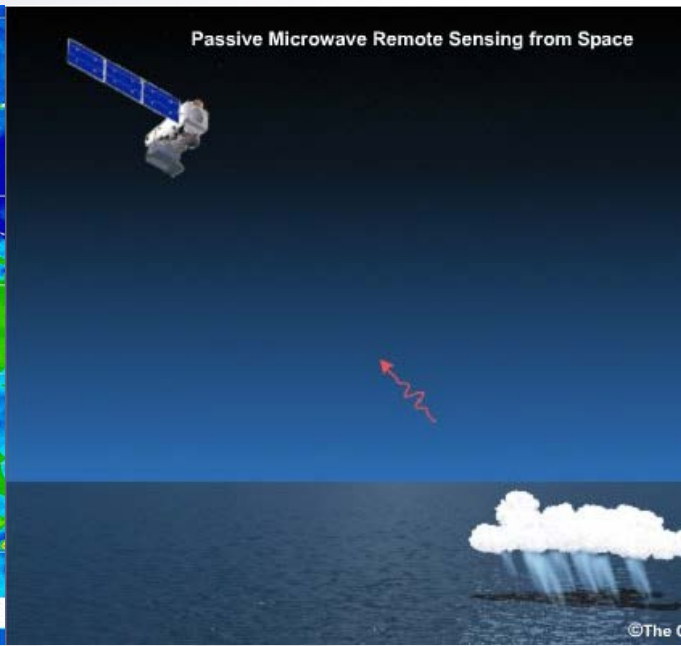
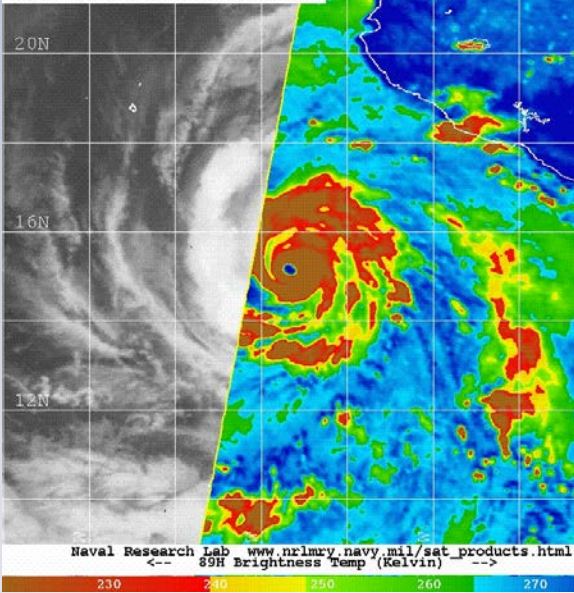
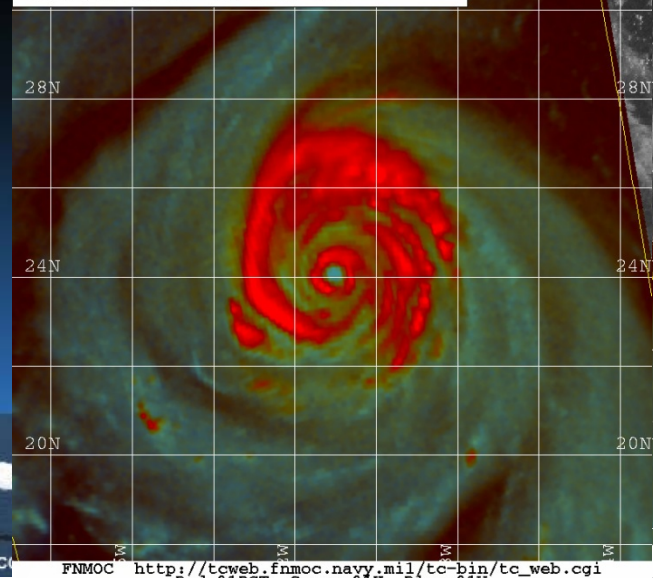


Interpretation and Application of Microwave Imagery

10/18/09 0600Z 20E RICK
 10/18/09 0831Z AQUA-1 89H
 10/18/09 0830Z GOES-11 IR



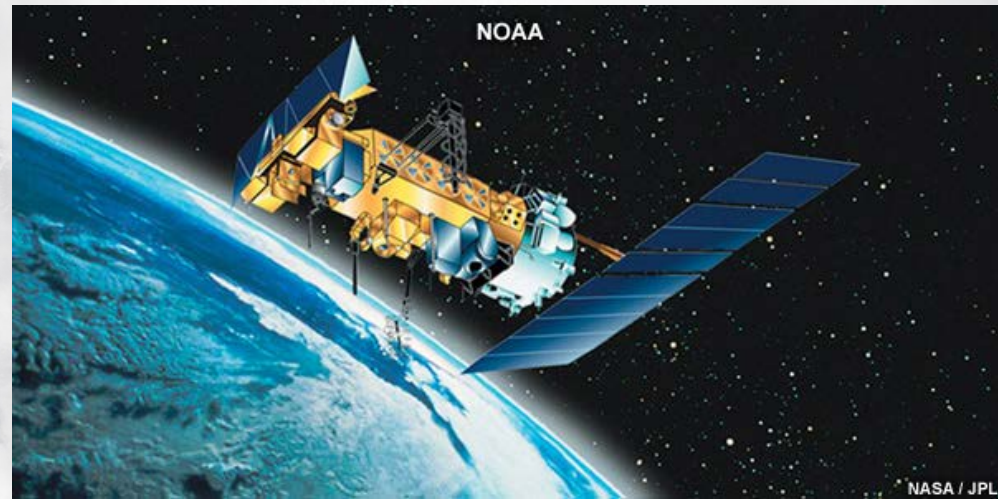
09/19/06 0000Z 08 HELENE
 09/19/06 0000Z 08 HELENE
 09/18/06 2322Z SSMIS F-16 COMPOSITE
 09/18/06 1115Z GOES-12 VIS



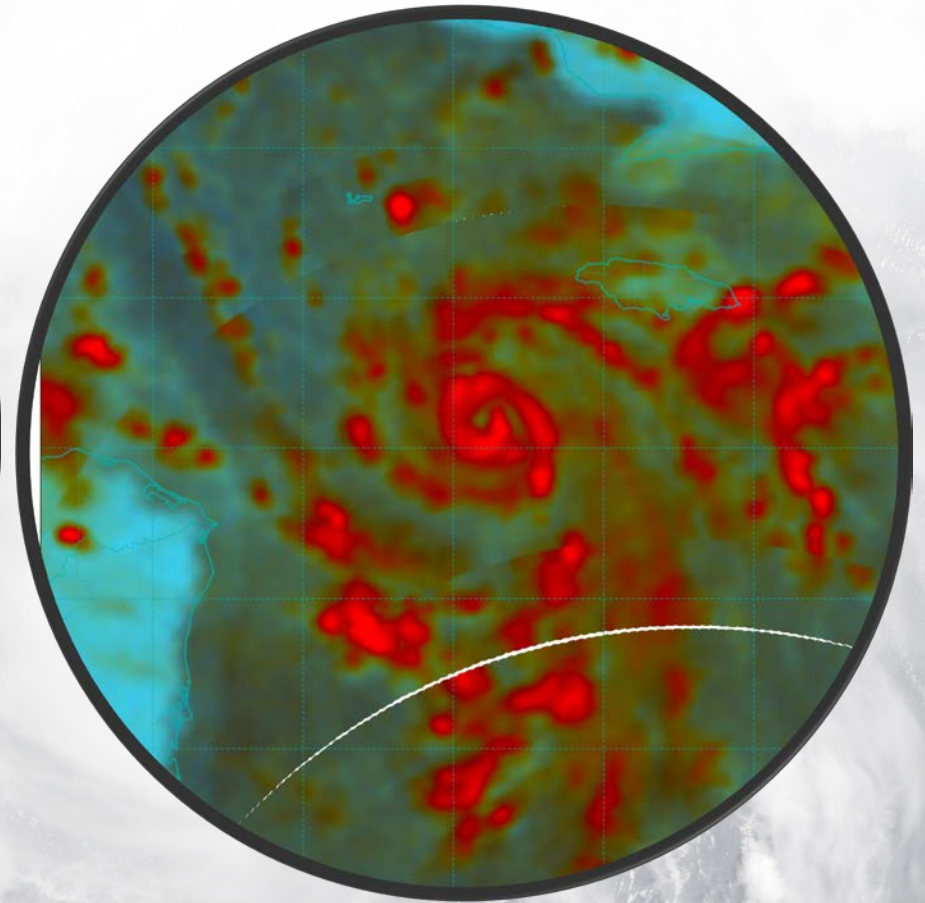
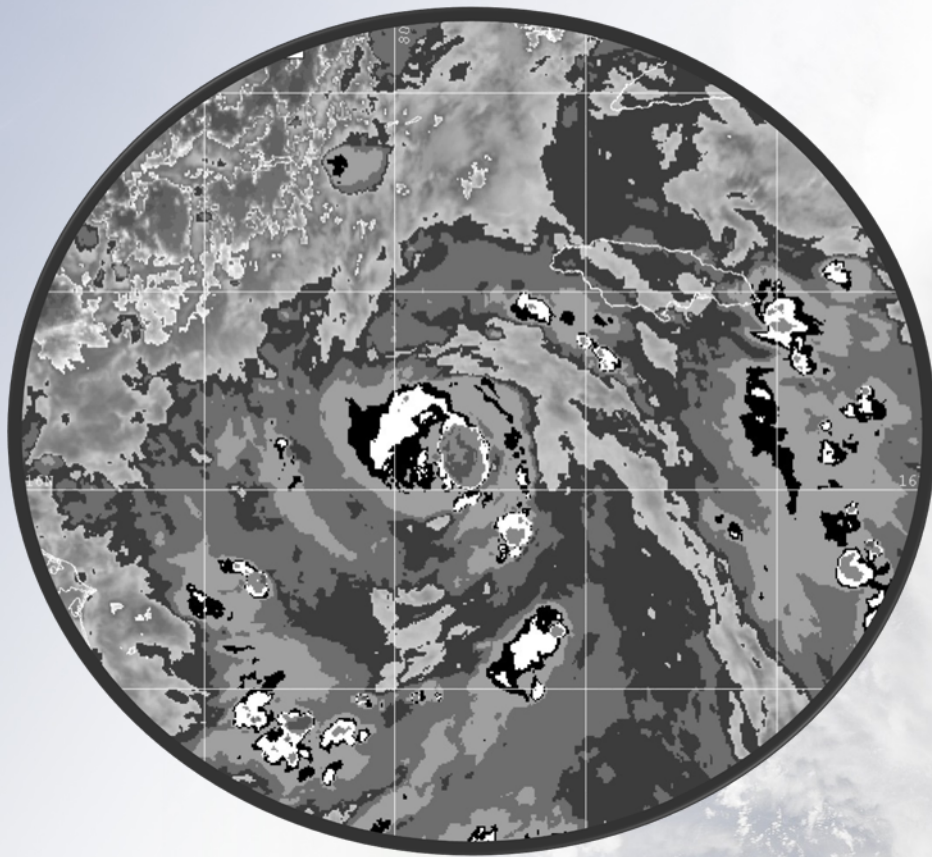
2022 RA-IV WMO Tropical Meteorology Course
 John Cangialosi and Brad Reinhart
 National Hurricane Center

Outline

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



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

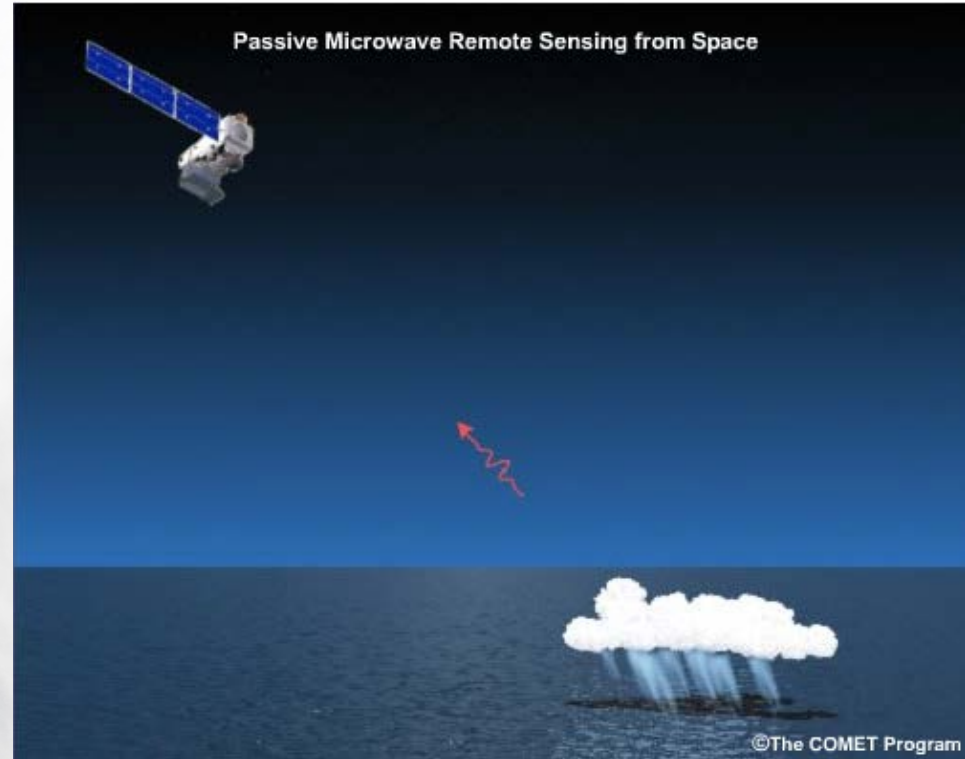


Image courtesy COMET

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



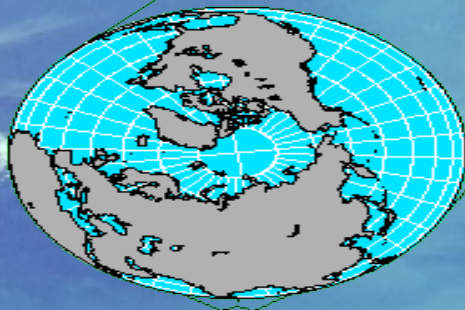
GEO vs. LEO Orbital Altitude Comparison



Geostationary Satellite
35,800 km altitude

mean distance to moon = 384,400 km

17.4°



110.8° **Polar Orbiting Satellite**
850 km altitude

earth radius = 6,370 km
typical shuttle orbit = 225 – 250 km
Hubble Space Telescope = 600 km

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

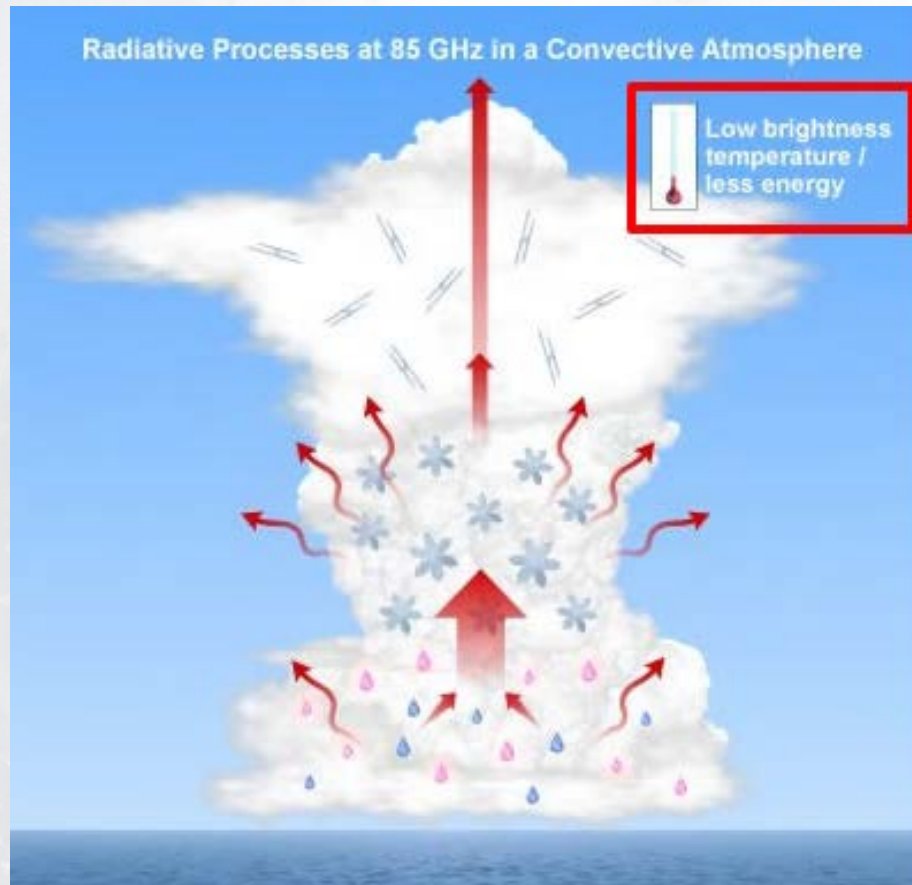


Image courtesy COMET

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

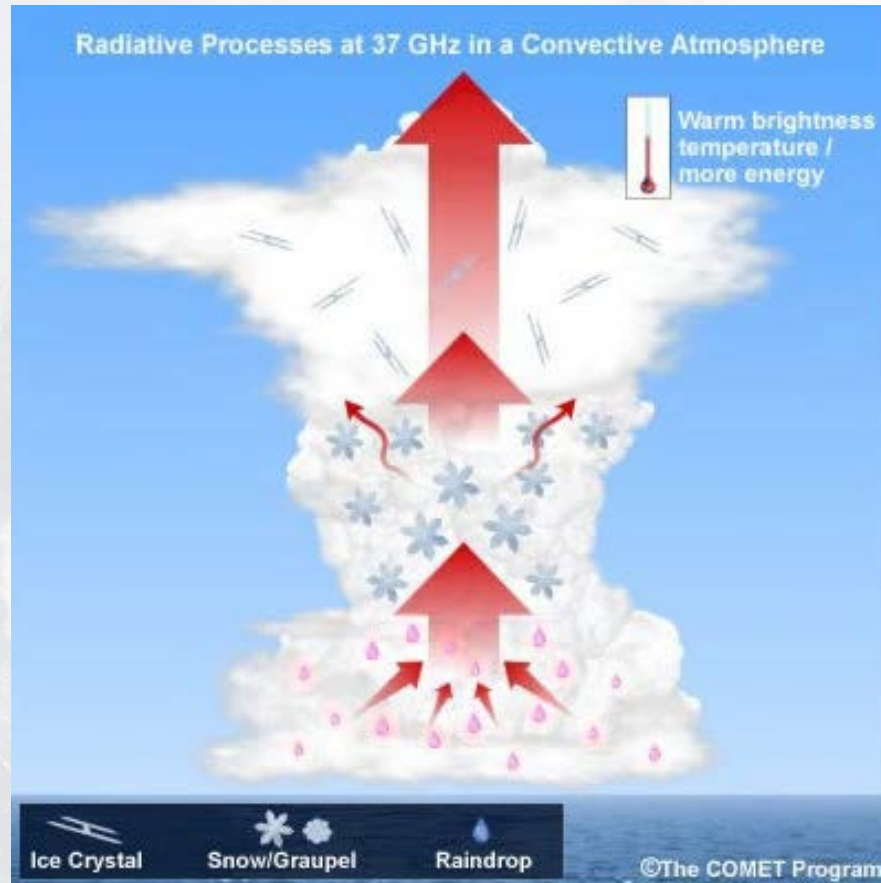
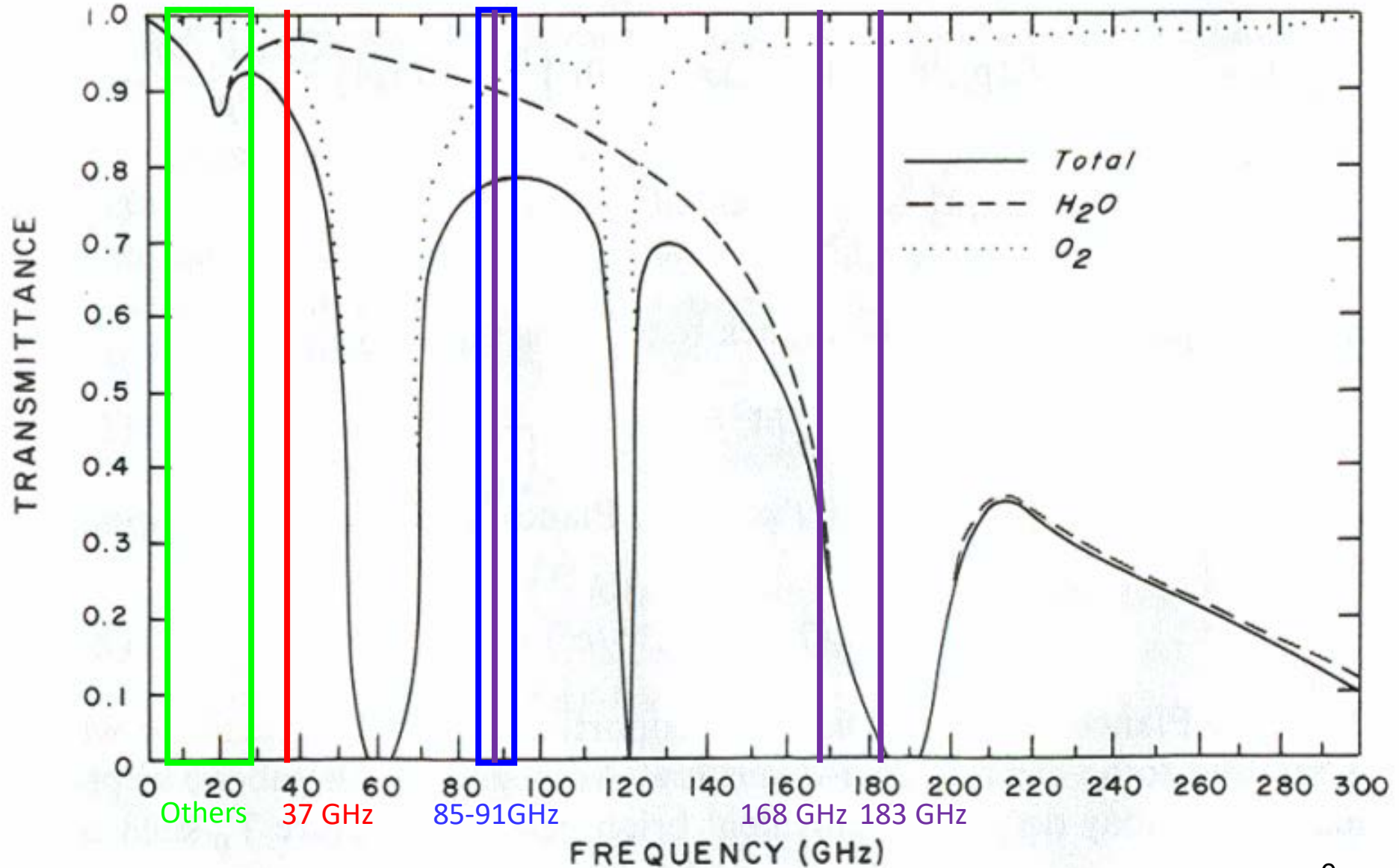


Image courtesy COMET

Microwave Transmittance



Data Timeliness

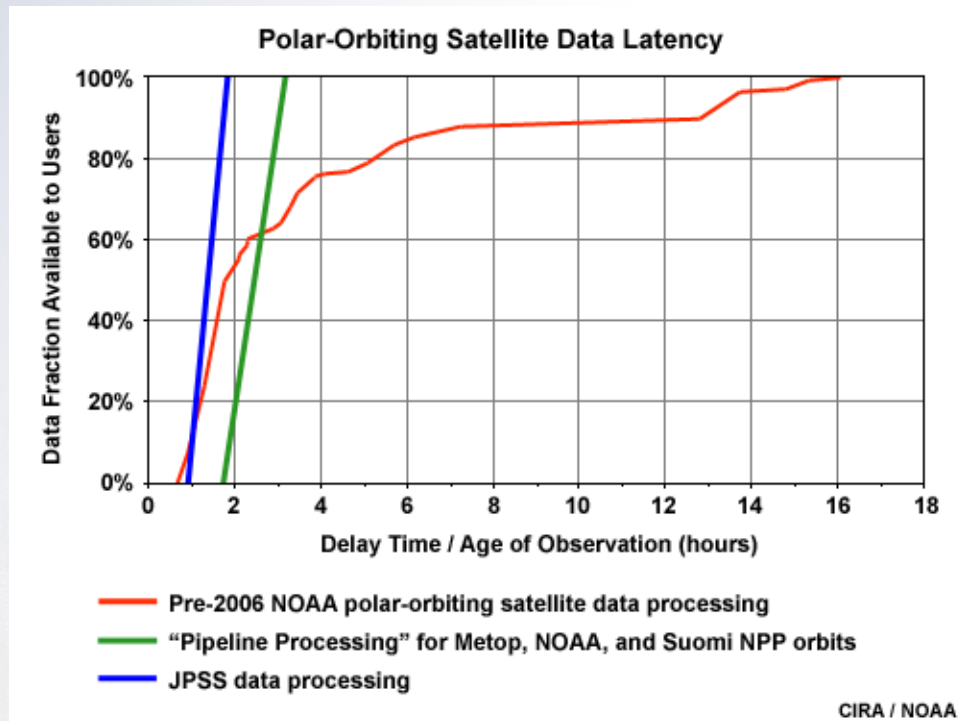


Image courtesy COMET

- 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.

