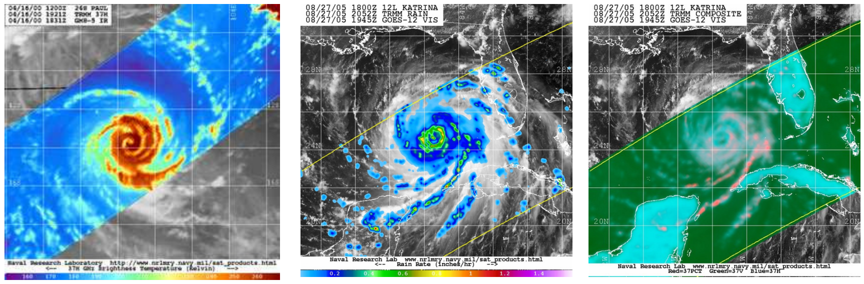


Advanced Satellite Remote Sensing: Microwave Remote Sensing

FIU HRSSERP Internship

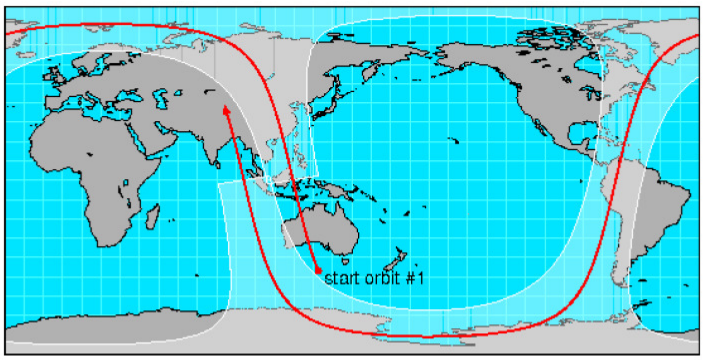
August 9, 2012

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 (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"



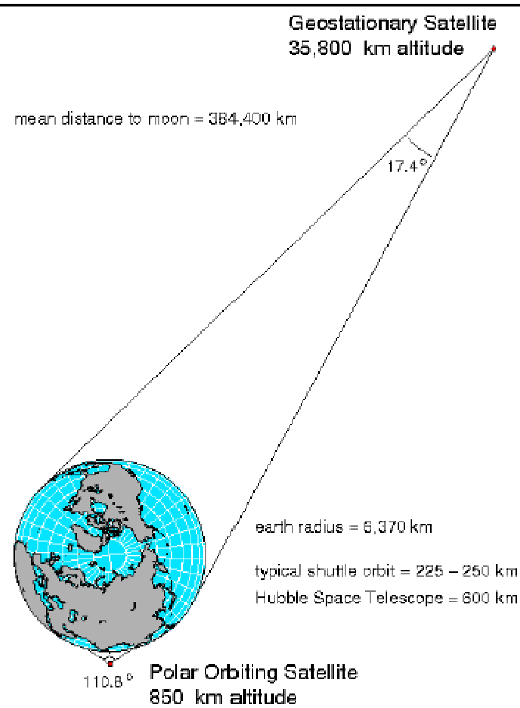
Polar Orbit

Advantages:

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

Disadvantages:

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

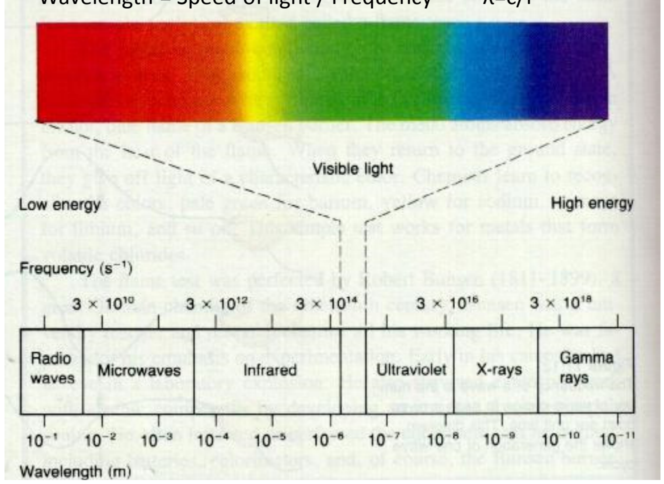


Polar-Orbiting Environmental Satellite Microwave Instruments

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 $\lambda = c/f$



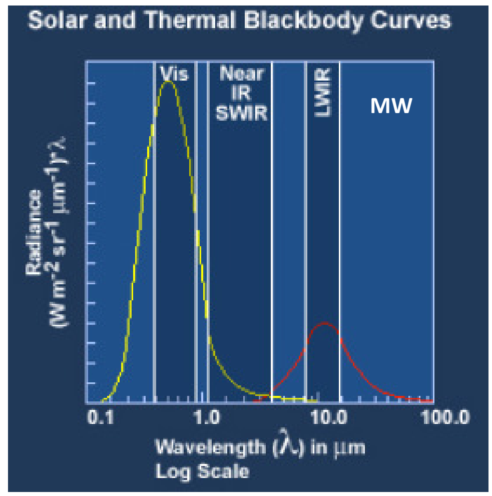
Long wavelength
Low Frequency

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?

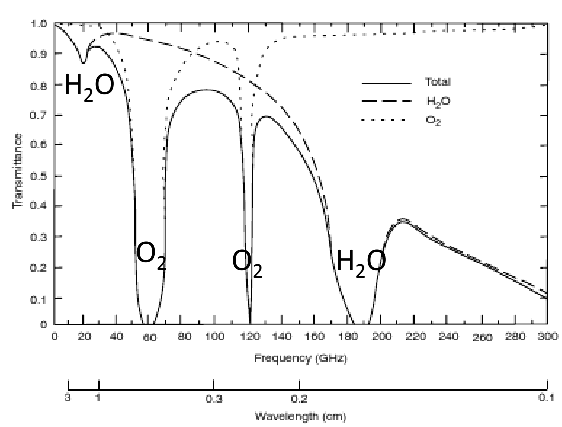
- MW satellites detect Brightness Temperature, just like IR Satellites
- The difference is that instead of measuring the temperature of the cloud tops (10.7 µm IR) or water vapor (6.7 µm WV), the MW satellites usually measure
  - Cloud droplets
  - Rain droplets
  - Ice/Snow/Hail

