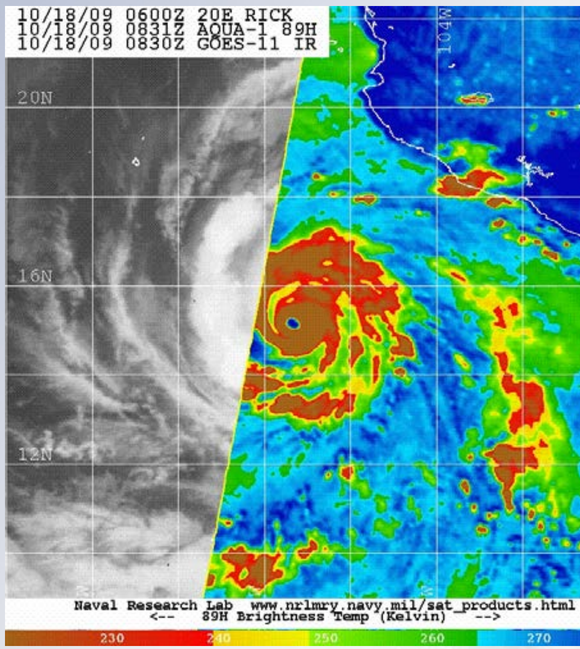
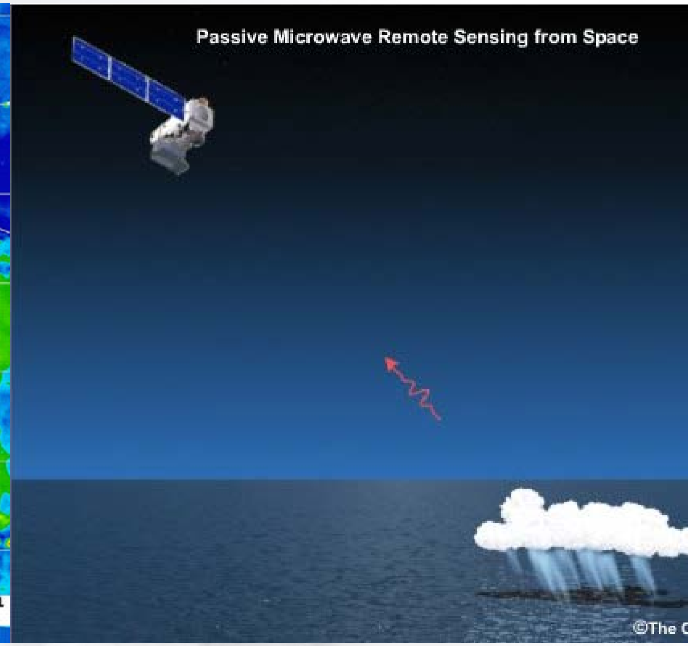
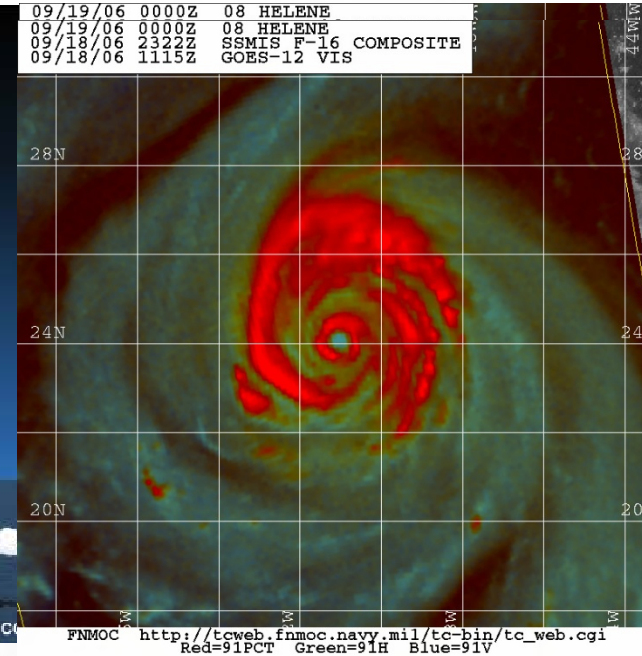
Interpretation and Application of Microwave Imagery







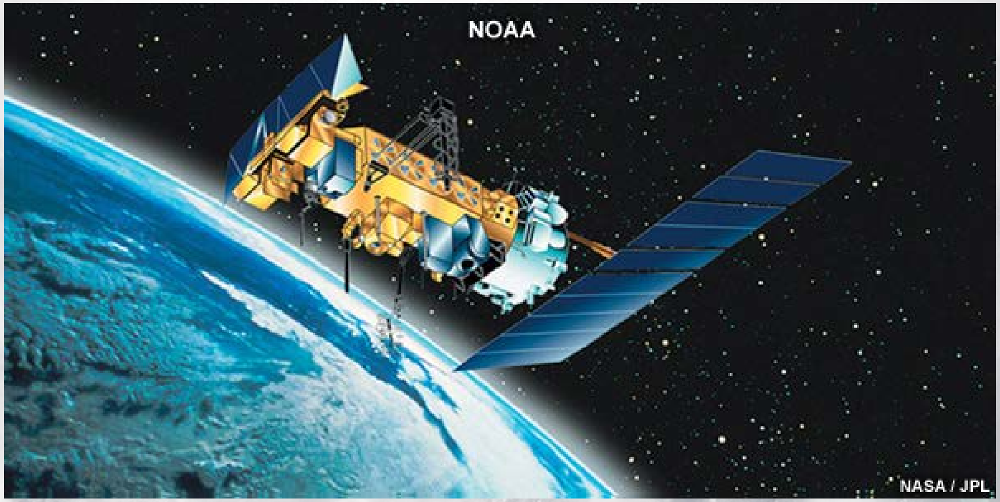
2022 RA-IV WMO Tropical Meteorology Course

John Cangialosi and Brad Reinhart

National Hurricane Center

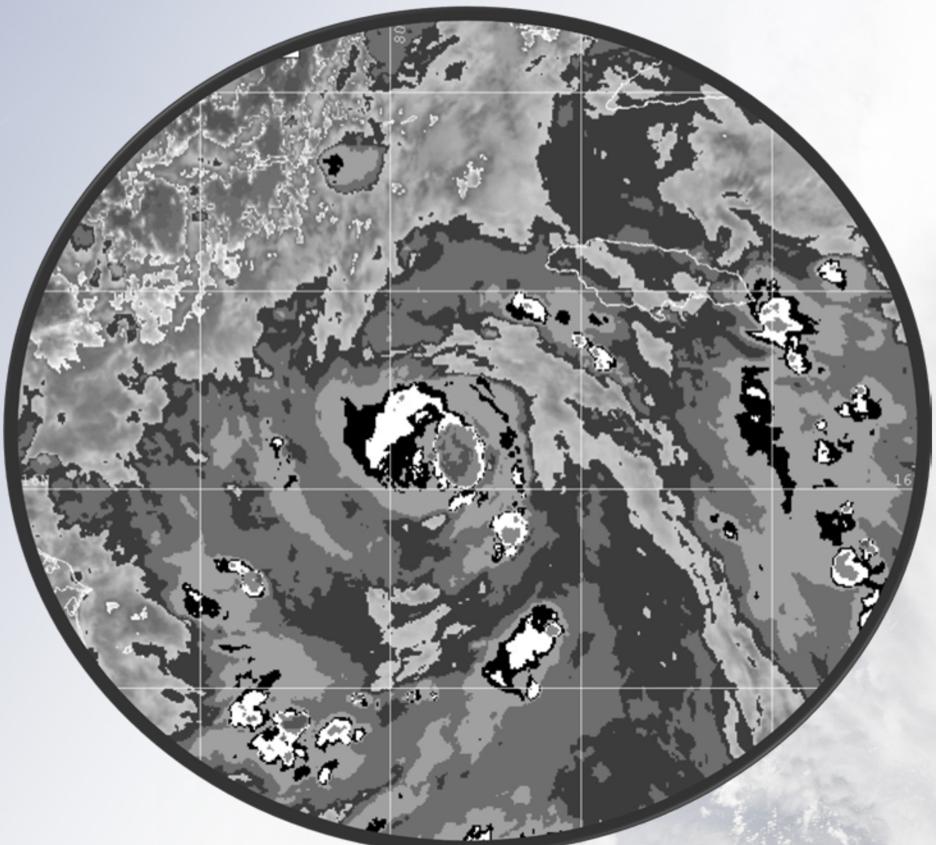
Outline

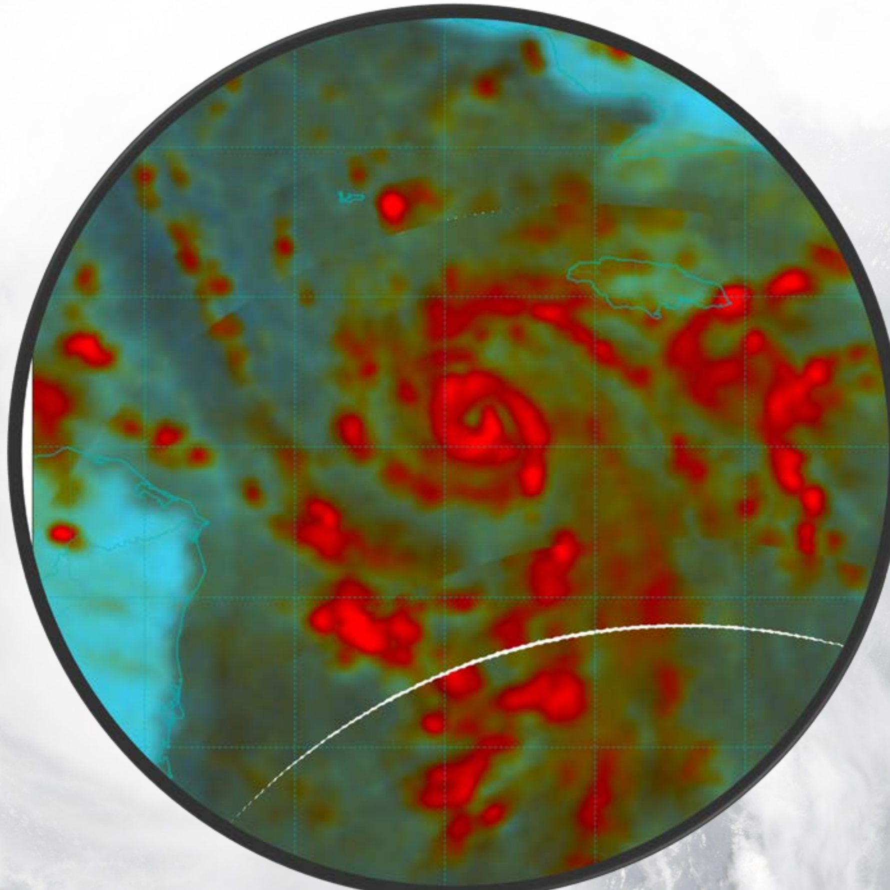
- Overview of basic principles/availability of microwave sensors
- Orbital characteristics
- Single frequency channels
- Scatterometry
- Exercise



* 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

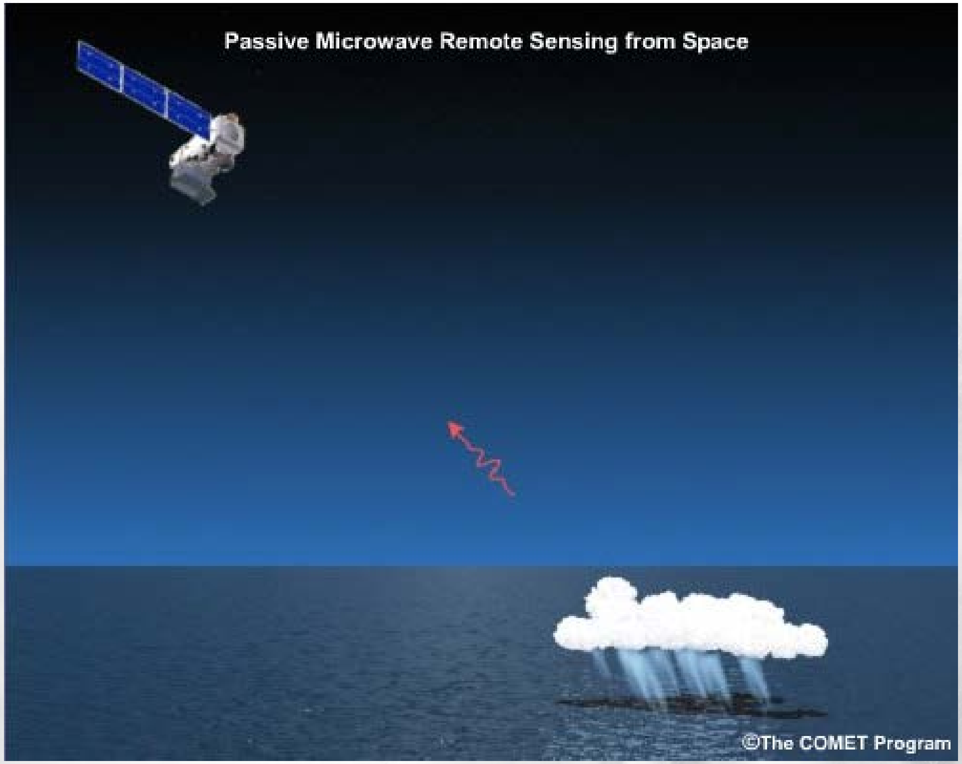
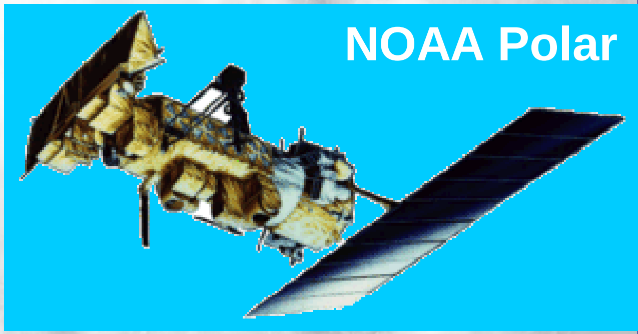


