MET 4994 Remote Sensing: Radar and Satellite Meteorology
MET 5994 Remote Sensing in Meteorology

Lecture 19: Operational Remote Sensing in Visible, IR, and Microwave Channels

Before you use data from any remote sensing instrument, you should know...

1. Frequencies/Channels: visible, IR, microwave, or other...

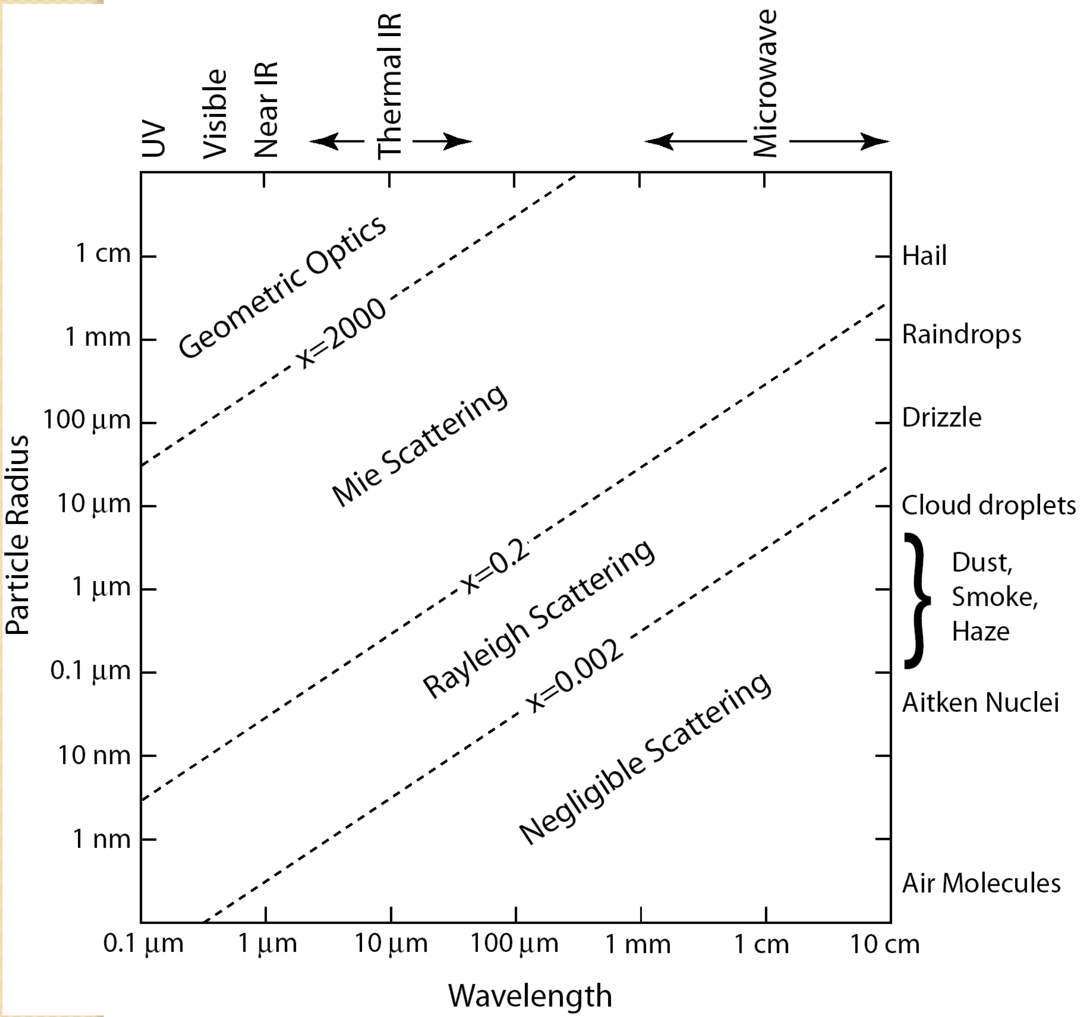
2. Footprints on each channel: spatial resolution

3. Scanning geometry: conical or cross-track or along track

4. Measured/retrieved physical parameters

5. Data dimensions

When Does Scattering Matter?



In general, particles that are far smaller than the wavelength will scatter only very weakly.

Size Parameter:

$$x \equiv \frac{2\pi r}{\lambda}$$

Visible Channels

Spectrum: wavelengths around 0.5 μm

Rain or cloud droplets are geometric or Mie scatters ($r >> \lambda$), so we use reflection/refraction to replace scattering. A cloud only a few of tens meters thick is sufficient to scatter all of the visible radiation incident on it.

Absorption is negligible.

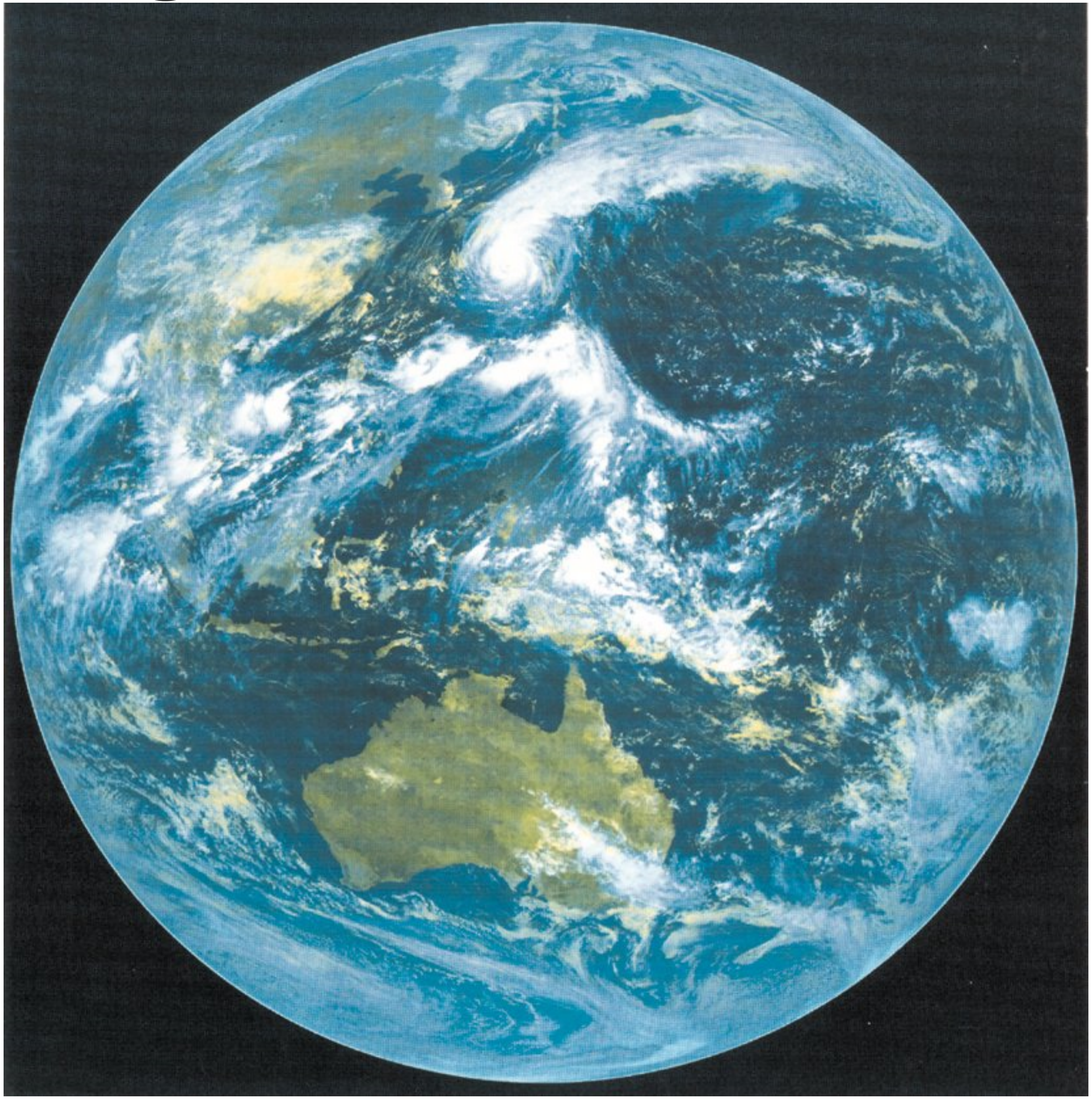
So visible channels detect sunlight reflected by clouds and the earth's surface -- *REFLECTANCE*.

Visible Image Interpretation

Thick clouds (White) are bright in the visible imagery because thicker clouds generally have higher reflectance.

High clouds (White) are often semi-transparent and low clouds (Yellow) can be seen through them.

The land surface (Yellow) reflects sunlight less than clouds but more than the sea surface (Blue).



IR Channels

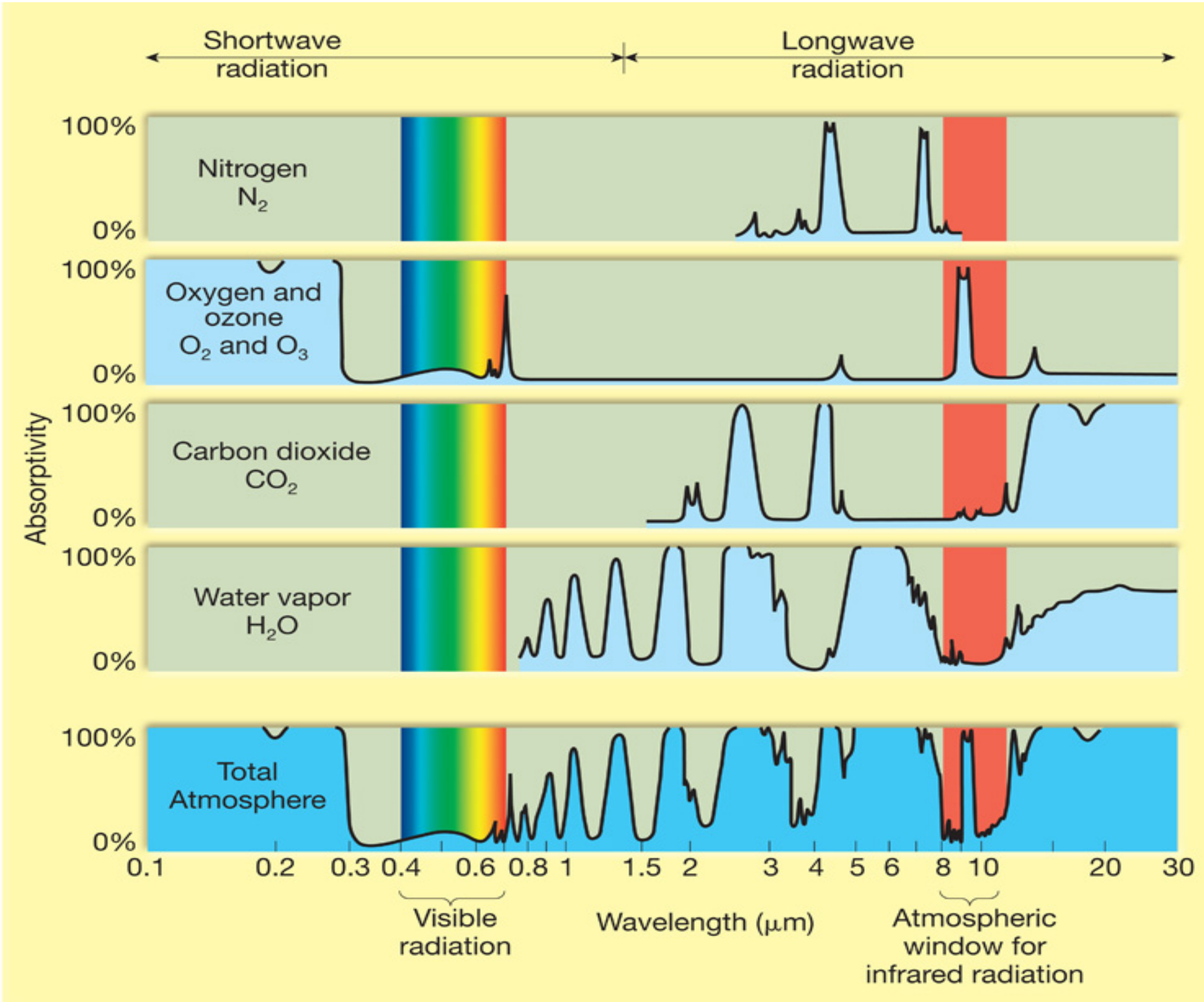
Spectrum: usually referred as the 10-12.5 µm window, in which the atmosphere is relatively transparent to the long-wave radiation from the Earth.

IR sensors from space measure the thermal IR emission (radiation) from the Earth surface & clouds.

The measured radiation can be converted to brightness temperature (T_B) using Planck's function. In IR channel, both clouds and Earth surface act as blackbody. So T_B is equal to actual physical temperature.

The higher the temperature of clouds or earth surface is, the stronger the measured infrared radiation. High clouds are very cold, while low clouds are much warmer. Thus, both the temperature and the height of the cloud top can be derived from the intensity of the infrared radiation.

Absorptivity of the Atmosphere



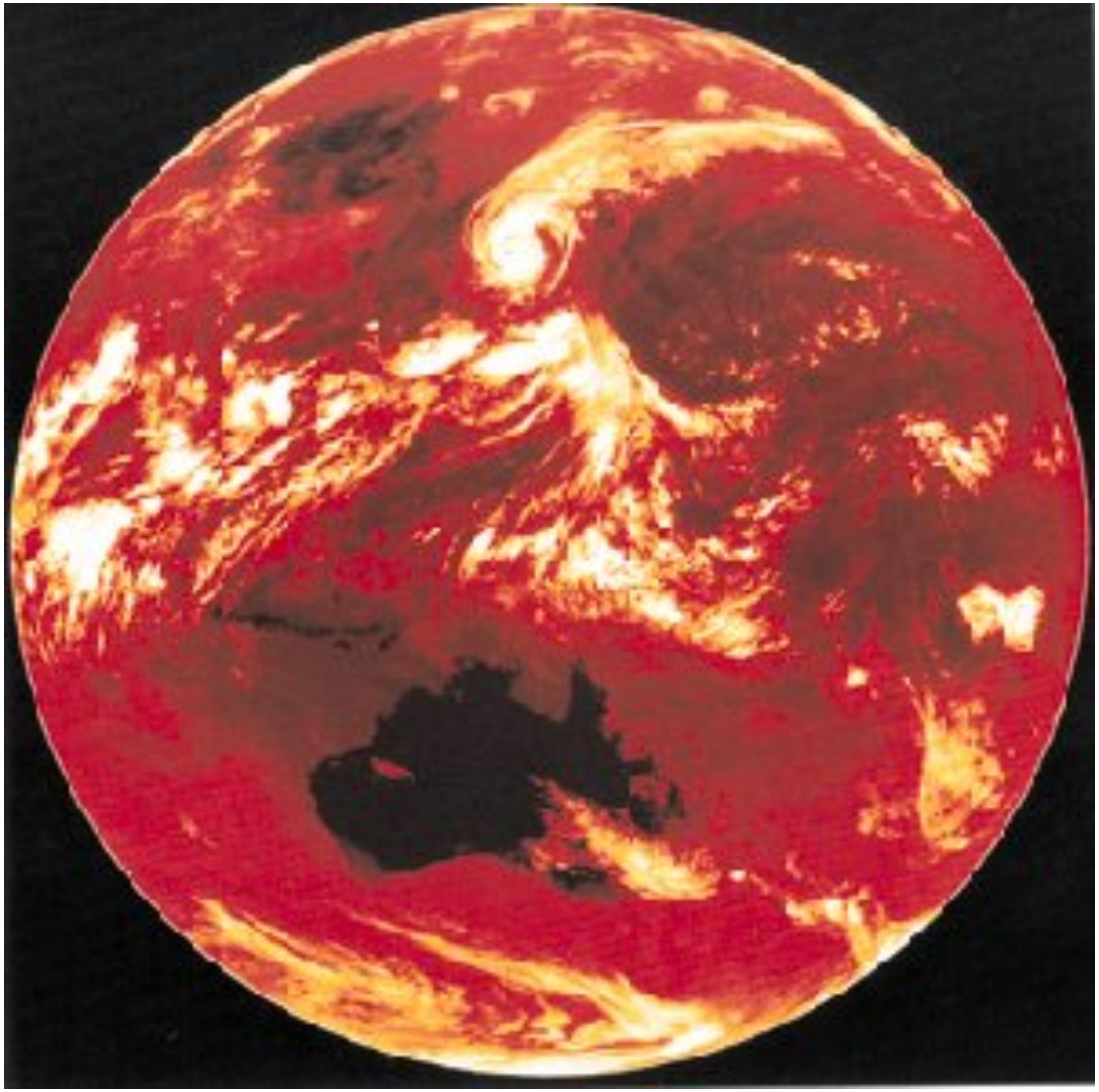
IR Image Interpretation

Thick clouds, such as those associated with the typhoon, look **white** (lowest temperature).

High clouds, which look semi-transparent in the visible imagery, are also shown **white or yellow**.

Low clouds are displayed as **red**. They may have temperatures close to that of the underlying ocean and are more difficult to identify in the infrared than in the visible imagery.

The desert in Australia is much hotter (**black**) than any cloud and shows up clearly.



IR Water Vapor Channels

- Spectrum: water vapor absorption band around 6.7 μm.

- As absorption by water vapor is strong in this band, radiation from the low clouds and the earth's surface do not normally reach the satellite.

- ***The intensity of the radiation received at these channels depends on the amount of water vapor in the upper and mid-troposphere as well as the temperature of the radiation source. Water vapor image does not only represent moisture, it is proportional to the mean temperature where roughly the top 3 mm of precipitable water exists. Both moisture and temperature are important factors.***

- The temporal changes of the humidity patterns can identify air movement and vortices even in the absence of clouds.

Water Vapor Image Interpretation

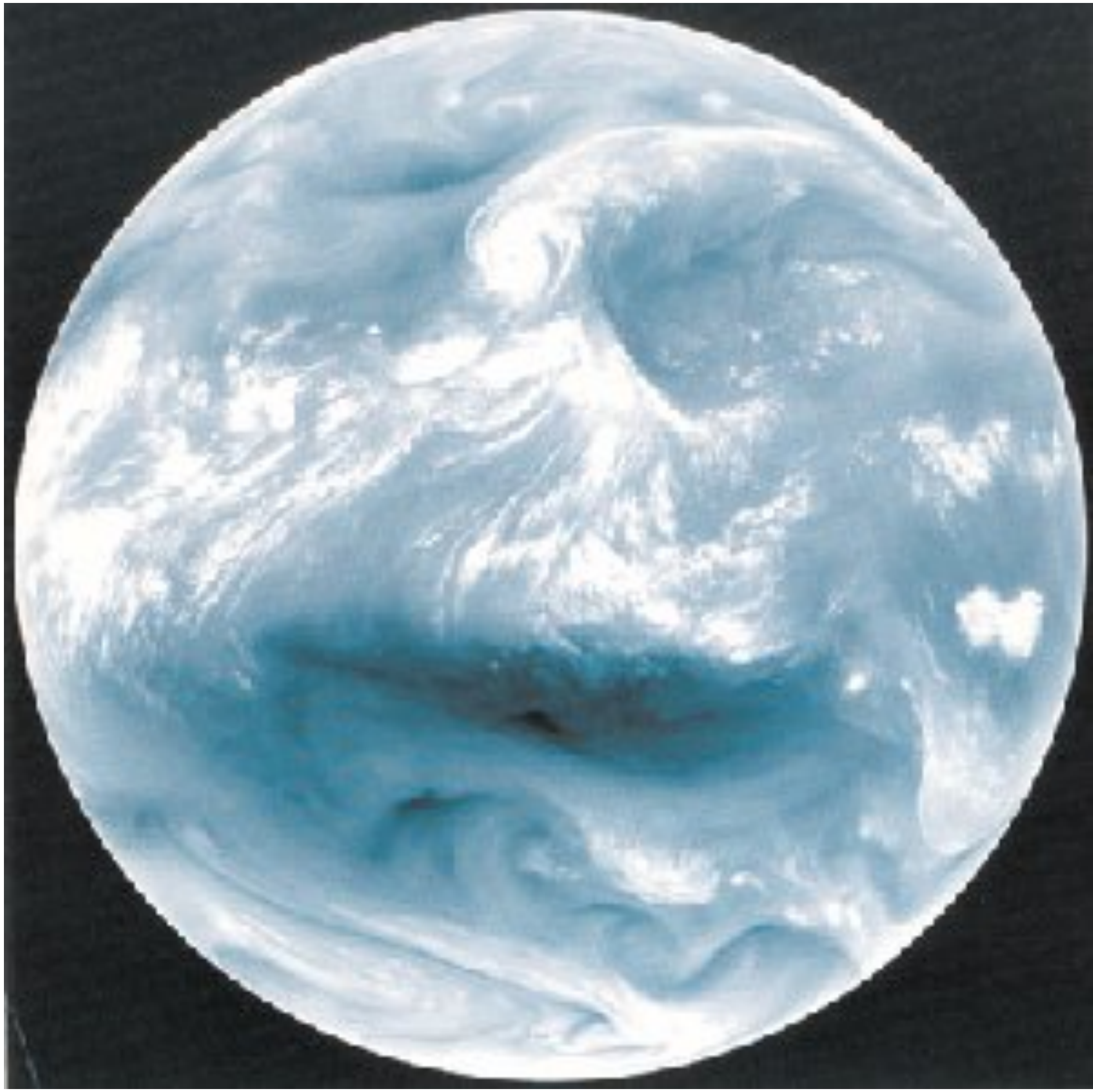
The brighter parts show the moister parts of the upper and mid-troposphere.