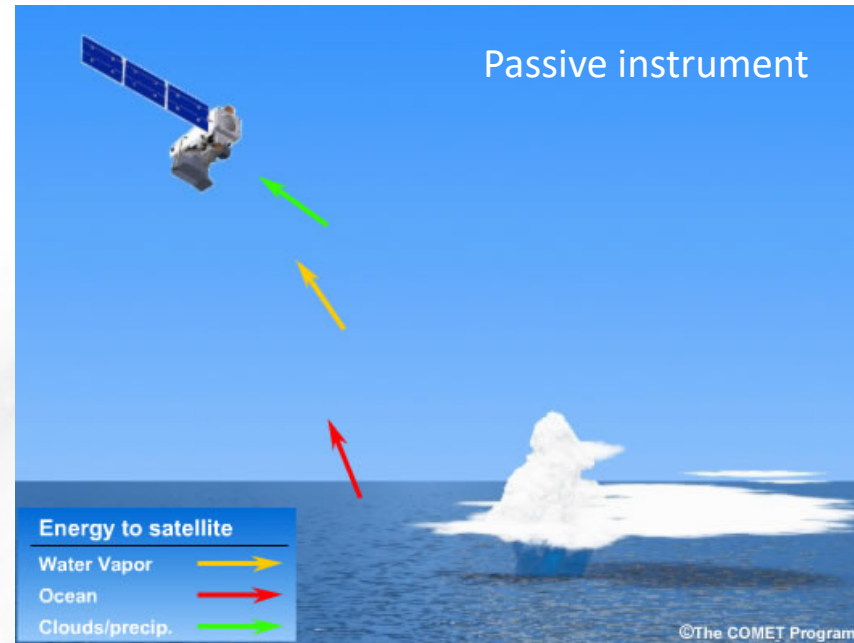
Measuring Electromagnetic Energy

- **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



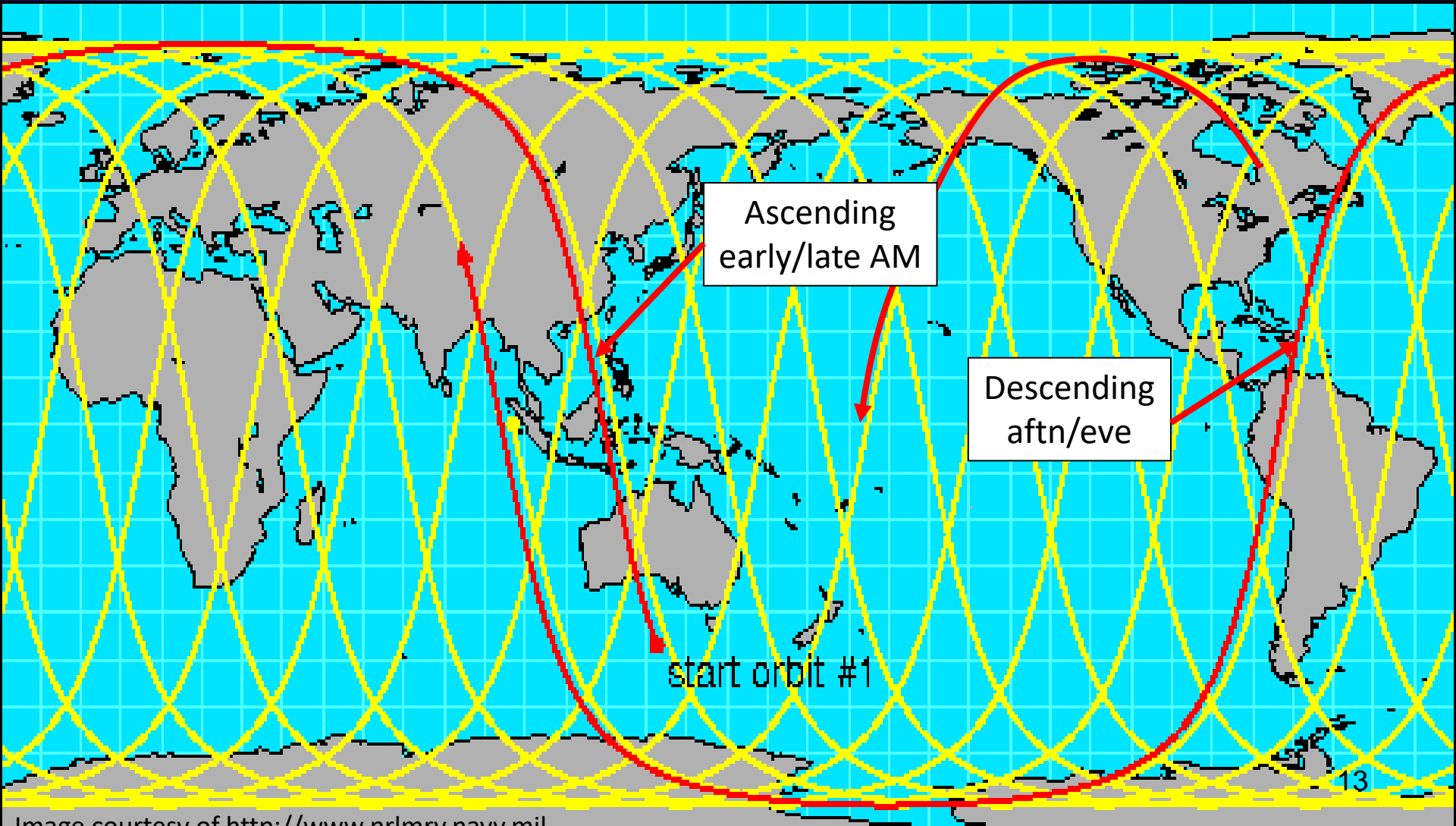
A satellite image of Earth showing a large, well-defined cyclone or hurricane in the center. The cyclone has a clear eye and is surrounded by dense, swirling cloud bands. The surrounding Earth's surface shows some landmasses and other cloud patterns. In the top left corner, there is a blue logo consisting of a circle and a swoosh.

Orbital and Scan Characteristics

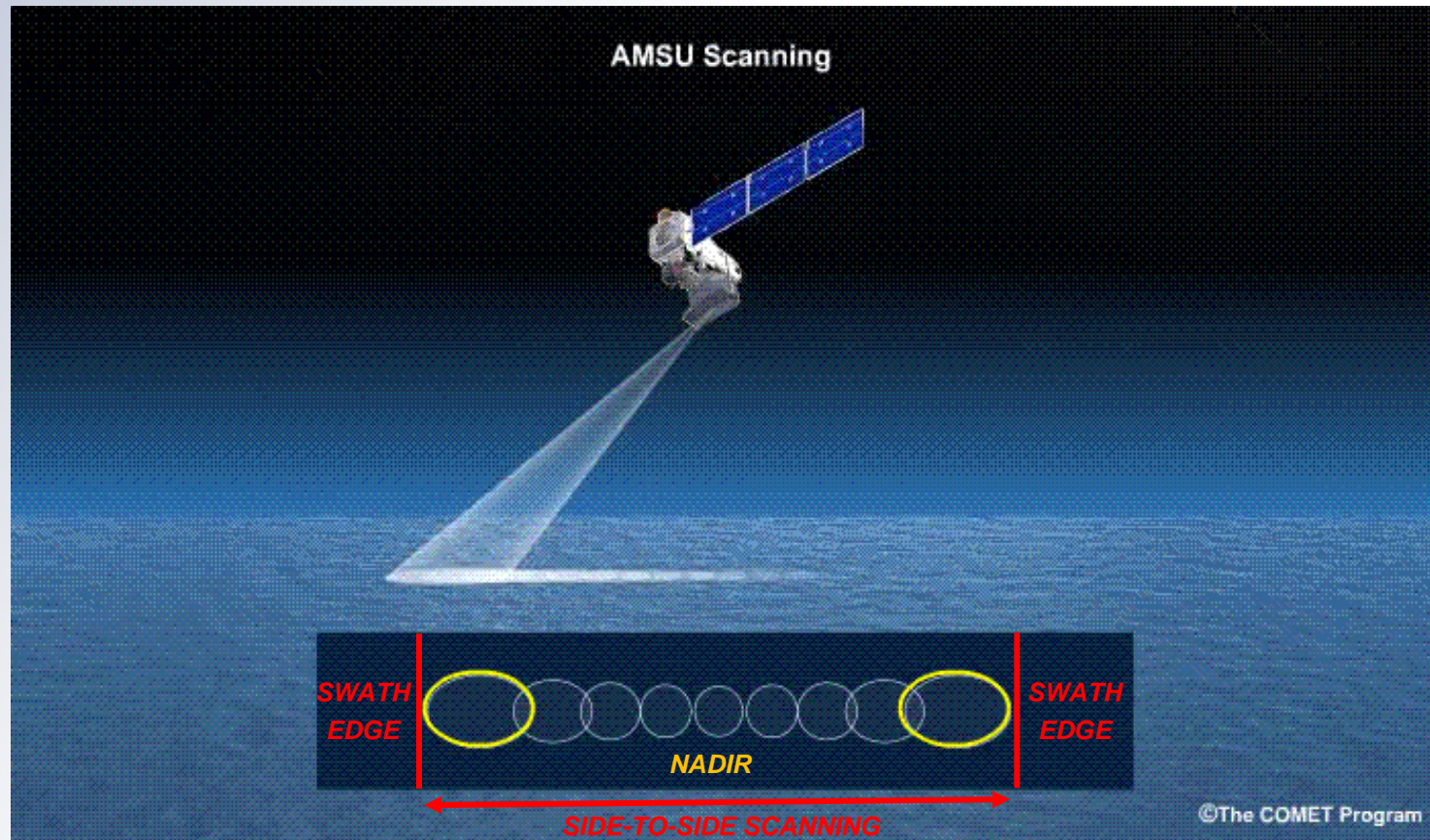
Sun-Synchronous Daily Orbital Path

~12 hr to observe the entire Earth

Same location twice daily (ascending/descending)

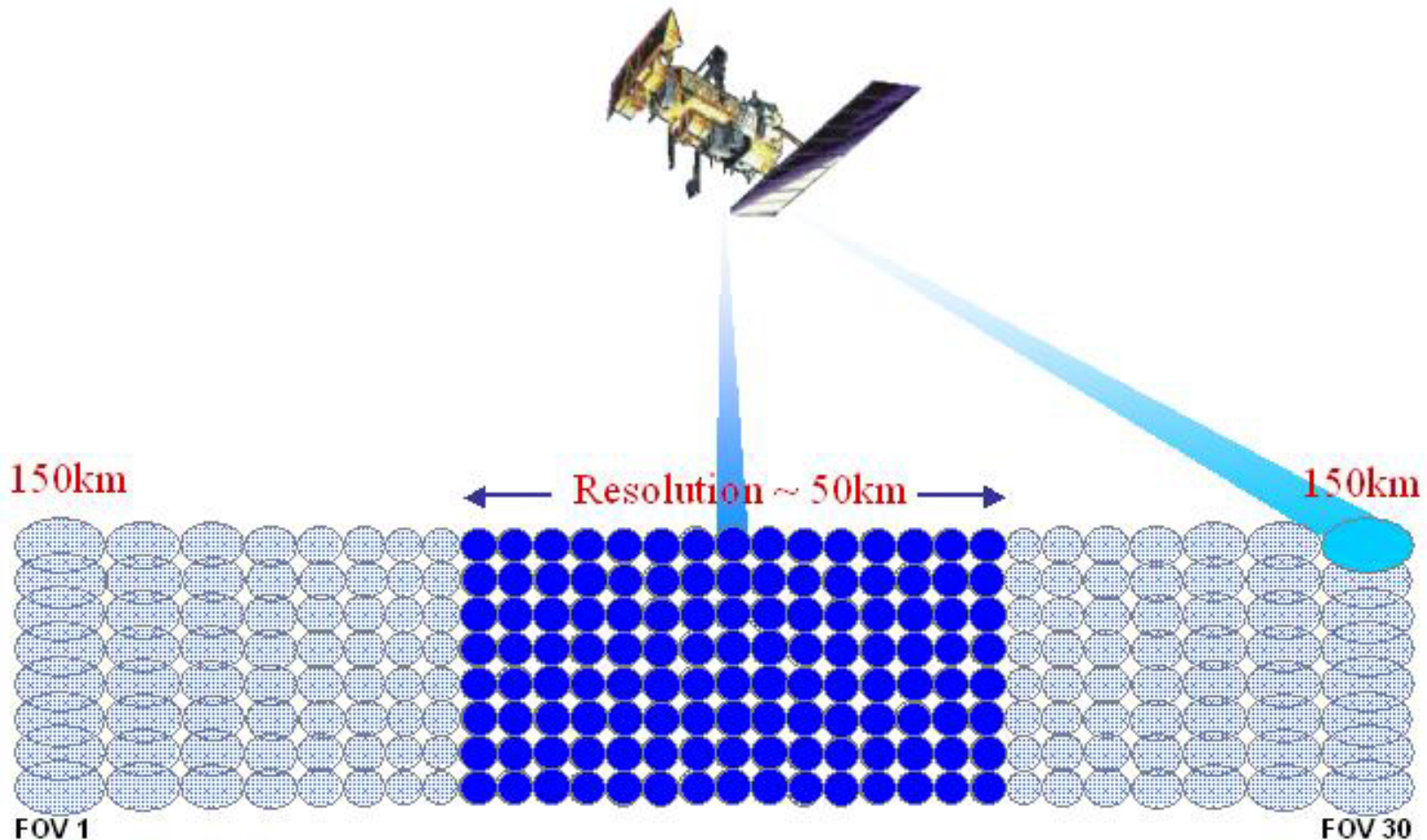


Cross Track Scan Strategy



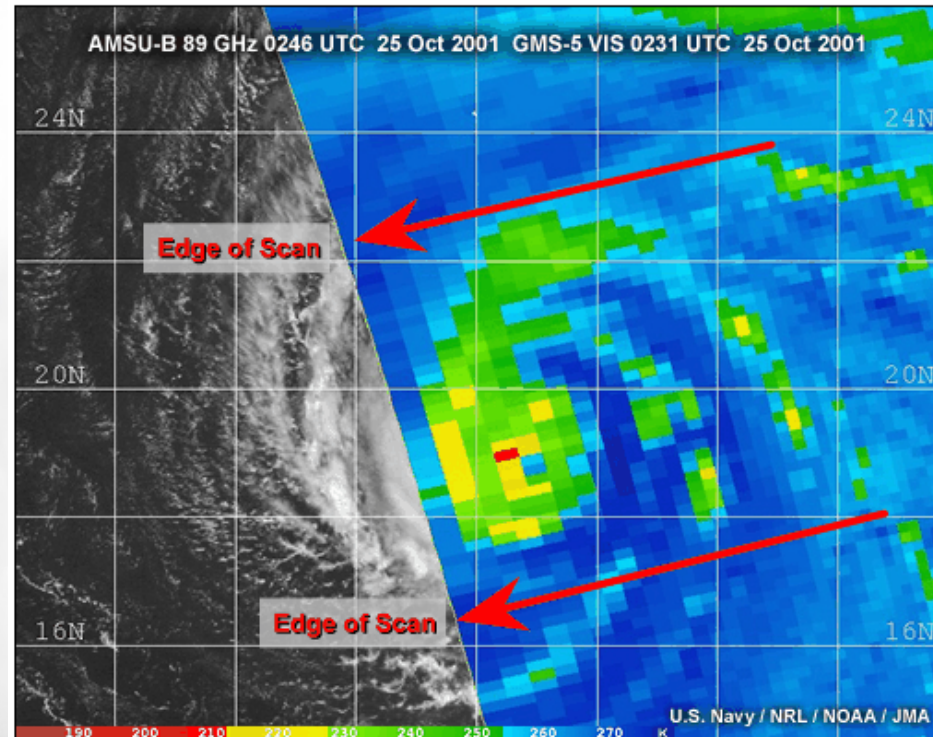
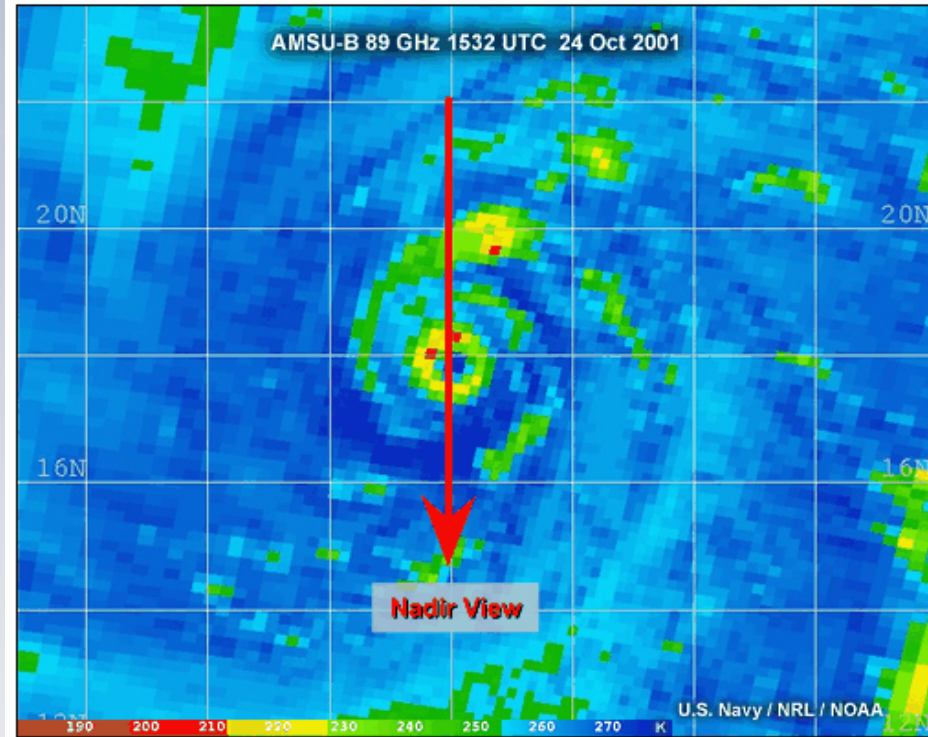
- **Advantage:** Larger coverage swath relative to conical scan
- **Disadvantage:** Resolution varies across the swath (coarser resolution at swath edge relative to nadir)

