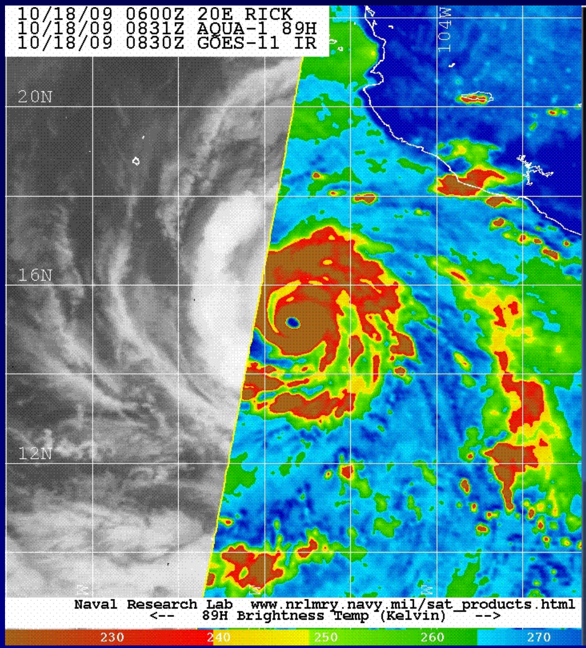
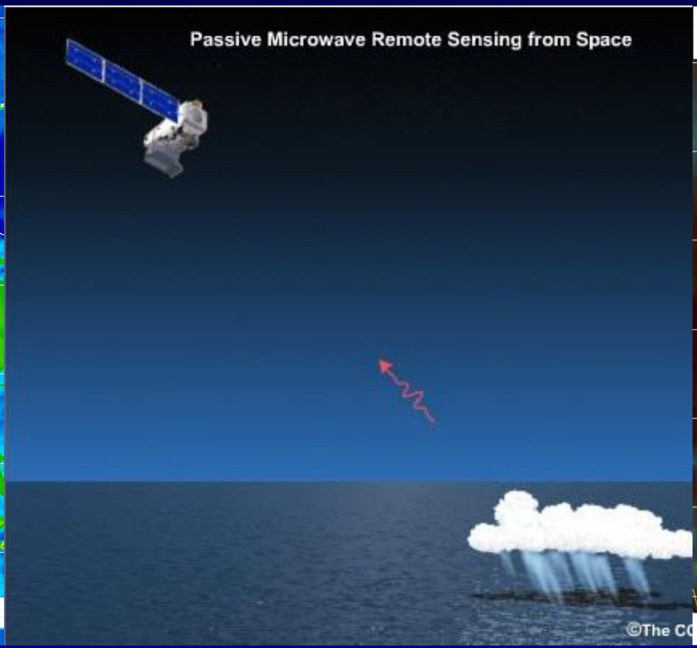
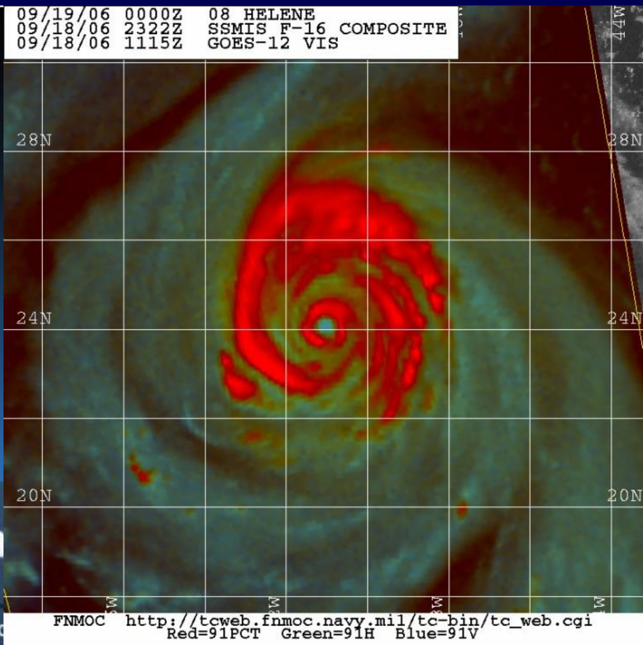
Interpretation and Application of Microwave Imagery and Scatterometry







Dave Roberts and John Cangialosi

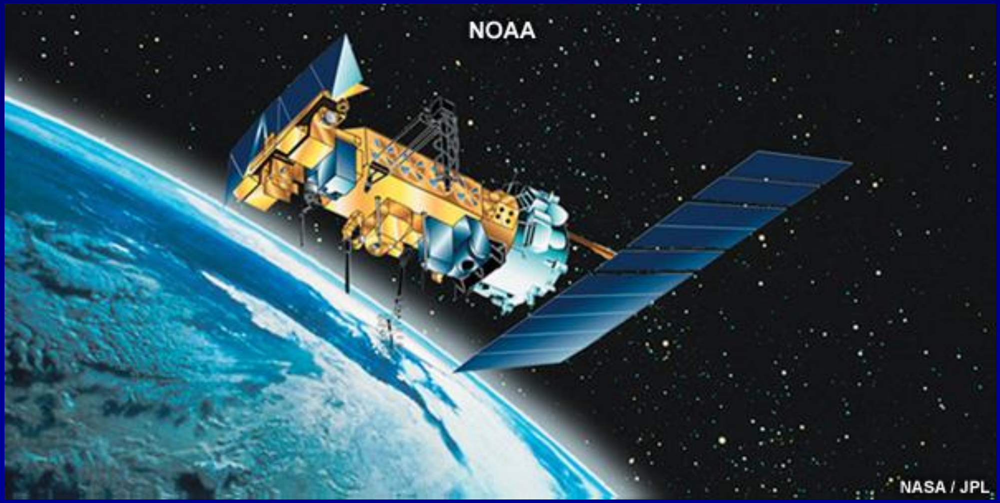
National Hurricane Center

1 March 2017

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

Outline

- Review of basic principles of Remote Microwave Sensing
- Orbital and Scan Strategies
- Single frequency image interpretation
- Understanding Color composite images
- Data availability
- Analysis and Interpretation
- Practical Exercises



A Quick Review of Remote Sensing Basics

- Passive sensors (SSM/I, SSMIS, AMSU, AMSR-2, etc.) measure emitted microwave energy from 5 to 200 GHZ
- Emissivity, or "return energy" is directly related to brightness temperatures (T_b)
- Key Radiative Processes
    - 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 radiative processes

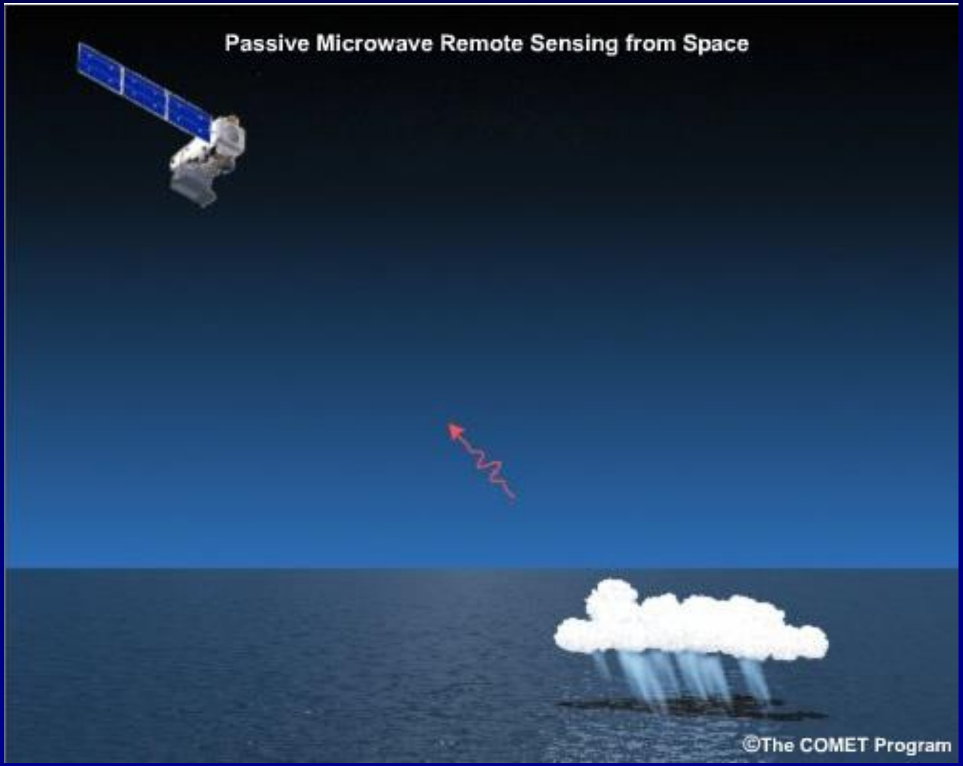


Image courtesy COMET

A Quick Review of Remote Sensing Basics

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

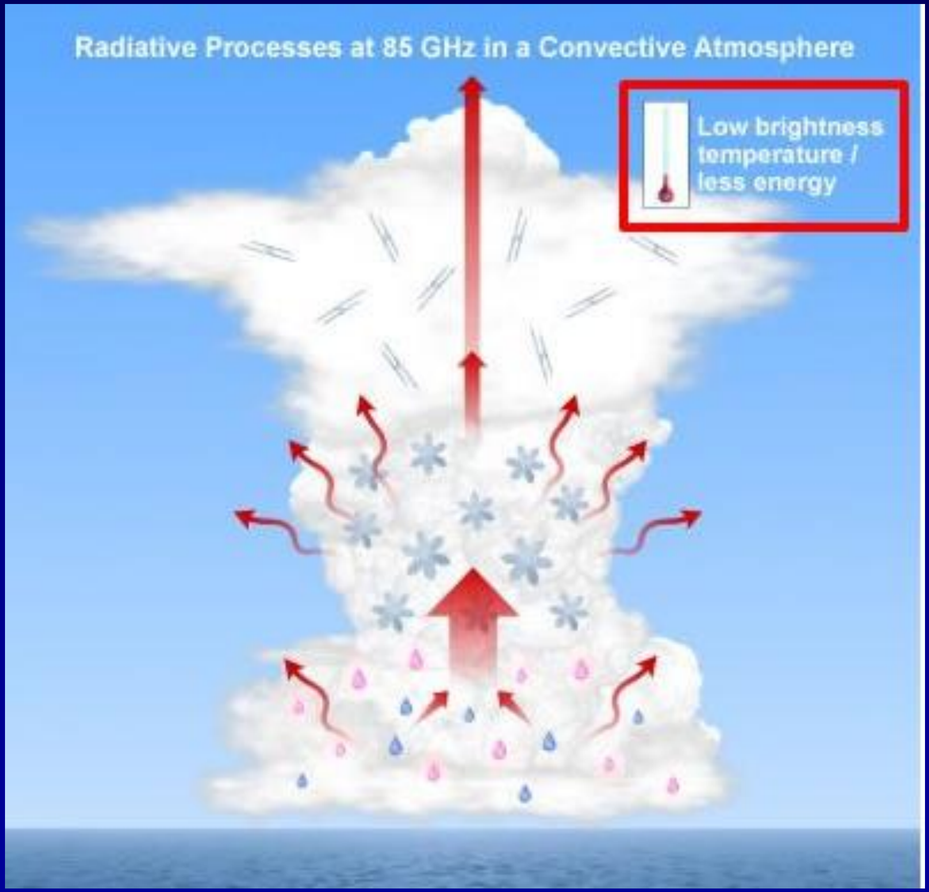


Image courtesy COMET

A Quick Review of Remote Sensing Basics

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

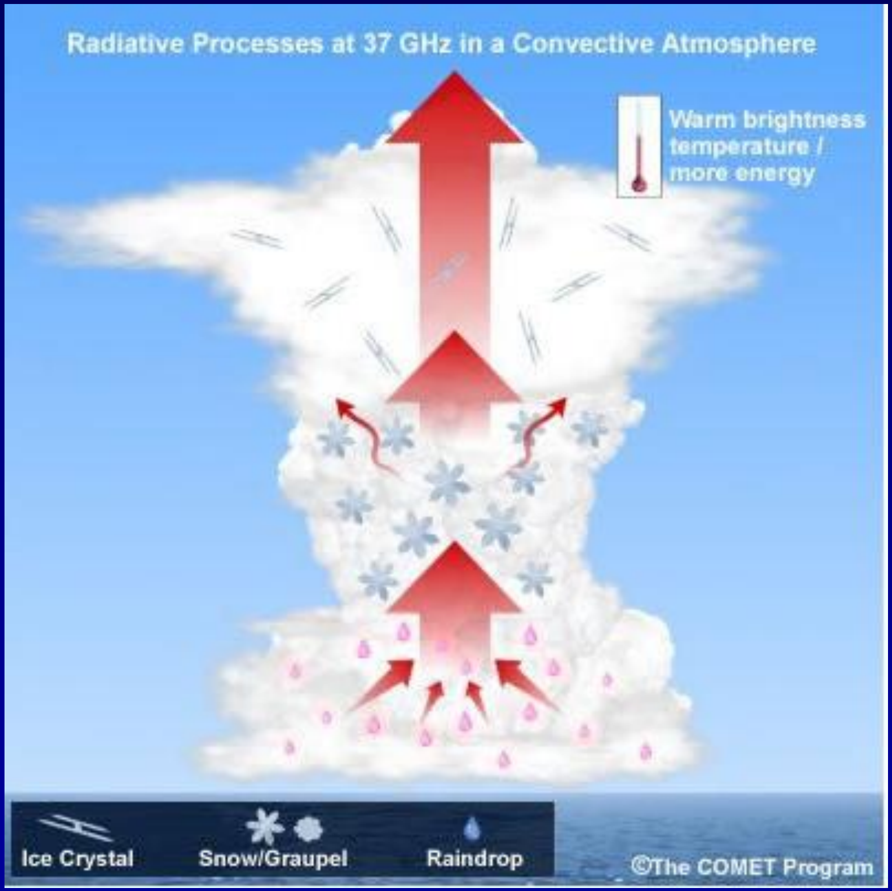
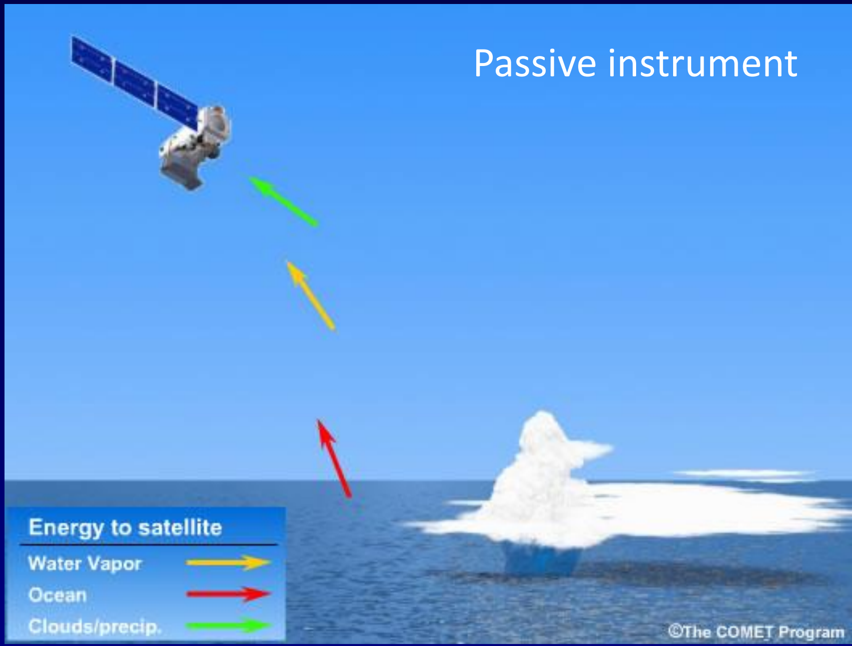
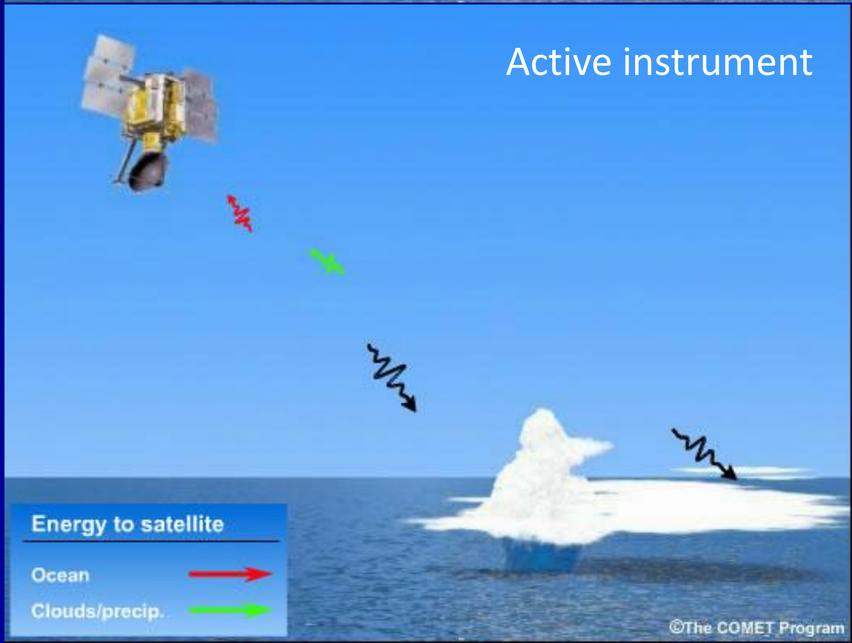


Image courtesy COMET

Measuring Electromagnetic Energy

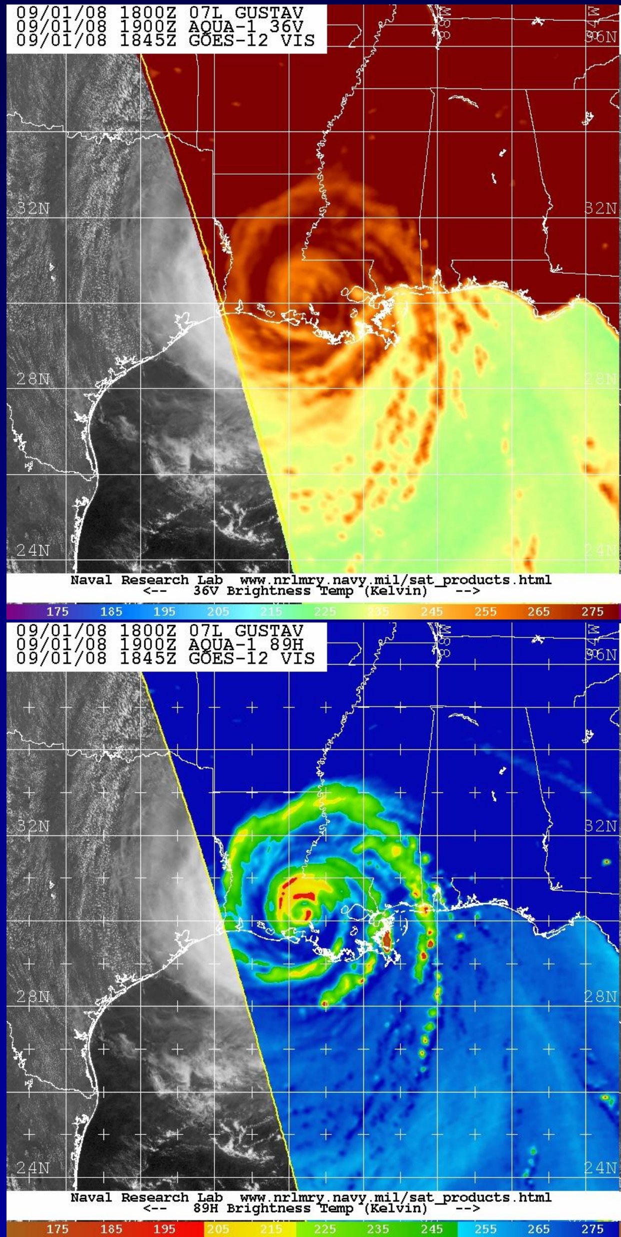
- **Passive Instruments:**
  - Receive radiation leaving the earth-atmosphere system
  - Measure solar radiation reflected by earth/atmosphere targets
  - Measure emitted and scattered infrared radiation
  - Measure microwave radiation resulting from emission, scattering and absorption
- **Active Instruments:**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



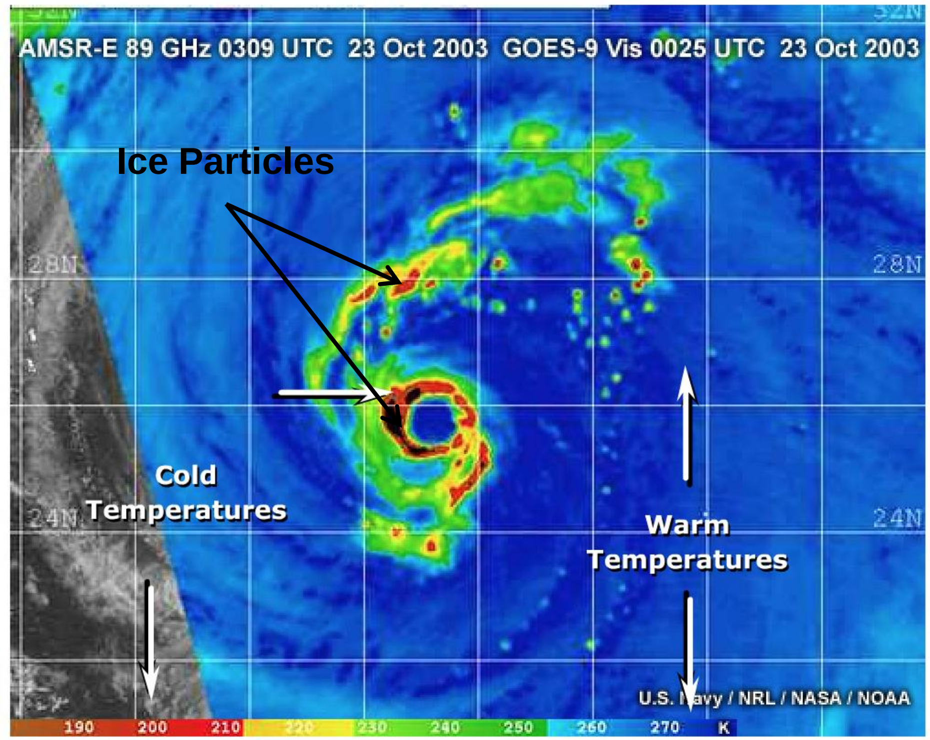


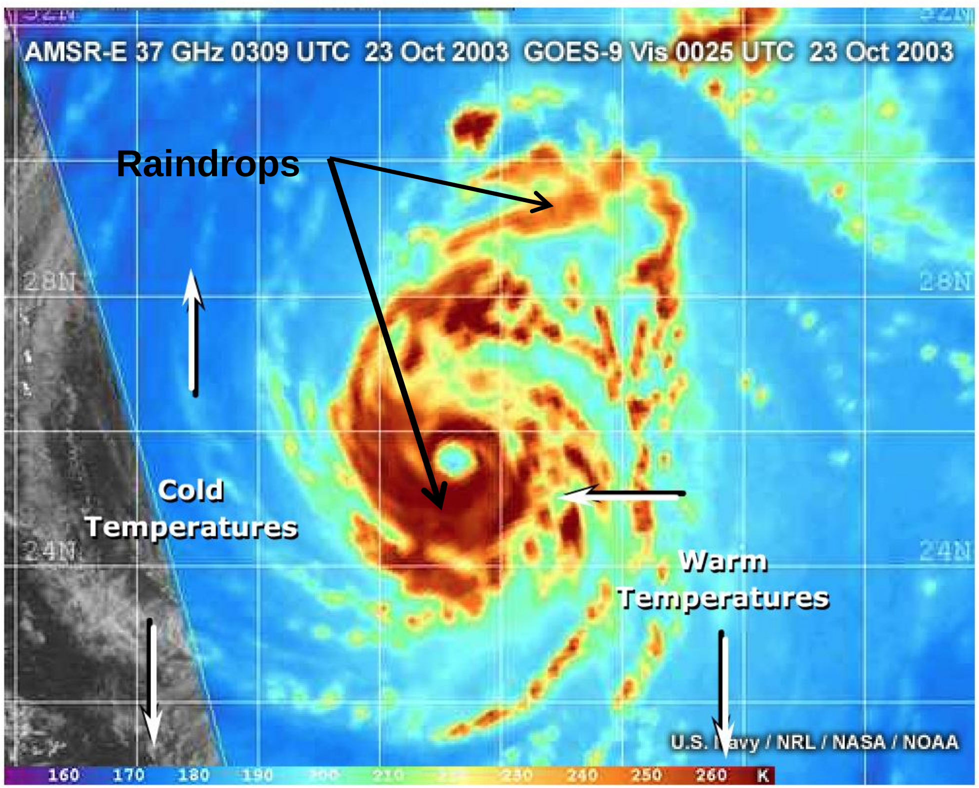
Key Characteristics of Microwave Radiation

- For Low frequencies, (~37 GHz) water surfaces (e.g., oceans) have low emissivity (~0.4-0.5) and appear "cool" at microwave frequencies
- Land surfaces have a much greater emissivity (~0.9) and appear "warm"
- Raindrops also have high emissivity and are "warmer"; they contrast against a "cooler" ocean background
- For High frequencies, microwaves (~85 GHz) are scattered by ice particles in precipitating clouds, reducing reducing the return energy and subsequently appear "cold".

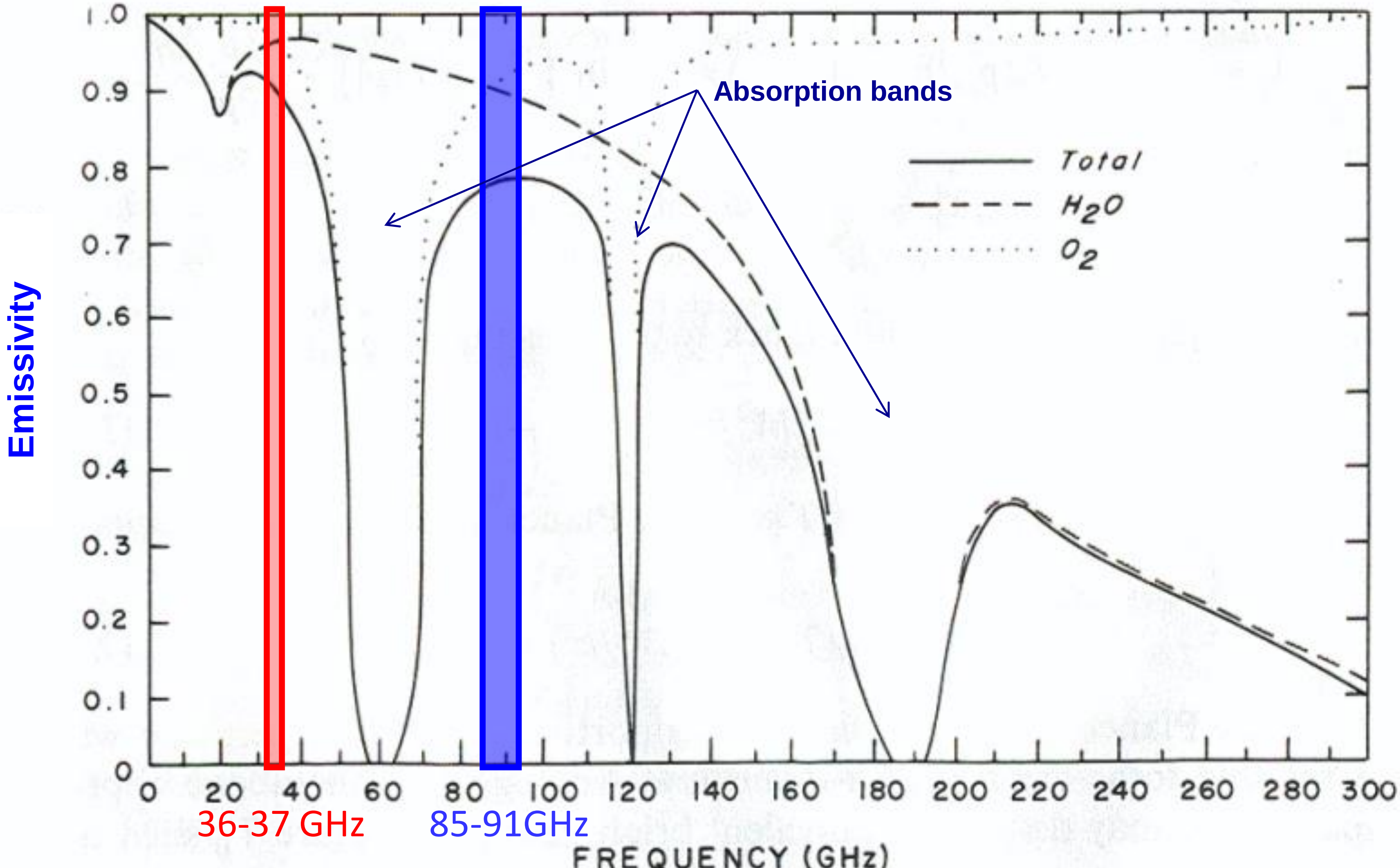


Color Imagery Examples





Microwave Transmittance "Windows"

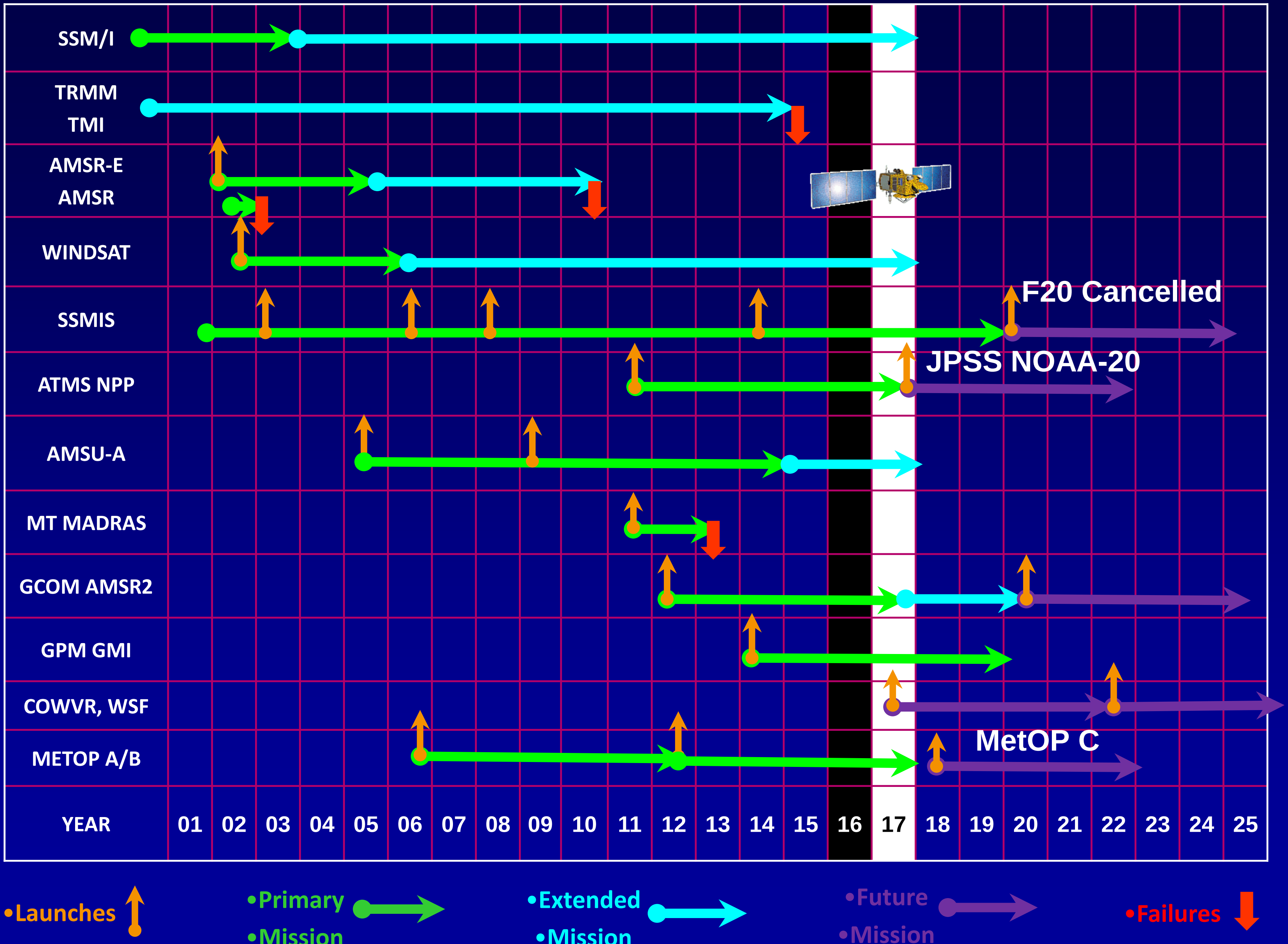


Current/Operational Passive Microwave Imagers and Sounders/Platforms

- AMSU-A/B – 4 satellites (NOAA 18/19) and EUMETSAT MetOP-A/B
- SSM/I – 1 DMSP satellite (F-15)
- SSMIS – 3 DMSP satellites (F-16, F-17, F-18)
- GMI – GPM – JAXA/NASA
- AMSR-2 – GCOM-W1 – Japan (JAXA)
- WindSat – Navy NRL Coriolis (37-GHz Only)

Passive Microwave Imager Missions *(D. Roberts and NRL)*

Feb 2017



Microwave Imager Characteristics

Evolution of Passive Microwave Instruments

Instrument	Characteristic						
	Operating Period	Type	Scan Strategy	No. of Channels	Frequencies (GHz)	Resolution FOV's (km)**	Swath Width (km)
SMMR	1978 - 1997	imager	conical	10	6.6 - 37	22 - 122	780
MSU	1978 - 2007	sounder	cross-track	5	50.3 - 57.95	110 - 200	2000
SSM/I SSM/T1 SSM/T2	1987 - present	imager sounder sounder	conical cross-track cross-track	7 7 5	19.35 - 85 50.5 - 59.4 92 - 183	15 - 69 SSM/T1 (SSM/T2) 174 (48 - 120) at nadir 309 (85 - 213) at limb	1400
TMI	1997 - present	imager	conical	9	10.65 - 85.5	5 - 50	780
AMSU	1998 - 2020[1]	sounder	cross-track	20	50 - 183	AMSU-A (AMSU-B) 45 (15) at nadir 150 (50) at limb	2200
AMSR-E	2002 - 2011	imager	conical	14	6.9 - 89	5 - 50	1600
SSMIS	2004 - 2020[1]	imager & sounder	conical	24	19 - 183	12 - 55	1700
WindSat	2003 - present	imager	conical	22	6.8 - 37[2]	11 - 55	1025
Microwave Imager/ Sounder	future DWSS	imager & sounder	conical	TBD	TBD	TBD	TBD
ATMS	NPP & future JPSS	sounder	cross-track	22	24 - 183	16 - 75 at nadir 68 - 323 at limb	2500

**Instrument resolution is proportional to frequency

1 Projected dates

2 WindSat channels at 10.7, 18.7, and 37 GHz are fully polarimetric

Instrument includes fully polarimetric channels

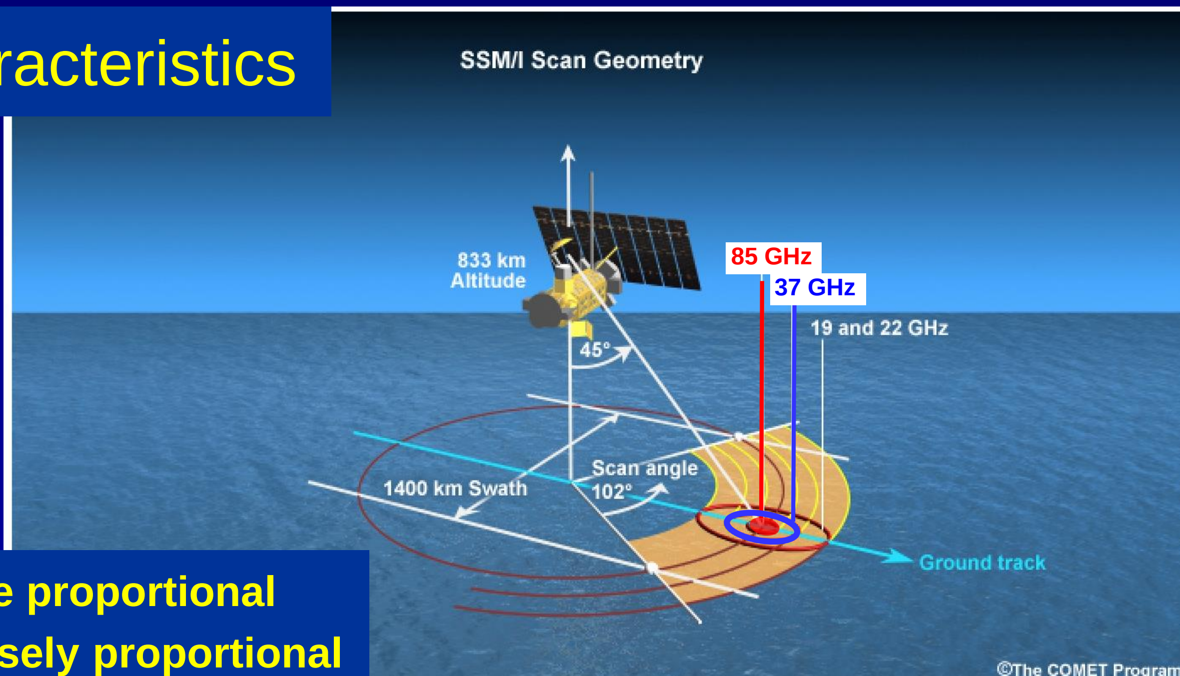
Instrument includes dual polarimetric channels

FOV: Field of view

SSM/I and CMIS Footprint Resolutions

SSM/I		CMIS (imaging channels)	
1400 km width		1700 km width	
Channel frequency (GHz) / polarization	FOV resolution (km x km)	Channel frequency (GHz) / polarization	FOV resolution (km x km)
		6 H, V	68 x 40
		10 V, H, L, R	48 x 28
19.35 V, H	69 x 43	18 V, H, P, M, L, R	24 x 15.5
22.235 V	60 x 40	23 V, H	18 x 12
37.0 V, H	37 x 29	37 V, H, P, M	16 x 12
85.5 V, H	15 x 13	89 V, H	16 x 12

Polarizations: V = Vertical, H = Horizontal, P = +45 degrees, M = -45 degrees, L = Left-hand circular, R = Right-hand circular



- •Frequency and FOV resolution are proportional
- •Frequency and footprint are inversely proportional

Summary Questions

1. The primary measurement Tb signature for 85 or 89 GHz imagery is:

    A. Lowered Tb
    B. Elevated Tb
    C. Cool or cold Tb
    D. Both A and C
    E. Warm Tb

2. With respect to FOV resolution and frequency:

    A. Resolution increases with decrease in frequency
    B. Image footprint decreases with increase of frequency
    C. Resolution decreases with decrease in frequency
    D. Image footprint increases with increase of frequency
    E. Both B and C