Image courtesy COMET

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



GEO vs. LEO Orbital Altitude Comparison

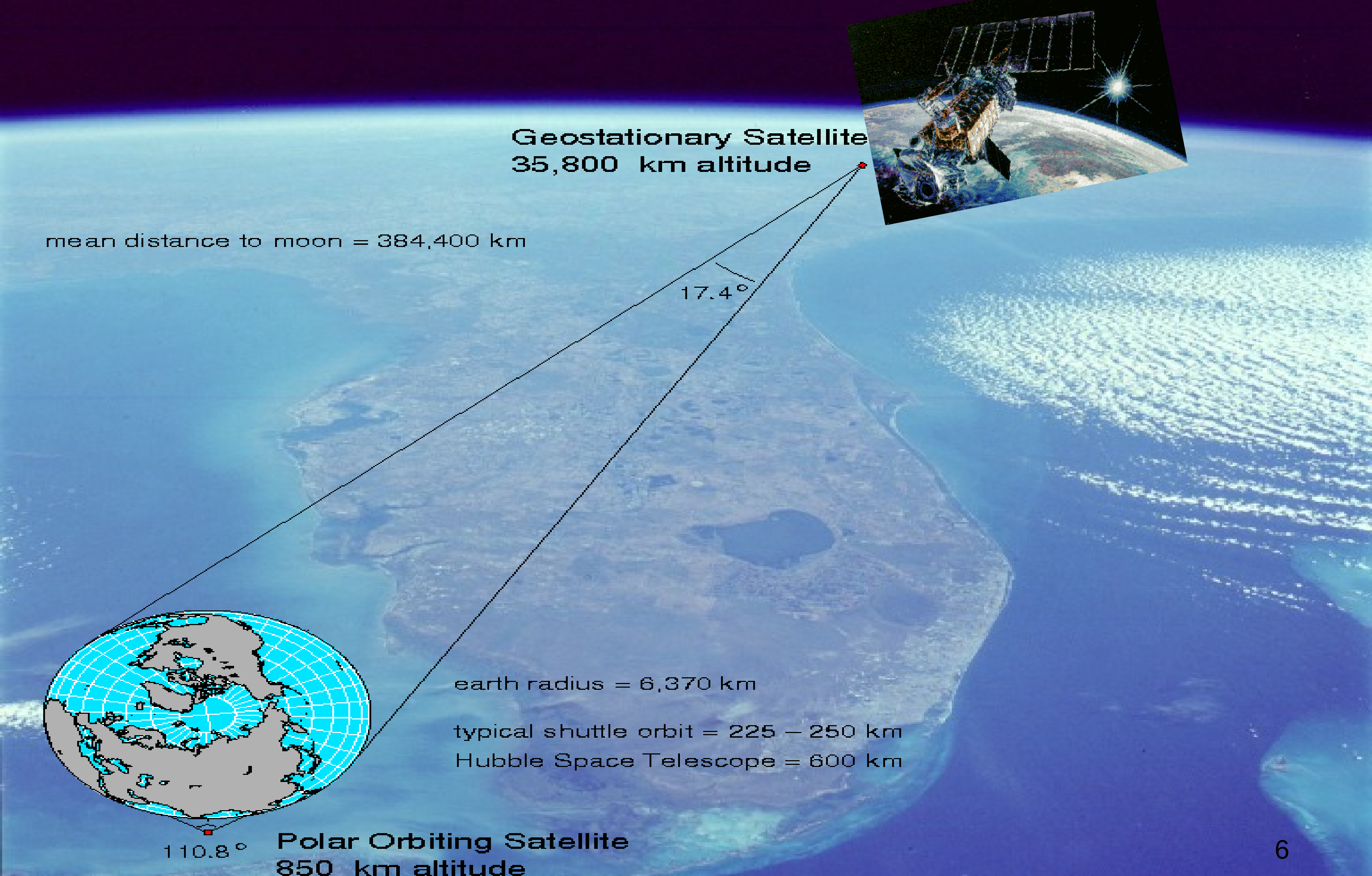


Image courtesy of http://www.nrlmry.navy.mil

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

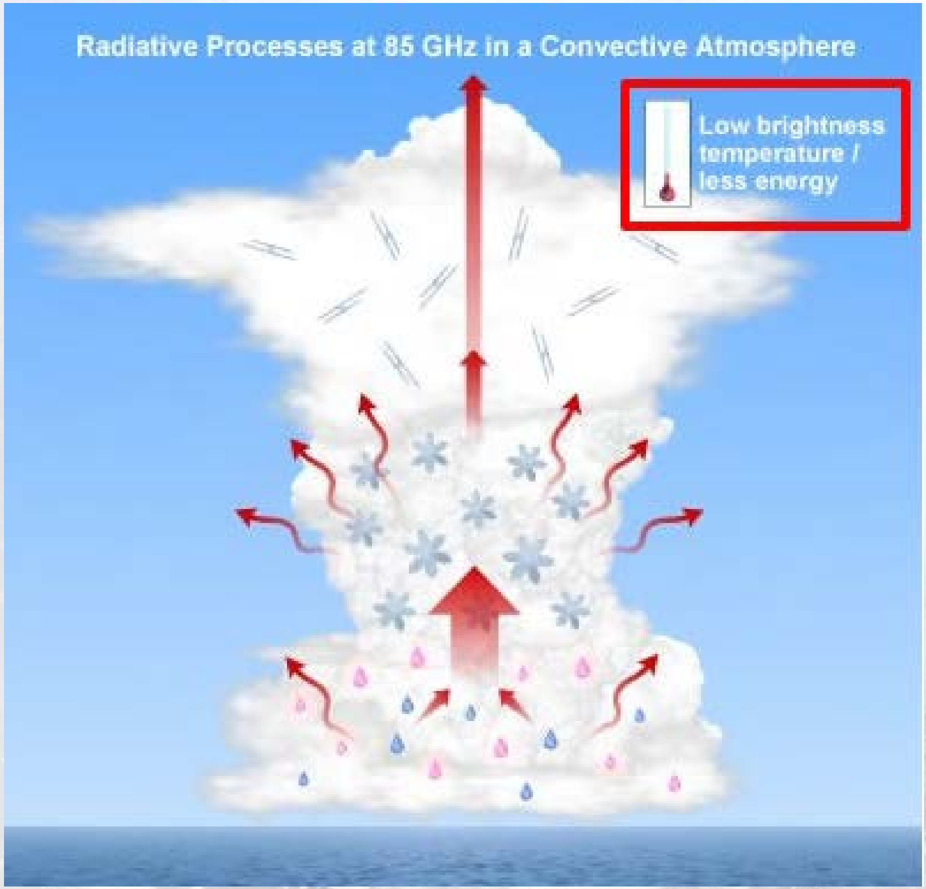


Image courtesy COMET

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

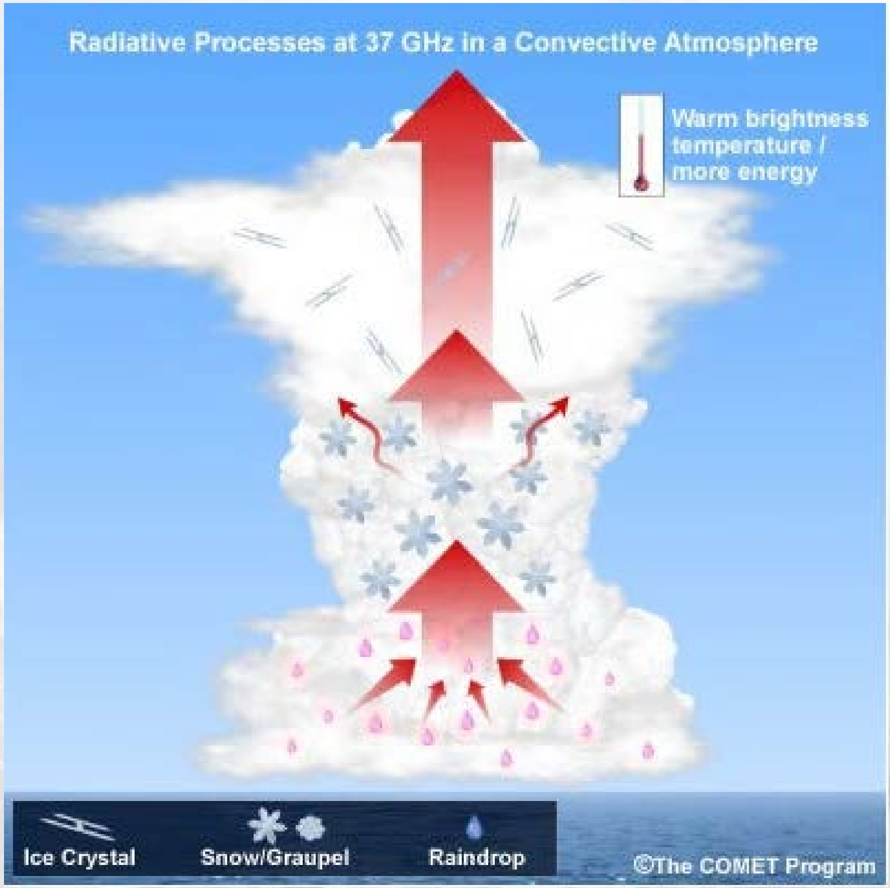
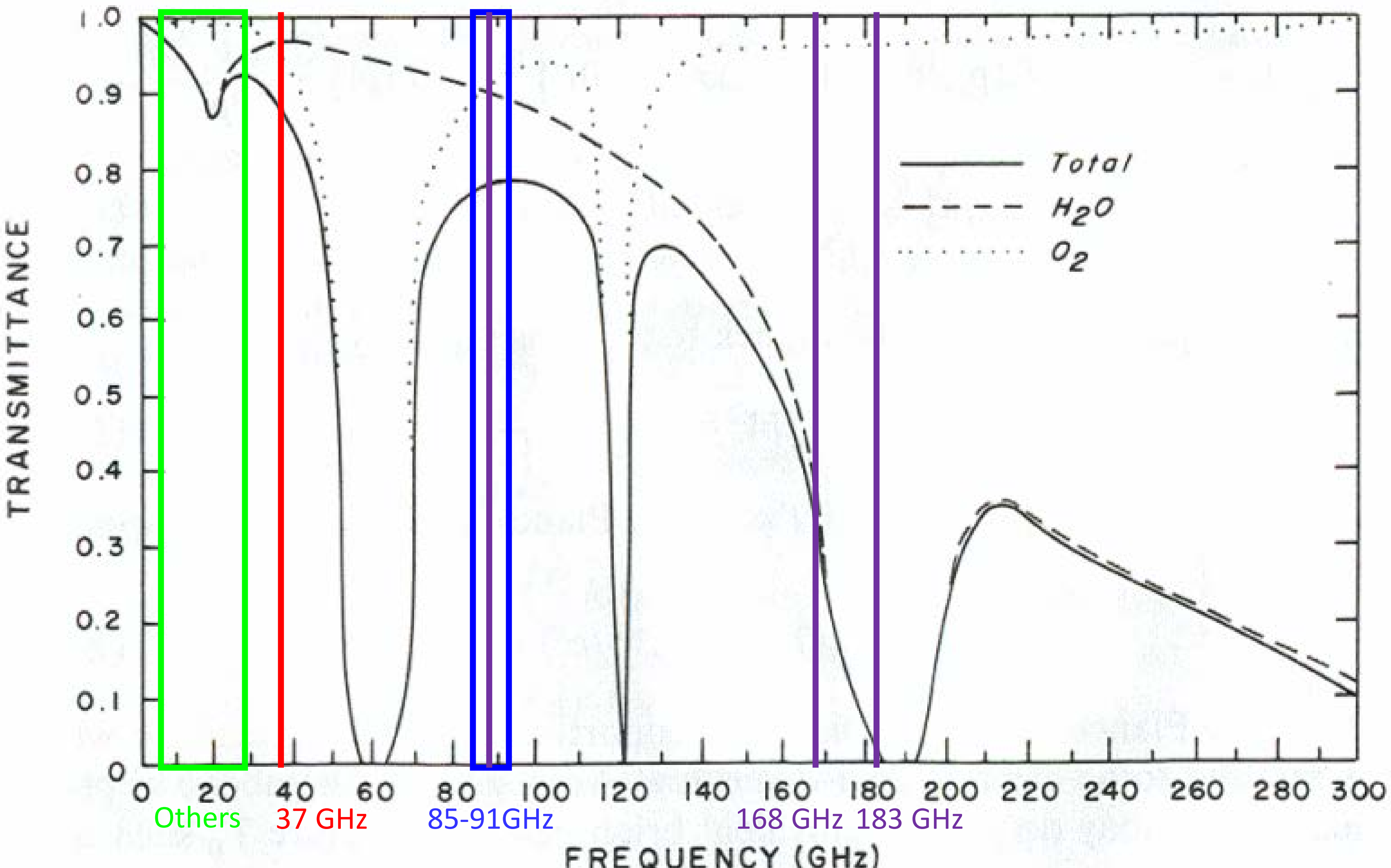


Image courtesy COMET

Microwave Transmittance



Data Timeliness

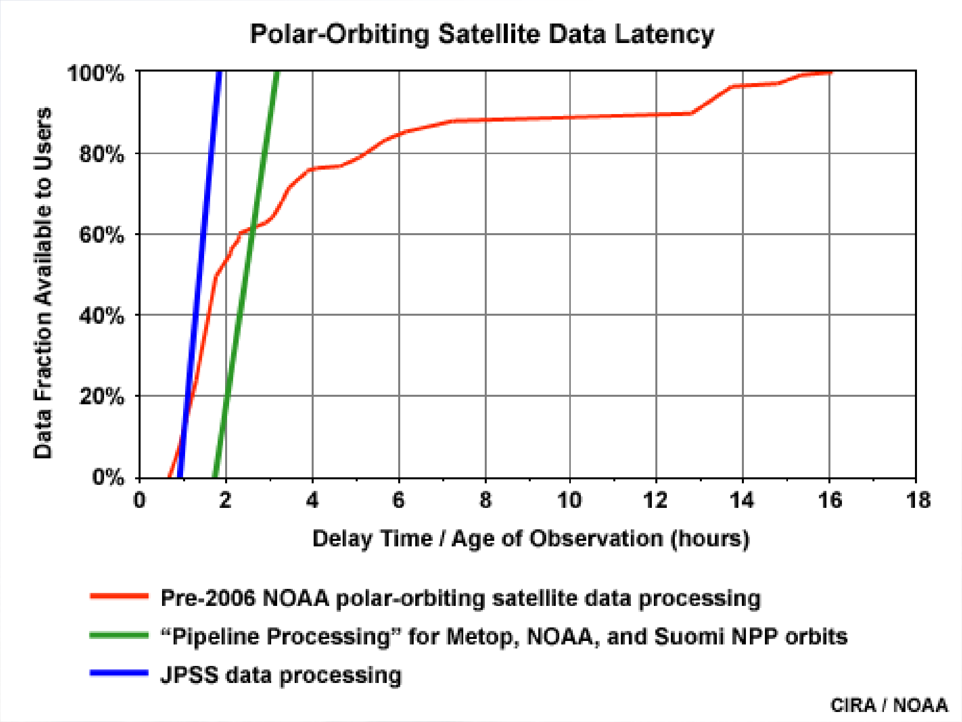
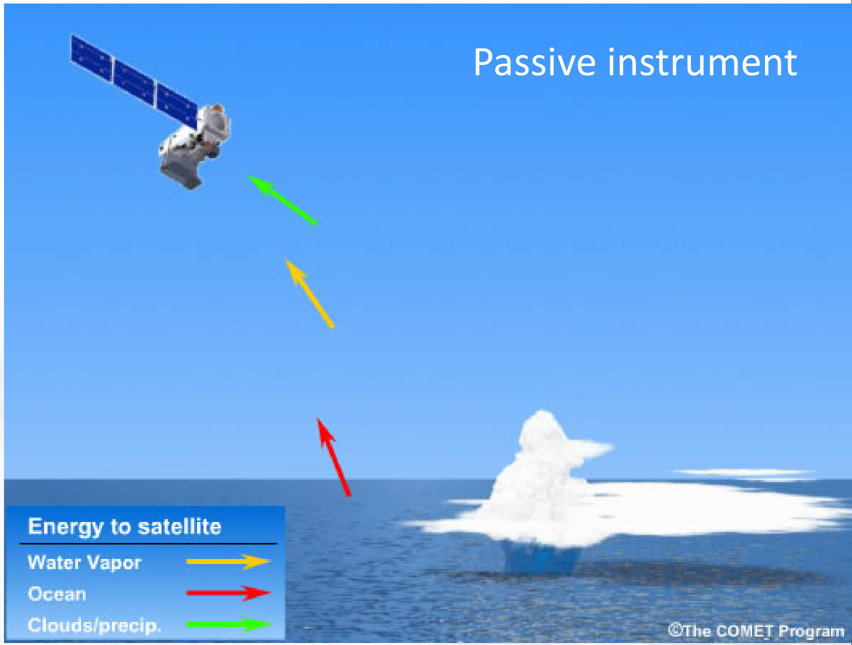


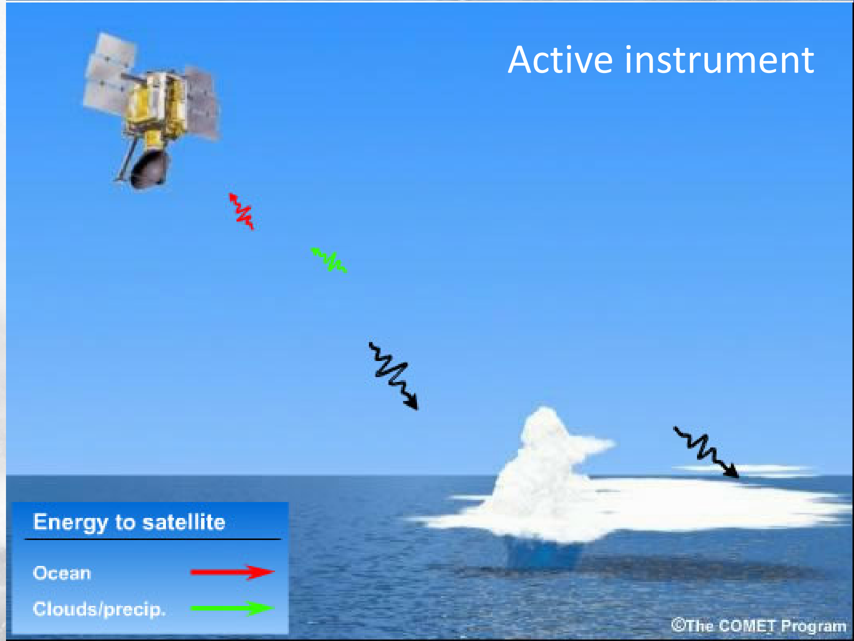
Image courtesy COMET

- 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





Orbital and Scan Characteristics

Sun-Synchronous Daily Orbital Path

~12 hr to observe the entire Earth

Same location twice daily (ascending/descending)

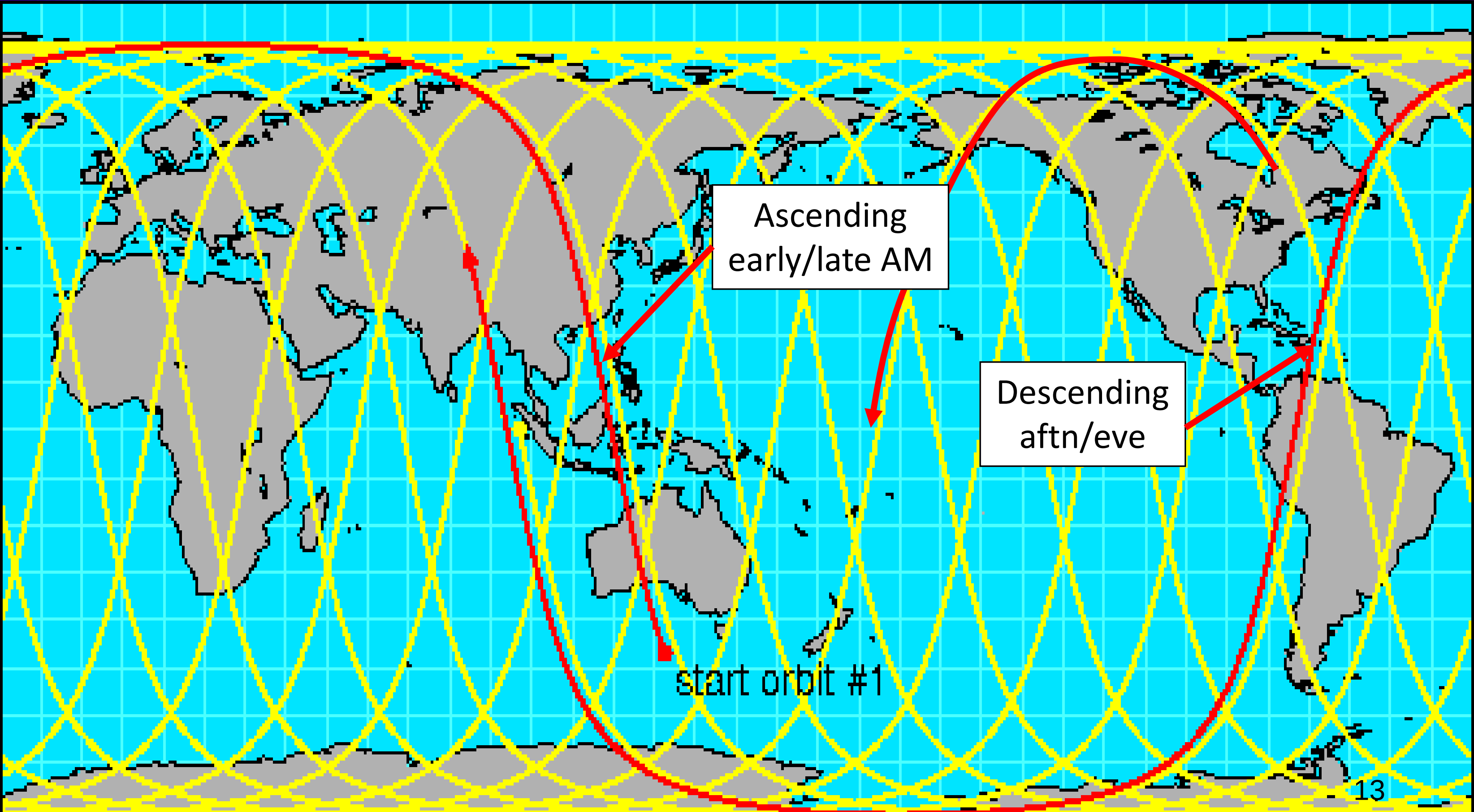
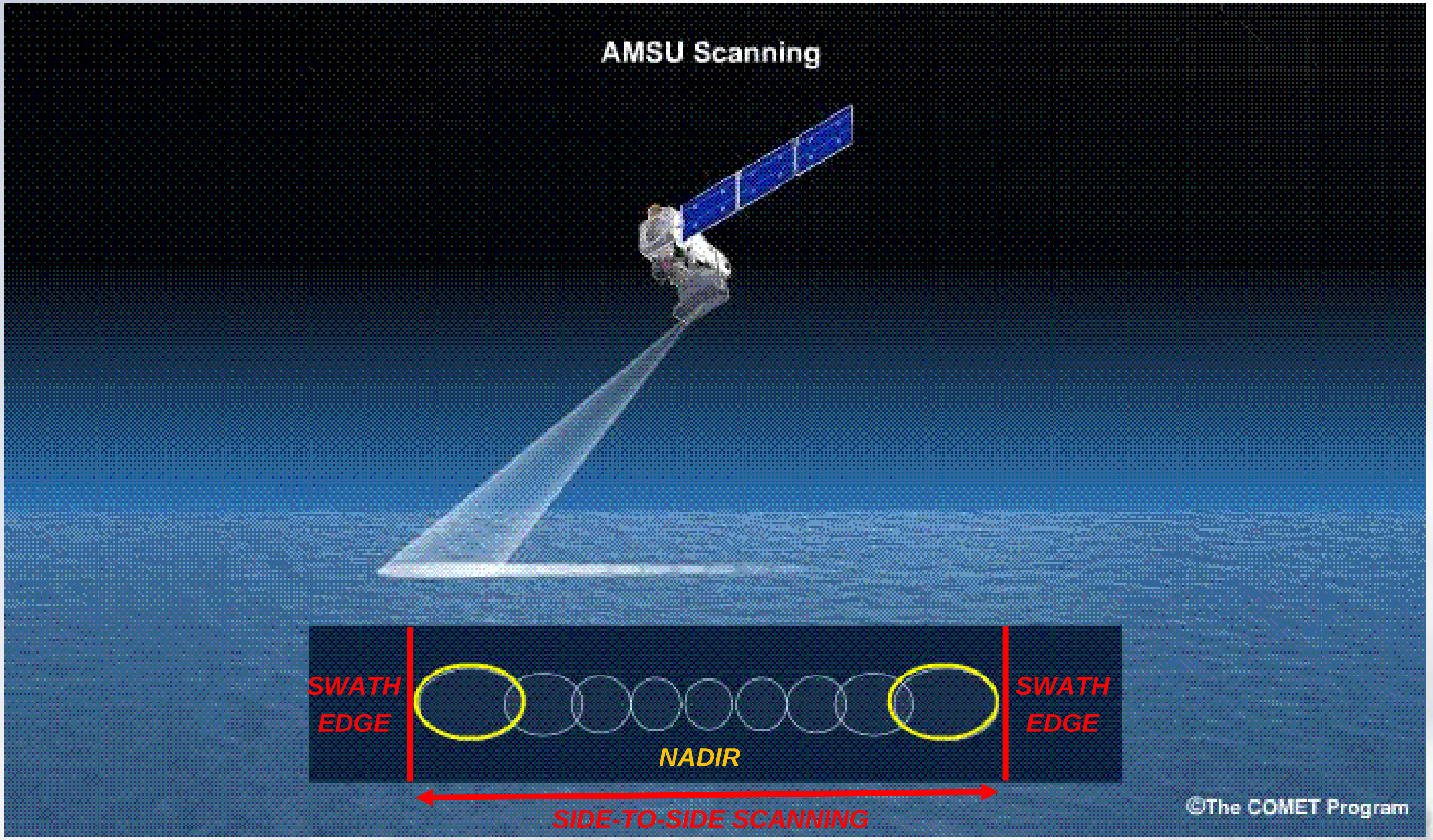


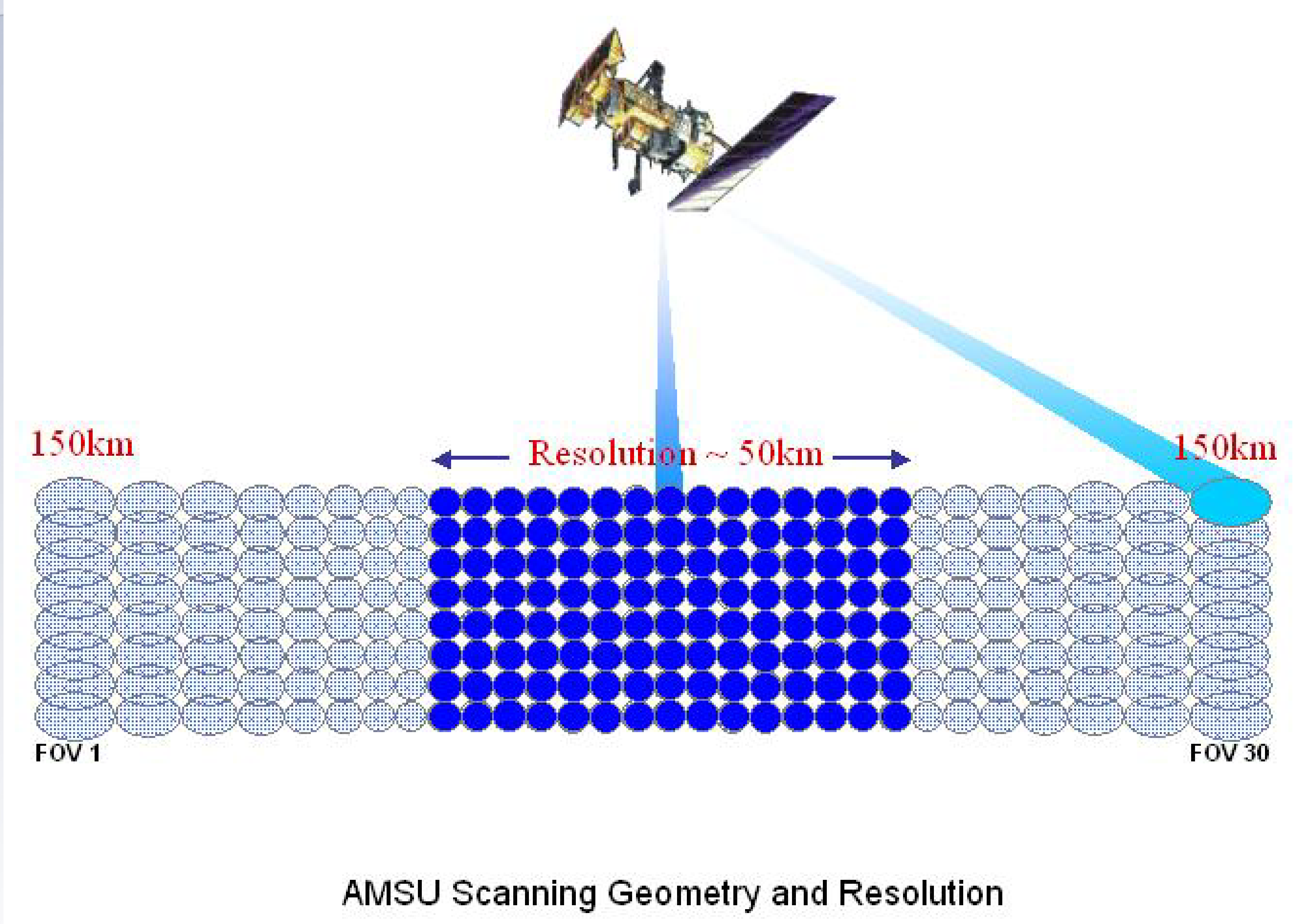
Image courtesy of http://www.nrlmry.navy.mil