Cross Track Scan Strategy



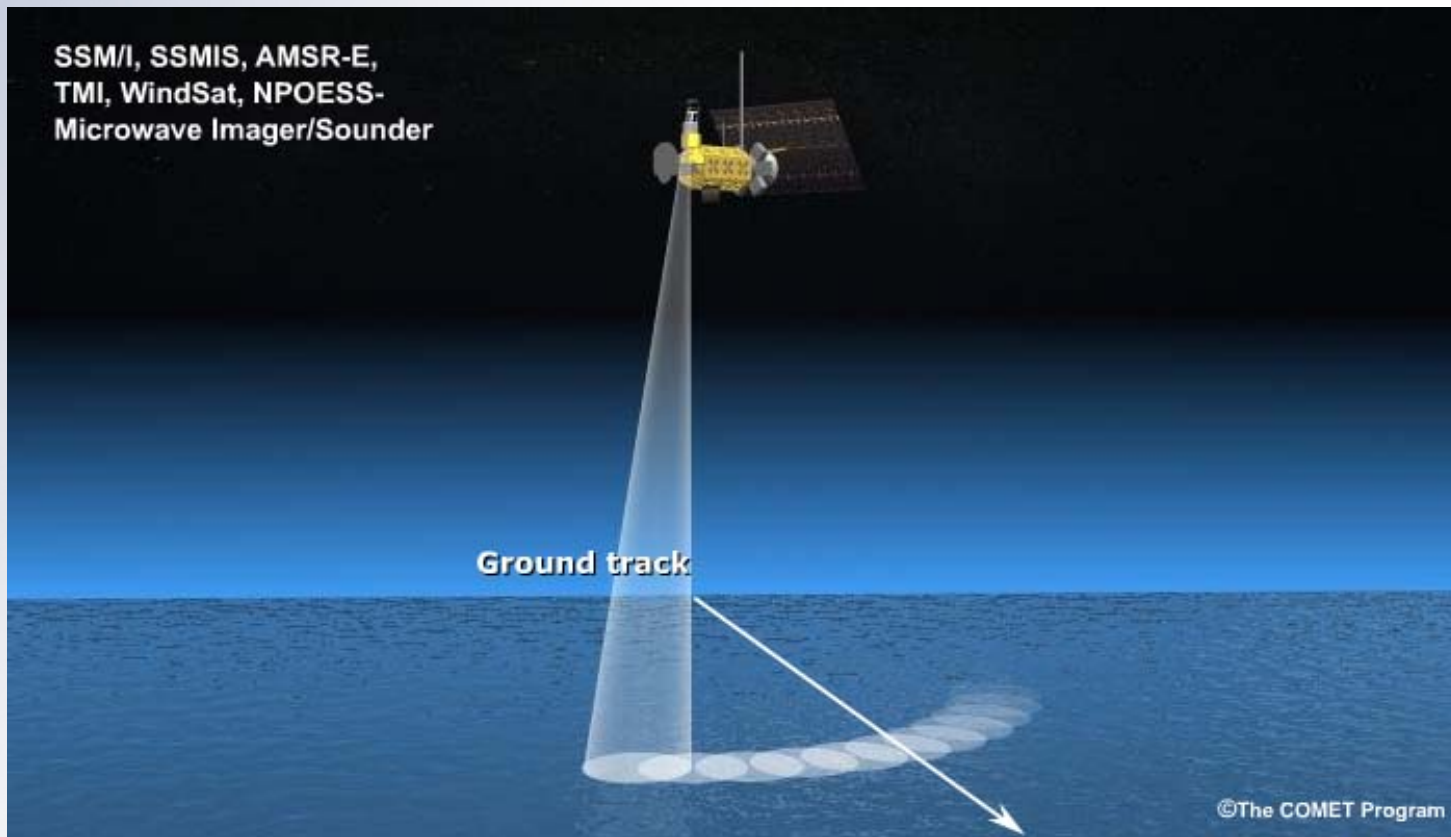
AMSU Scanning Geometry and Resolution

Cross Track Scan Strategy



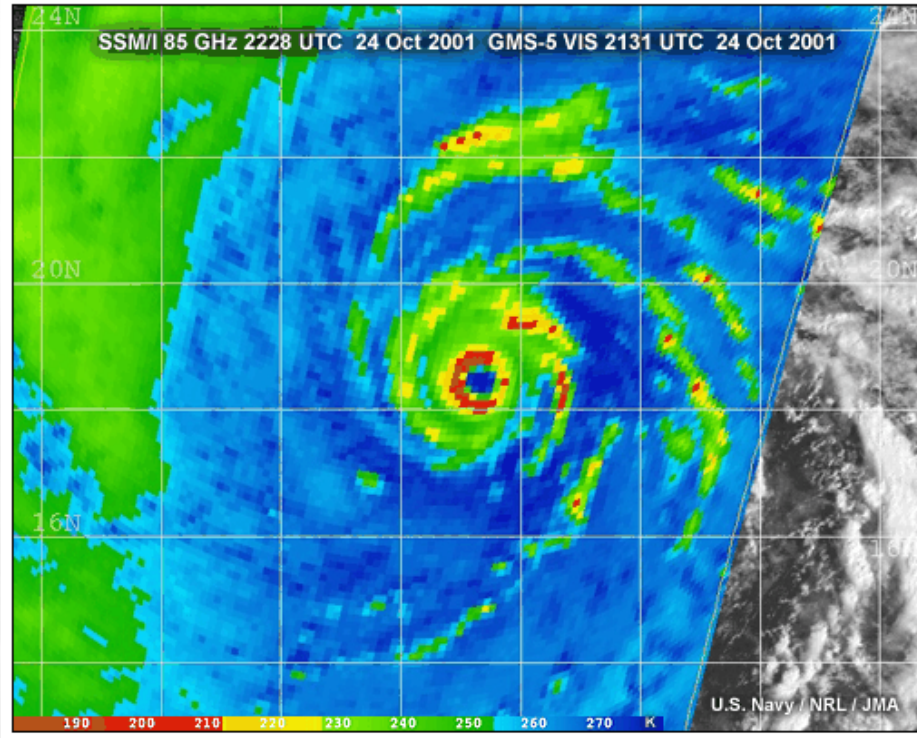
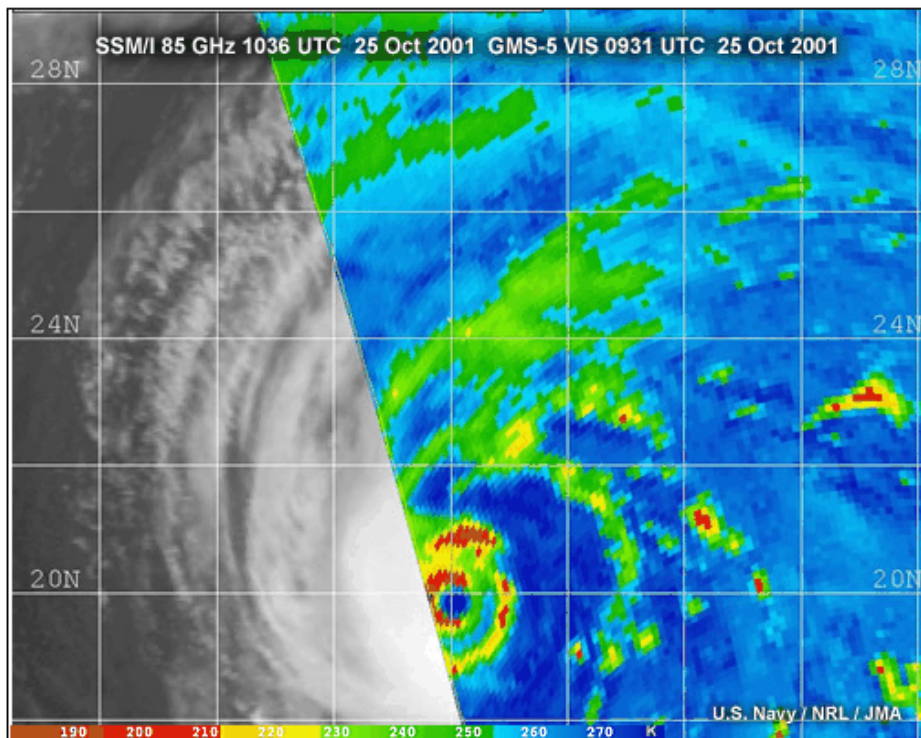
Note degradation in resolution at edge of scan compared to nadir

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 atcf2ctr 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_S50_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

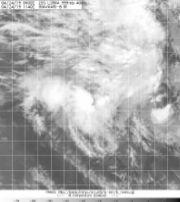
Forecast by [Joint Typhoon Warning Center/Naval Maritime Forecast Center](#)

Graphic by [Naval Maritime 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 fl5 1039	04/24 21:24Z F-15 4
		04/24 10:35Z F-16 235
		04/25 01:19Z F-17 658
SSMIS	04/24 1033Z fl6 235	04/24 11:30Z F-18 747
GMI	None	
MHS	04/25 03:03Z N-18 335	
	04/24 0408Z metopa 0	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

20

NRL Tropical Cyclone Webpage

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

← → ↻ 🏠 <https://www.nrlmry.navy.mil/TC.html> YEAR=2019&MO=04&BASIN=SHEM&STORM_NAME=24S.KENNETH&PROD=tra

Apps NHC HSU Intranet Hurricane Diagnosti... Recon Time Series atcf2ctr Files ATCF2GIS TC-genesis probs HSU-Wiki

[Privacy Policy](#) [Disclaimer](#) **NRL Tropical Cyclone Page** [Development Team](#)

NOTE: this page is short lived (10 m). Please DO NOT bookmark it or save it to Favorites; instead, bookmark <http://www.nrlmry.navy.mil/TC.html> thank you.
 NOTE: Web page not available Wed April 24 1300 to 1600 UTC.

2019 Season Storms
 All Active Your

Atlantic
 East Pacific
 Central Pacific
 West Pacific
 Indian Ocean
 91B.INVEST
 Southern Hem.
 92S.INVEST
 25S.LORNA
 24S.KENNETH

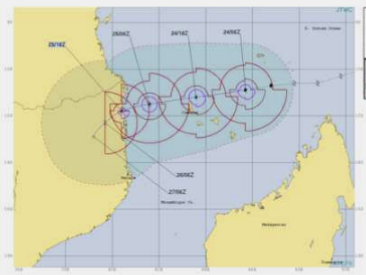
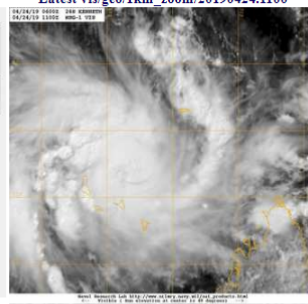
Environment TPW TPW+NAVEM_TPW TPW+NAVEM_850_Winds Wind_Shear **COMPS_TC**

Sensor	% Cov	VIS	IR	IR-BD	Multi Sens.	85GHz H	85GHz weak	85GHz PCT	Color	Rain	Wind	37GHz Color	37GHz V	37GHz H	SSM/I Vapor	VIS	IR	Vapor
SSM/I	47	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SSM/S	91	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
GMI	30	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
AMSR2	30	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
WINDSAT	88	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
AMSUB		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

24S.KENNETH, TRACK_VIS, 24 APR 2019 1100Z [12:25:16 UTC (Z)] [Overview](#) Tutorials: **COMET**

Forecast by: Joint Typhoon Warning Center (JTWC)
 Graphic by: Joint Typhoon Warning Center (JTWC)

Latest ATCF Track: <smsh242019.19042400.jpg> Latest vis/geo/1km_zoom/20190424.1100

(Click product for full sized image)

Sensor	Satellite Pass Info	
	Latest	Next (View All)
SSM/I	04/23 2320 Z, F-15 0935	04/23 2340 Z, F16 1771
TC_SSMIS	04/24 0313 Z, F-17 0342	04/24 0356 Z, F18 2662
GMI	04/24 0451 Z, GPM 0562	04/24 1450 Z, GPM 1381
AMSR2	04/23 2131 Z, GCOMW-1 0000	04/23 2134 Z, GCOM-W1 1334
WINDSAT	04/24 0259 Z, CORIOLIS 1067	04/24 0301 Z, CORIOLIS 0019
AMSUB	/ Z Z, 0000	/ Z Z, 0000
SCATT	/ Z Z, 0000	/ Z Z, 0000

[Sat_Home](#) [East_Pacific-WestCoast](#) [Global](#) [RainRate](#) [CloudTops](#) [Training](#) [TropCyclones](#)
[NexSat](#) [Tropics](#) [CloudWinds](#) [ScatWinds](#)

NRL Home Page | Search

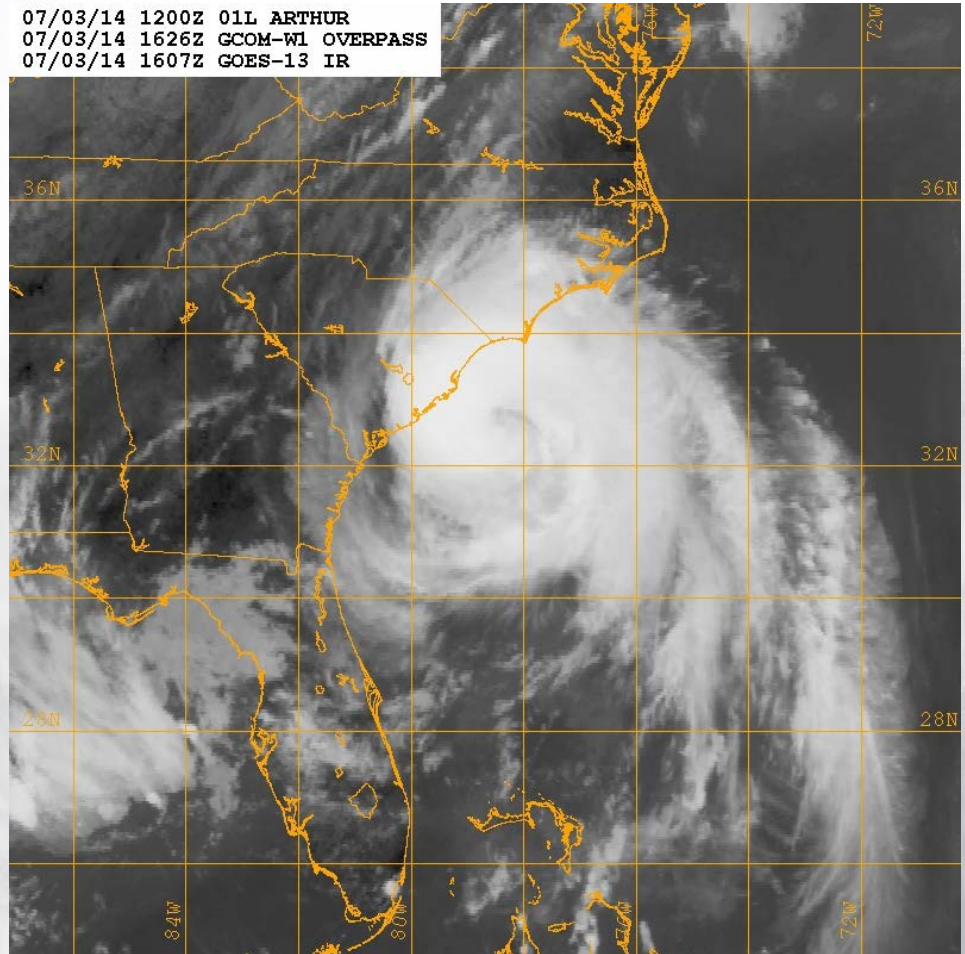
Page Generated: Wed Apr 24 12:24:58 2019 GMT
 To Page For: 4.59.02 (3/9/2019)
 Approved for public release by: Superintendent
 Sat Section Head
 Webmaster

A satellite image of a tropical cyclone, showing a well-defined eye and spiral cloud bands. The image is centered on the cyclone, with the eye appearing as a bright white circle in the middle. The surrounding clouds are dense and spiral outwards, creating a characteristic eye-wall structure. The background is a light blue gradient, suggesting the sky or the ocean surface.

Imagery Characteristics and Applications

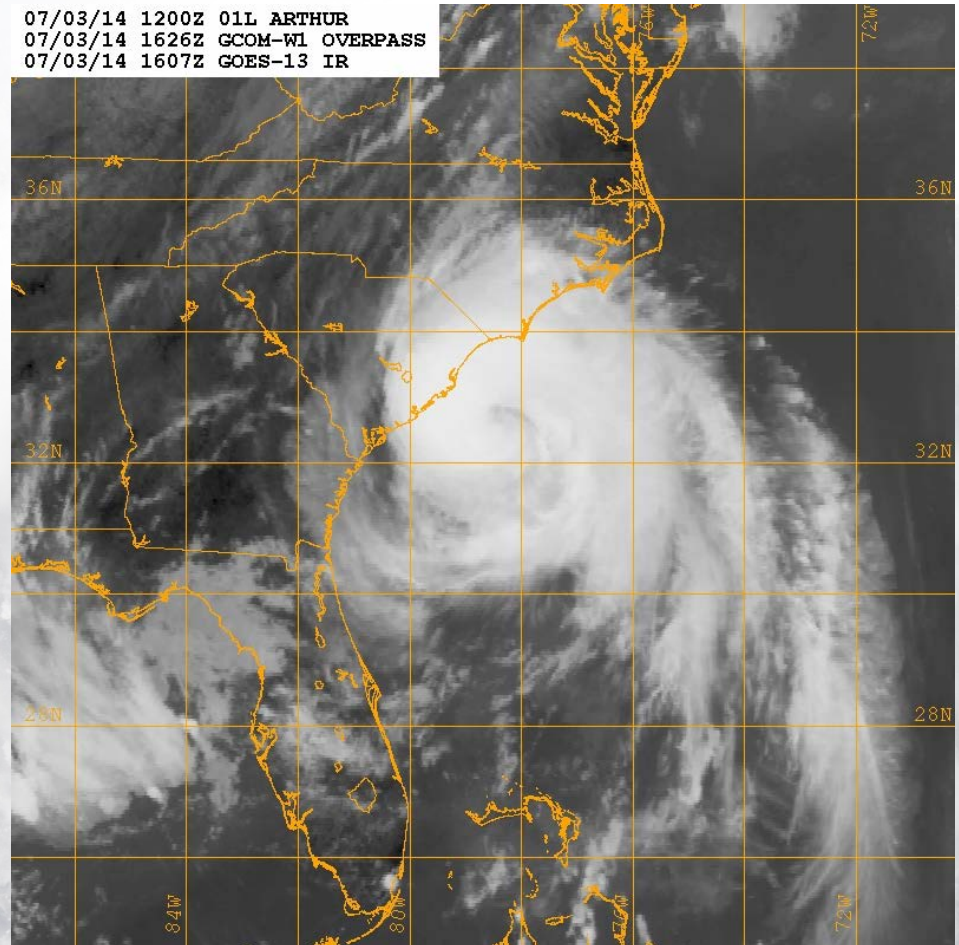
85-GHz Imagery

- 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)



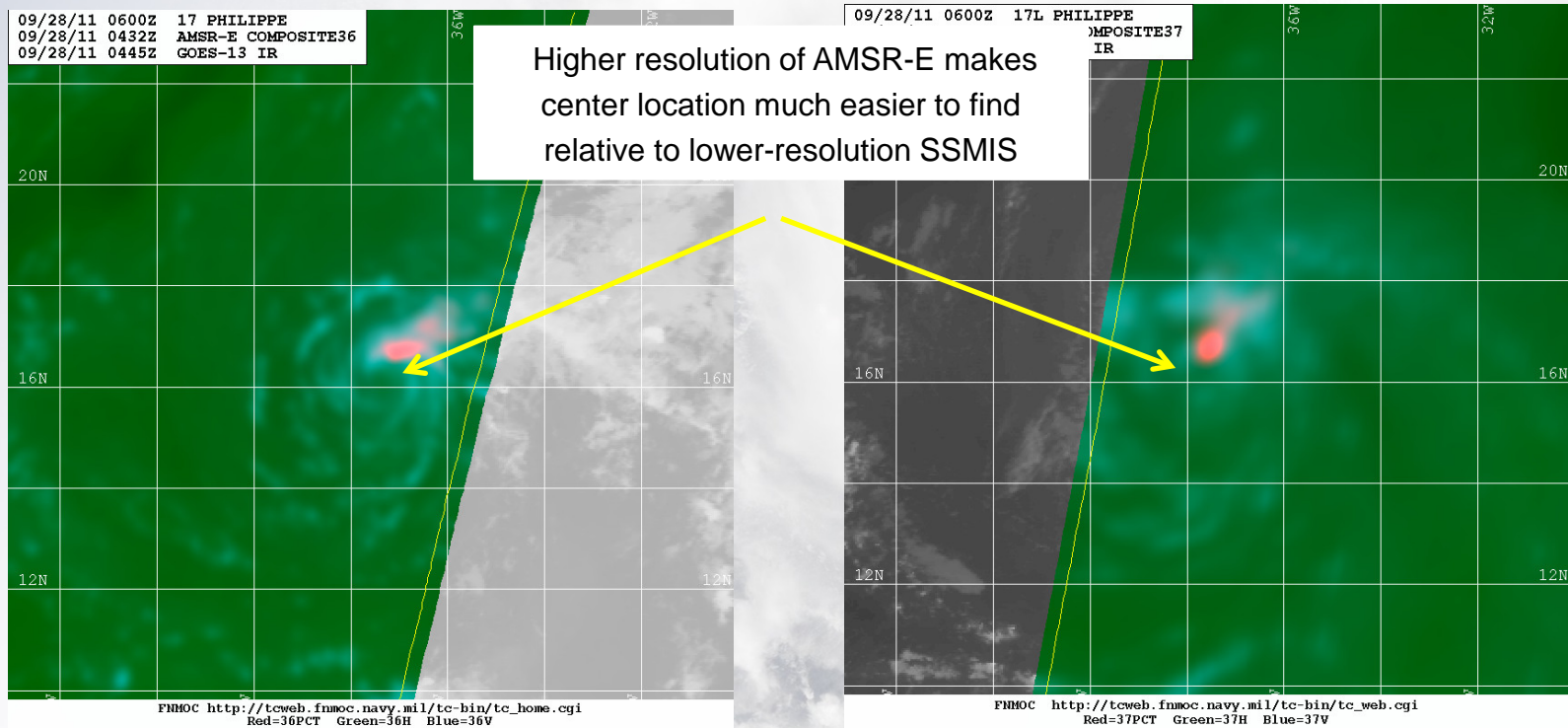
Advantages of Using 85-GHz and 37-GHz Imagery for TC Analysis

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 are directly related to intensification of the TC
- Monitoring structural changes such as eyewall formation and eyewall replacement cycles

