# Satellite Remote Sensing Part 1

FIU Undergraduate Hurricane Internship

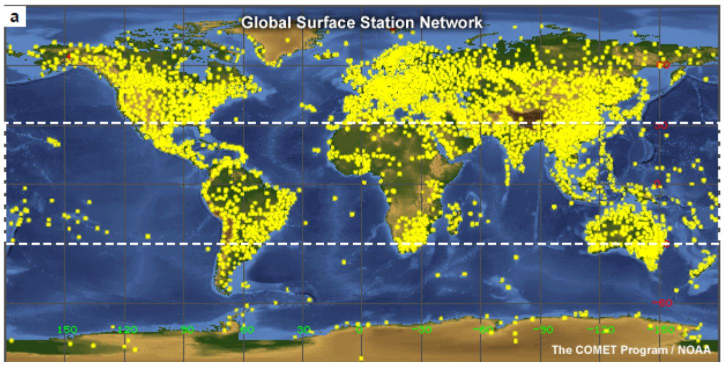
August 2011

## Objectives

- From this lecture, you should understand:
  - Why satellites are beneficial for studying tropical cyclones
  - Conceptually know what electromagnetic radiation is and how satellites measure it
  - What a blackbody and Planck curve represent
  - Differences between the Visible, IR, and Microwave spectrums
  - Most importantly, how to intelligently interpret Visible, IR, and Microwave satellite images

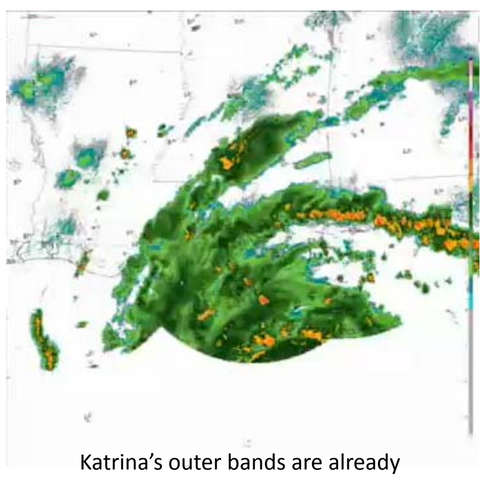
# Why Use Satellites to study Hurricanes?

- Coverage of surface stations, rain gauge, and radiosonde (weather balloon) mostly over land
- Less data available over oceans




- Ground-based Radar is only useful when the storm is making landfall
- Radar stations can be damaged by winds and often incorrectly measures the heavy rain in TCs
- Reconnaissance (aircraft) missions cannot provide continuous observations

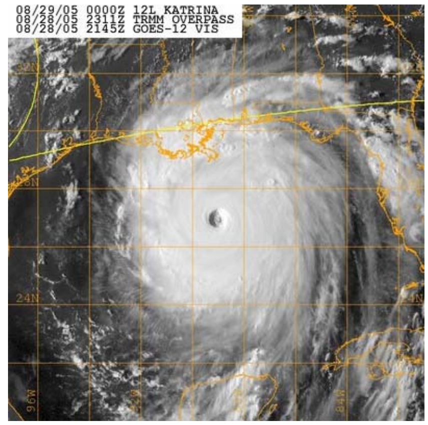
Katrina's landfall on WSR-88D Radar



Katrina's outer bands are already impacting the coast and the eyewall isn't even visible on radar yet. Landfall is imminent and the forecast track/intensity are unlikely to change significantly by this point!

# Benefits of Satellites

- Coverage of entire storm, even over open ocean areas
- No risk of instrument damage or human injury
- Most common method used for observing hurricanes and other activity over oceans




This visible satellite image shows the entire storm and updates every 15 minutes…but smaller-scale details like rainbands are not apparent

# What is Remote Sensing?

- **Remote sensing** is the acquisition of information about an object or phenomenon, without making physical contact with the object.
- **Sensors** are used to measure the **electromagnetic radiation** emitted from the object of interest
  - Example: using your eyes to see the visible light emitted from the projector

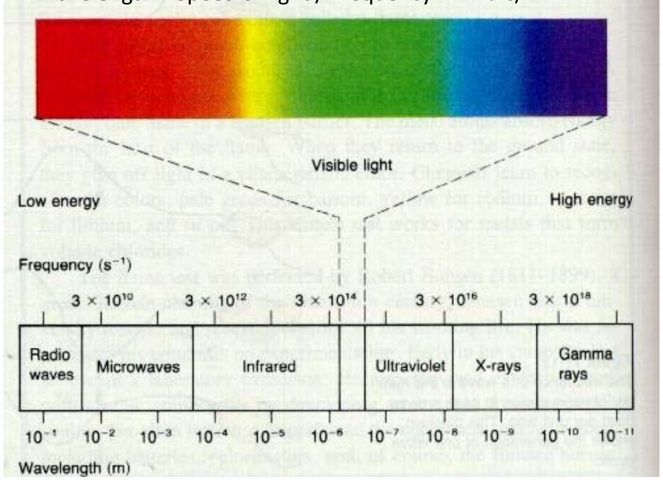
# Two types of Remote Sensors

1) Active
   - -Emits electromagnetic waves that travel to an object and are reflected back toward the sensor
   - -Examples: Radar, X-ray
2) Passive
   - -Observes electromagnetic waves emitted by objects
   - -Examples: Camera, **Visible/Infrared satellite**, Eye

**All the satellite images in this presentation (Visible, IR, and Water Vapor IR) are derived from measured outgoing radiation to space, emitted by the earth/clouds/atmosphere.**

# Electromagnetic Spectrum

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

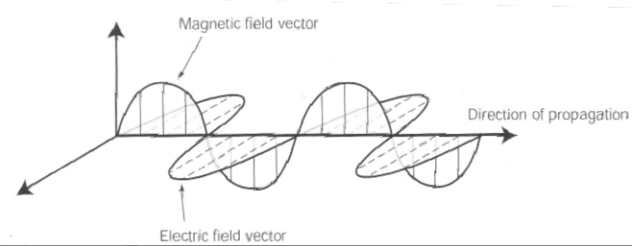



Long wavelength
Low Frequency

Short Wavelength
High Frequency

## Properties of Electromagnetic Radiation

- EM waves consist of an electric and magnetic field, perpendicular to each other and to the direction of propagation.
- EM waves propagate in 3D-space and require no material medium in which to propagate.
- In a vacuum, EM-waves move at the speed of light. In a material medium (atmosphere, clouds, rain), EM-waves can be absorbed, scattered, or emitted.