Cross Track Scan Strategy

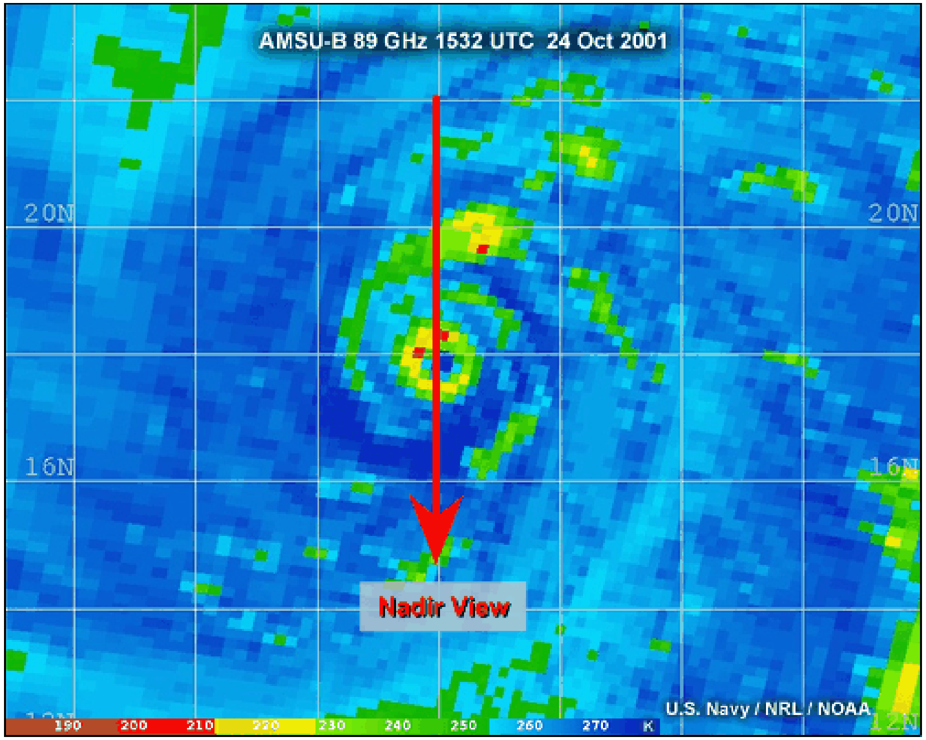


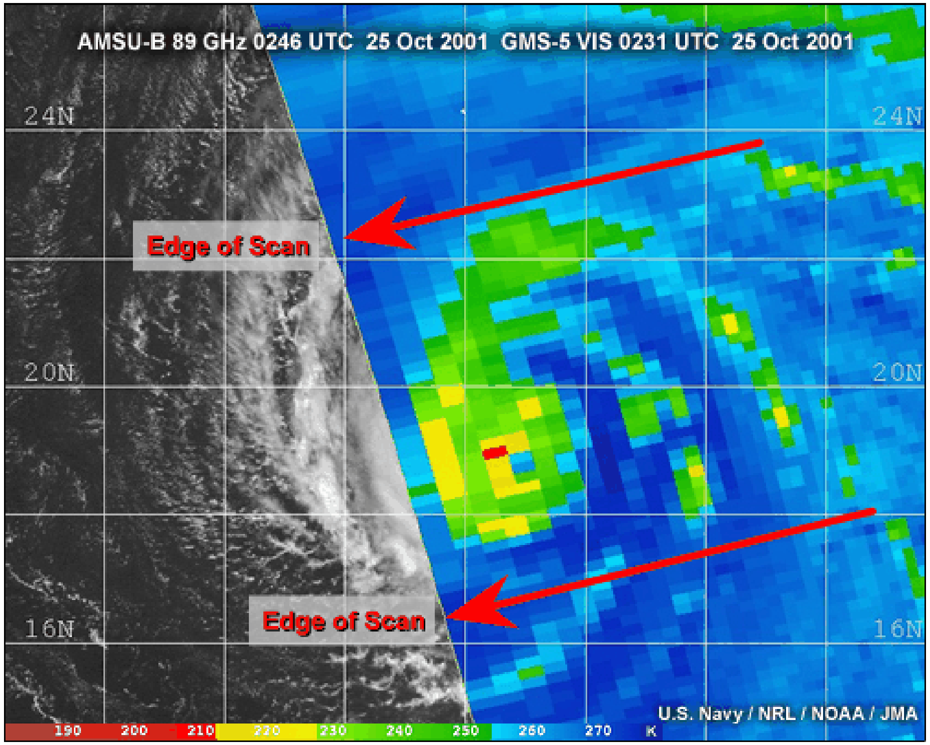
- **Advantage**: Larger coverage swath relative to conical scan
- **Disadvantage**: Resolution varies across the swath (coarser resolution at swath edge relative to nadir)

Cross Track Scan Strategy



Cross Track Scan Strategy

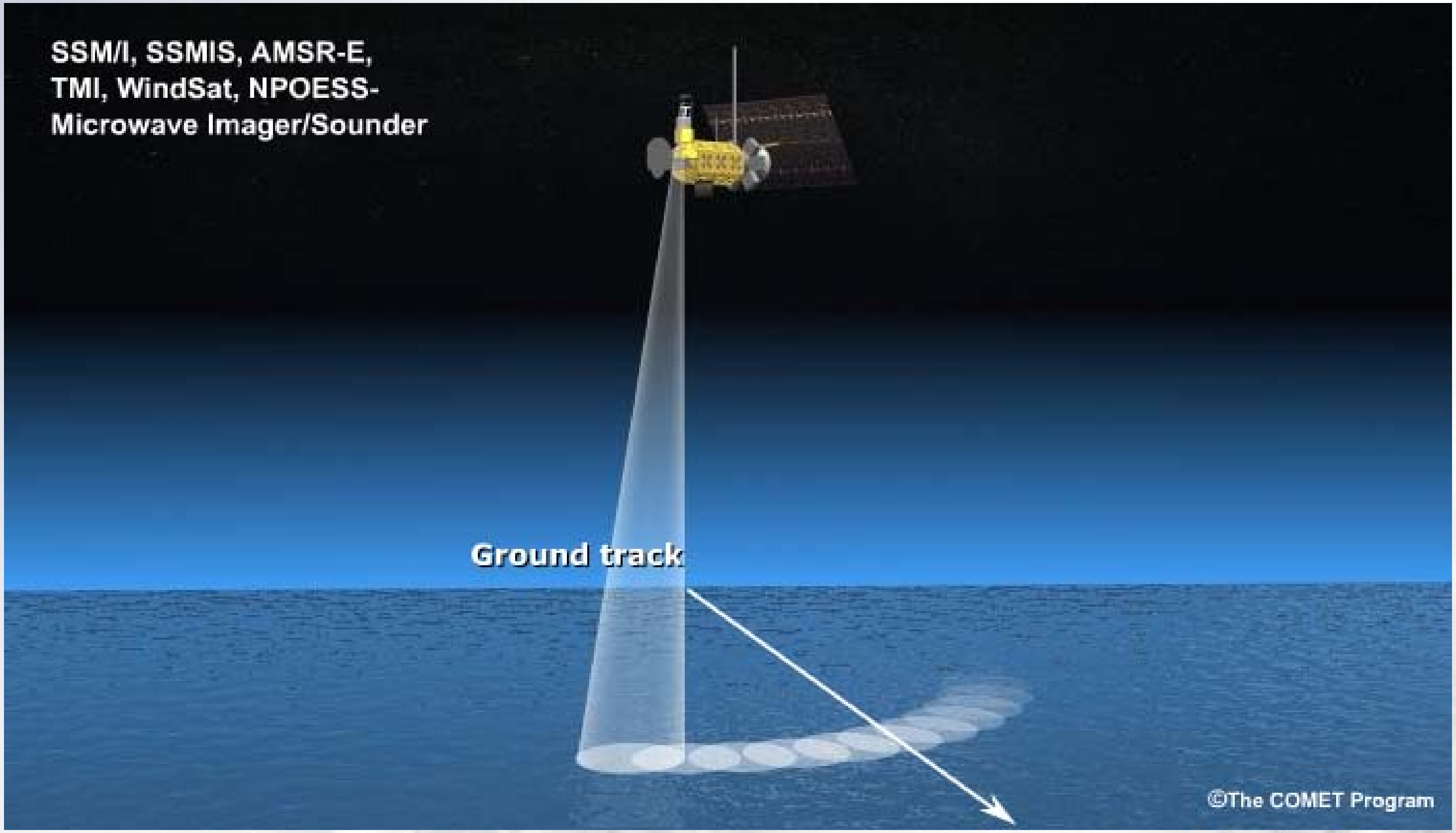




Note degradation in resolution at edge of scan compared to nadir

Images courtesy COMET

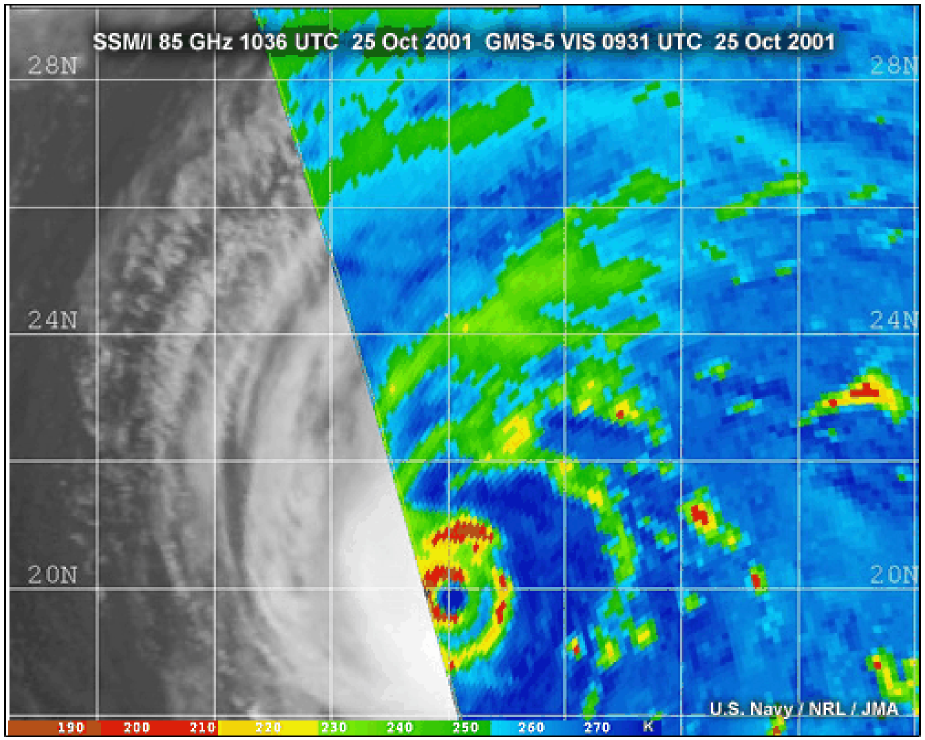
Conical Scan Strategy

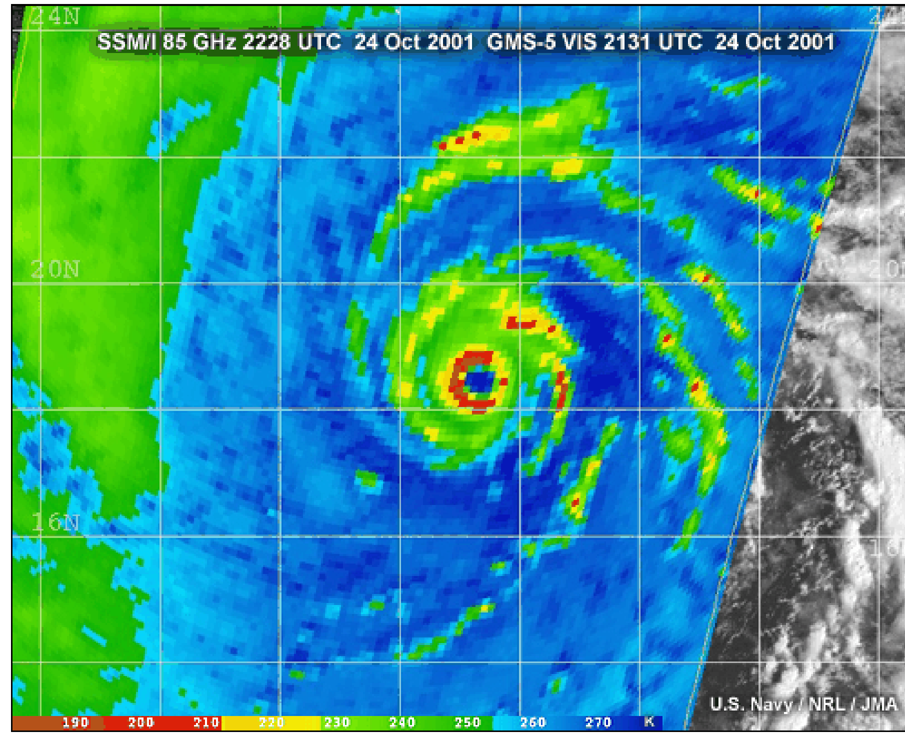


- Advantage: Resolution remains constant because scan footprints are the same size throughout the entire swath

- Disadvantage: Narrower coverage swath relative to cross-track scan

Conical Scan Strategy





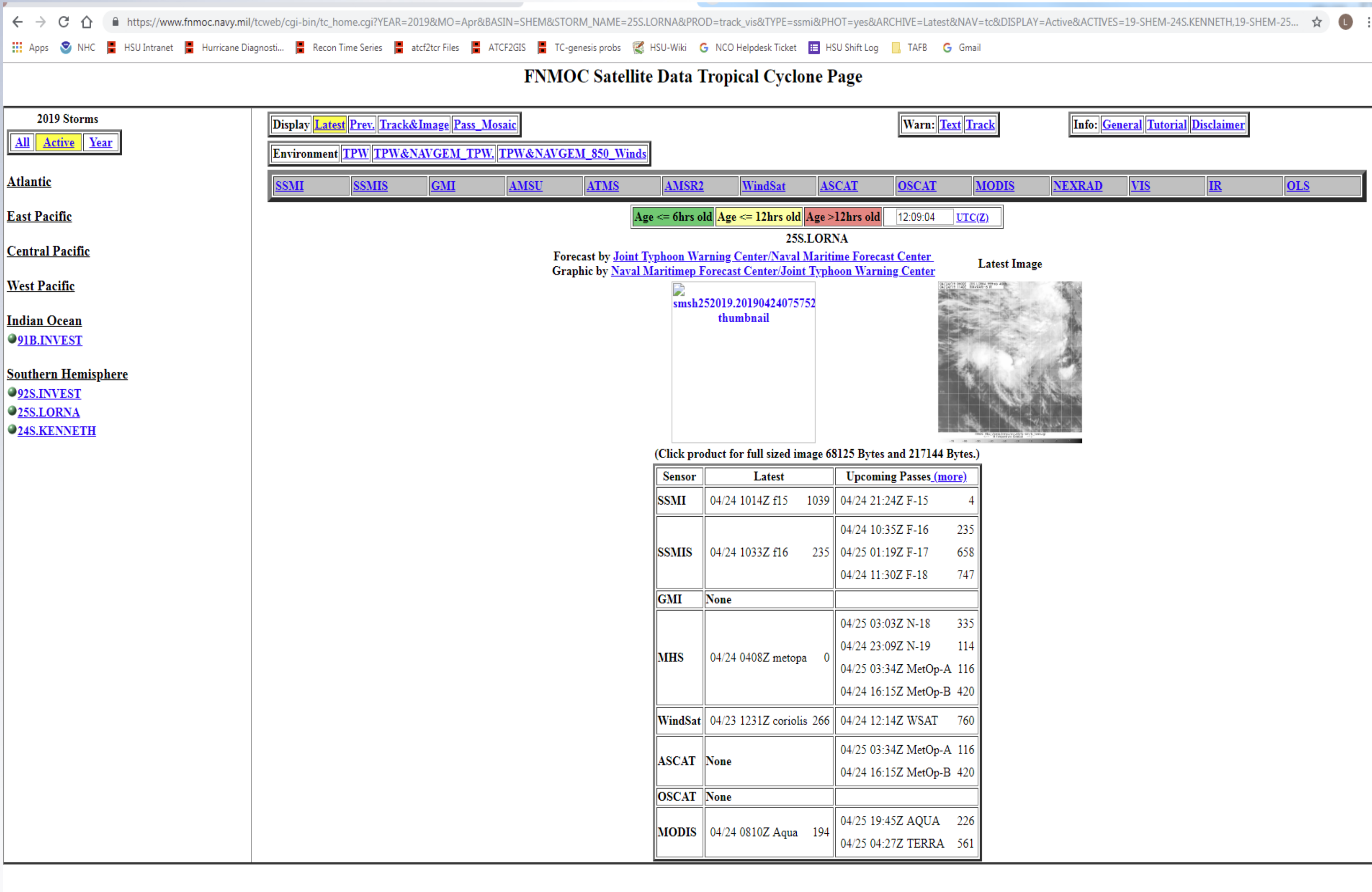
Resolution remains constant across swath

Images courtesy COMET

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

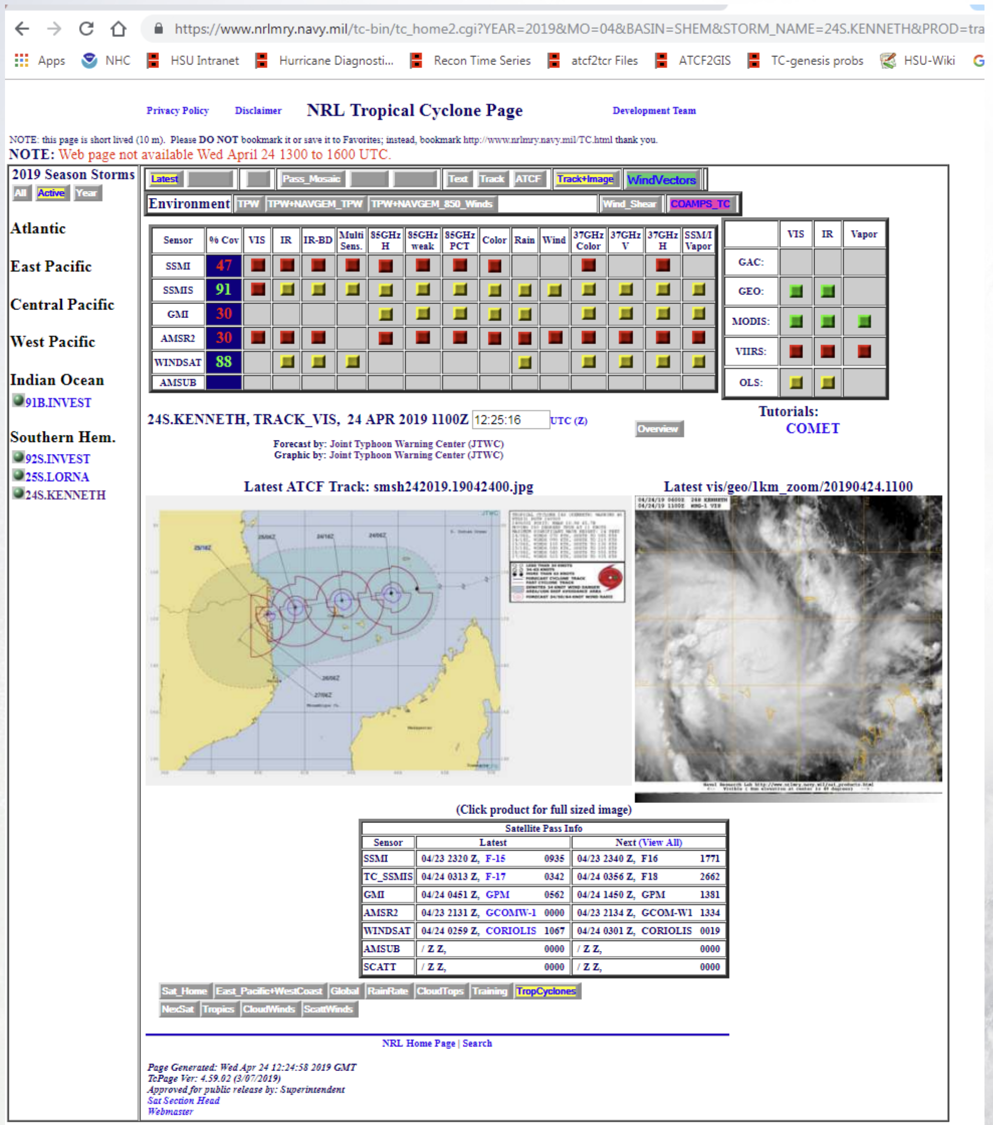
Latest Image

(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

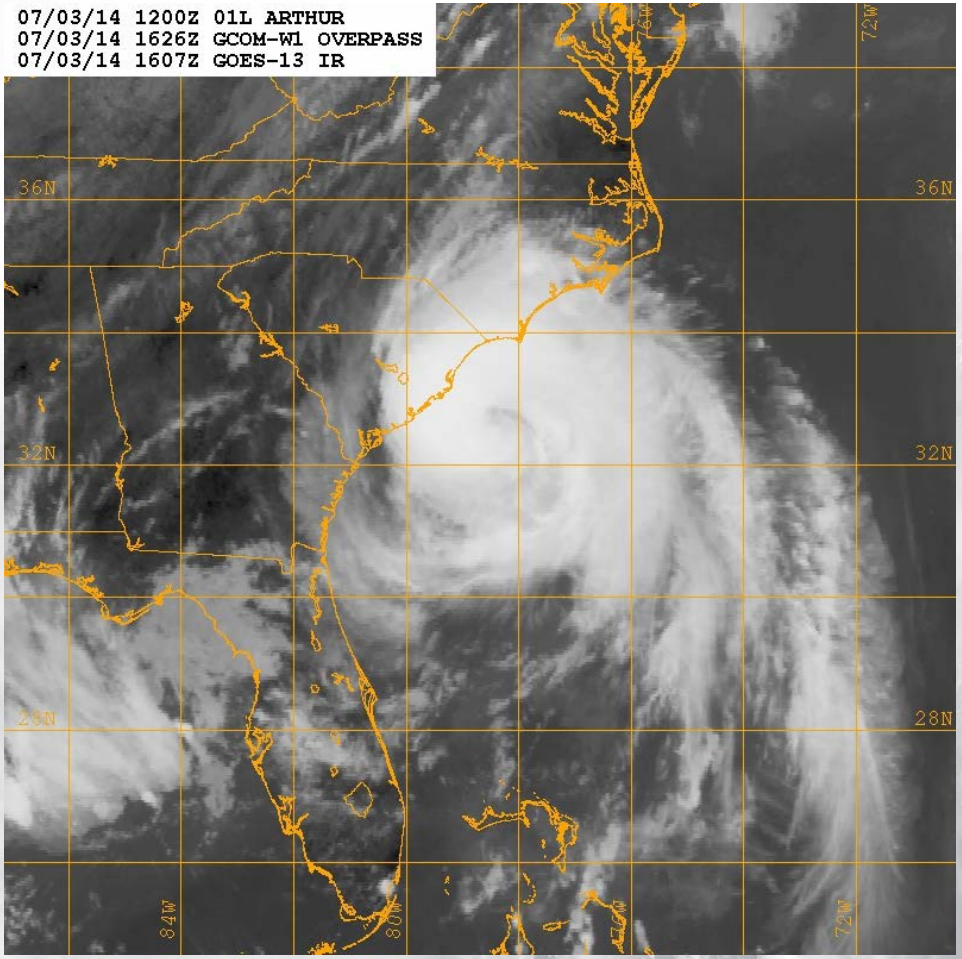
https://www.nrlmry.navy.mil/TC.html



Imagery Characteristics and Applications

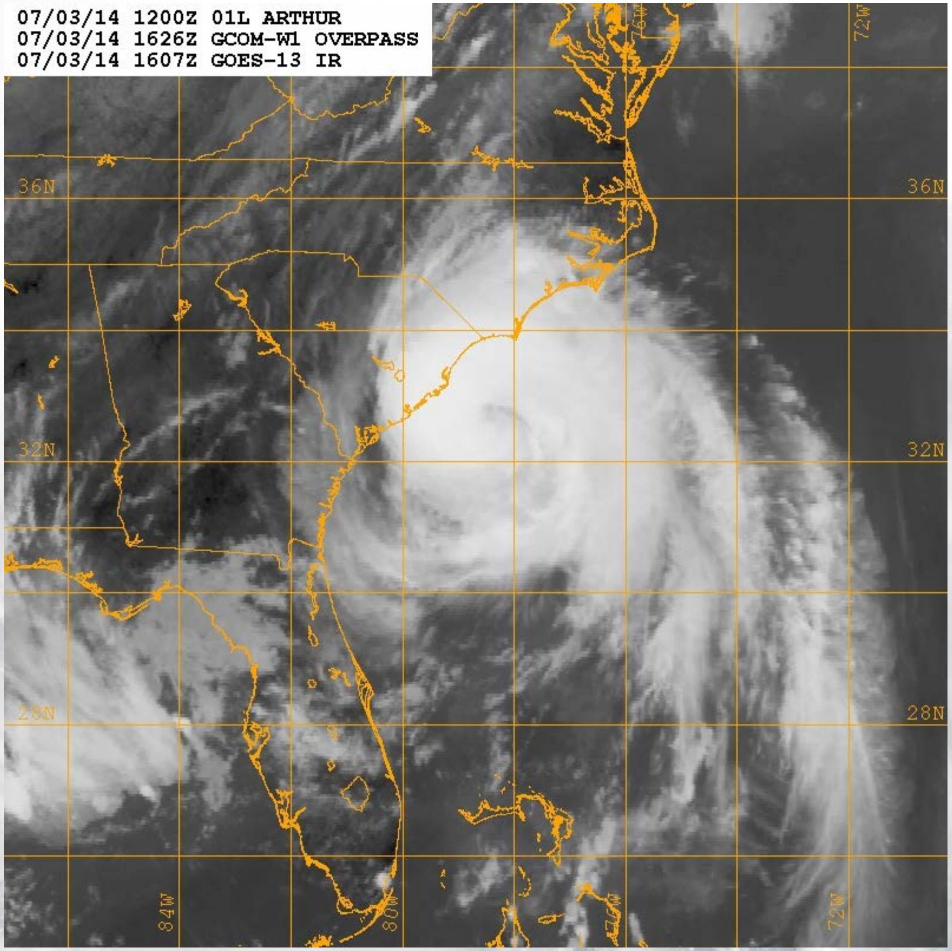
85-GHz Imagery

- Imagery can penetrate through clouds and reveal internal storm structure
- Imagery is better at locating TC centers than conventional visible and infrared
- Land appears warm relative to water surfaces
- Water surfaces and deep convection appear cold (due to scattering from ice)
- Imagery can not always see low-level circulations
- 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)



