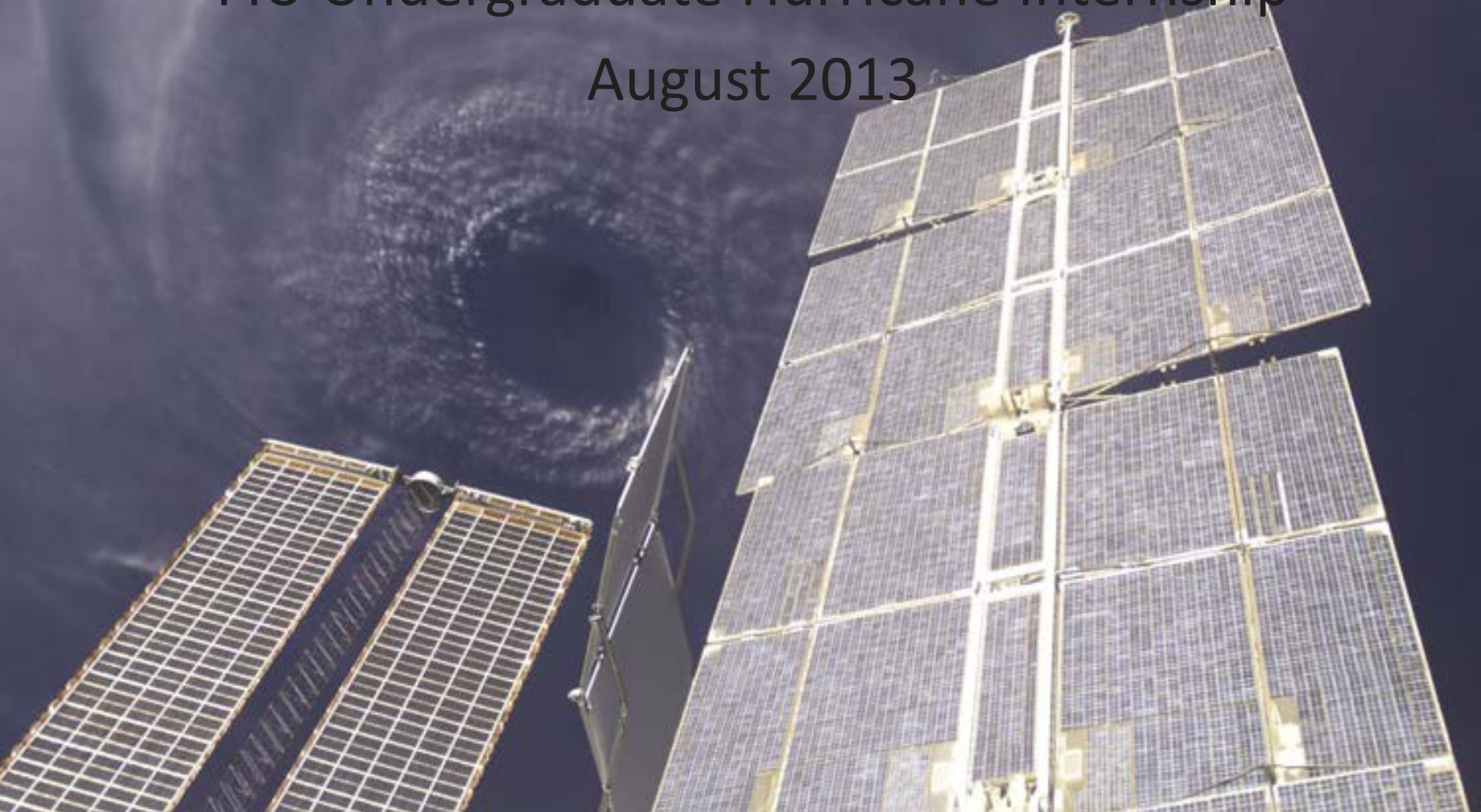# Satellite Remote Sensing Part 1

FIU Undergraduate Hurricane Internship
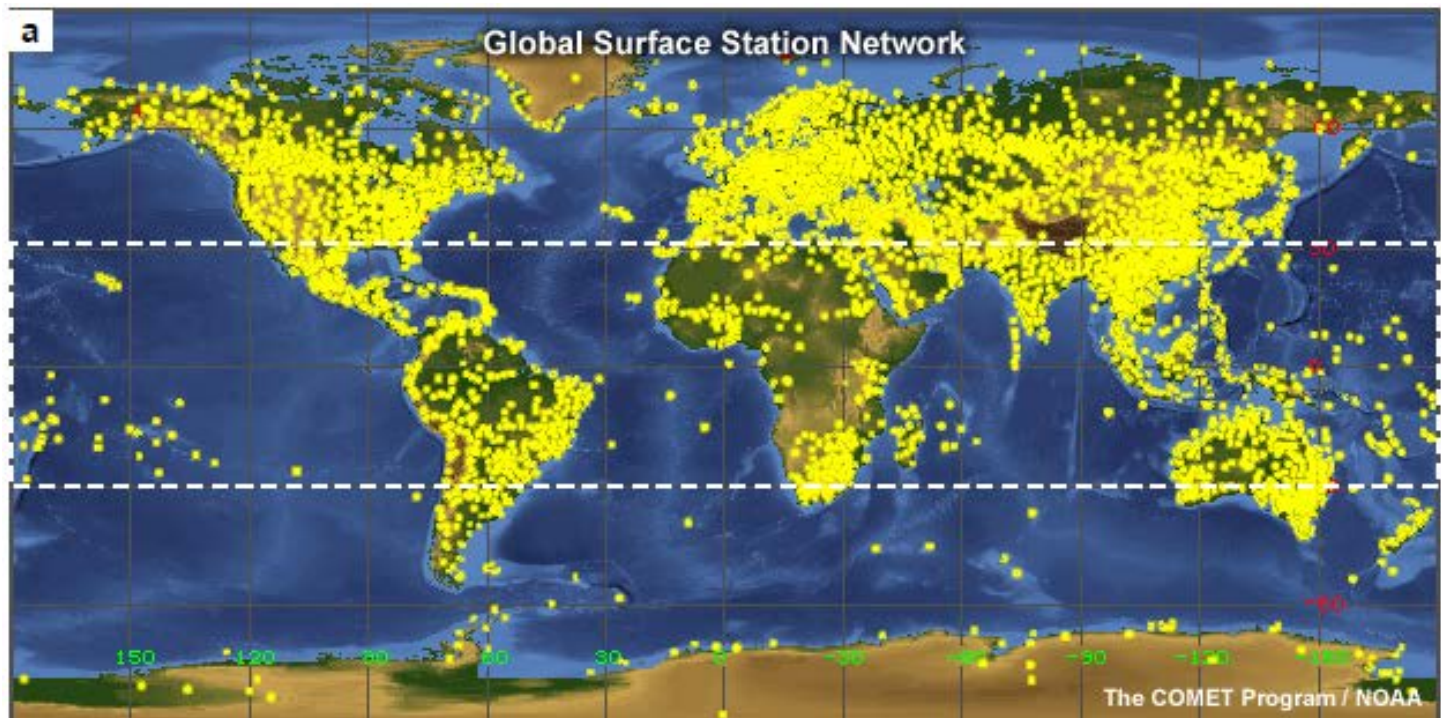
August 2013

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

a   Global Surface Station Network

The COMET Program / NOAA

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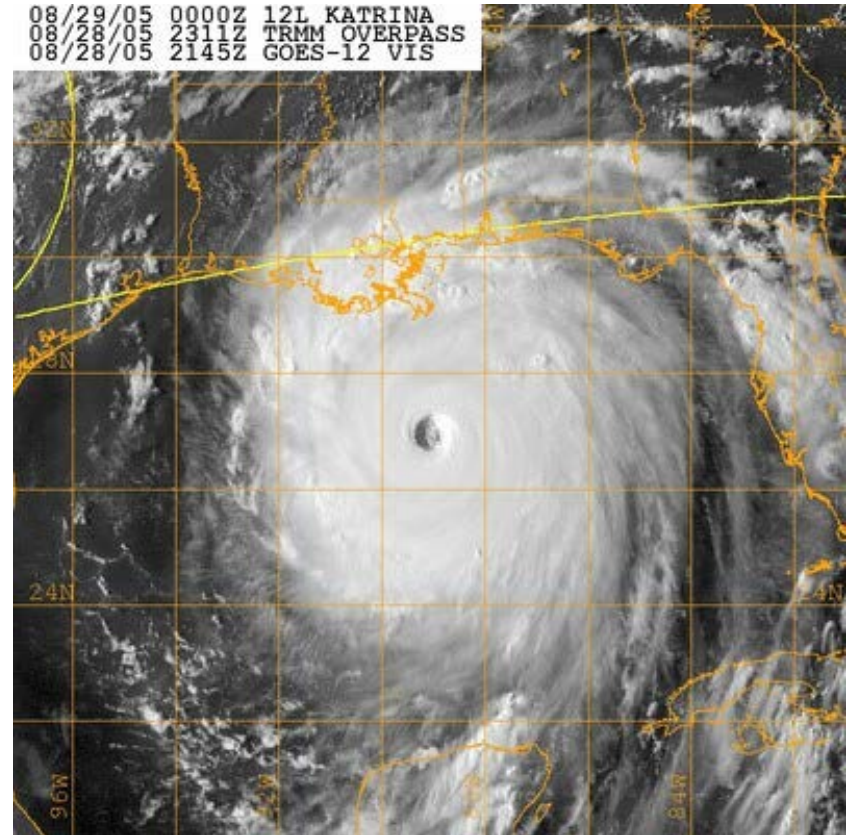
This visible satellite image shows the entire storm and updates every 15 minutes…but smaller-scale details like rainbands are not apparent

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
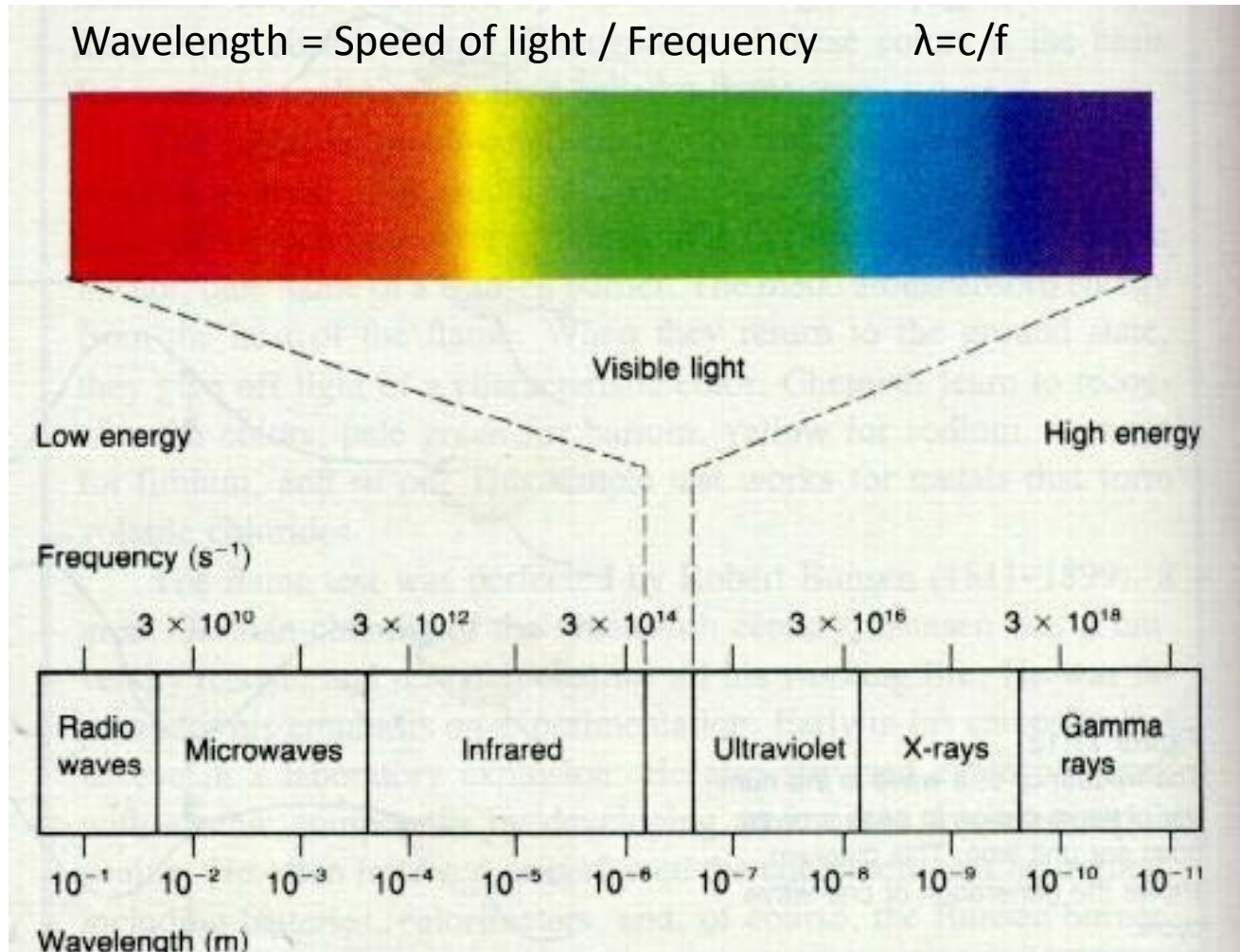
Two types of Remote Sensors

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.
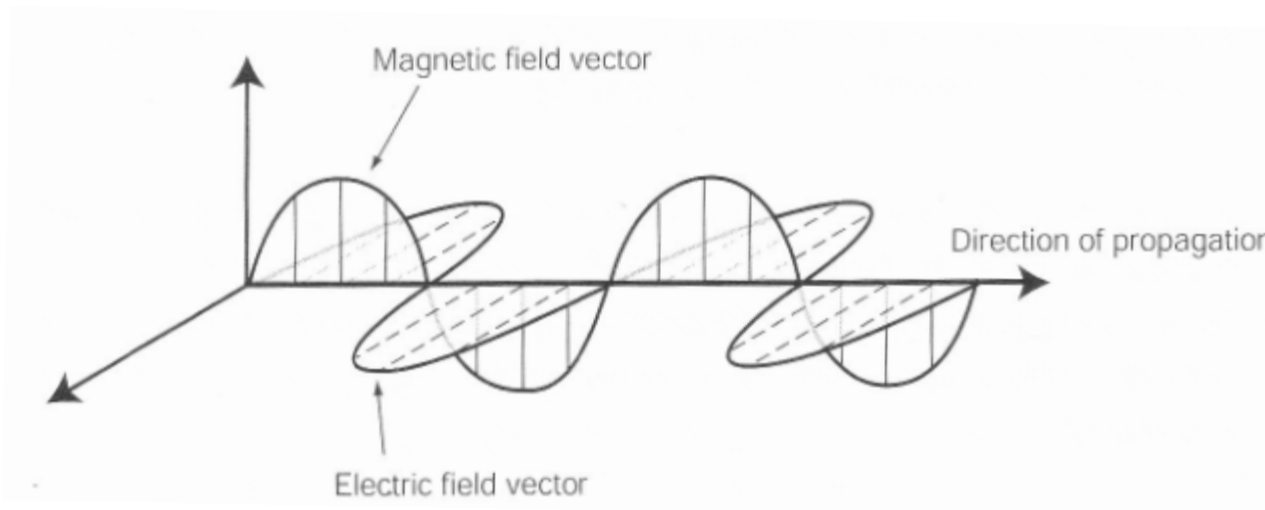
Electromagnetic Spectrum

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

Visible light

Low energy   High energy

Frequency (s^{-1})

3×10^{10} 3×10^{12} 3×10^{14} 3×10^{16} 3×10^{18}

Radio waves	Microwaves	Infrared	Ultraviolet	X-rays	Gamma rays

10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11}

Wavelength (m)

Long wavelength   Short Wavelength
Low Frequency   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.

