Meteorological Satellites and Satellite Interpretation

JACK BEVEN
NATIONAL HURRICANE CENTER

WHERE AMERICA'S CLIMATE AND WEATHER SERVICES BEGIN

Overview

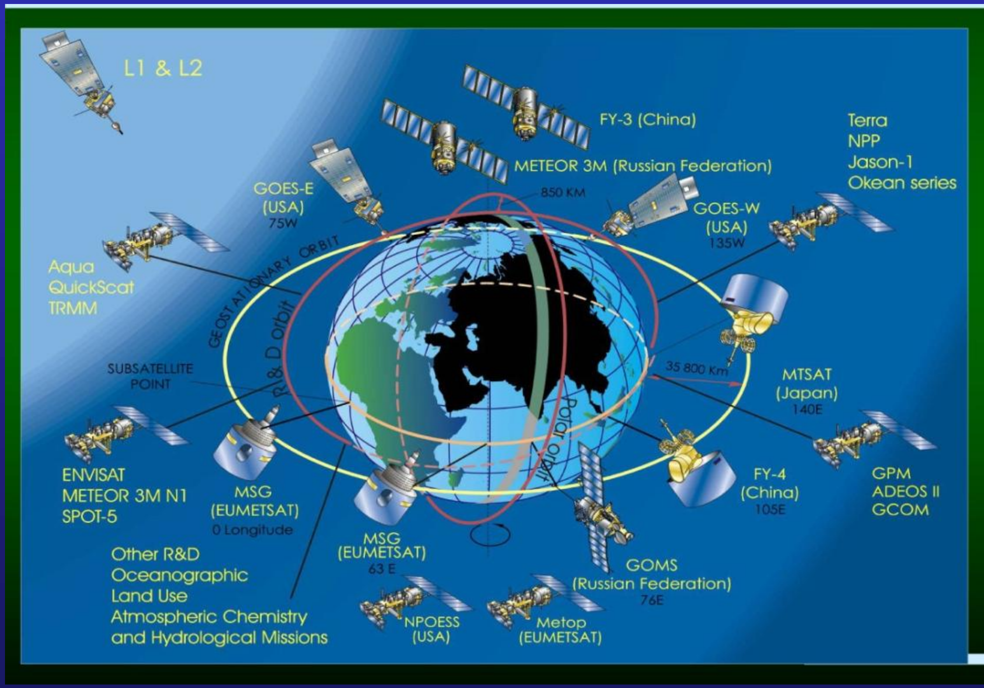
- Introduction
- Some Physical Principles
- Classes of Satellites
- Instruments and Data
- Basics of Interpretation
- The Future

Introduction

- Meteorological satellites are remote-sensing instruments that can sample large parts of the atmosphere spatially and temporally
- Meteorological satellites use a variety of orbits, with geostationary and polar orbiting being the most common
- Some satellite instruments are passive - they receive a signal from the atmosphere or Earth's surface (radiometers)
- Other instruments are active - they transmit and receive a signal (radar or scatterometers)

Introduction

- 1957 - First satellite (Sputnik)
- 1960 - First weather satellite (TIROS)
- Mid-1960's - First polar-orbiting weather satellites
- Late 1960's – First geostationary weather satellites
- Today - global weather satellite coverage



An Occupational Hazard with Satellites

GOES-N launch

Uh-oh!

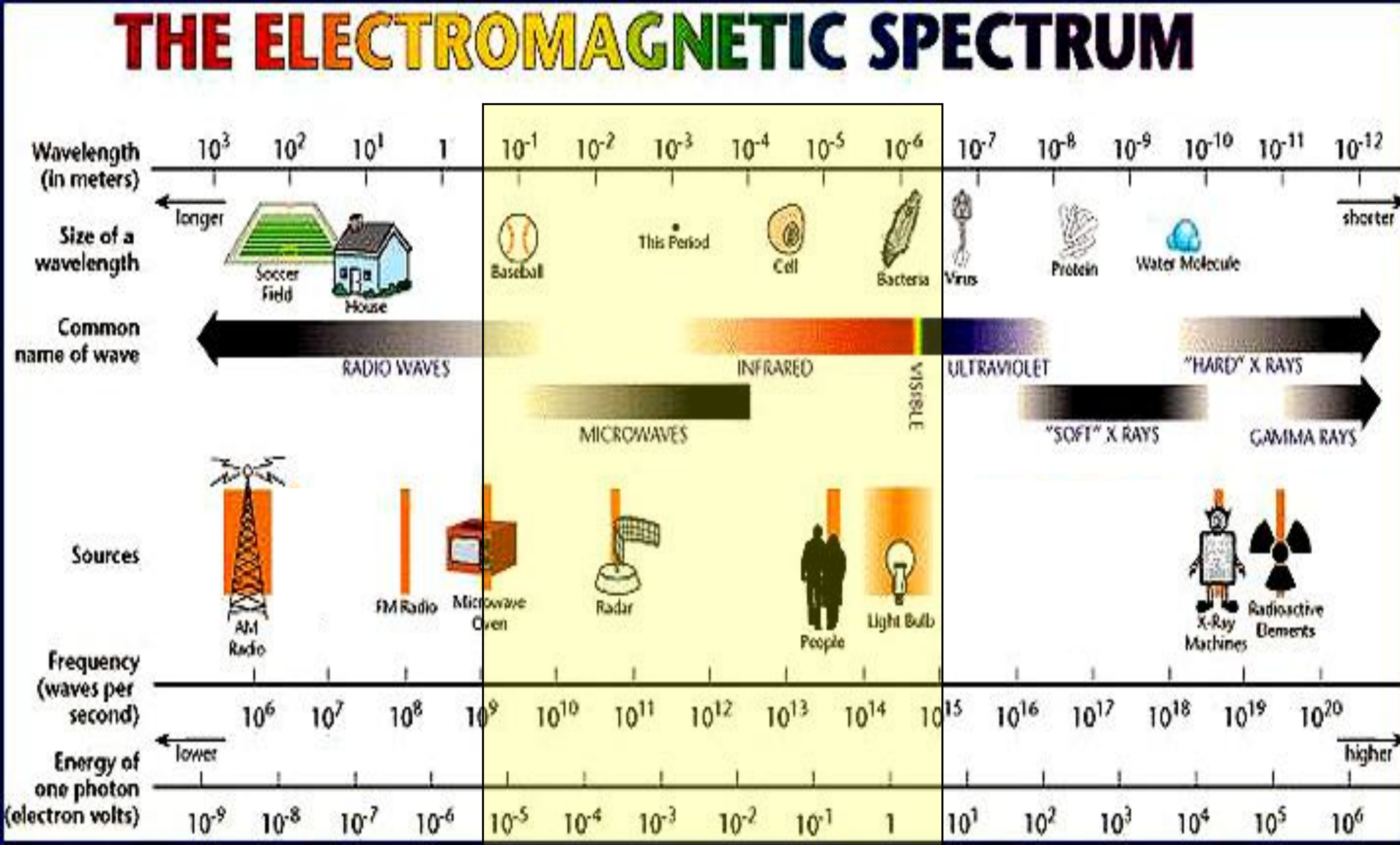
Other Possible Satellite Problems

- Satellites do not always last their full expected lifetime (ADEOS/NSCAT, ADEOS II)
- Meteorological satellites cannot be repaired in orbit (yet)
- Satellites take time (and money) to build and cannot normally be replaced quickly

How do meteorological satellites work?

- The instruments on the satellites measure radiation from the Earth's land surface, ocean surface, atmosphere, and clouds
- Radiation can be reflected from the Earth's surface, emitted from the surface straight to space, or absorbed and re-emitted in the atmosphere
- Use of radiation in various parts of the electromagnetic spectrum allows many meteorological quantities to be measured

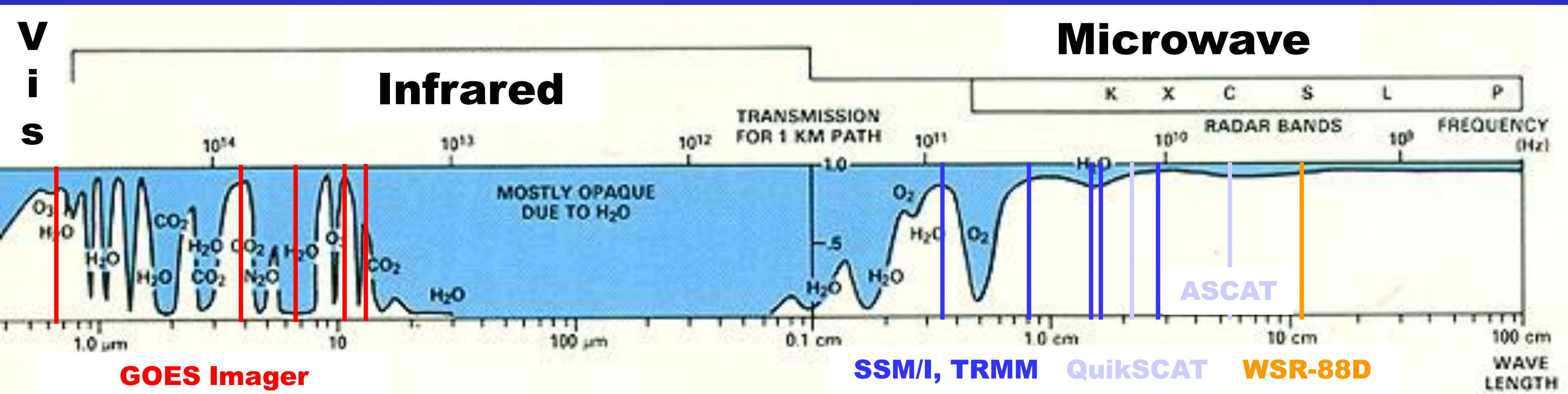
Meteorology mainly uses radiation from the visible (VIS), infrared (IR), and microwave (MW)/radio portions of the electromagnetic spectrum (wavelengths from about 0.5 µm to about 12 cm).

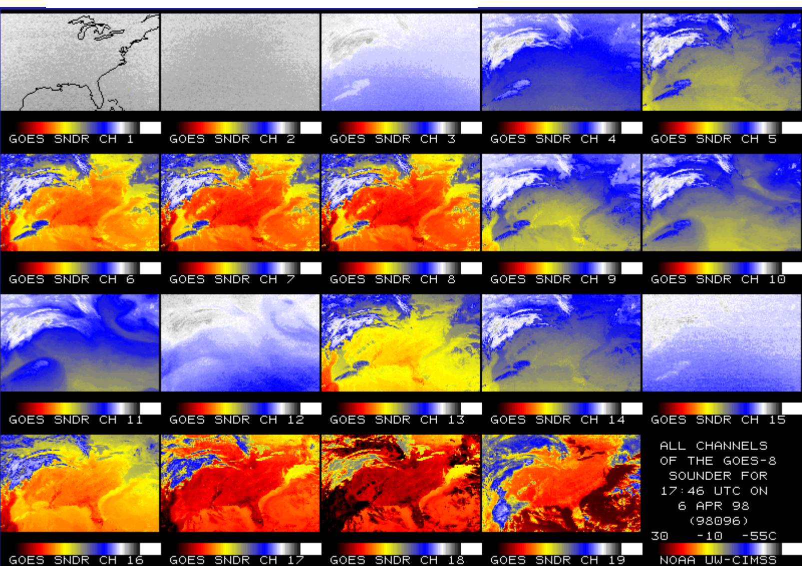


Absorption and Atmospheric "Windows"

Longer wavelength

Higher frequency

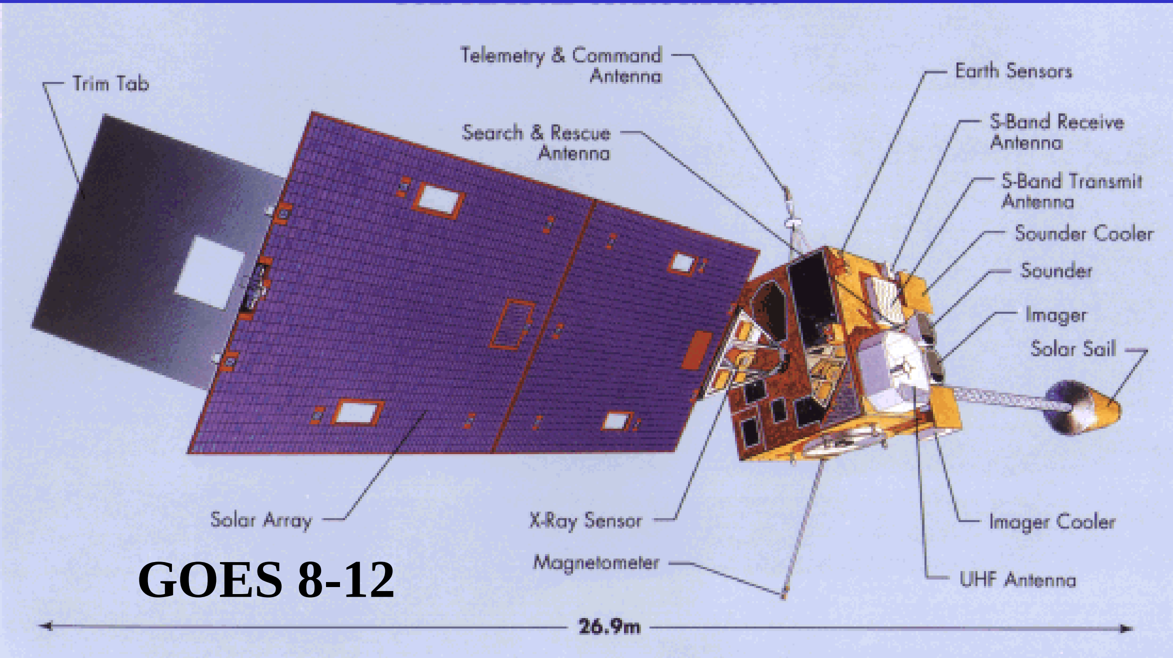




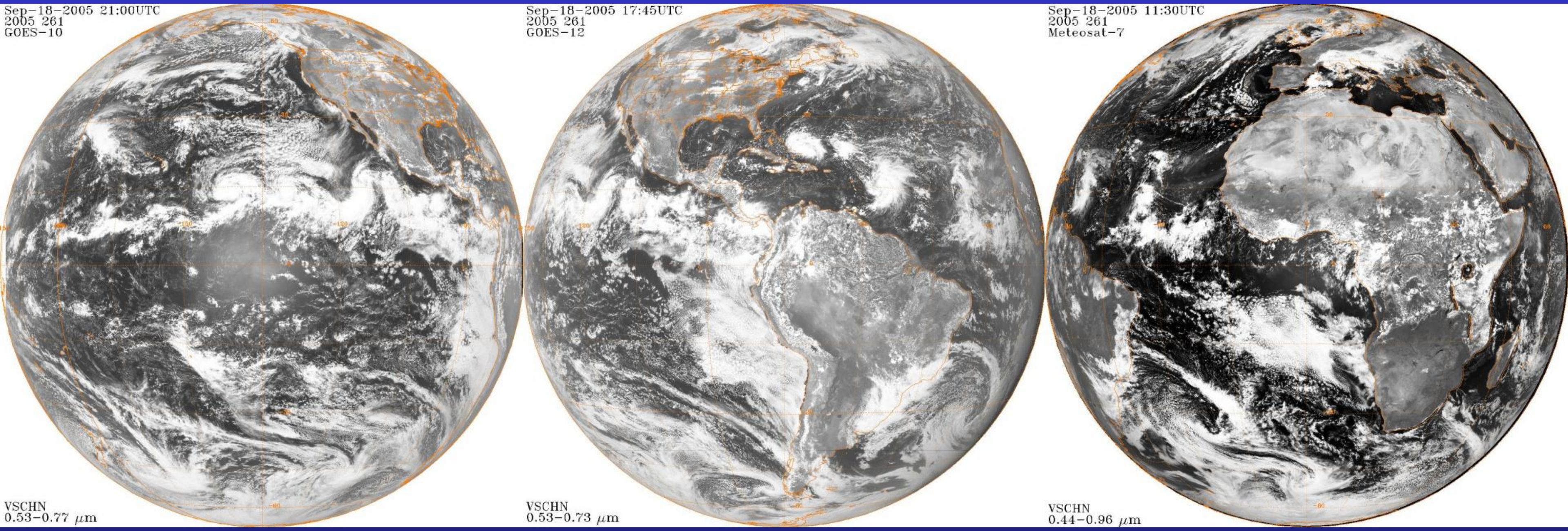
Various frequencies show different atmospheric and surface features depending on atmospheric absorption of the frequency and the composition of the absorber.

Satellite Classes - Geostationary

- Orbits called "geostationary" as satellite does not move with respect to the Earth's surface
- Geostationary satellites are located 22,000 miles (35,000 km) above the Earth's Equator



Geostationary Advantages

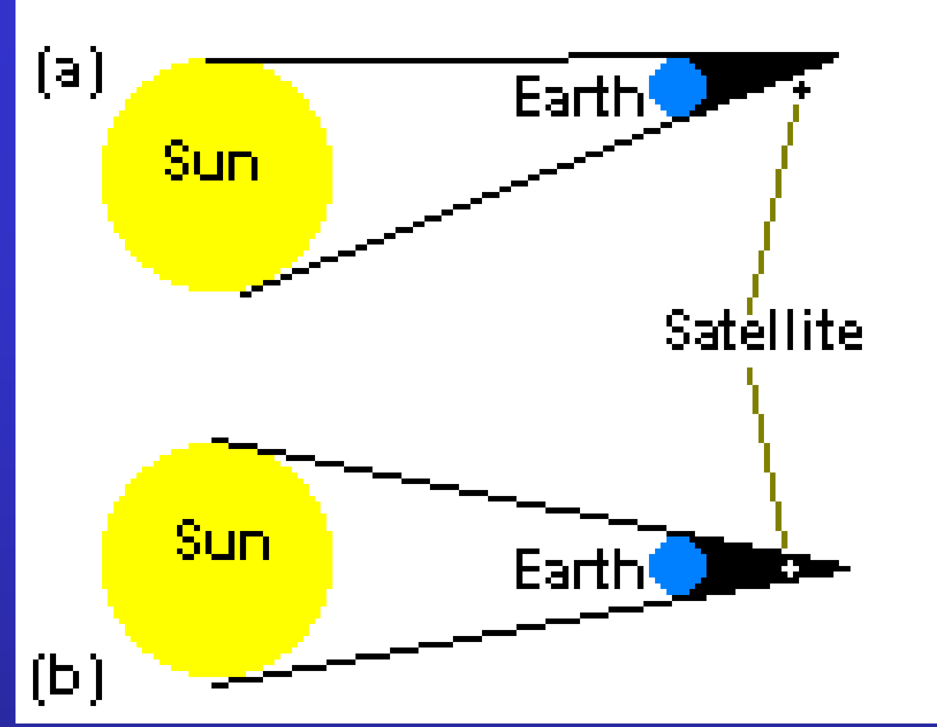


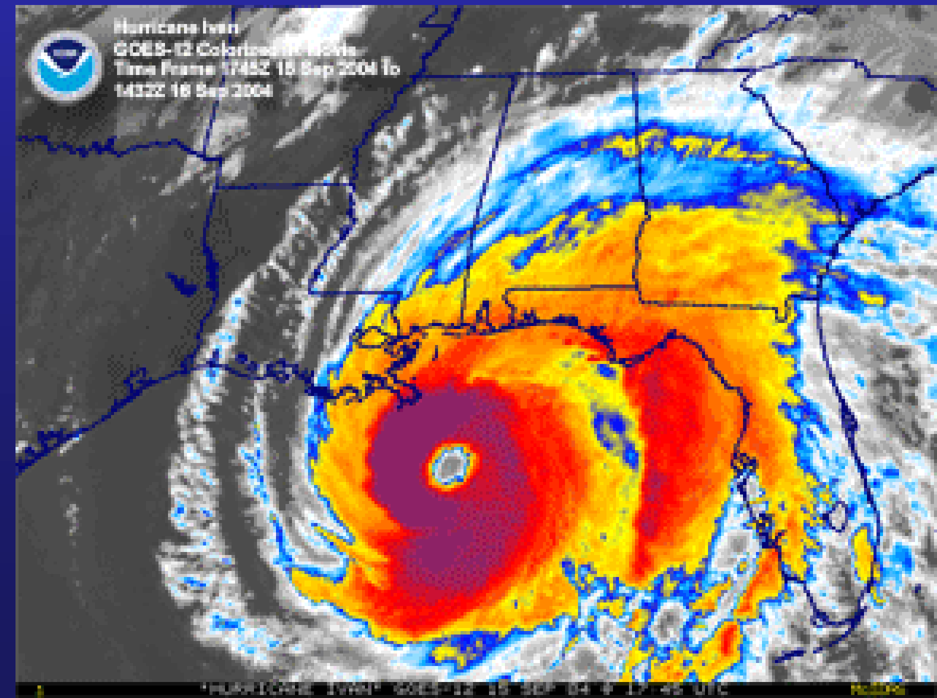
GOES-W **GOES-E** **METEOSAT**

- **Satellite sees almost half of the Earth at one time, allowing good temporal coverage over a large area**

Geostationary Disadvantages

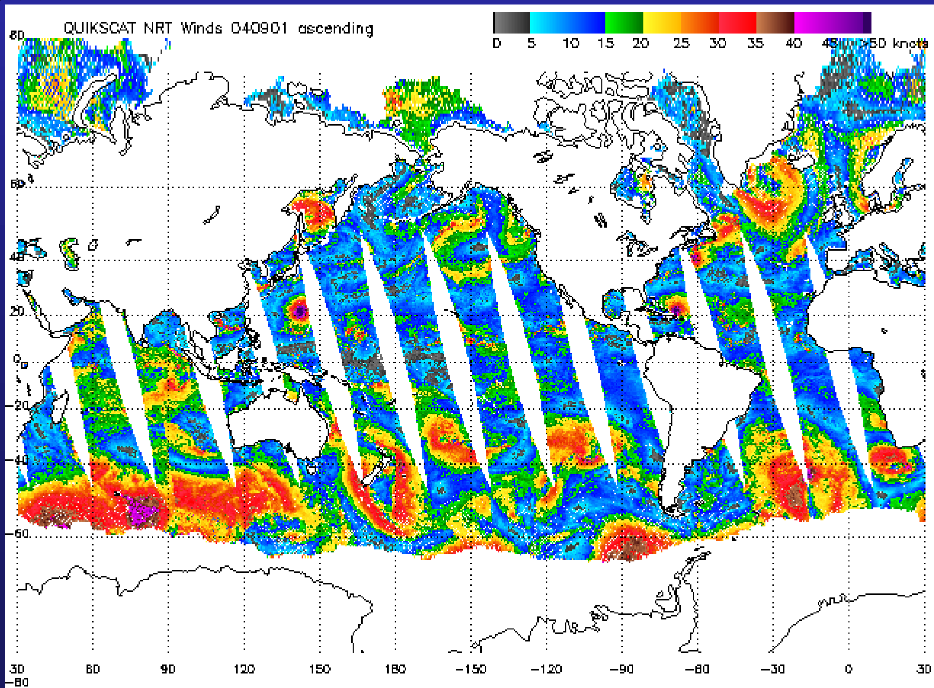
- High altitude means lower spatial resolution
- Data quality degraded at large distances from the satellite sub-point (the edges of the images)
- Satellite vulnerable to eclipse near the equinoxes (March and September) – loss of data at crucial times