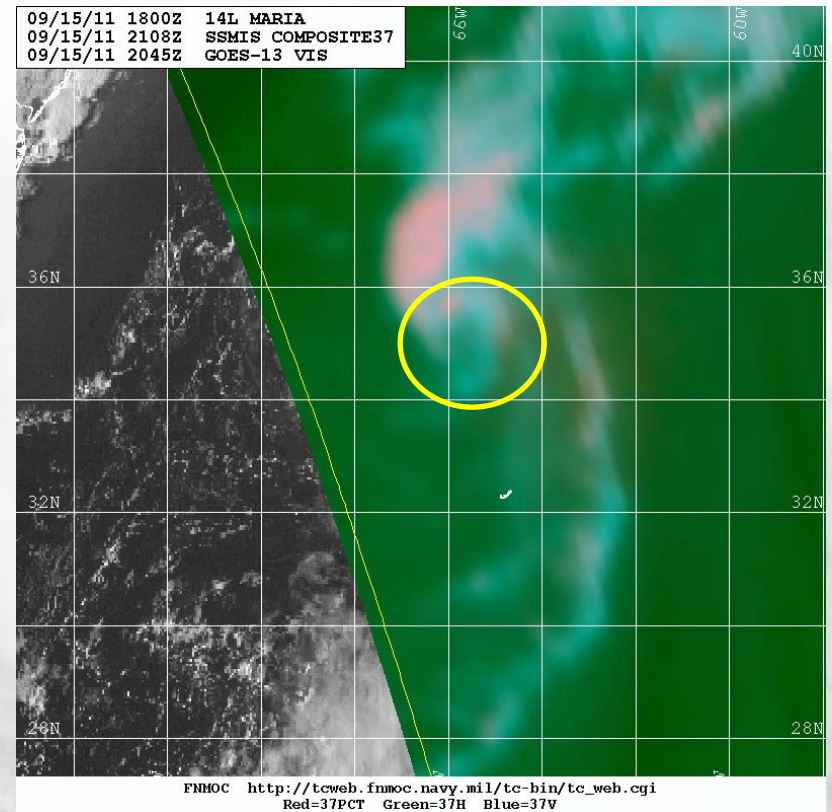
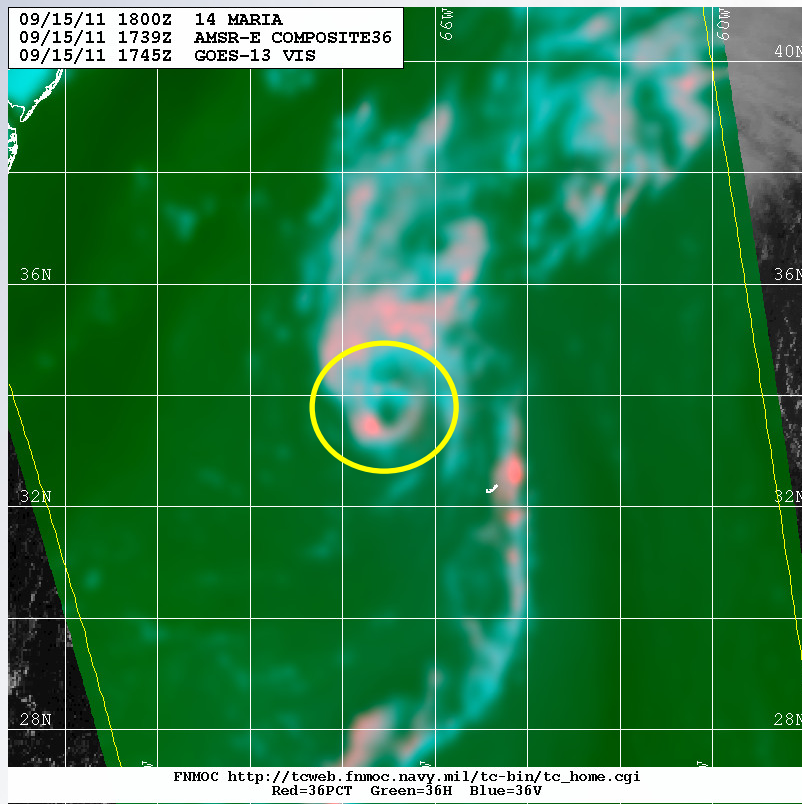
Effects of Resolution

- 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



Effects of Resolution

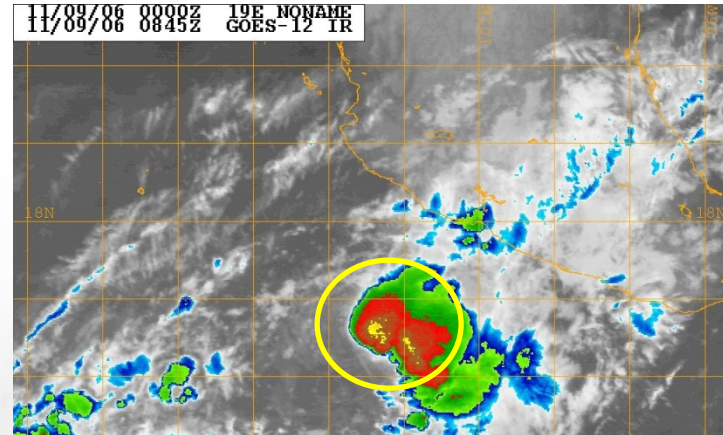
- Resolution differences also affect the ability to resolve low to mid-level eyewall structure



- 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.

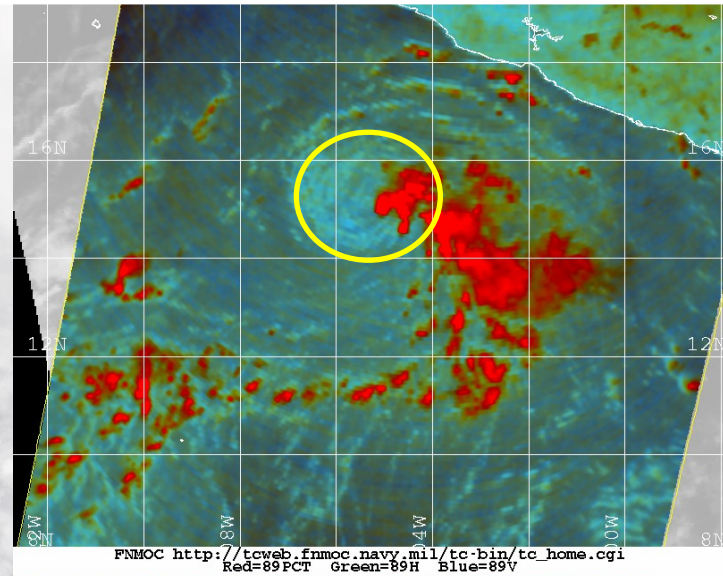
Importance of Center Location

- 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



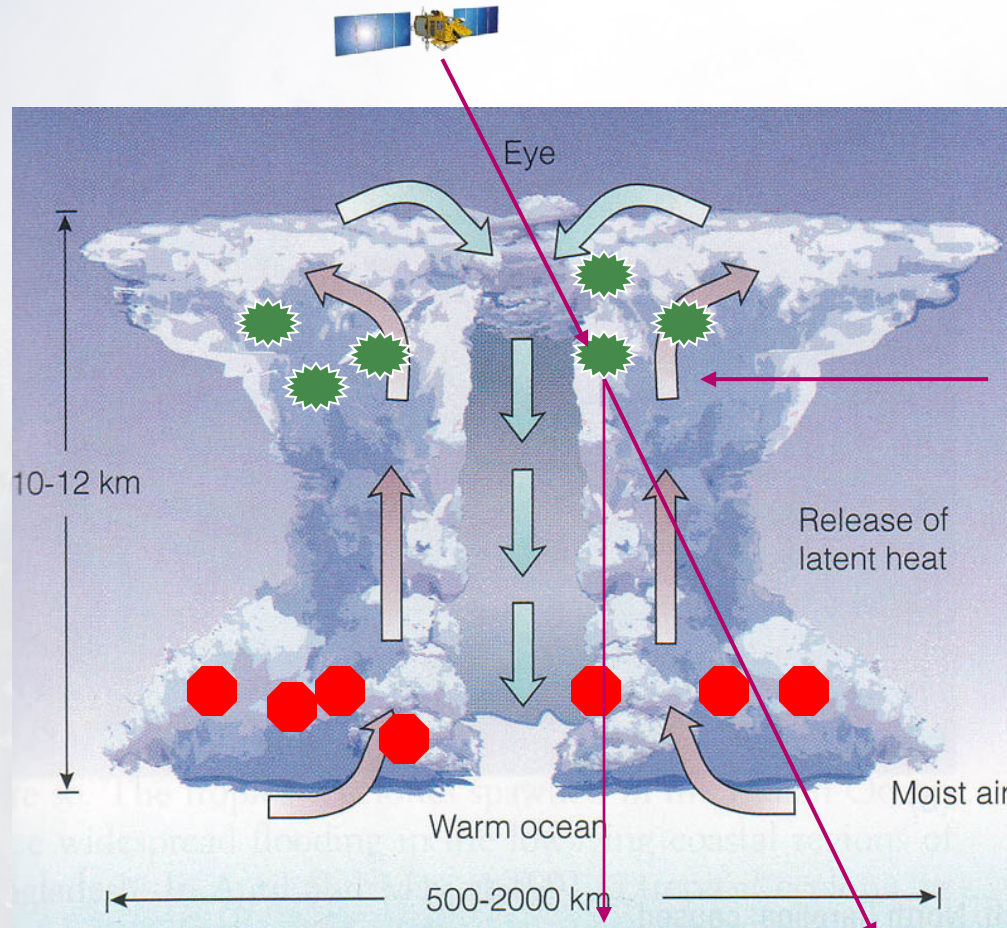
Parallax Error in Center Fixing

- 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)



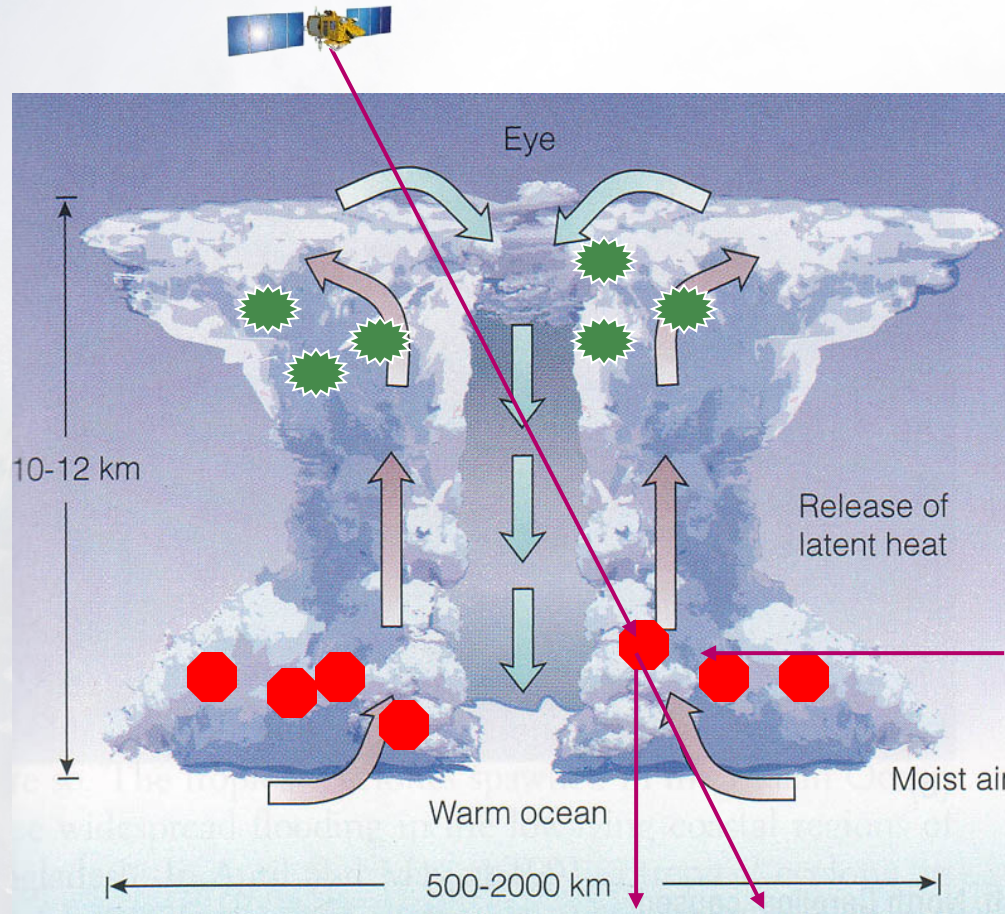
Effective
Level of
hydrometeors

85 GHz
Parallax

37-GHz Parallax

Ice Crystals
(85 GHz)

Raindrops
(37 GHz)

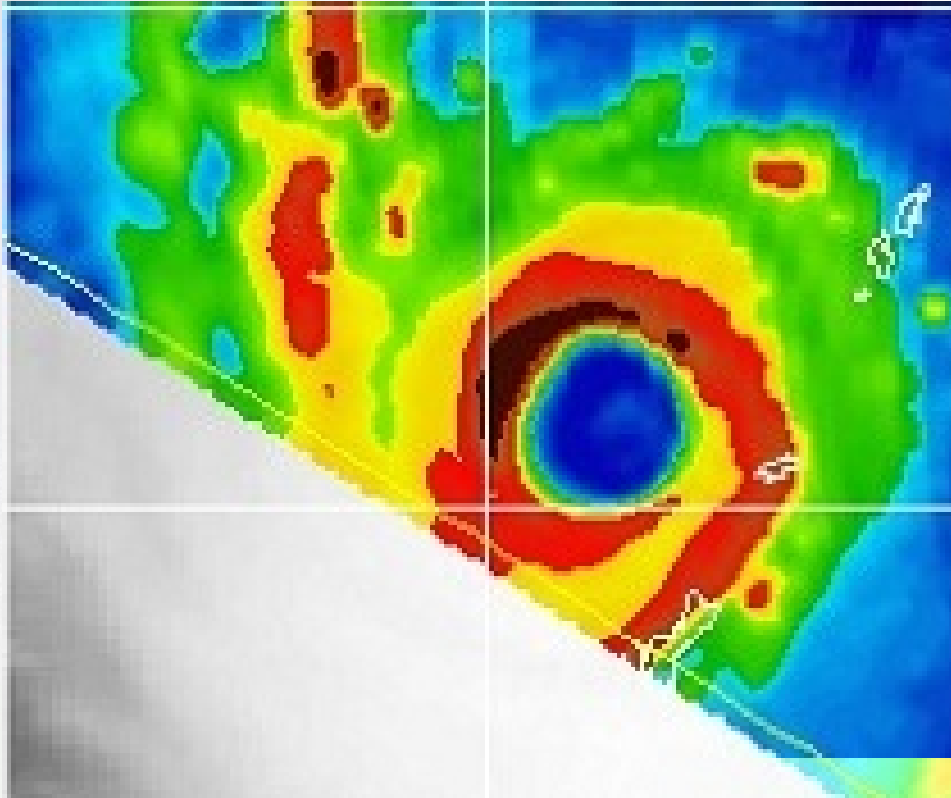


Effective
Level of
hydrometeors

X Y

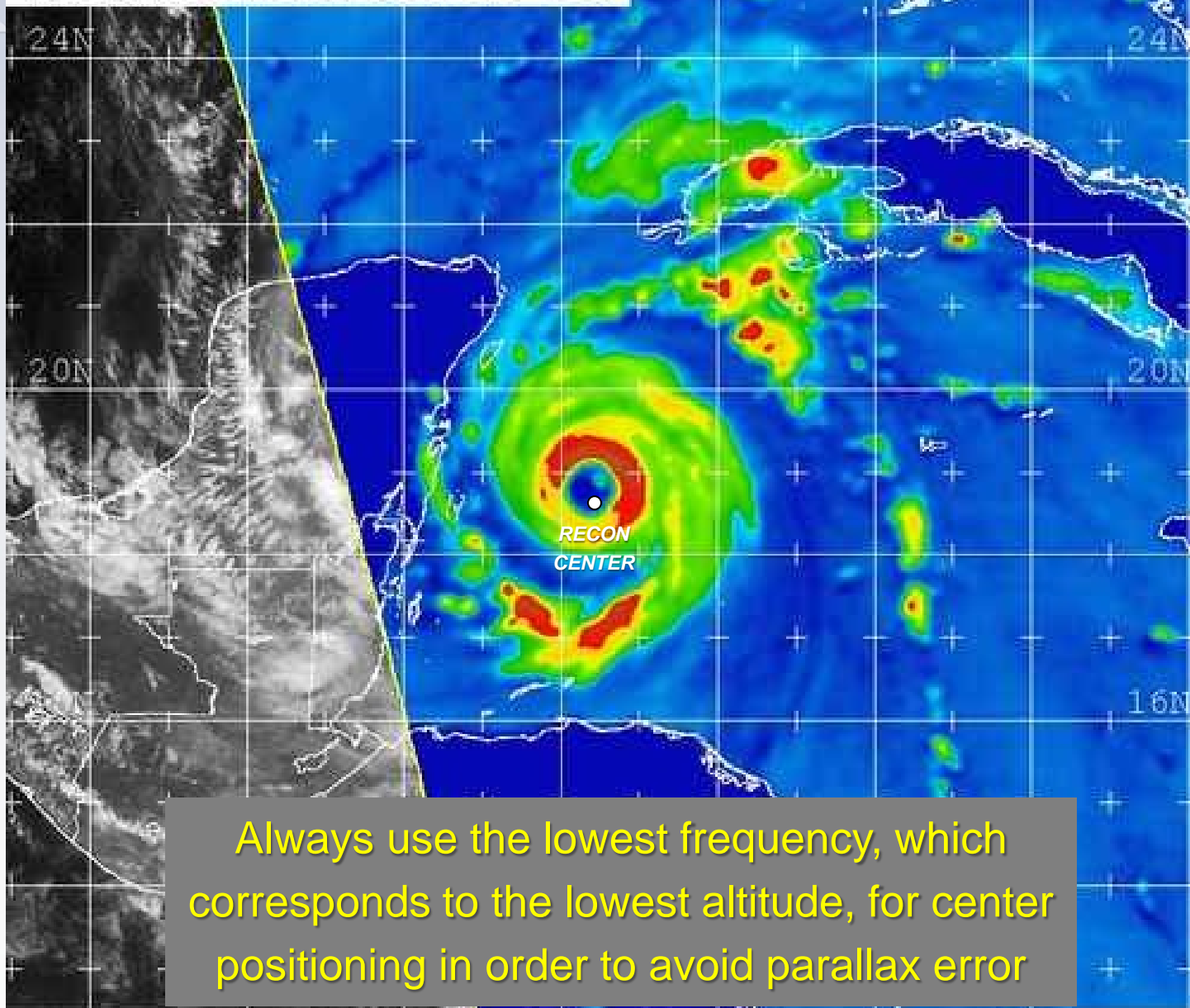
37 GHz
Parallax

Eye Size Example



85 H
37 V

10/20/05 1800Z 24L WILMA
10/20/05 1845Z AQUA-1 89H
10/20/05 1745Z GOES-12 VIS

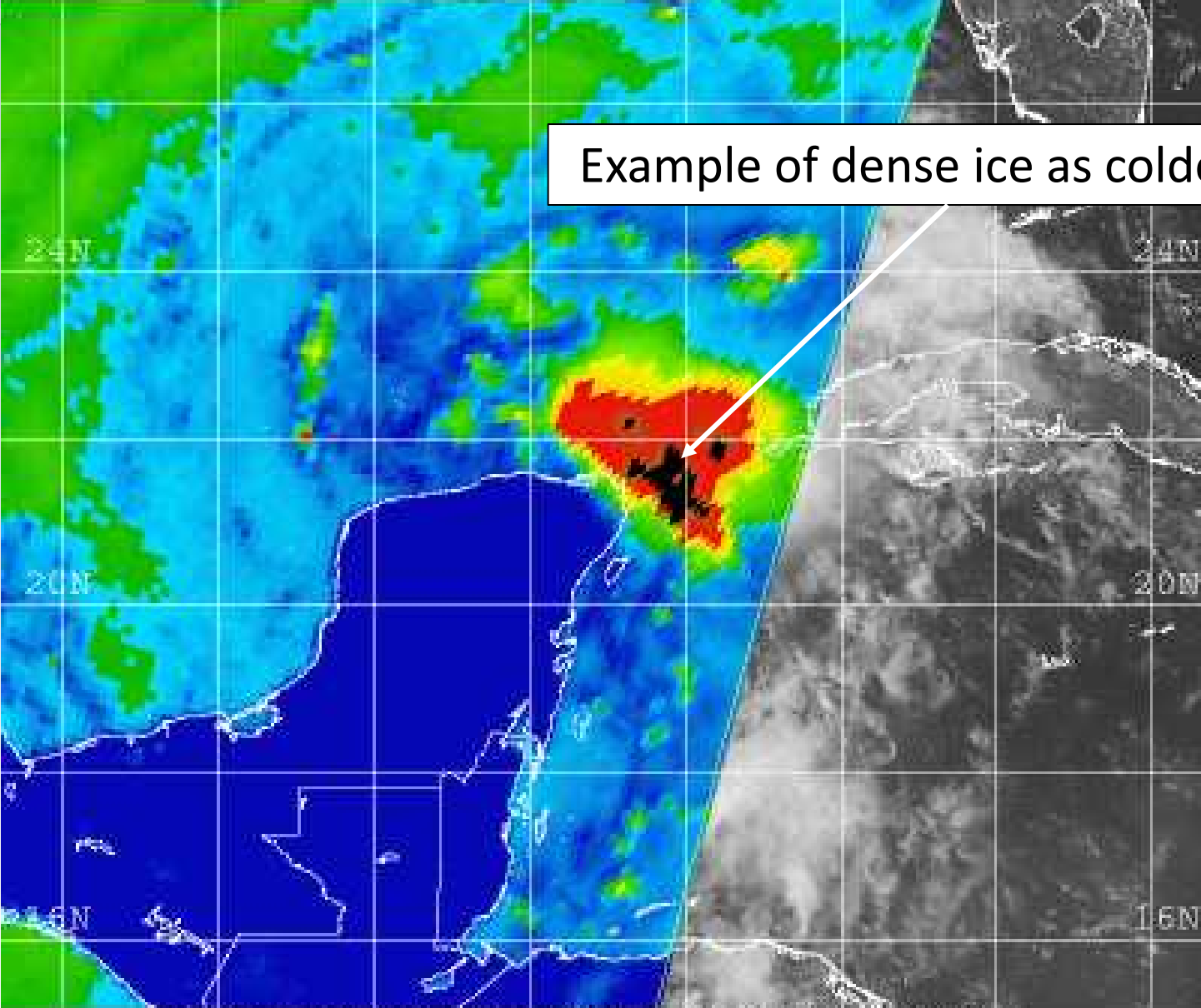


Always use the lowest frequency, which corresponds to the lowest altitude, for center positioning in order to avoid parallax error