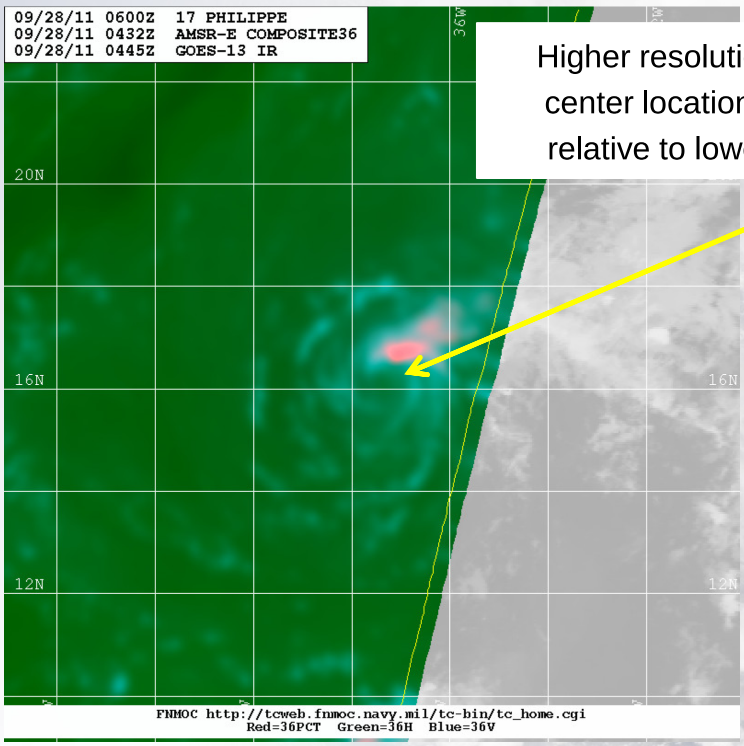
Advantages of Using 85-GHz and 37-GHz Imagery for TC Analysis

<u>In a sense, “sees” through clouds</u>

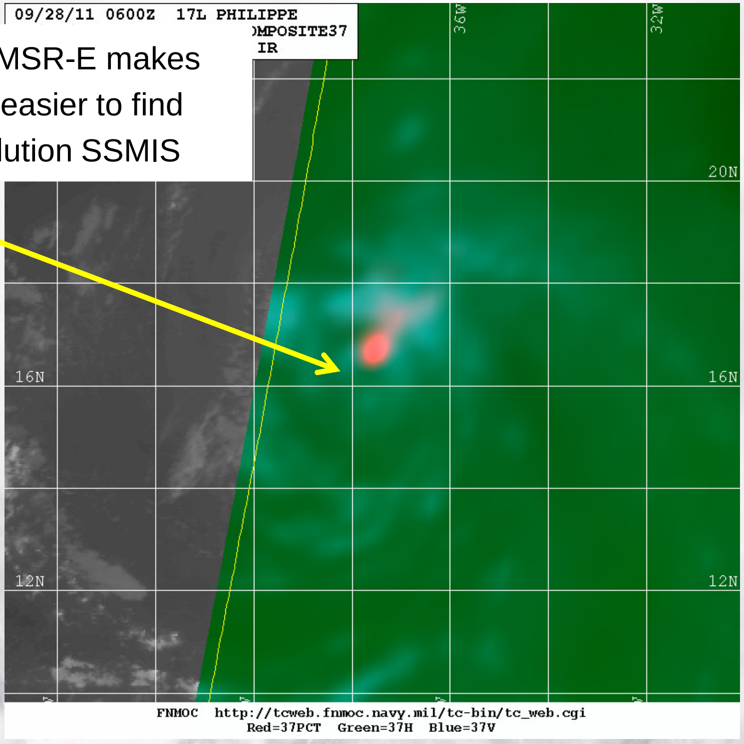
- Identification of circulation center (critical step in initiating TC advisories)
- Acquire positioning of TCs in difficult situations (especially in early stages of development and at night)
- View of convective rain bands that are directly related to intensification of the TC
- Monitoring structural 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

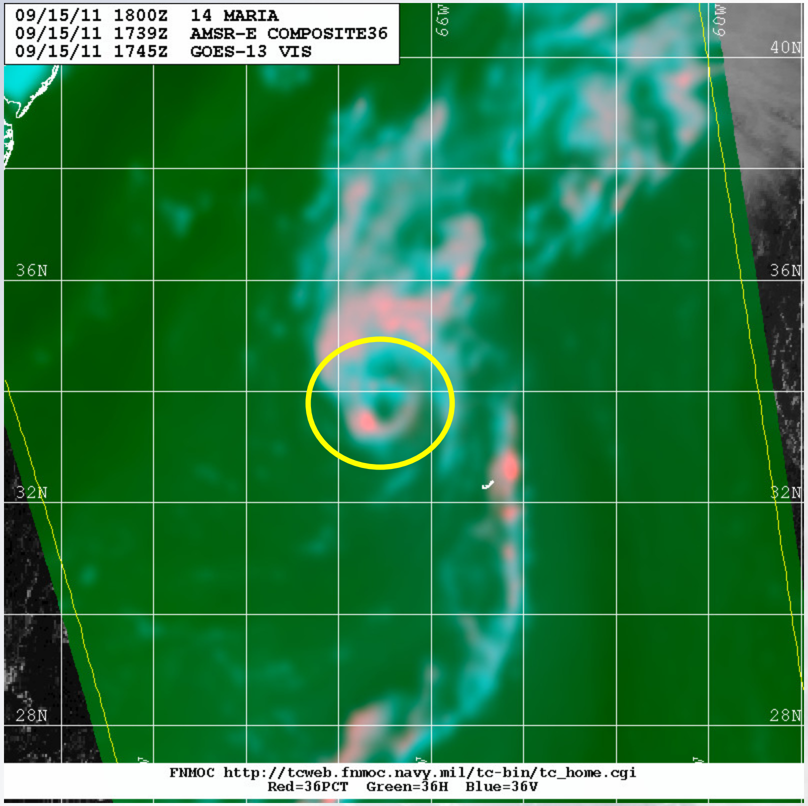


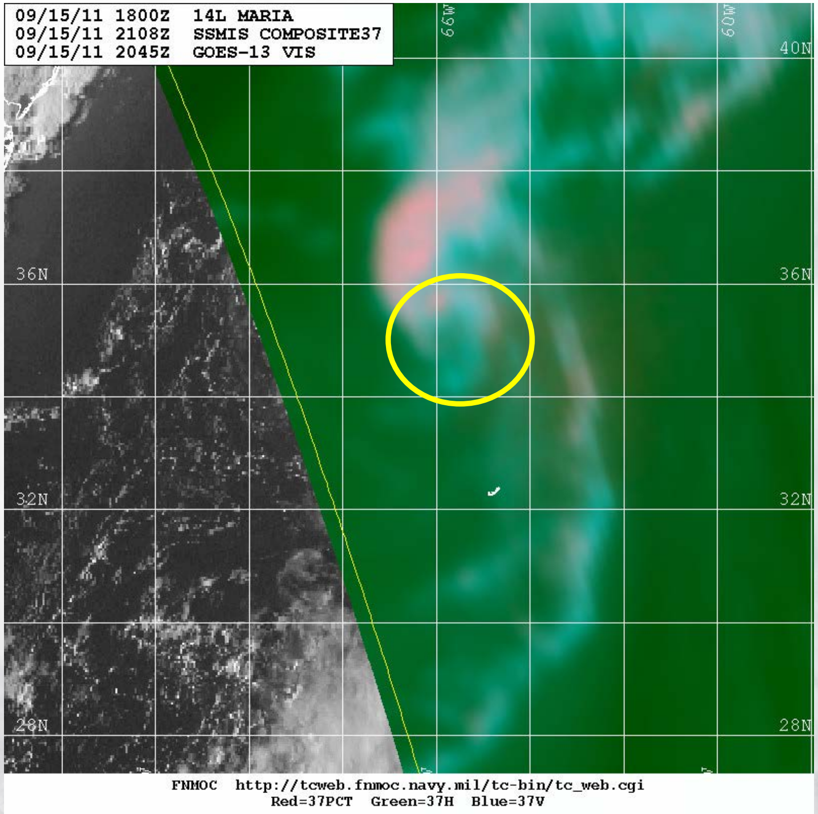
Higher resolution of AMSR-E makes center location much easier to find relative to lower-resolution SSMIS



Effects of Resolution

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



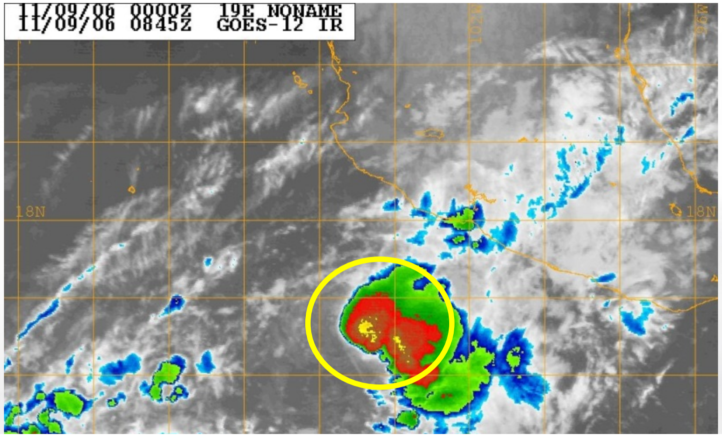


•Comparison of 36/37-GHz color composite imagery over Hurricane Maria from AMSR-E (left) and SSMIS (right) at 1739 UTC and 2018 UTC 15 September 2011.

Importance of Center Location

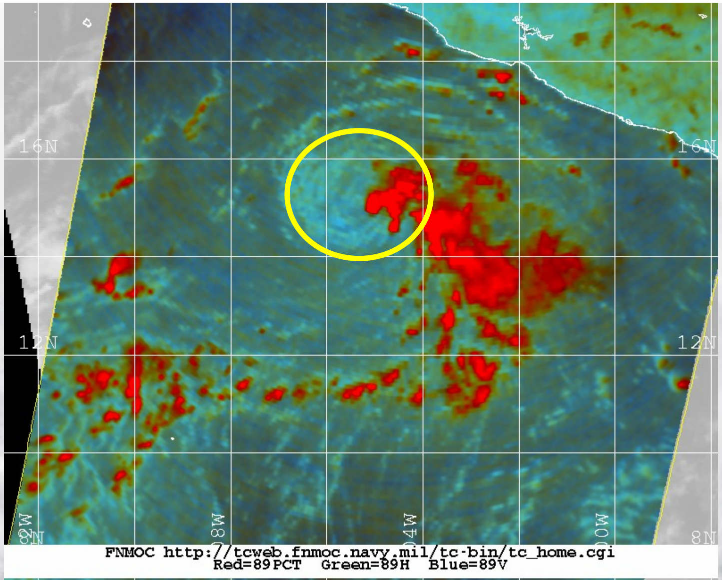
- Locating the center is critical for the initial motion, initializing model guidance, and assessing the organization and intensity of the cyclone

- Dvorak estimates are very sensitive to incorrect center locations



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

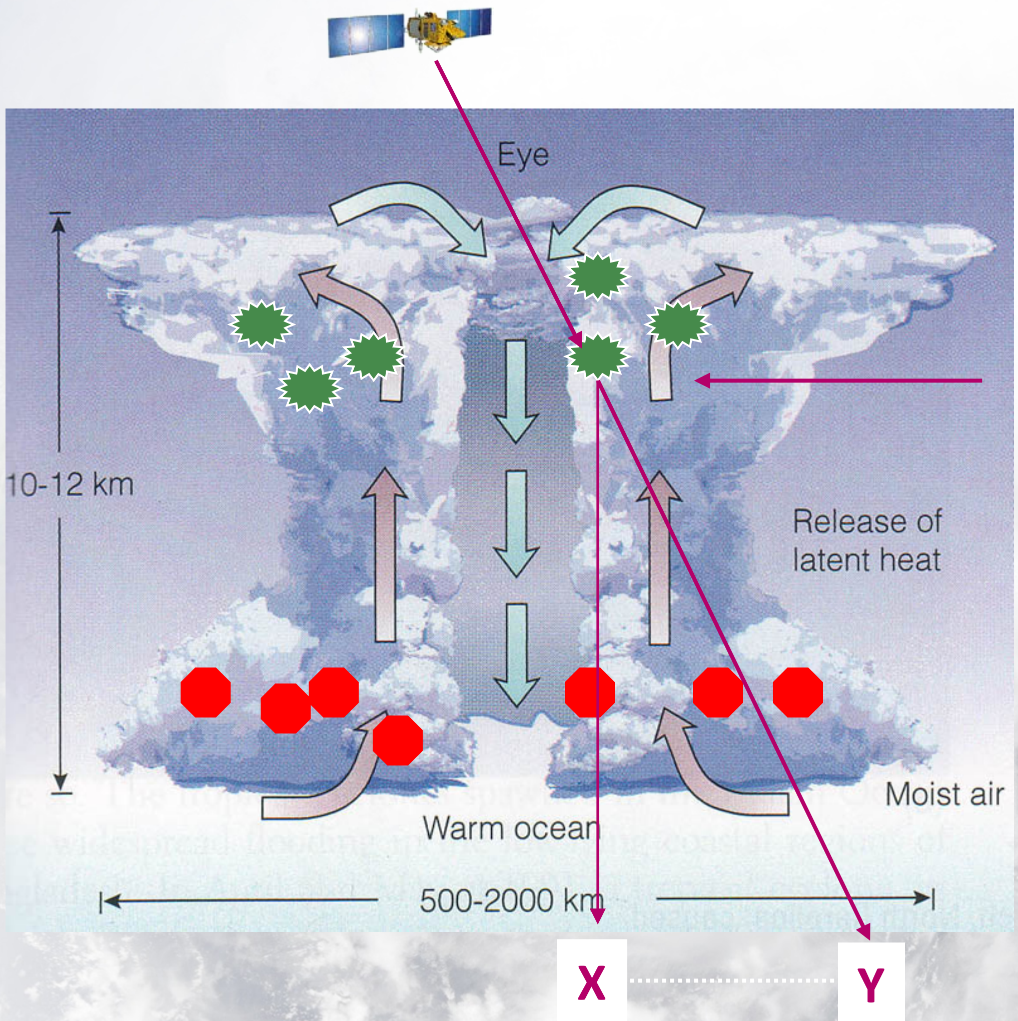
- Occurs due to conical viewing angle and/or viewing geometry of the satellite

- 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)

Raindrops
(37 GHz)



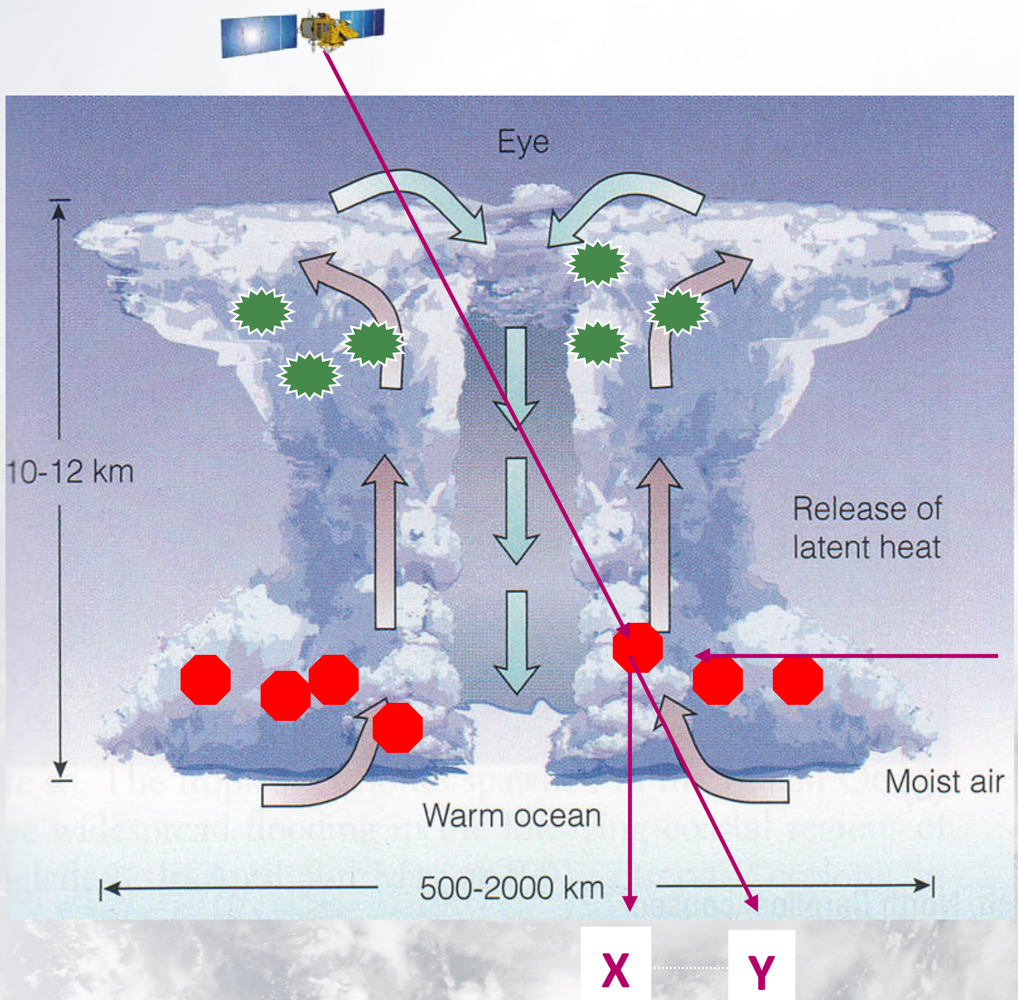
Effective
Level of
hydrometeors

85 GHz
Parallax

37-GHz Parallax

Ice Crystals (85 GHz)

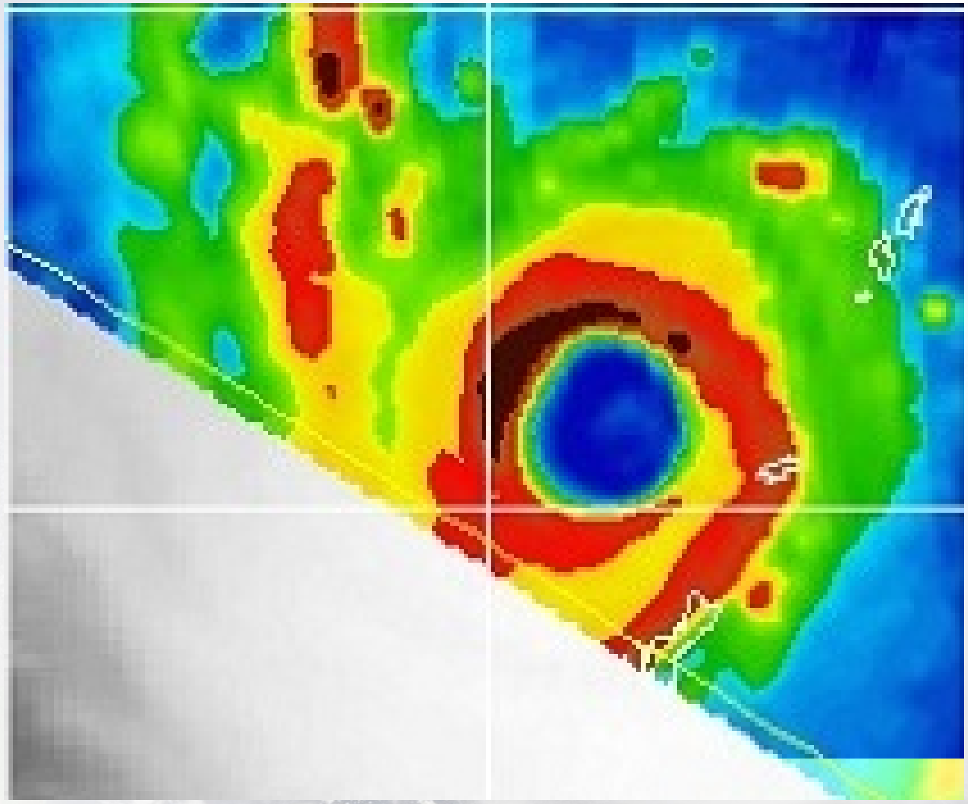
Raindrops (37 GHz)



