Meteorological Satellites: Principles of Operation, Instruments, Orbits, and Data Types

Jack Beven, Todd Kimberlain, and Colleagues

### Tropical Prediction Center

March 2016

1

Outline

- **Refresher on radiative transfer – the physical basis for meteorological satellites**

  - **The electromagnetic spectrum**

  - **Basic quantities**

  - **Radiation interacting with the atmosphere**

- **Meteorological Satellites**

  - **Designing a meteorological satellite**

  - **Satellite platforms and orbits**

  - **Satellite instruments and channels**

  - **Data types**

- **The GOES-R satellite**

Electromagnetic Energy (Radiation)

▪ **All objects at temperatures above absolute zero emit radiation which moves through space, or a medium, in the form of waves with electric and magnetic fields.**

▪ **Radiation usually has a broad range of wavelengths that travel through a vacuum at the "speed of light" (c).**

▪ **The range of all possible wavelengths is described by the *electromagnetic spectrum*.**

What does radiation look like?

•3
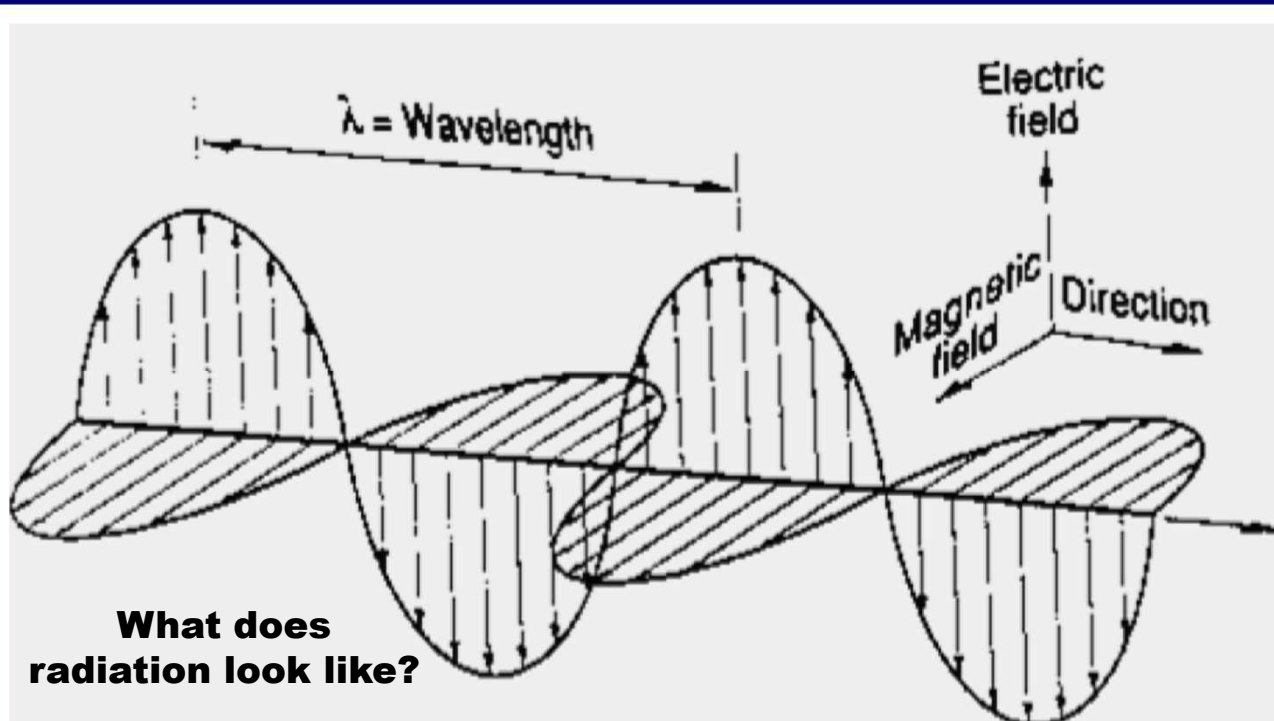
Basic Relationships and Units

wavelength

$\lambda = c/f$ Units of micrometers (10^{-6} m, μm, "microns"), Used for visible and infrared radiation

Wavelength (λ) = the distance between successive maxima in electric field strength (peak to peak)

Long Wave Length   Short Wave Length

Low Frequency   High Frequency

Low Energy   High Energy

(NOTE: Frequency refers to number of crests of waves of same wavelength that pass by a point in one second.)

frequency

$f = c/\lambda$ Units of cycles (number of waves) per second, or hertz (Hz)

Frequency (f) = the number of waves passing a given point per unit time

Often used to describe microwaves (gigahertz, GHz = 10^9 Hz) and radio waves (megahertz, MHz = 10^6 Hz)

•4
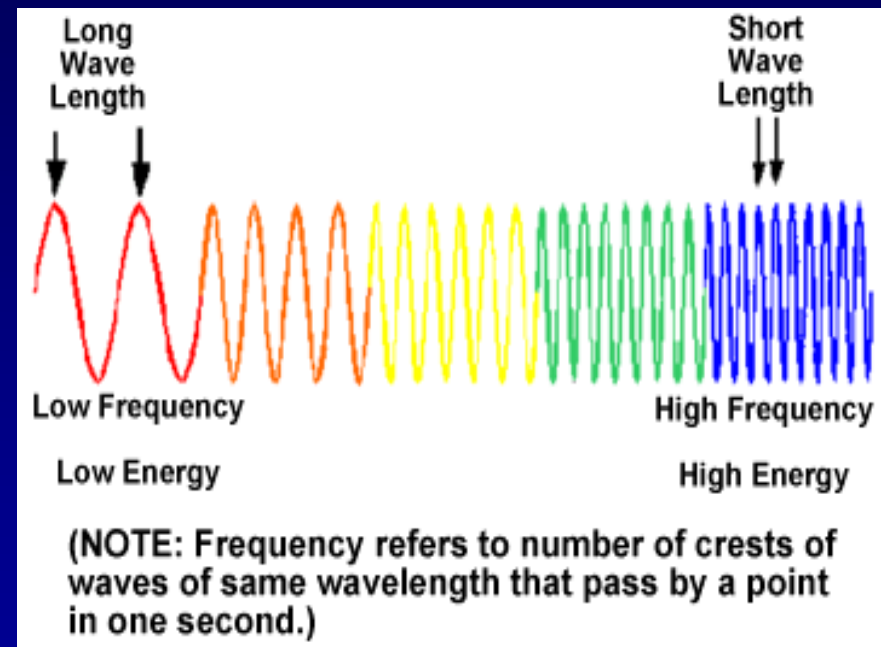
Meteorology primarily involves radiation within the visible, infrared, and microwave/radio portions of the electromagnetic spectrum (wavelengths from about 0.5 μm to about 12 cm).

THE ELECTROMAGNETIC SPECTRUM
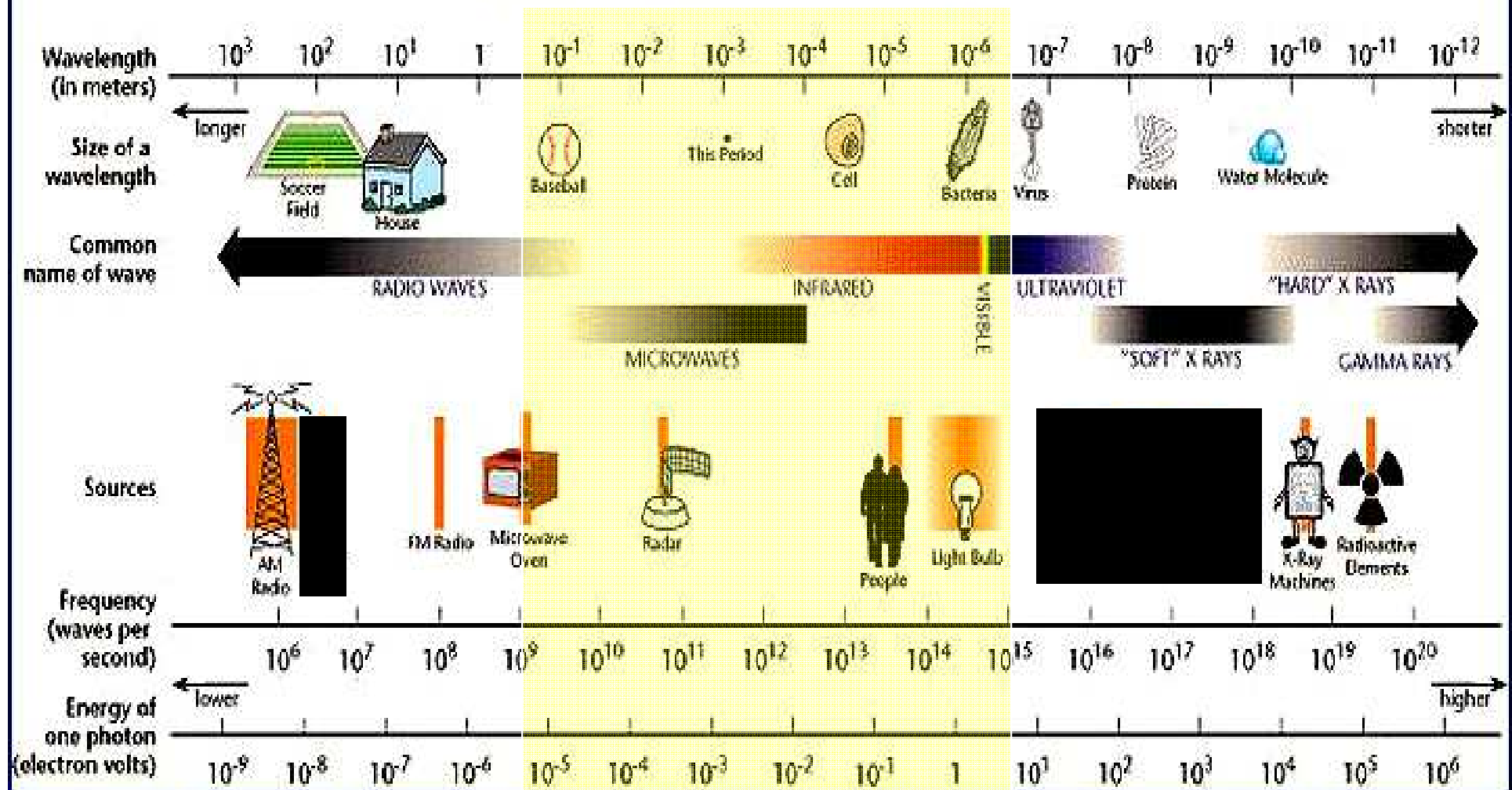
Polarization

• The plane in which the electric field oscillates determines the polarization of the radiation.

• Radiation in the atmosphere is usually unpolarized, but it can become polarized due to particular wavelength-dependent interactions with surfaces or air constituents.
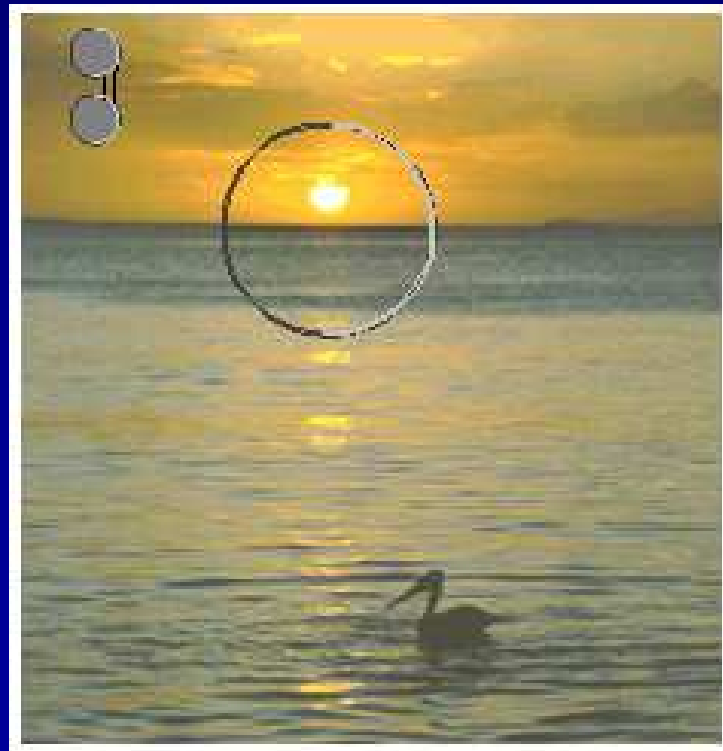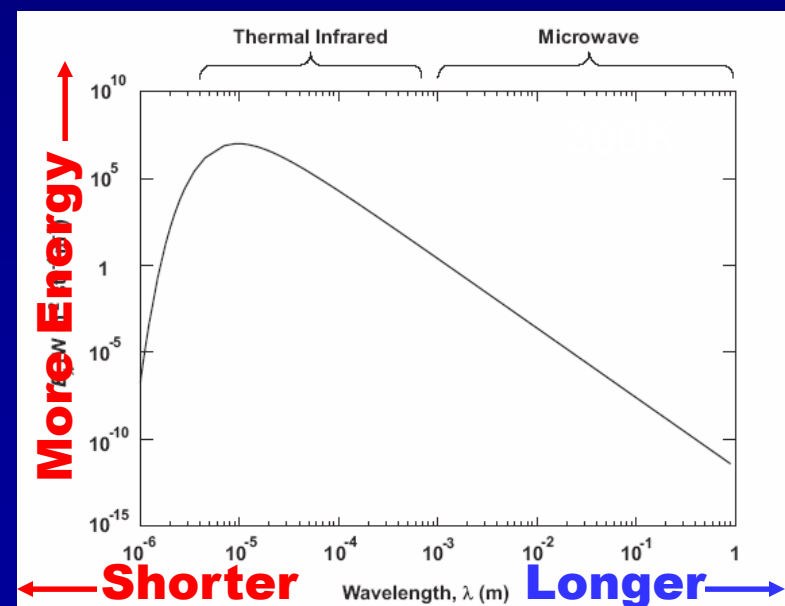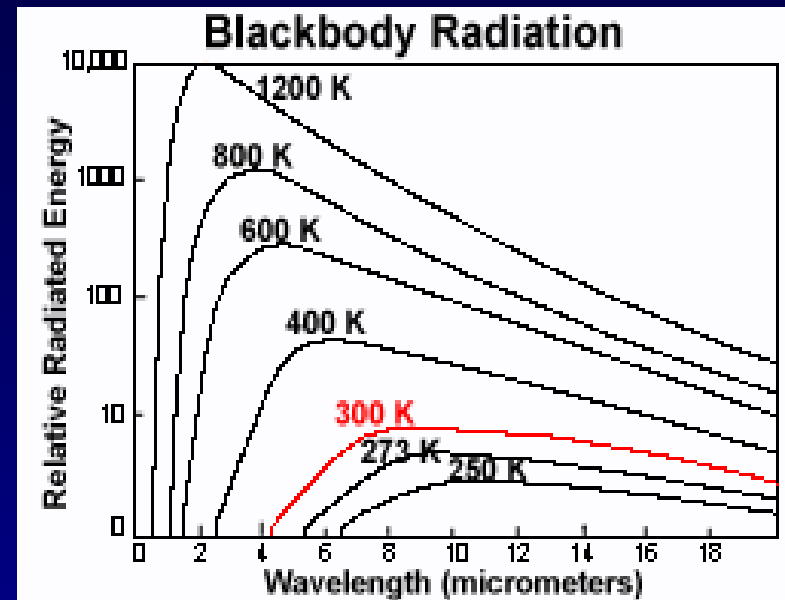
Planck Function

Tells you the amount of energy a blackbody object radiates at a particular wavelength, given its temperature

(A blackbody, an idealized radiator, emits its maximum possible radiation at all wavelengths; not all objects do this)

Hotter objects:

- Emit more energy

- Emit most of their radiation at shorter wavelengths and higher frequencies

Wien's Displacement Law

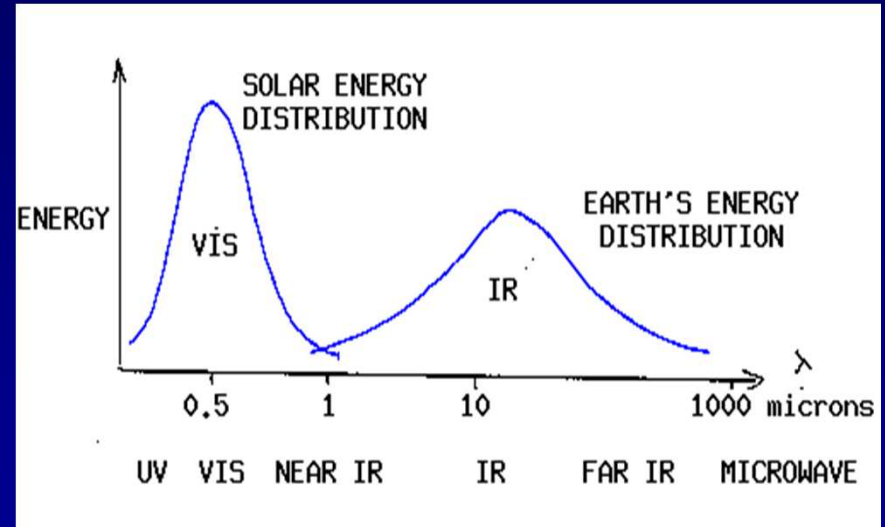The wavelength of peak emission (λ_m) for a blackbody object is:

$$\lambda_m = 2897 / T$$

Where:

λ_m has units of μm

T is the temperature of the object in degrees Kelvin (K)

Example: The very hot Sun emits radiation concentrated at shorter wavelengths, while the much cooler earth-atmosphere system emits radiation concentrated at longer wavelengths.

•8

Radiation Interacting with the Atmosphere

Radiation passing in any direction through the earth's atmosphere is subject to 4 processes:
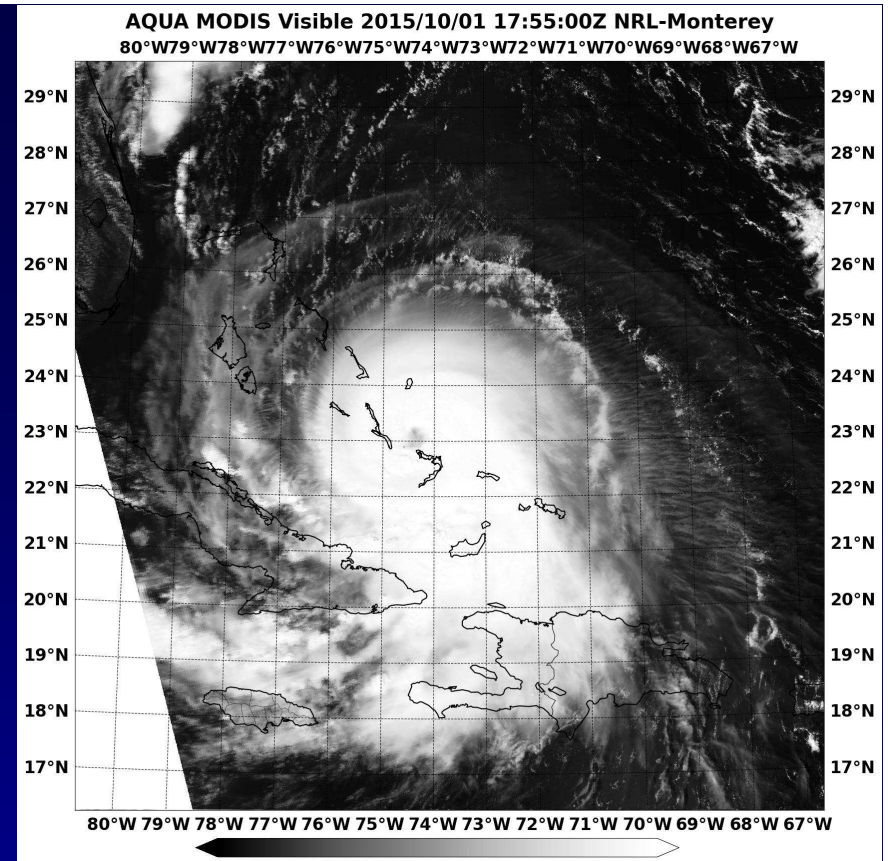
- **reflection**

- **scattering**

- **absorption**

- **emission**

These processes behave differently at various wavelengths, and they determine how remote sensing instruments work.

Reflection

Radiation sent back in the direction from which it came

• **Reflection occurs more readily as the wavelength decreases and/or size of the reflecting object increases.**

• **Albedo is the fraction of the incident sunlight that is reflected.**

• **Clouds are the primary reflectors of radiation in the atmosphere.**

• **Thick clouds reflect about twice as much visible radiation as thin clouds.**

• **Fresh white snow reflects about 75-95% of solar radiation; water reflects about 10%.**

AQUA MODIS Visible 2015/10/01 17:55:00Z NRL-Monterey

Hurricane Joaquin (20015) Visible imagery using reflected sunlight – water/ice clouds appear bright while land/water appear dark

•10

Scattering

Radiation diverted in various directions

- **In general, occurs when radiation strikes an object with a size similar to its wavelength.**

- **The amount and direction of scattering depends on the ratio between particle size and radiation wavelength.**

Why is the sky blue?

Why are clouds white?

Examples of Scattering

- **Air molecules and very small particles (aerosols) tend to scatter the sun's visible radiation**
  - **Rayleigh scattering: Air molecules scatter mostly shorter-wavelength blue light (causes blue sky)**
  - **Mie scattering: Water droplets, pollen, dust, smoke scatter all visible wavelengths (cumulus clouds appear white); occurs when particles causing the scattering are larger than wavelengths of radiation striking them**
  - **Non-selective scattering: occurs in lower part of atmosphere, when particles >> incident radiation. E.g., haze**

  Ice particles in tall thunderstorms tend to scatter certain wavelengths of the earth's microwave radiation

Absorption and Emission

▪ All objects absorb and emit radiation, with the amounts depending on the object's characteristics such as temperature, color, moisture, and texture.

▪ If an object absorbs more energy than it emits, it warms.

▪ An blackbody object absorbs and emits all possible radiation and has emissivity = 1 − no reflection or transmission.

▪ Many objects do not emit all possible radiation at certain wavelengths.

  ▪ For example, oceans have low emissivity at microwave wavelengths.

▪ Absorption varies with respect to wavelength, and each atmospheric element characteristically absorbs in specific wavelength intervals called absorption bands.

  ▪ For example, ozone in the upper atmosphere absorbs *only* ultraviolet radiation.

