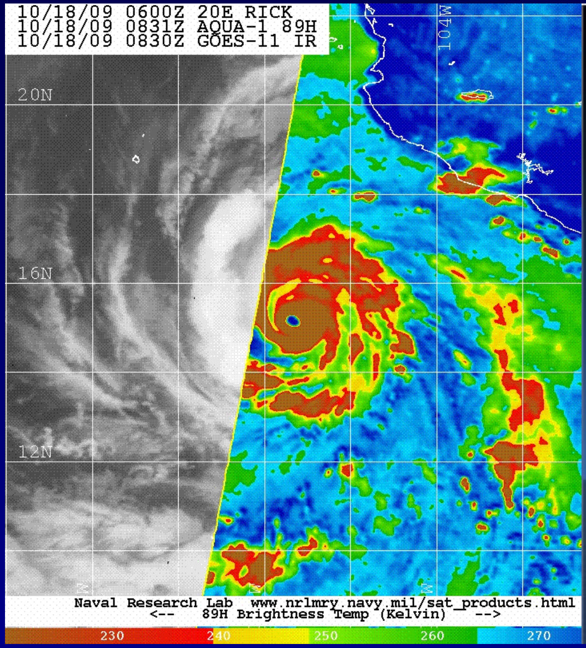
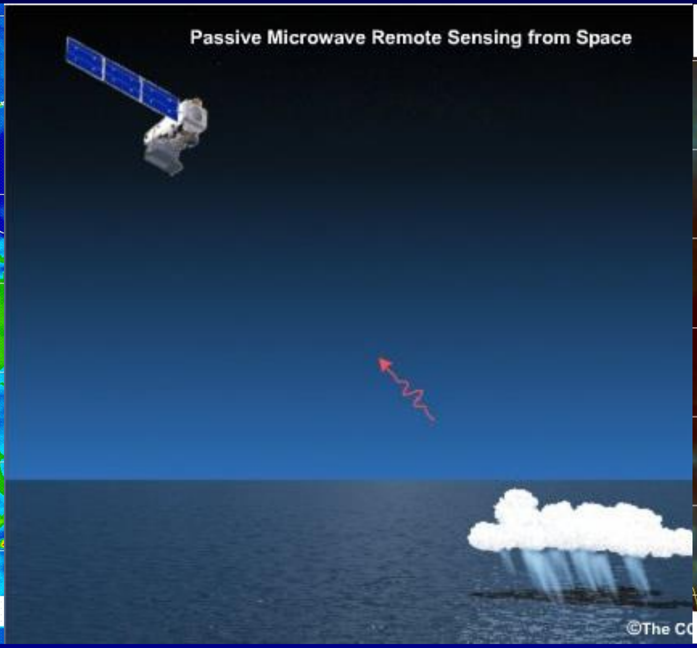
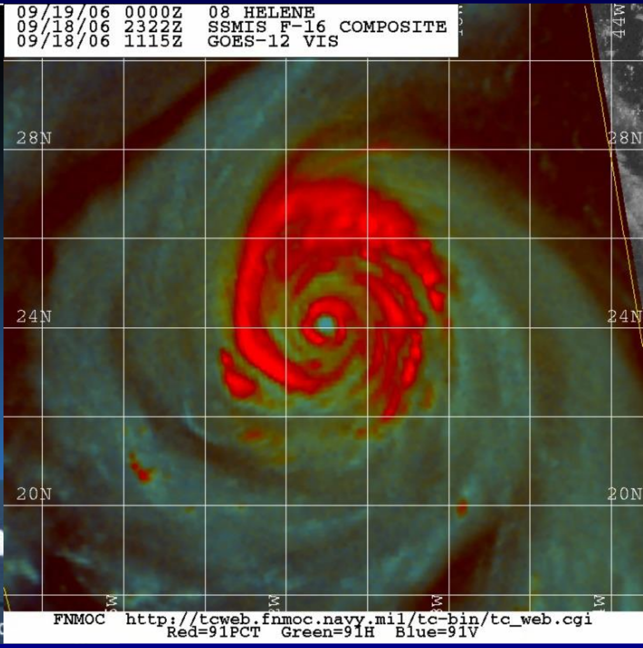
Interpretation and Application of Microwave Imagery and Scatterometry







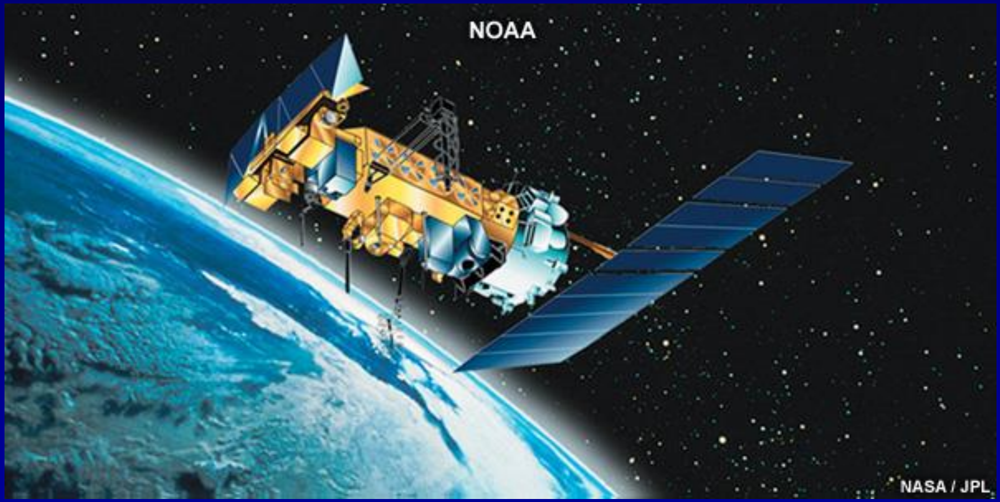
2020 RA-IV WMO Tropical Meteorology Course

John Cangialosi and Brad Reinhart

National Hurricane Center

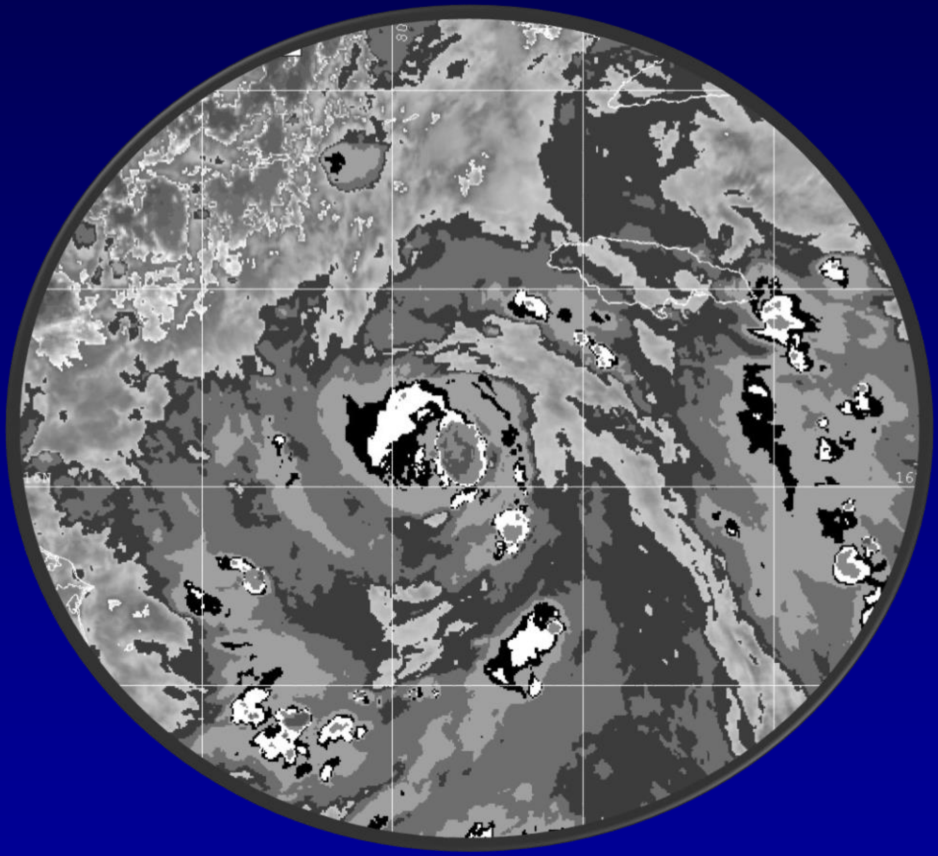
Outline

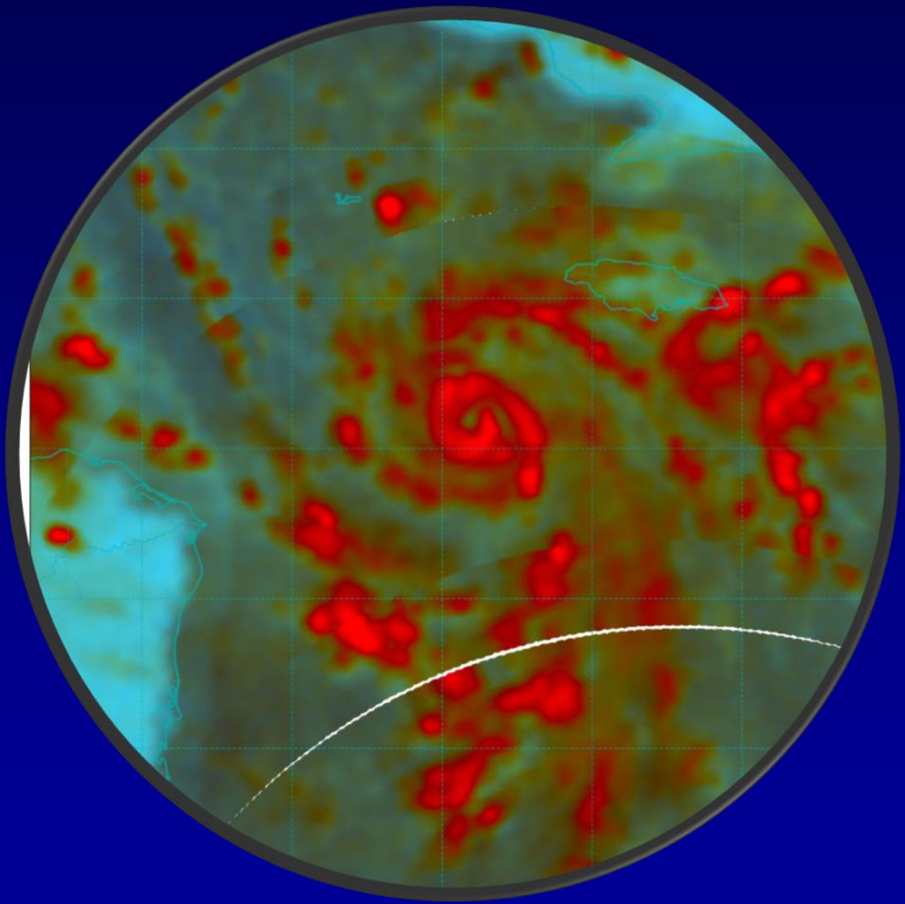
- Overview of basic principles/availability of microwave sensors
- Orbital characteristics
- Single frequency channels
- Color composite images
- Scatterometry
- Exercise



* Acknowledgements to COMET, NRL, and FNMOC for many of the images shown here

Advantages of Microwave Images?





Hurricane Delta, 22Z 5 October

Max winds ~65 kt, just prior to RI

How Does it Work? Overview of Remote Sensing Basics

- Passive sensors (SSM/I, SSMIS, AMSU, AMSR2, etc.) measure emitted microwave energy from 19 to 200 GHZ

- Emissivities are directly related to brightness temperatures (T_b)
    - scattering effects by ice
    - emission by light precipitation
    - emission/absorption by cloud liquid water and rain droplets

- Microwave window channel T_b can be used to quantify these emissivities

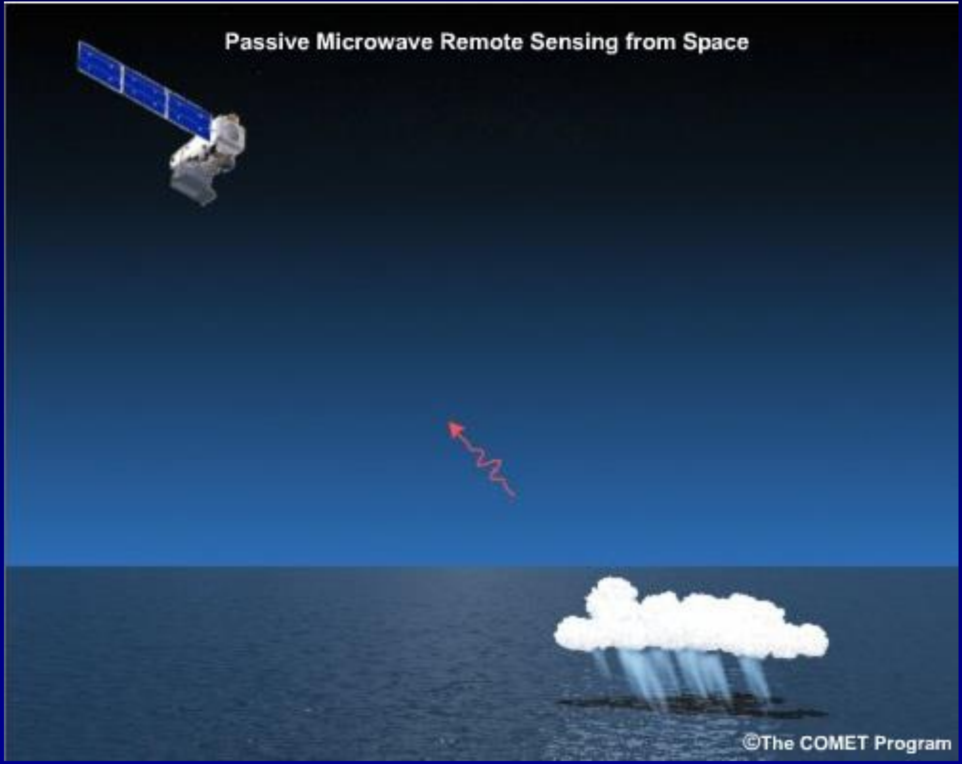


Image courtesy COMET

Overview of Remote Sensing Basics

- 85-GHz images → primary signature is lowered T_b caused by ice scattering and cloud and rain droplets within deep convection and precipitating anvil clouds

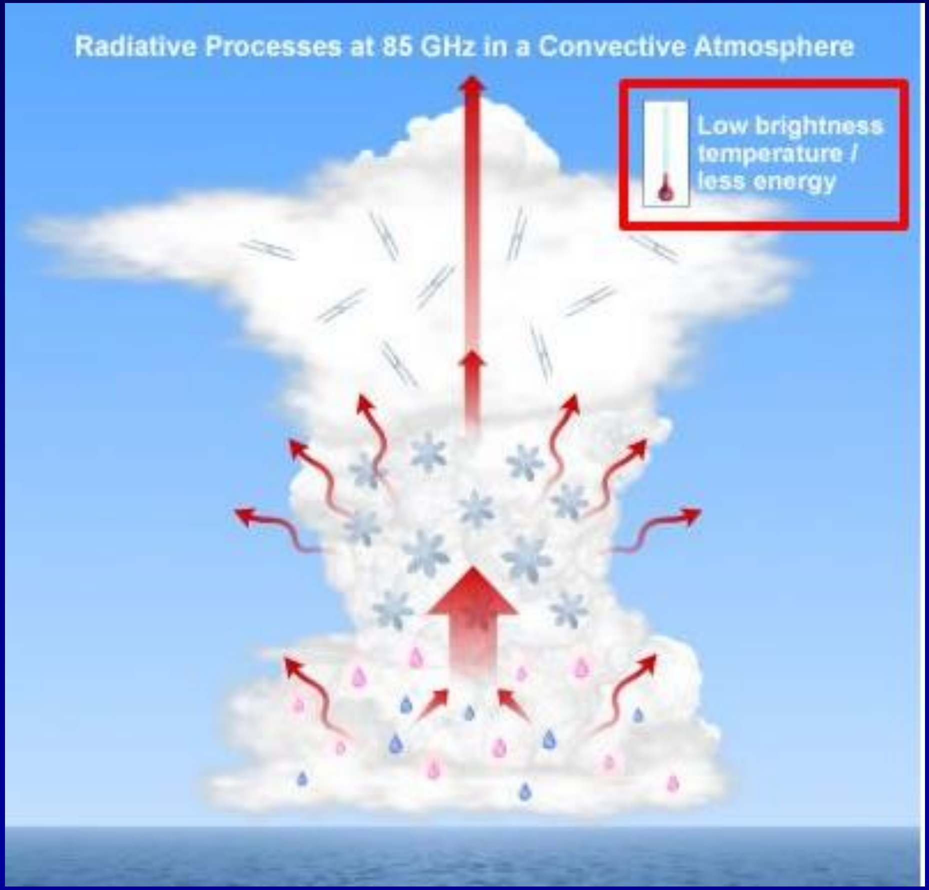


Image courtesy COMET

Overview of Remote Sensing Basics

• 37-GHz images → primary signature is elevated T_b because of minor emission from liquid hydrometeors near or below the freezing level

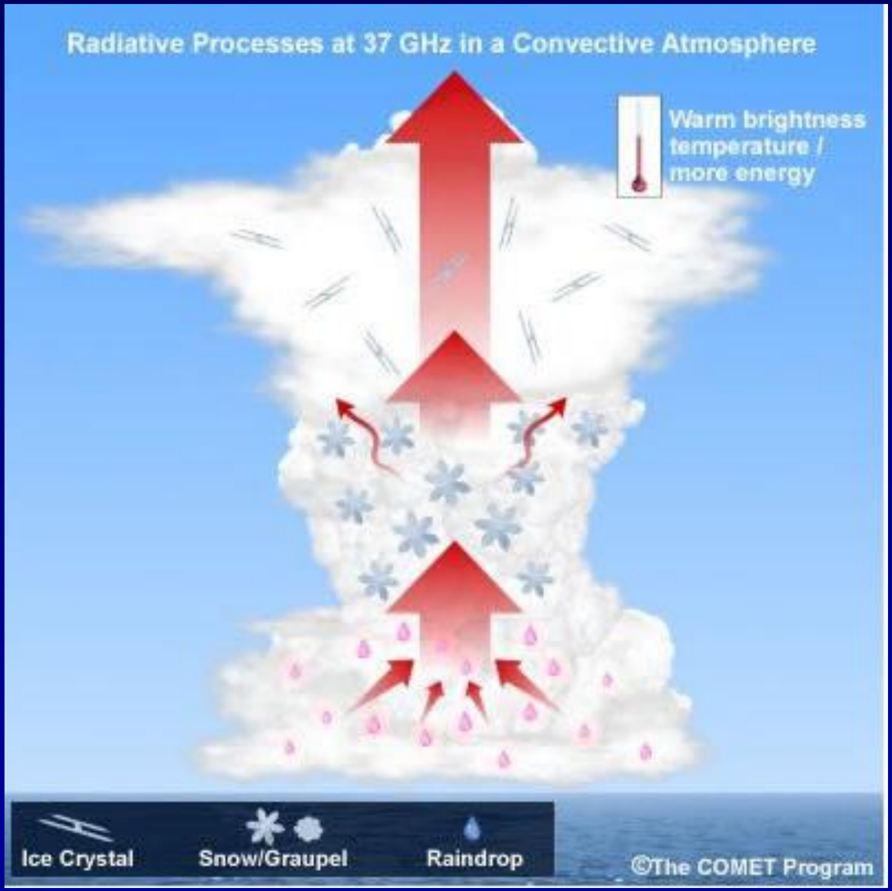


Image courtesy COMET

Remote Sensing Satellites - Orbits

- Geostationary (GEO) satellites
  - Orbit at 35,800 km altitude over same spot on the equator
  - Good for continuous monitoring on a large scale
  - Good for visible and infrared, not good for microwave
  - Good for passive, not good for active

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

Data Timeliness

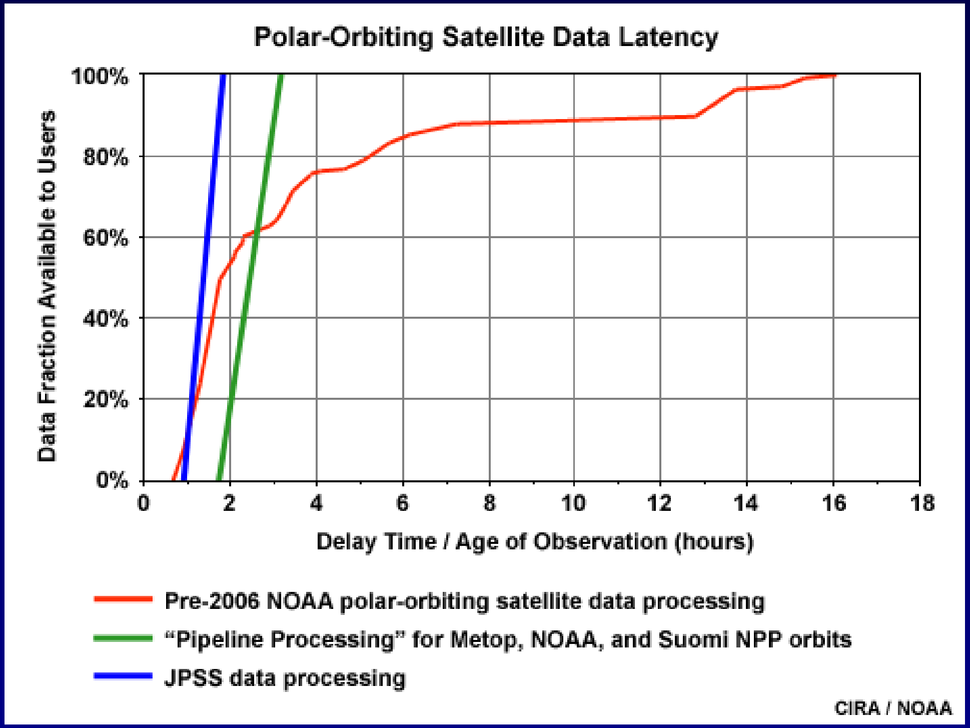
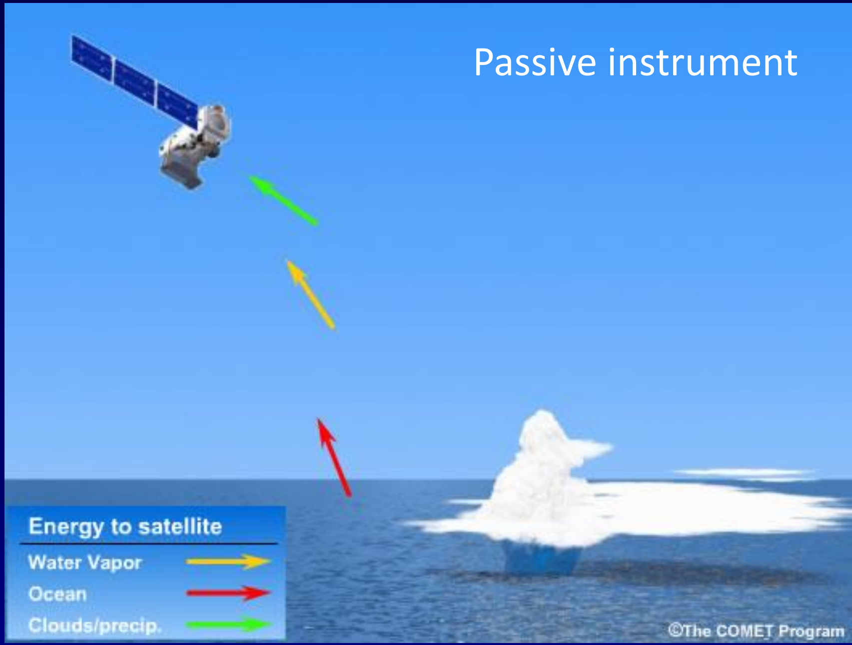


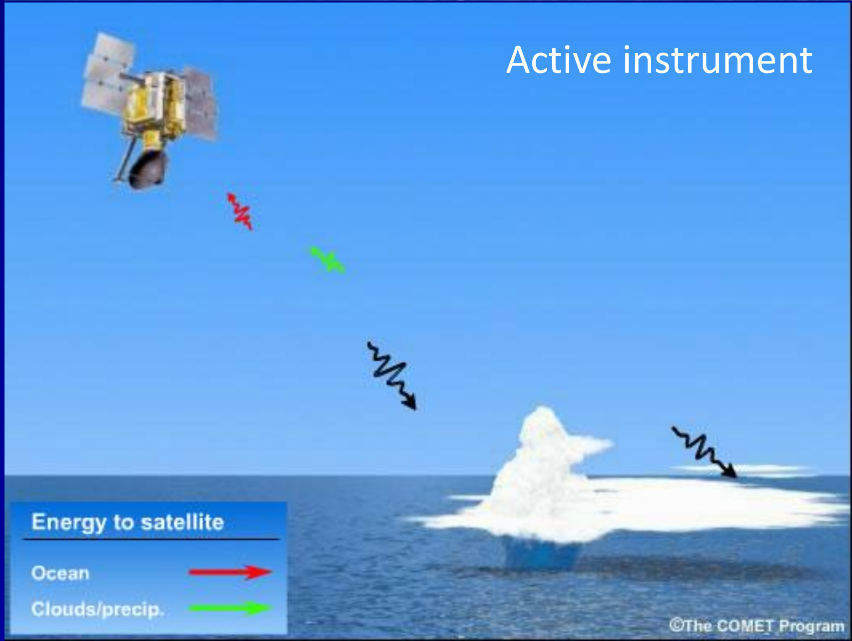
Image courtesy COMET

- LEO satellites are not continuously in view of data receiving stations
- They can only download data when in range of those stations, which leads to delays in data transmission and processing by a couple of hours for most cases.

