

Interpretation and Application of Microwave Imagery and Scatterometry



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Outline

- Overview of basic principles/availability of Low Earth Orbit (LEO) microwave sensors
- Orbital characteristics
- Single frequency characteristics
- Color composite images
- Scatterometry
- Data availability
- Application/Exercises



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

Overview of Remote Sensing Basics

- Passive sensors (SSM/I, SSMIS, TMI, AMSU, AMSR2, etc.) measure emitted microwave energy from 19 to 200 GHz
- Emissivities are directly related to **brightness temperatures (T_b)**
 - **scattering** effects by ice
 - **emission** by light precipitation
 - **emission/absorption** by cloud liquid water and rain droplets
- Microwave window channel T_b can be used to quantify these emissivities

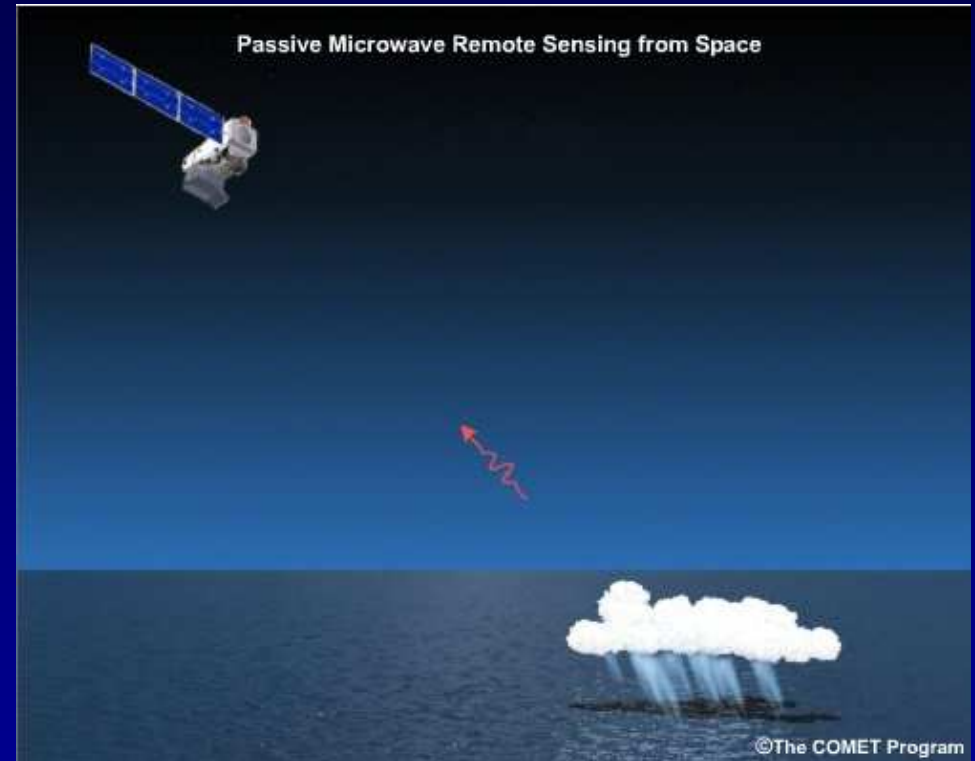


Image courtesy COMET

Overview of Remote Sensing Basics

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

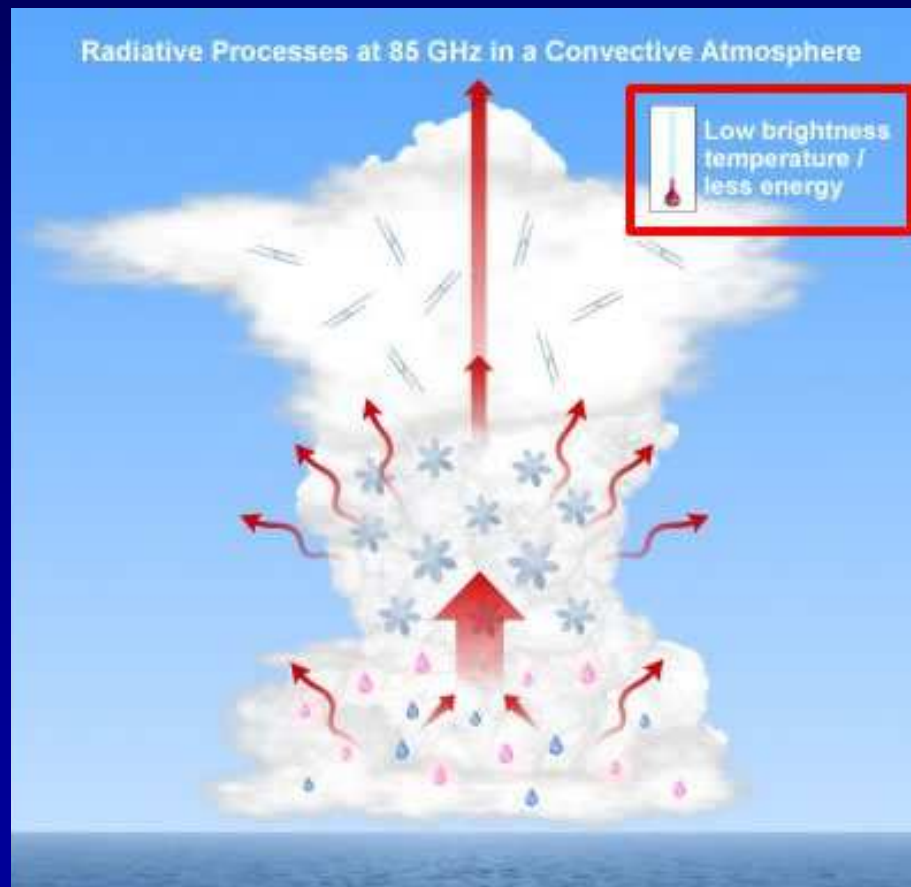


Image courtesy COMET

Overview of Remote Sensing Basics

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

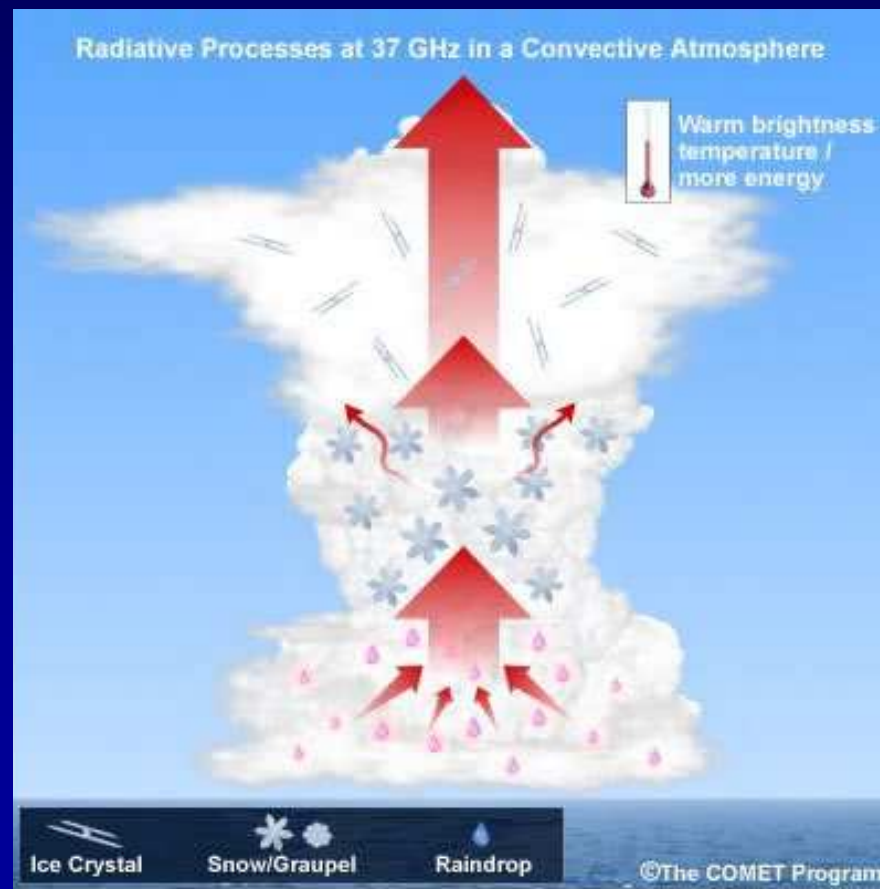
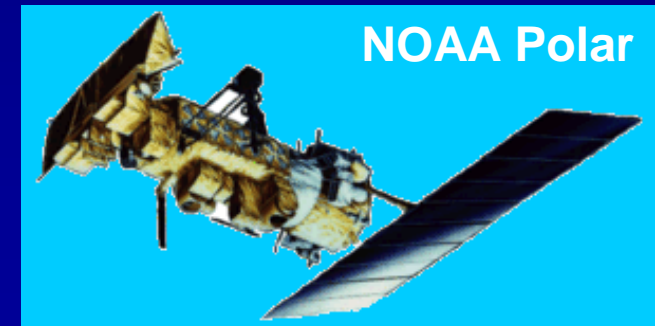