Infrared Imagery
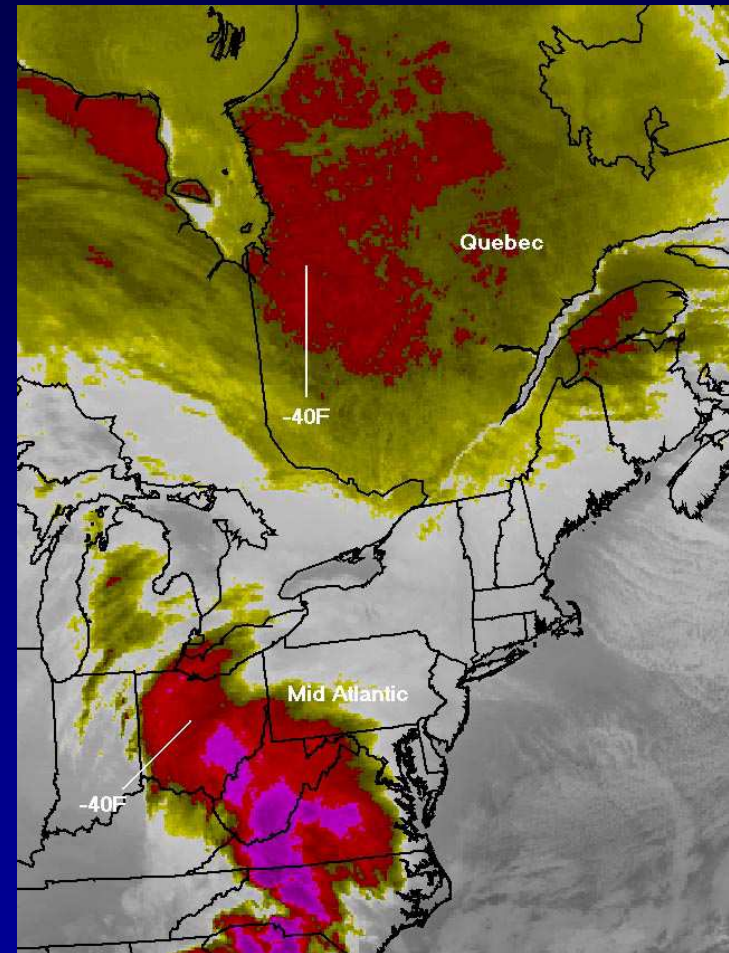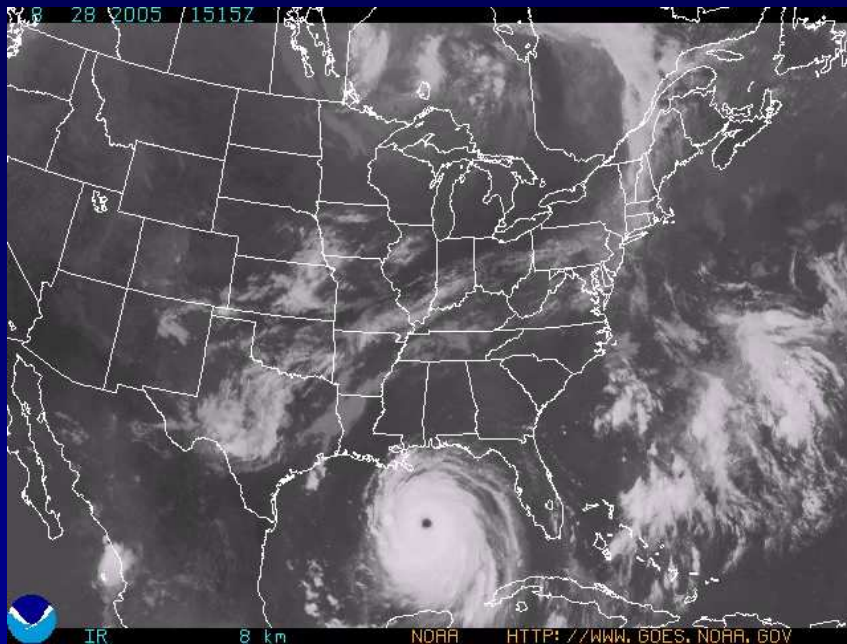
Standard infrared imagery uses wavelengths with low atmospheric absorption – "window" channels (e. g. 10.7 μm)

•14

The Radiative Transfer Equation:

Combining the effects of emission, absorption, and reflection (non-scattering example)
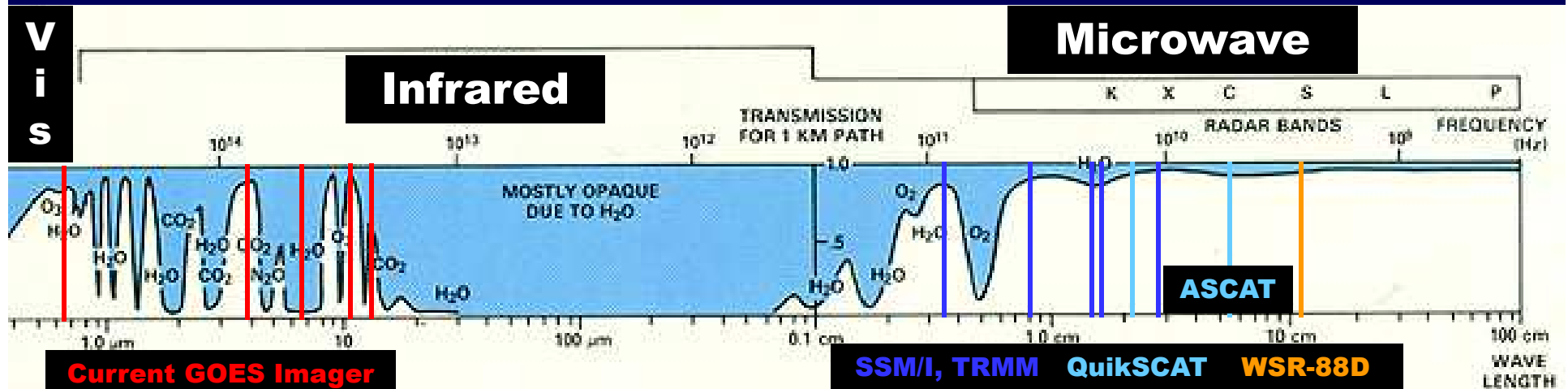
Surface Emission   Atmosphere   Surface Reflection

ϵ_ν $(1-\epsilon_\nu)$
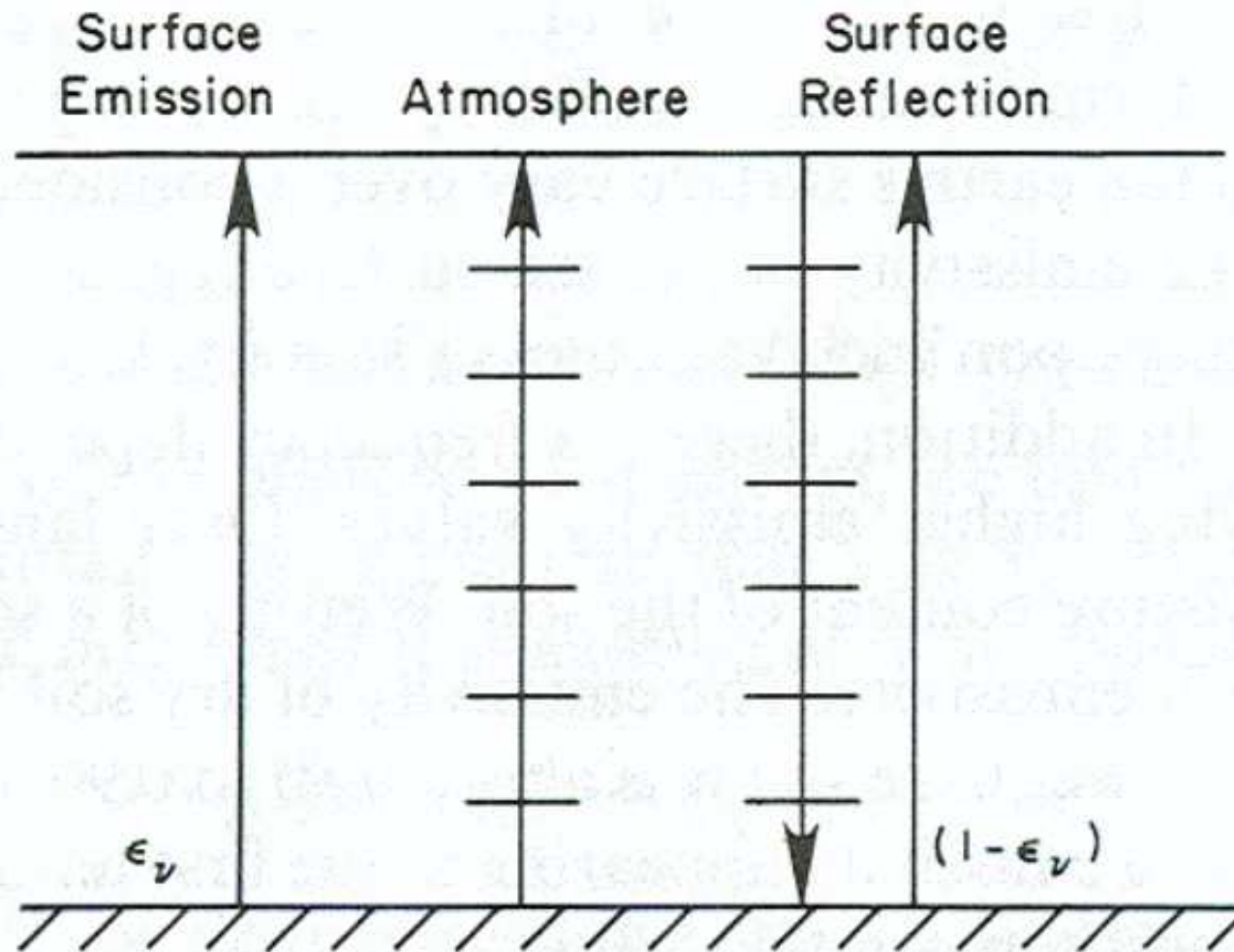
Contribution of brightness temperature at the top of a clear atmosphere.

Parts of the Radiative Transfer System

- **The Sun**

- **The atmospheric constituents:**
  - **Water vapor (varies greatly in space and time)**
  - **Liquid water and ice (clouds; also vary greatly)**
  - **Carbon dioxide (well-mixed)**

- **The major wavelength bands of interest:**
  - **Atmospheric infrared "window" (emissions from the earth)**
  - **Water vapor infrared absorption region**
  - **Shortwave infrared region**
  - **Visible region (reflection)**
  - **Microwave region (can pass through clouds but not rain)**

- **Surfaces:**
  - **Land**
  - **Ocean**
  - **Clouds**

Atmospheric Absorption/Emission Spectrum

Vis

Infrared

Microwave

K   X   C   S   L   P

RADAR BANDS   FREQUENCY (Hz)

TRANSMISSION FOR 1 KM PATH

MOSTLY OPAQUE DUE TO H₂O

O_3 H_2O CO_2 H_2O CO_2 N_2O H_2O O_2 CO_2 H_2O O_2 H_2O H_2O H_2O O_2 H_2O

ASCAT

Current GOES Imager

SSM/I, TRMM   QuikSCAT   WSR-88D

WAVE LENGTH

Longer wavelength

Higher frequency

•17

Microwave Transmittance
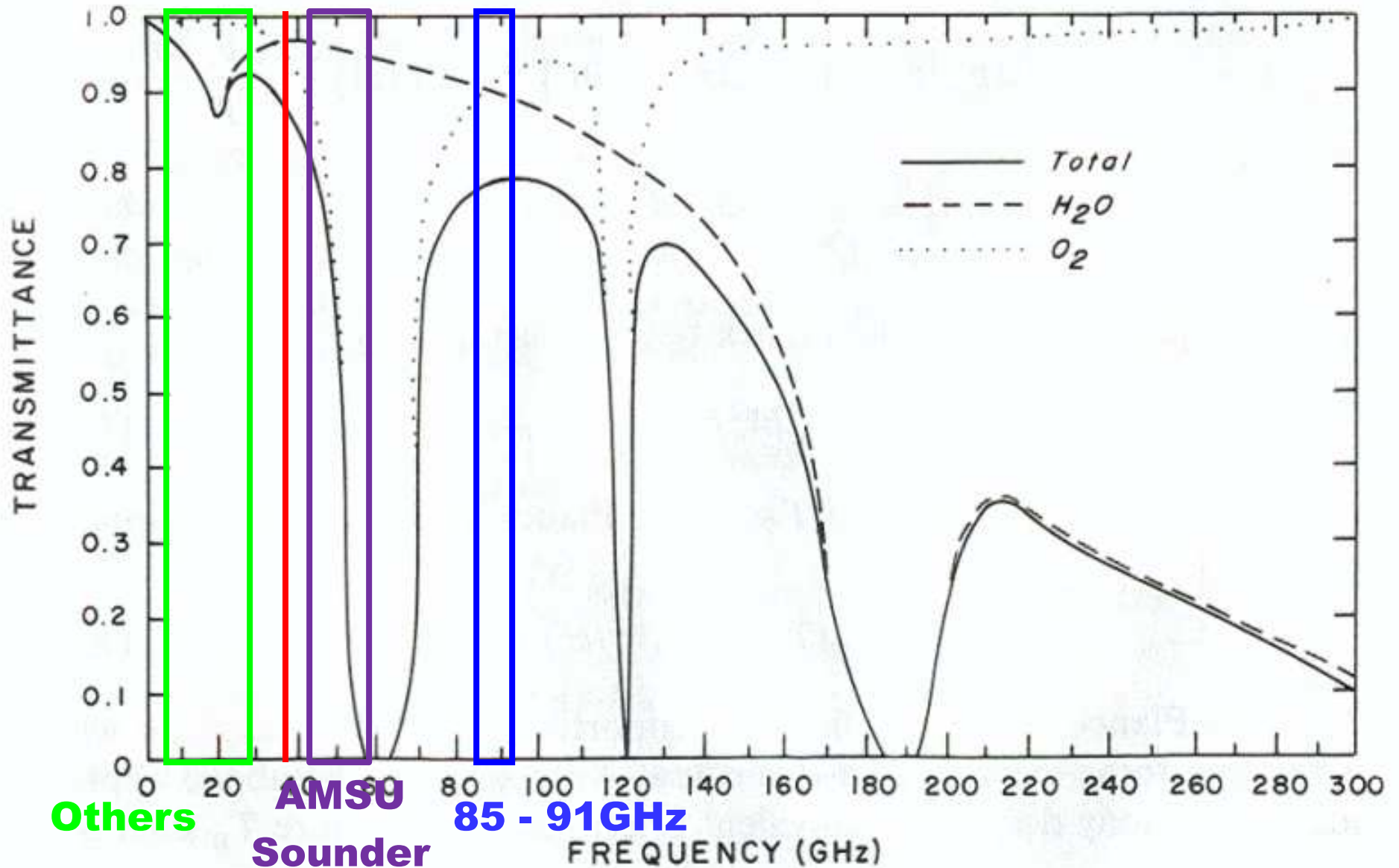
Measuring Electromagnetic Energy

- **Passive Instruments:**

    – **Receive radiation leaving the earth-atmosphere system**

    – **Measure solar radiation reflected by earth/atmosphere targets**

    – **Measure emitted and scattered infrared radiation**

    – **Measure microwave radiation resulting from emission and scattering**

- **Active Instruments:**

    – **Send out pulses of radiation, usually at microwave frequencies**

    – **Measure radiation returned to the sensor**

    – **Examples**

        - **Surface-based and airborne radars**

        - **Satellite scatterometers**

Passive instrument

Energy to satellite
Water Vapor
Ocean
Clouds/precip.

©The COMET Program

Active instrument

Energy to satellite
Ocean
Clouds/precip.

©The COMET Program
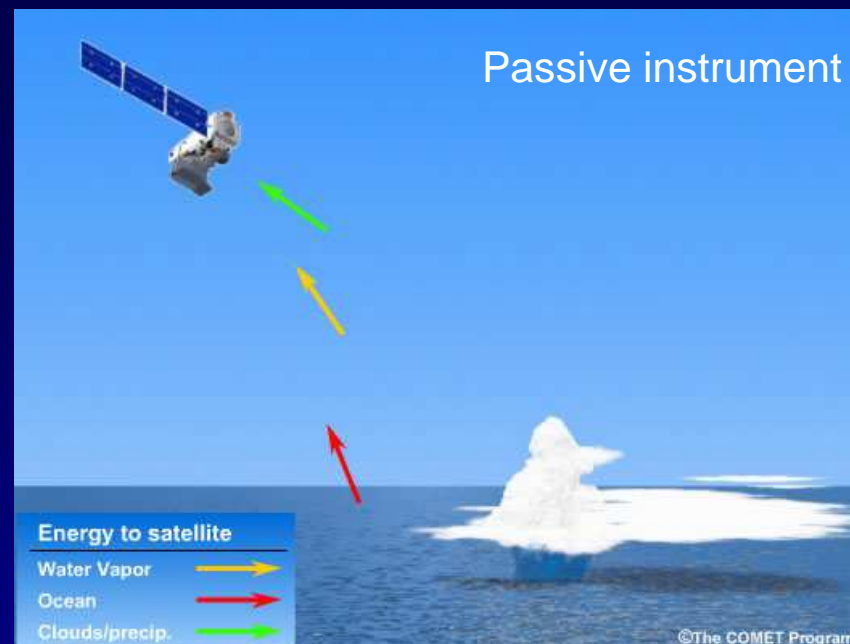
Remote Sensing Satellites

- **These "look" down from a great height and can thus see more detail depending on the height above the Earth's surface.**

- **Remote sensing can be thought of as how to obtain information about an object of interest without being in physical contact with it.**

- **Satellite instruments can be designed to observe many types of atmospheric, oceanic, and land-surface phenomena based on the instrument frequencies chosen.**

•20
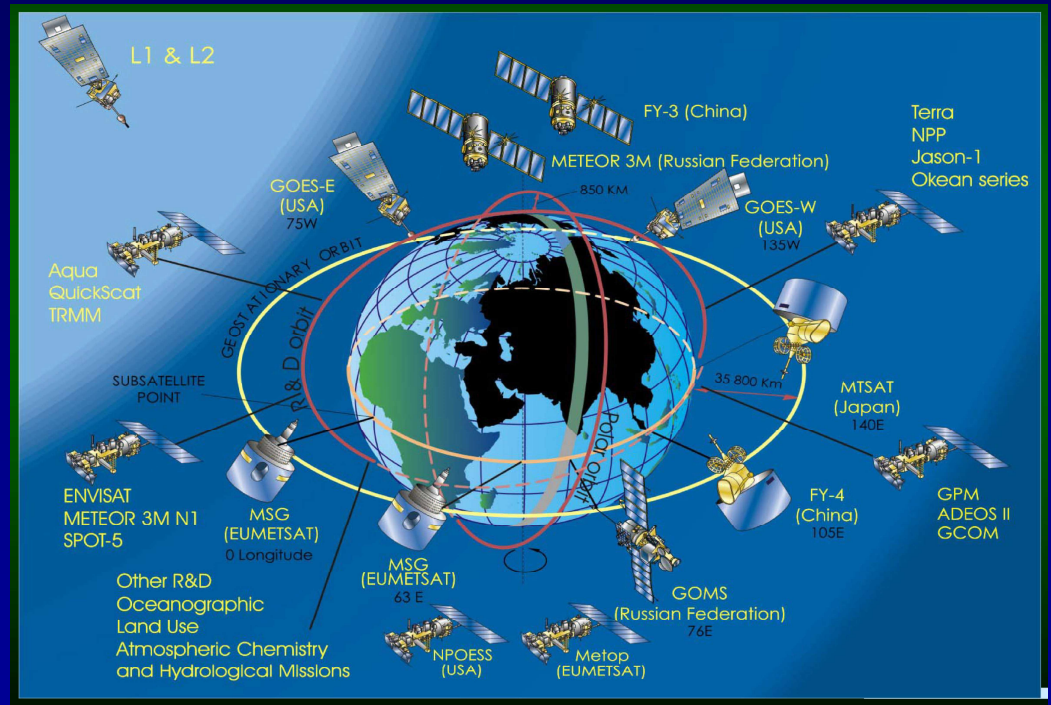
Remote Sensing Satellites - Orbits

- **Geostationary (GEO) satellites**

  - Orbit at 35,800 km altitude over same spot on the equator
  - Good for continuous monitoring, not good for high resolution
  - Good for visible and infrared, not good for microwave
  - Good for passive, not good for active
  - Good for middle latitudes and tropics, not good for polar regions

- **Low earth orbit (LEO) satellites**

  - Good for microwave (active and passive), visible, and infrared
  - Lower altitude orbit, but not over same spot on earth
  - Finer spatial resolution
  - Views each area only twice per day (except near poles)
  - Limited spatial coverage (narrow swaths of data)
  - Depending on orbital configuration, can cover nearly entire globe each day

NOAA Polar

•21
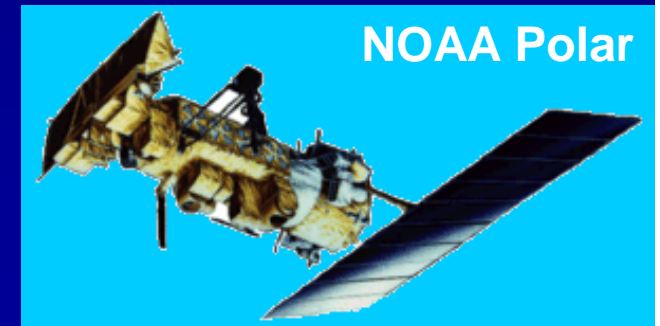
GEO vs. LEO Orbital Altitiude Comparison

Geostationary Satellite
35,800 km altitude

mean distance to moon = 384,400 km

17.4°

earth radius = 6,370 km

typical shuttle orbit = 225 – 250 km
Hubble Space Telescope = 600 km

110.8° Polar Orbiting Satellite
850 km altitude

Image courtesy of http://www.nrlmry.navy.mil
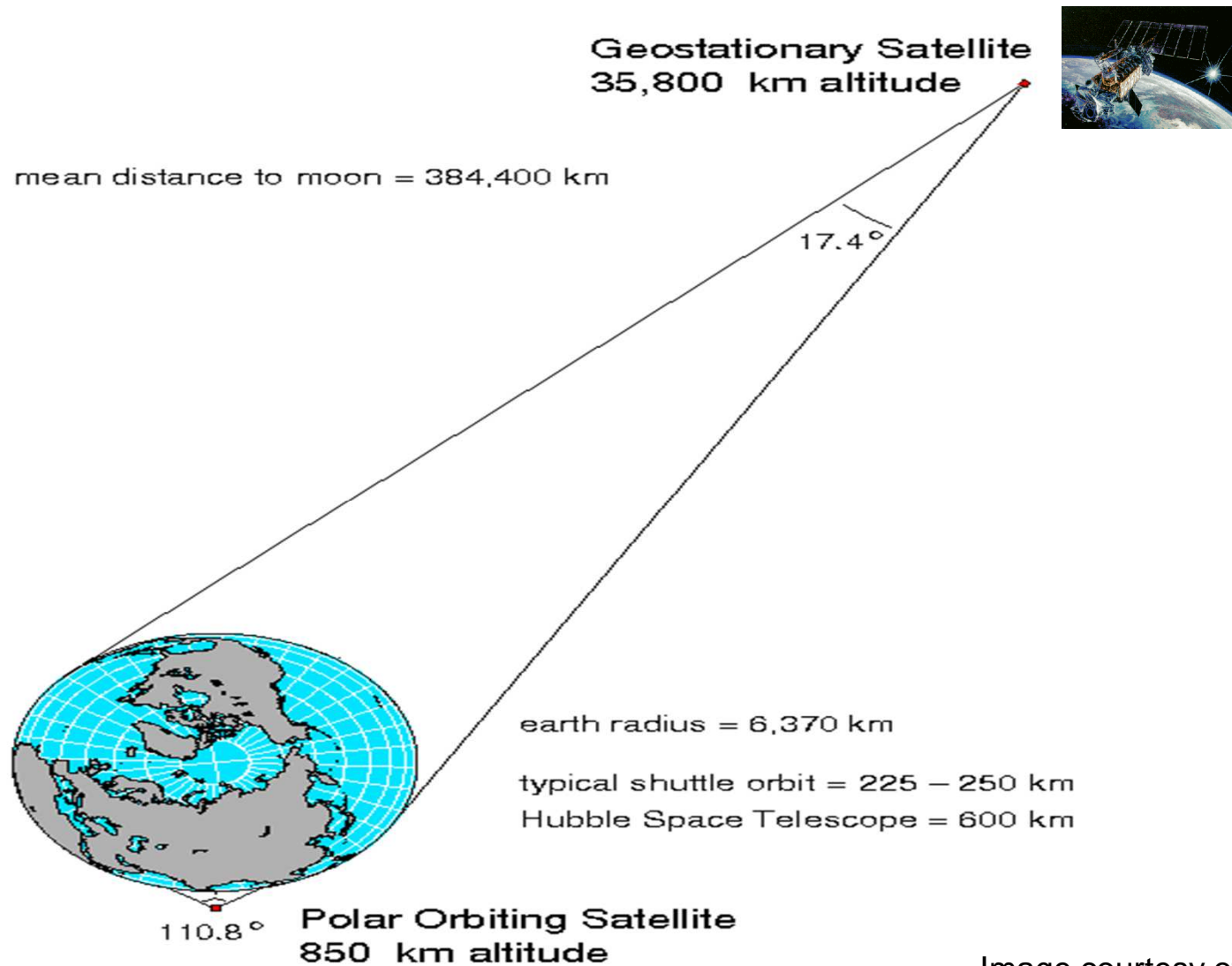
Geostationary Satellites
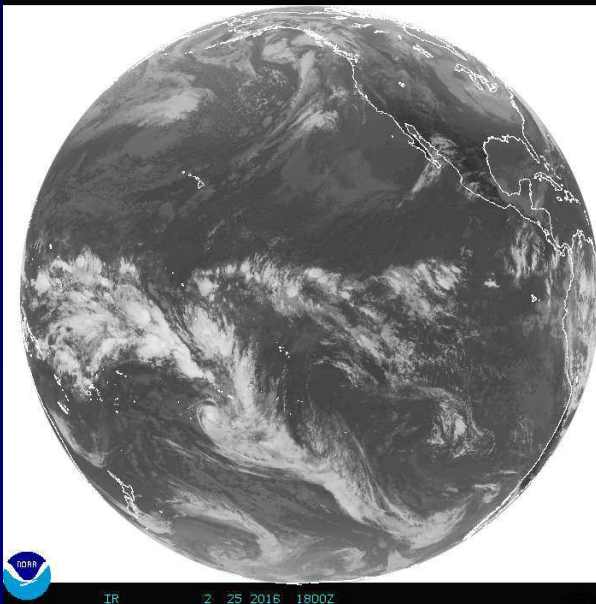