Measuring Electromagnetic Energy

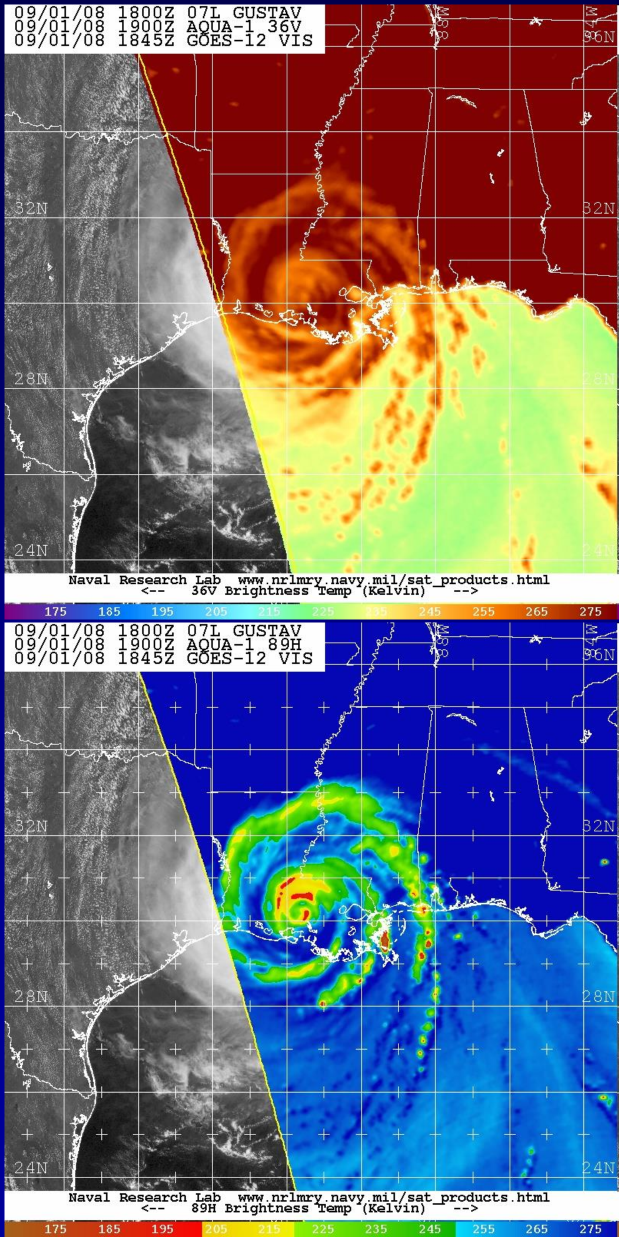
- **Passive Instruments:**
  - Receive radiation leaving the earth-atmosphere system
  - Measure solar radiation reflected by earth/atmosphere targets (visible light)
  - Measure emitted and scattered infrared radiation
  - Measure microwave radiation resulting from emission and scattering
- **Active Instruments:**
  - Send out pulses of radiation, usually at microwave frequencies
  - Measure radiation returned to the sensor
  - Examples
    - Surface-based and airborne radars
    - Satellite scatterometers



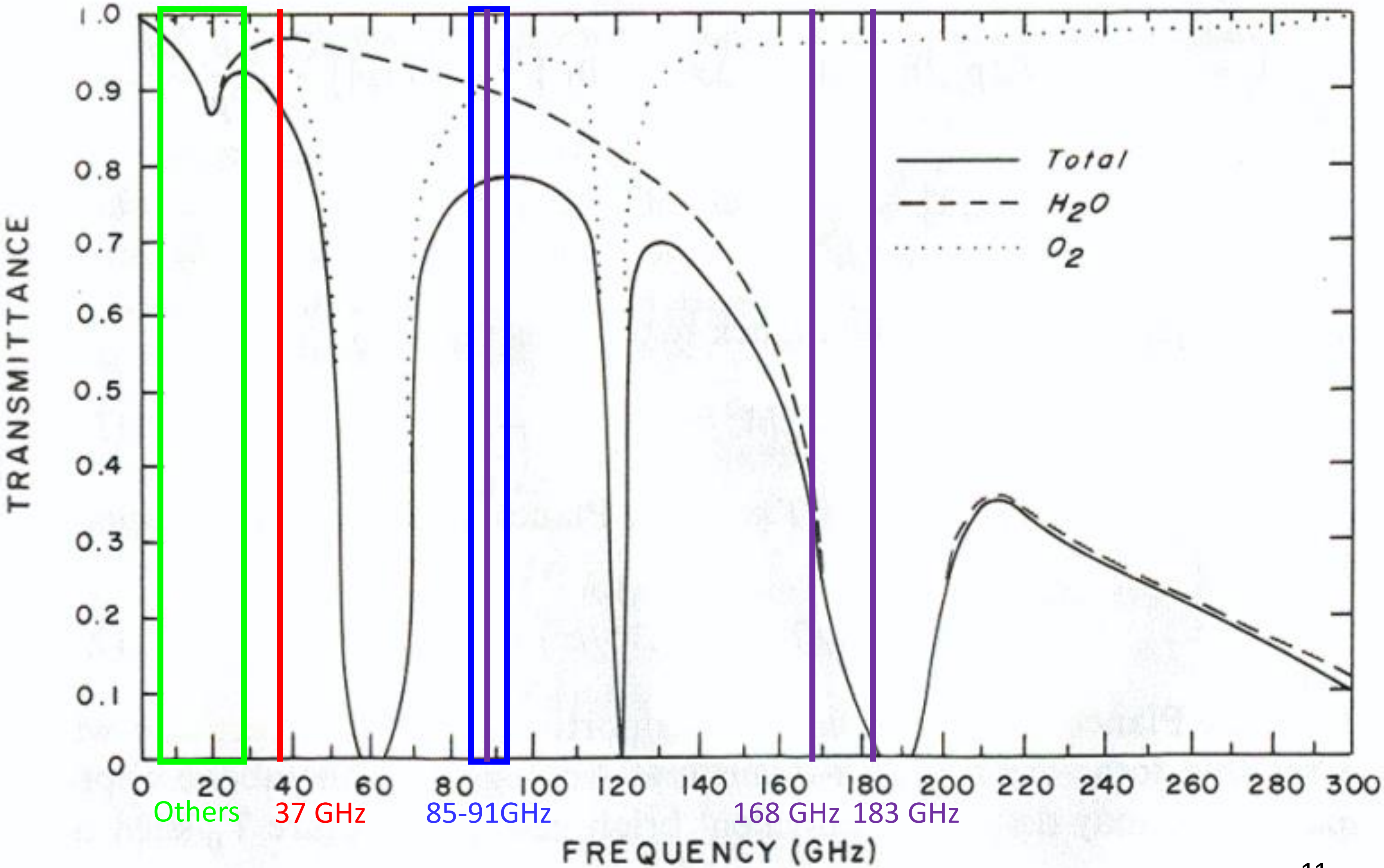


Key Characteristics of Microwave Radiation

- Water surfaces (e.g., oceans) have low emissivity (~0.4-0.5) and appear “cold” at microwave frequencies
- Land surfaces have a much greater emissivity (~0.9)
- Raindrops have high emissivity and are “warmer”; they contrast against a “colder” ocean background
- Higher frequency (shorter wavelength) microwaves (~85 GHz) are scattered by ice particles in precipitating clouds, reducing radiation reaching the satellite (these regions also look “cold”)

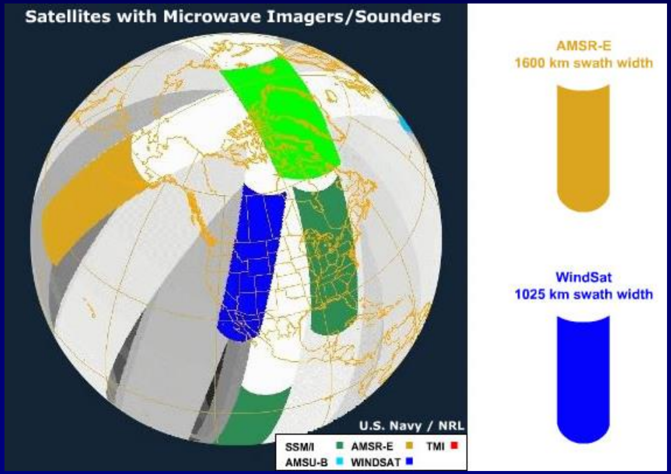


Microwave Transmittance



Current/Operational Microwave Imagers and Sounders

- AMSU-A/B: 6 satellites (NOAA 18/19) and European MetOP-A/B
- SSM/I: 1 DMSP satellite (F-15)
- SSMIS: 3 DMSP satellites (F-16, F-17, F-18)
- GMI–GPM: JAXA/NASA
- AMSR2-GCOM W1: Japan (JAXA)
- WindSat: Navy NRL Coriolis (37-GHz Only)
- ATMS: NASA
- SAR: NASA



Orbital and Scan Characteristics

GEO vs. LEO Orbital Altitude Comparison

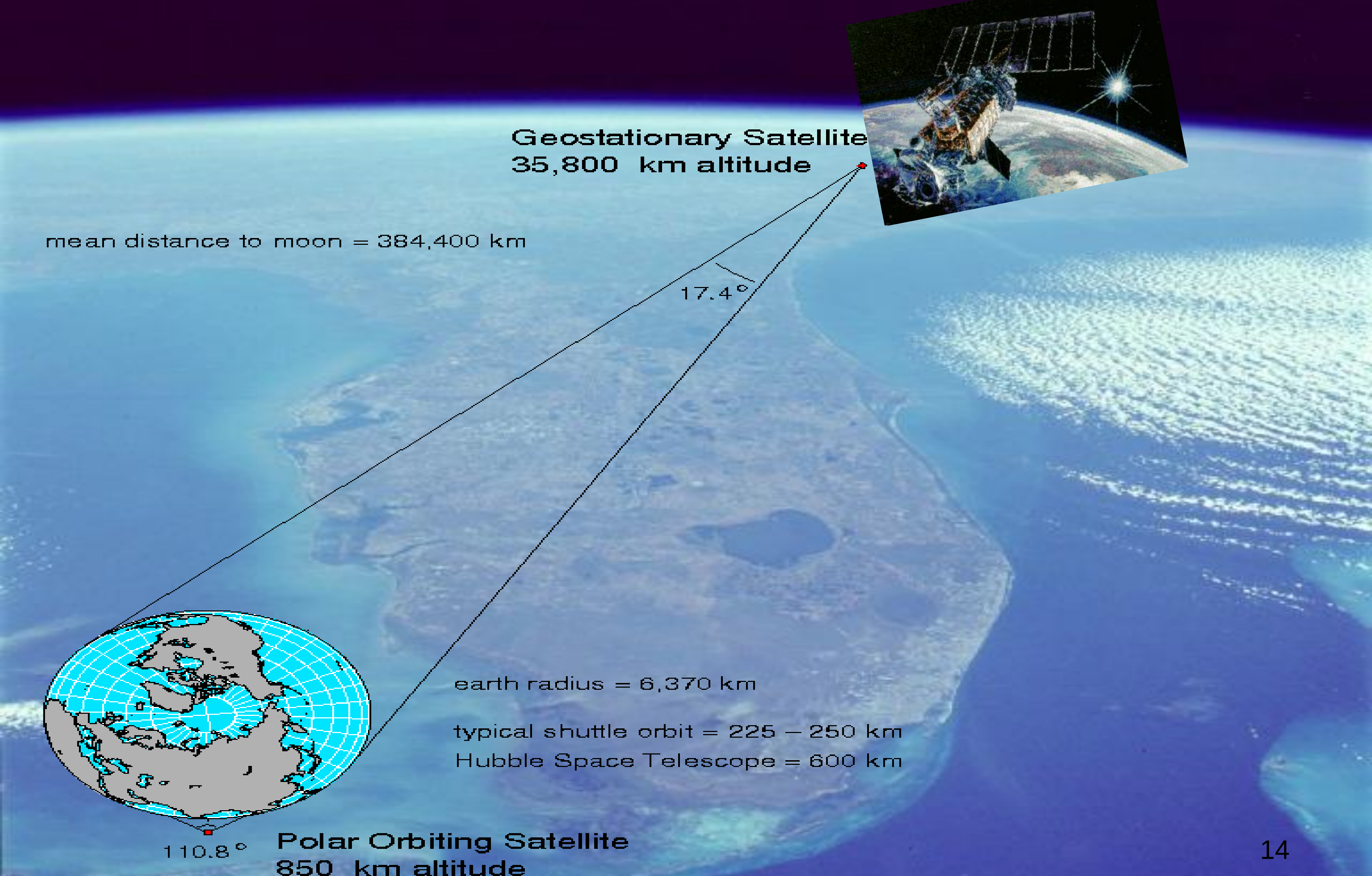


Image courtesy of http://www.nrlmry.navy.mil

Sun-Synchronous Daily Orbital Path

~12 hr to observe the entire Earth

Same location twice daily (ascending/descending)

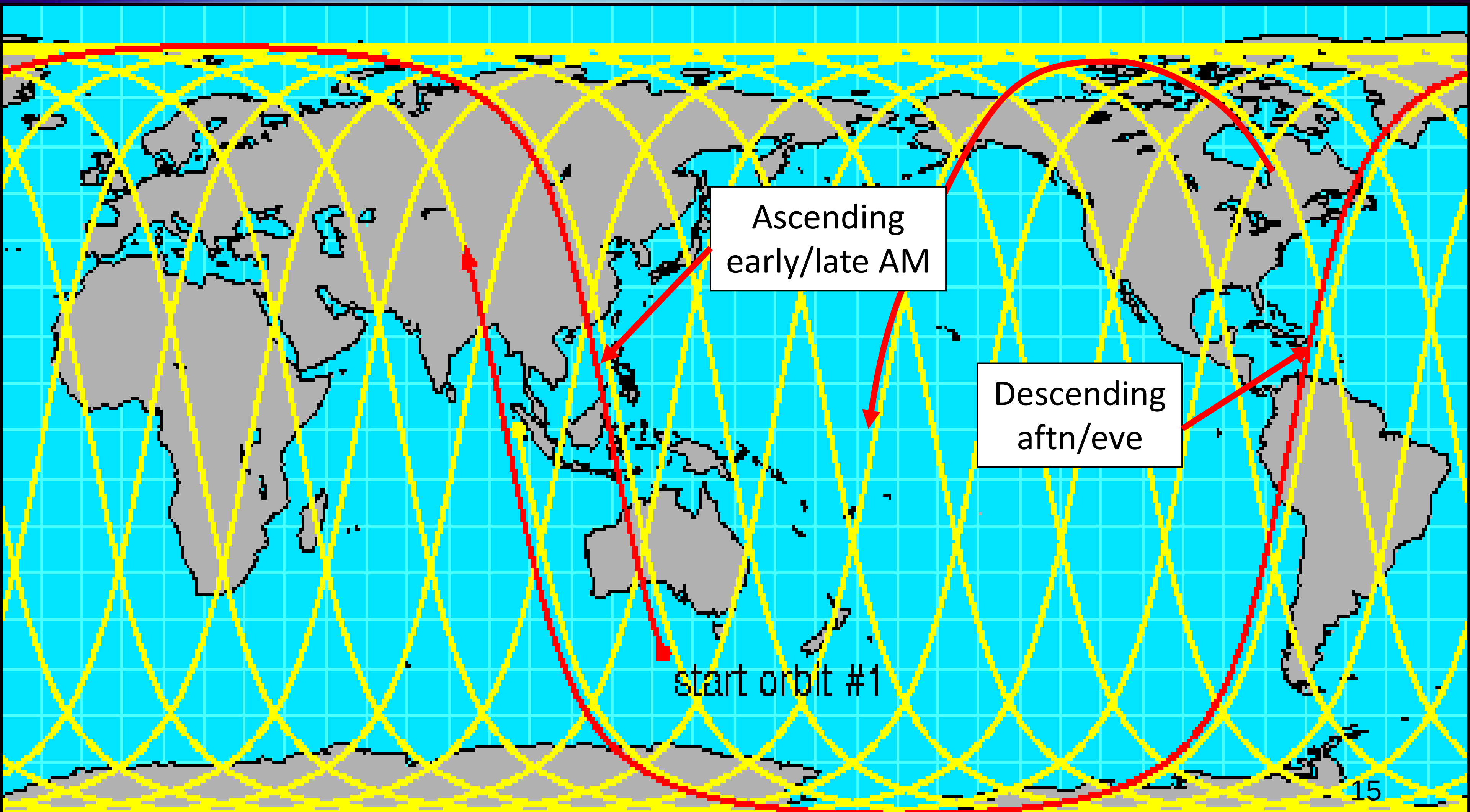
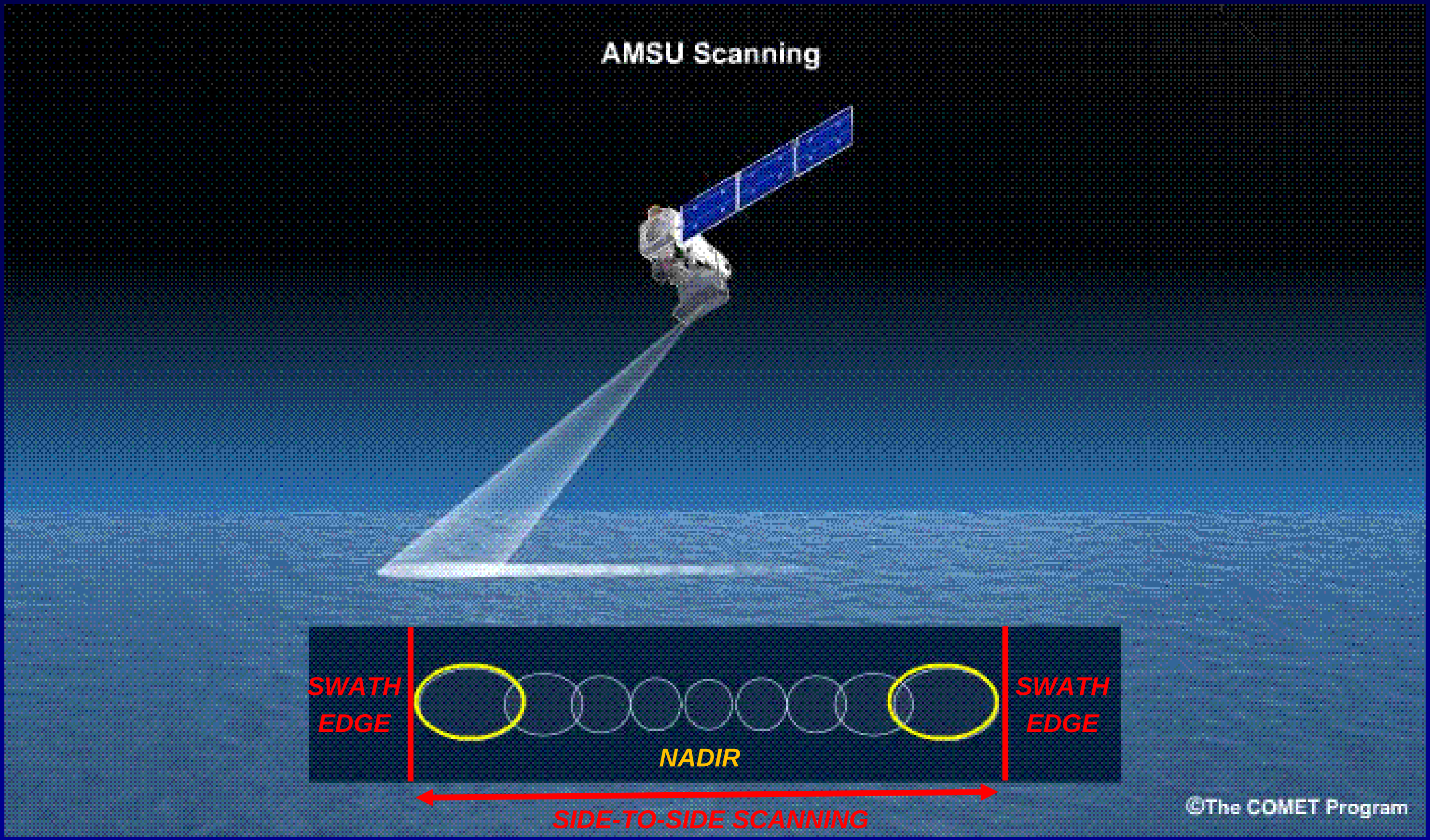


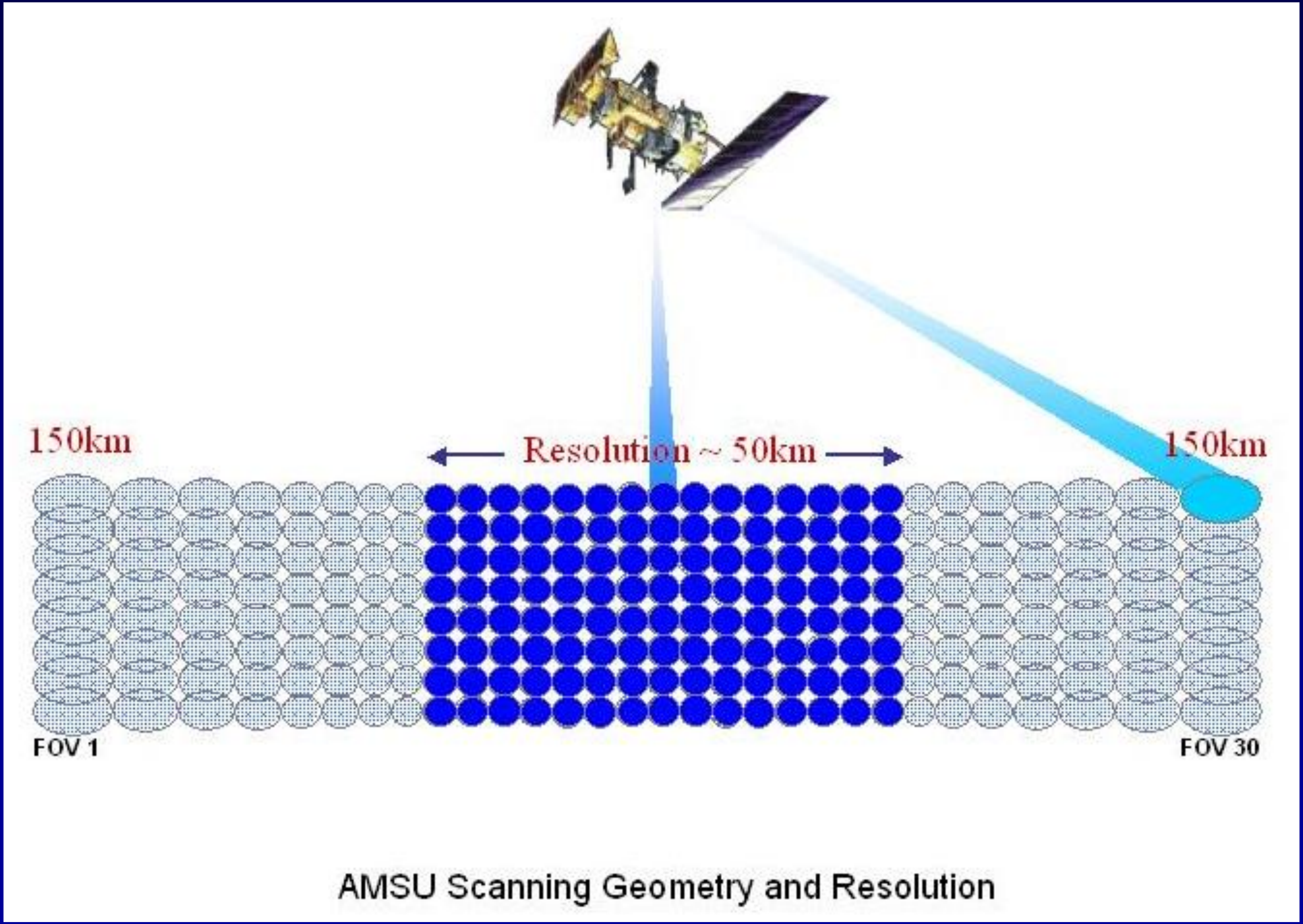
Image courtesy of http://www.nrlmry.navy.mil

Cross Track Scan Strategy

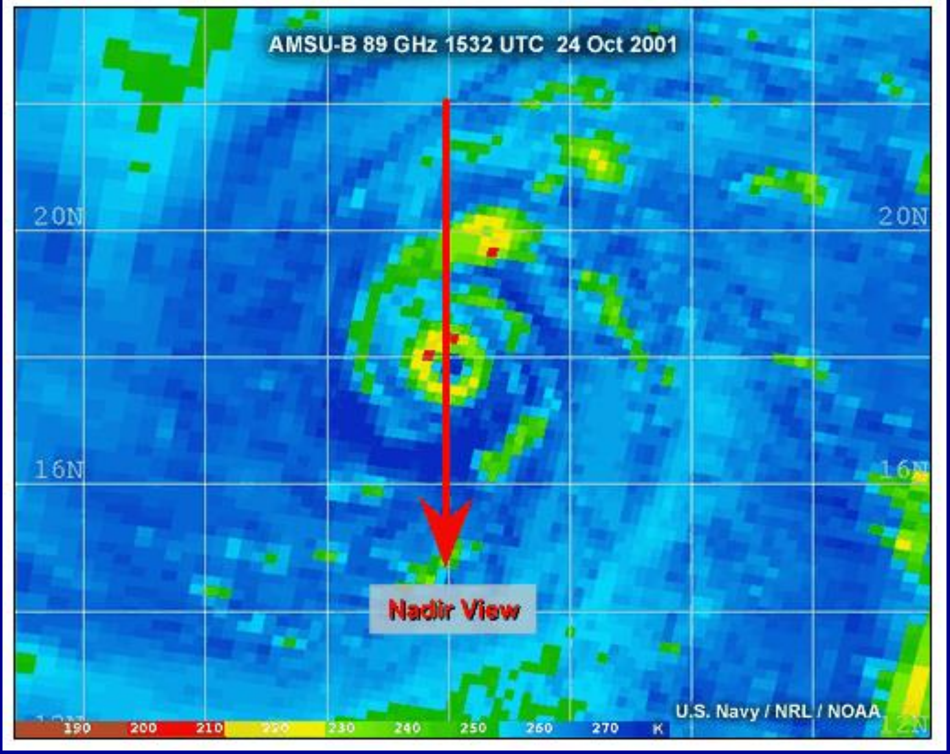


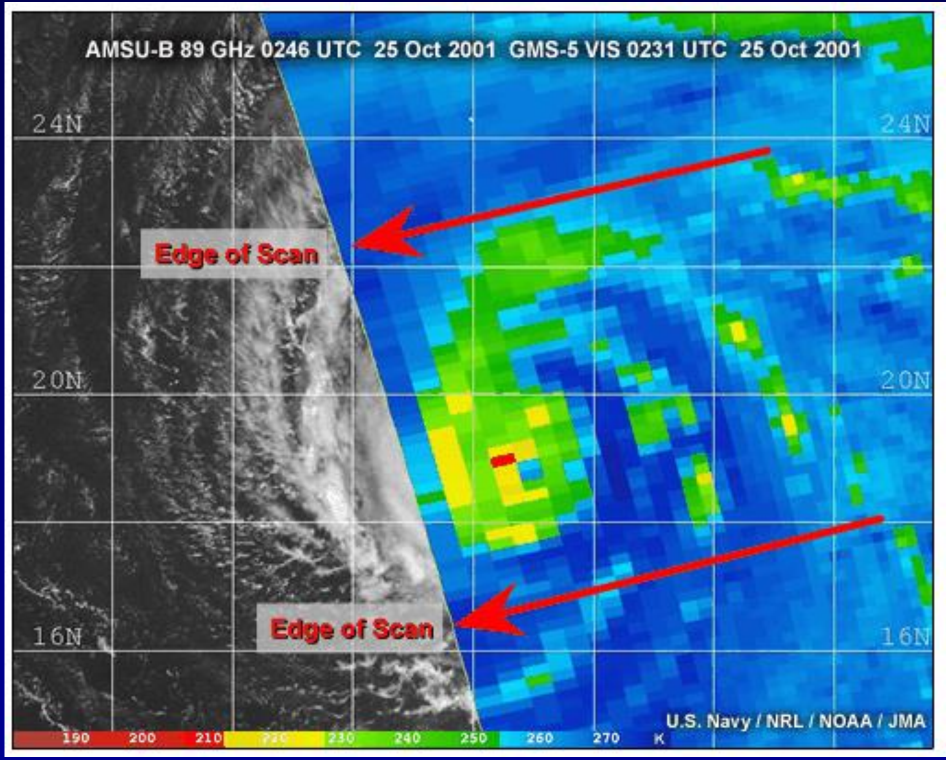
- **Advantage**: Larger coverage swath relative to conical scan
- **Disadvantage**: Resolution varies across the swath (coarser resolution at swath edge relative to nadir)