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

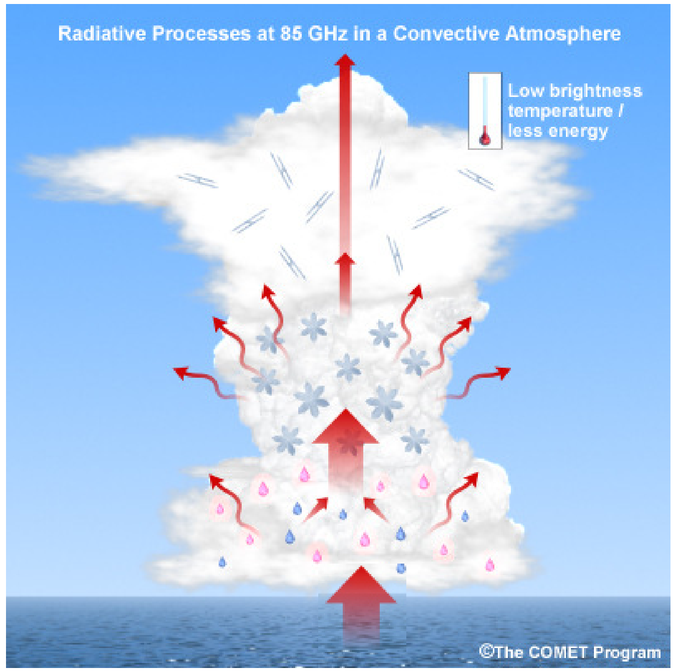
- 37/85 GHz frequencies chosen to avoid atmospheric gas absorption bands
- **Can not see clouds at all**, cloud droplets are too small and do not interact with EM-radiation at these frequencies
- Both channels can see difference between land and ocean
- **37 GHz** sees both emission from rain and cloud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



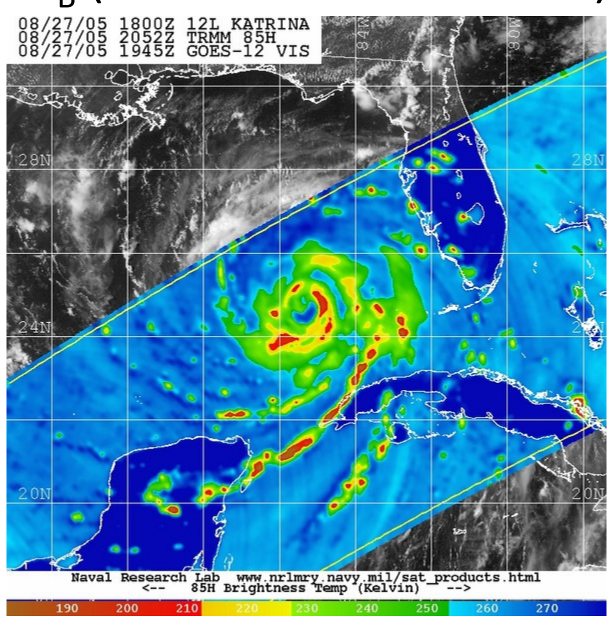
TRMM 85 GHz T_B (Horizontal Polarization)

-Land = Warm

-Ocean = Slightly cooler

-Low clouds and moisture = Warm

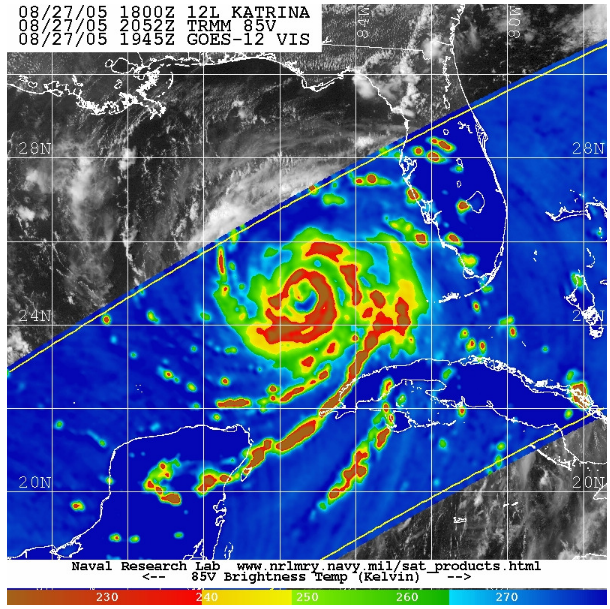
-Ice/Snow = Very cold



Note inverse scale!!!

TRMM 85 GHz T_B (Vertical Polarization)

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



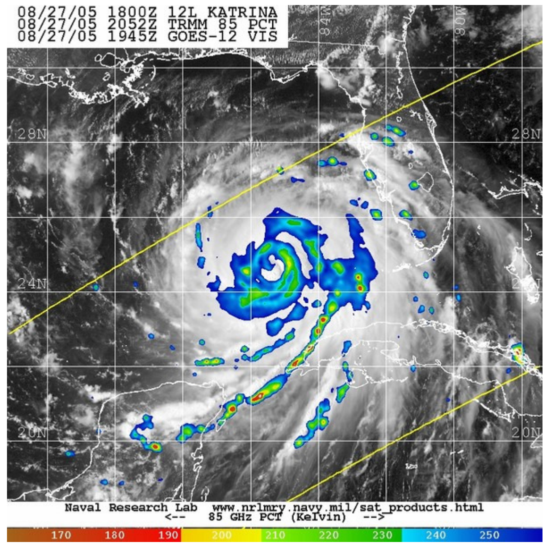
Different scale than 85-H

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

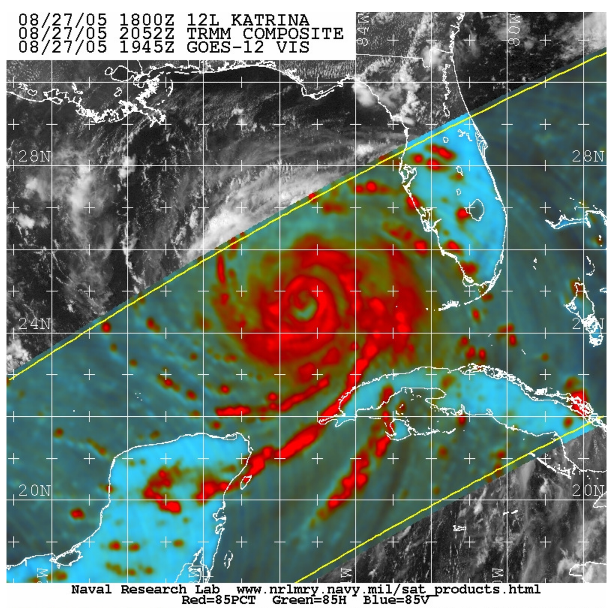
85 GHz Polarization Corrected Temperature (PCT)