GOES-15   135° W
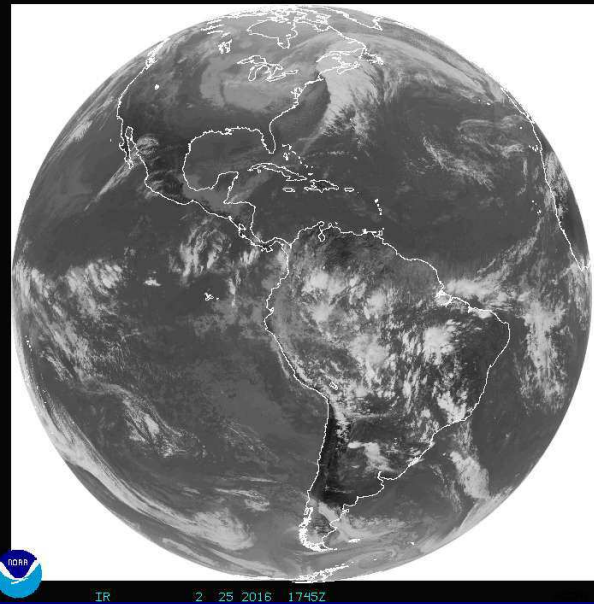
GOES-13   75° W
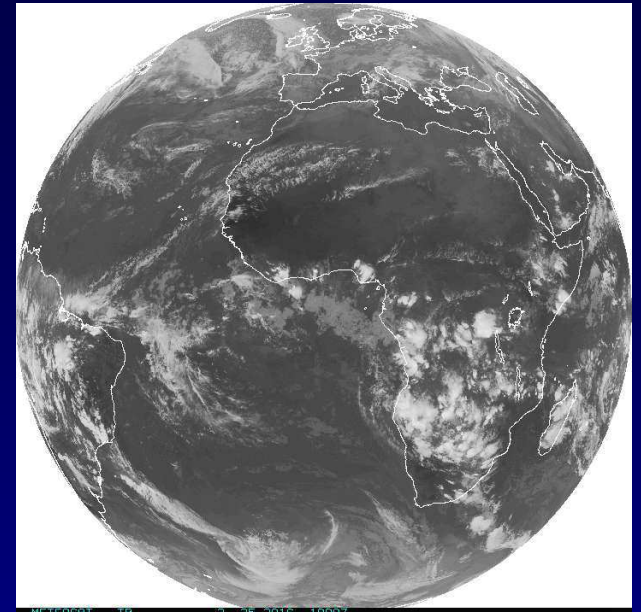
METEOSAT-10   0°

HIMAWARI-8   141° E

METEOSAT-7   57.5° E

•23
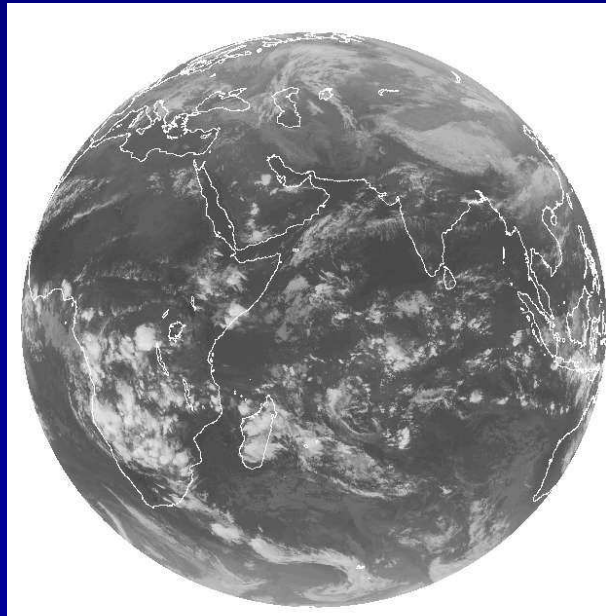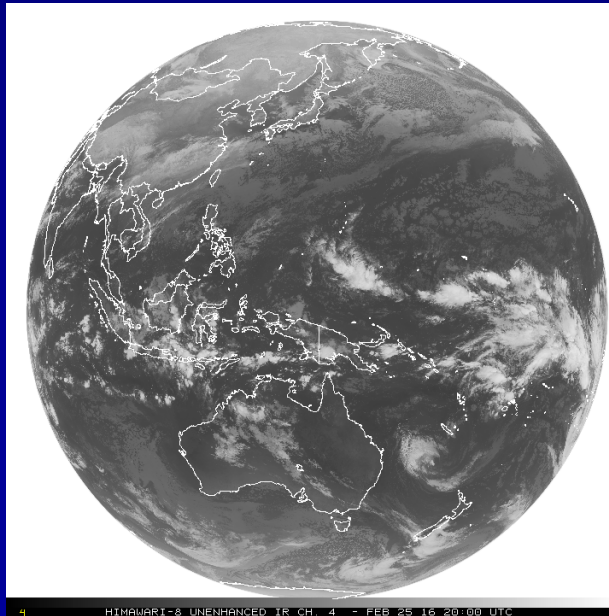
Low Earth Orbiting Satellites

- **Generally fly 300-1000 miles (500-1600 km) above the surface**
- **Many such satellite travel over the Earth almost from pole to pole – polar orbit.**
- **Polar orbiting satellites are usually <u>sun-synchronous</u> (the satellite crosses the Equator at the same local time every day).**
- **Sun-synchronous satellites make about 14 orbits of the Earth a day.**
- **There are other specialized low earth orbits such as that of the Global Precipitation Mission satellite.**

GCOM Polar Orbit

GPM Orbit

•24
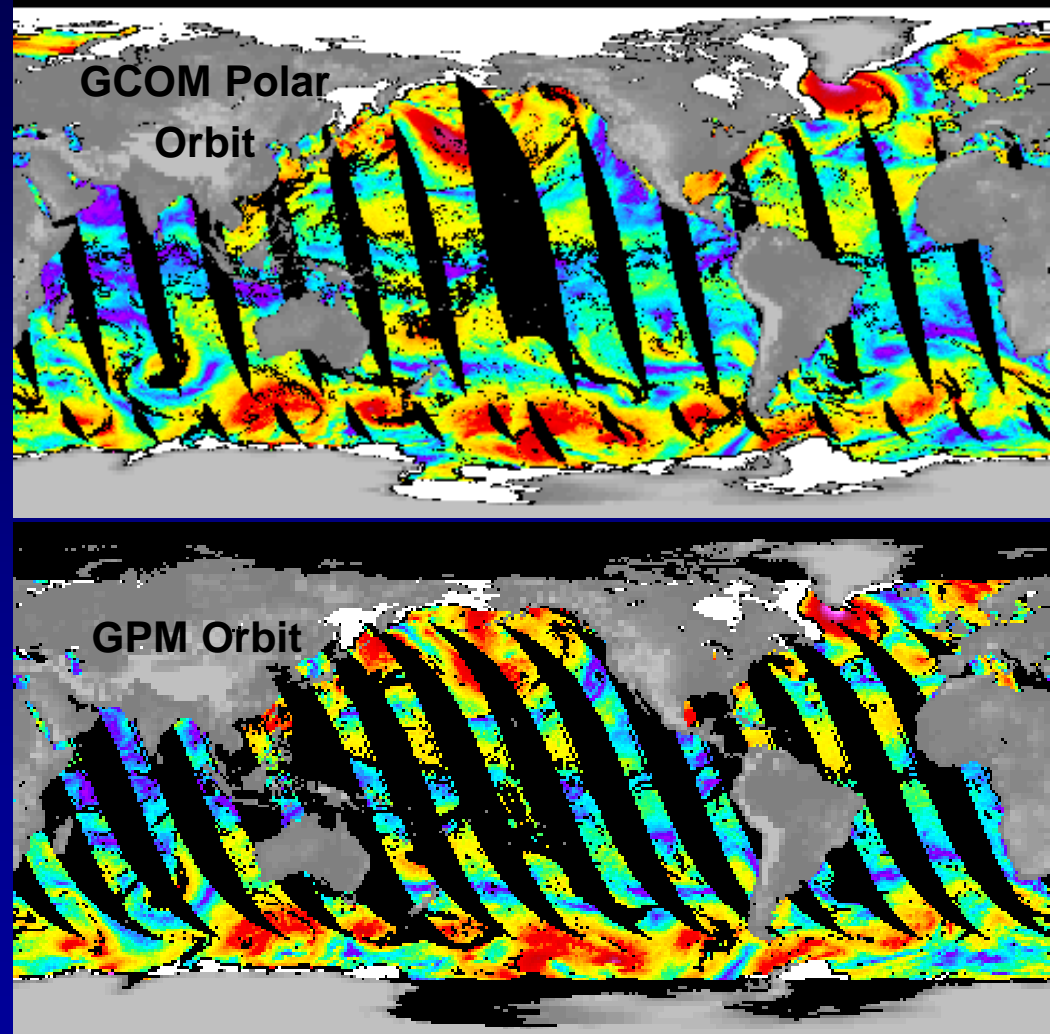
Data Latency Issue
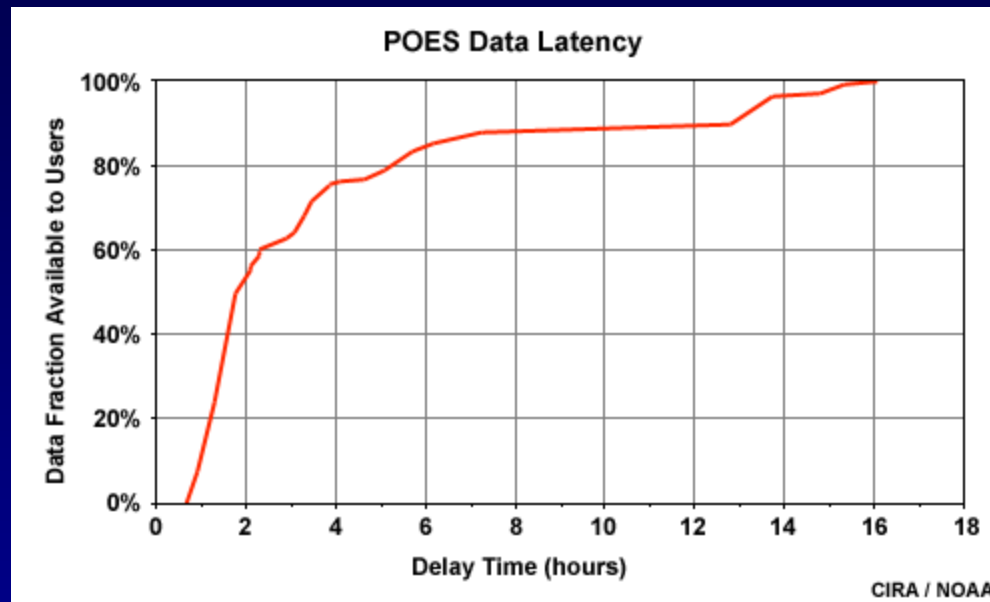
- **LEO satellites are not continuously in view of data receiving stations. They can only download data when they are in range of those stations, which leads to delays in data transmission and processing.**

Instruments - Imagers

- **An imager makes an image of some meteorological quantity.**

- ***Usually* use one wavelength/ frequency but can use combinations of wavelengths/ frequencies (multispectral)**

- **Satellite <u>imagery</u> is normally used for analysis and short-term forecasting.**

MODIS imager has <u>36</u> channels
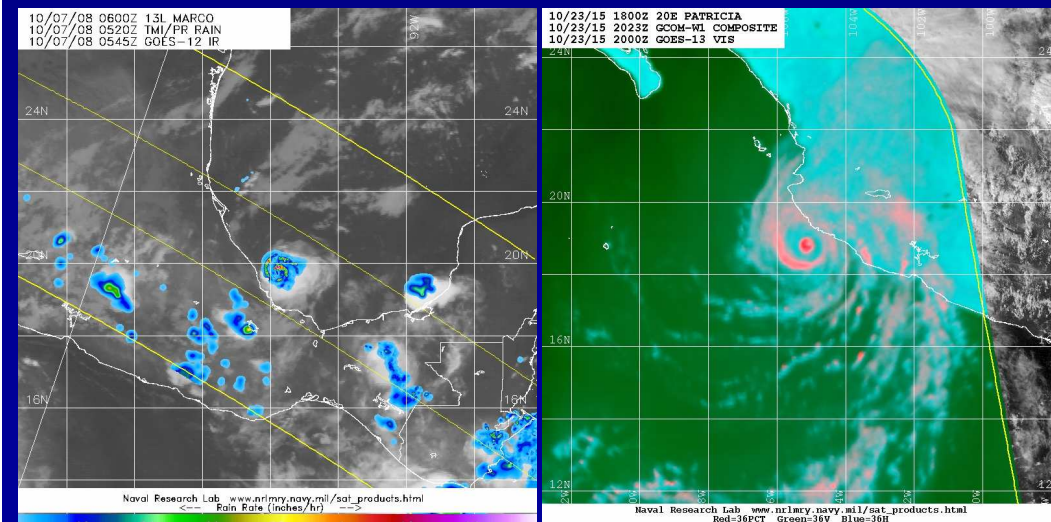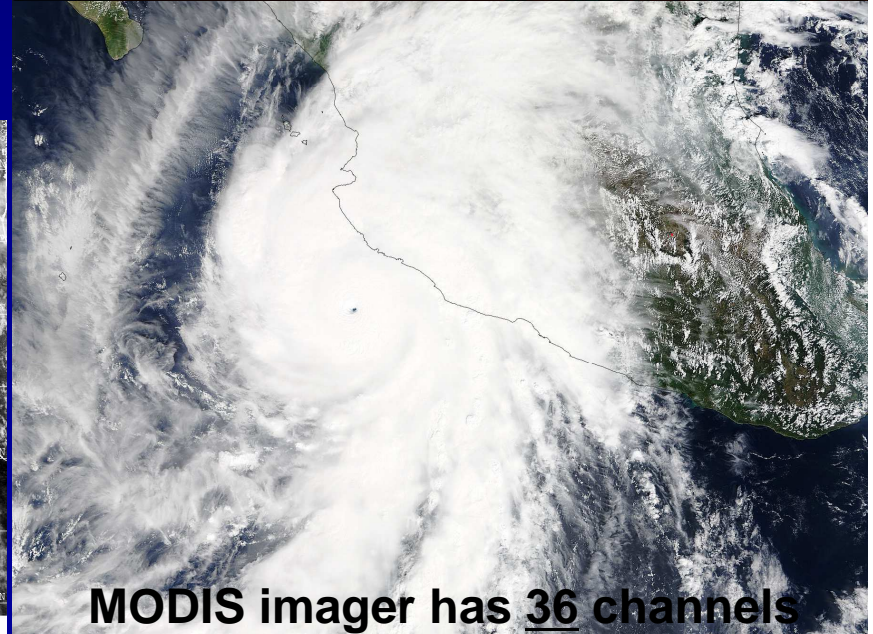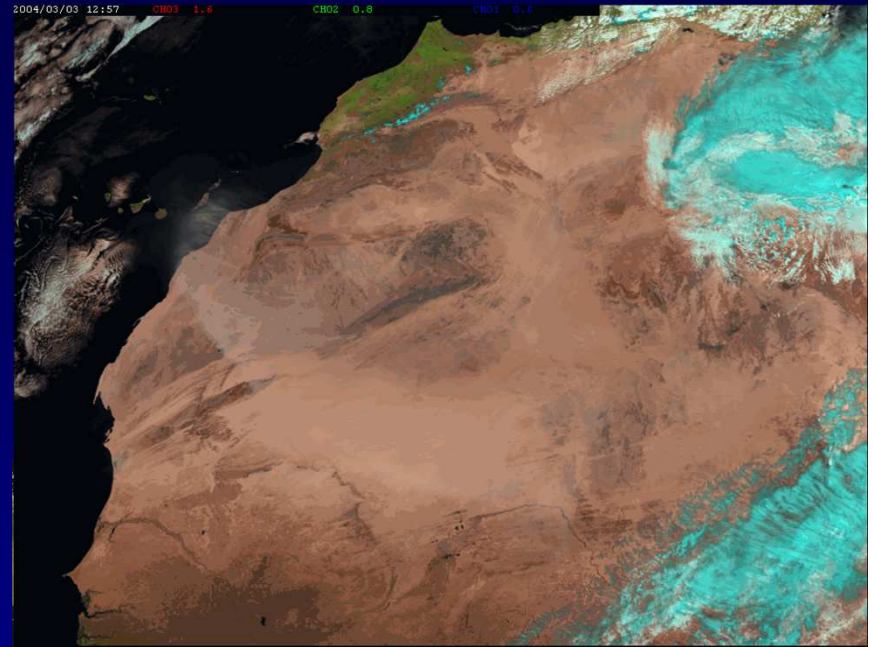
GOES-13/14/15 Imager Channels

Channel 1	Channel 2	Channel 3	Channel 4	Channel 5
0.65 µm 1 km	3.9 µm 4 km	6.5 µm 4 km	10.7 µm 4 km	13.3 µm 4 km
Visible	Shortwave IR	Water Vapor (IR)	IR Window	CO_2 (IR)
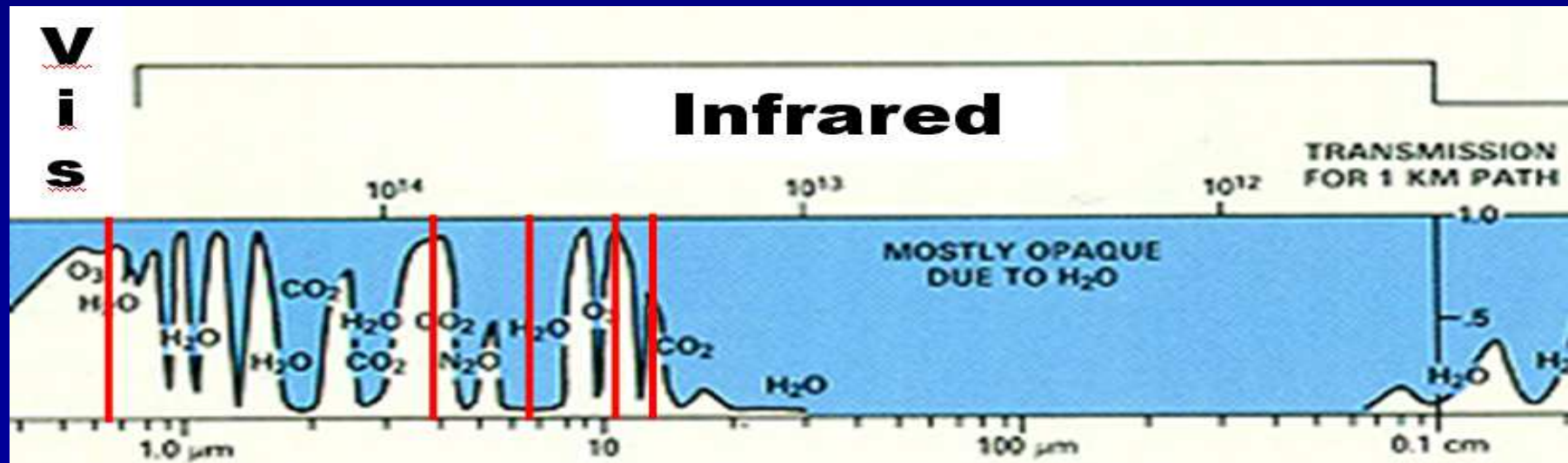
The WindSat Microwave Imager
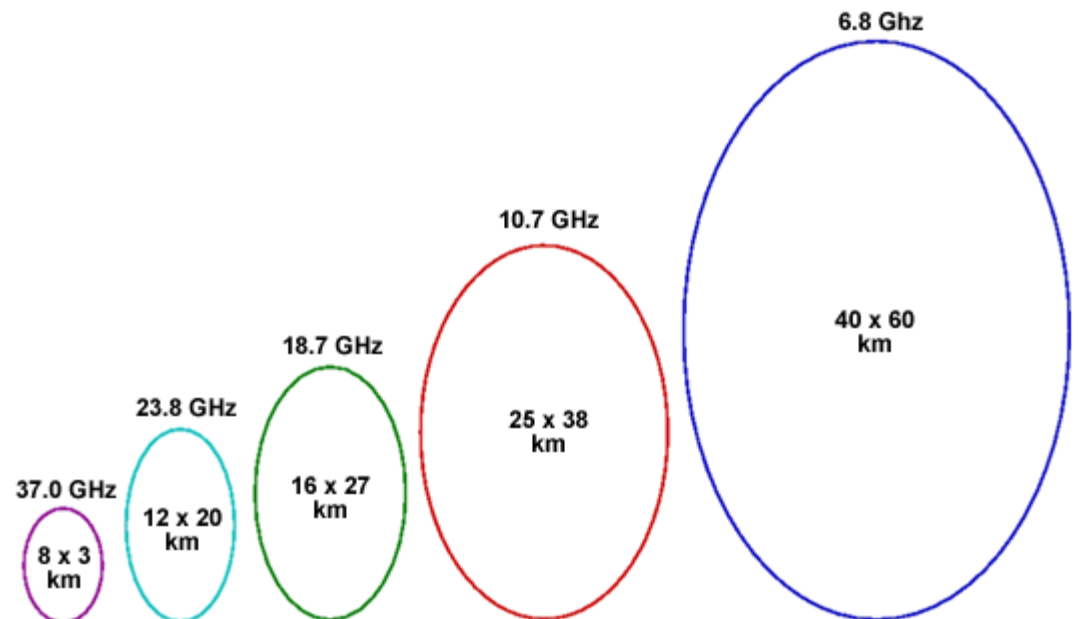
The footprint (pixel) size of the imager increases with decreasing frequency.