## Definitions:

- **Wavelength, λ,** the distance between crests of an electromagnetic wave (units: m)
- **Frequency, *f*,** the rate of oscillation of radiation at a point (units: 1/s = GHz)
- **Speed of light, c,** constant in a vacuum at 3.0 x $10^8$ m/s
- **λ=c/f,** Wavelength is inversely related to frequency
- **E = hf,** Energy of a photon of EM radiation is proportional to the frequency
  - **Note:** h=Planck's Constant., 6.626 x $10^{-34}$ J/s

## Blackbody (conceptually)

- **Blackbody**: a theoretical object that absorbs and emits all radiation perfectly.
- Useful concept because we can use **Planck's Function** to calculate the temperature of a blackbody, which we call **Brightness Temperature**.
- If the object we are observing is close to a blackbody (i.e. it absorbs/re-emits most incoming radiation for a particular wavelength), then we can approximate the **actual temperature** of the object as the calculated brightness temperature
- In this way, a satellite remote sensing device can approximate the temperature of the earth/clouds/rain from space.

## Blackbody (mathematically)

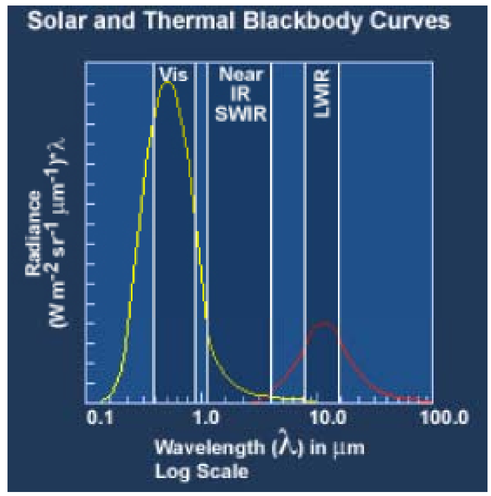
- Planck's Function: $B_\lambda(T) = \frac{2hc^2\lambda^{-5}}{(e^{hc/k\lambda T} - 1)}$
  – $B_\lambda(T)$ represents radiative intensity (energy) which can be measured directly by a satellite
- Invert Planck's Function to derive Brightness Temperature (solve the above equation for T):

$$T_B = \left(\frac{hc}{k\lambda}\right)\frac{1}{\ln\left[\frac{2hc^2\lambda^{-5}}{I_\lambda} + 1\right]}$$

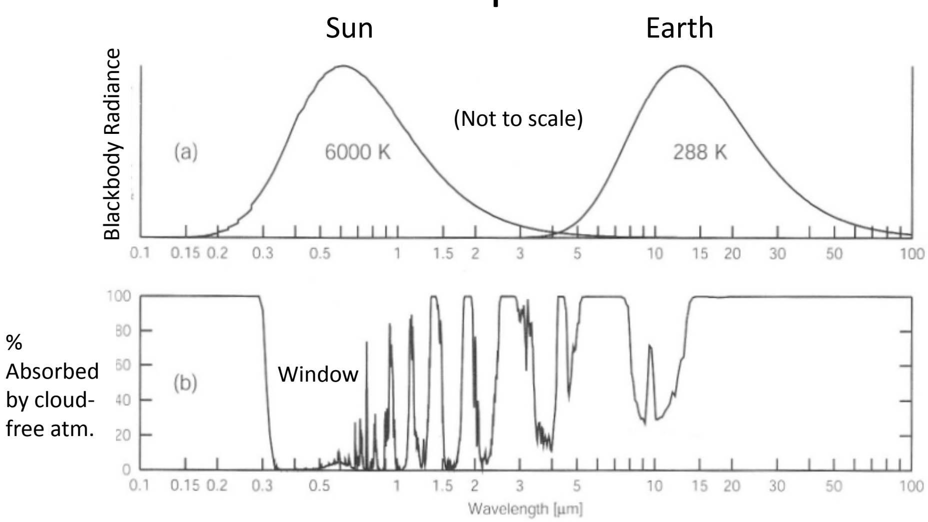
- If the object is close to a blackbody, $T_B$ represents the object's physical temperature

# Planck Curve

- Graphical display of Planck's Function for various wavelengths
- Yellow = Sun
- Red = Earth
- Remember, the Planck Function calculates radiance, which we can convert to Brightness Temperature




# Planck Curves and Atmospheric Absorption




0% = transparent; 100% = blackbody

# Visible Spectrum

- Wavelength 0.4 – 0.7 µm
- Maximum emission of radiation by the sun
- The cloud-free atmosphere is mostly transparent to all visible wavelengths (some scattering = blue sky)
- Clouds are remarkably reflective (white)
- Earth’s surface absorbs most visible radiation, resulting in the atmosphere heating from below

# IR Spectrum

- Longer wavelengths:
  - 0.7 µm – 1000 µm (1 mm)
- Maximum emission of radiation by Earth
- Atmospheric absorption is highly variable, some portions of the spectrum are nearly transparent, others are strongly absorbed/attenuated by atmospheric constituents (like water vapor)
- Clouds are highly absorbent in the IR, close to a blackbody. Therefore, IR satellite images can only “see” the top of clouds