Satellite Classes - Polar Orbiting

- Orbits called "polar orbiting" as the satellite pass over the Earth almost from pole to pole
- Polar orbiting satellites are generally 300-1000 miles (500-1600 km) above the surface
- Usually sun-synchronous (the satellite crosses the Equator at the same local time every day)



Polar Orbiter Advantages

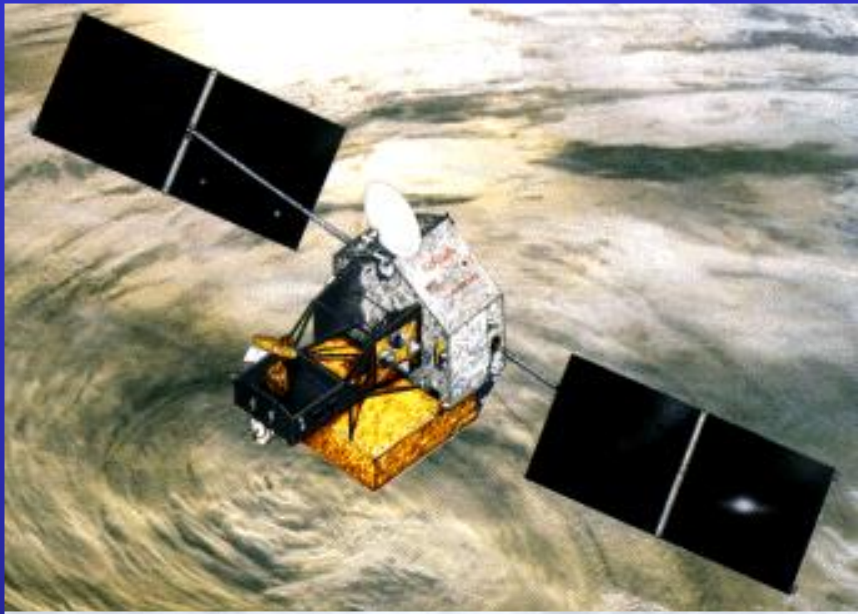
- Relatively small distance from Earth allows higher resolution data (also true for other low altitude orbiting satellites). This is most important for microwave instruments.
- Good temporal data coverage near the poles

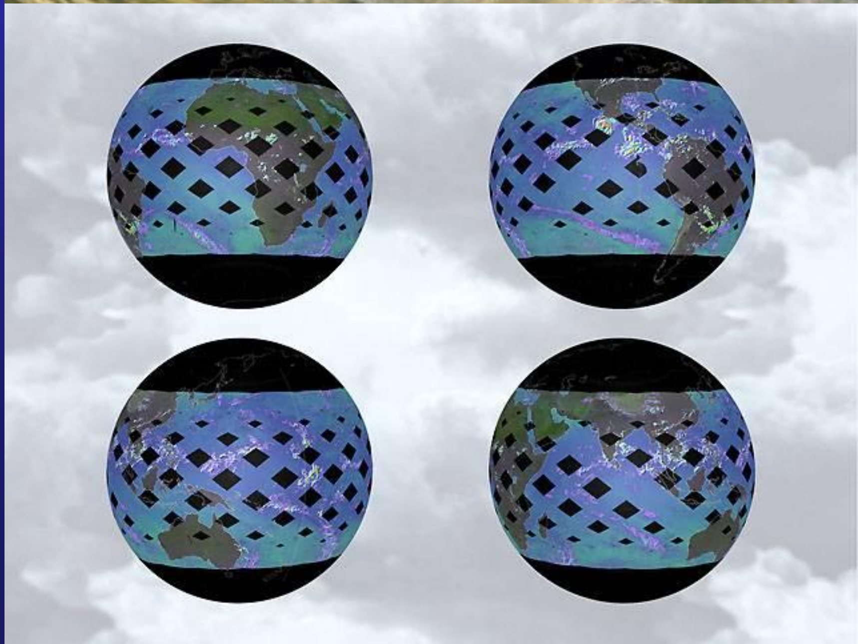
Polar Orbiter Disadvantages

- Limited temporal coverage - *except near poles* a polar orbiter only passes over an area twice per day
- Limited spatial coverage - satellite can only see a relatively small area near the orbit due to the size of the footprint (the swath covered by the satellite scanners)

Satellite Classes - Other Orbits

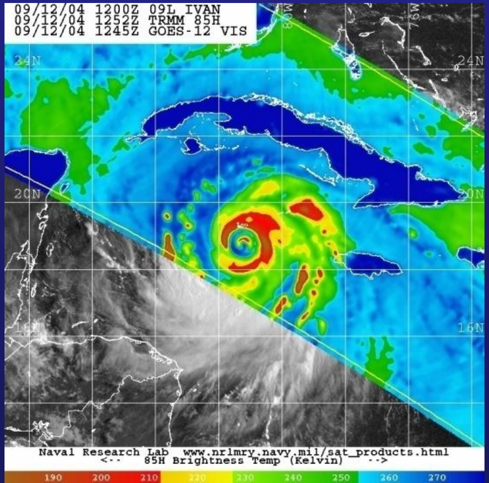
- Satellites such as the Tropical Rainfall Measuring Mission (TRMM) have specialized low-earth orbits allowing more frequent passes over certain areas, such as the tropics
- More frequent passes in certain areas usually means few or no passes over other areas

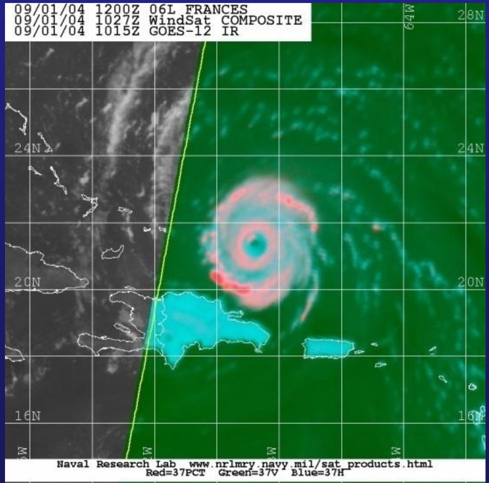


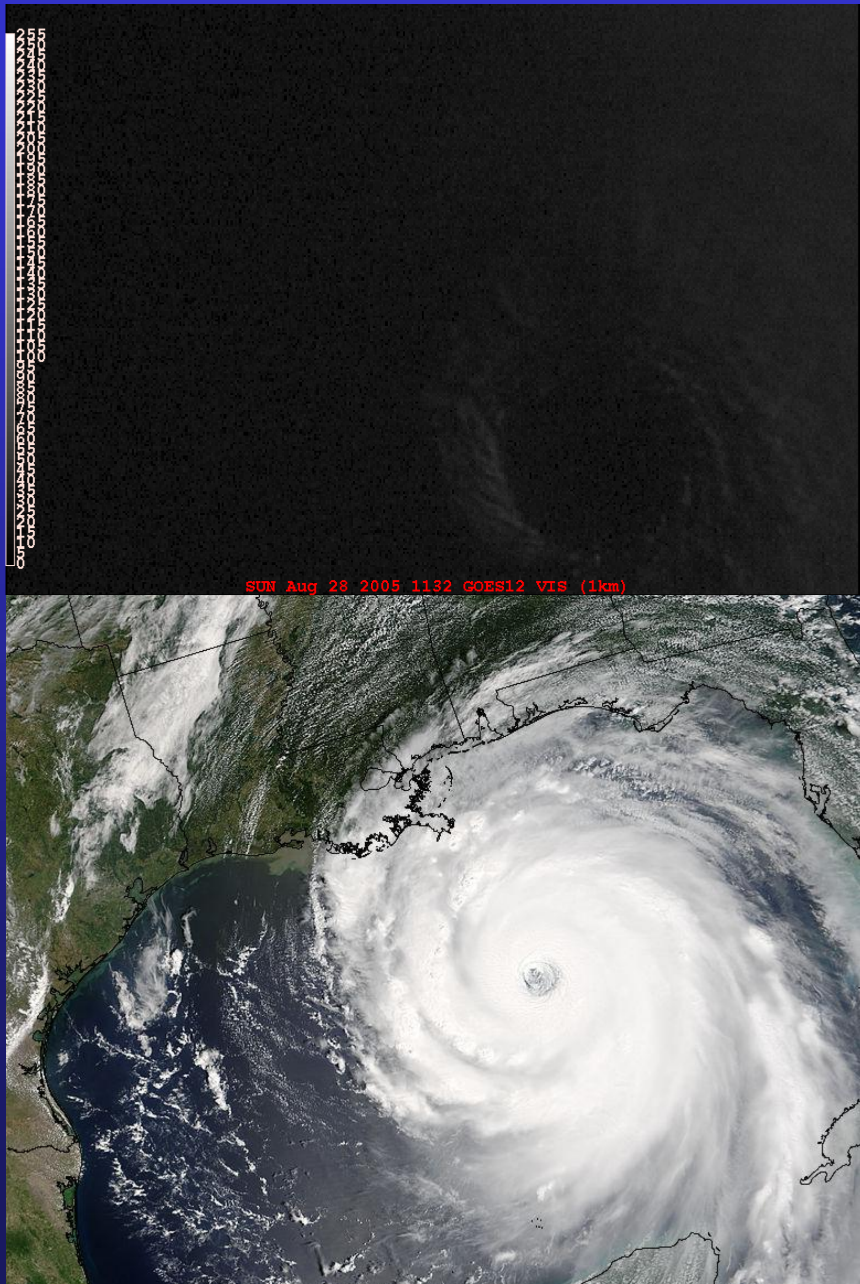


Classes of Instruments

- **Imager - Makes an image of some meteorological quantity - images are *usually* from one wavelength/frequency but can use several (<u>multispectral</u>)**
- **Satellite imagery is normally used for analysis and short-term forecasting**

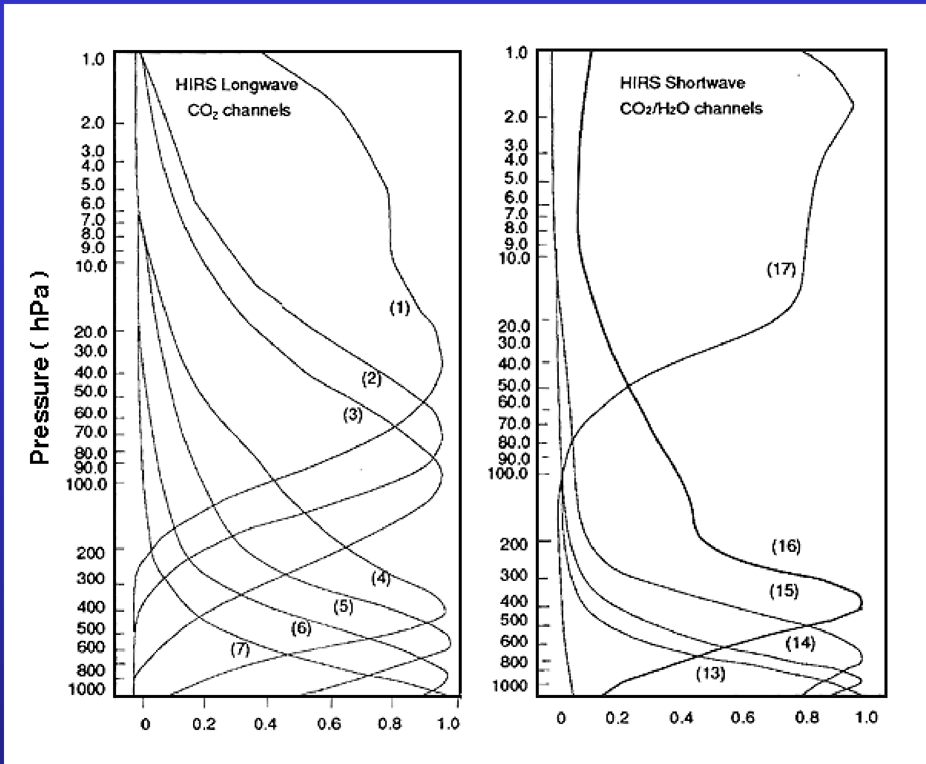


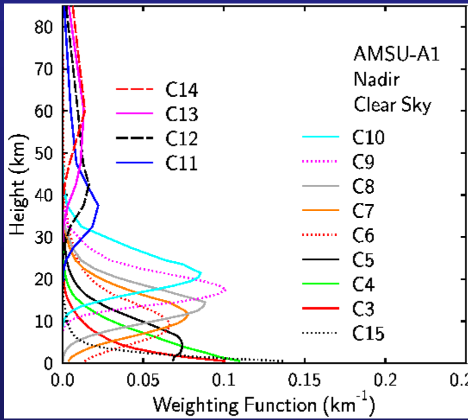


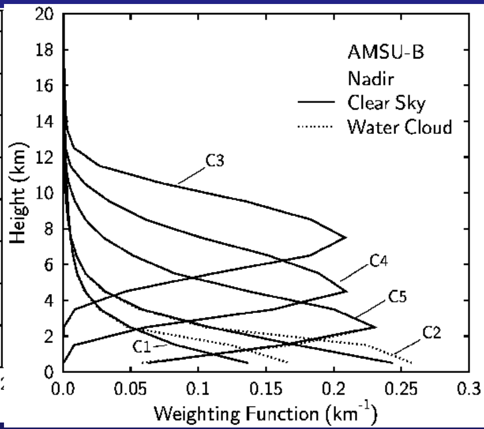


Classes of Instruments

- Sounder - Makes a vertical profile of some meteorological quantity - usually uses combinations of IR or MW frequencies
- Satellite soundings can be used for analysis and short-term forecasting, and are also assimilated into numerical weather models
- Present sounders have coarse vertical resolution and IR-based sounders cannot sound through clouds







Some satellite instruments

- Advanced Microwave Sounding Unit (AMSU) on NOAA polar orbiting satellites
- Advanced Microwave Scanning Radiometer - EOS (AMSR-E) on NASA's Aqua satellite
- Advanced Scatterometer (ASCAT) on the European METOP polar orbiting satellites
- Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra and Aqua satellites
- SeaWinds on the NASA QuikSCAT satellite
- Special Sensor Microwave/Imager (SSM/I) on the DMSP polar orbiters
- TRMM Microwave Imager (TMI) on NASA's TRMM satellite
- Windsat on the DoD Coriolis satellite

Satellite Data

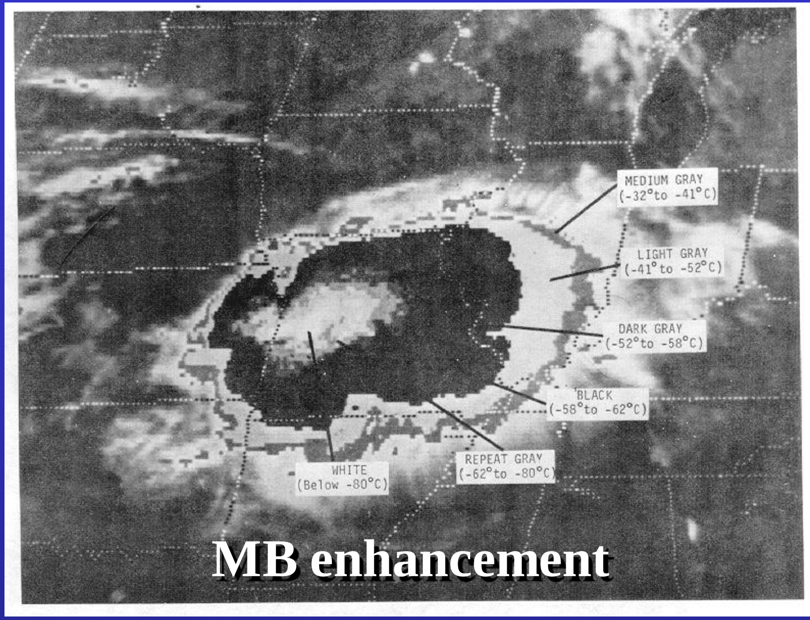
- Imagery: VIS, IR, Water Vapor (WV), MW, Multispectral - all meteorological satellites
- Satellite Atmospheric Winds: from multiple images (VIS, IR, WV) - geostationary satellites
- Sea Surface Temperatures (IR, MW) - GOES, NOAA, TRMM, Aqua, METOP
- Ocean Surface Wind Speeds (MW) * - DMSP, TRMM, Aqua, QuikScat, Coriolis/Windsat, METOP
- Precipitation Estimates (IR, MW) * - geostationary satellites, TRMM (PR), Aqua, DMSP

Satellite Data

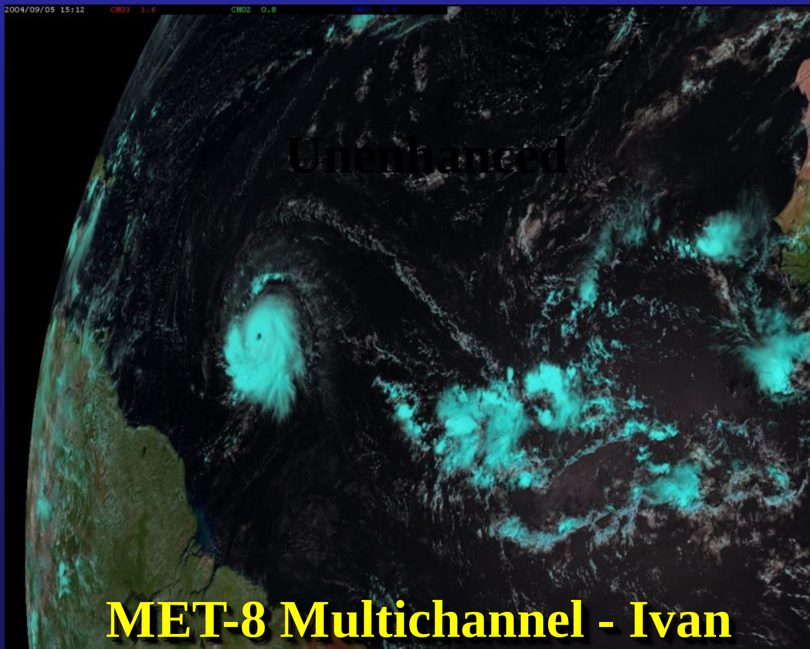
- Tropical Cyclone Intensity Estimates (VIS, IR, MW) * - geostationary satellites, NOAA (AMSU), DMSP, TRMM, Aqua, METOP
- Satellite Vertical Soundings (IR, WV, MW) - GOES, NOAA, DMSP, Aqua, METOP
- Ocean Wave Heights - Envisat, TOPEX, Jason
- Oceanic Heat Content - Envisat, TOPEX, Jason
- Total Preciptable Water (MW) - DMSP, Aqua
- Aerosol Detection (VIS, IR) – geostationary satellites, NOAA, METOP

Image Enhancements

- False coloring added to a satellite image for easier interpretation or to highlight important features
- Useful enhancements include ZA (general use), MB (high clouds and convection), BD (tropical cyclones), and JF (low clouds)
- Increasing computer power resulting in multi-channel false color imagery