Naval Research Lab www.nrlmry.navy.mil/sat_products.html
<-- 89H Brightness Temp (Kelvin) -->

175 185 195 205 215 225 235 245 255 265 275

07/11/03 1200Z 04 CLAUDETTE
07/11/03 1543Z SSMI F-15 85H
07/11/03 1515Z GOES-12 VIS



Example of dense ice as coldest T_b

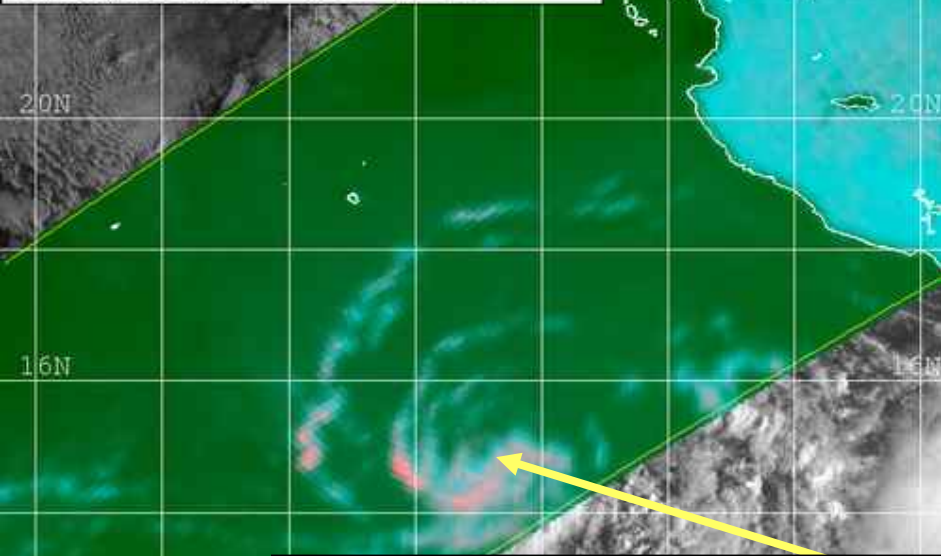
FMOC http://www.fmoc.navy.mil/tc_web.html
← 85H GHz Brightness Temperature (Kelvin) →



Color Composite Imagery

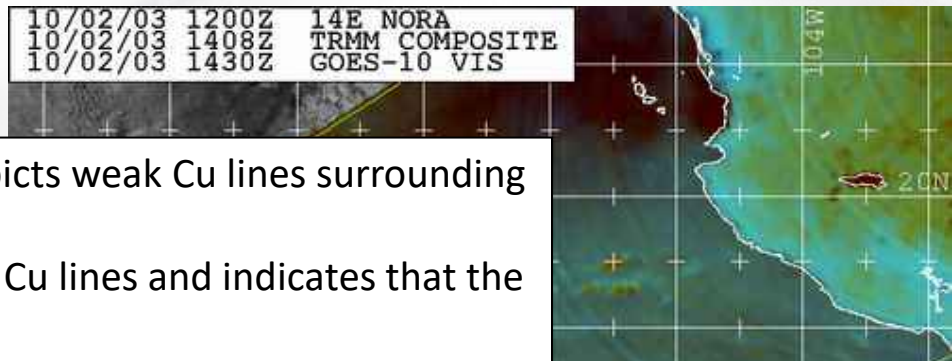
- Color composite images combine PCT with V and H polarizations to remove ambiguities between convection and the sea surface
 - 85 color composite- PCT (red), V (blue), H (green)
 - Deep convection (red)
 - Low-level clouds, water vapor, warm precipitation (blue-green)
 - Relatively cloud-free (gray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

10/02/03	1200Z	14E NORA
10/02/03	1408Z	TRMM COMPOSITE37
10/02/03	1430Z	GOES-10 VIS



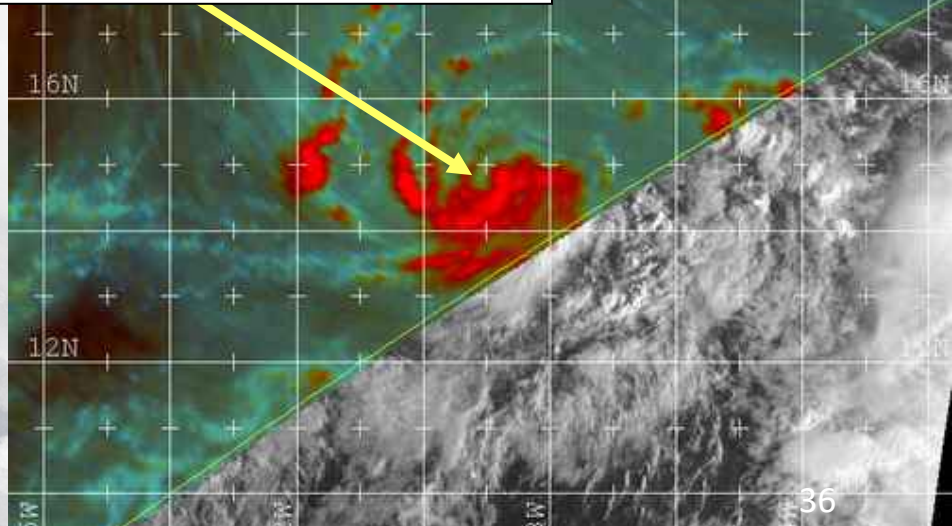
Color Composite

10/02/03	1200Z	14E NORA
10/02/03	1408Z	TRMM COMPOSITE
10/02/03	1430Z	GOES-10 VIS

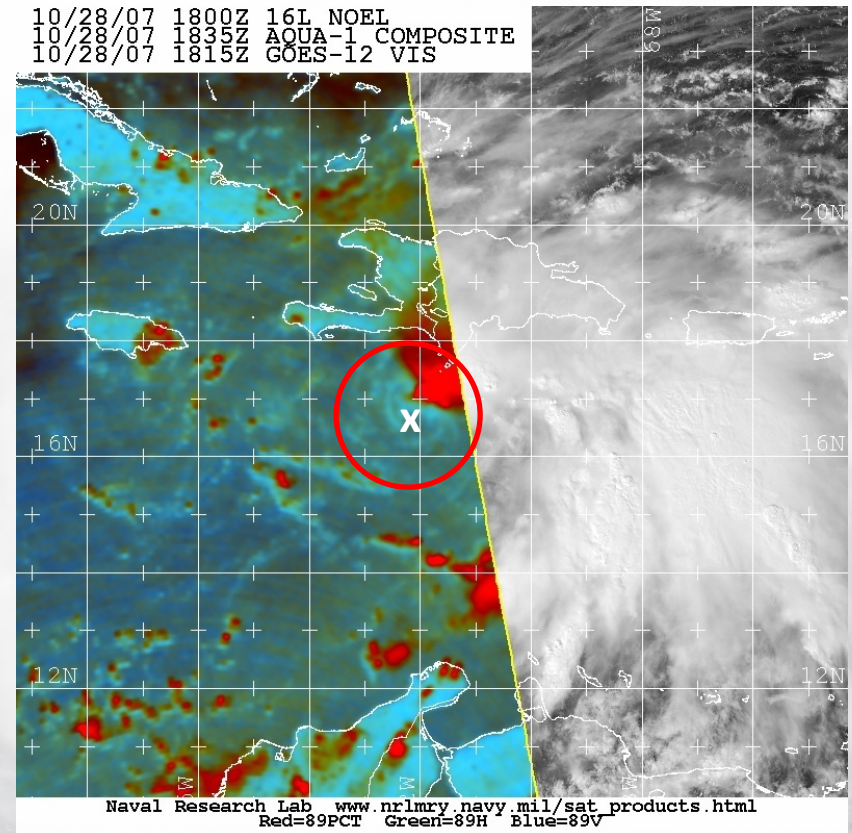
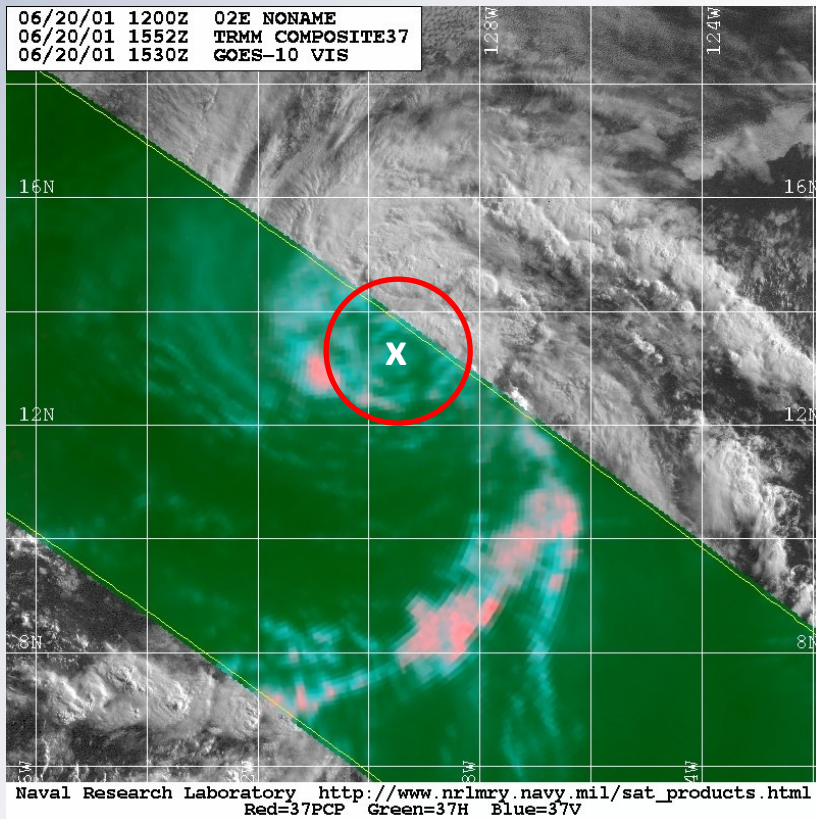


- 37-GHz PCT (37H/37V composite) depicts weak Cu lines surrounding the LLCC
- 85-GHz PCT fails to define the weaker Cu lines and indicates that the center may be further south

10/02/03	1200Z	14E NORA
10/02/03	1408Z	TRMM COMPOSITE
10/02/03	1430Z	GOES-10 VIS



Positioning in Microwave Imagery

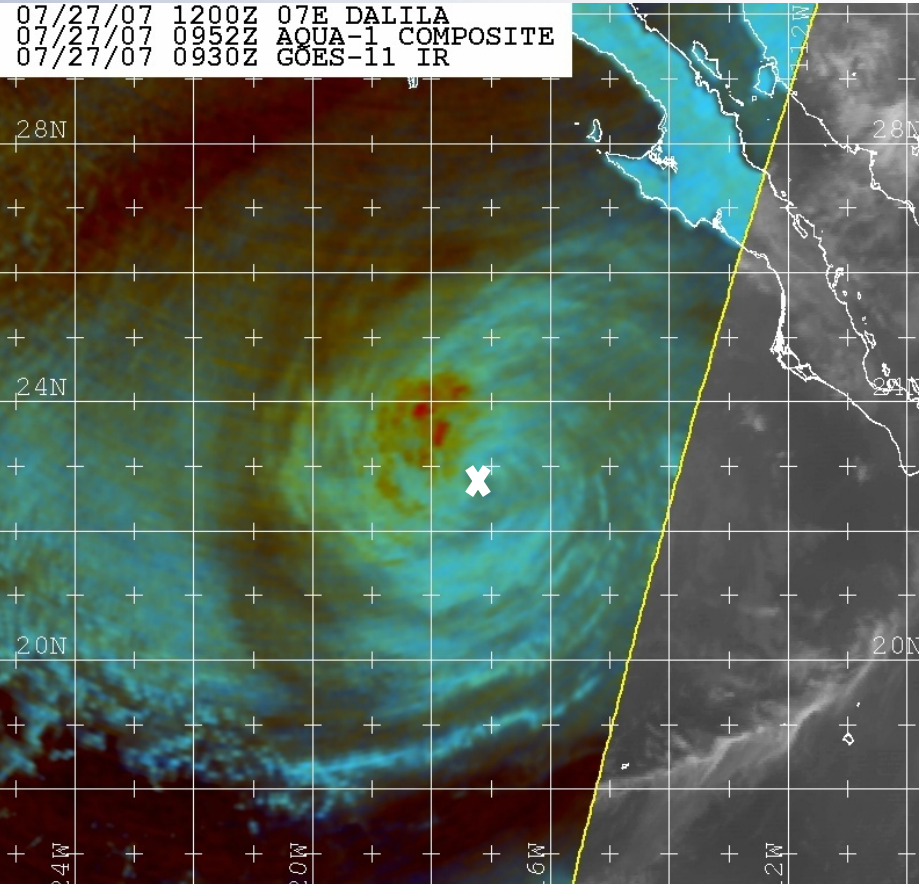


Try to position in the rain-free dry area—out of the convection

Positioning in Microwave Imagery

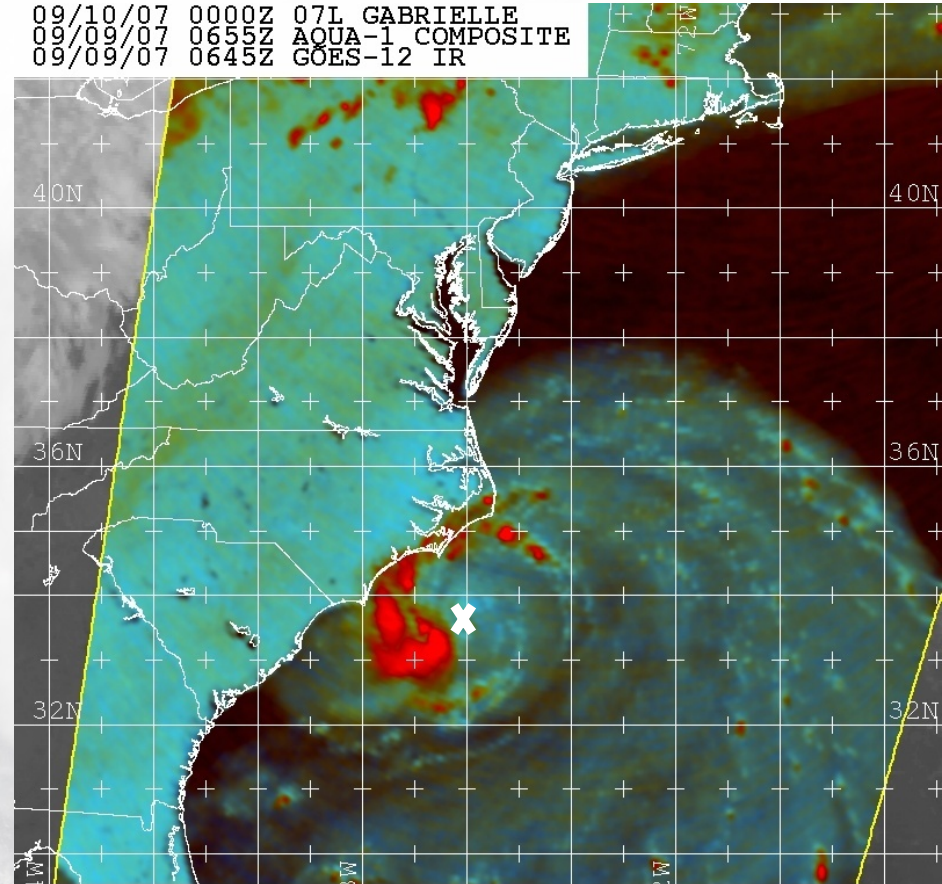
Look for convective free darker areas

07/27/07 1200Z 07E DALILA
07/27/07 0952Z AQUA-1 COMPOSITE
07/27/07 0930Z GOES-11 IR



Naval Research Lab www.nrlmry.navy.mil/sat_products.html
Red=89PCT Green=89H Blue=89V

09/10/07 0000Z 07L GABRIELLE
09/09/07 0655Z AQUA-1 COMPOSITE
09/09/07 0645Z GOES-12 IR

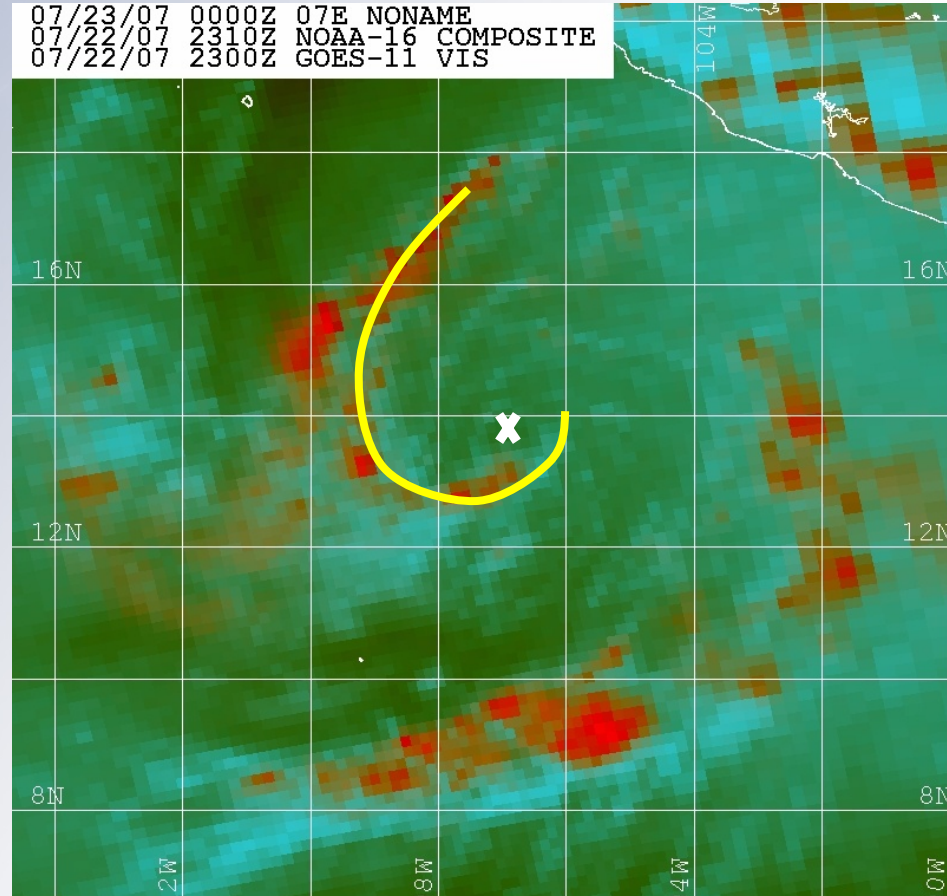


Naval Research Lab www.nrlmry.navy.mil/sat_products.html
Red=89PCT Green=89H Blue=89V

Positioning in Microwave Imagery

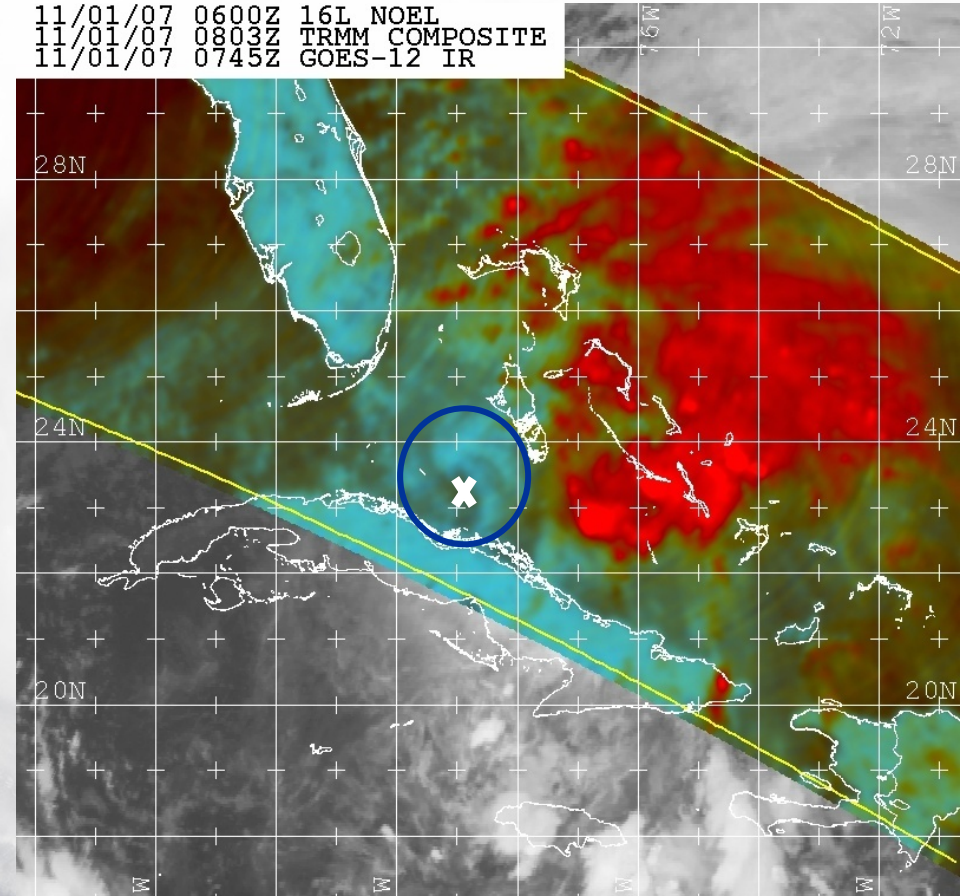
Look for low cloud curvature

07/23/07 0000Z 07E NONAME
07/22/07 2310Z NOAA-16 COMPOSITE
07/22/07 2300Z GOES-11 VIS

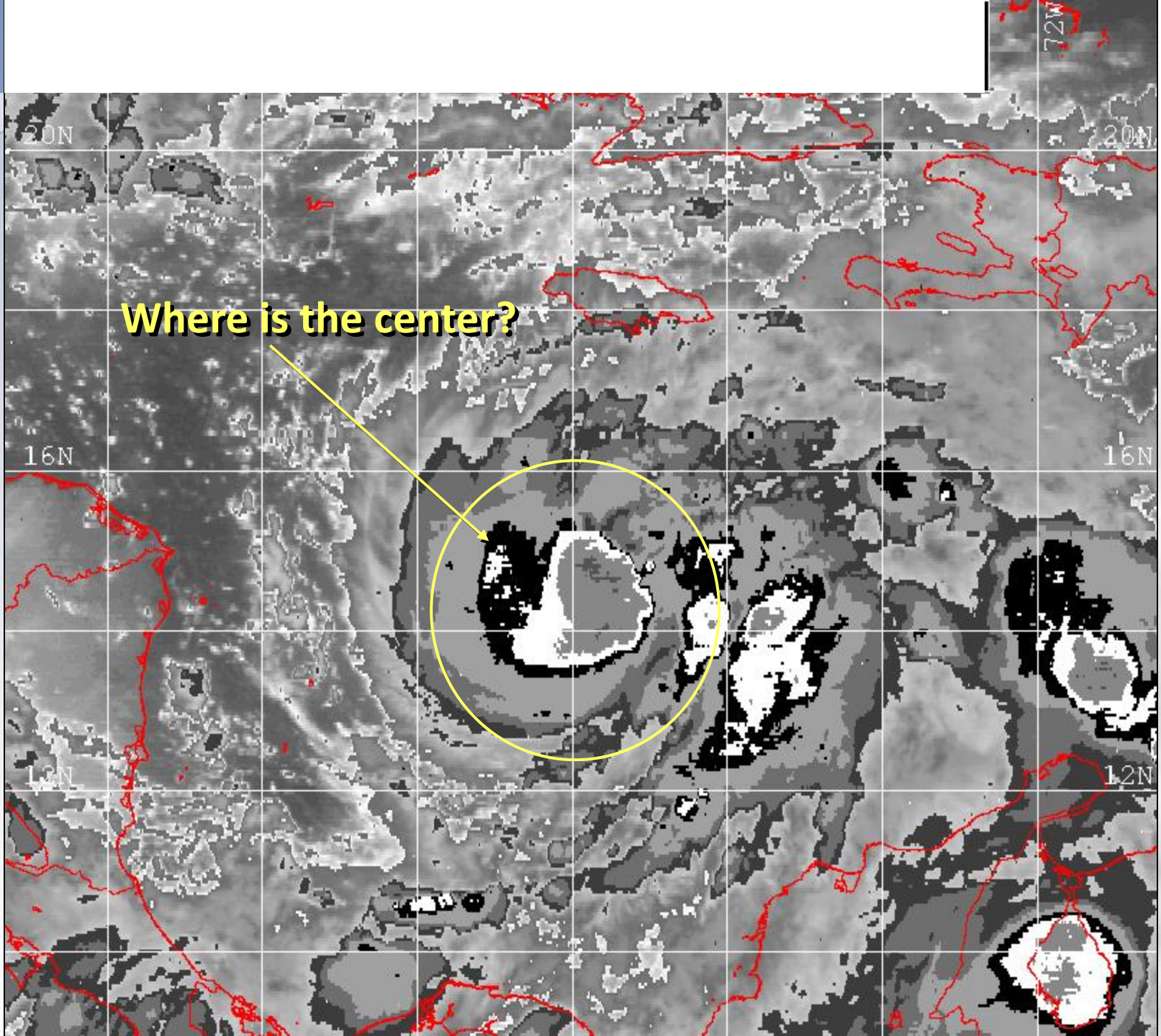


Naval Research Lab www.nrlmry.navy.mil/sat_products.html
Red=150 Green=89 Blue=89