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

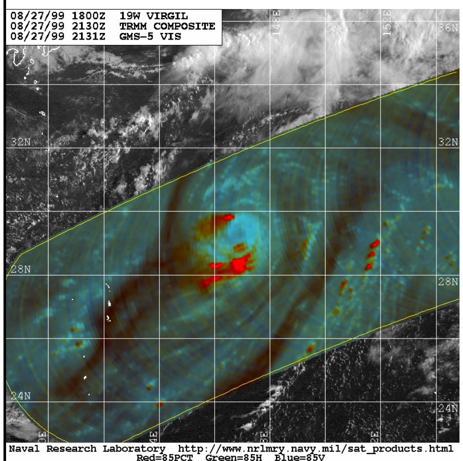


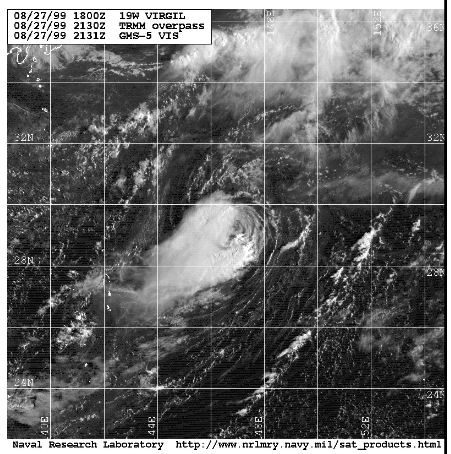
85 GHz Color Enhancement

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



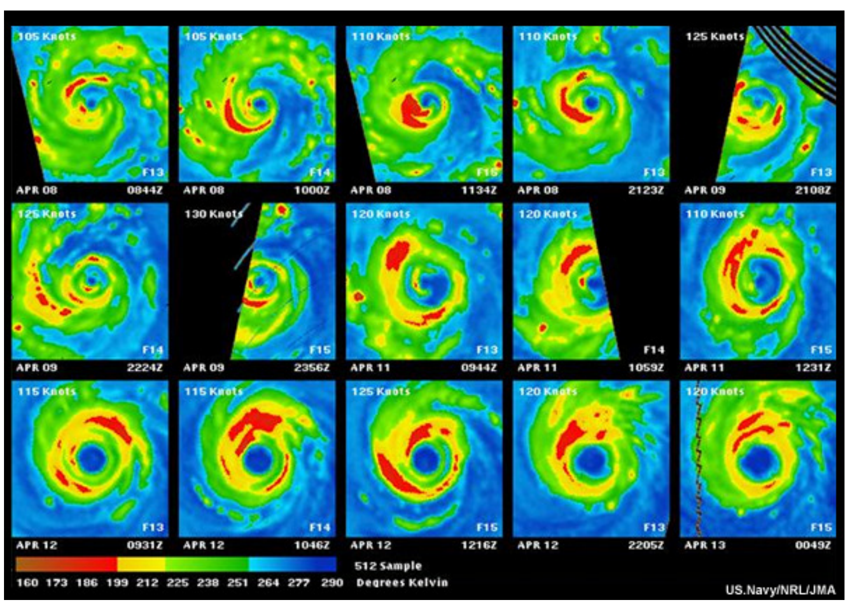
85 GHz color vs. Visible



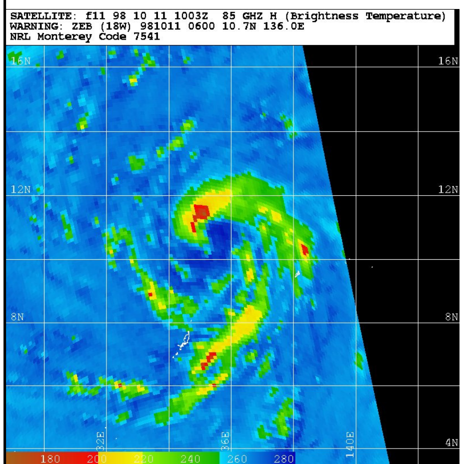


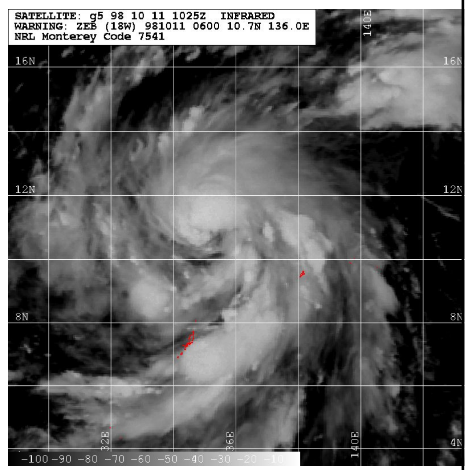
- Deep convection = Red
- Low-level swirl = Blue-Green

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

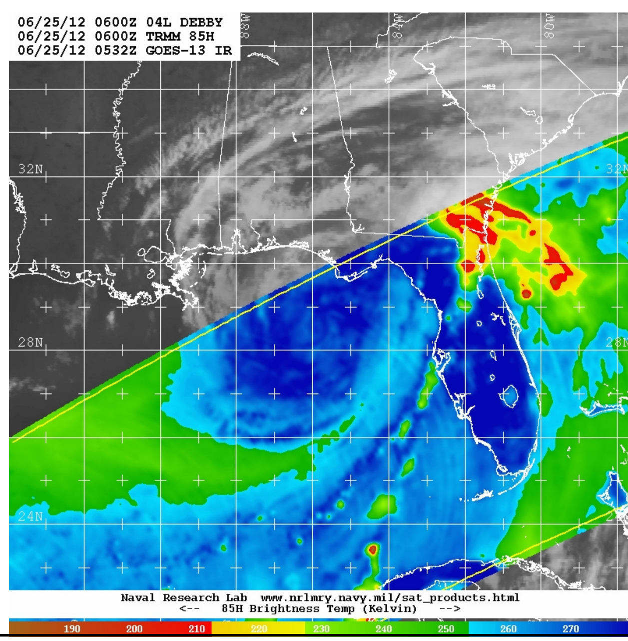
85 GHz Limitations

- 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

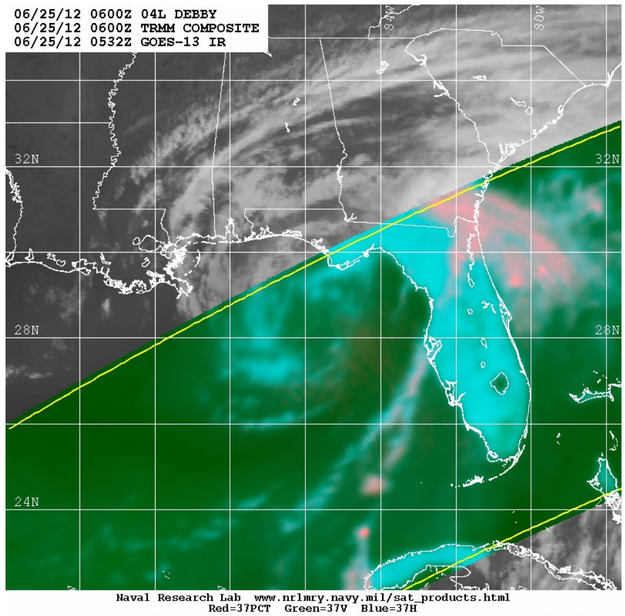
85 GHz Applications

- You want to know…
  1. Whether or not a storm has partial/concentric eyewalls:
     - Use 85 GHz H
  2. The details of the structure of the rain bands
     - Depends, usually 85 H is better for stronger storms (hurricanes), 37 color is almost always better for weaker storms
  3. What about the 85 GHz color (red) images?
     - 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)

Where is the center?