MB enhancement

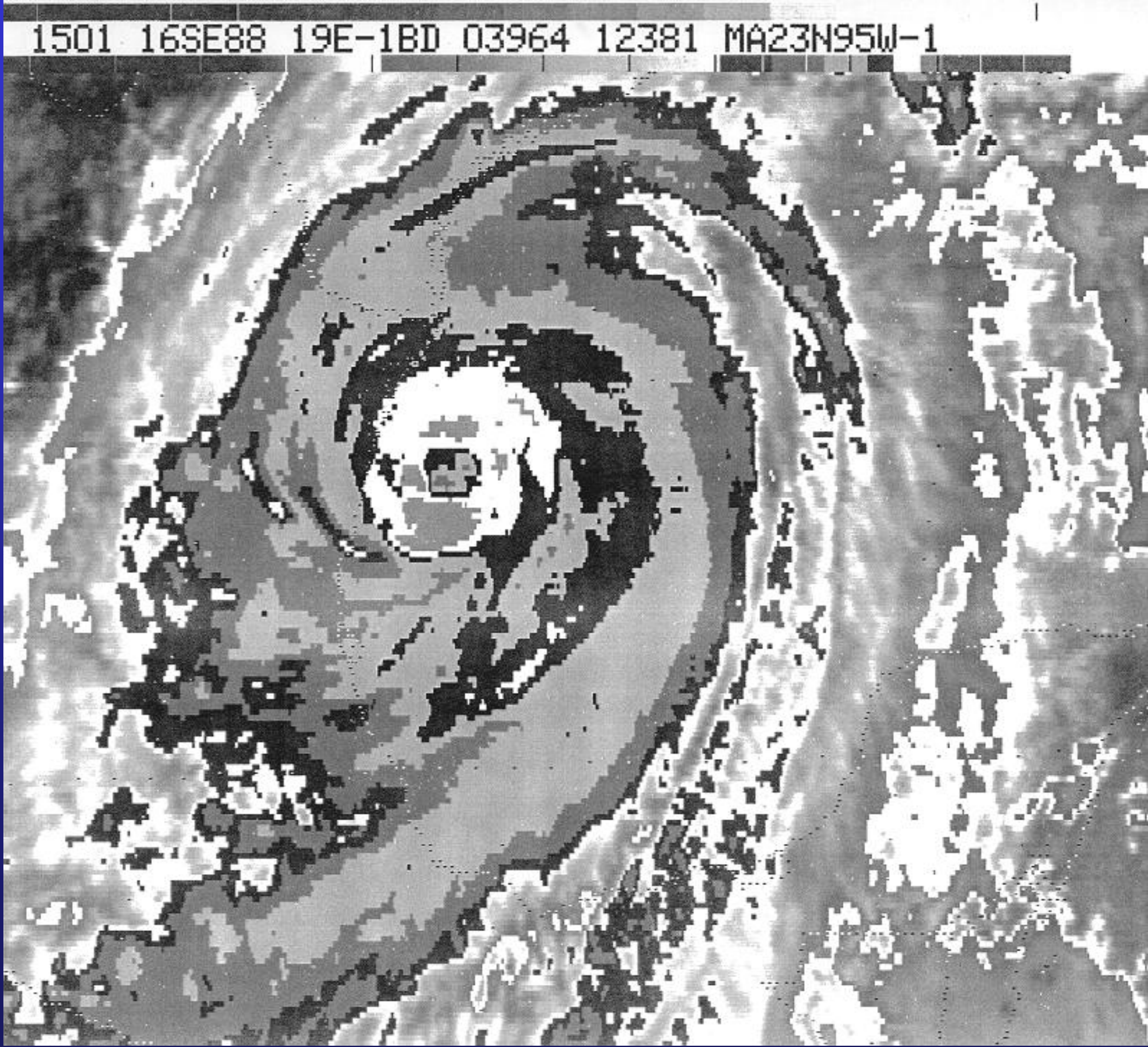


Unenhanced

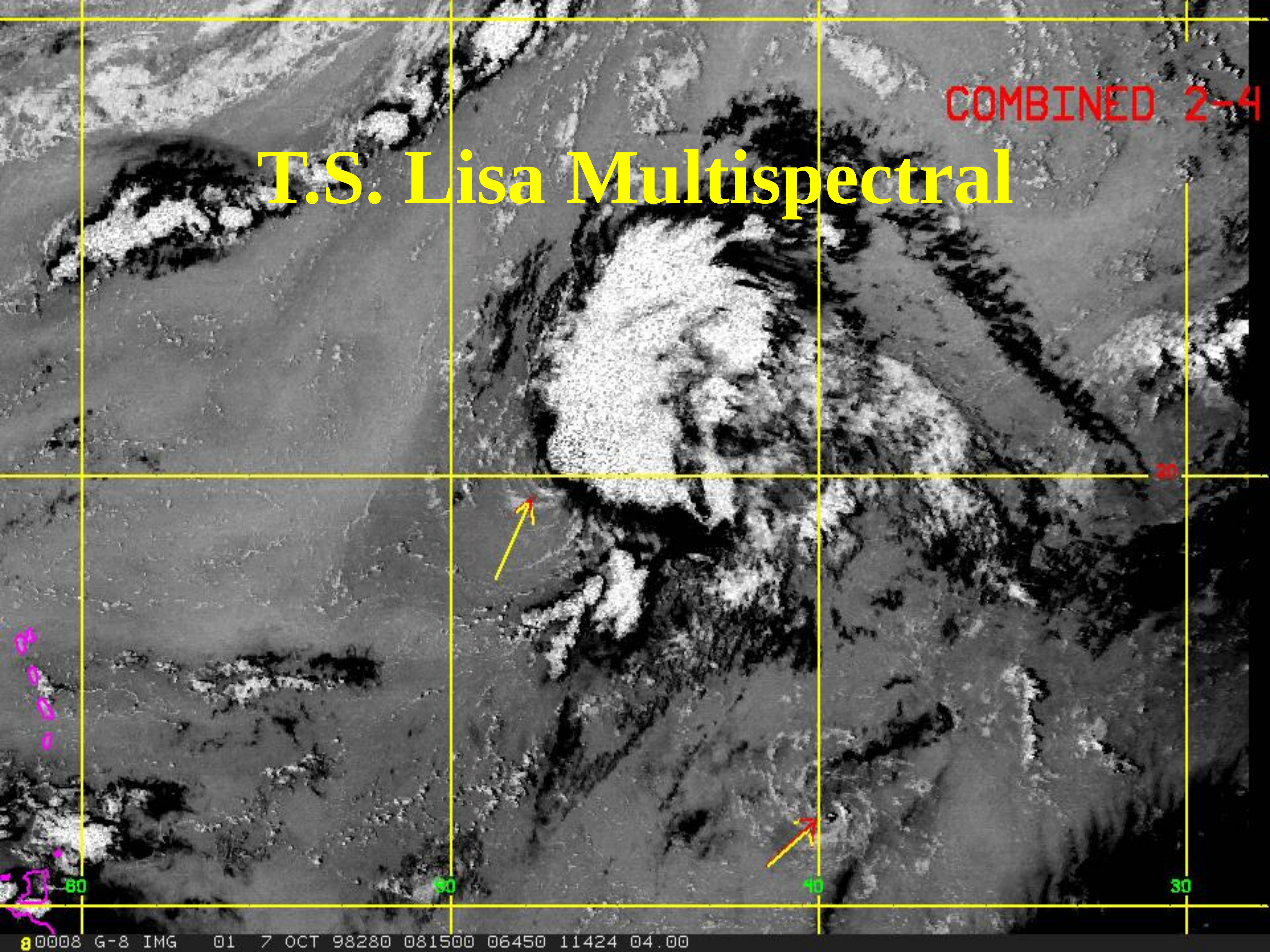
MET-8 Multichannel - Ivan

Enhanced IR Imagery (BD)

The BD curve is used with the Dvorak technique for estimating the intensity of tropical cyclones (TCs)

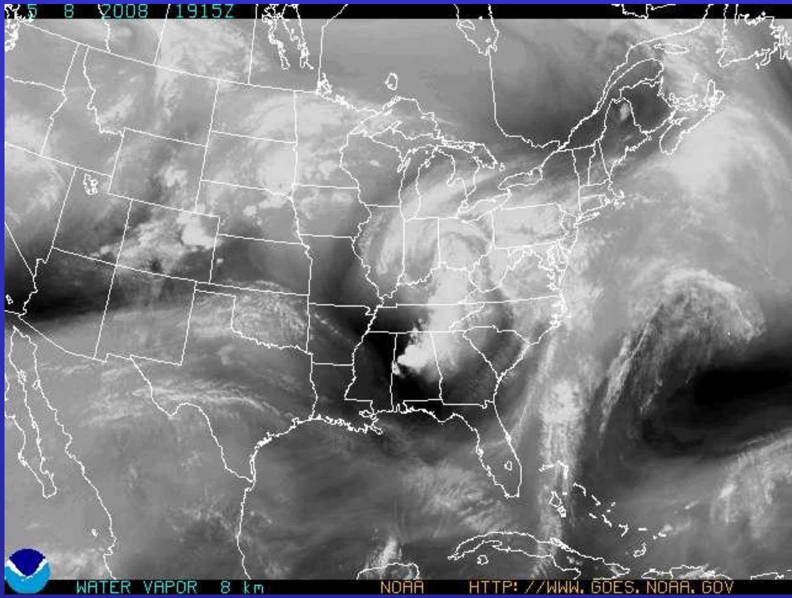


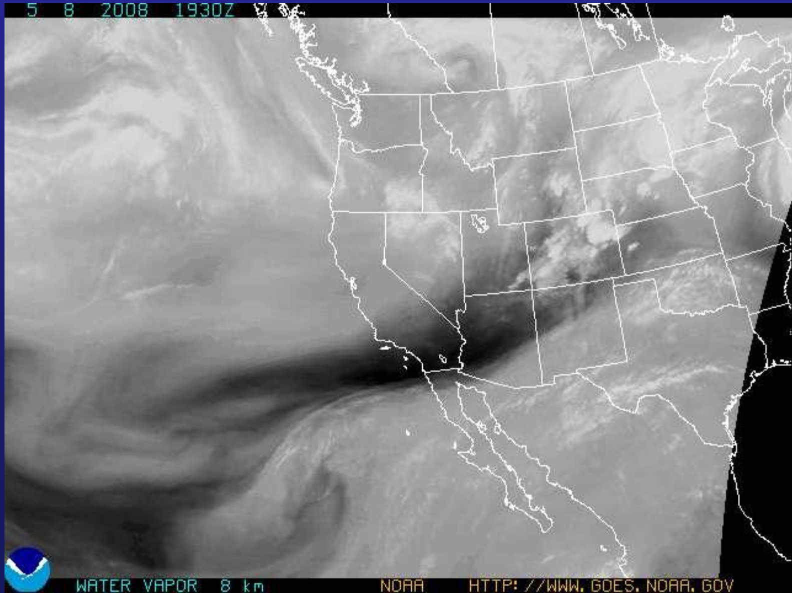
T.S. Lisa Multispectral



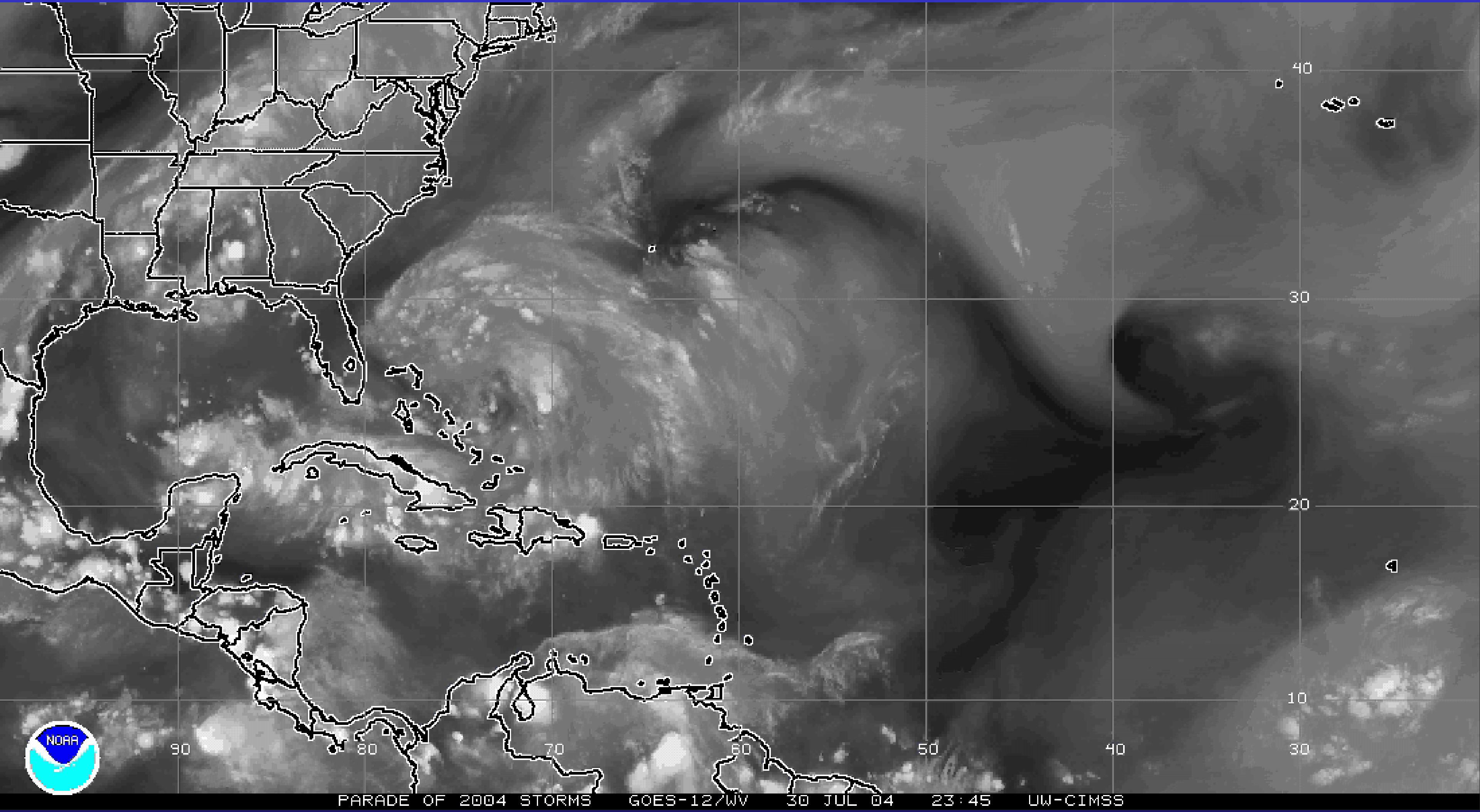
Water Vapor Imagery

- GOES 6.7 μm channel is sensitive to water vapor in the mid to upper troposphere (generally 200-500 mb)
- Other WV channels are sensitive at other levels – 7.3 μm channel on METEOSAT-9 is most sensitive near 500 mb
- WV imagery can reveal features that don't generate clouds
- WV imagery animation can reveal steering flows, shearing winds, or outflows for TCs





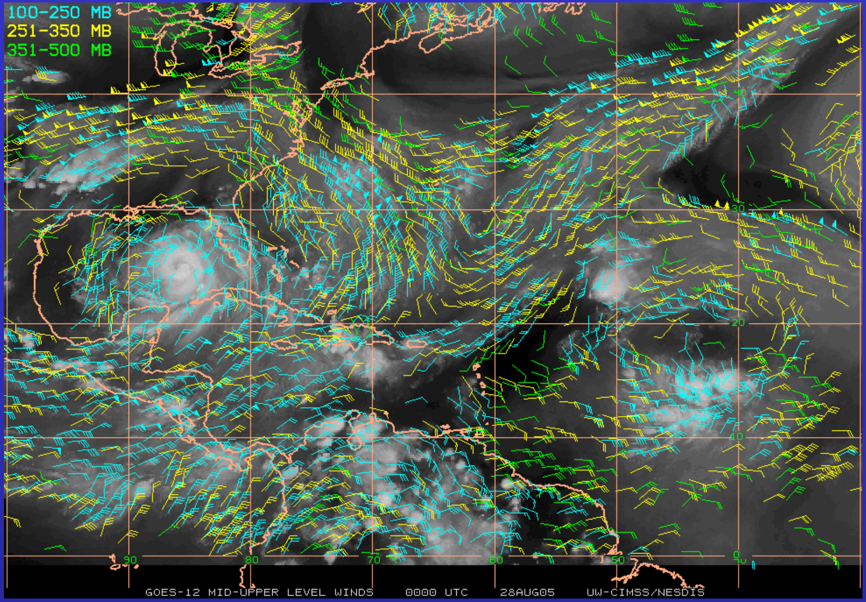
Water Vapor Imagery – 2004 Season

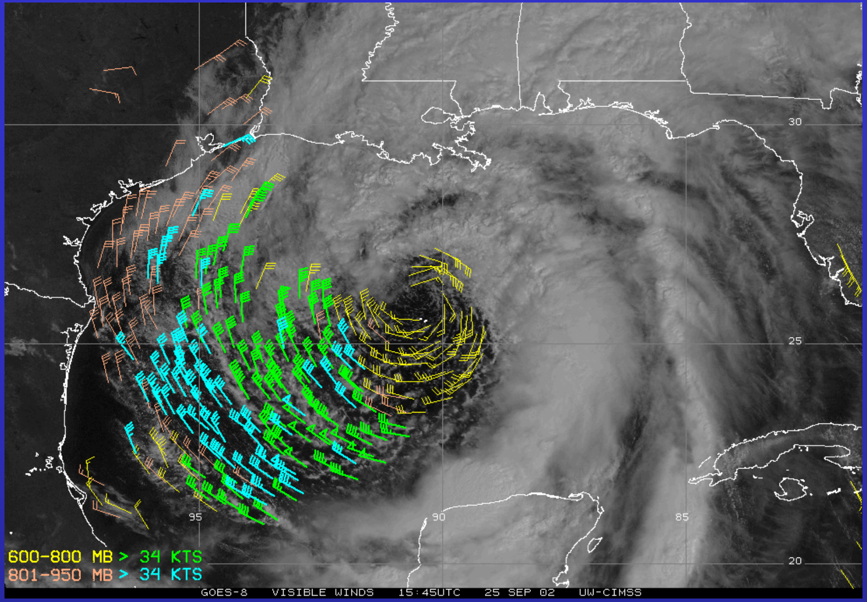


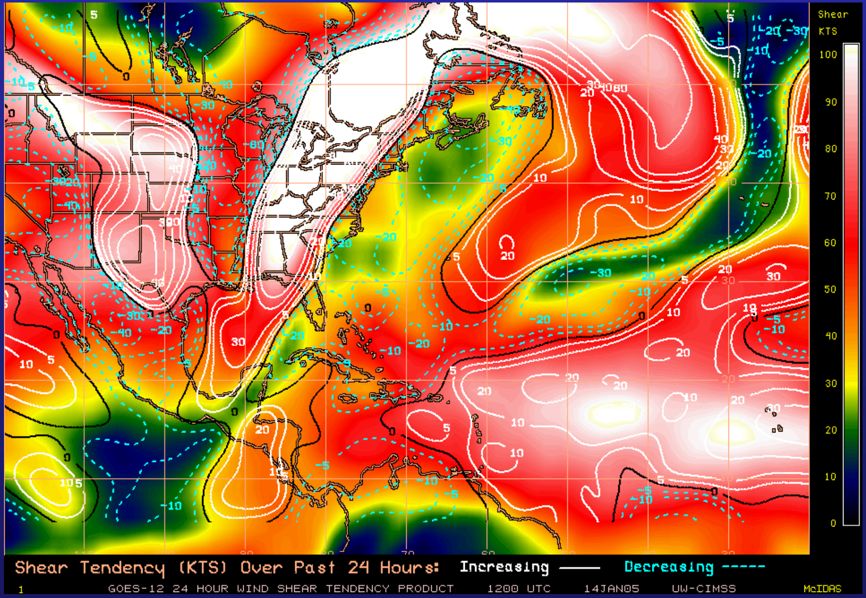
Satellite Motion Winds

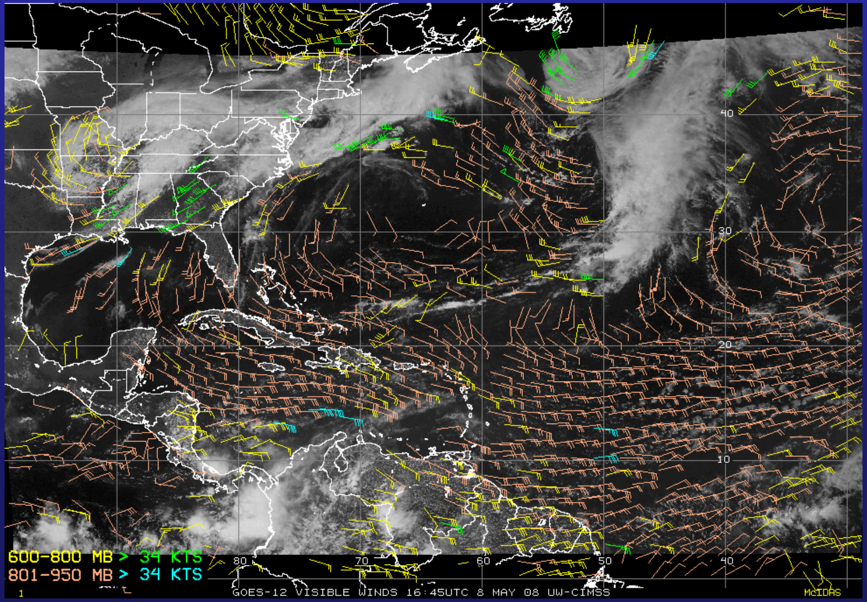
- Satellite motion winds are computed from the displacement of targets on two or more successive images
- Targets include clouds in VIS or IR imagery and coherent features in WV imagery
- Temperature of cloud or water vapor feature is used for height assignment
- Satellite winds can show TC steering, 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