11/01/07 0600Z 16L NOEL
11/01/07 0803Z TRMM COMPOSITE
11/01/07 0745Z GOES-12 IR

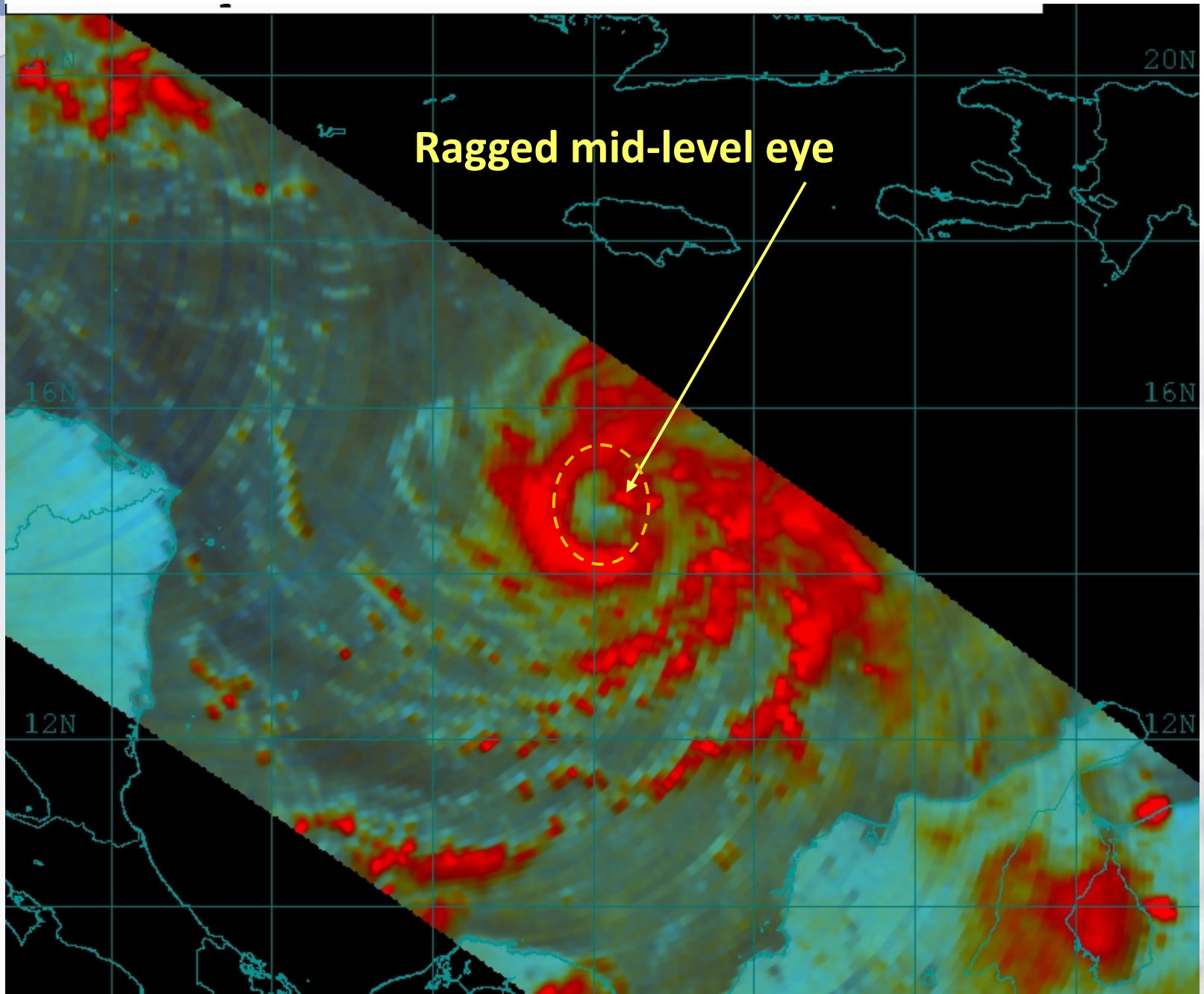


Naval Research Lab www.nrlmry.navy.mil/sat_products.html
Red=85PCT Green=85H Blue=85V

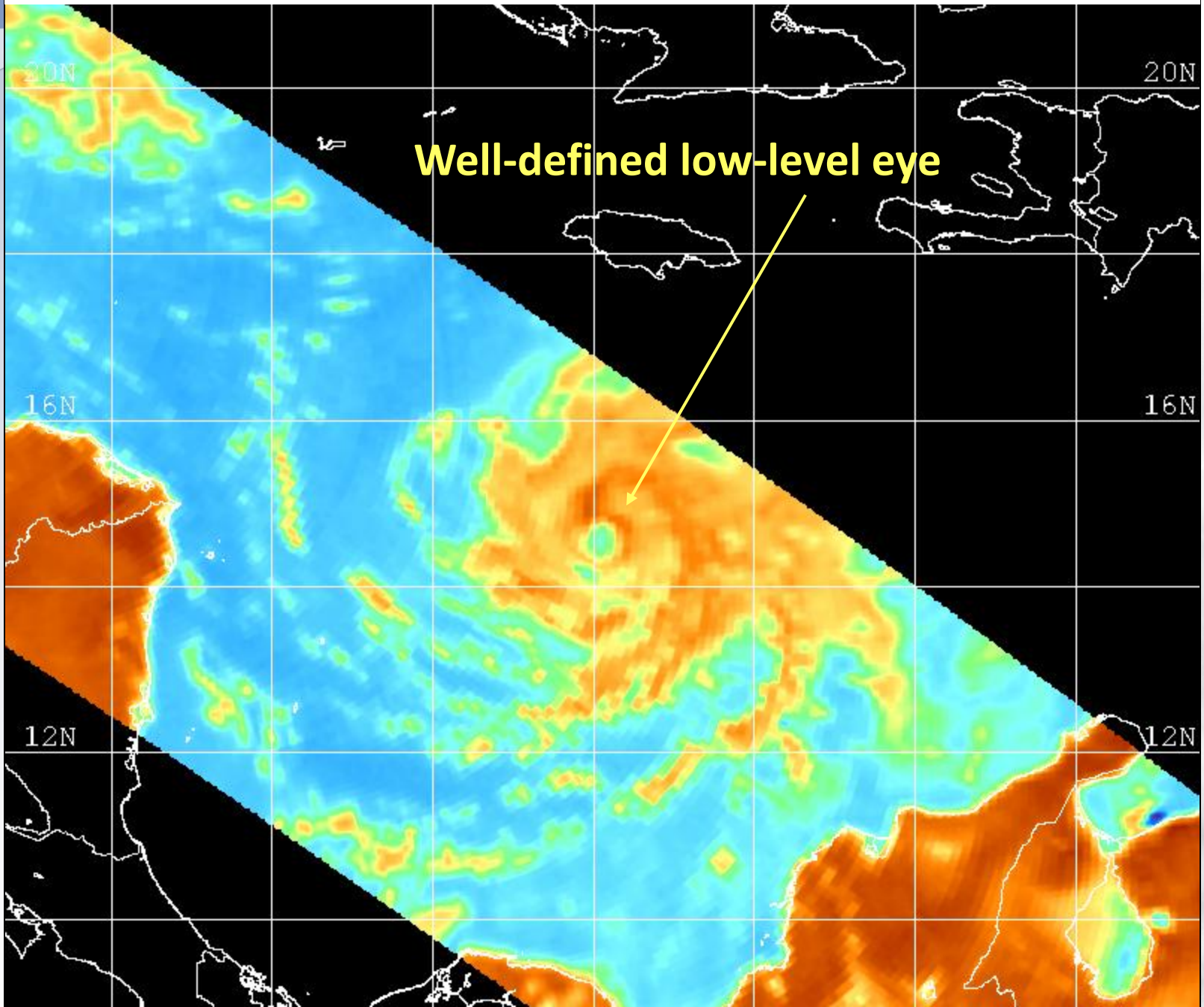


Where is the center?

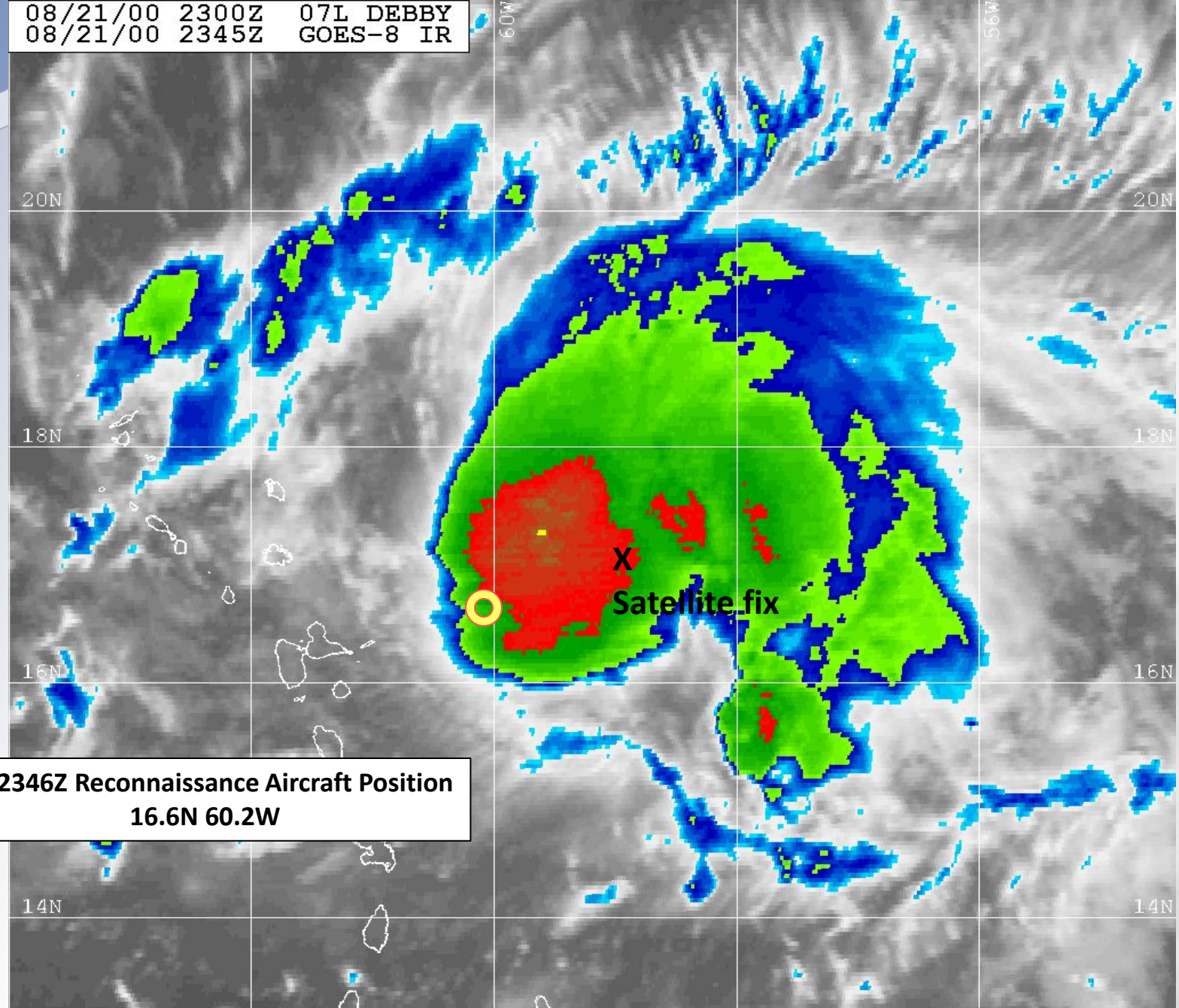
85 GHz Color-Composite Example



37 GHz Example



08/21/00 2300Z 07L DEBBY
08/21/00 2345Z GOES-8 IR

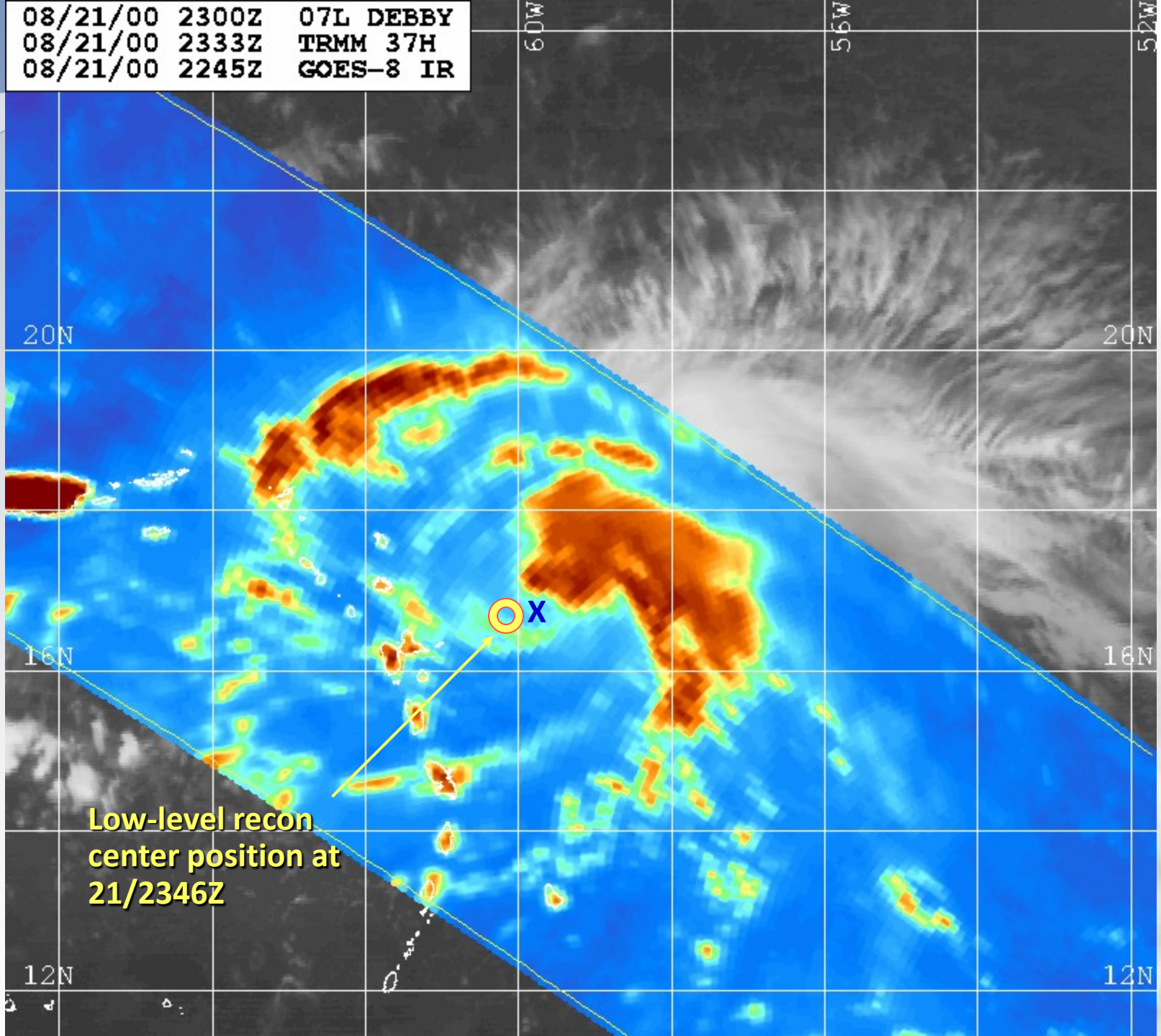


**21/2346Z Reconnaissance Aircraft Position
16.6N 60.2W**

Naval Research Laboratory http://www.nrlmry.navy.mil/sat_products.html
← IR Temperature (Celsius) →