Image courtesy COMET

Remote Sensing Satellites - Orbits

- Geostationary (GEO) satellites
 - Orbit at 35,800 km altitude over same spot on the equator
 - Good for continuous monitoring, not good for high resolution
 - Good for visible and infrared, not good for microwave
 - Good for passive, not good for active
 - Good for middle latitudes and tropics, not good for polar regions
- Low earth orbit (LEO) satellites
 - Good for microwave (active and passive), visible, and infrared
 - Lower altitude orbit, but not over same spot on earth
 - Finer spatial resolution
 - Limited spatial coverage (narrow swaths of data)
 - Views each area only twice per day (except near poles)
 - Depending on orbital configuration, can cover nearly entire globe each day



Data Timeliness

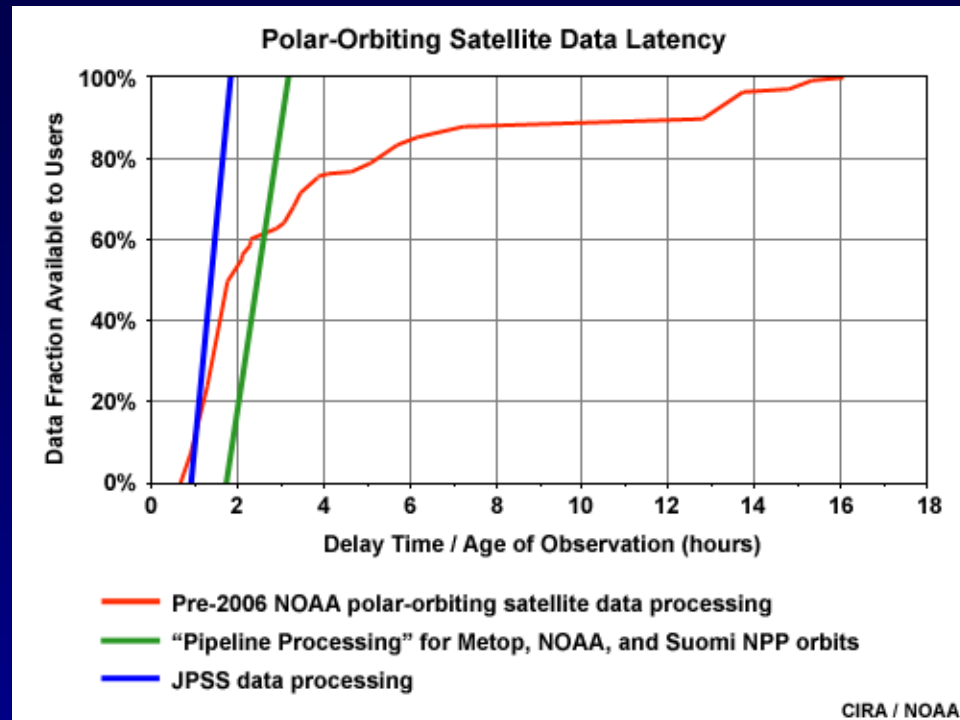


Image courtesy COMET

- LEO satellites are not continuously in view of data receiving stations
- They can only download data when they are in range of those stations, which leads to delays in data transmission and processing

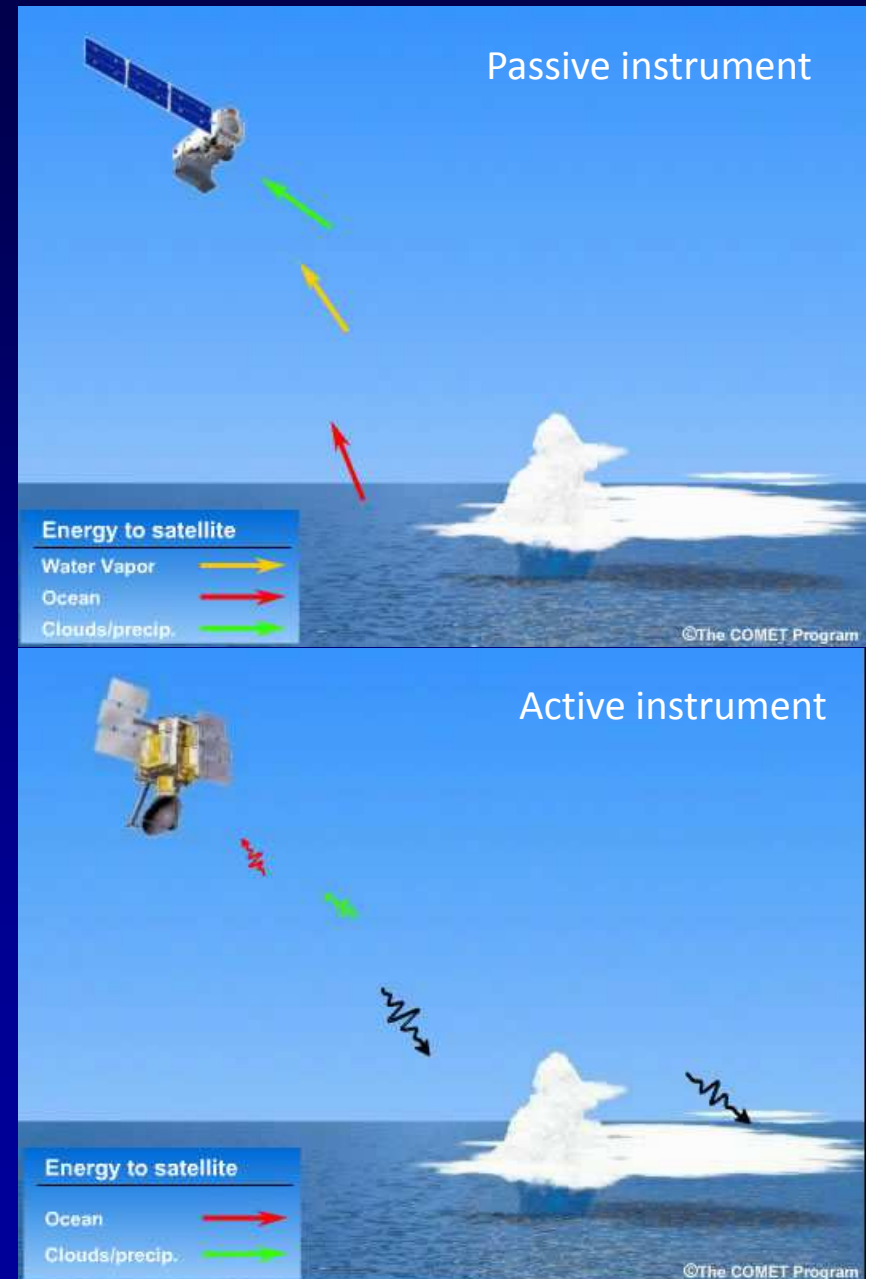
Measuring Electromagnetic Energy

- **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 and scattering

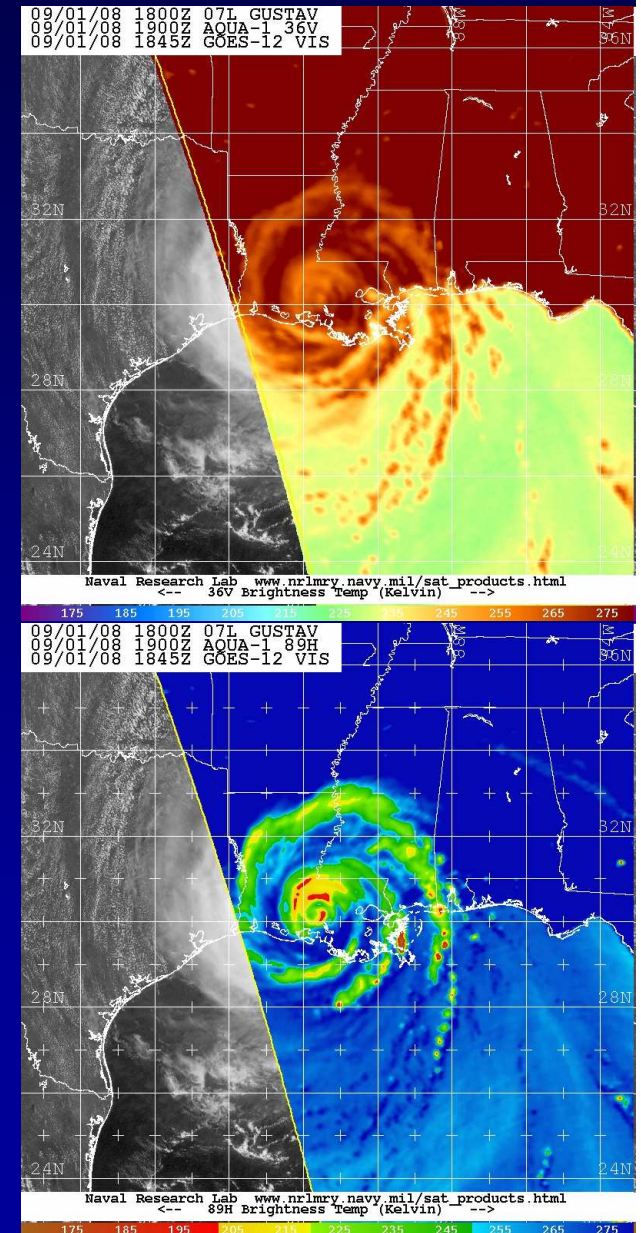
- **Active Instruments:**

- Send out pulses of radiation, usually at microwave frequencies
- Measure radiation returned to the sensor
- Examples
 - Surface-based and airborne radars
 - Satellite scatterometers