Thick clouds and high clouds are seen **white** (similar to IR and visible images). The earth's surface and low clouds are undetectable .

Grey shades corresponding to water vapor amounts are seen where there are no high and middle clouds.

In the southern hemisphere, **dark areas** can be seen, associated with dry upper air.

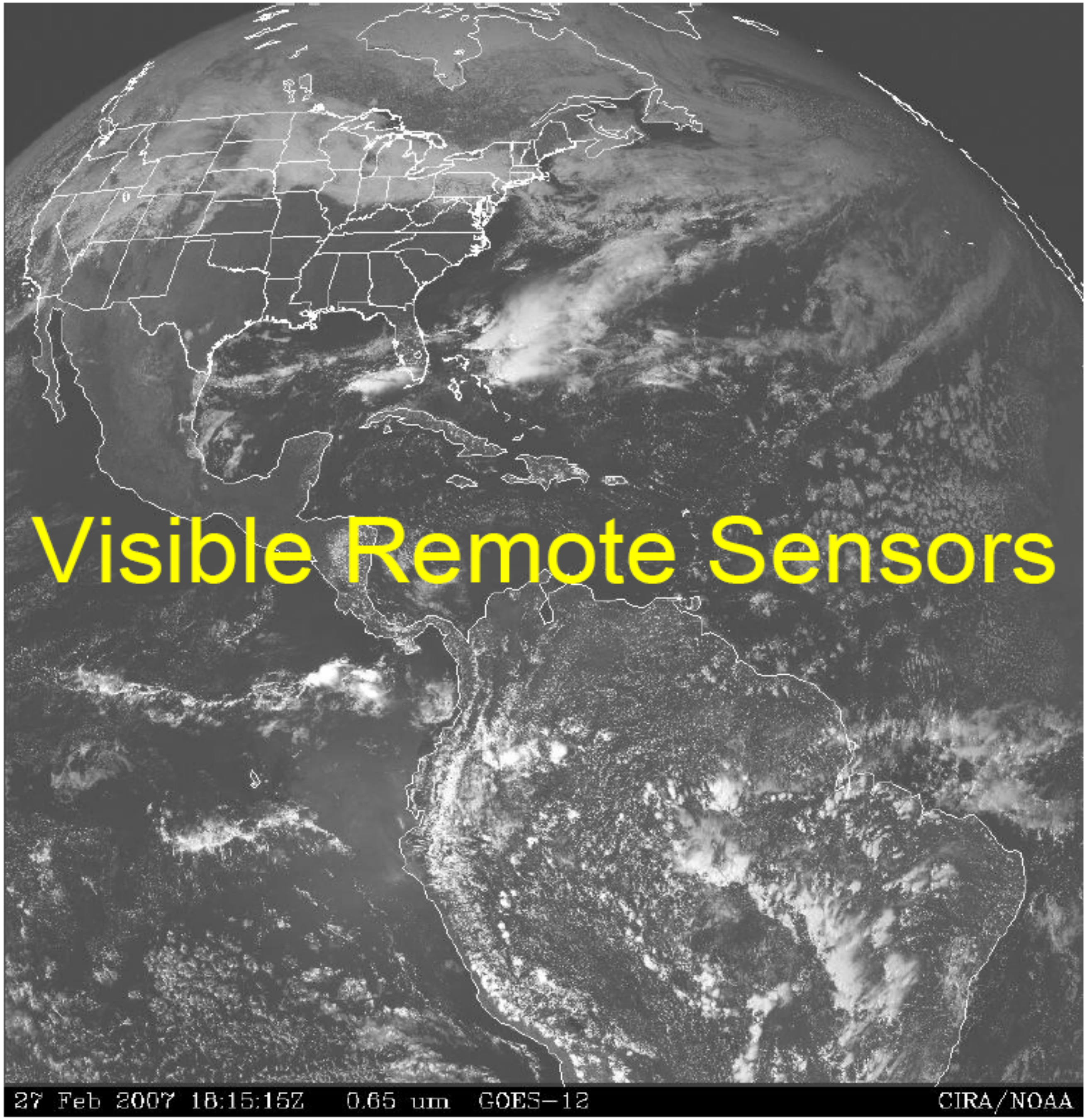
Many vortices of grey shades are also seen, associated with upper tropospheric lows.



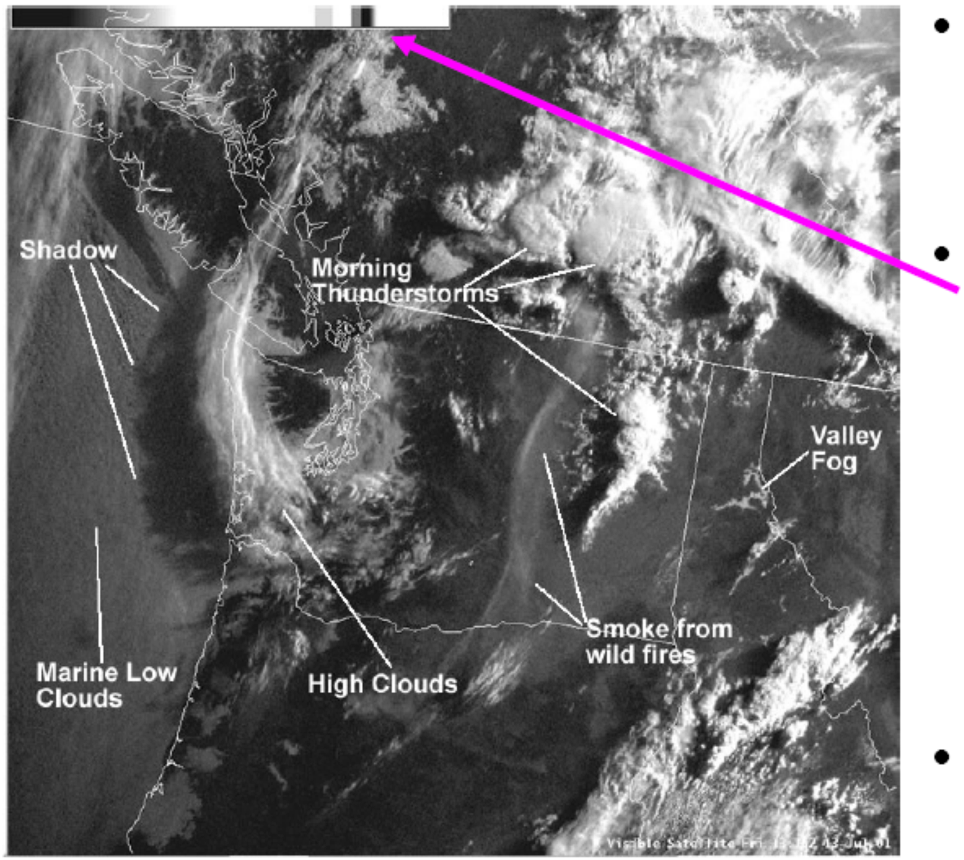
Interpreting Satellite Imagery

	Visible	Infrared	Water Vapor
Satellite measures	reflected solar radiation	emitted infrared (temperature)	infrared radiation emitted by water vapor only
Brightest regions	thick clouds, snow	coldest clouds or surfaces	moist air
Darkest regions	ocean, forests	warmest clouds or surfaces	dry air

Visible Remote Sensors



The Lookup Table for Visible Imagery



- Enhancements are colors or gray shades applied to an image to make it easier to see objects.
- Colors or gray shades are matched to particular values.
- The **lookup table** is a legend showing the relationship between color/gray shade and value.
  - Also called an **enhancement table**.
- In visible remote sensing, gray shades are assigned to **reflectance** values.

Coverage of Geostationary Satellites

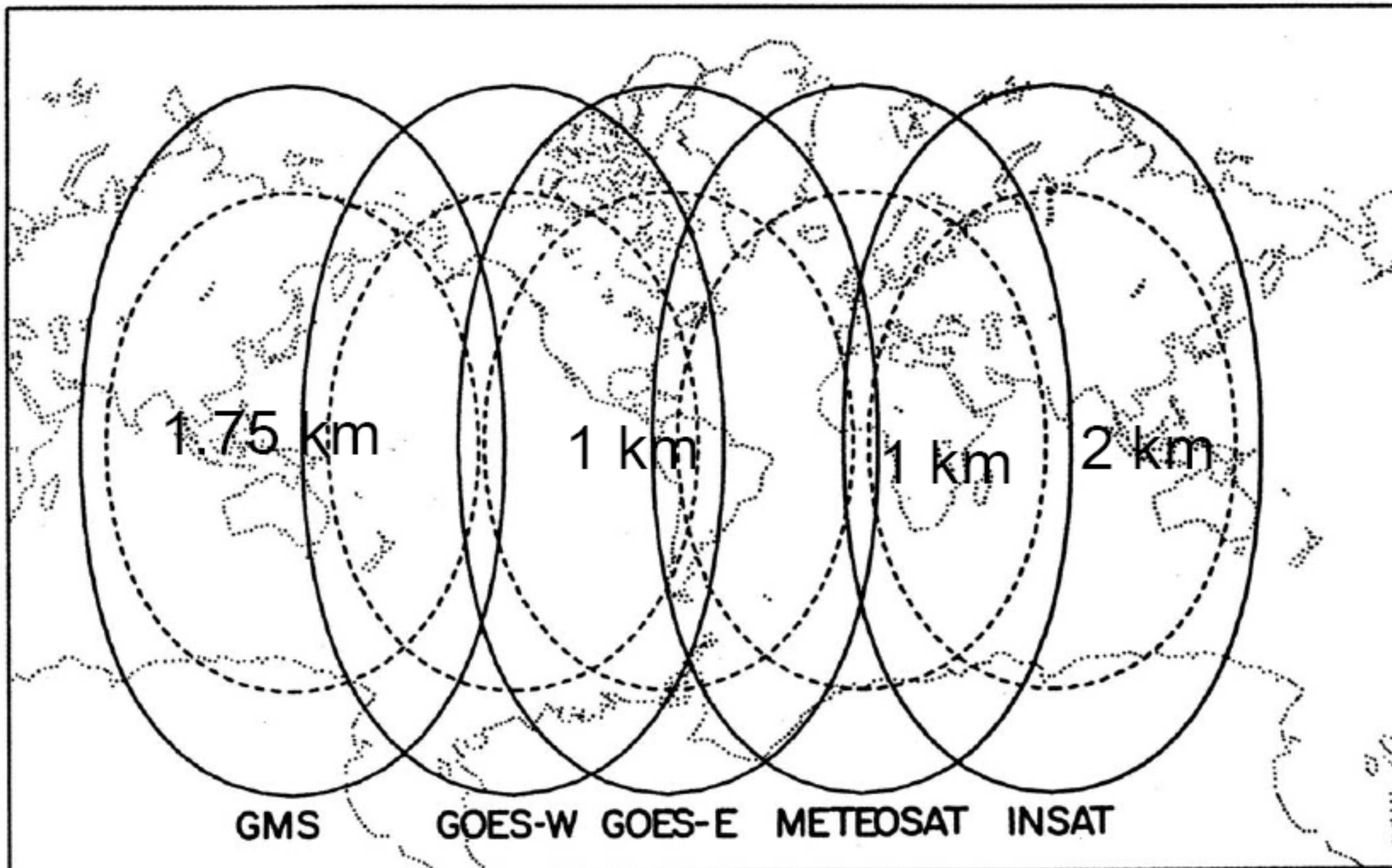
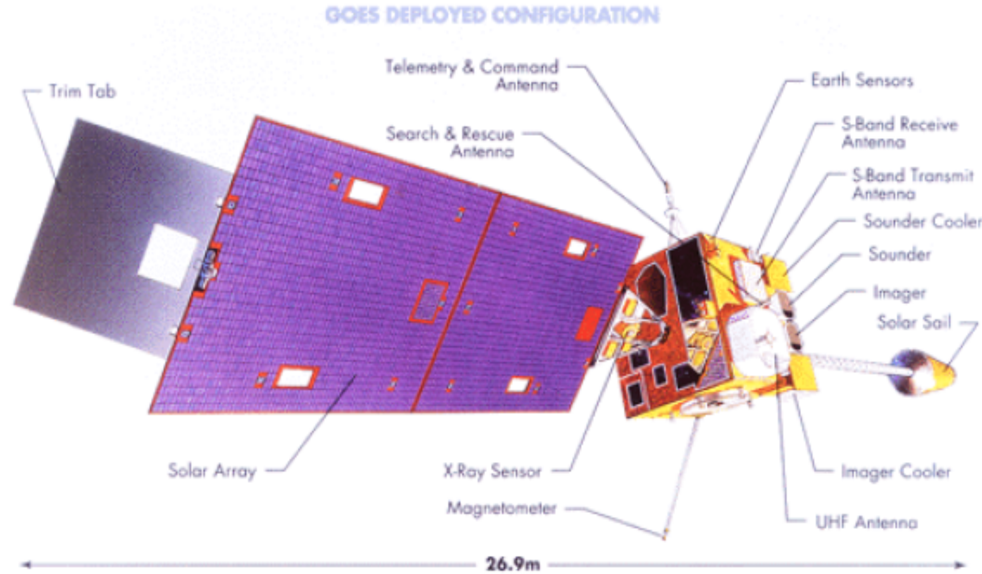
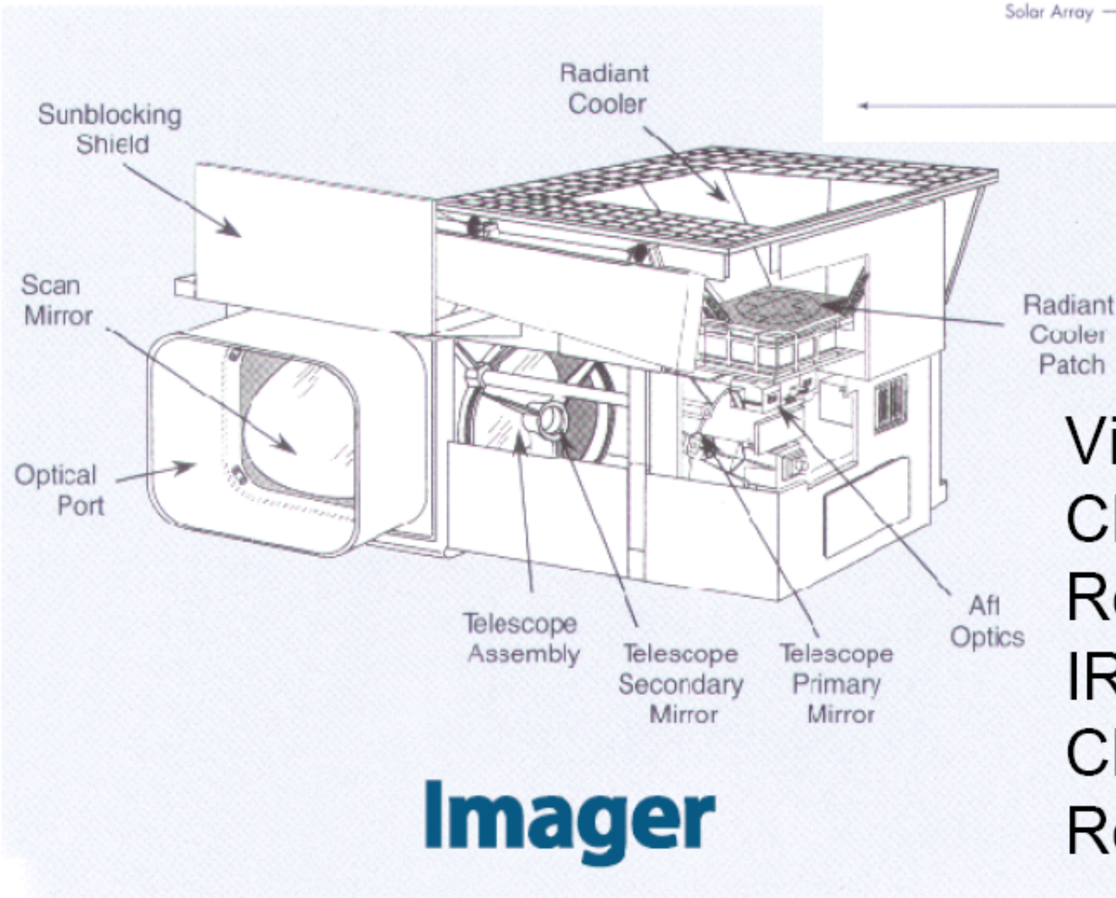


FIGURE 4.21. Areas viewed by geostationary meteorological satellites. The solid line shows the limb; a satellite sees nothing outside this area. The dashed line encloses the area of useful data where the satellite is at least 10° above the horizon.

Resolution at nadir for visible imagery indicated on viewing area.