•28

Multi-spectral Imagery

- **Combinations of channels can show important features that a single channel cannot, such as enhanced convection or aerosols.**

- **Taking advantage of radiative properties can maximize image amount of information in an image.**

- **Nighttime visible is an example, along with the EUMETSAT dust imagery.**
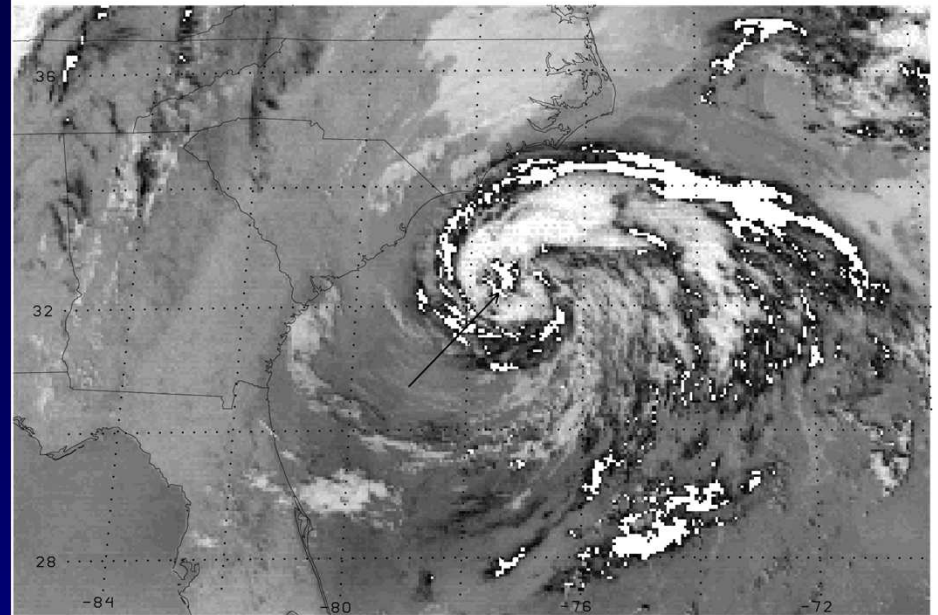
GOES-E NIGHT NC 32.2 -77.5 20150509_0545

2004/03/03 12:57 Inv CH09 10.8-CH10 12.0   CH09 10.8-CH07 8.7
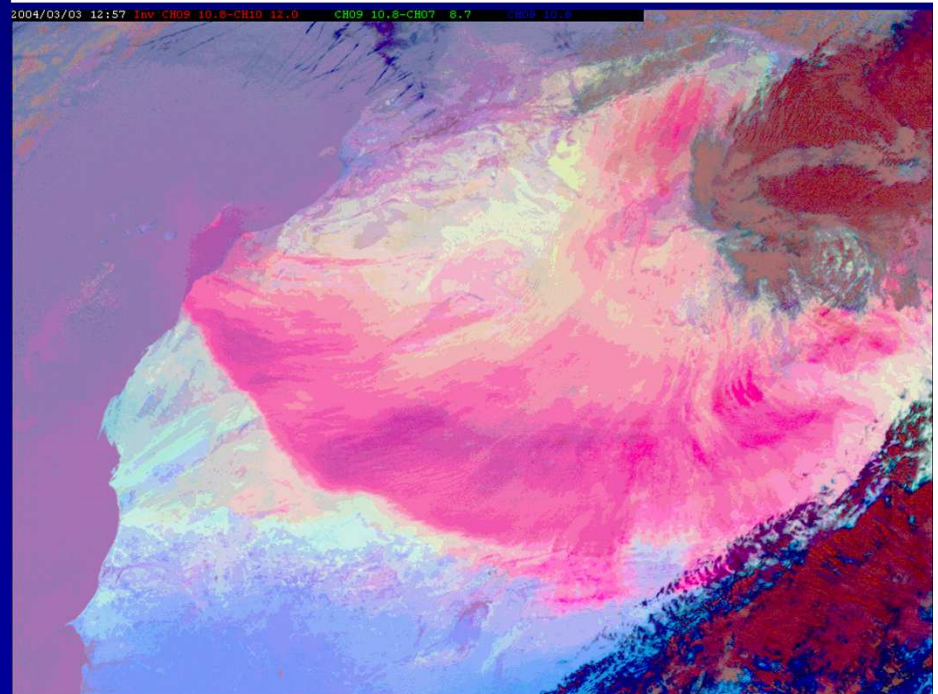
Day-Night Band Imagery

- **DMSP and NPP satellites have the ability to take visible images by reflected moonlight.**

- **This allows the resolution of visible imagery at night, which is useful for diagnosing the structure of tropical cyclones and other weather systems.**
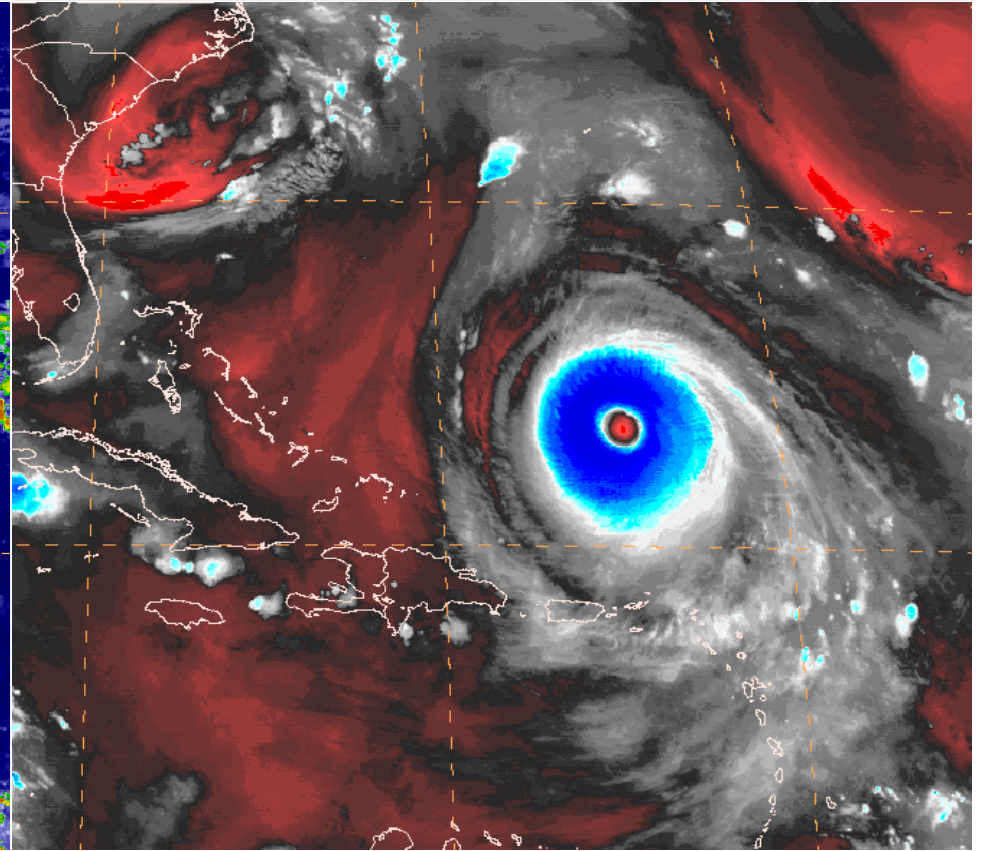

DMSP Moonlight VIS

NPP Day-Night Band
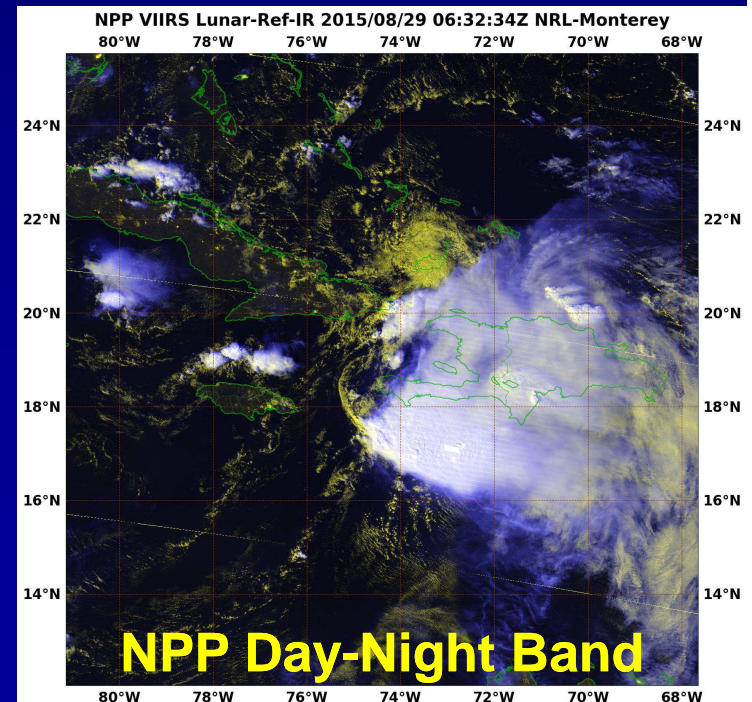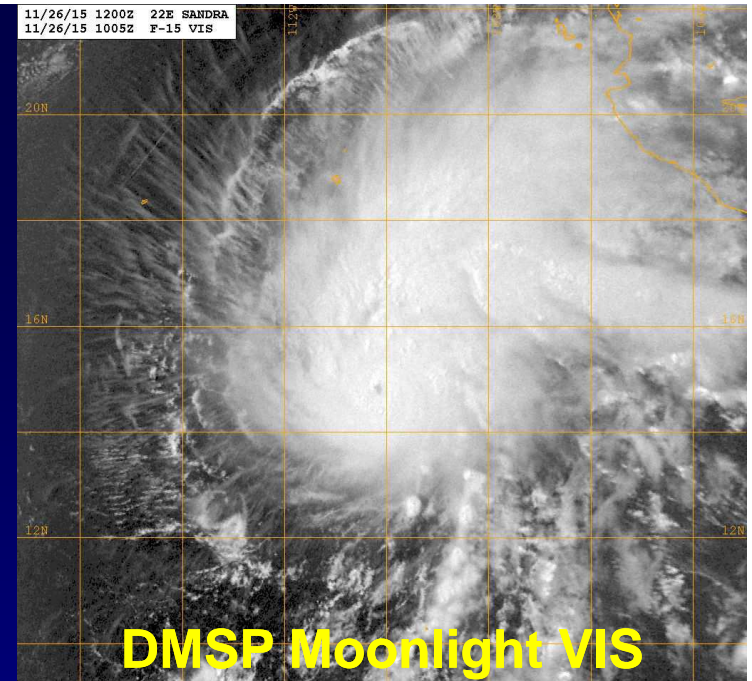
Are we looking at levels or layers?
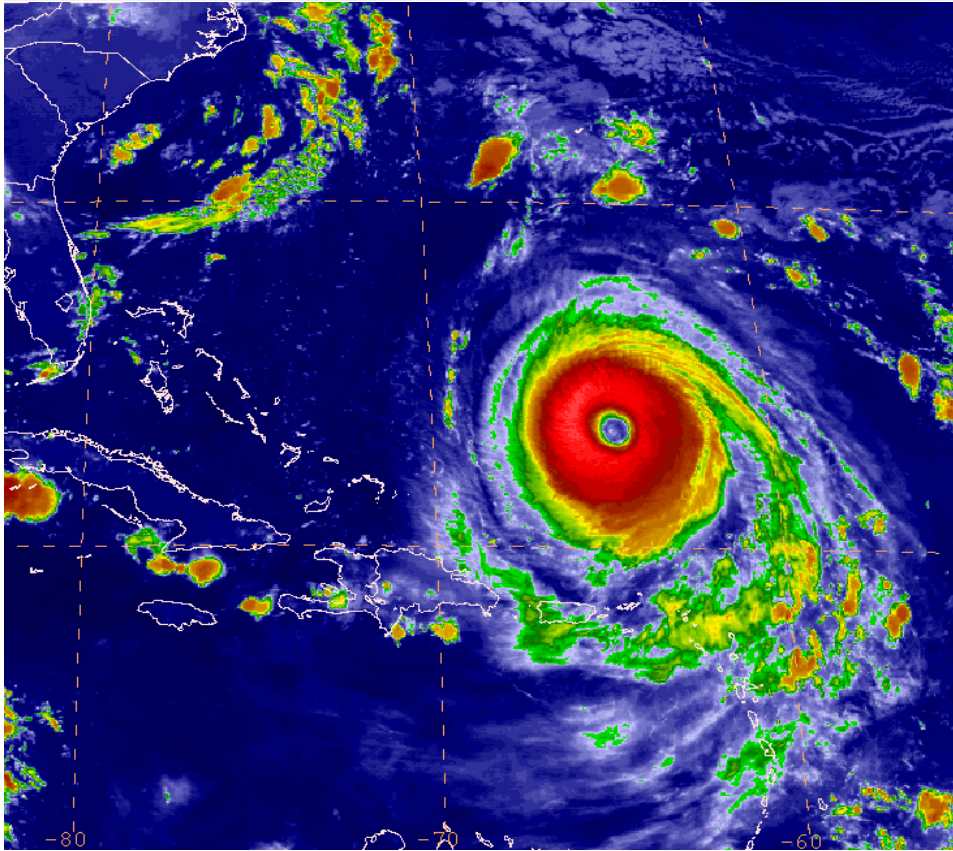
Conventional IR 10.7 μm

More of a level quantity.

Water Vapor IR 6.5 μm

More of a layer quantity.

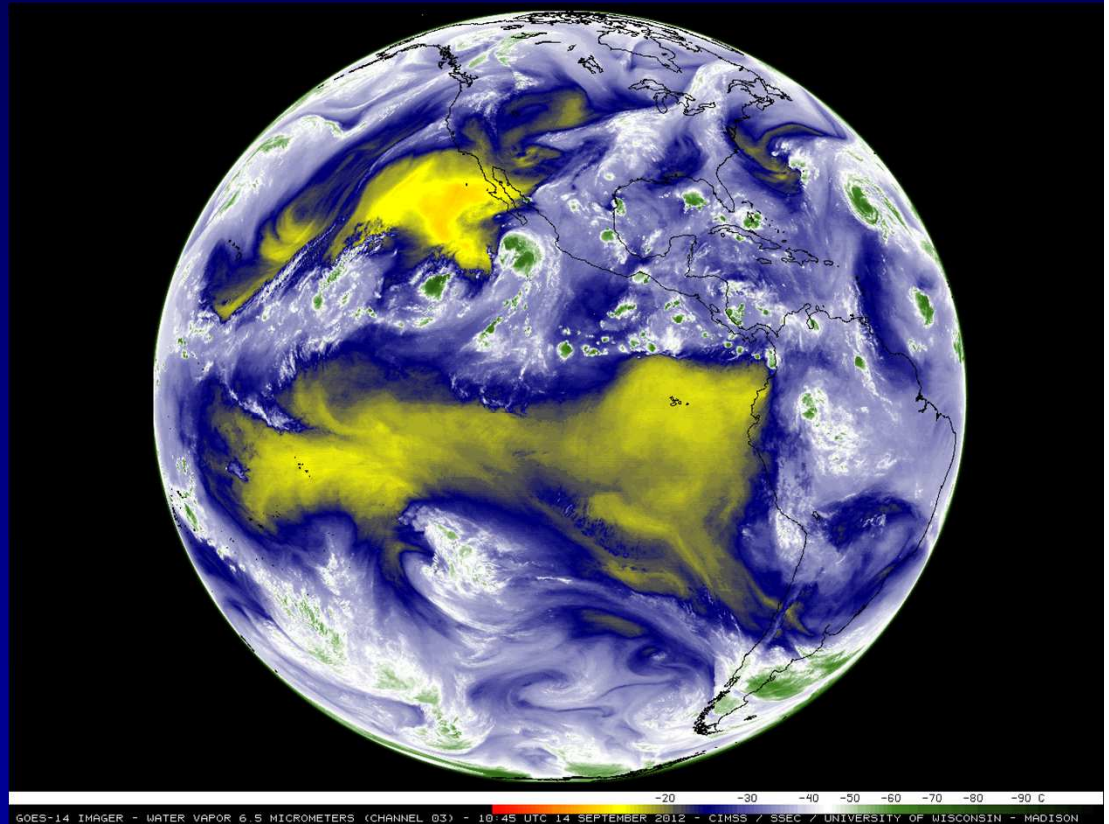GOES-12 0600 UTC 14 Sep 2003

•31

Weighting Functions

- *Weighting function*, the derivative of transmittance with respect to height, specifies the relative contribution that each atmospheric layer makes to the radiation emitted to space.

- Therefore determines those regions of the atmosphere, which are sensed from space at a particular wavelength λ.

- Since water vapor concentrations are highly variable, weighting functions will also vary by location.

- A good choice of λ on a satellite instrument can allow for atmospheric vertical profiling or "sounding".
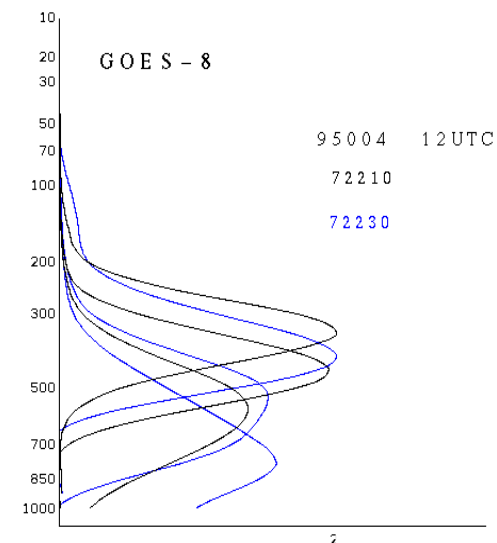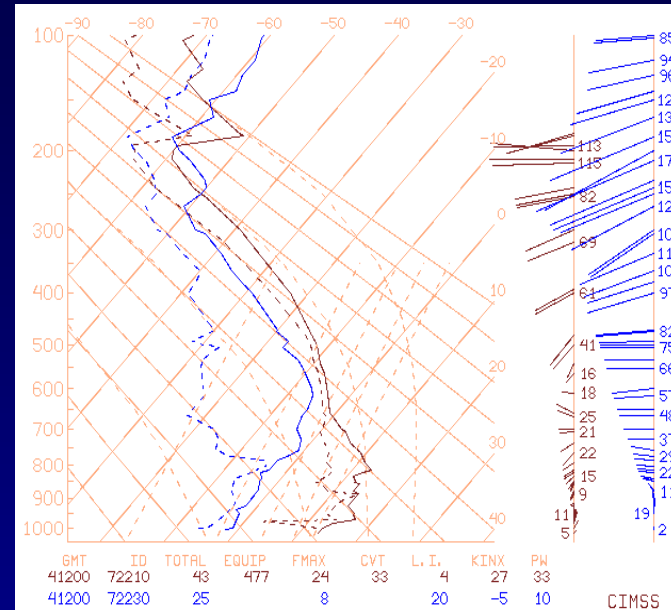
Water Vapor Imagery

- 6.5 μm channel is sensitive to water vapor in the mid to upper troposphere (generally 200-500 mb).

- Other channels are sensitive to vapor at other levels – 7.3 μm channel on METEOSAT-8/10 is most sensitive near 500 mb.

- Water vapor imagery can reveal features that don't generate visible clouds.

- Animation can reveal steering flows, shearing winds, or outflow for tropical cyclones.


GOES-14 IMAGER - WATER VAPOR 6.5 MICROMETERS (CHANNEL 03) - 10:45 UTC 14 SEPTEMBER 2012 - CIMSS / SSEC / UNIVERSITY OF WISCONSIN - MADISON

-20 -30 -40 -50 -60 -70 -80 -90 C

●33

Instruments - Sounders

- **Sounder – A sounder makes a vertical profile of some meteorological quantity - usually uses combinations of infrared or microwave frequencies**

- **Satellite soundings can be used for analysis and short-term forecasting, and are also assimilated into numerical weather prediction models**

- **Infrared-based sounders cannot sound through clouds, while microwave sounders like AMSU are affected by heavy precipitation**

- **Hyperspectral sounders like AIRS or IASI use interferometry to create thousands of channels**
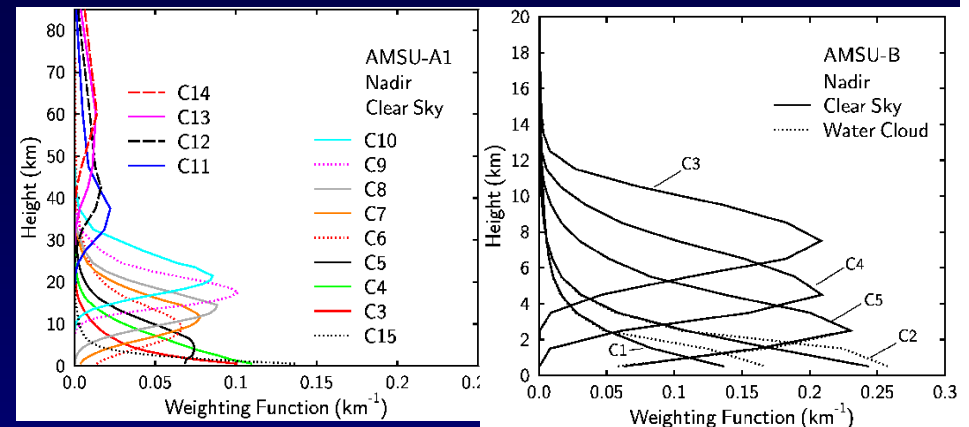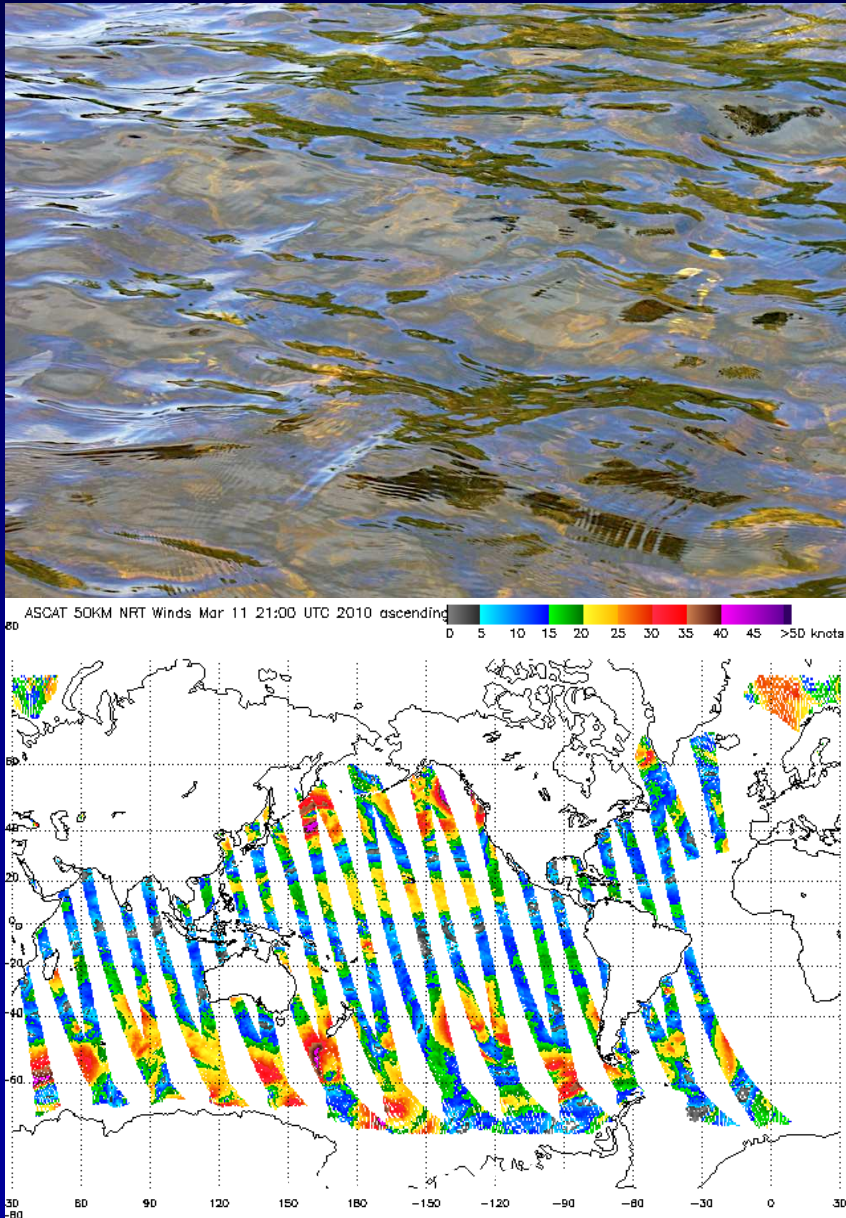