Magnetic field vector

Direction of propagation

Electric field vector

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 = 1 Hz, 10^9 Hz = 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: $B_\lambda(T) = \dfrac{2hc^2\lambda^{-5}}{(e^{hc/k\lambda T} - 1)}$

  - $B_\lambda(T)$ 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):

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

- 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

Solar and Thermal Blackbody Curves
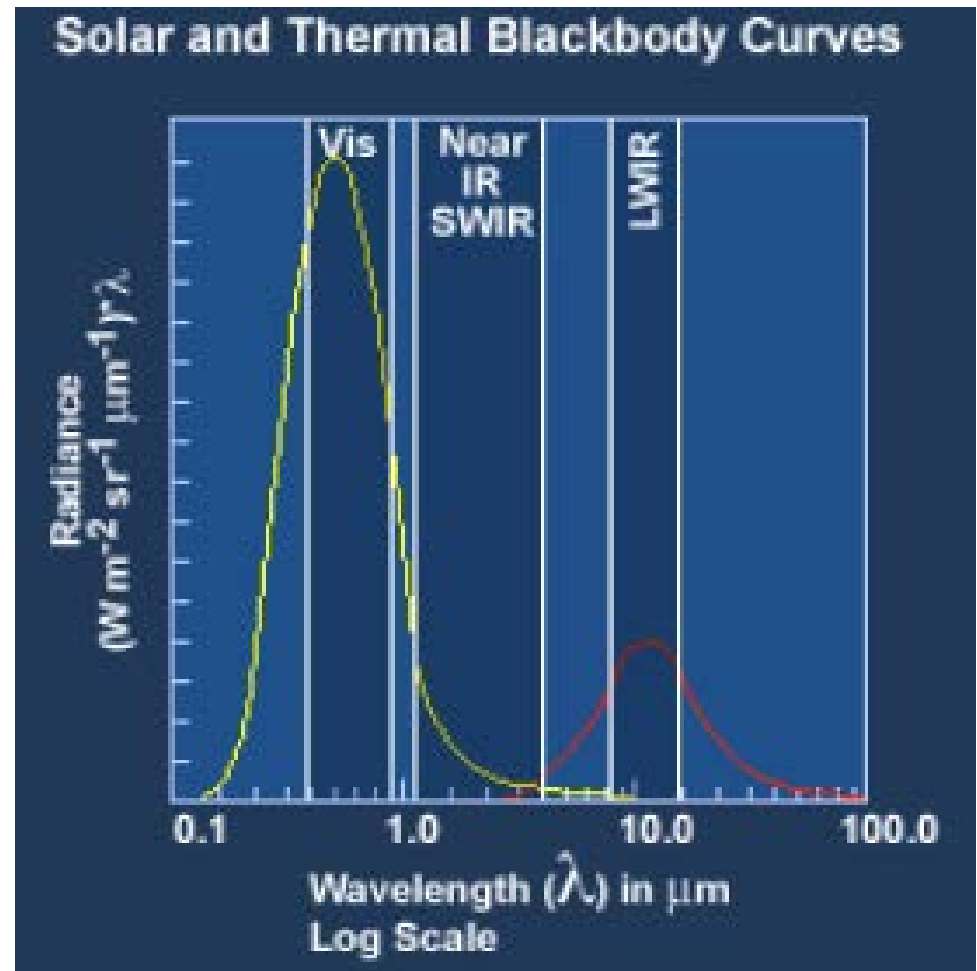
Planck Curves and Atmospheric Absorption
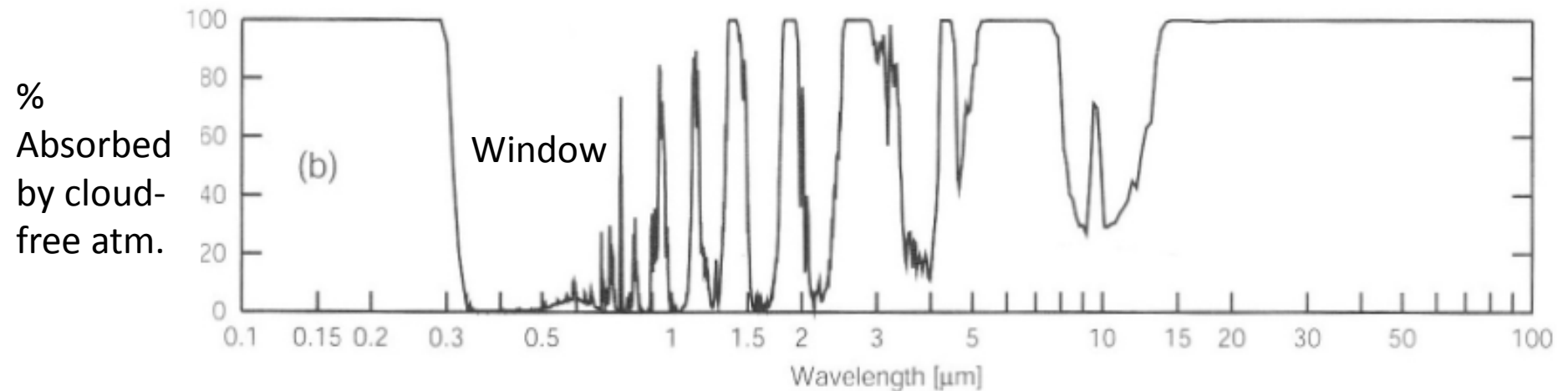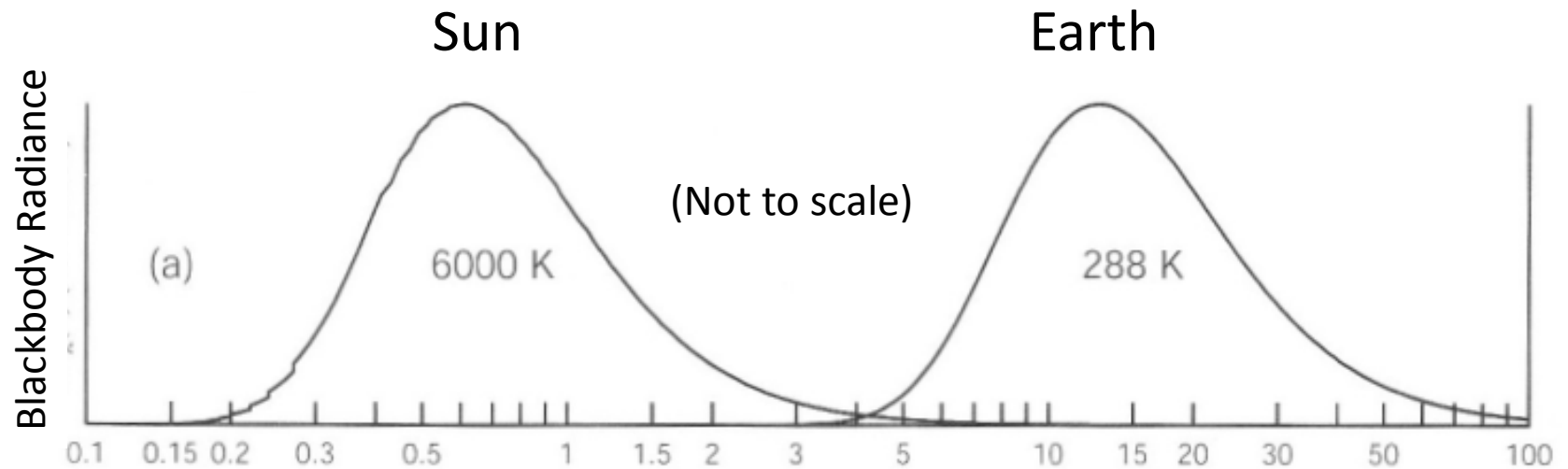
0% = transparent; 100% = blackbody

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
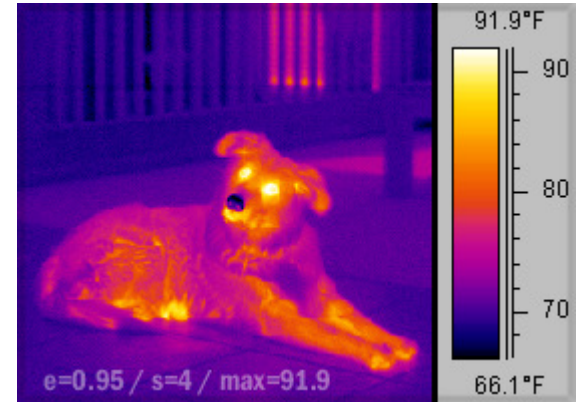
Microwave Band

- 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: unable to observe through clouds

GOES Satellites

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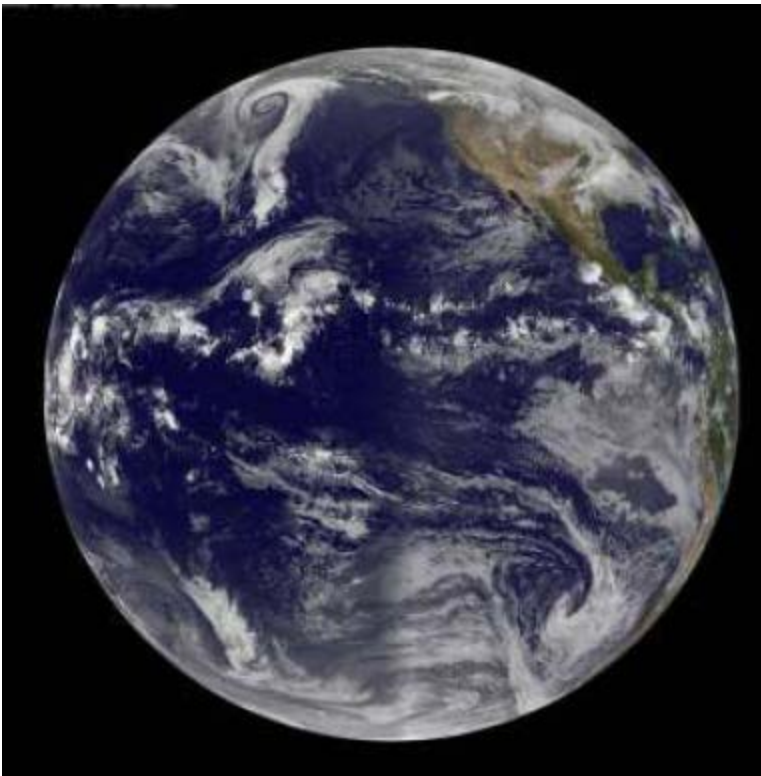
GOES-West