Cross Track Scan Strategy



Cross Track Scan Strategy

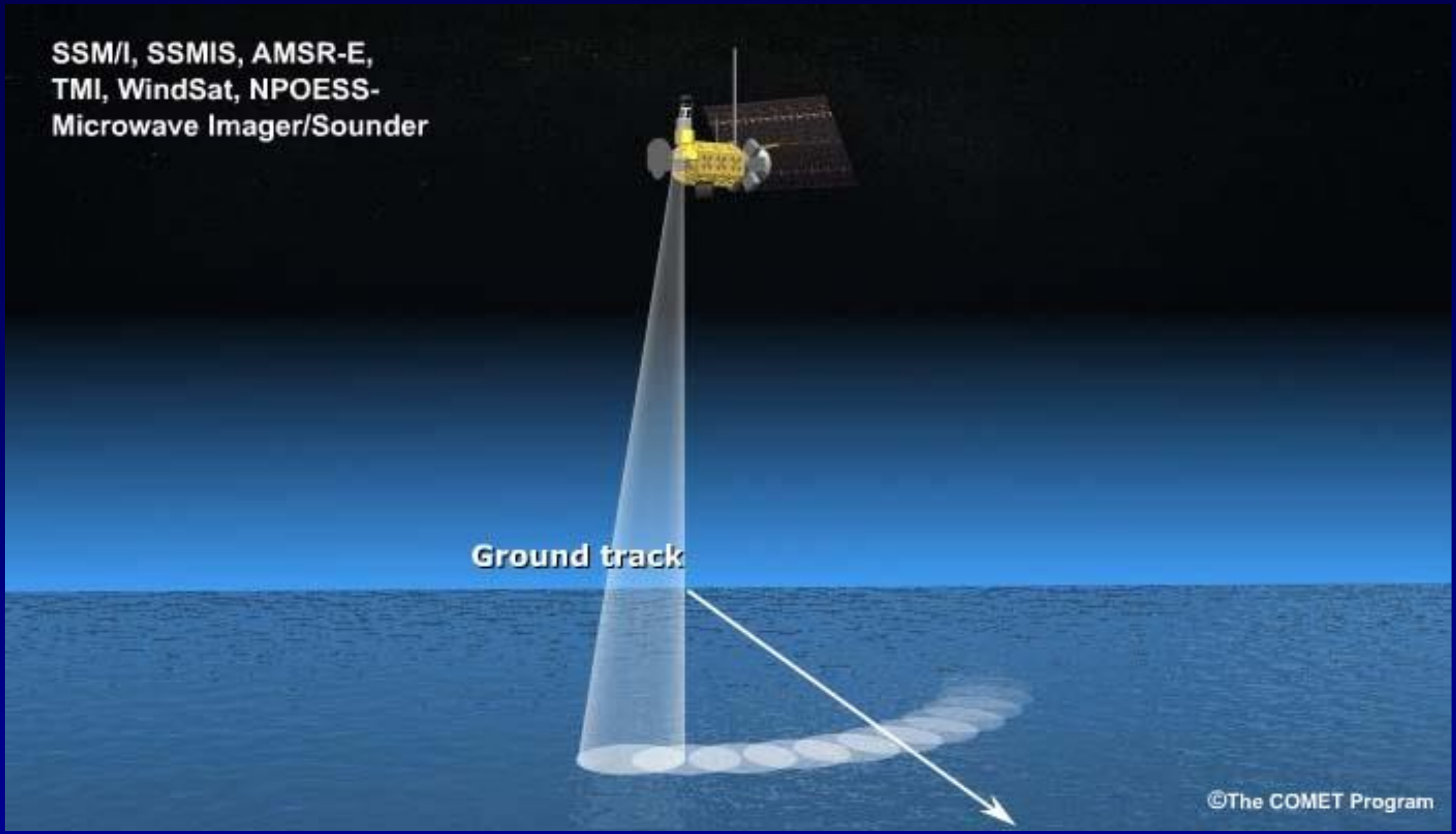




Note degradation in resolution at edge of scan compared to nadir

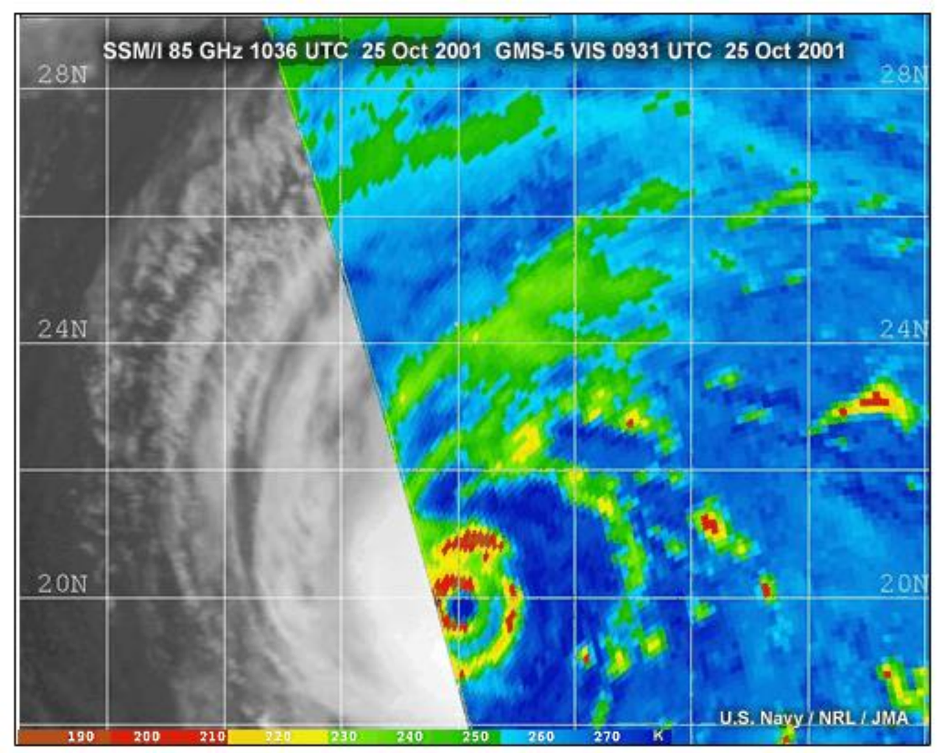
Images courtesy COMET

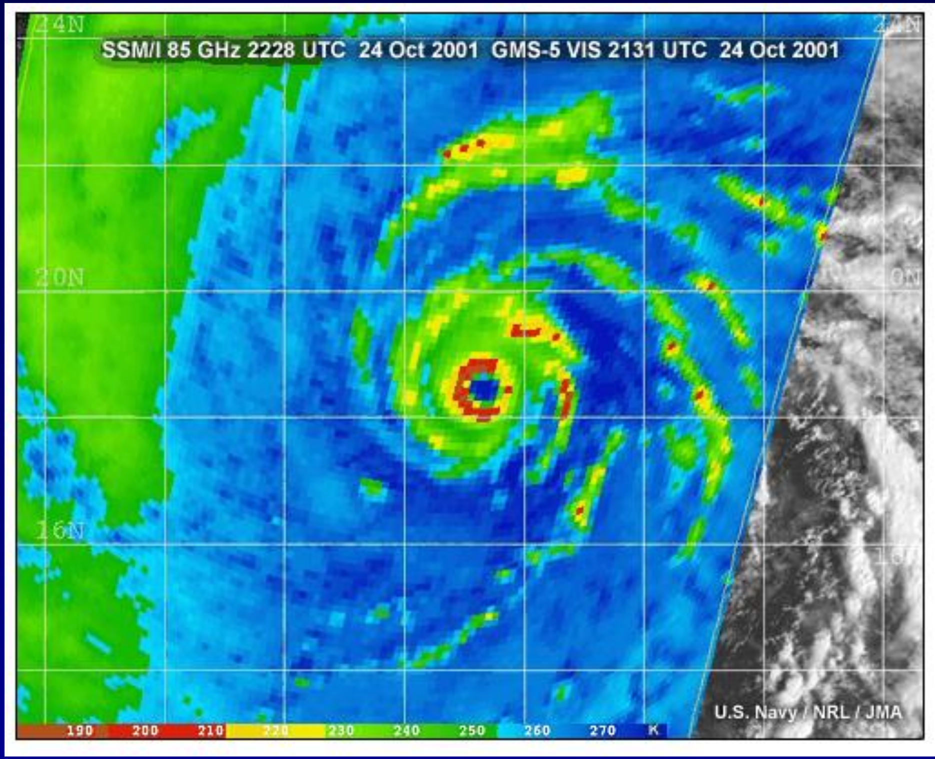
Conical Scan Strategy



- Advantage: Resolution remains constant because scan footprints are the same size throughout the entire swath
- Disadvantage: Narrower coverage swath relative to cross-track scan

Conical Scan Strategy





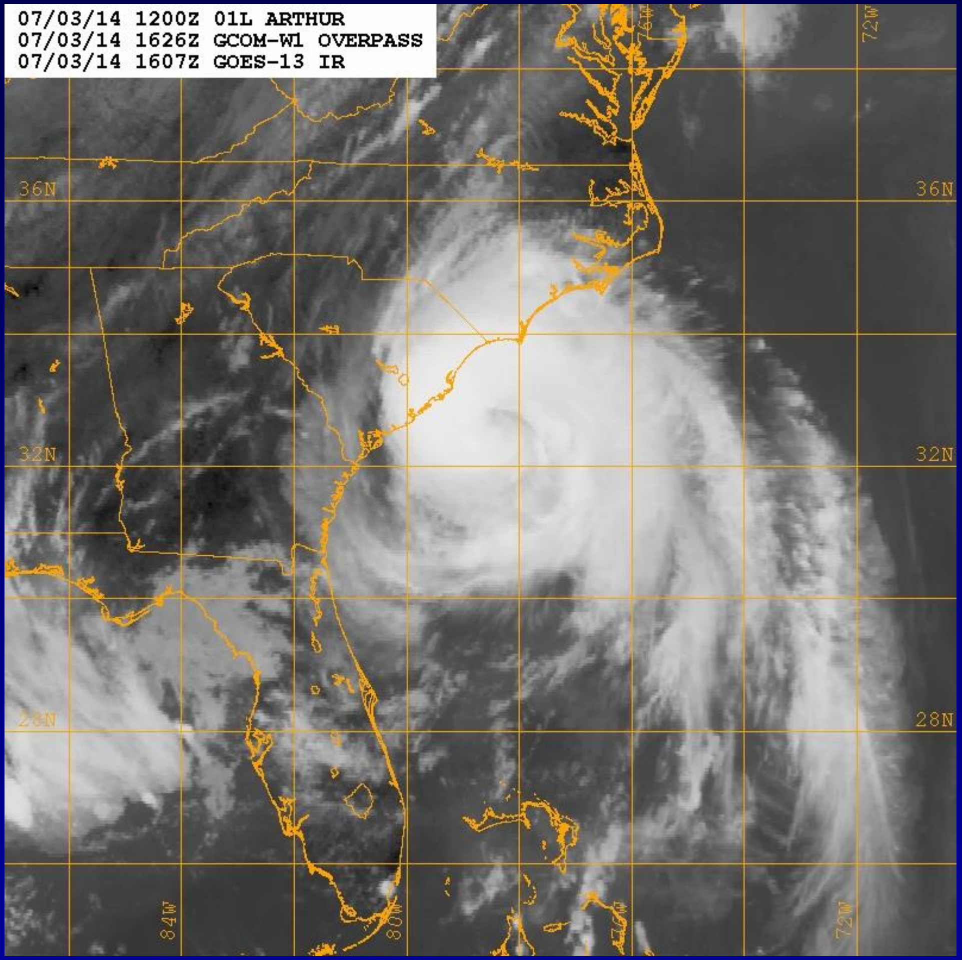
Resolution remains constant across swath

Images courtesy COMET

Imagery Characteristics and Applications

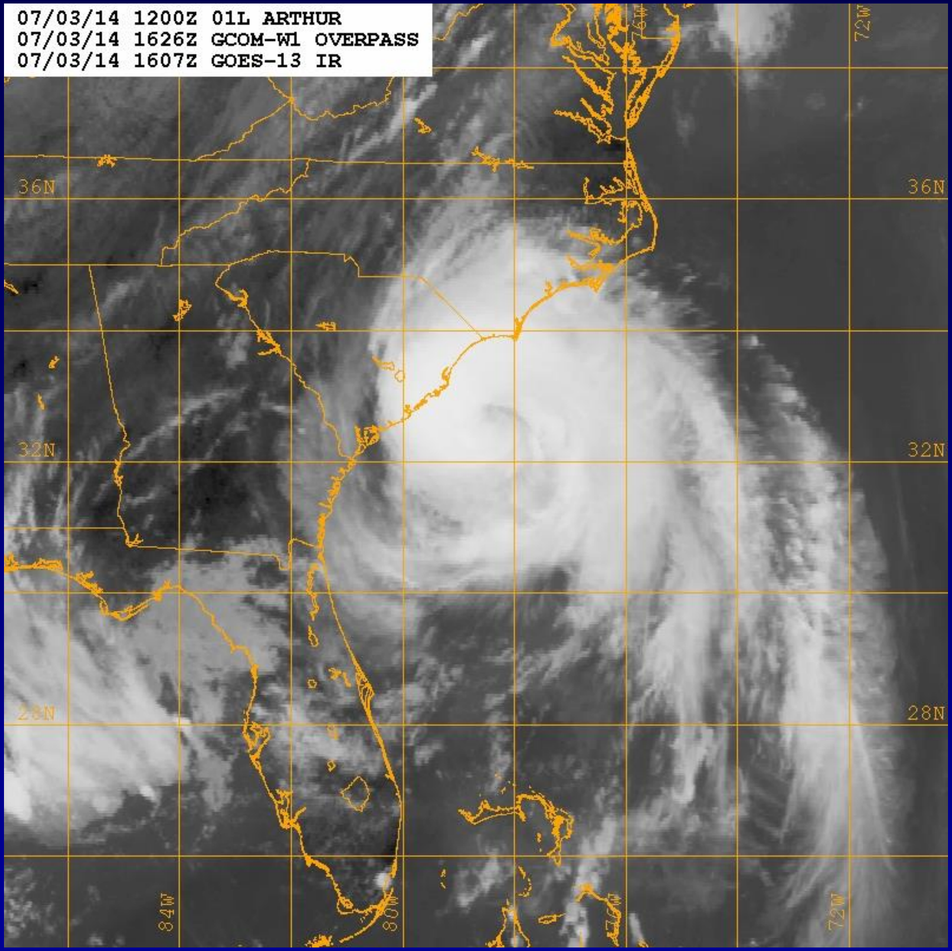
85-GHZ Imagery Interpretation

- Imagery can penetrate through clouds and reveal internal storm structure
- Imagery is better at locating tropical cyclone centers than conventional visible and infrared
- Land appears warm relative to water surfaces
- Water surfaces and deep convection appear relatively cold (due to scattering from ice)
- Imagery can not always see low-level circulations associated primarily with low-level clouds
- Offers higher spatial resolution than imagery at lower microwave frequencies



37-GHZ Imagery Interpretation

- Precipitating clouds and land surface appear warm
- Cold features: sea surface only
- Imagery highlights low-level cloud features and storm structure
- Imagery identifies cirrus-covered eyes and gives a ‘true’ low-level center instead of a mid/upper-level center (as in 85-91 GHz imagery)

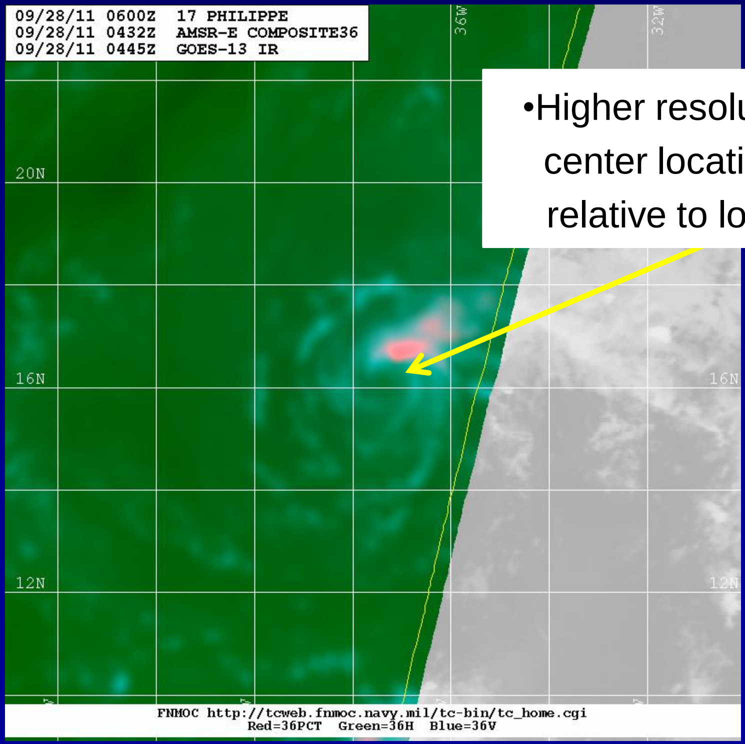


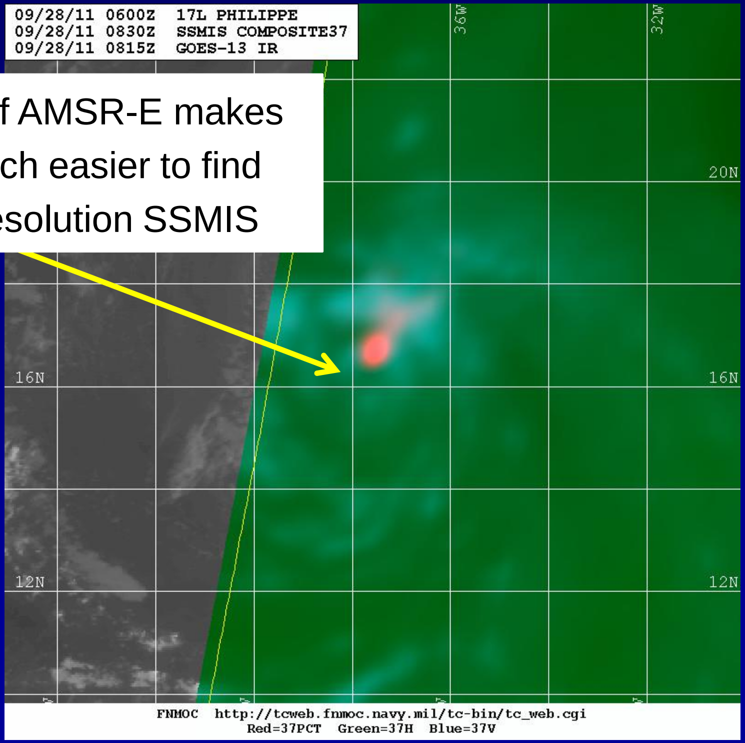
Advantages of Using 85-GHz and 37-GHz Imagery for TC Analysis

- In a sense, “sees” through clouds
- Identification of circulation center (critical step in initiating TC advisories)
- Acquire positioning of TCs in difficult situations (especially in early stages of development and at night)
- View of convective rain bands that is directly related to intensification of the TC
- Monitoring structural changes such as eyewall formation and eyewall replacement cycles

Effects of Resolution

- Comparison of 36/37-GHz color composite imagery over TS Philippe from AMSR-E (left) and SSMIS (right) at 0432 UTC and 0830 UTC 28 September 2011, respectively – Images courtesy FNMOC TC webpage

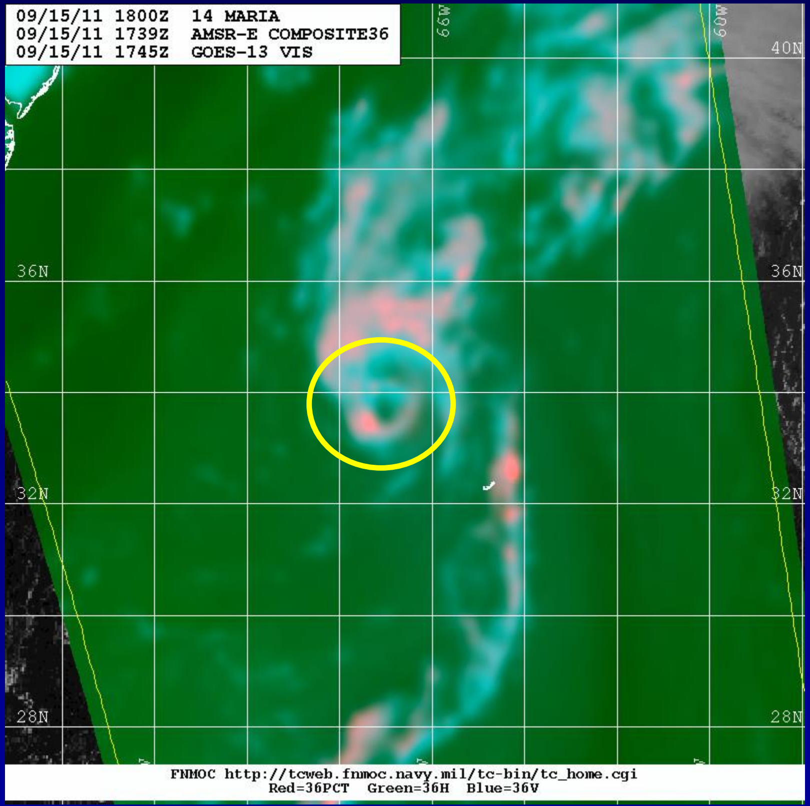


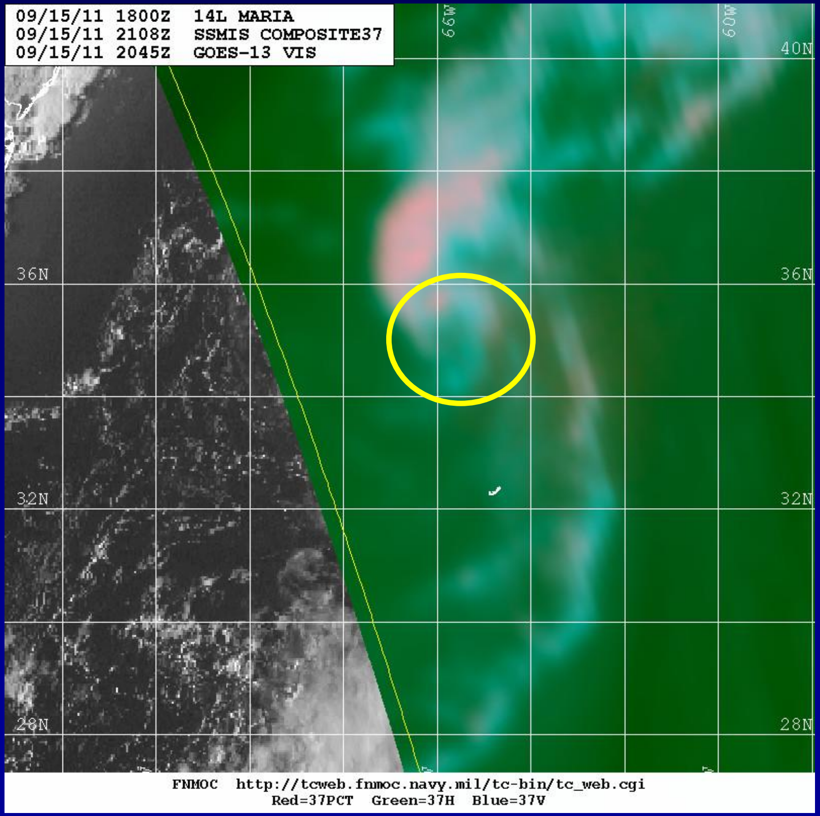


•Higher resolution of AMSR-E makes center location much easier to find relative to lower-resolution SSMIS

Effects of Resolution

- Resolution differences also affect the ability to resolve low to mid-level eyewall structure

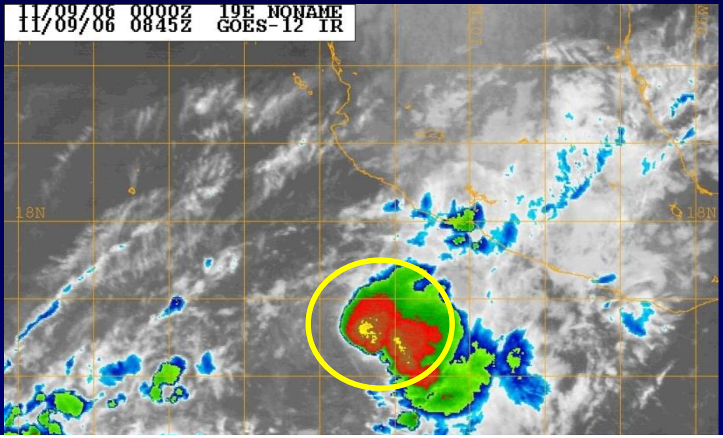




•Comparison of 36/37-GHz color composite imagery over Hurricane Maria from AMSR-E (left) and SSMIS (right) at 1739 UTC and 2018 UTC 15 September 2011, respectively – Images courtesy FNMOC TC webpage

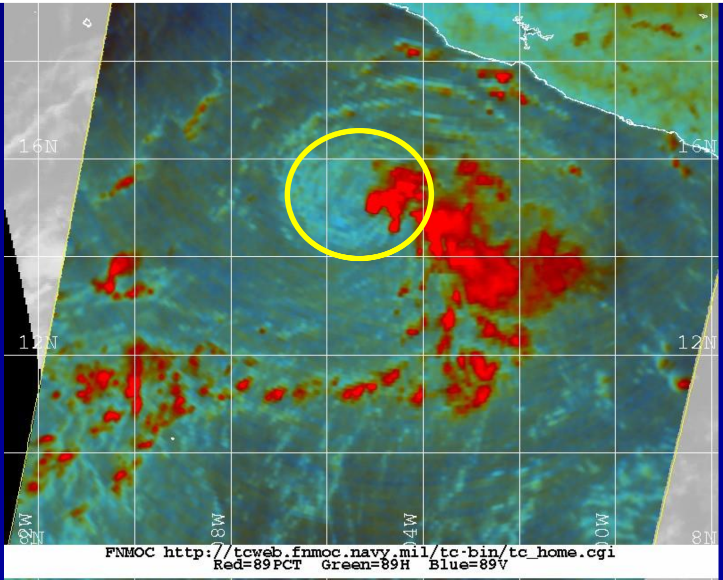
Importance of Center Location

- Locating the center is critical for the initial motion, initializing model guidance, and assessing the organization and intensity of the cyclone
- Dvorak estimates are very sensitive to incorrect center locations at certain stages of development, especially for sheared systems and systems with embedded centers in infrared imagery



There is a large difference in the Dvorak intensity estimate if the center is located in the deep convection or exposed well to the west

Tropical Storm Rosa – 9 November 2006



Parallax Error in Center Fixing

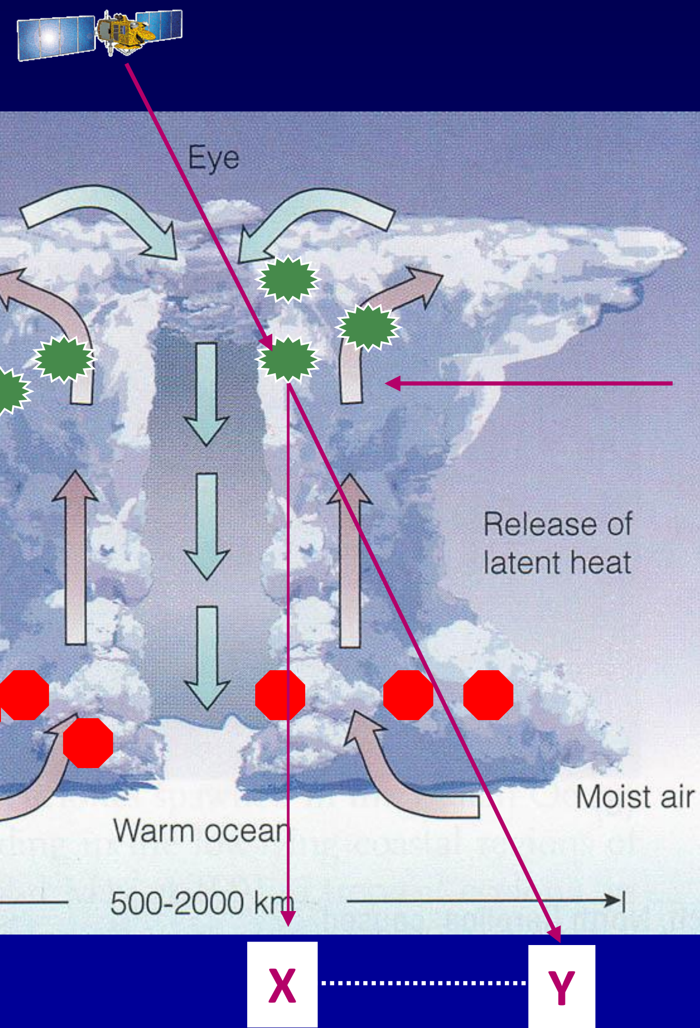
- Satellite-derived position error exists, potentially up to 20 km (~10.8 n mi) from actual position

- Occurs due to conical viewing angle and/or viewing geometry of the satellite

- Higher parallax error in 85-GHz images since scattering hydrometeors produce a signature much higher in the eyewall at 85 GHz than at 37 GHz

85-GHz Parallax

Ice Crystals
(85 GHz)



Effective
Level of
hydrometeors

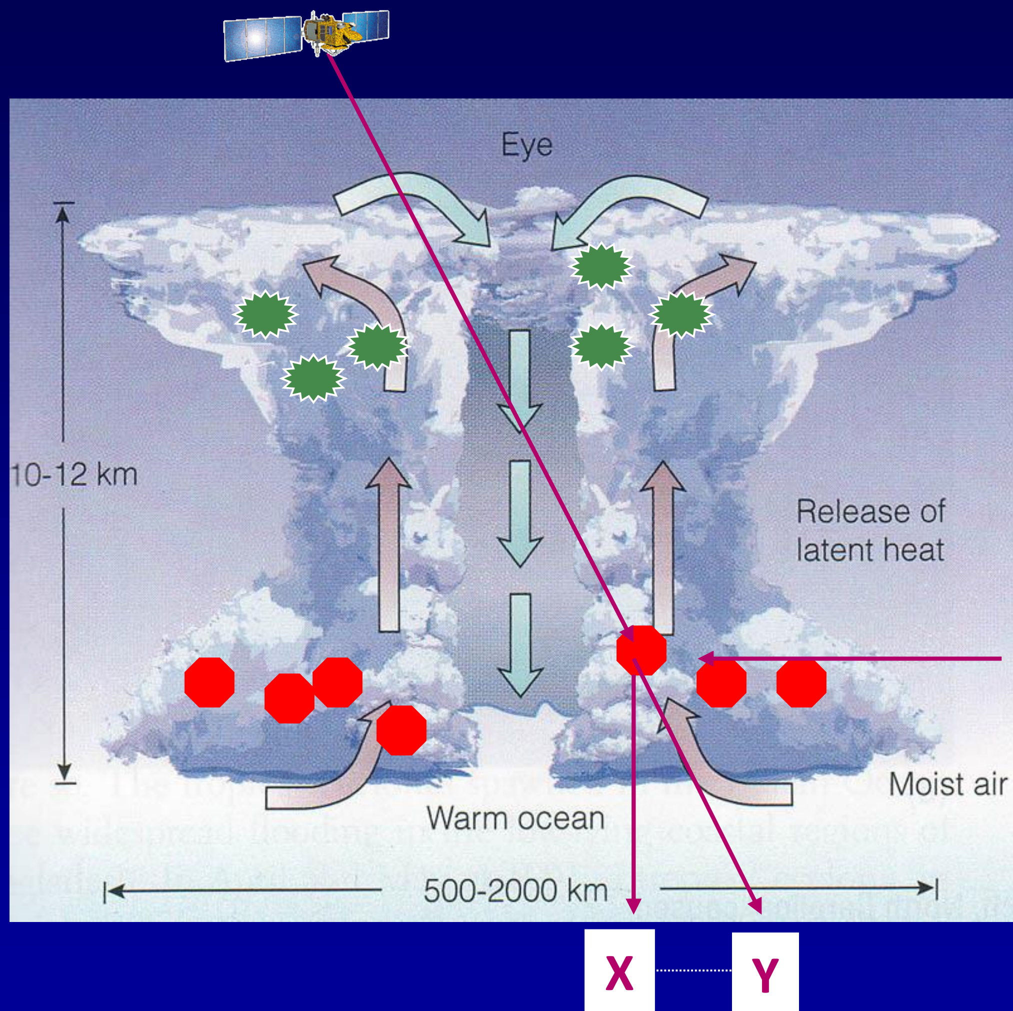
Raindrops
(37 GHz)