AMSU vertical weighting functions
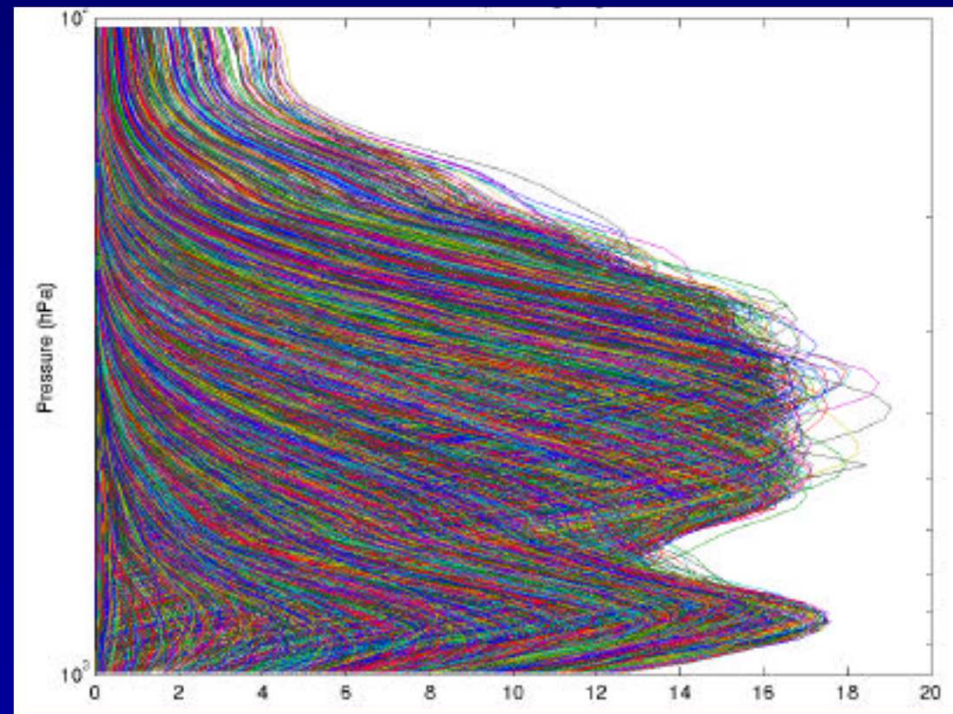
Hyperspectral weighting functions

Scatterometry and Scatterometers

ASCAT 50KM NRT Winds Mar 11 21:00 UTC 2010 ascending

- **Small-scale roughness elements are scatterers.**

- **Fundamental assumption/ paradigm: small-scale roughness elements on the ocean surface are function of local wind speed/ direction.**

- **Radar pulses can measure these roughness elements and return estimates of wind speed/direction. Instruments that do this are called <u>scatterometers.</u>**

- **Currently active scatterometers fly on the METOP satellites and the International Space Station.**

- 35

Types of Satellite Data

- **Imagery: Visible (VIS), Infrared (IR), Water Vapor (WV), Shortwave Infrared (SWIR), Microwave (MW), Multispectral – most meteorological satellites**

- **Satellite Atmospheric Winds: from multiple images (VIS, IR, WV) - geostationary satellites, some LEO satellites near the poles**

- **Sea Surface Temperatures (IR, MW) - GOES, NOAA, GPM, GCOM, METOP, NPP**

- **Ocean Surface Wind Speeds (MW) * - DMSP, GPM, GCOM, Coriolis, METOP, ISS**

- **Precipitation Estimates (IR, MW) * - geostationary satellites, GPM (including the <u>Precipitation Radar</u>), GCOM, DMSP, METOP**

Types of Satellite Data

- **Tropical Cyclone Intensity Estimates (VIS, IR, MW) * - geostationary satellites, NOAA (Advanced Microwave sounding Unit or AMSU), DMSP (SSM/IS), GPM, GCOM, METOP, NPP (ATMS)**

- **Satellite Vertical Soundings (IR, WV, MW) - GOES, NOAA, DMSP, METOP, Aqua, NPP**

- **Ocean Wave Heights (Jason2, Jason 3, Cryosat, Altika)**

- **Oceanic Heat Content (Jason2, Jason 3, Cryosat, Altika)**

Satellite-derived winds

- **Satellite winds are computed from the displacement of targets on two successive geostationary images.**

- **Targets can include clouds in visible or infrared imagery and features in water vapor imagery.**

- **Temperature of cloud or water vapor feature is used for height assignment.**

- **Satellite winds can show tropical cyclone steering, shearing, and outflow patterns, but cannot be made below the central cirrus canopy of a TC.**

- **Satellite winds are used for analysis as well as to initialize numerical weather prediction models.**

- **Reference: Velden et al., BAMS, 1997**
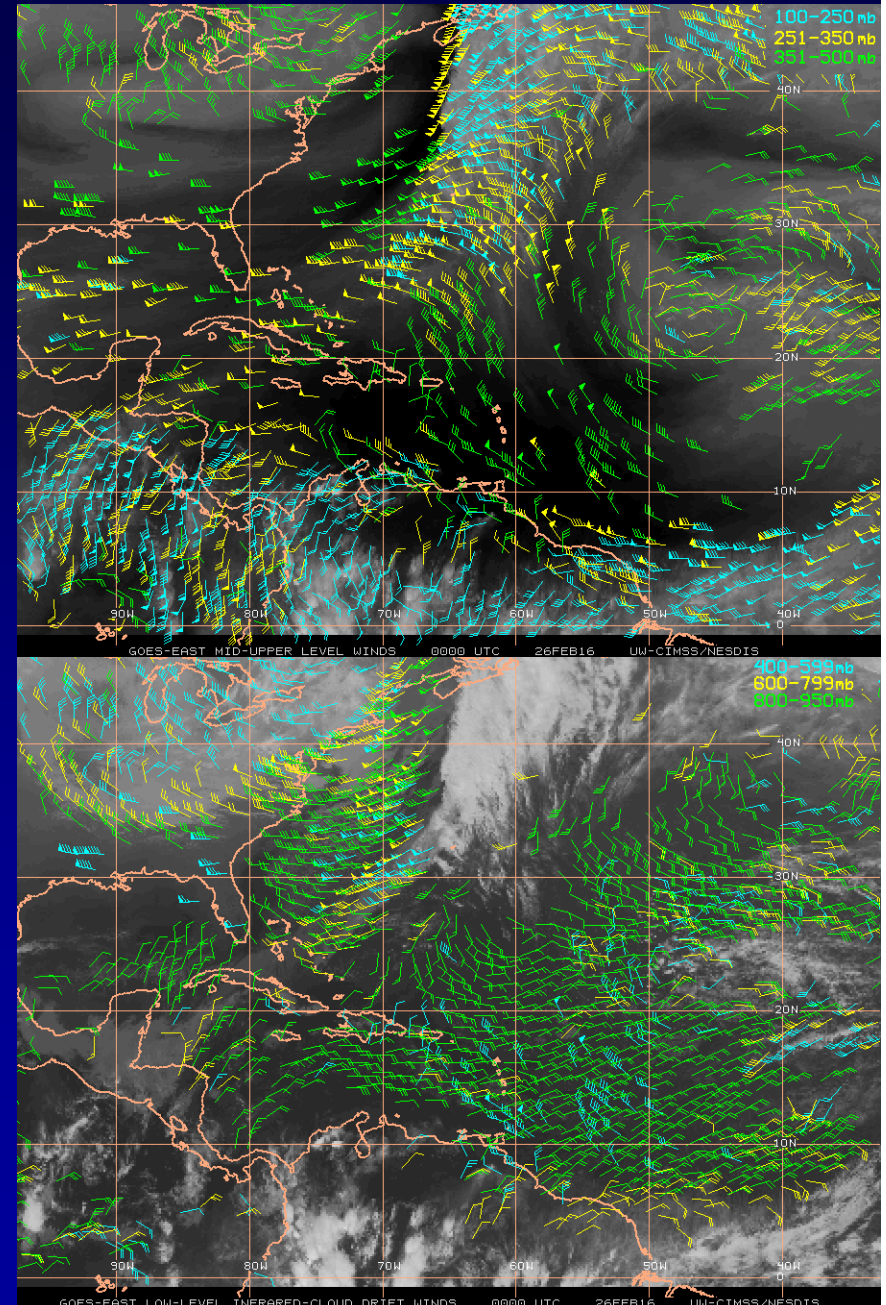
Microwave imagery of TCs

Images provided by the Fleet Numerical Meteorology and Oceanography Center (FNMOC).

Certain microwave frequencies can see through the ice clouds at the top of a tropical cyclone.
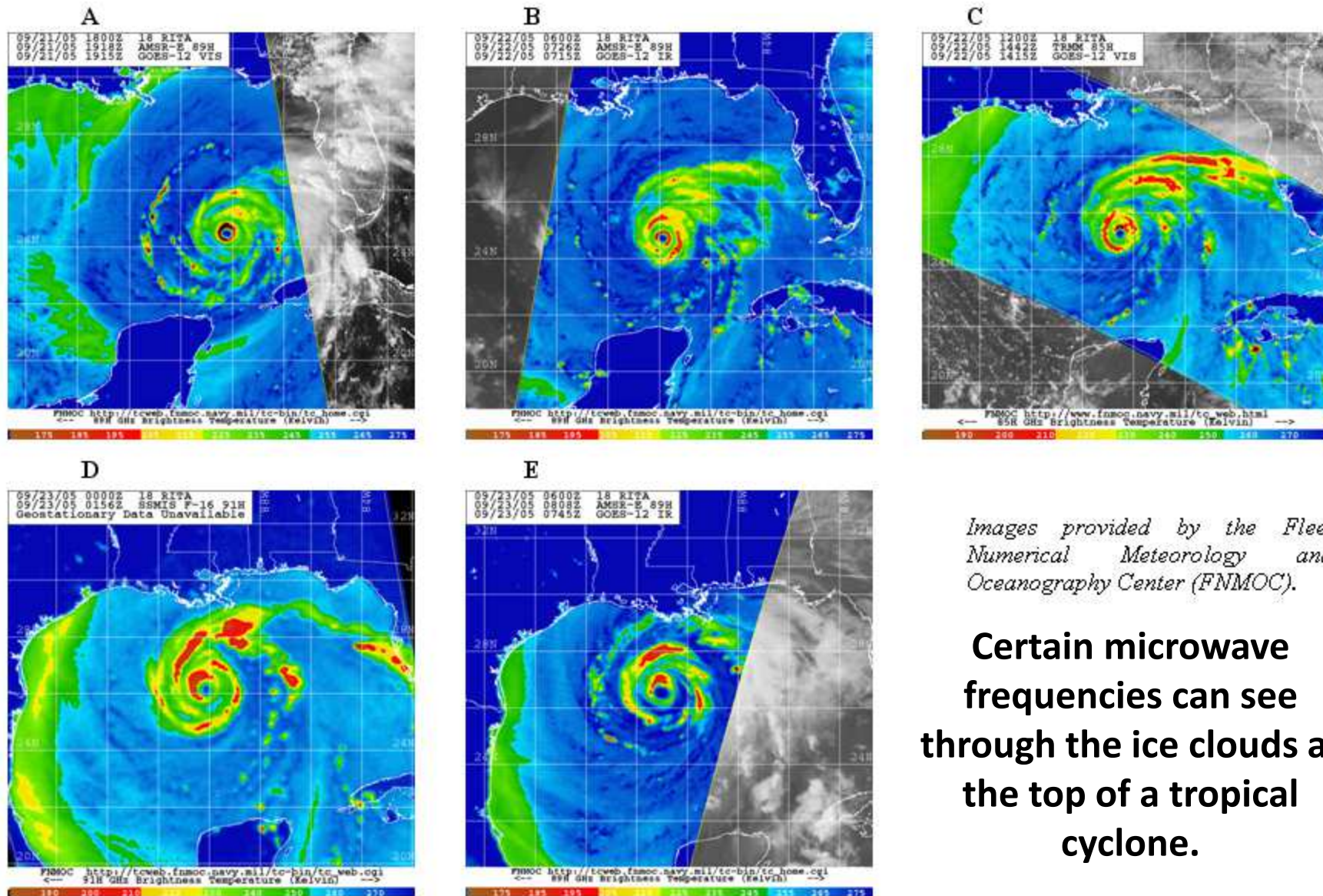
Figure 4.   Series (in order A-E) of 85-91 GHz passive microwave images of Hurricane Rita during 21-23 September 2005.
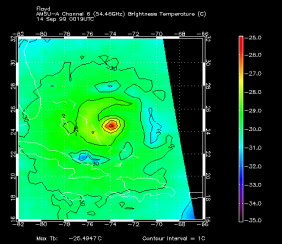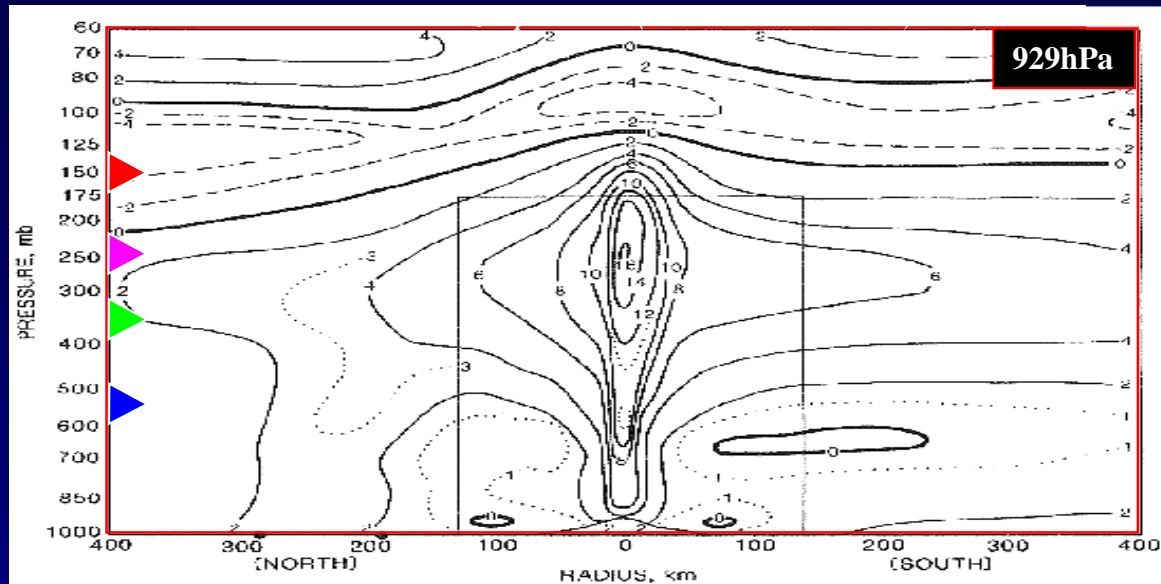
AMSU-based intensity estimates from CIMSS and CIRA
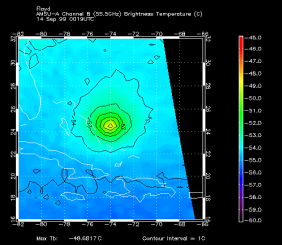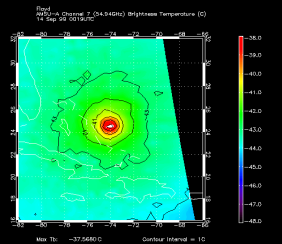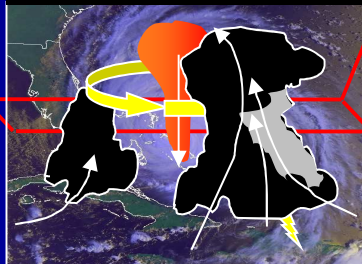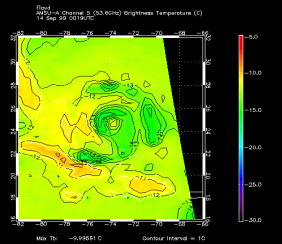
Hurricane Floyd Sept 14 1999

929hPa

4 AMSU-A temperature sounder channels that span warm core

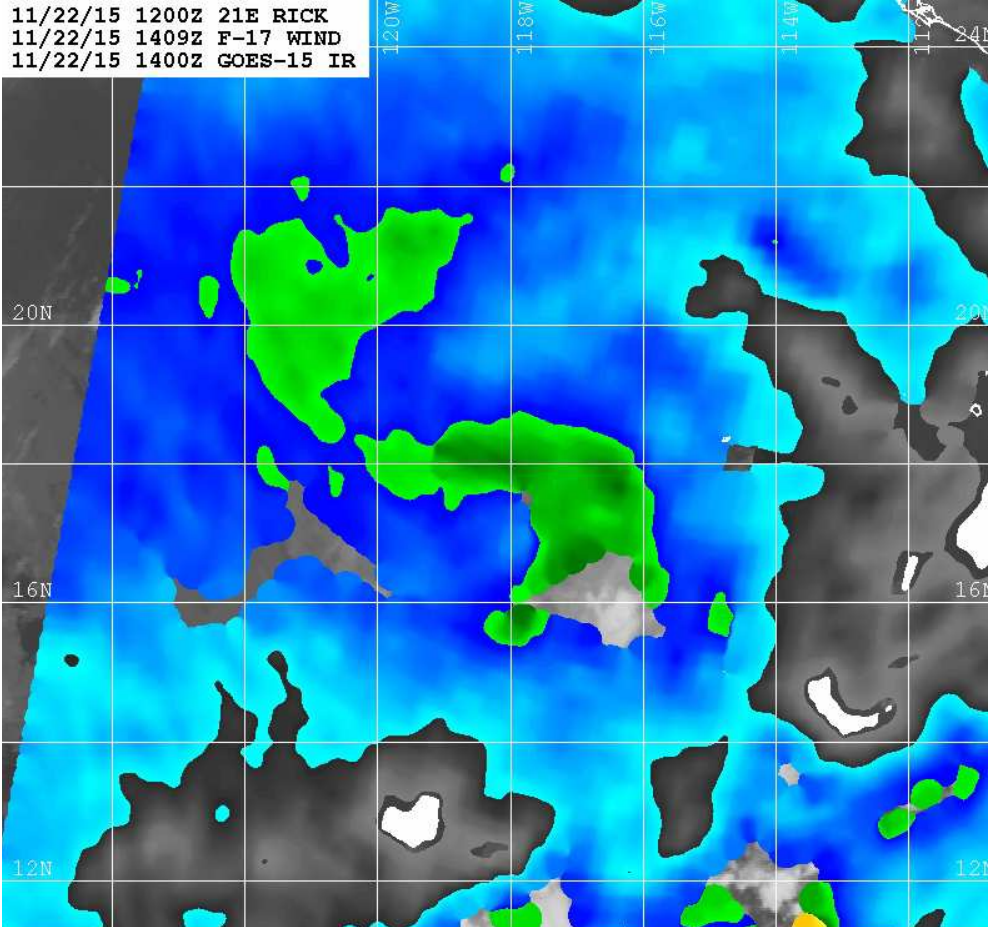*Ch. 7-8 (54.94 GHz) weighting function peak at level of historically-observed peak warming*

Ch. 7-8 (54.94 GHz) largely unaffected by lower tropospheric scattering / surface emission
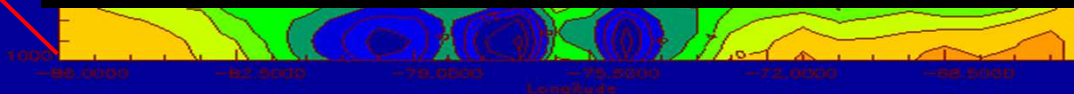
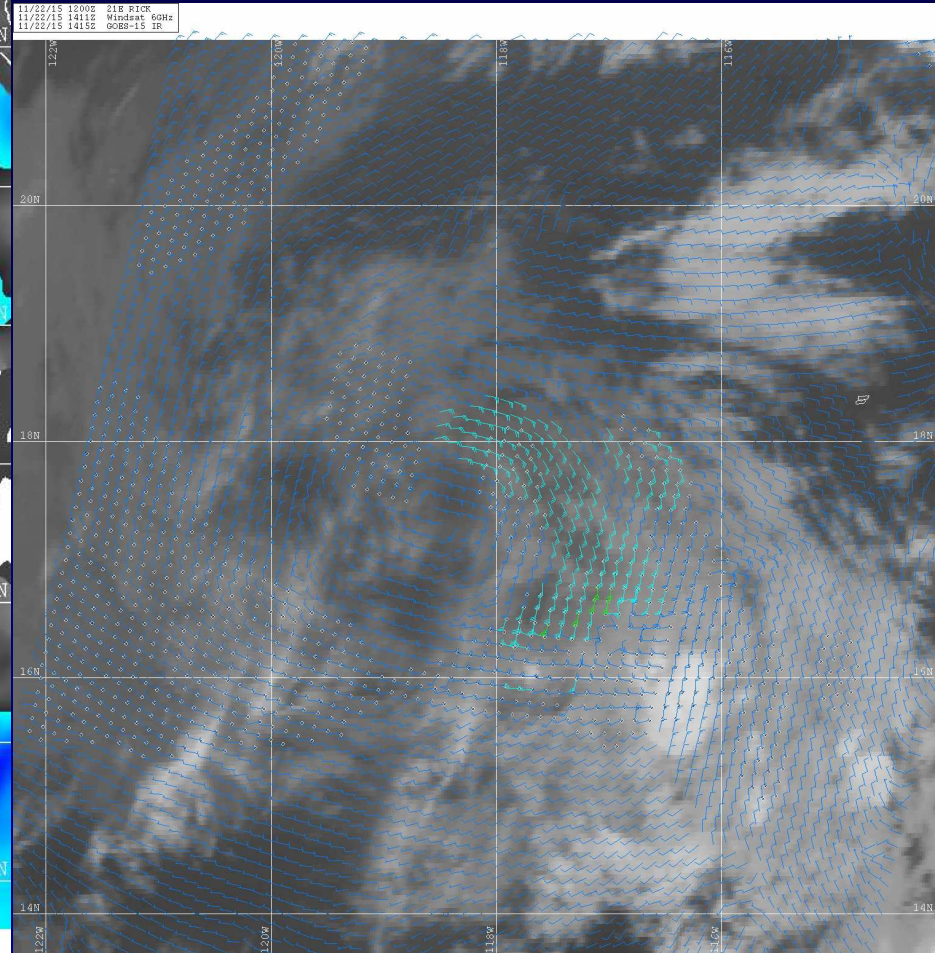Slide courtesy of Velden et al CIMSS/NRL

Passive Ocean Surface Winds

SSM/I Winds – Rick (2015)

Windsat vector winds – Rick (2015)

Passive microwave winds work well in areas of dry weather.