GOES-East

Geostationary Satellite Coverage
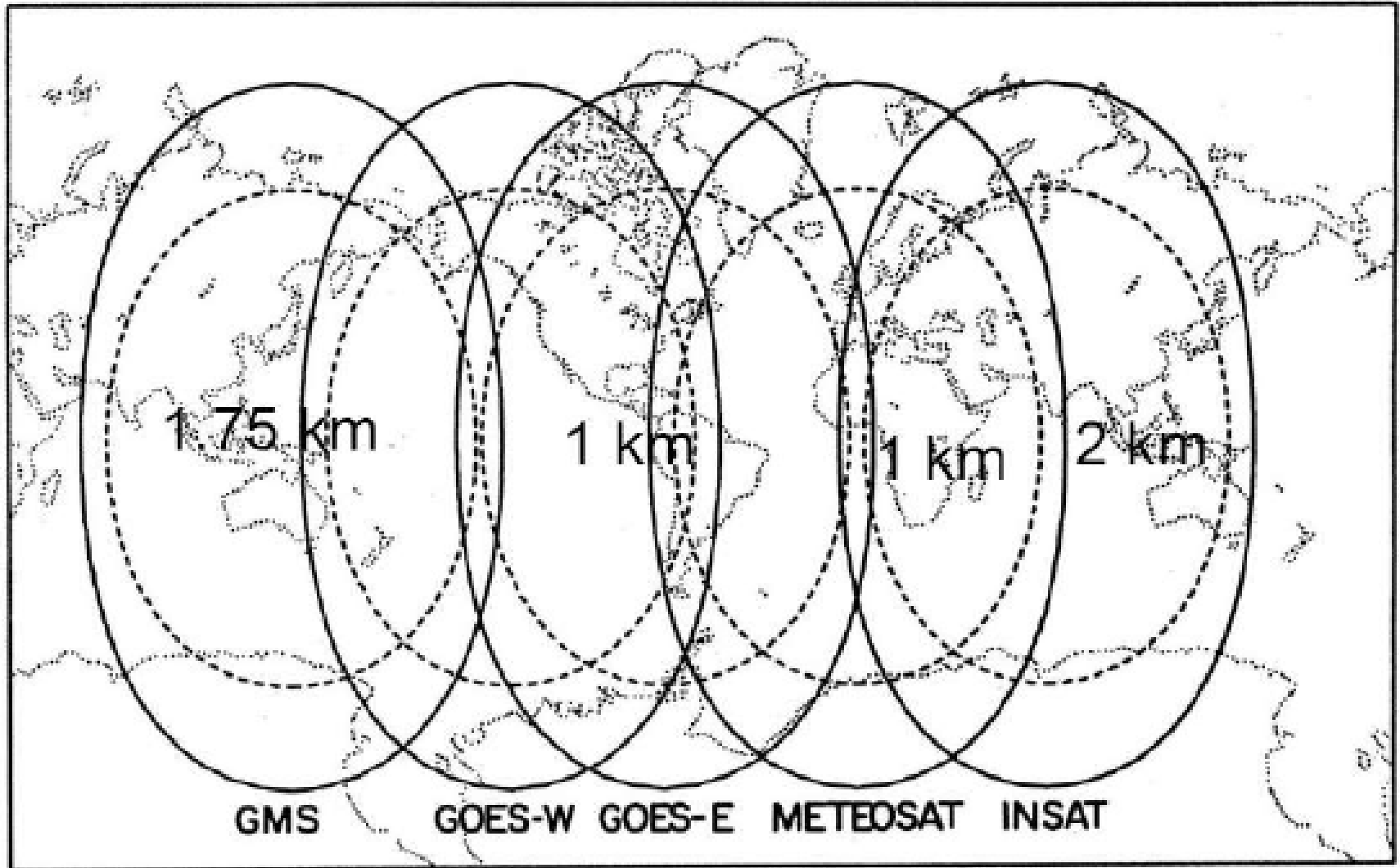
Properties of Visible Satellite Images

- 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
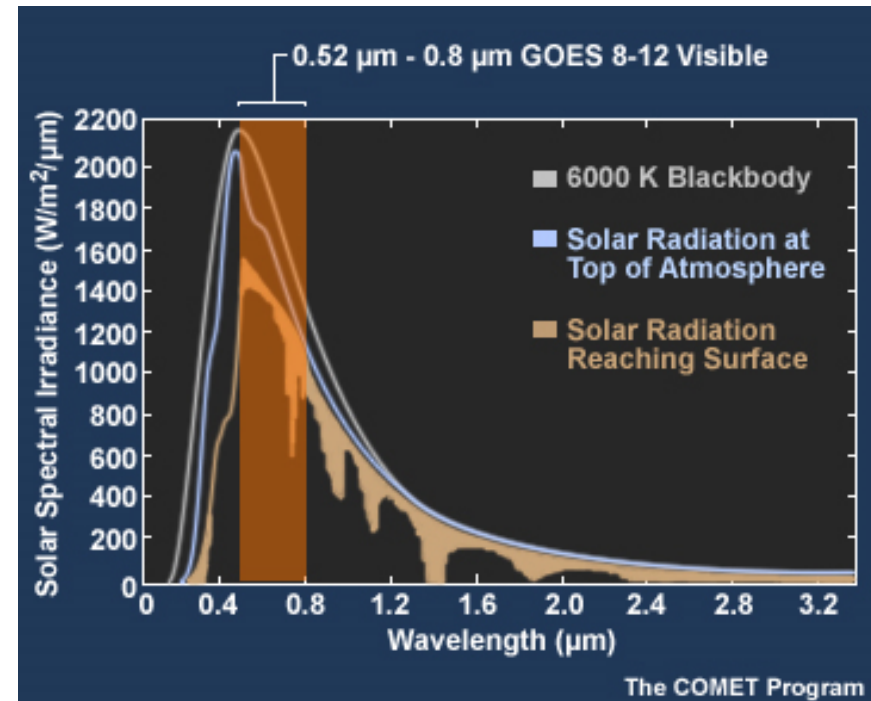
How would this image look from a satellite in the visible spectrum?
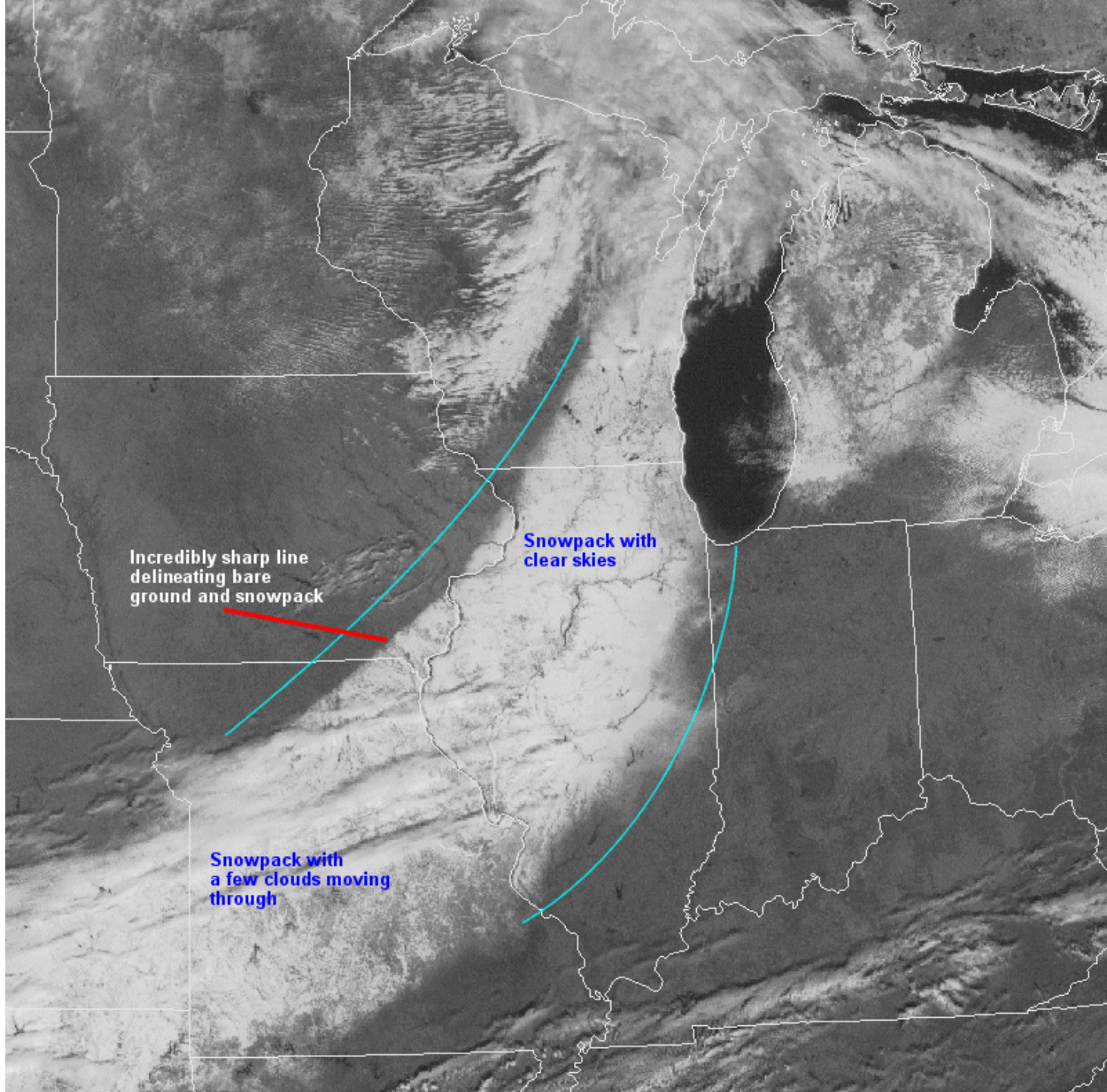
Incredibly sharp line
delineating bare
ground and snowpack

Snowpack with
clear skies

Snowpack with
a few clouds moving
through

Visible Satellite
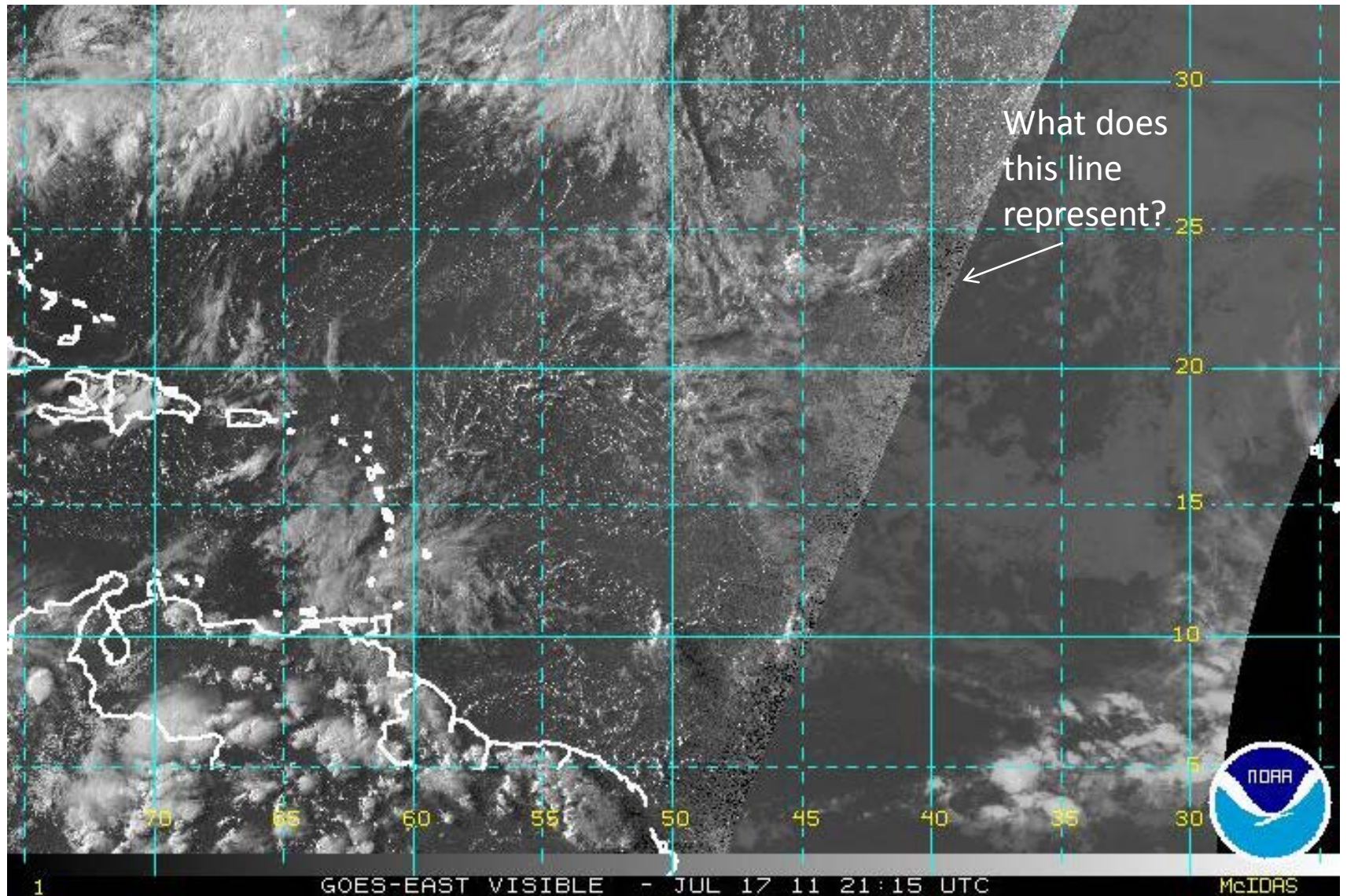
GOES-13 Vis 1932 to 2315 UTC 02 Sep 2010
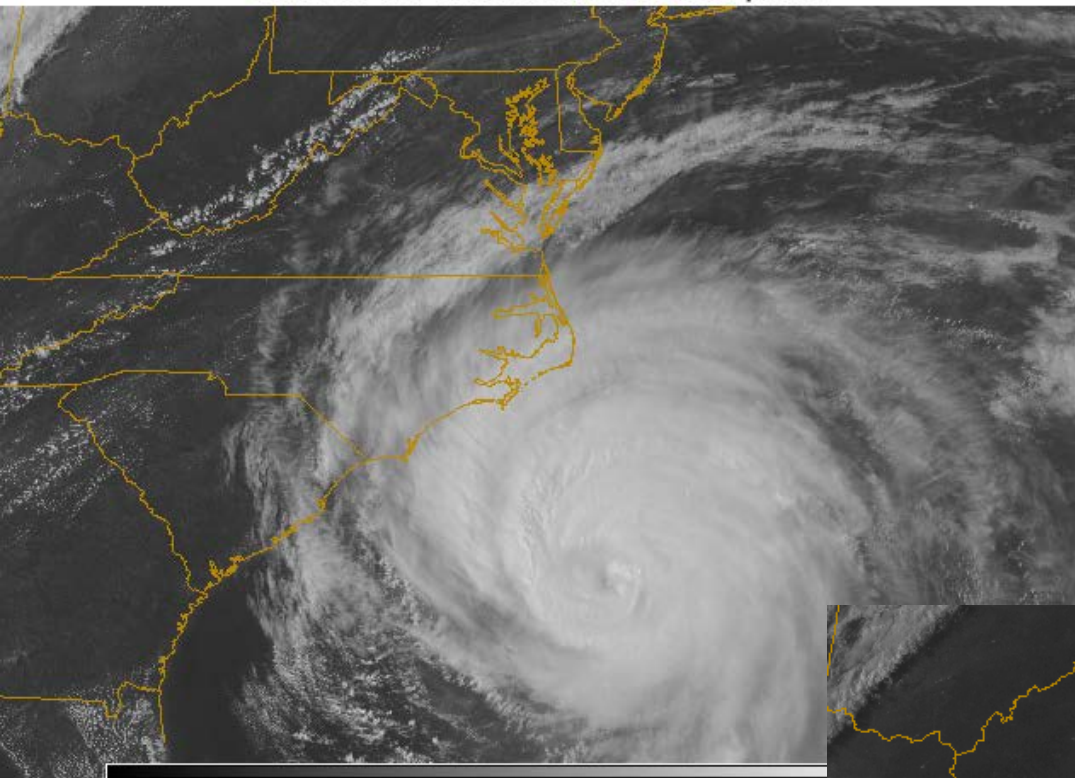
Visible
Earl (2010)