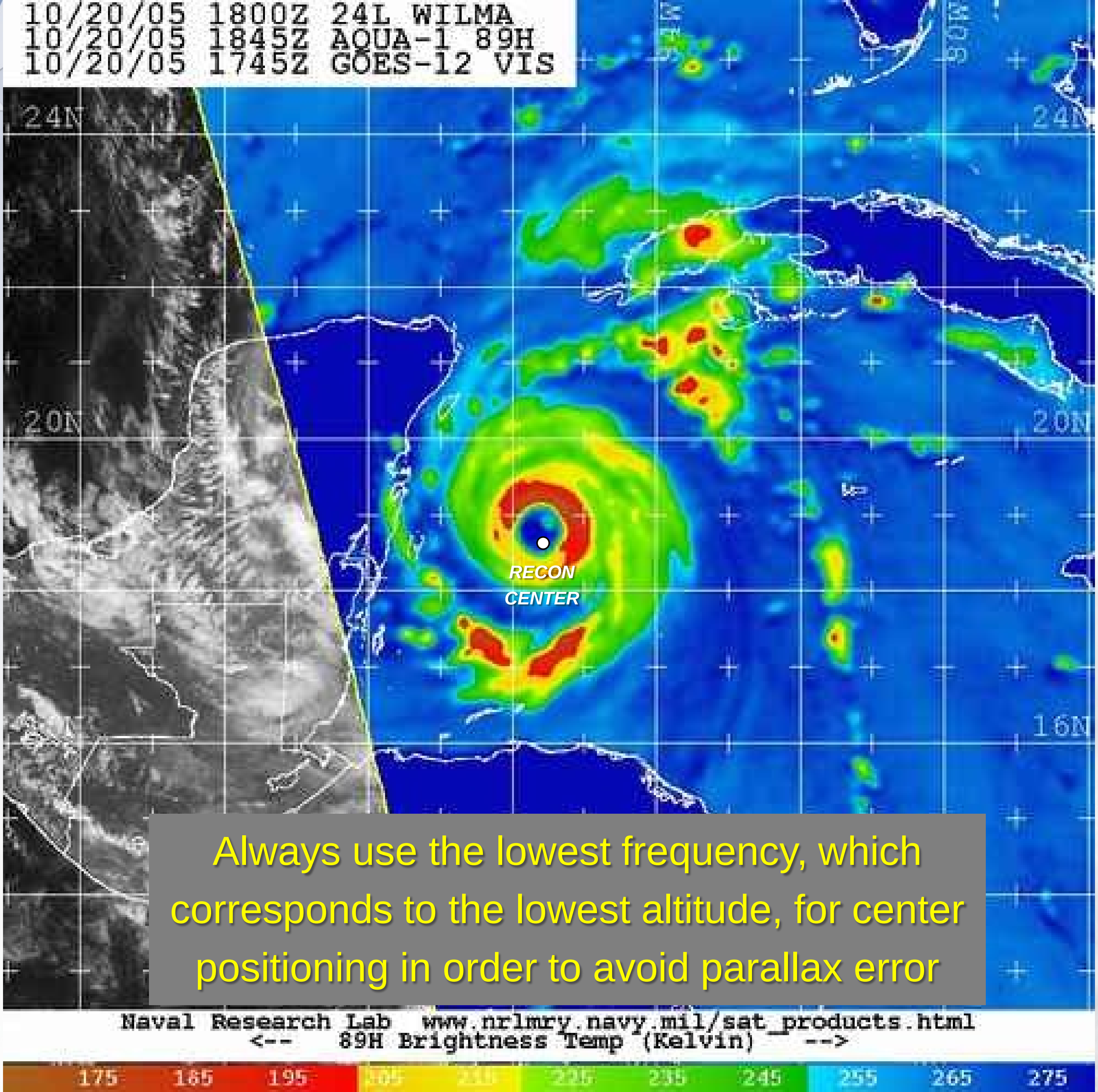
Effective Level of hydrometeors

37 GHz Parallax

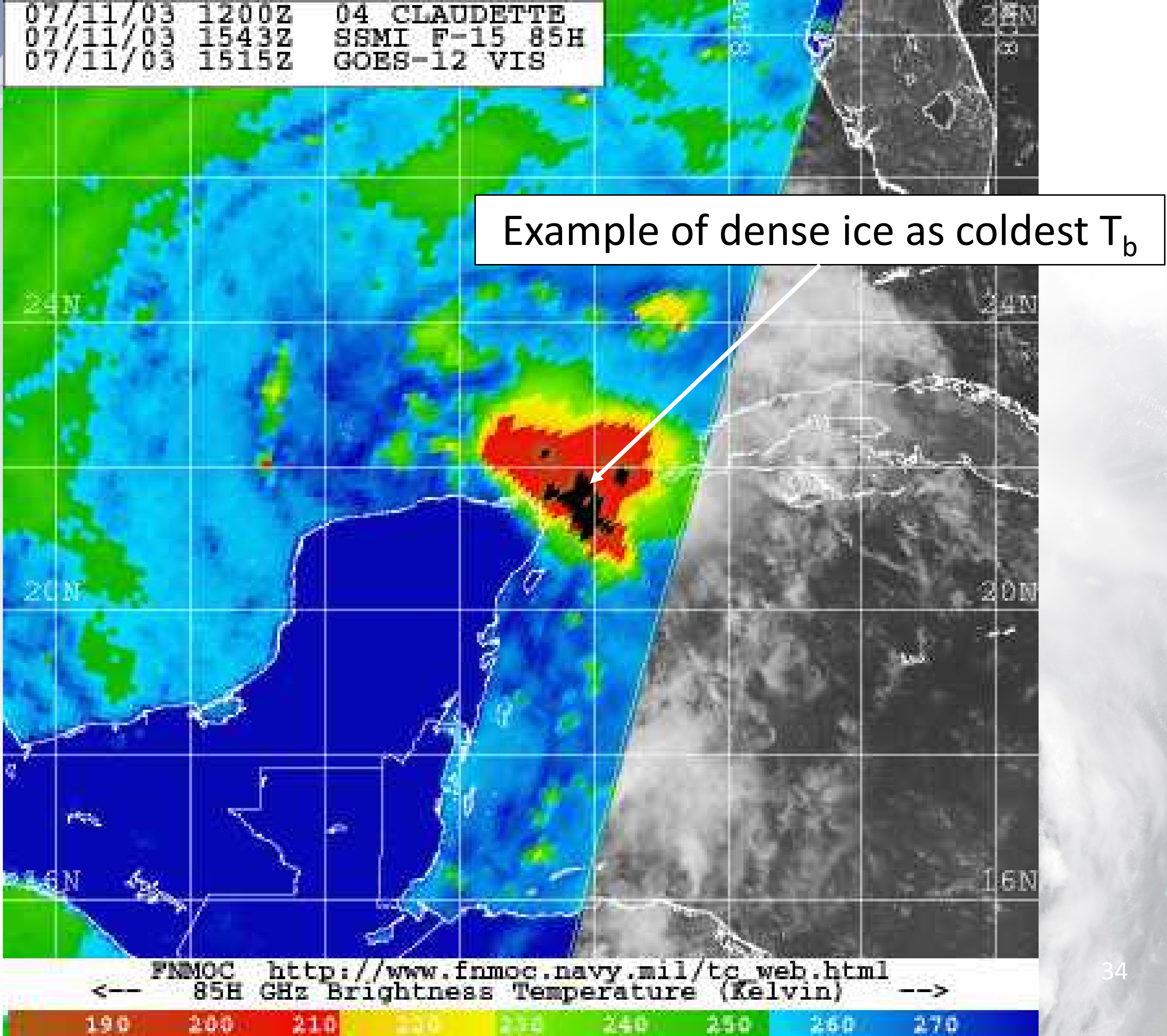
Eye Size Example



85 H
37 V



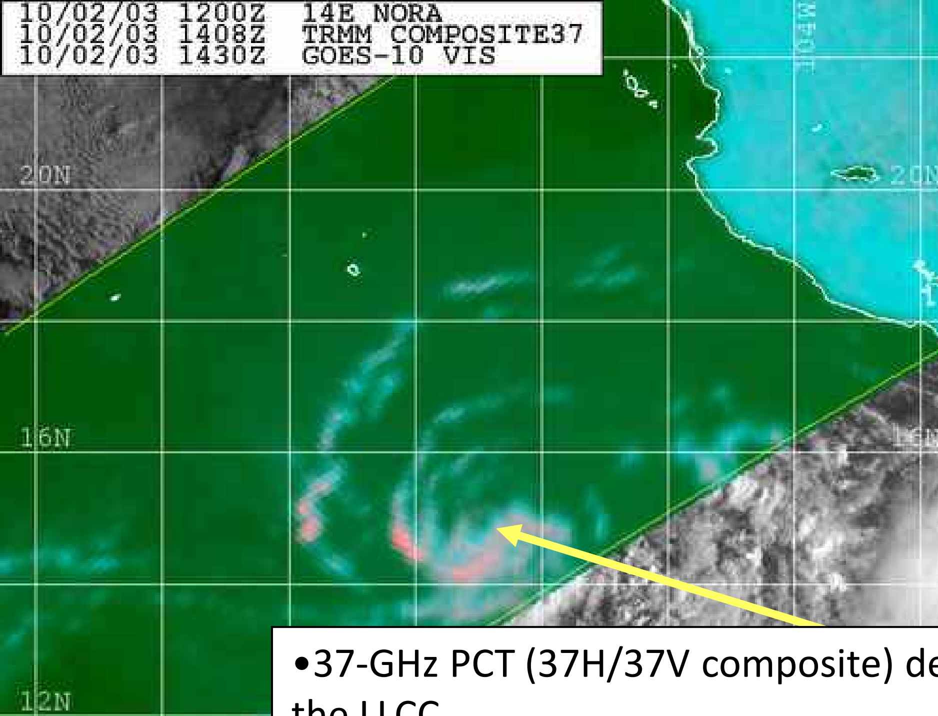
Always use the lowest frequency, which corresponds to the lowest altitude, for center positioning in order to avoid parallax error

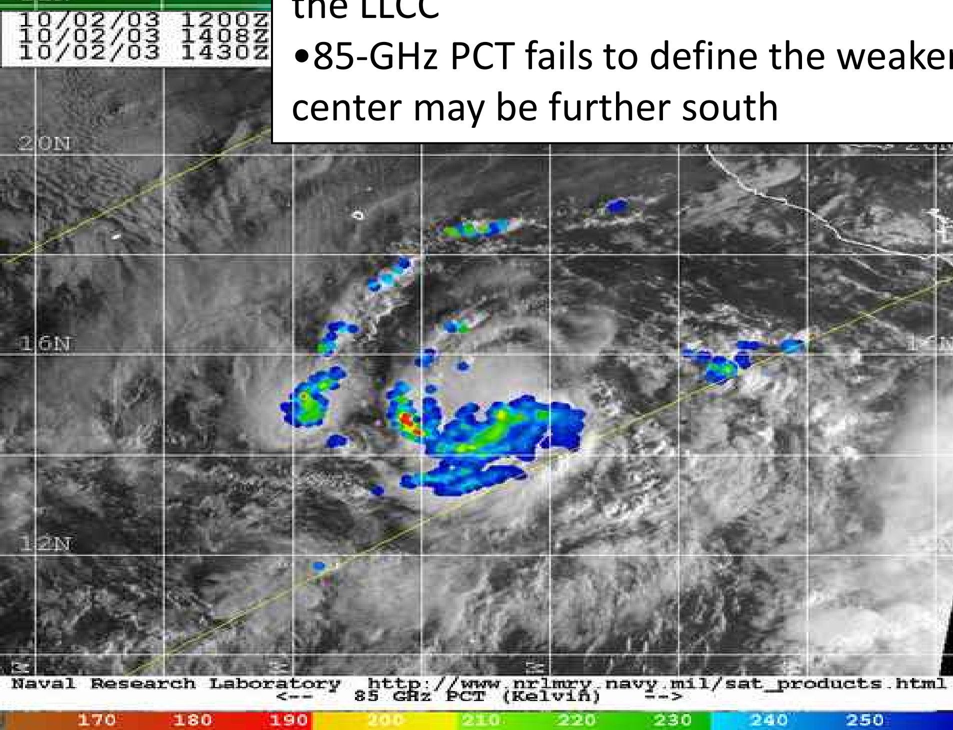

07/11/03 1200Z 04 CLAUDETTE
07/11/03 1543Z SSMI F-15 85H
07/11/03 1515Z GOES-12 VIS
24N
20N
16N
Example of dense ice as coldest T_b
FNMOC http://www.fnmoc.navy.mil/tc_web.html
<-- 85H GHz Brightness Temperature (Kelvin) -->
190
200
210
240
250
260
270

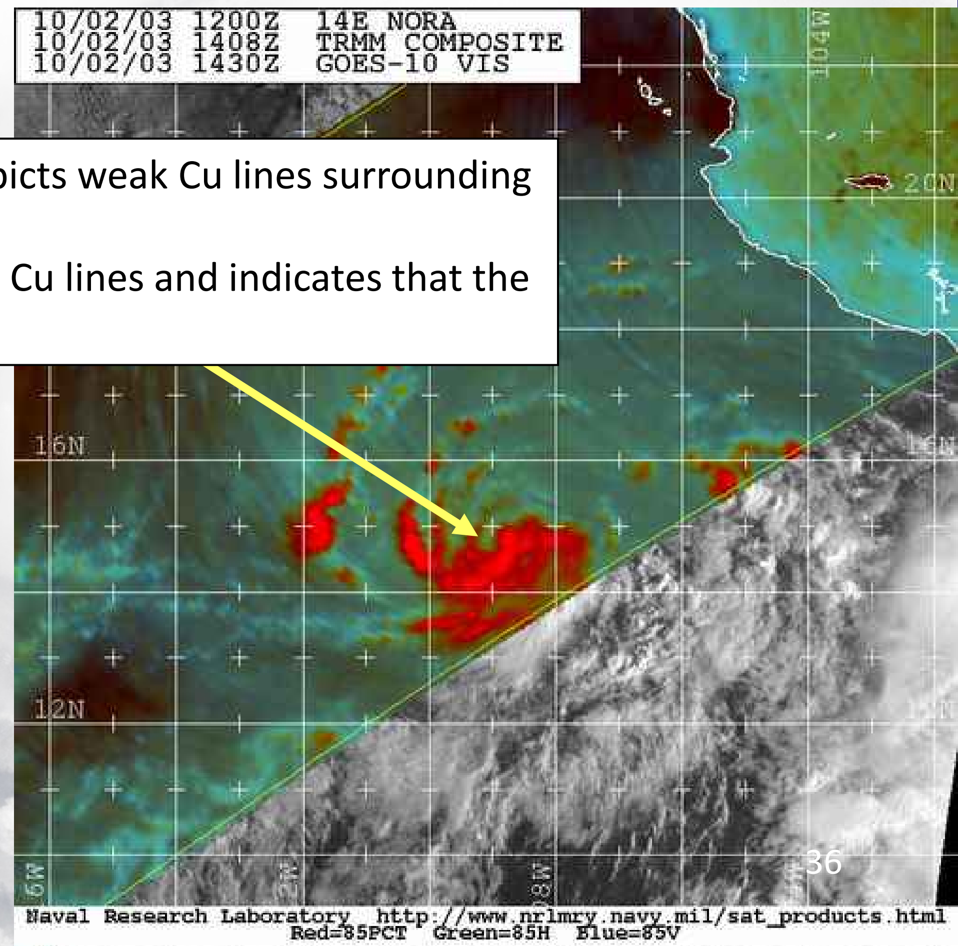
Color Composite Imagery

- 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

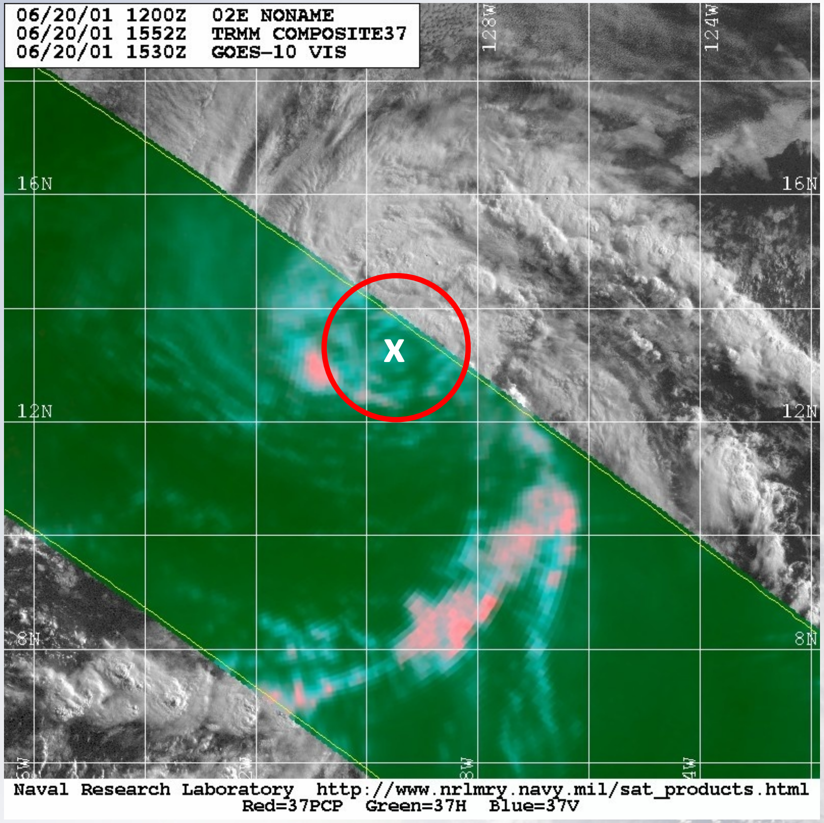


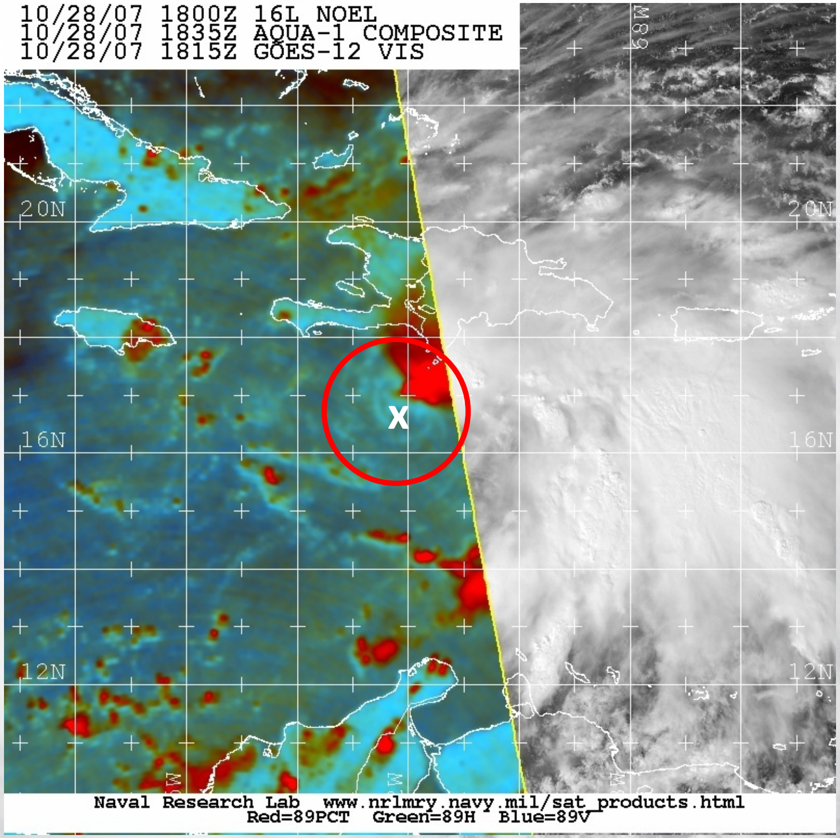




- 37-GHz PCT (37H/37V composite) depicts weak Cu lines surrounding the LLCC
- 85-GHz PCT fails to define the weaker Cu lines and indicates that the center may be further south