GOES Imager





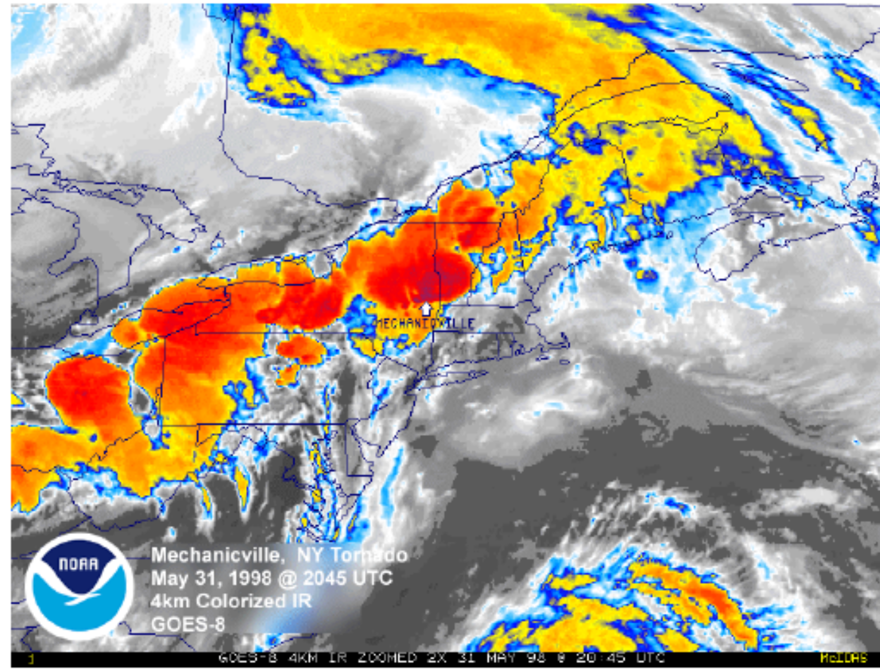
Vis (0.55–0.75 μm)
Channel 1
Resolution at nadir, 1.0 km
IR (10.2–11.2 μm)
Channel 4
Resolution at nadir, 4.0 km

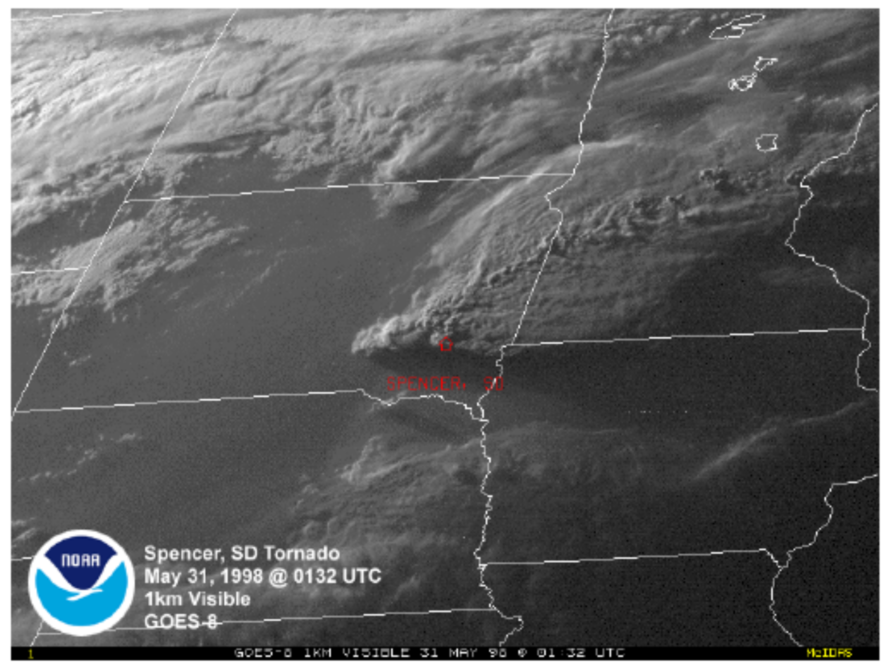
GOES Scanning Schedule

- **Full disk scan** – scans western hemisphere followed by star looks and instrument calibration (30 min).
- **Routine operation** - a repeated 3-hour sequence. Each hour has
  - A full disk scan (30 min)
  - An extended northern hemisphere scan (15 min)
  - A continental U.S. (CONUS) scan (10 min)
  - A limited southern hemisphere scan (5 min);
- **Rapid scan operation** - a repeated 3-hour sequence
  - Fewer extended and full scans
  - 4 views of the CONUS at 7.5 min intervals in a 30-min period
  - Limited southern hemisphere scan
- Regular schedule has both routine and rapid scan operations scheduled.

Super Rapid Scan Operation

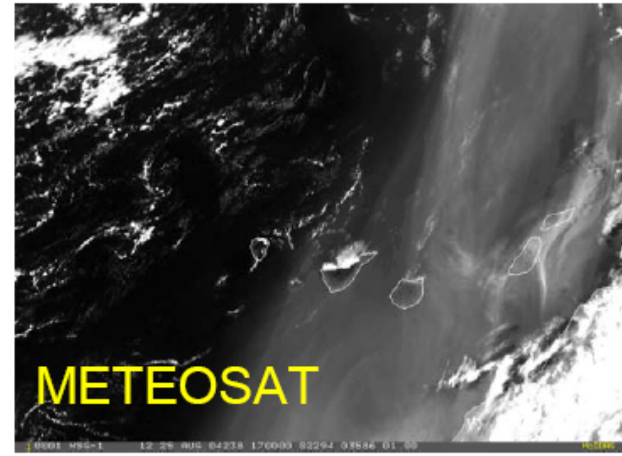
- Used when severe weather threatens.
- In the first 30 min, there are 10 one-minute interval scans.
- In prescribed 1000 × 1000 km sectors.
- The remaining 30 min are assigned to scans of North America.

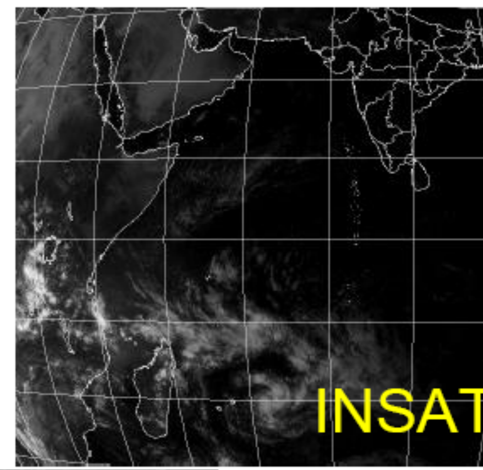


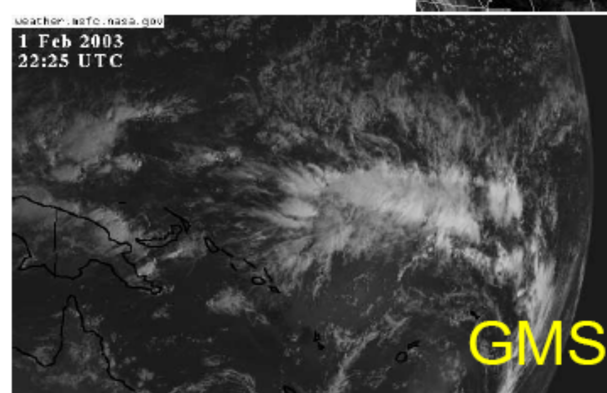


Visible Sensors on Geostationary Satellites

- The METEOSAT Spinning Enhanced Visible and Infrared Imager (SEVIRI)
- The INSAT Very High Resolution Radiometer (VHRR)
- The GMS Visible and Infrared Spin Scan Radiometer (VISSR)
- The GOES Imager

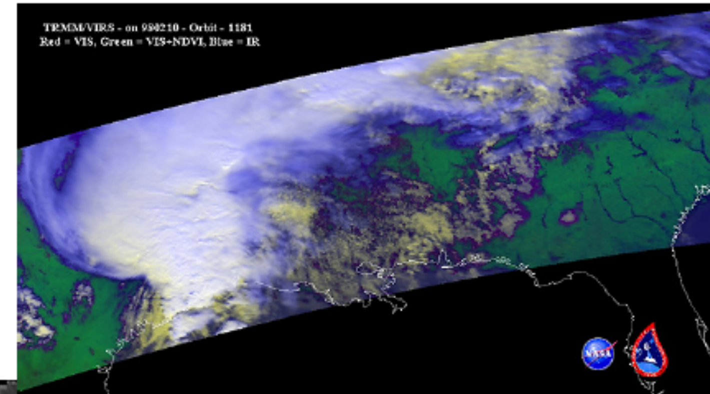


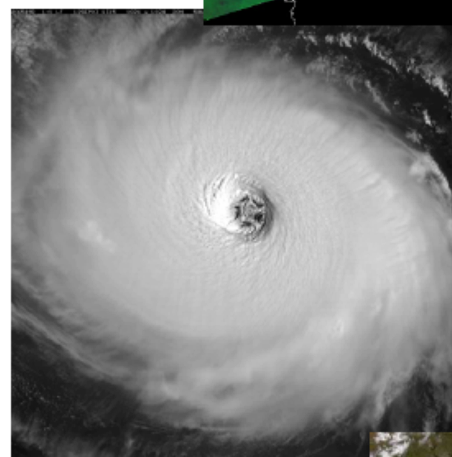




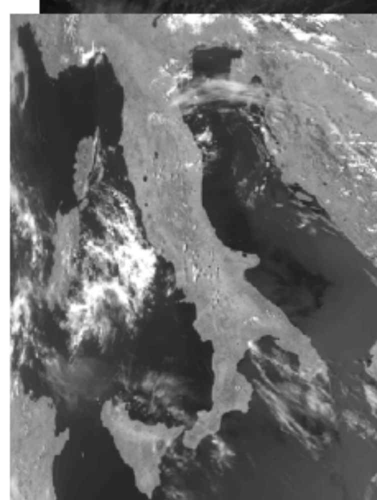
Visible Sensors on LEO Satellites

- TRMM Visible Infrared Scanner (VIRS)
- DMSP Operational Linescan System (OLS)
- Moderate Resolution Imaging Spectroradiometer (MODIS) on the Aqua and Terra satellites
- NOAA POES Advanced Very High Resolution Radiometer (AVHRR)



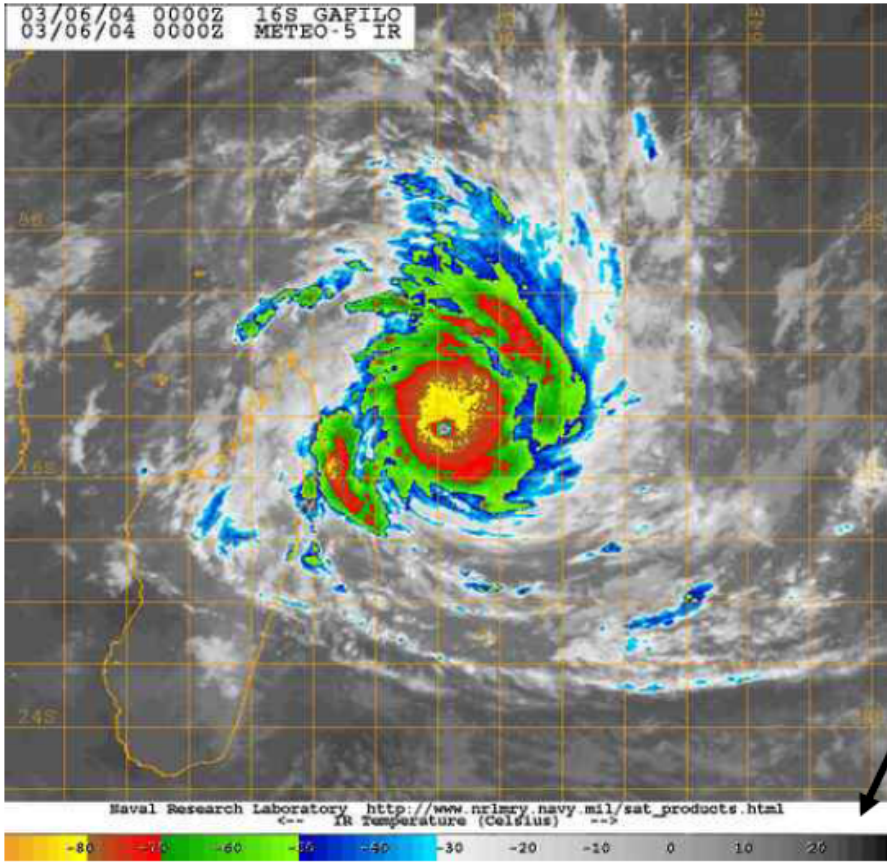


TRMM top
DMSP left
Terra below
POES bottom left




IR Remote Sensors
27 Feb 2007 18:15:15Z 10.70 um GOES-12
CIRA/NOAA

The Lookup Table for IR Imagery

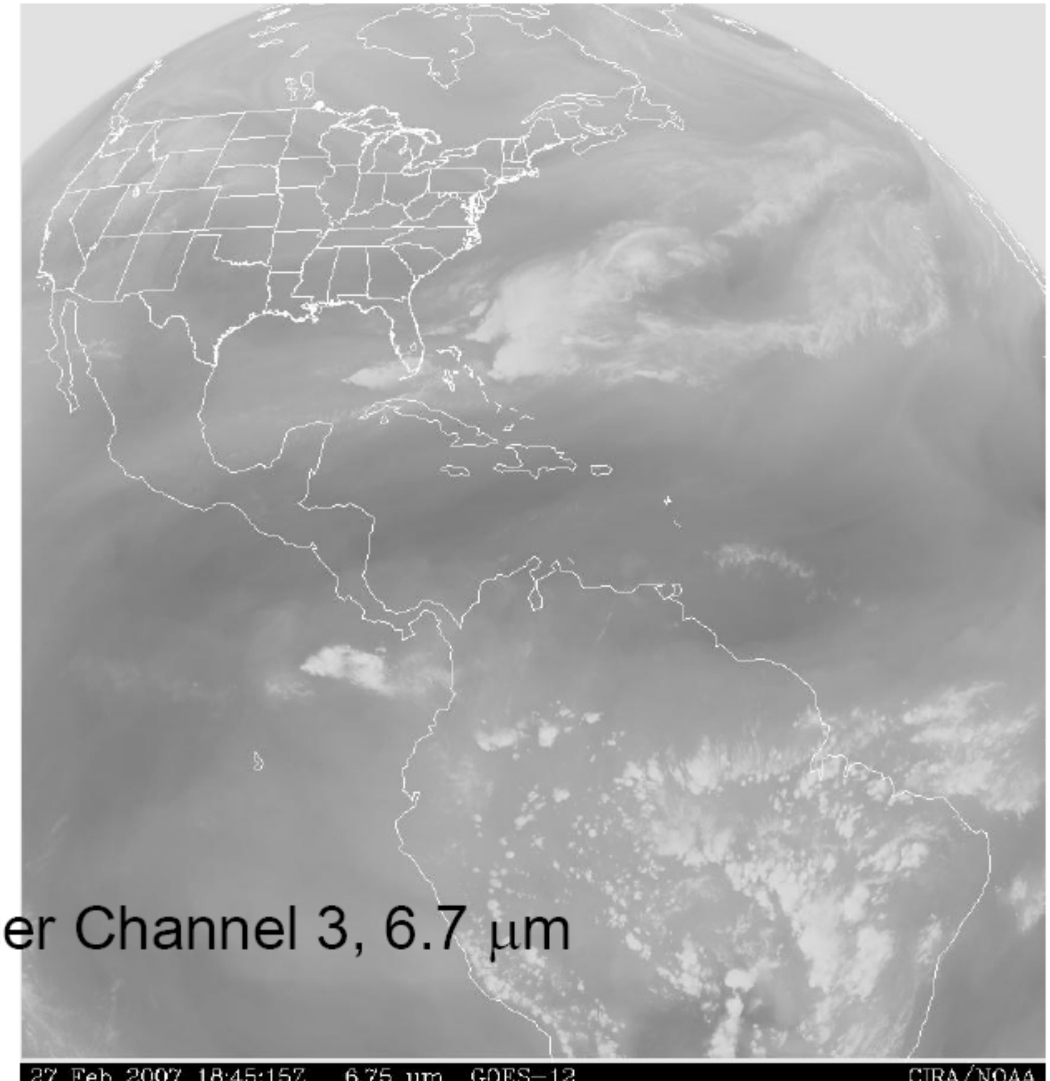


- Enhancements are colors or gray shades applied to an image to make it easier to see objects.
- Colors or gray shades are matched to particular values.
- The **lookup table** is a legend showing the relationship between color/gray shade and value.
  - Also called an **enhancement table**.
- IR remote sensing assigns colors and grayshades to the **equivalent blackbody temperature**.

$$T_{EBT} = \frac{c_2}{\lambda \ln\left(\dfrac{c_1}{B_\lambda \lambda^5}\right)}$$

- For color schemes, lookup tables are particularly important, as the choice of color vs. T_{EBT} is arbitrary.

Water Vapor Imagery



GOES Imager Channel 3, 6.7 μm

IR Imagers on Geostationary Satellites

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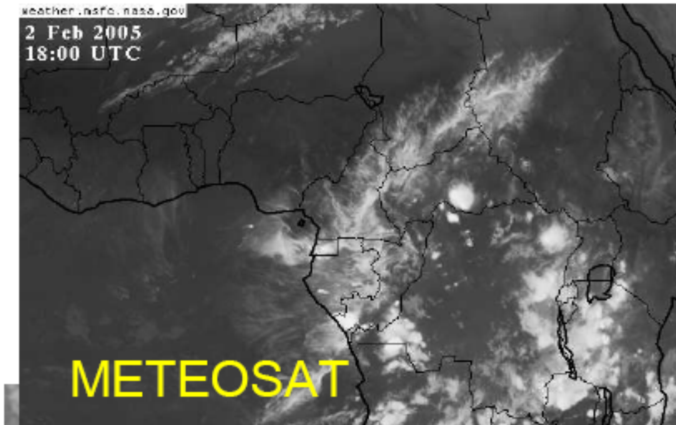
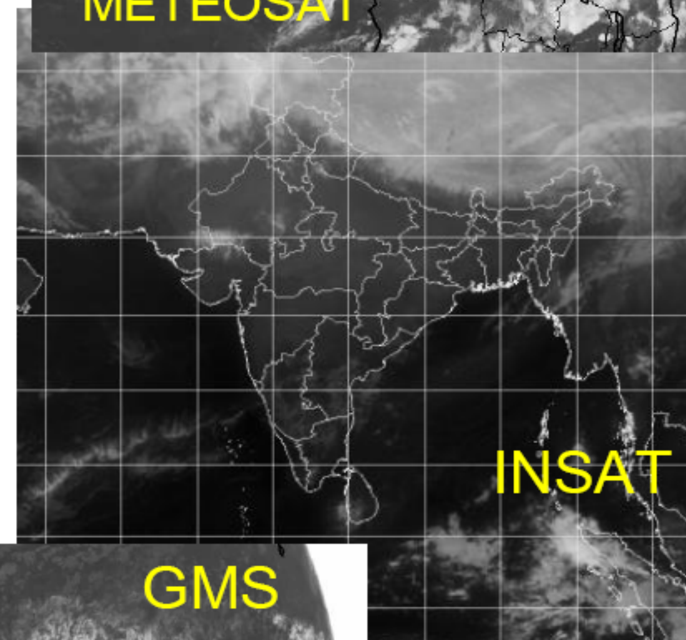
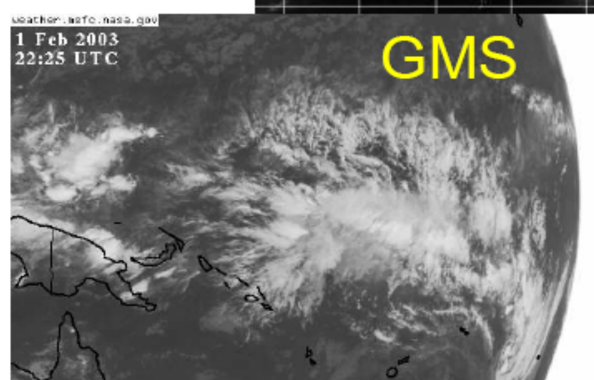
- The GOES Imager