# Microwave Band

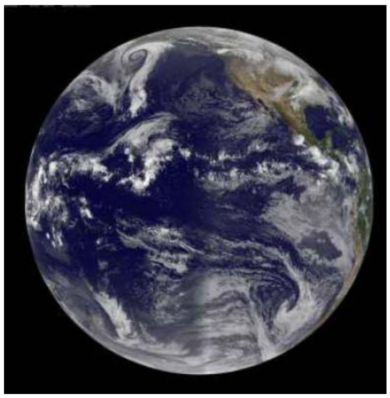
- Very long wavelengths:
  - 1000 μm (1 mm) to 10 cm
- Biggest advantage is that clouds are relatively transparent to microwave radiation because the cloud droplets are too small to be attenuated by the longer MW wavelengths. Depending on the choice of wavelength, a satellite can detect primarily clouds, rain drops, or ice particles
- Major differences when observing over land vs. ocean.
- More details in advanced lecture

# Geostationary Satellites

- Most visible, IR, and WV images come from geostationary satellites
- Geostationary orbit:
  - Synchronized with the earth’s rotation, so the satellite remains over the same geographic location at the equator
  - Located approximately 35,000 km above earth’s surface
  - Advantage: provides continuous observation of a large geographic area (image every 15 min)
  - Disadvantage: relatively low resolution due to high orbit

# GOES Satellites

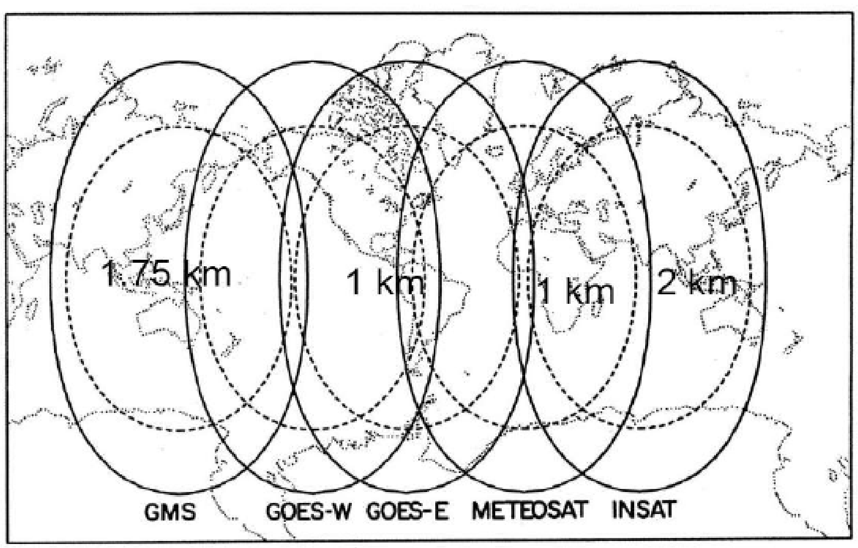
- GOES: Geostationary Operational Environmental Satellite
- GOES-East: Atlantic Ocean, Eastern US
- GOES-West: East Pacific Ocean, Western US