Positioning in Microwave Imagery

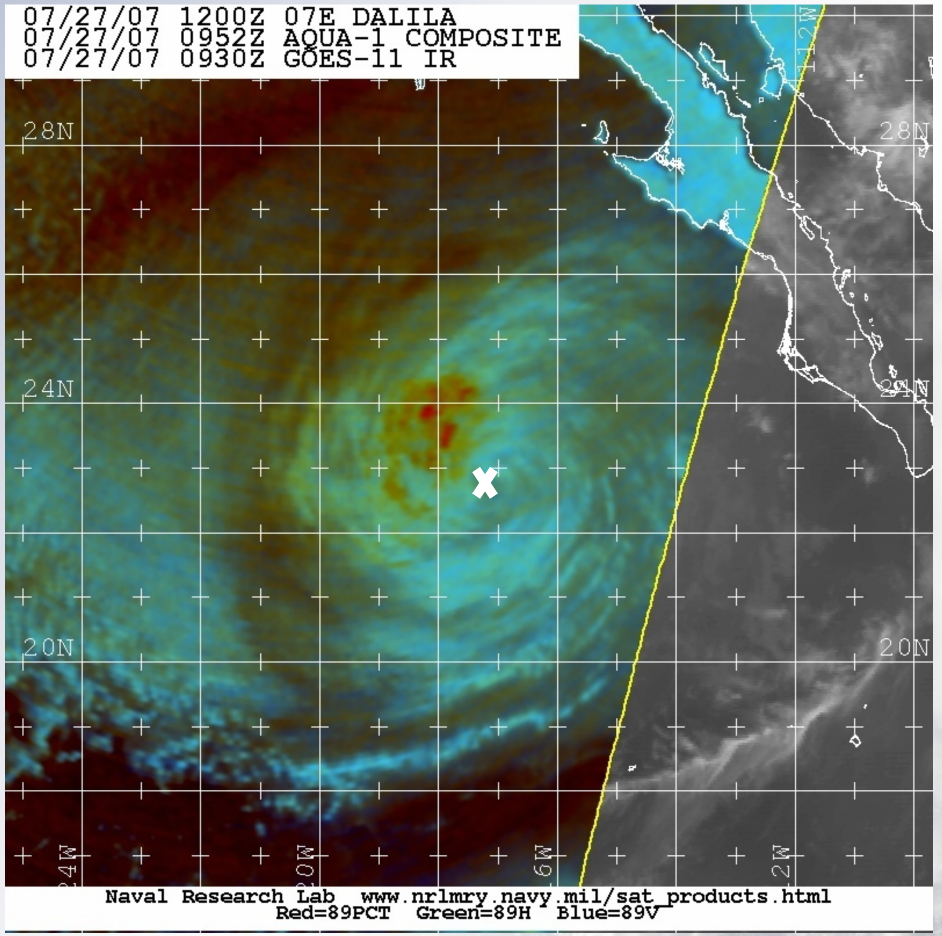


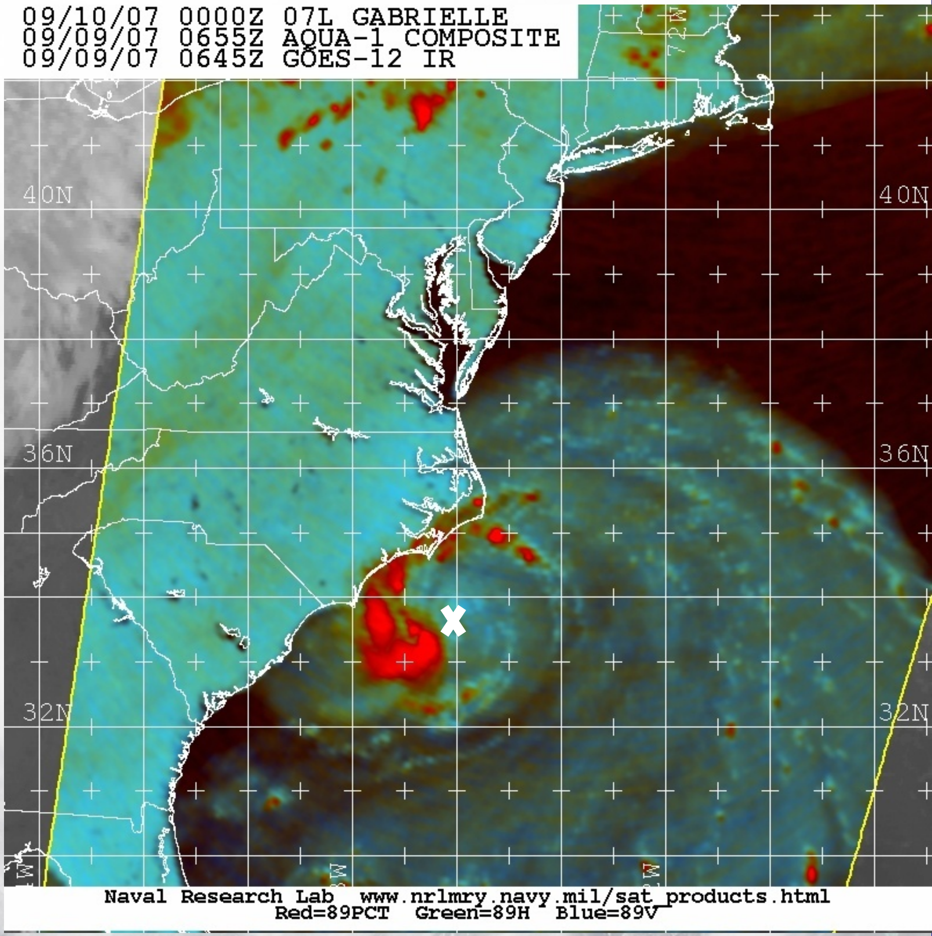


Try to position in the rain-free dry area—out of the convection

Positioning in Microwave Imagery

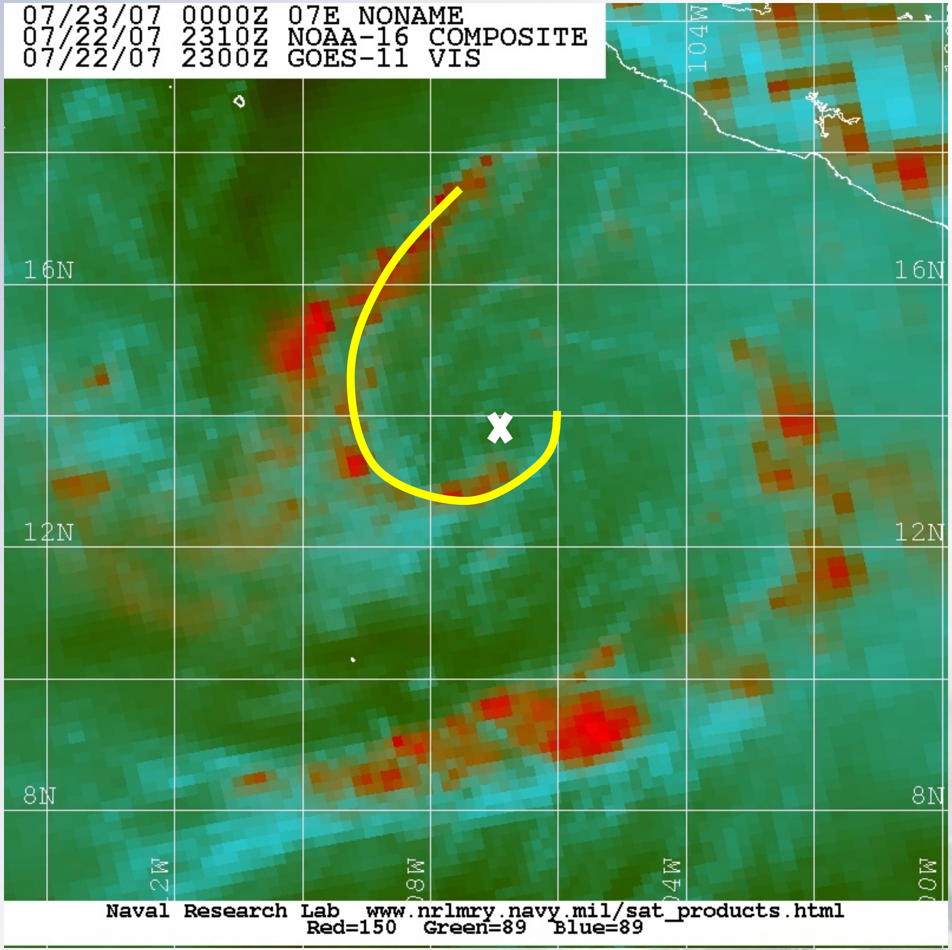
Look for convective free darker areas

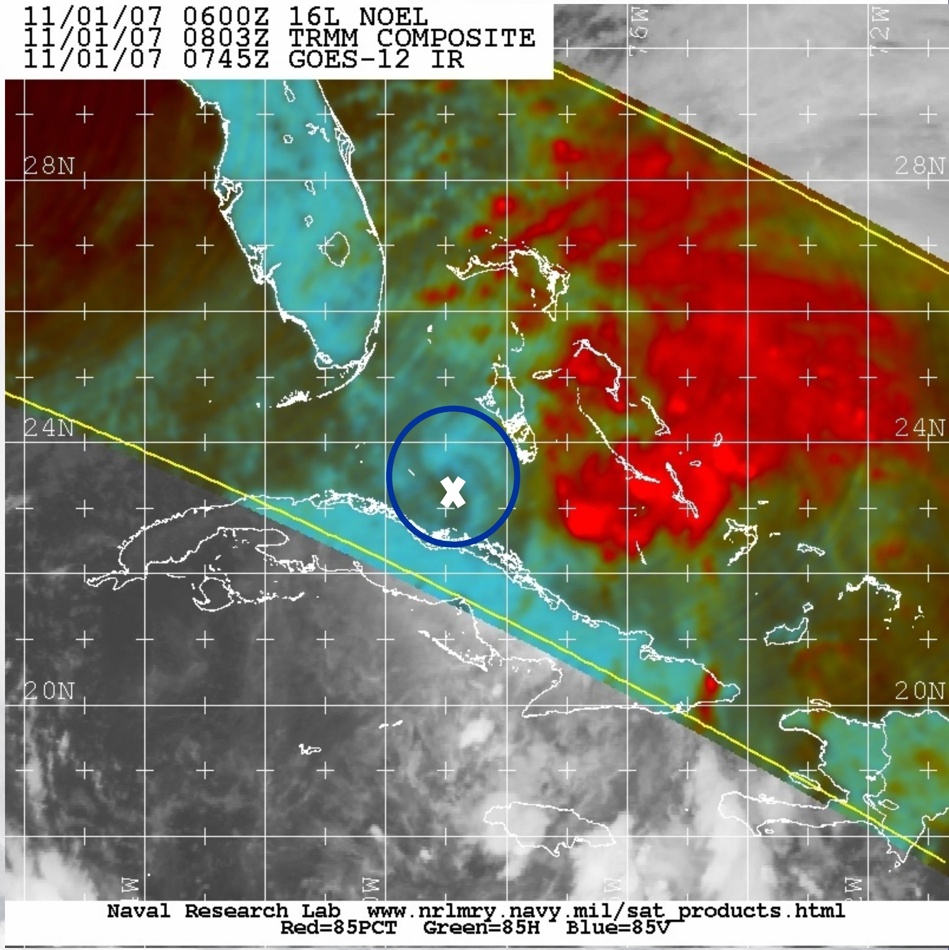


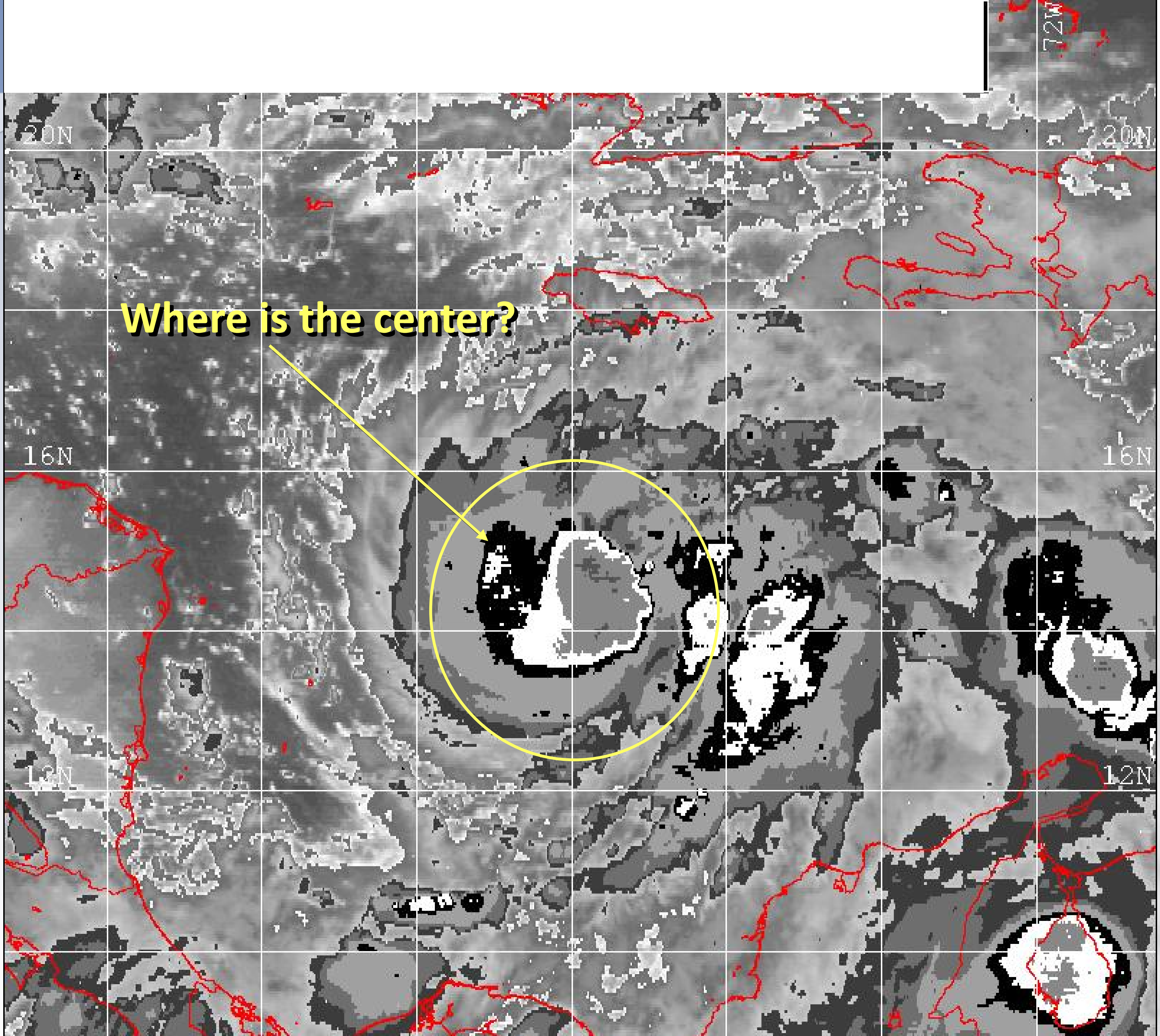


Positioning in Microwave Imagery

Look for low cloud curvature

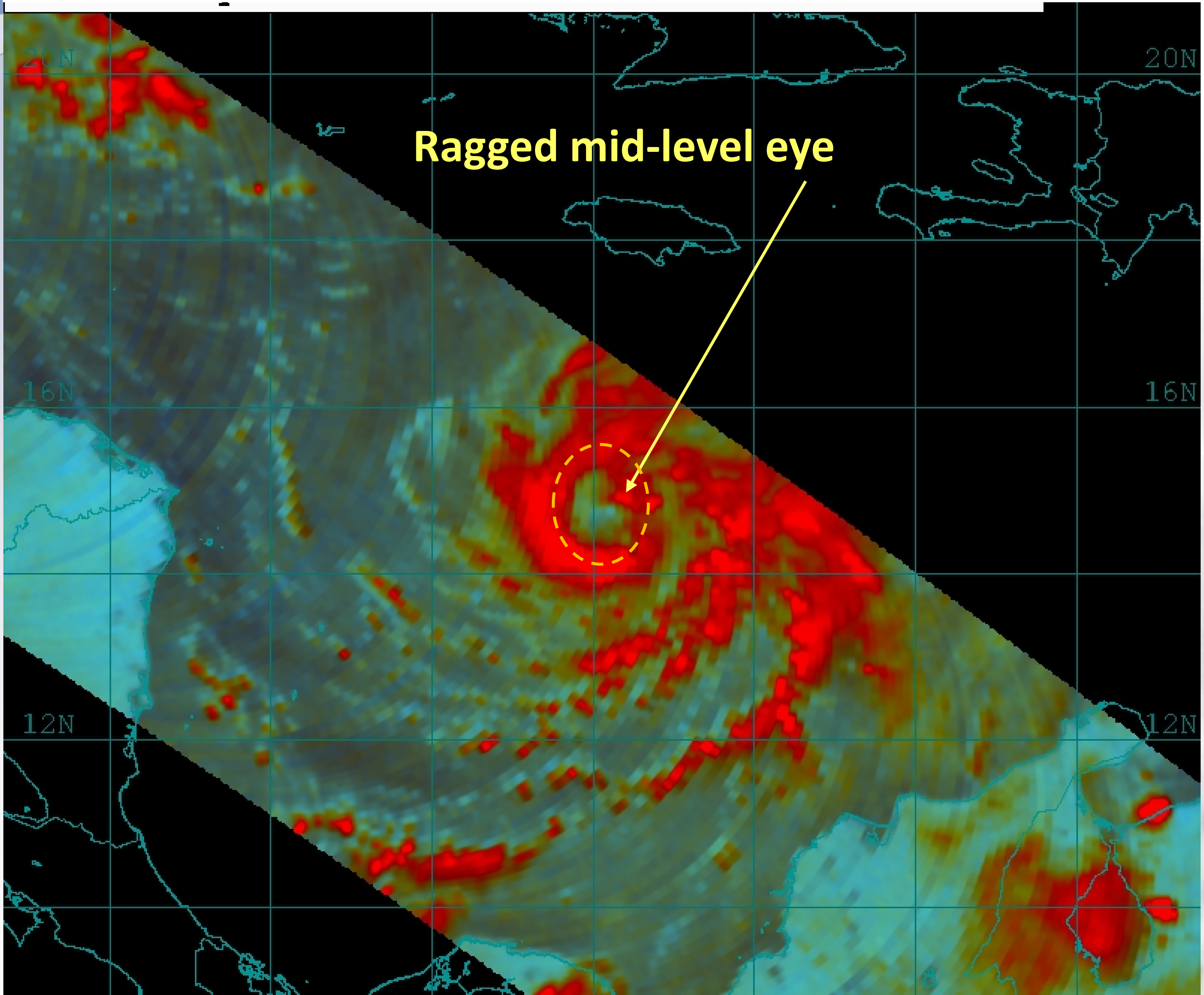




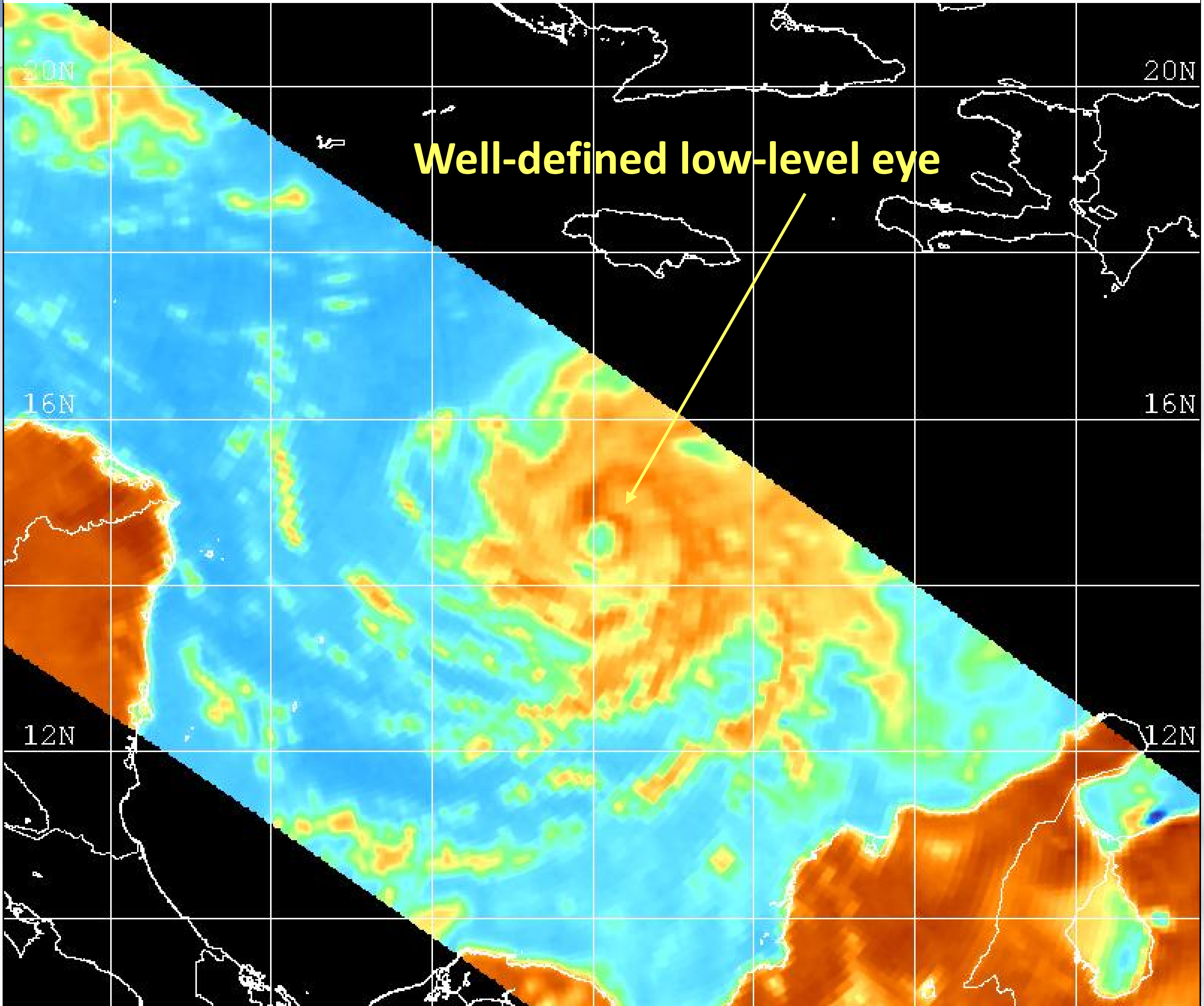


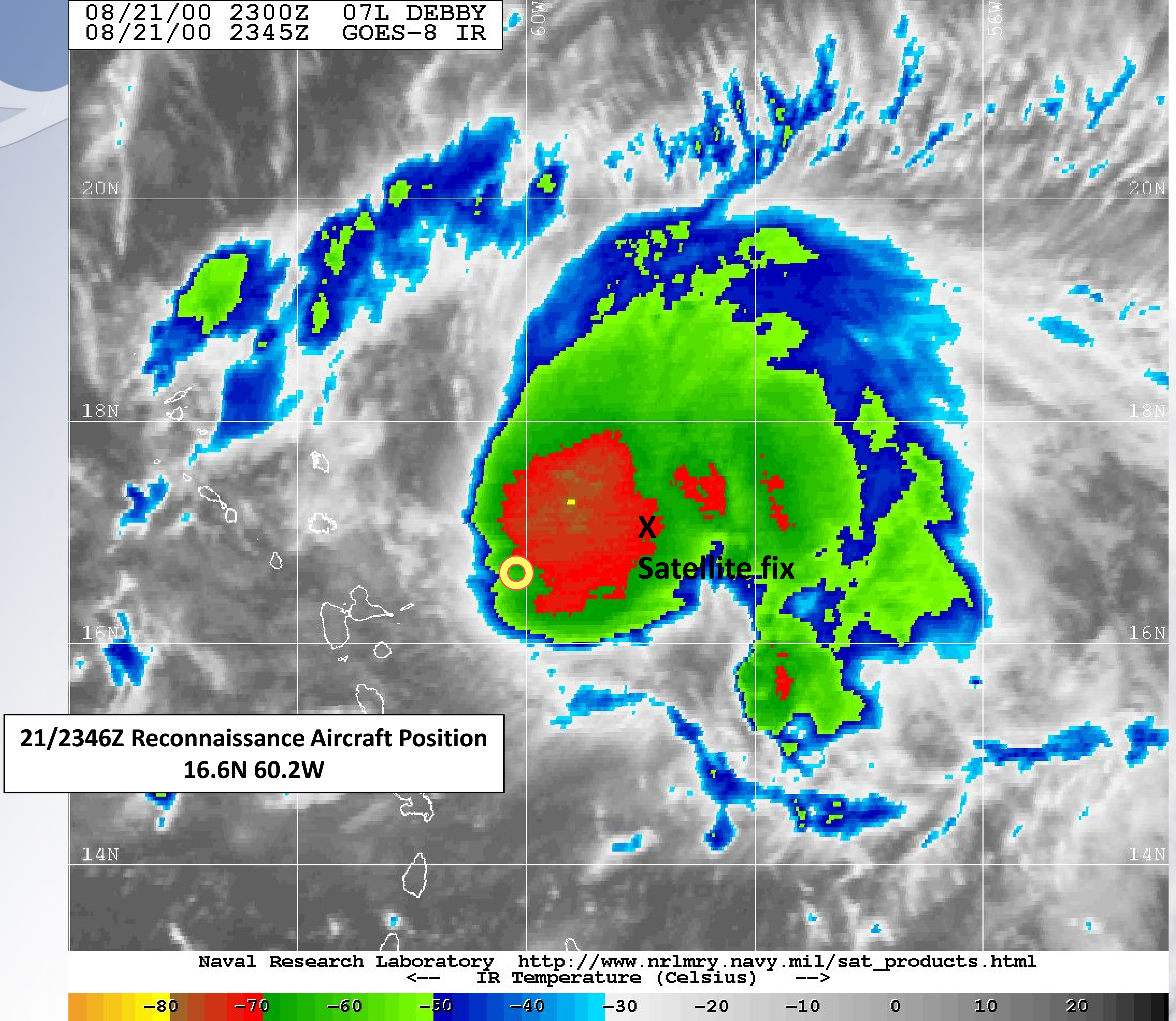
72W
20N
20N
Where is the center?
16N
16N
12N
12N