IR Imagers on LEO Satellites

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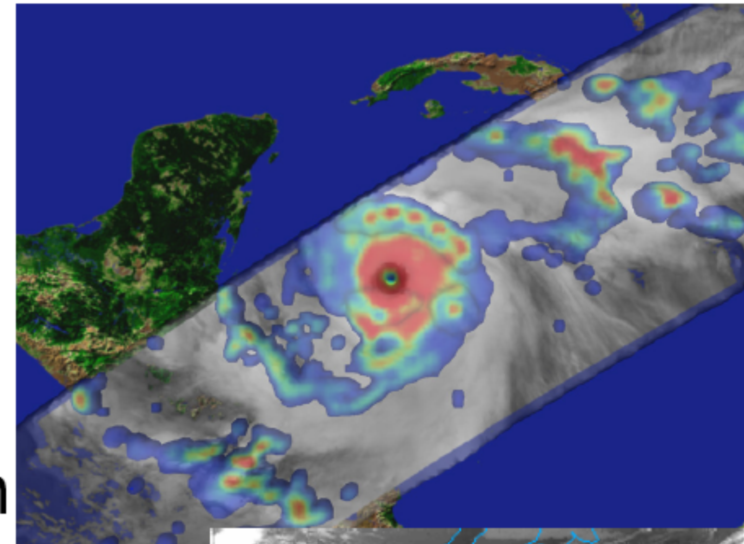
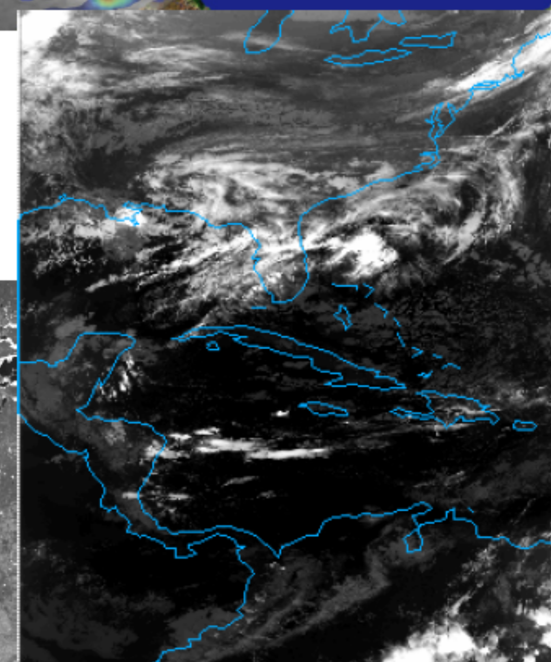
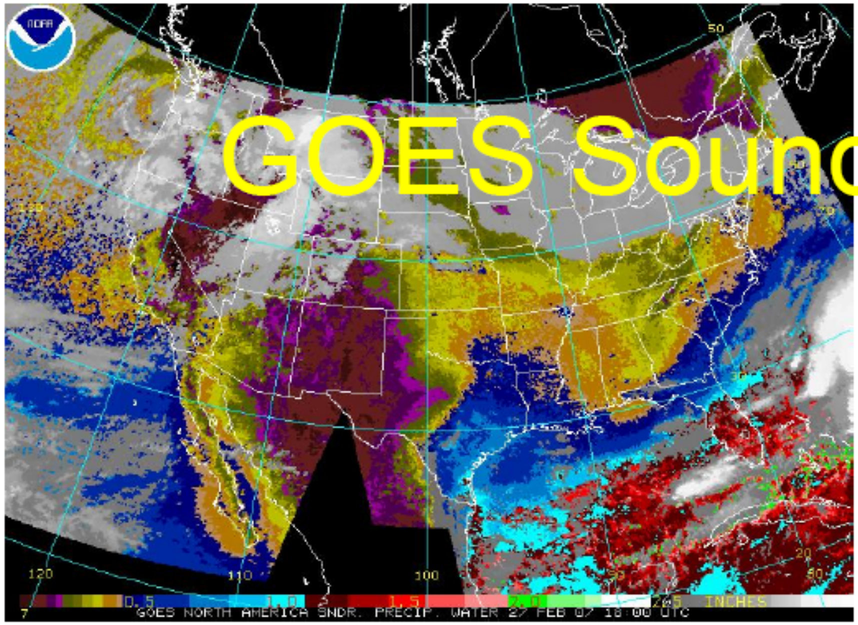




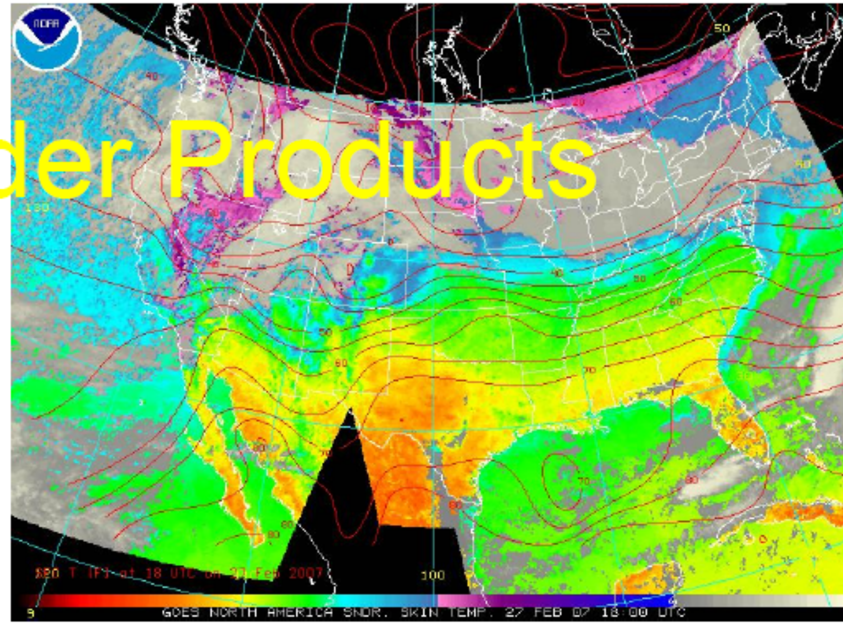
TRMM top
DMSP middle
POES bottom

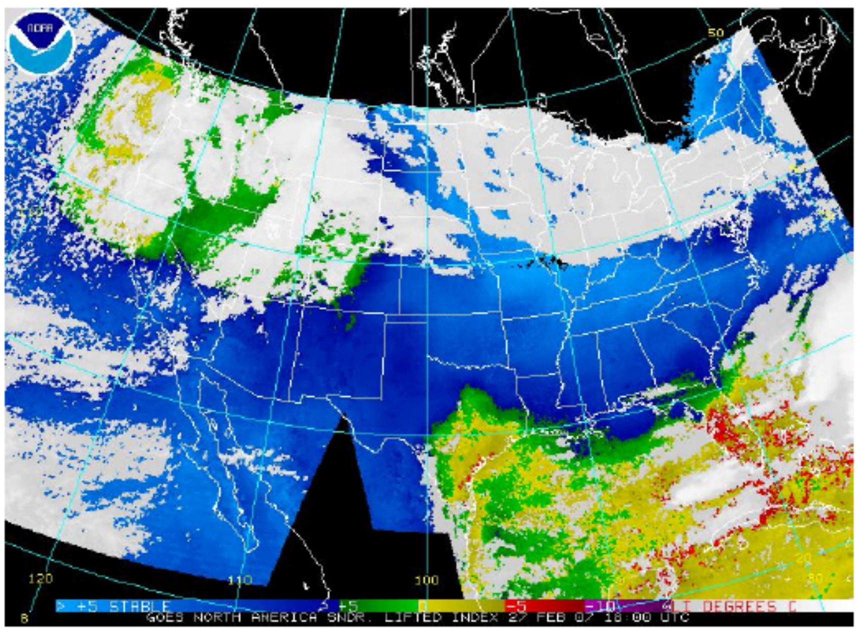
GOES Sounder Products

TPW

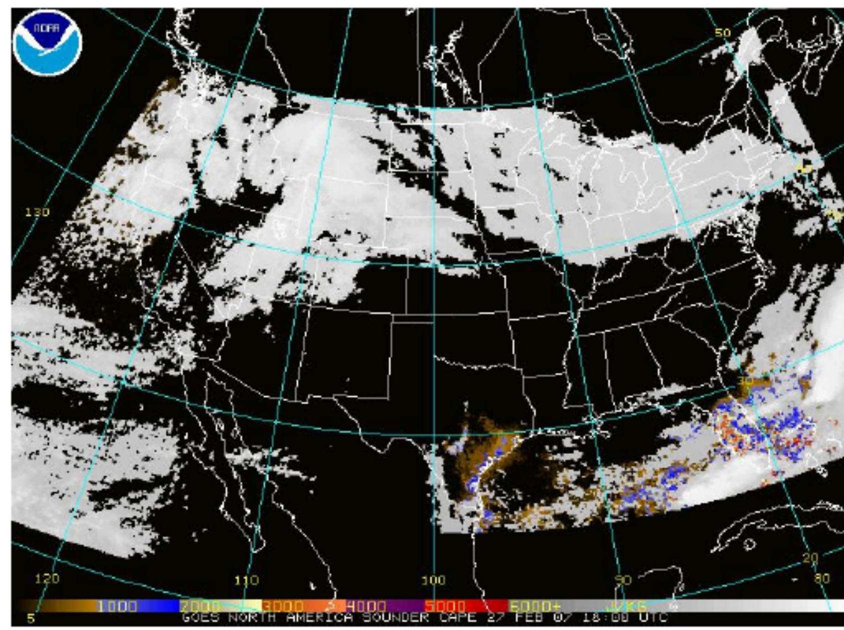


Skin Temperature



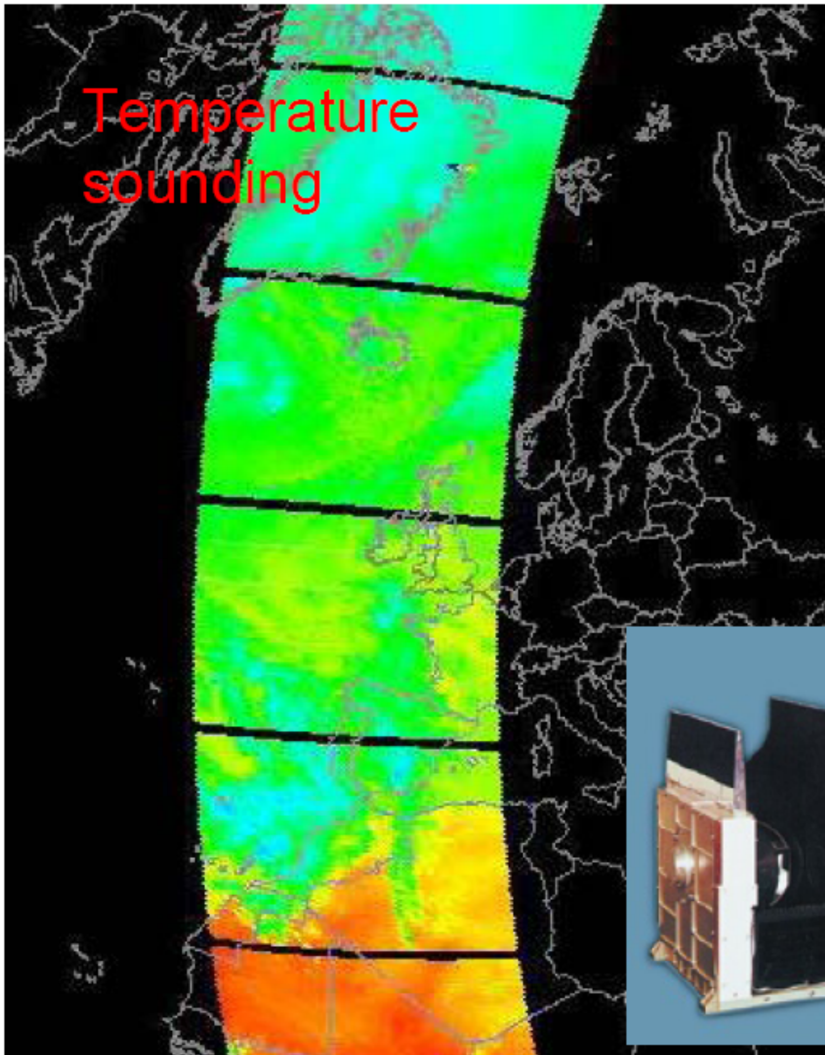


Lifted Index



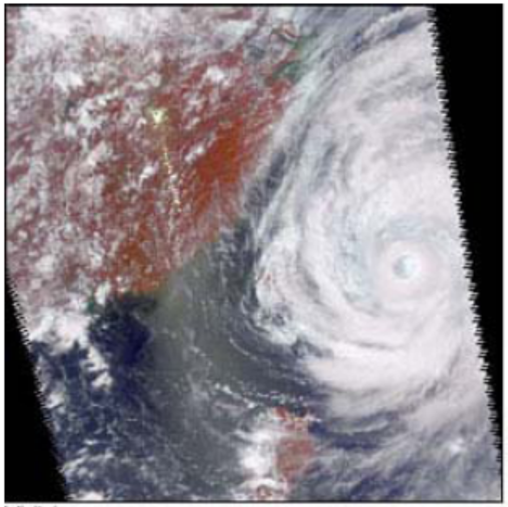
CAPE

High Resolution IR Radiation Sounder (HIRS/3)

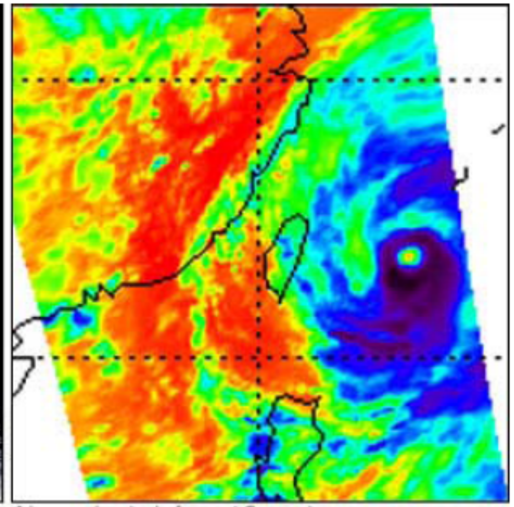


- Carried by NOAA POES
- Resolution at nadir, 20 km
- Temperature and humidity profiles available.

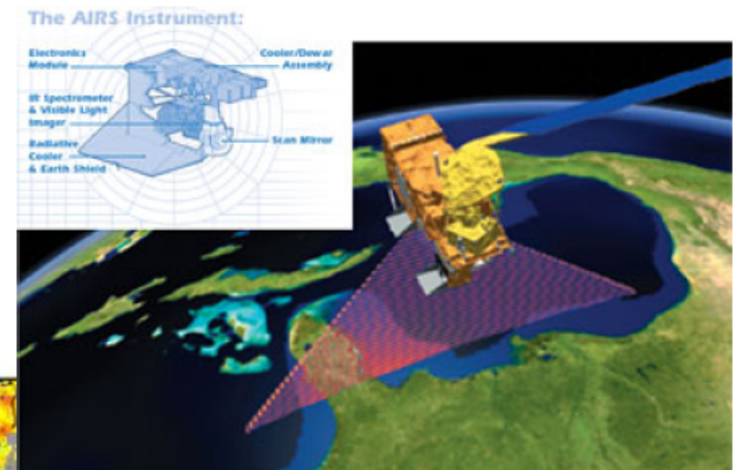
Aqua's AIRS

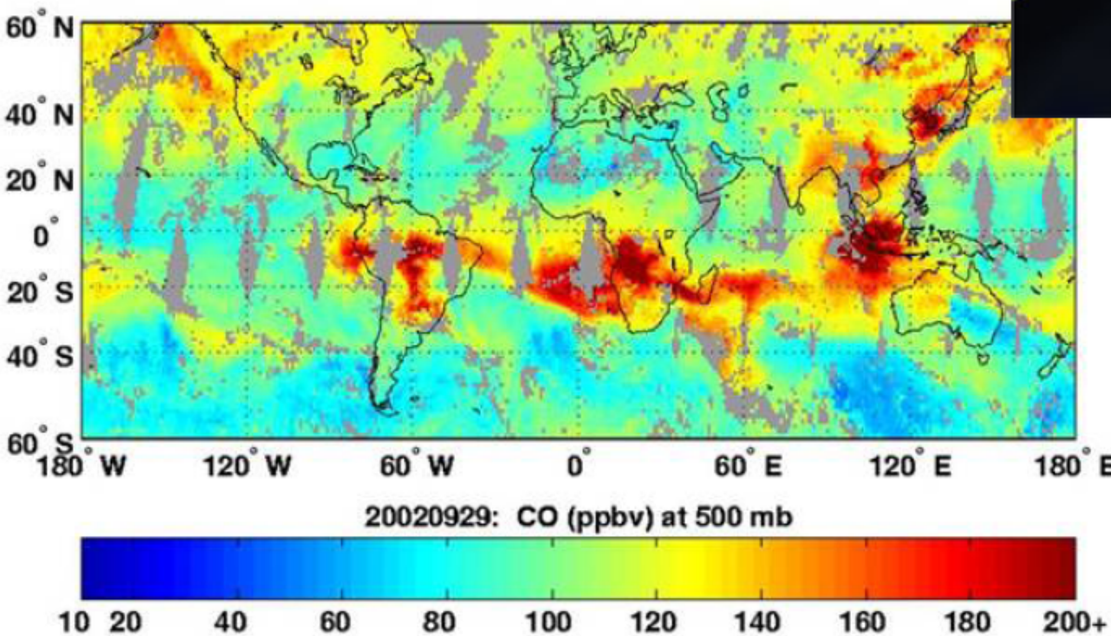


Visible



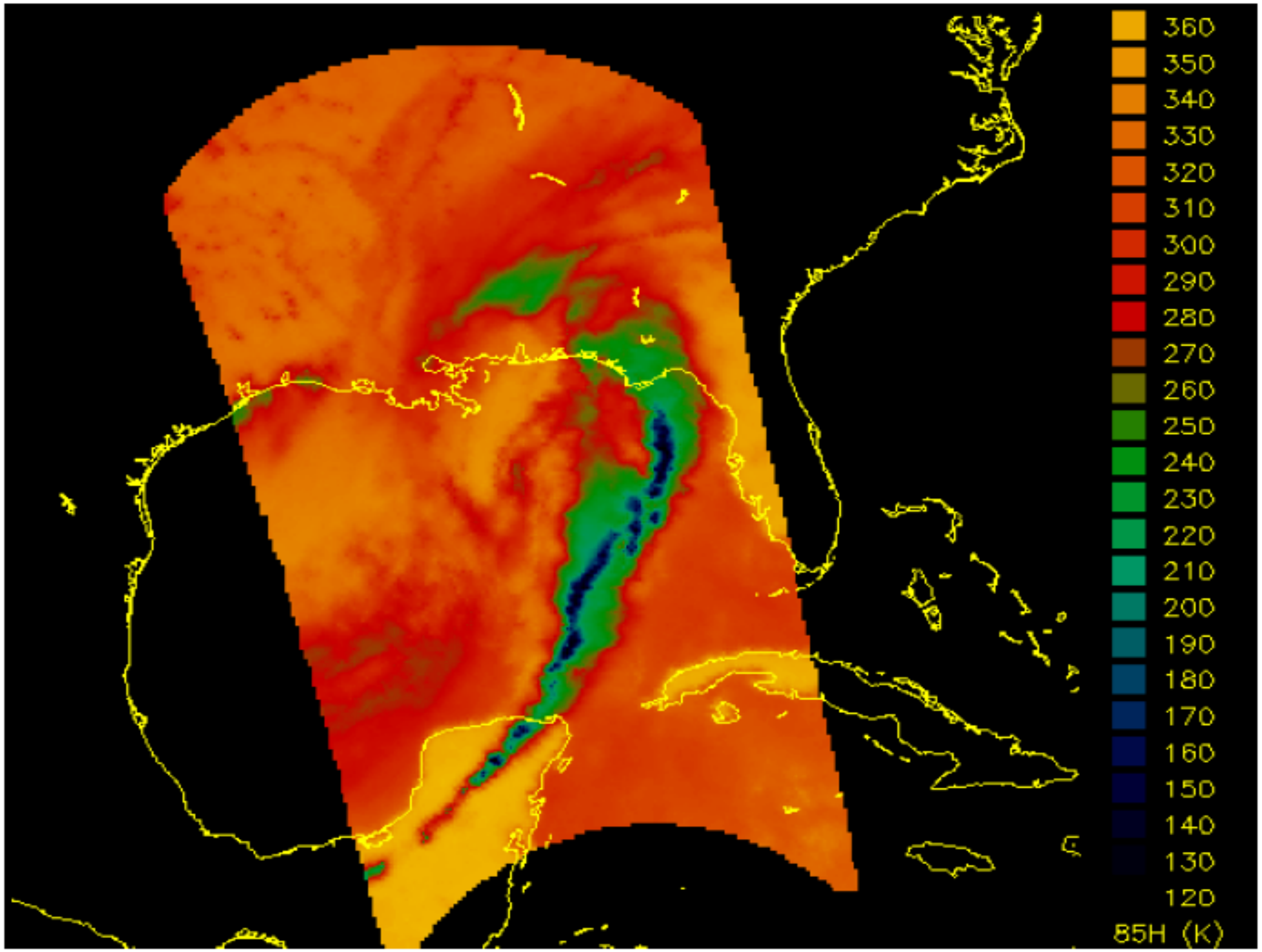
Atmospheric Infrared Sounder





NASA's Aqua satellite has a visible imager (MODIS) and the Advanced IR Sounder (AIRS).