GOES-West

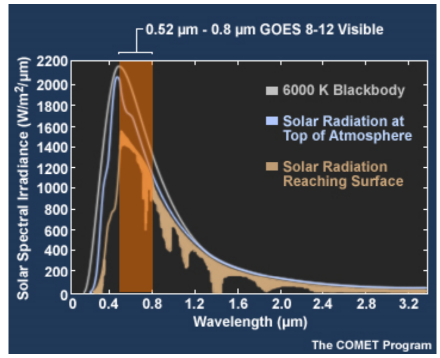
GOES-East

# Geostationary Satellite Coverage

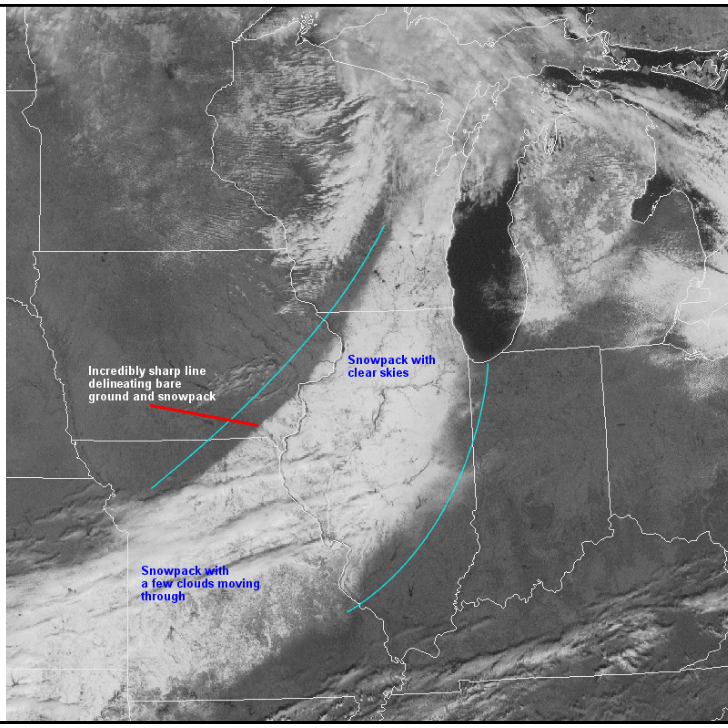


# Properties of Visible Satellite Images

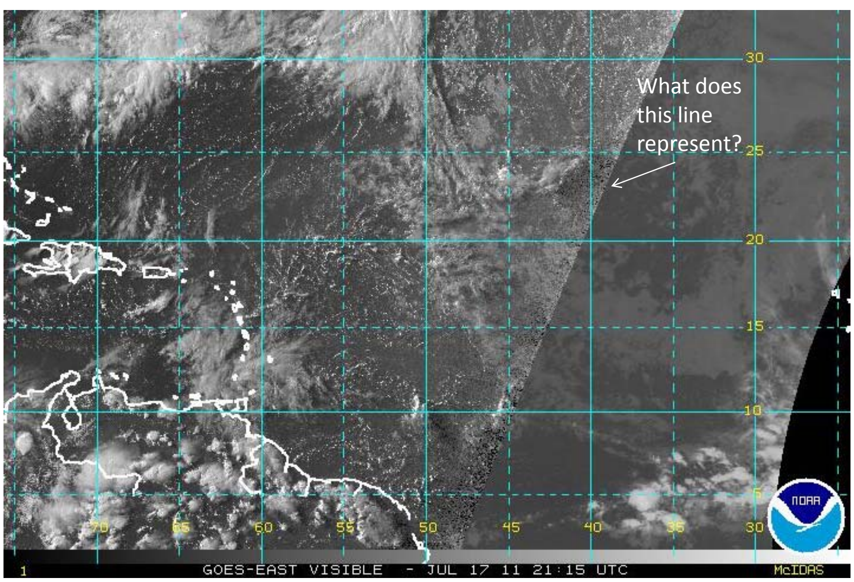
- Available during daylight hours only
- Sees scattered and reflected energy
- Clouds appear white (highly reflective)
- Water and earth's surface appear dark (highly absorbent)
- Higher resolution than IR (usually 1 km)
- Shadows can be used to estimate cloud height