41

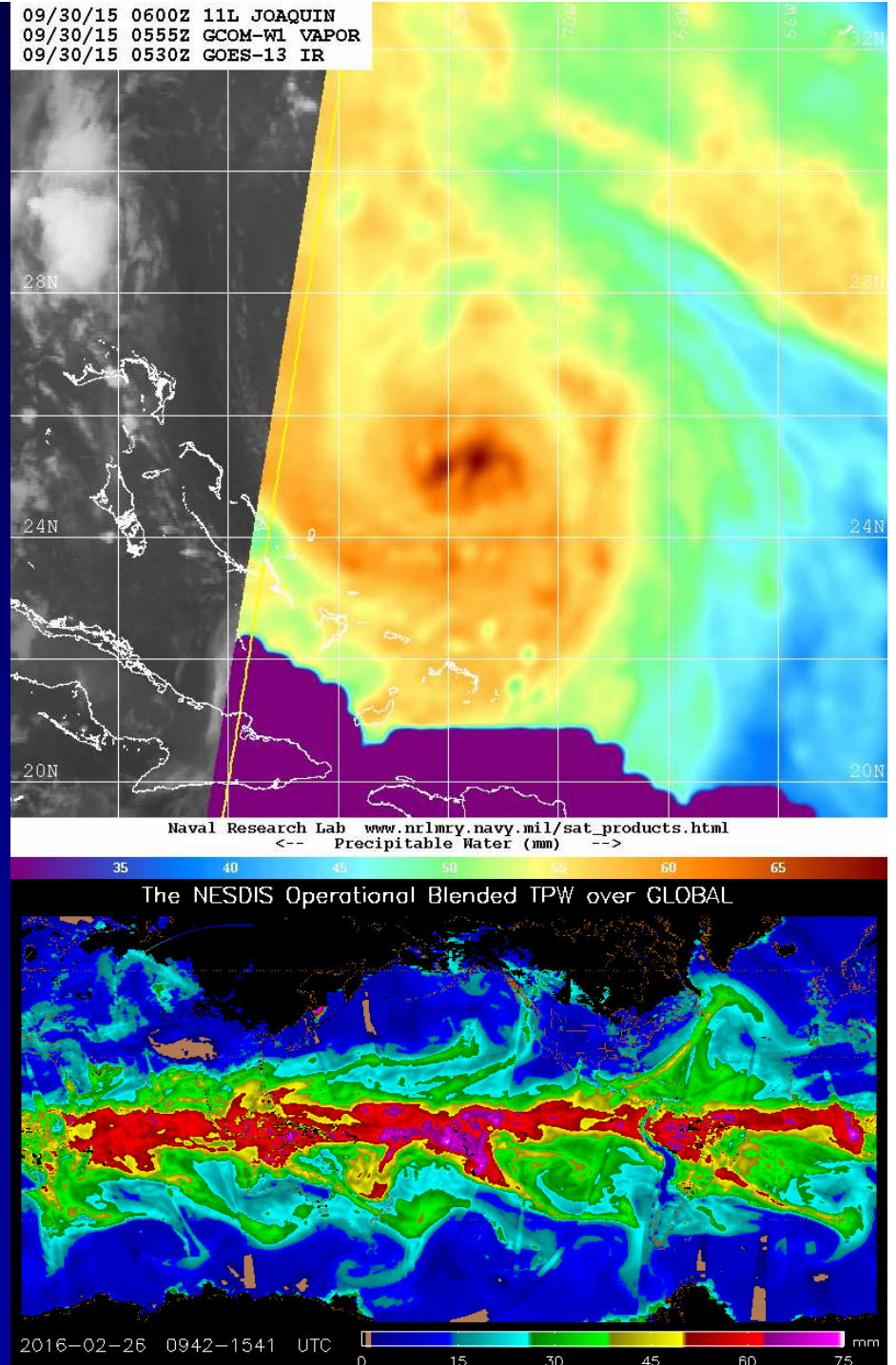# Microwave Satellite Rainfall Estimates

Observed Rainfall Rate
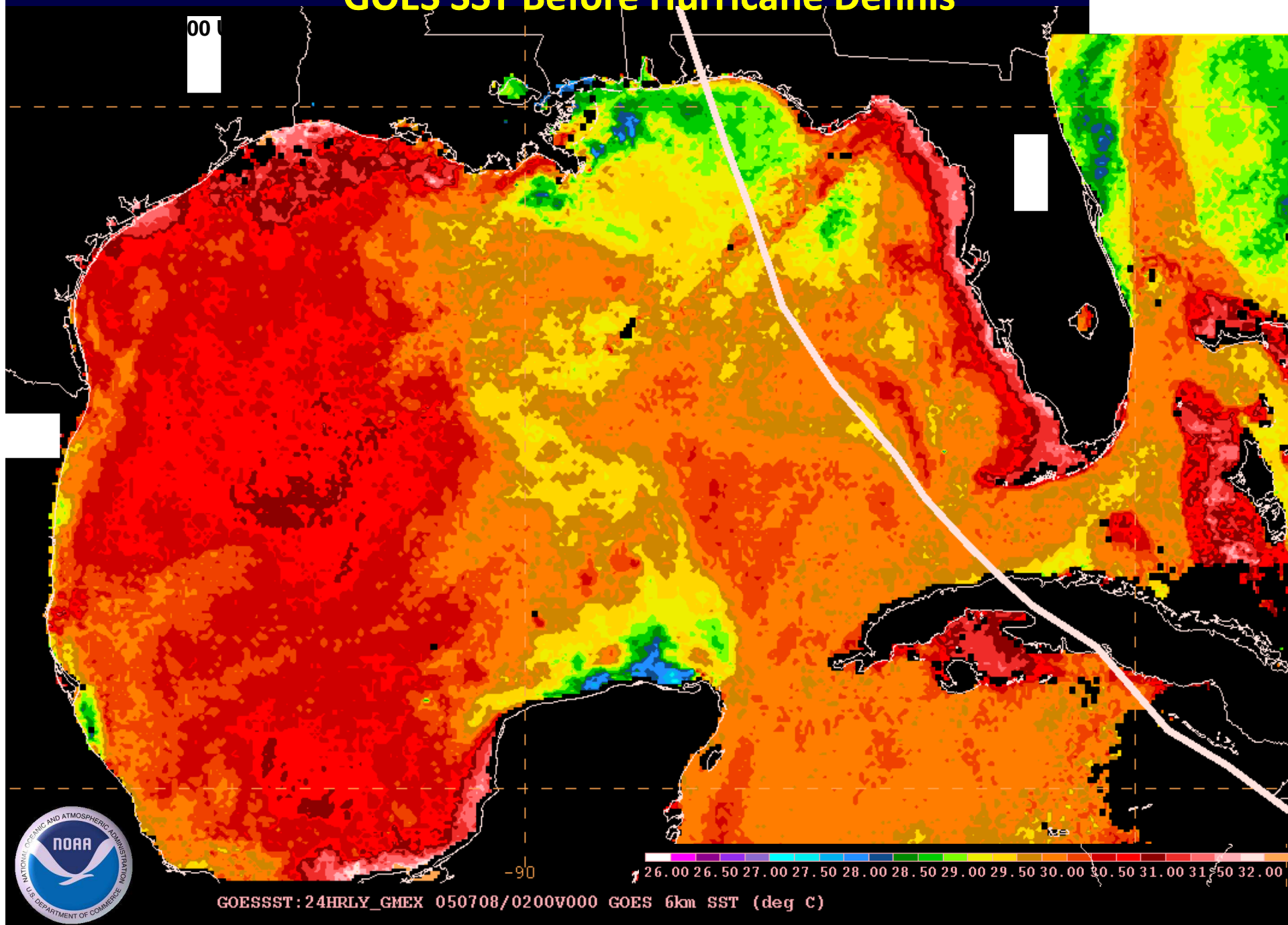
Forecast Precipitation Totals

The Ensemble Tropical Rainfall Potential (eTRaP) technique is based on extrapolation of microwave convective patterns into the future.
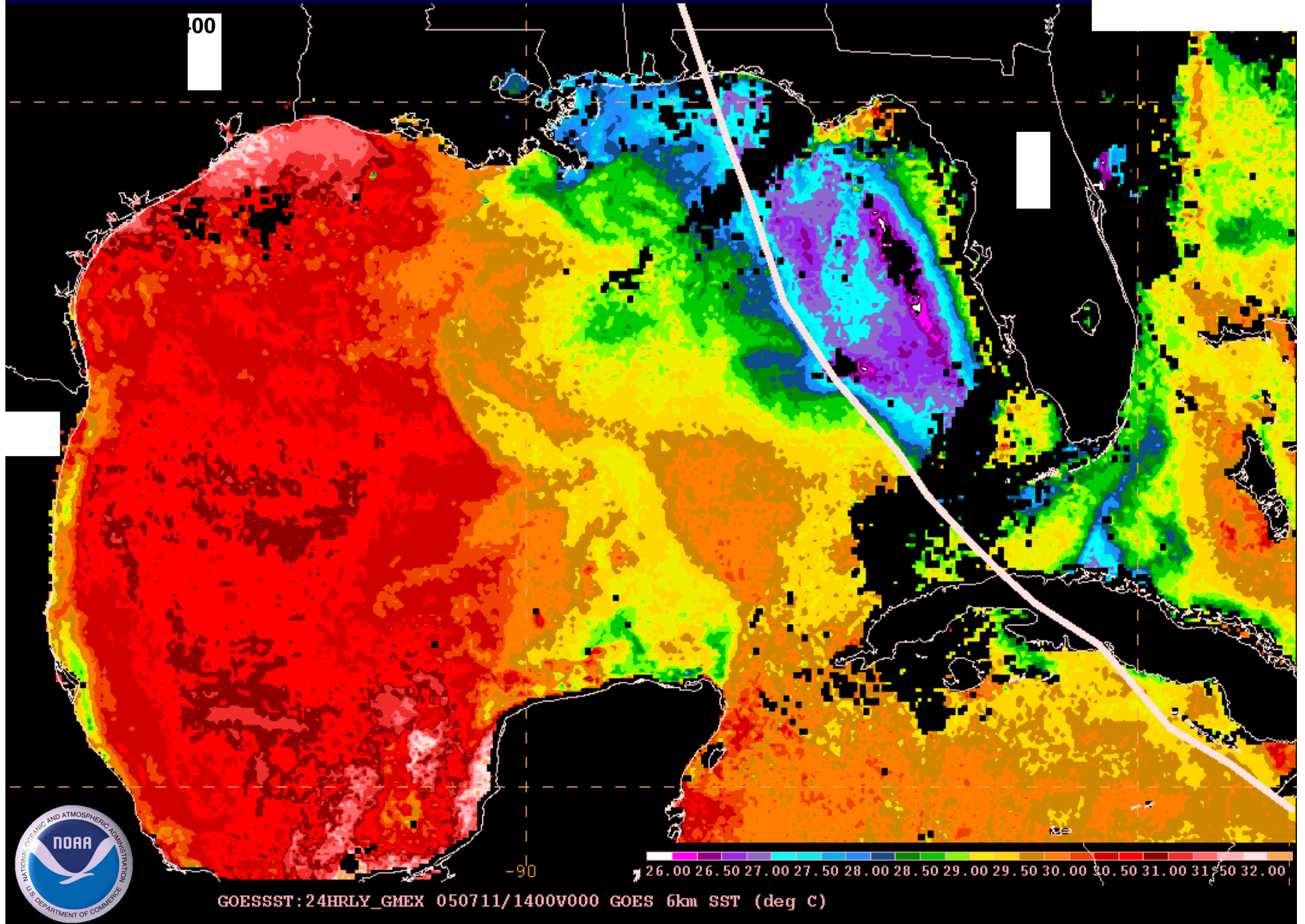
42

Total Precipitable Water Products

- **Microwave sounders measure moisture, which allows for the determination of the total amount of water and water vapor in a column of atmosphere – the total precipitable water (TPW).**

- **The TPW is used to track moist and dry air masses in weather systems, for determination of cyclone structure, and determination of how much atmospheric moisture is available to become rain.**

09/30/15 0600Z 11L JOAQUIN
09/30/15 0555Z GCOM-W1 VAPOR
09/30/15 0530Z GOES-13 IR

Naval Research Lab   www.nrlmry.navy.mil/sat_products.html
<-- Precipitable Water (mm)   -->

The NESDIS Operational Blended TPW over GLOBAL

2016-02-26 0942-1541 UTC

GOES SST Before Hurricane Dennis

GOESSST:24HRLY_GMEX 050708/0200V000 GOES 6km SST (deg C)

26.00 26.50 27.00 27.50 28.00 28.50 29.00 29.50 30.00 30.50 31.00 31.50 32.00

Hurricane Dennis' Cool Wake

26.00 26.50 27.00 27.50 28.00 28.50 29.00 29.50 30.00 30.50 31.00 31.50 32.00

GOESSST:24HRLY_GMEX 050711/1400V000 GOES 6km SST (deg C)
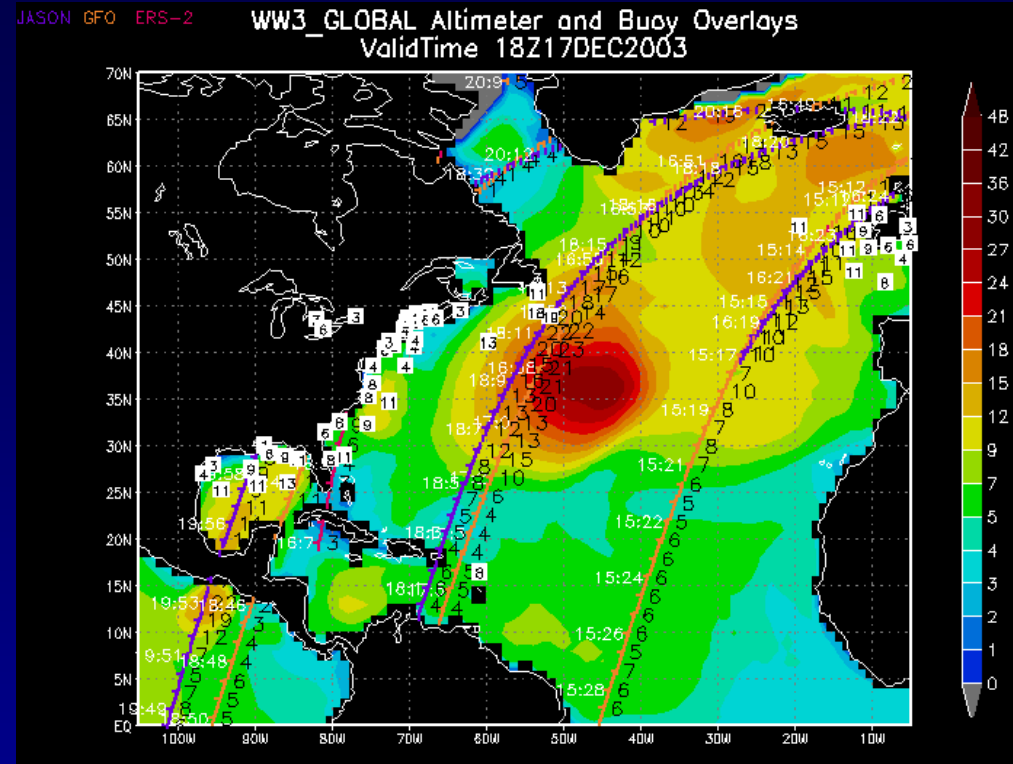
Other useful satellite data
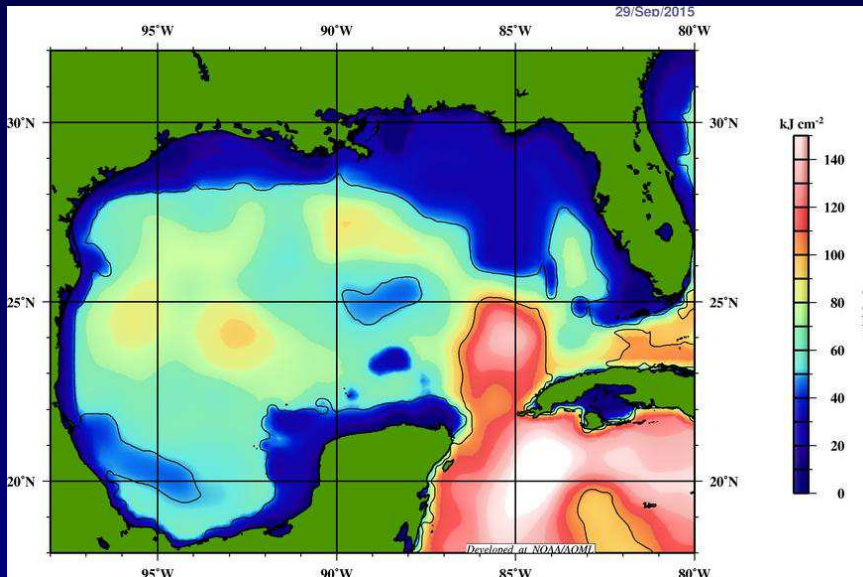
Ocean height and heat content for TC intensity forecasting

Radar altimeter wave heights
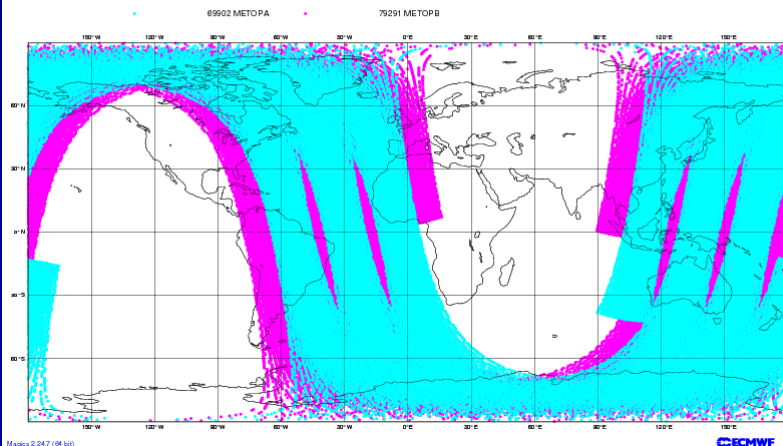
Satellite temperature and moisture soundings for use in numerical models – not used directly at NHC but of vital importance in forecasting
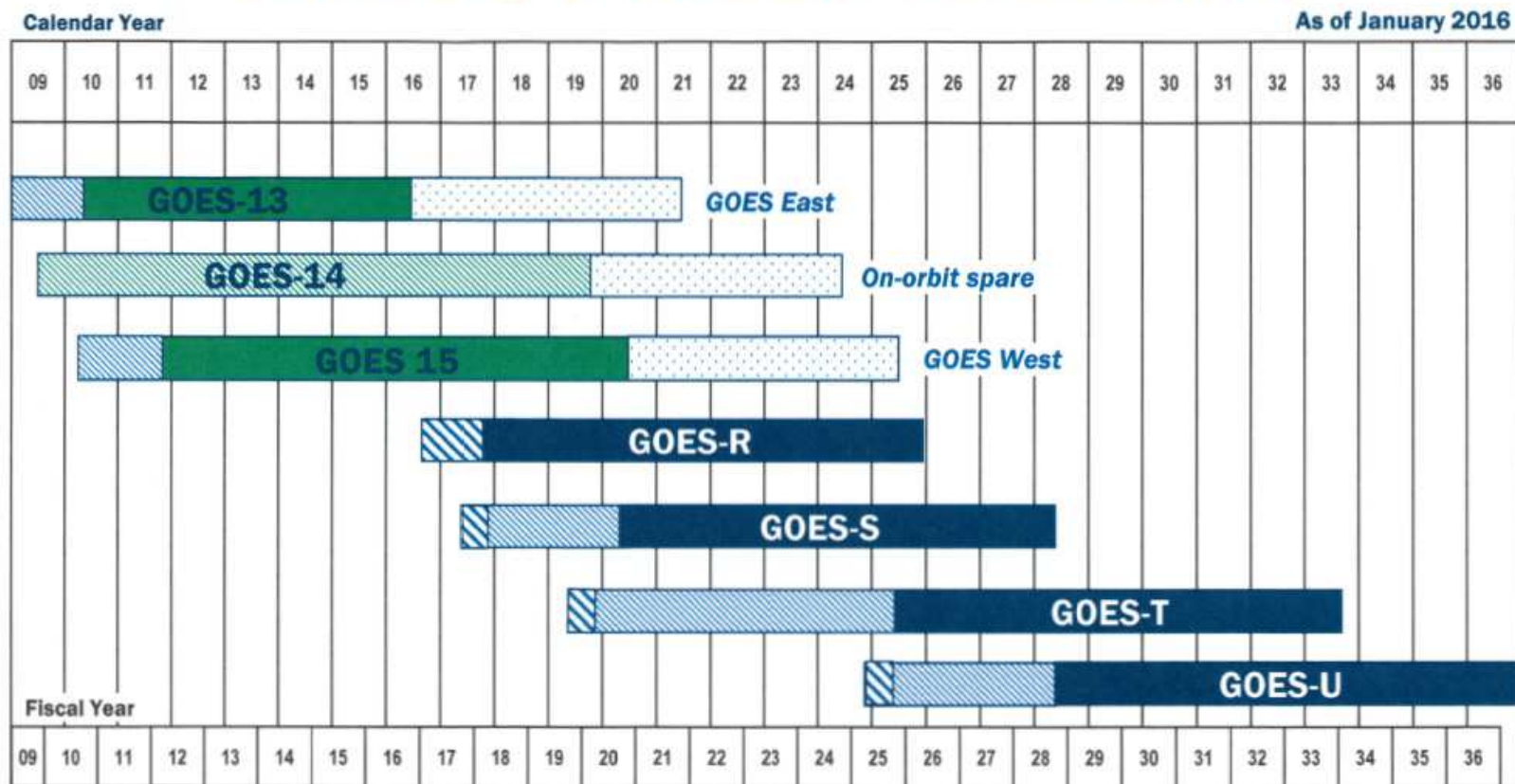
Future Meteorological Satellites

- There are numerous new meteorological satellites being planned around the world.

- Some of the planned improvements are to the ongoing geostationary and polar-orbiting satellite constellations.

- Others are research satellites that will produce data useable for operations.