Microwave Remote Sensing



March 1993 Superstorm as viewed by the Special Sensor Microwave Imager (SSM/I) on DMSP.

These frequencies represent important absorption/emission or scattering bands for ice, water, and oxygen.

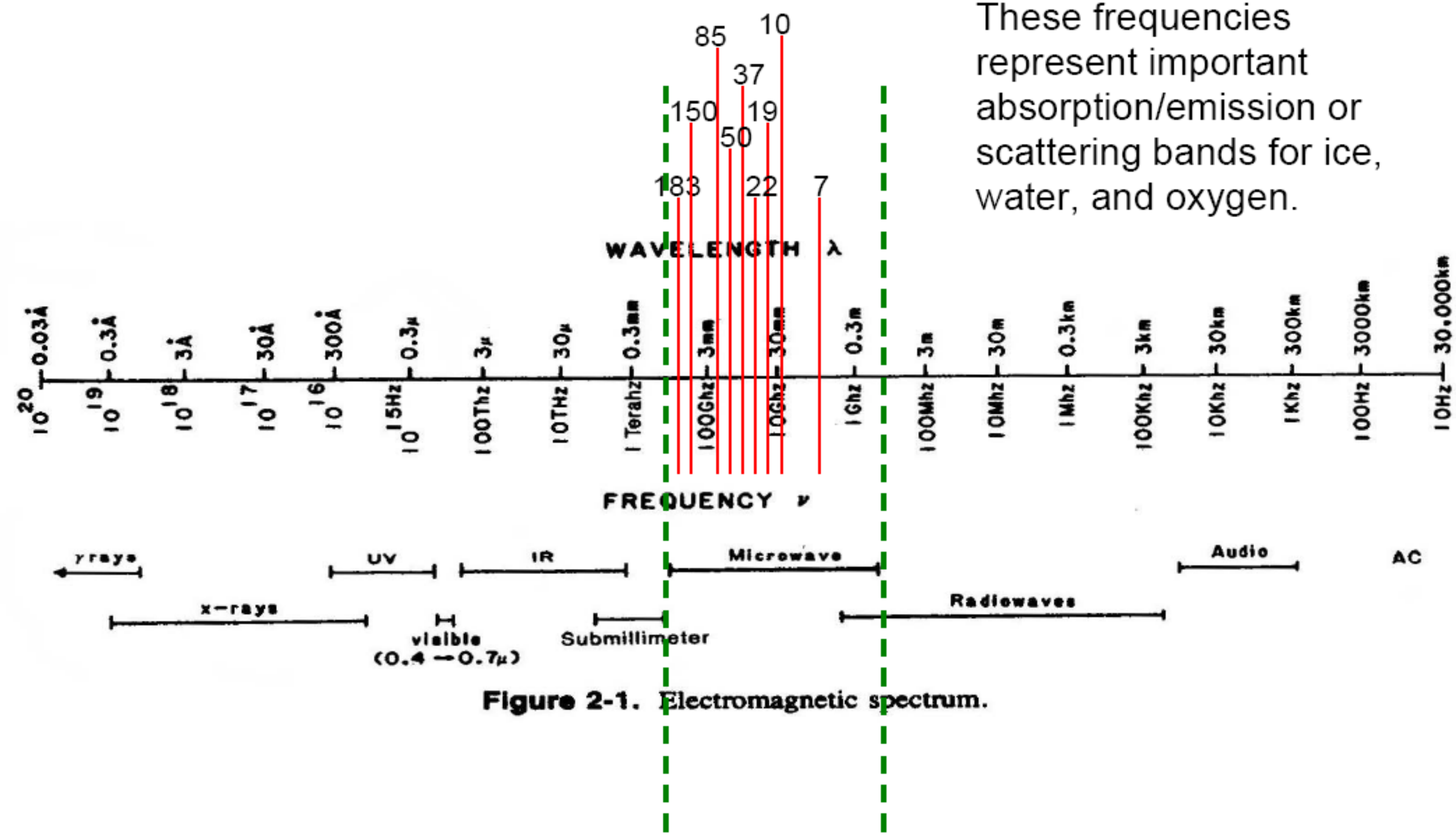


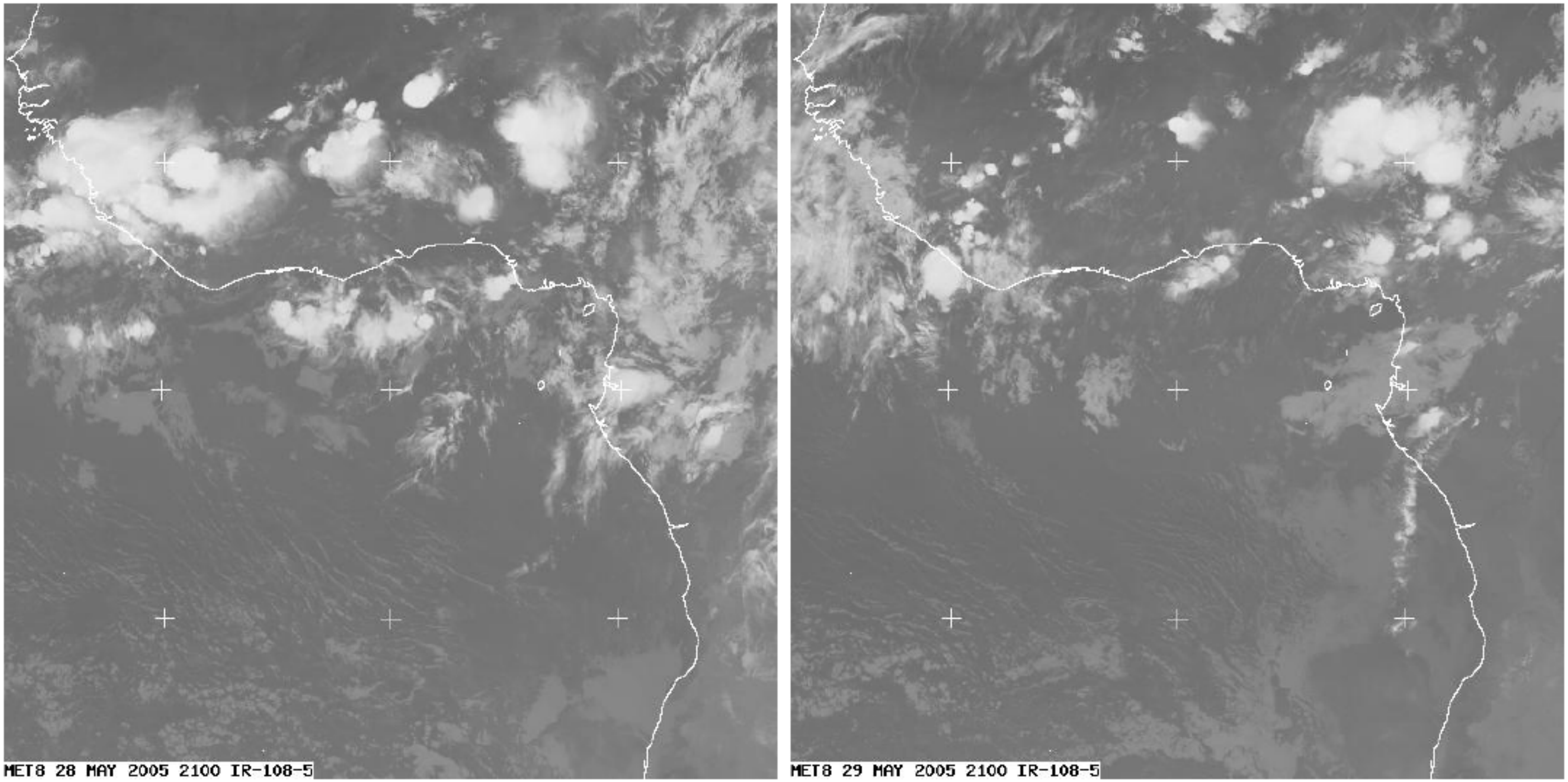
Figure 2-1. Electromagnetic spectrum.

Frequencies Measured by Satellite Microwave Imagers/Sounders

Satellite Imagers and Sounders

- Imagers: measure the horizontal field of meteorological parameter(s); no vertical information
- Sounders: are able to measure temperature and moisture changes with height. Sounders from the past two decades used about 20 spectral bands, while current sounders are hyperspectral, i.e., they use an order of magnitude more bands. For example, the polar-orbiting NASA Atmospheric Infrared Sounder (AIRS) uses 65 spectral radiances for temperature, 42 for water vapor, 26 for ozone, and 23 for surface temperature. Hyperspectral sounders provide profiles of about 1K/1-2km depth.

The Big Blob



IR cold cloud tops are many times larger than the actual precipitating area.

Precipitation and Convection Detection by Microwave Channels

Non-raining clouds are nearly transparent (no absorption, no scattering) in microwave band, but raining clouds are not. Thus microwave is very useful to detect convection and precipitation.

Passive microwave sensors detect the microwave scattering and emission signatures of liquid water or ice particles.

In 10 GHz channel, ice scattering can be neglected. Only emission from rain and liquid water and background (ocean or land) is significant.

The 19 and 37 GHz channels are sensitive to both emission from rain particles and scattering from ice particles.

The 85 GHz and above channels are mainly sensitive to scattering from ice particles.

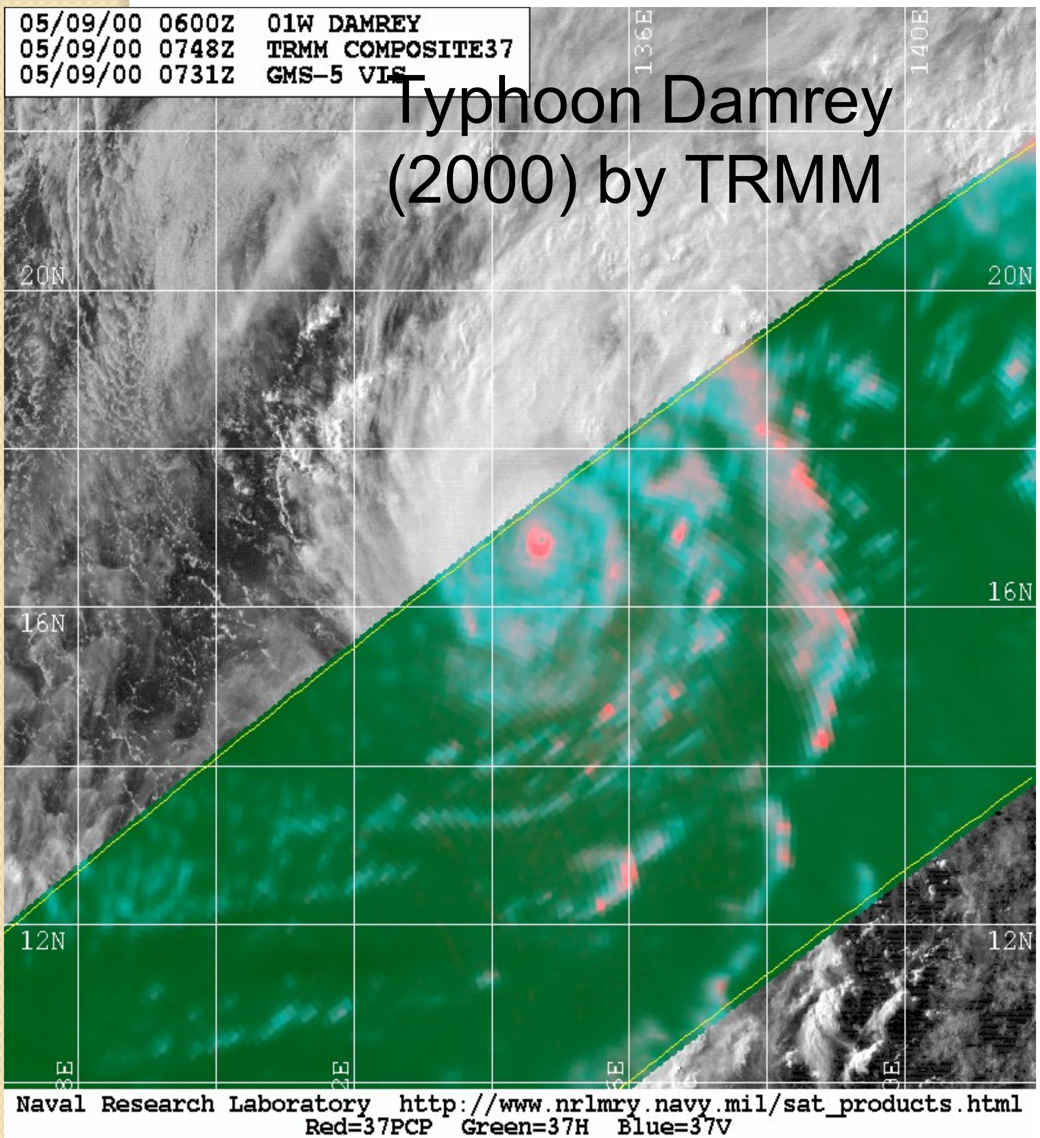
37 and 85 GHz Polarization Corrected Temperature (PCT)

Unlike the infrared where convection appears cold, and the sea surface warm, in the microwave both deep convection and the sea surface can be cold.

PCT (Spencer et al. 1989) is defined by a combination of V & H brightness temperatures to remove the cold sea surface effect.

In Navy Research Lab (NRL)'s Tropical Cyclone satellite webpage, the 37color product is generated from the combination of 37 PCT, horizontally and vertically polarized brightness temperatures. The sea surface appears dark green, warm rain and low-level clouds appears as cyan, and deep convection appears as pink.

37 GHz Image Interpretation

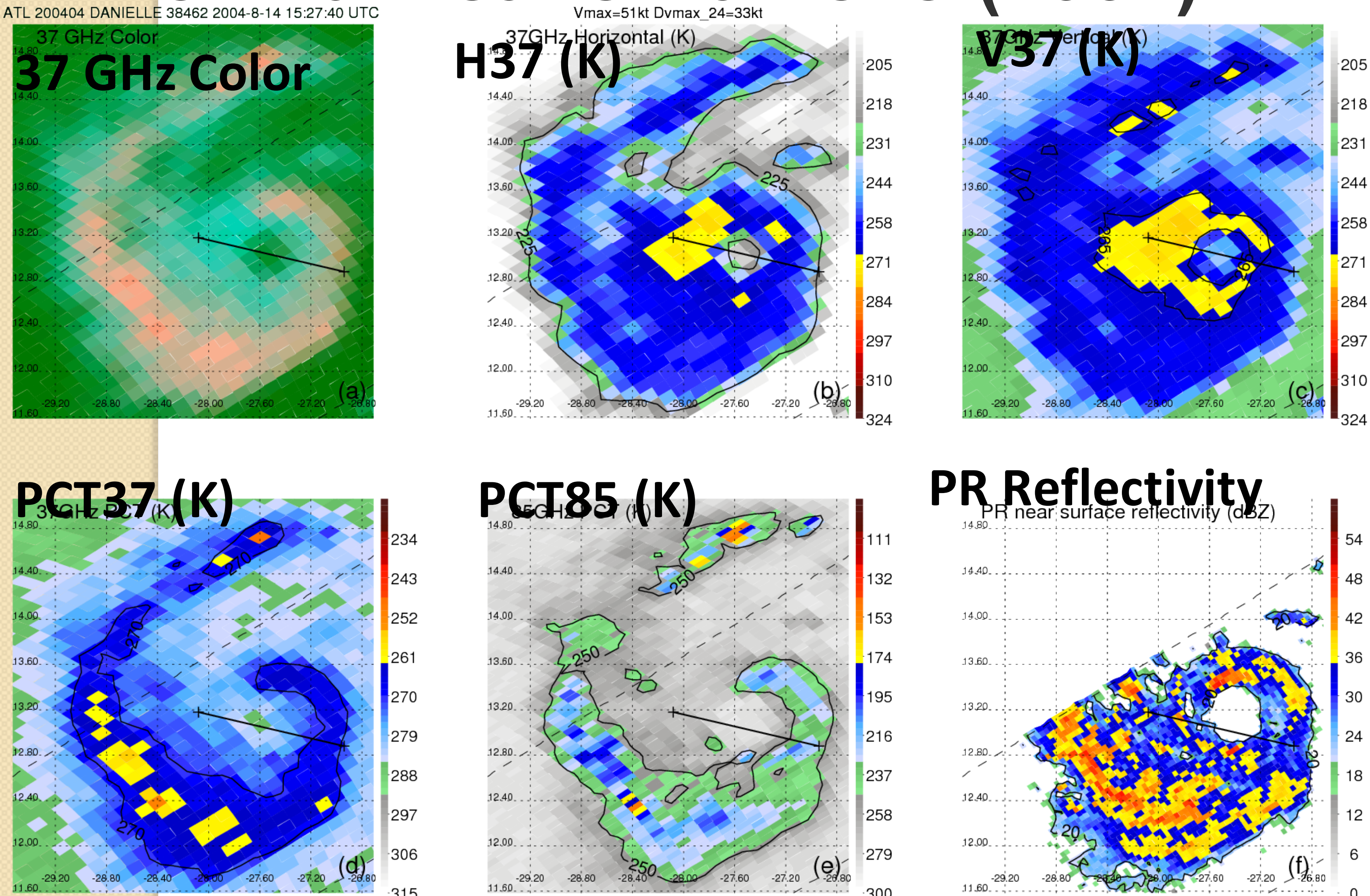


At 37 GHz:

1. Water clouds and precipitating clouds appear warm against a relatively cold ocean

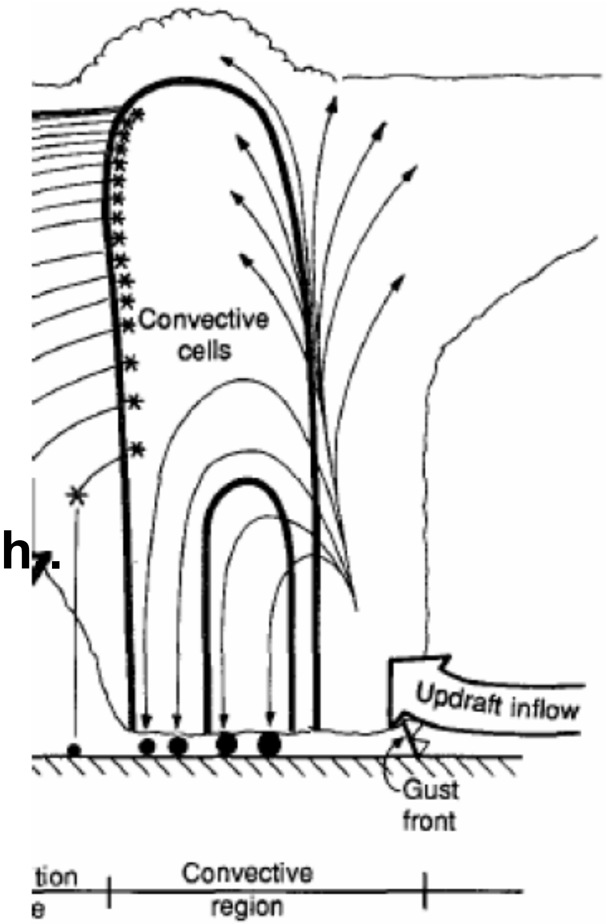
2. Imagery resolves details missed by 85-91 GHz, for example, low-level clouds and rain

TRMM 37 GHz & 85 GHz Images for Hurricane Danielle (2004)