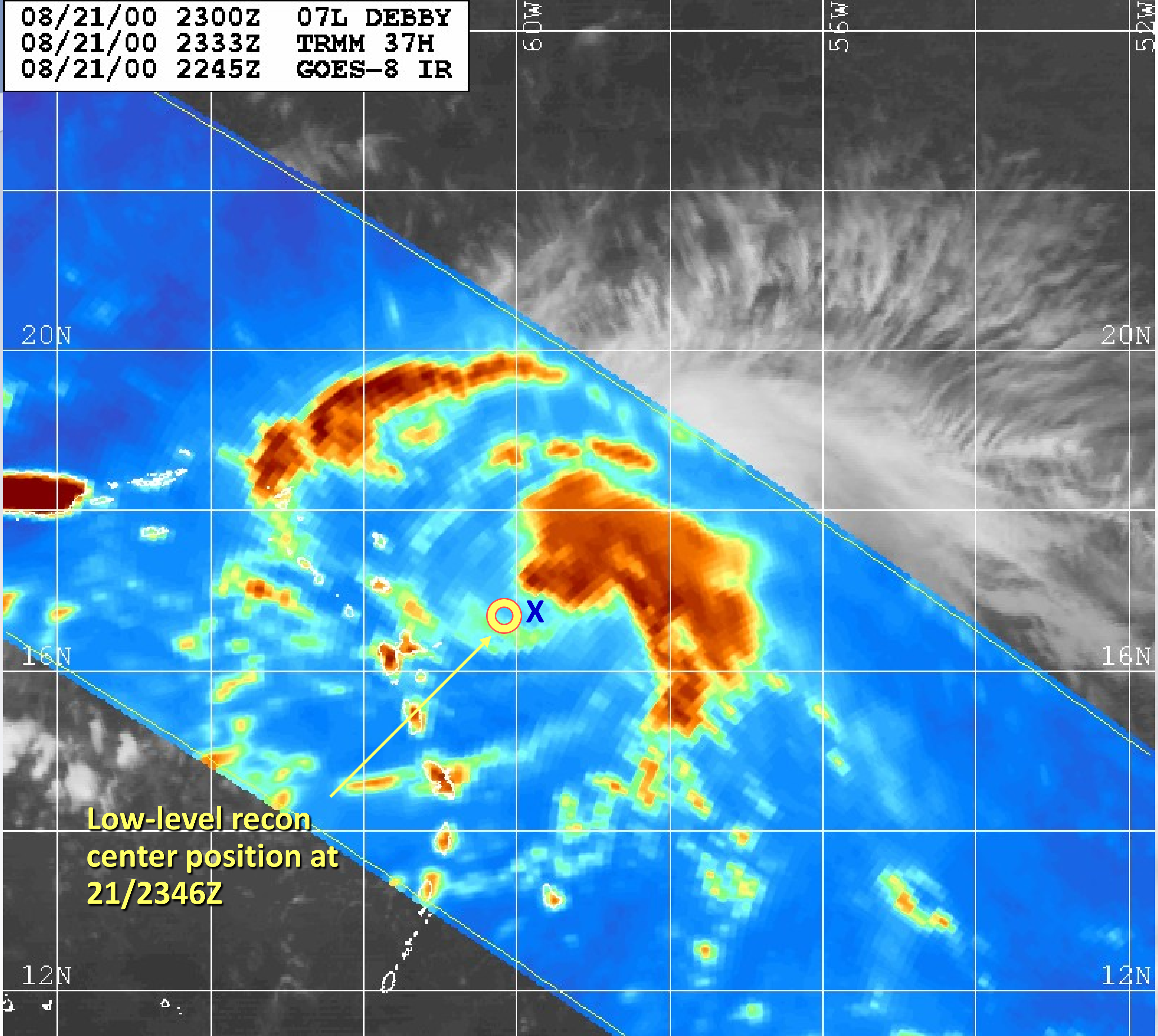
85 GHz Color-Composite Example

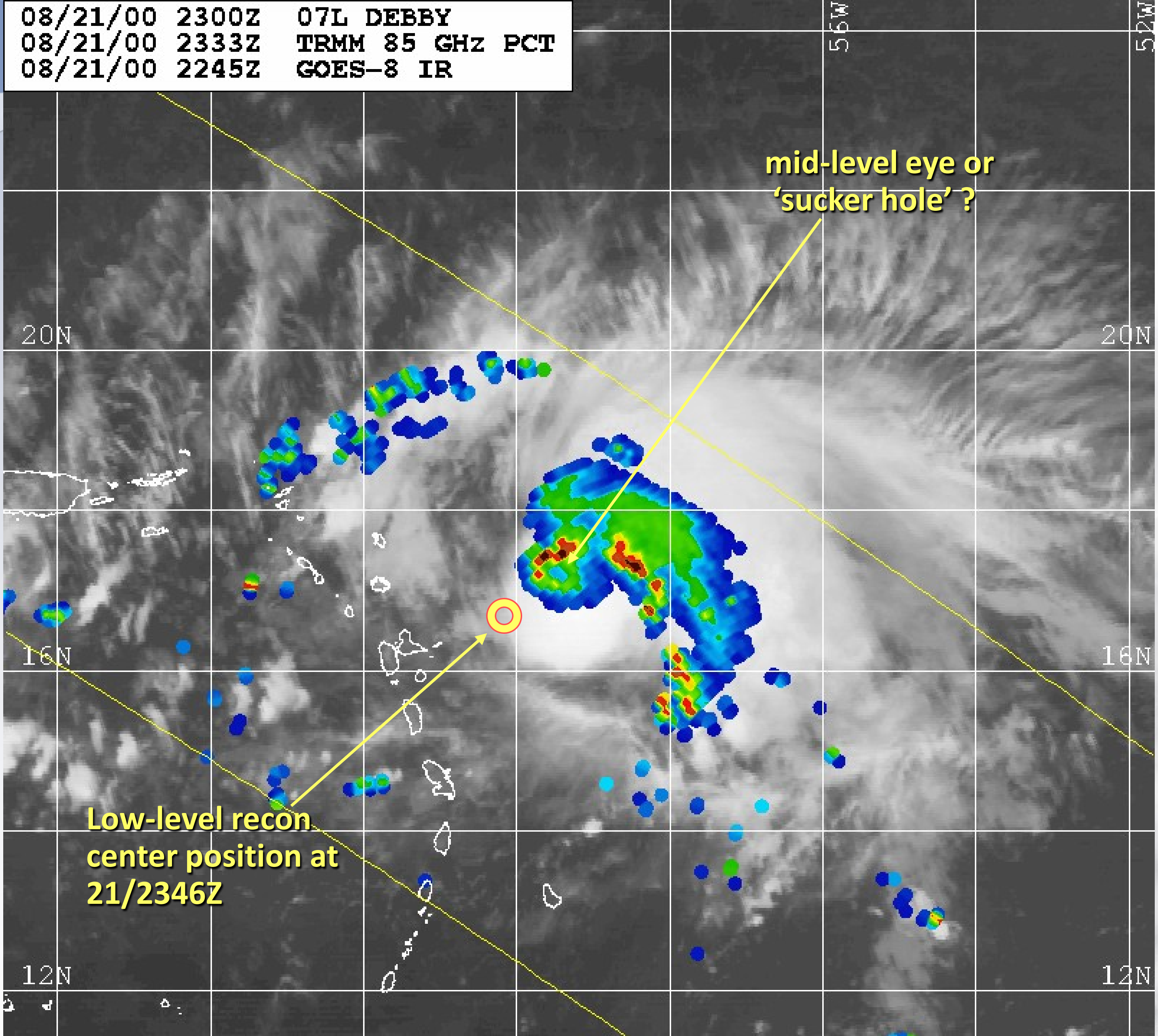


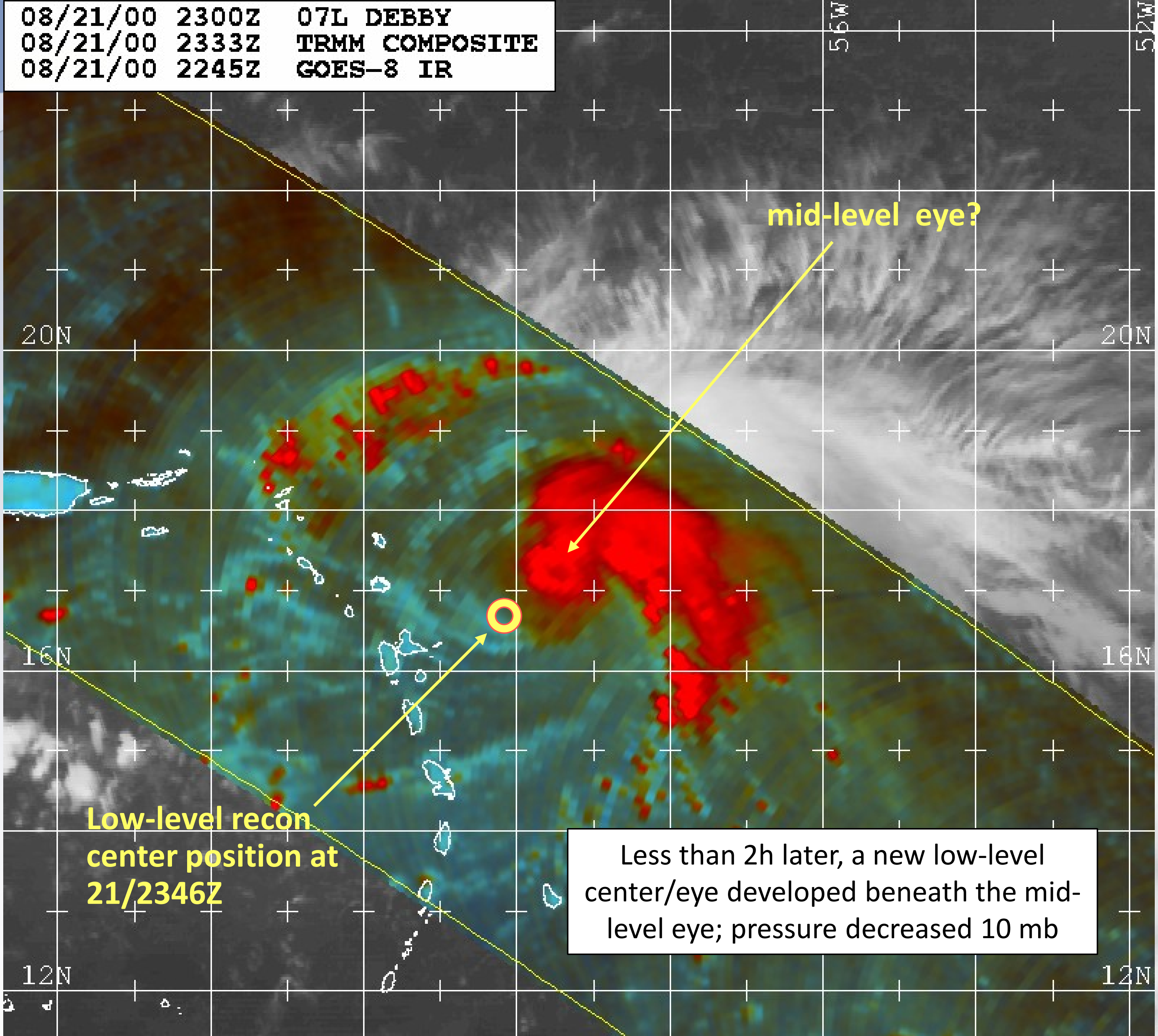
37 GHz Example




08/21/00 2300Z 07L DEBBY
08/21/00 2345Z GOES-8 IR
60W
56W
20N
18N
16N
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

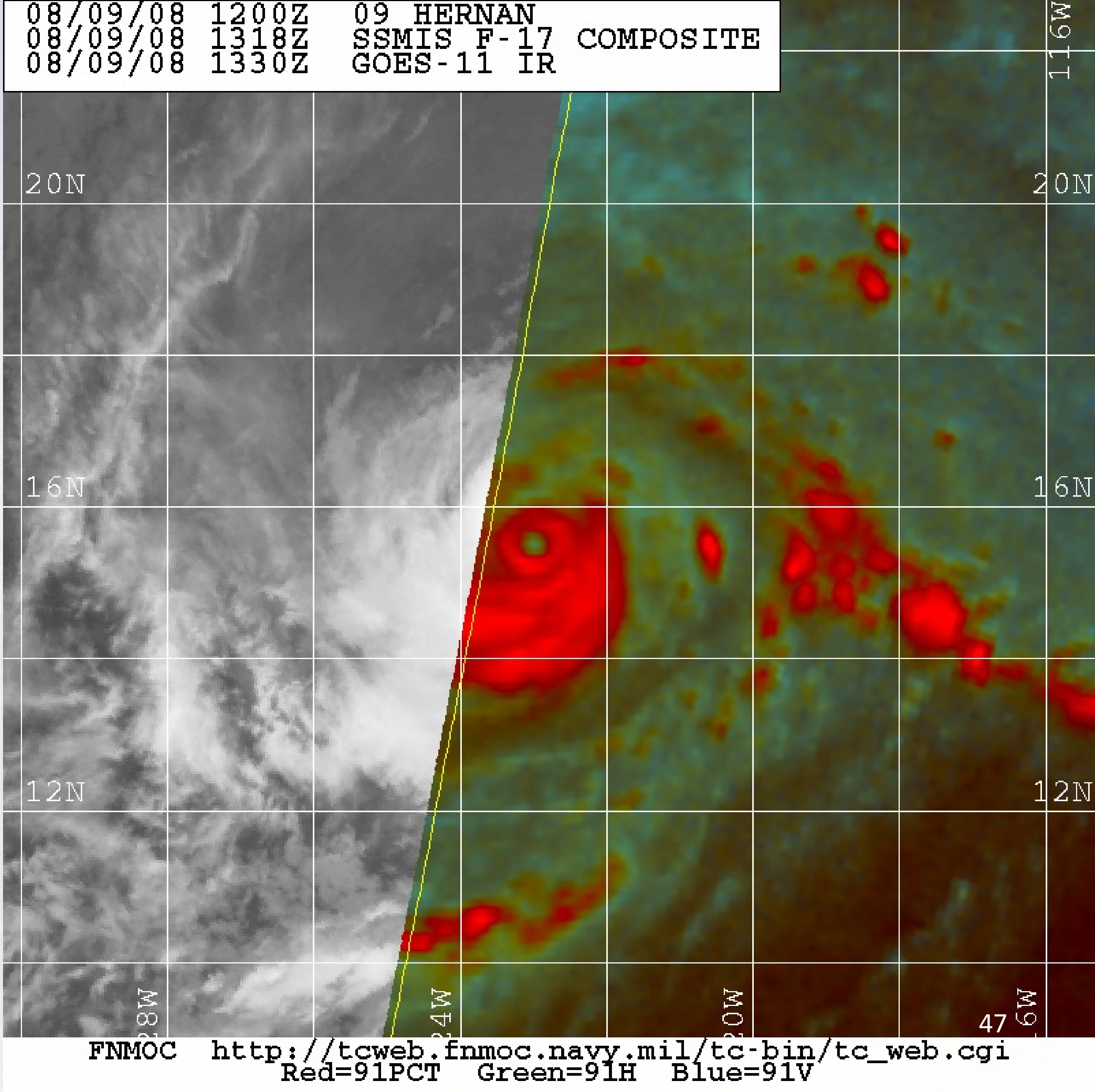

08/21/00 2300Z 07L DEBBY
08/21/00 2333Z TRMM 37H
08/21/00 2245Z GOES-8 IR
60W
56W
52W
20N
16N
12N
X
Low-level recon center position at 21/2346Z


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

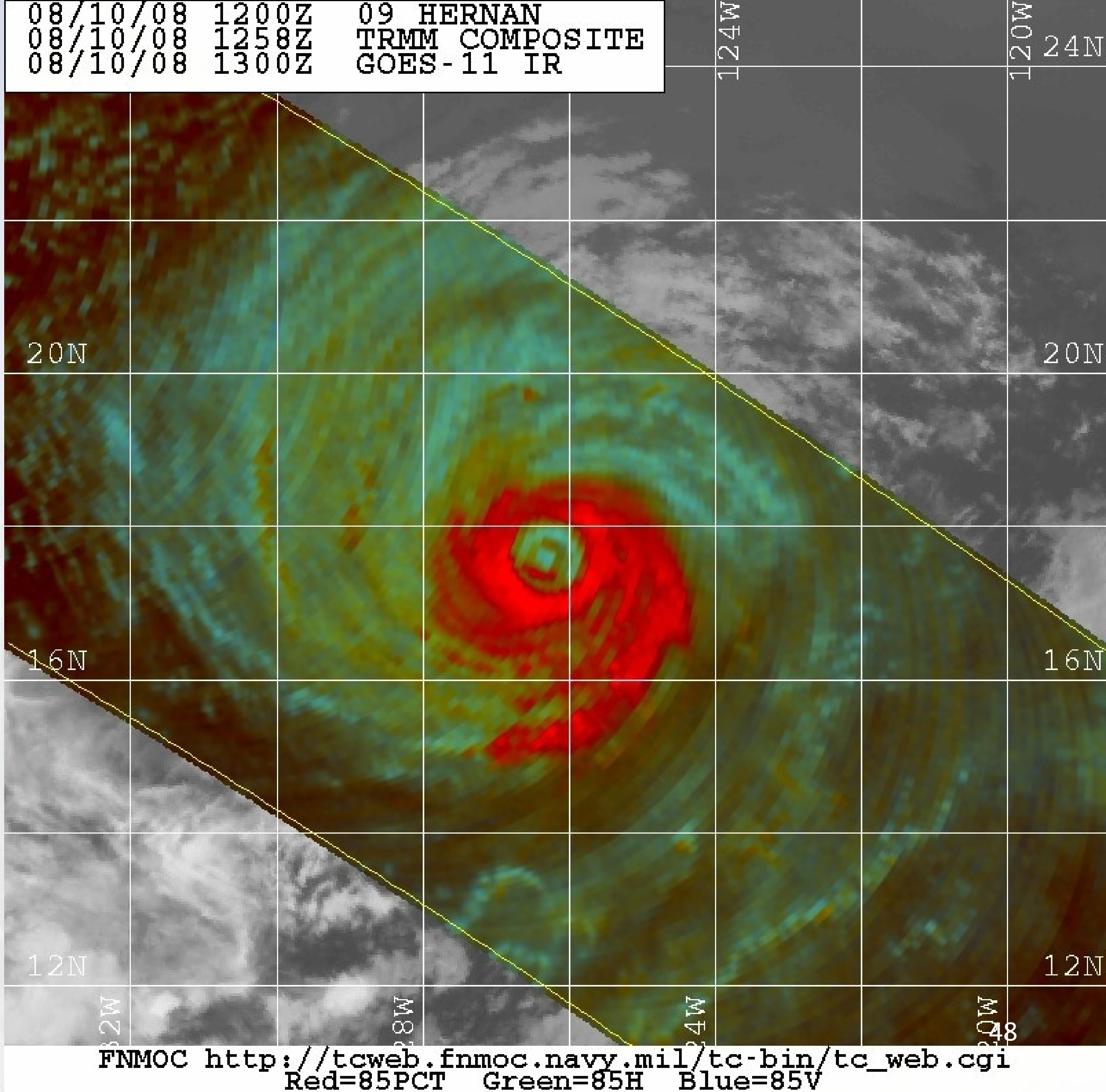
Hernan near peak intensity

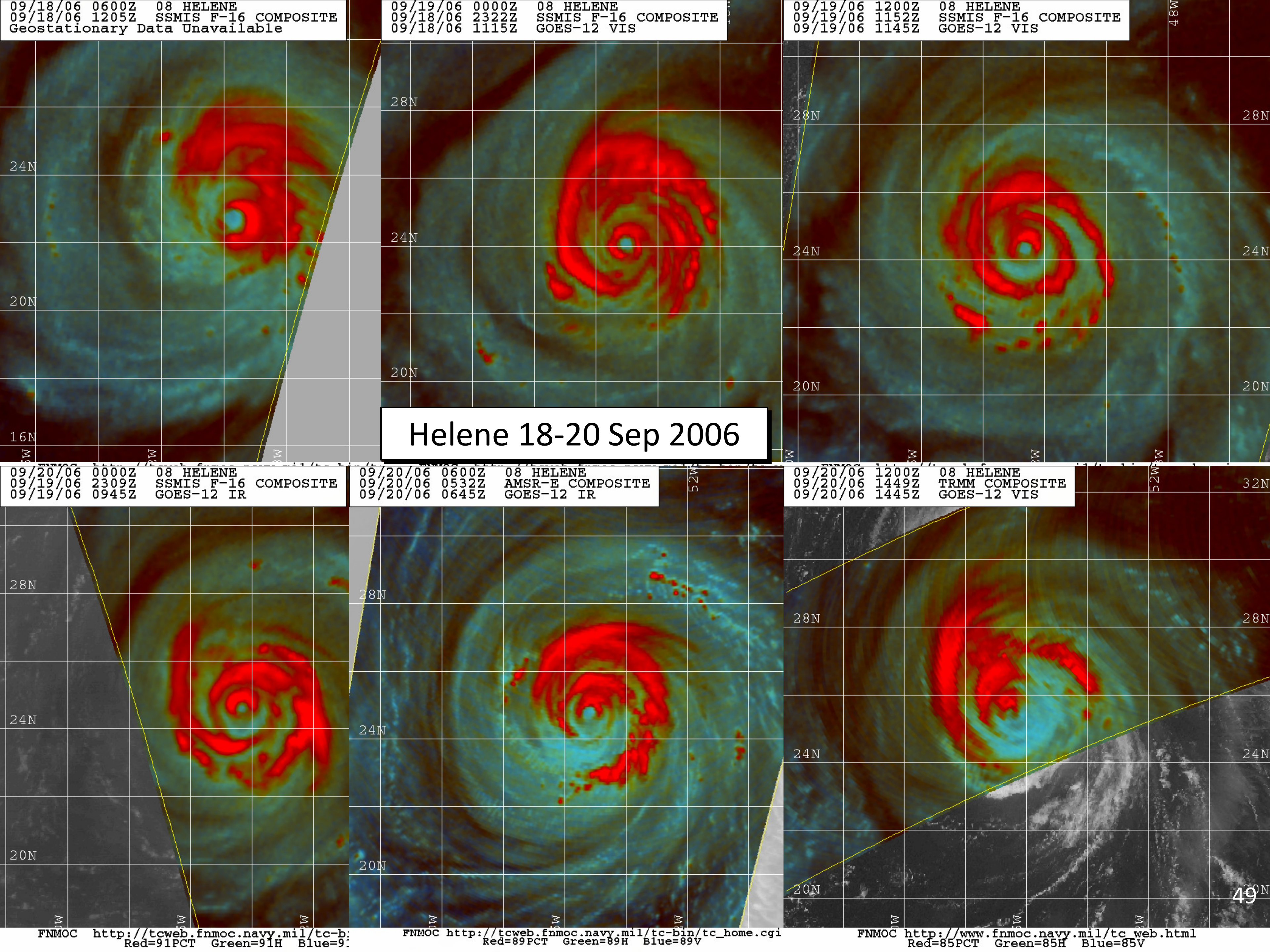
9 Aug 2008



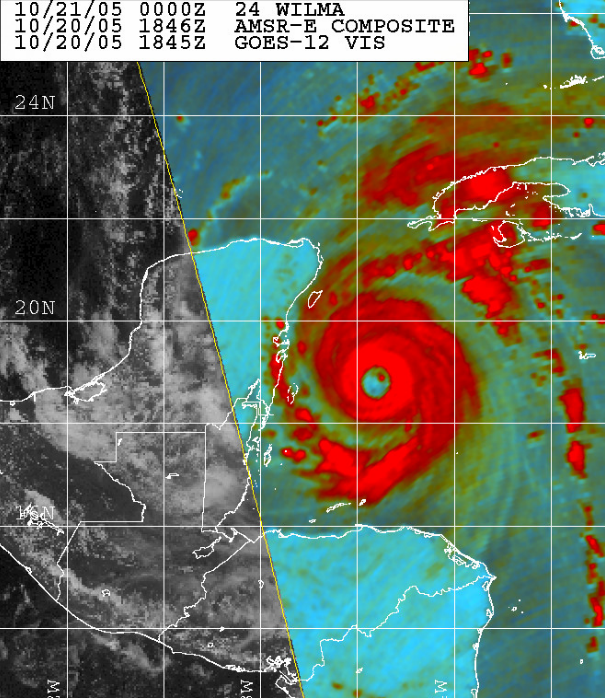
Hernan Eyewall Replacement Cycle 24 h later