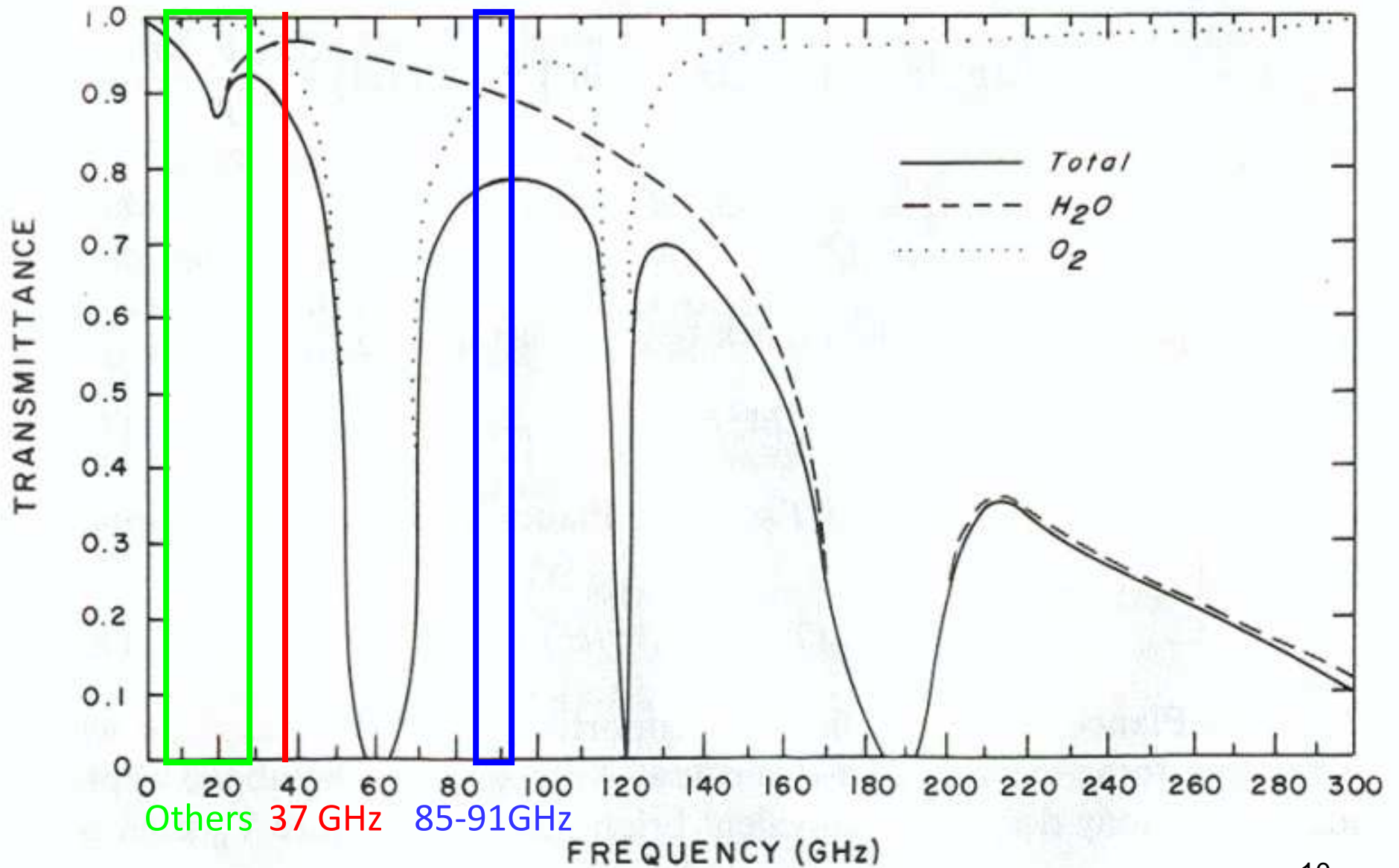


Key Characteristics of Microwave Radiation

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

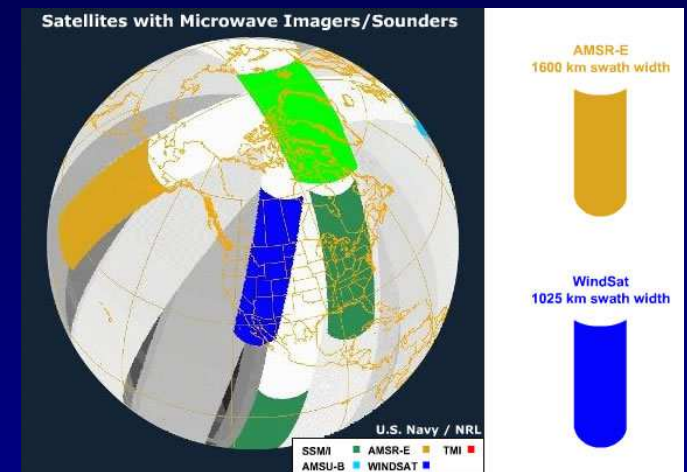


Microwave Transmittance



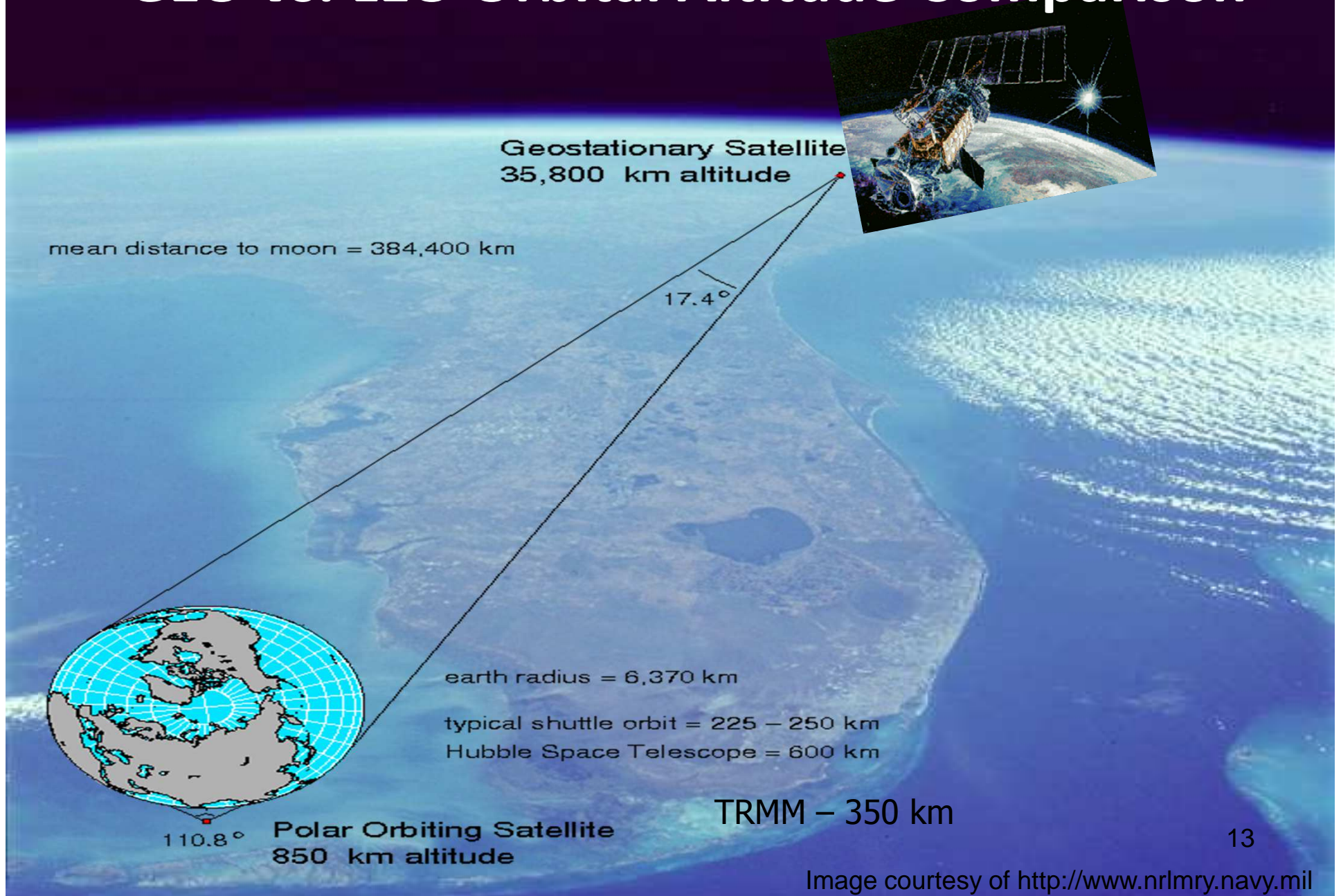
Current/Operational Passive Microwave Imagers and Sounders/Platforms