Sunset

Afternoon

Visible: 1 km resolution

MTSAT-1R - VISIBLE 0.68 (CHANNEL 01) - 02:30 UTC 18 OCTOBER 2010 - CIMSS
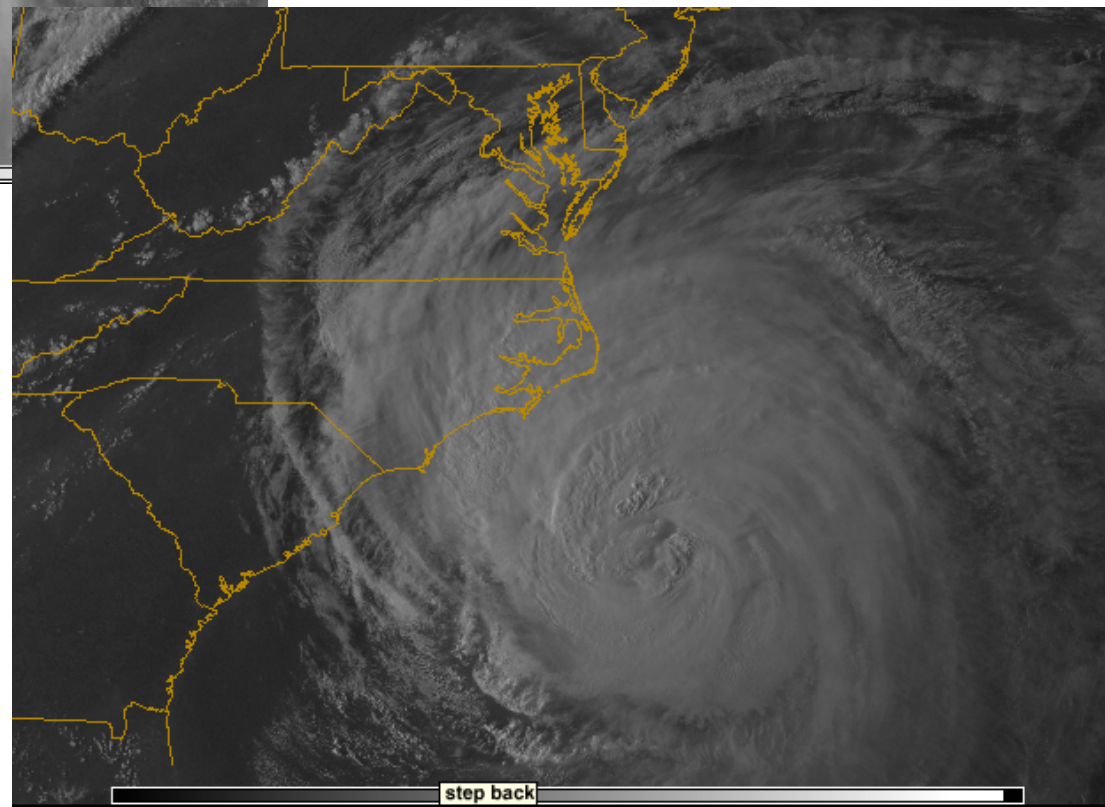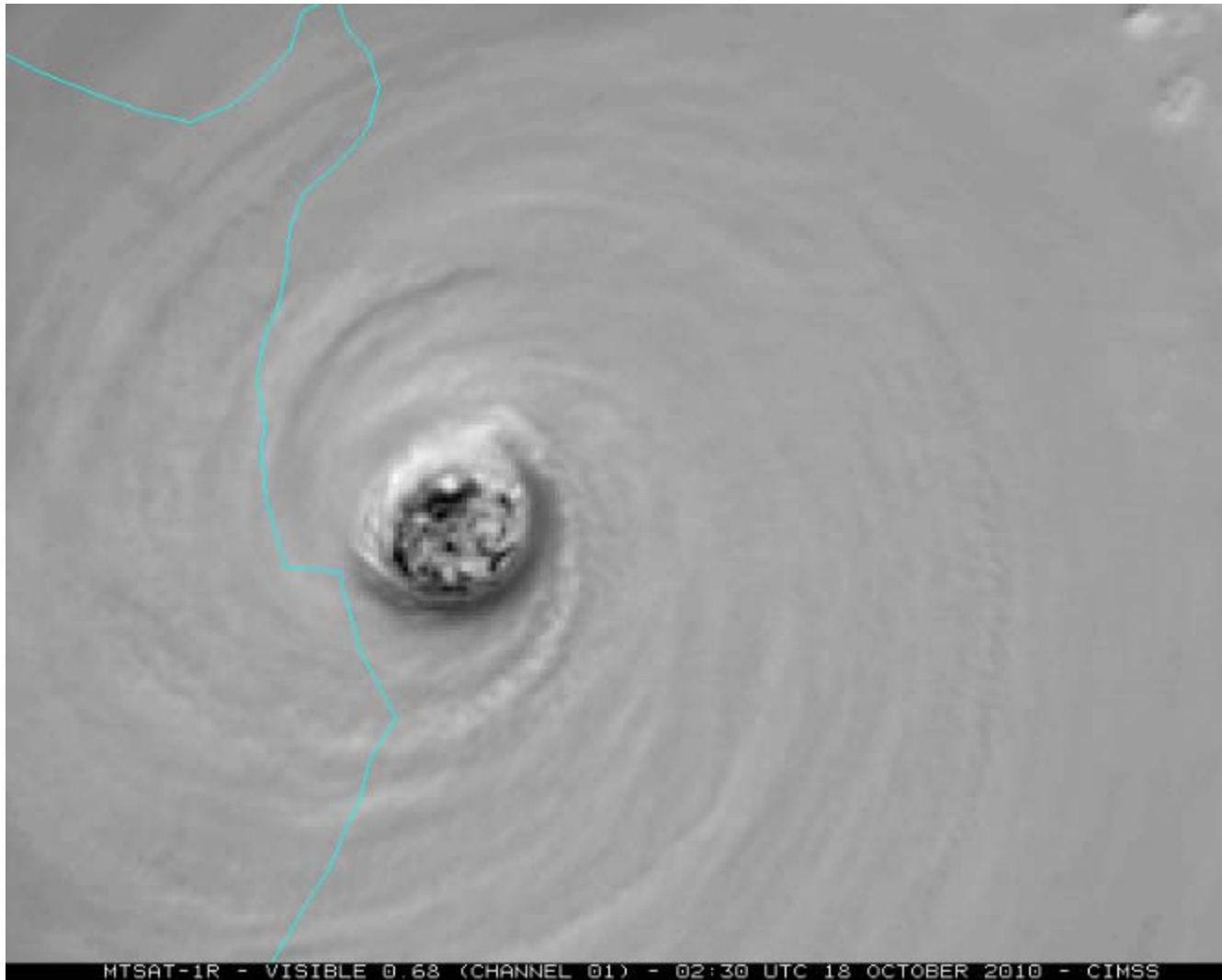
Properties of IR Satellite Images

- 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)
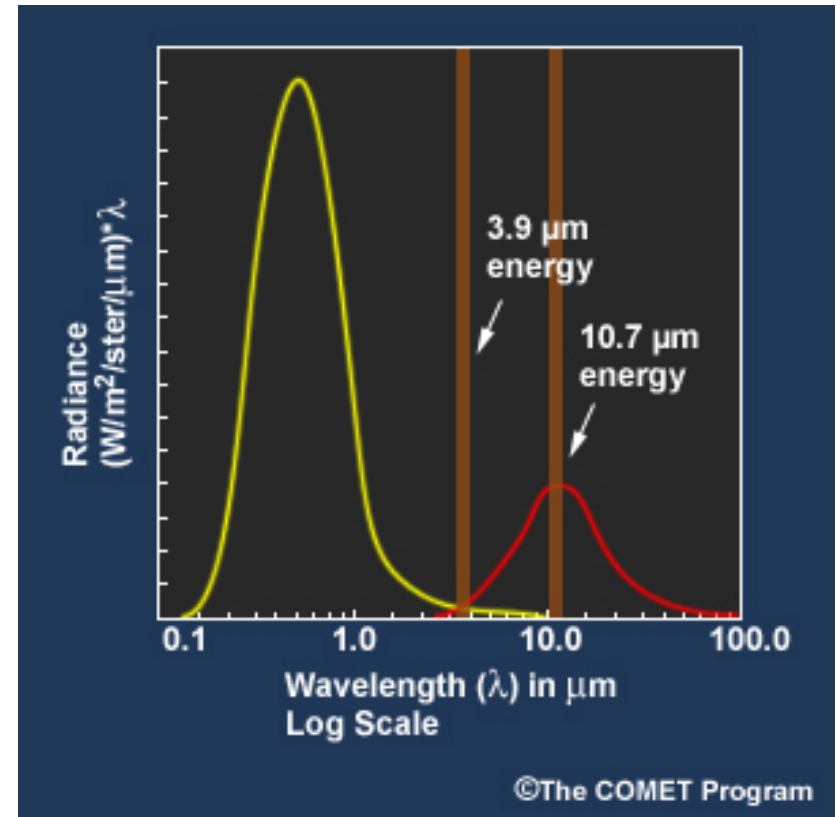
How would this landscape look from a satellite in the IR spectrum?
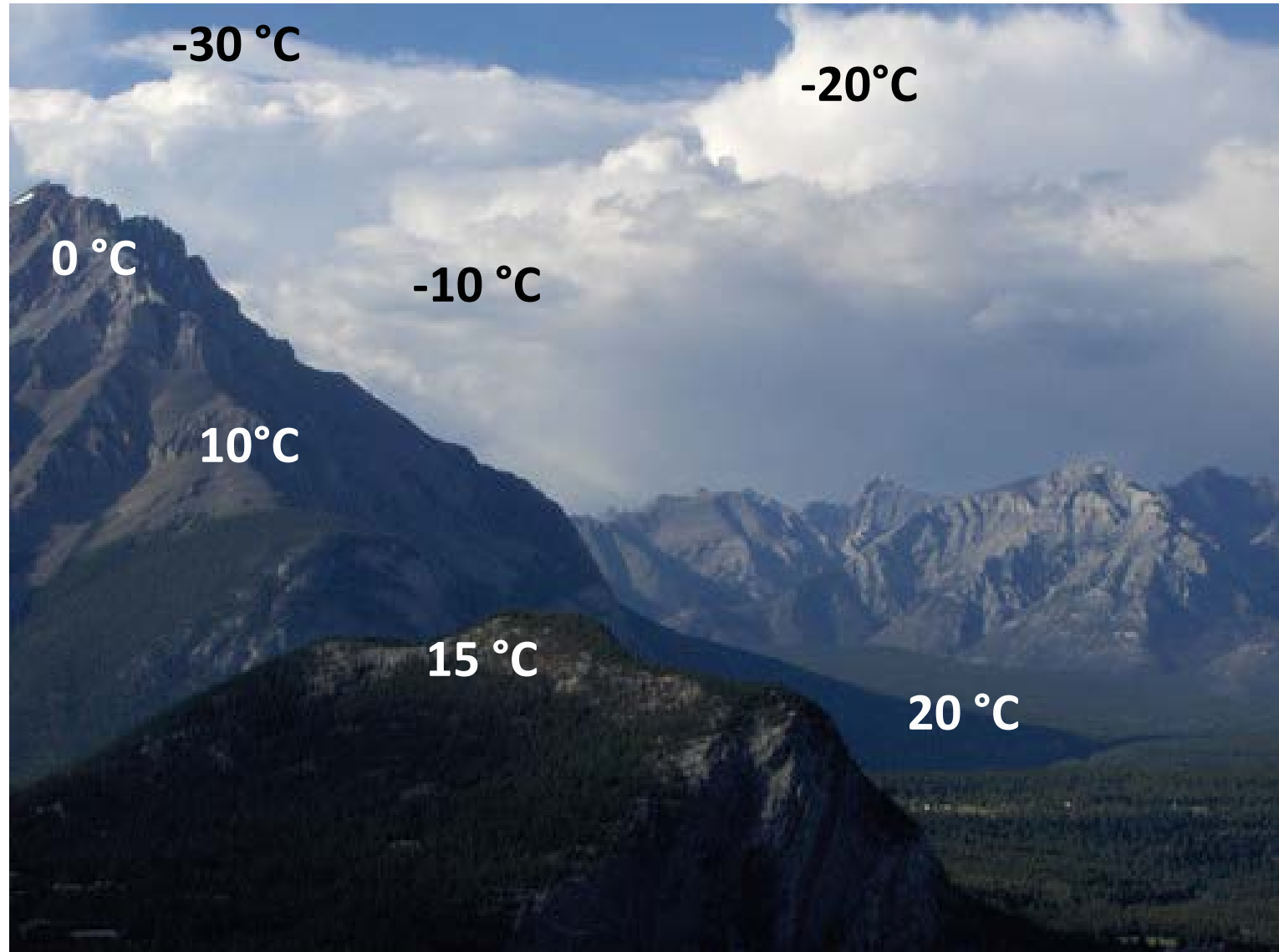
07/01/11 0000Z   01L ARLENE
07/01/11 0632Z   GOES-13 IR
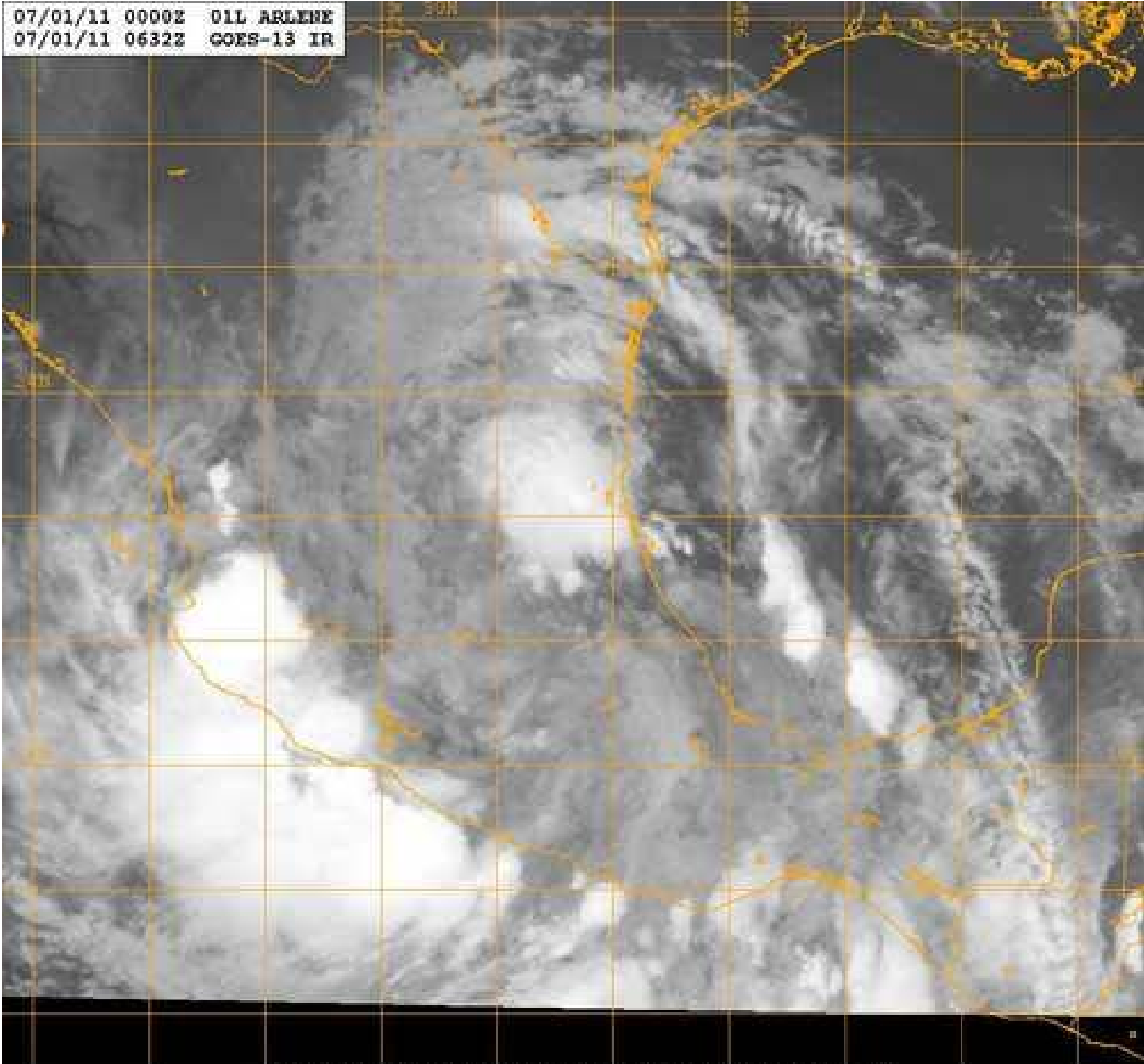
Naval Research Lab http://www.nrlmry.navy.mil/sat_products.html
<-- IR Temperature (Celsius) -->

