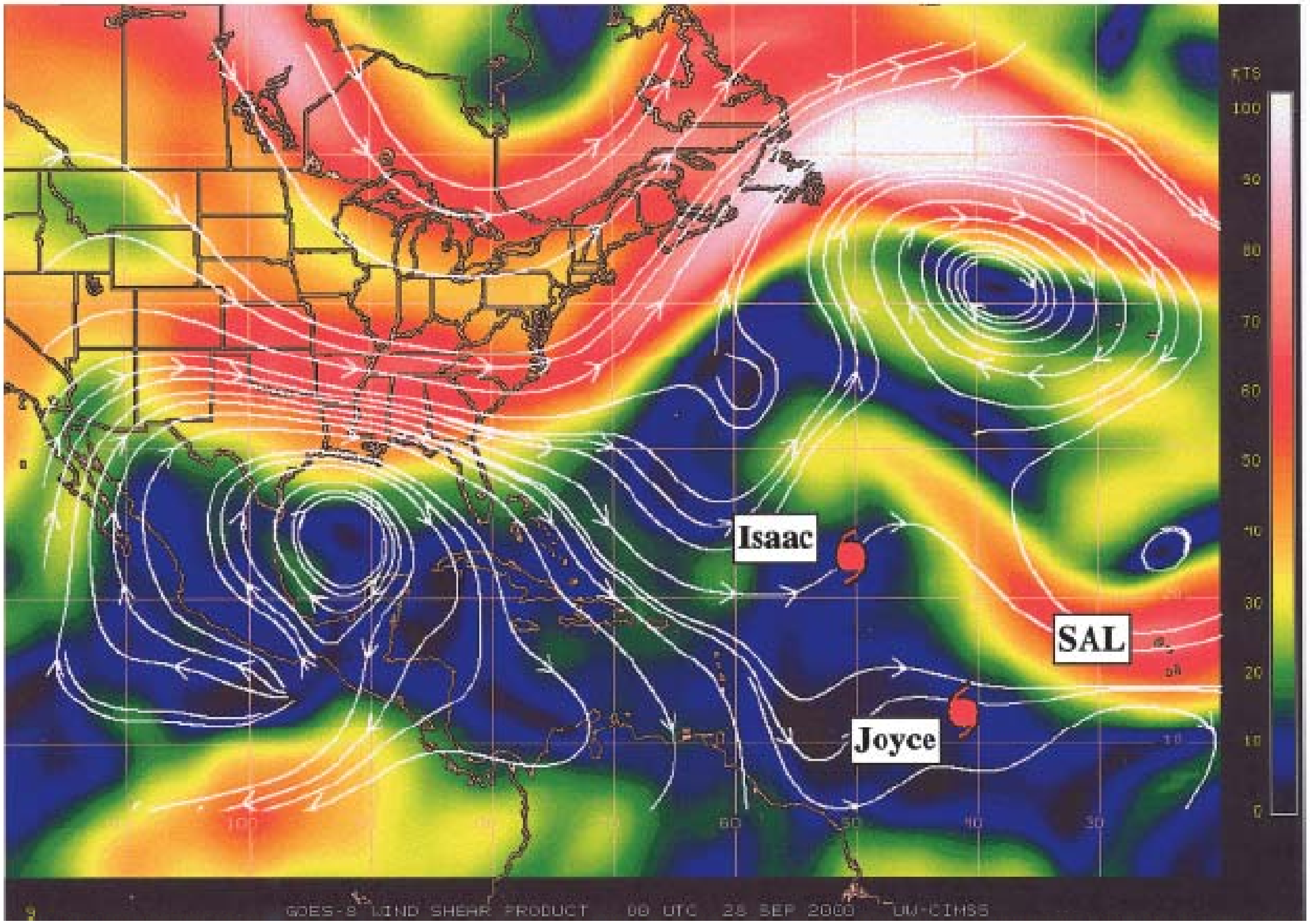
GOES Detection of the SAL

- 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



Wind Shear/SAL Relation



- Easterly Jet commonly located on south end of SAL

Multiplatform Satellite Wind Analysis

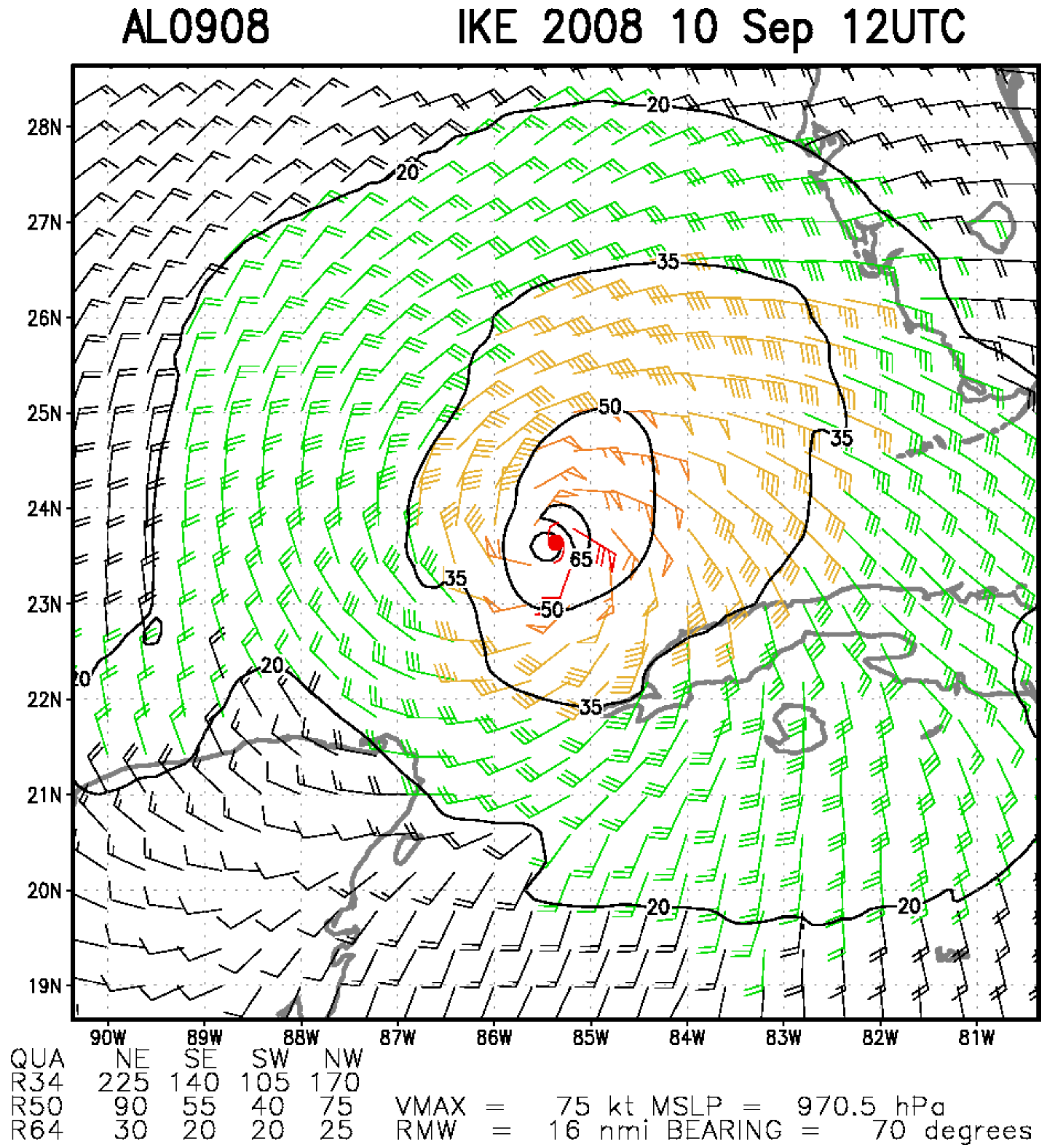
- Located on RAMMB site
- Best source for radius of maximum winds
- Shows if TC is symmetrical or if wind shear/dry air is causing asymmetries
- Is an estimate, not as accurate as Recon:
  - Winds are turned 20 degrees toward low and extrapolated to surface (from 700 mb) artificially

QUA = Quadrant

R34 = Radius of TS force winds (km)

R64 = Radius of hurricane force winds

VMAX = Max winds at time of image



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