Orbital and Scan Strategies

GEO vs. LEO Orbital Altitude Comparison

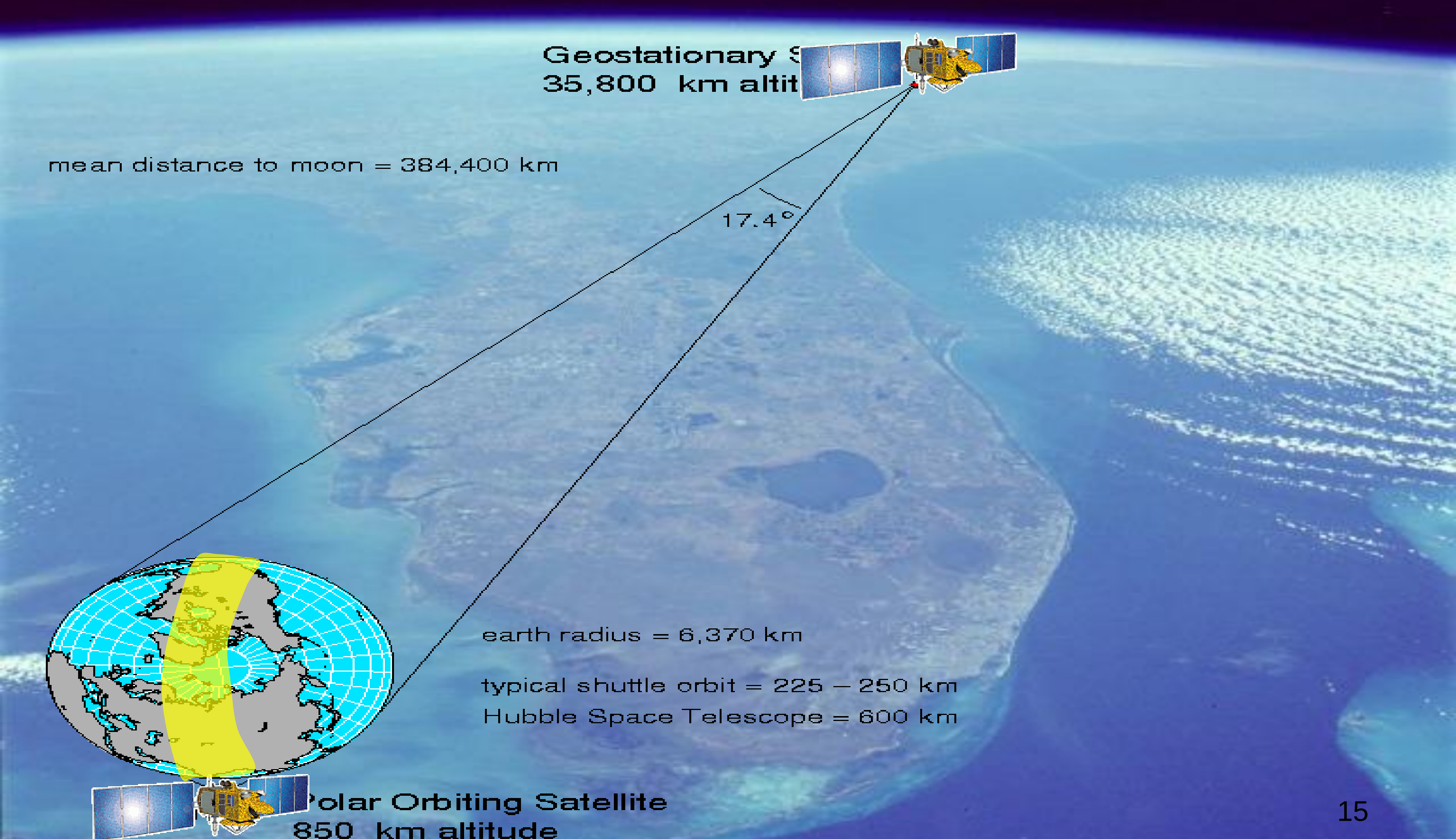


Image courtesy of http://www.nrlmry.navy.mil

Sun-Synchronous Daily Orbital Path

~12 hr to observe the entire Earth

Same location twice daily (ascending/descending)

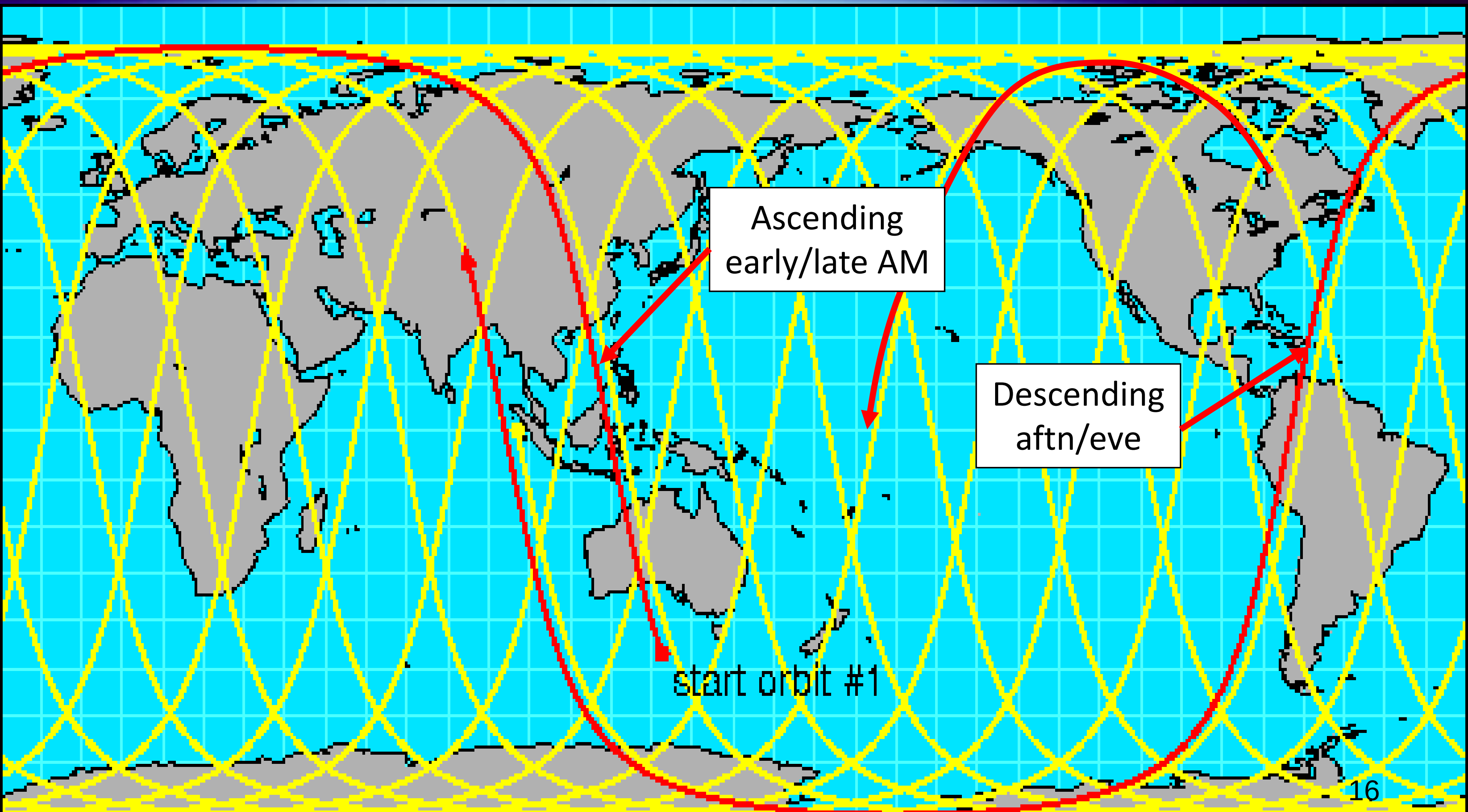


Image courtesy of http://www.nrlmry.navy.mil

Data Timeliness

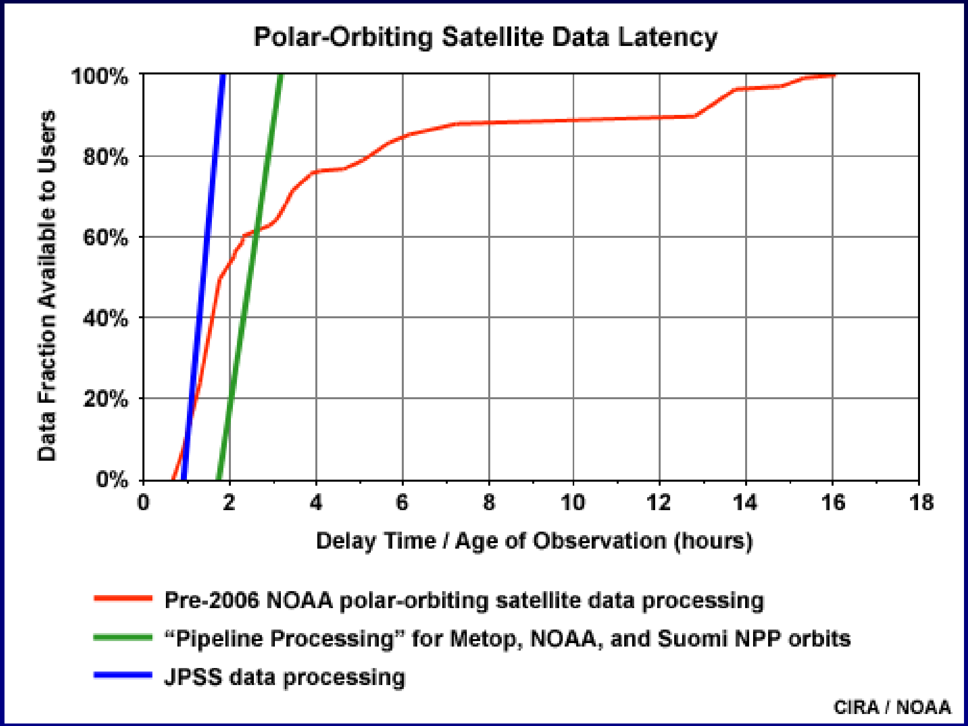
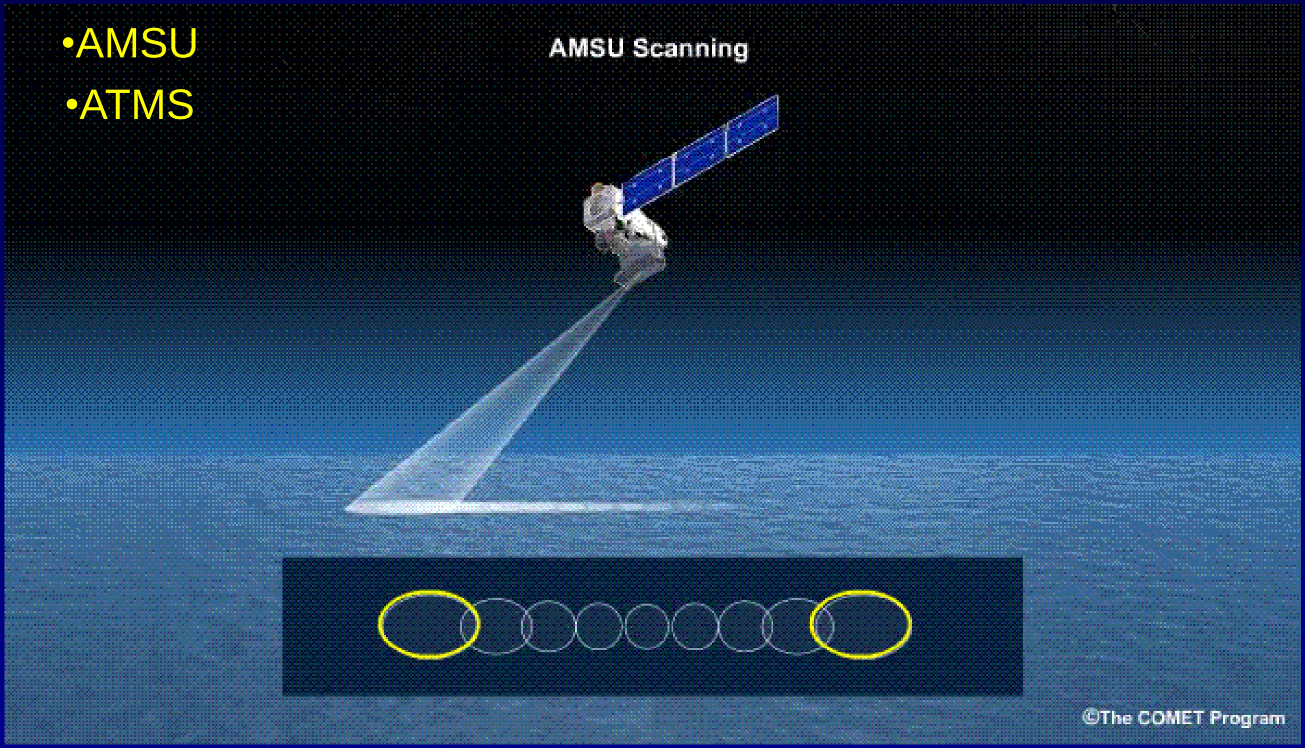


Image courtesy COMET

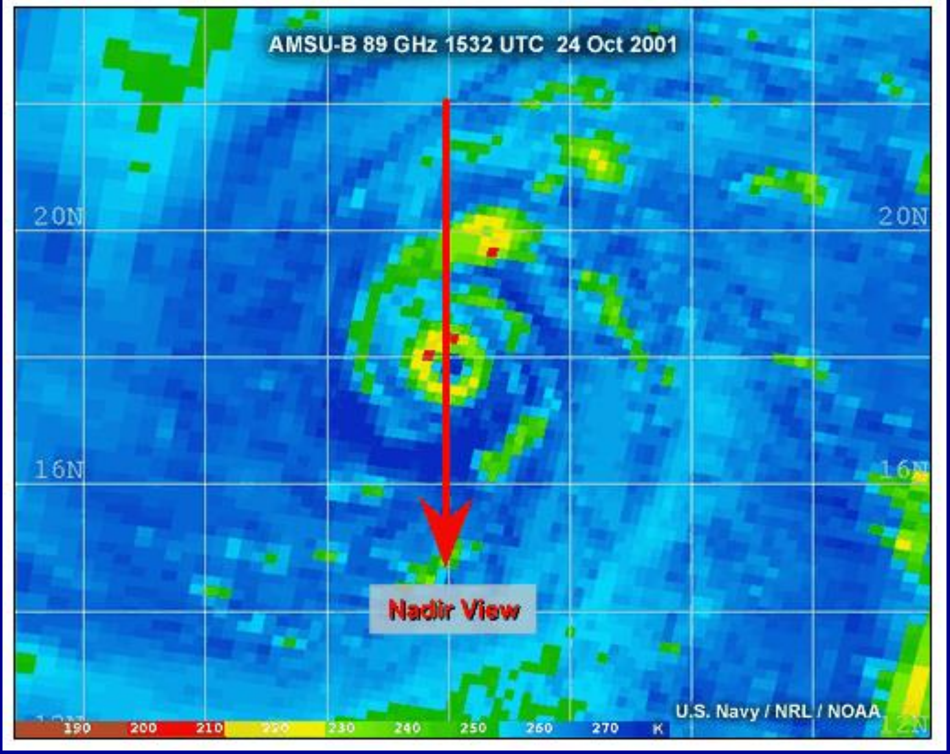
- A lack of continuous viewing range of the ground stations leads to delay in transmission and processing
- Additional ground stations and advance processing reduce the data latency. 3 total stations: Fairbanks AK, McMurdo, Svalbard Norway, and a backup in Fairmount WV.

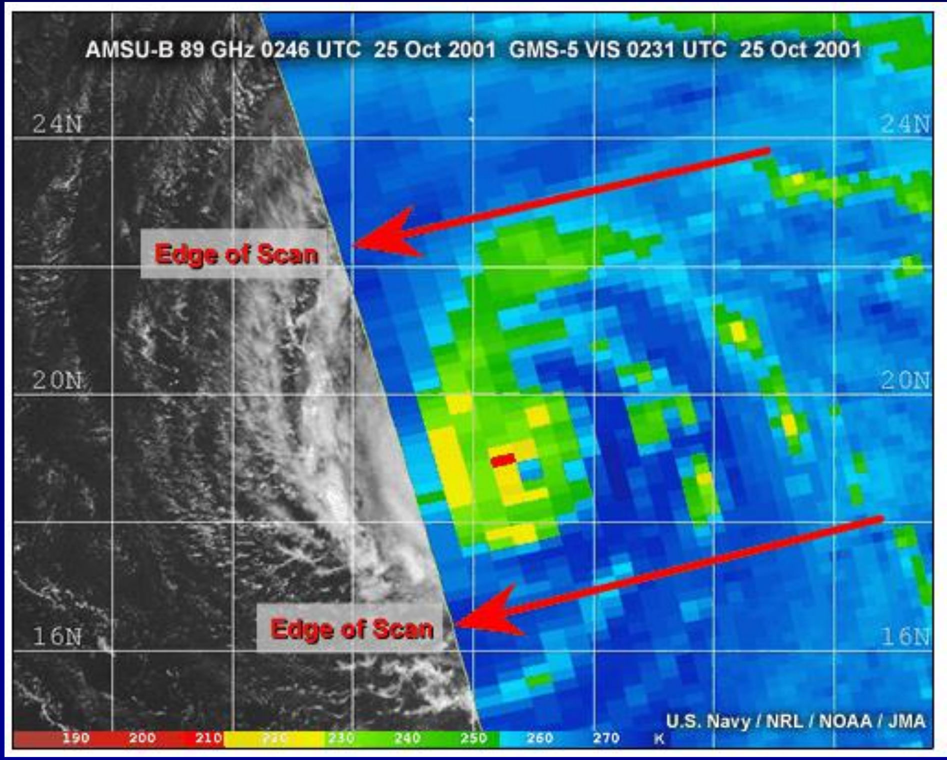
Cross Track Scan Strategy



- Advantage: Larger coverage swath relative to conical scan
- Disadvantage: Resolution varies across the swath (degraded spatial resolution as the viewing angle increases relative to nadir)

Cross Track Scan Strategy

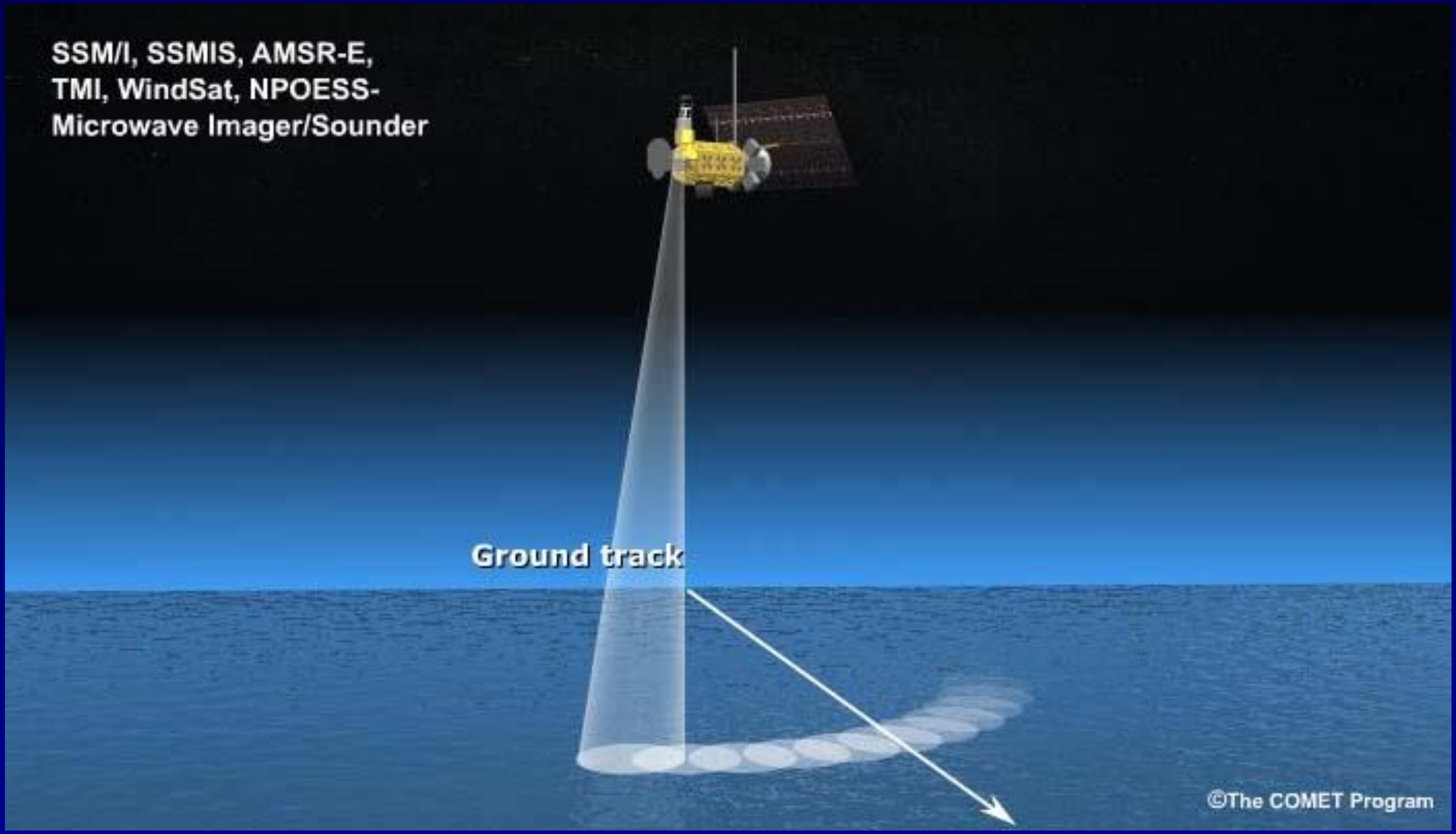




Note degradation in resolution at edge of scan compared to nadir

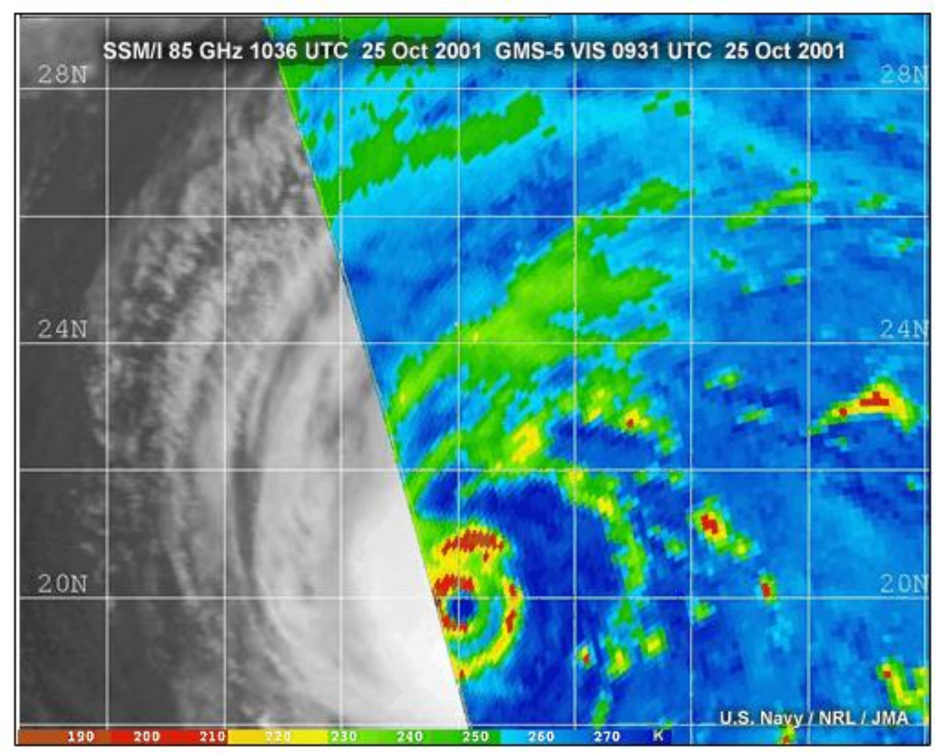
Images courtesy COMET

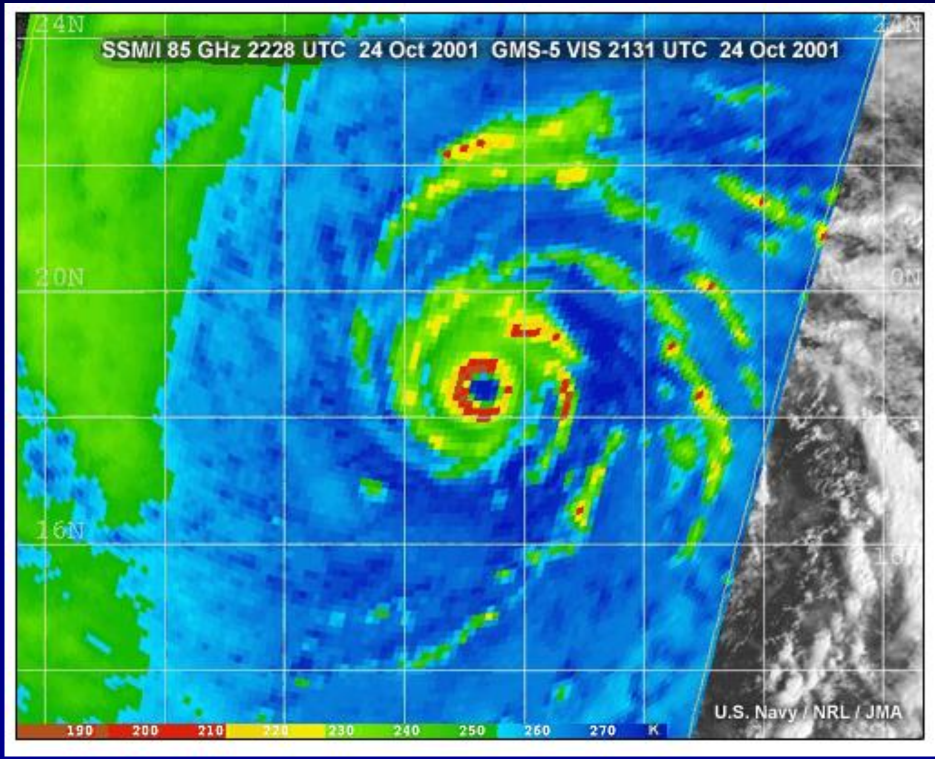
Conical Scan Strategy



- 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

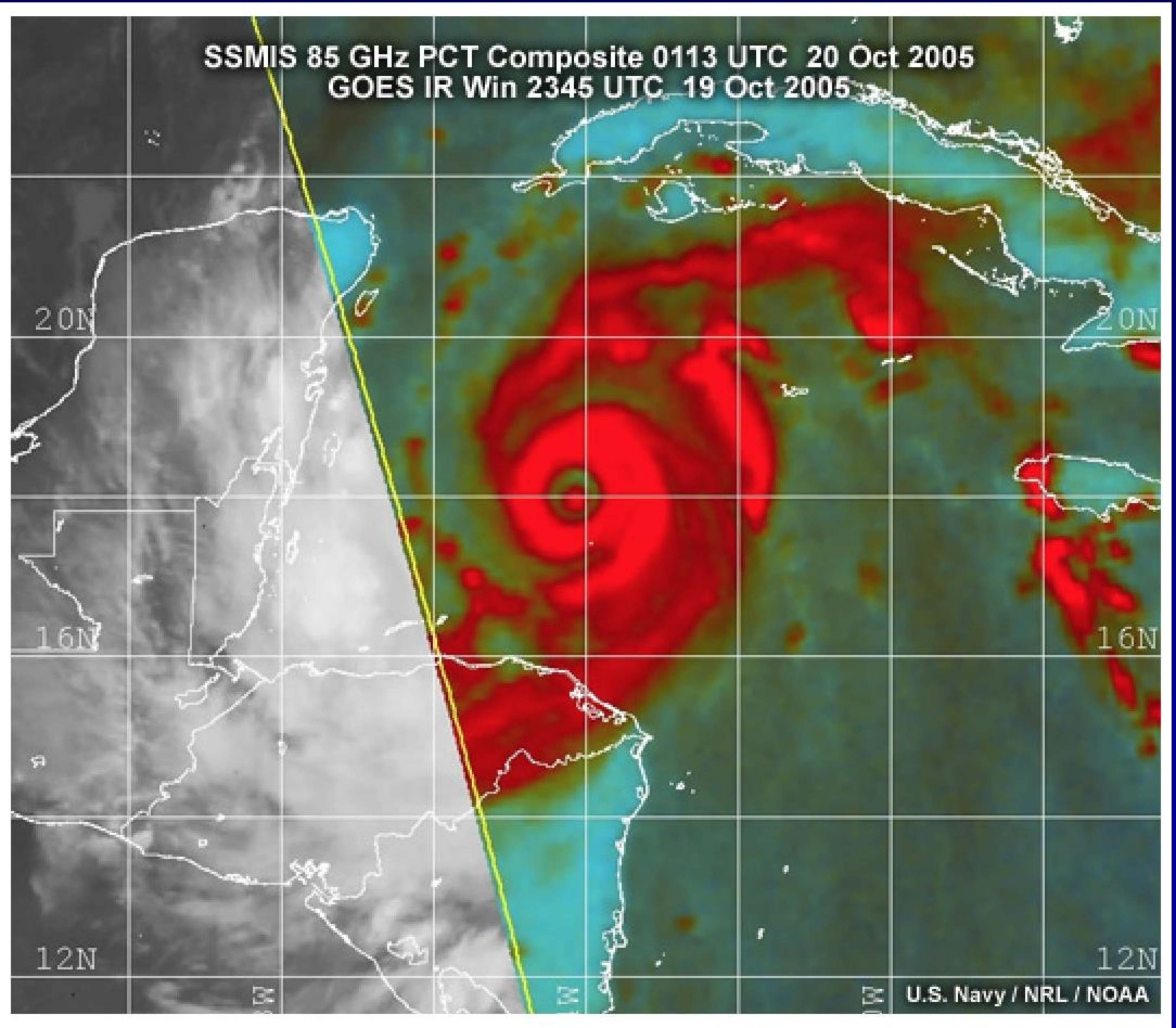




Resolution remains constant across swath

Images courtesy COMET

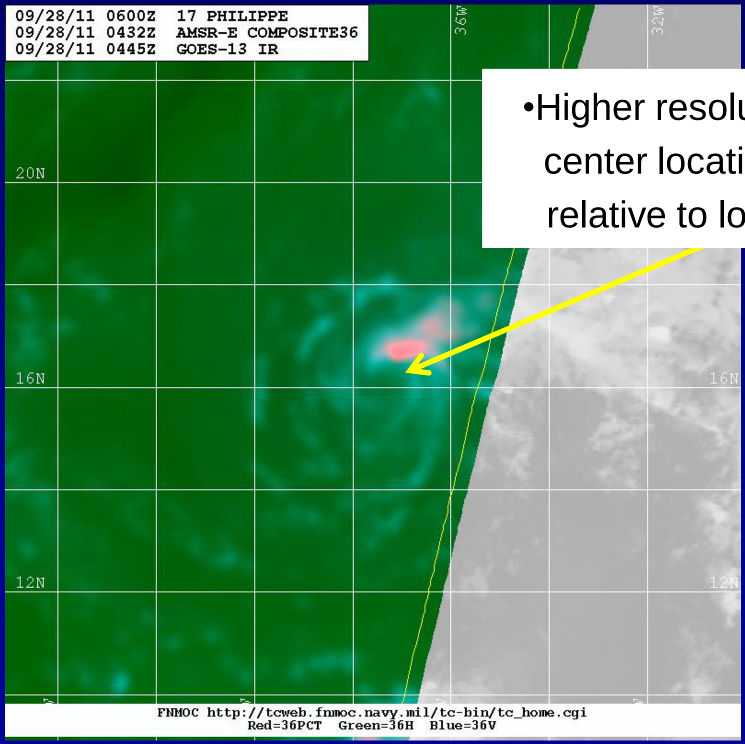
Swath Coverage



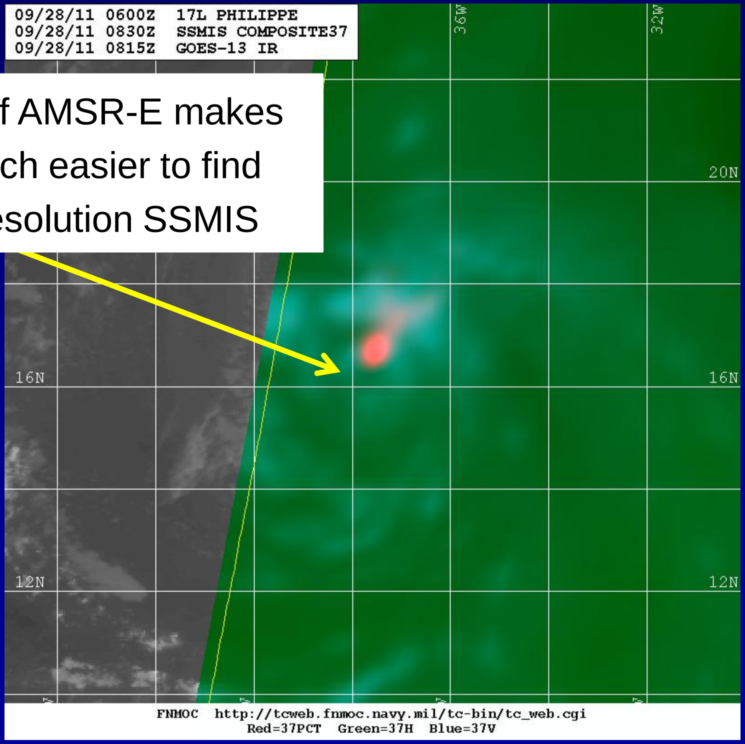
Microwave Imagery Advantages and Applications

Impact 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

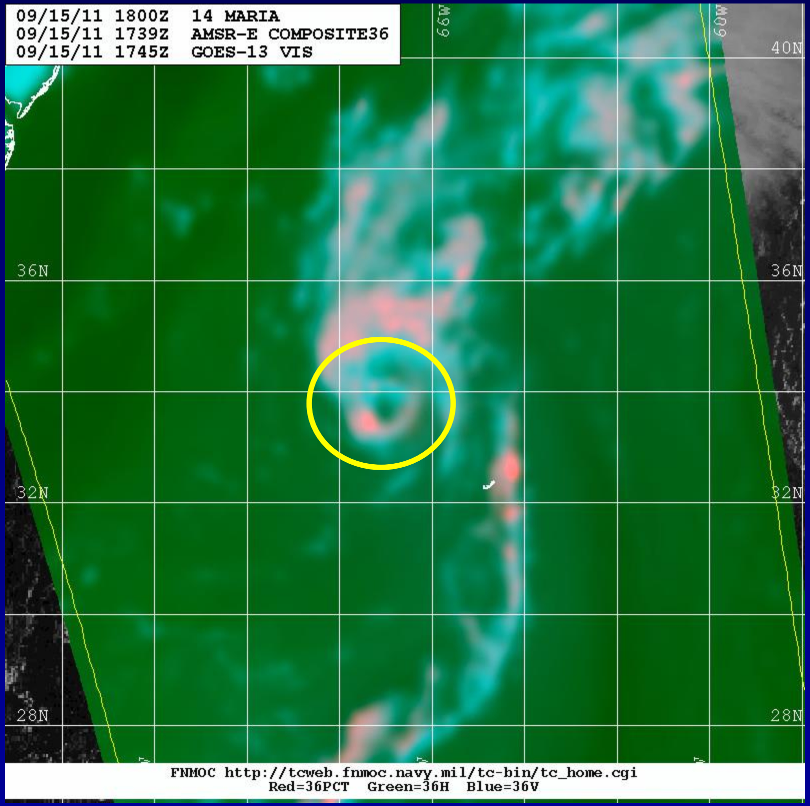


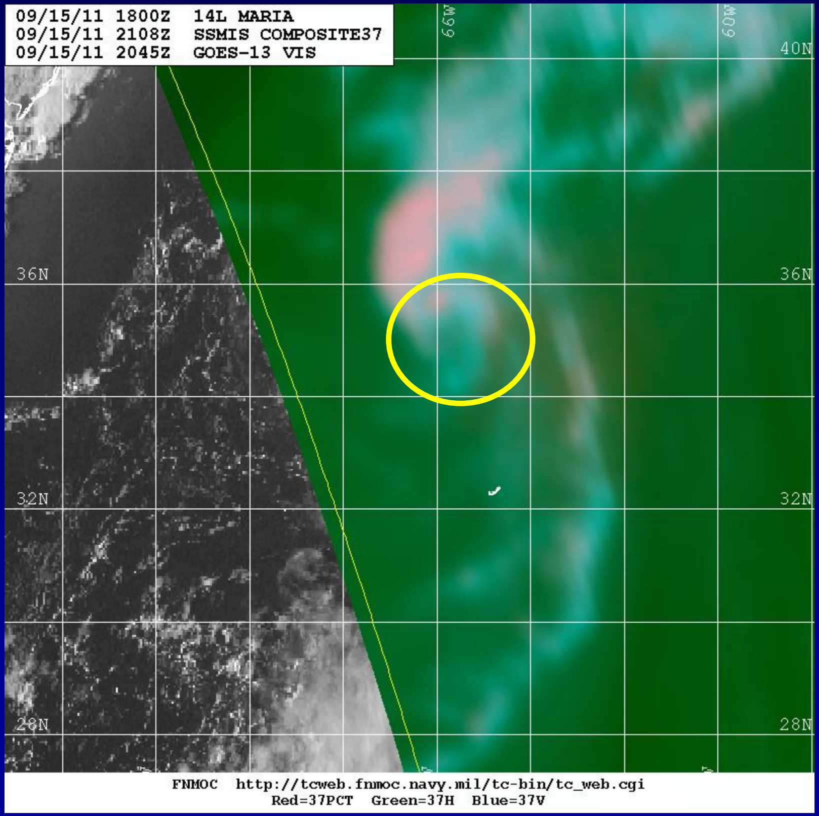
•Higher resolution of AMSR-E makes center location much easier to find relative to lower-resolution SSMIS



Impact of Resolution

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

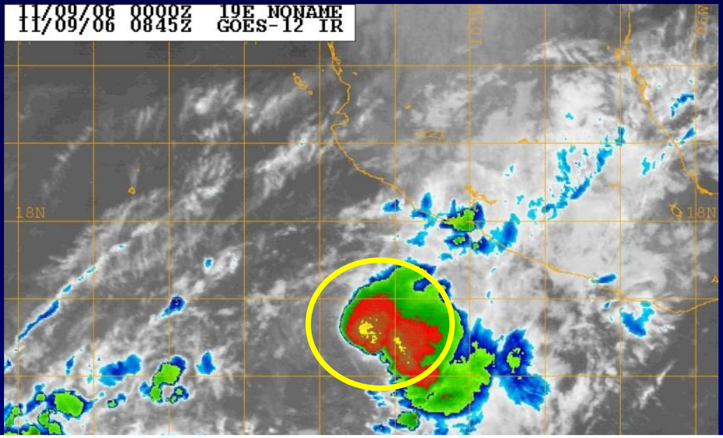




•Comparison of 36/37-GHz color composite imagery over Hurricane Maria from AMSR-E (left) and SSMIS (right) at 1739 UTC and 2018 UTC 15 September 2011, respectively – Images courtesy FNMOC TC webpage