37 GHz color—can see rainbands now



37 GHz Channel

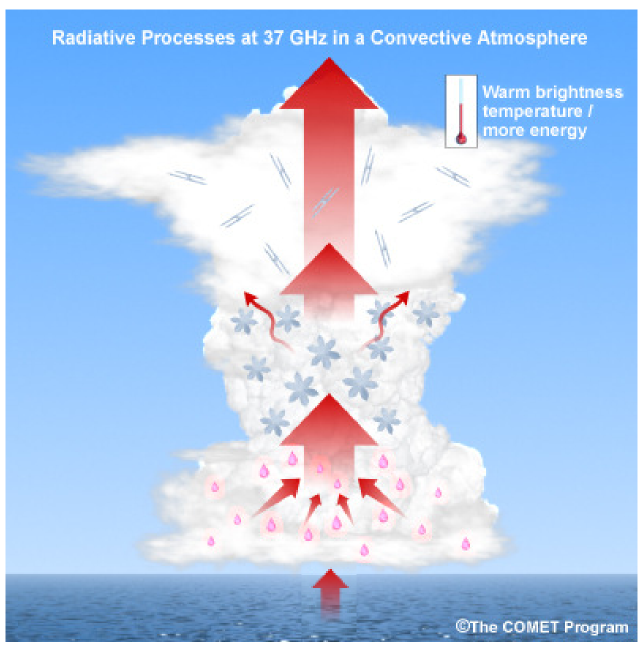
- Most noticeably detects **large ice particles and liquid rain** in the lower levels of the atmosphere
  - T_B ranges from 210-270 K in rain bands
  - Heavier rain= **warmer** T_B compared to ocean surface
  - Unless there is ice, then **colder** T_B
- In regions with no rain, detects emission of land 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
- Mix of warmer (rain) and colder areas (ice) makes interpretation tricky

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.

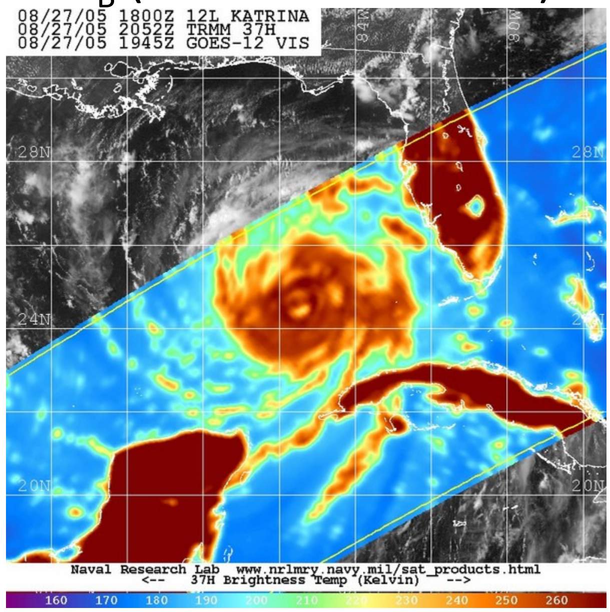
Unlike 85 GHz, only very large ice crystals cause measurable scattering

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



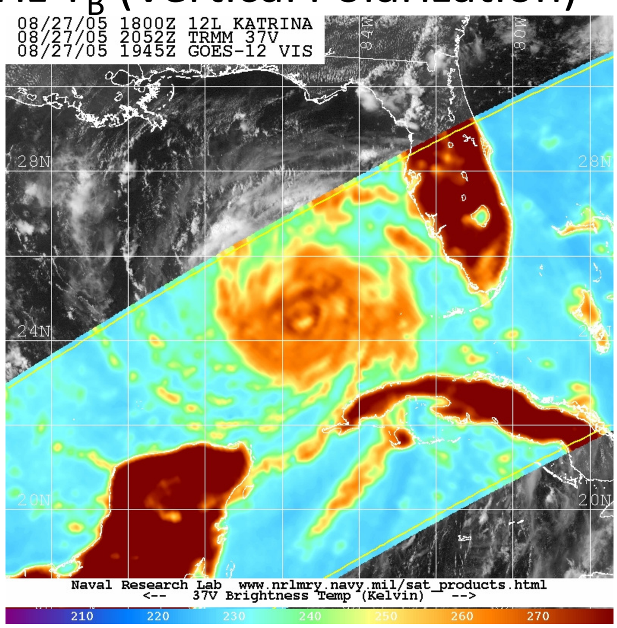
TRMM 37 GHz T_B (Horiz. Polarization)

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



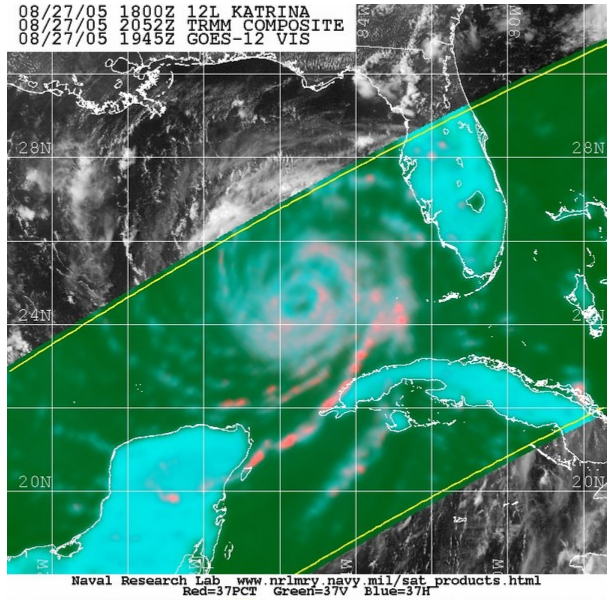
TRMM 37 GHz T_B (Vertical Polarization)

- -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 = deep convection with large ice particles (usually heavy rain below)



37 GHz Color (continued)

- Advantages:

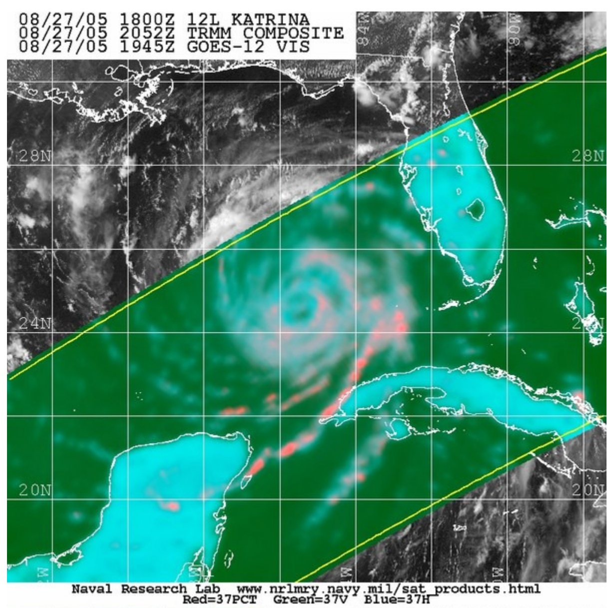
-Shows good contrast between light and heavy rain