-70   -60   -50   -40   -30   -20   -10   0   10   20

IR Color Enhancement

- Used to emphasize the coldest (highest) cloud tops found in deep convection
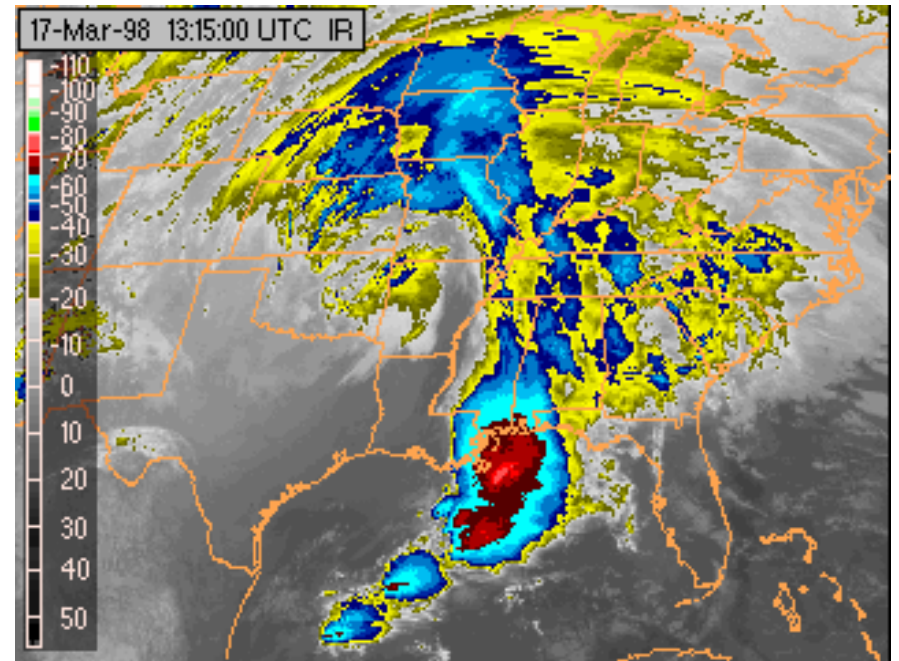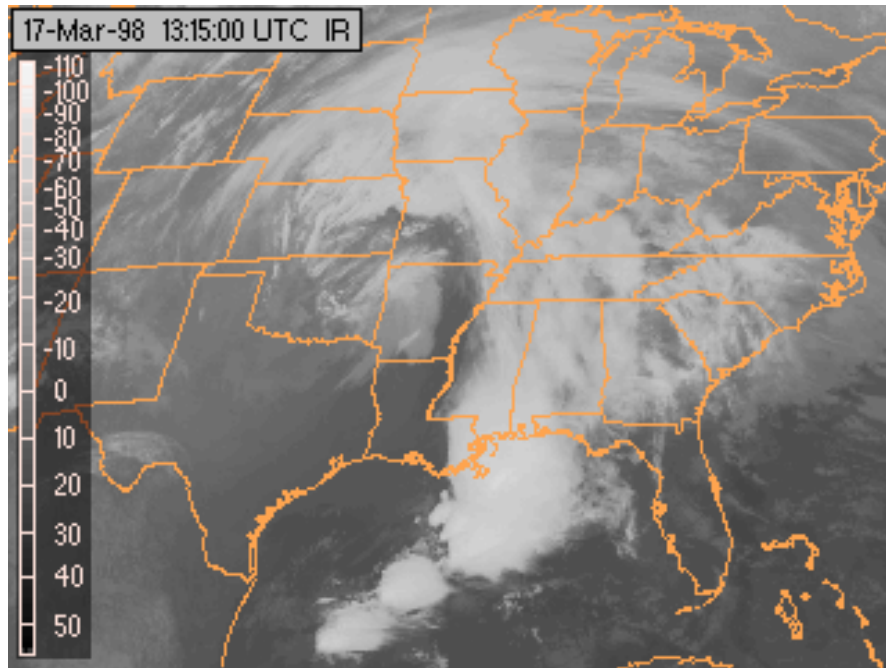
Hard to tell the difference between -60 to -90 °C without the color enhancement

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
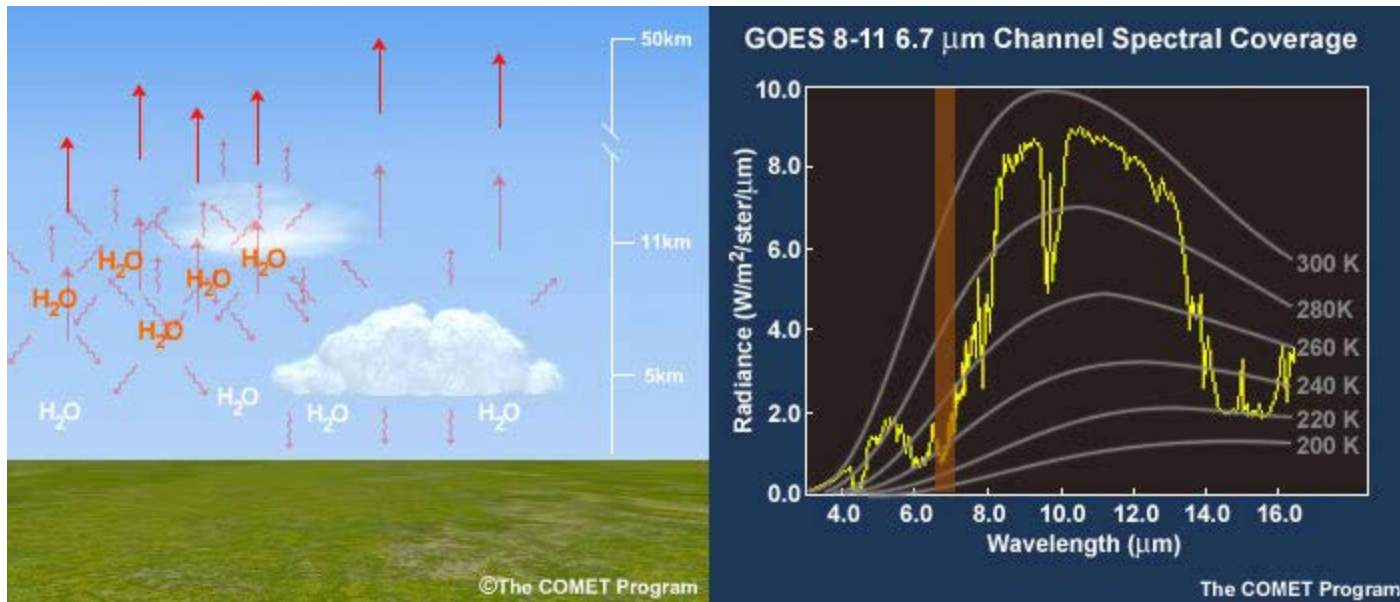
6.7 μm Weighting Function

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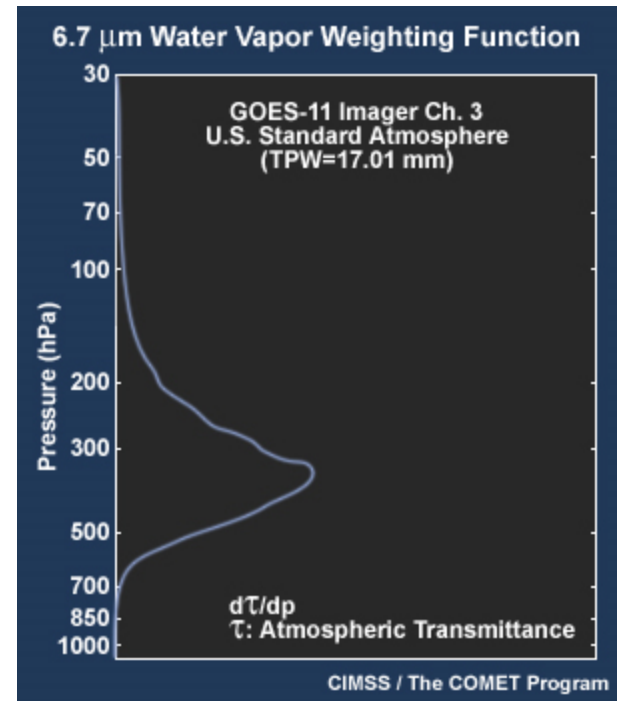
"Weighting function" for 6.7 μm channel under standard conditions. The curve shows the relative vertical contribution to the measured radiance