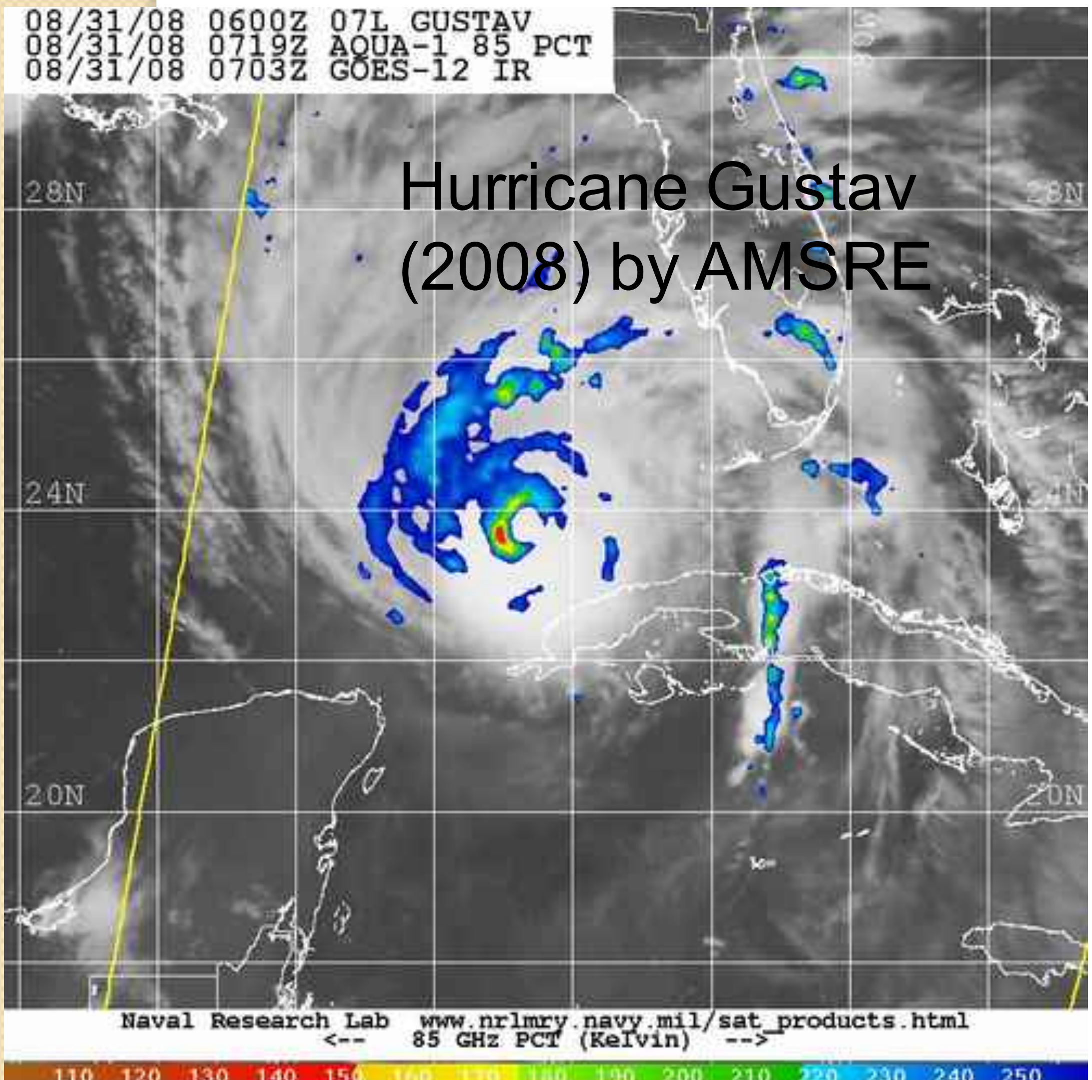


The 85 GHz Ice Scattering Signature

- 85 GHz radiation is scattered out of the sensor field of view by ice hydrometeors, primarily graupel and hail.
- The brightness temperature (TB85) is **inversely proportional** to the density of ice hydrometeors**and ice water path.**
- Thus inversely proportional to the speed (intensity) of convective updrafts and
- Linking TB85 to the *convective intensity*.



85 GHz Image Interpretation



At 85-91 GHz:

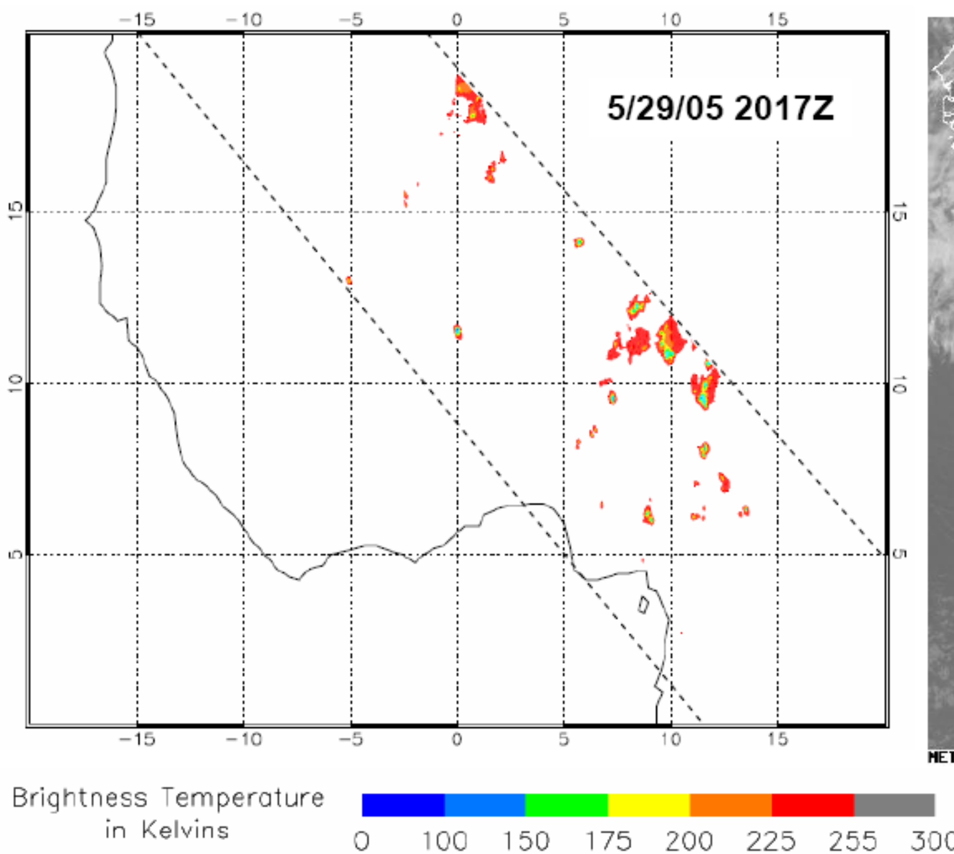
1. Deep convection appear relatively cold

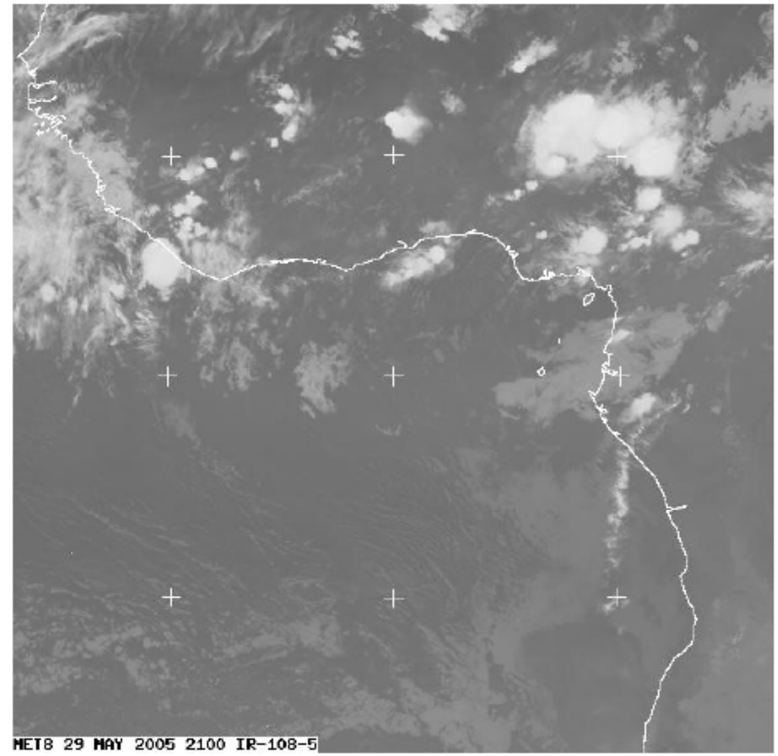
2. Imagery can penetrate thin cirrus canopies and reveal internal storm structure

3. Imagery is able to distinguish deep convection, but can not always see low-level circulations which are associated primarily with low-level water clouds

4. Spatial resolution is higher than for imagery at lower microwave frequencies

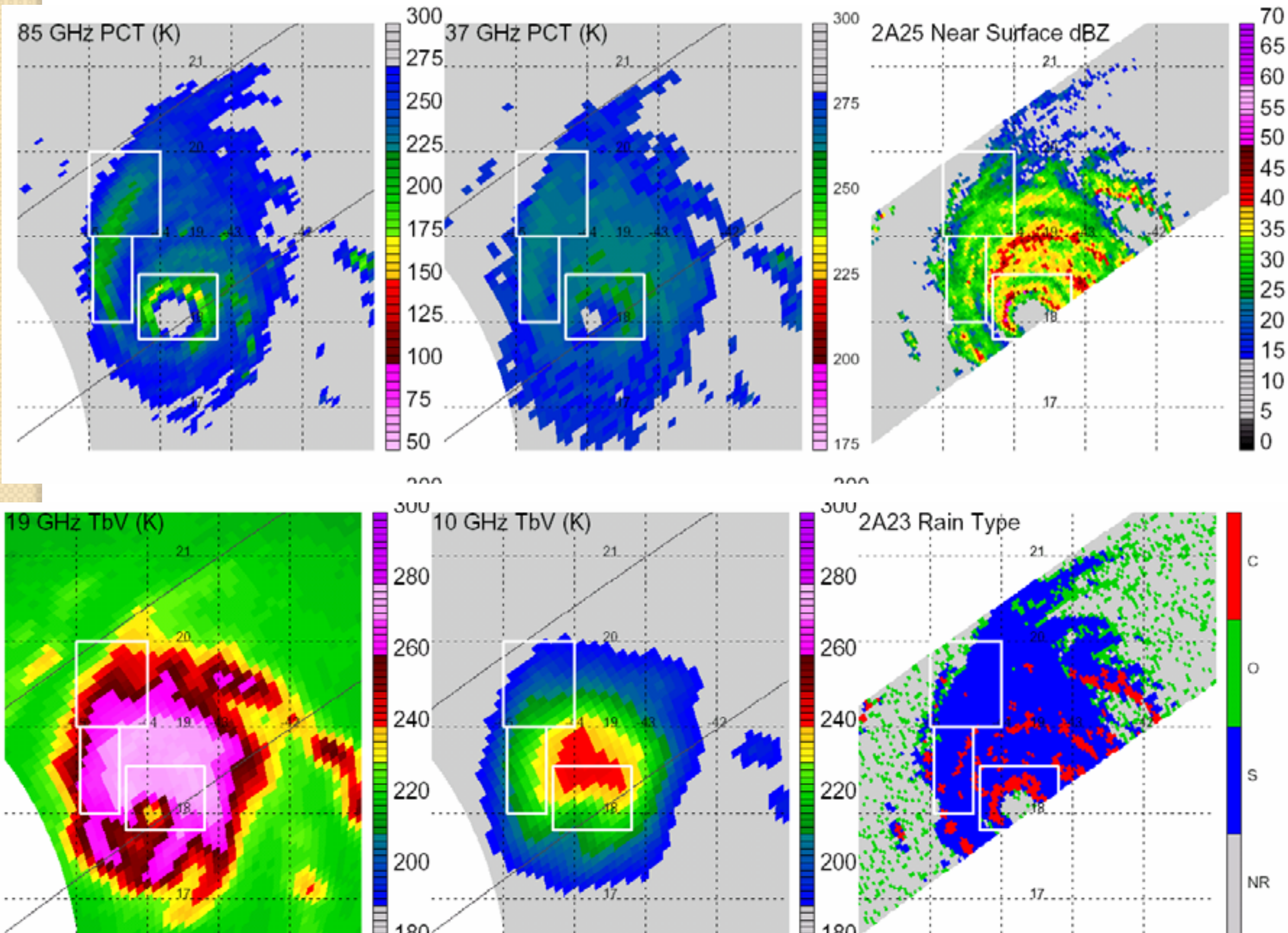
TRMM Observed Convective Systems





What looks like a single large MCS in IR is often a cluster of small convective systems in the TRMM Microwave Imager (TMI).

TRMM 10, 19, 37, 85 GHz: Hurricane Isabel (2003)



Absorption/Emission in the Microwave

- Water vapor emits at 22 GHz and absorbs at 150 and 183 GHz.
- Oxygen (O_2) is a strong emitter at 50–60 GHz.
- Rain and cloud liquid water are strong emitters at 10 and 19 GHz.
  - Rainfall mapping combines the ice scattering and rain emission signatures to account for both high and low precipitating clouds.
- Soil water is a strong emitter at 1.4 GHz
- Microwave imagers and sounders measure these frequencies for a wide variety of applications.

Applications of Microwave Data

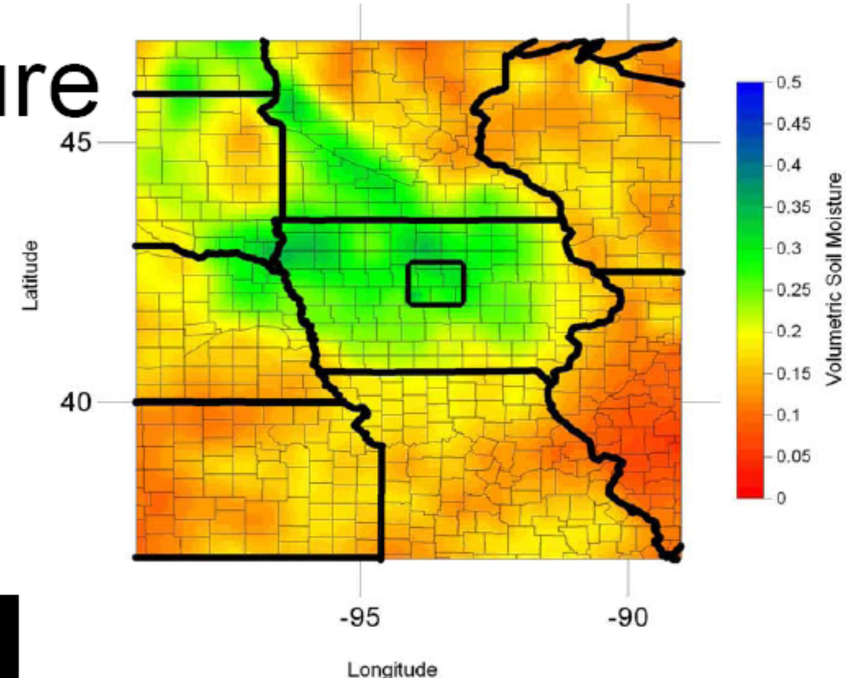
Comparing Active and Passive Microwave Sensors

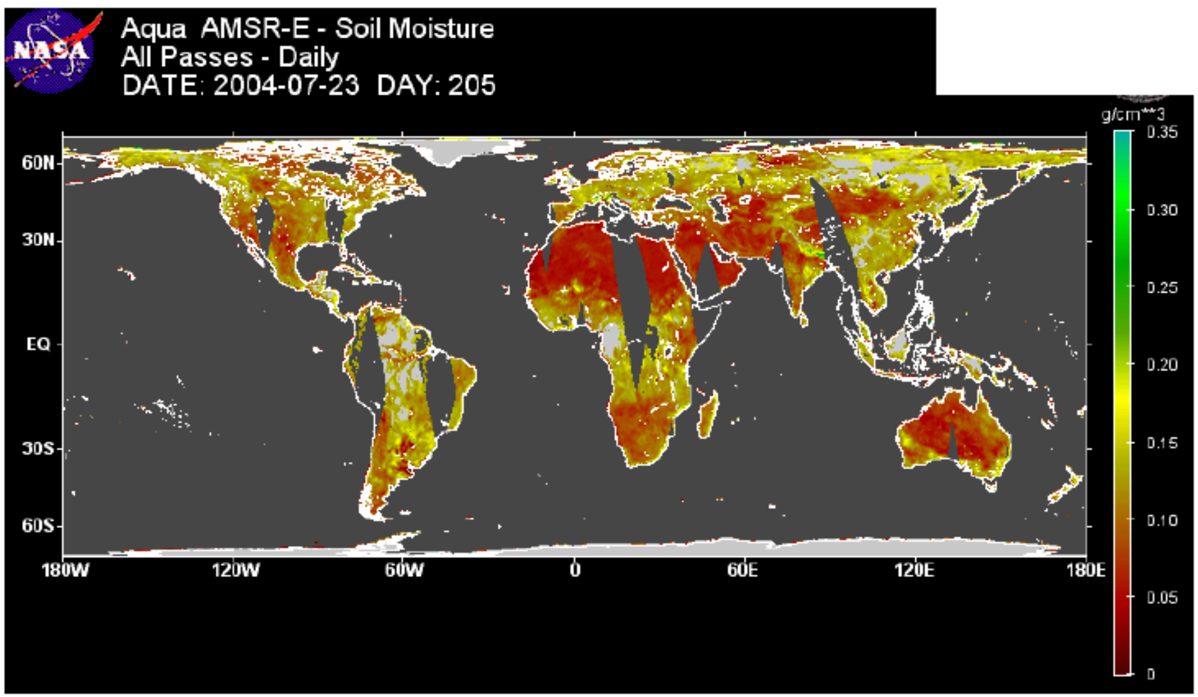
Passive Microwave Remote Sensing	Active Microwave Remote Sensing
Sensor Examples	
MSU, AMSU, AMSR-E, SSM/I, SSMIS, SSM/T1, SSM/T2, TMI, WindSat	QuikSCAT, TRMM-PR, RADARSAT, ASCAT, CloudSat, U.S. Navy GFO, Jason-1 and 2, ERS-2, ENVISAT ASAR and RA-2
Measurement Capabilities	
Sense emitted microwave energy from terrestrial sources	Send and receive electromagnetic pulses of energy
Cloud and precipitation information from layers	Cloud and precipitation information from discrete levels
Sea surface wind vectors (WindSat, AMSR), salinity	Sea surface wind vectors, salinity
Precipitation (rain rate and snowfall)	Precipitation (rain rate and snowfall)
Cloud properties (microphysics, cloud top and base)	Cloud properties (microphysics, cloud top and base)
Atmospheric temperature and moisture profiling	
Snow and sea ice coverage and extent, sea ice age	Snow and sea ice coverage and extent, river ice movement
Snow cover characteristics	Snow cover characteristics
Soil Moisture / Surface Wetness	Soil Moisture / Surface Wetness
	Vegetation, biomass, land use, surface roughness, topography, and geology (ASCAT, RADARSAT)
Sea surface temperature	Ocean surface topography, sea surface state, heat storage and transfer (from radar altimeters)

Legend: (shaded) Different capabilities of active and passive sensors

Mapping Soil Moisture

Images at 7 GHz from the AMSR-E (**A**dvanced **M**icrowave **S**canning **R**adiometer-**E**arth observing) on NASA's polar orbiting Aqua satellite.