- AMSU-A/B – 6 satellites (NOAA 18/19) and European MetOP-A/B
- SSM/I – 1 DMSP satellite (F-15)
- SSMIS – 3 DMSP satellites (F-16, F-17, F-18)
- GMI – GPM – JAXA/NASA
- AMSR-2 – GCOM-W1 – Japan (JAXA)
- WindSat – Navy NRL Coriolis (37-GHz Only)



Orbital and Scan Characteristics

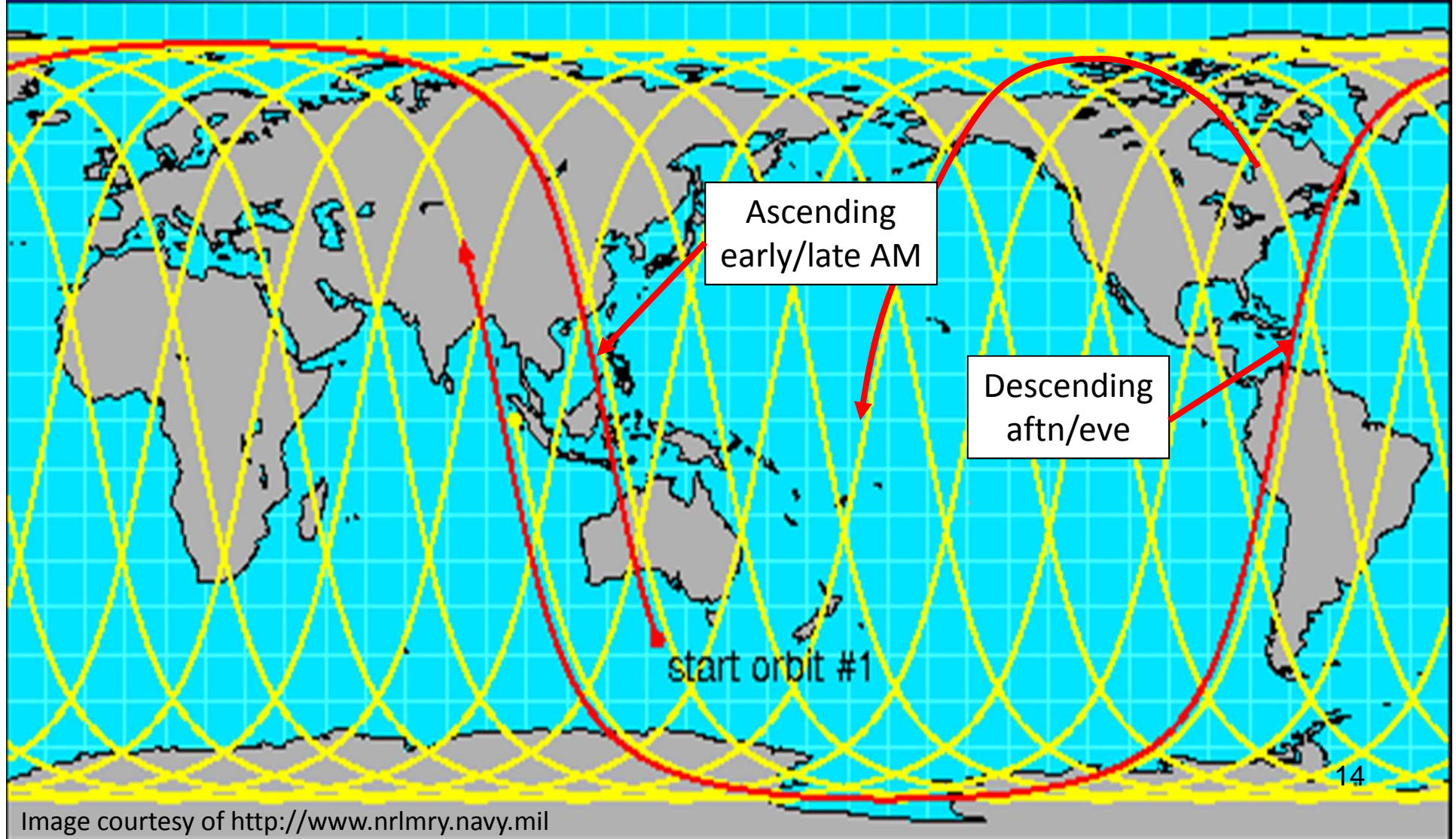
GEO vs. LEO Orbital Altitude Comparison



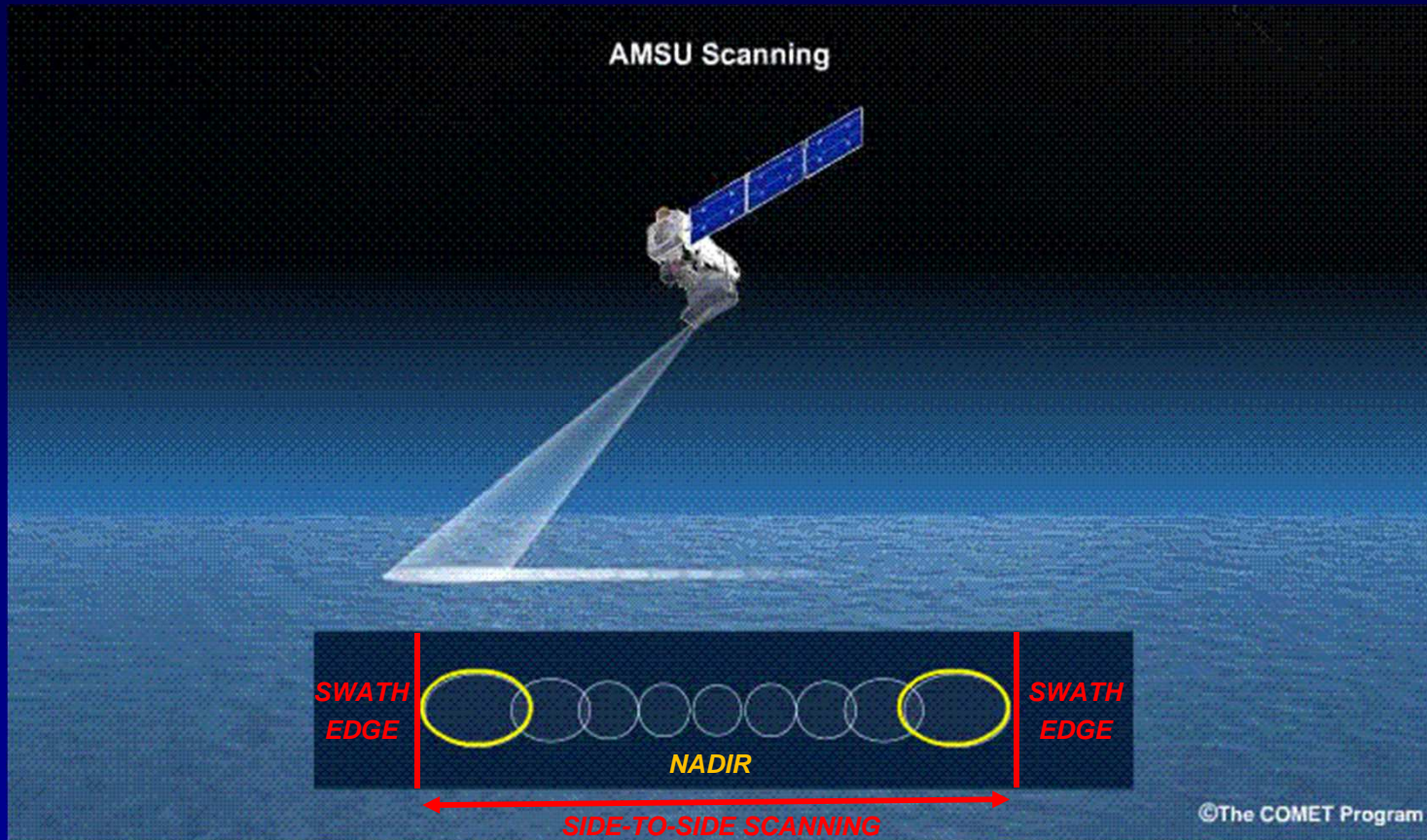
Sun-Synchronous Daily Orbital Path

~12 hr to observe the entire Earth

Same location twice daily (ascending/descending)