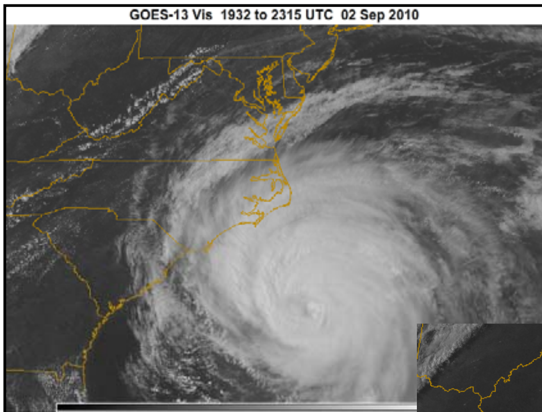

# How would this image look from a satellite in the visible spectrum?




# Visible Satellite

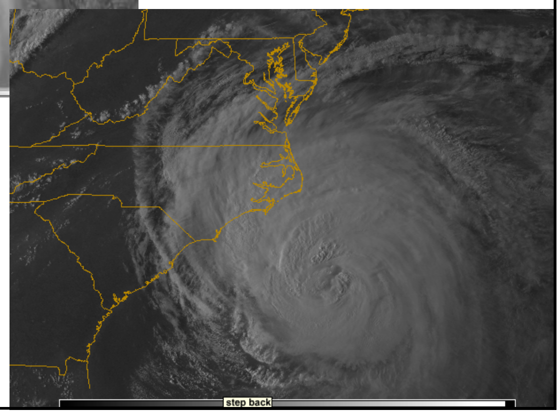


# Visible Earl (2010)

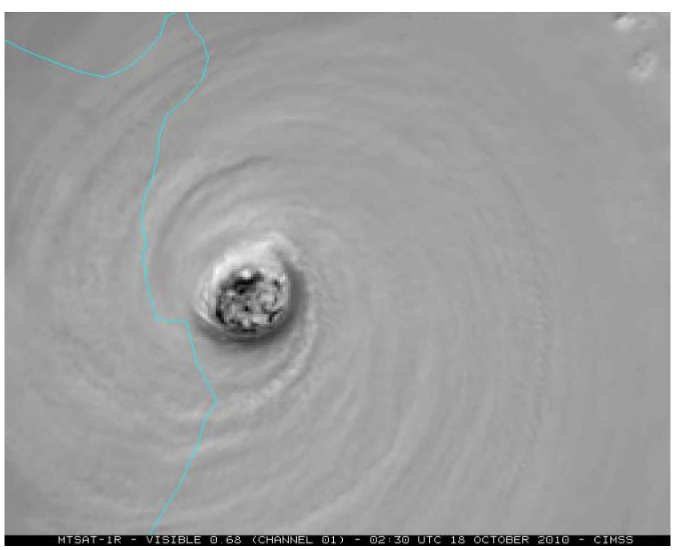



Afternoon

Sunset

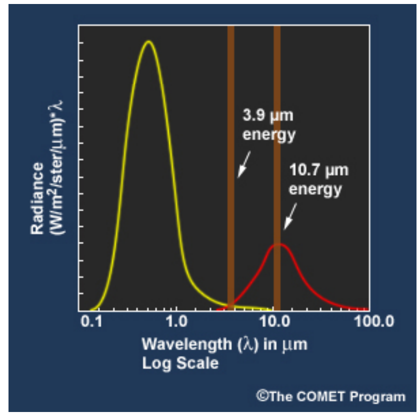



# Visible: 1 km resolution

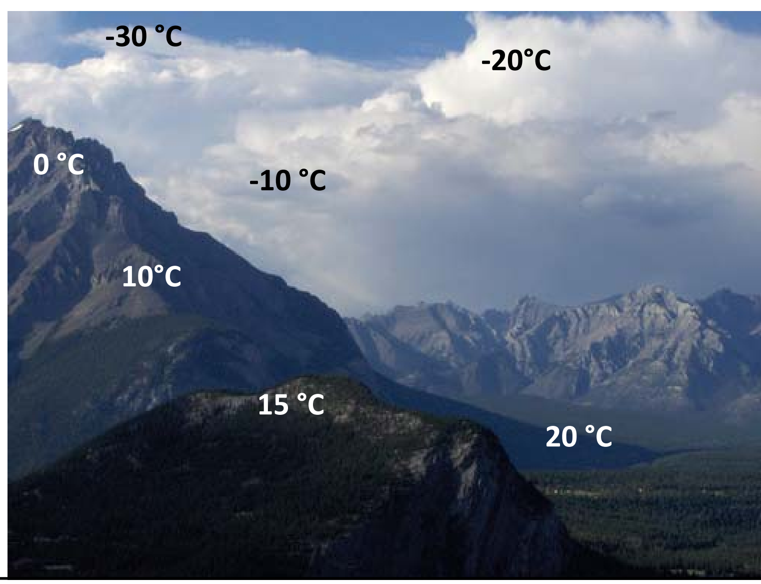


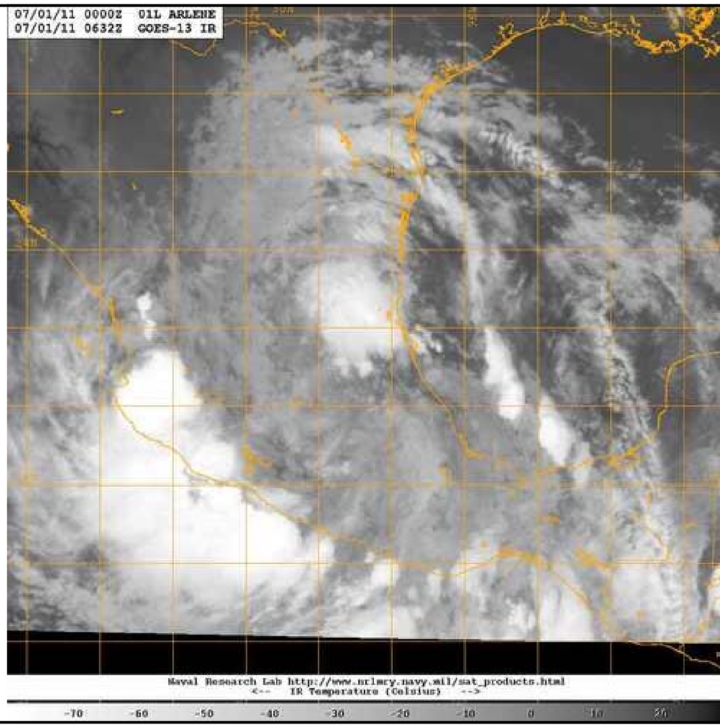
## Properties of IR Satellite Images

- 10.7 µm IR spectrum located at peak of Earth's Planck curve
- Detects emitted radiation from earth's surface and clouds, works during day and night.
- Clouds and earth are close to a blackbody
- Lower resolution (4 km)



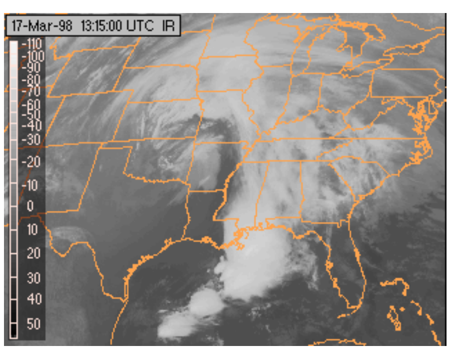

## How would this landscape look from a satellite in the IR spectrum?

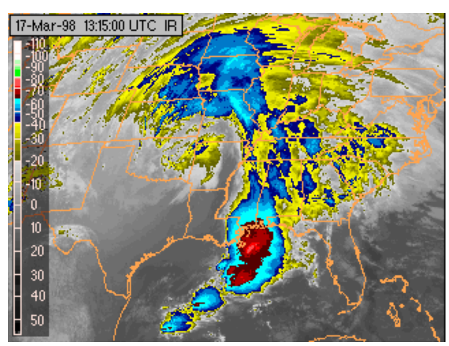





# IR Color Enhancement

- Used to emphasize the coldest (highest) cloud tops found in deep convection

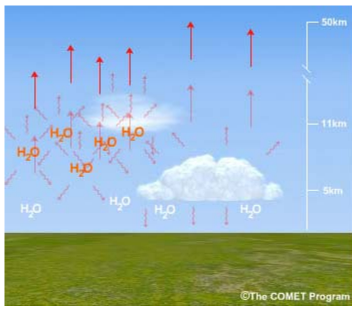


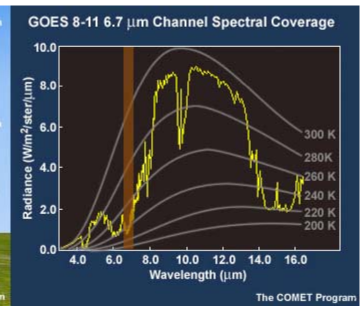




Hard to tell the difference between -60 to -90 °C without the color enhancement

## Properties of Water Vapor (WV) Images

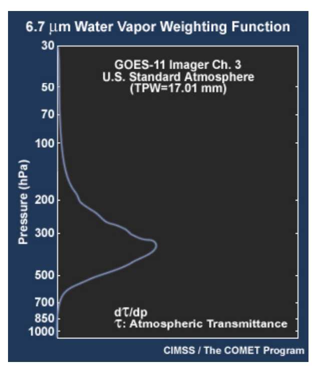
- 6.7 µm IR channel is in a water vapor absorption band
- 4 km resolution
- Highly sensitive to atmospheric moisture, can also see atmospheric waves and the jet stream




## 6.7 µm Weighting Function

- Due to strong attenuation of water vapor, images are only sensitive to WV in the **upper half of the troposphere**, 200-500 mb
- Even in dry conditions, the WV channel gives no information about the lower troposphere or surface