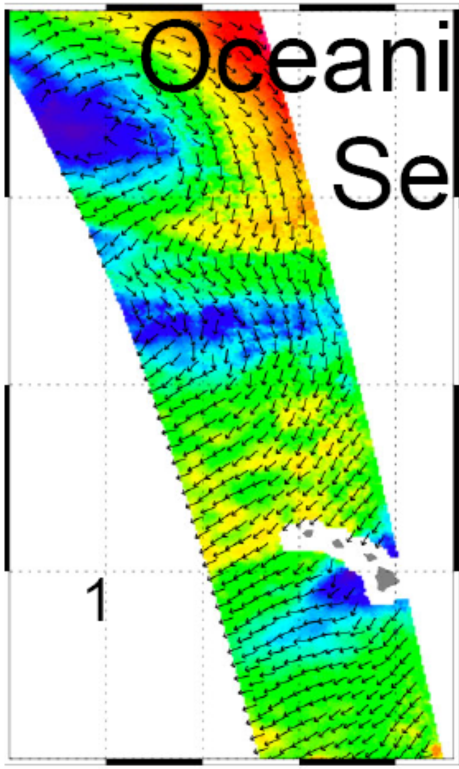


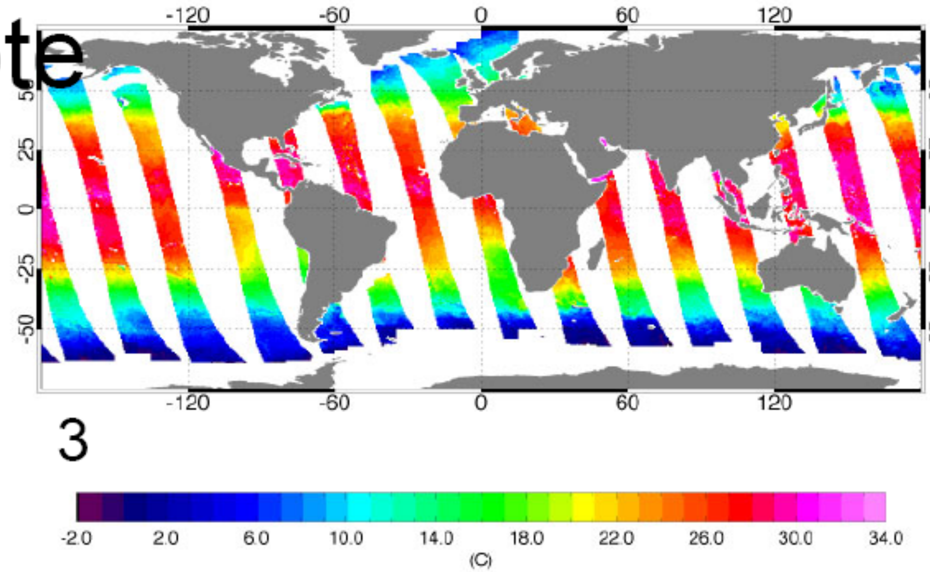


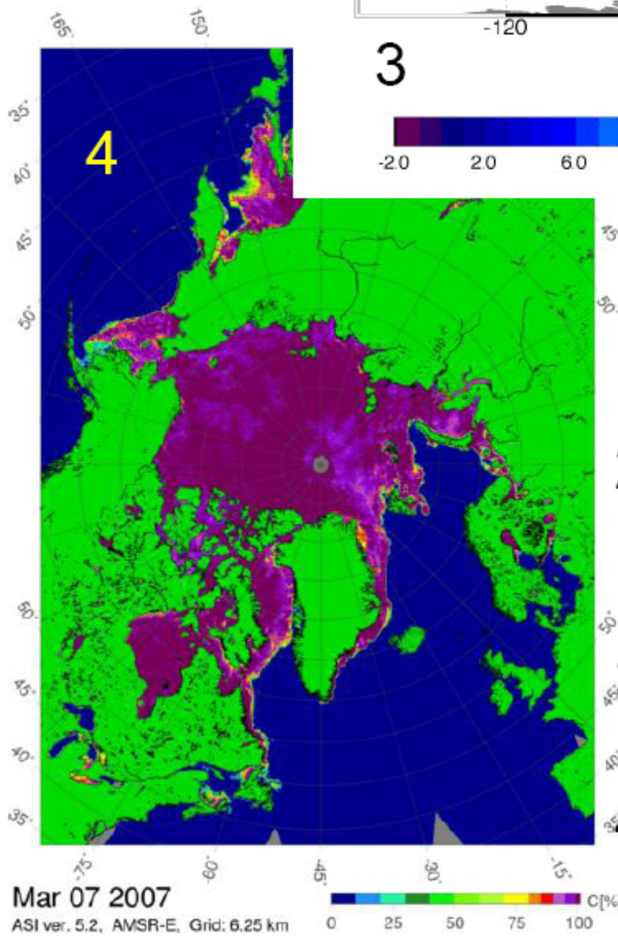
Only surface < 5cm soil moisture can be retrieved.

This is okay in humid regions but not in semi-arid and arid regions.

Oceanic Remote Sensing

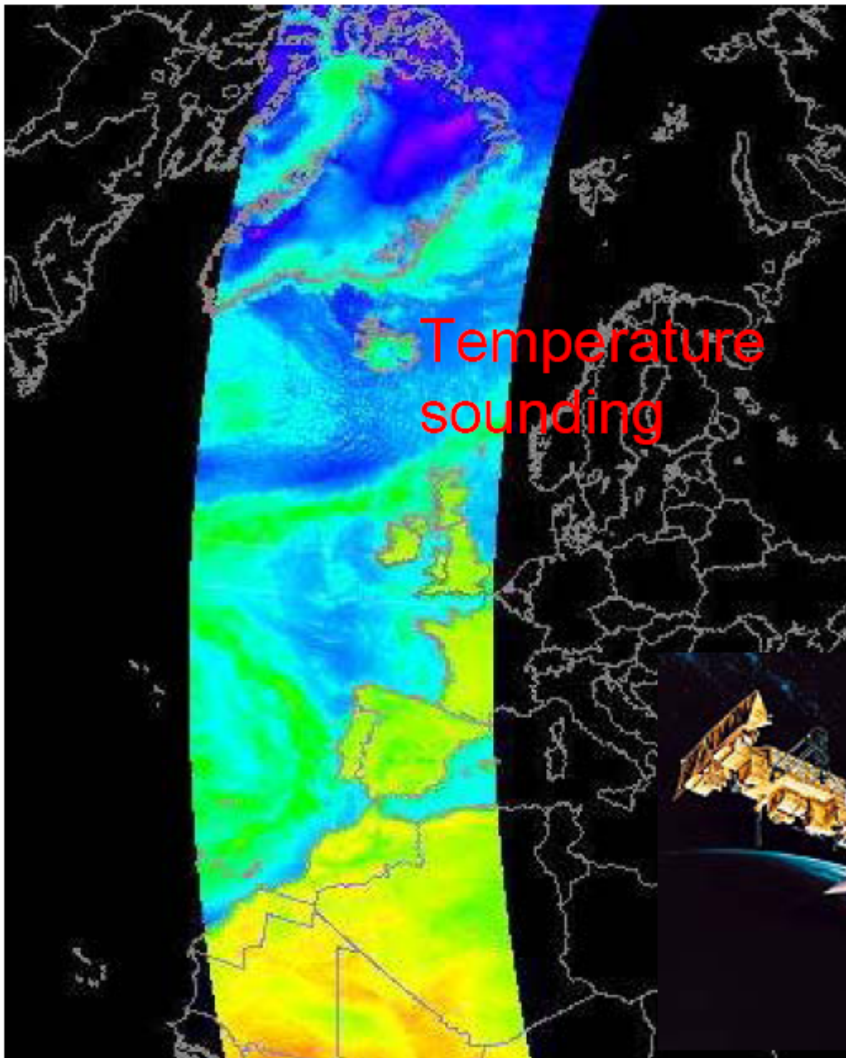




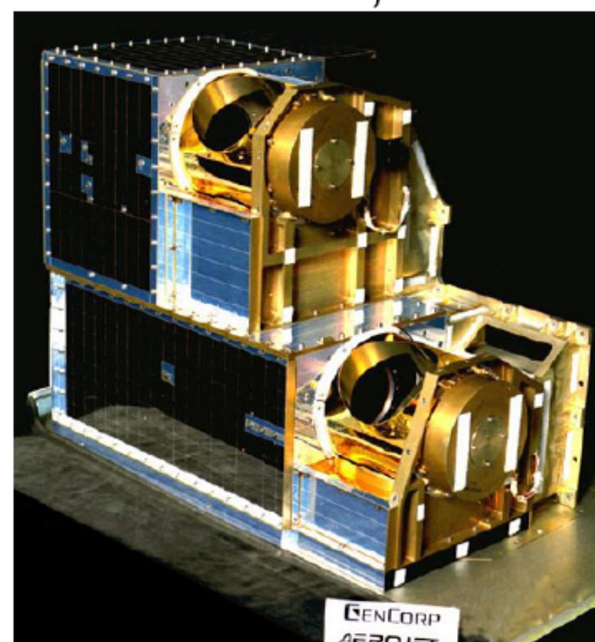


1. Ocean surface winds from the WindSat sensor.
2. NASA's Coriolis satellite carrying the WindSat sensor.
3. WindSat sea surface temperatures.
4. AMSR-E sea ice extent.

Microwave **S**ounding **U**nit (MSU)

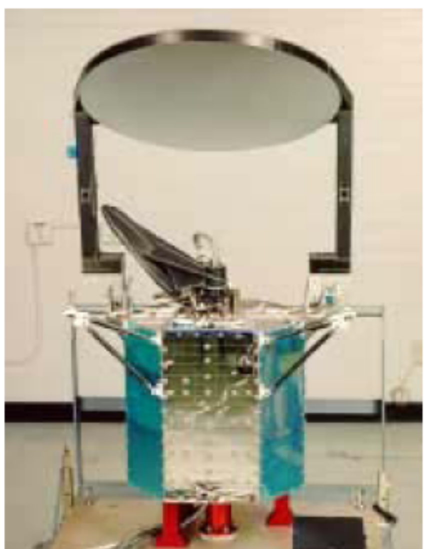


- Carried on NOAA POES
- 4 channels 50–58 GHz.
- Lower resolution than HIRS/3
  - Resolution at nadir, 105 km



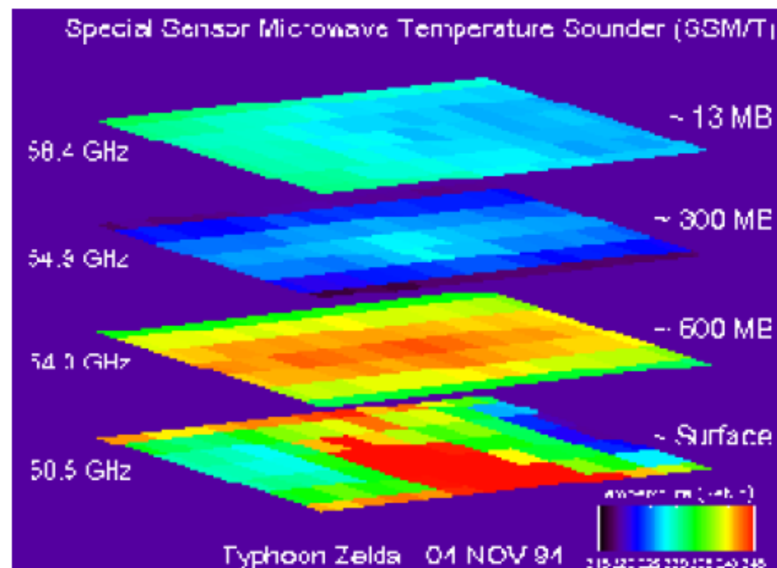
Microwave Sounders on DMSP

- 1993–Present:
  - SSM/T1: temperature profiling at 50 GHz.
  - SSM/T2: humidity profiling at 183 GHz.
- 2003–Present
  - SSMIS: **S**pecial **S**ensor **M**icrowave **I**mager and **S**ounder, combines imager and sounder functions.
- Resolution at nadir, 175 km

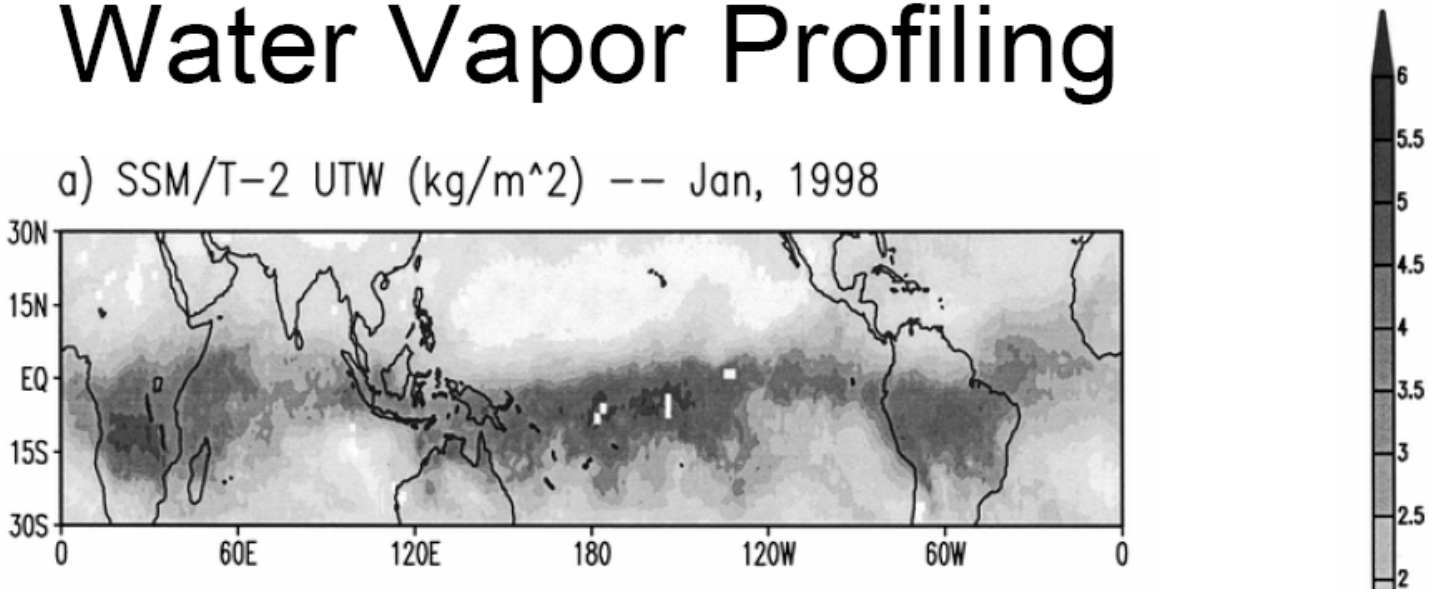


SSMIS: the latest microwave sensor in the DMSP constellation.

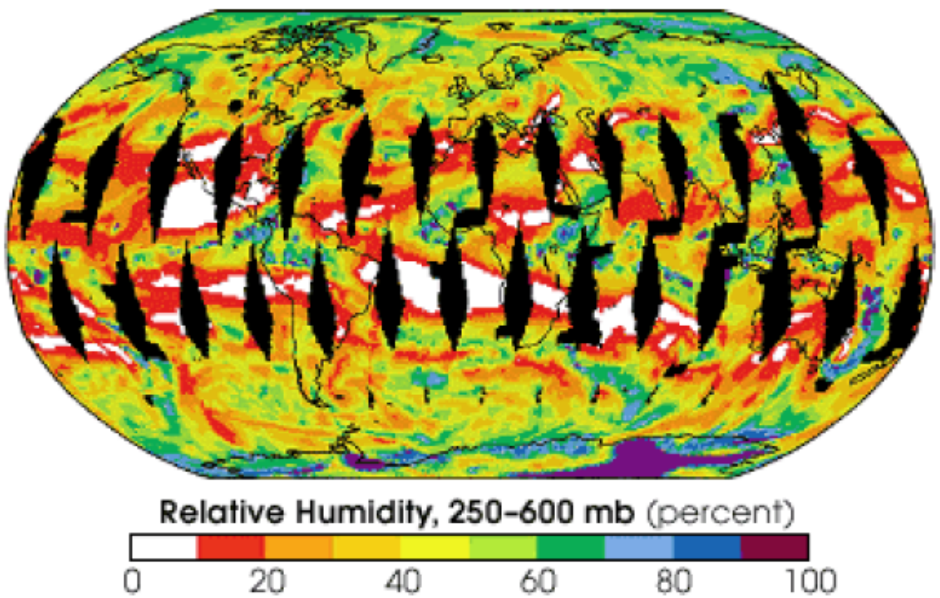
Note: Does not improve resolution.



Water Vapor Profiling

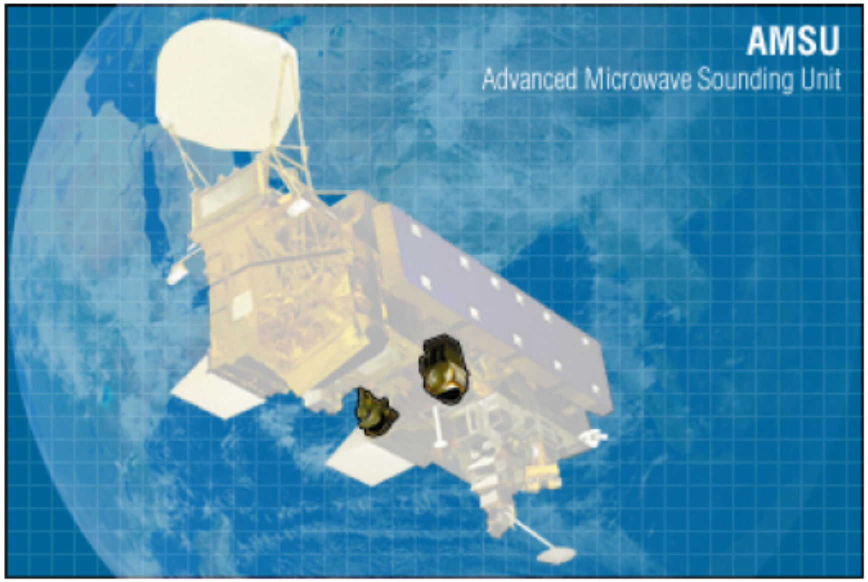


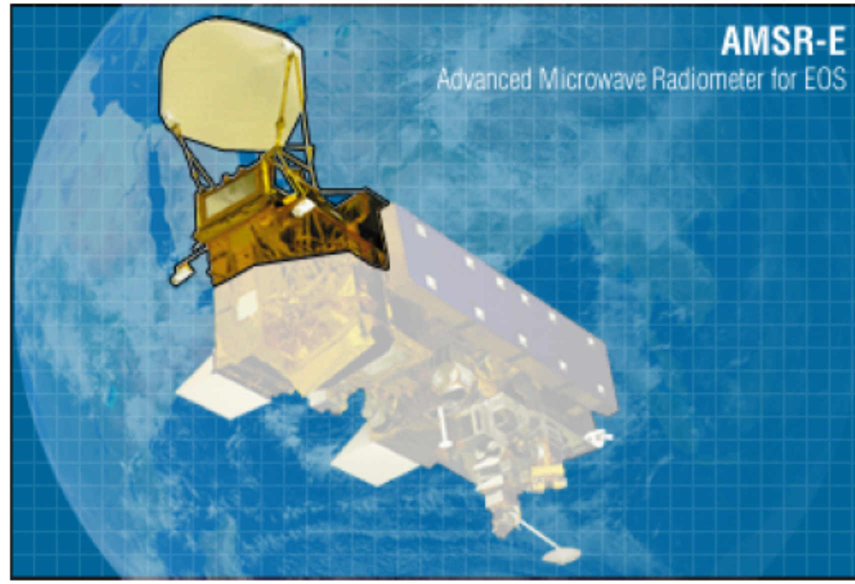
Upper (top) and mid (bottom) tropospheric water vapor

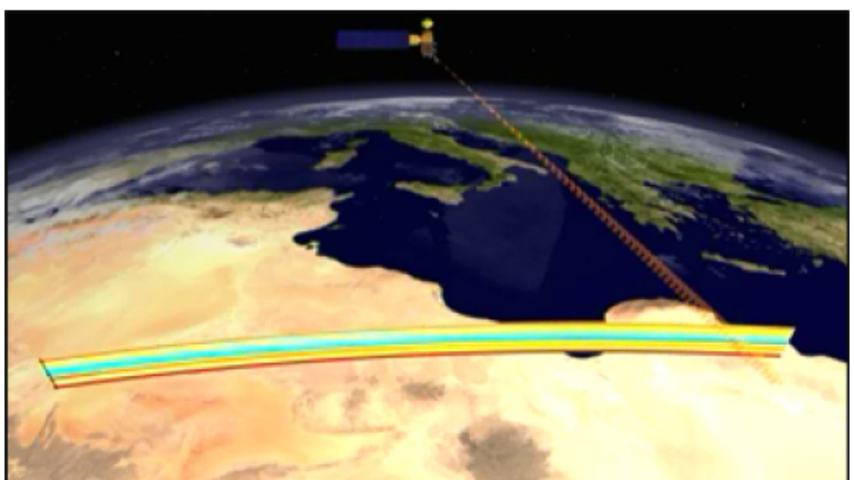


Images from the DMSP Special Sensor Microwave/Temperature and Humidity Profiler (SSM/T2).