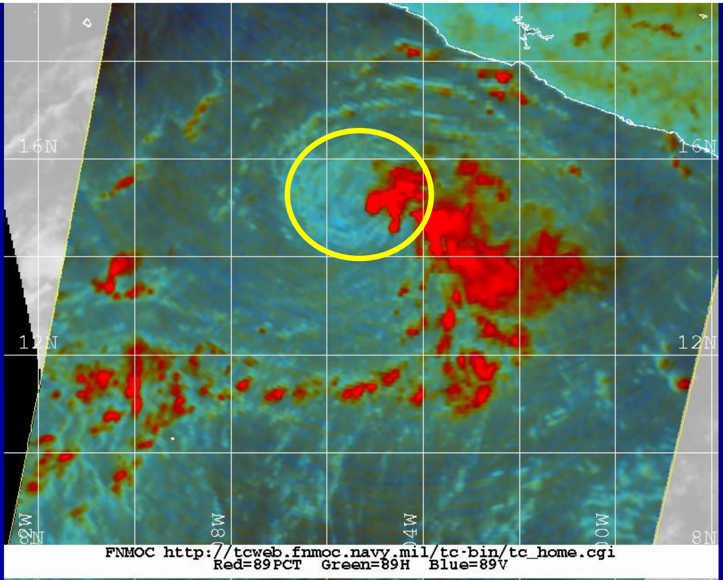
Impact of Center Location

- Locating the center of a tropical cyclone is critical to establishing initial motion, initializing model guidance, and assessing the organization and intensity of the cyclone
- Microwave imagery, especially at the 36/37-GHz channels helps improve position estimates for Dvorak intensity estimates and provide better fix-to-fix continuity
- Dvorak estimates are very sensitive to 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

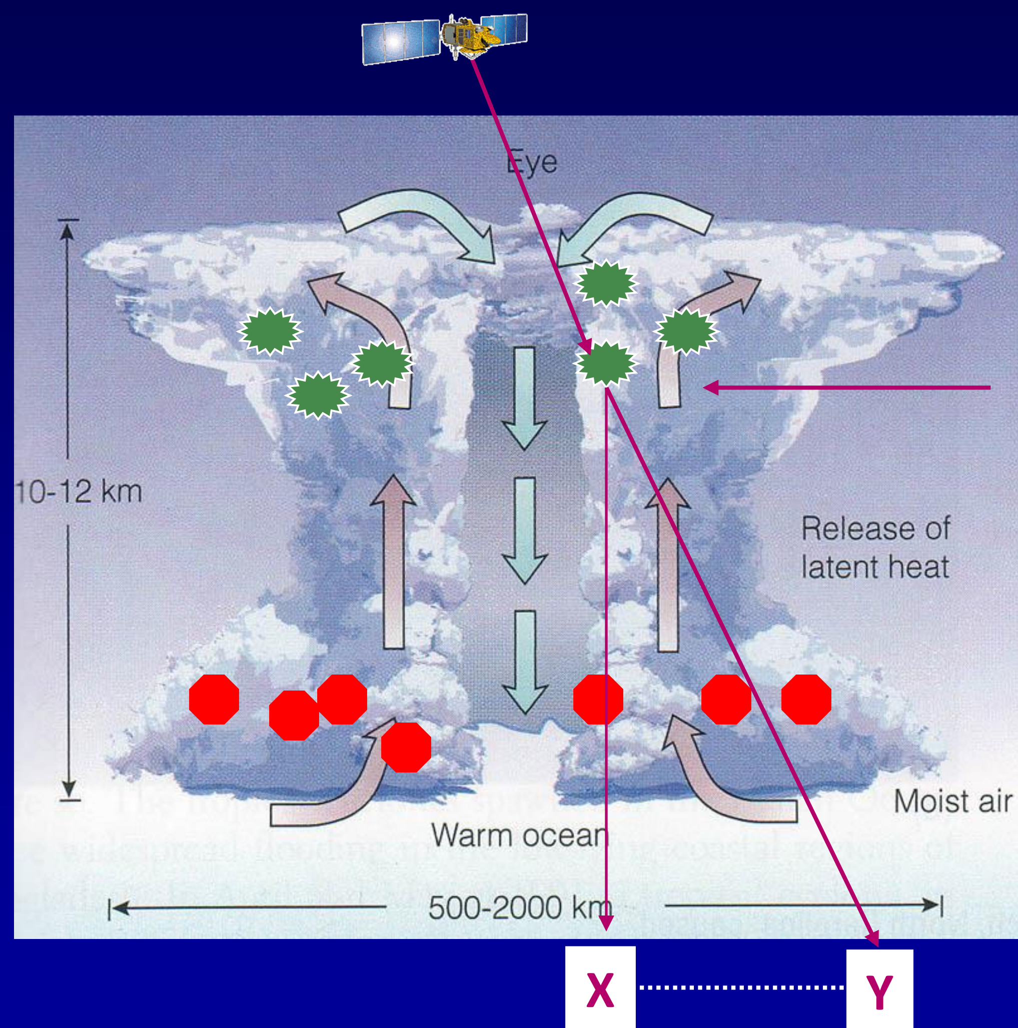


Parallax Error in Center Fixing

- Satellite derived position error exists, potentially up to 20 km 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



Effective
Level of
hydrometeors

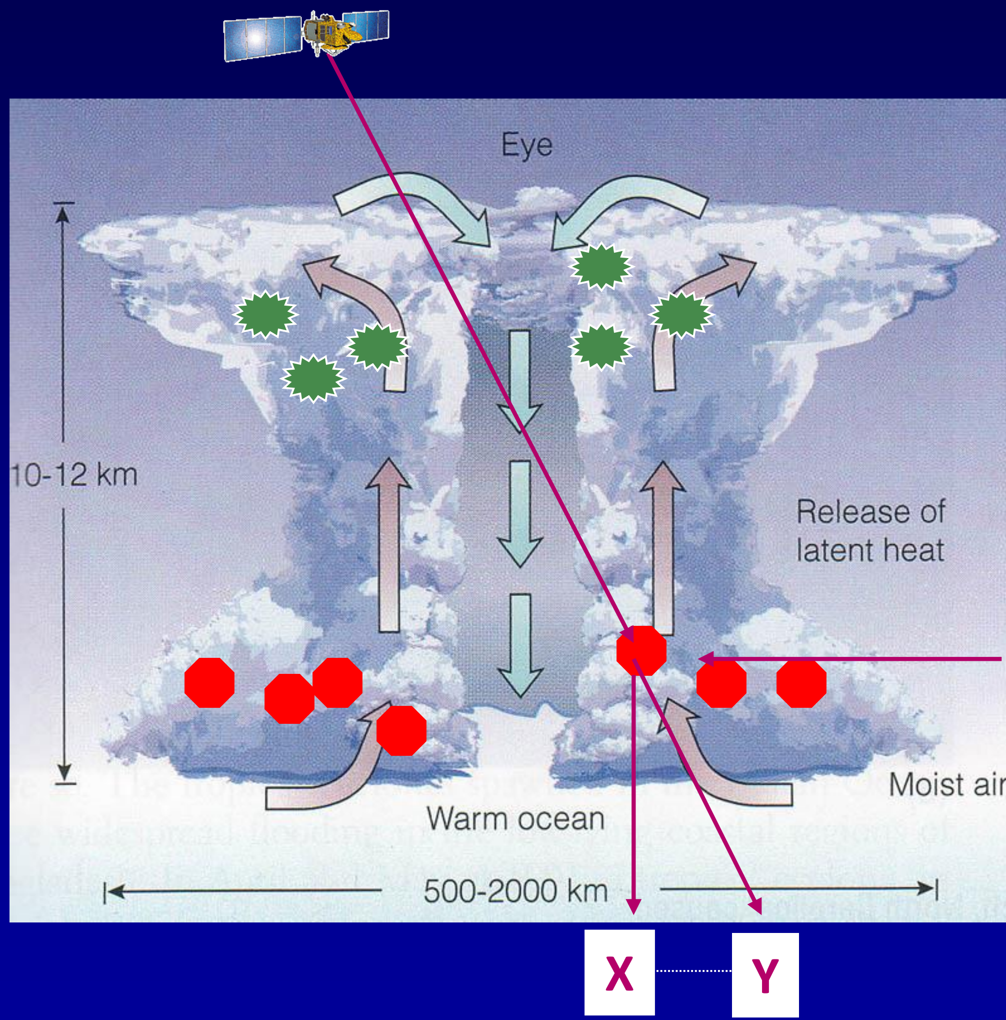
Raindrops

85 GHz
Parallax

37-GHz Parallax

Ice Crystals

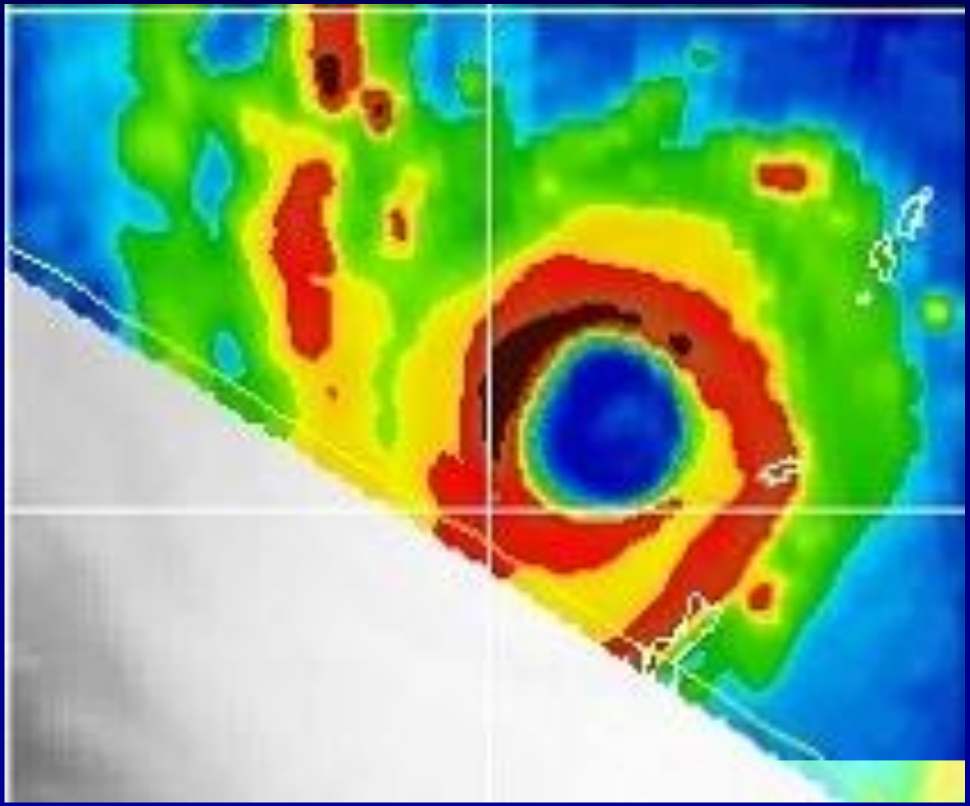
Raindrops



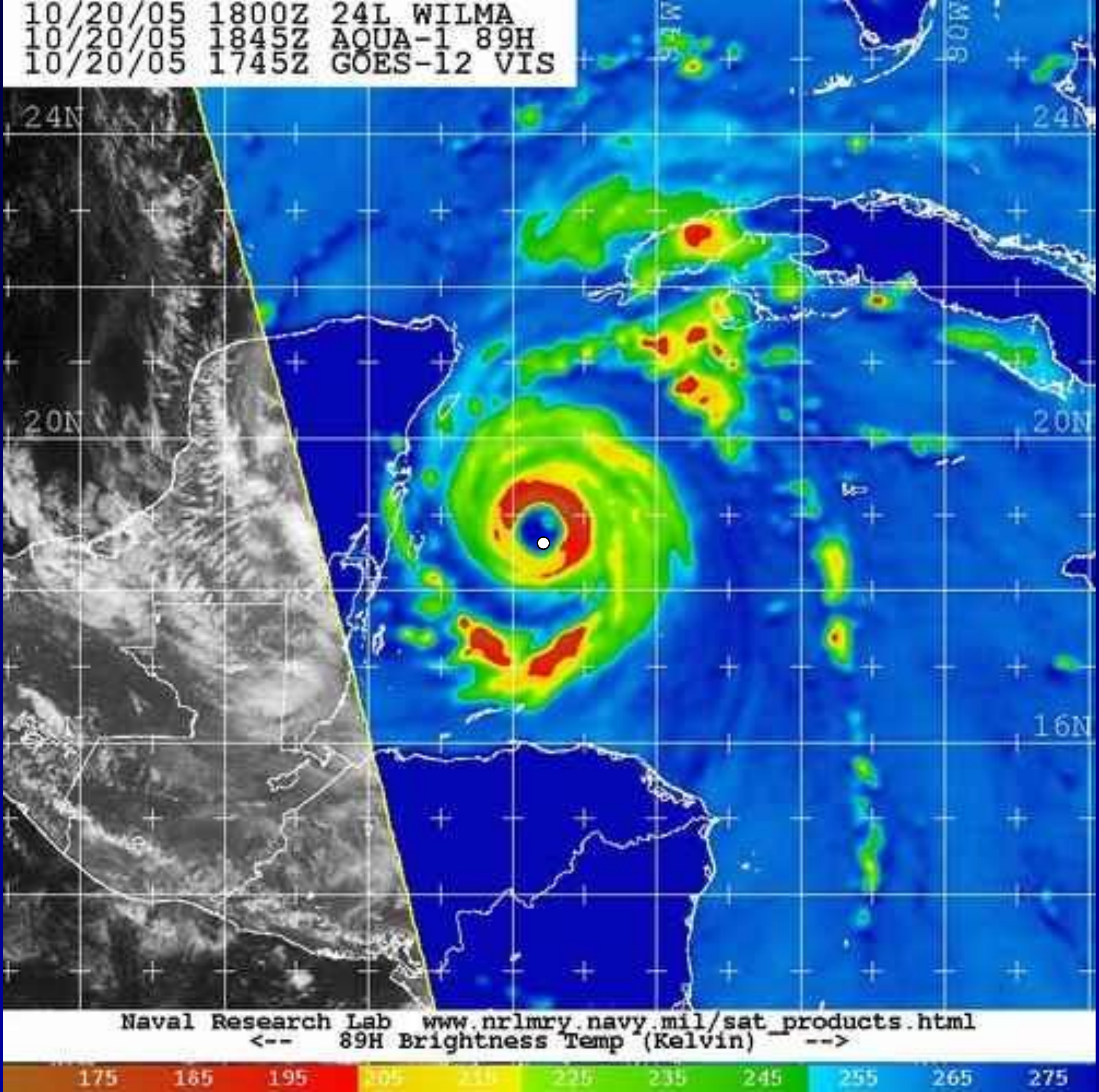
Effective Level of hydrometeors

37 GHz Parallax

Eye Size Example



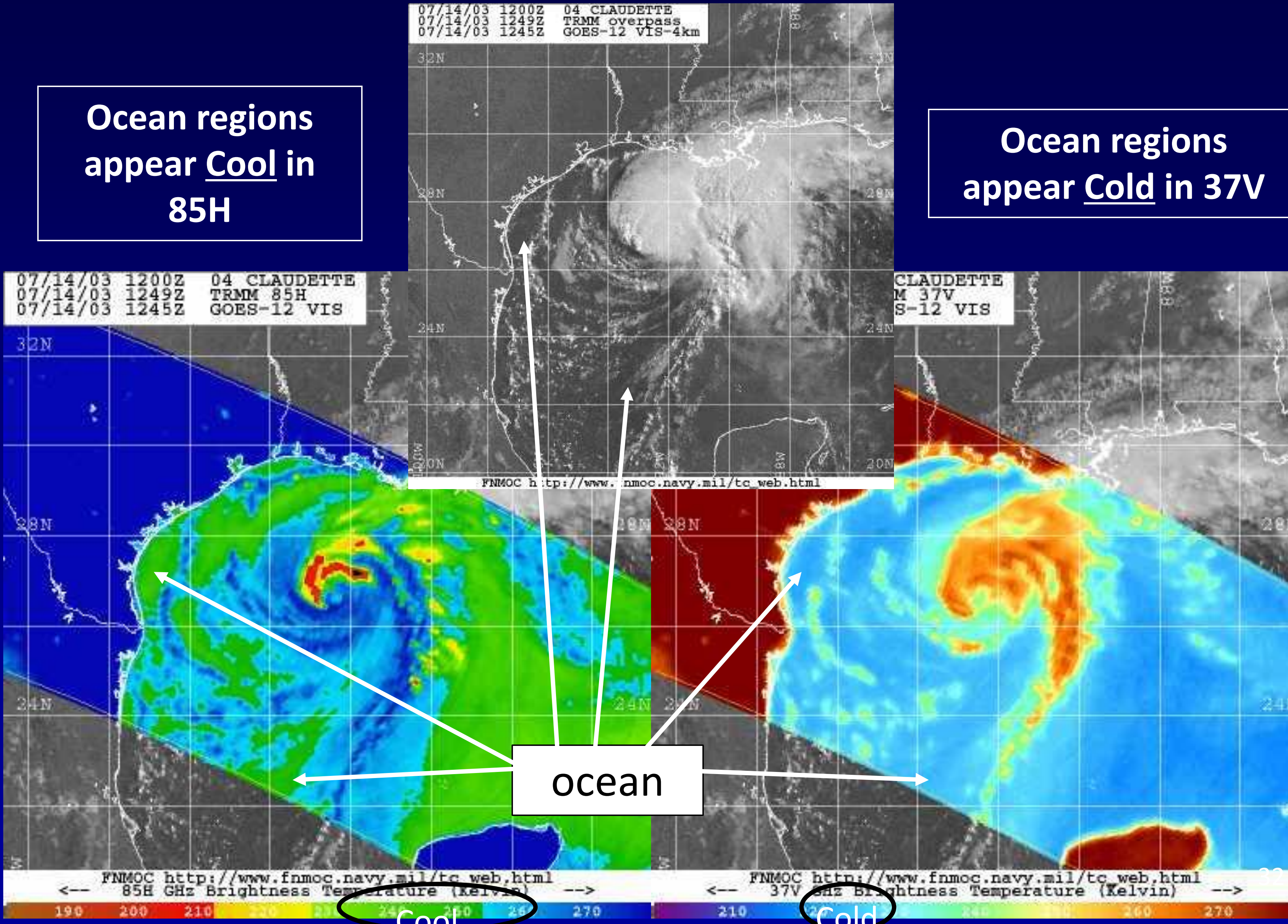
85 M
87 V


10/20/05 1800Z 24L WILMA
10/20/05 1845Z AQUA-1 89H
10/20/05 1745Z GOES-12 VIS
24N
20N
16N
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

Single Frequency Interpretation

Ocean regions appear <u>Cool</u> in 85H

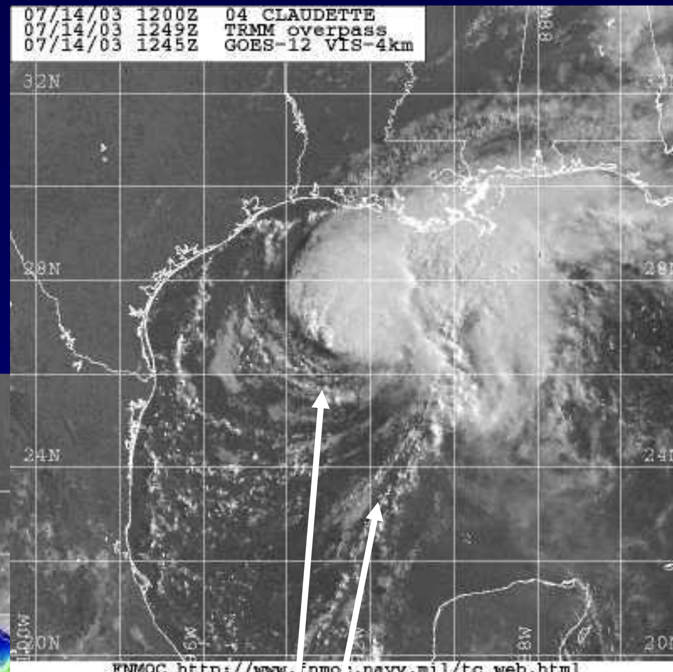
Ocean regions appear <u>Cold</u> in 37V

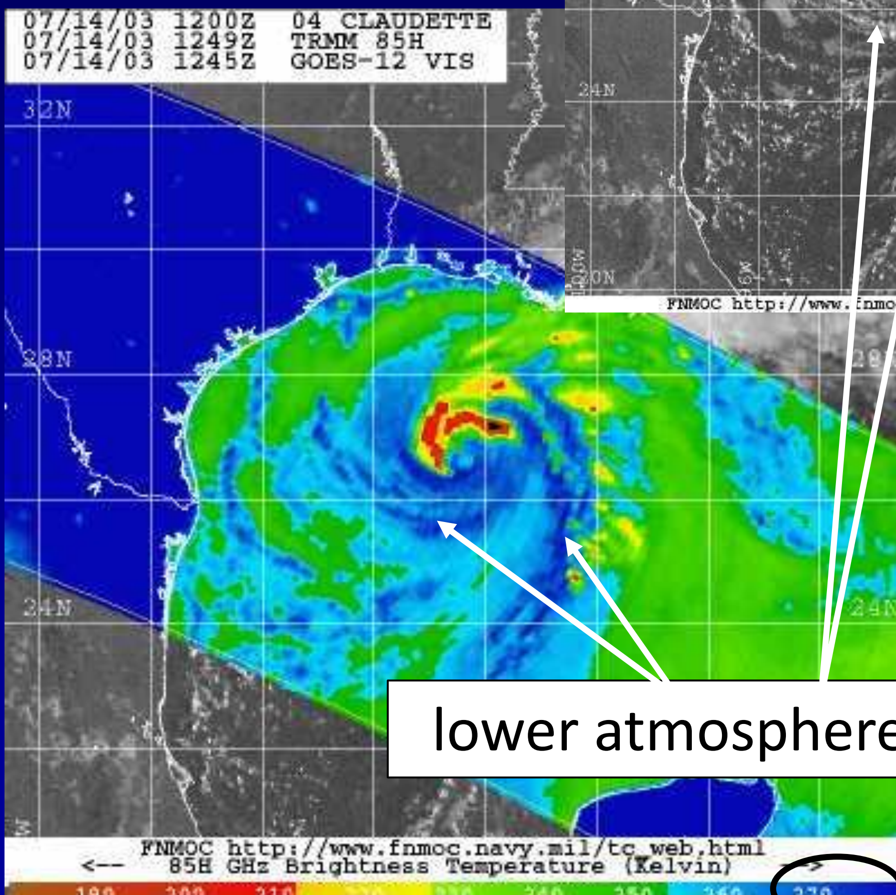


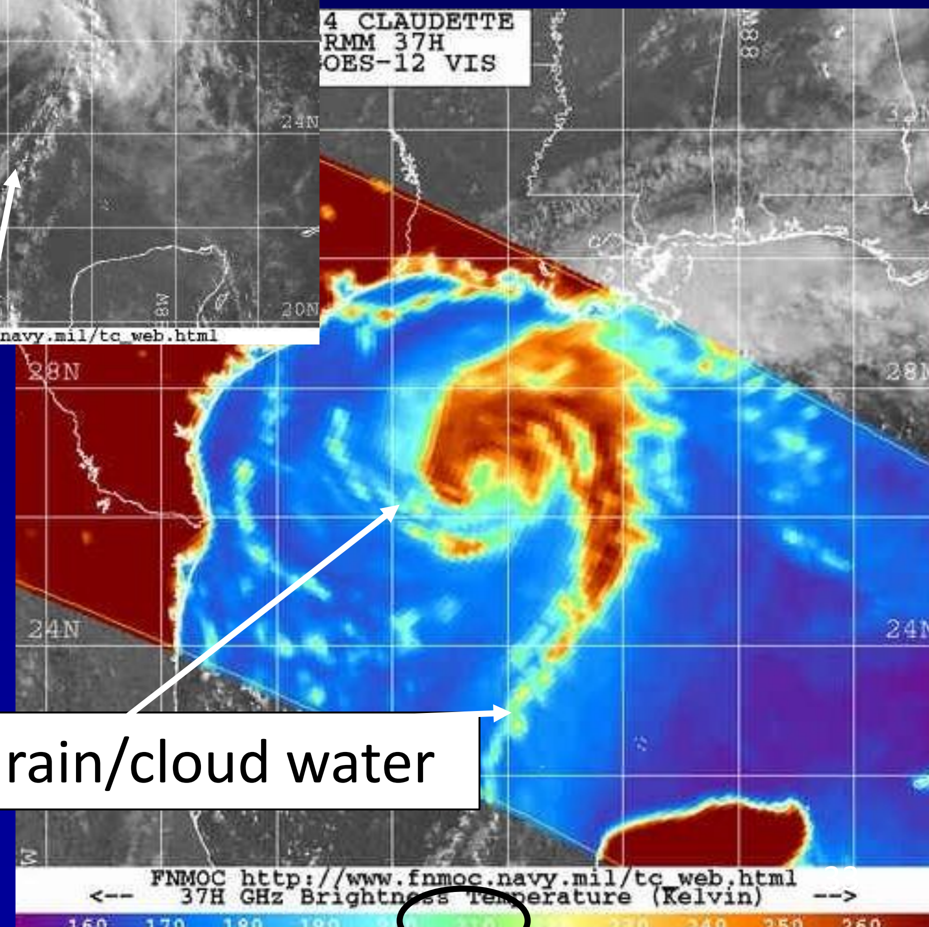
Single Frequency Interpretation

Rain appears <u>Warm</u> in 85H

Lower-based Rain appears <u>Cool</u> in 37H



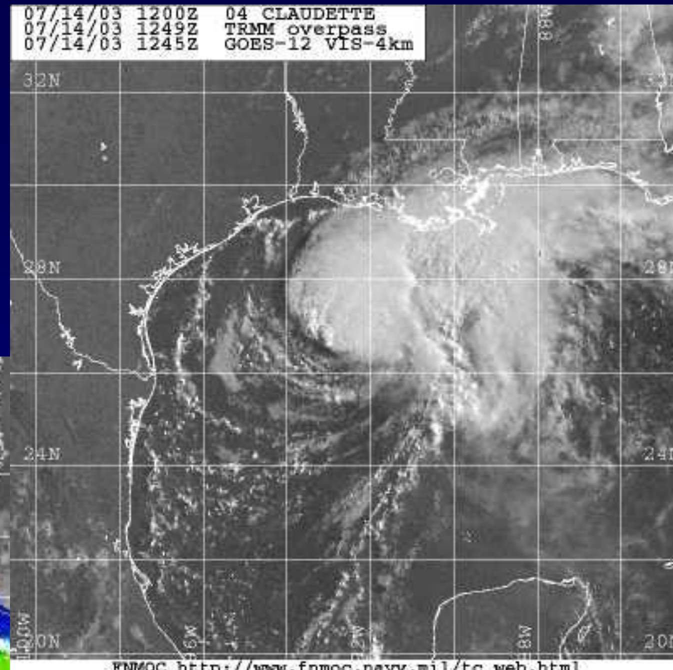




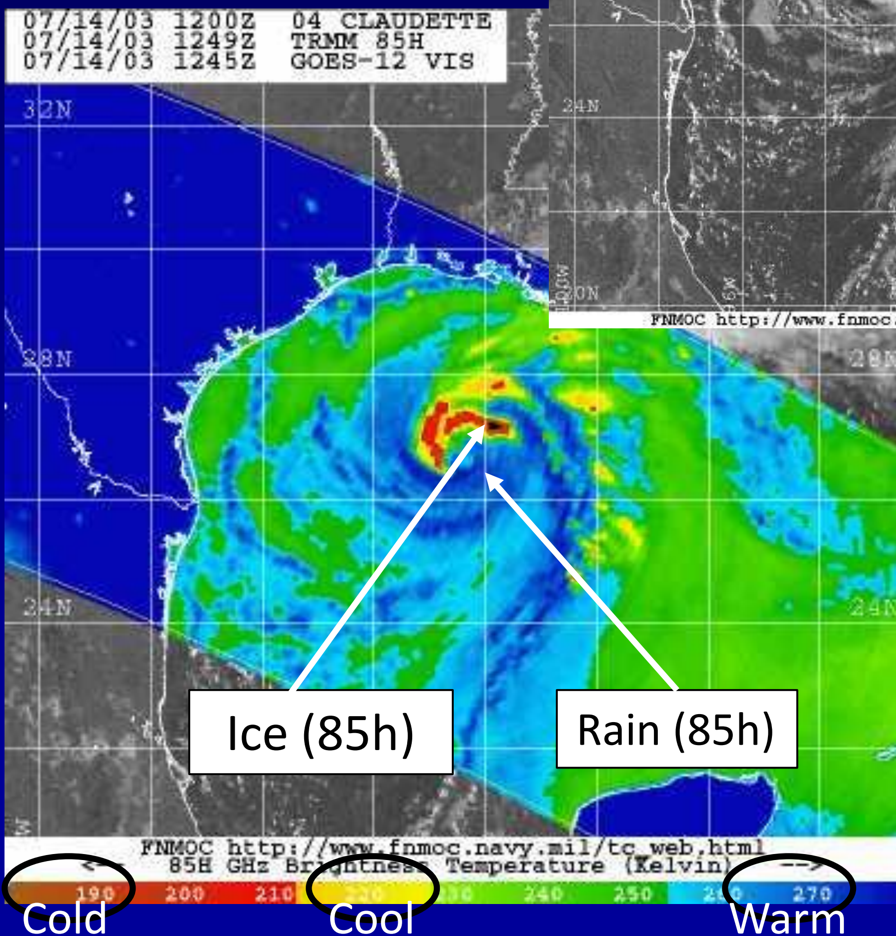
lower atmosphere rain/cloud water

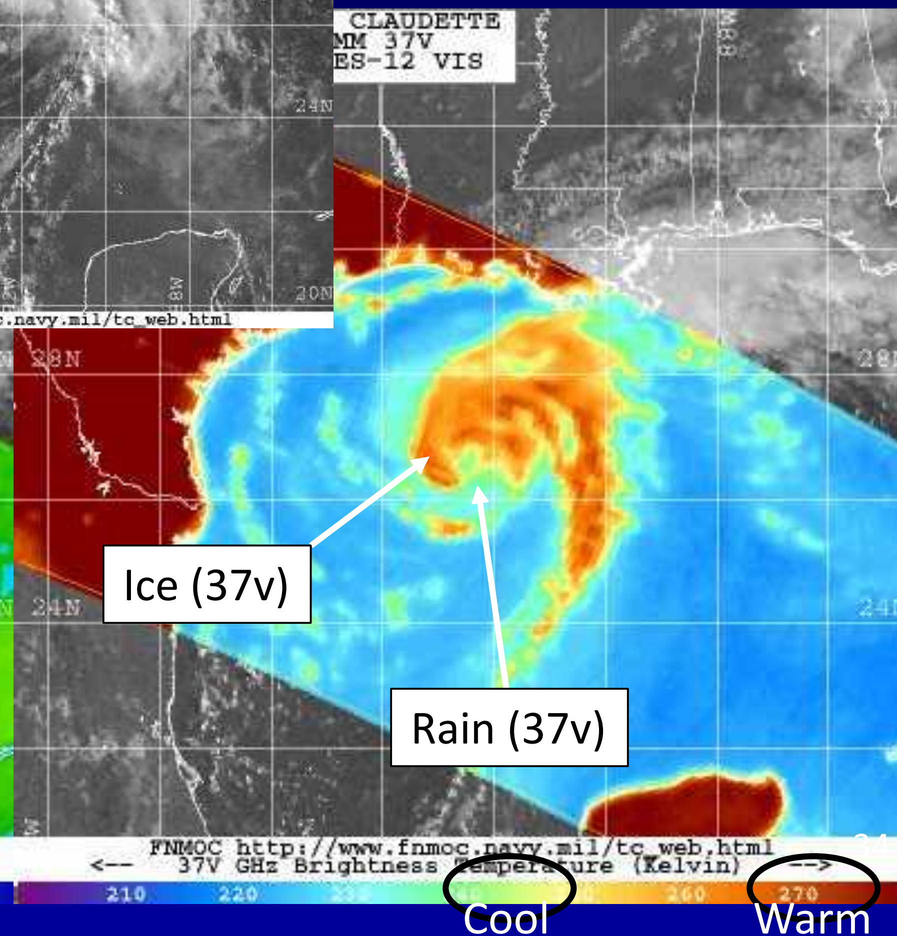
Single Frequency Interpretation

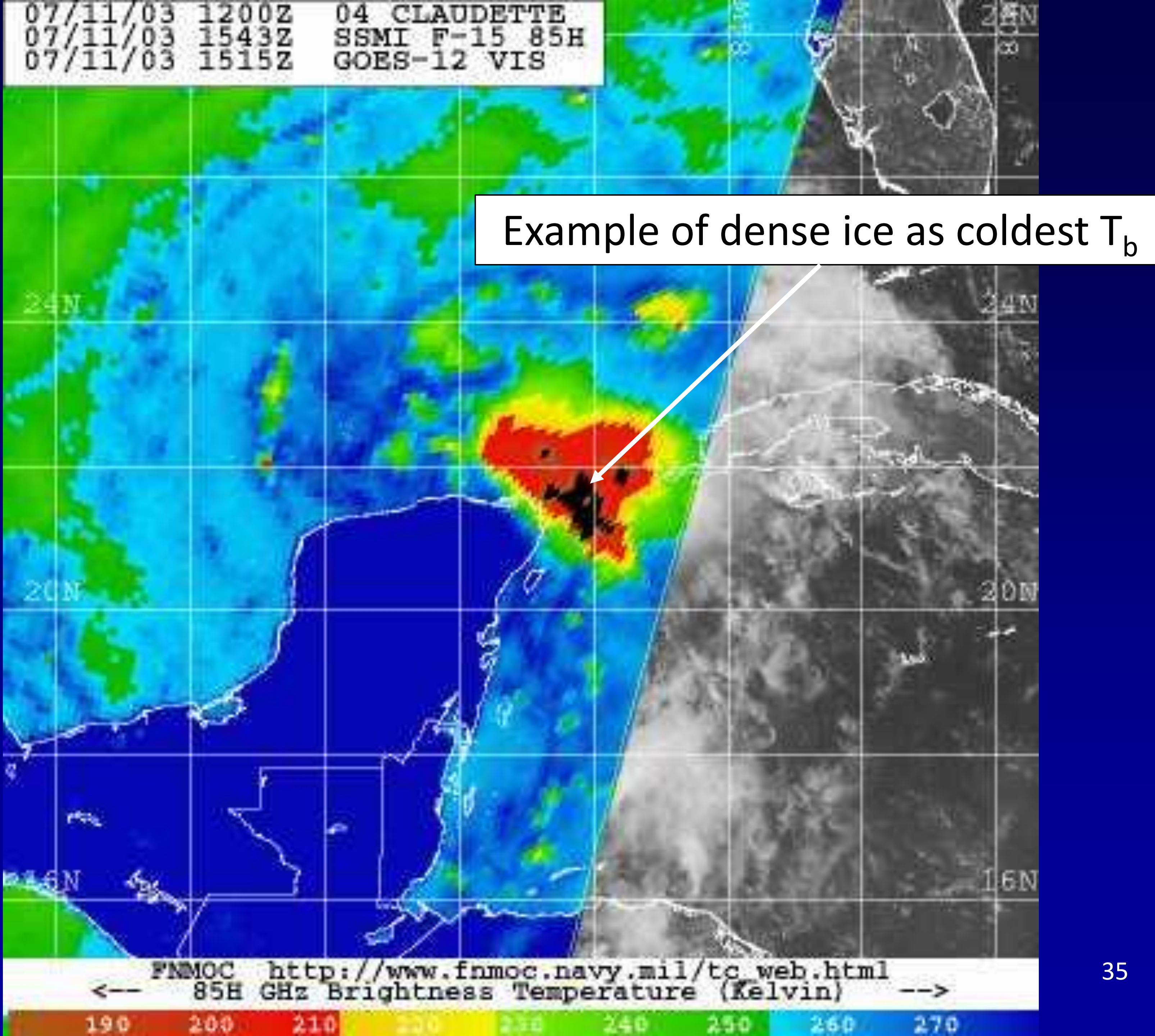
Ice appears <u>Cool</u> to <u>Cold</u> in 85H; rain is <u>Warm</u>



Rain appears <u>Cool</u> in 37V (<u>less cold</u> over water) Dense ice looks <u>Warm</u>



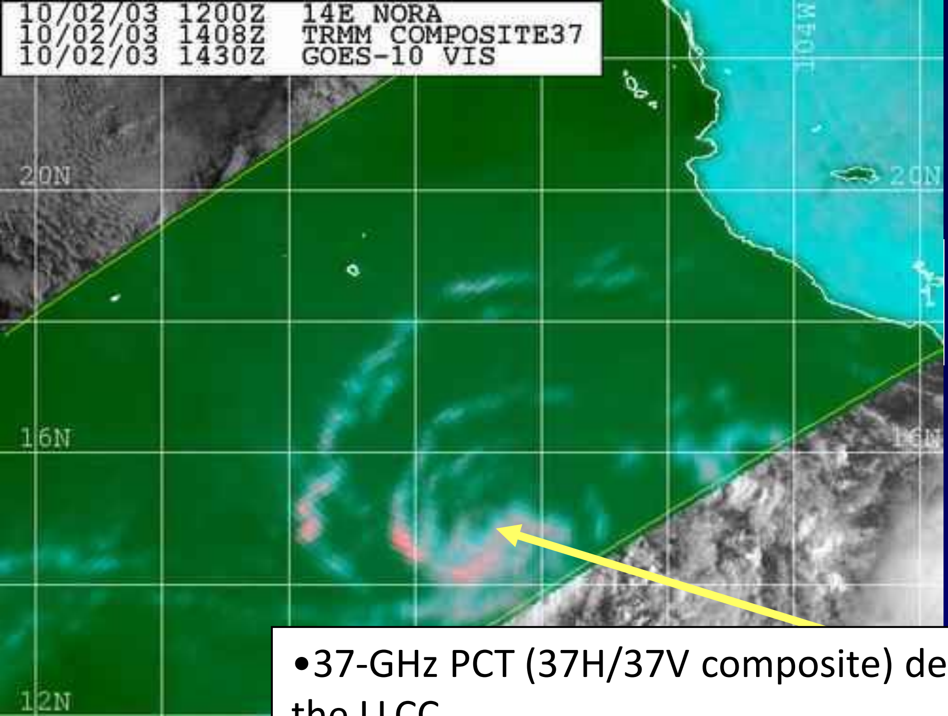


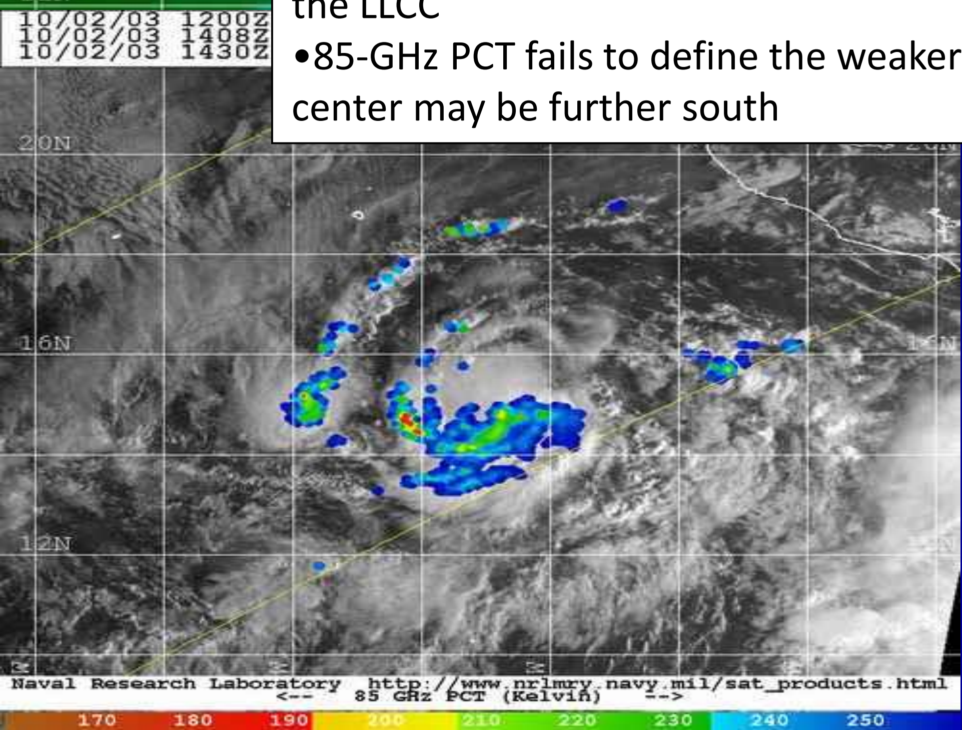

07/11/03 1200Z 04 CLAUDETTE
07/11/03 1543Z SSMI F-15 85H
07/11/03 1515Z GOES-12 VIS
24N
20N
16N
Example of dense ice as coldest T_b
FNMOC http://www.fnmoc.navy.mil/tc_web.html
<-- 85H GHz Brightness Temperature (Kelvin) -->
190 200 210 220 230 240 250 260 270