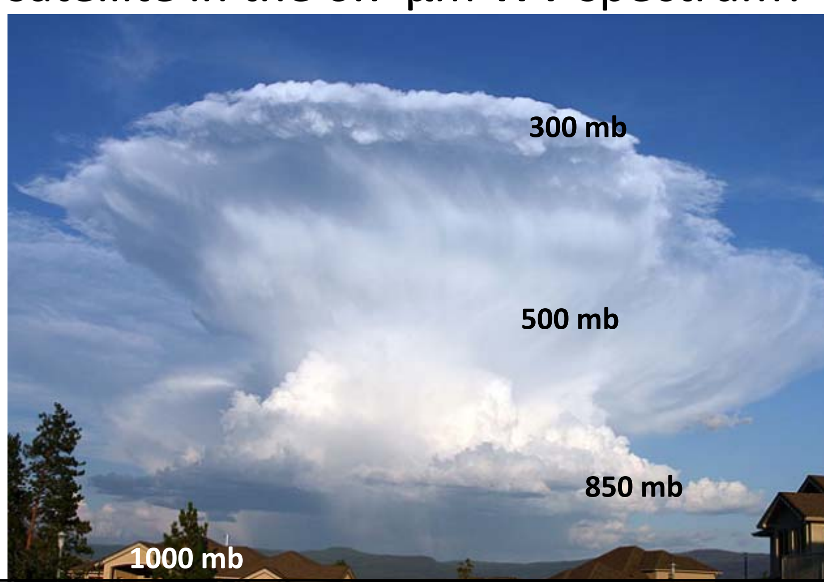


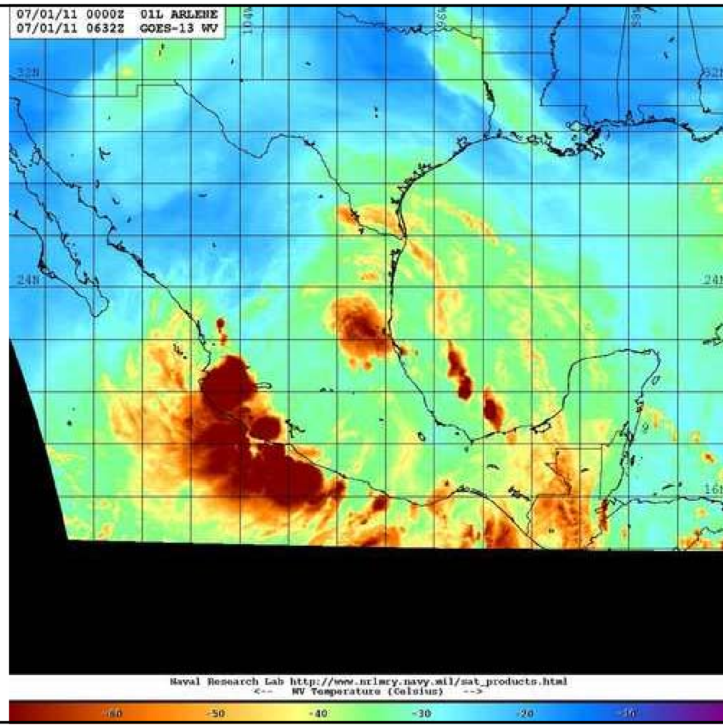

"Weighting function" for 6.7 µm channel under standard conditions. The curve shows the relative vertical contribution to the measured radiance

# What is the WV channel sensing?

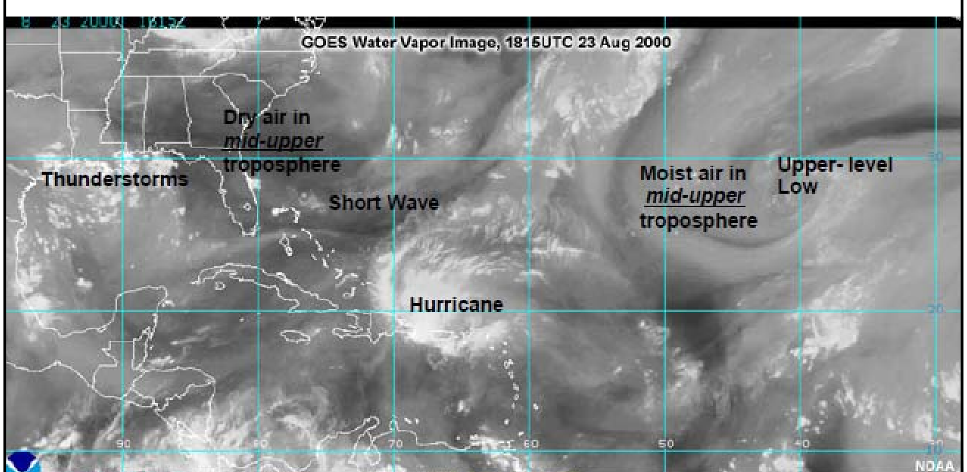
- The water vapor image does not directly represent moisture, it is proportional to the mean temperature of the top 3 mm of water vapor in the atmosphere.
- **Cold (white):** thick and high clouds
- **Moderate (grey):** no high clouds, but moist mid-upper atmosphere
- **Warm (black):** Dry upper atmosphere