Aqua: AMSR-E and AMSU







The Aqua satellite showing locations of AMSU and AMSR.

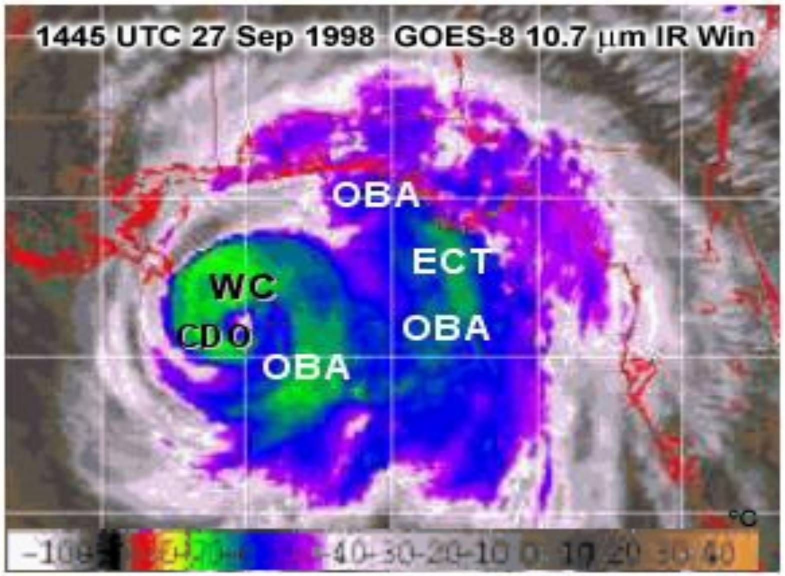
(Left) Schematic of AMSU's 5-layer temperature sounding.

Summary of Characteristics of some Passive Microwave Instruments

	SSM/I	AMSU-B	TRMM TMI	AMSR-E
Spectral bands	19, 22, 37, 85 GHz	89, 150, and three at ~ 183 GHz	10.7, 19, 22, 37, 85 GHz	6.9, 10.7, 18.7, 23.8, 36.5, 89 GHz
Horizontal Resolution (at nadir)	12.5 - 50km	16.3km	4.6 x 6.95 km at 85.5 GHz to 45 km at 10.7 GHz	6 x 4km at 89GHz to 74 x 43 km at 6.9GHz
Swath Width	1400km	2343 km	780 km	1440 km

Precipitation Retrieval from Satellite Observations

Rainfall Retrieval from IR



Hurricane Cloud Signatures

Cloud Signature	Subjective rain rate
Central Dense Overcast	12.5-51 mm h^{-1} (0.50-2 in h^{-1})
Wall Cloud	25-76 mm h^{-1} (1-3 in h^{-1})
Outer Band Area	2.5-51 mm h^{-1} (0.10-2 in h^{-1})
Embedded Convective Tops	1.25-102 mm h^{-1} (0.05-4 in h^{-1})

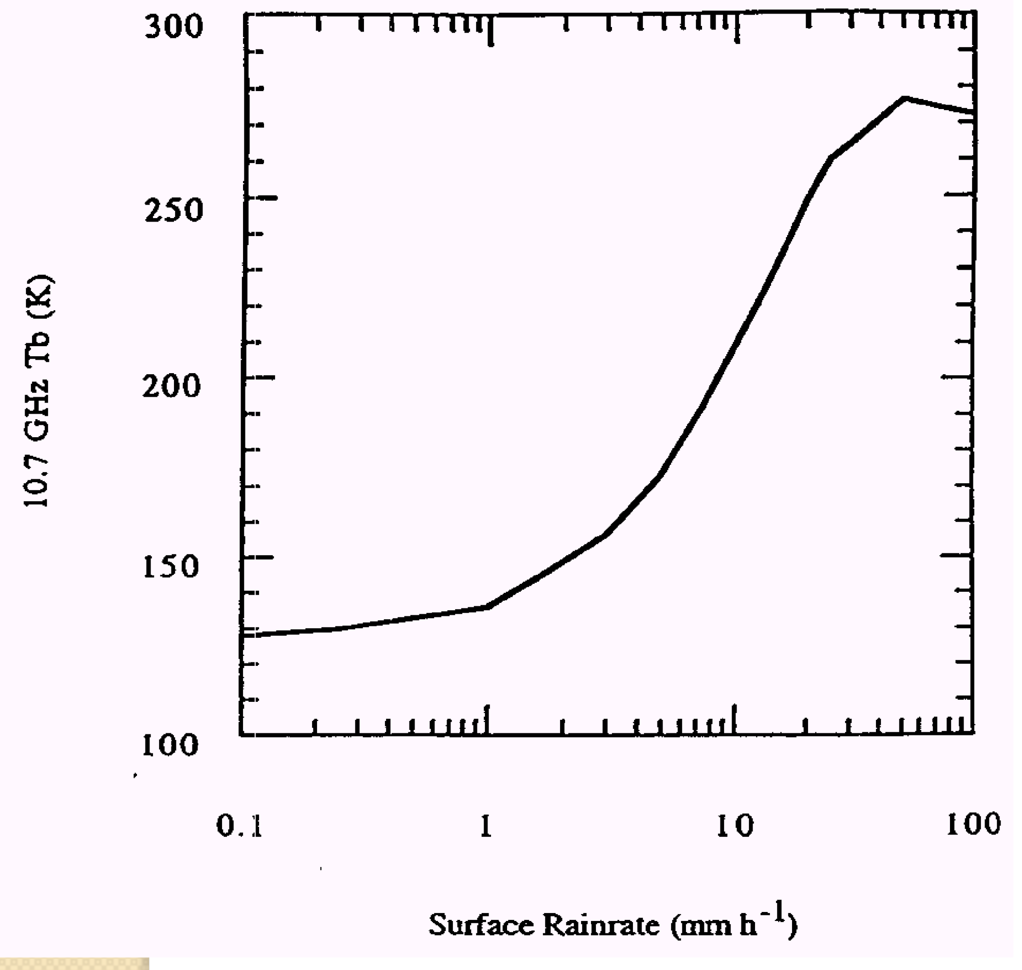
NOAA

IR cloud top temperatures are averaged over various areas and times. Those averages are then compared with rain-gauge precipitation measurements to arrive at an operational temperature-precipitation correlation. One example of this is the **GOES Precipitation Index (GPI).**

Advantage: High temporal resolution

Disadvantage: Clouds with high cloud top temperature is not necessarily clouds producing heavy rainfall.

Rainfall Retrieval from Passive Microwave: Emission-based



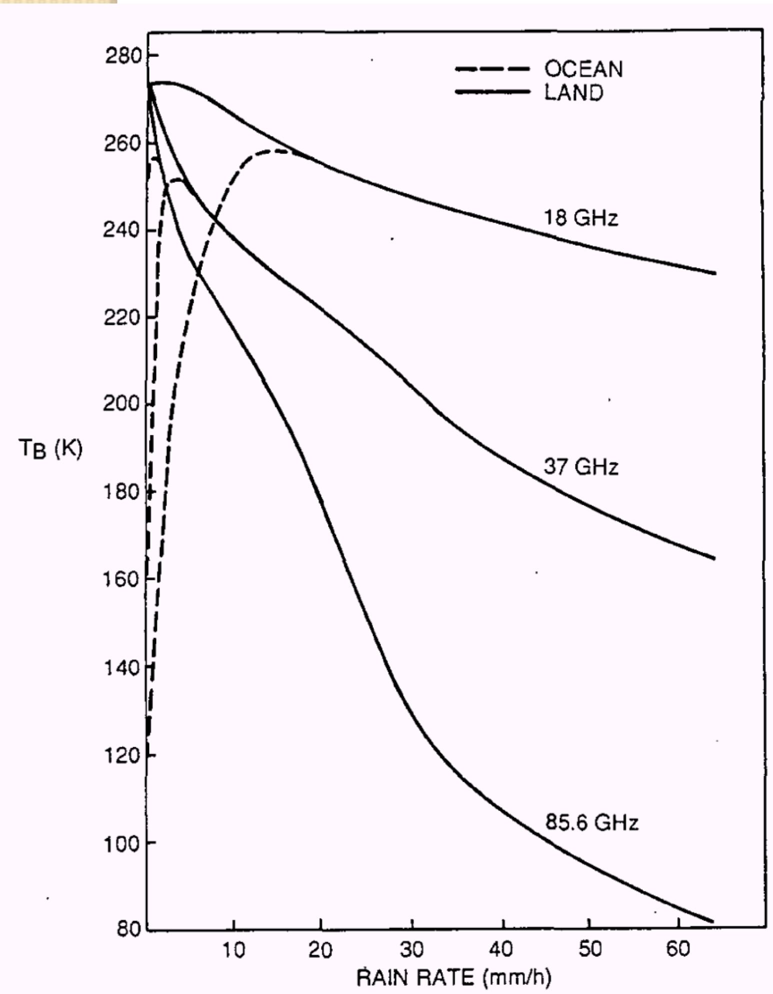
McGaughey et al. 1996

Emission-based algorthms are based on 10 & 19-GHz or lower channels.

Advantage: Nearly linear relationship up to 50 mm/h without saturation at 10 GHz

Disadvantages:
1.Low spatial resolution: 72x43 km^2 at 10GHz; 35x21 km^2 at 19 GHz; Beamfilling problem.
2. Doesn't work for over land

Rainfall Retrieval from Passive Microwave: Scattering-based



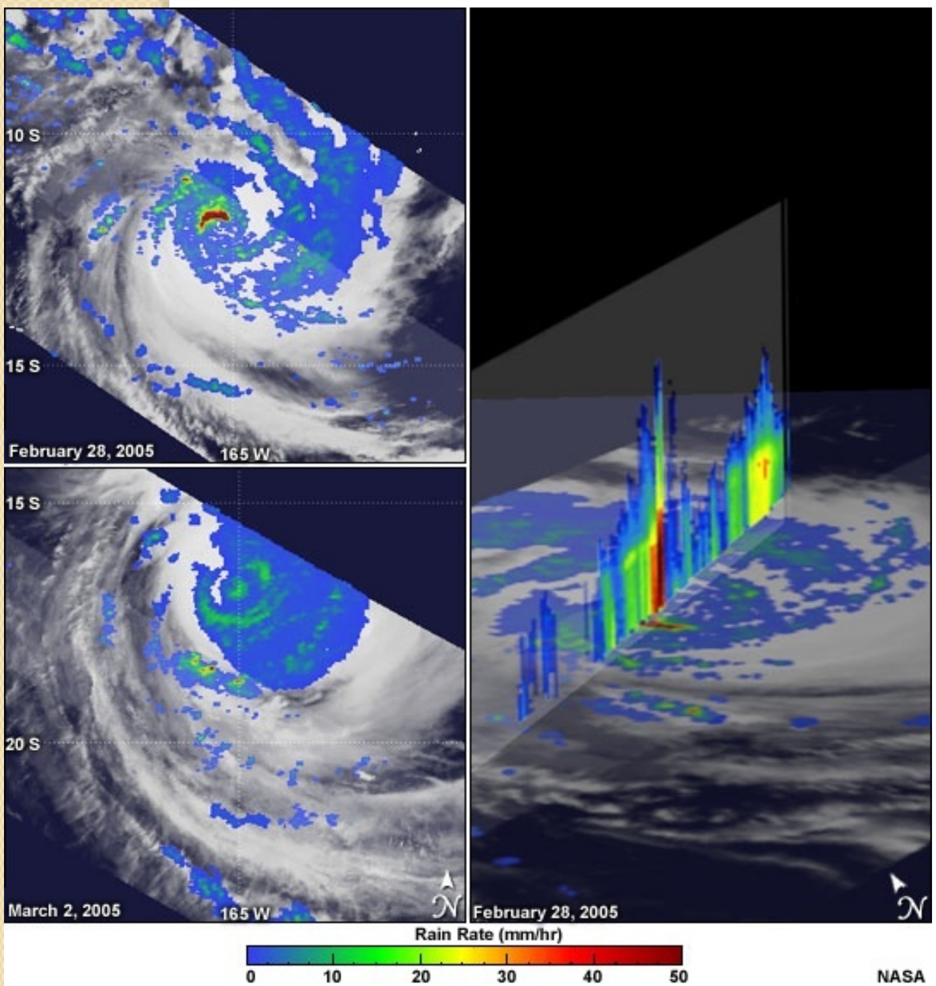
Spencer et al. 1989

Scattering-based algorithms use microwave observations at high frequencies (greater than 37 GHz).

Advantages:
1. Higher spatial resolution;
2. works for both over land and over ocean.

Disadvantage:
The direct relationship is actually between Tb and total ice water instead of rain rate.

Rainfall Retrieval from TRMM Satellite Precipitation Radar

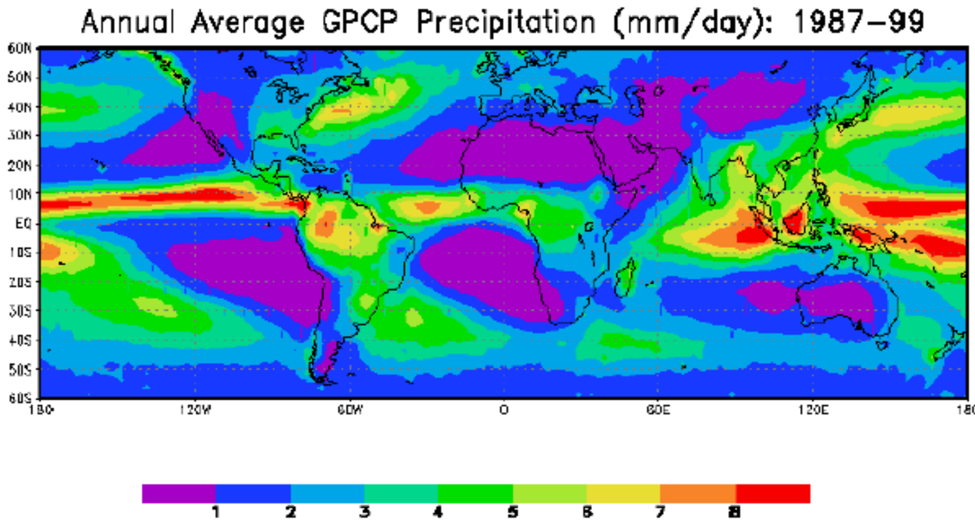


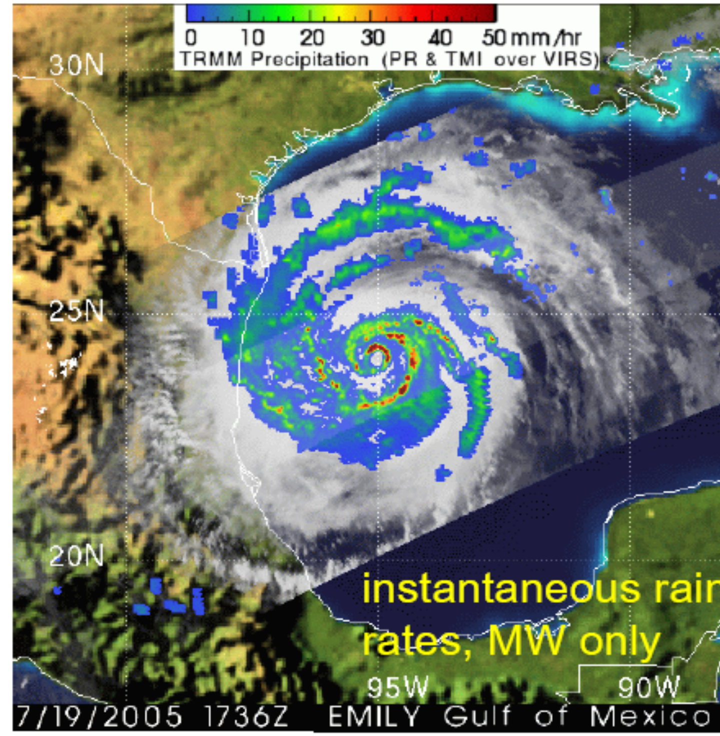
TRMM PR 2A25 rain algorithm: Assuming different particle size distributions for different rain types to get Z-R relationships.

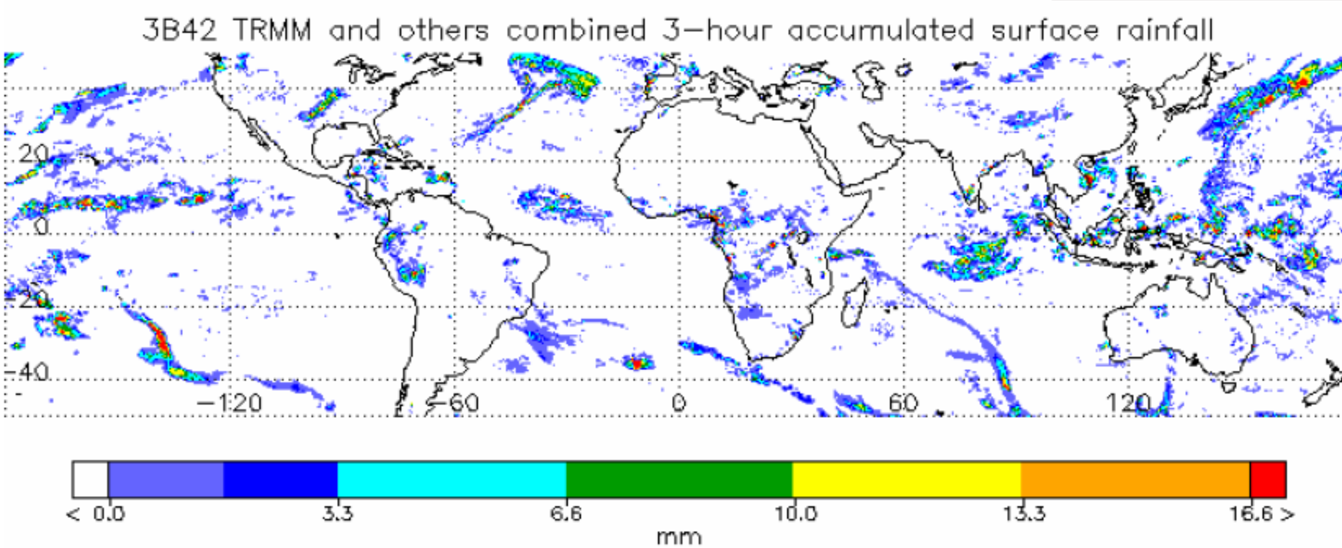
Advantages:
1. Higher spatial resolution: 4~5 km;
2. 3D structure;
3. works for both over land and over ocean;
4. Generally, it's more accurate than passive microwave retrievals.

Disadvantage:
PR's swath is narrow: 217 km

Retrieving Rainfall







Accumulated rainfall products combine geostationary IR and microwave. Longer time periods also include surface observations.

Satellite Microwave Instrument Scan Strategies and Viewing Geometry

NCAR COMET lecture (you need to register, it's free!):

http://stream1.cmatc.cn/pub/comet/QPF-QPE/microwave/comet/npoess/microwave_topics/resources/print.htm#s5p0

Review section 5.1-5.13 of the above link