-Can see eyewall forming earlier than other methods

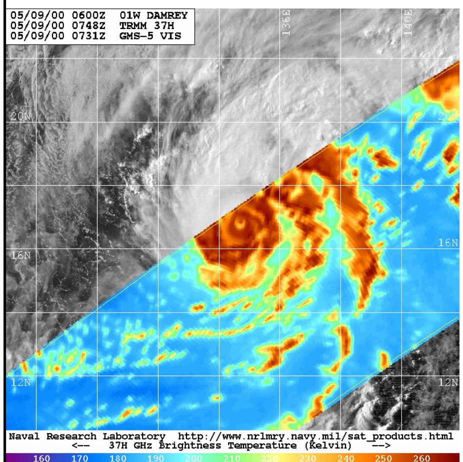
- Disadvantages:

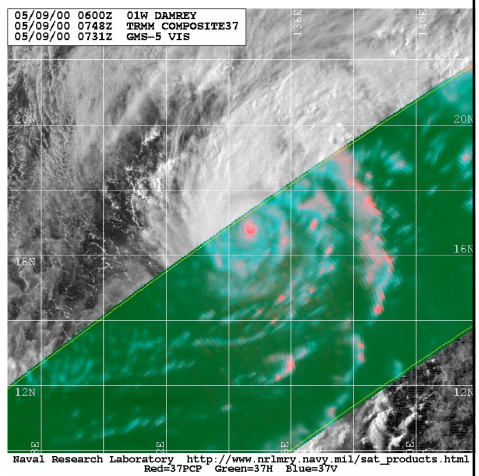
-Does not work over land

-Lower resolution than 85 GHz



37 GHz H vs. 37 GHz Color

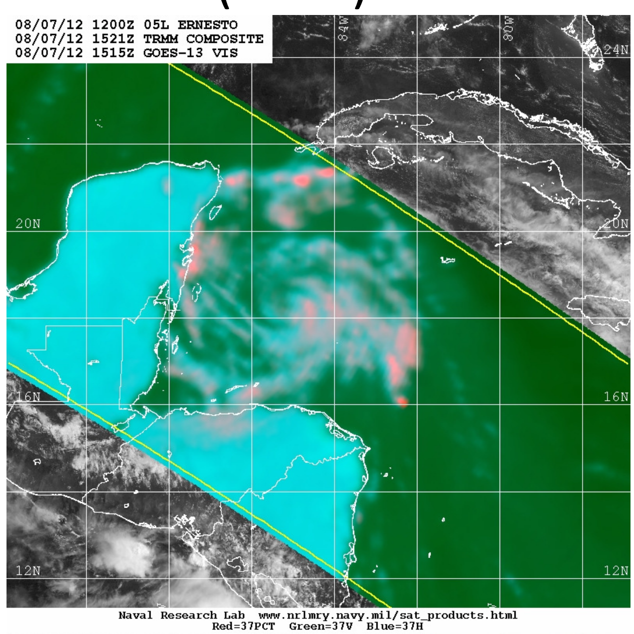




-All rain looks brown in 37-H, but it is easy to distinguish convective eyewall in 37 Color

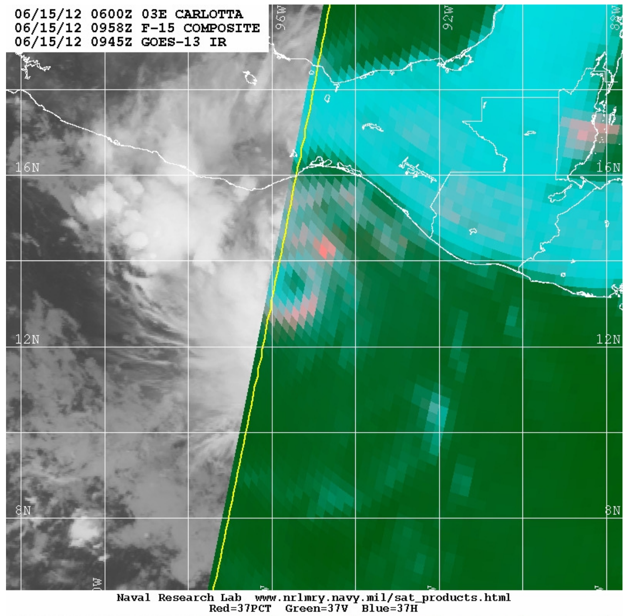
Ernesto (2012)

- The NW quadrant of the inner core is open, the majority of deeper convection (pink) is to the west of the center



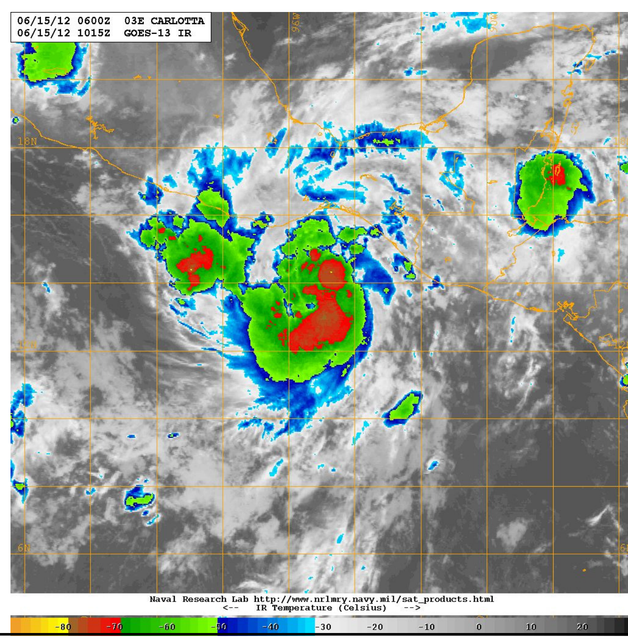
Carlotta (2012)

- 37 GHz Margie Kieper precipitative ring is present!
- Intensity was only 65 kt at the time
- Intensified to 90 kt in 12 hours



IR image at the same time (2012 Carlotta)

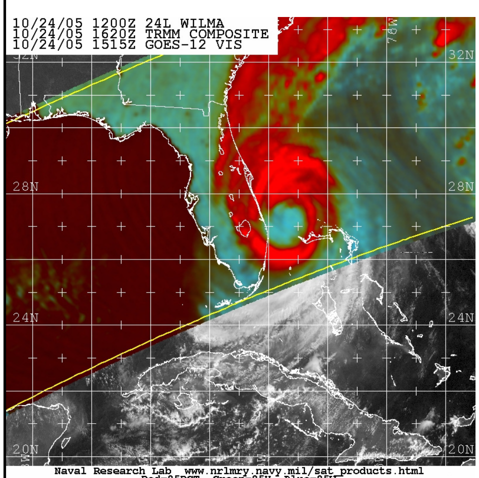
- No way to tell on IR that the storm had an eyewall forming
- No visible available because it was before dawn