85 GHz
Parallax

37-GHz Parallax

Ice Crystals (85 GHz)

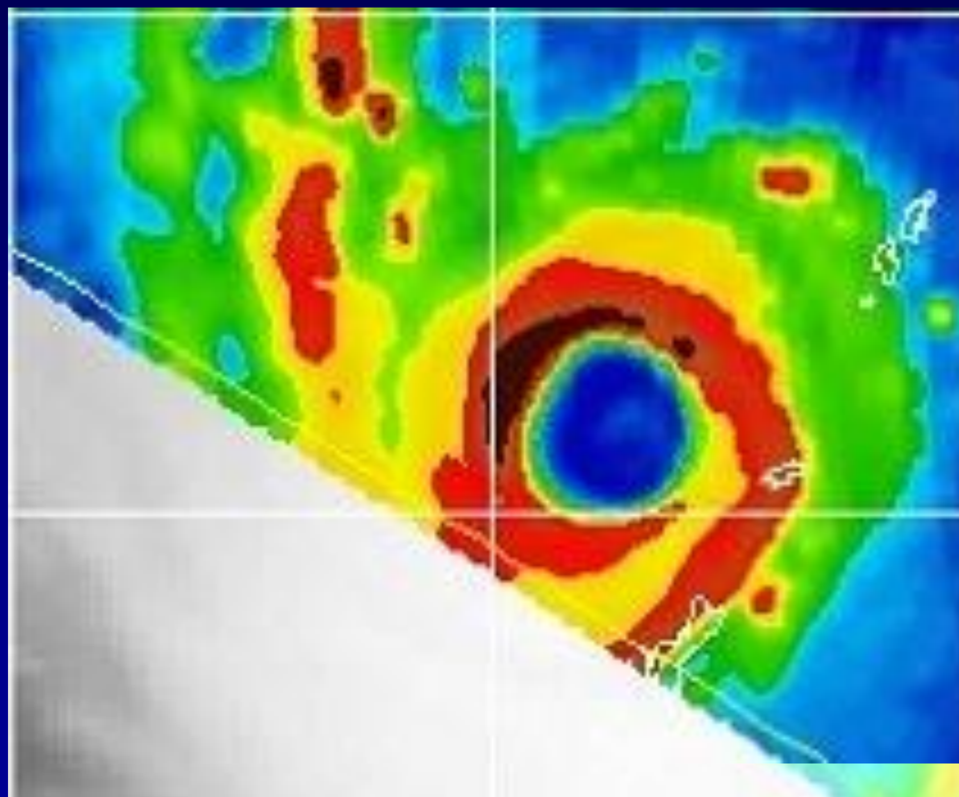
Raindrops (37 GHz)



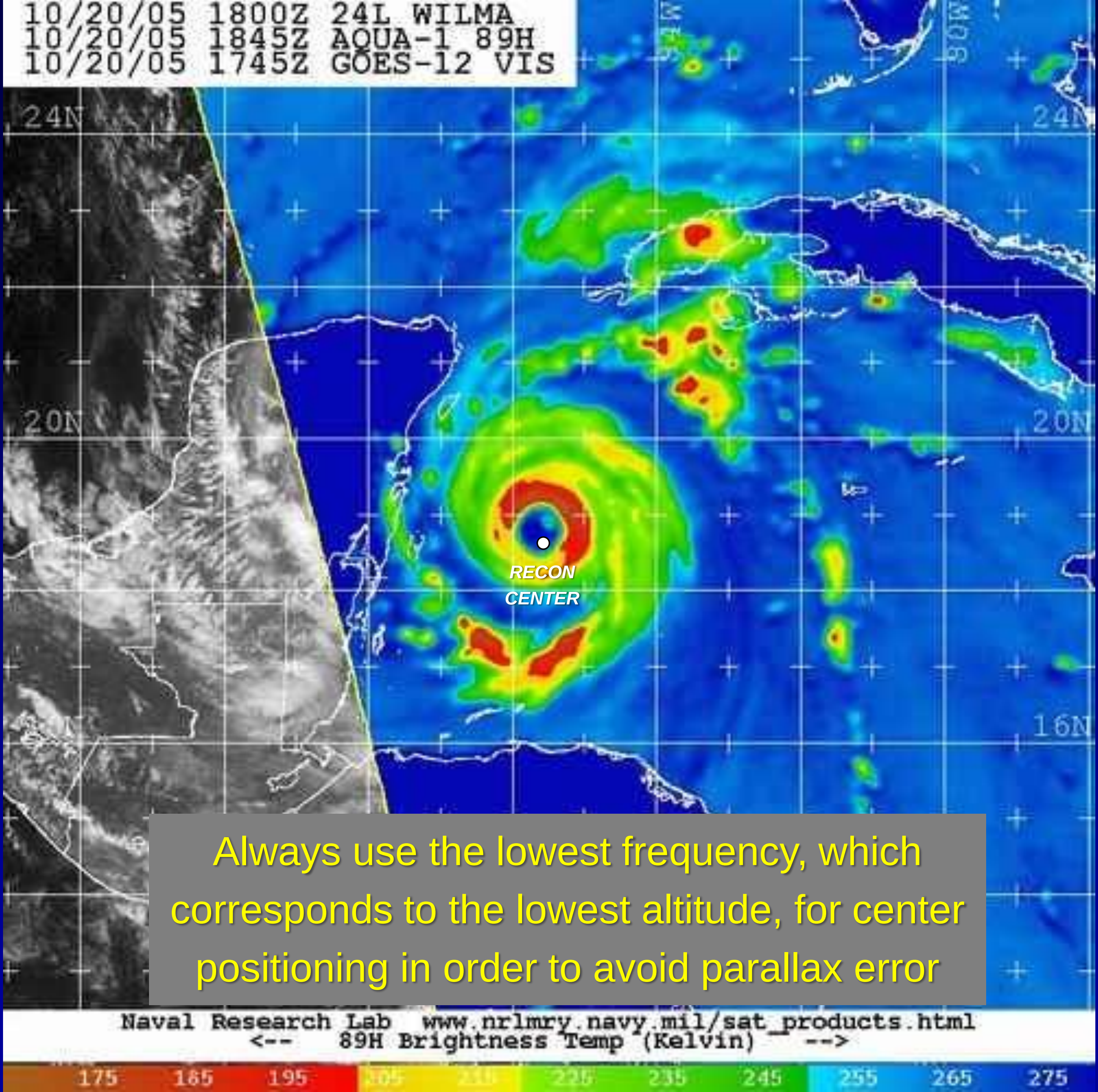
Effective Level of hydrometeors

37 GHz Parallax

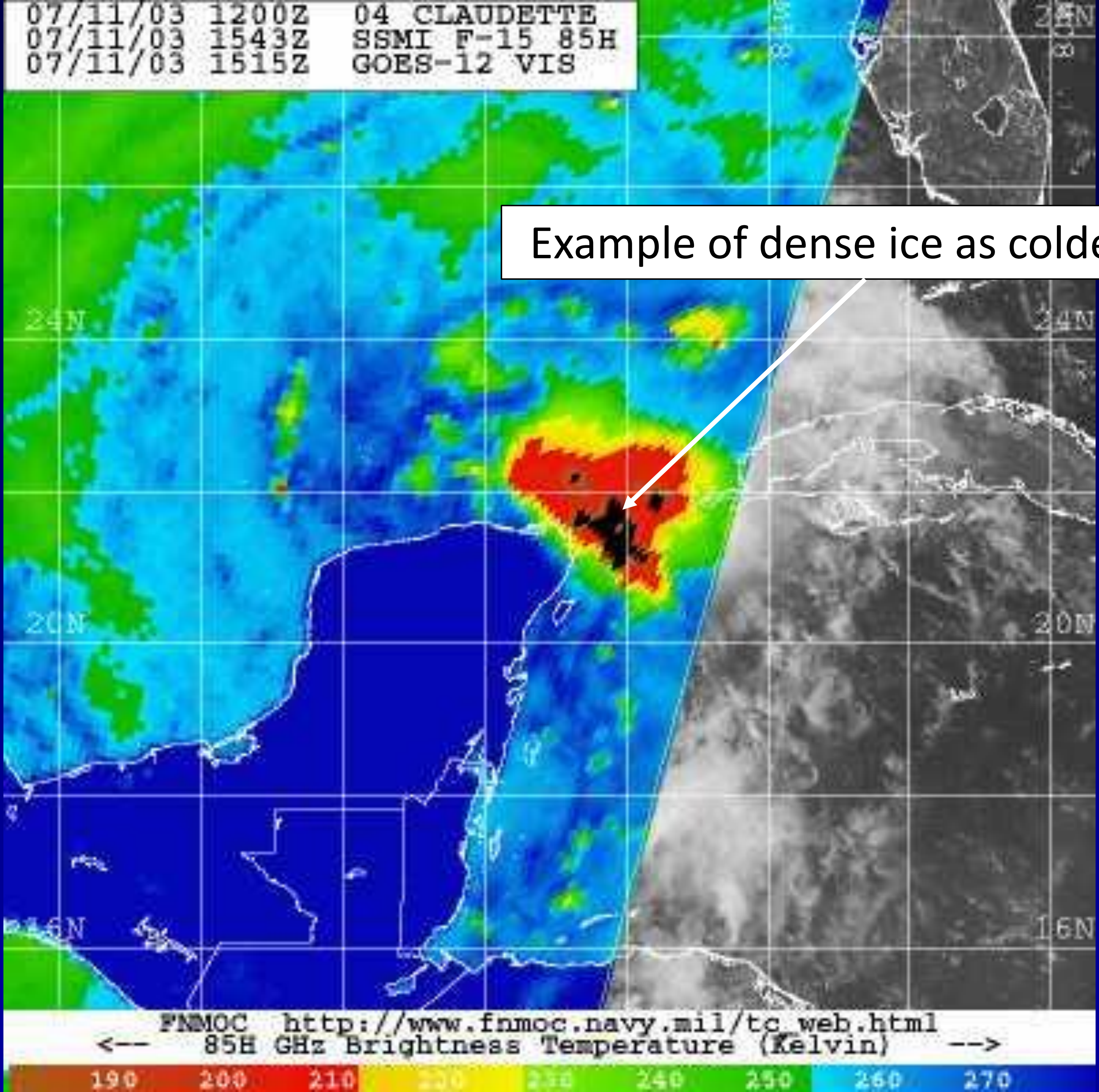
Eye Size Example



85 H
37 V



Always use the lowest frequency, which corresponds to the lowest altitude, for center positioning in order to avoid parallax error

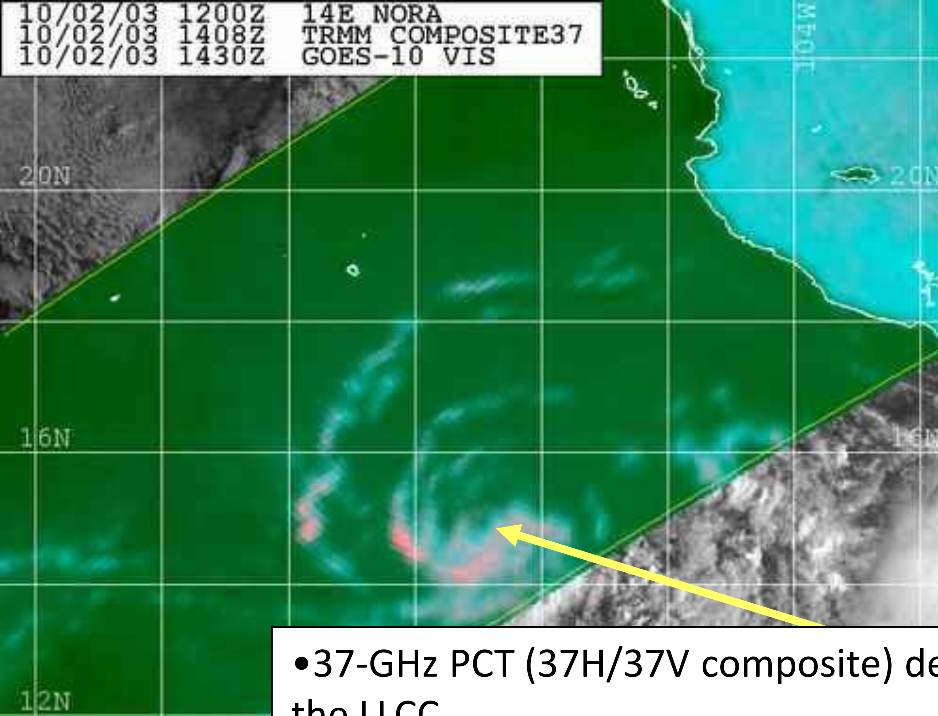


Example of dense ice as coldest T_b

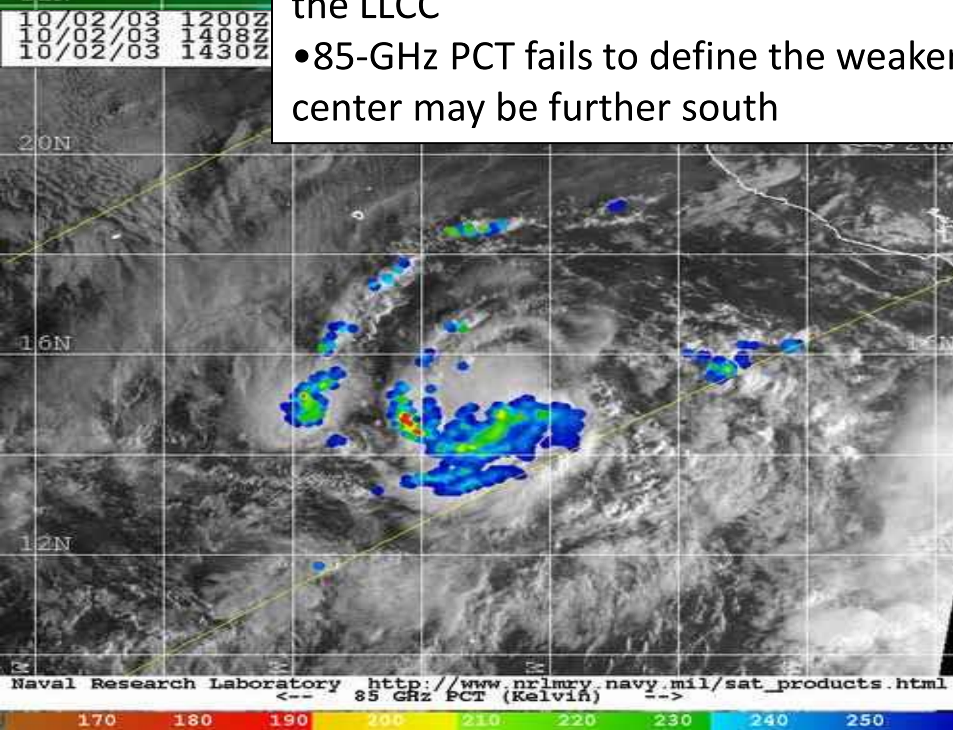
Color Composite Imagery

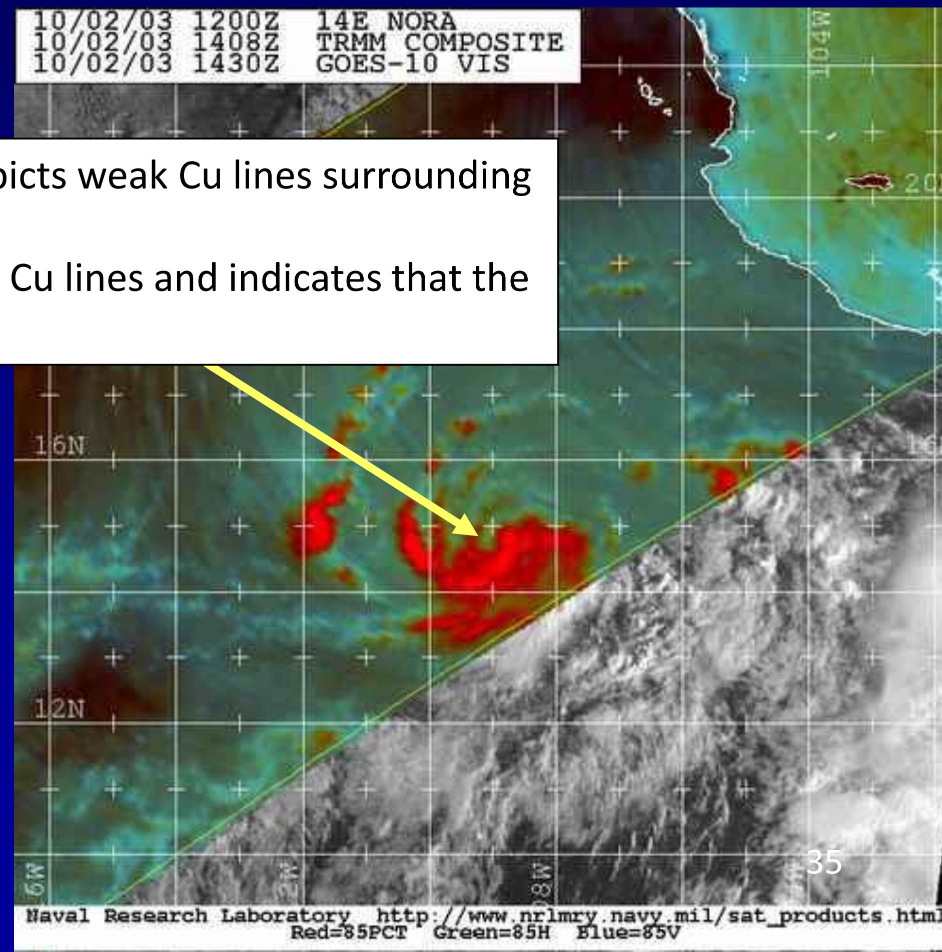
- Color composite images combine PCT with V and H polarizations to remove ambiguities between convection and the sea surface
  - 85 color composite- PCT (red), V (blue), H (green)
    - Deep convection (red)
    - Low-level clouds, water vapor, warm precipitation (blue-green)
    - Relatively cloud-free (gray or black)
  - 37 color composite- PCT (red), V (green), H (blue)
    - Deep Convection/intense ice scattering (pink)
    - Rain/clouds (cyan)
    - Sea surface (green)

Color Composite



- •37-GHz PCT (37H/37V composite) depicts weak Cu lines surrounding the LLCC
- •85-GHz PCT fails to define the weaker Cu lines and indicates that the center may be further south





Access to Online Microwave Imagery

FNMOC Tropical Cyclone Webpage

https://www.fnmoc.navy.mil/tcweb/cgi-bin/tc_home.cgi

https://www.fnmoc.navy.mil/tcweb/cgi-bin/tc_home.cgi?YEAR=2019&MO=Apr&BASIN=SHEM&STORM_NAME=25S.LORNA&PROD=track_vis&TYPE=ssmi&PHOT=yes&ARCHIVE=Latest&NAV=tc&DISPLAY=Active&ACTIVES=19-SHEM-24S.KENNETH,19-SHEM-25...

Apps NHC HSU Intranet Hurricane Diagnosti... Recon Time Series atcf2tcr Files ATCF2GIS TC-genesis probs HSU-Wiki NCO Helpdesk Ticket HSU Shift Log TAFB Gmail

FNMOC Satellite Data Tropical Cyclone Page

2019 Storms

All | Active | Year

Atlantic

East Pacific

Central Pacific

West Pacific

Indian Ocean
- 91B.INVEST

Southern Hemisphere
- 92S.INVEST
- 25S.LORNA
- 24S.KENNETH

Display | Latest | Prev. | Track&Image | Pass_Mosaic

Warn: | Text | Track

Info: | General | Tutorial | Disclaimer

Environment | TPW | TPW&NAVGEM_TPW | TPW&NAVGEM_850_Winds

SSMI | SSMIS | GMI | AMSU | ATMS | AMSR2 | WindSat | ASCAT | OSCAT | MODIS | NEXRAD | VIS | IR | OLS

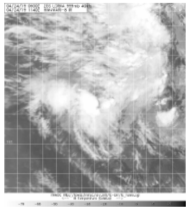
Age <= 6hrs old | Age <= 12hrs old | Age >12hrs old | 12:09:04 | UTC(Z)

25S.LORNA

Forecast by Joint Typhoon Warning Center/Naval Maritime Forecast Center
Graphic by Naval Maritimep Forecast Center/Joint Typhoon Warning Center

smsh252019.20190424075752 thumbnail

Latest Image

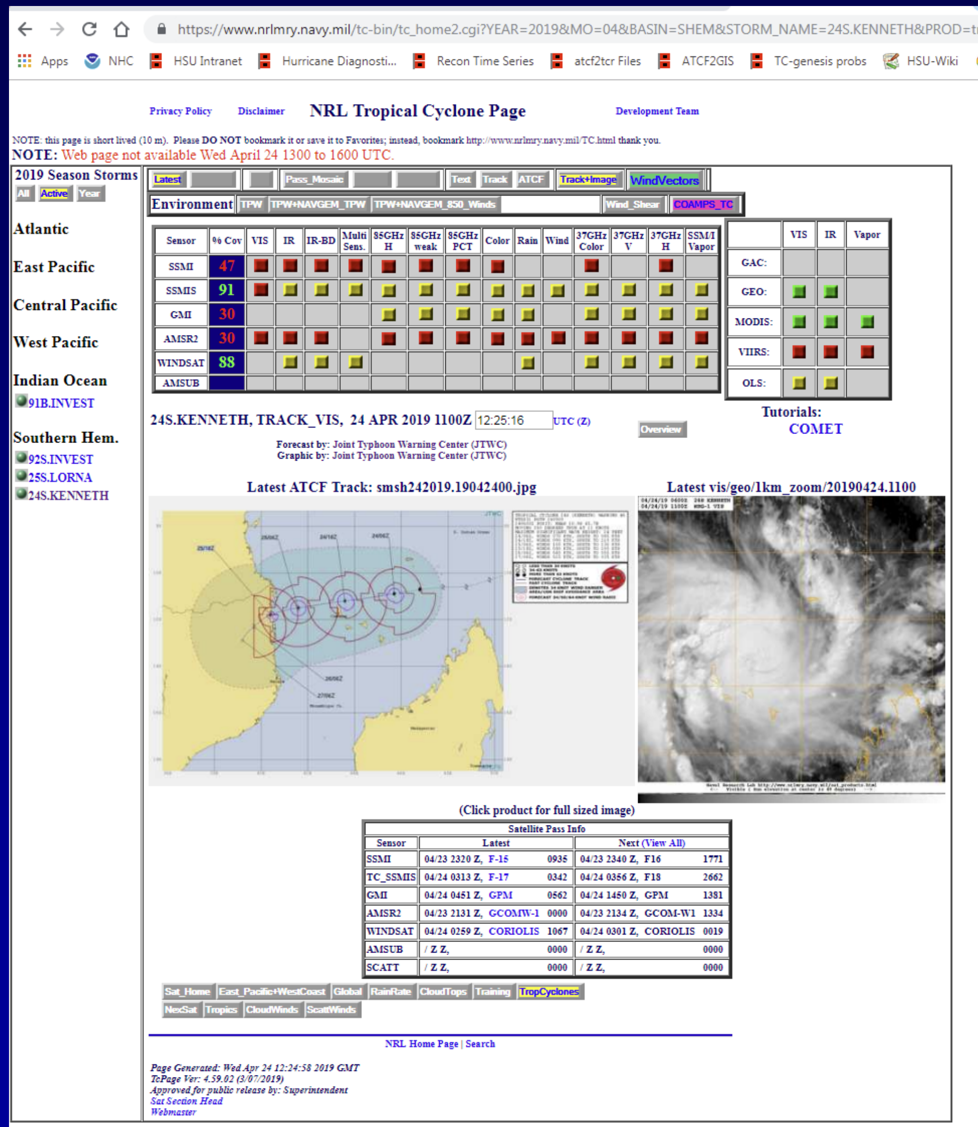


(Click product for full sized image 68125 Bytes and 217144 Bytes.)