# How would this image look from a satellite in the 6.7 μm WV spectrum?

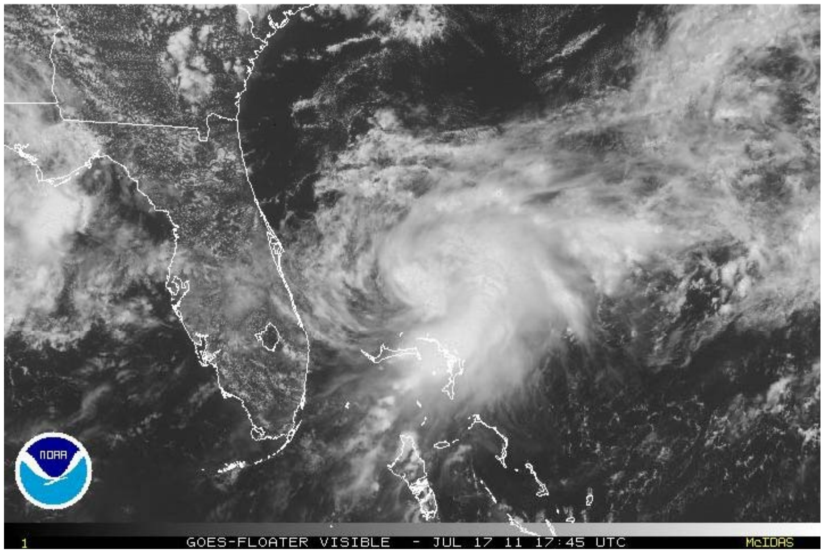




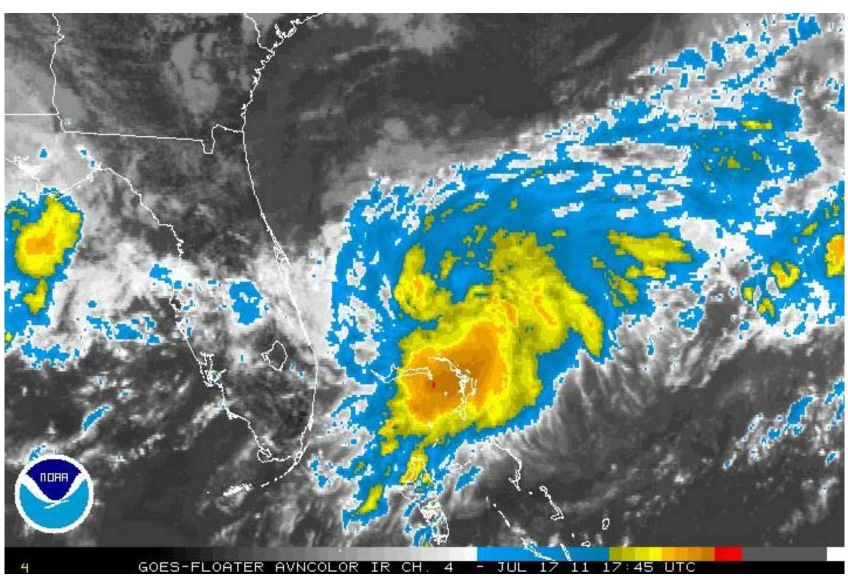

# Common features on WV images



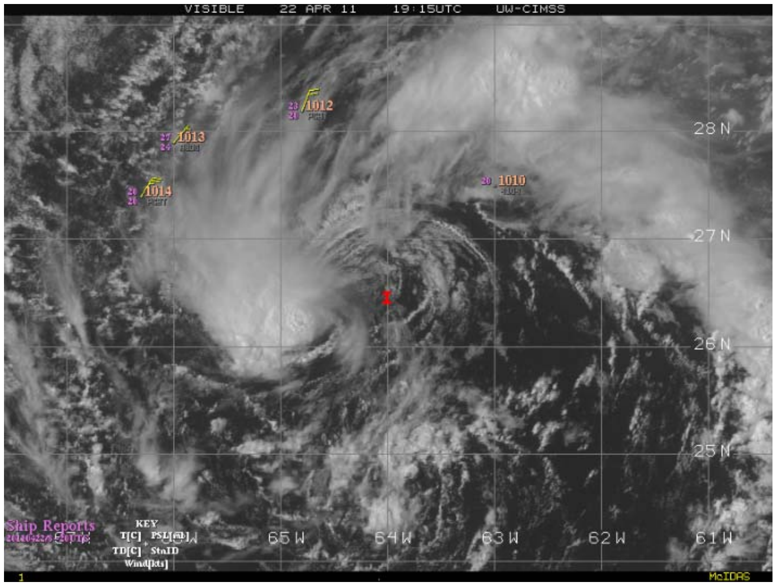
# TD #2 (2011) Visible



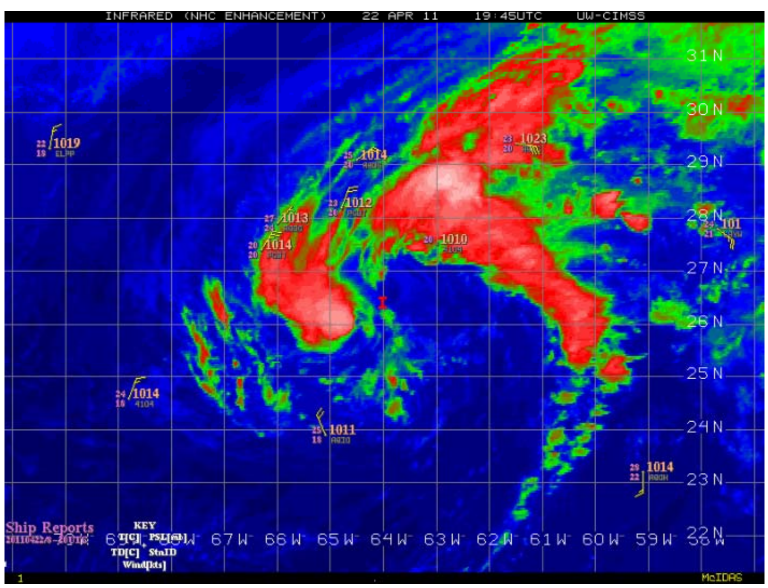

# TD #2 (2011) IR Color



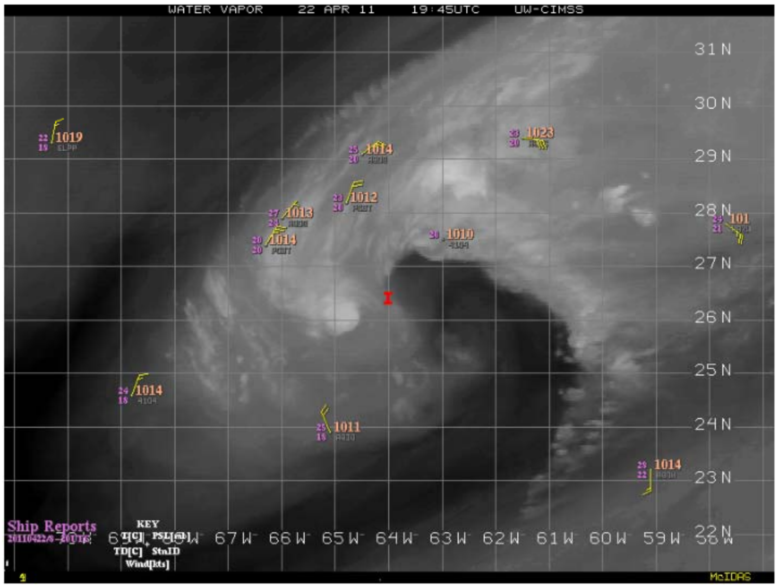
# Subtropical Storm: Visible



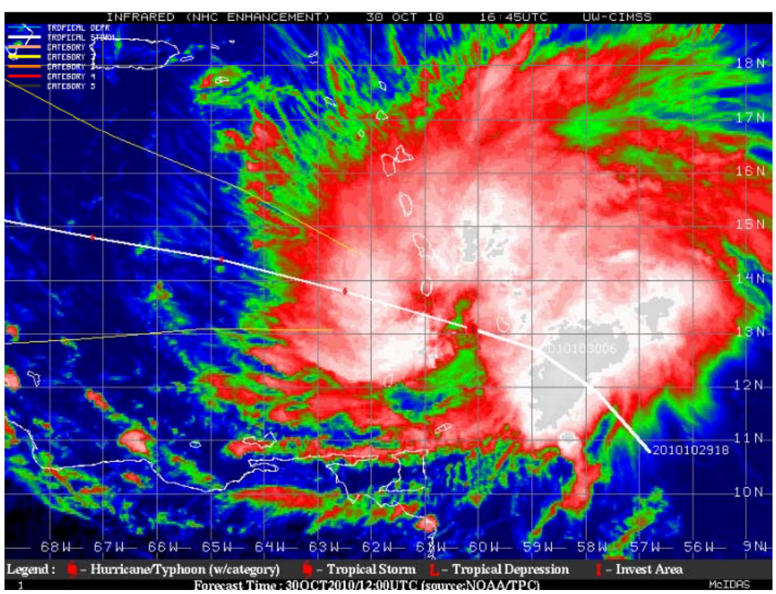

# Enhanced IR



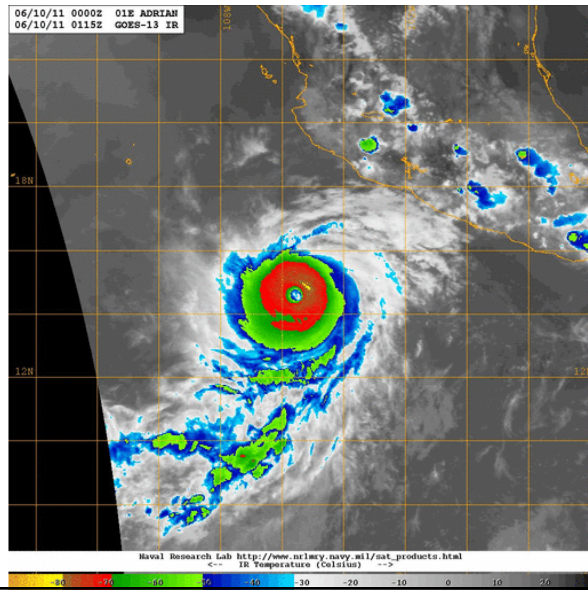