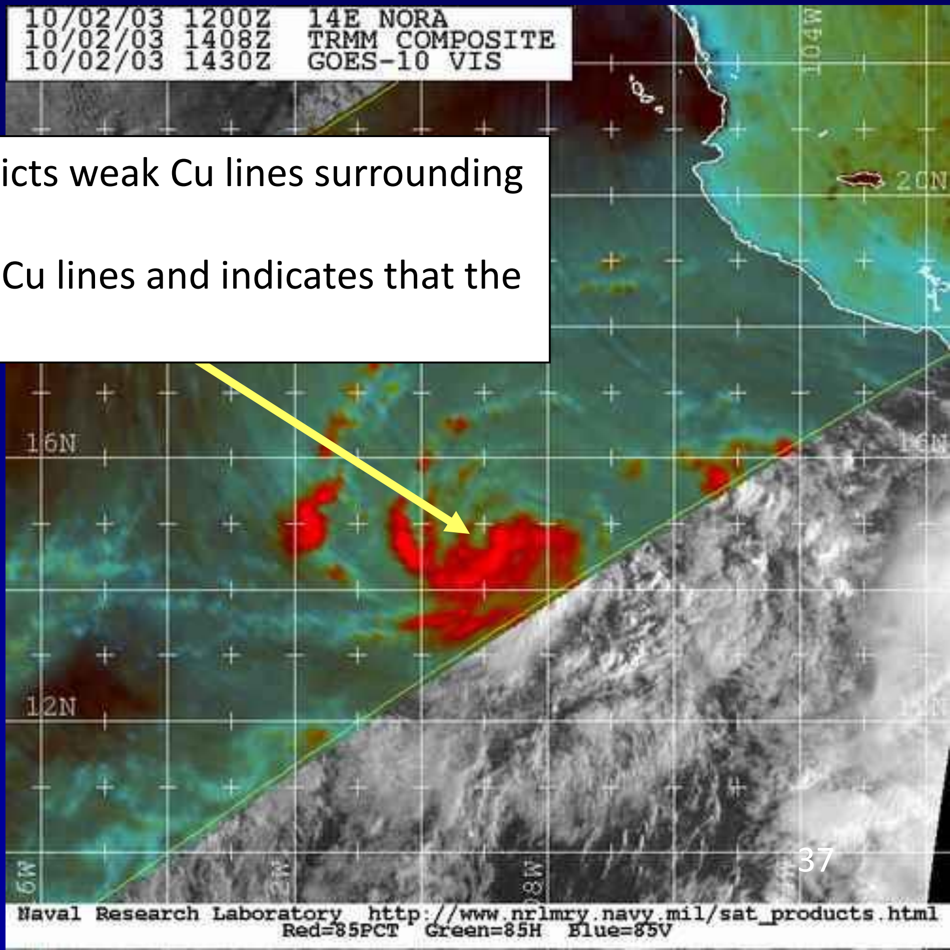
Color Composite Imagery

- Significant ambiguities (low clouds, sea surface, land features) exist when interpreting single frequency 85/37-GHz images
- Polarization Correction Temp (PCT) and color composite images correct T_b in regions of little or no clouds or rain (low emissions) to approximately the surface air temperature
- Color composite images combine PCT with V and H polarizations to removes 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

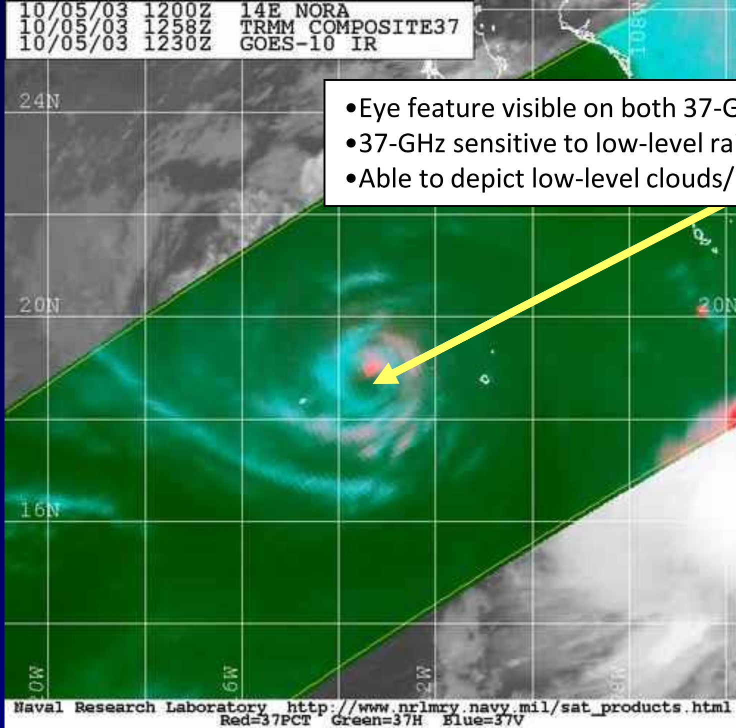


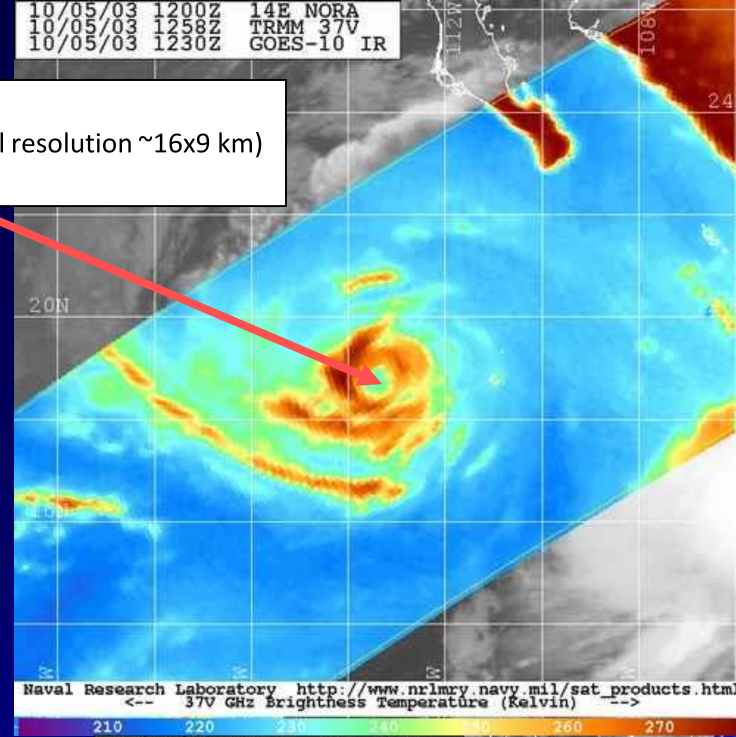




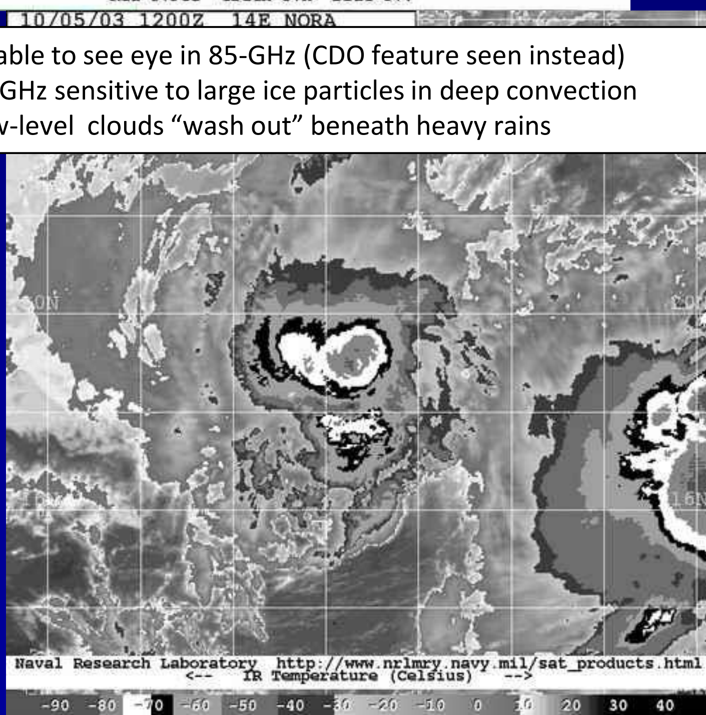
- •37-GHz PCT (37H/37V composite) depicts weak Cu lines surrounding the LLCC
- •85-GHz PCT fails to define the weaker Cu lines and indicates that the center may be further south

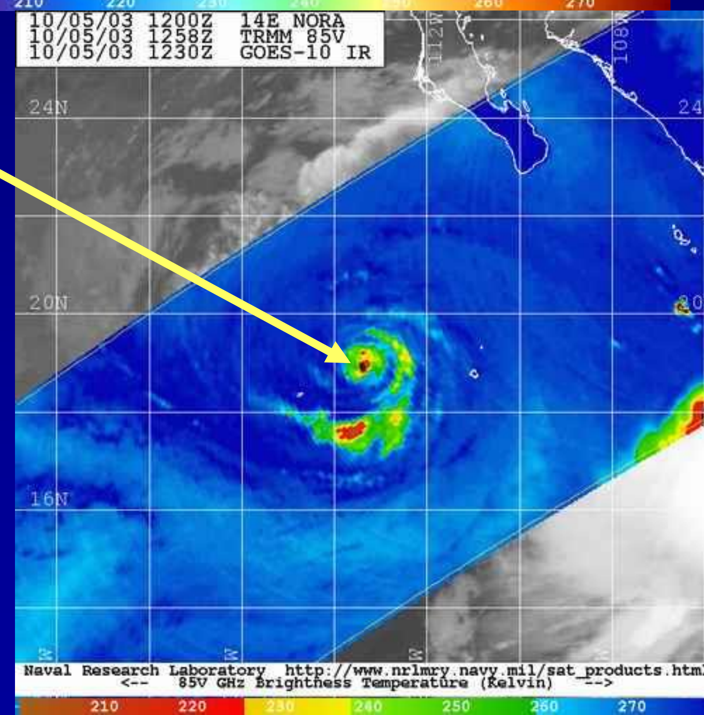
- Eye feature visible on both 37-GHZ images
- 37-GHz sensitive to low-level rain (high spatial resolution ~16x9 km)
- Able to depict low-level clouds/rainbands

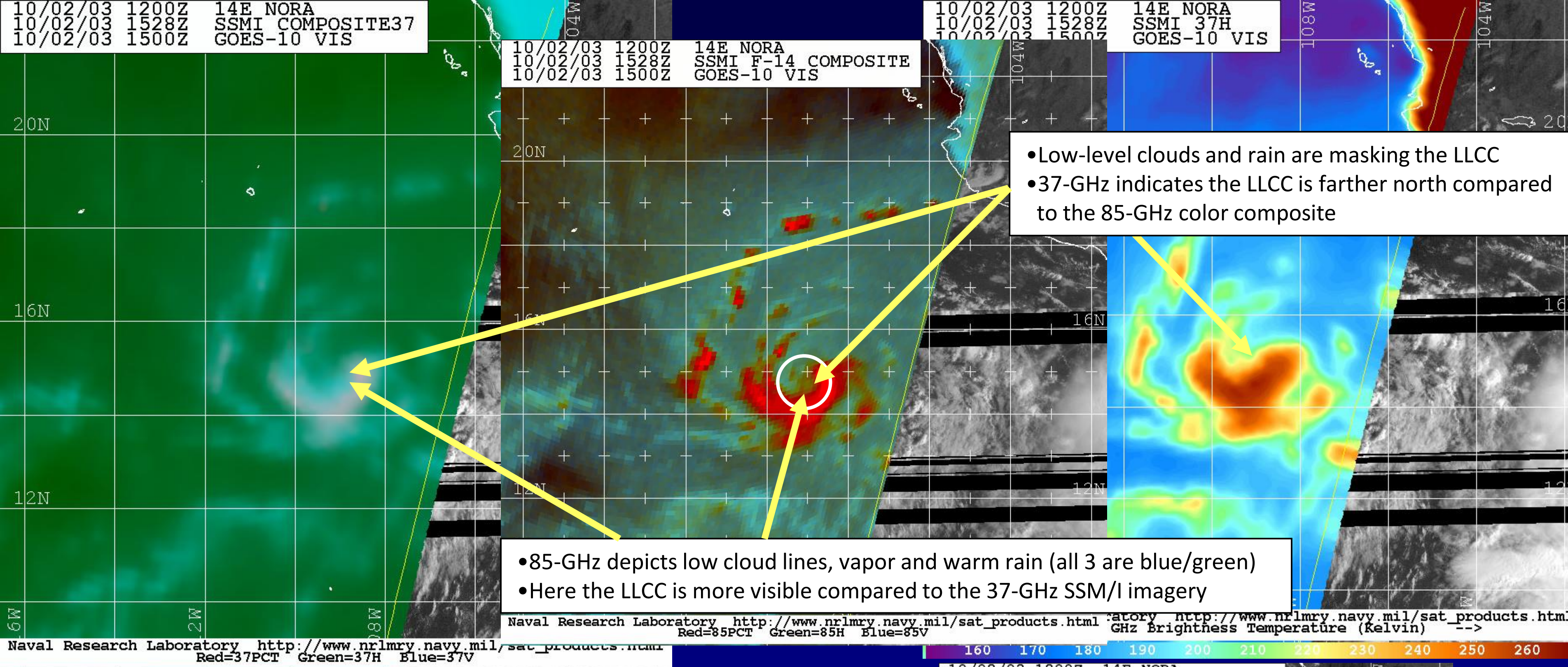




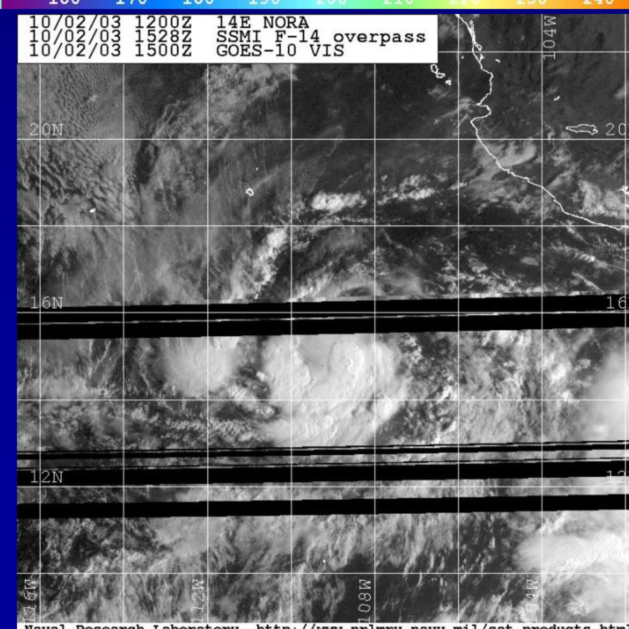
- Unable to see eye in 85-GHz (CDO feature seen instead)
- 85-GHz sensitive to large ice particles in deep convection
- Low-level clouds “wash out” beneath heavy rains

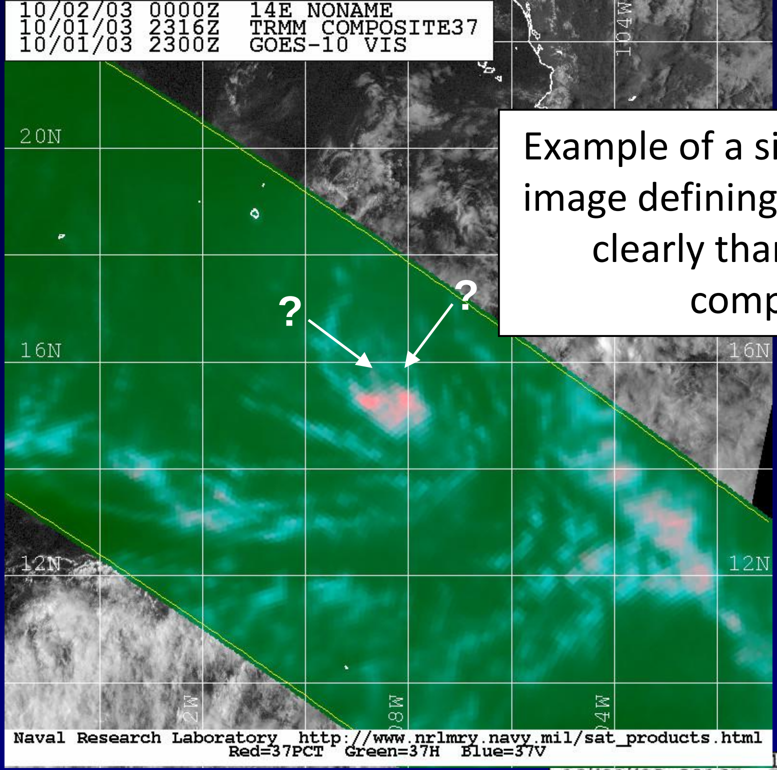




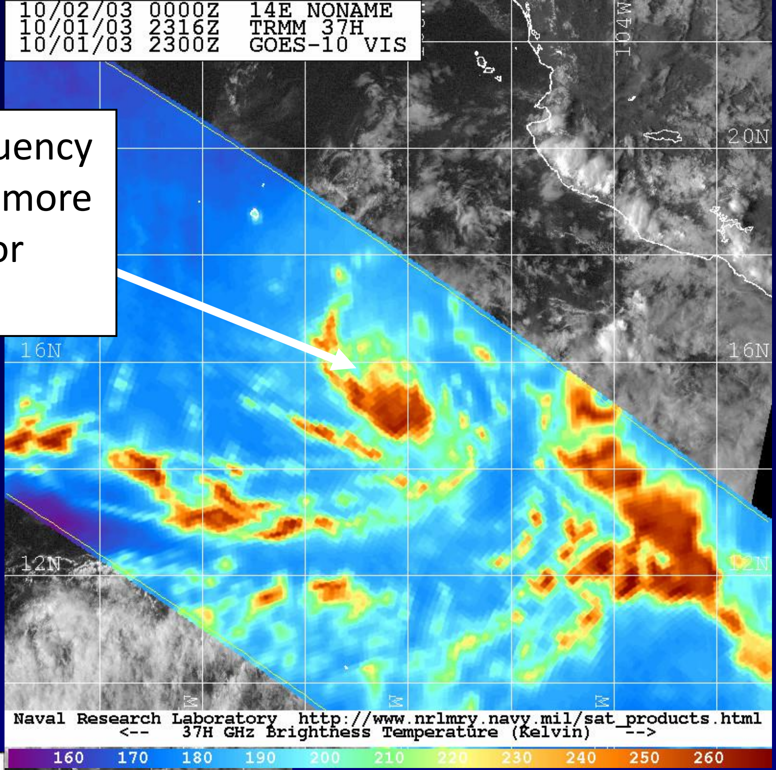


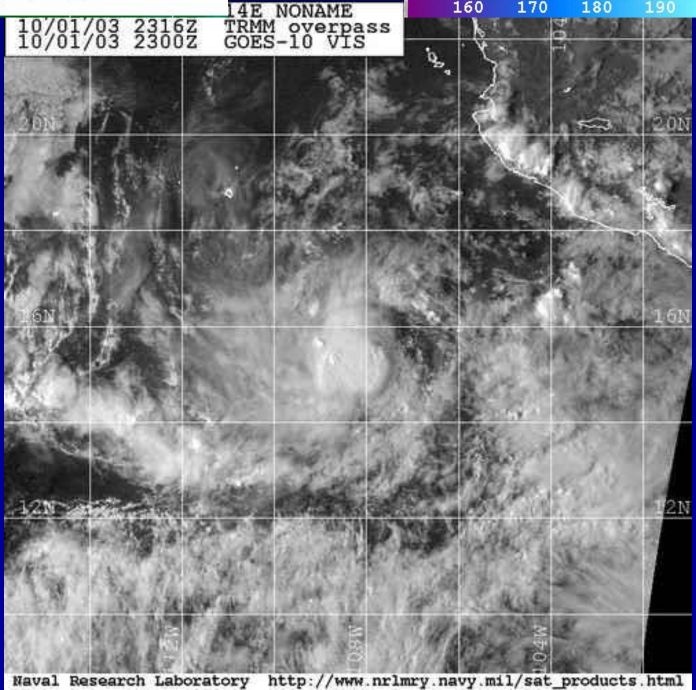
- 85-GHz color composite helps verify the possible solution seen on the 37-GHz color composite
- 37-GHz SSM/I and SSMIS spatial resolution is coarser (37x28 km) than the 37-GHz TRMM
- As a result, during relatively weak stages of a TC, SSM/I and SSMIS 37GHz H/V are difficult stand-alone images to interpret → recommend using corrected images instead





Example of a single frequency image defining the LLCC more clearly than the color composite





Summary Questions

1. The parallax error due to the viewing geometry of the imager is larger at:

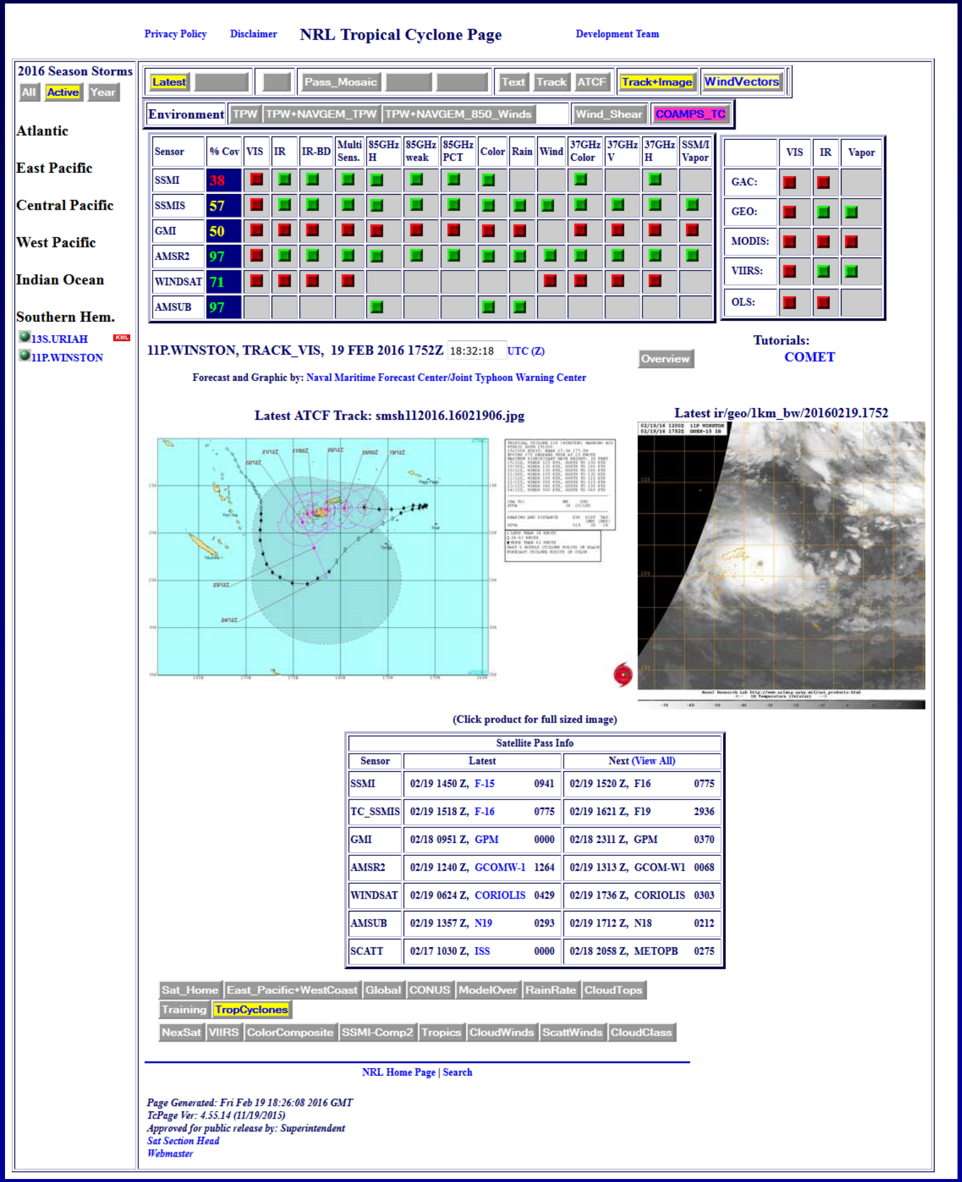
    A. higher frequencies
    B. lower frequencies
    C. all imager frequencies

2. For a more precise estimation of the eye size of a hurricane, it's best to use:

    A. the high frequency images
    B. the low frequency images
    C. conventional imagery
    D. a combination of B and C
    E. a combination of A and C

Access to Online Microwave Imagery

NRL Tropical Cyclone Webpage



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
SSMI	38														
SSMIS	57														
GMI	50														
AMSR2	97														
WINDSAT	71														
AMSUB	97														

Sensor	Latest		Next (View All)	
SSMI	02/19 1450 Z, F-15	0941	02/19 1520 Z, F16	0775
TC_SSMIS	02/19 1518 Z, F-16	0775	02/19 1621 Z, F19	2936
GMI	02/18 0951 Z, GPM	0000	02/18 2311 Z, GPM	0370
AMSR2	02/19 1240 Z, GCOMW-1	1264	02/19 1313 Z, GCOM-W1	0068
WINDSAT	02/19 0624 Z, CORIOLIS	0429	02/19 1736 Z, CORIOLIS	0303
AMSUB	02/19 1357 Z, N19	0293	02/19 1712 Z, N18	0212
SCATT	02/17 1030 Z, ISS	0000	02/18 2058 Z, METOPB	0275

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

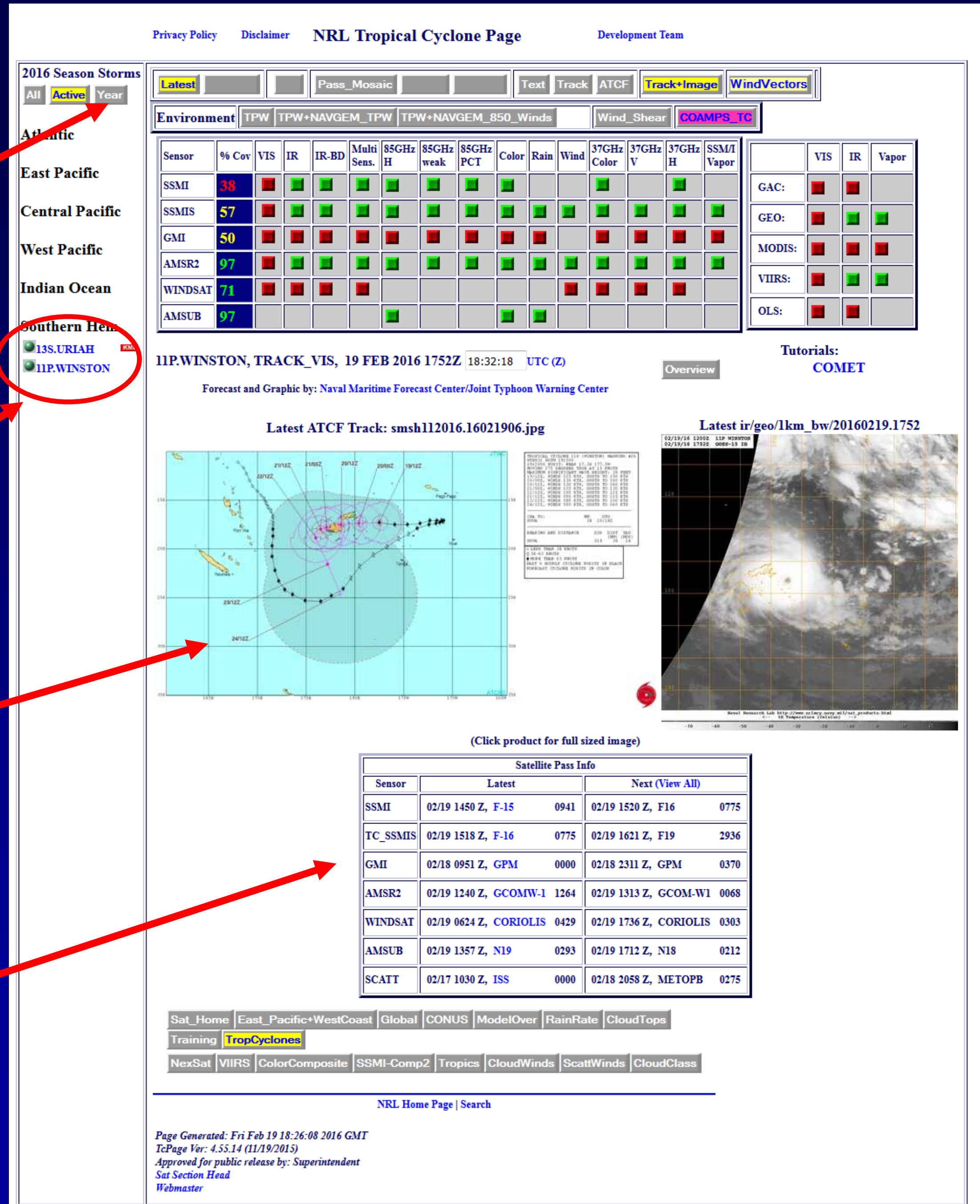
NRL TC Page

Archive data available (click "year")

Active TCs or Invest areas

Forecast Track from RSMC, if available

Satellite Pass Information



Product List

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.

Latest | Previous | Full | Pass_Mosaic | Mosaic | Loop | Text | Track | ATCF | Track+Image | WindVectors

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
SSMI	87	■	■	■	■	■	■	■	■			■		■	
SSMIS	94	■	■	■	■	■	■	■	■	■	■	■	■	■	■
GMI	41	■	■	■	■	■	■	■	■	■		■	■	■	■
AMSR2	76	■	■	■	■	■	■	■	■	■	■	■	■	■	■
WINDSAT	83	■	■	■	■						■	■	■	■	
AMSUB	29					■				■					

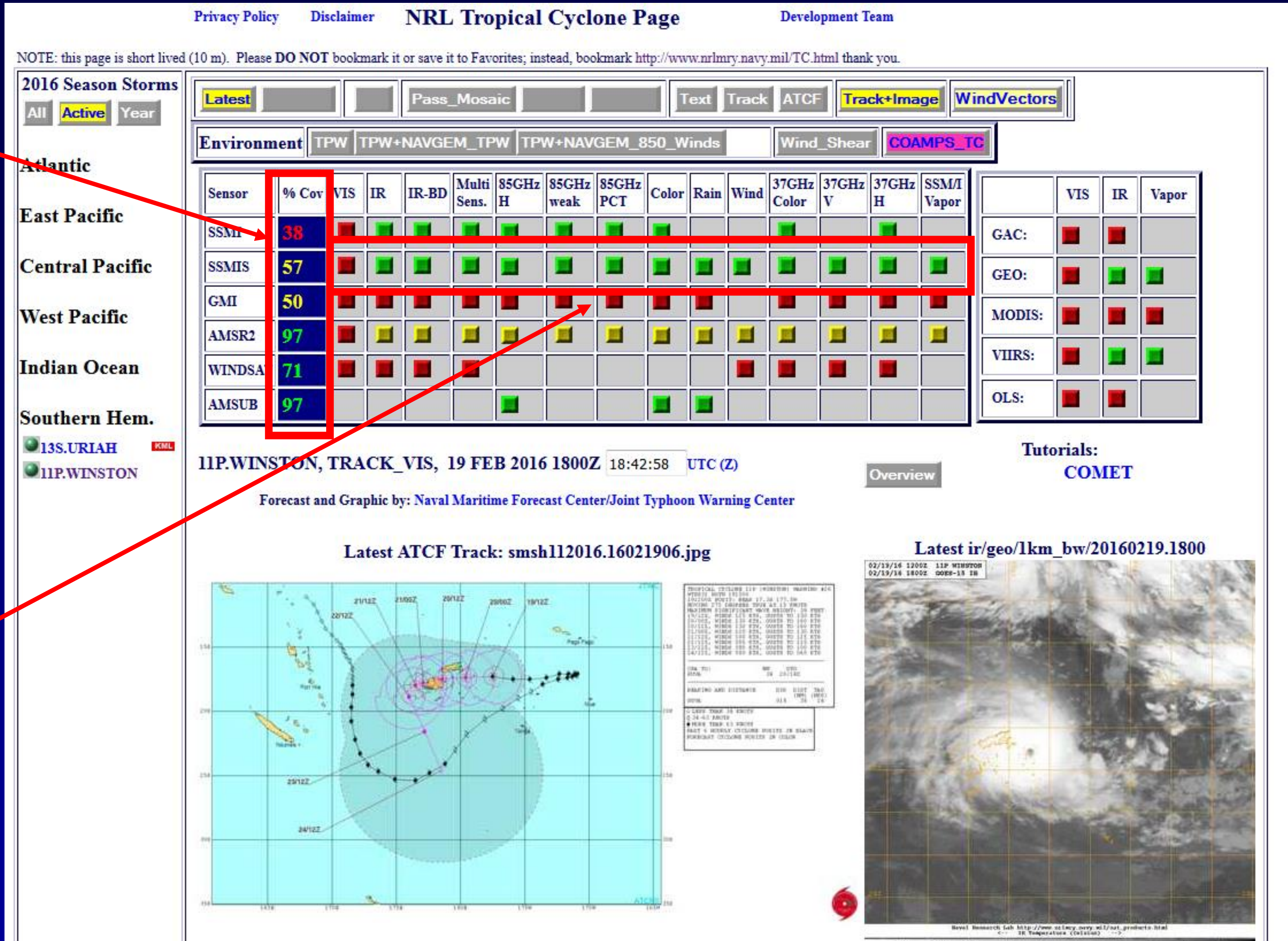
	VIS	IR	Vapor
GAC:	■	■	
GEO:	■	■	■
MODIS:	■	■	■
VIIRS:	■	■	■
OLS:	■	■	

Index of: /SATPRODUCTS/TC/tc15/ATL/11L.JOAQUIN/gmi/color/2degreeticks

20151013.1411.gpm.x.colorpct_89h_89v.11LJOAQUIN.30kts-999mb-426N-120W.41pc.jpg (226840)
20151012.2311.gpm.x.colorpct_89h_89v.11LJOAQUIN.30kts-999mb-426N-120W.40pc.jpg (246128)
20151012.1506.gpm.x.colorpct_89h_89v.11LJOAQUIN.30kts-999mb-426N-120W.58pc.jpg (224445)
20151012.0001.gpm.x.colorpct_89h_89v.11LJOAQUIN.30kts-999mb-426N-120W.49pc.jpg (227834)
20151010.2321.gpm.x.colorpct_89h_89v.11LJOAQUIN.30kts-998mb-426N-129W.34pc.jpg (228699)
20151010.1516.gpm.x.colorpct_89h_89v.11LJOAQUIN.35kts-992mb-431N-140W.57pc.jpg (286763)
20151010.0011.gpm.x.colorpct_89h_89v.11LJOAQUIN.40kts-989mb-442N-182W.59pc.jpg (354901)
20151009.1611.gpm.x.colorpct_89h_89v.11LJOAQUIN.40kts-989mb-442N-182W.41pc.jpg (489126)
20151009.0106.gpm.x.colorpct_89h_89v.11LJOAQUIN.40kts-987mb-440N-238W.40pc.jpg (317653)
20151008.1701.gpm.x.colorpct_89h_89v.11LJOAQUIN.45kts-977mb-430N-273W.63pc.jpg (459232)
20151008.0156.gpm.x.colorpct_89h_89v.11LJOAQUIN.45kts-977mb-430N-273W.59pc.jpg (345090)
20151007.1751.gpm.x.colorpct_89h_89v.11LJOAQUIN.60kts-978mb-408N-476W.33pc.jpg (491795)
20151007.0421.gpm.x.colorpct_89h_89v.11LJOAQUIN.70kts-974mb-396N-549W.49pc.jpg (348744)
20151006.0516.gpm.x.colorpct_89h_89v.11LJOAQUIN.75kts-970mb-364N-634W.51pc.jpg (381709)
20151004.2026.gpm.x.colorpct_89h_89v.11LJOAQUIN.75kts-964mb-346N-649W.58pc.jpg (384604)
20151002.2031.gpm.x.colorpct_89h_89v.11LJOAQUIN.110kts-942mb-238N-748W.32pc.jpg (584070)
20151002.0711.gpm.x.colorpct_89h_89v.11LJOAQUIN.115kts-935mb-230N-747W.36pc.jpg (408268)
20151001.2126.gpm.x.colorpct_89h_89v.11LJOAQUIN.115kts-936mb-230N-742W.51pc.jpg (518508)
20151001.0806.gpm.x.colorpct_89h_89v.11LJOAQUIN.105kts-948mb-235N-735W.46pc.jpg (425002)
20150929.2136.gpm.x.colorpct_89h_89v.11LJOAQUIN.55kts-992mb-260N-708W.62pc.jpg (495211)
20150929.0816.gpm.x.colorpct_89h_89v.11LJOAQUIN.35kts-1002mb-266N-704W.51pc.jpg (405905)
20150927.2146.gpm.x.colorpct_89h_89v.11LELEVEN.30kts-1006mb-276N-691W.38pc.jpg (384274)
20150925.0836.gpm.x.colorpct_89h_89v.11LELEVEN.30kts-1006mb-276N-691W.44pc.jpg (233133)

Color-coded by percent coverage

Color-coded with Green being latest overpass



FNMOC Satellite Data Tropical Cyclone Page

2009 Storms

All | Active | Year

Atlantic

East Pacific

Central Pacific

West Pacific

Indian Ocean

Southern Hemisphere

- 90P.INVEST
- 24S.IZILDA
- 23P.JASPER
- 22S.ILSA

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

Info: | General | Tutorial | Disclaimer

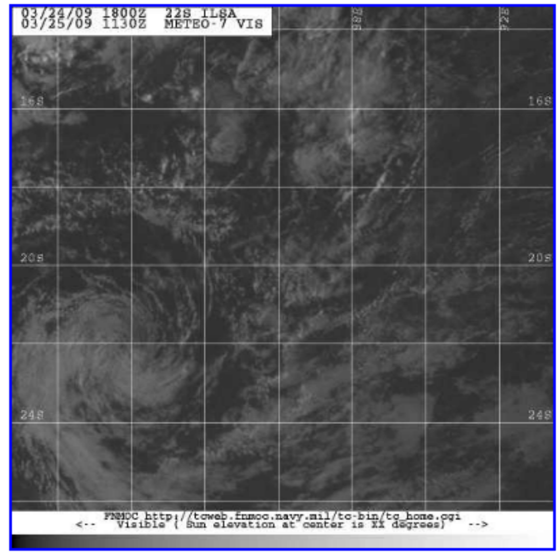
Environment | TPW | TPW&NOGAPS_TPW. | TPW&NOGAPS_850_Winds

SSMI | SSMIS | TRMM | AMSU | QuikScat | AMSR | WindSat | MODIS | VIS | IR | OLS

Age <= 6hrs old | Age <= 12hrs old | Age >12hrs old | 12:49:39 | UTC(Z)

22S.ILSA 25 MAR 2009 1130Z

Half-sized, (27 K) click image to get full-size (213 K).