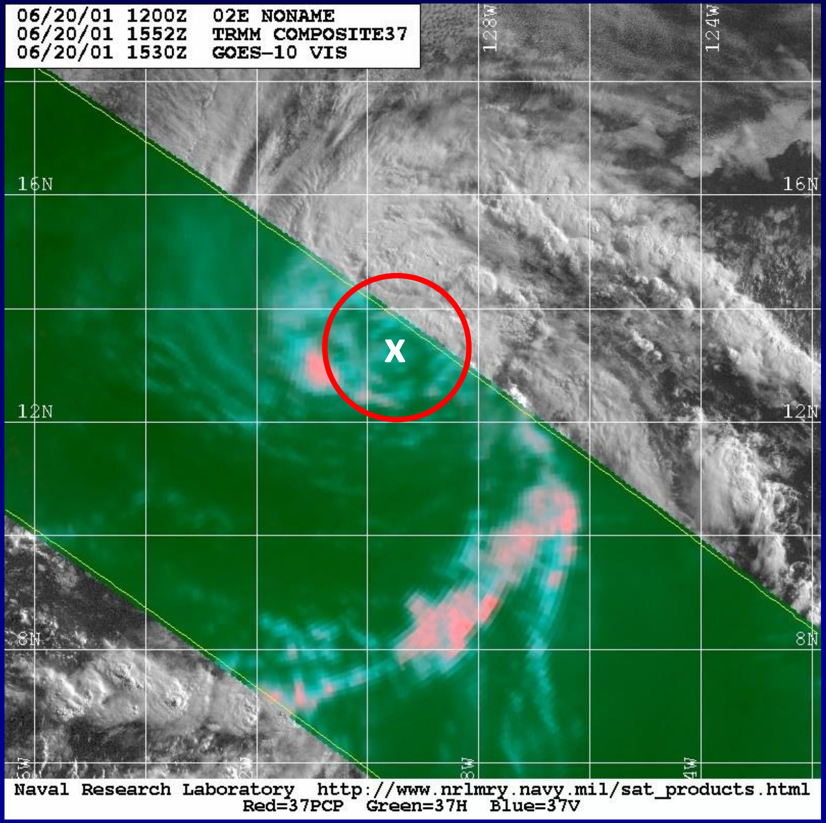
Sensor	Latest	Upcoming Passes (more)
SSMI	04/24 1014Z f15 1039	04/24 21:24Z F-15 4
SSMIS	04/24 1033Z f16 235	04/24 10:35Z F-16 235 04/25 01:19Z F-17 658 04/24 11:30Z F-18 747
GMI	None	
MHS	04/24 0408Z metopa 0	04/25 03:03Z N-18 335 04/24 23:09Z N-19 114 04/25 03:34Z MetOp-A 116 04/24 16:15Z MetOp-B 420
WindSat	04/23 1231Z coriolis 266	04/24 12:14Z WSAT 760
ASCAT	None	04/25 03:34Z MetOp-A 116 04/24 16:15Z MetOp-B 420
OSCAT	None	
MODIS	04/24 0810Z Aqua 194	04/25 19:45Z AQUA 226 04/25 04:27Z TERRA 561

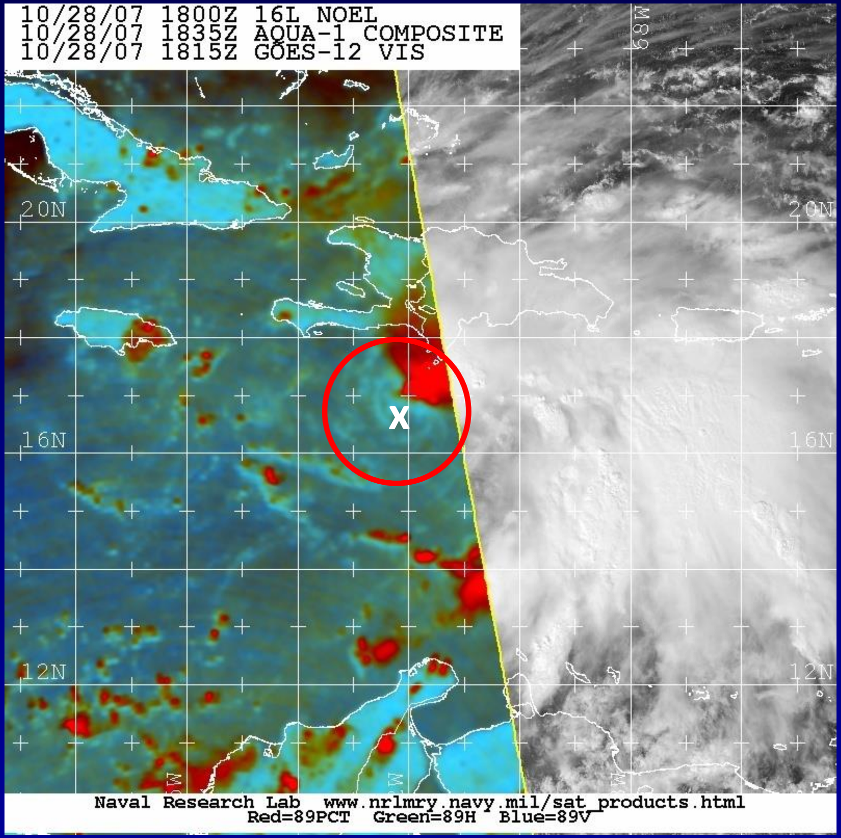
NRL Tropical Cyclone Webpage

https://www.nrlmry.navy.mil/TC.html



Positioning in Microwave Imagery

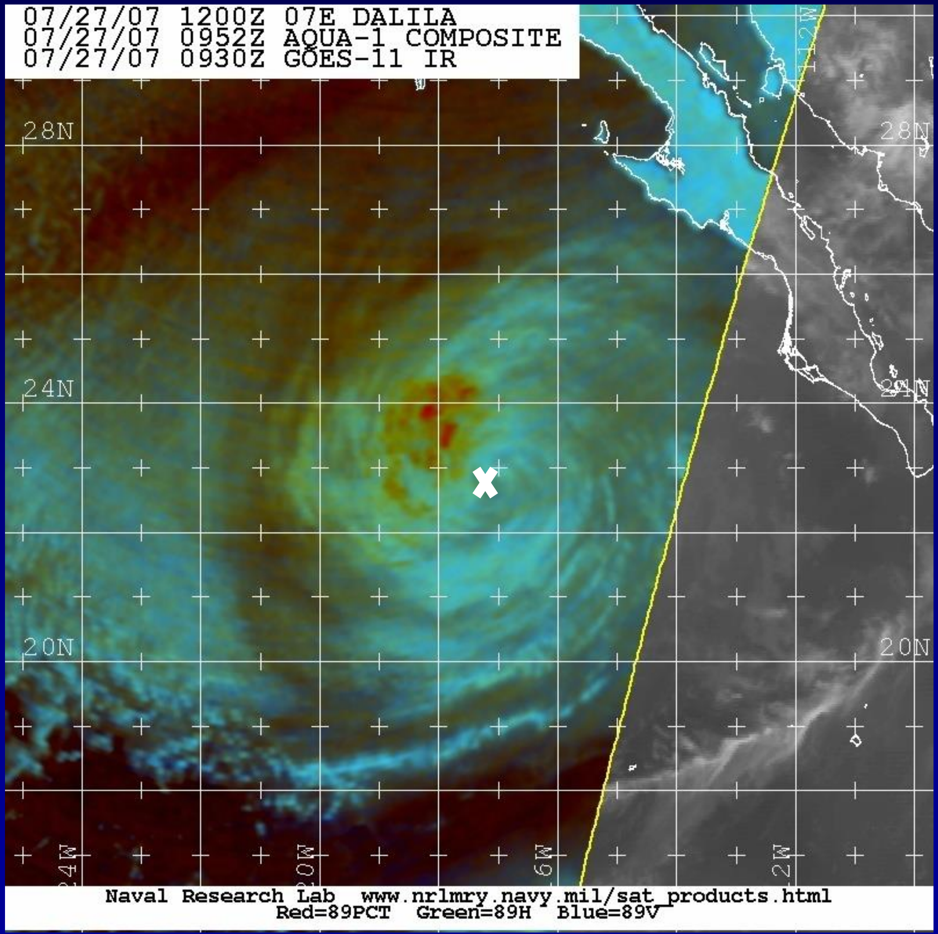


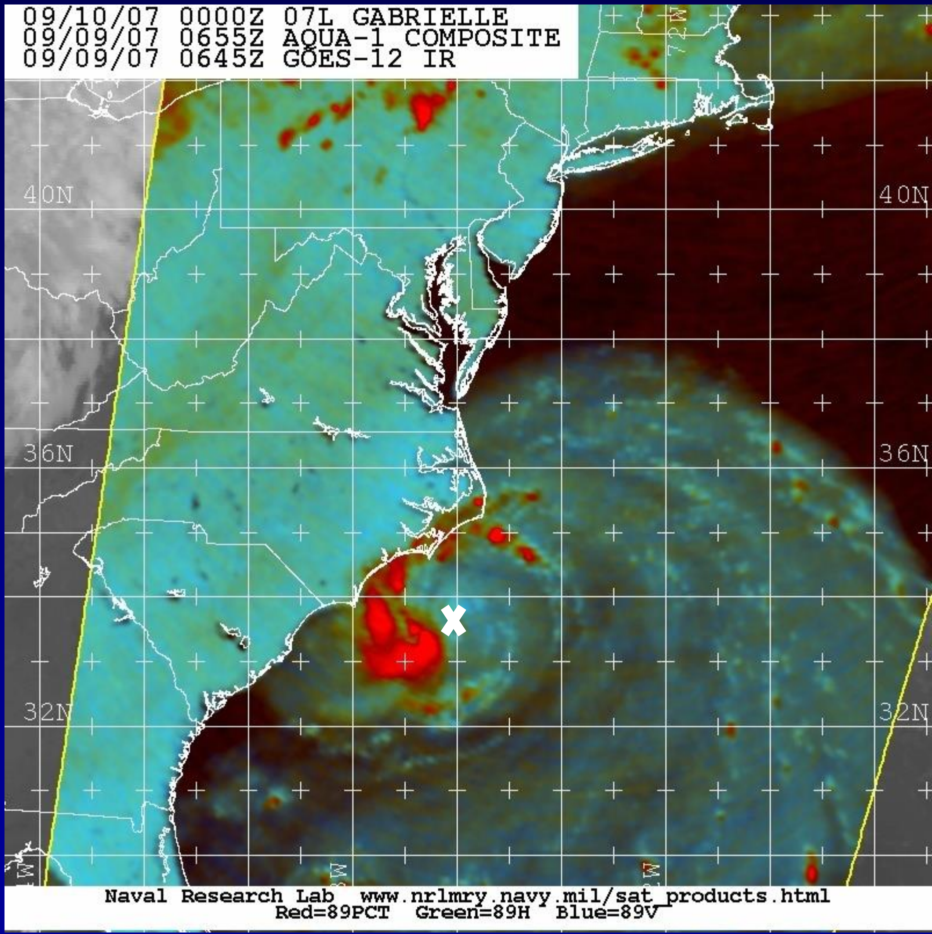


Try to position in the rain-free dry area—out of the convection

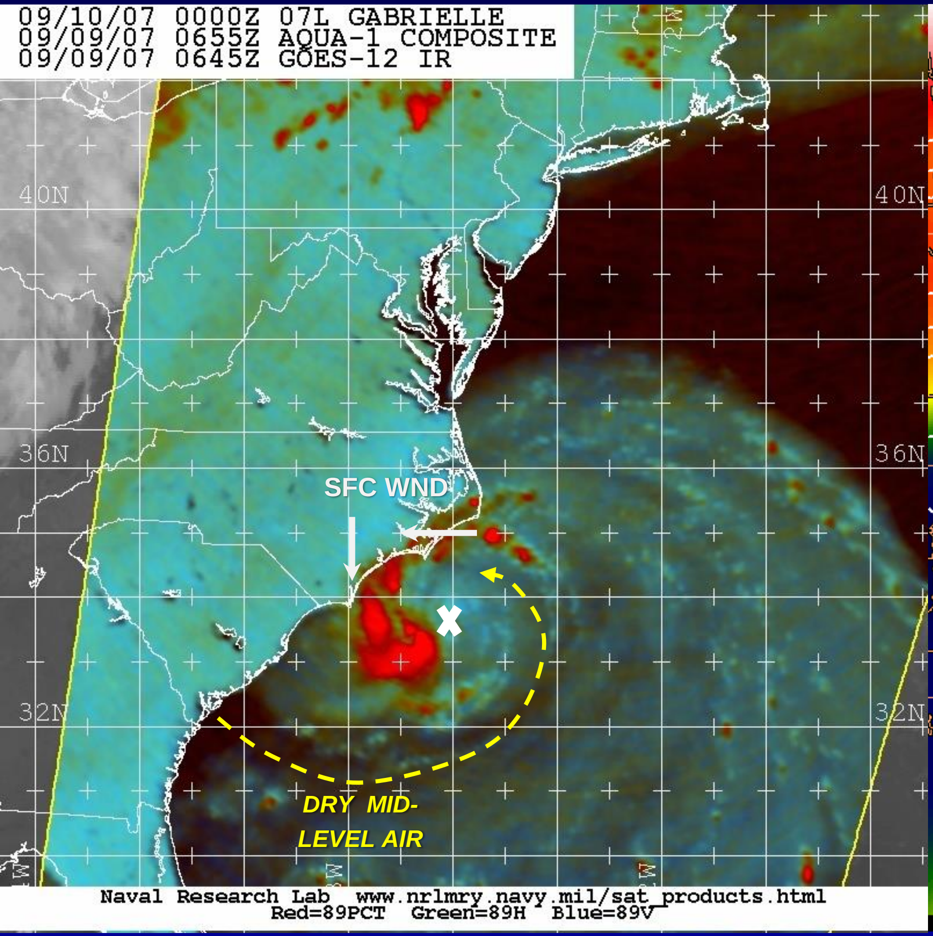
Positioning in Microwave Imagery

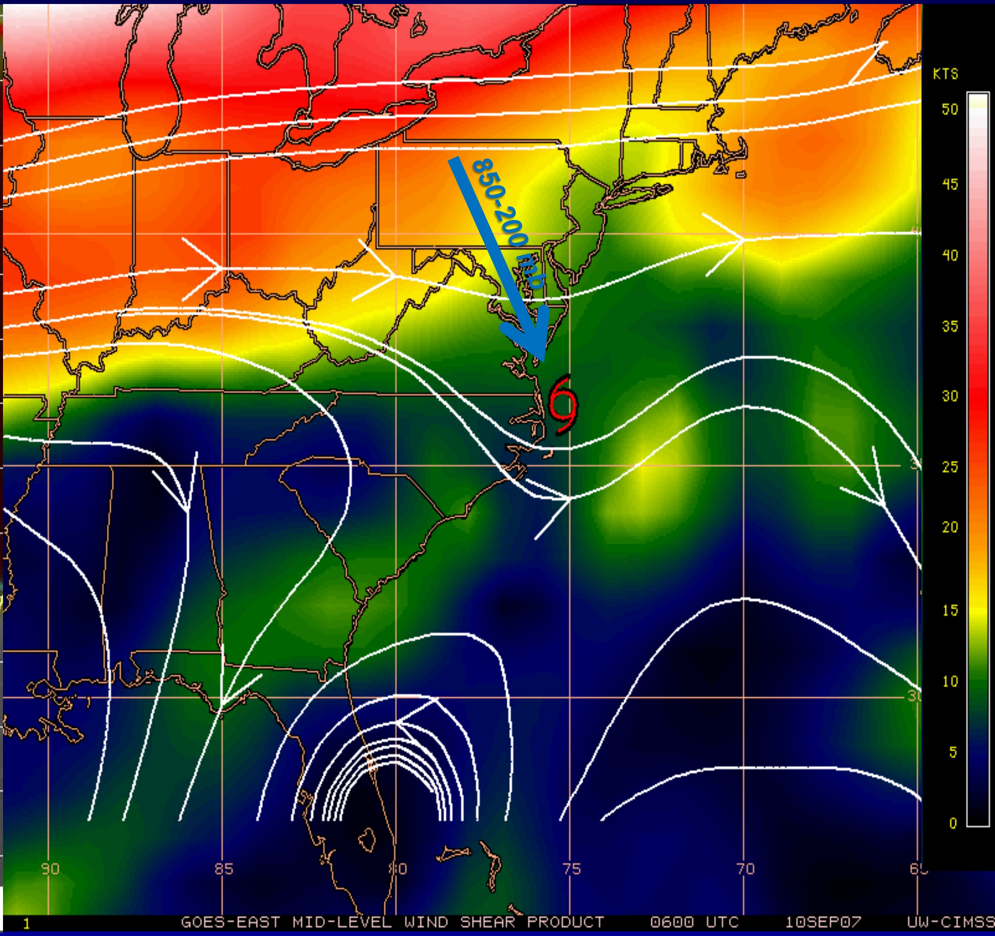
Look for convective free darker areas





Effect of Vertical Wind Shear on Center Positioning in Microwave Imagery

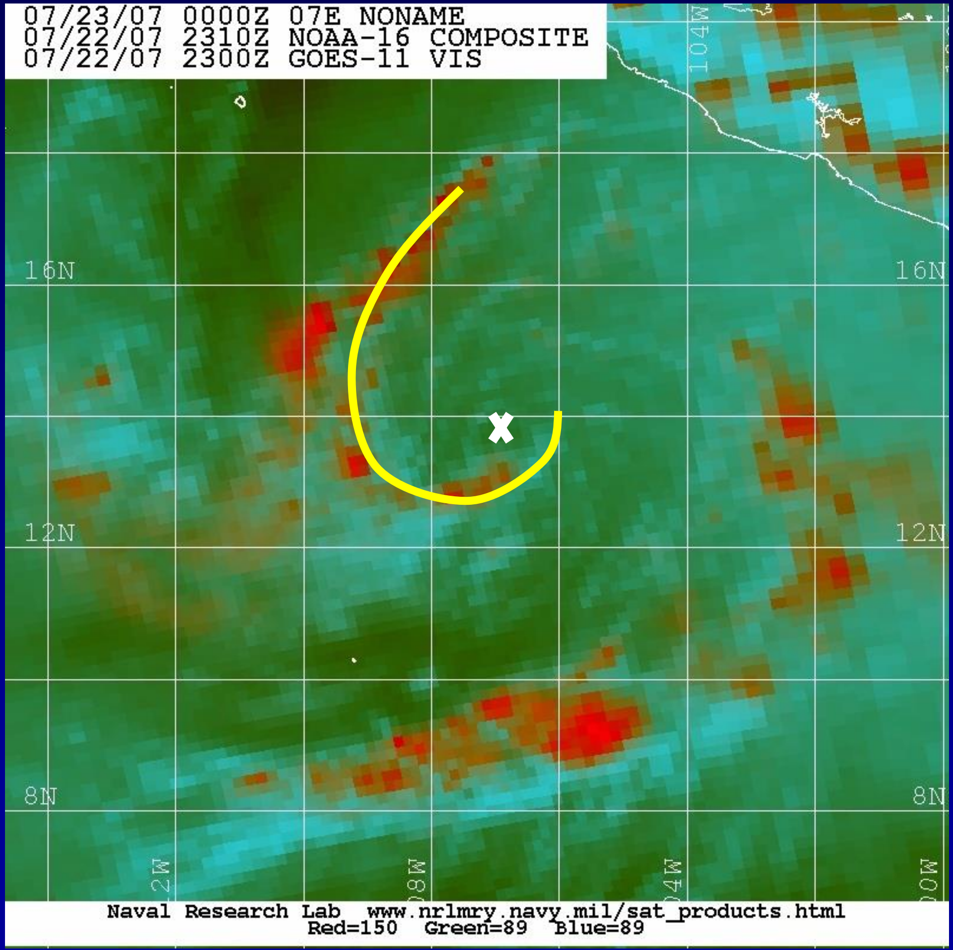


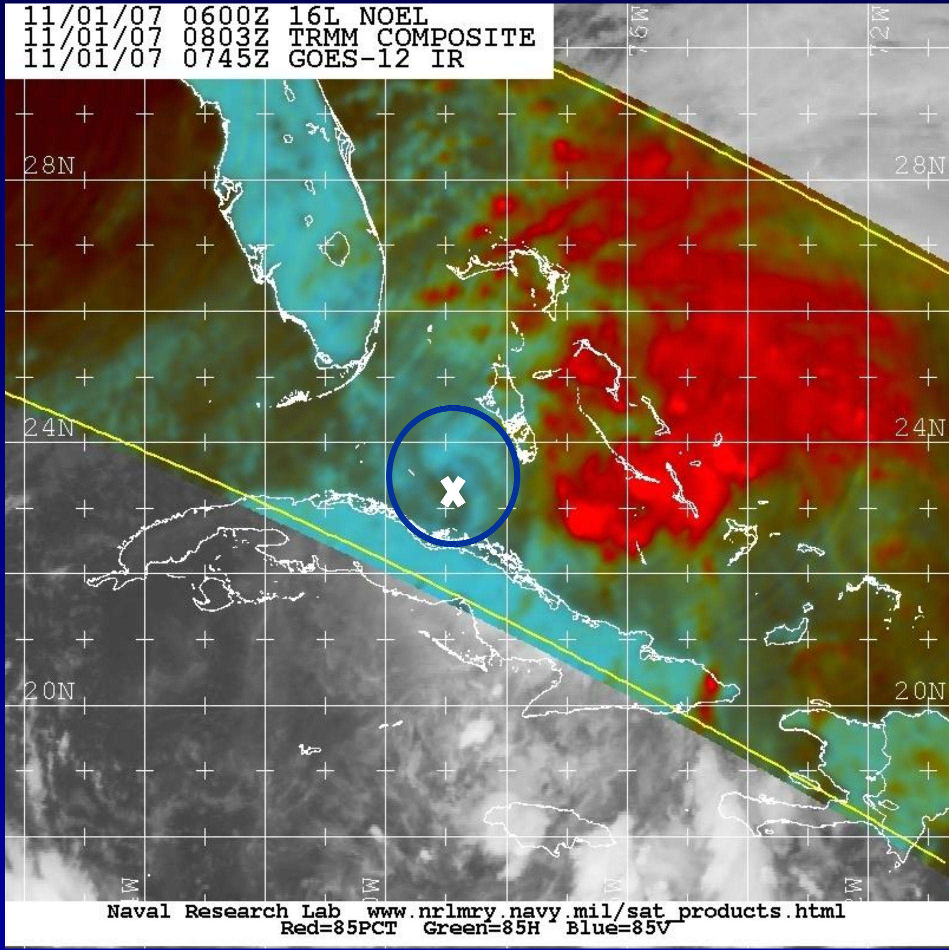


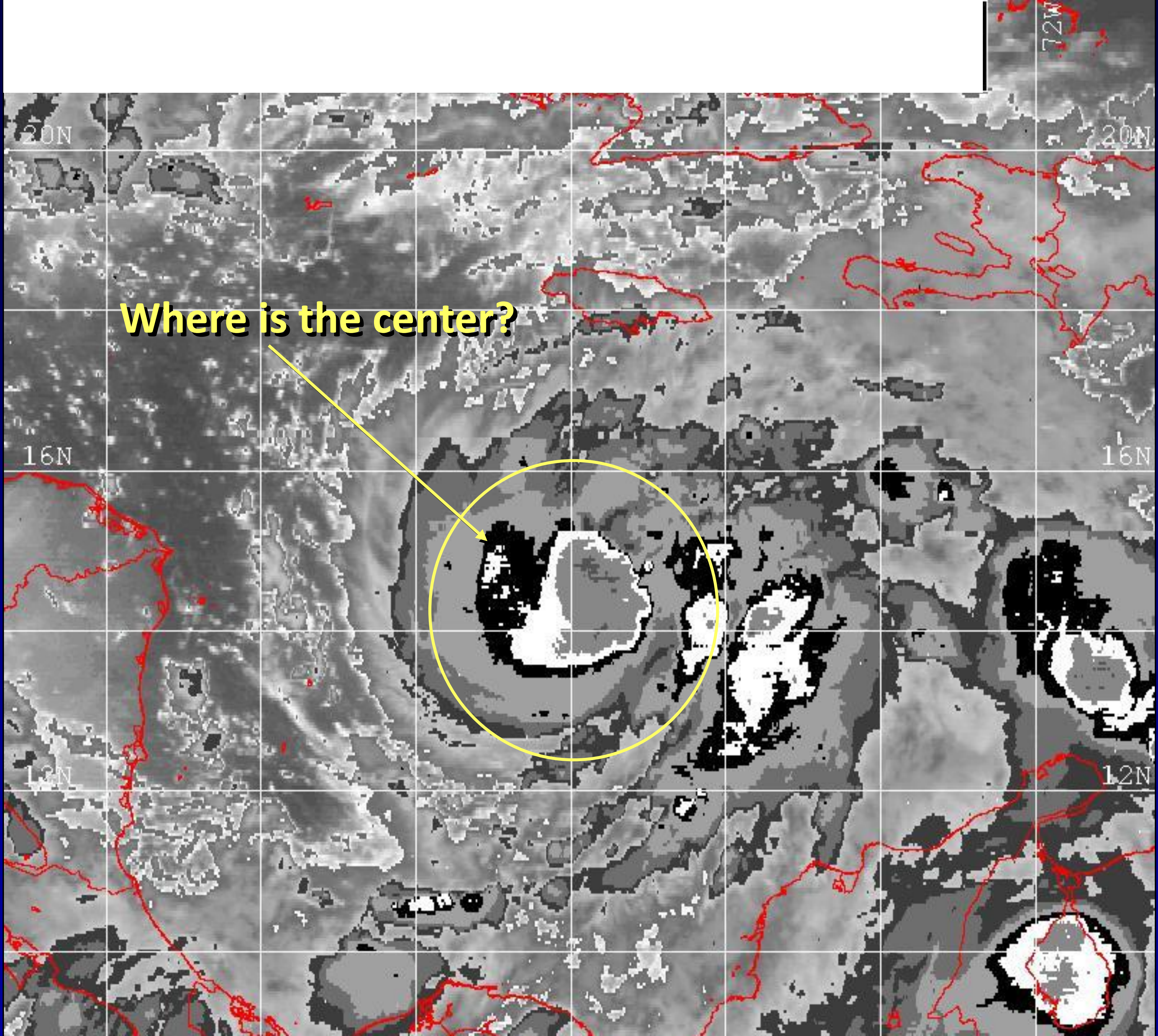
Anticipating the location of the LLCC based on vertical wind shear creating asymmetry in the deep convection pattern helps, ***BUT*** it can not always be used as an absolute as this case clearly indicates.