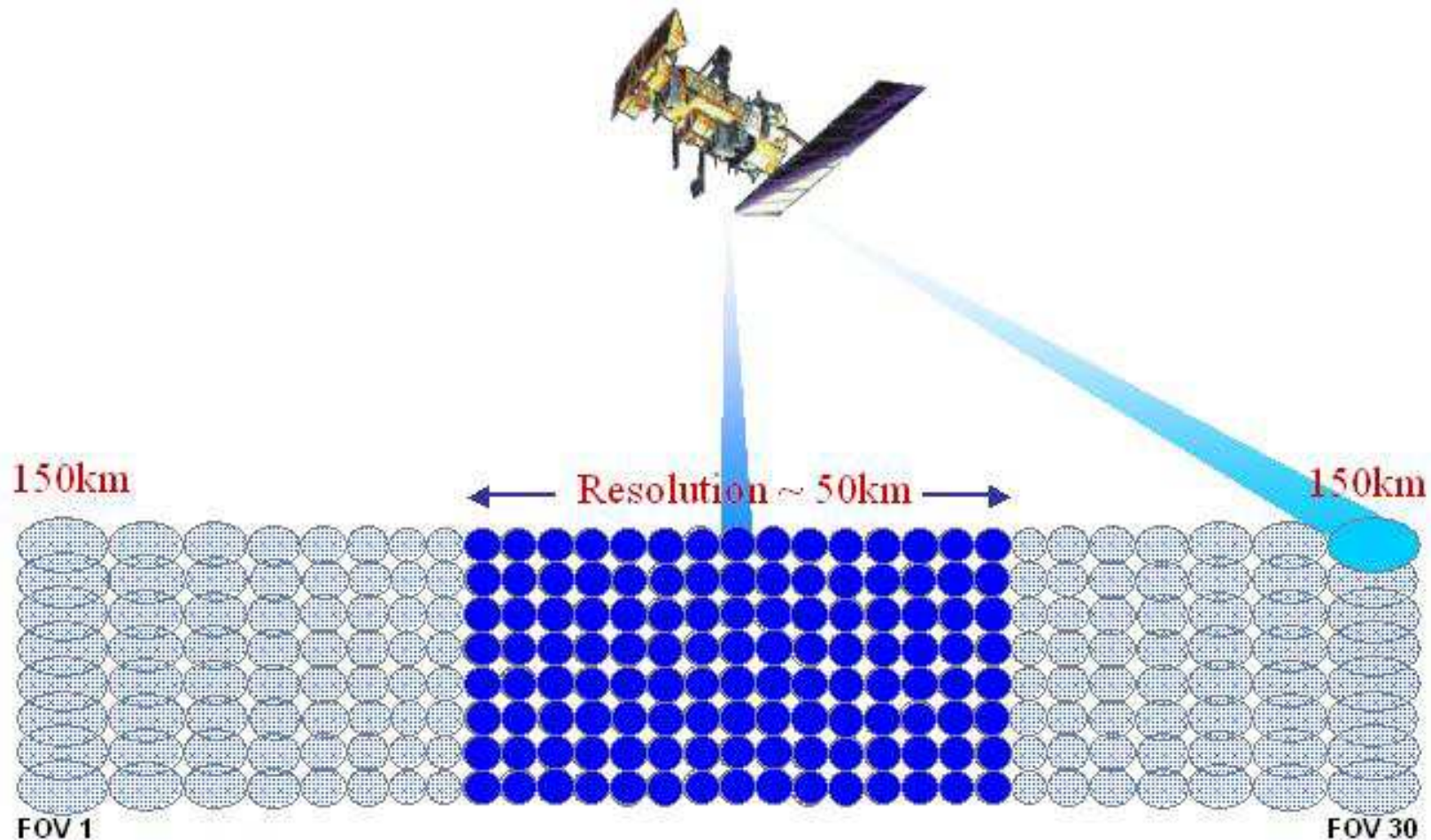


Cross Track Scan Strategy



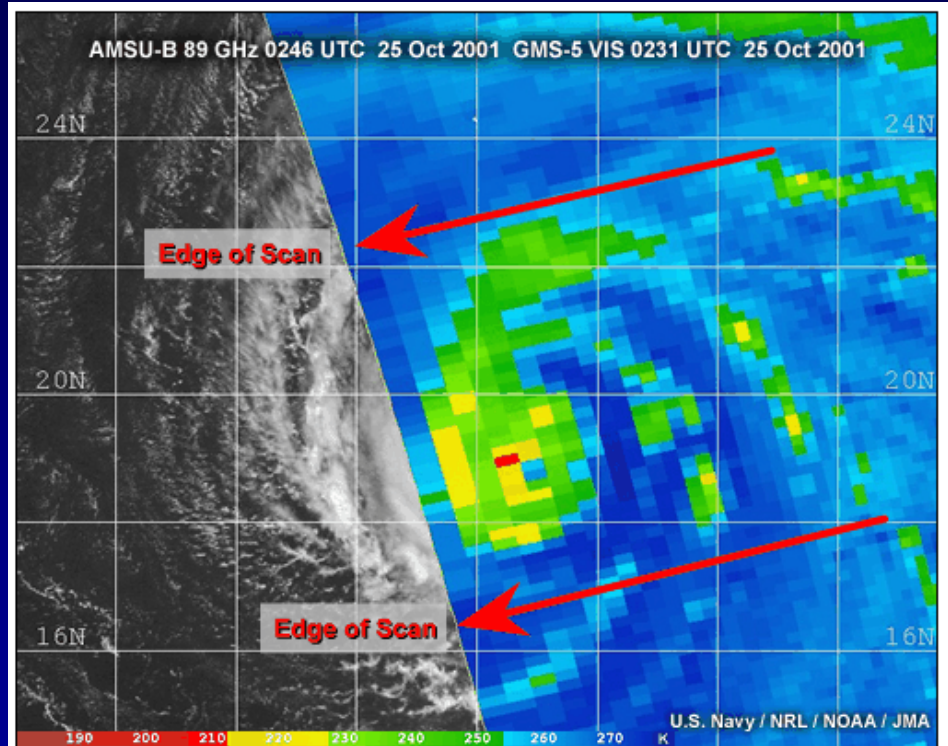
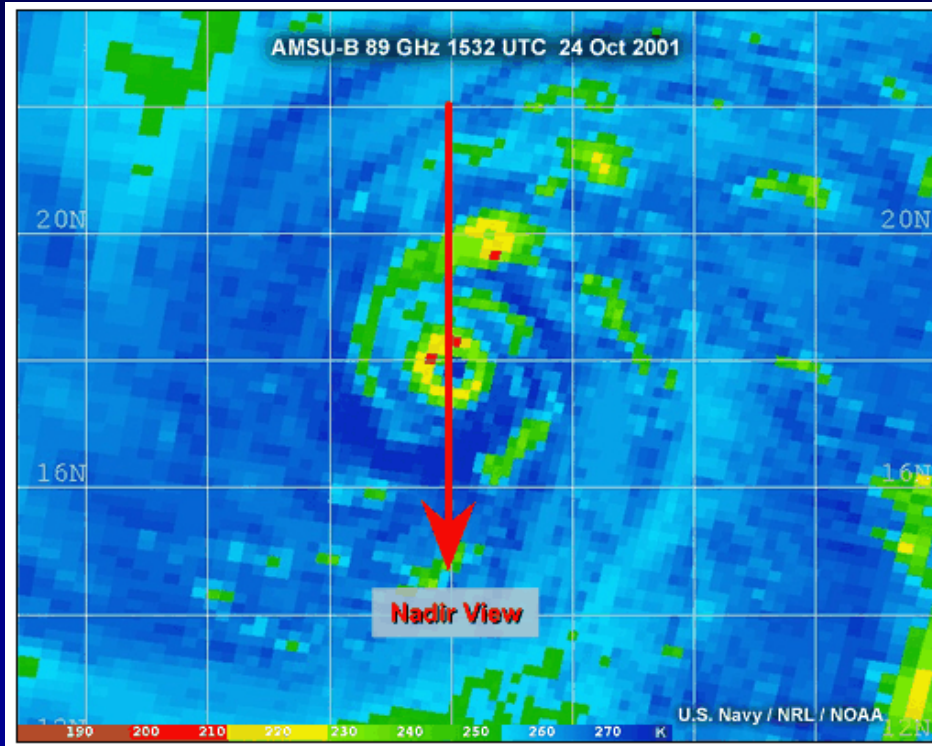
- **Advantage:** Larger coverage swath relative to conical scan
- **Disadvantage:** Resolution varies across the swath (coarser resolution at swath edge relative to nadir)