NOAA Geostationary Satellite Programs Continuity of Weather Observations

Calendar Year

As of January 2016

Calendar Year: 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

- GOES-13 — GOES East
- GOES-14 — On-orbit spare
- GOES 15 — GOES West
- GOES-R
- GOES-S
- GOES-T
- GOES-U

Fiscal Year

Fiscal Year: 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

Approved: _Stephen Volz_

Assistant Administrator for Satellite and Information Services

Legend:
- In orbit, operational
- In orbit, storage
- Fuel-Limited Lifetime Estimate
- Planned On-orbit Storage
- Test & Checkout
- Planned Mission Life

The GOES-R Series

- GOES-R series being developed to replace GOES-N series.
- First launch planned for October 2016
- Significant improvement in technology over GOES-I and GOES-N series


GOES-R under construction

Improvements over current capabilities:

- *Advanced Baseline Imager (ABI)*
  - *Better resolution (4X), faster coverage (5X), more bands (3.2X) and more coverage simultaneously*
- *(NEW!!!) Lightning detection (GLM)*
  - *Continuous coverage of total lightning flash rate over land and water*
- **Solar/Space Monitoring (SUVI, EXIS, SEISS)**
  - Better Imager (UV over X-Ray)
  - Better Heavy Ion detection, adds low energy electrons and protons
- **Unique Payload Services**
  - Higher Data Rates for Environmental Data Relay **(GRB, DCS, EMWIN, LRIT)**
  - Continued Search and Rescue

The ABI Imager

- **16 channel imager, including 11 channels not flown on GOES 13-15**

- **Increased spatial and spectral resolution over the current GOES imagers**
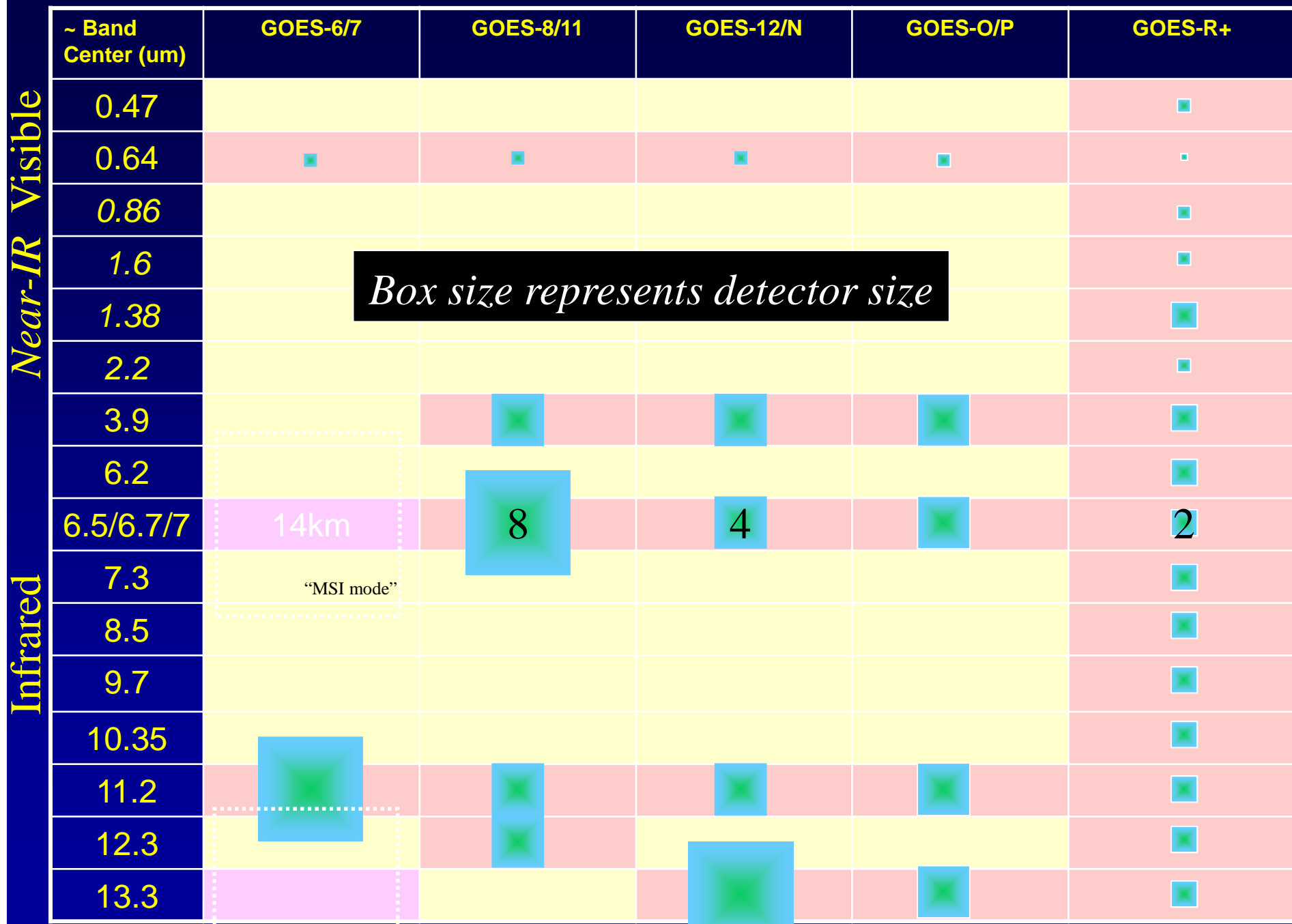
Table and image courtesy of Tim Schmit, CIMSS
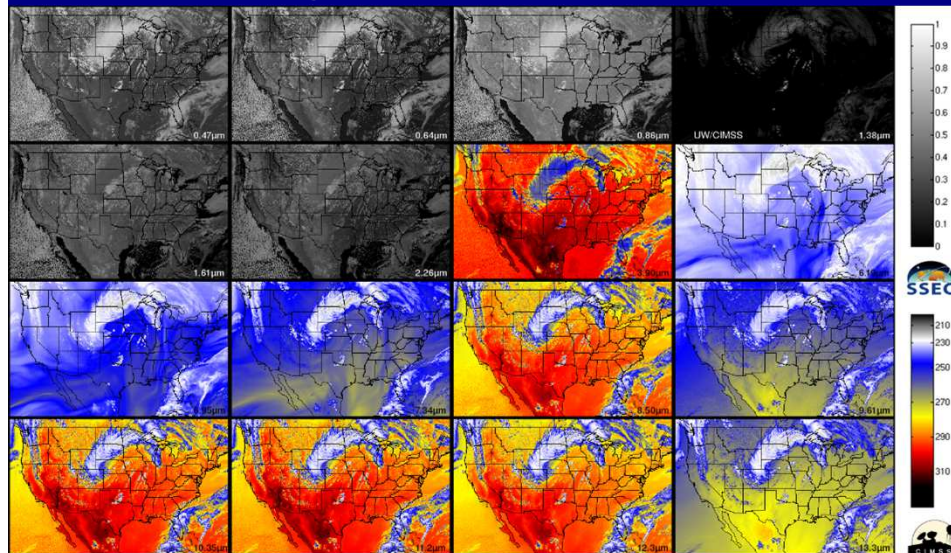
ABI band data for 2005 June 04 22:00 UTC

GOES-R ABI Imager Channels

Future GOES imager (ABI) band	Wavelength range (μm)	Central wavelength (μm)	Nominal subsatellite IGFOV (km)	Sample use
1	0.45–0.49	0.47	1	Daytime aerosol over land, coastal water mapping
* 2	0.59–0.69	0.64	0.5	Daytime clouds fog, insolation, winds
3	0.846–0.885	0.865	1	Daytime vegetation/burn scar and aerosol over water, winds
4	1.371–1.386	1.378	2	Daytime cirrus cloud
5	1.58–1.64	1.61	1	Daytime cloud-top phase and particle size, snow
6	2.225–2.275	2.25	2	Daytime land/cloud properties, particle size, vegetation, snow
* 7	3.80–4.00	3.90	2	Surface and cloud, fog at night, fire, winds
8	5.77–6.6	6.19	2	High-level atmospheric water vapor, winds, rainfall
* 9	6.75–7.15	6.95	2	Midlevel atmospheric water vapor, winds, rainfall
10	7.24–7.44	7.34	2	Lower-level water vapor, winds, and SO_2
11	8.3–8.7	8.5	2	Total water for stability, cloud phase, dust, SO_2 rainfall
12	9.42–9.8	9.61	2	Total ozone, turbulence, and winds
13	10.1–10.6	10.35	2	Surface and cloud
* 14	10.8–11.6	11.2	2	Imagery, SST, clouds, rainfall
* 15	11.8–12.8	12.3	2	Total water, ash, and SST
16	13.0–13.6	13.3	2	Air temperature, cloud heights and amounts

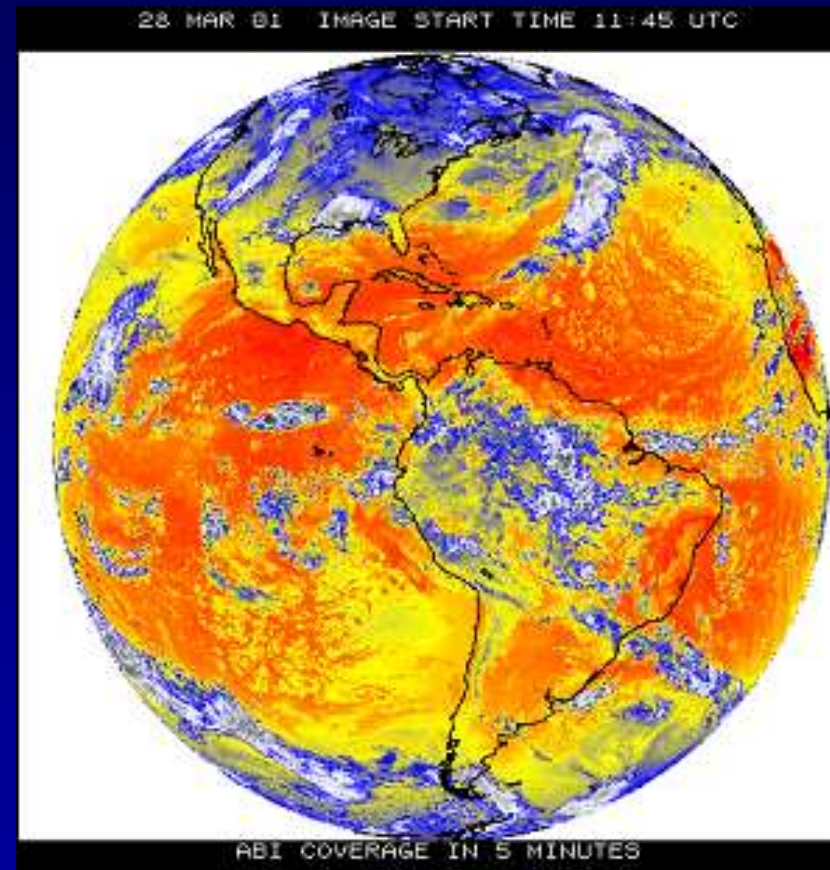# Approximate spectral and spatial resolutions of US GOES Imagers

~ Band Center (um)		GOES-6/7	GOES-8/11	GOES-12/N	GOES-O/P	GOES-R+
Visible	0.47					▪
	0.64	▪	▪	▪	▪	·
Near-IR	0.86					▪
	1.6					▪
	1.38					▪
	2.2					▪
Infrared	3.9		▪	▪	▪	▪
	6.2					▪
	6.5/6.7/7	14km	8	4	▪	2
	7.3	"MSI mode"				▪
	8.5					▪
	9.7					▪
	10.35					▪
	11.2	▪	▪	▪	▪	▪
	12.3		▪			▪
	13.3			▪	▪	▪

Box size represents detector size

Increased Imaging Capability

5 Minute Coverage

GOES-I/P   **GOES-R**
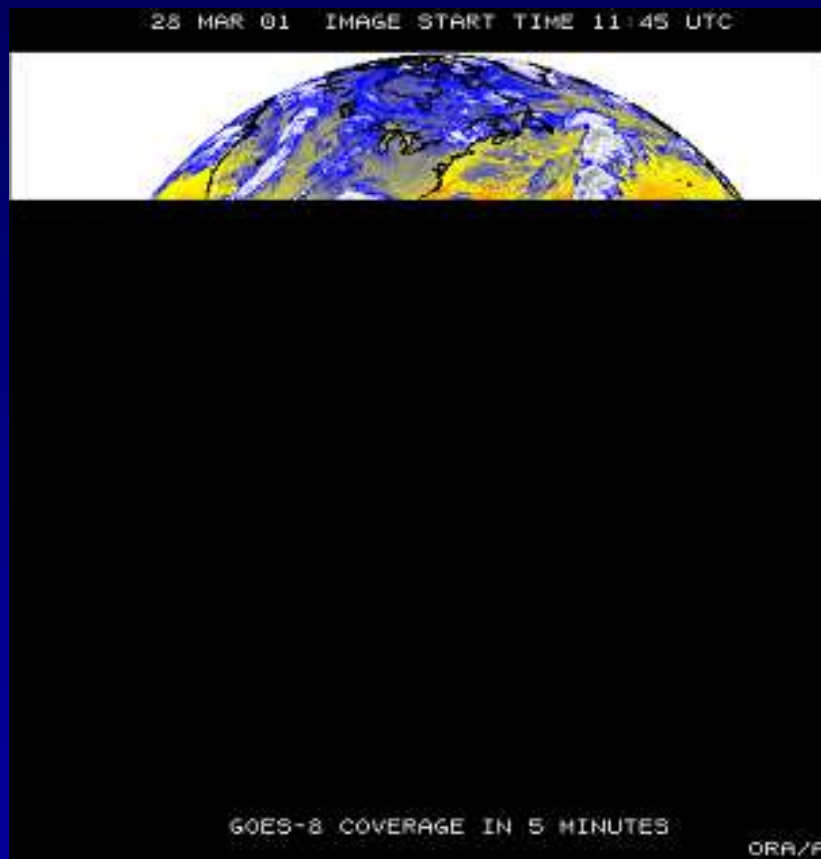
1/5 Disk   Full Disk

GOES-R Super-Rapid Scan Capabilities
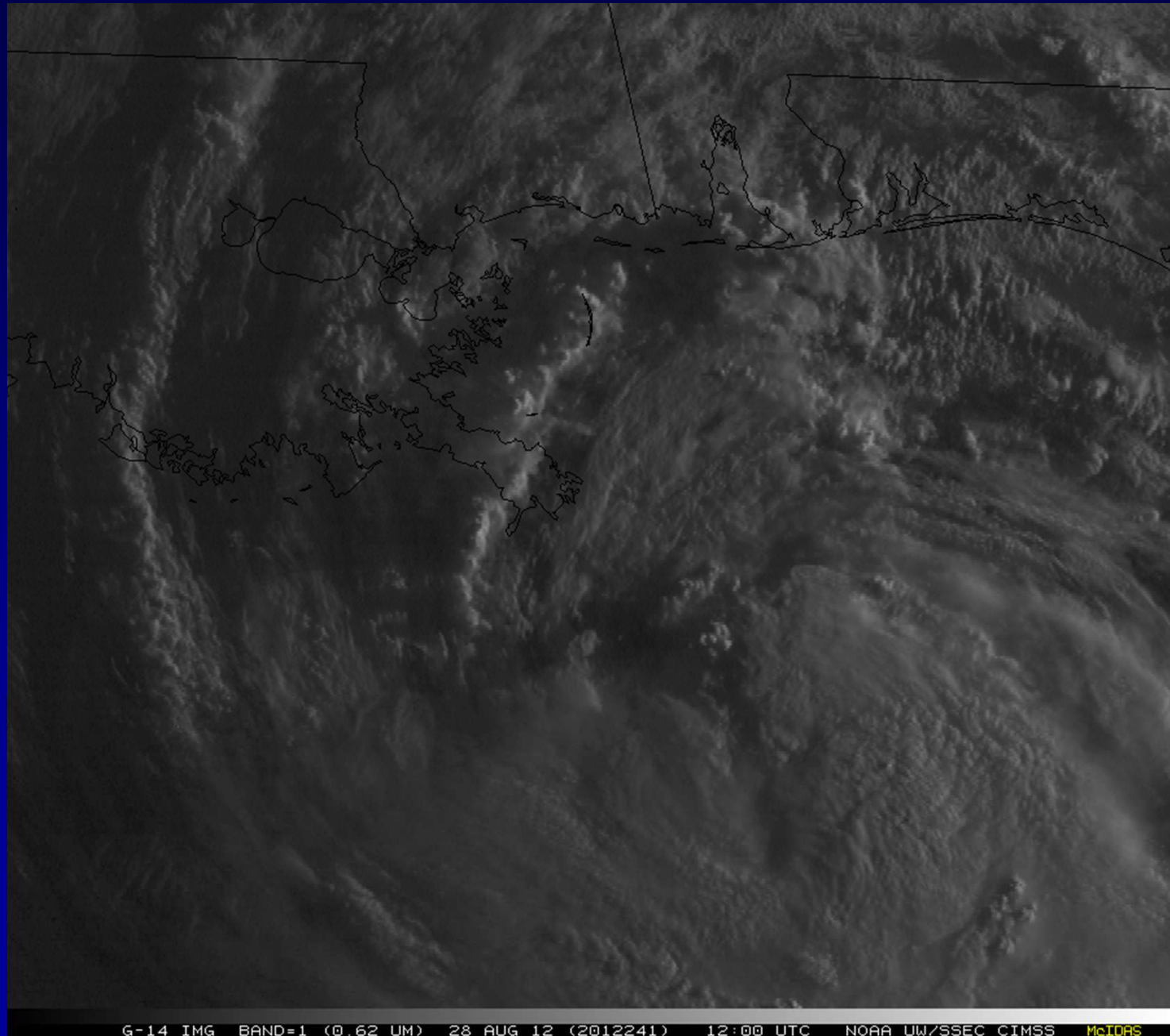
G-14 IMG   BAND=1 (0.62 UM)   28 AUG 12 (2012241)   12:00 UTC   NOAA UW/SSEC CIMSS   McIDAS

•53

Pseudo-Natural Color Imagery

- **The ABI does not have a channel for green visible imagery, so it cannot make true/natural color visible images. (The Himawari-8 imager includes a green channel.)**

- **Data for the green channel can be estimated form other channels to help create pseudo-natural color imagery.**
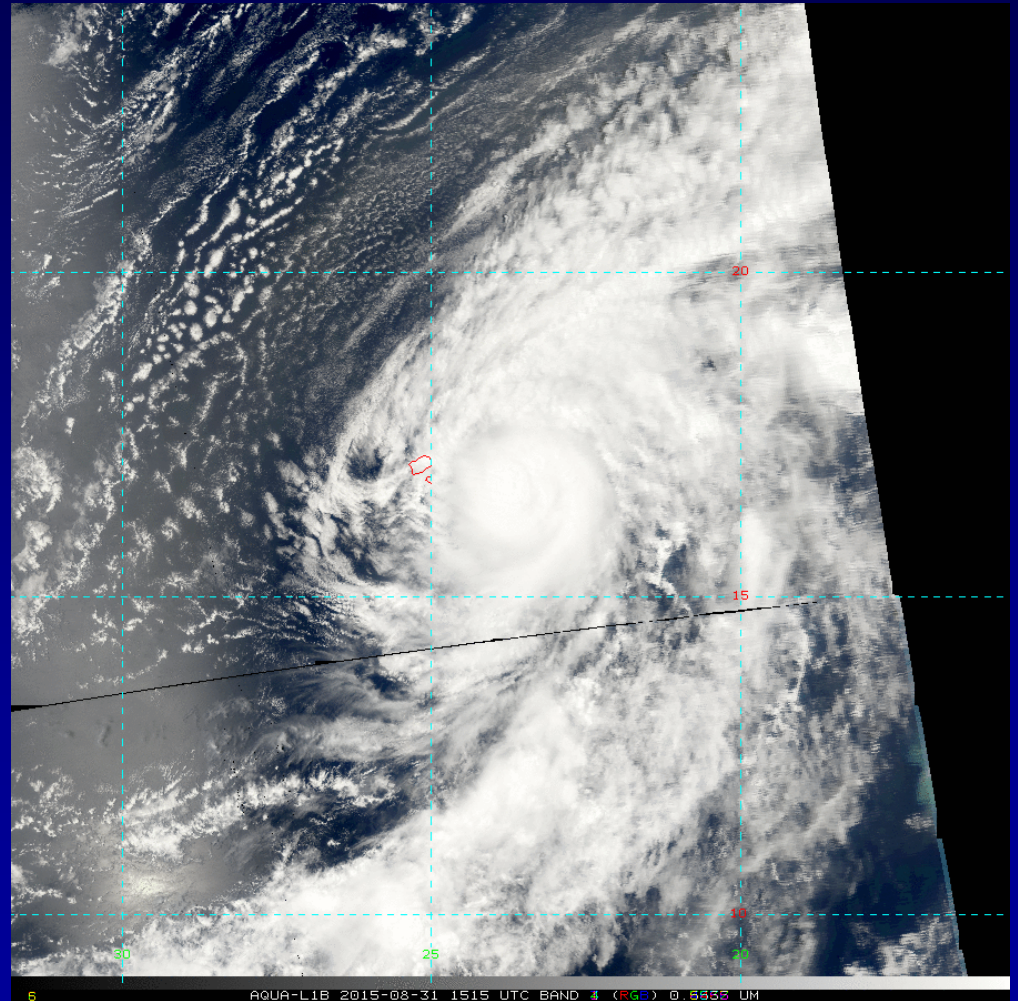
Airmass RGB: Colour Interpretation
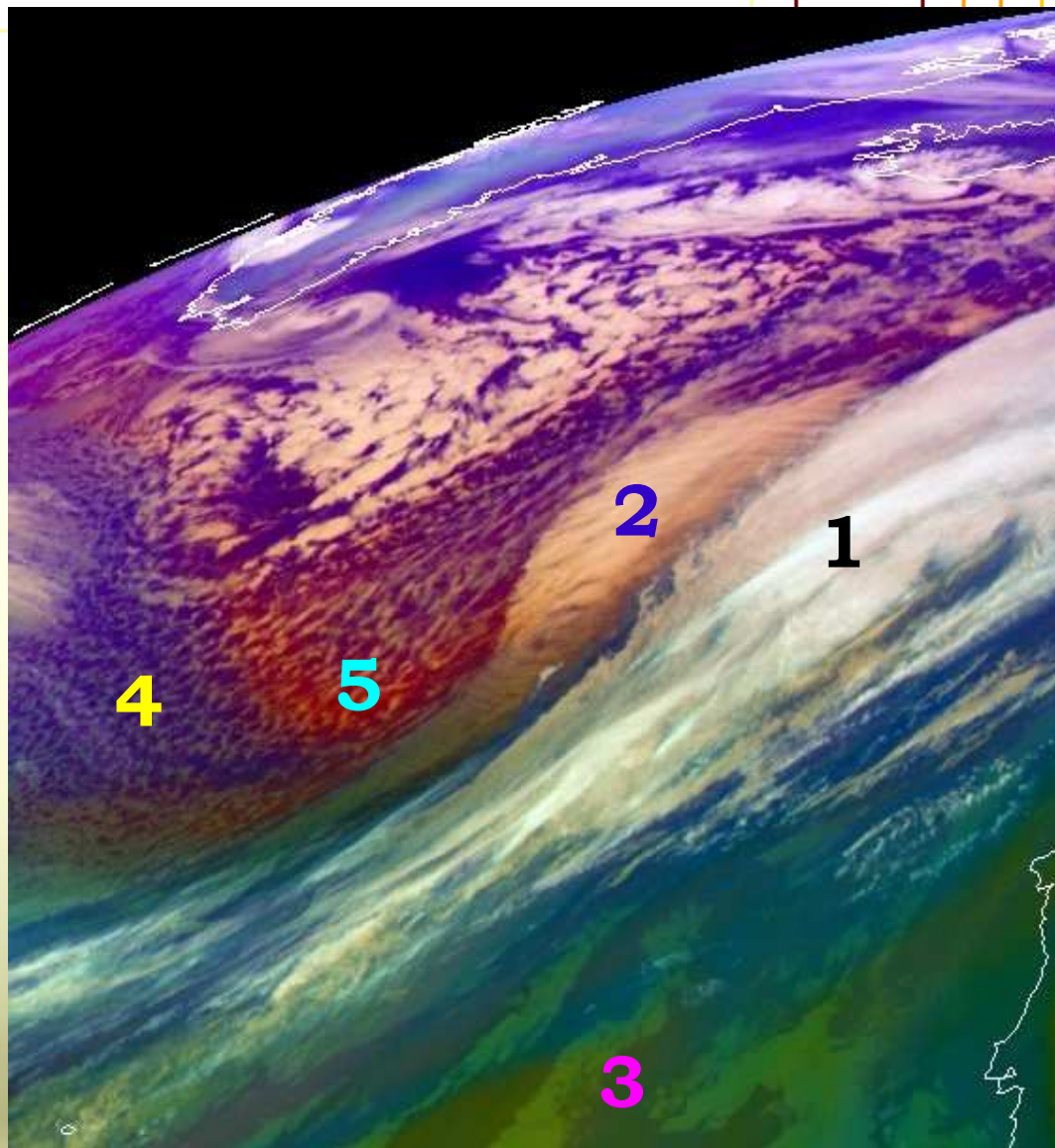
1 = high clouds
2 = mid-level clouds
3 = warm airmass, high tropopause
4 = cold airmass, low tropopause
5 = dry descending stratospheric air

MSG-1
07 January 2005
15:00 UTC
RGB Composite
R = WV6.2 - WV7.3
G = IR9.7 - IR10.8
B = WV6.2