Positioning in Microwave Imagery

Look for low cloud curvature

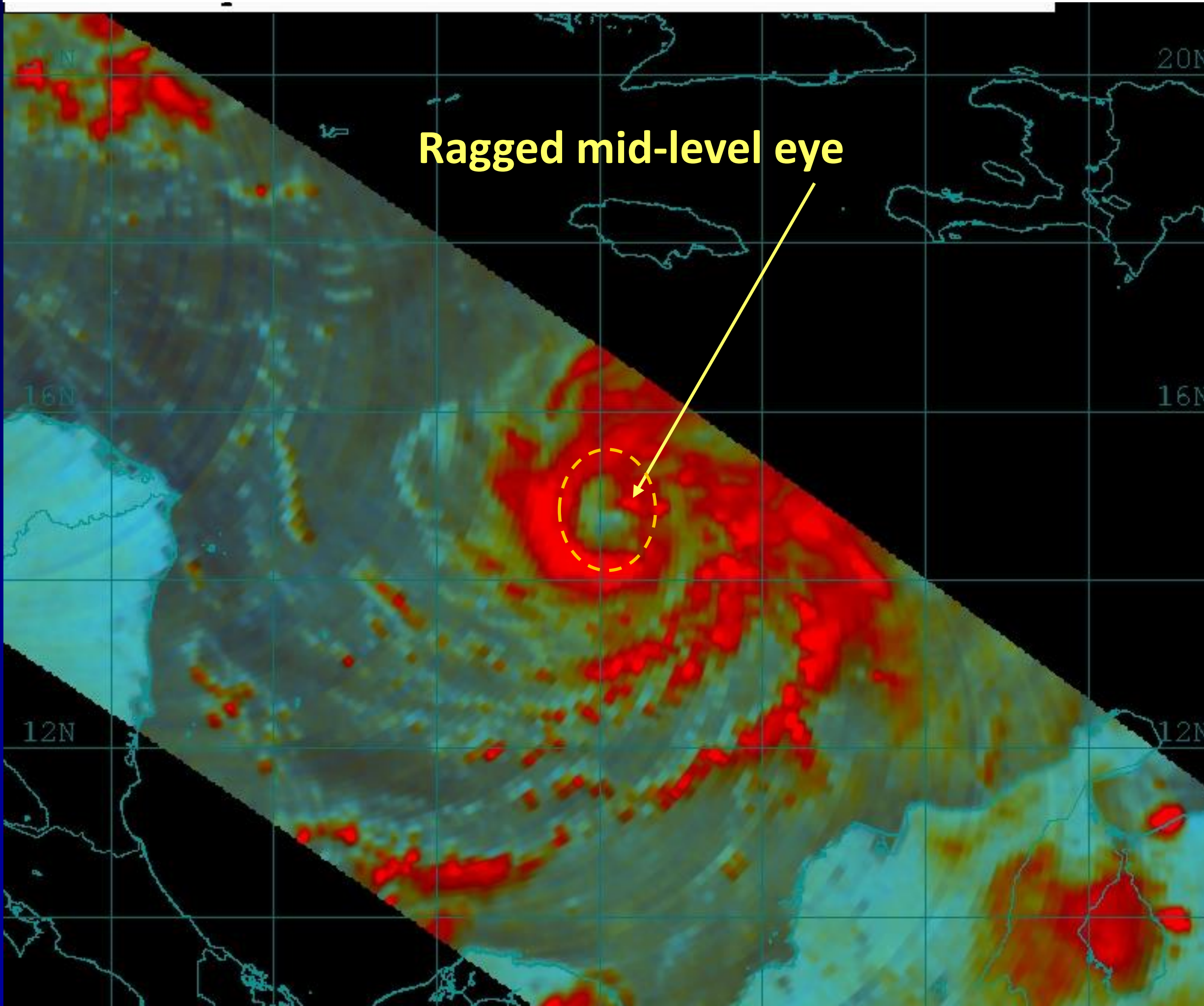




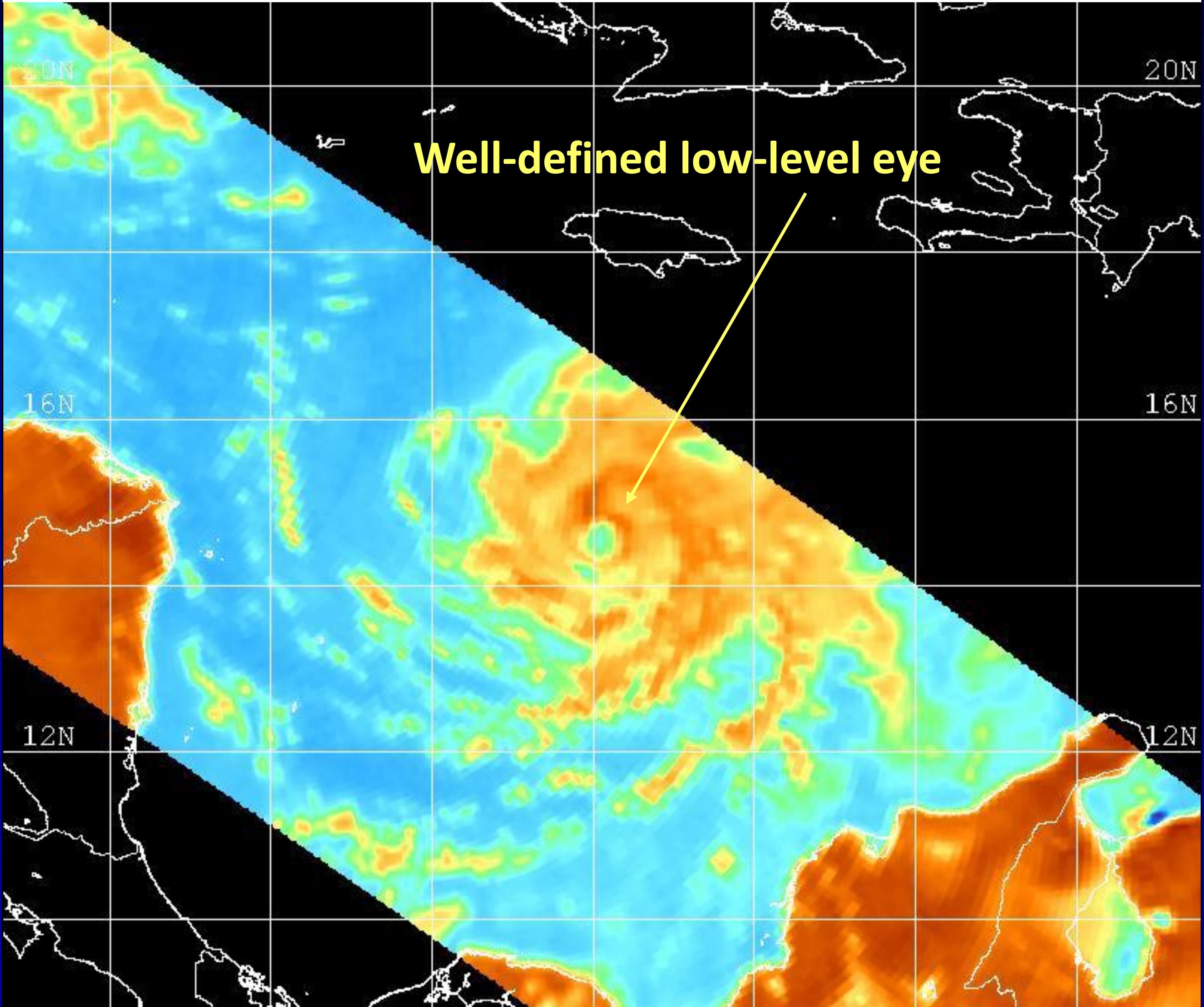


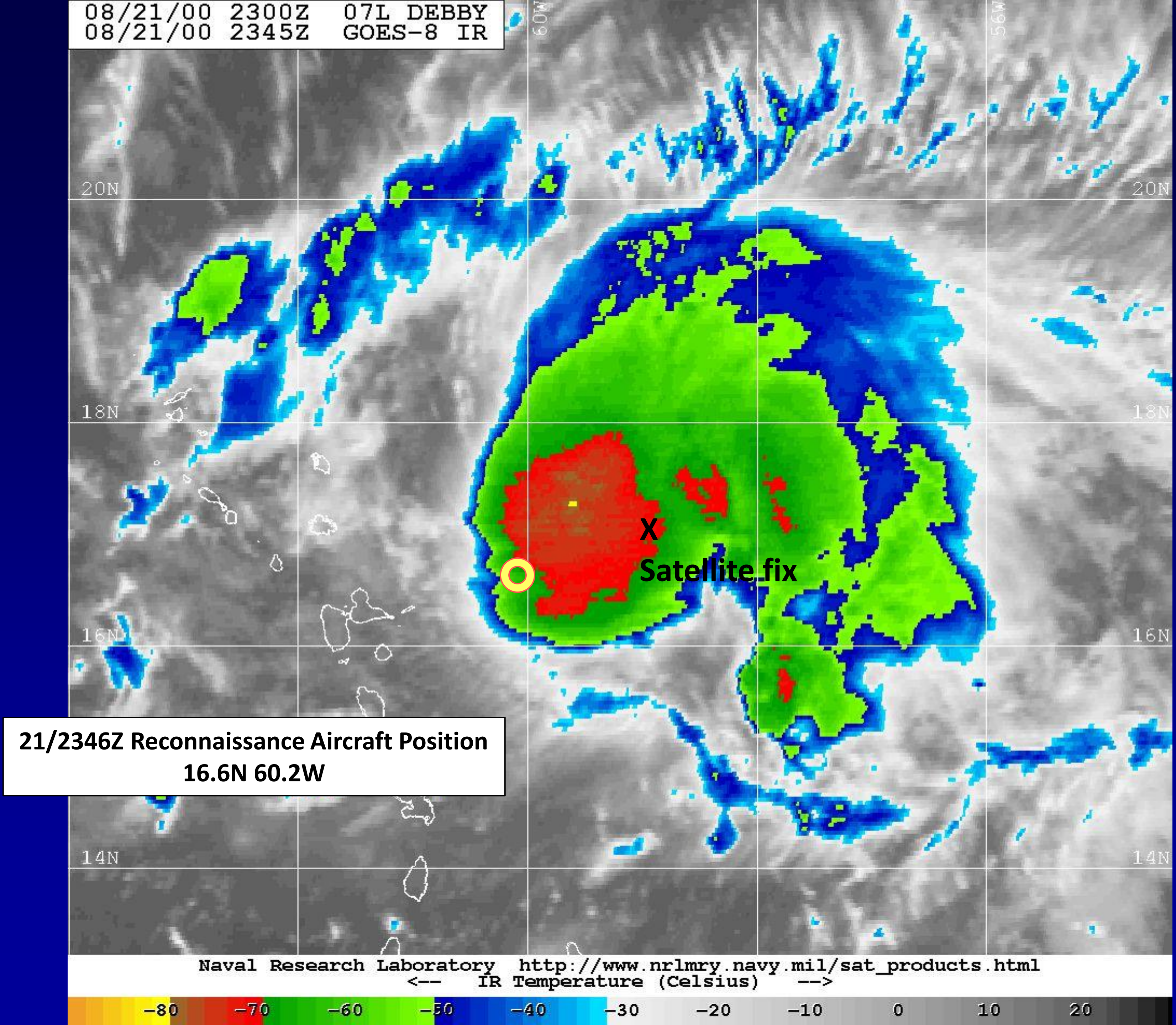
Where is the center?
20N
20N
16N
16N
12N
72W

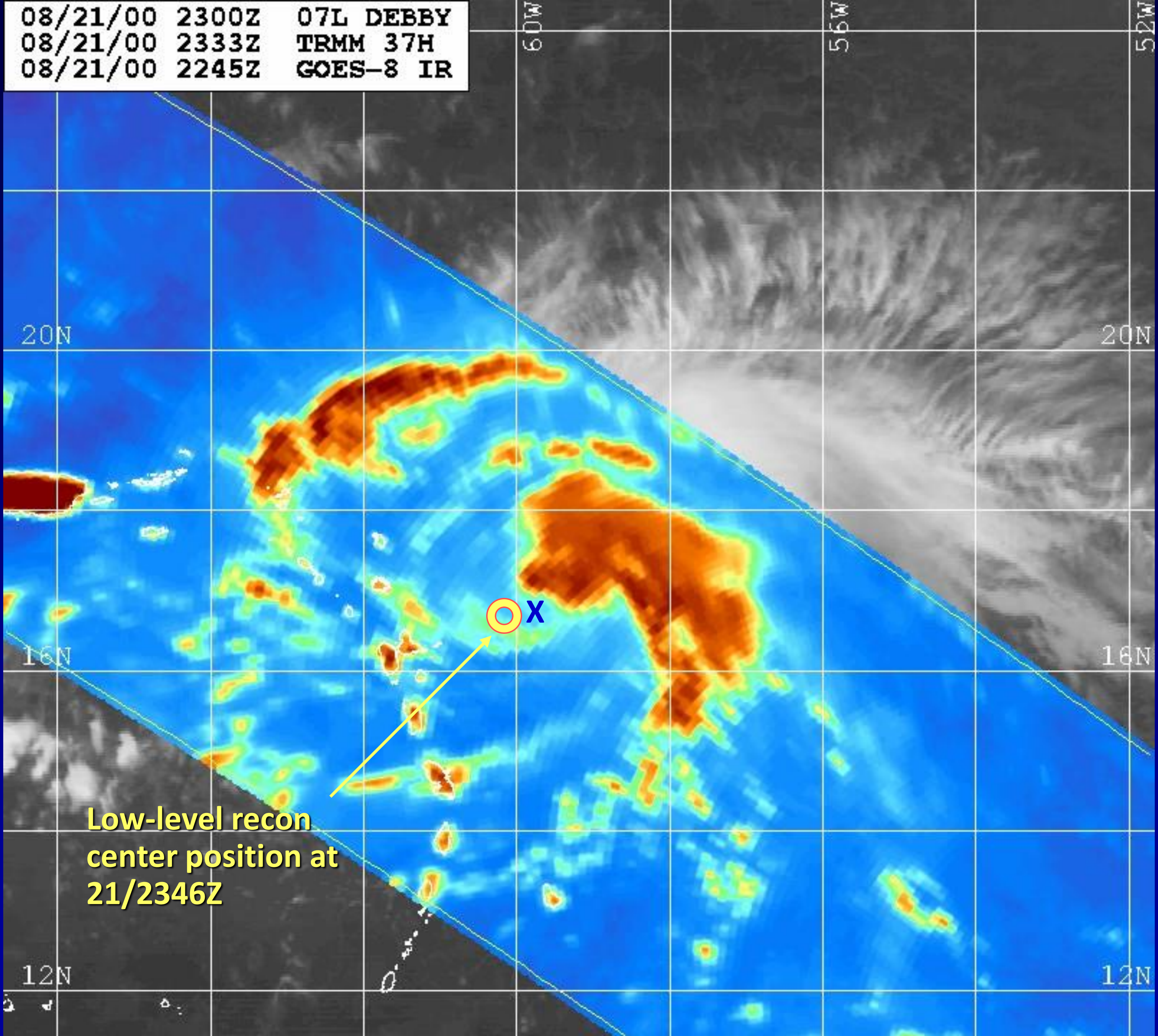
85 GHz Color-Composite Example

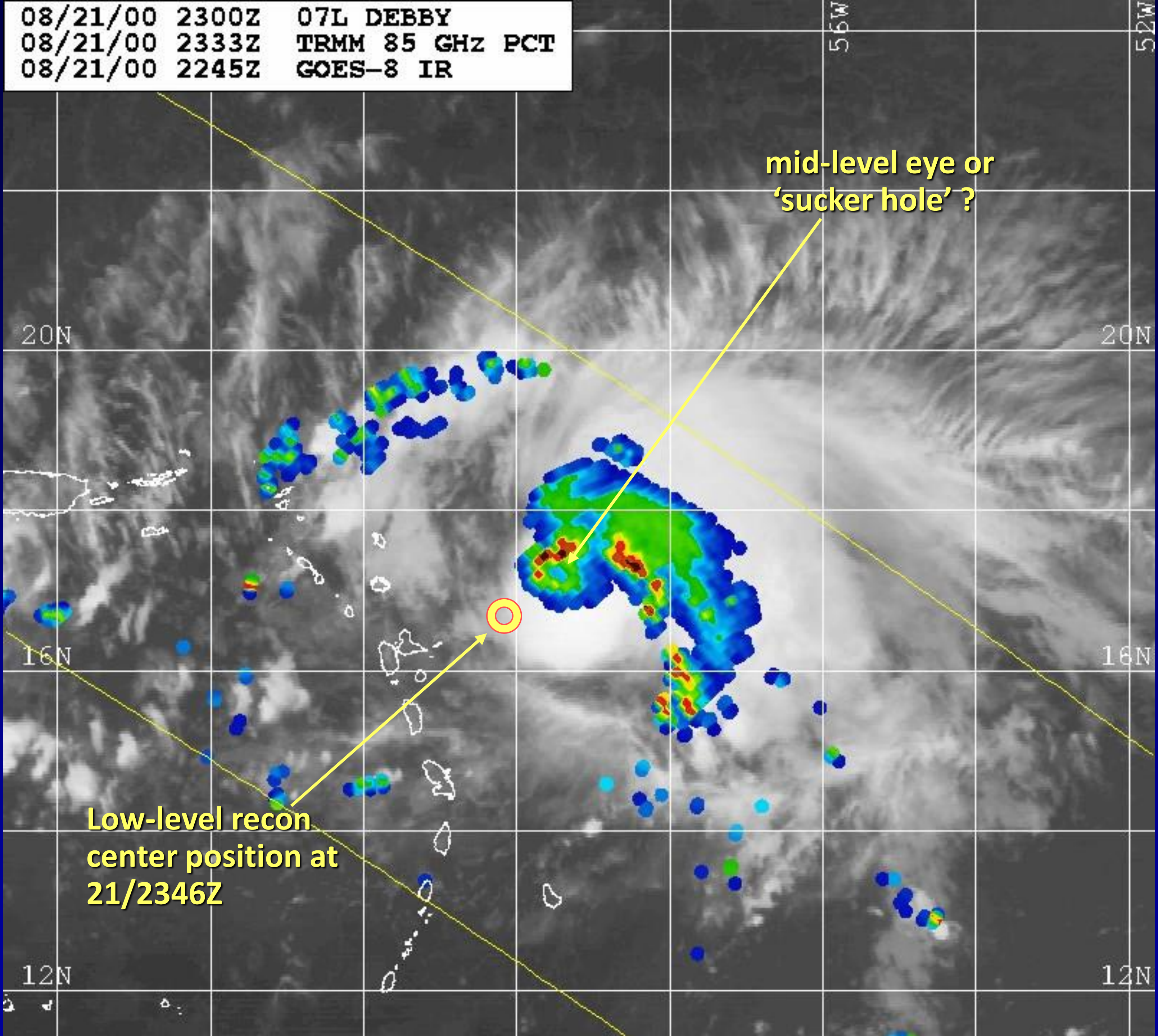


37 GHz Example

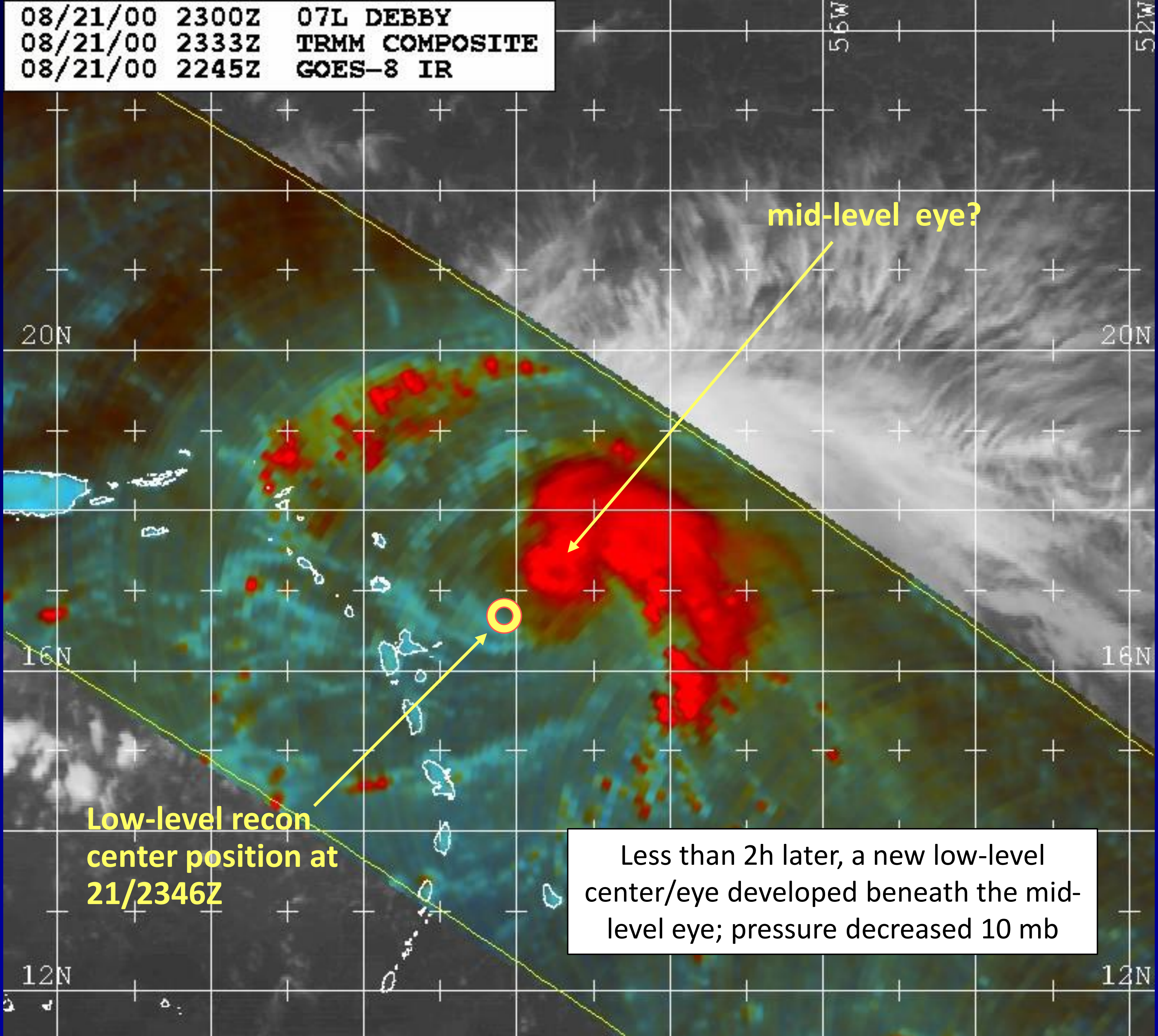



08/21/00 2300Z 07L DEBBY
08/21/00 2345Z GOES-8 IR
60W
56W
20N
20N
18N
18N
16N
16N
14N
14N
X
Satellite fix
21/2346Z Reconnaissance Aircraft Position
16.6N 60.2W
Naval Research Laboratory http://www.nrlmry.navy.mil/sat_products.html
<-- IR Temperature (Celsius) -->
-80 -70 -60 -50 -40 -30 -20 -10 0 10 20


08/21/00 2300Z 07L DEBBY
08/21/00 2333Z TRMM 37H
08/21/00 2245Z GOES-8 IR
60W
56W
52W
20N
20N
16N
16N
12N
12N
X
Low-level recon center position at 21/2346Z

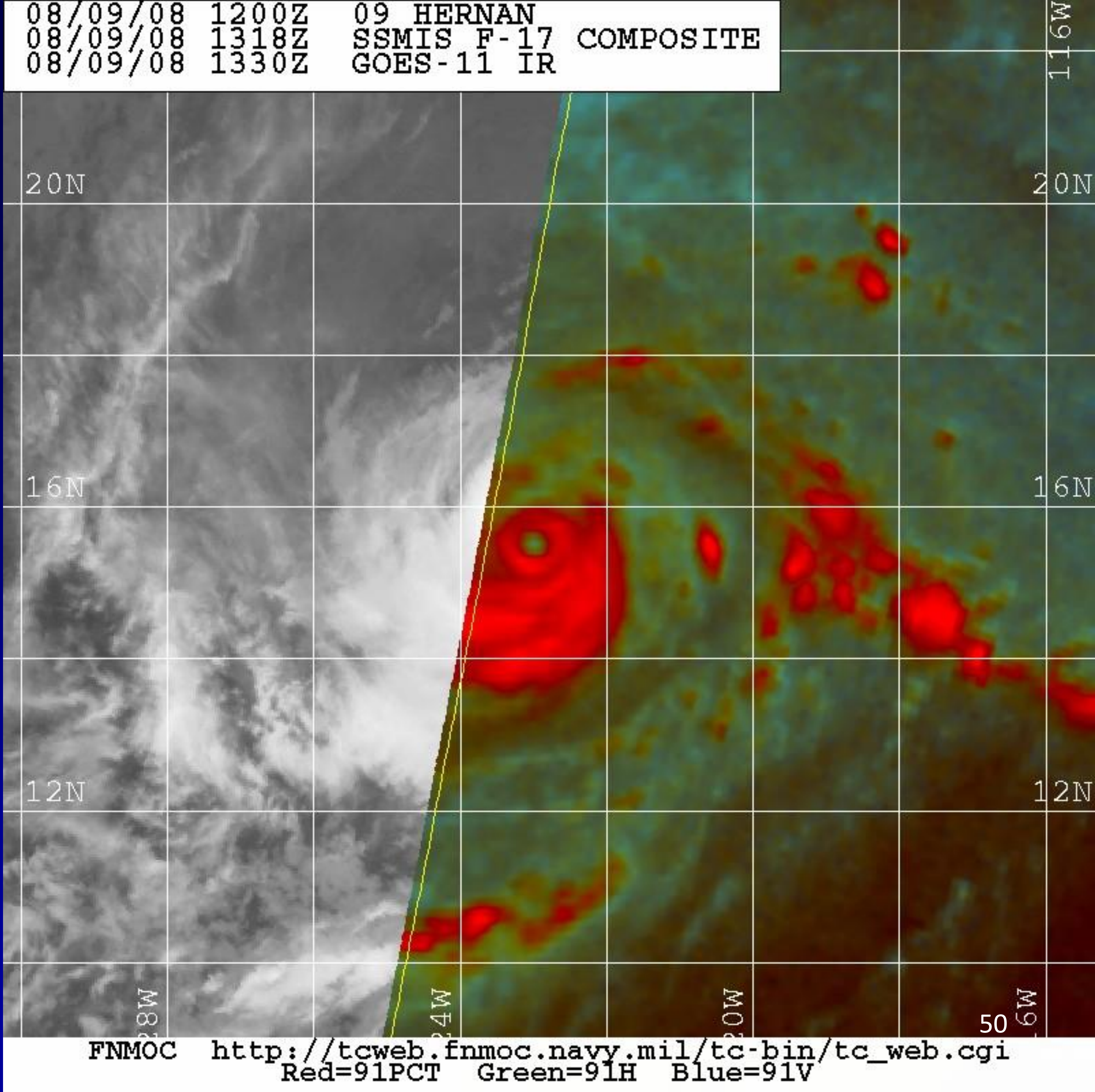


08/21/00 2300Z 07L DEBBY
08/21/00 2333Z TRMM 85 GHz PCT
08/21/00 2245Z GOES-8 IR
56W
52W
20N
16N
12N
mid-level eye or
'sucker hole' ?
Low-level recon
center position at
21/2346Z


08/21/00 2300Z 07L DEBBY
08/21/00 2333Z TRMM COMPOSITE
08/21/00 2245Z GOES-8 IR
56W
52W
20N
16N
12N
mid-level eye?
Low-level recon center position at 21/2346Z
Less than 2h later, a new low-level center/eye developed beneath the mid-level eye; pressure decreased 10 mb