# Water Vapor




# Hurricane Tomas (2010)



## Temperature of coldest cloud tops?

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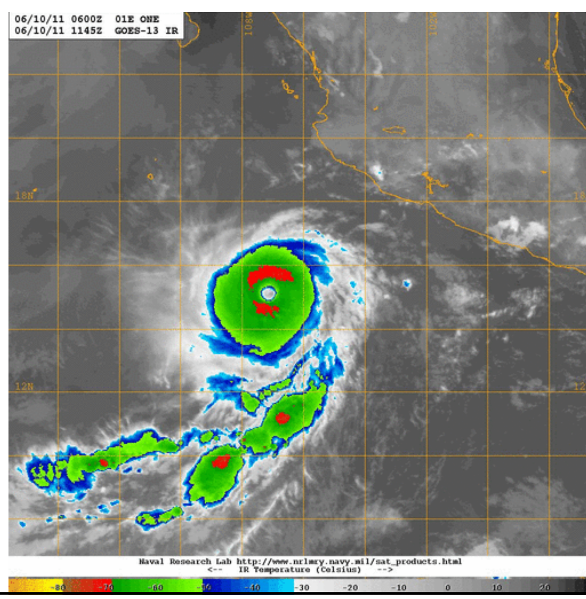

# Review: Fill in the blanks

| | Visible | Infrared | Water Vapor |
|---|---|---|---|
| **Satellite measures** | Reflected solar radiation | Emitted IR Temperature | Emitted IR temperature (of water vapor only) |
| **Brightest regions** | Thick clouds<br>Snow | Coldest clouds<br>Coldest surfaces (i.e. snow) | Moist mid/upper-level air |
| **Darkest regions** | Water/Oceans<br>Forests | Warmest clouds<br>Warmest surfaces (i.e. hot desert) | Dry mid/upper-level air |