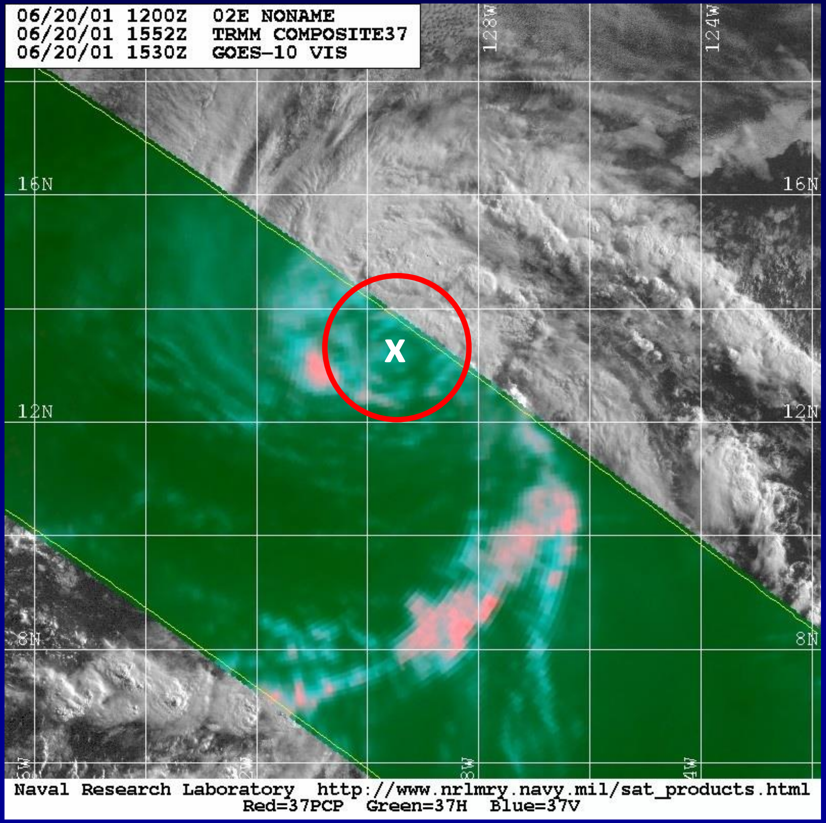
Latest		Upcoming Passes (more)		
SSMI:	03/25 0029Z 244	03/25 13:03	F-15	408
SSMIS:	03/25 0131Z 0	03/25 14:07	F-16	138
TMI:	03/25 0839Z 678	03/25 15:14	TRMM	76
AMSU:	03/25 0729Z 0	03/25 11:28	N-15	273
QScat:	03/25 0014Z 570	03/26 12:34	QUIK	658
WSat:	03/25 0038Z 0	03/26 00:23	WSAT	672
AMSR:	03/25 0825Z 496	03/25 19:22	AQUA	562
MODIS:	03/25 0400Z 0	03/26 04:42	TERRA	223