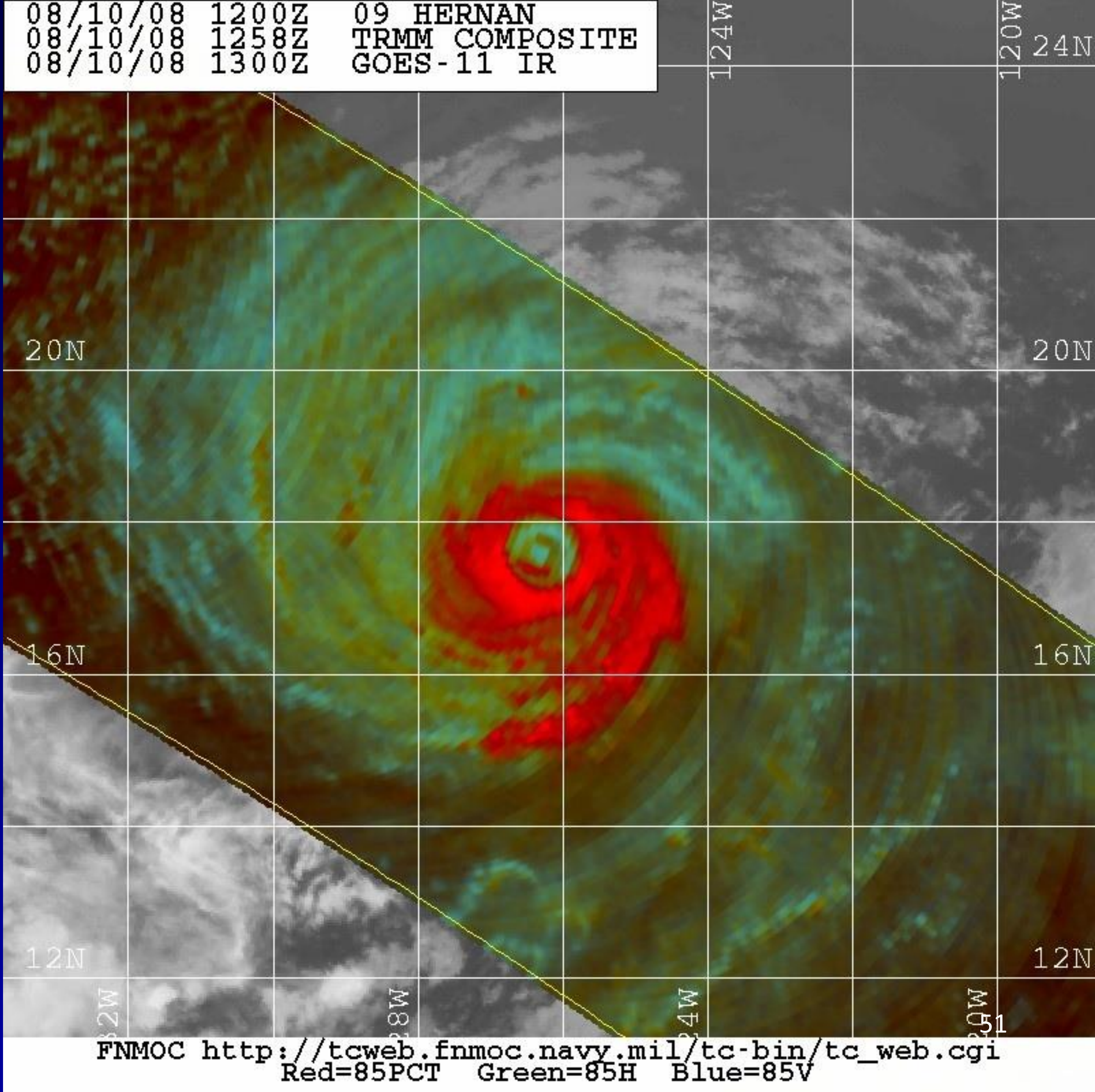
Hernan near peak intensity

9 Aug 2008

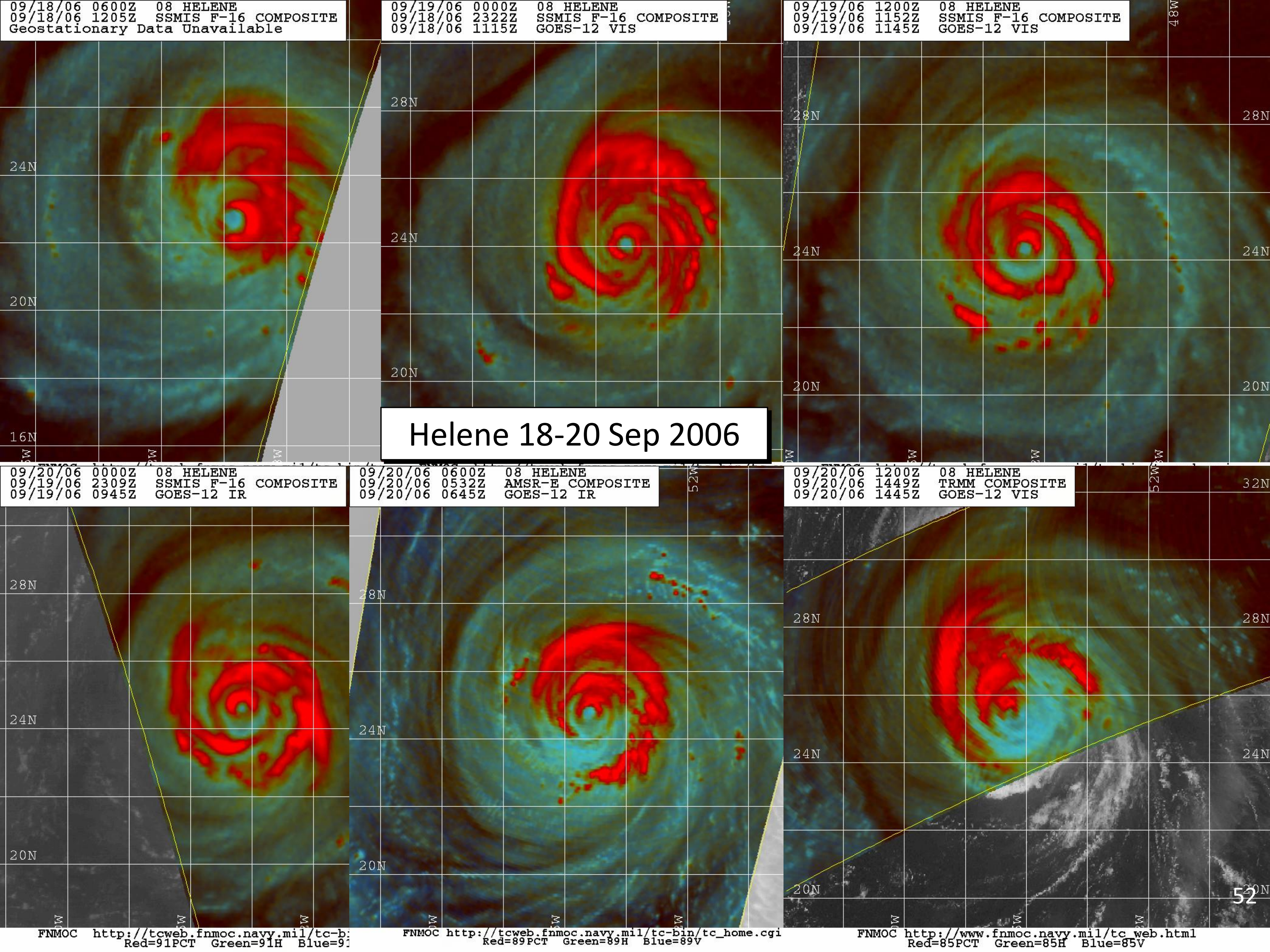


Hernan Eyewall Replacement Cycle 24 h later

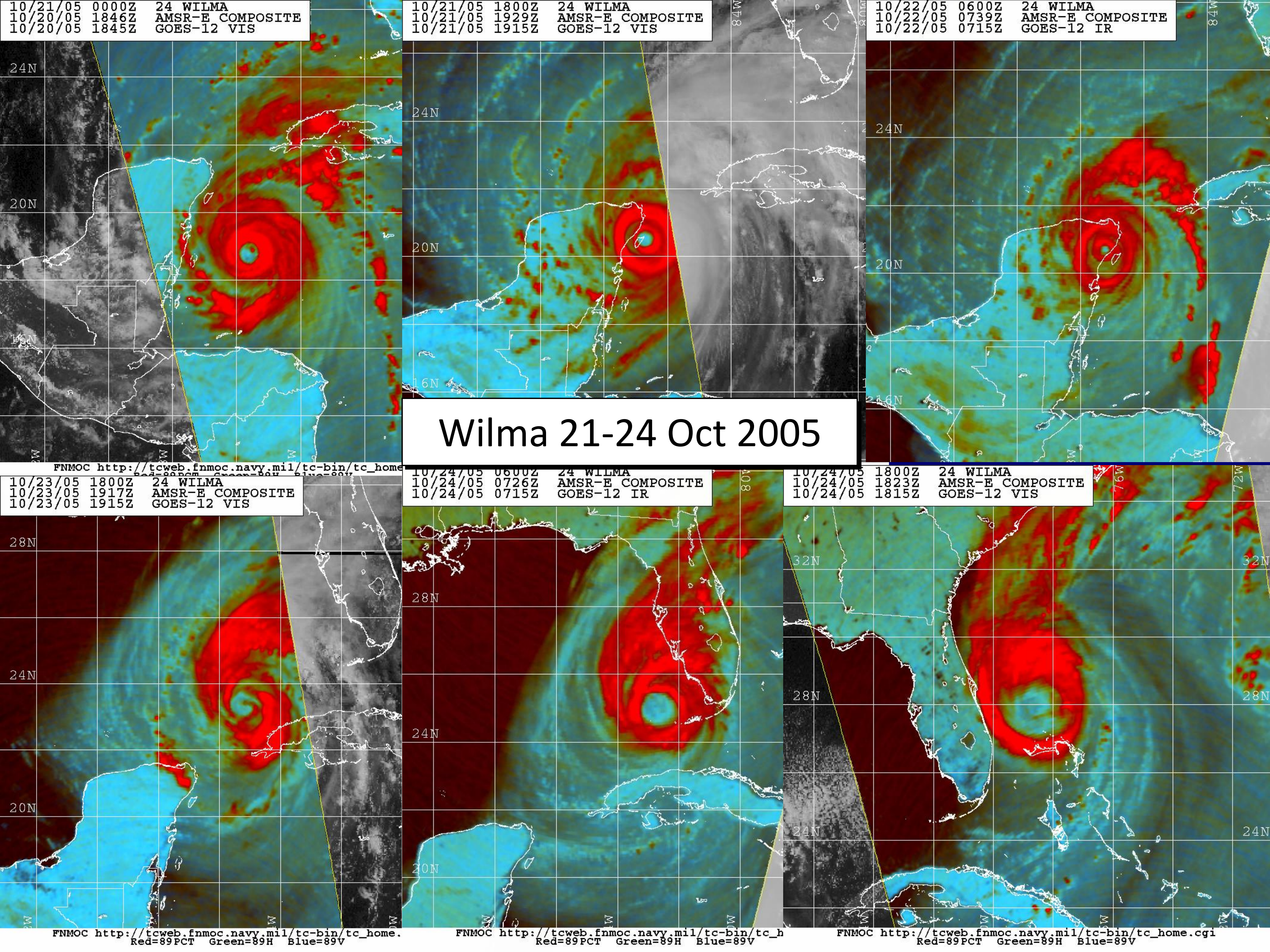
10 Aug 2008



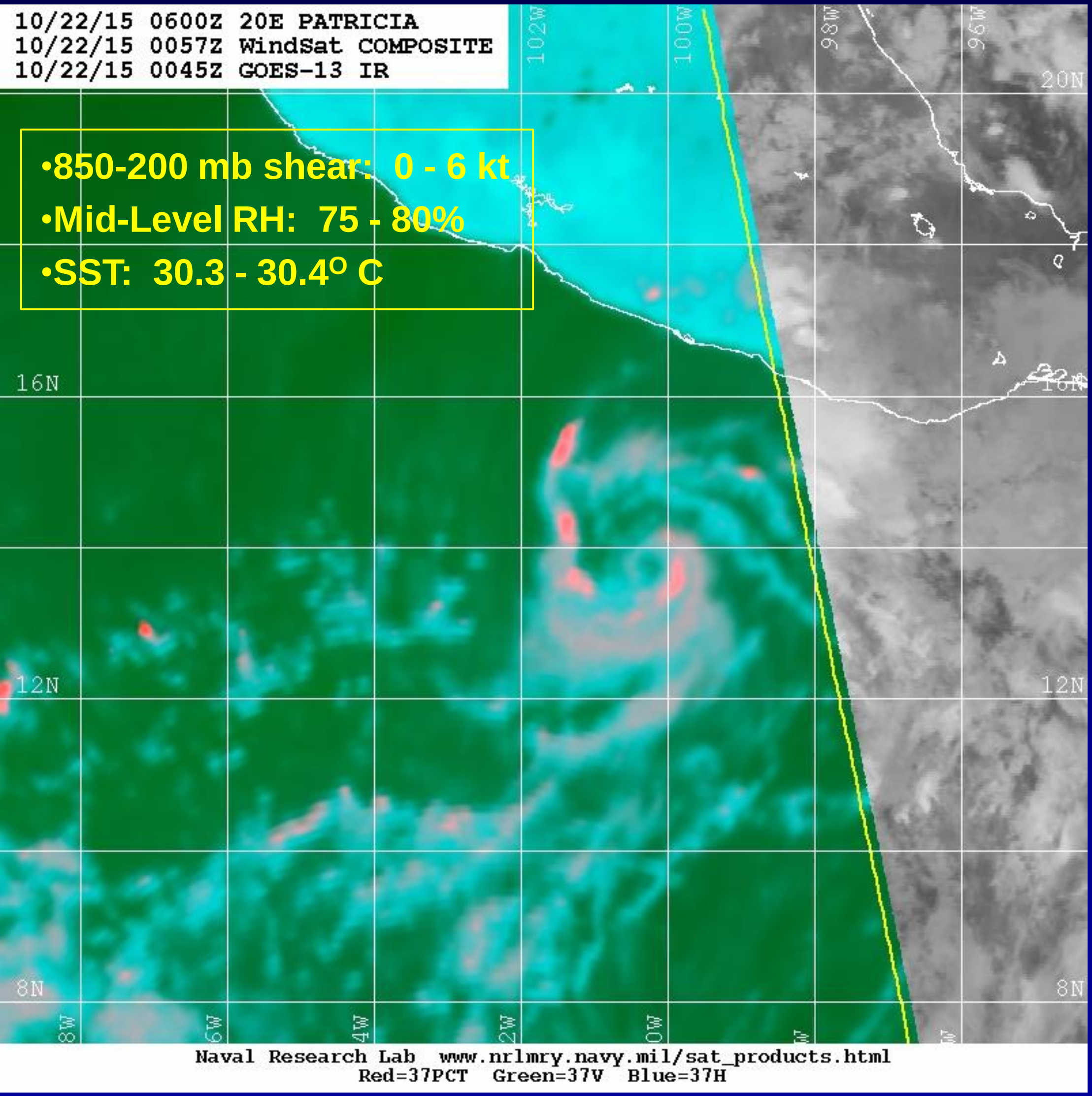
Helene 18-20 Sep 2006



Wilma 21-24 Oct 2005



Precursor Structure Before Rapid Intensification



- A closed low-level ring of convection in 37-GHz imagery can be a precursor signal to rapid intensification *IF* other environmental factors (e.g., vertical wind shear) are favorable

- In the case shown here, Patricia strengthened an incredible 90 kt from 60 kt to 150 kt in only 24 hours!

Satellite Ocean Surface Vector Winds

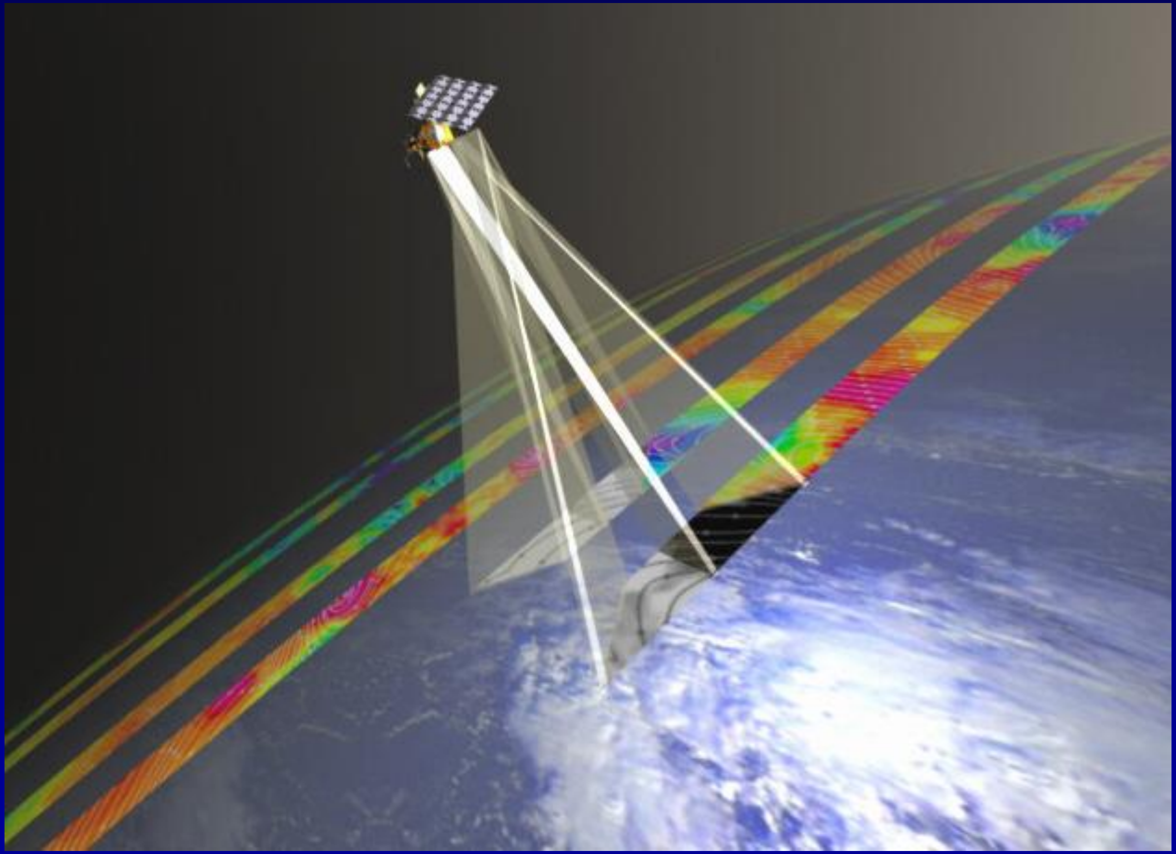
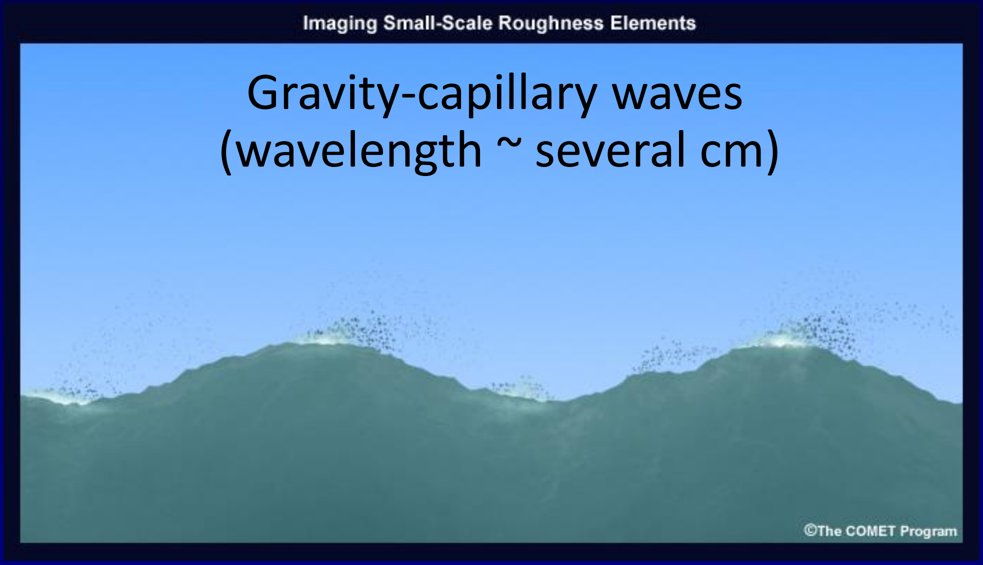
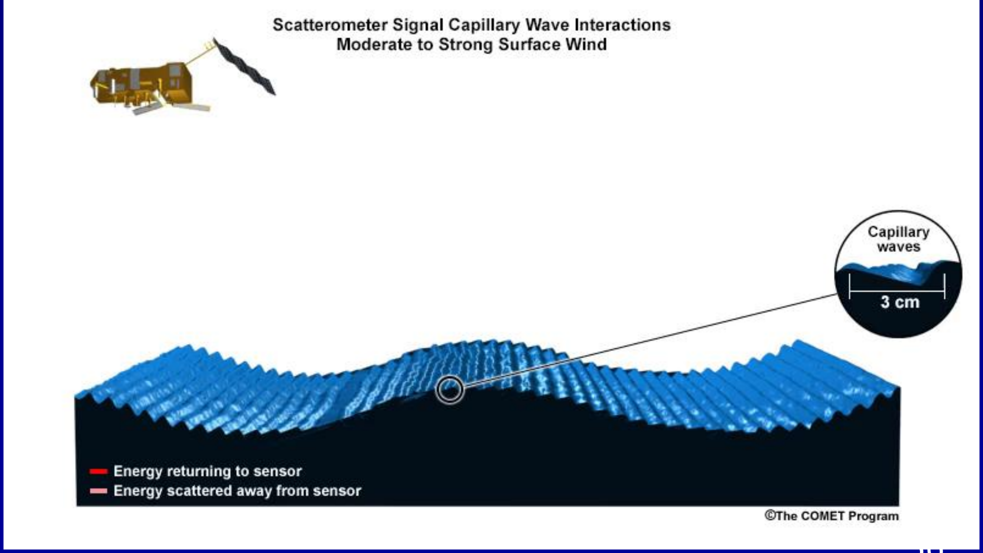


Image courtesy EUMETSAT

Scatterometry Basics

- Scatterometer → **ACTIVE** microwave imager
- Microwave energy is sensitive to small-scale roughness of the ocean surface that is generated by surface winds
- By viewing the same patch of ocean from several angles, it is possible to derive wind speed and direction





Images courtesy COMET

Advanced Scatterometer (ASCAT)

Satellites: MetOp-1, -2, -3
Launched: 2006, 2012, 2018
Operator: EUMETSAT

Image courtesy EUMETSAT

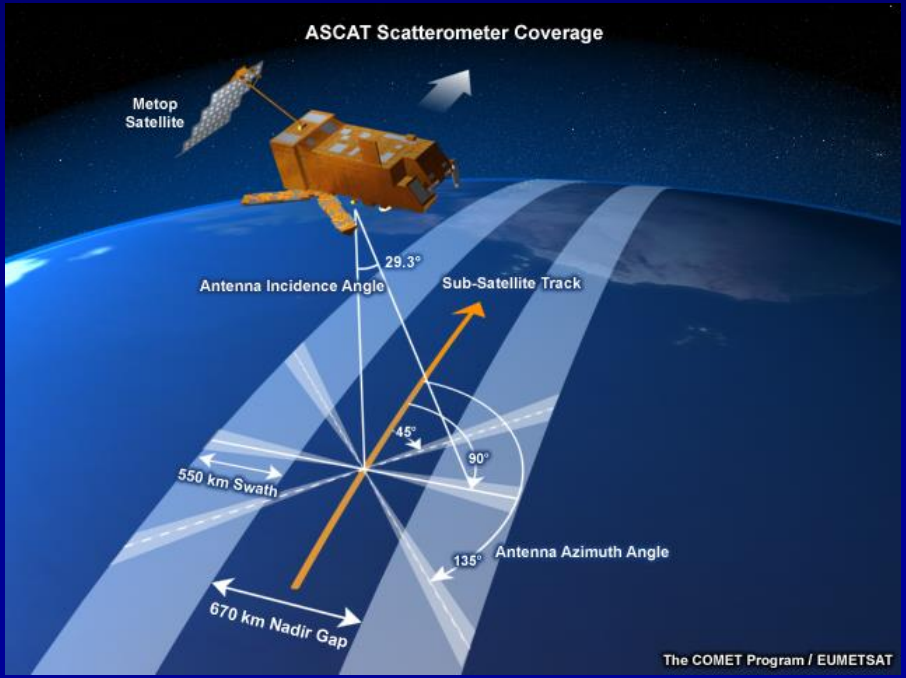


Image courtesy COMET

Sensor: Microwave radar
Channel: 5.25 GHz (C-band)

Swath: Two 550-km swaths; 670 km nadir gap

Advanced Scatterometer (ASCAT)

- 25- and 50-km ASCAT wind vector products available online: https://manati.orbit.nesdis.noaa.gov/datasets/ASCATData.php

Benefits

- Long-term, operational scatterometer series
- C-band scatterometer is less susceptible to rain contamination than legacy Ku-band instruments
- High-quality data for TC wind speed/radii analysis

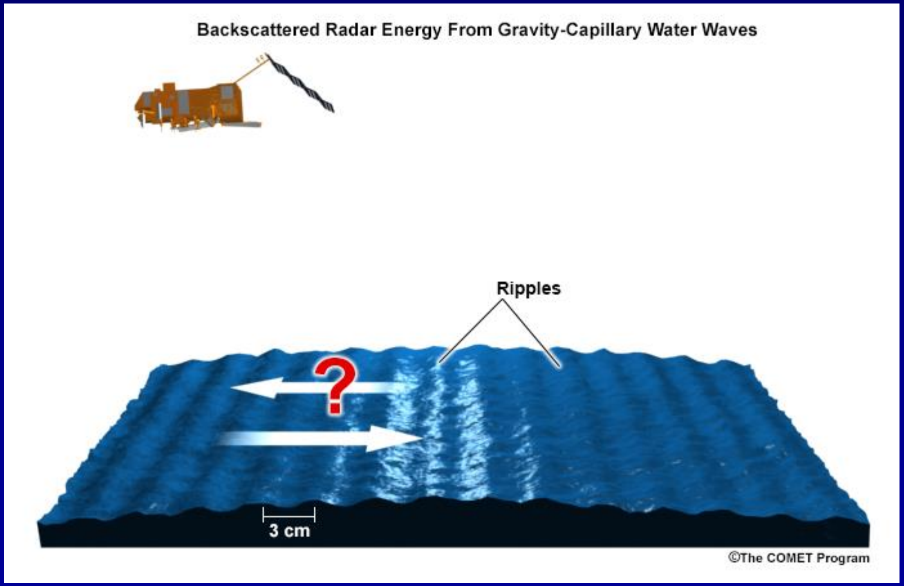
Limitations

- Gaps over the tropics reduce spatial coverage, and swaths may miss features of interest
- Spatial sampling/resolution leads to a low wind speed bias for stronger TCs
- Directional ambiguity

Scatterometer Ambiguity

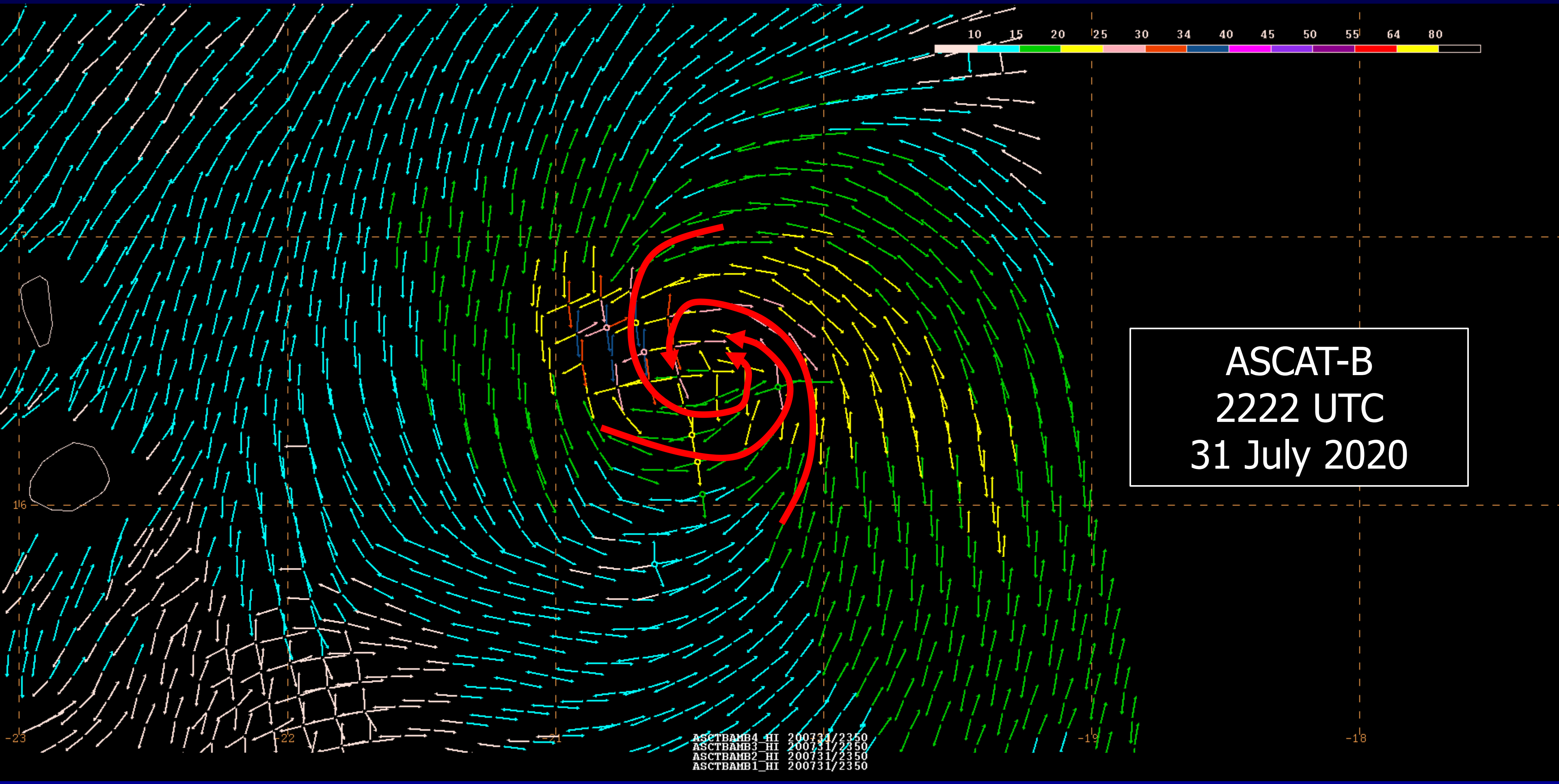
- Wind direction is derived by determining the angle that is most likely consistent with the backscattered energy

- The best fit *usually* matches the true wind direction
- But what if it doesn't?
  - Look at ambiguities to view other possible directions and identify the most likely solution



Images courtesy COMET

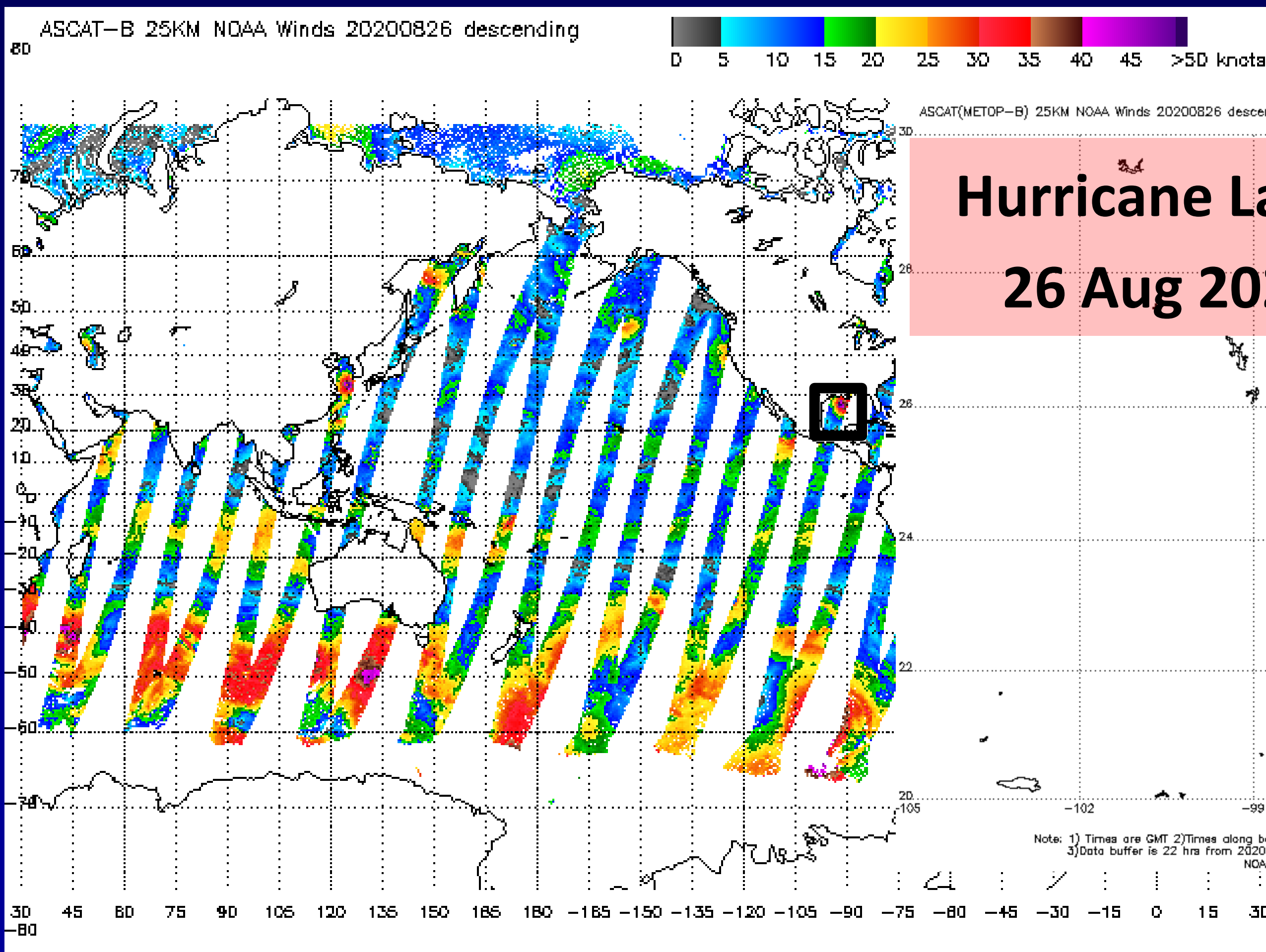
Ambiguity Analysis

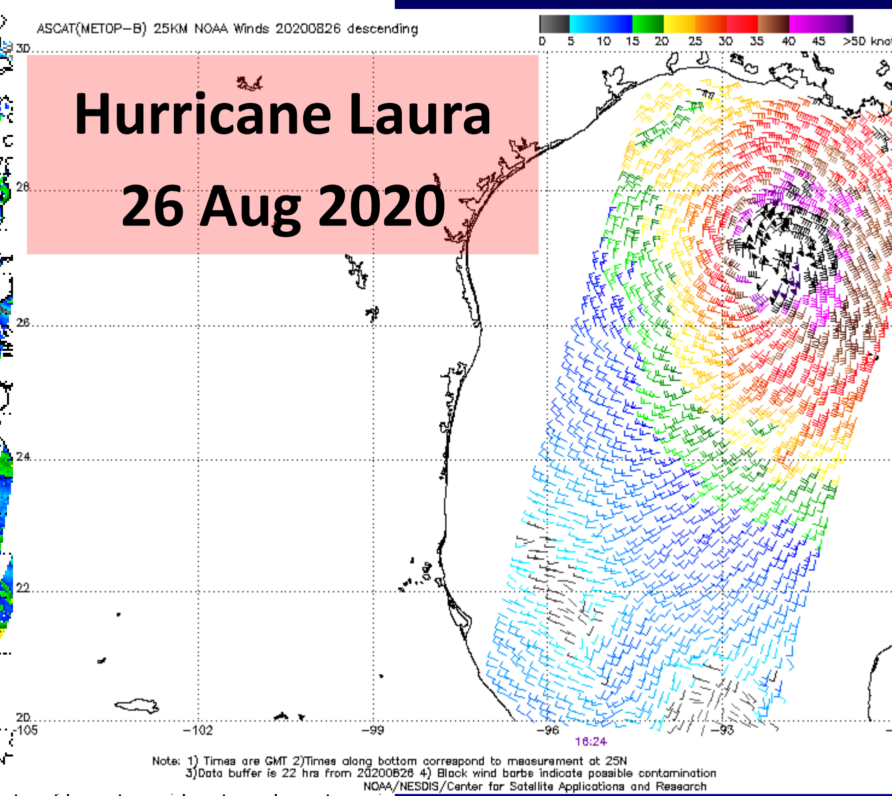


- ASCAT ambiguities can be used to help assess appropriate wind directions and improve the center fix for developing TCs