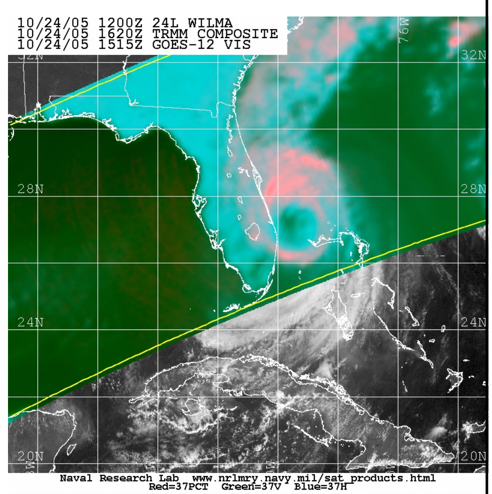


37 GHz Applications

- You want to know…
  1. Whether a storm is beginning to develop an eye or banding/eyewall features:
     - Use 37 Color
  2. If a TC or TC region has deep convection or shallow convection:
     - Compare 85 H and 37 color
  3. The details of the structure of the rain bands below the freezing level:
     - Use 37 GHz Color
     - In rare situations (very weak TC with no convection), 37 H might be better than 37 color

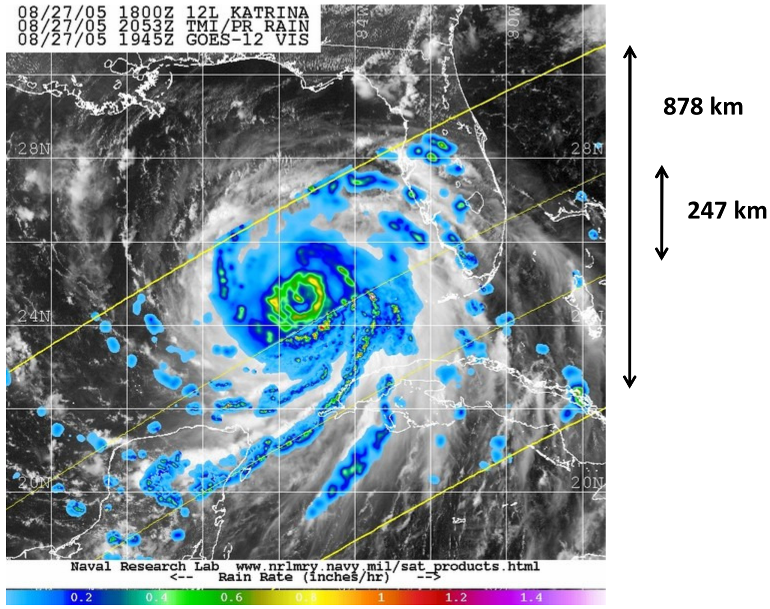
85 Color vs. 37 Color





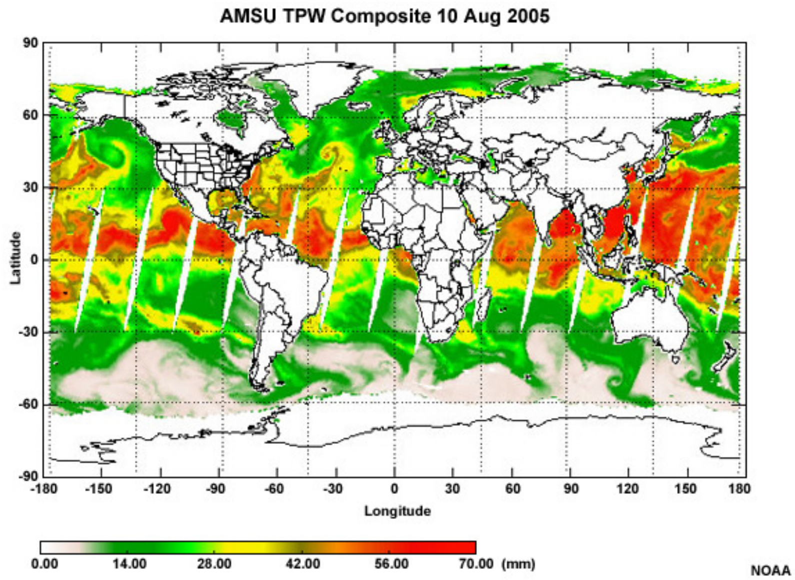
- Even though the 37 GHz has a lower resolution, it shows more details than the 85 GHz color
- The 85 GHz is better over land, however

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



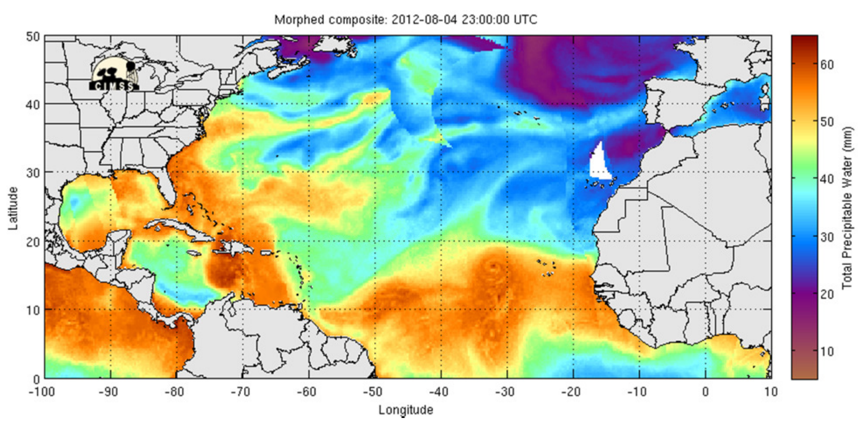
Total Precipitable Water (TPW)

- 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.
- Microwave TPW product combines 19, 22, and 37 GHz channels to estimate amount of water vapor in whole column



- Considered to be as accurate as a weather balloon
- Not available over land

TPW Multi-Satellite Composite

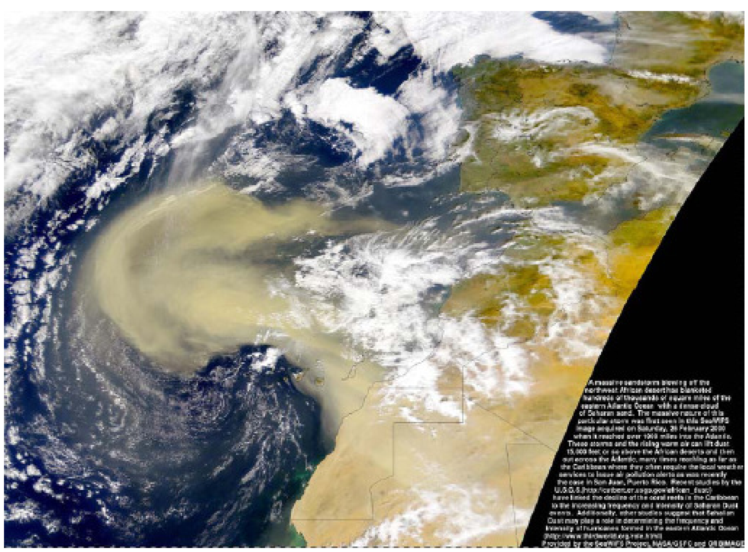


- Which regions are favorable for TC development?
- What is that giant mass of dry air to the west of Africa?