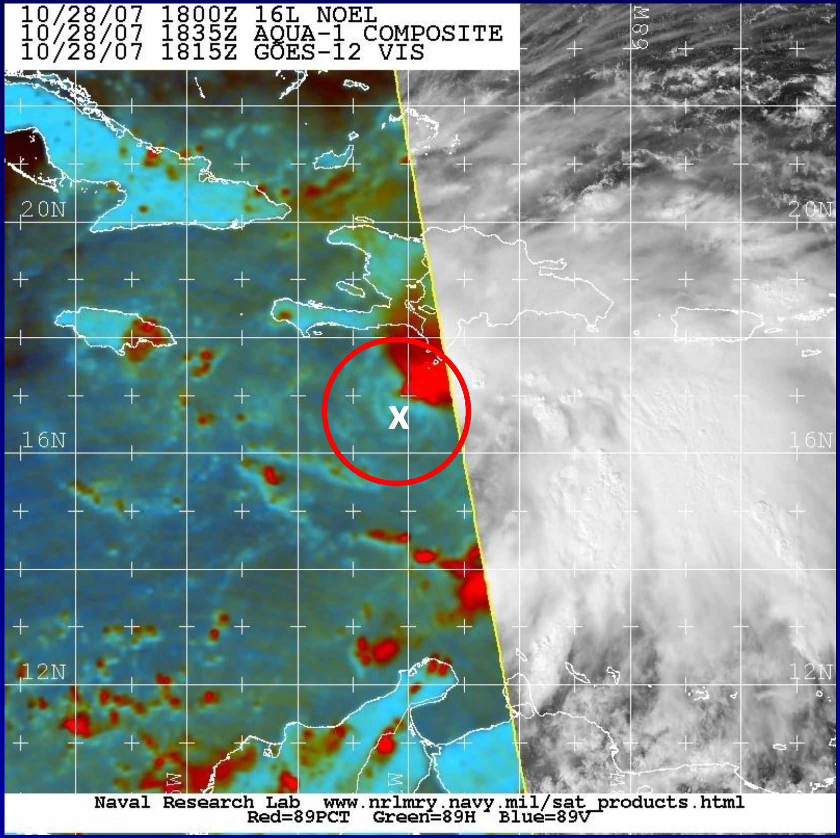
Navy FNMOC TC Webpage

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

Tropical Cyclone Positioning Using Passive Microwave Data

Positioning in Microwave Imagery

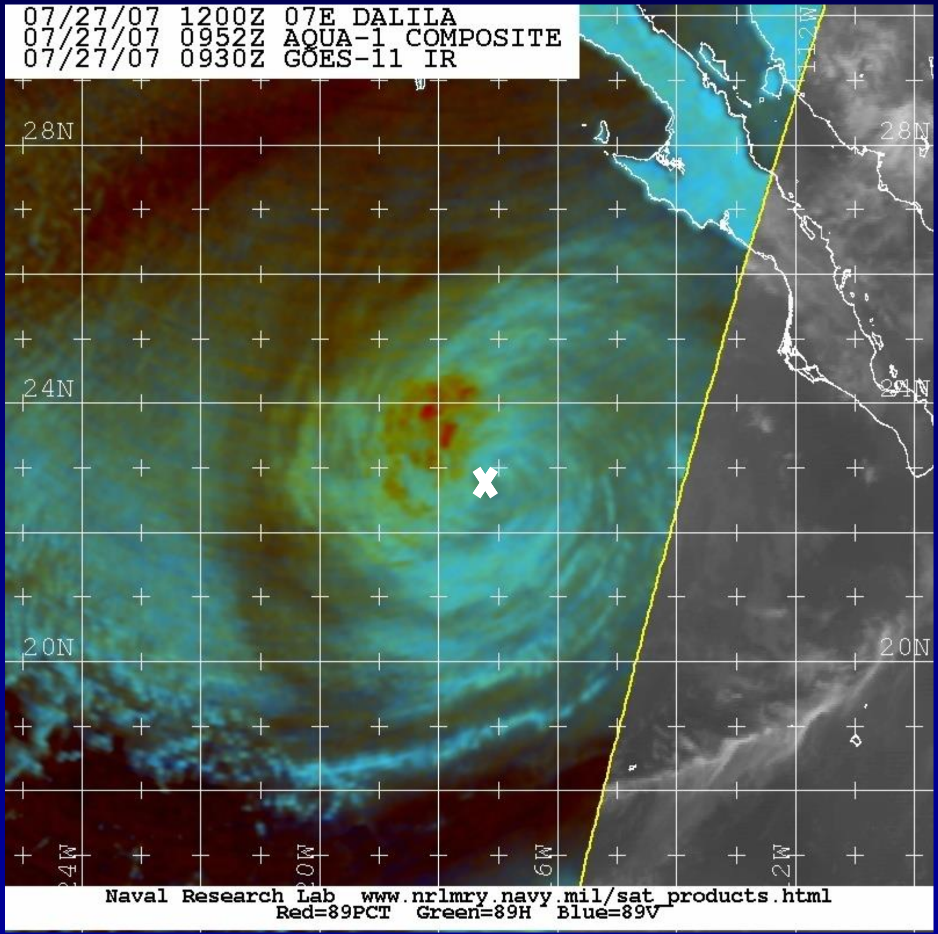


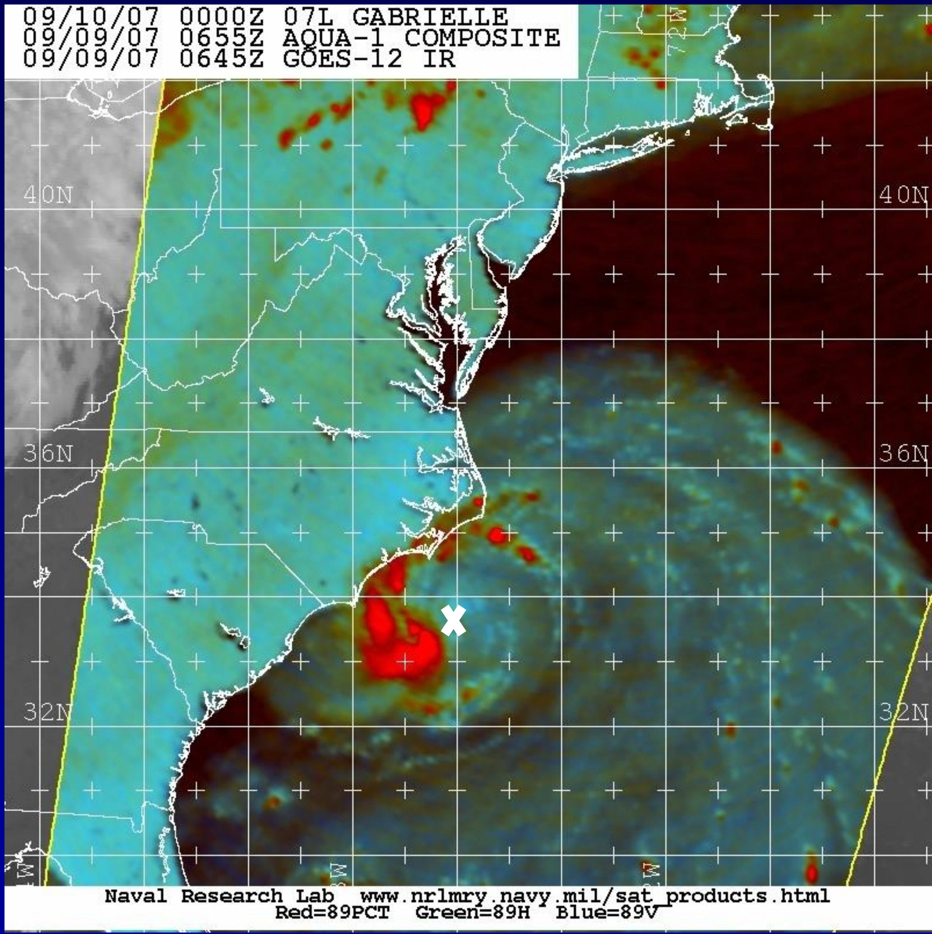


Try to position in the rain-free dry area—out of the convection

Positioning in Microwave Imagery

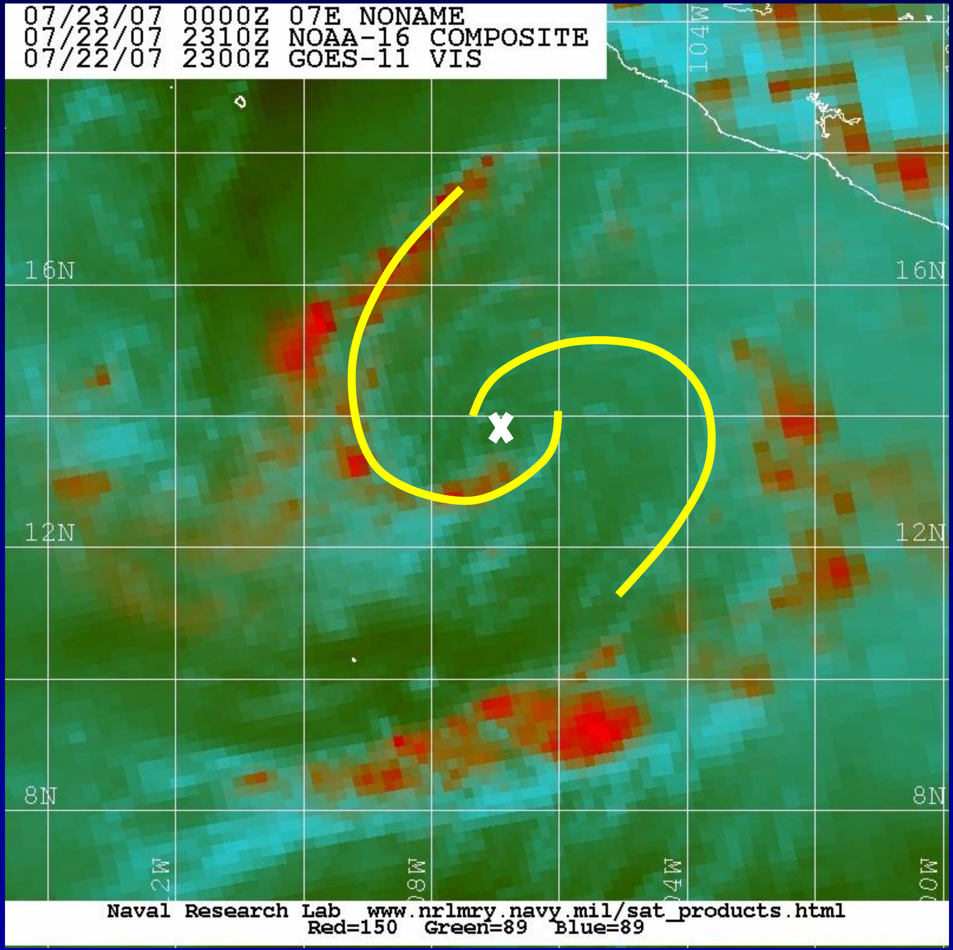
Look for convective free darker areas

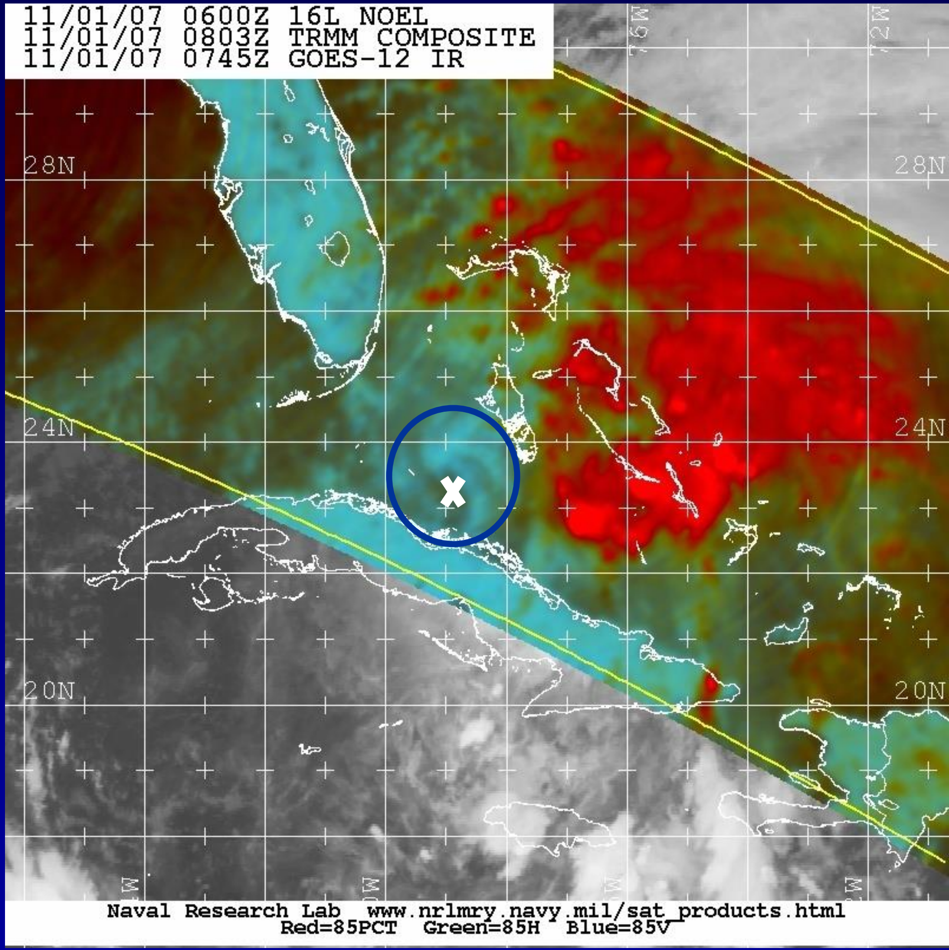


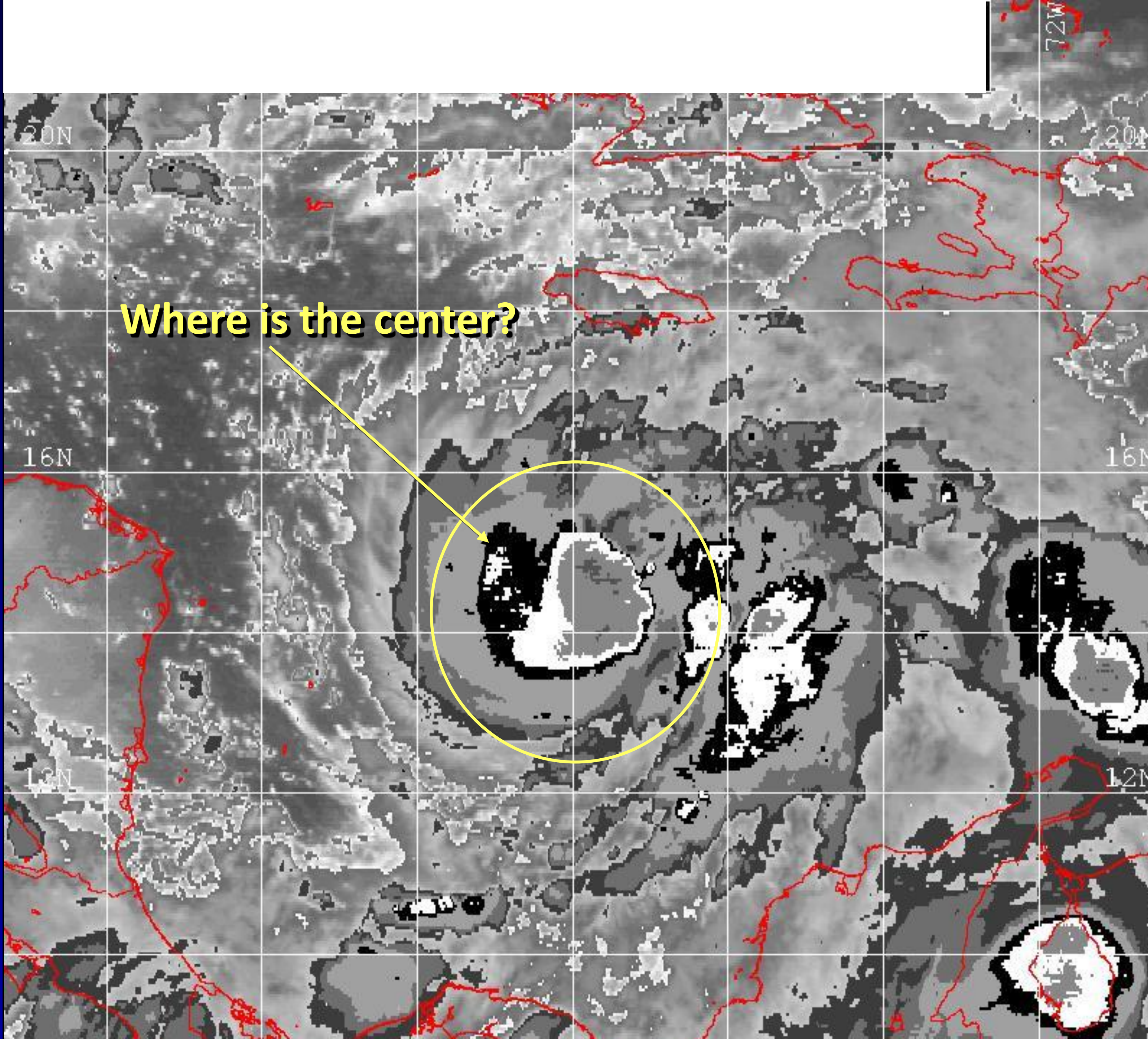


Positioning in Microwave Imagery

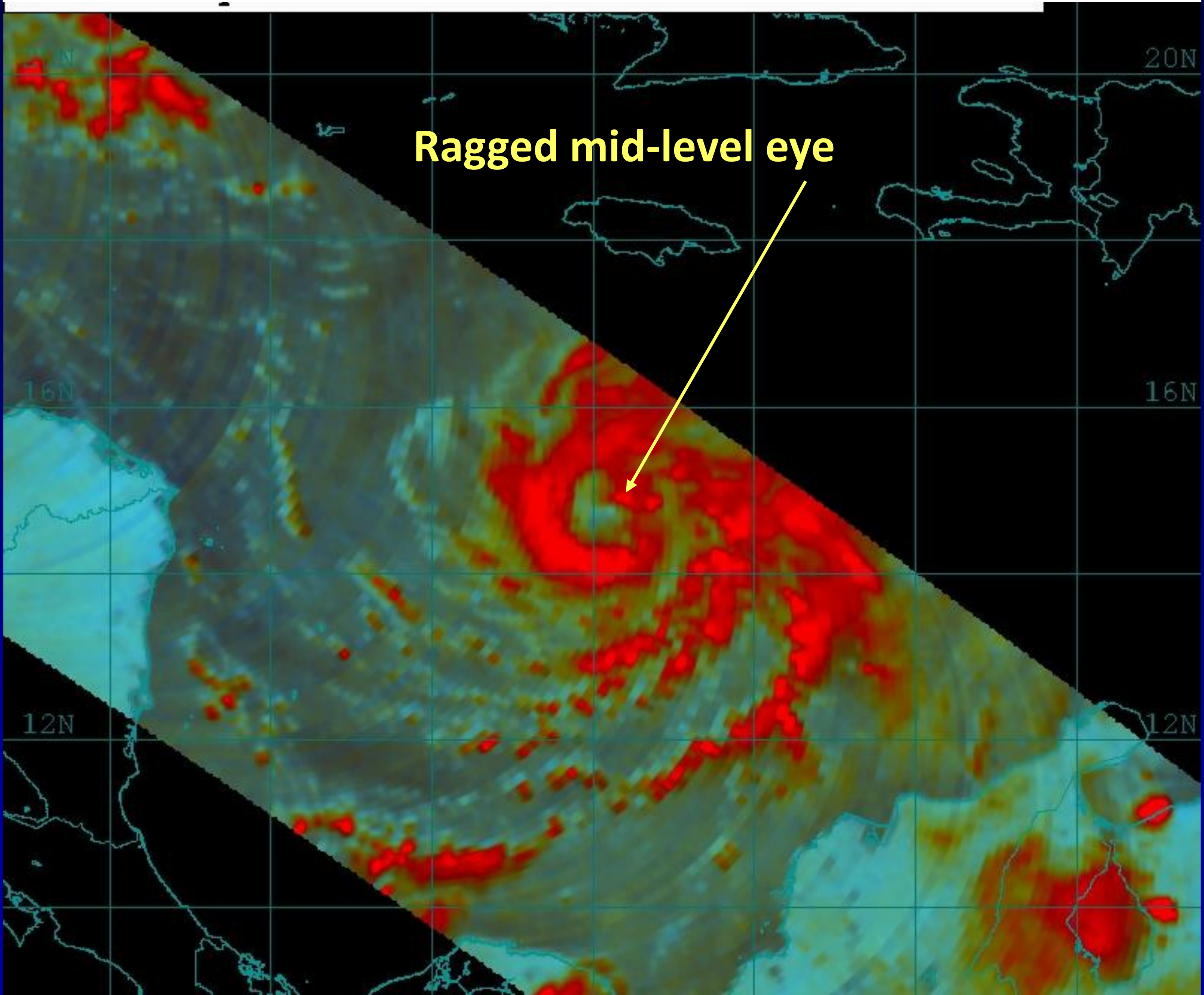
Look for low cloud curvature



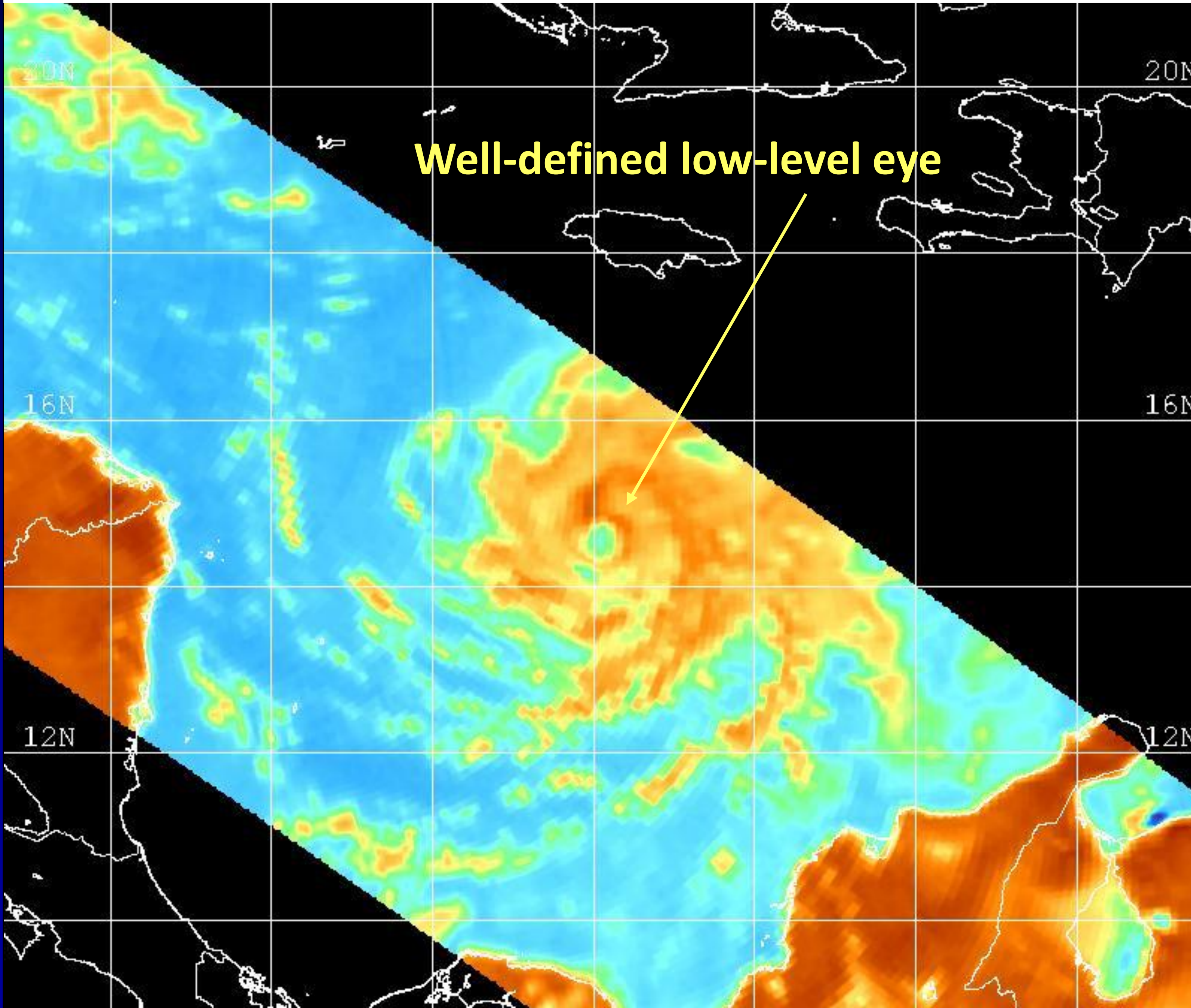


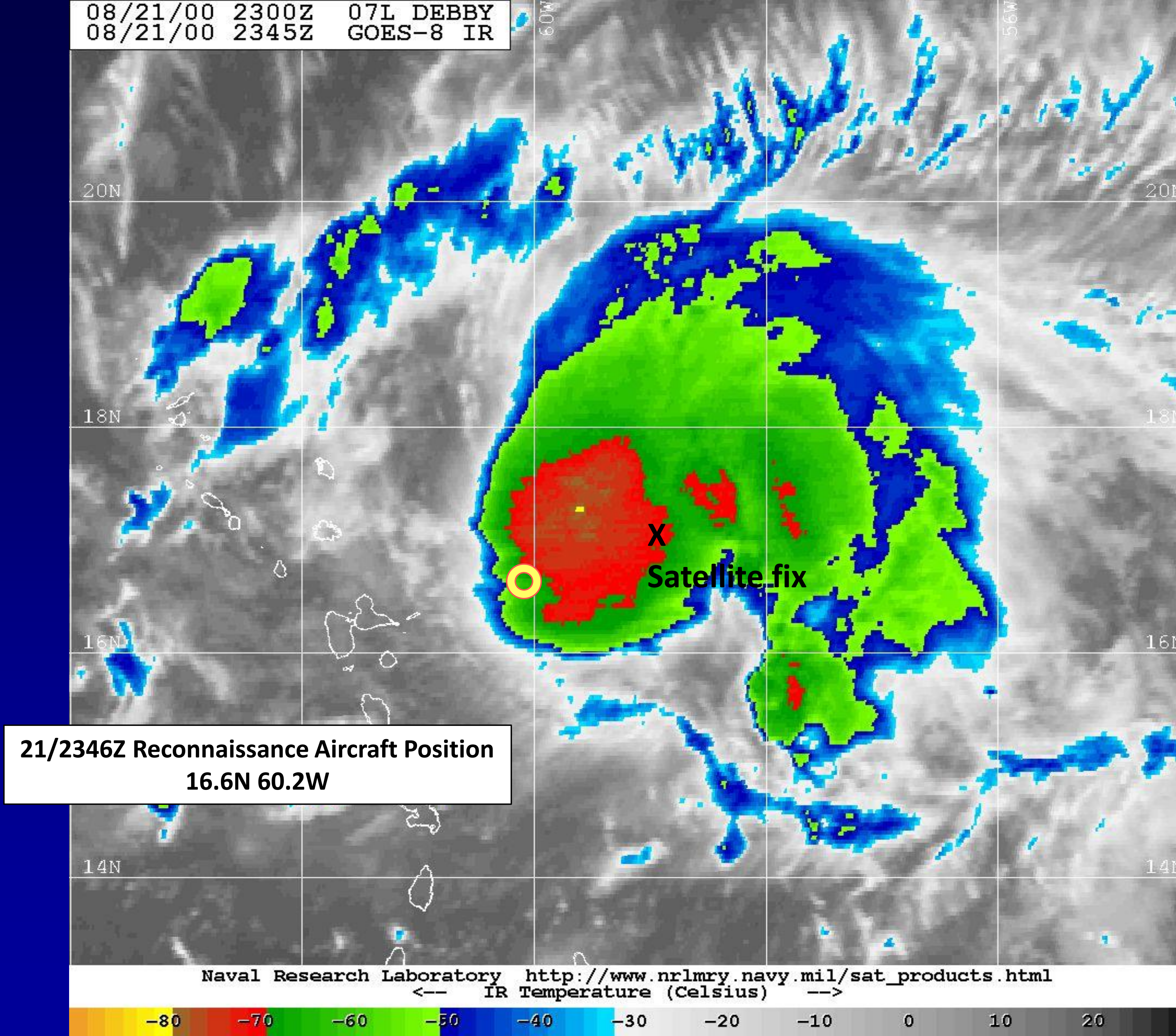

Where is the center?
20N
20N
16N
16N
12N
72W

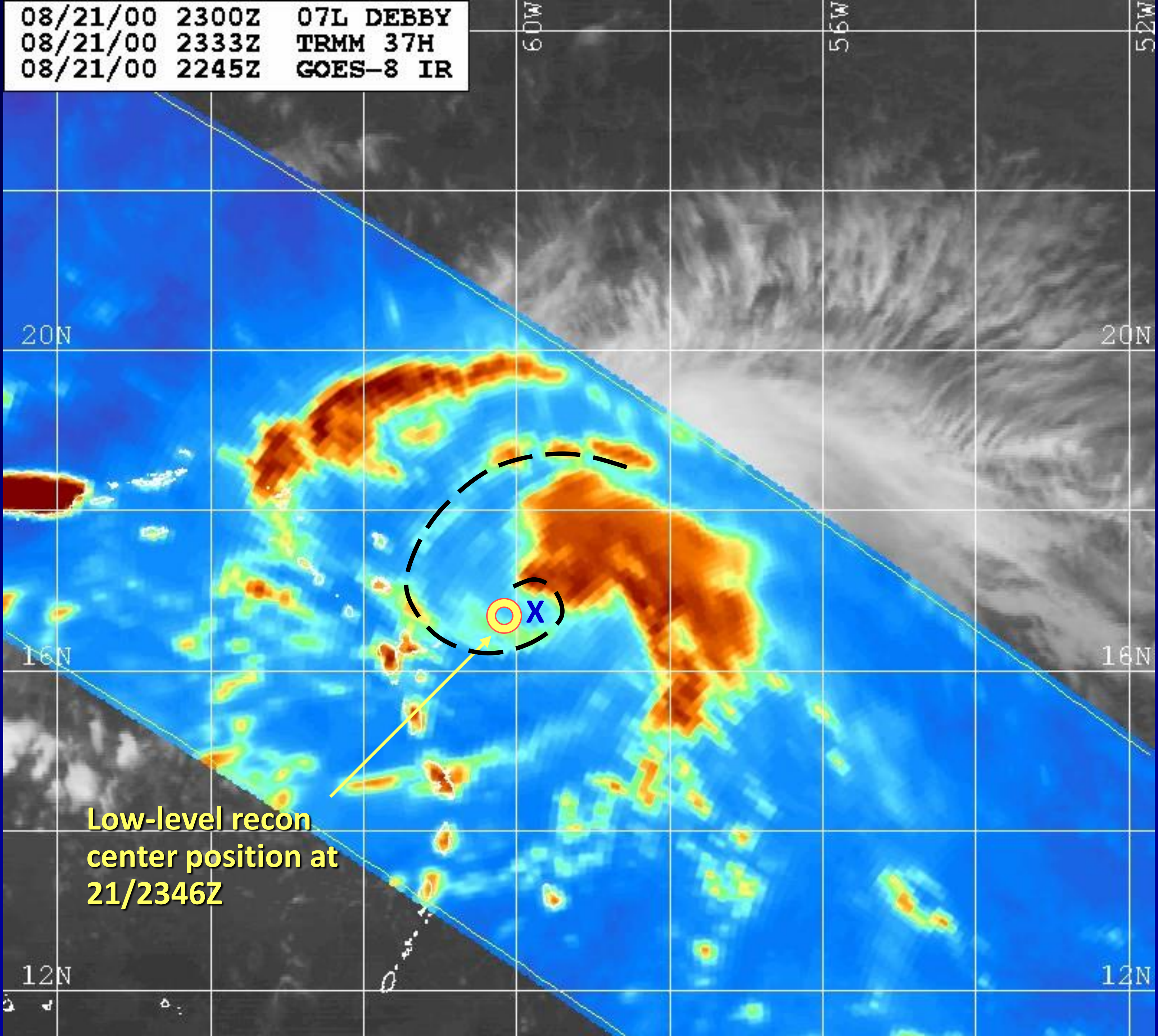
85 GHz Color-Composite Example

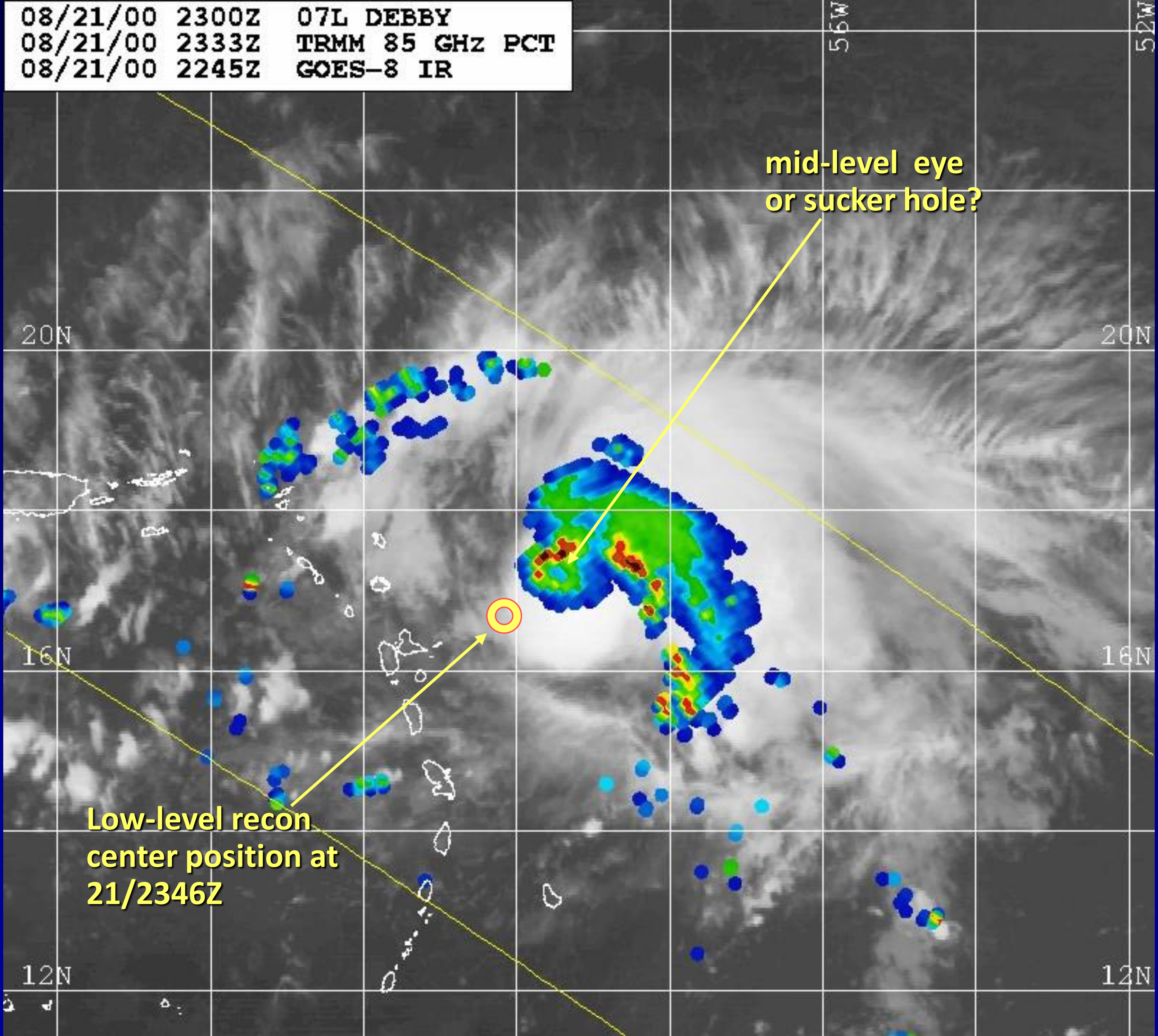


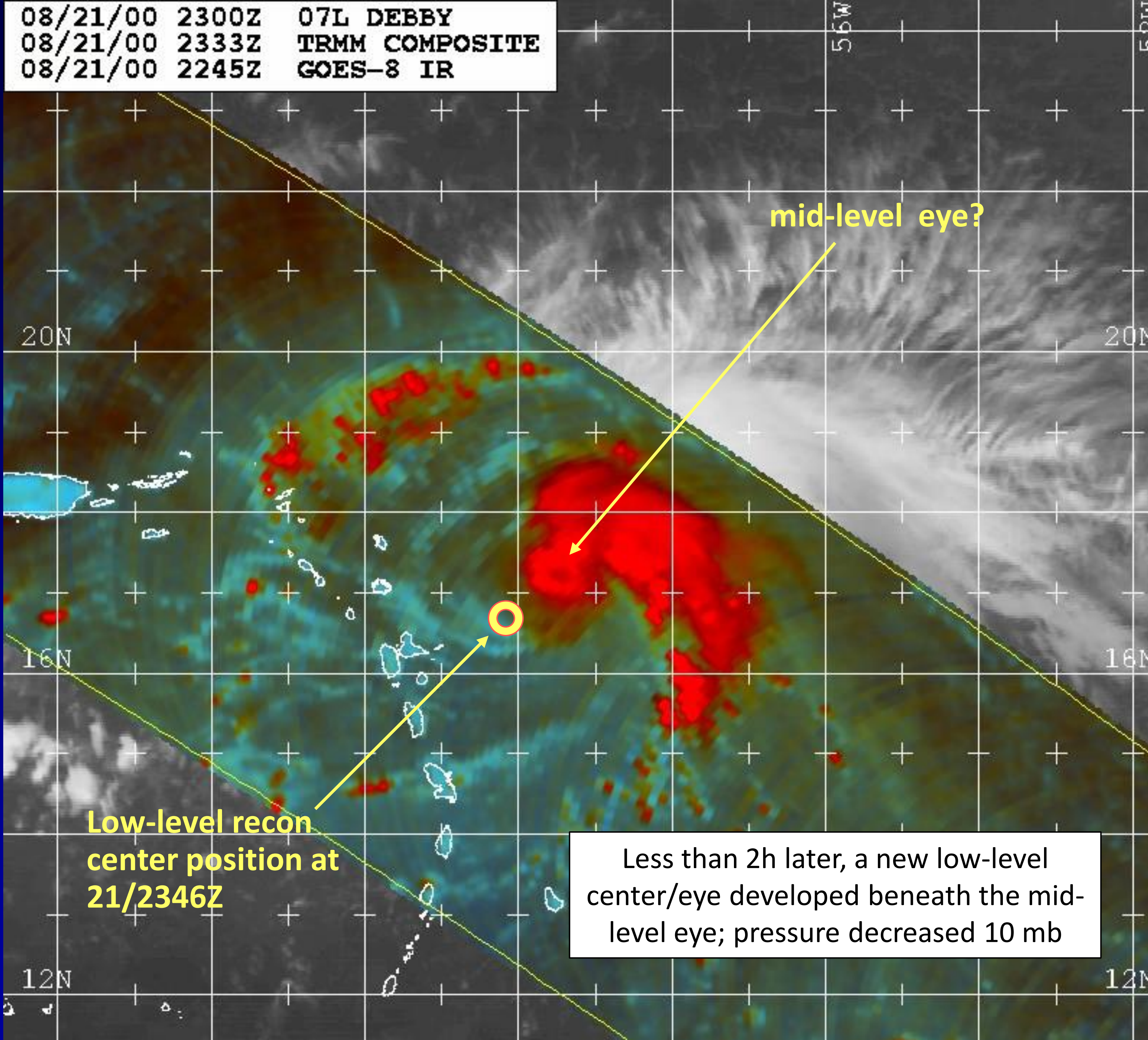
37 GHz Example




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

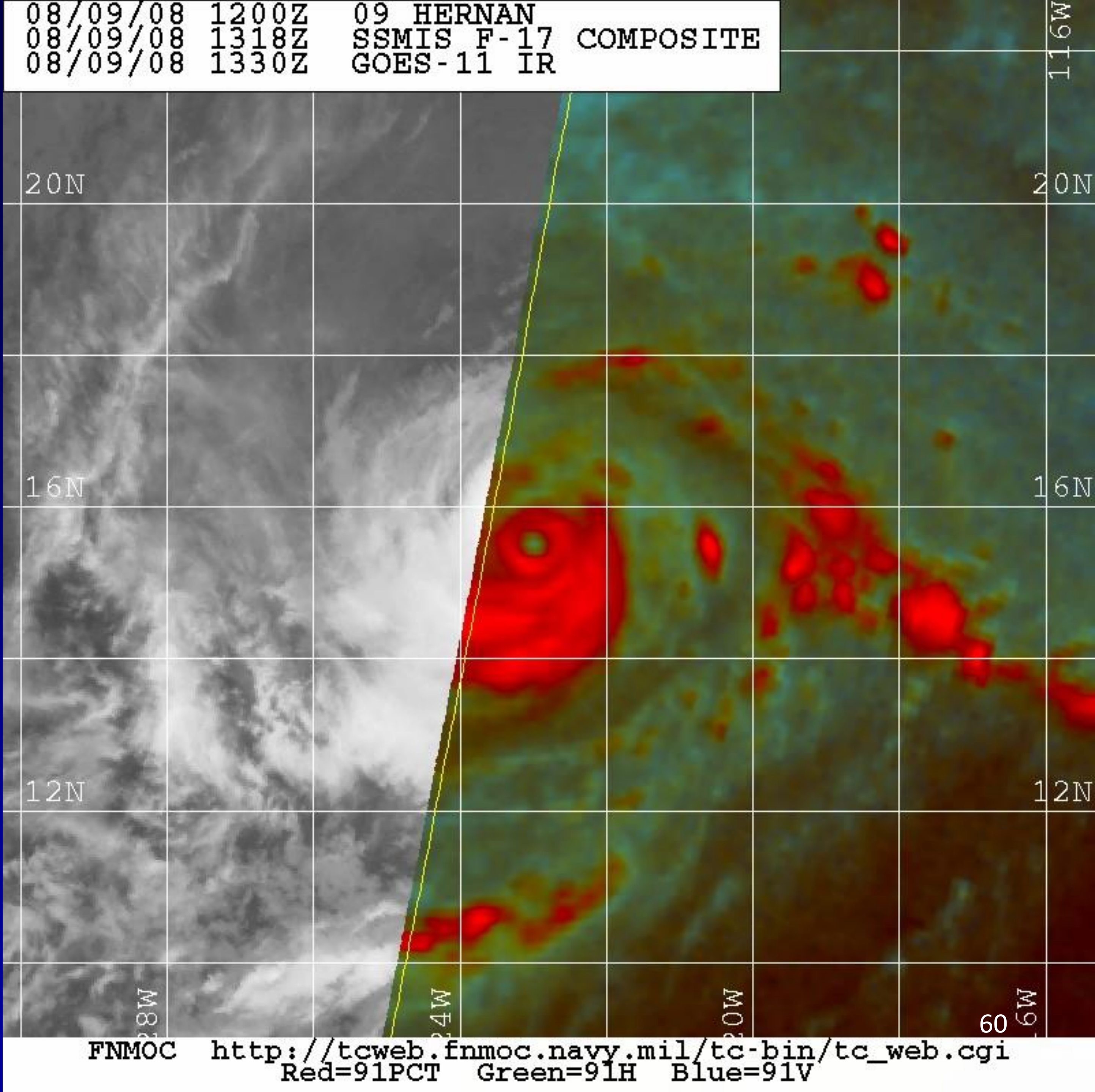

08/21/00 2300Z 07L DEBBY
08/21/00 2333Z TRMM COMPOSITE
08/21/00 2245Z GOES-8 IR
56W
52W
20N
16N
12N
mid-level eye?
Low-level recon center position at 21/2346Z
Less than 2h later, a new low-level center/eye developed beneath the mid-level eye; pressure decreased 10 mb

Expanded Use of Microwave Imagery for Tropical Cyclone Analysis

- Improve position estimates for Dvorak intensity estimates
  - Helps locate center when obscured by clouds
  - Incorrect center location can yield incorrect intensity estimates, especially when using embedded center or shear patterns
- Monitoring internal TC structure
  - Eye formation/dissipation
  - Eyewall replacement cycles

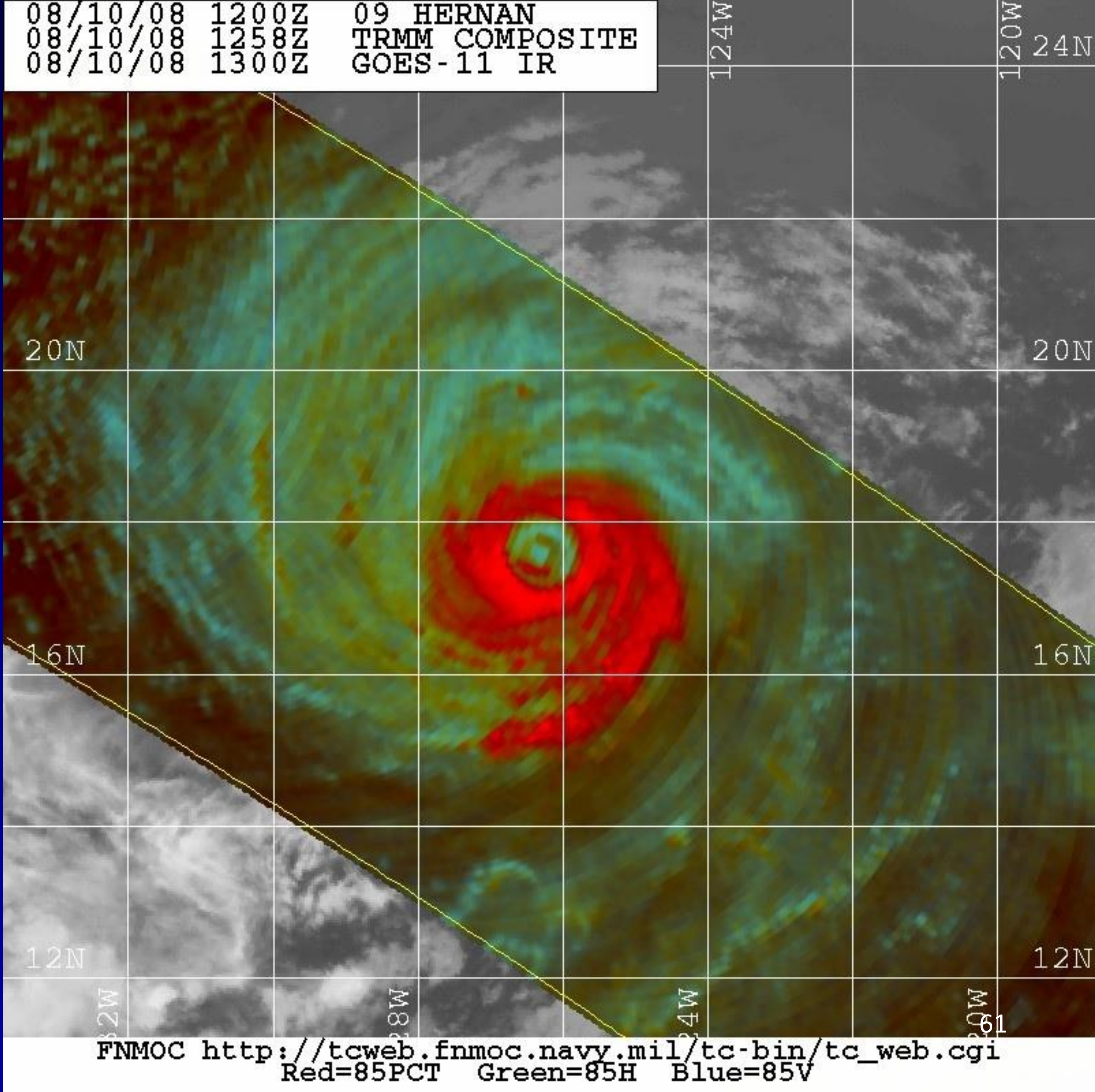
Hernan near peak intensity

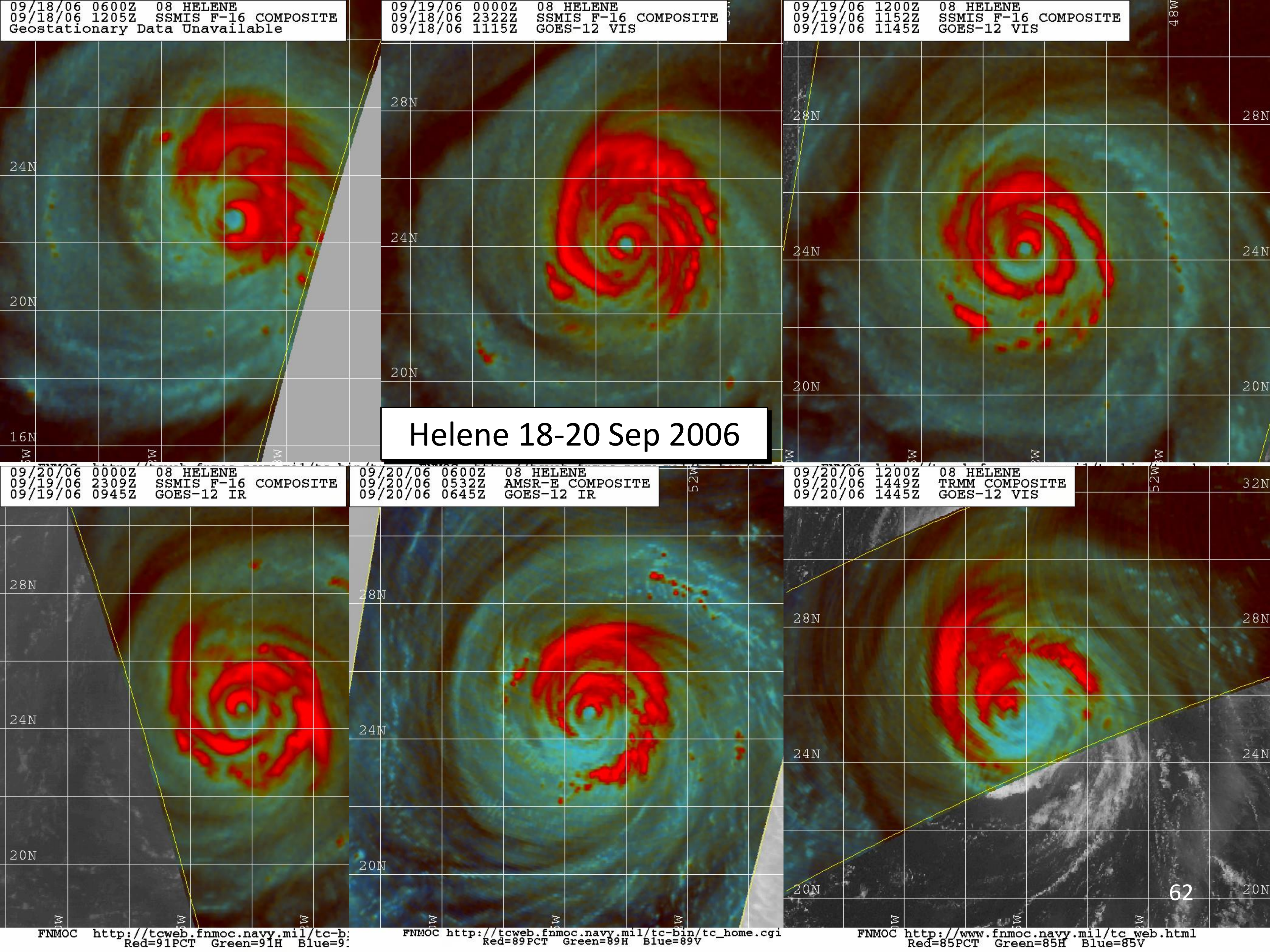
9 Aug 2008



Hernan Eyewall Replacement Cycle

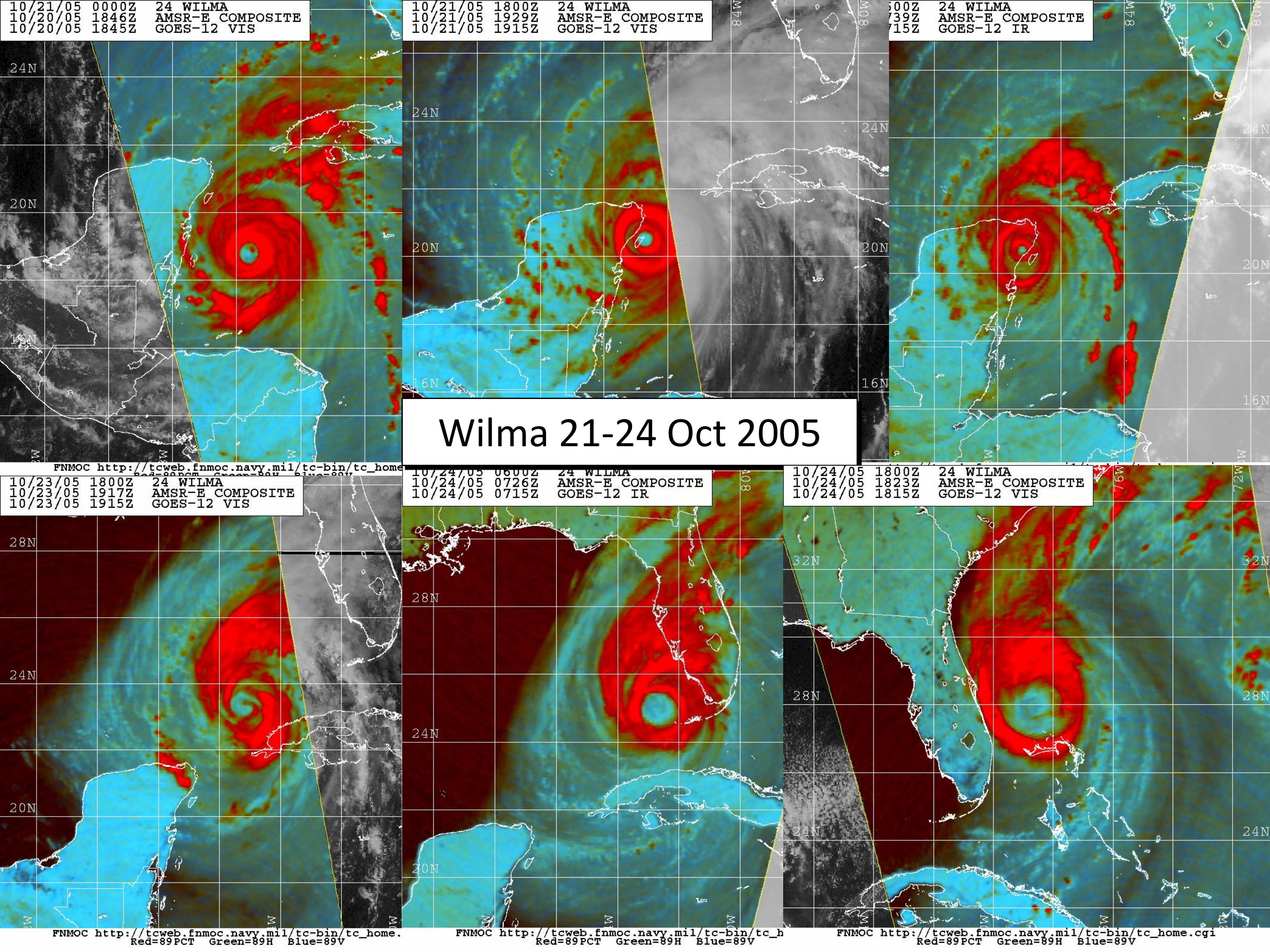
10 Aug 2008



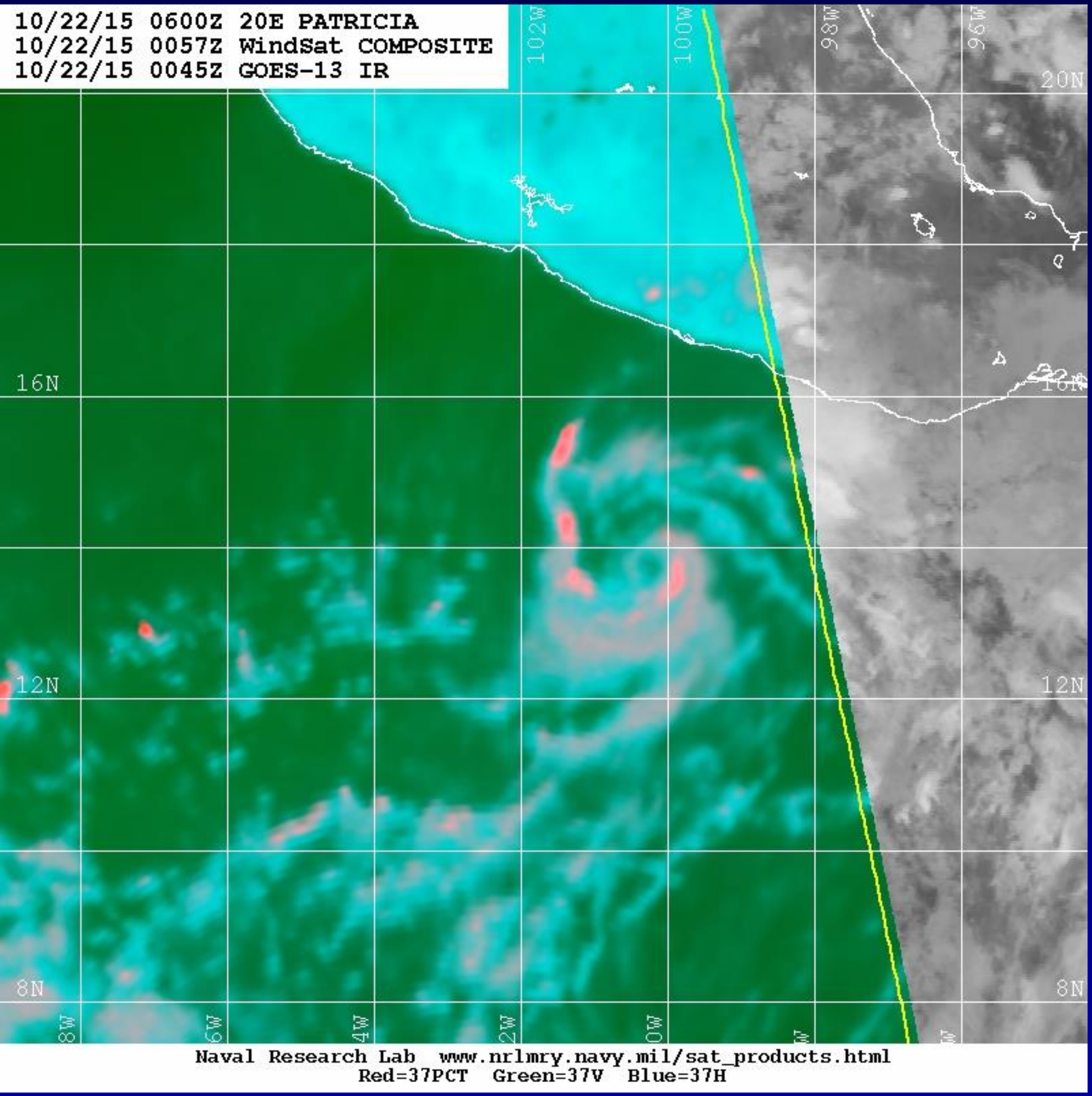


Helene 18-20 Sep 2006

Wilma 21-24 Oct 2005

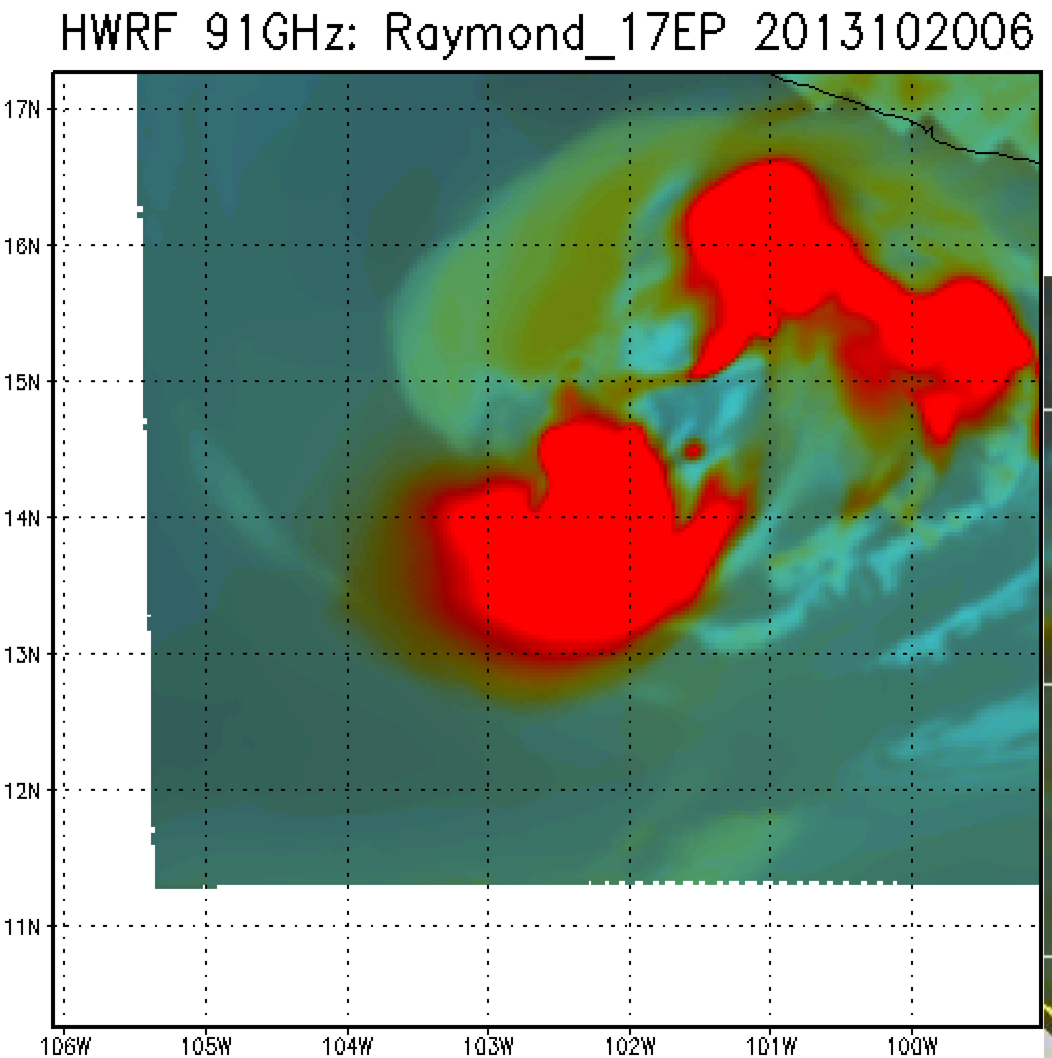


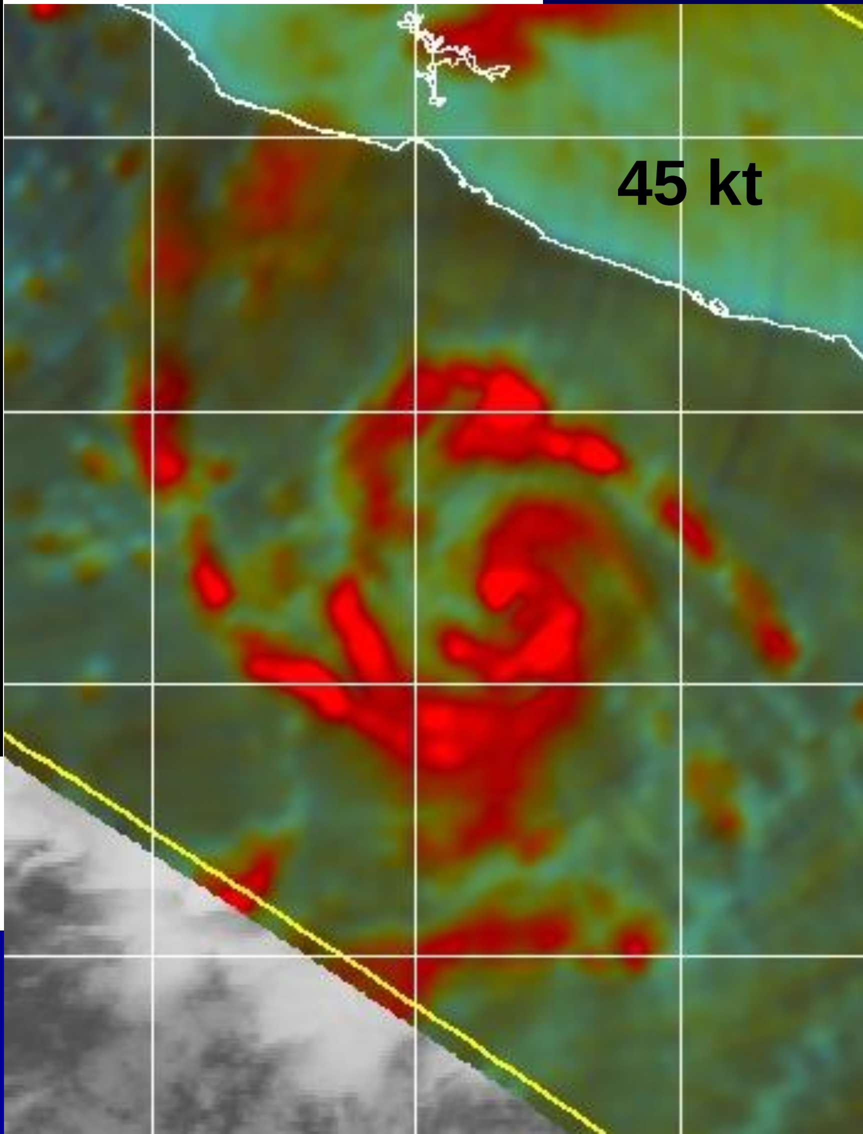
Precursor Structure Before Rapid Intensification



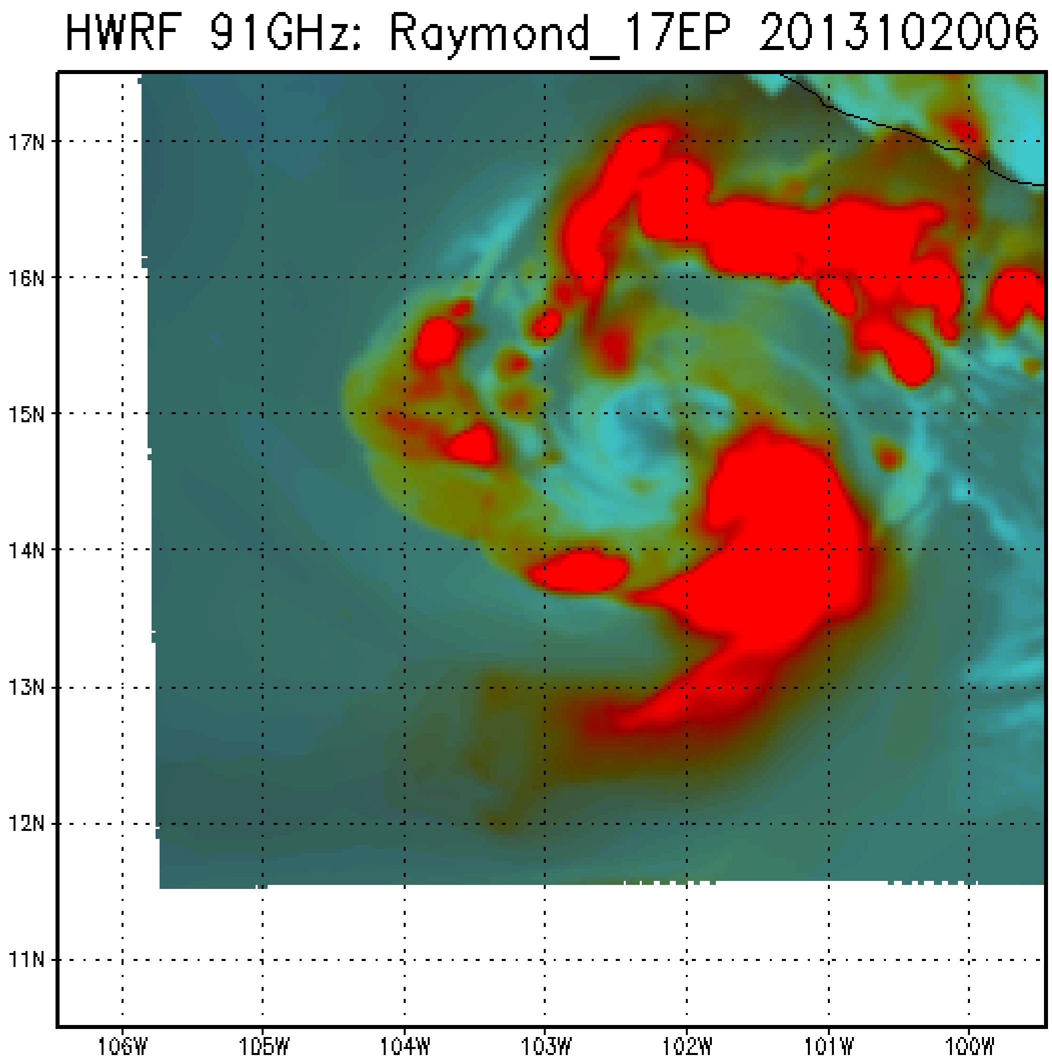
- Research suggests that a closed low-level ring of convection in 37-GHz imagery is a precursor signal to rapid intensification
- In the case shown here, Patricia strengthened from 60 kt to 150 kt in 24 hours

Simulated Microwave Imagery from HWRF Model Output

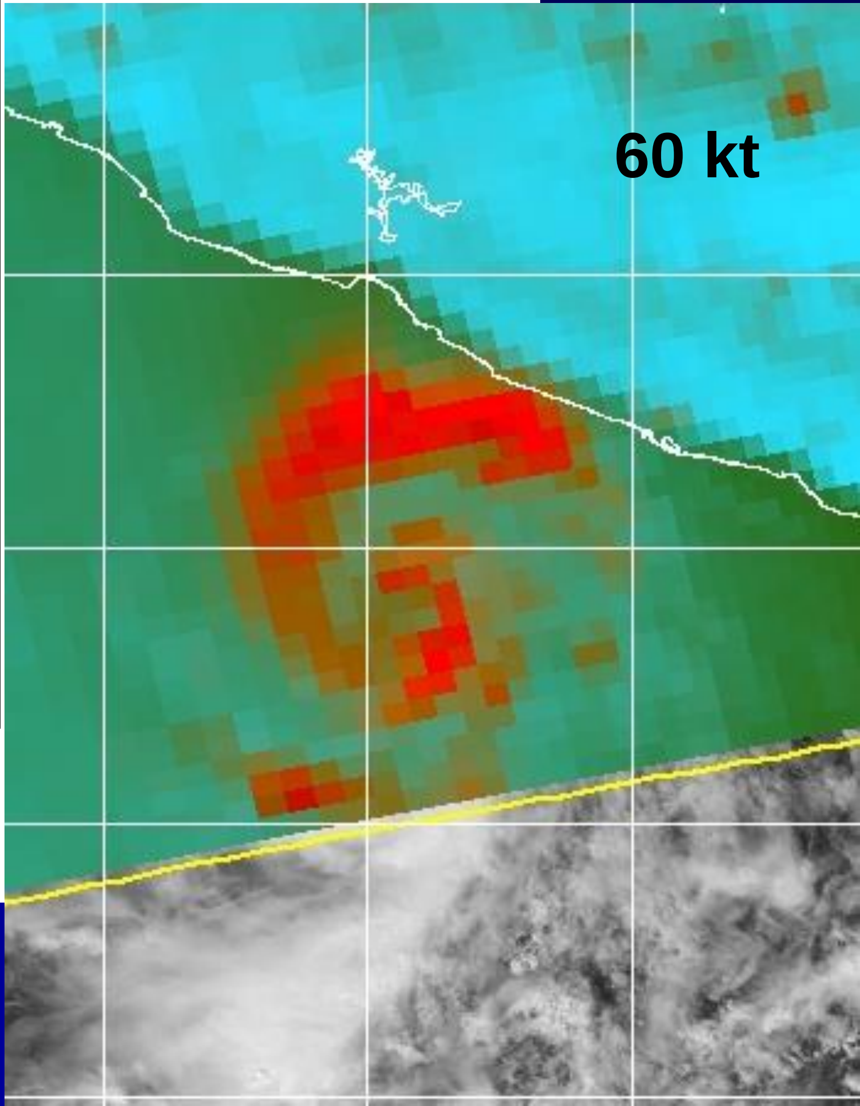




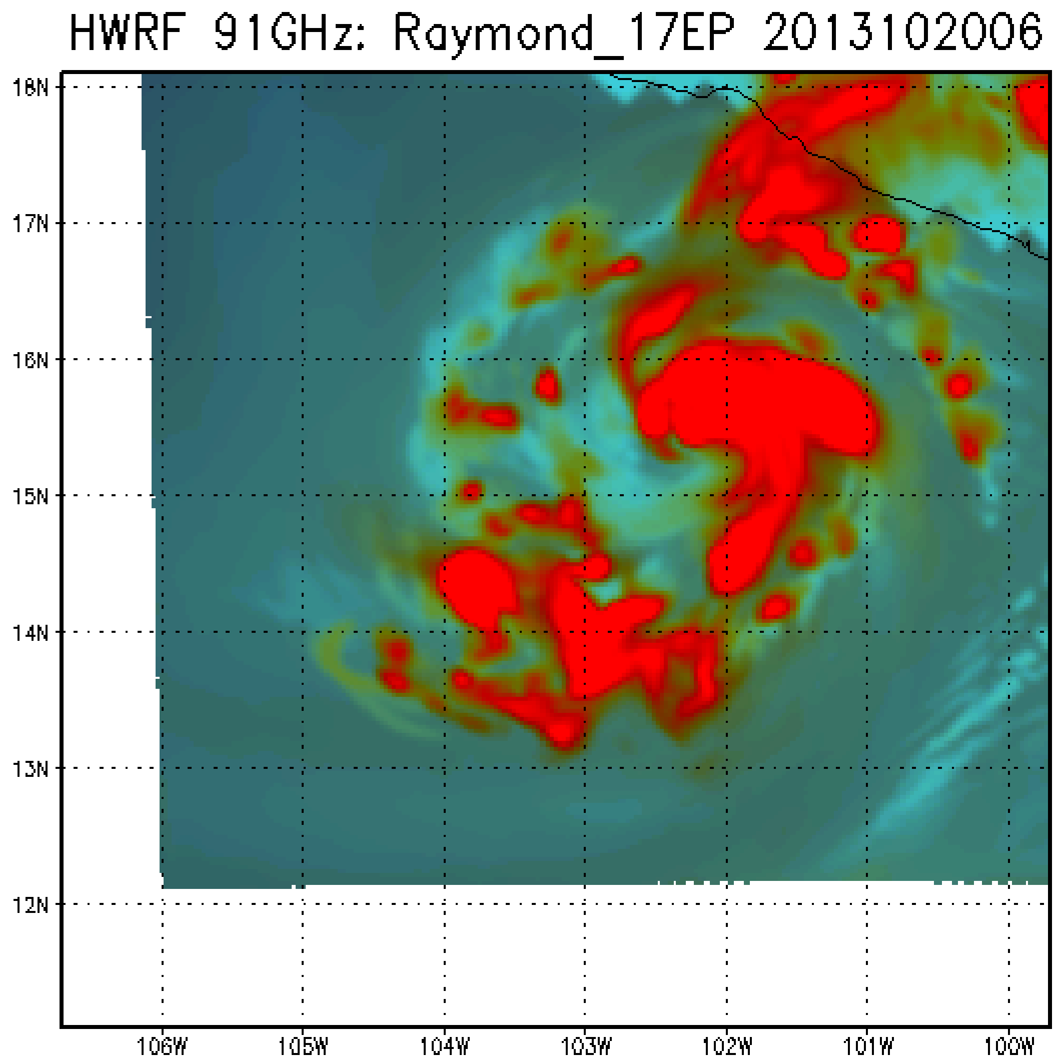
Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed microwave images (right)