Access to Scatterometer Data

https://manati.orbit.nesdis.noaa.gov/datasets/ASCATData.php

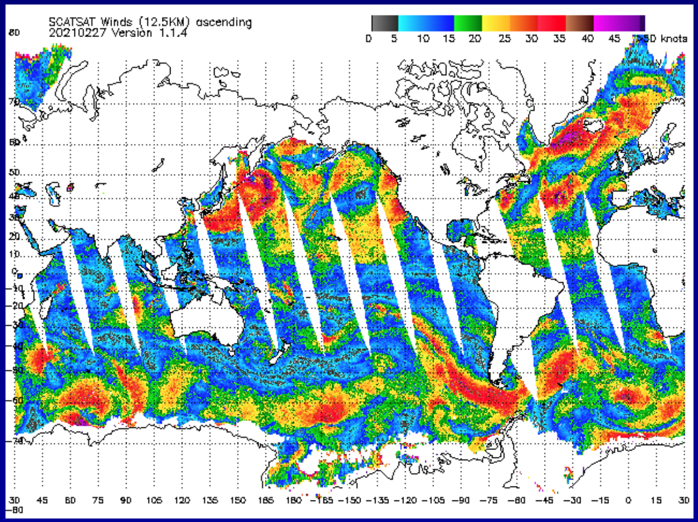




Other Scatterometer Data

Satellites: SCATSat-1 (2016)
Operator: Indian Space Research Organization (ISRO)

Processed data available through NOAA:
https://manati.orbit.nesdis.noaa.gov/datasets/SSCATData.php



Note: Unavailable since 28 Feb 2021 due to an instrument anomaly

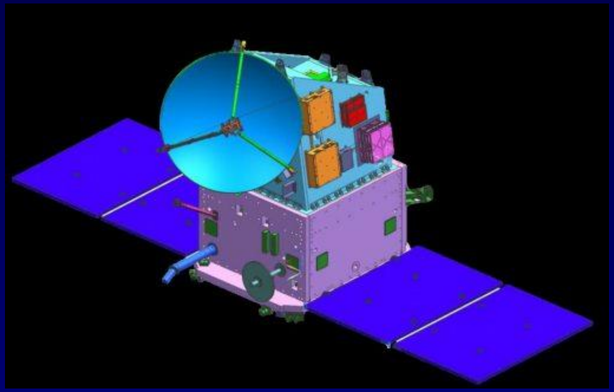


Image courtesy ISRO

Sensor: Microwave radar
Channel: 13.5 GHz (Ku-band)
Swath: 1800 km

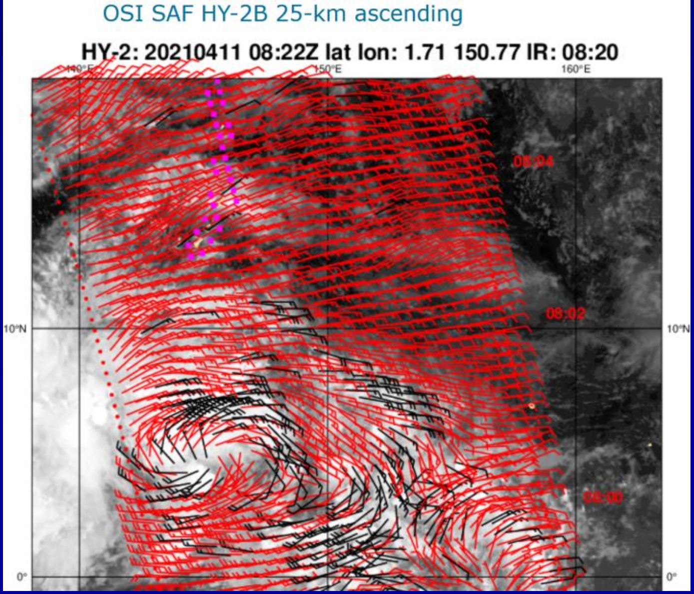
Note: Ku-band more sensitive to rain contamination, which can lead to overestimated winds

Other Scatterometer Data

Satellites: HY-2B (2018), -2C (2020)
Operator: Chinese National Satellite Ocean Application Service (NSOAS)

Image courtesy NSOAS

Processed data available through EUMETSAT:
https://scatterometer.knmi.nl/



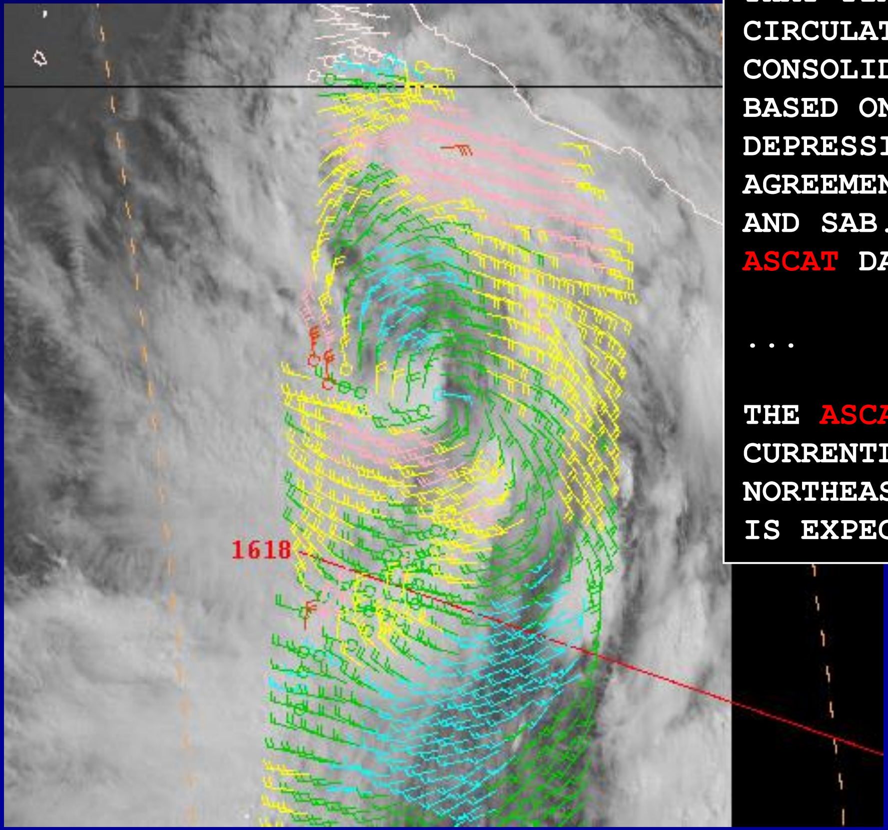
Black wind barbs = QC flagged data

Sensor: Microwave radar
Channel: 13.3 GHz (Ku-band)
Swath: 1300 km

Note: Ku-band more sensitive to rain contamination, which can lead to overestimated winds

Applications: TC Genesis

- Used as justification to initiate advisories on TD Four-E (later TS Douglas) and set initial intensity at 30 kt



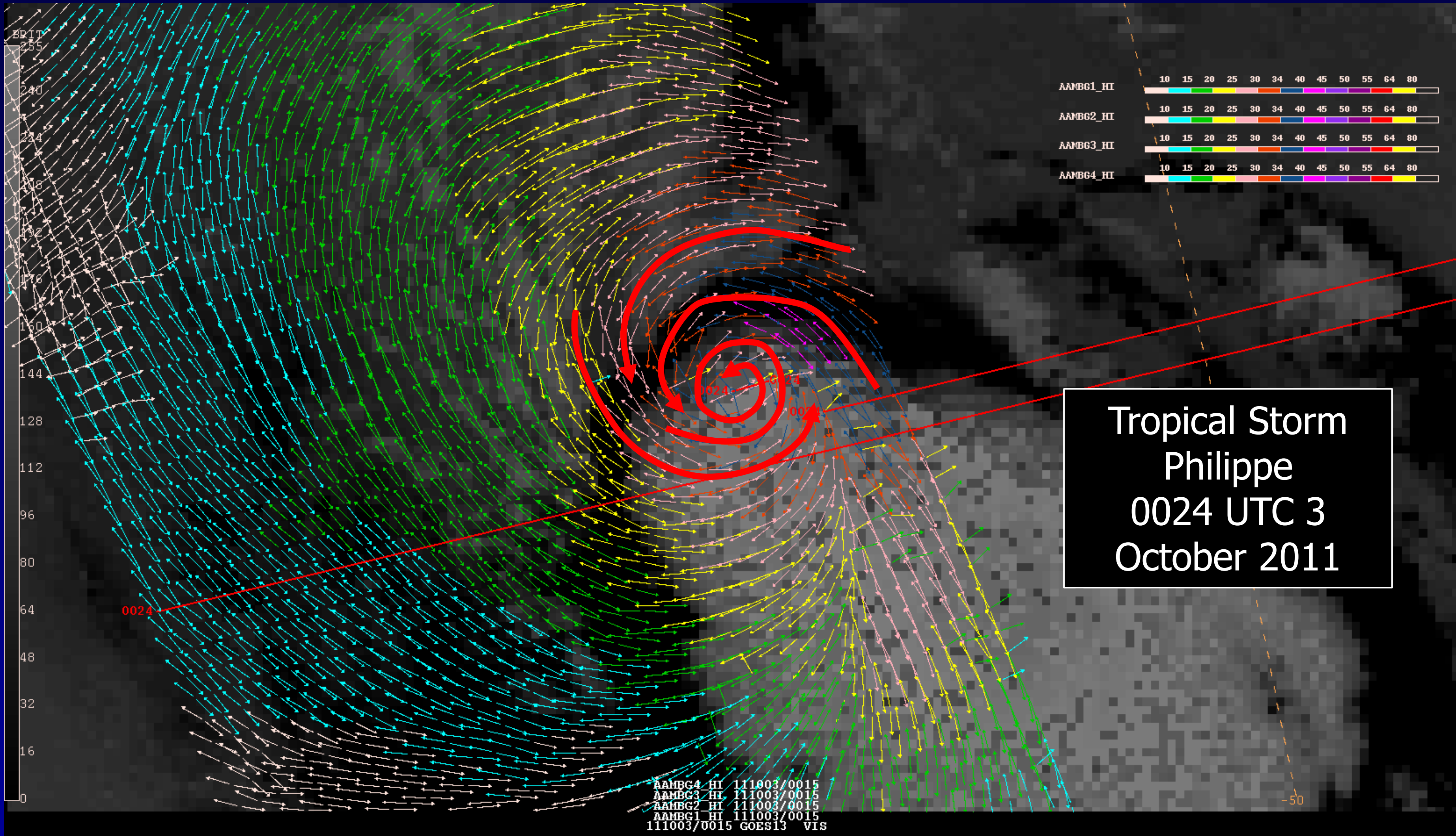
TROPICAL DEPRESSION FOUR-E DISCUSSION NUMBER 1
NWS TPC/NATIONAL HURRICANE CENTER MIAMI FL EP042008
800 PM PDT TUE JUL 01 2008

ASCAT DATA AT AROUND 16Z SHOWED THAT THE LOW PRESSURE AREA SOUTHWEST OF MANZANILLO MEXICO HAD A BROAD CENTER ELONGATED NORTH-NORTHWEST TO SOUTH-SOUTHEAST. SINCE THAT TIME...SATELLITE IMAGERY INDICATES THAT THE CIRCULATION AND ASSOCIATED SHOWER ACTIVITY HAS SOMEWHAT CONSOLIDATED AT THE SOUTHERN END OF THE ELONGATION. BASED ON THIS...ADVISORIES ARE INITIATED ON TROPICAL DEPRESSION FOUR-E. THE INITIAL INTENSITY IS 30 KT IN AGREEMENT WITH SATELLITE INTENSITY ESTIMATES FROM TAFB AND SAB...AS WELL AS THE OBSERVED WINDS IN THE EARLIER ASCAT DATA.

...

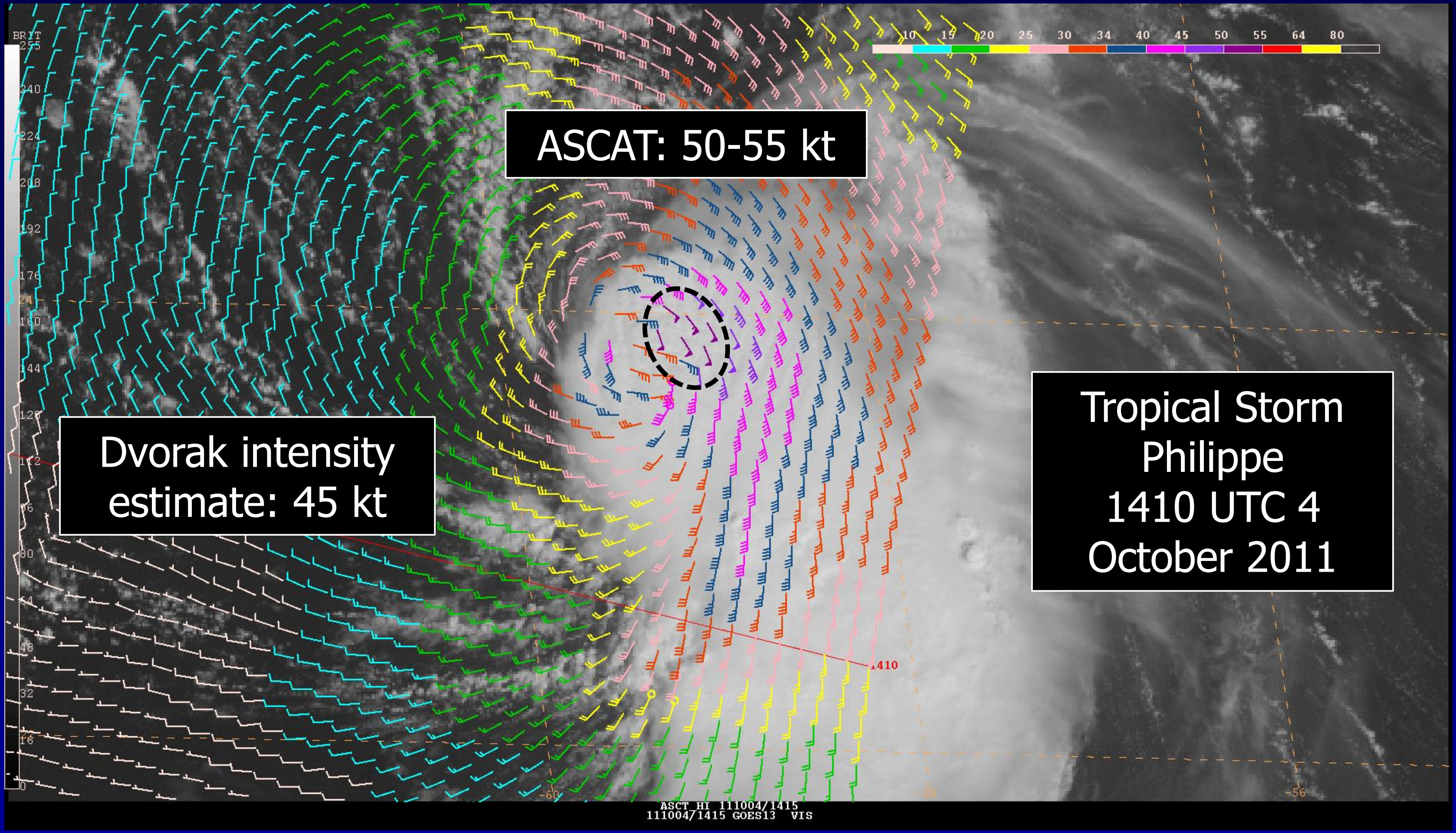
THE ASCAT DATA SHOWED 25-30 KT WINDS IN A BAND THAT IS CURRENTLY ABOUT 200 N MI FROM THE CENTER IN THE NORTHEASTERN QUADRANT. WHILE THE CENTER OF THE CYCLONE IS EXPECTED TO REMAIN WELL OFFSHORE...

Applications: TC Center Fixing



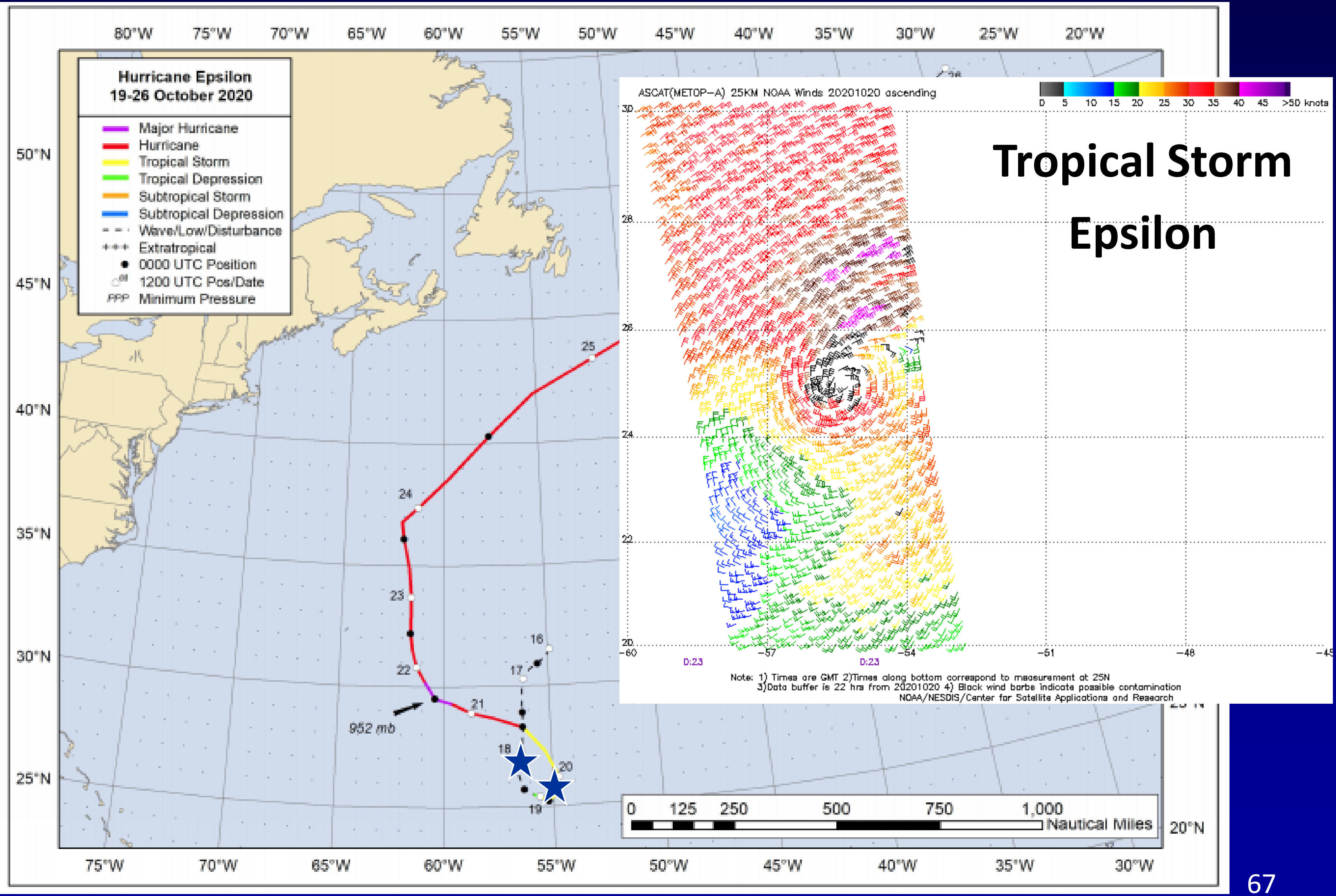
- Reduced ASCAT rain contamination and prevalence of 3rd and 4th ambiguities in areas of low winds can help make center fixing easier

Applications: TC Intensity Analysis

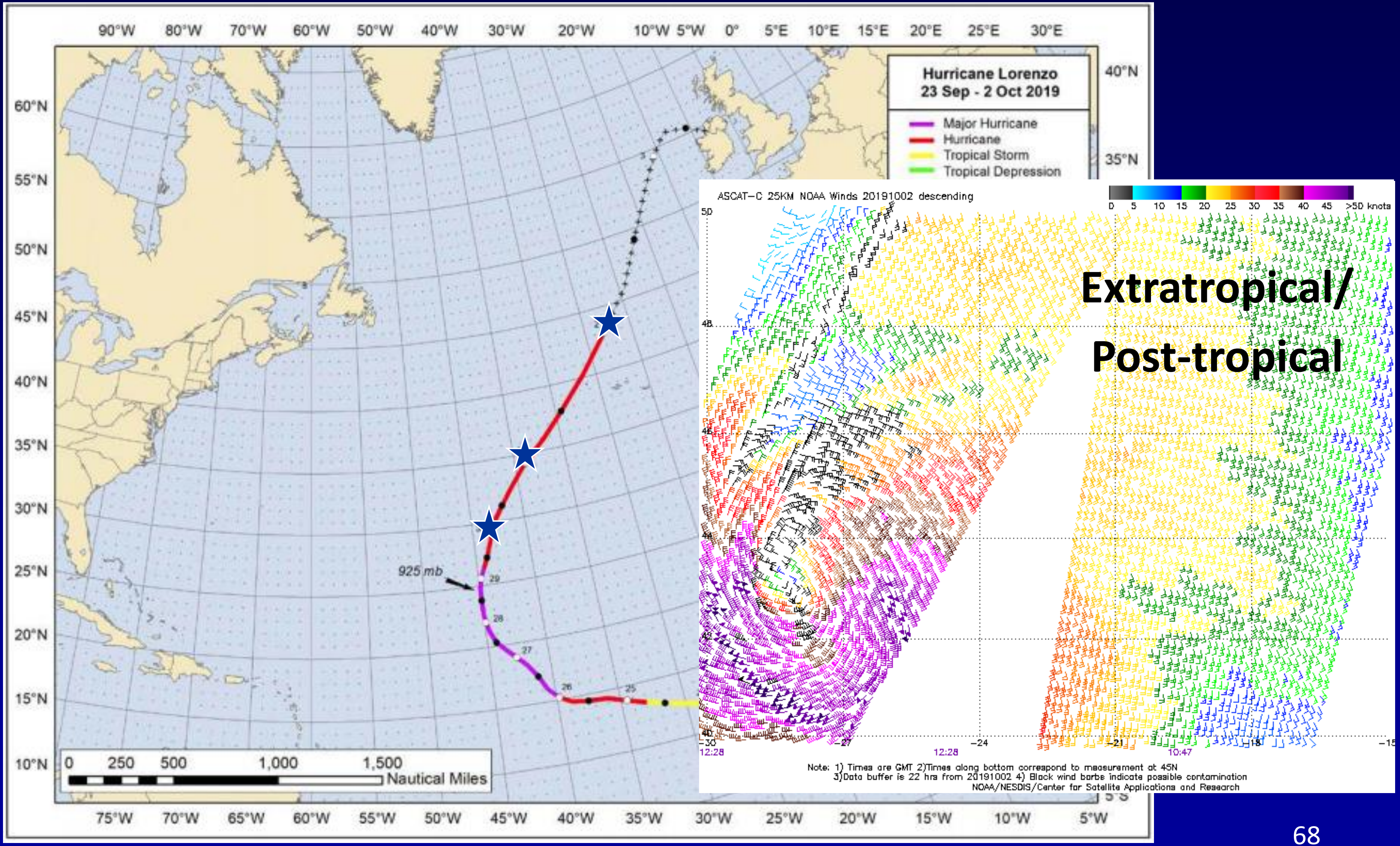


- Reminder: ASCAT cannot be used to determine the peak intensity of stronger tropical storms or hurricanes

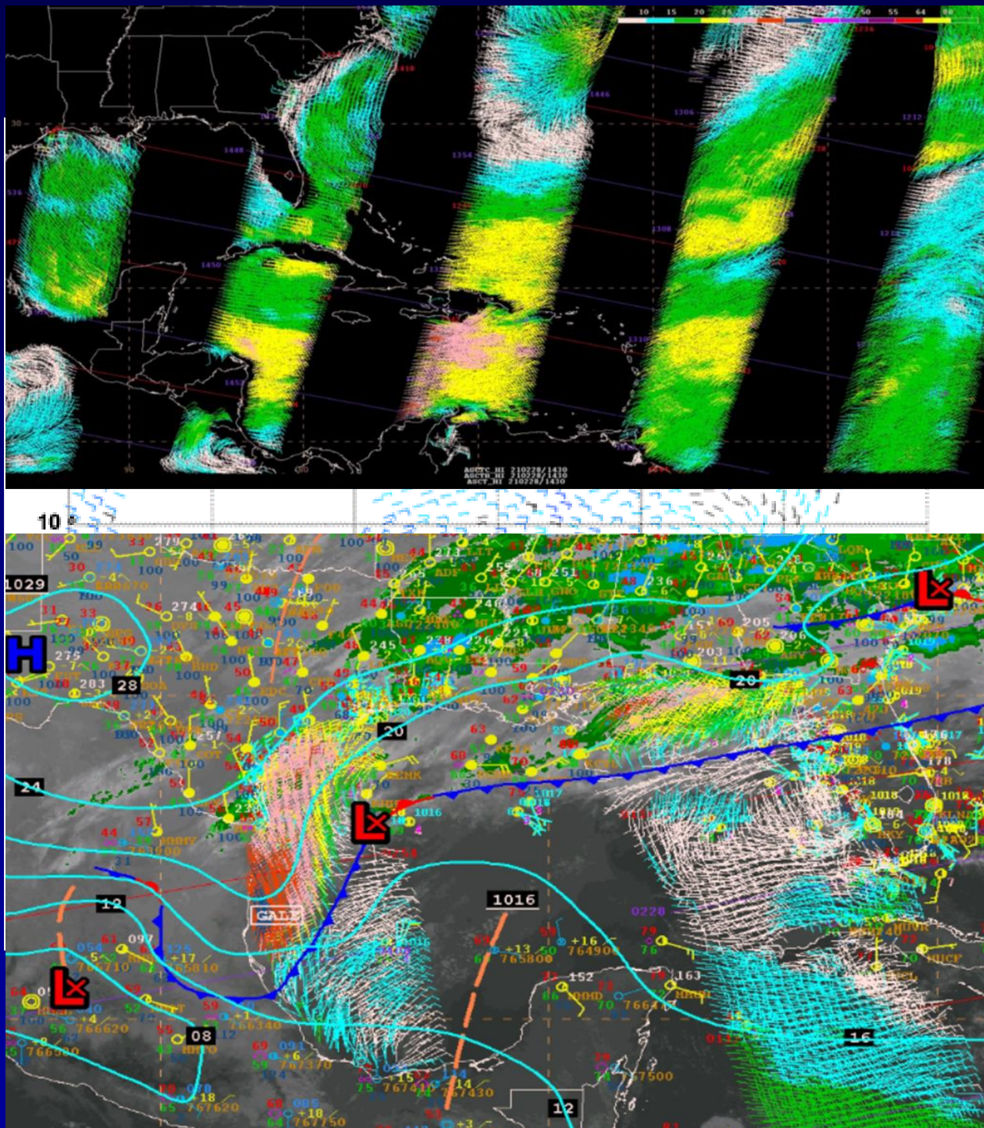
Applications: Cyclone Phase Transition



Applications: Extratropical Transition



Applications: Marine Surface Analysis



- Surface troughs/ tropical waves
- Orientation of the surface ridge axis
- Extratropical cyclones and fronts

Questions?