Satellite Winds and Products





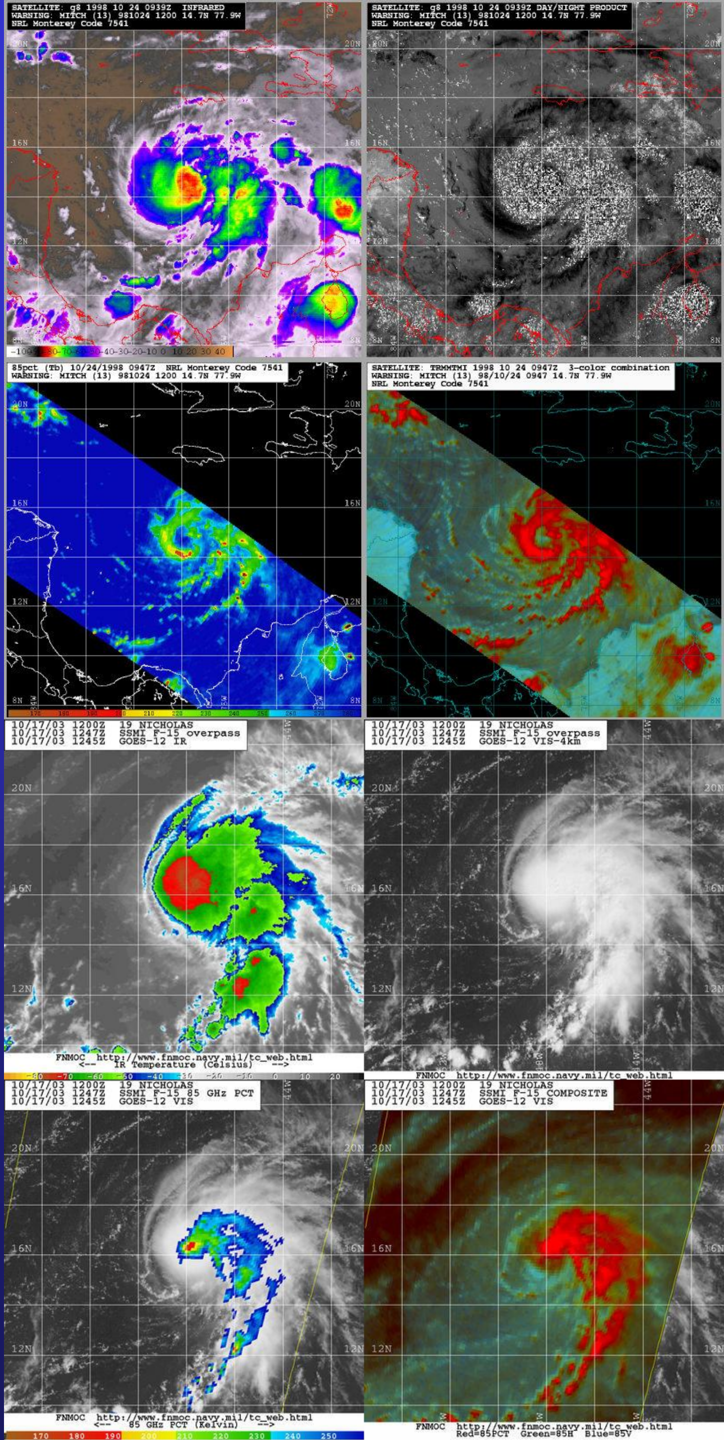




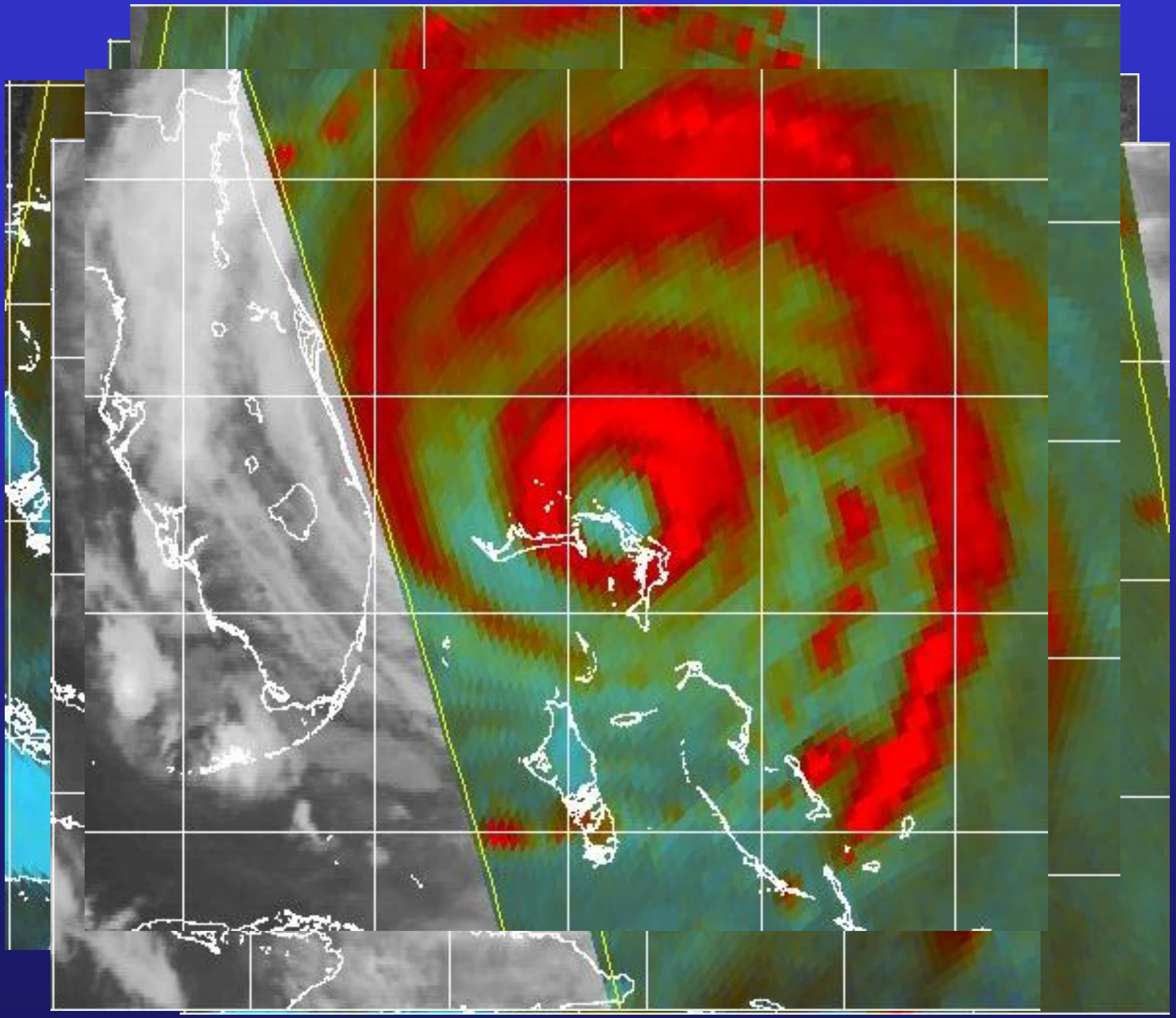
Velden et al., BAMS, 1997

Microwave Imagery

- MW frequencies can see through cirrus clouds (ice) at the top of a TC
- MW imagery is used for center finding and analyzing TC structure
- Some MW instruments detect ocean surface winds, mainly in areas without rain
- MW sounders are used to estimate the intensity of a TC



CONCENTRIC EYEWALL CYCLE
HURRICANE FLOYD



13 / 0116Z

13 / 1122Z

13 / 1347Z

13 / 2240Z

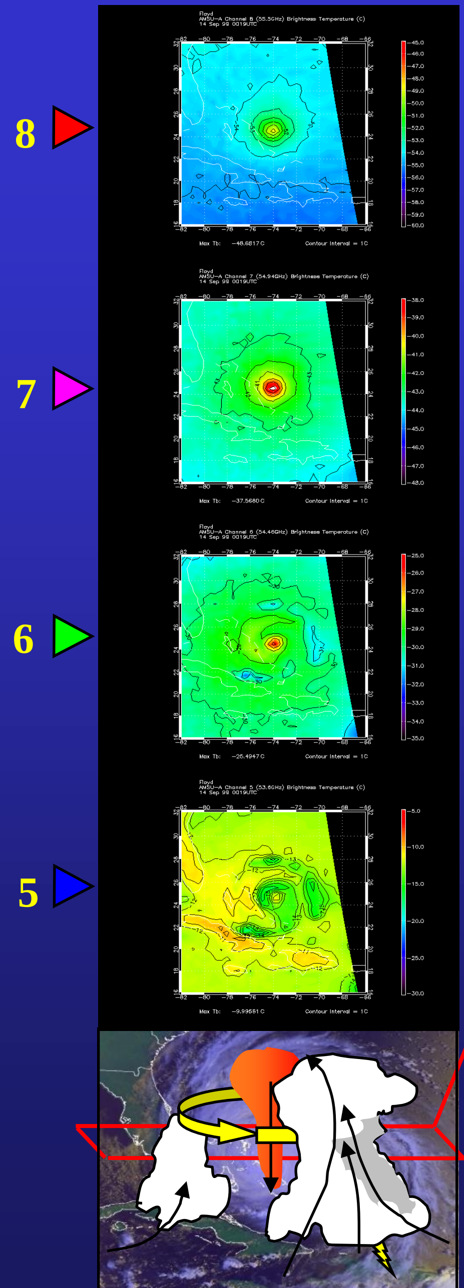
14 / 0104Z

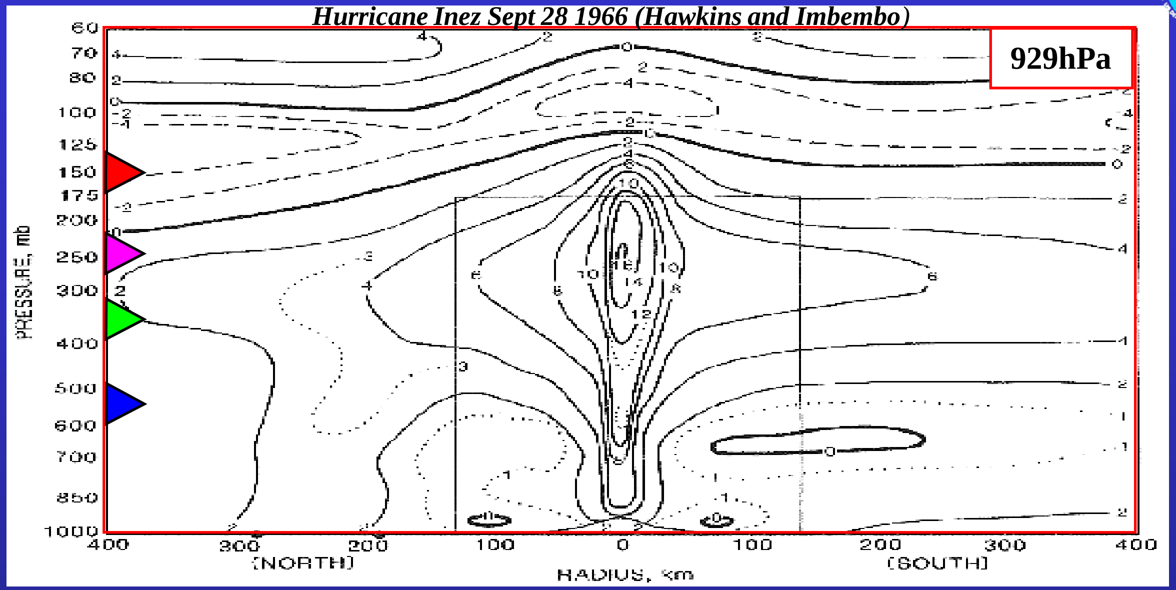
14 / 1110Z

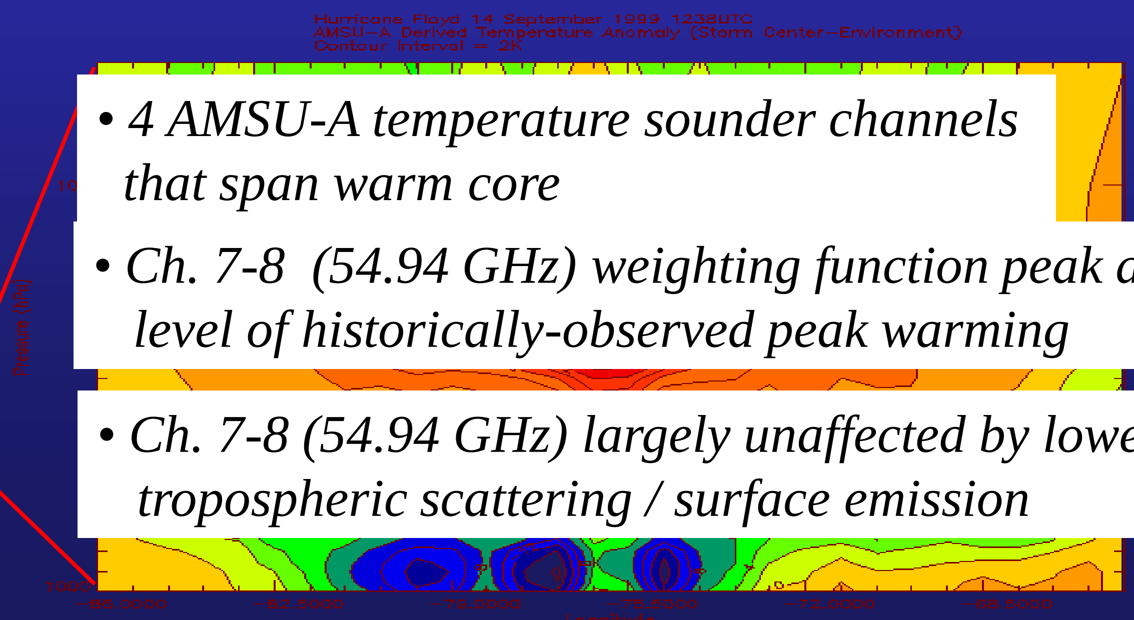
14 / 2228Z

Hurricane Floyd Sept 14 1999

Suitability of the AMSU



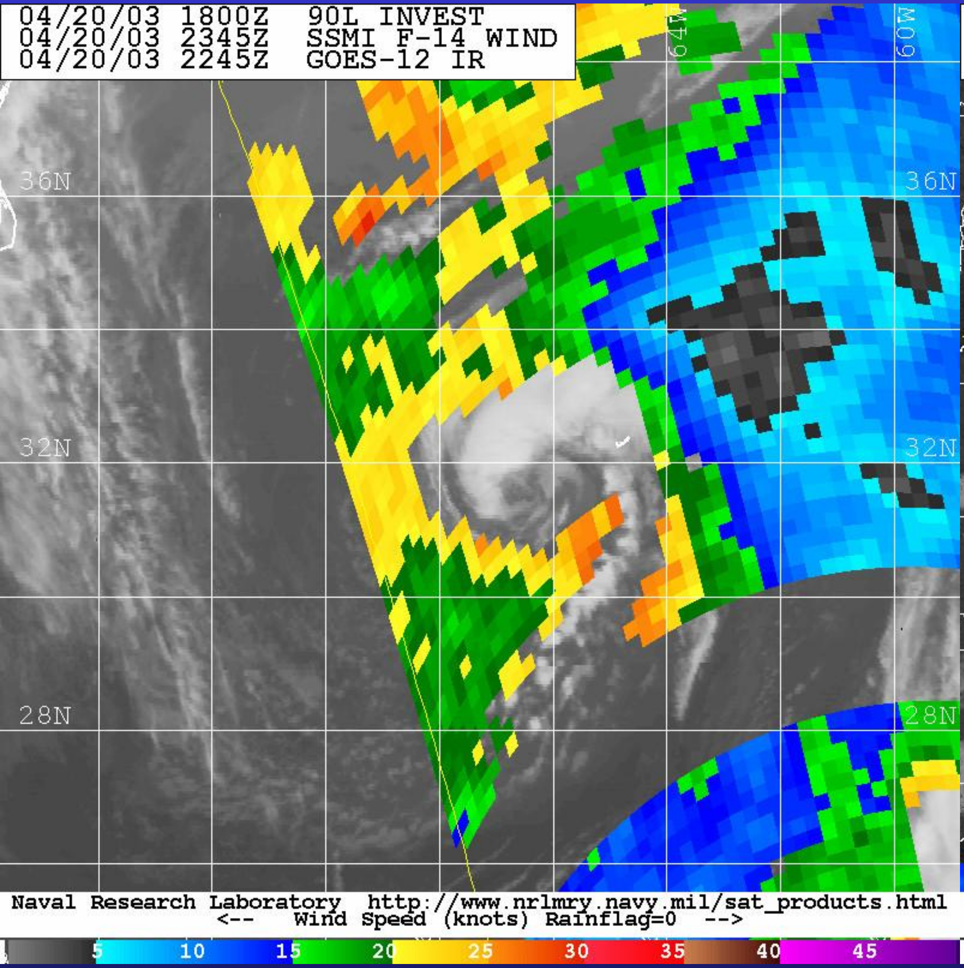




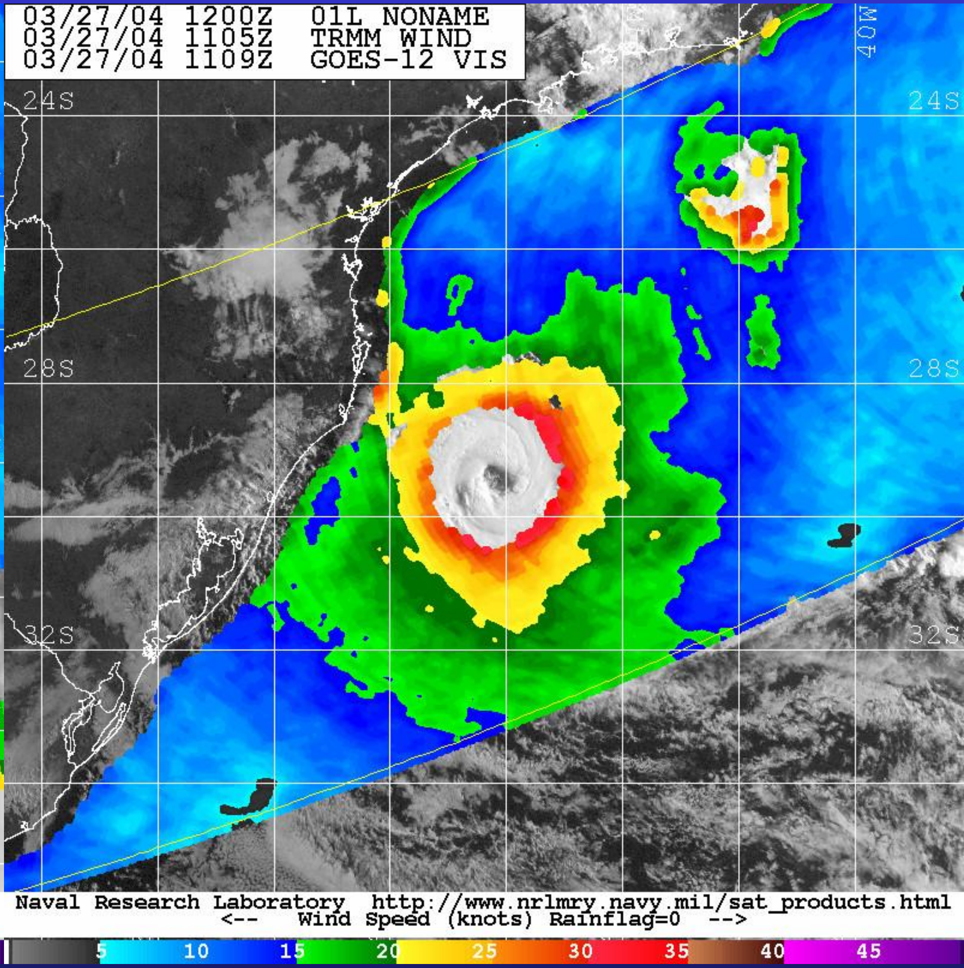
- *4 AMSU-A temperature sounder channels that span warm core*
- *Ch. 7-8 (54.94 GHz) weighting function peak at level of historically-observed peak warming*
- *Ch. 7-8 (54.94 GHz) largely unaffected by lower tropospheric scattering / surface emission*

Slide courtesy of Velden et al CIMSS/NRL

Ocean Surface Winds Speeds

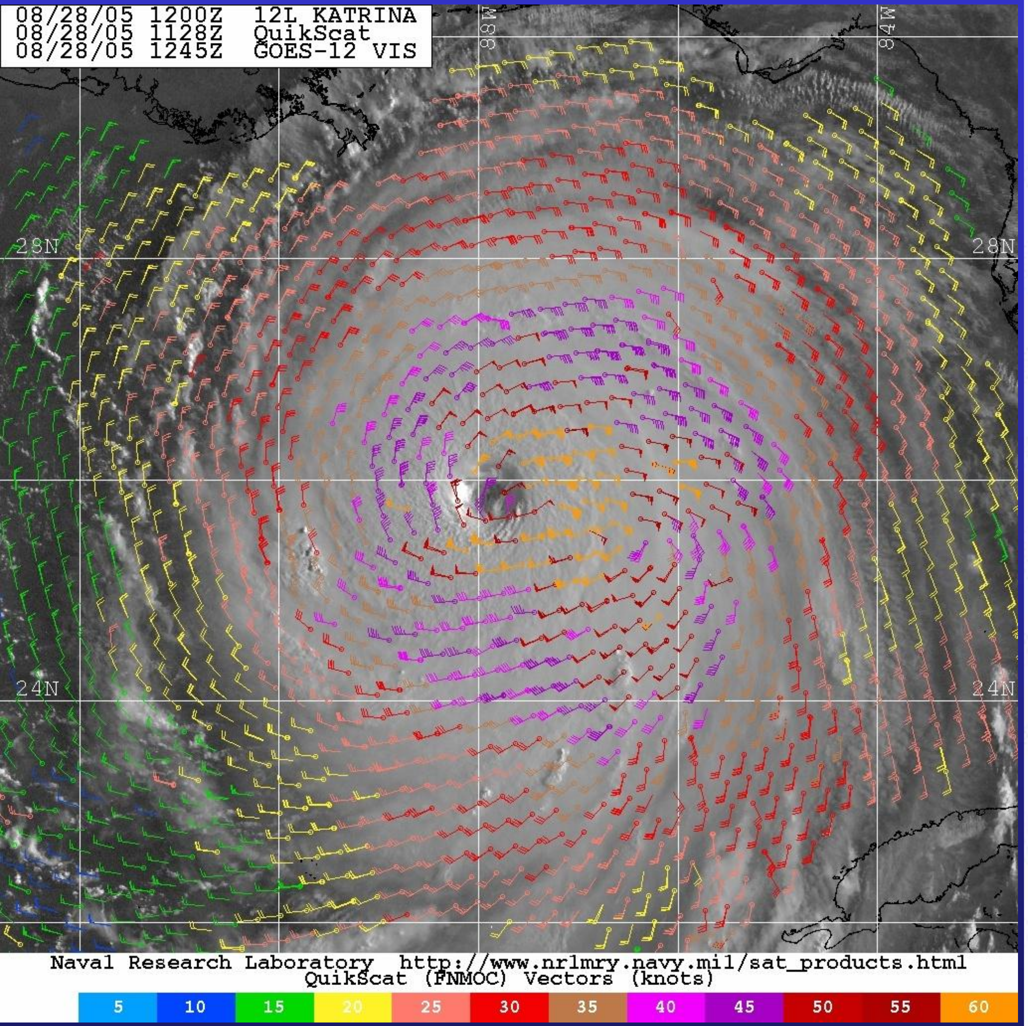


SSM/I Winds – Ana (2003)