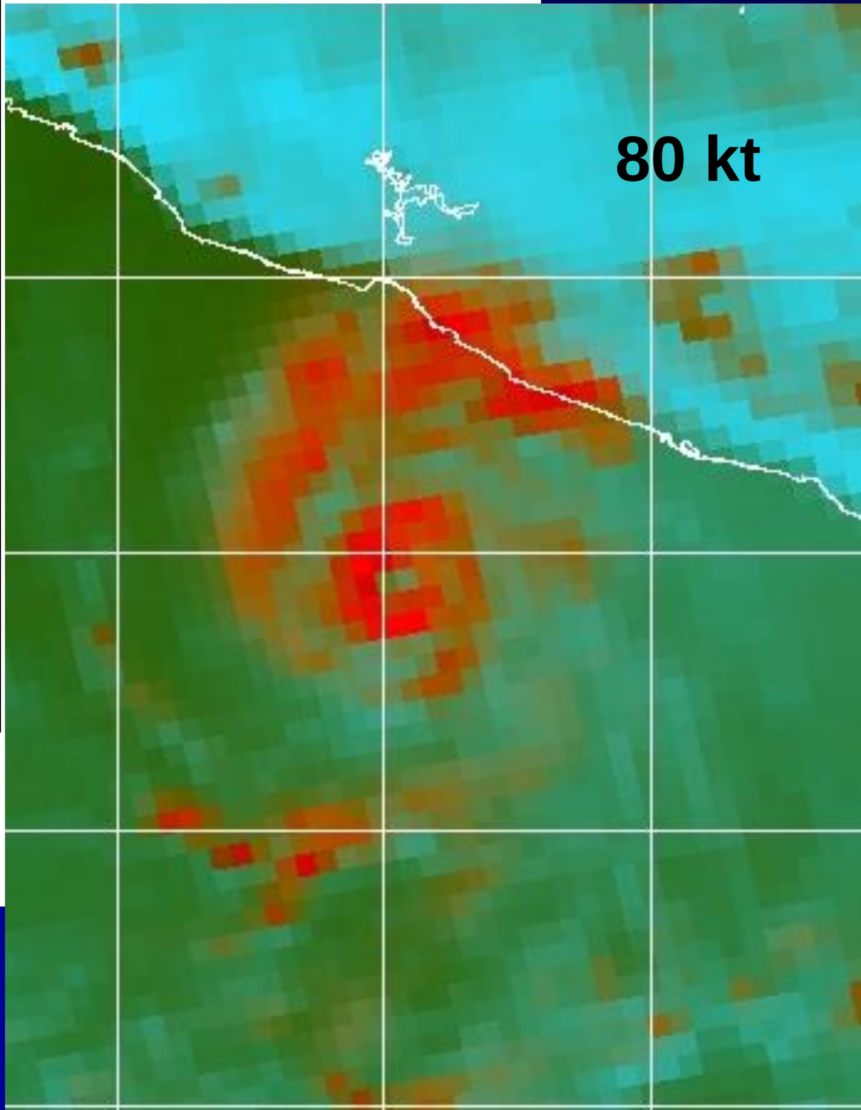
Forecast Valid:
18Z20OCT2013



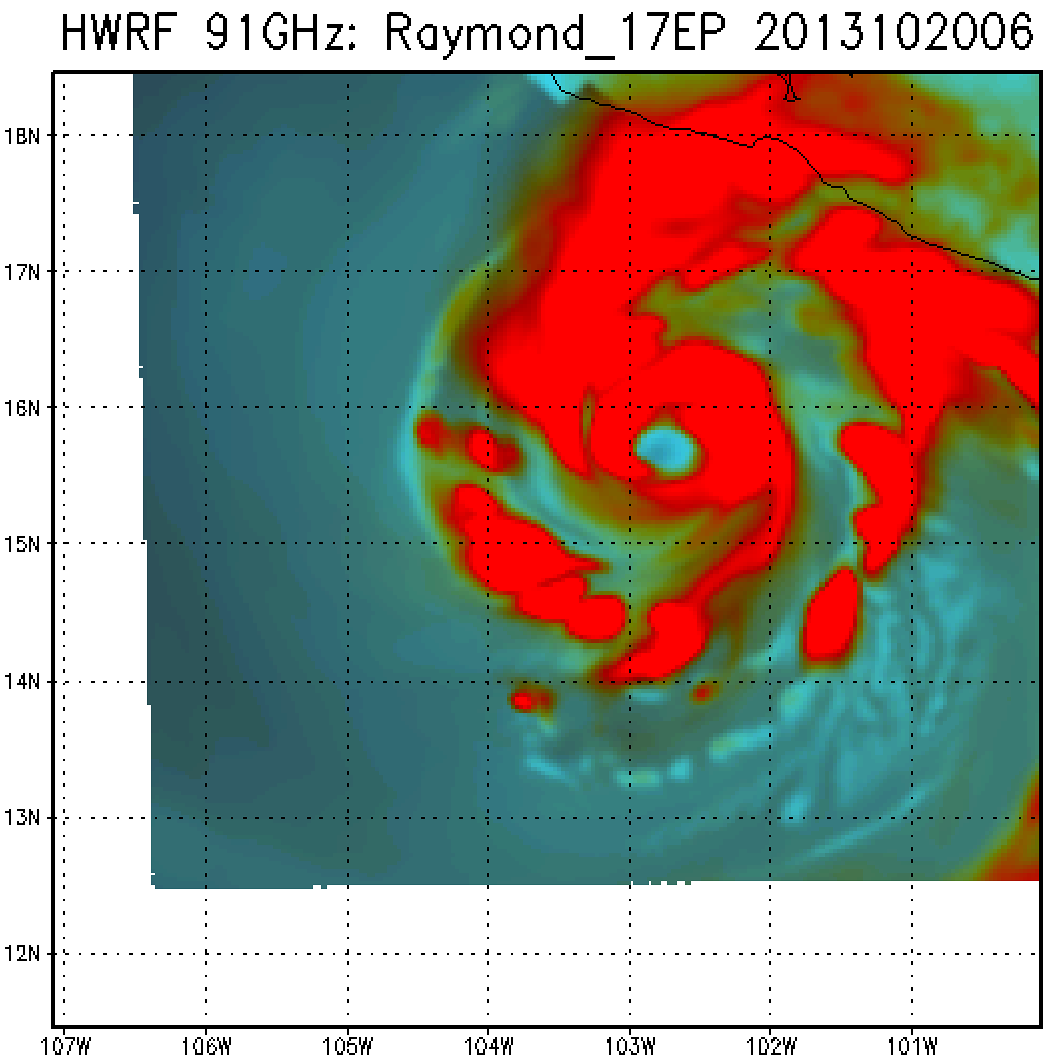
Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed microwave images (right)



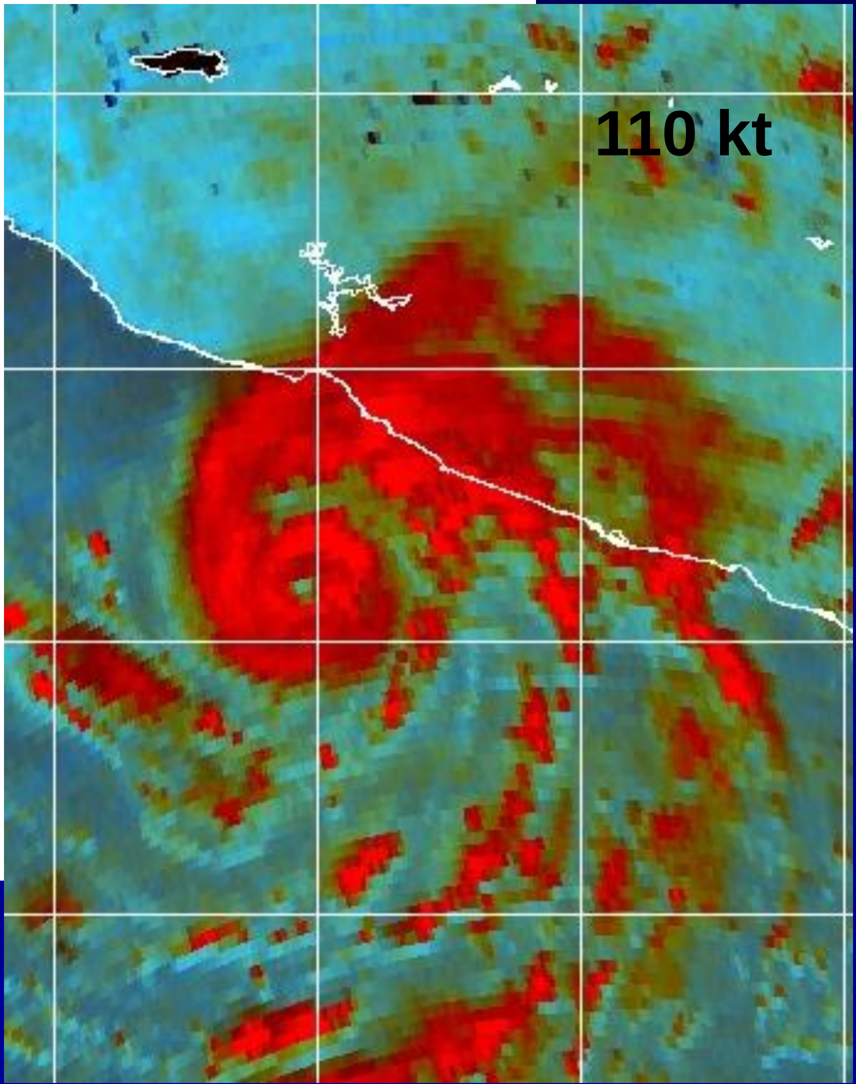
Forecast Valid:
00Z21OCT2013



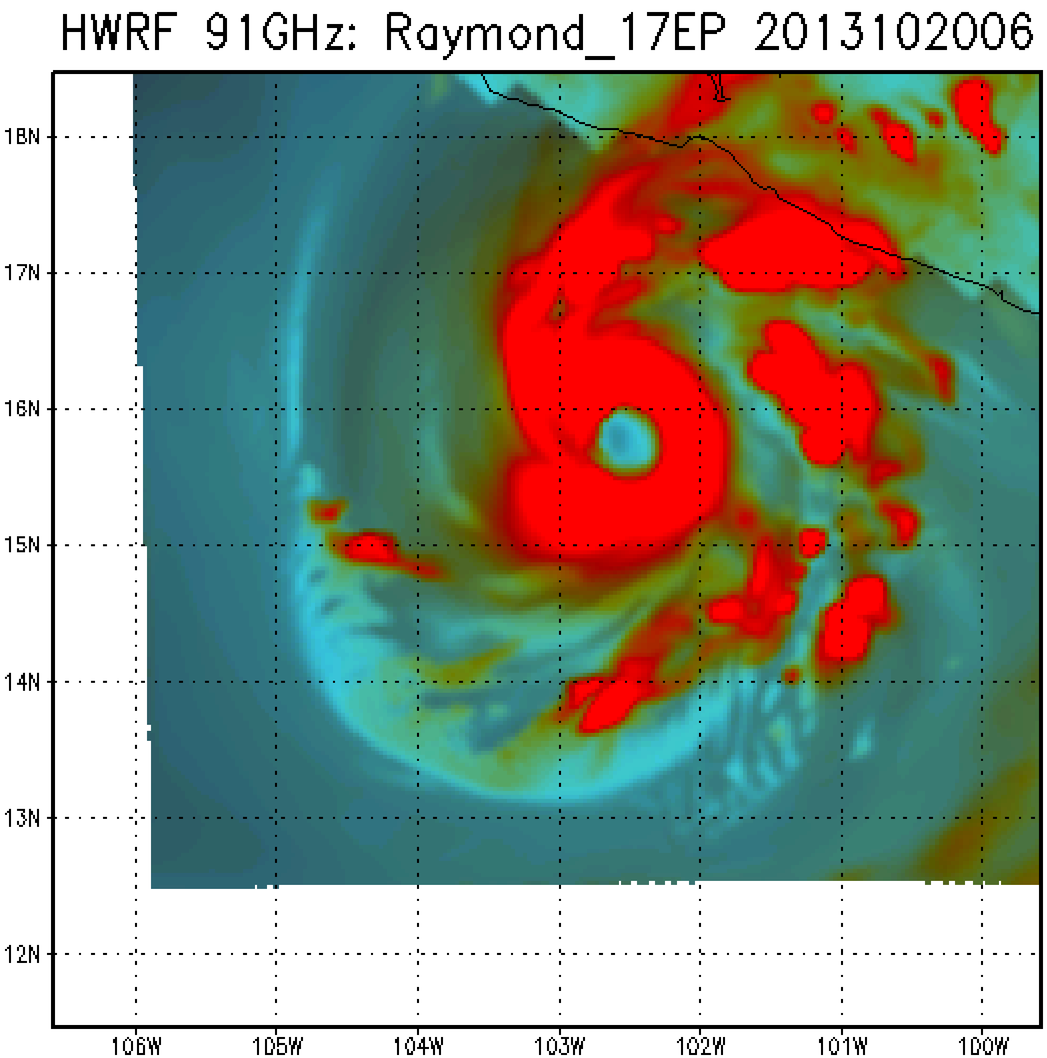
Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed microwave images (right)



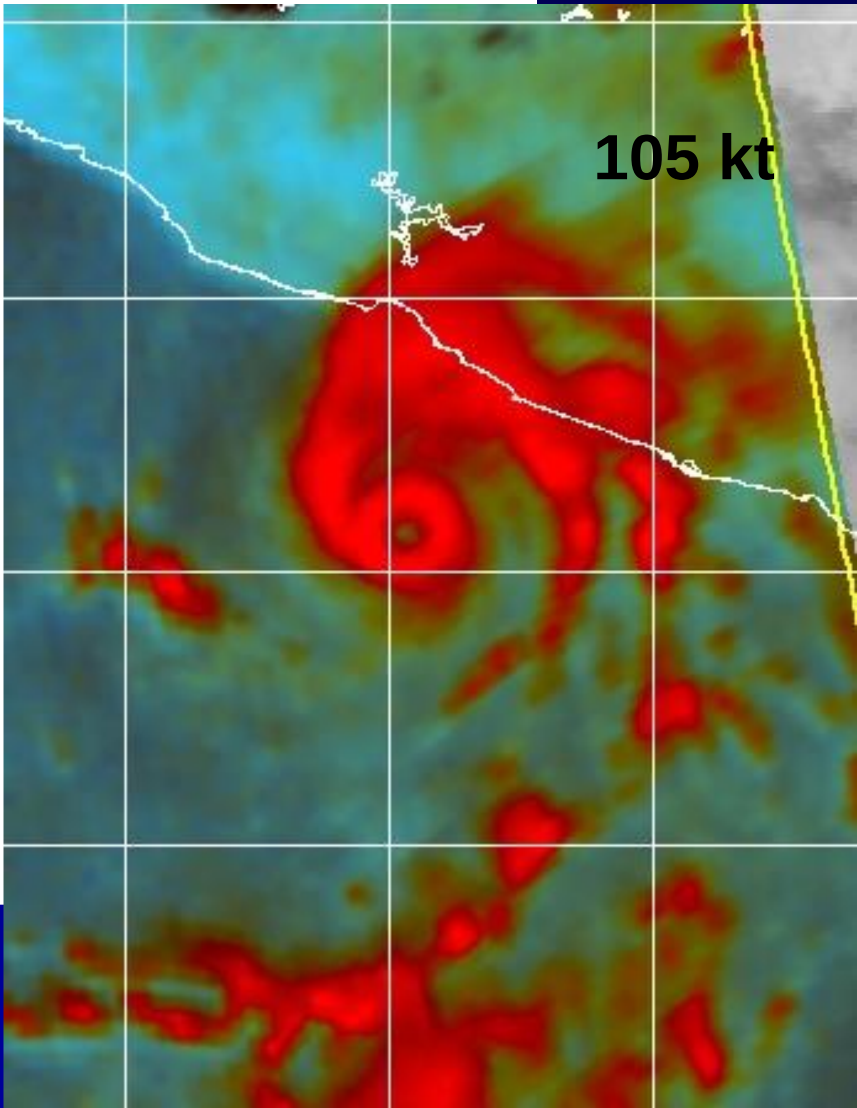
Forecast Valid:
18Z21OCT2013



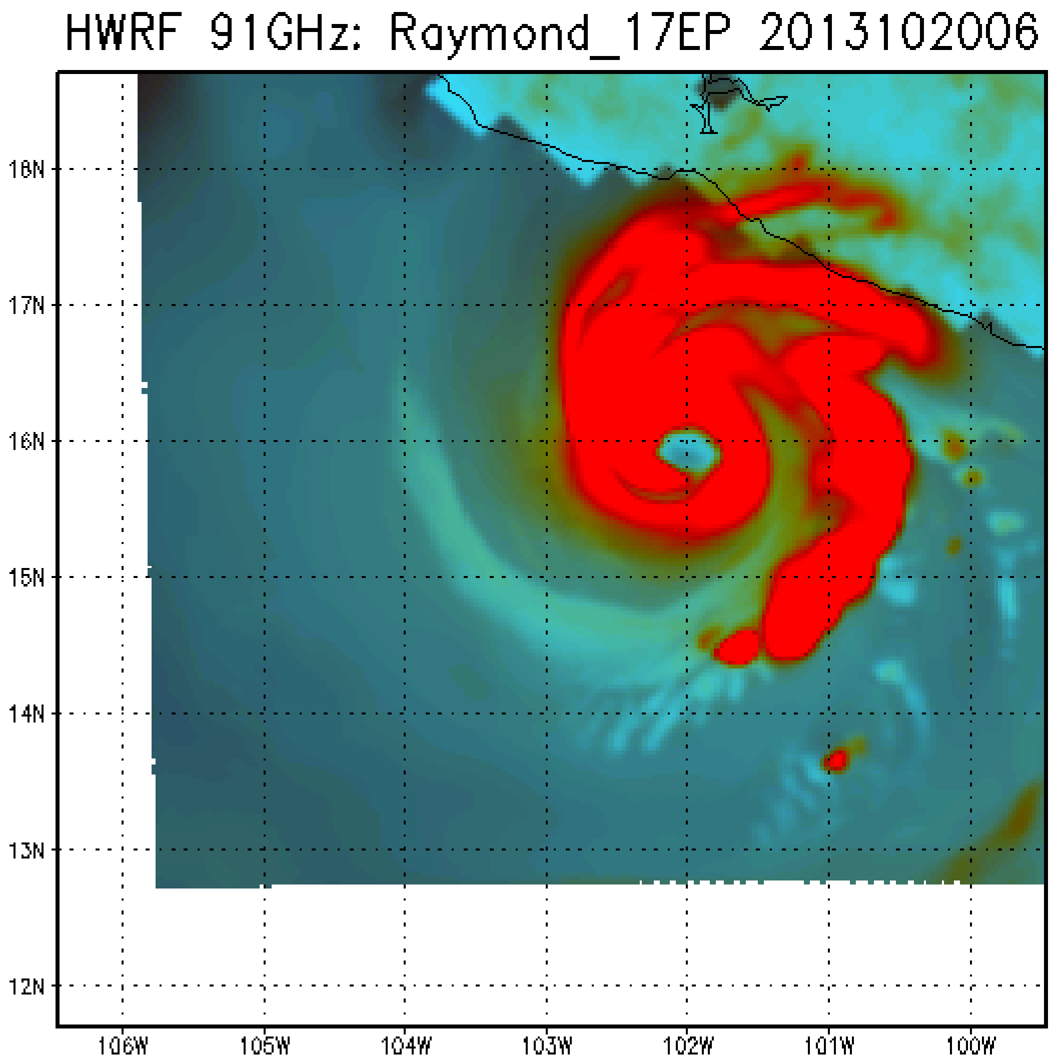
Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed microwave images (right)

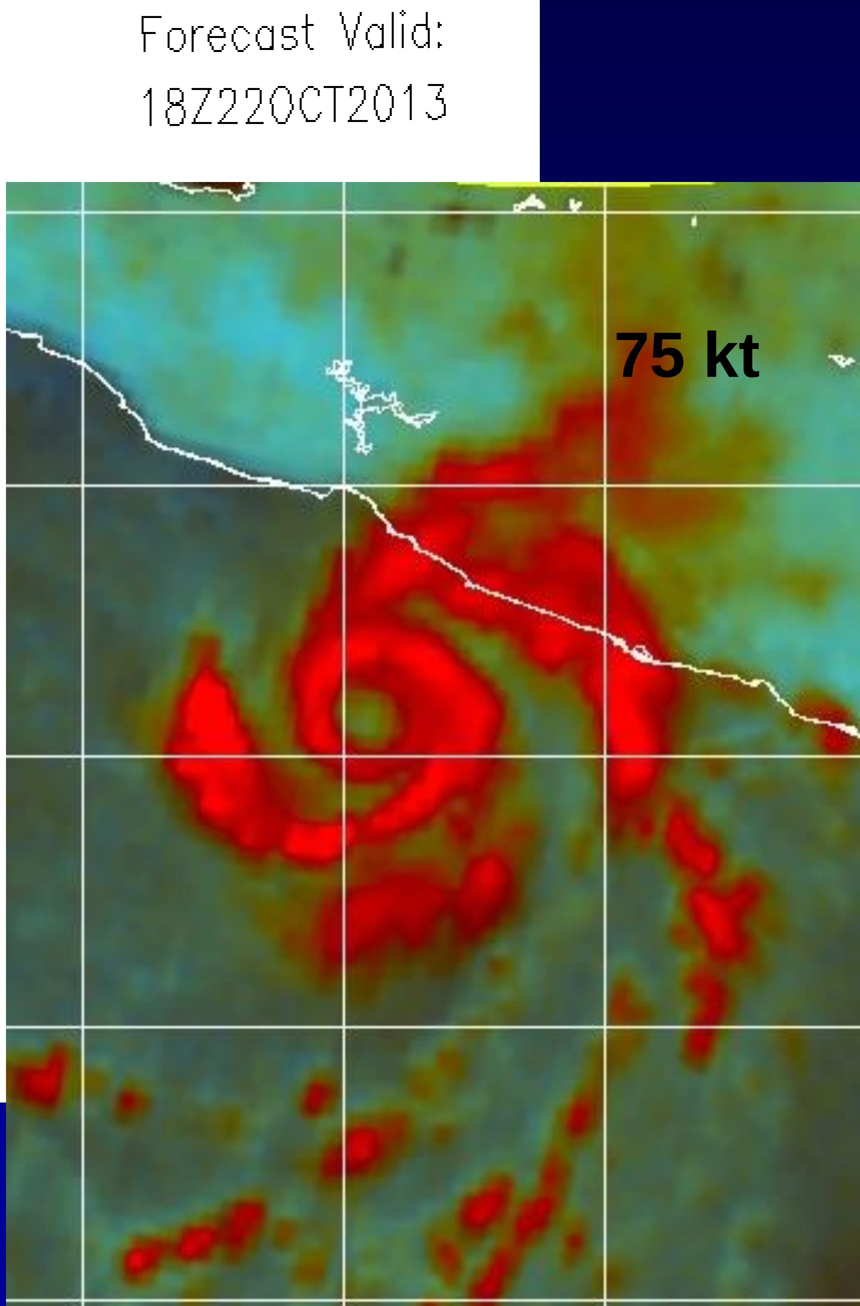


Forecast Valid:
00Z22OCT2013

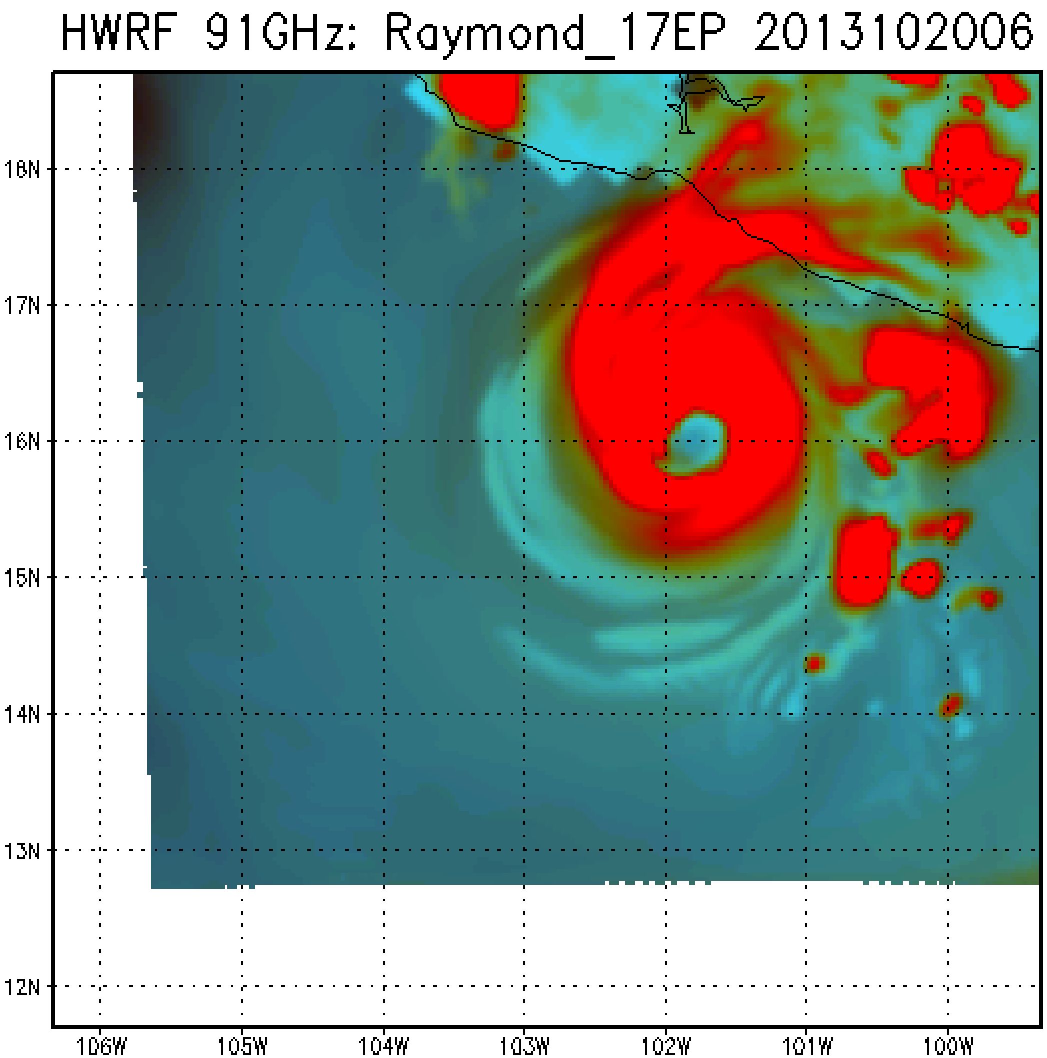


Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed microwave images (right)

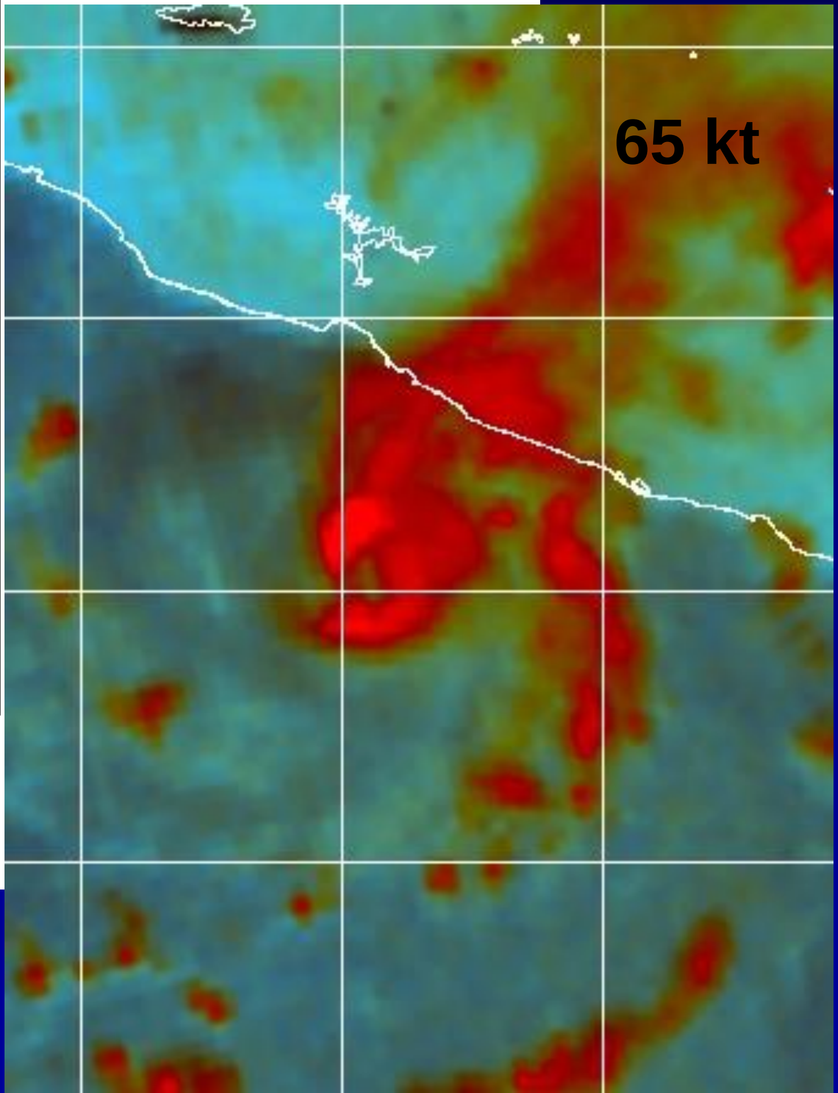




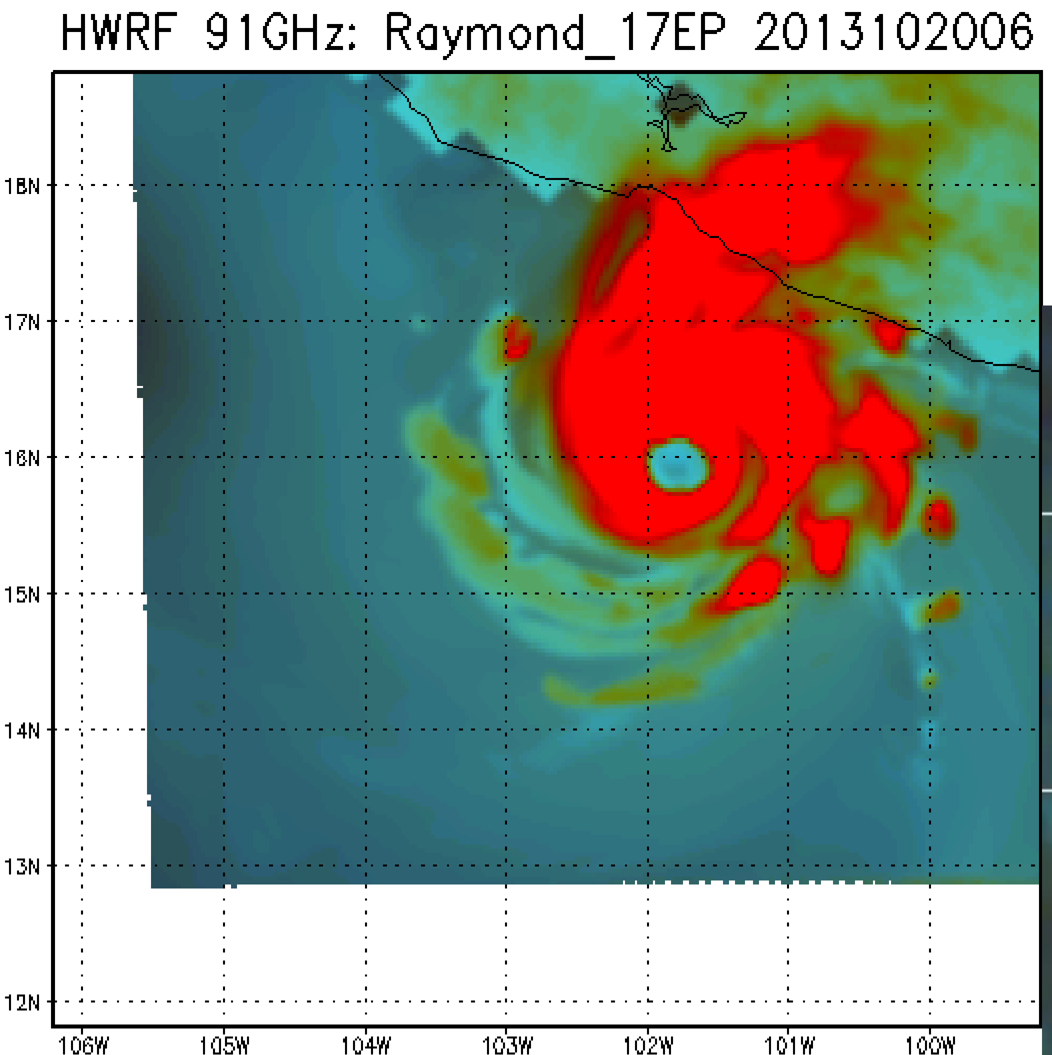
Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed microwave images (right)



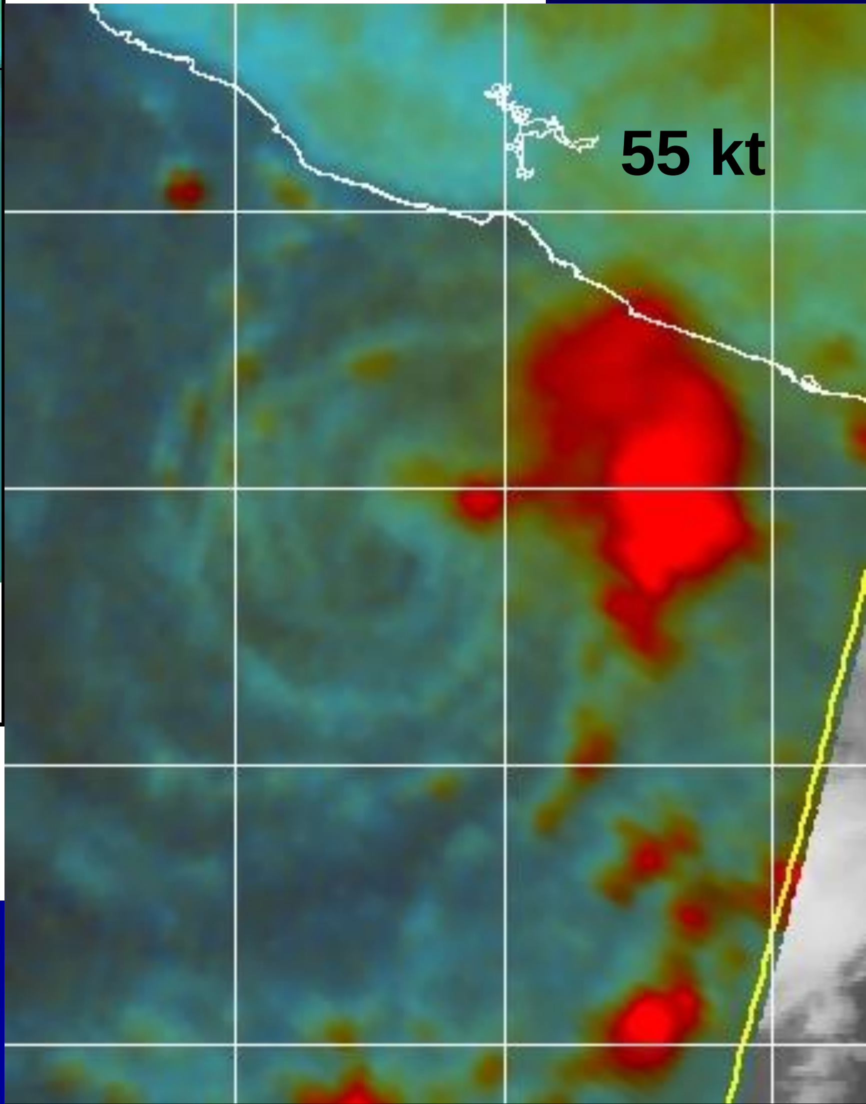
Forecast Valid:
00Z23OCT2013



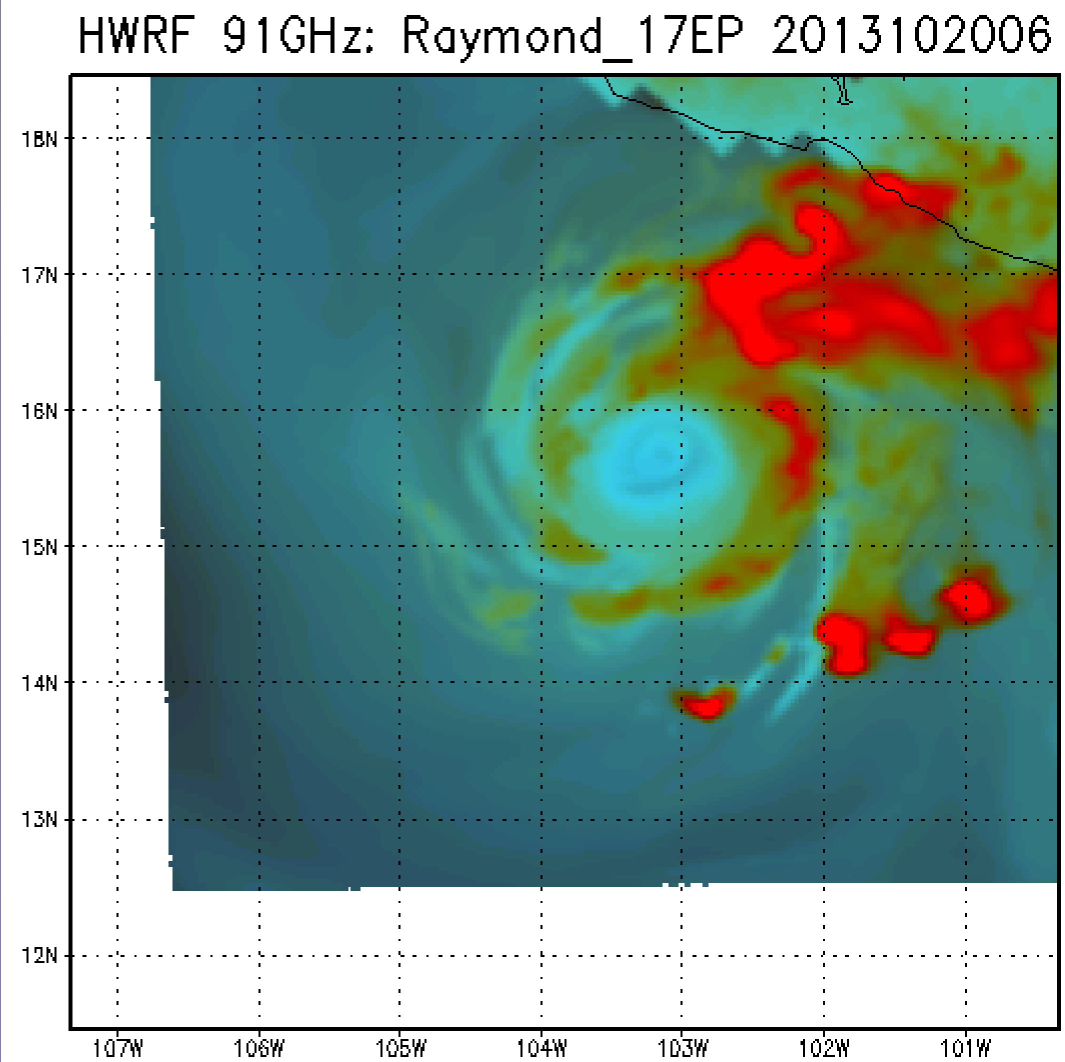
Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed microwave images (right)