Cross Track Scan Strategy



AMSU Scanning Geometry and Resolution

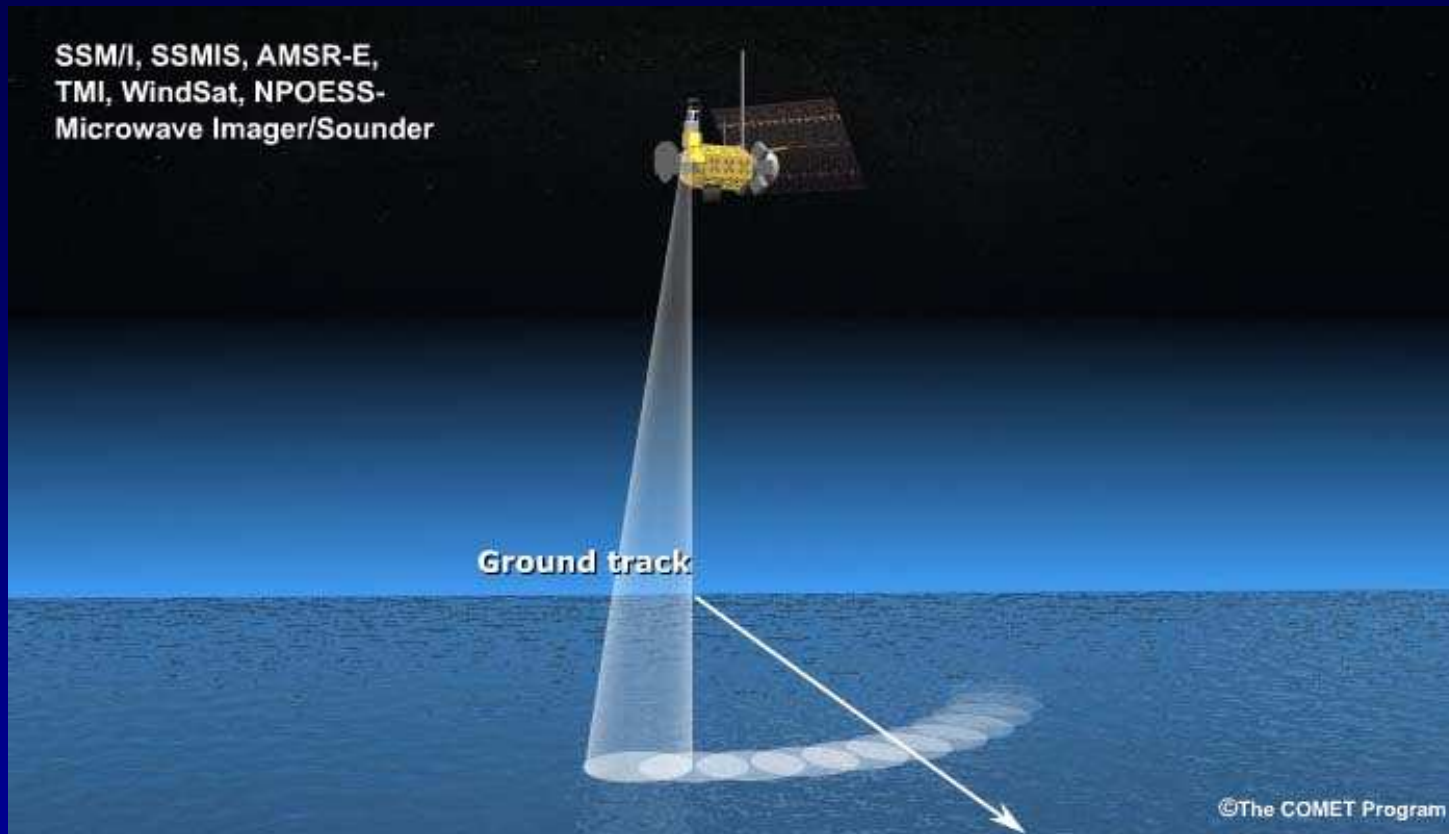
Cross Track Scan Strategy



Note degradation in resolution at edge of scan compared to nadir

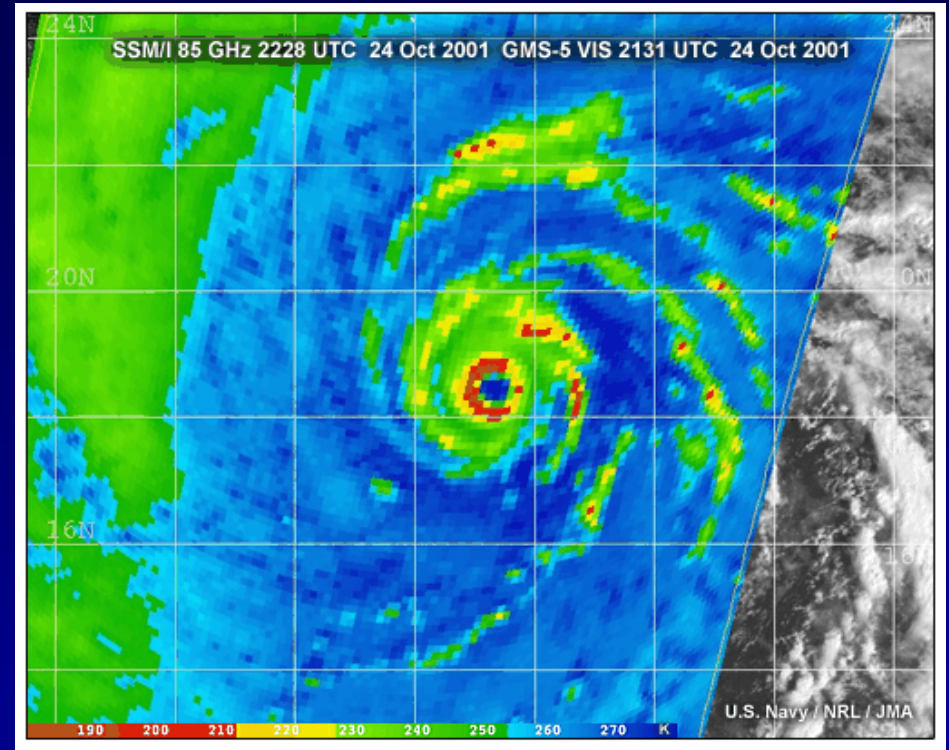
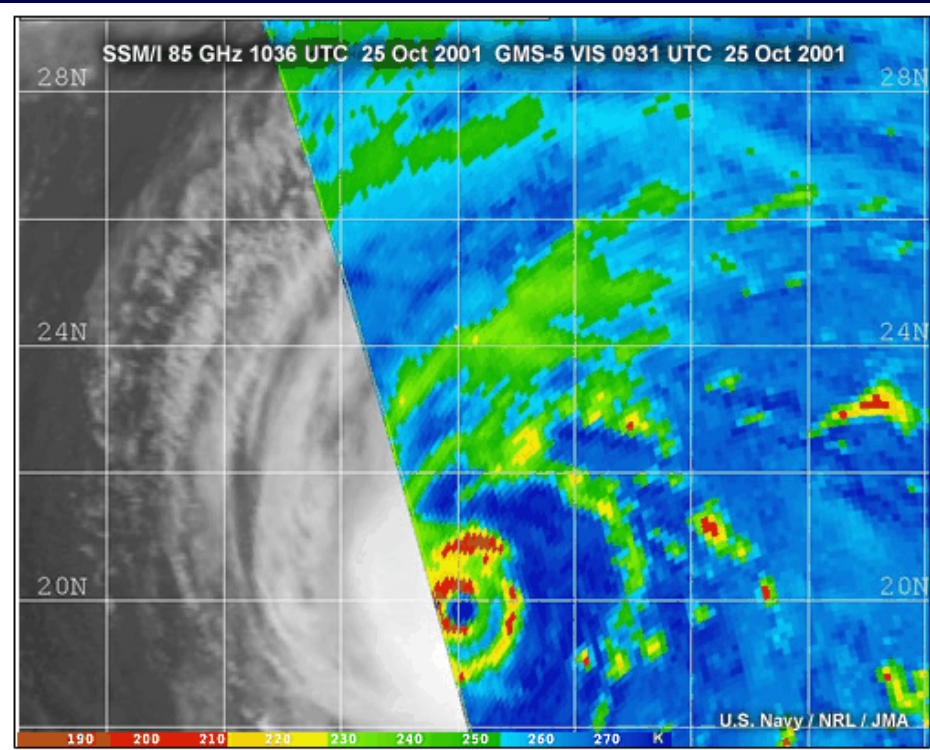
Images courtesy COMET