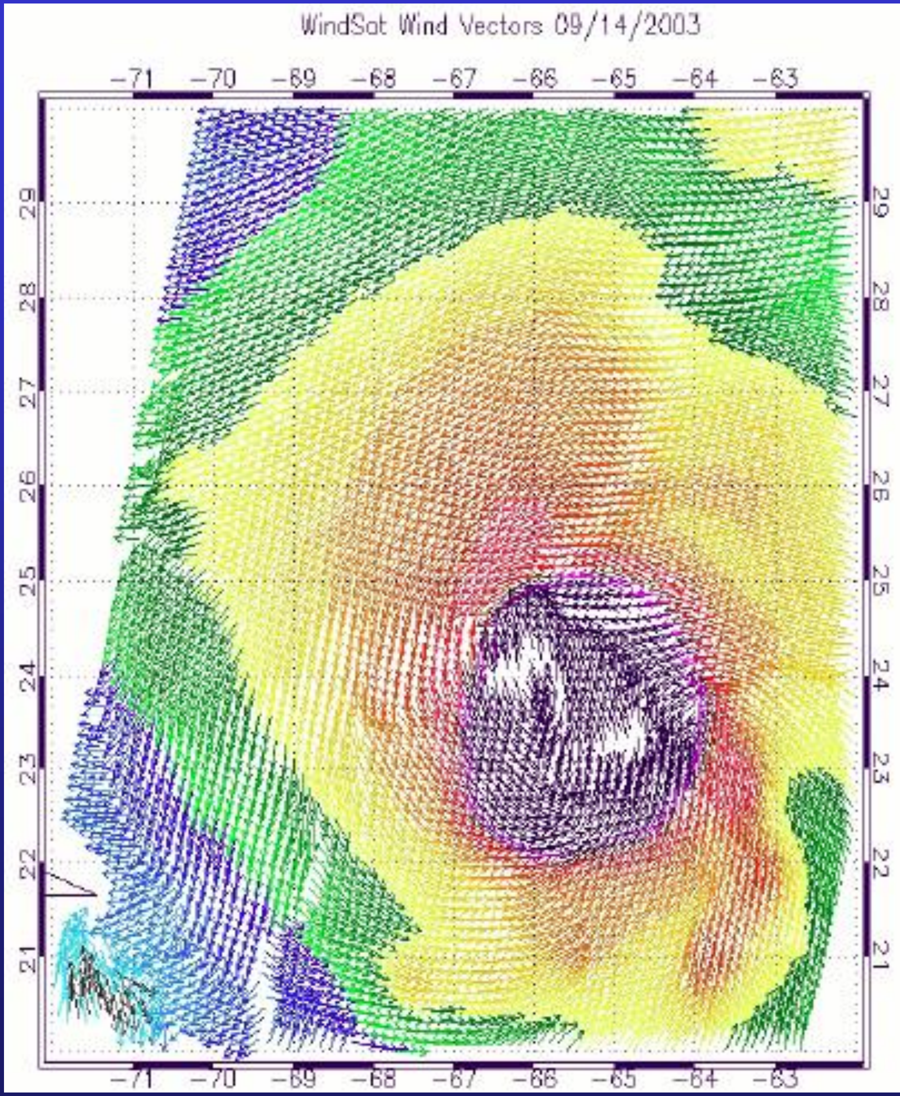


TRMM Winds – Catarina (2004)

Ocean Surface Vector Winds

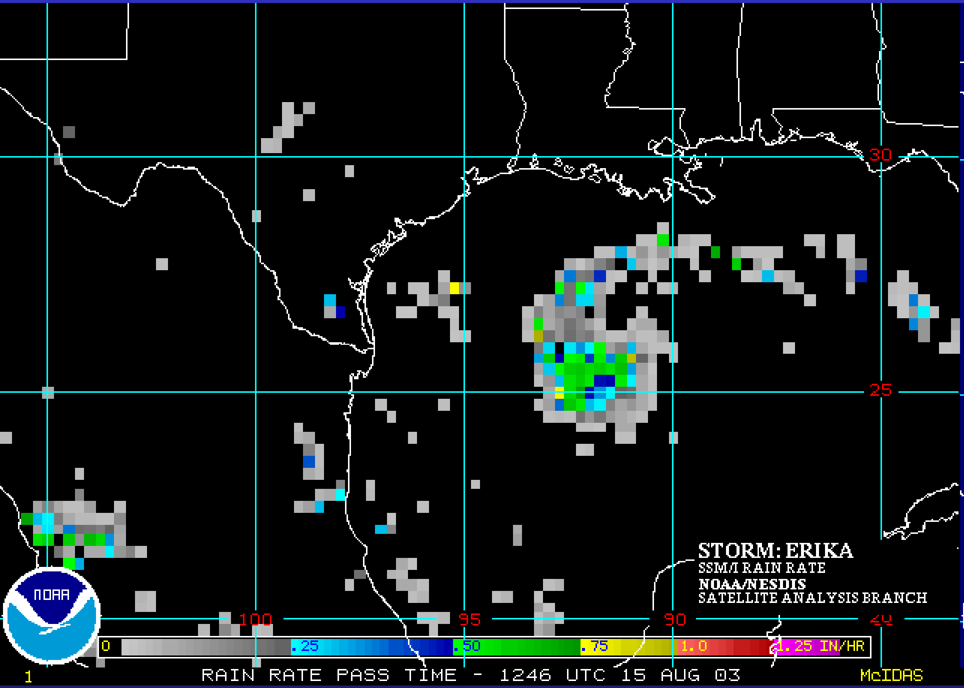


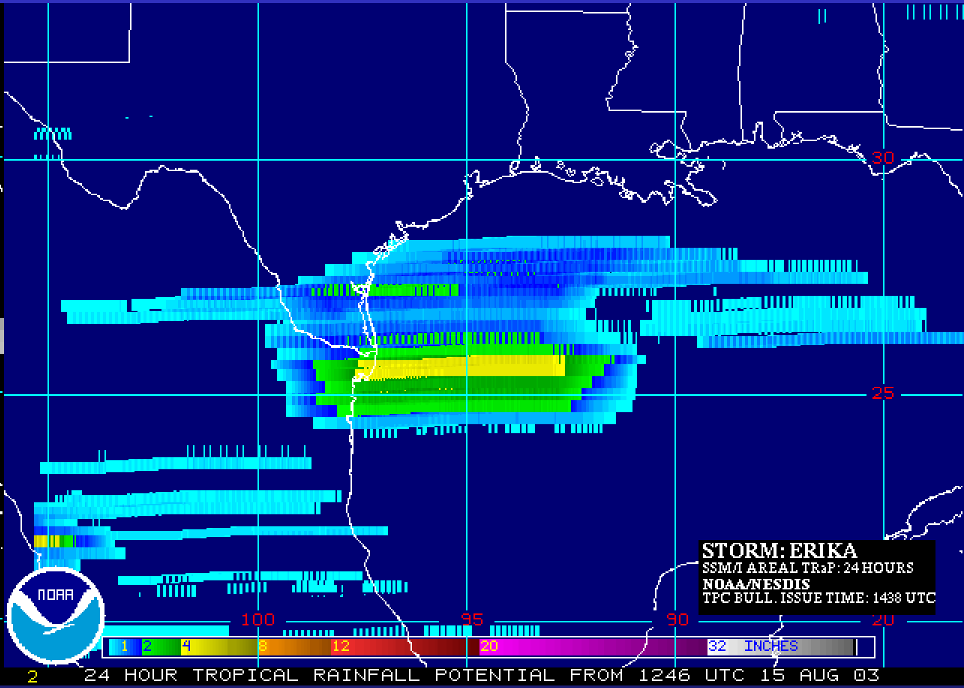
QuikScat detail – Katrina (2005)



Windsat detail – Isabel (2003)

Microwave Satellite Rainfall Estimates

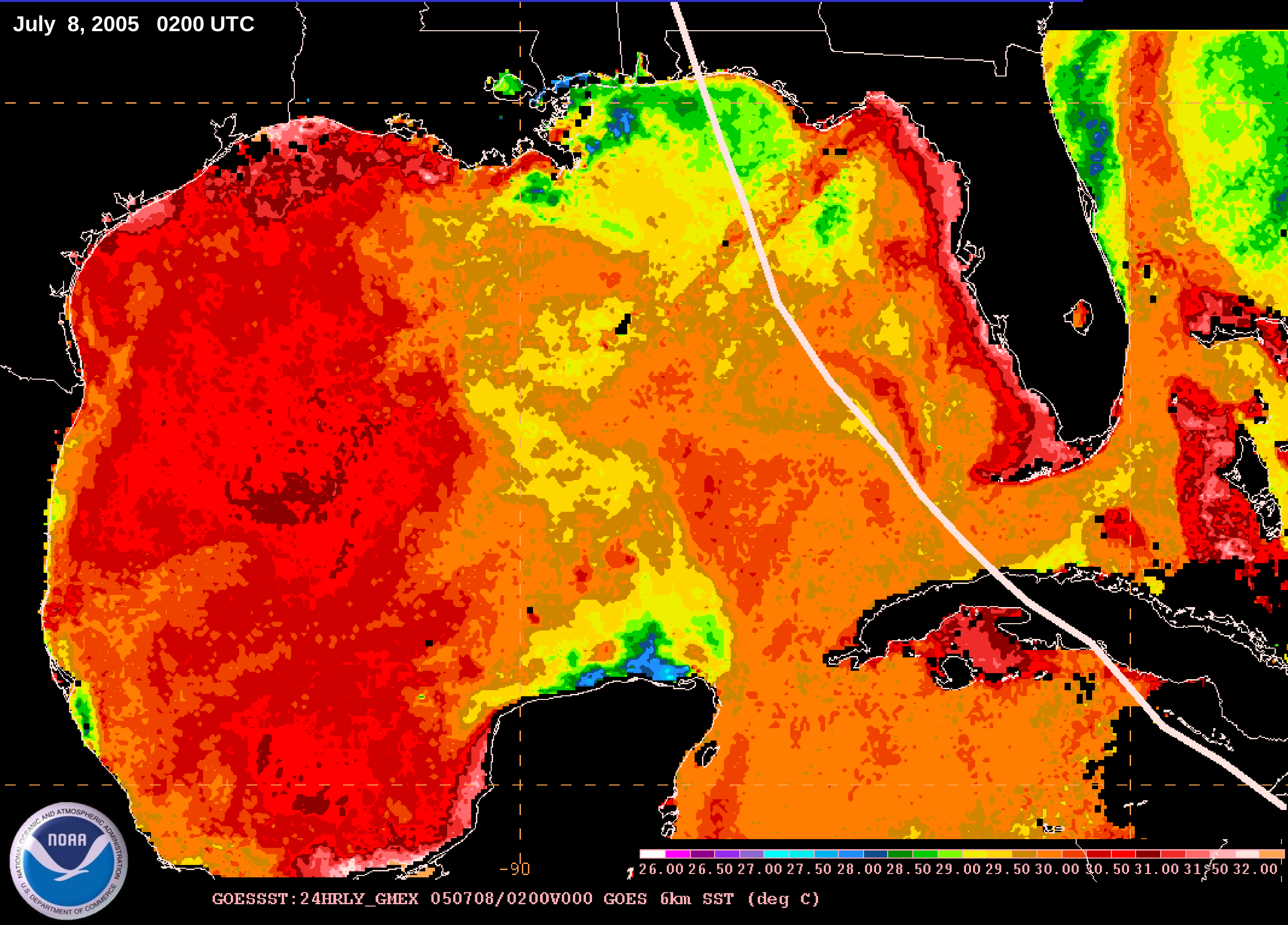




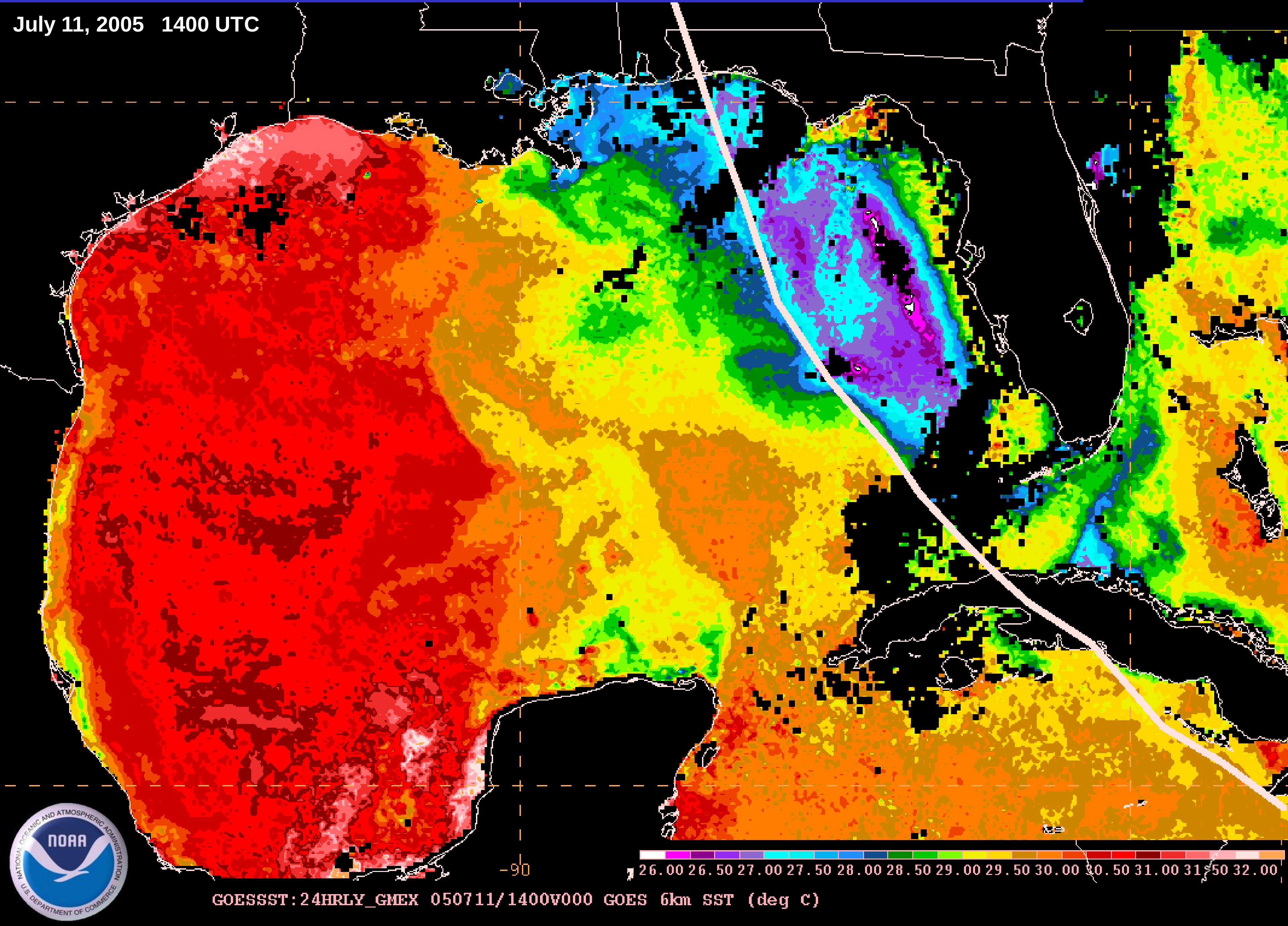
Observed Rainfall Rate **Forecast Precipitation Totals**

The Tropical Rainfall Potential (TRaP) technique is based on extrapolation of the current convective pattern into the future

SST Before Hurricane Dennis

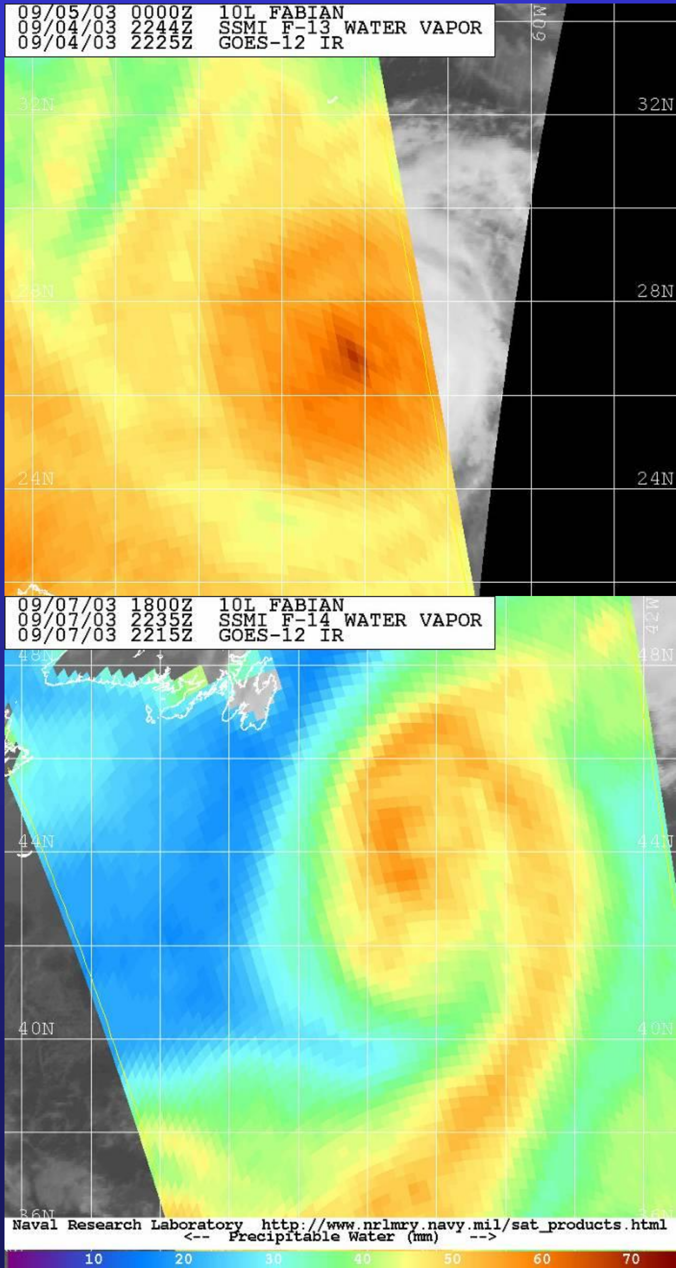


Hurricane Dennis' Cool Wake

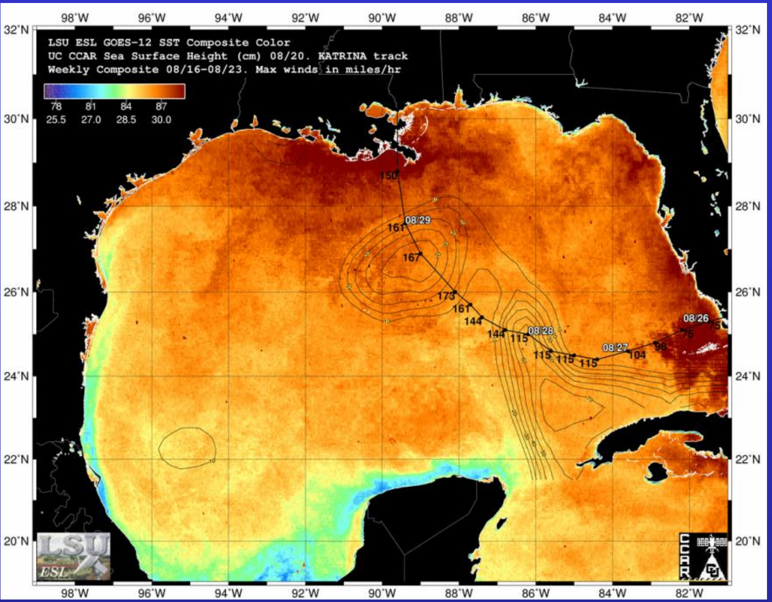


Total Precipitable Water Products

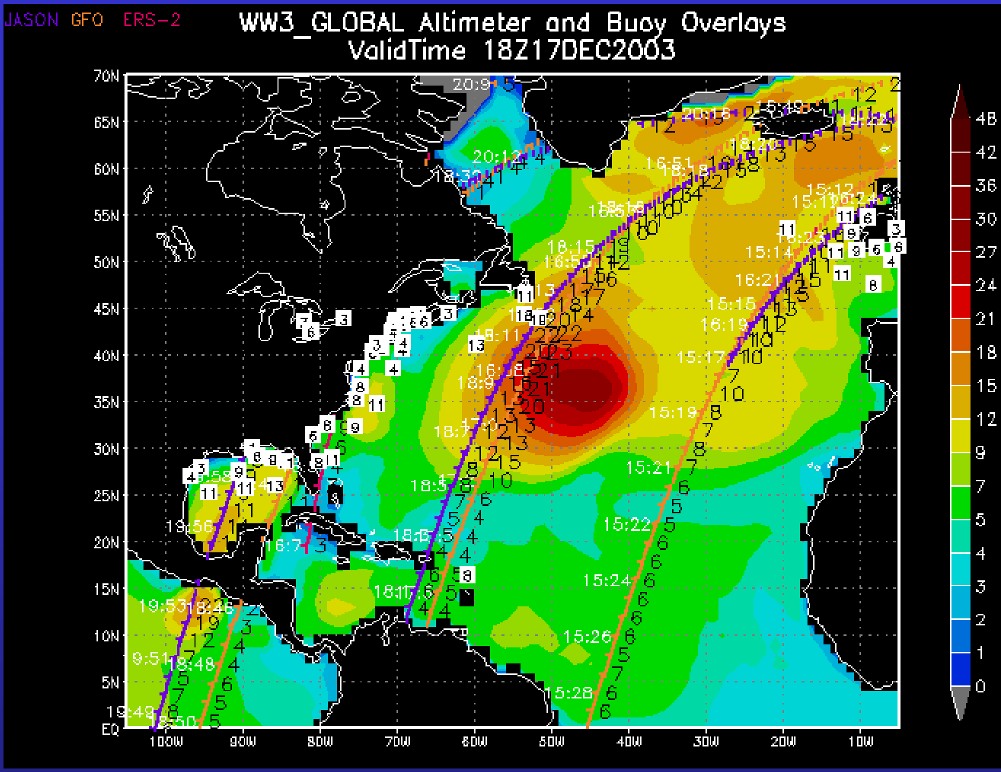
- Microwave sounders measure moisture, which allows for the determination of the total amount of water and water vapor in a column of atmosphere – the total precipitable water (TPW)
- The TPW is used to track moist and dry air masses in weather systems, for determination of cyclone structure, and determination of how much atmospheric moisture is available to become rain.