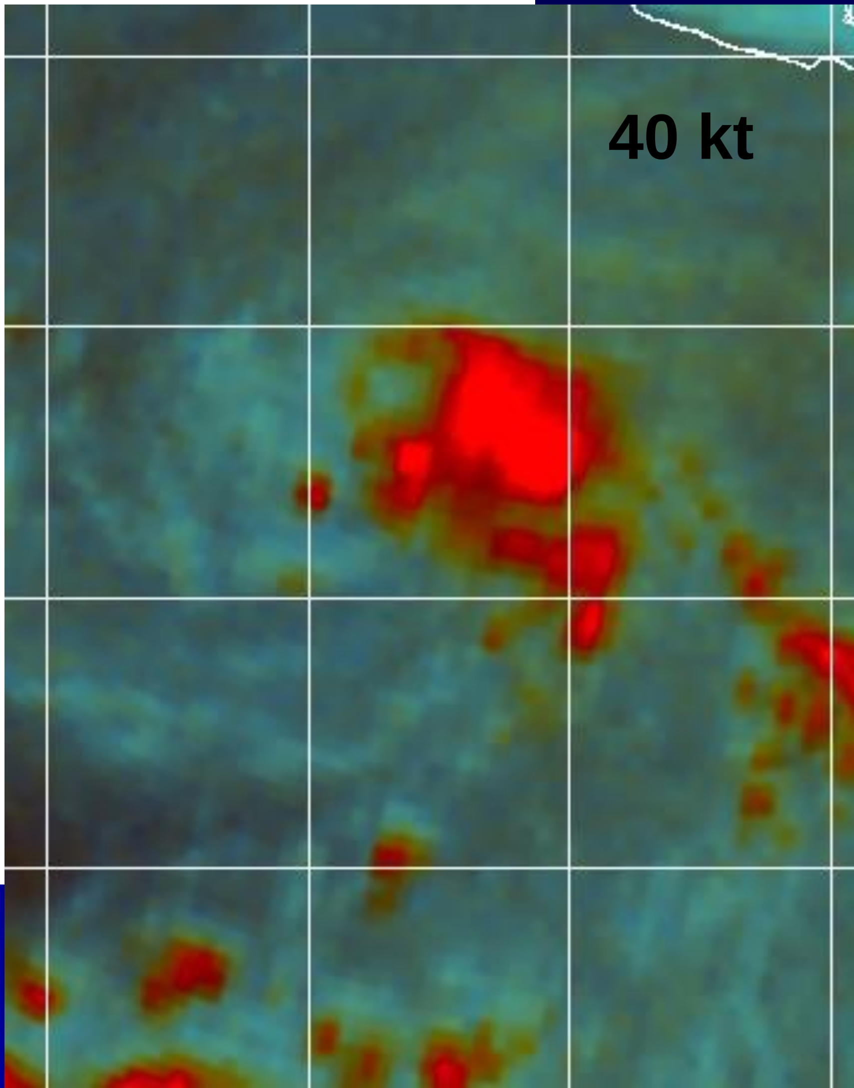


Forecast Valid:
12Z23OCT2013

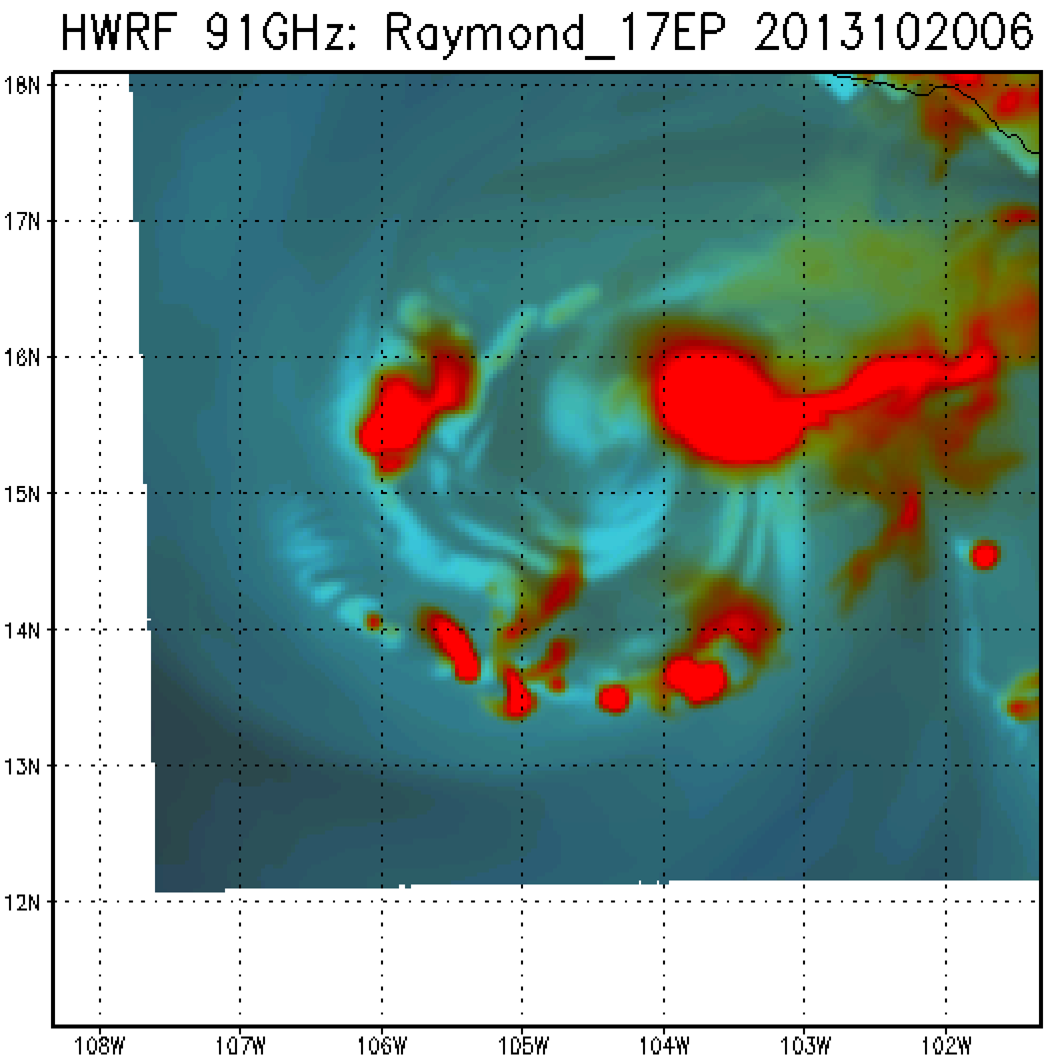


Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed microwave images (right)

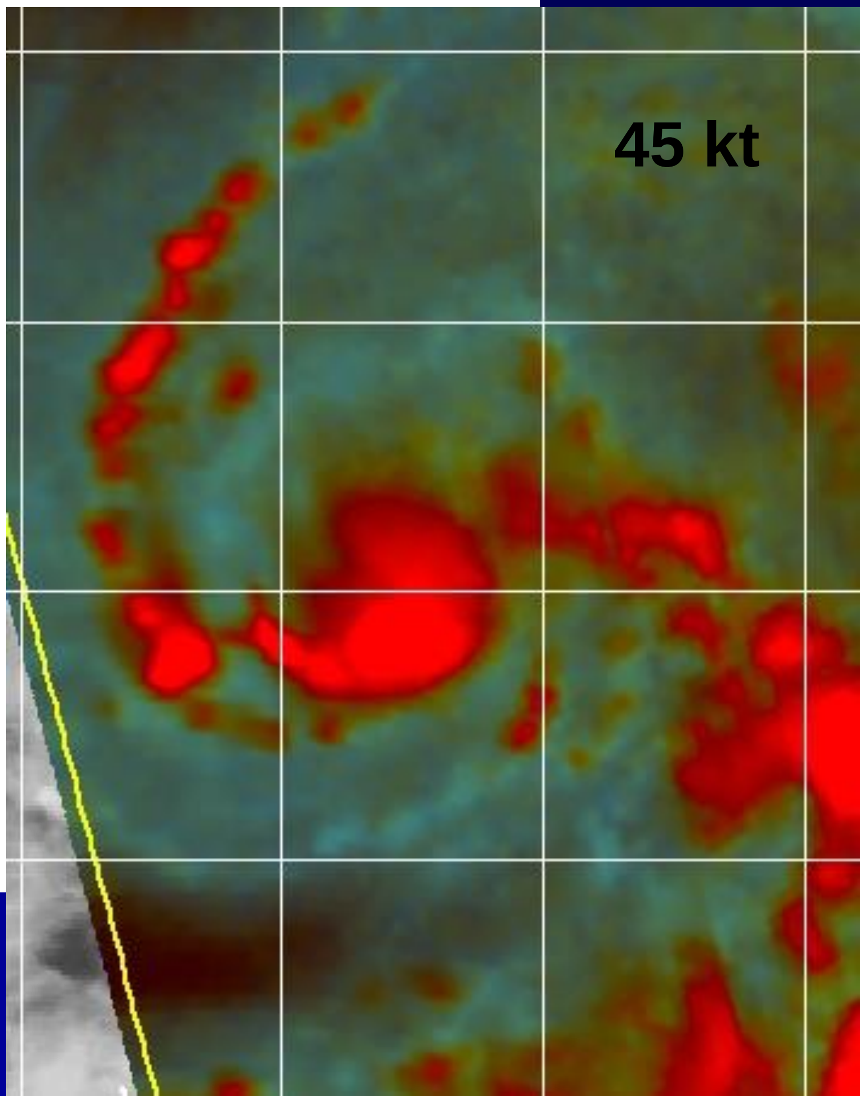




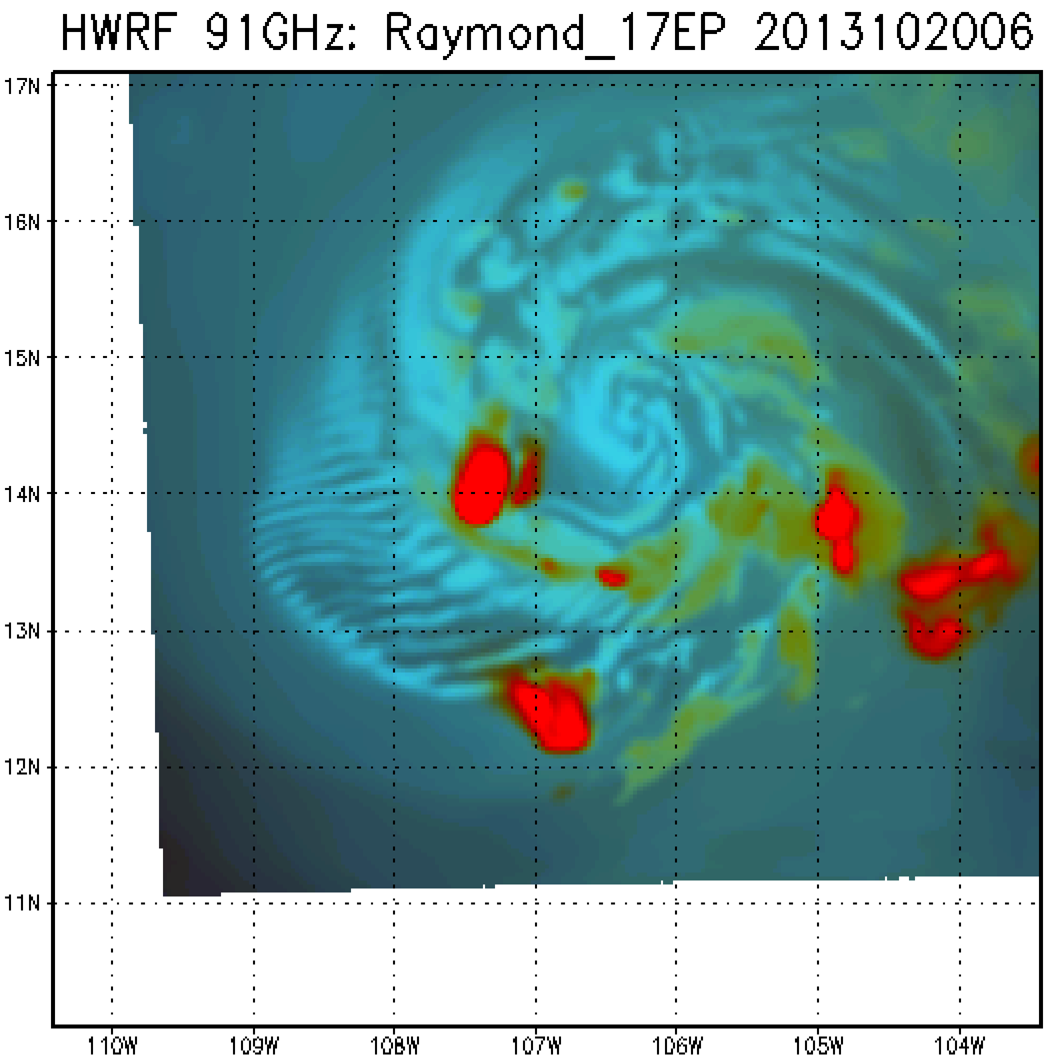
Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed microwave images (right)



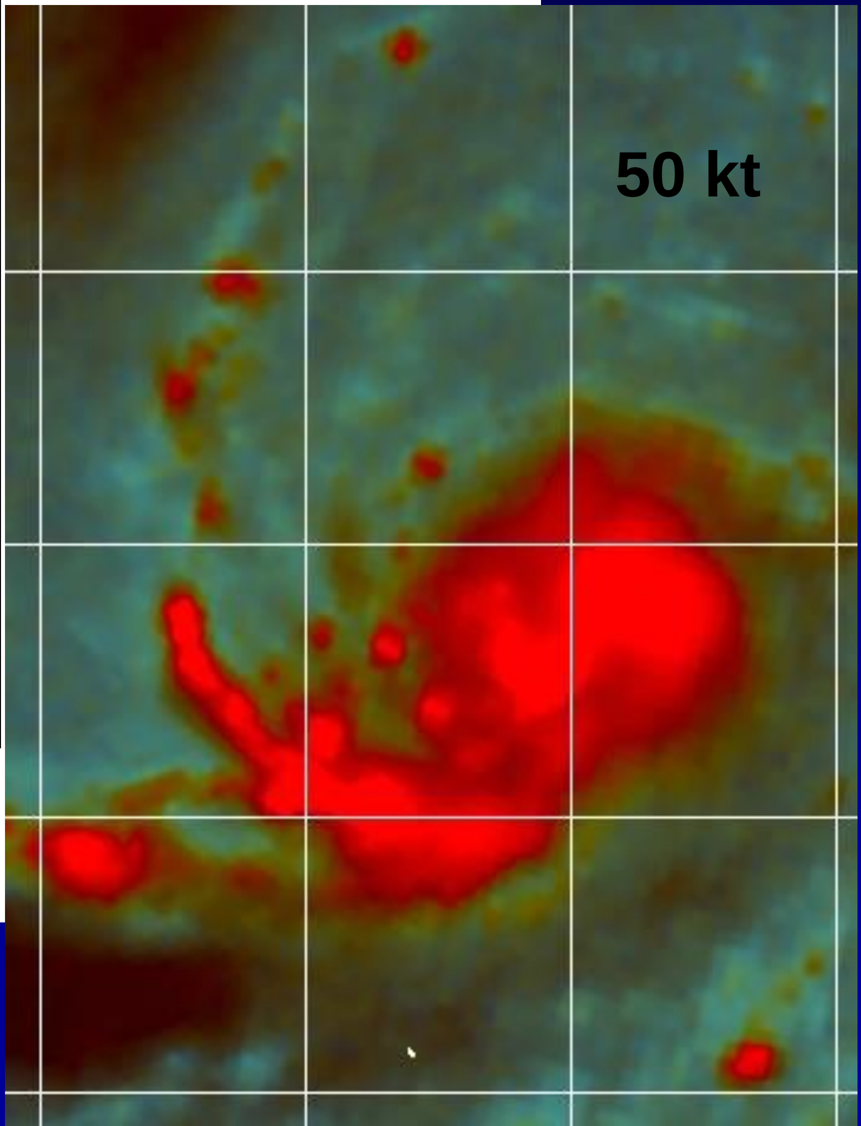
Forecast Valid:
00Z25OCT2013



Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed microwave images (right)



Forecast Valid:
12Z25OCT2013



Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed microwave images (right)

Satellite Ocean Surface Vector Winds

Scatterometry Basics

- Scatterometer → active microwave imager
- Microwave energy sensitive to roughness of ocean surface generated by the surface winds
  - Small capillary-scale Bragg Waves
- By viewing the same patch of ocean from several angles, it is possible to derive wind speed and direction

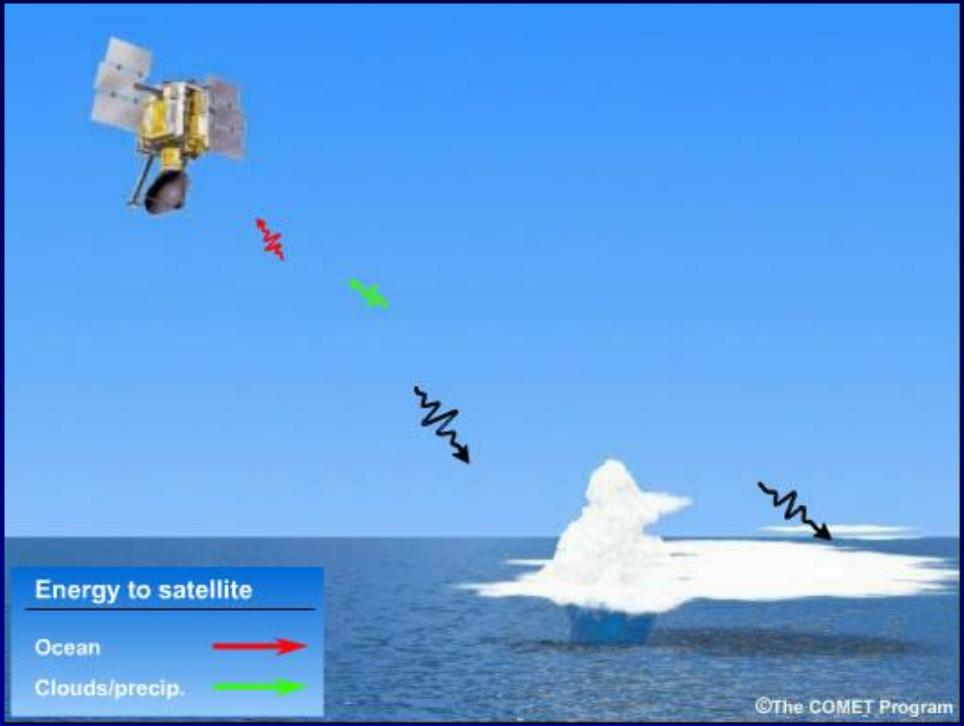


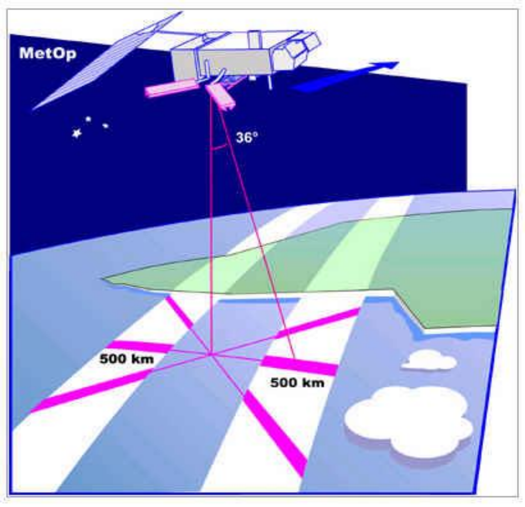
Image courtesy COMET

Advanced SCATterometer (ASCAT)

Sensor: Microwave radar
Spacecraft: MetOp-A, B, C (2018 launch)
Launch: 2006, 2012
Heritage: ERS-1, 2

Channel: 5.25 GHz, C-band

Swath: Two 520-km swaths, with 700-km nadir gap



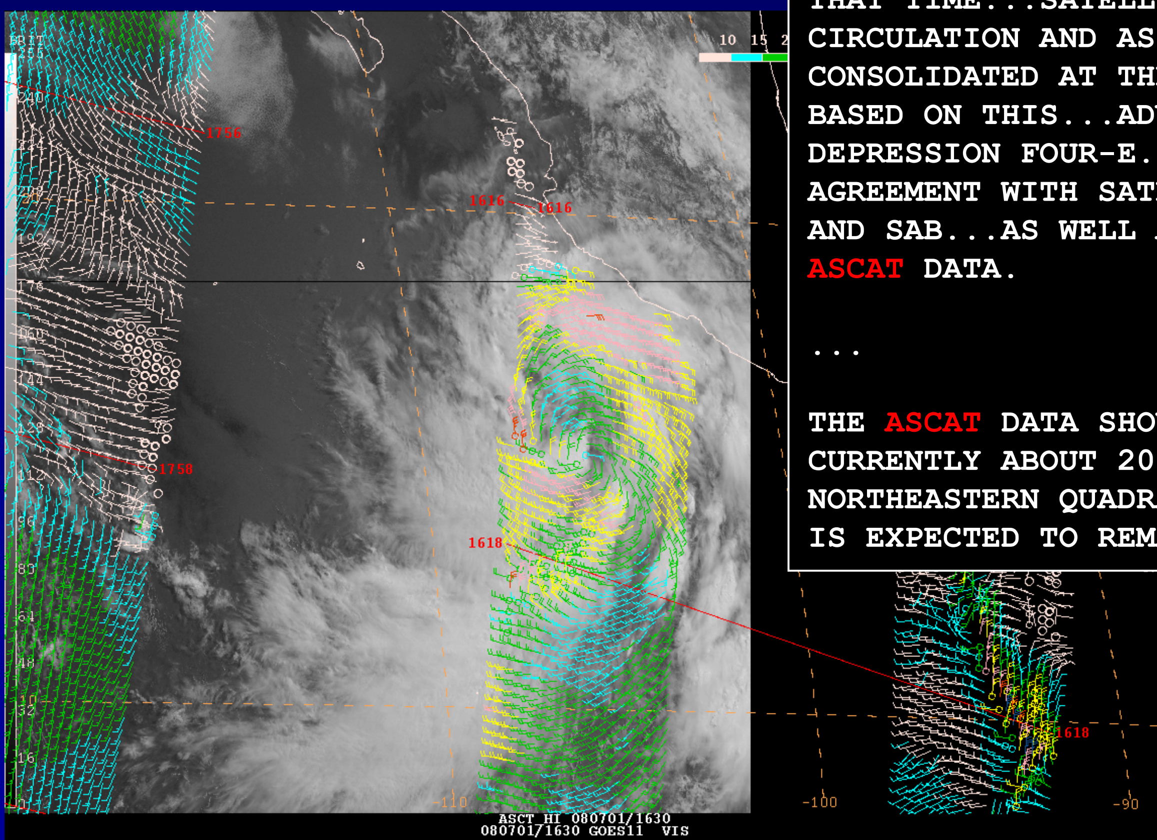
Utility for TC Applications:

(1) Only long term operational scatterometer series
(2) C-band, less rain contamination, larger footprint
(3) 25- and 50-km wind vector products, good for winds up to gale force (low bias above 35-40 kt)
(4) Gap in swath center is a major drawback for coverage

NOAA processed data: http://manati.orbit.nesdis.noaa.gov/datasets/ASCATData.php

Example of ASCAT Use

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



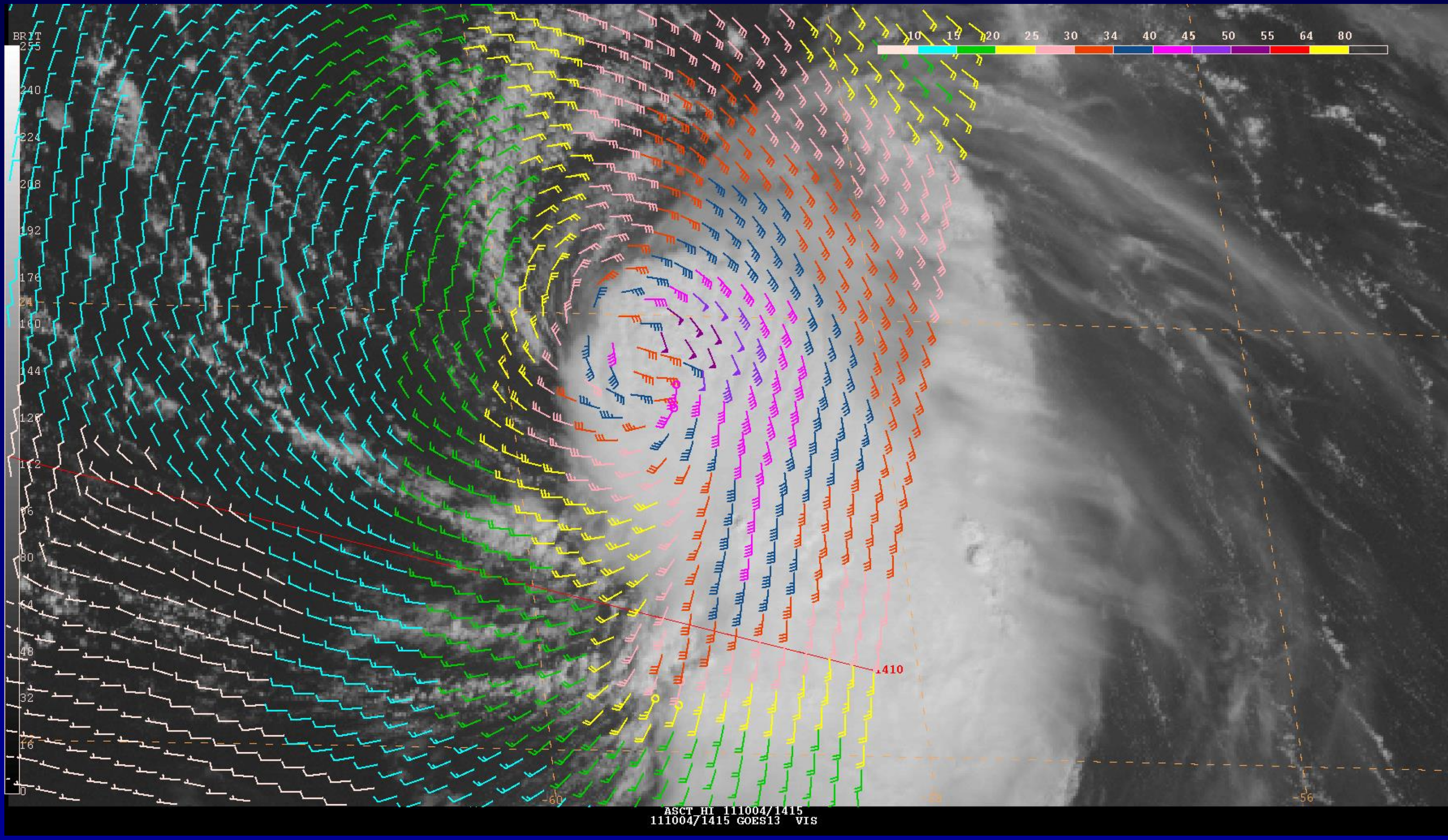
TROPICAL DEPRESSION FOUR-E DISCUSSION NUMBER 1
NWS TPC/NATIONAL HURRICANE CENTER MIAMI FL EP042008
800 PM PDT TUE JUL 01 2008

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.

...

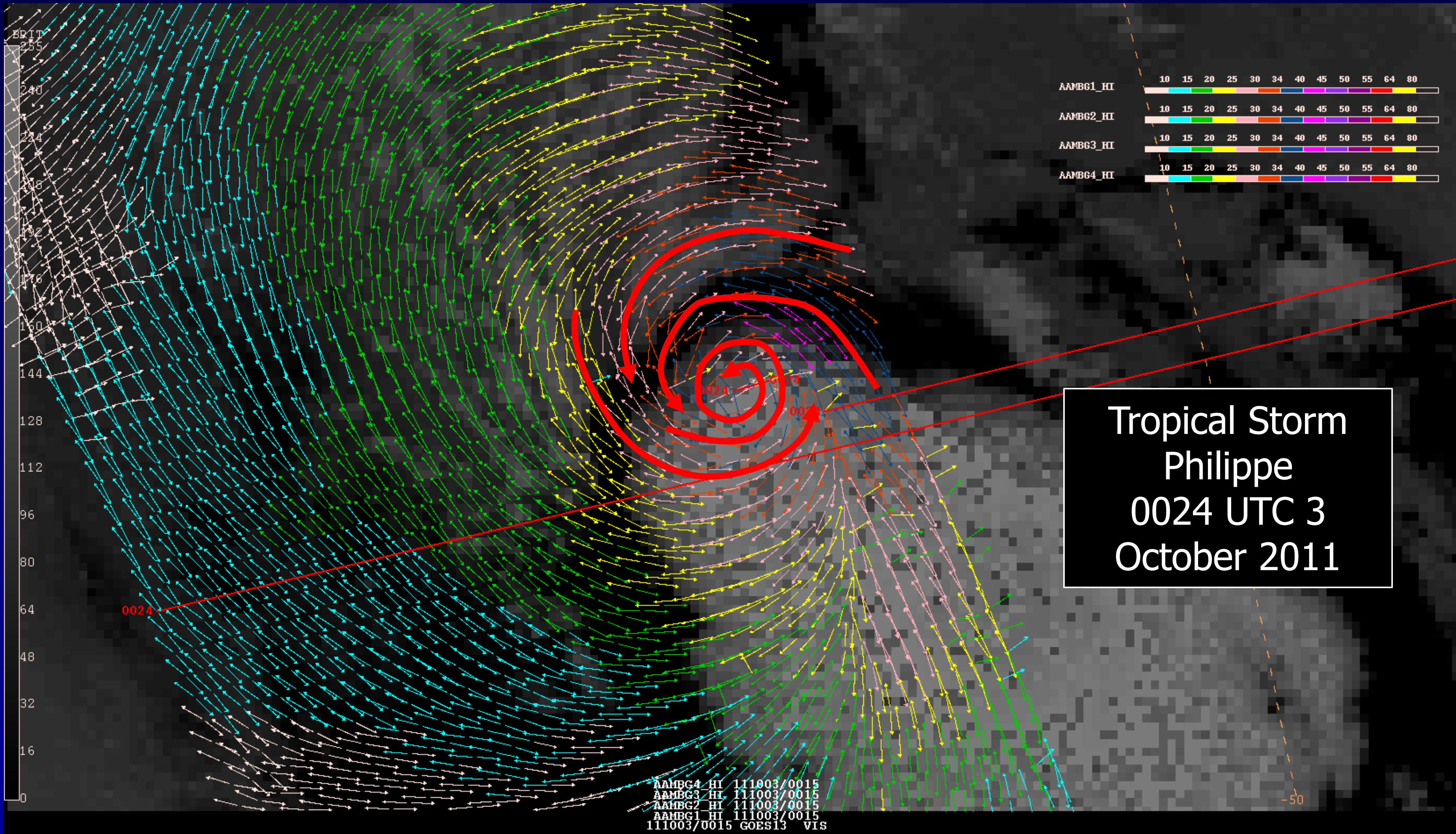
THE ASCAT DATA SHOWED 25-30 KT WINDS IN A BAND THAT IS CURRENTLY ABOUT 200 N MI FROM THE CENTER IN THE NORTHEASTERN QUADRANT. WHILE THE CENTER OF THE CYCLONE IS EXPECTED TO REMAIN WELL OFFSHORE...

ASCAT Use in TC Intensity Analysis



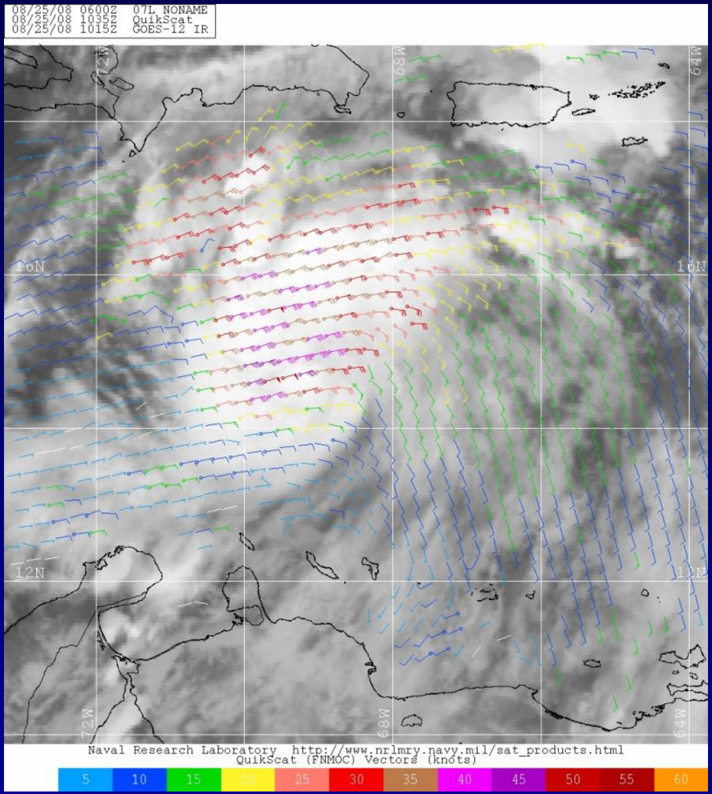
- ASCAT pass over Tropical Storm Philippe at 1410 UTC 4 October 2011 revealed the cyclone to be stronger (50-55 kt) than suggested by Dvorak satellite intensity estimates (45 kt)
- It is difficult to assess the peak intensity with ASCAT however due to spatial sampling considerations, especially in stronger TCs

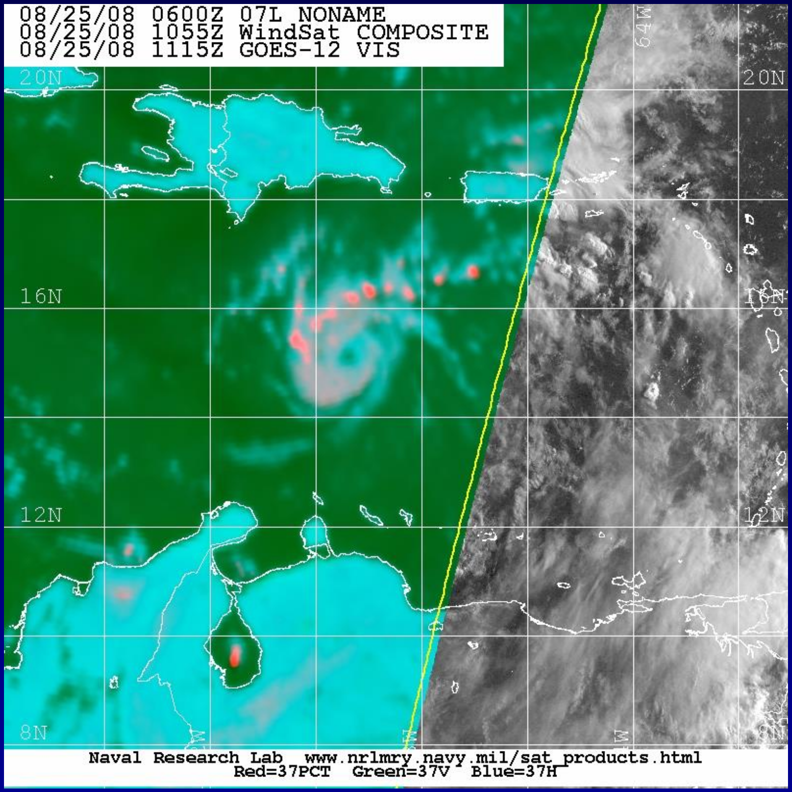
ASCAT Use in TC Center Fixing



- Reduced rain contamination and prevalence of 3rd and 4th ambiguities in areas of low winds can help make center fixing easier with ASCAT if the pass samples the center location

Using Microwave Imagery and Scatterometery Together





- Near co-located QuikSCAT and WindSat passes around 1045 UTC 25 August 2008 over TD 7 (later Hurricane Gustav)
- Advisories initiated at 15Z based partly on evidence of closed circulation from QuikSCAT pass
- Low-level circulation confirmed in microwave imagery from WindSat and aircraft recon found a Tropical Storm at 18Z

Questions?