Conical Scan Strategy



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

Conical Scan Strategy



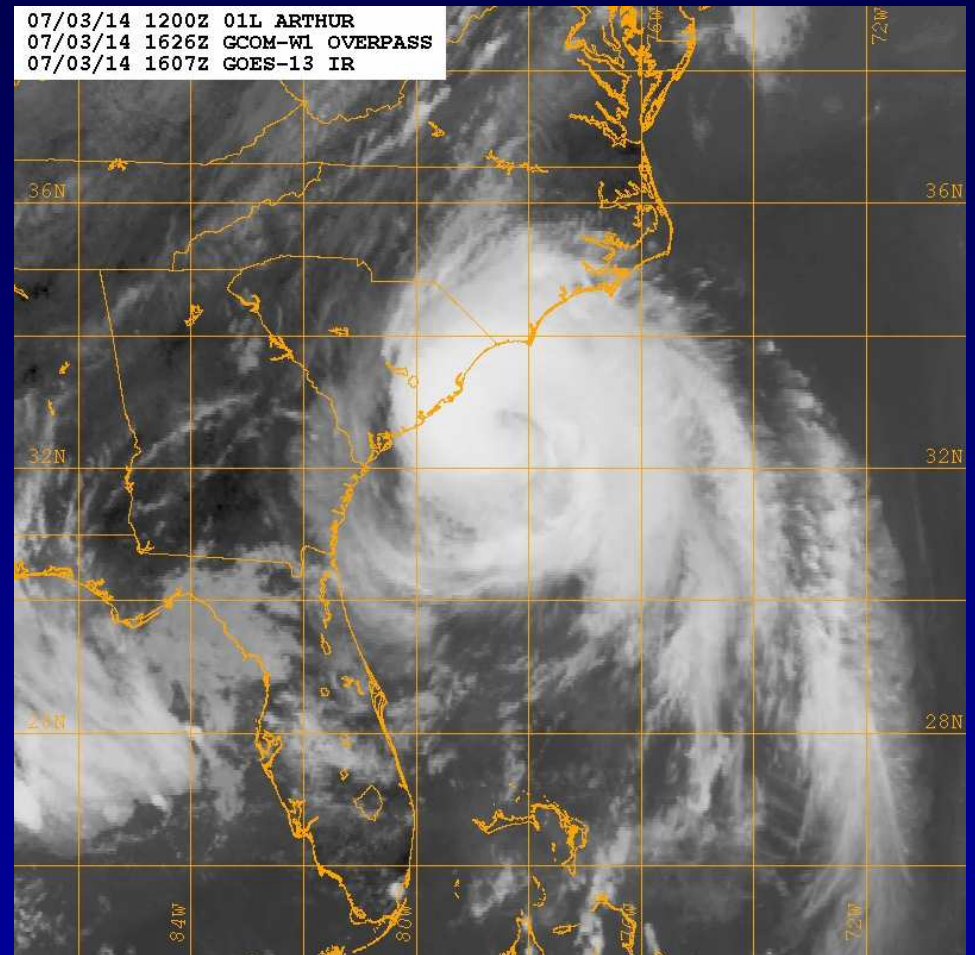
Resolution remains constant across swath

Images courtesy COMET

Imagery Characteristics and Applications

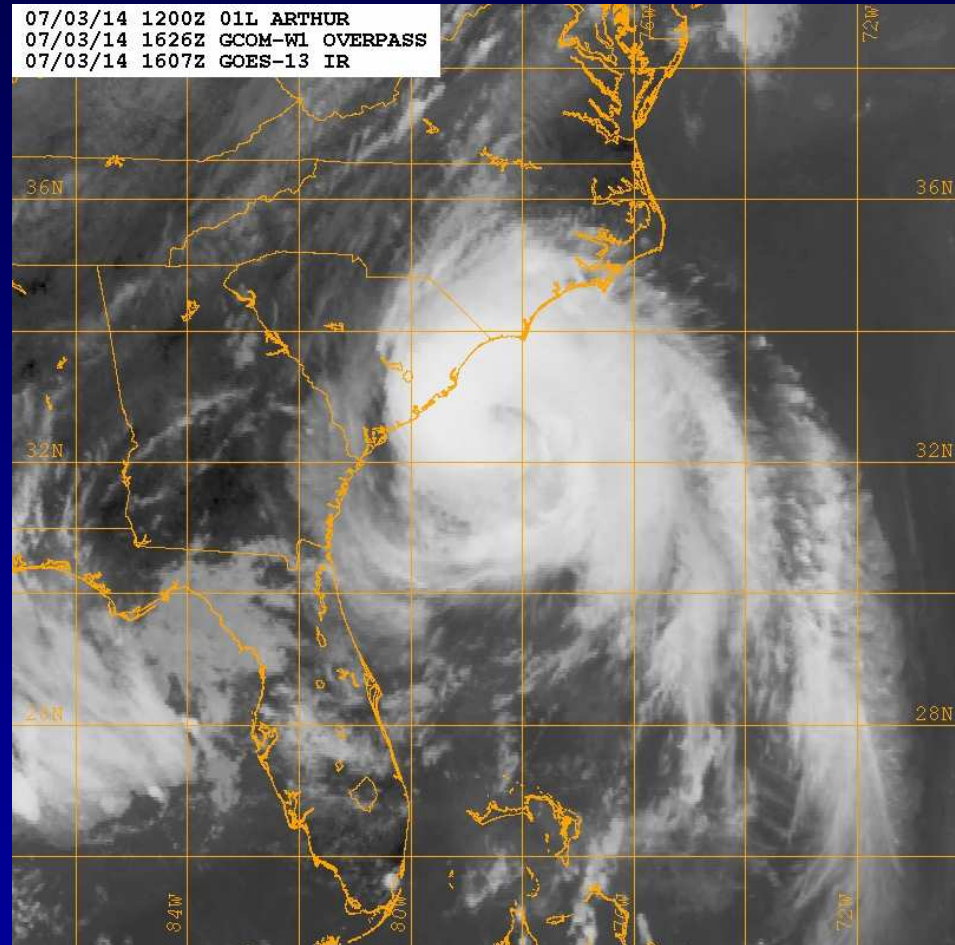
85-GHZ Imagery Interpretation

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



37-GHZ Imagery Interpretation

- Precipitating clouds and land surface appear **warm** against a relatively **cold** ocean background
- **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)