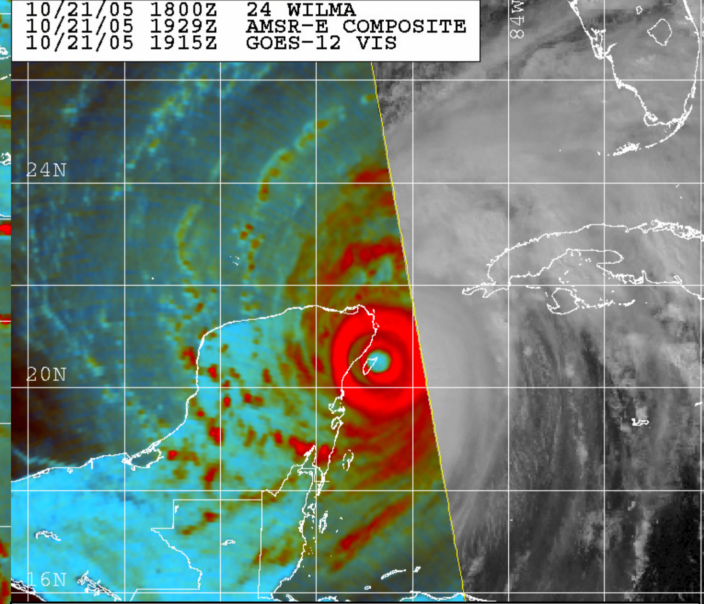
10 Aug 2008

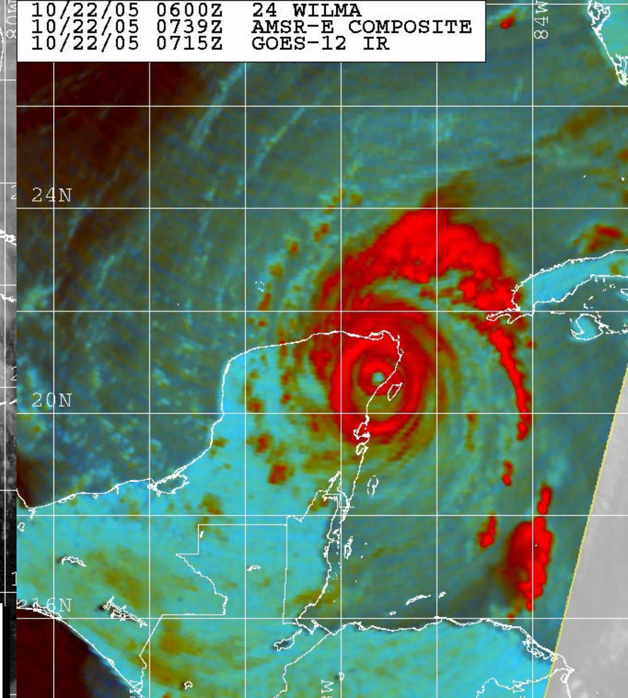


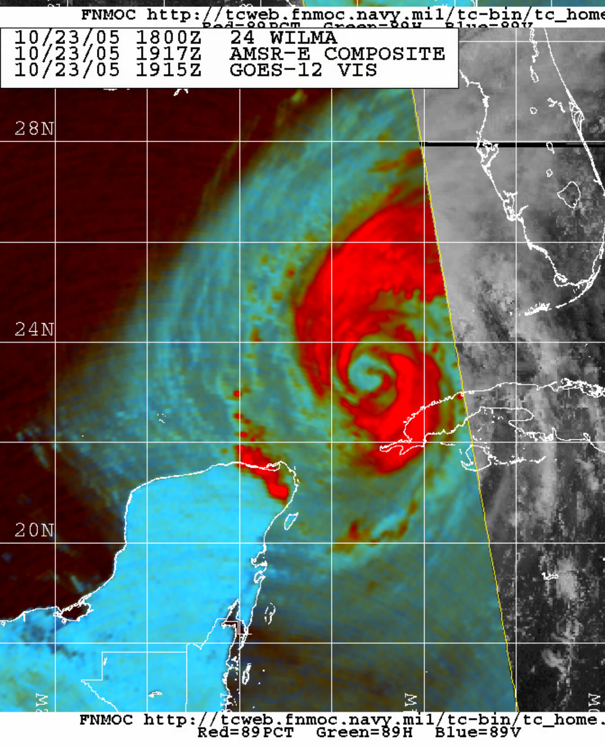

09/18/06 0600Z 08 HELENE
09/18/06 1205Z SSMIS F-16 COMPOSITE
Geostationary Data Unavailable
09/19/06 0000Z 08 HELENE
09/18/06 2322Z SSMIS F-16 COMPOSITE
09/18/06 1115Z GOES-12 VIS
09/19/06 1200Z 08 HELENE
09/19/06 1152Z SSMIS F-16 COMPOSITE
09/19/06 1145Z GOES-12 VIS
Helene 18-20 Sep 2006
09/20/06 0000Z 08 HELENE
09/19/06 2309Z SSMIS F-16 COMPOSITE
09/19/06 0945Z GOES-12 IR
09/20/06 0600Z 08 HELENE
09/20/06 0532Z AMSR-E COMPOSITE
09/20/06 0645Z GOES-12 IR
09/20/06 1200Z 08 HELENE
09/20/06 1449Z TRMM COMPOSITE
09/20/06 1445Z GOES-12 VIS
28N
24N
20N
16N
32N
FNMOC http://tcweb.fnmoc.navy.mil/tc-bi
Red=91PCT Green=91H Blue=91
FNMOC http://tcweb.fnmoc.navy.mil/tc-bin/tc_home.cgi
Red=89PCT Green=89H Blue=89V
FNMOC http://www.fnmoc.navy.mil/tc_web.html
Red=85PCT Green=85H Blue=85V

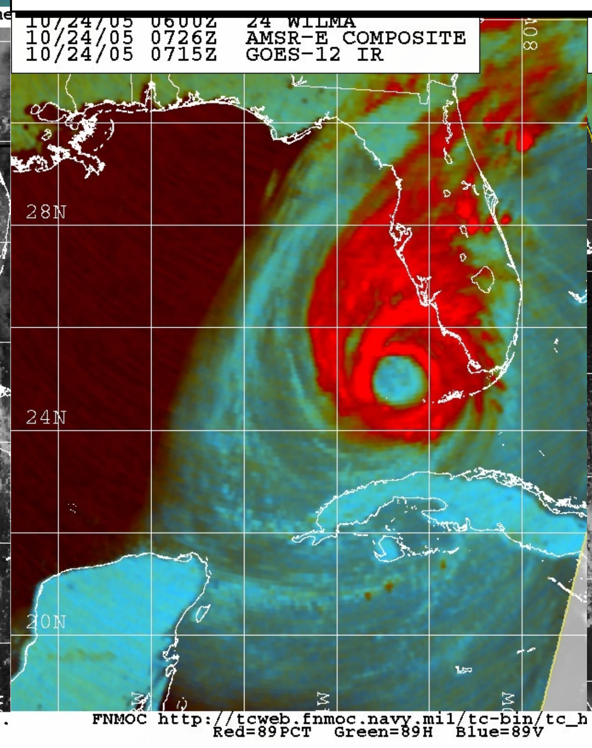
Wilma 21-24 Oct 2005

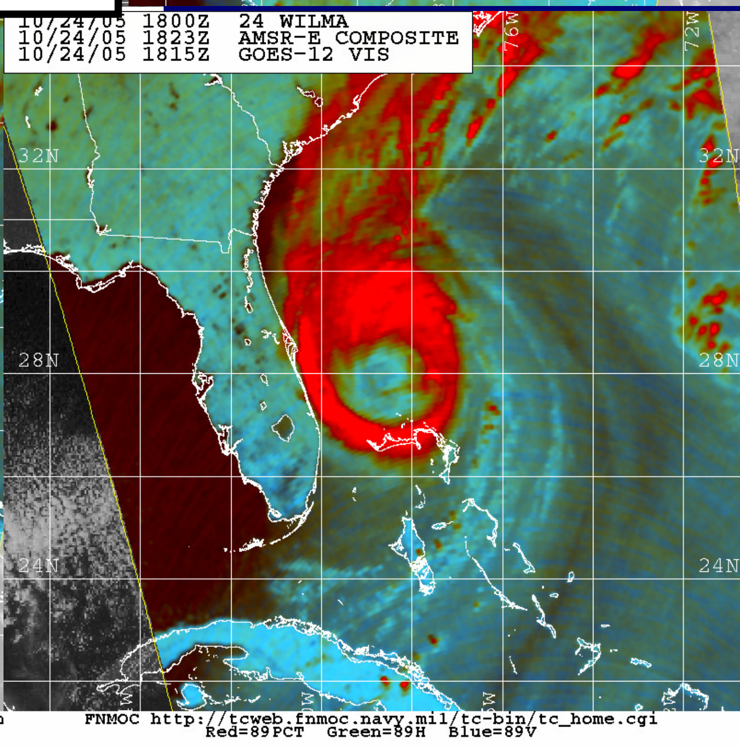




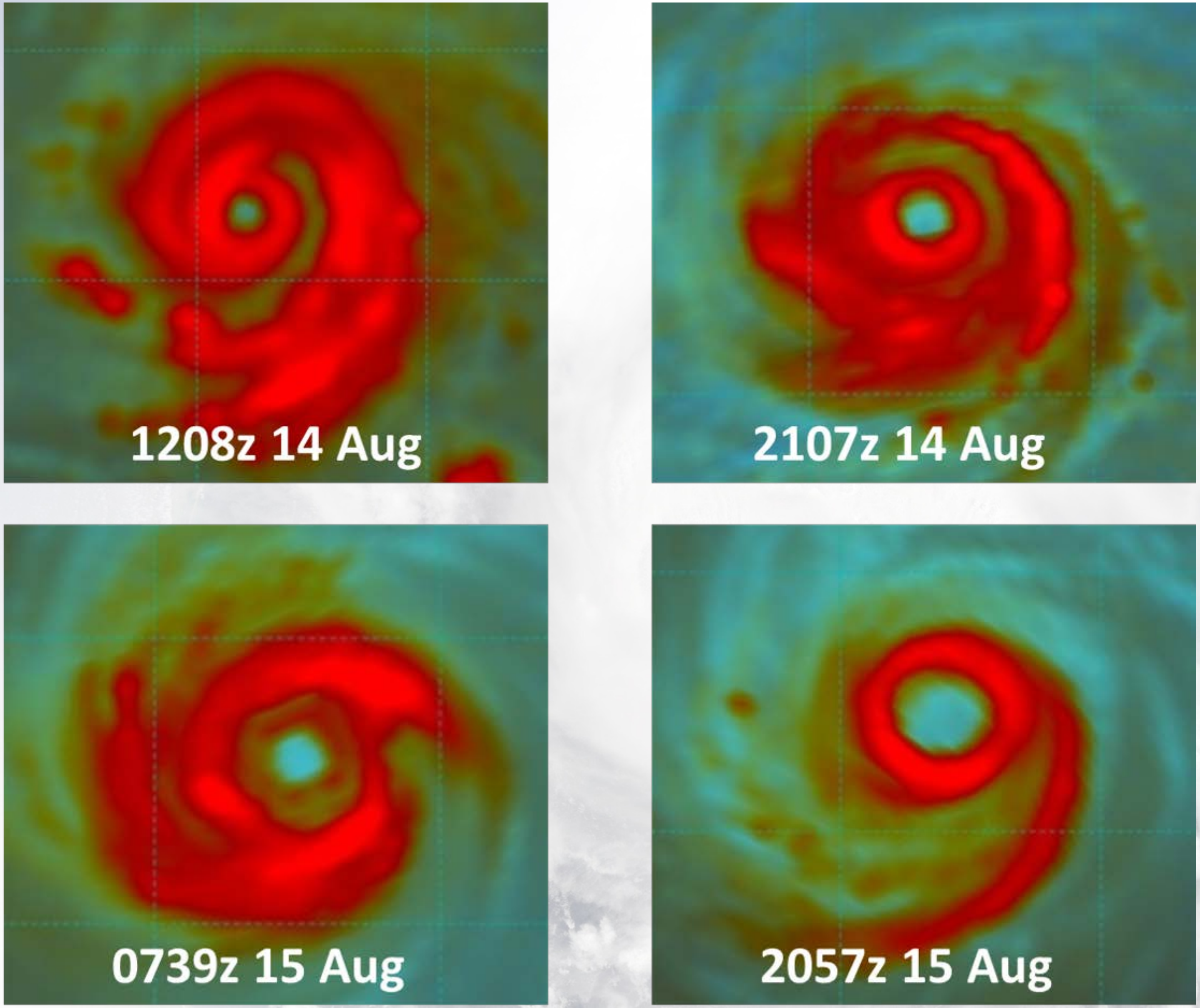




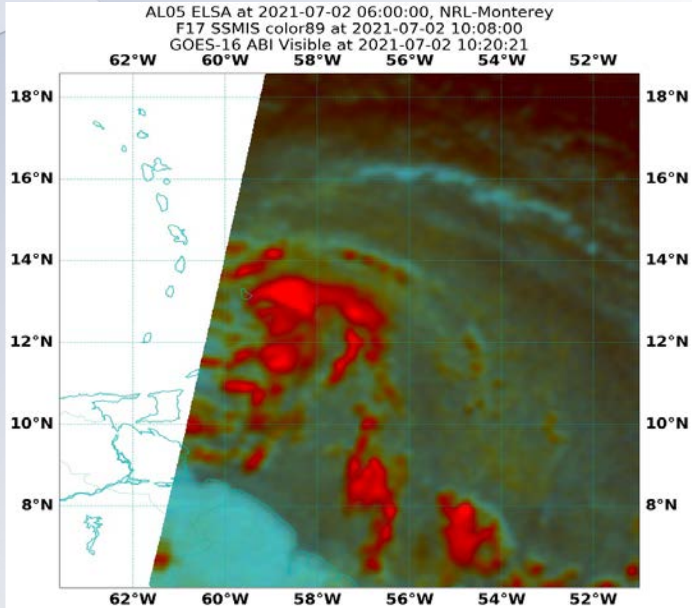


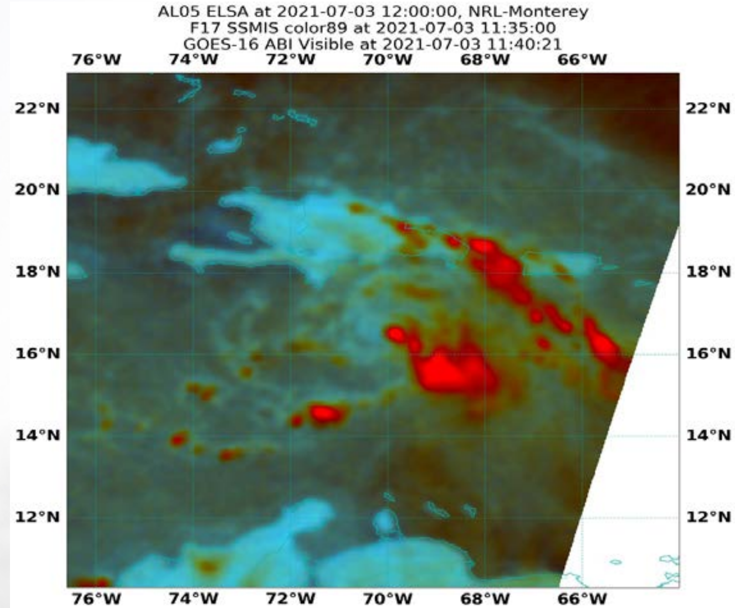


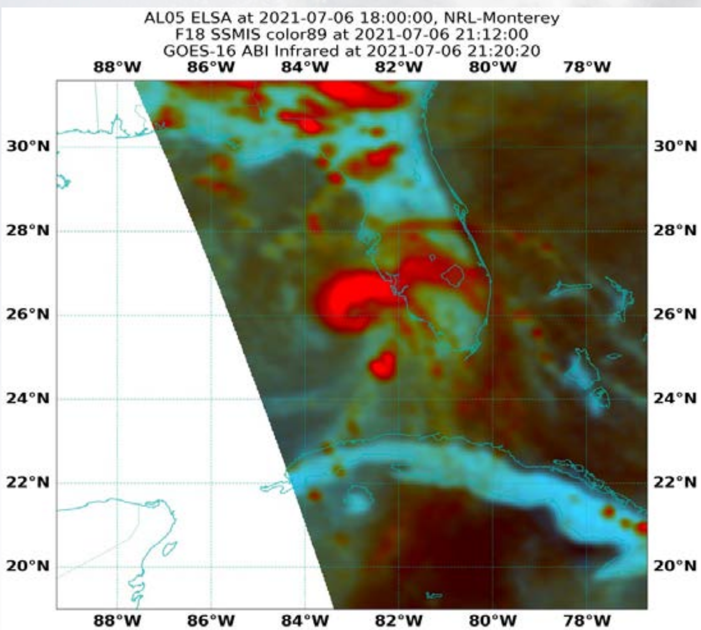
Hurricane Linda (2021)

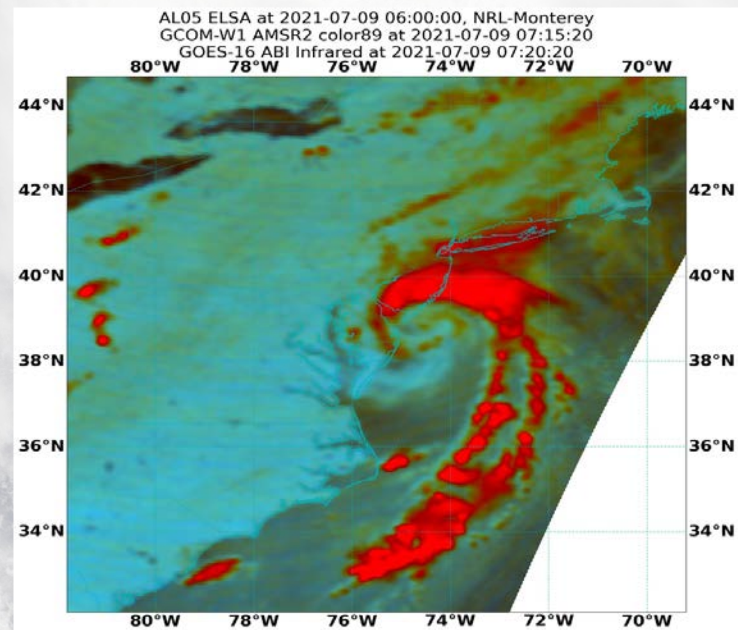


Hurricane Elsa (2021)

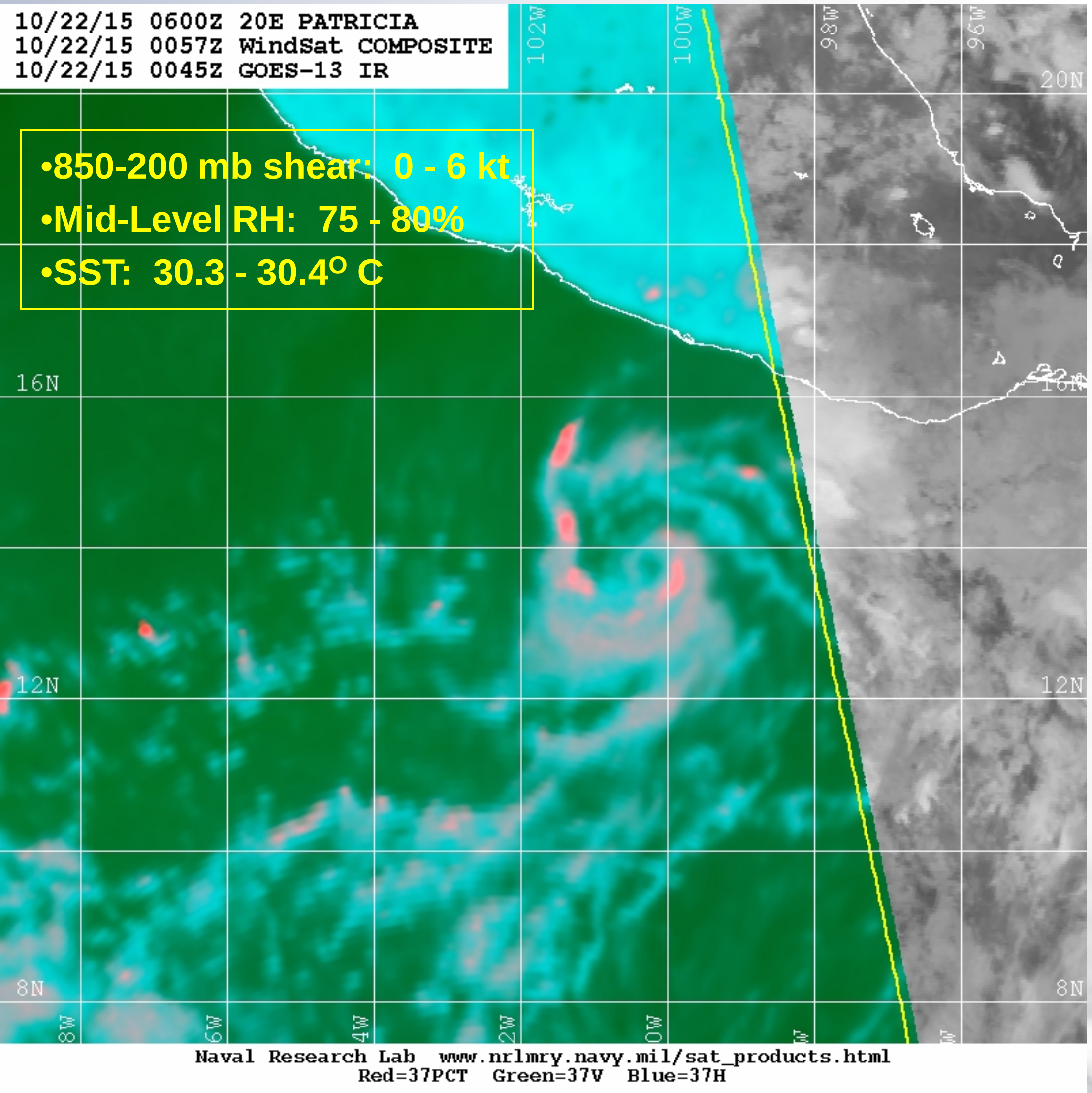








Precursor Structure Before Rapid Intensification



- A closed low-level ring of convection in 37-GHz imagery can be a precursor signal to rapid intensification
- In the case shown here, Patricia strengthened an incredible 90 kt from 60 kt to 150 kt in only 24 hours!

Questions?