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

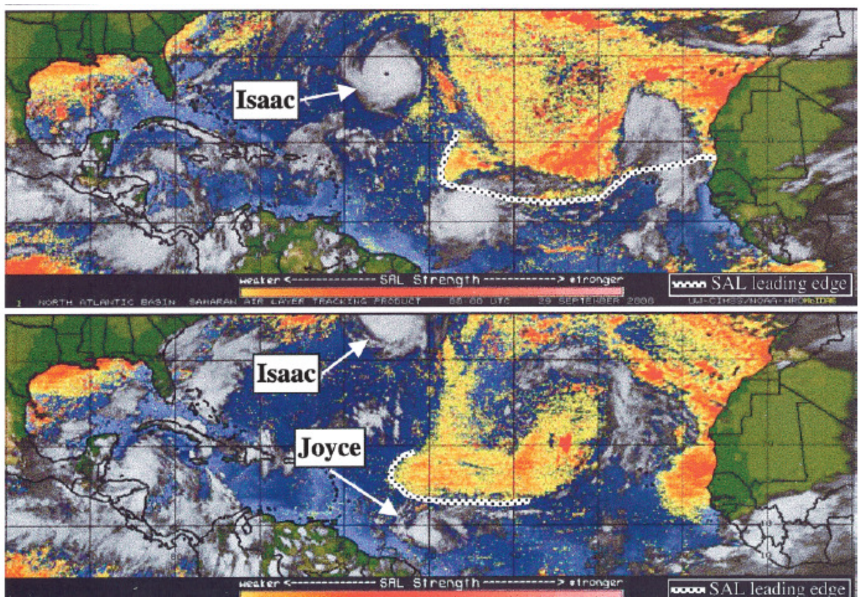
- Extremely unfavorable due to dry air, convection is suppressed or quickly dissipated
- Can completely prevent tropical cyclogenesis
- Can wrap into a mature hurricane and cause significant weakening
- SAL is often accompanied by an easterly jet stream moving 20-45 knots.
  - Causes significant wind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

GOES Detection of the SAL

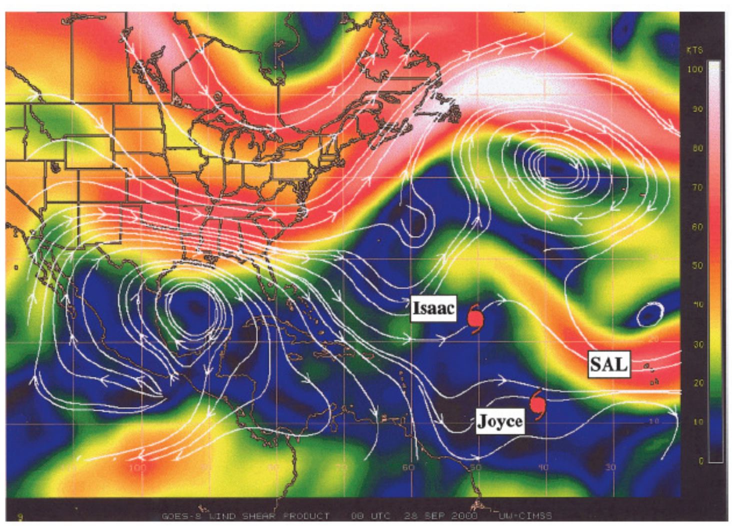
- First thought: Use the water vapor channel?
  - No, SAL only extends up to about 500 mb, too low to be seen by 6.7 µm channel if there is upper-level moisture
- Use difference between 10.7 µm and 3.9 µm IR channels
  - 10.7 µm is nearly completely transparent to water vapor
  - 3.9 µm picks up some 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

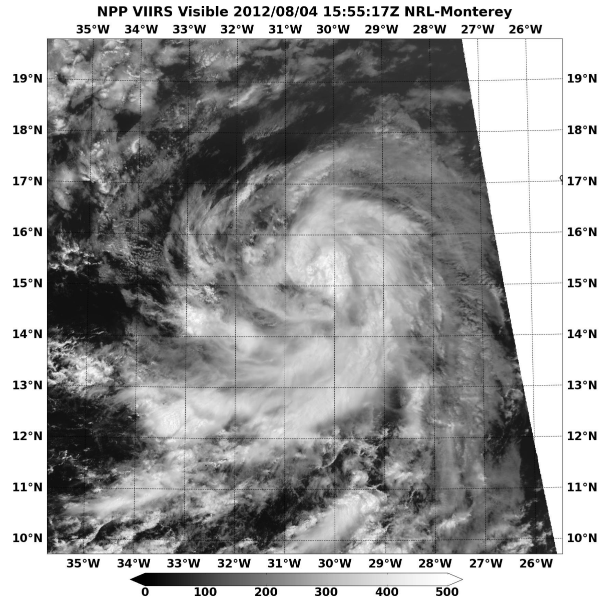


Wind Shear/SAL Relation



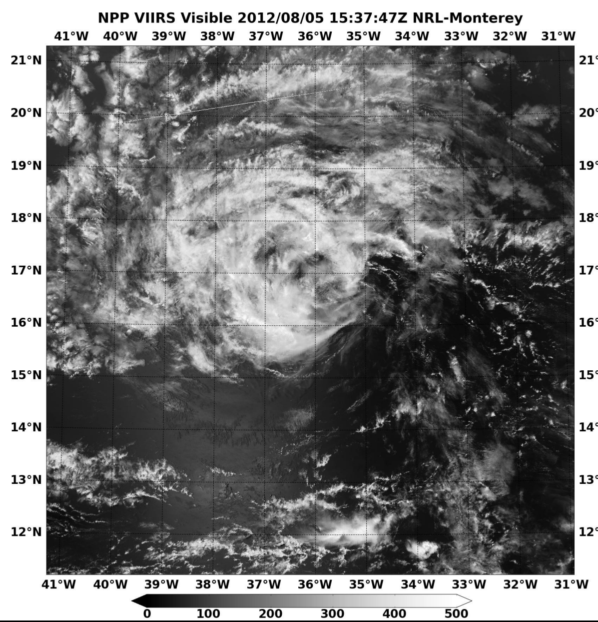
- Easterly Jet commonly located on south end of SAL

Death by SAL—Florence (2012)