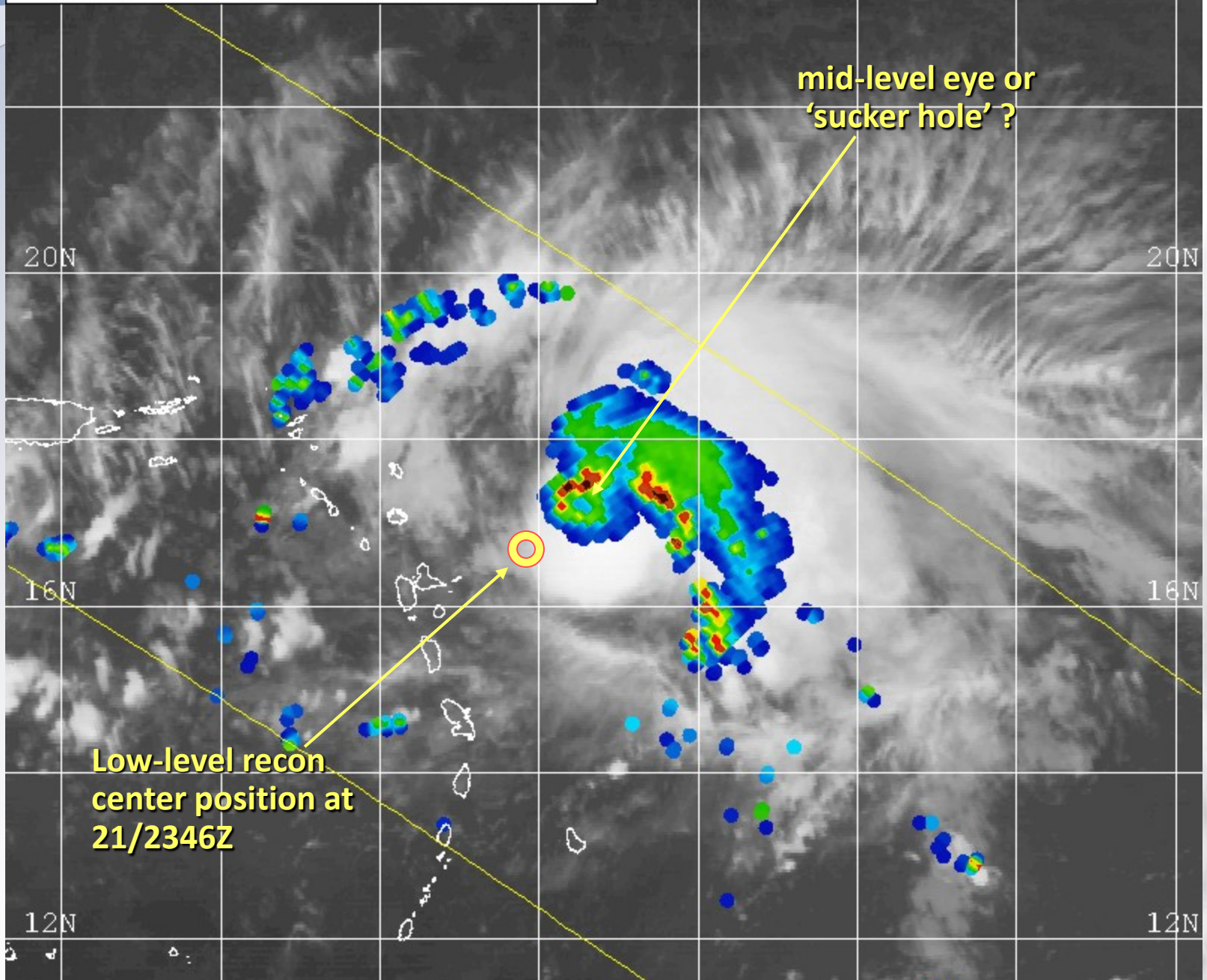


08/21/00 2300Z 07L DEBBY
08/21/00 2333Z TRMM 37H
08/21/00 2245Z GOES-8 IR



**Low-level recon
center position at
21/2346Z**

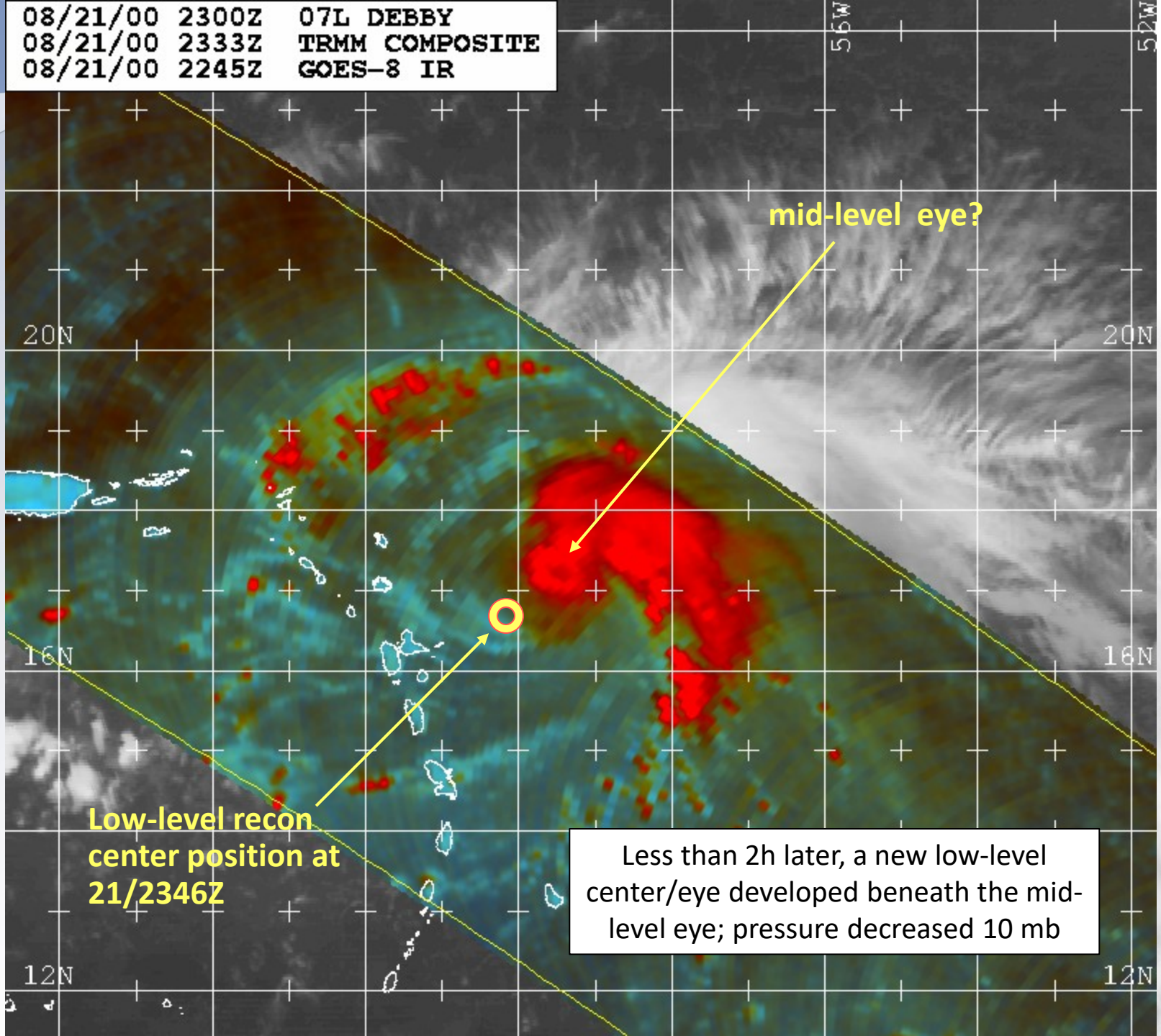
08/21/00 2300Z 07L DEBBY
08/21/00 2333Z TRMM 85 GHz PCT
08/21/00 2245Z GOES-8 IR



Low-level recon
center position at
21/2346Z

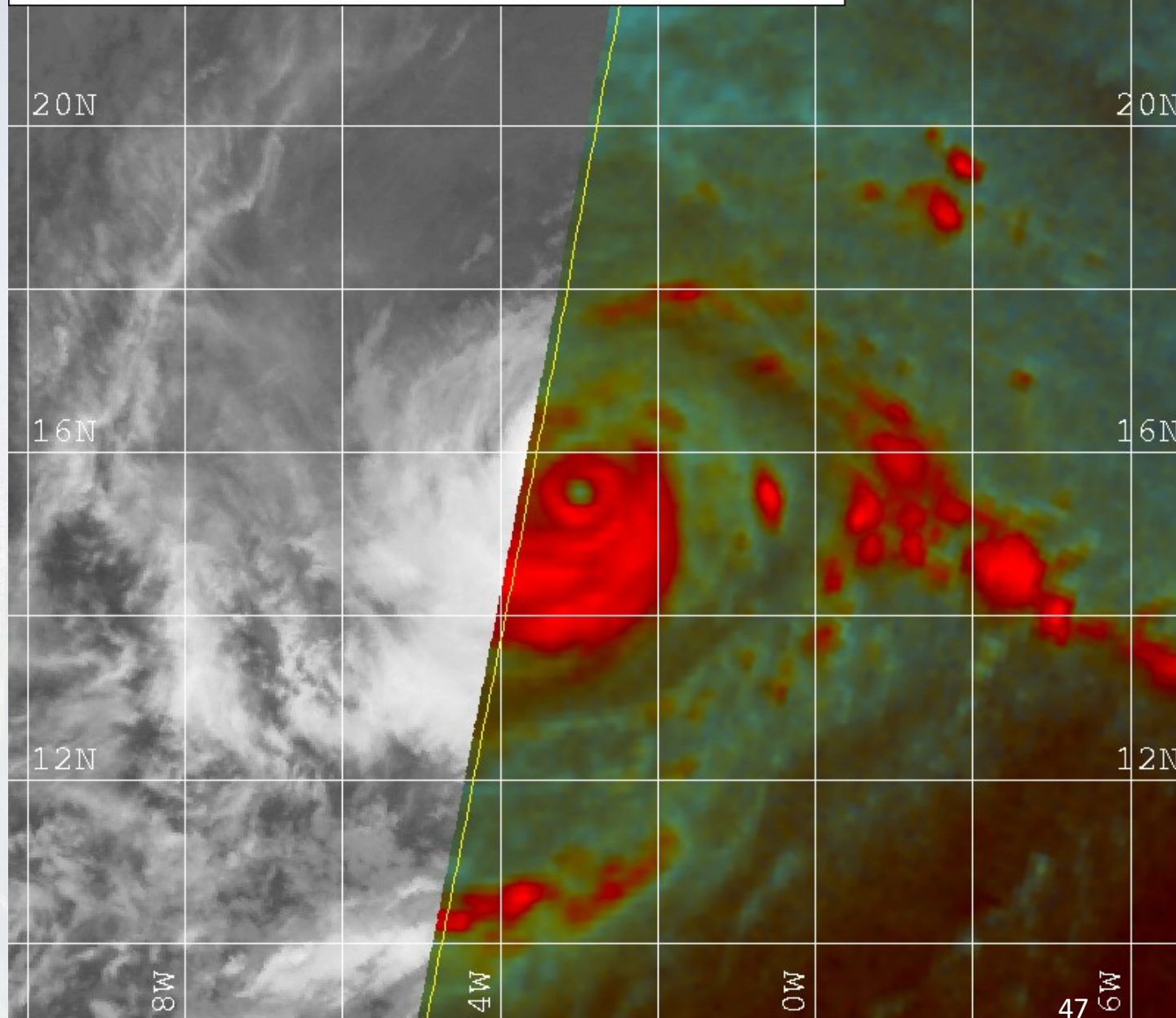
mid-level eye or
'sucker hole'?

08/21/00 2300Z 07L DEBBY
08/21/00 2333Z TRMM COMPOSITE
08/21/00 2245Z GOES-8 IR



08/09/08 1200Z 09 HERNAN
08/09/08 1318Z SSMIS F-17 COMPOSITE
08/09/08 1330Z GOES-11 IR

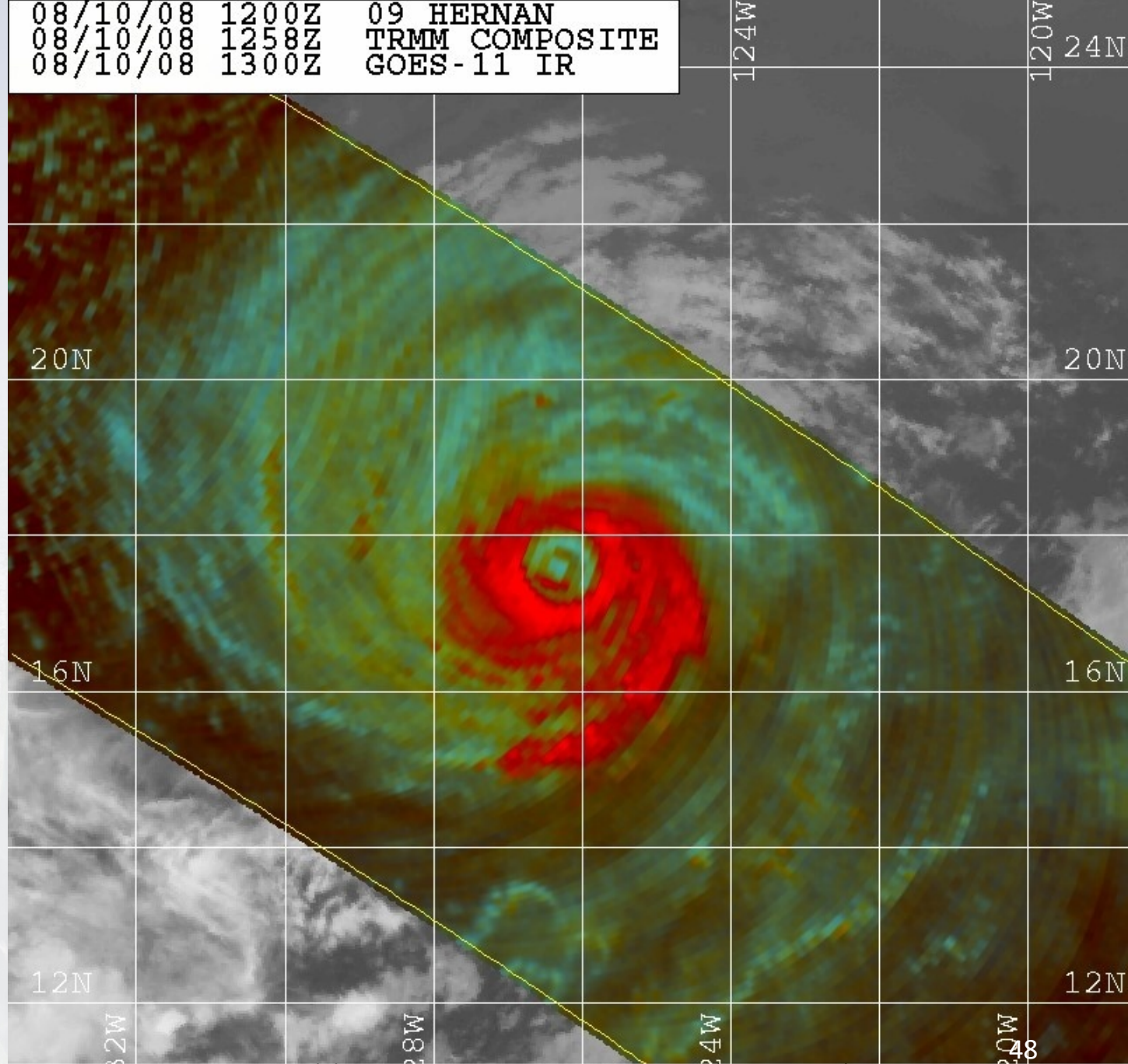
Hernan near
peak intensity
9 Aug 2008



FNMOC http://tcweb.fnmoc.navy.mil/tc-bin/tc_web.cgi
Red=91PCT Green=91H Blue=91V

08/10/08 1200Z 09 HERNAN
08/10/08 1258Z TRMM COMPOSITE
08/10/08 1300Z GOES-11 IR

Hernan Eyewall
Replacement
Cycle 24 h later
10 Aug 2008

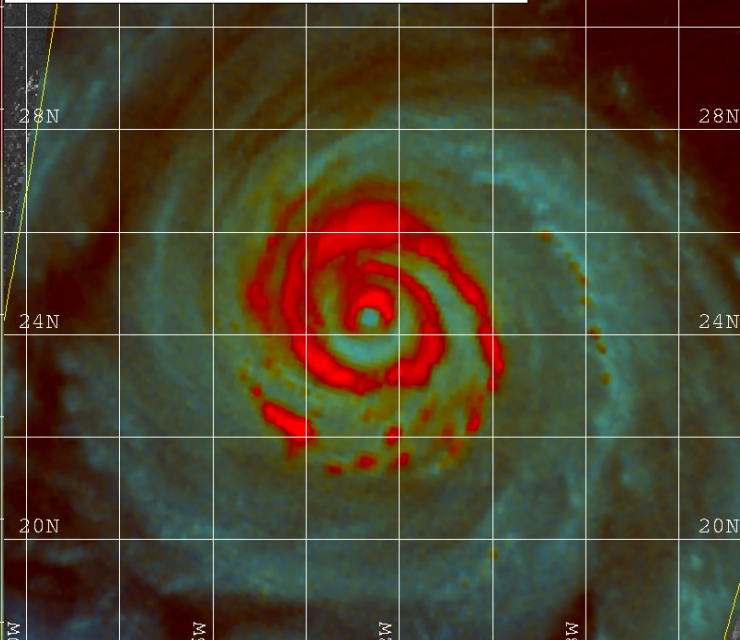
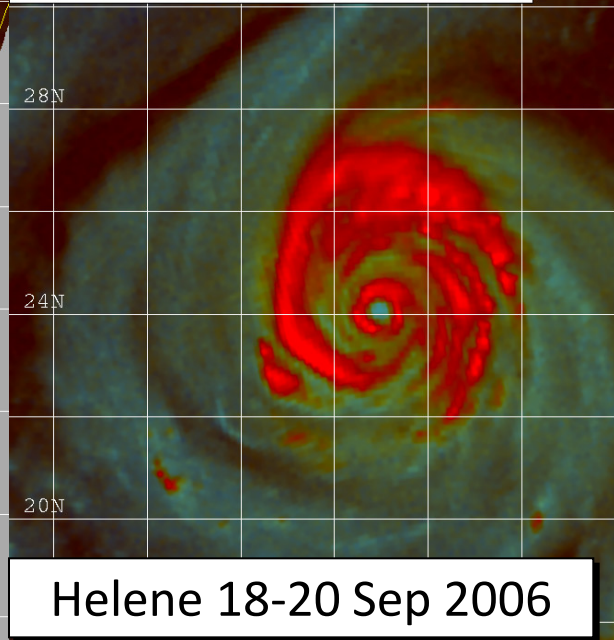
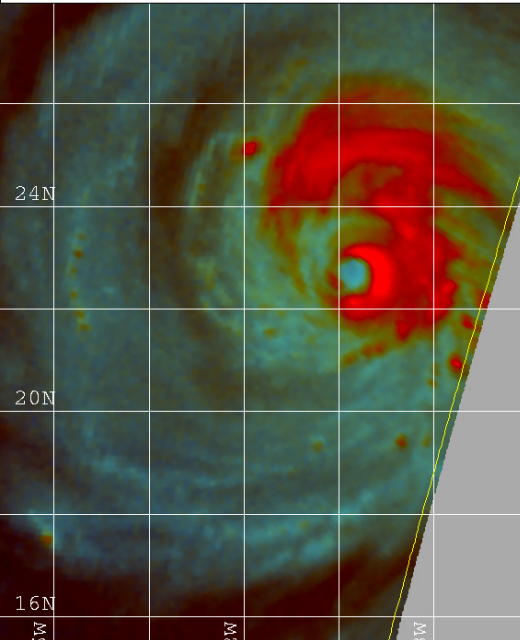


FNMOC http://tcweb.fnmoc.navy.mil/tc-bin/tc_web.cgi
Red=85PCT Green=85H Blue=85V

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

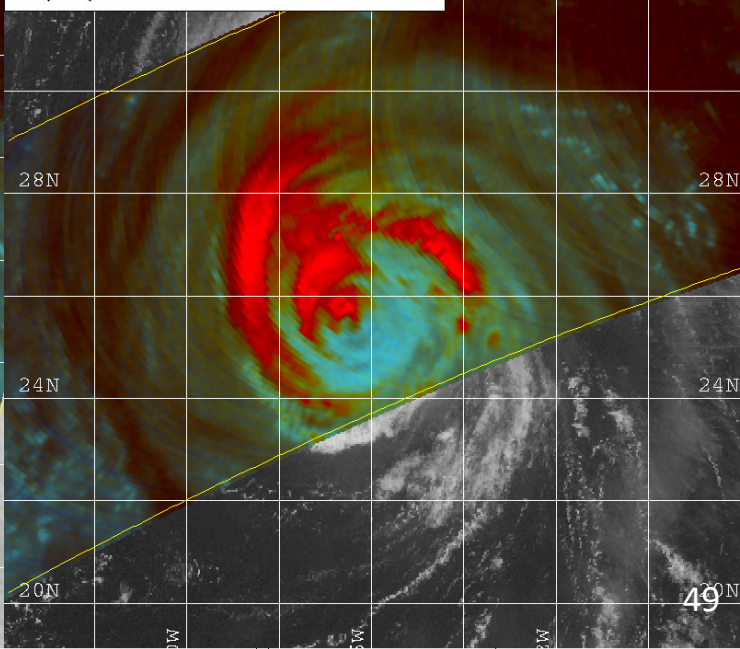
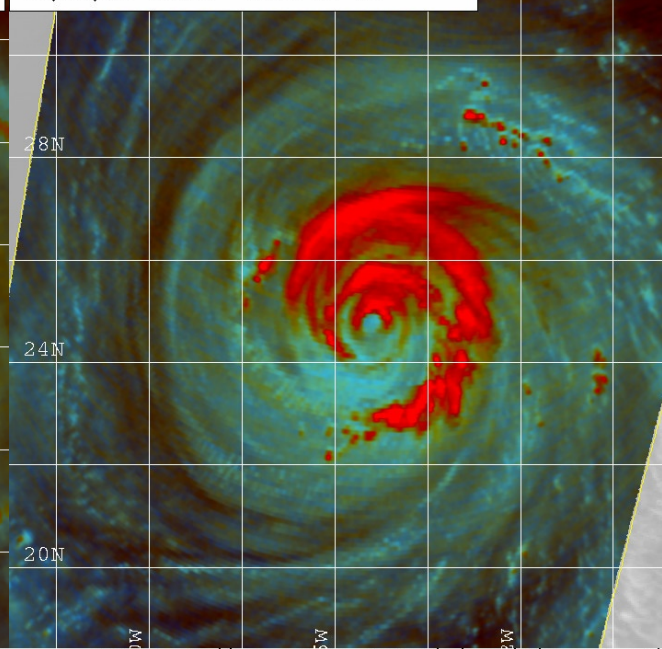
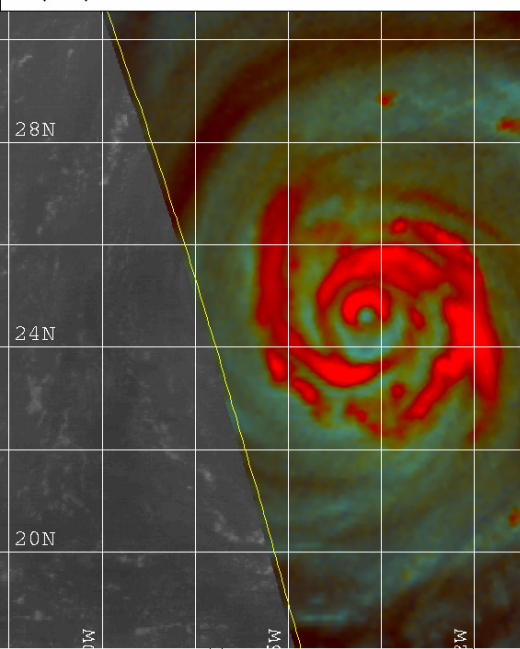
09/19/06 1200Z 08 HELENE
09/19/06 1152Z SSMIS F-16 COMPOSITE
09/19/06 1145Z GOES-12 VIS