EUMETSAT

Extratropical Transition of Katia (2011) in RGB Airmass Product

MET-9 KATIA RGB AIRMASS 20110909 2100 UTC
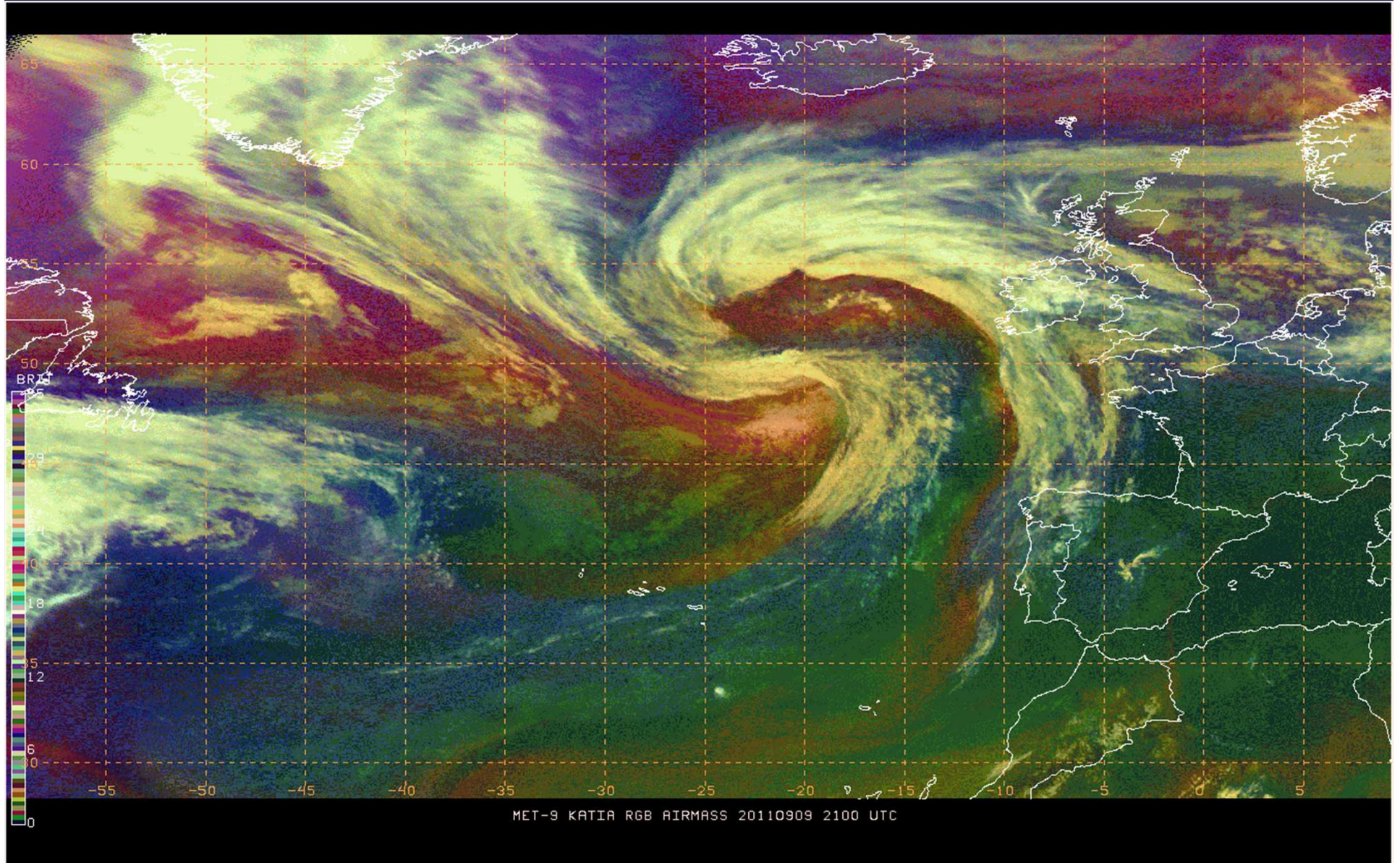
RGB Airmass Images of Alex (2016)
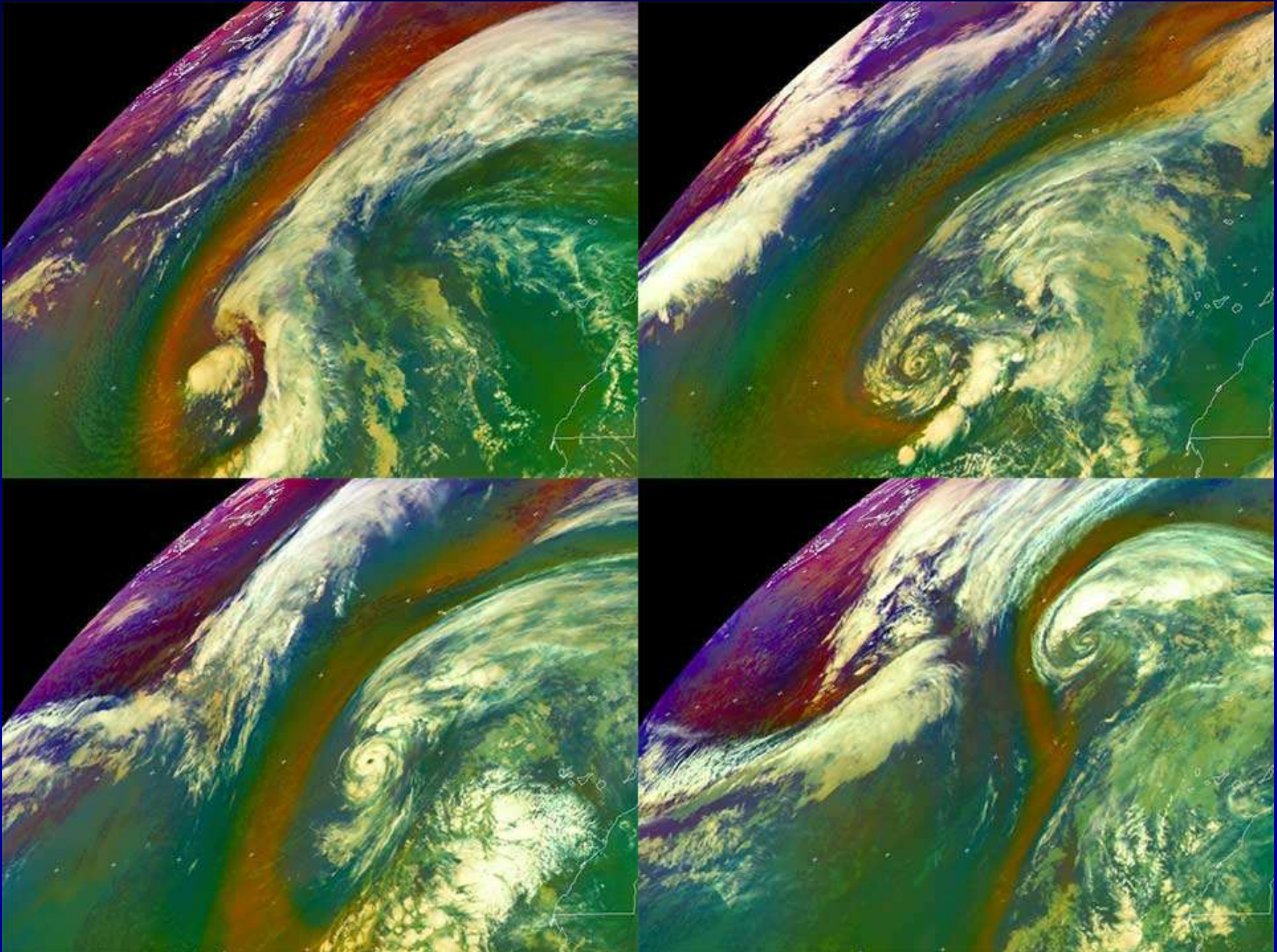
METEOSAT RGB Dust Imagery –
Evaluating Moisture

Met-10 Dust RGB, 18 Sep 2013, 12 Z

METEOSAT RGB Dust Imagery – Evaluating Moisture
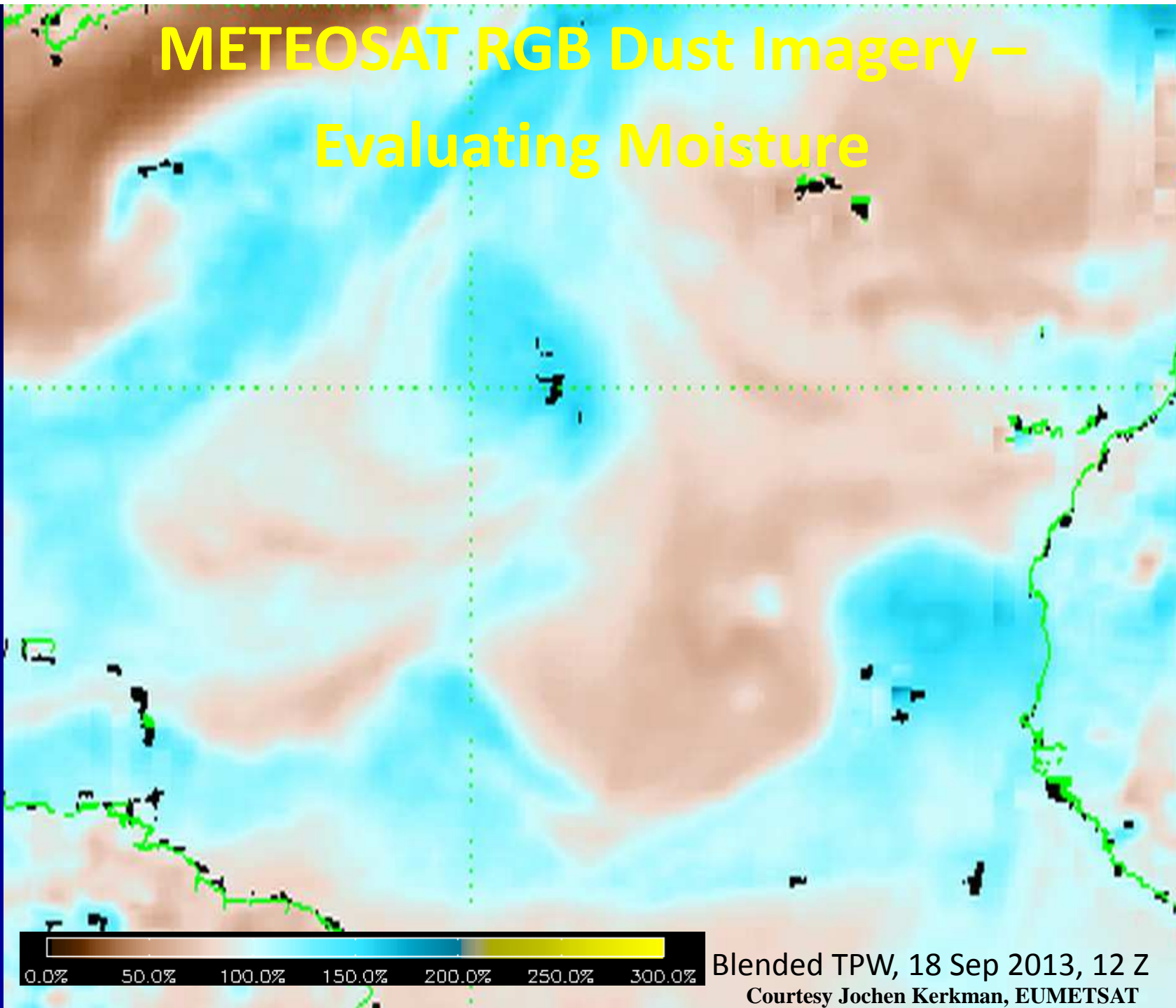
Blended TPW, 18 Sep 2013, 12 Z
Courtesy Jochen Kerkman, EUMETSAT

RGB Night Microphysics Image
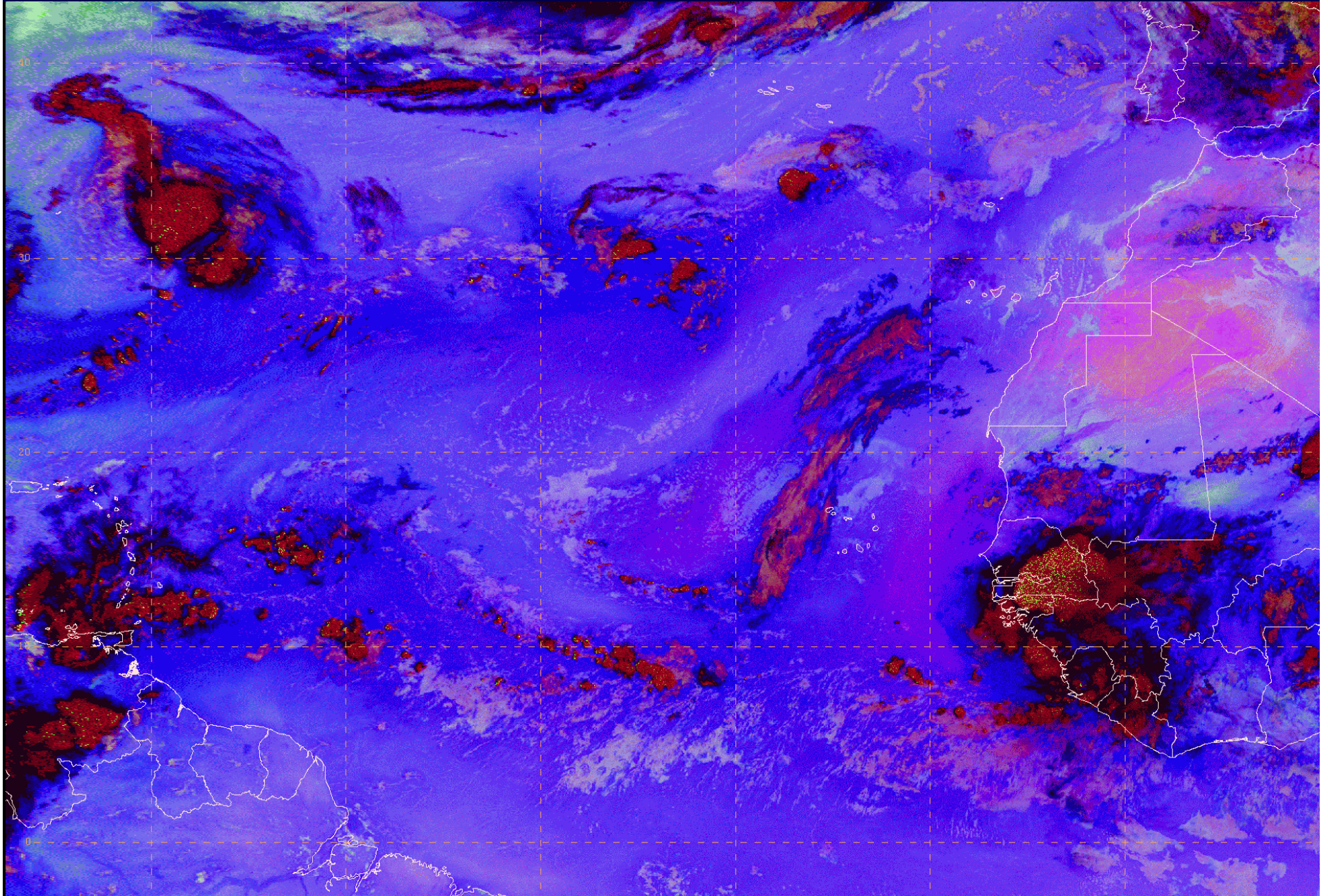
Daytime Convective Storms Product

- **Provides information about**
  - **Cloud top particle size (related to updraft strength)**
  - **Cloud top phase**
  - **Precipitation**
- **Tropical applications**
  - **Cloud discrimination (convective, stratiform)**
  - **Genesis and intensity forecasting**
- **Generated from MSG SEVIRI channels WV6.2, WV73, IR3.9, IR10.8, NIR1.6, VIS0.6**
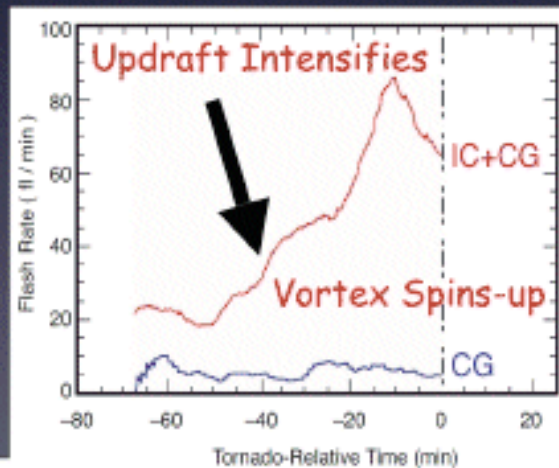- **Highlights differences between dry, tropical, and cold air masses**

TS Jerry (2013)

61
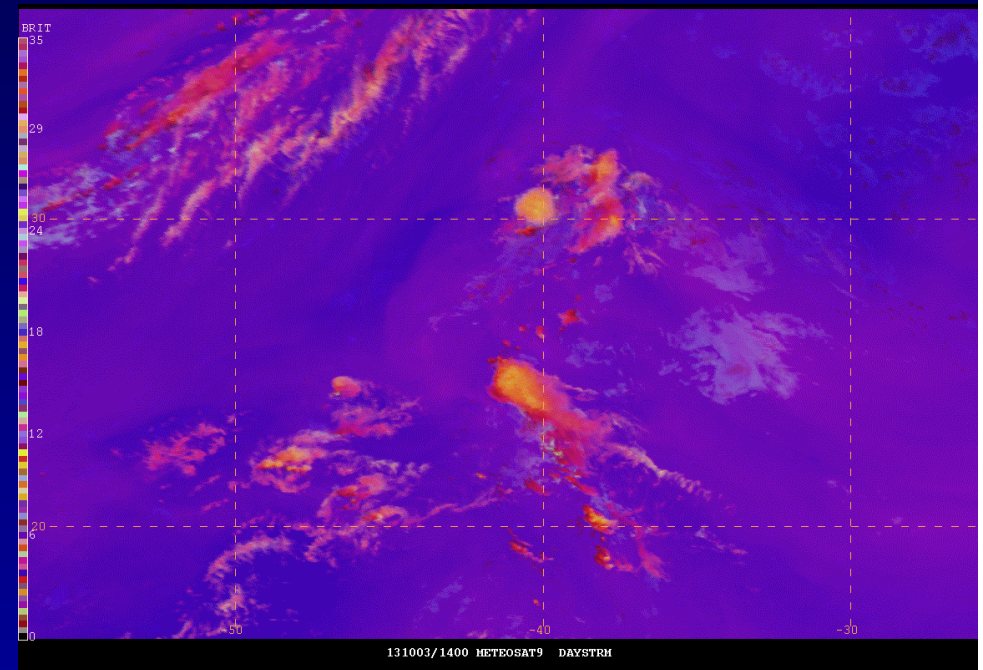
Geostationary Lightning Mapper (GLM) - Continuous GEO Total Lightning will identity severe storm potential
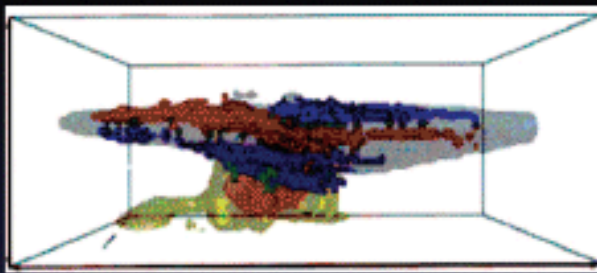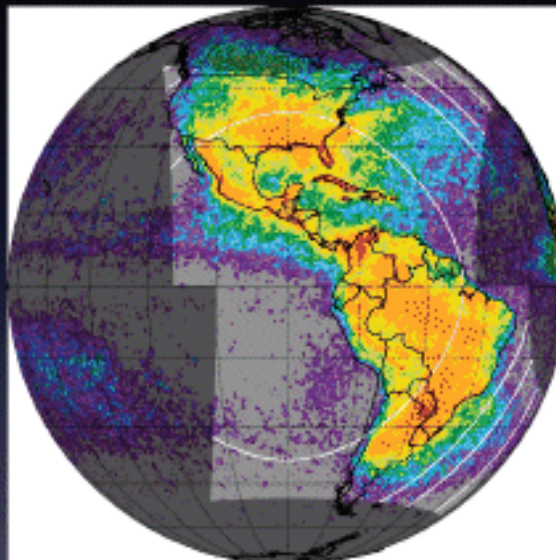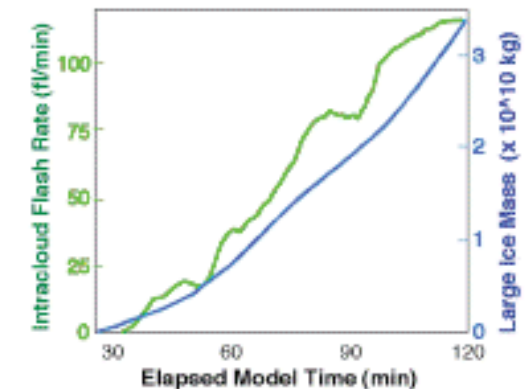
An Example of Lightning in Eastern Pacific Tropical Cyclones

Irwin – became a hurricane a few hours later

Jova – struggling against shear
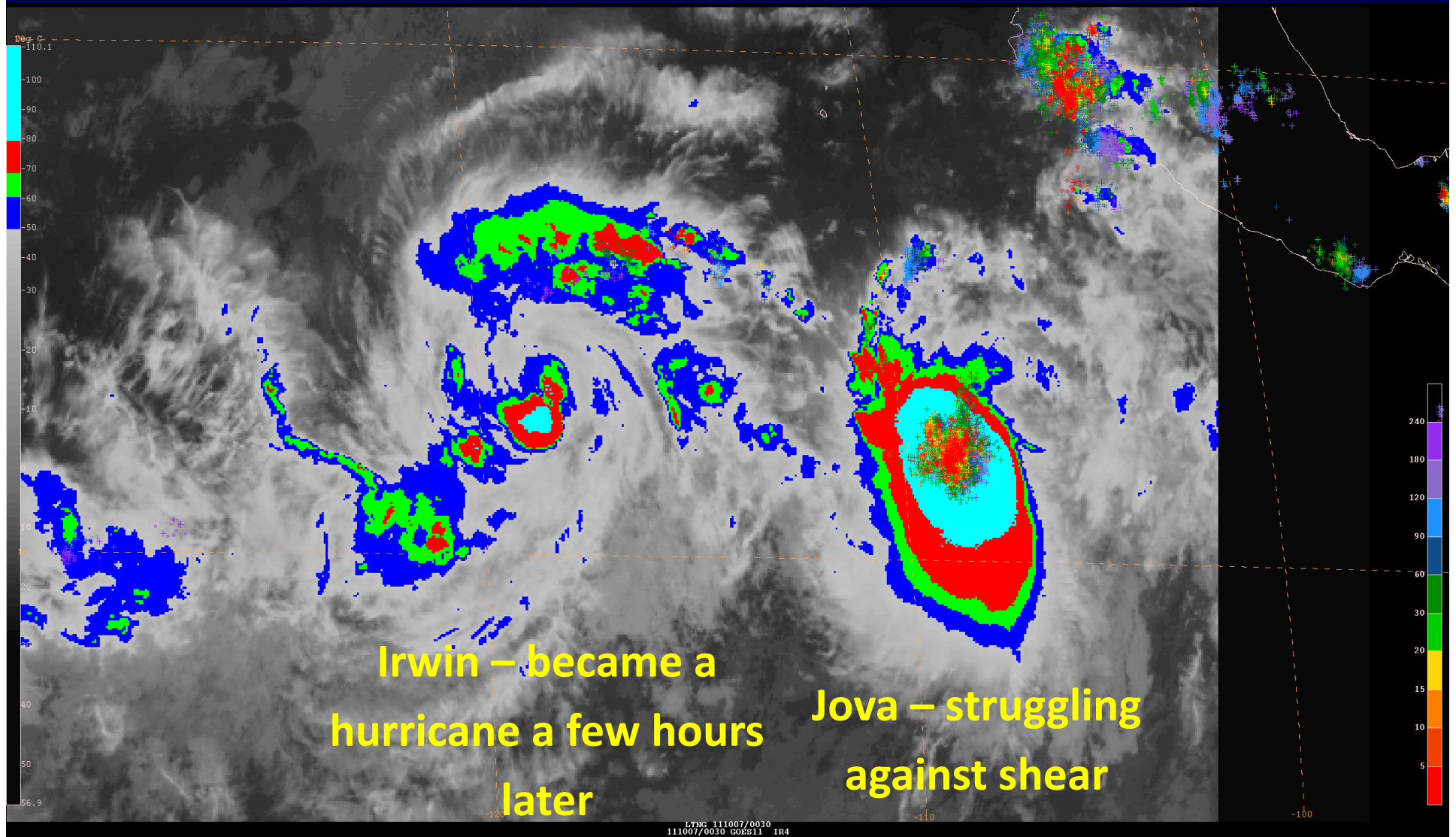
Conclusions

- **Remote sensing satellites use the principles of radiative transfer when designing the instrument type and the portions of the electromagnetic spectrum the instruments use.**

- **A large part of the TC forecast process is based on data from satellites.**

- **The GOES-R series of geostationary satellites will create new ways to monitor the tropical cyclone and the nearby environment.**

151023/0445 GOES13   IR4

Questions?