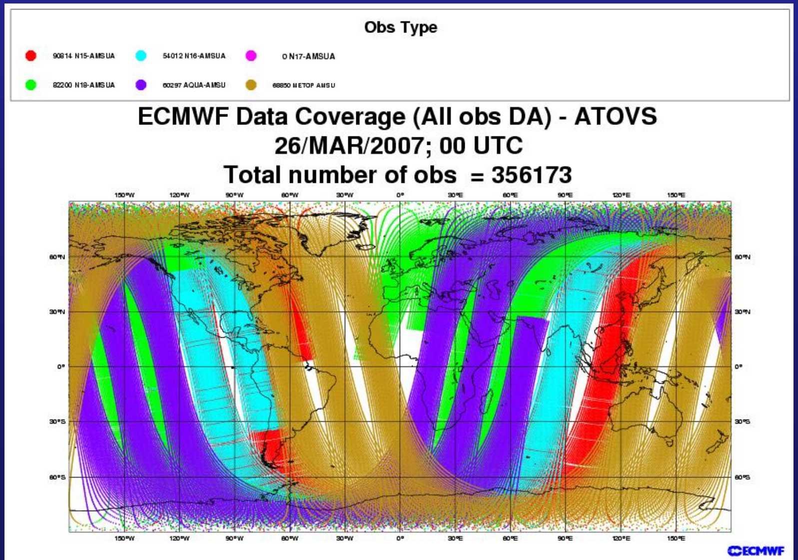
Other useful satellite data



Sea surface temperature and ocean height for intensity forecasting

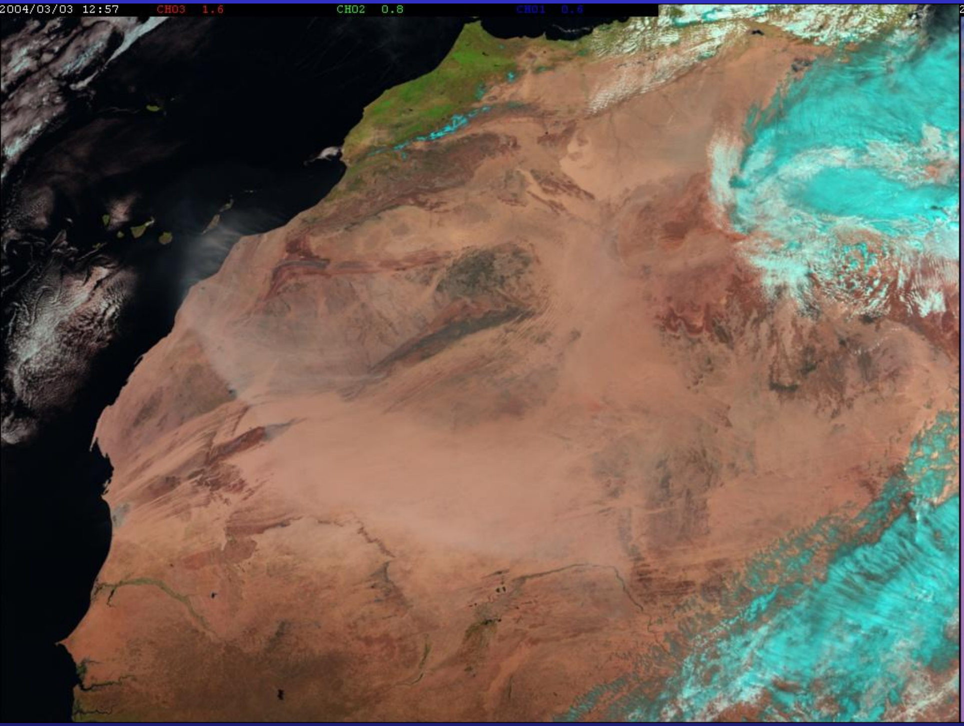


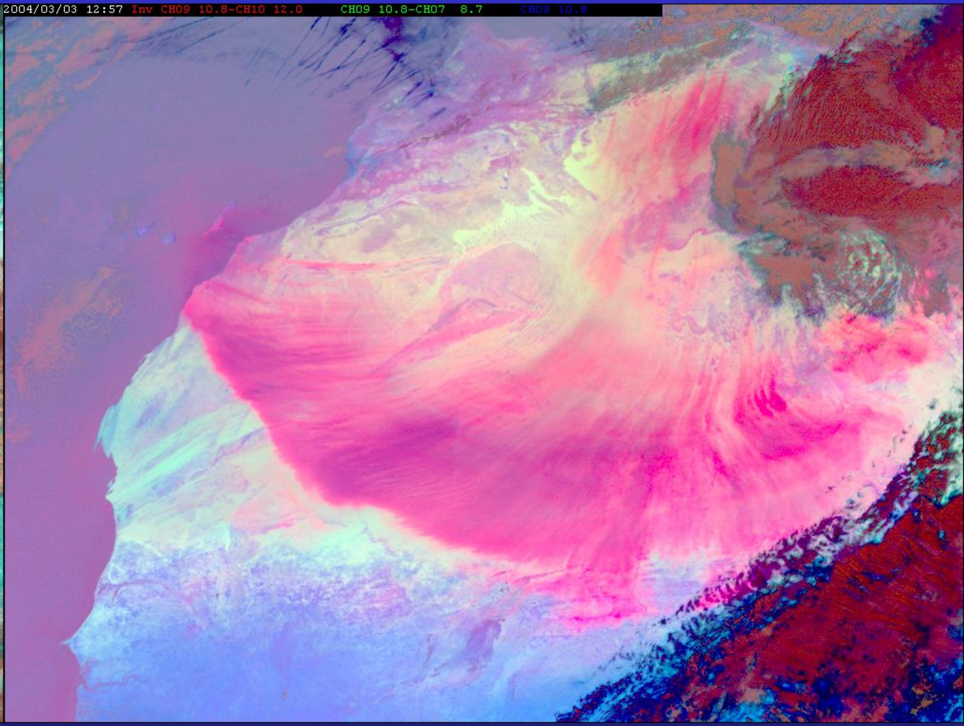
Radar altimeter wave heights



Satellite temperature and moisture soundings for use in numerical models – not used directly at NHC but of vital importance in forecasting

MET-8 African Dust Detection





Multispectral imagery uses the radiative properties of the dust to more easily detect it.

Satellite Imagery Interpretation

- Satellite imagery has been difficult to quantify, particularly in ways useful to numerical weather prediction models
- Qualitative interpretation of satellite imagery/animation is a very useful tool for analyzing meteorological features of all scales
- Interpretation methods include formal techniques such as the Dvorak and Hebert-Poteat techniques for estimating the intensities of tropical and subtropical cyclones

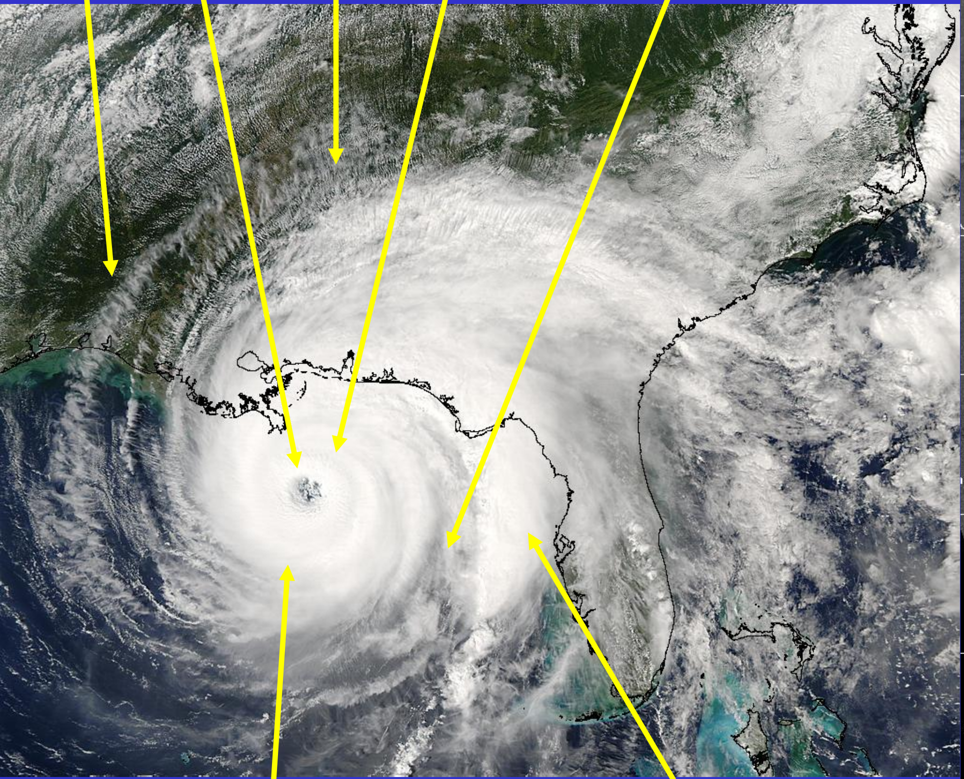
What can be seen in these images?

cirrus outflow (high clouds)

eye

eyewall

dry slot

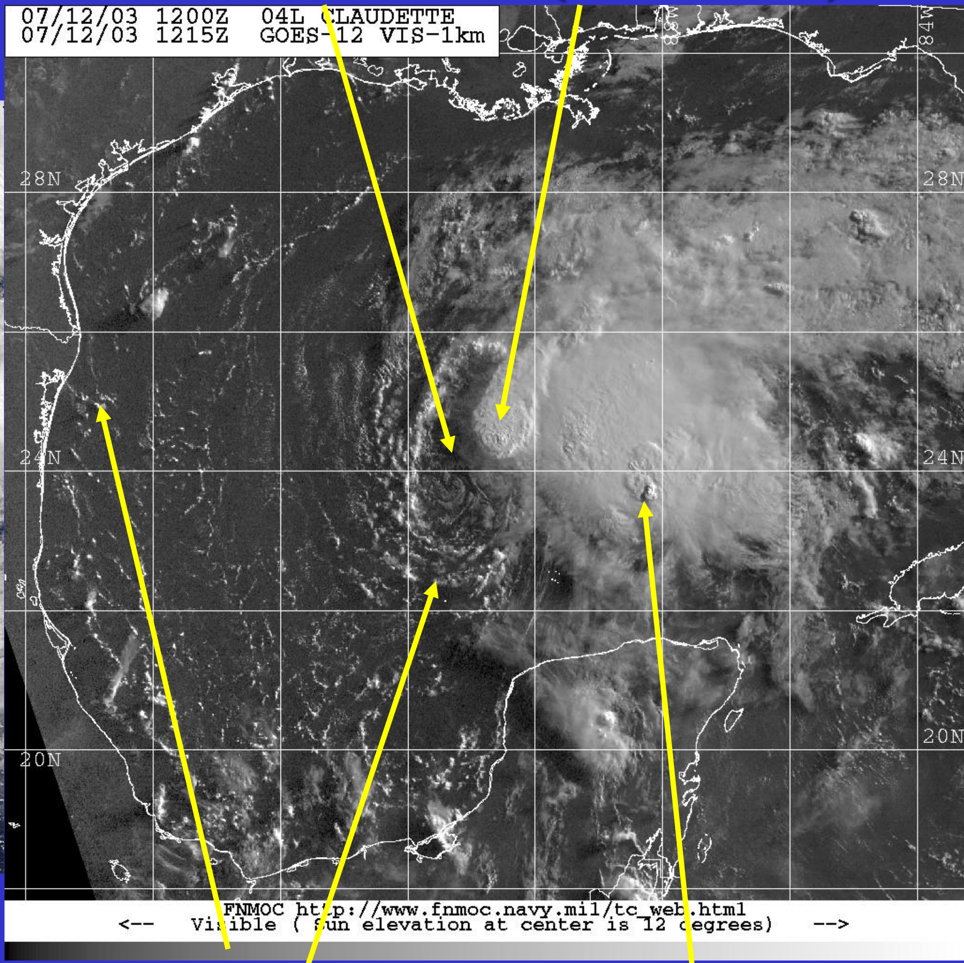


central dense overcast (CDO)

outer band (tornadic supercells)

exposed low-level center

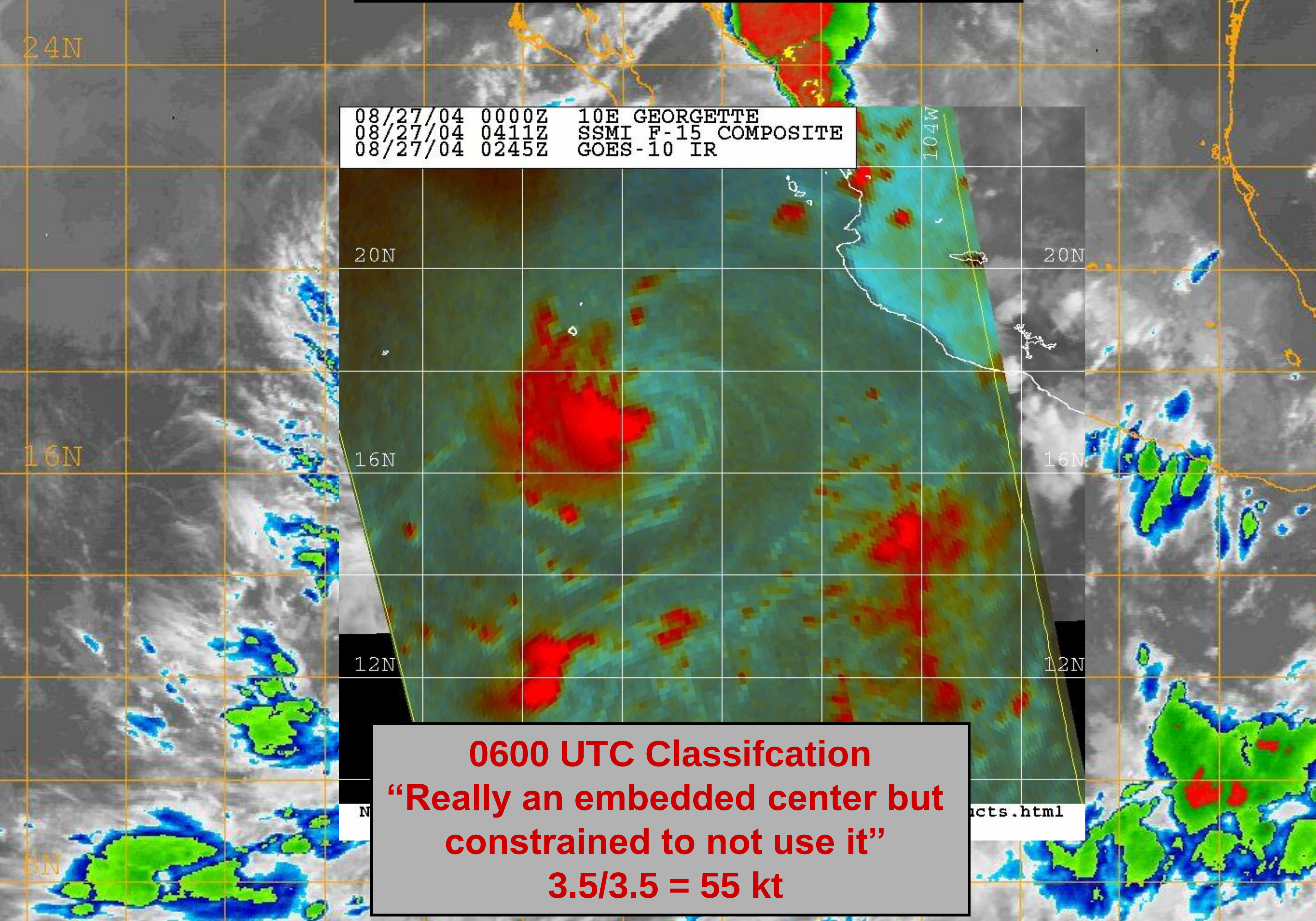
convective burst (hot tower)



low clouds

sheared convection

0430 UTC 27 August GOES-10 IR

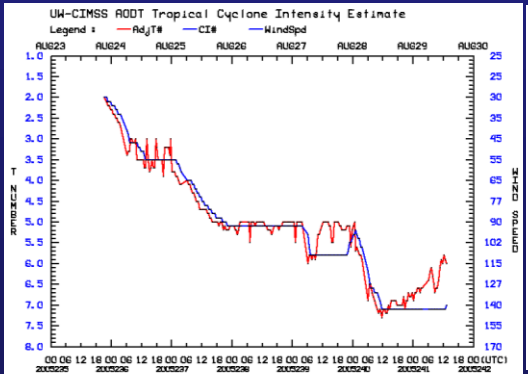


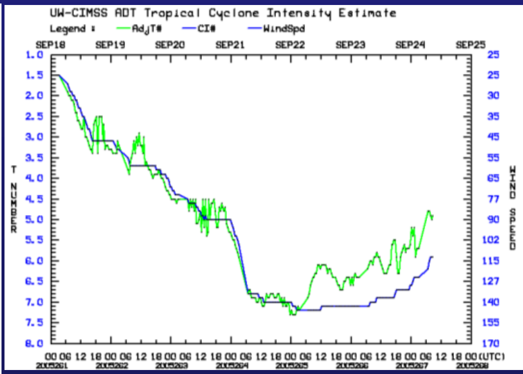
0600 UTC Classifcation
“Really an embedded center but constrained to not use it”
3.5/3.5 = 55 kt

The Dvorak Technique

- A statistical method for <u>estimating</u> the intensity of tropical cyclones from satellite imagery
- Uses IR and VIS imagery
- Based on a "measurement" of the TC convective cloud pattern and rules
- Comes in manual and automated versions

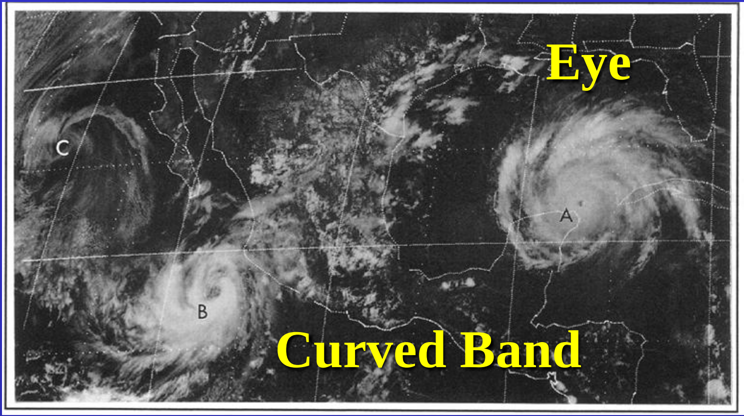
CI Number	MWS (kt)	MSLP (Atlantic)	MSLP (NW Pacific)
1.0	25		
1.5	25		
2.0	30	1009 mb	1000 mb
2.5	35	1005 mb	997 mb
3.0	45	1000 mb	991 mb
3.5	55	994 mb	984 mb
4.0	65	987 mb	976 mb
4.5	77	979 mb	966 mb
5.0	90	970 mb	954 mb
5.5	102	960 mb	941 mb
6.0	115	948 mb	927 mb
6.5	127	935 mb	914 mb
7.0	140	921 mb	898 mb
7.5	155	906 mb	879 mb
8.0	170	890 mb	858 mb

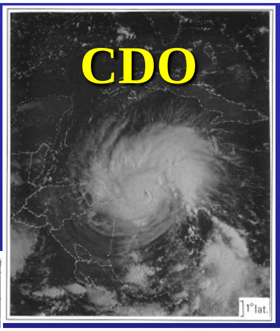


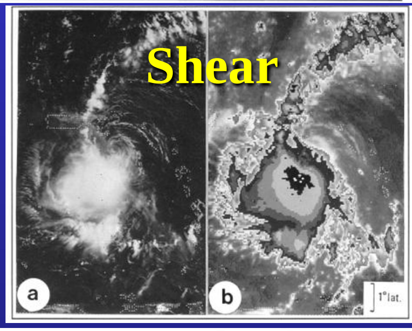


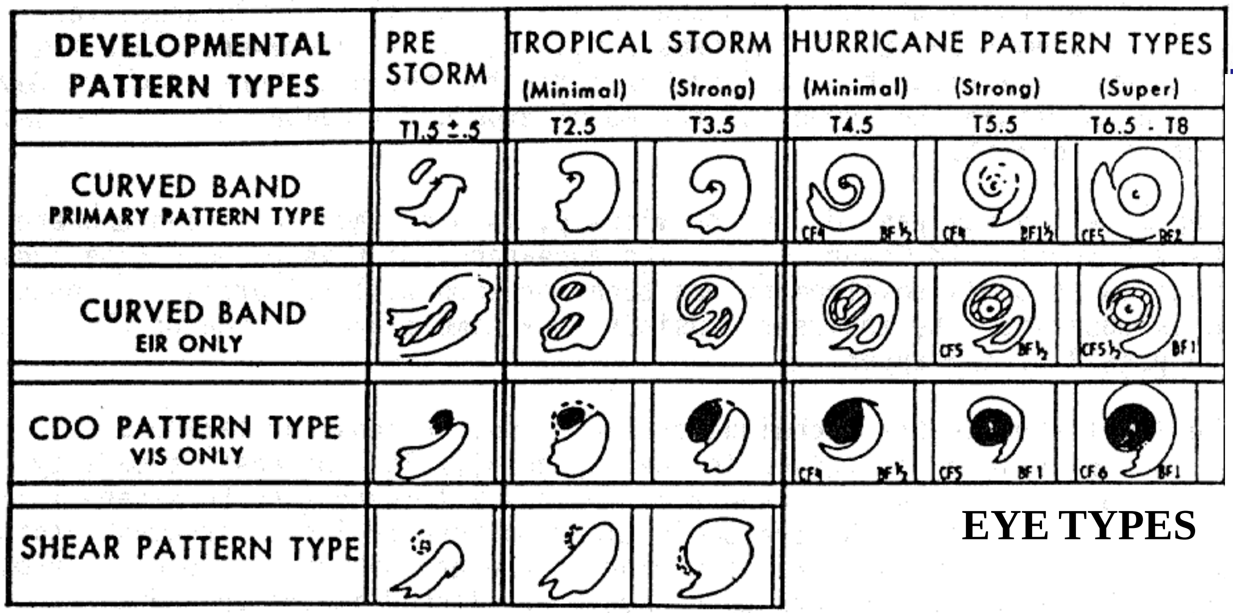
Dvorak Technique Cloud Patterns

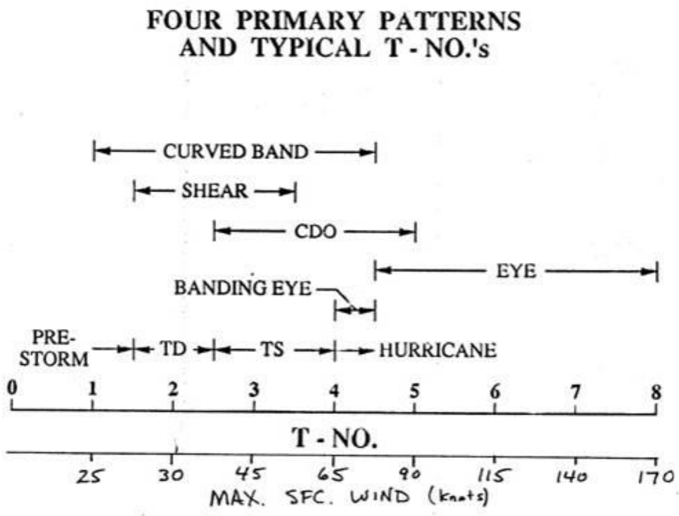
- Curved Band (VIS and IR)
- Shear (VIS and IR)
- Eye (VIS and IR)
- Central Dense Overcast (VIS)
- Embedded Center (IR)
- Central Cold Cover (VIS and IR)