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

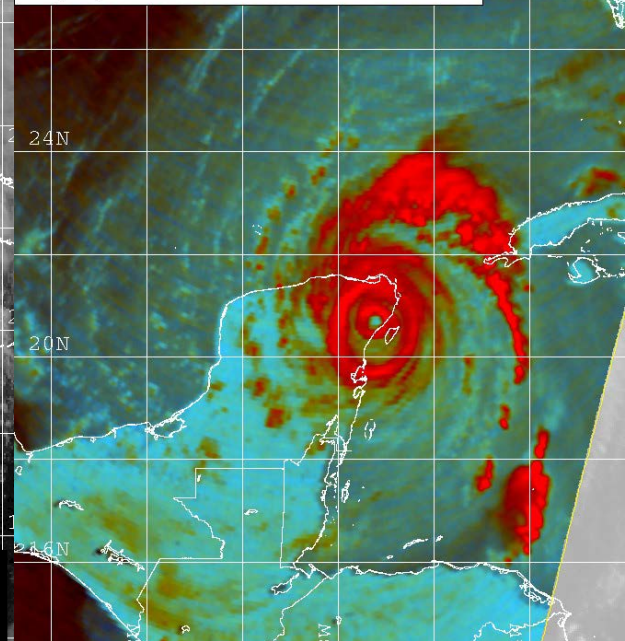
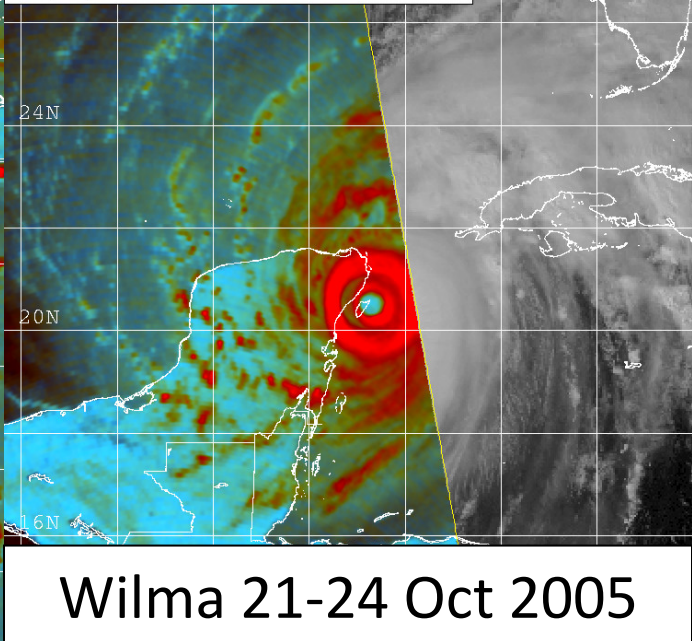
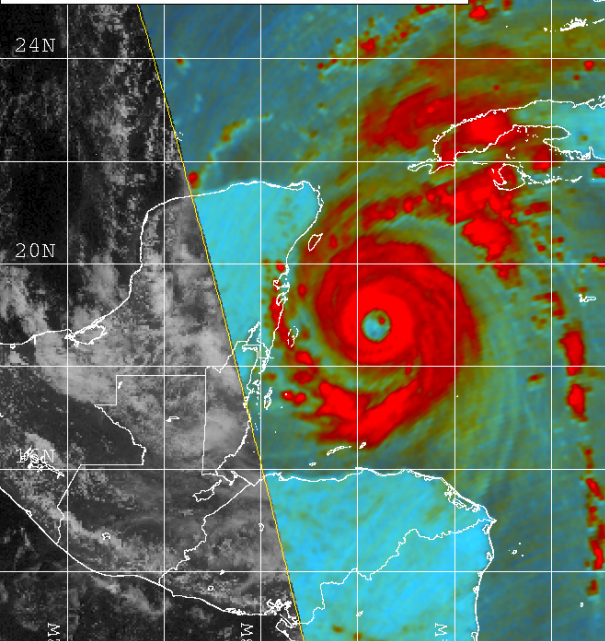
09/20/06 1200Z 08 HELENE
09/20/06 1449Z TRMM COMPOSITE
09/20/06 1445Z GOES-12 VIS



10/21/05 0000Z 24 WILMA
10/20/05 1846Z AMSR-E COMPOSITE
10/20/05 1845Z GOES-12 VIS

10/21/05 1800Z 24 WILMA
10/21/05 1929Z AMSR-E COMPOSITE
10/21/05 1915Z GOES-12 VIS

10/22/05 0600Z 24 WILMA
10/22/05 0739Z AMSR-E COMPOSITE
10/22/05 0715Z GOES-12 IR

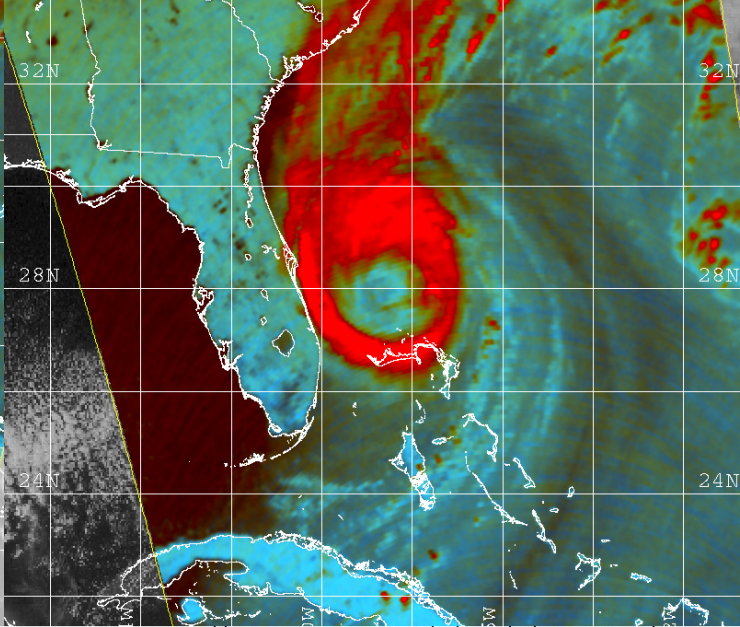
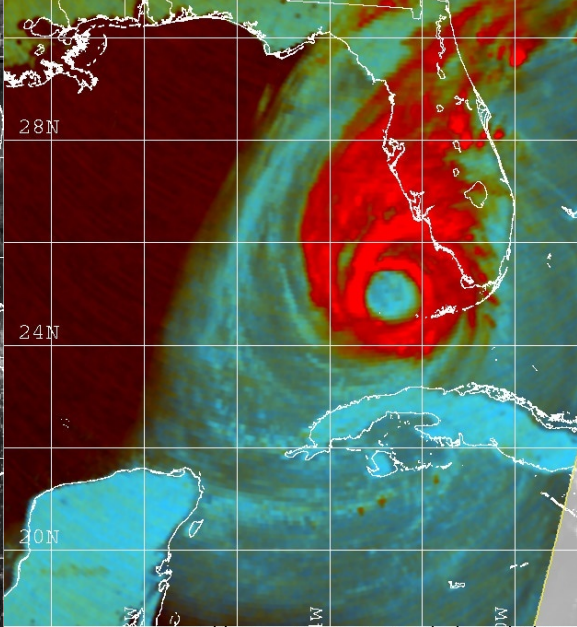
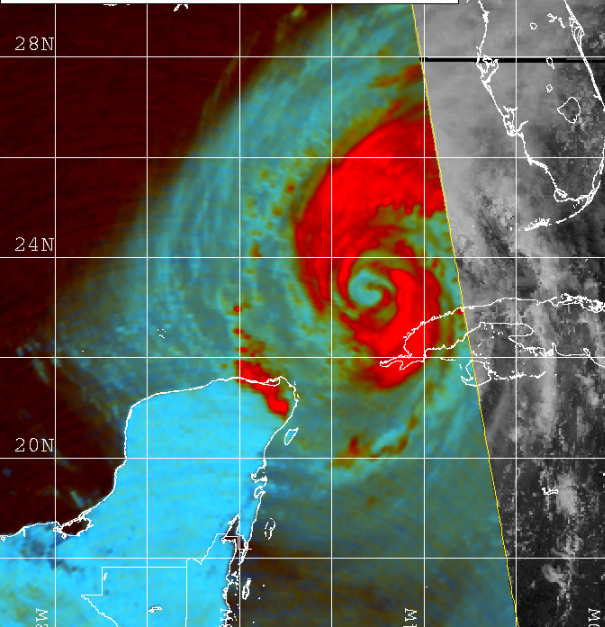


Wilma 21-24 Oct 2005

FNMOC http://tcweb.fnmoc.navy.mil/tc-bin/tc_home.cgi
10/23/05 1800Z 24 WILMA
10/23/05 1917Z AMSR-E COMPOSITE
10/23/05 1915Z GOES-12 VIS

10/24/05 0600Z 24 WILMA
10/24/05 0726Z AMSR-E COMPOSITE
10/24/05 0715Z GOES-12 IR

10/24/05 1800Z 24 WILMA
10/24/05 1823Z AMSR-E COMPOSITE
10/24/05 1815Z GOES-12 VIS

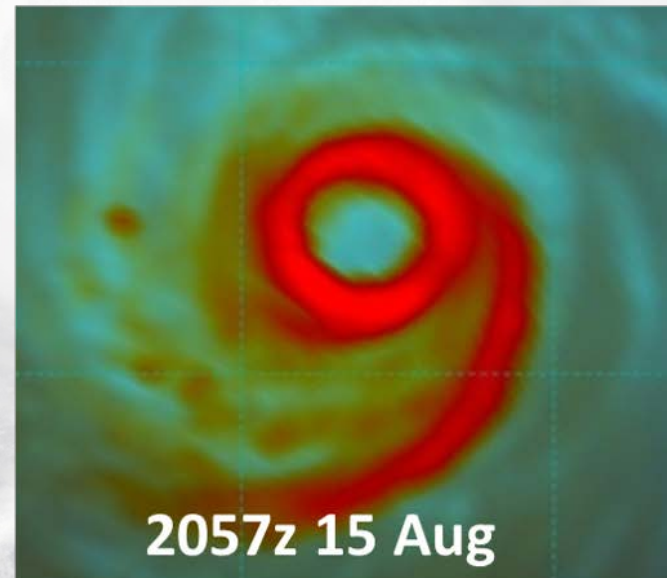
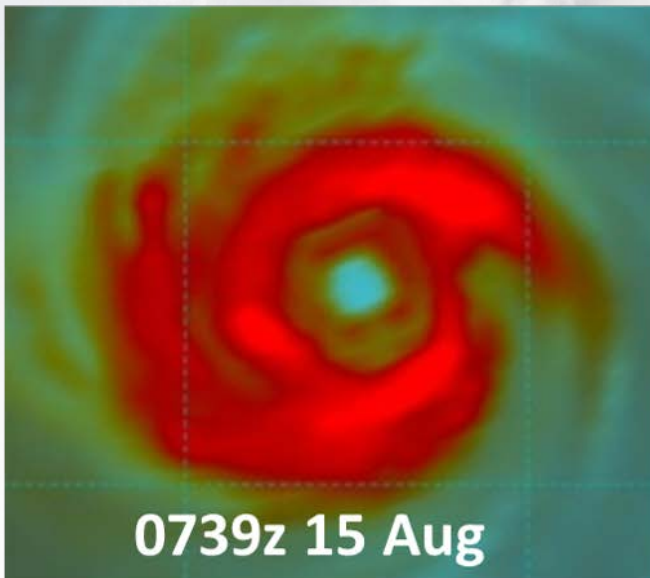
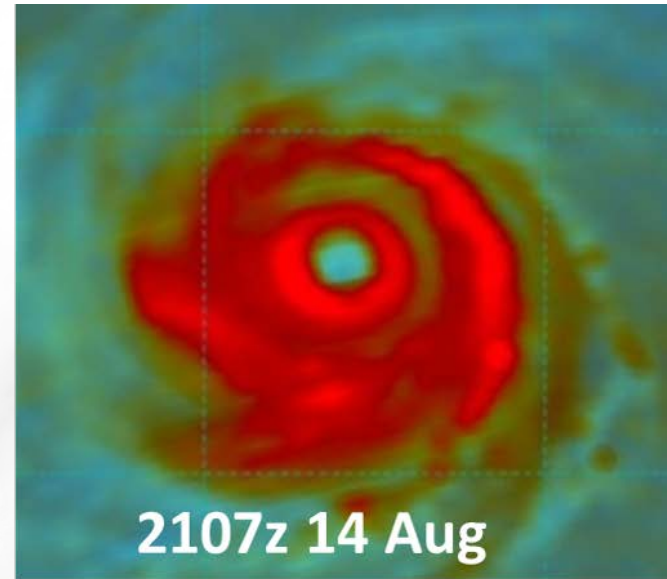
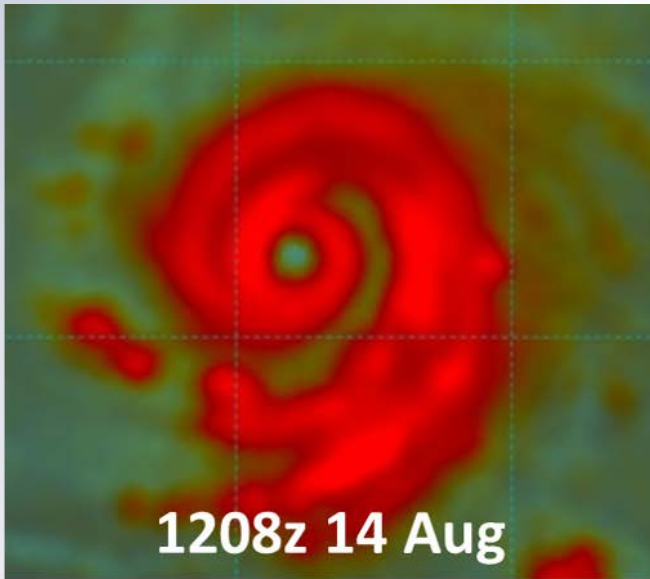


FNMOC http://tcweb.fnmoc.navy.mil/tc-bin/tc_home.cgi
Red=89PCT Green=89H Blue=89V

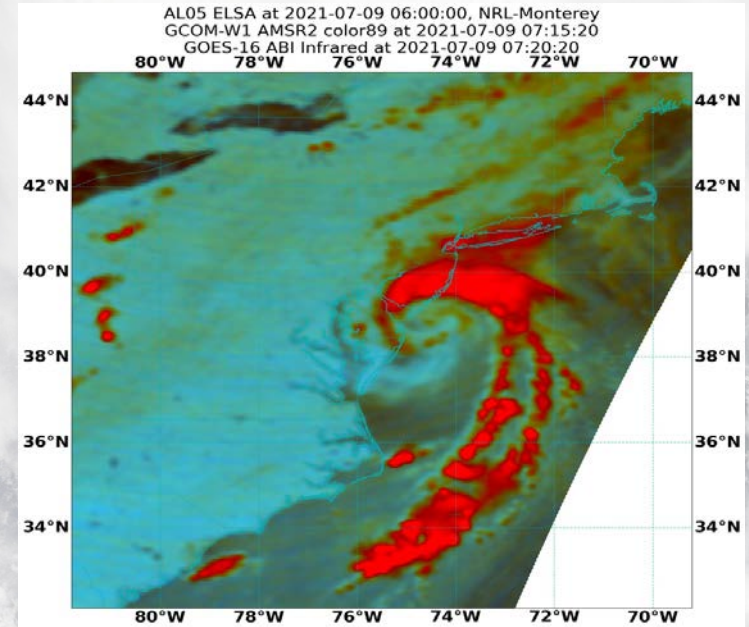
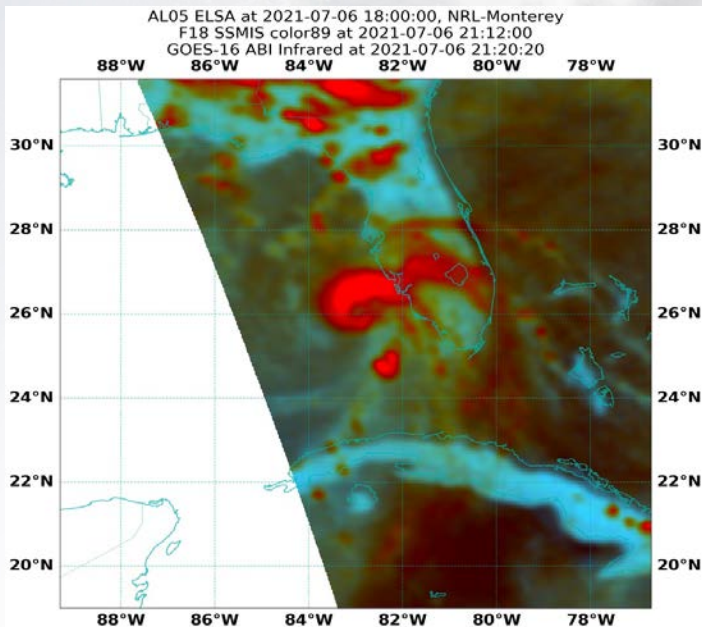
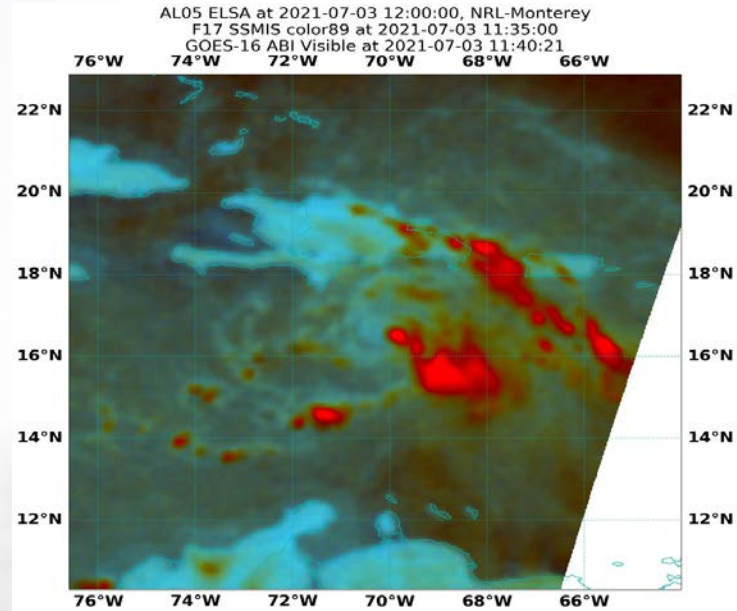
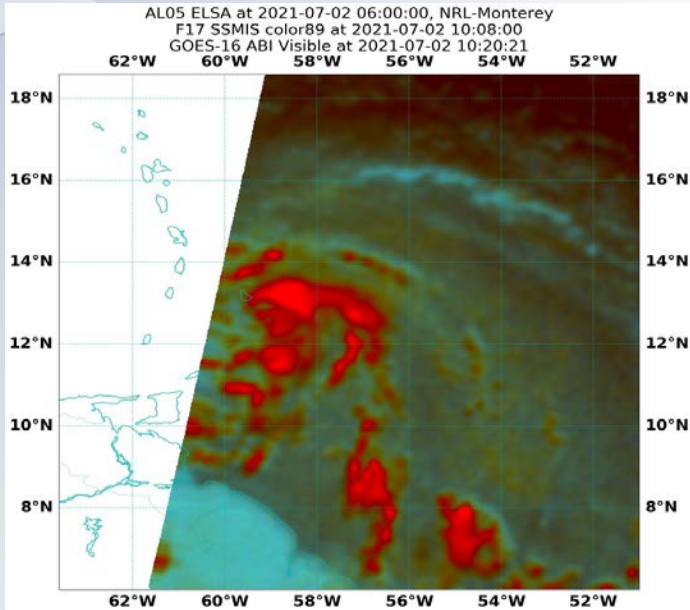
FNMOC http://tcweb.fnmoc.navy.mil/tc-bin/tc_home.cgi
Red=89PCT Green=89H Blue=89V

FNMOC http://tcweb.fnmoc.navy.mil/tc-bin/tc_home.cgi
Red=89PCT Green=89H Blue=89V

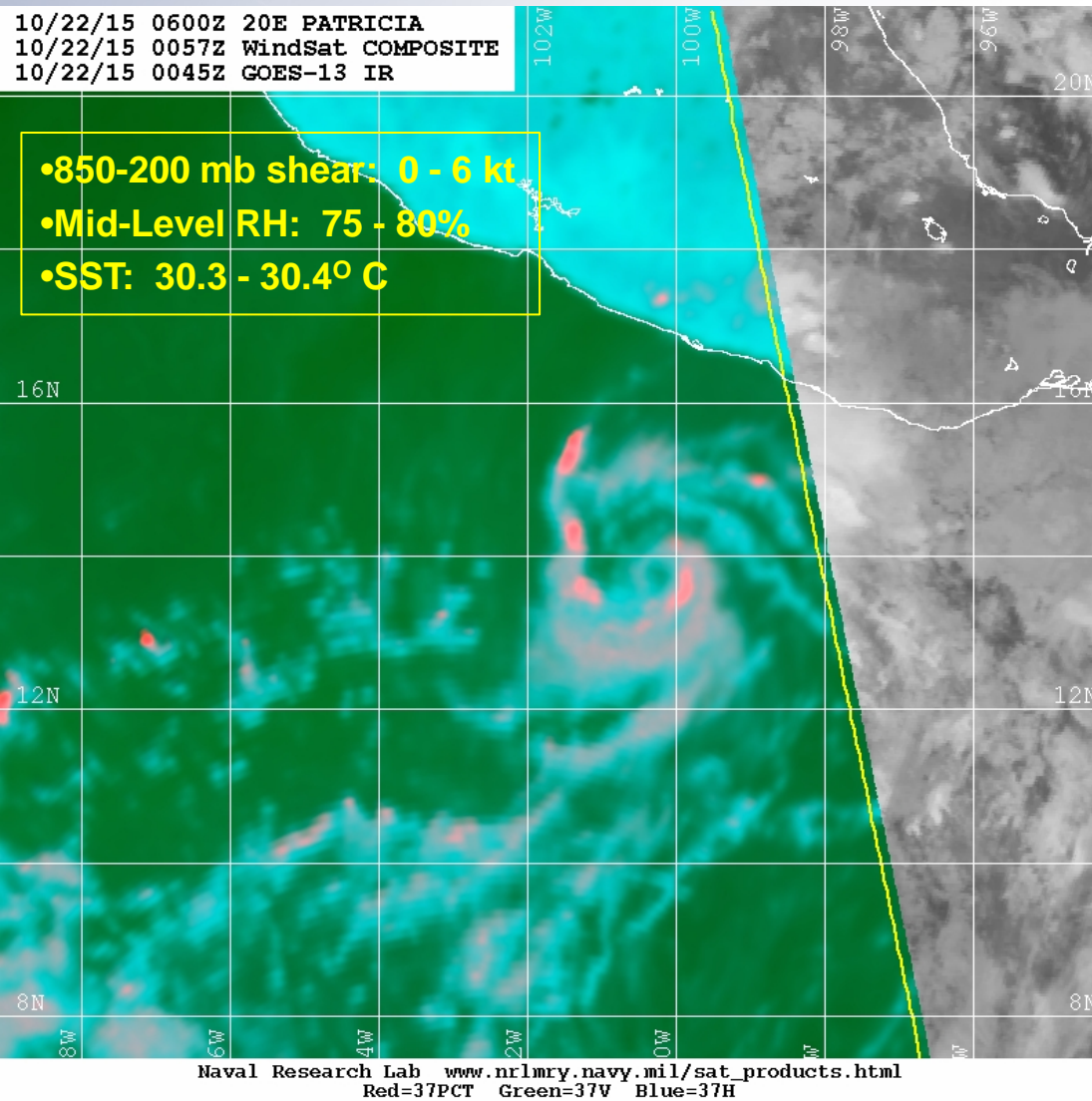
Hurricane Linda (2021)



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?