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
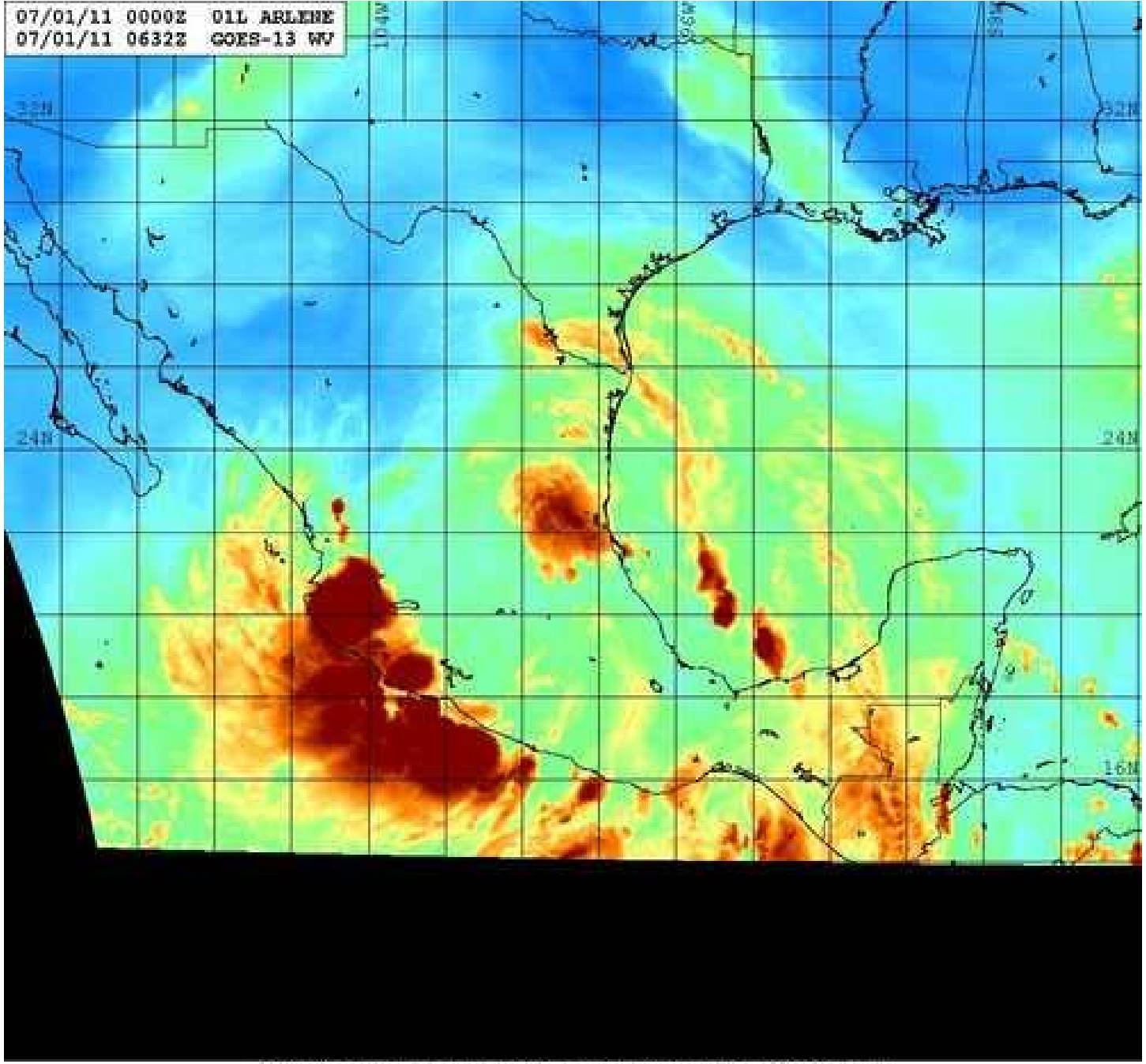
- **Warm (black):** Dry upper atmosphere

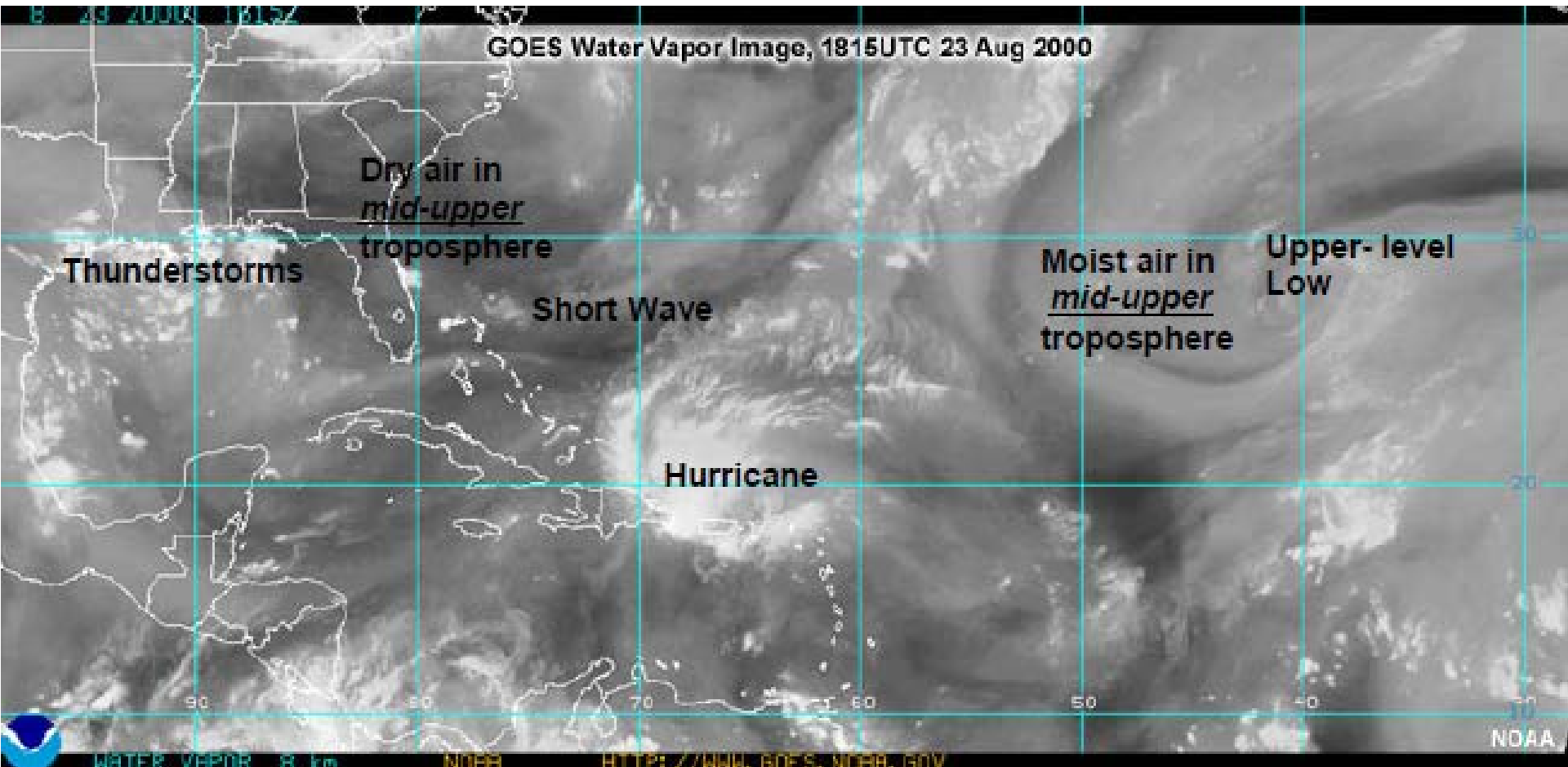# How would this image look from a satellite in the 6.7 μm WV spectrum?

300 mb

500 mb

850 mb

1000 mb
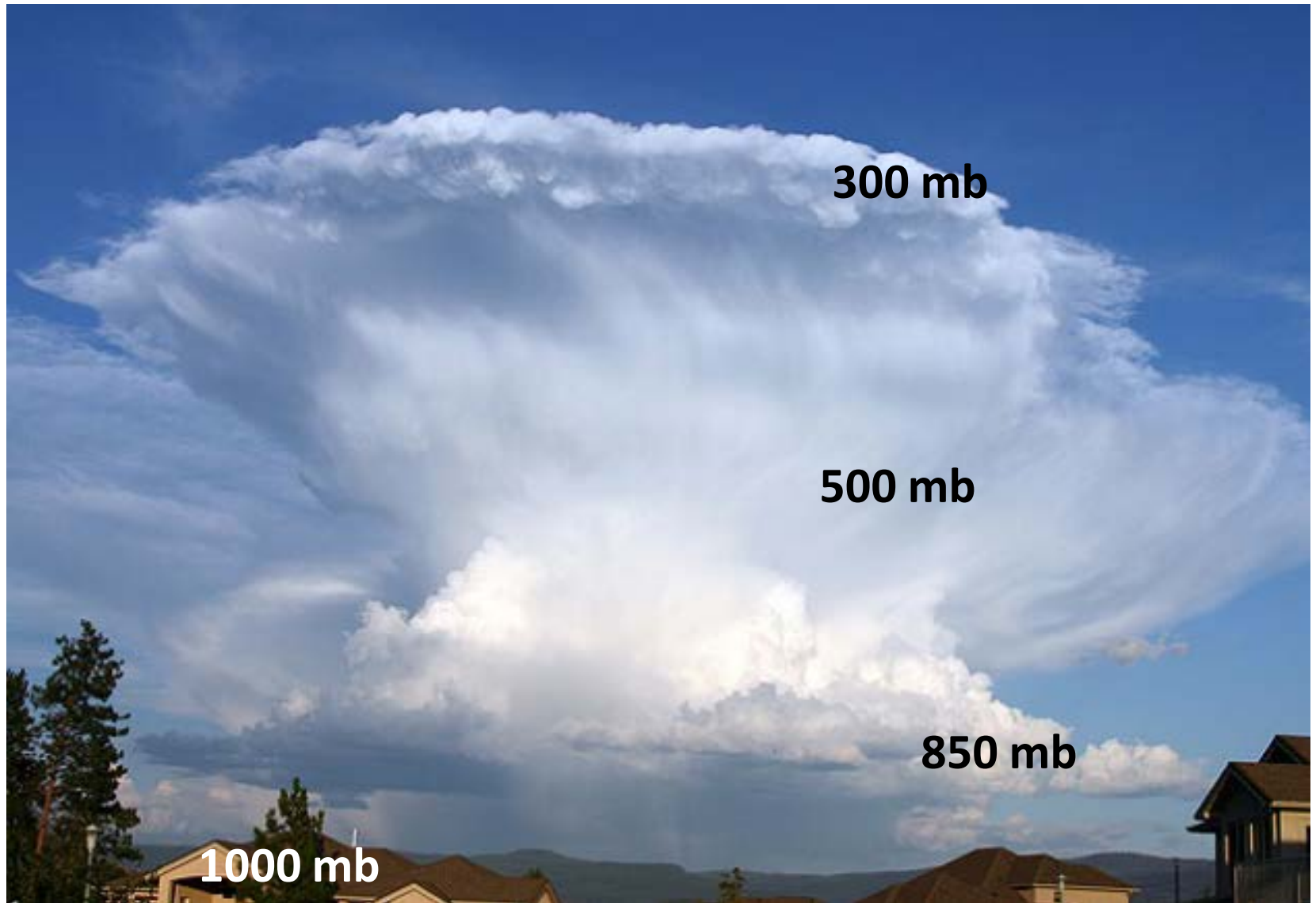
07/01/11 0000Z   01L ARLENE
07/01/11 0632Z   GOES-13 WV

Naval Research Lab http://www.nrlmry.navy.mil/sat_products.html
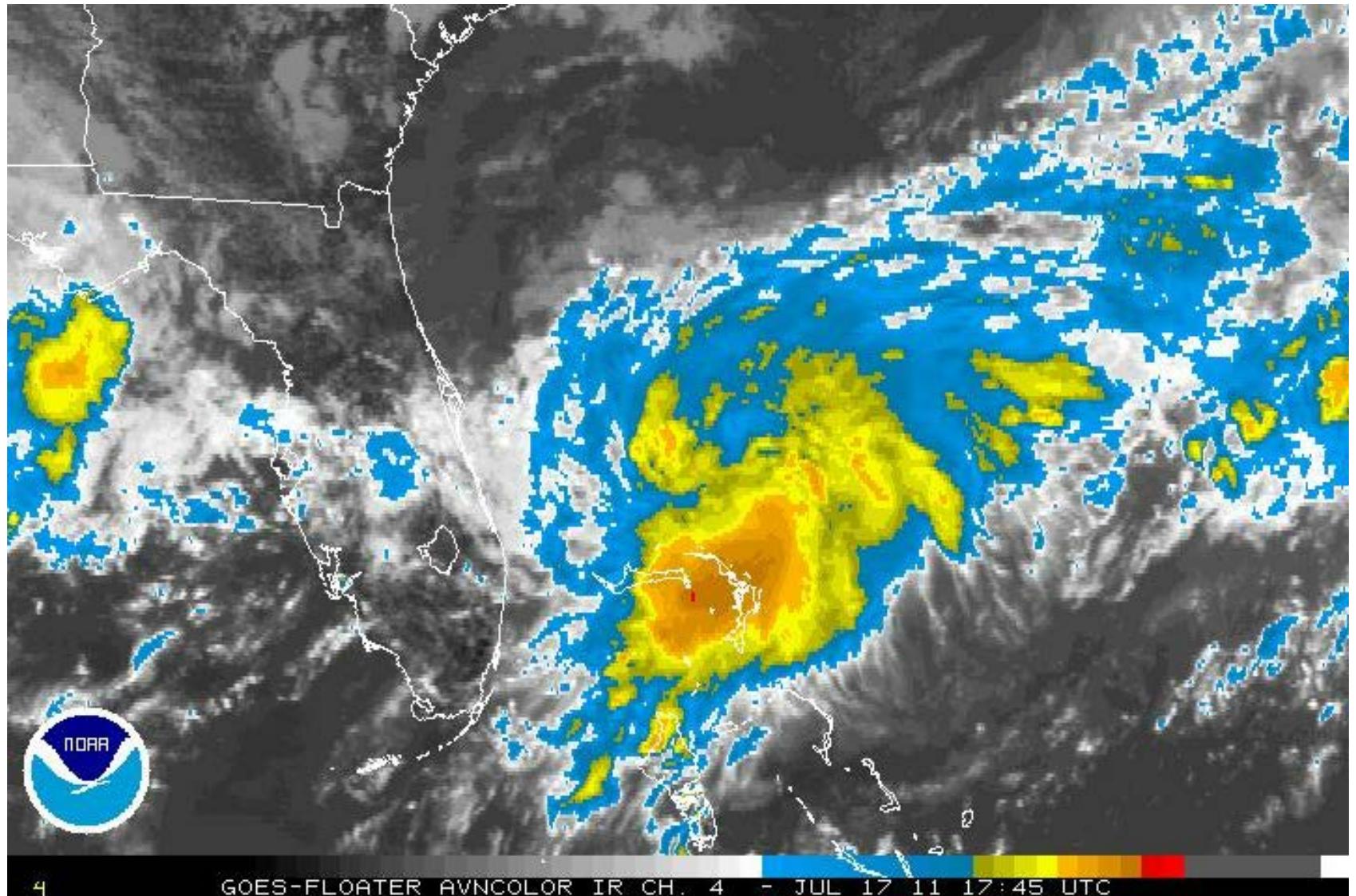WV Temperature (Celsius)