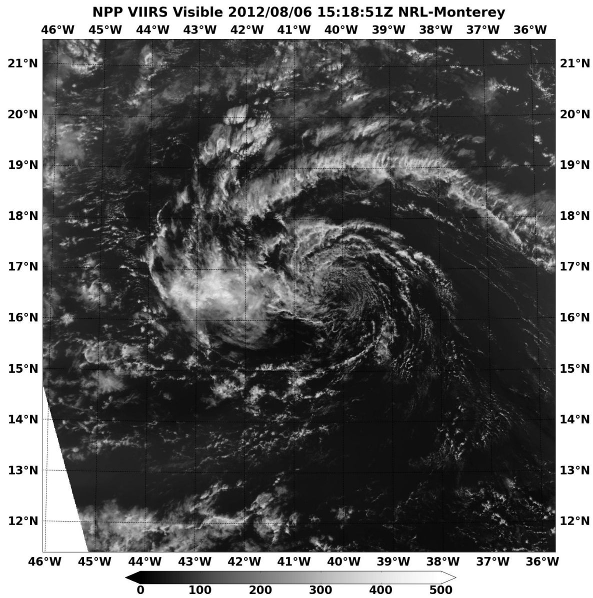


Day 1

Day 2



Day 3

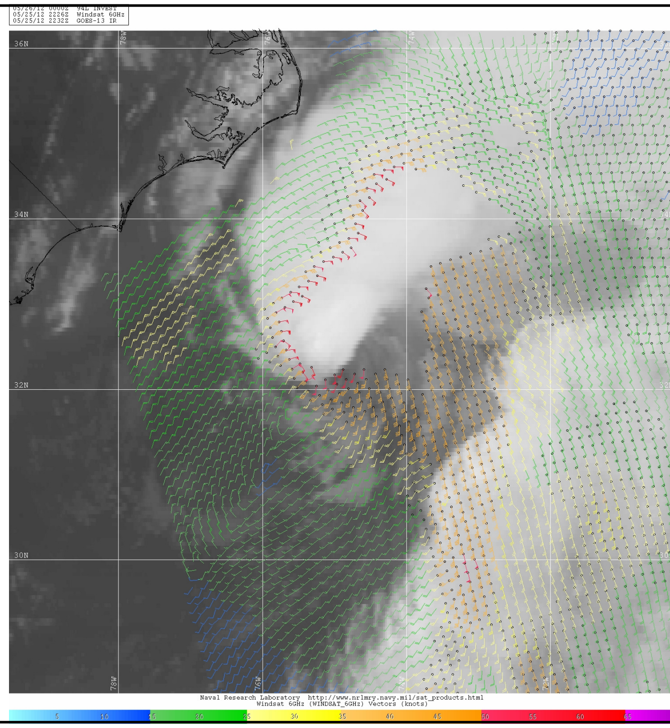


Satellite-Derived Wind Products

- Two types:
  - Geostationary satellite products
    - Uses movement of clouds
    - Example: CIMSS Shear Product
  - Microwave satellite products
    - Uses a combination of several microwave channels to measure the changes in brightness temperature and polarization caused by changes in ocean waves due to different wind speeds and directions
    - Example: WindSat surface wind vector

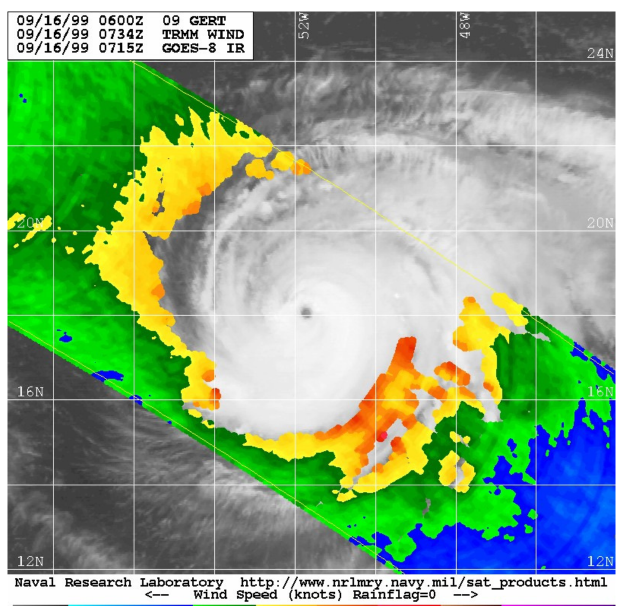
Windsat

- Most useful for determining the intensity of weak or sheared storms
- In this case, cyclonic turning and wind magnitudes greater than 40 kt resulted in this system being upgraded to a Tropical Storm



TRMM 37 GHz Wind

- Not very useful for TCs because it can't see through clouds and does not detect direction



Multiplatform Satellite Wind Analysis

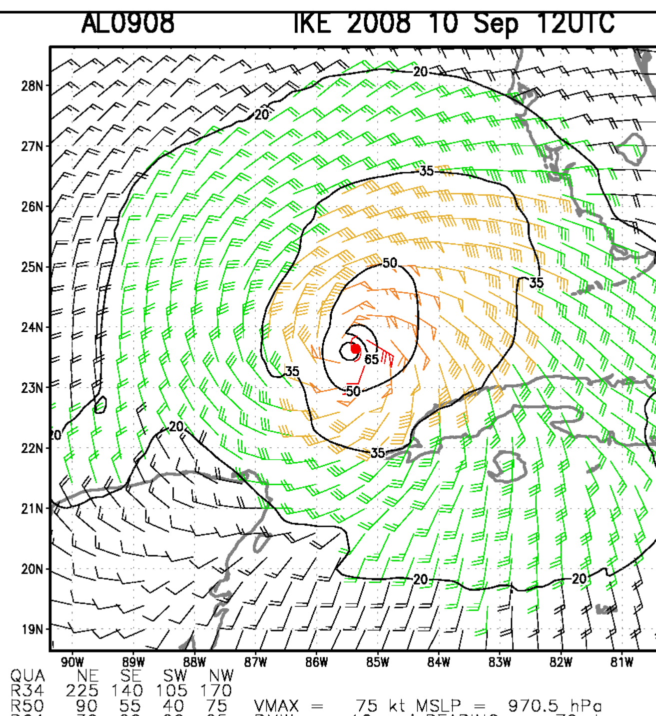
- Located on RAMMB site
- Combines multiple wind products
- Shows if TC is symmetrical or if wind shear/dry air is causing asymmetries
- Is an estimate, not as accurate as Recon:
  - Winds are turned 20 degrees toward low and extrapolated to surface (from 700 mb) artificially
- For past storms (with aircraft data), a more accurate product is available from HRD

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 Warm rain	Land surface Warm 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 wrap completely around the center
- Weaker storms or Tropical Storms
  - 37 GHz color is almost always the best to determine the structure of the rainbads
- Major Hurricanes
  - Can use 85 or 37 GHz, the 85 GHz color may also be helpful because the bright red around the eye is a good measure of the strength/size of the eyewall