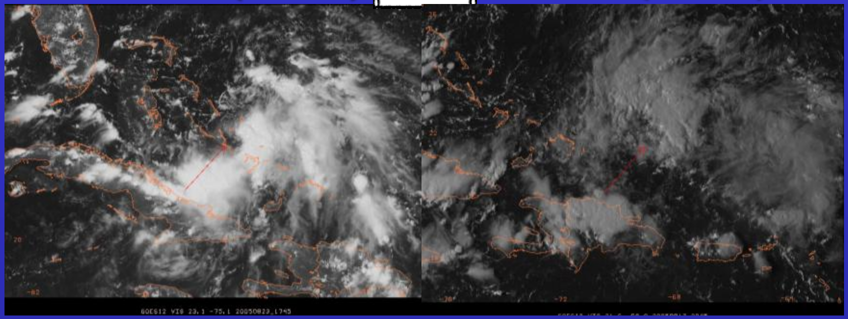


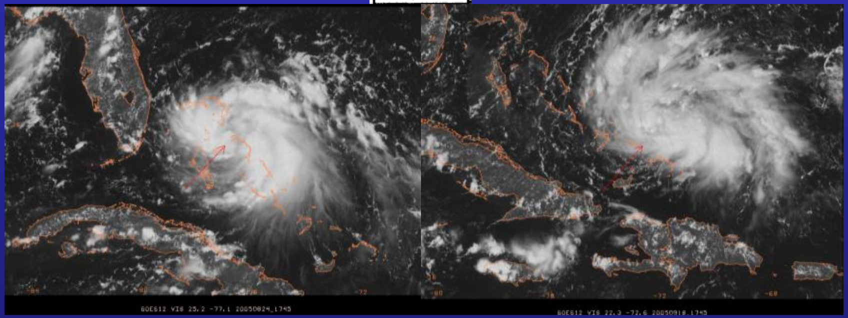


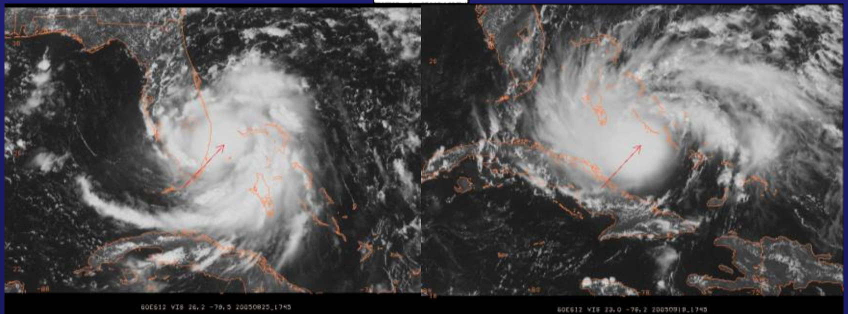


TC Cloud Patterns – Developing

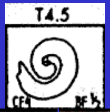
Katrina (2005) Rita (2005)

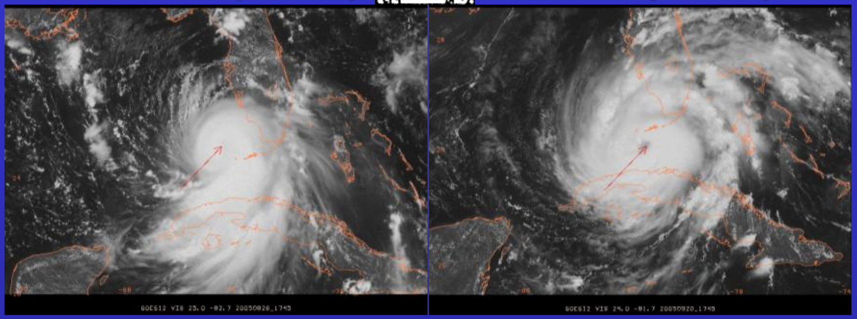


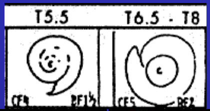


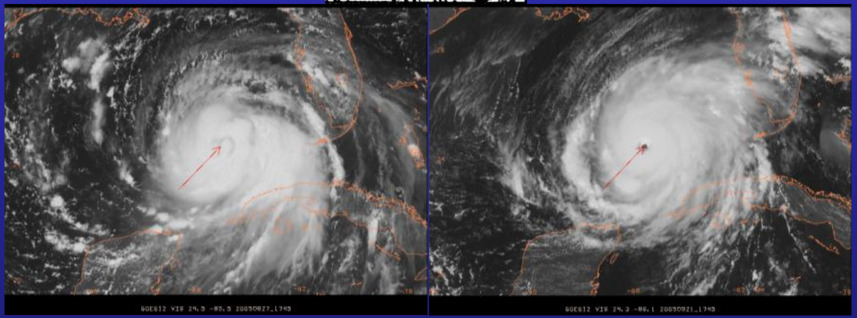


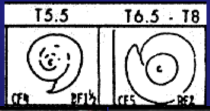
Katrina (2005) Rita (2005)

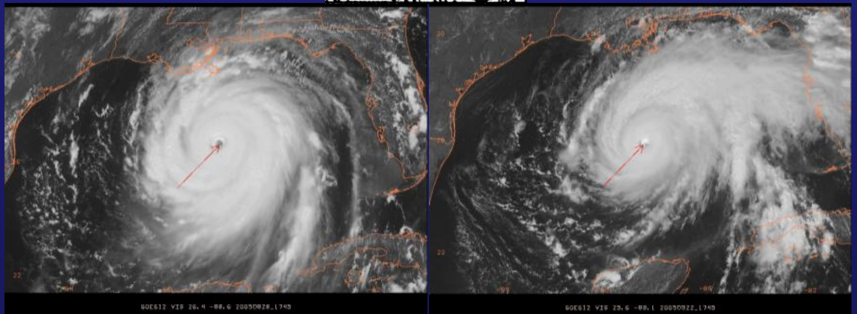






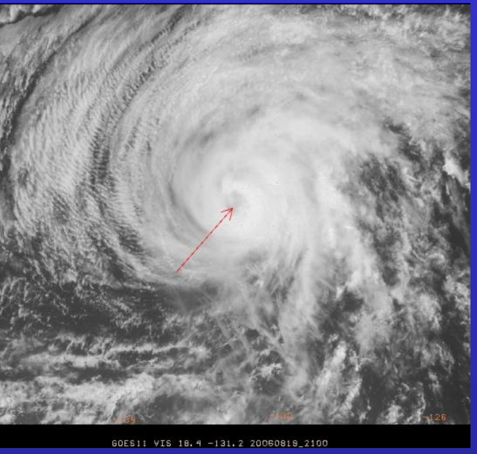




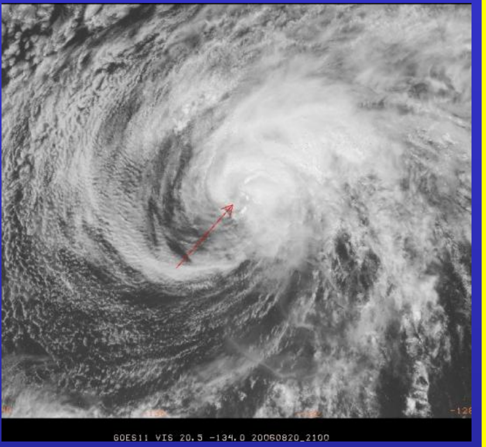


TC Cloud Patterns - Weakening

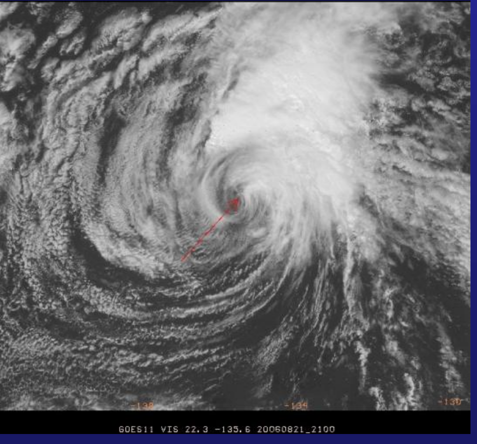
Hector 2006



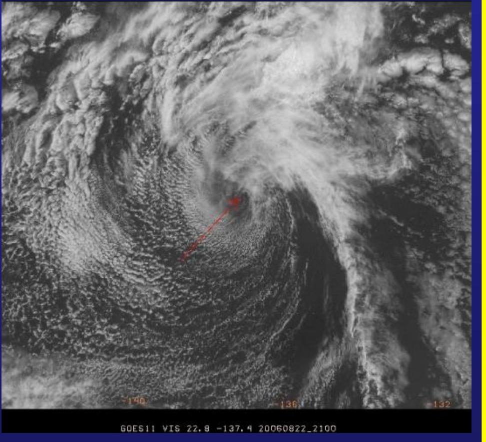
19 Aug. 2100 UTC



20 Aug. 2100 UTC

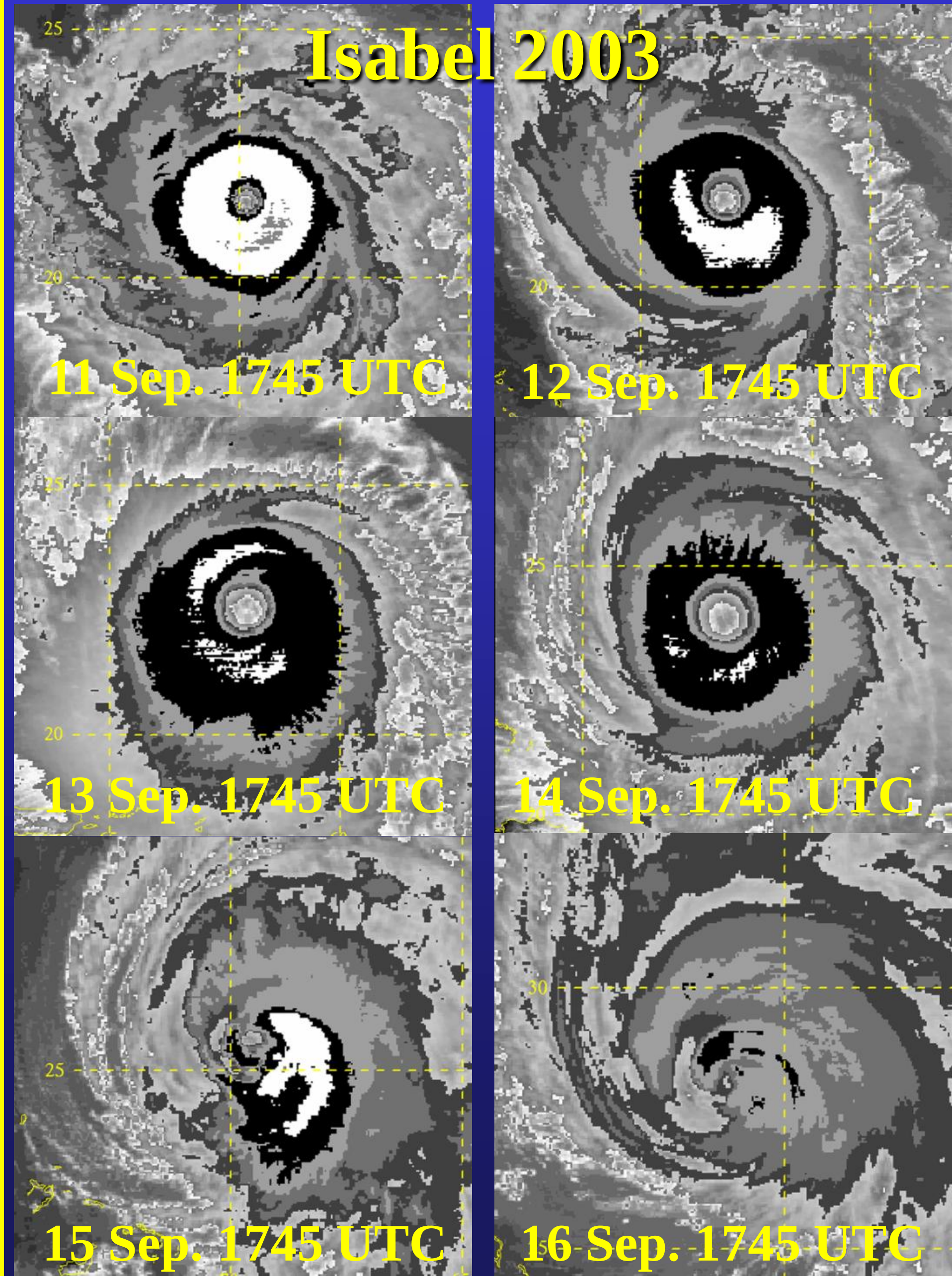


21 Aug. 2100 UTC

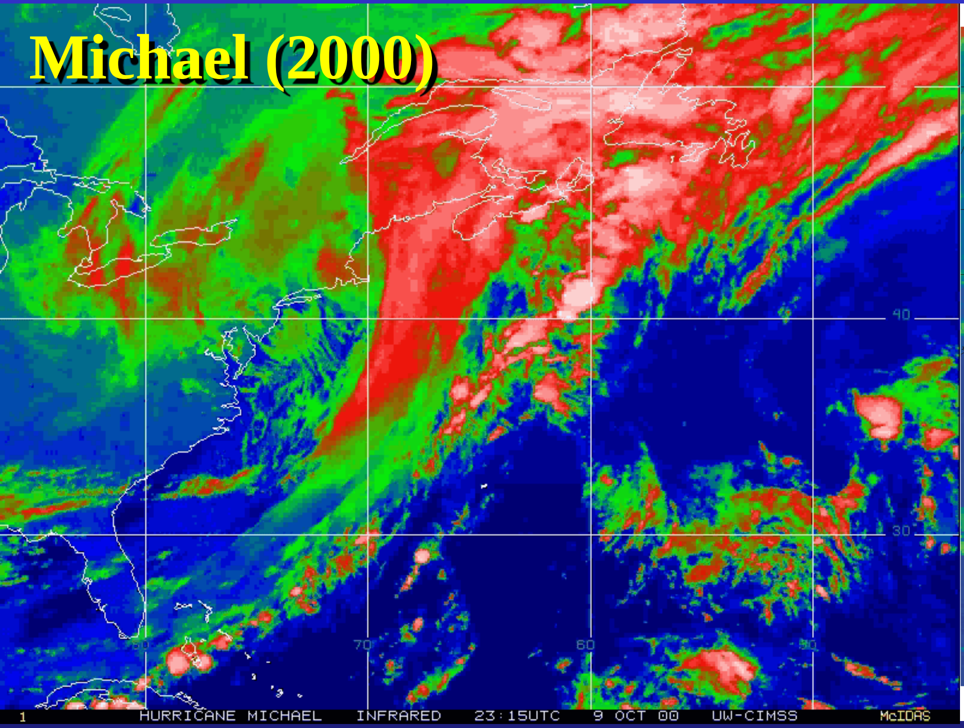


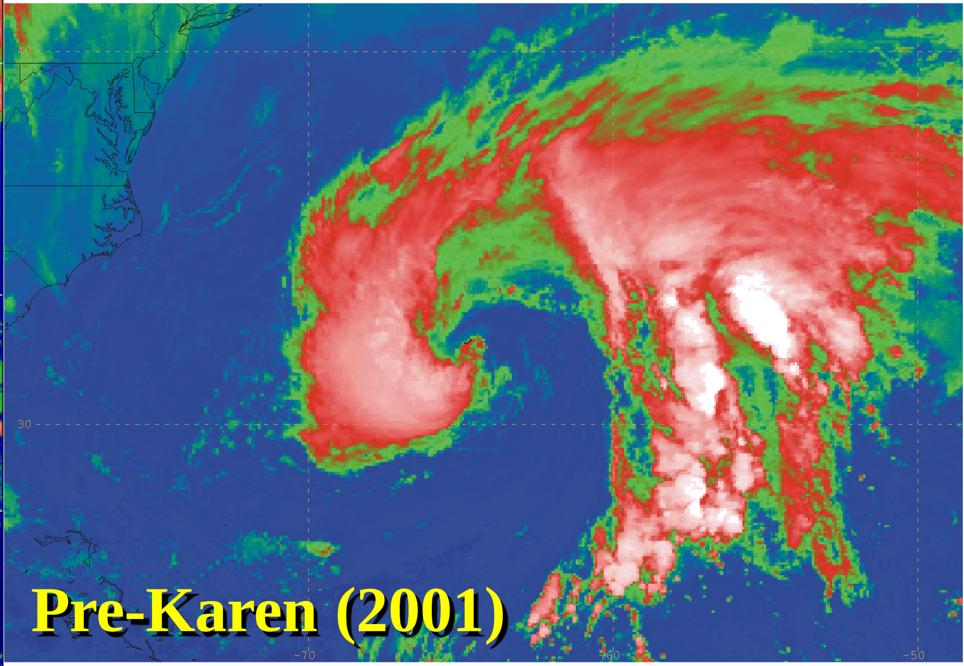
22 Aug. 2100 UTC

Isabel 2003



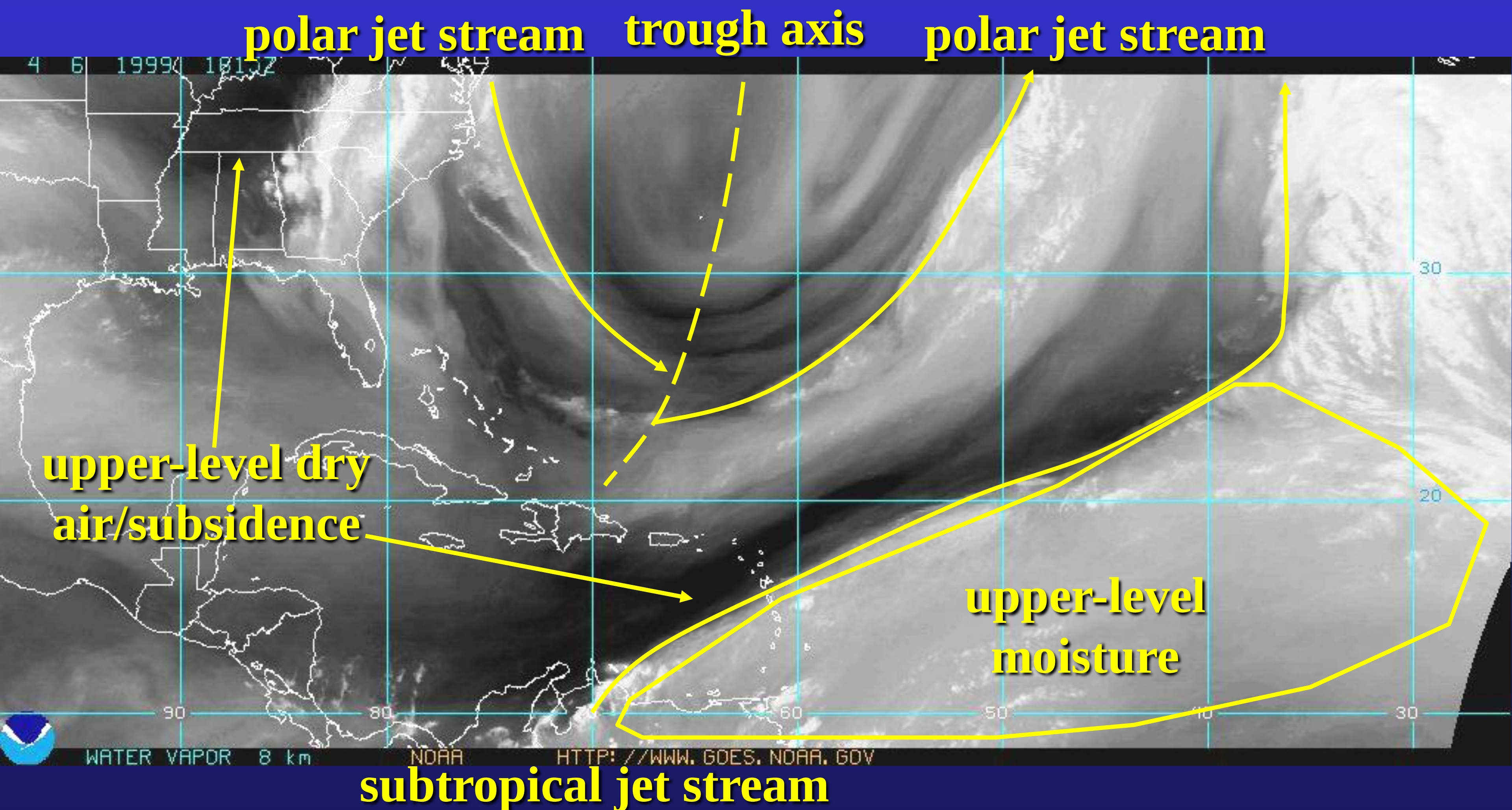
Subtropical Cyclones
Hebert-Poteat Technique