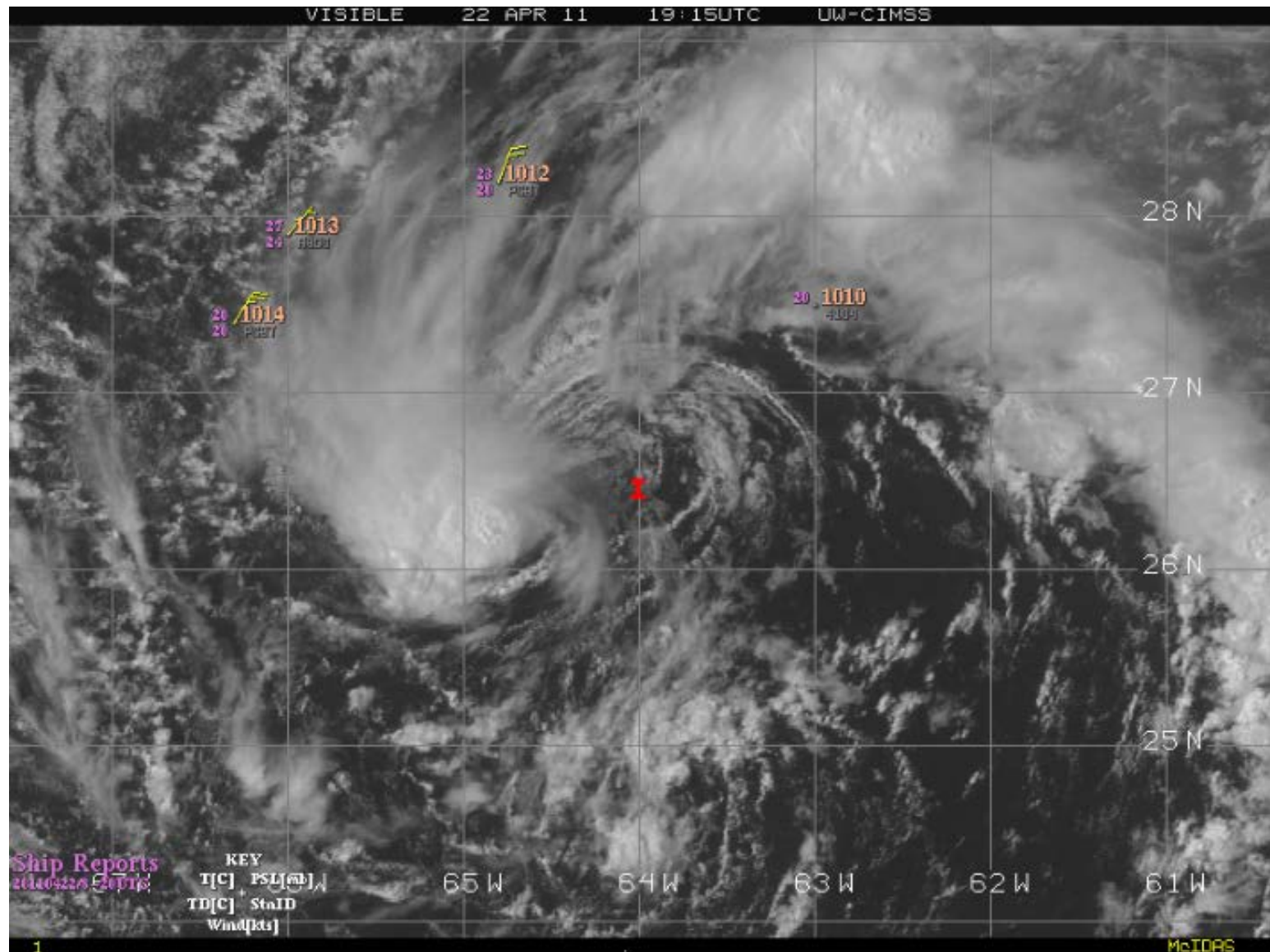-60   -50   -40   -30   -20   -10

Common features on WV images

GOES Water Vapor Image, 1815UTC 23 Aug 2000

Thunderstorms

Dry air in *mid-upper* troposphere

Short Wave

Hurricane

Moist air in *mid-upper* troposphere

Upper- level Low

NOAA

WATER VAPOR 8 km

TD #2 (2011) Visible

GOES-FLOATER VISIBLE - JUL 17 11 17:45 UTC

TD #2 (2011) IR Color

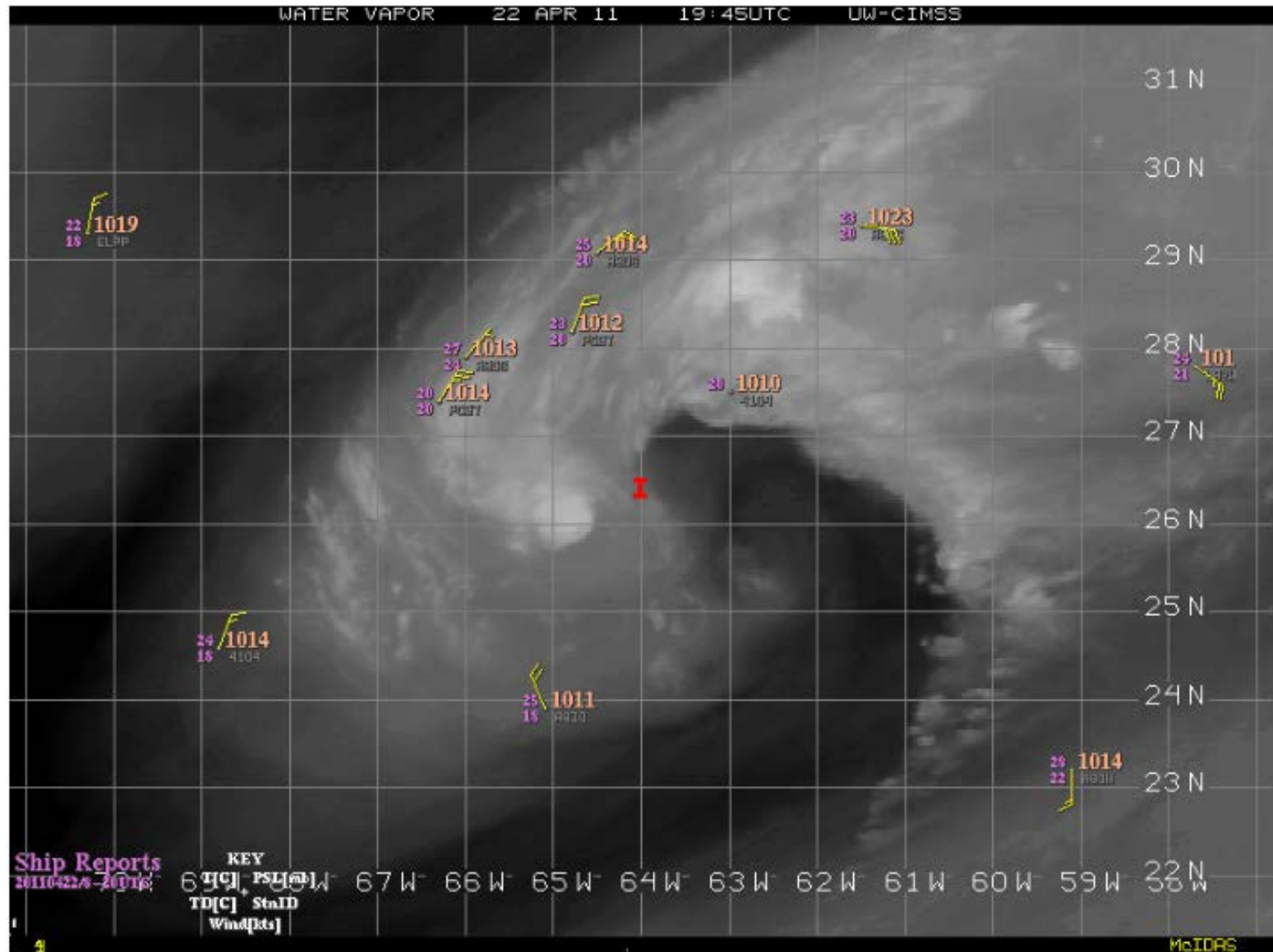GOES-FLOATER AVNCOLOR IR CH. 4 - JUL 17 11 17:45 UTC
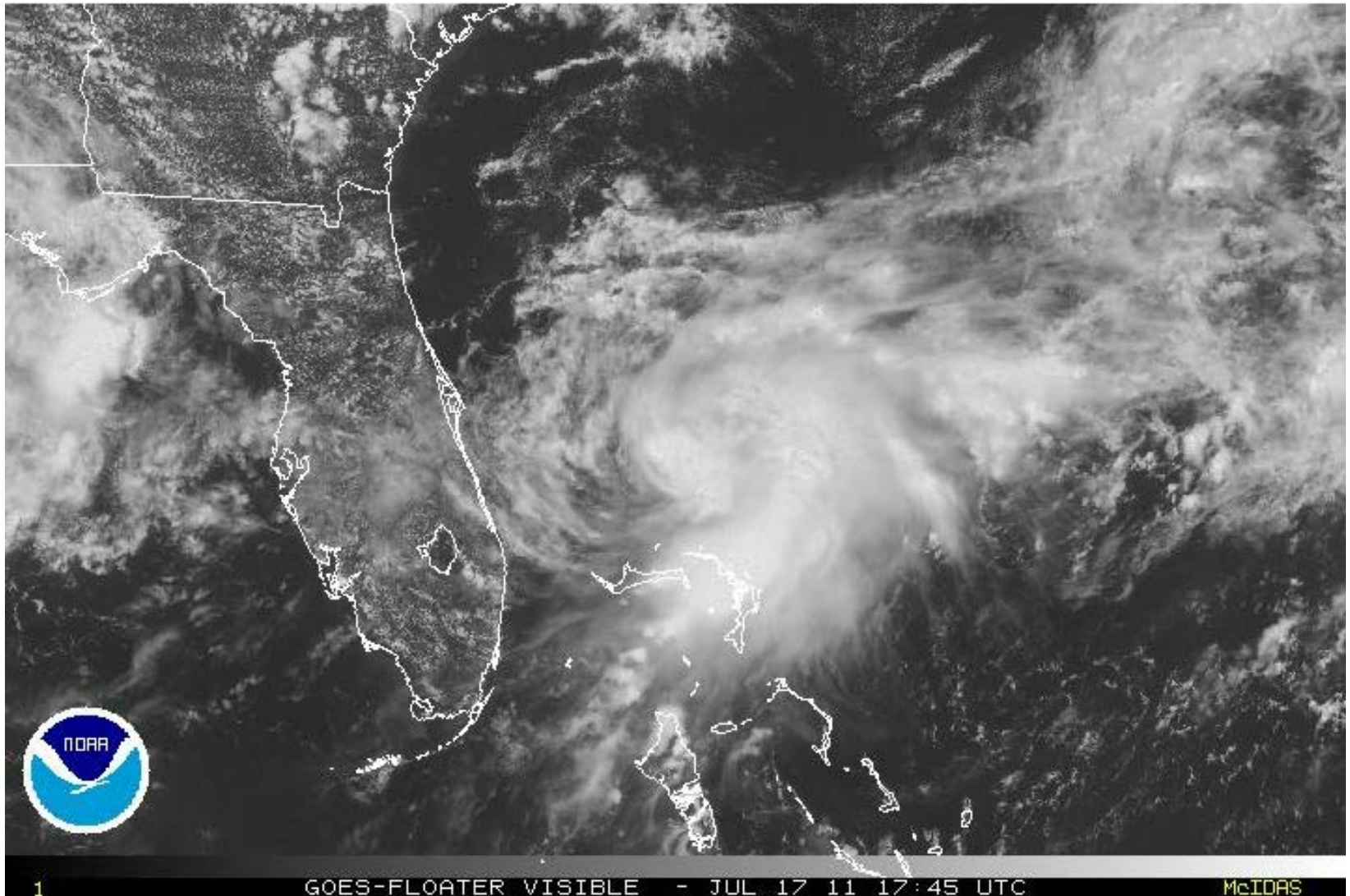
Subtropical Storm: Visible

Enhanced IR
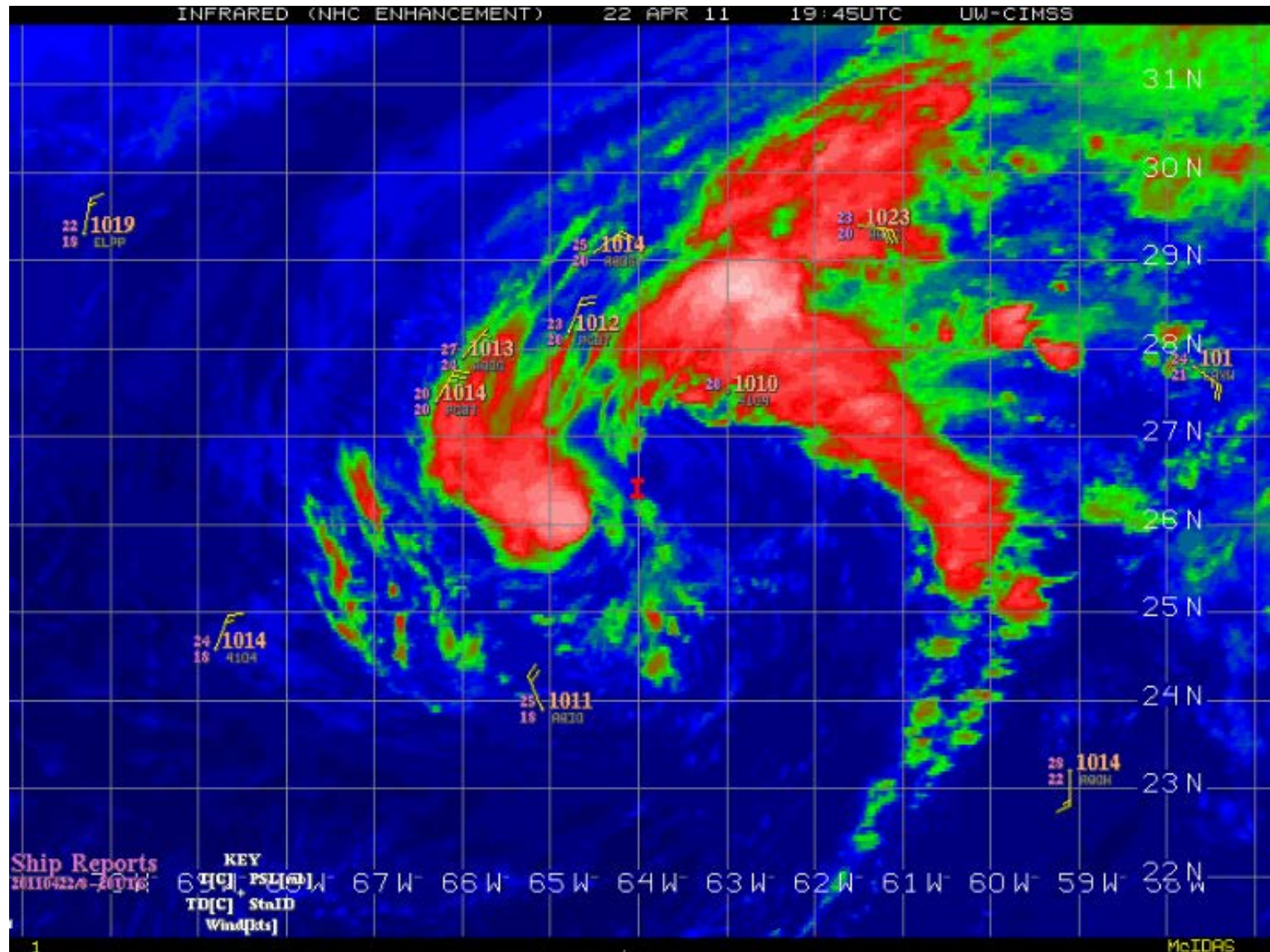
Water Vapor

Hurricane Tomas (2010)
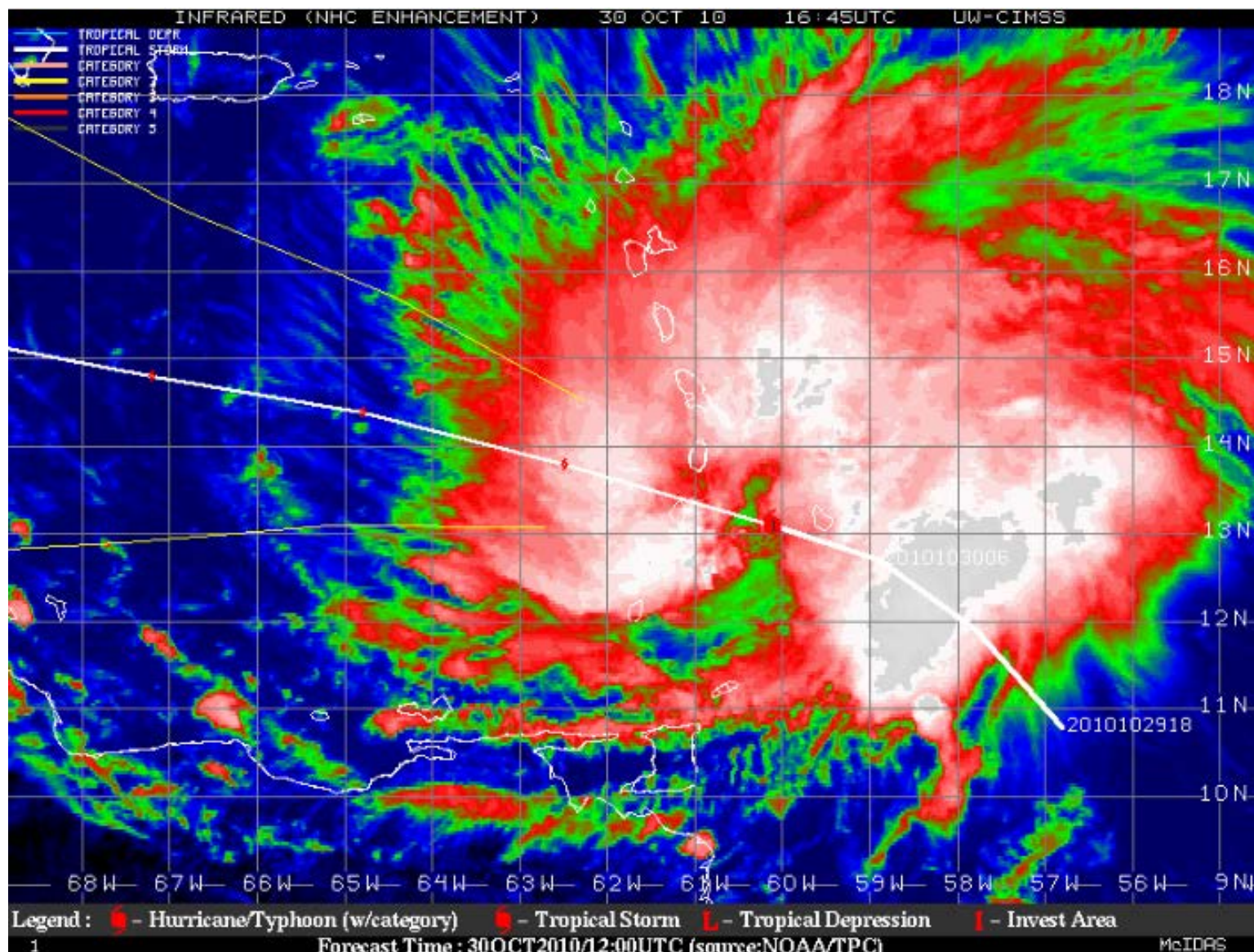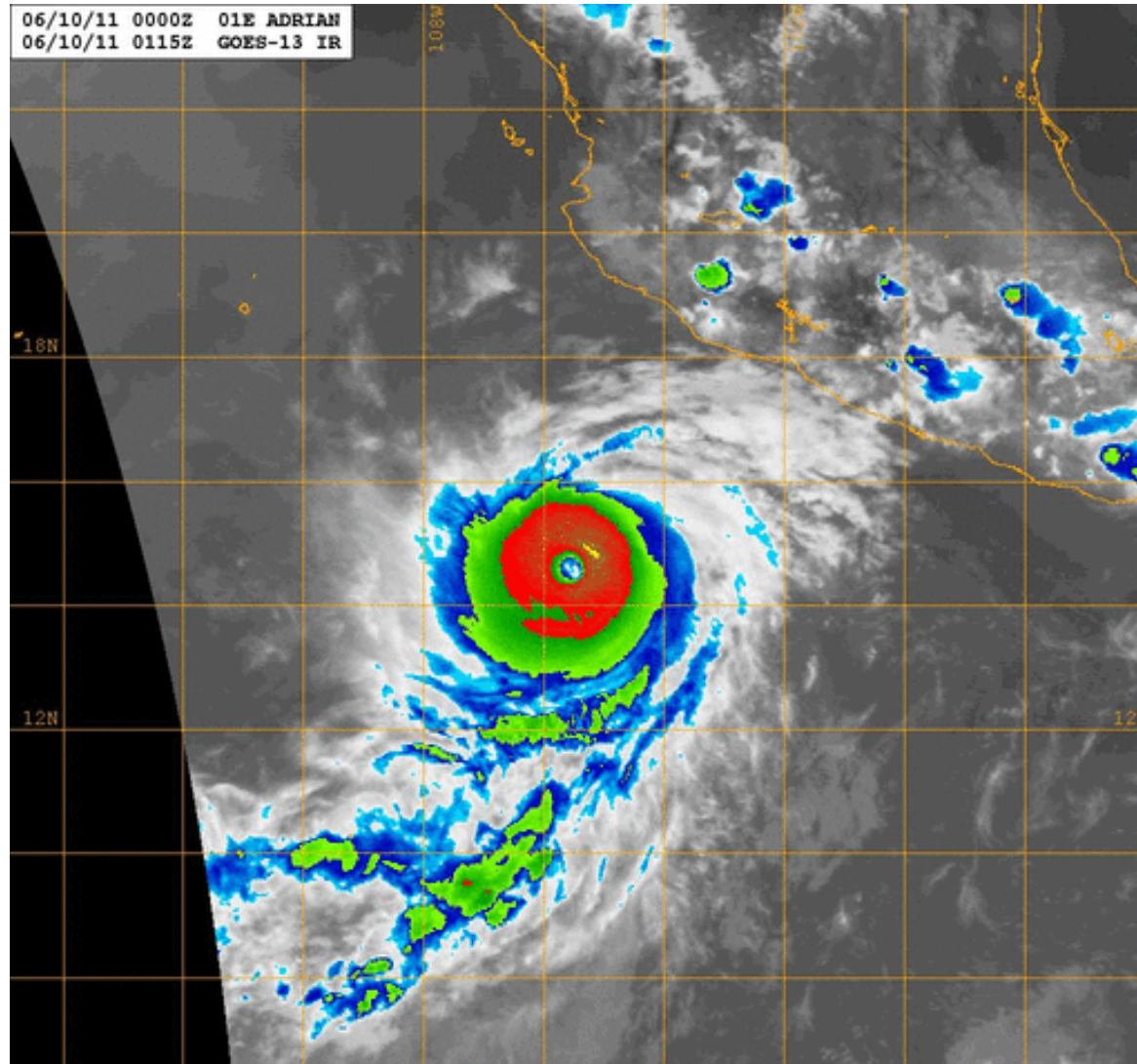
Temperature of coldest cloud tops?

Temperature of coldest cloud tops?
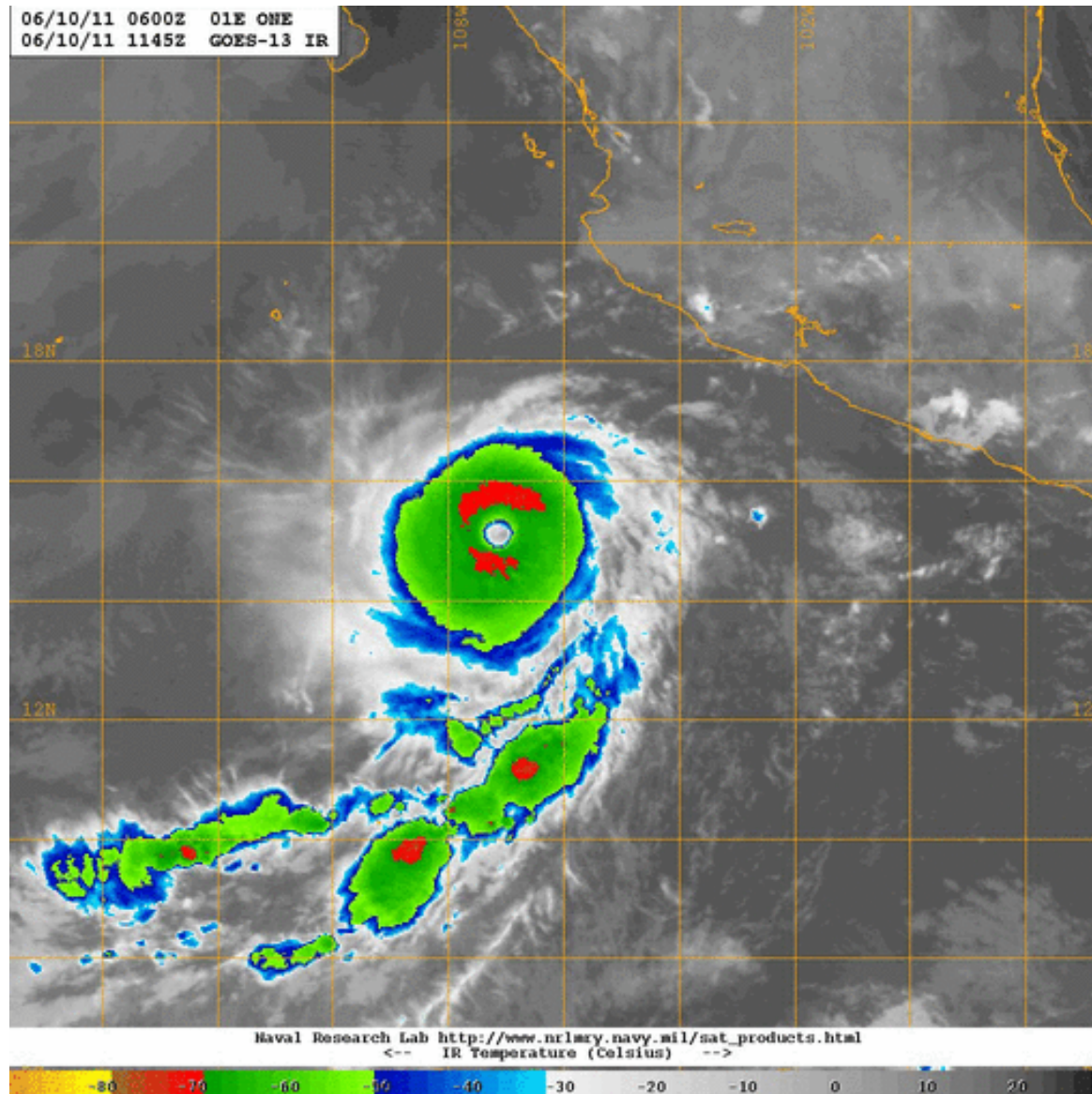
Review: Fill in the blanks

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