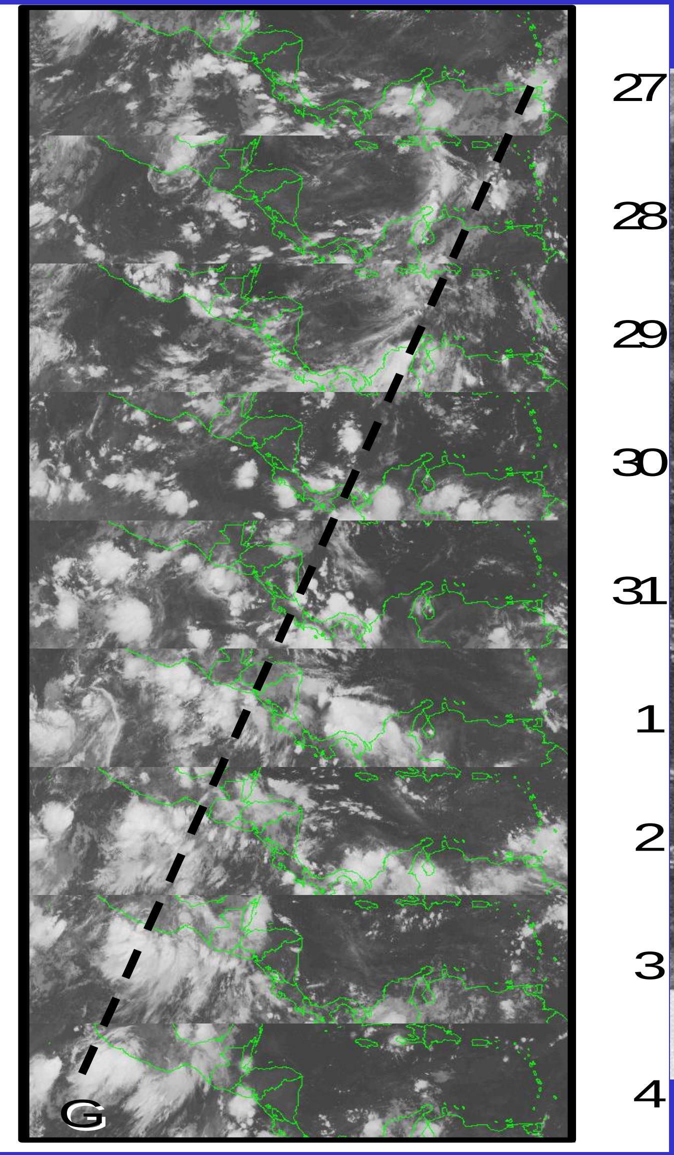


Subtropical cyclones have characteristics of both tropical cyclones and extratropical lows

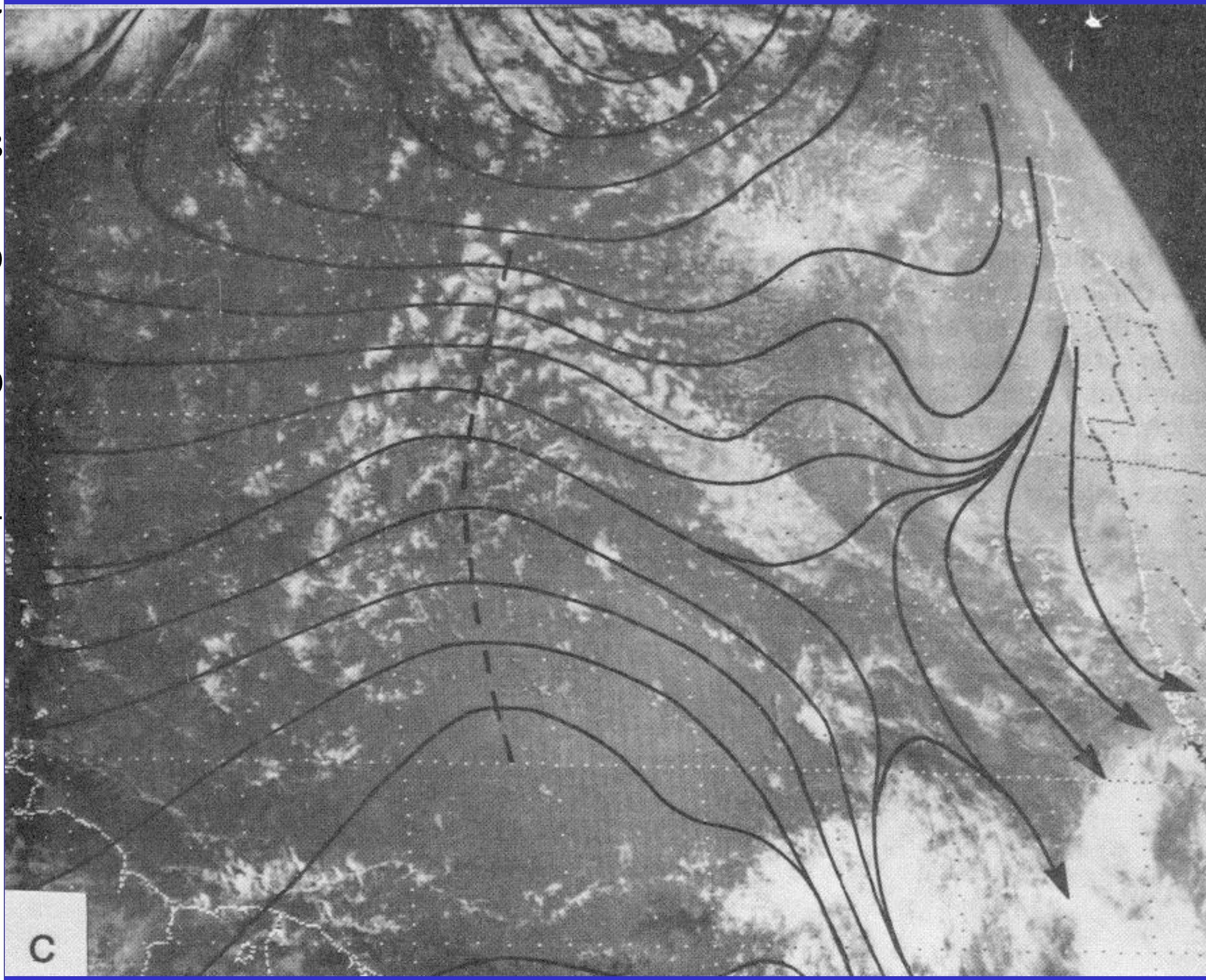
Large-scale features in WV imagery



Tracking Tropical Waves

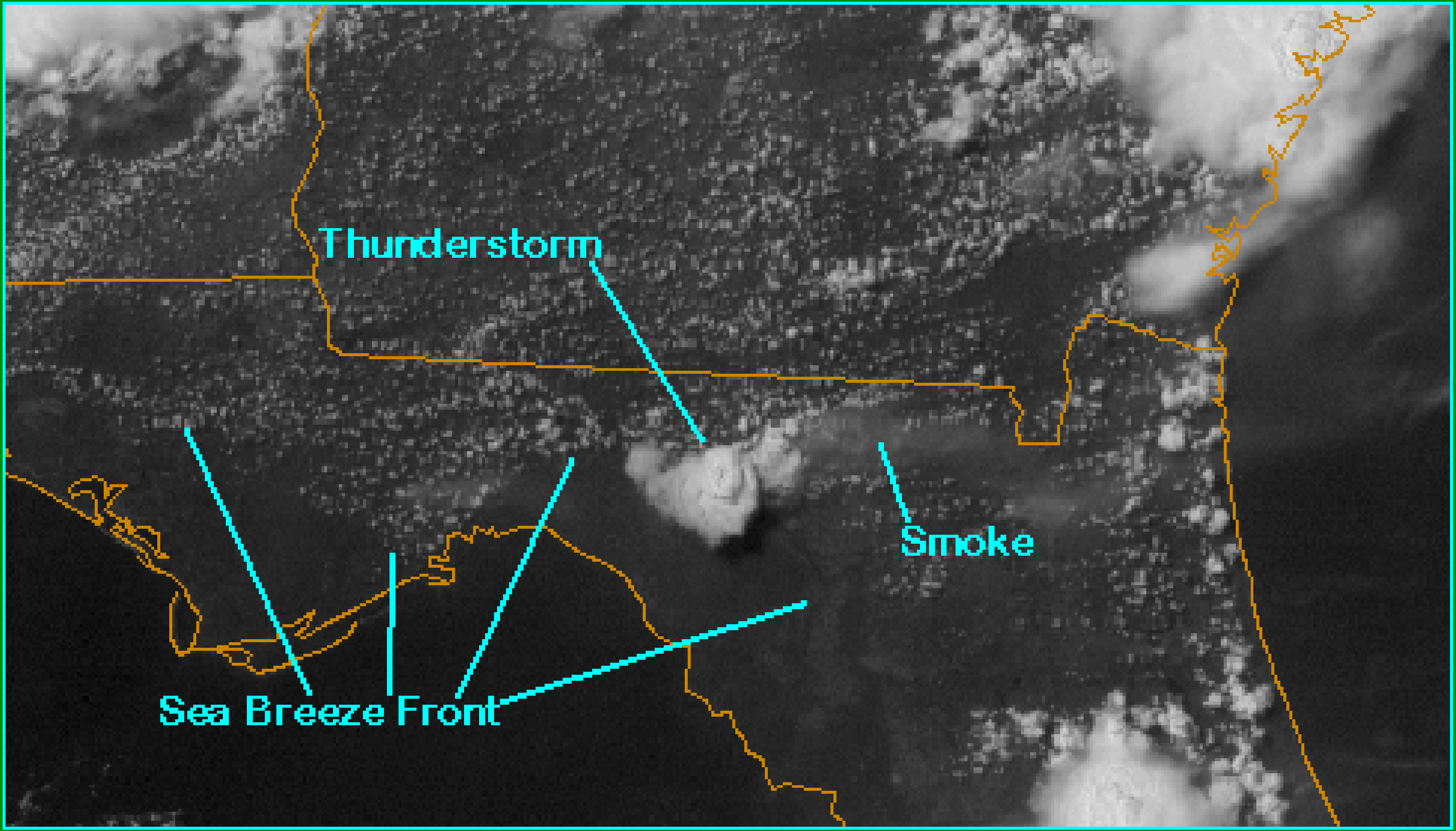


Hovmuller diagram



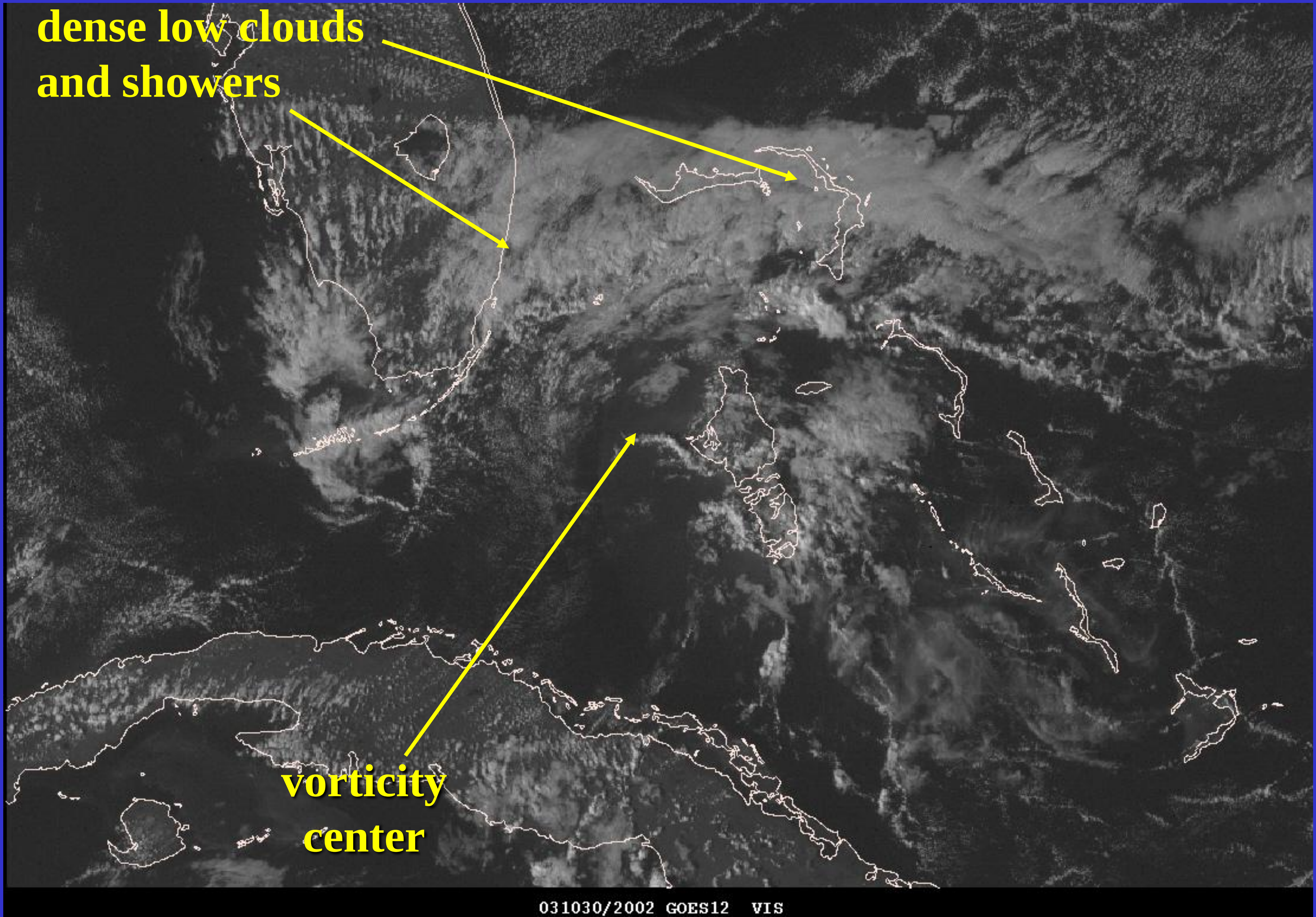
Non-convective wave defined by low clouds

Sea Breeze Fronts

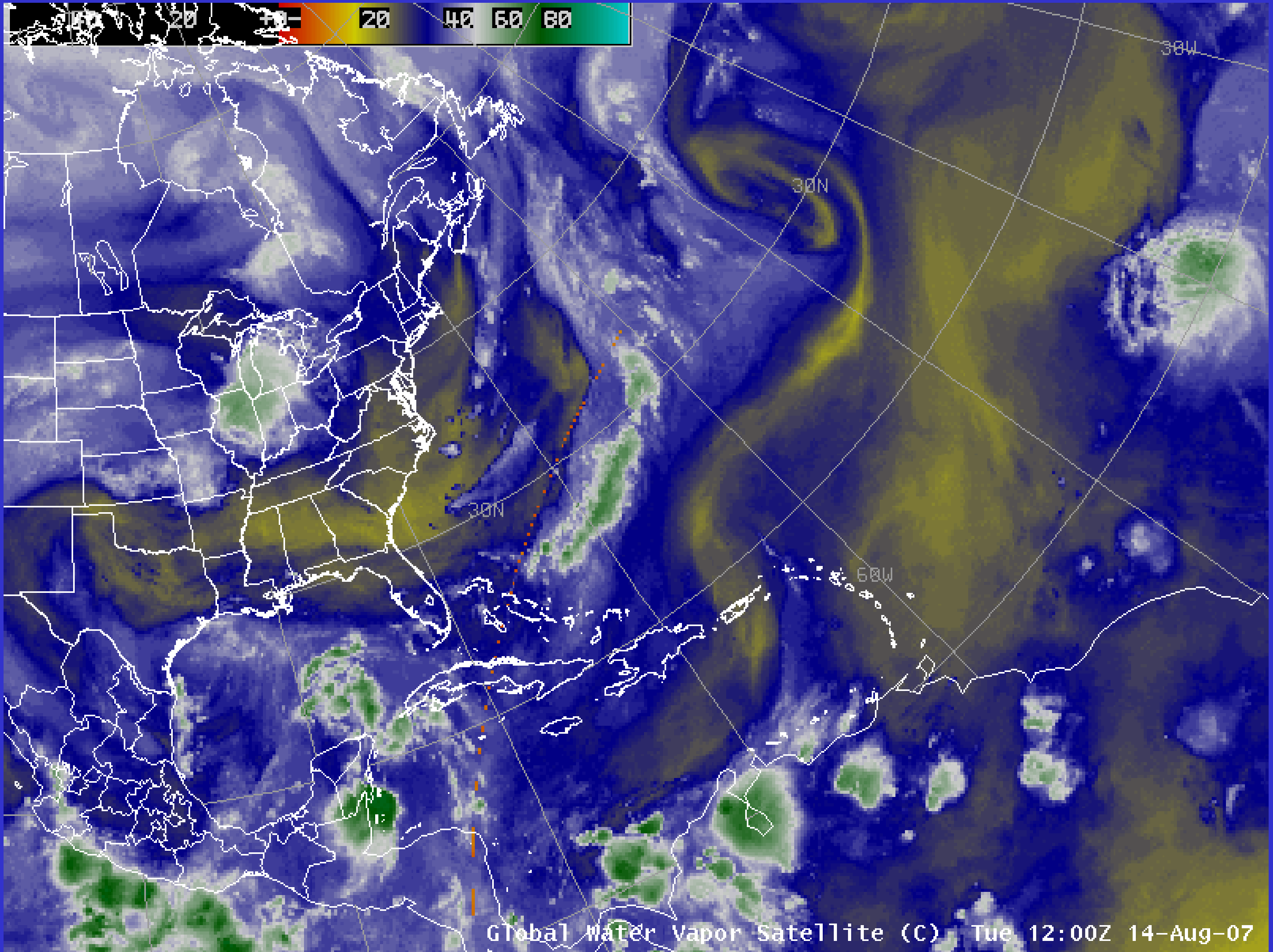


SEA BREEZE THUNDERSTORM FORMS OVER FLORIDA FOREST FIRE
19 June 1998   1932Z (1532 EDT) GOES-8 Visible Image

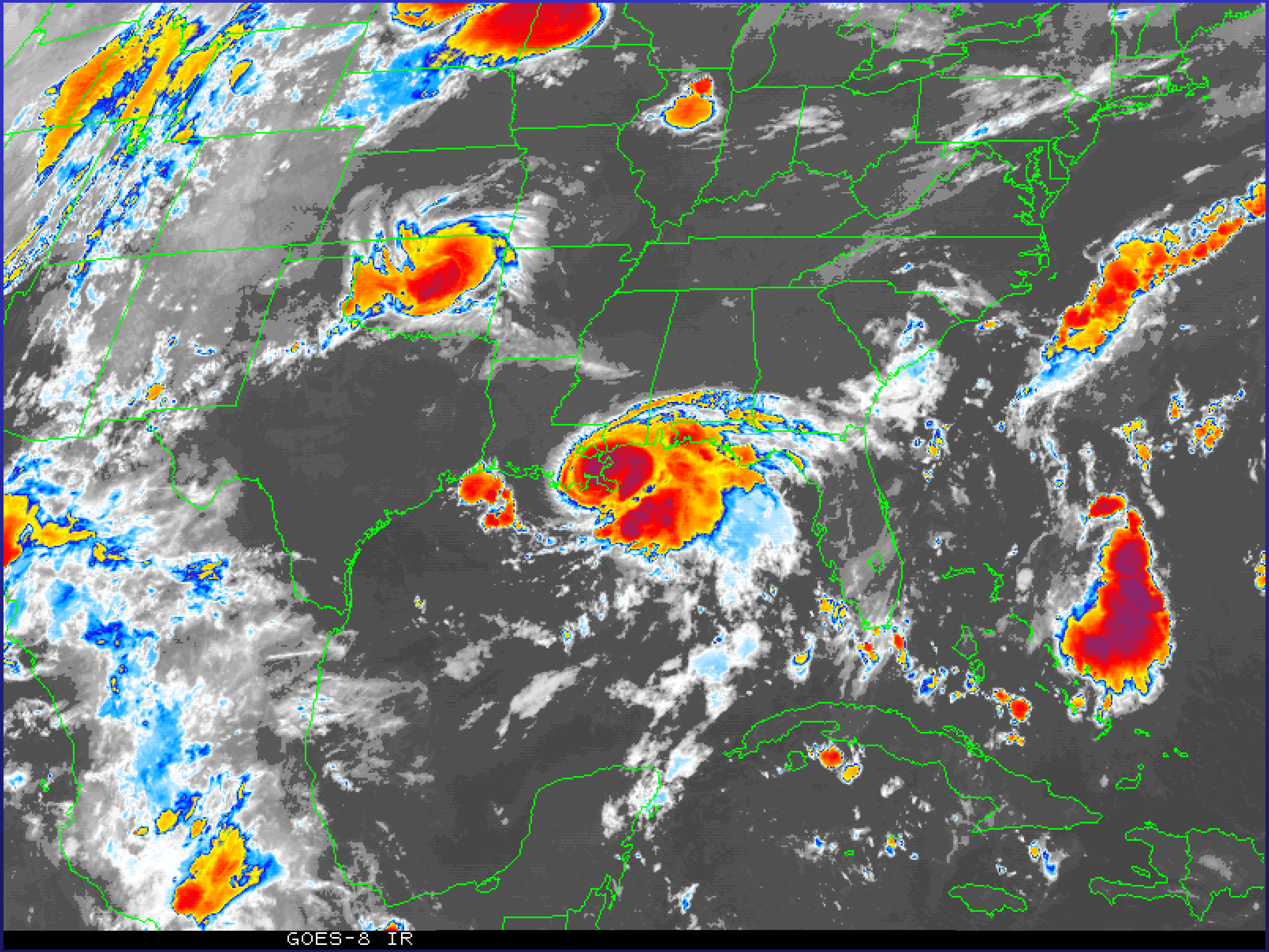
Low-level perturbation or "Screaming Eagle"



What features can be seen here?



How Many Tropical Cyclones?



Upcoming Meteorological Satellite Launches (tentative!)

- Chinese FY-3A – May 2008
- Jason-2 Ocean Monitoring – June 15, 2008
- DMSP F18 – June 29, 2008
- Indian INSAT-3D – Summer 2008
- Russian Meteor-M – Fall 2008
- Chinese FY-2E – October 2008
- Indian Oceansat-2 Ocean Monitoring – Fall 2008
- Russian Elektro-L – November 2008
- GOES O – December 12, 2008

Future Satellite Programs (also tentative)

- NPOESS Polar orbiting series
- GOES-R Next generation geostationary
- METEOSAT Third Generation
- NASA Global Precipitation Measuring Mission
- Next generation ocean surface vector winds
- NEXRAD in Space
- GeoStar Geostationary microwave sounder

Summary

- Meteorological satellites measure data from a great variety of atmospheric phenomena on a variety of space and time scales.
- The satellites are a vital part of NHC forecasting, as well as other meteorological operations.
- Satellite data can be used both objectively and subjectively – human data analysts still play an important role.