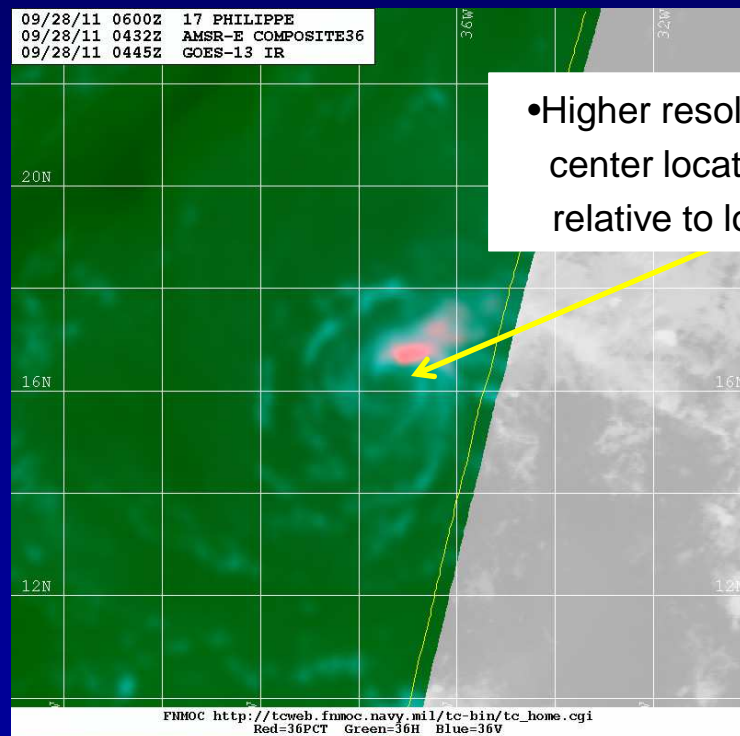


Advantages of Using 85-GHz and 37-GHz Imagery for TC Analysis

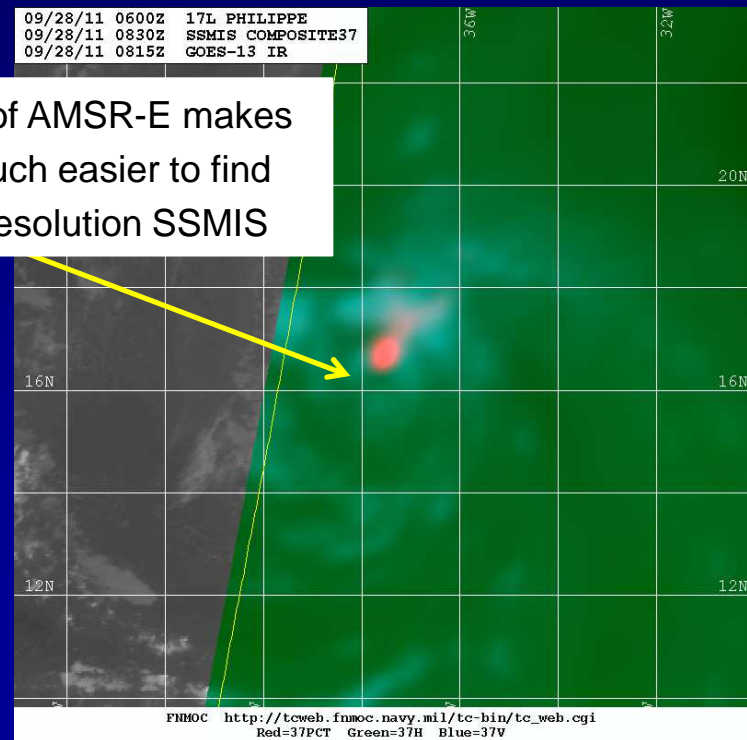
- In a sense, “sees” through clouds
- Identification of circulation center (critical step in initiating TC advisories)
- Acquire positioning of TCs in difficult situations (especially in early stages of development and at night)
- View of convective rain bands is more directly related to intensification 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-R (left) and SSMIS (right) at 0432 UTC and 0830 UTC 28 September 2011, respectively – Images courtesy FNMOC TC webpage

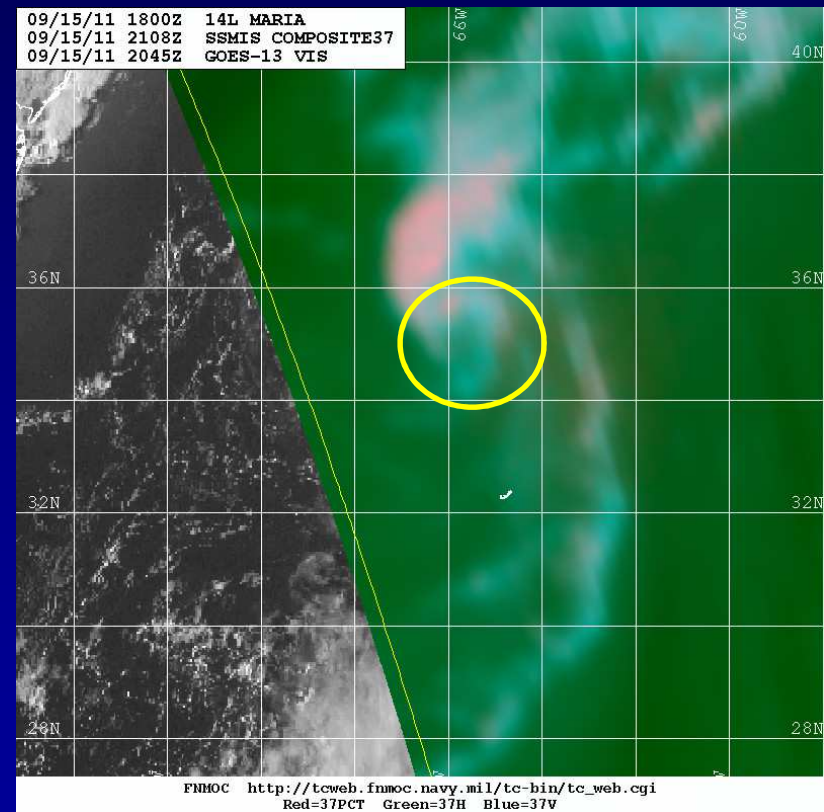
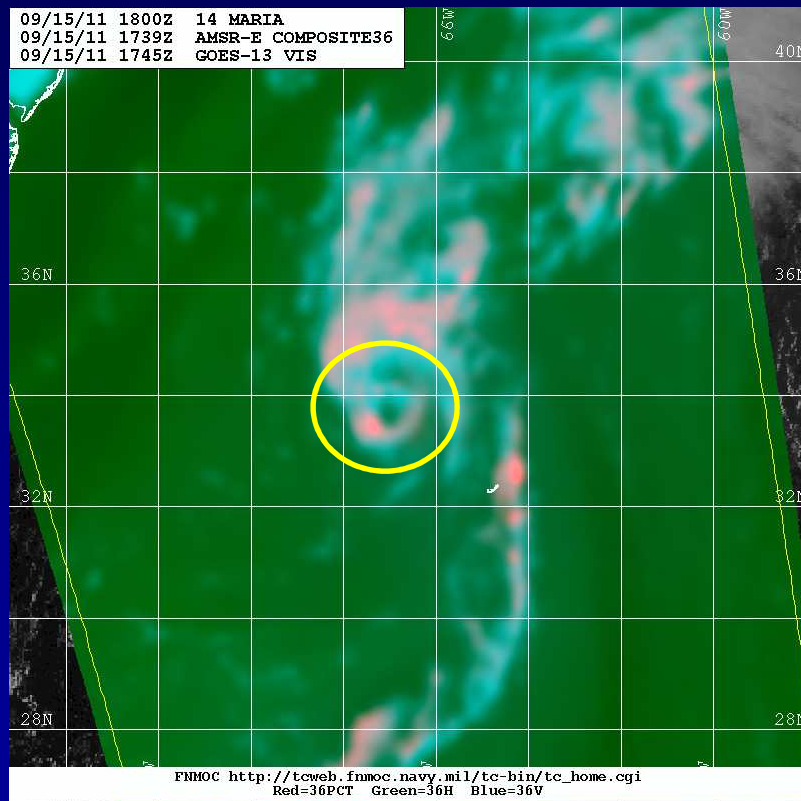


• Higher resolution of AMSR-E makes center location much easier to find relative to lower-resolution SSMIS



Effects of Resolution

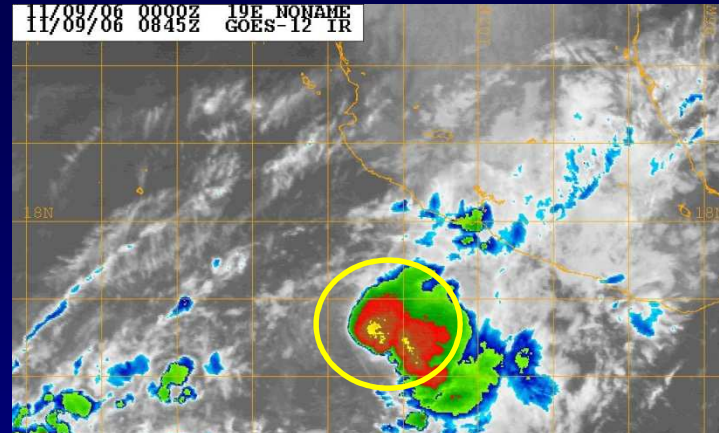
- Resolution differences also affect the ability to resolve low to mid-level eyewall structure



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

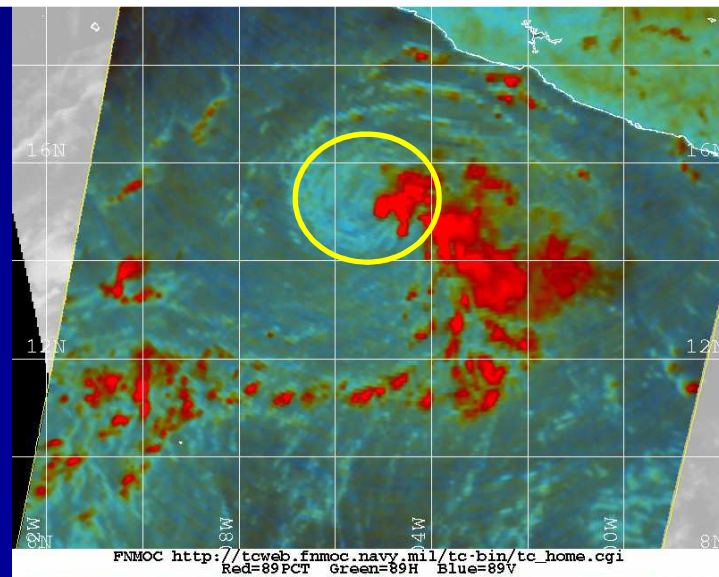
Importance of Center Location

- Locating the center 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 incorrect center locations at certain stages of development, especially for sheared systems and systems with embedded centers in infrared imagery



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

Tropical Storm Rosa – 9 November 2006



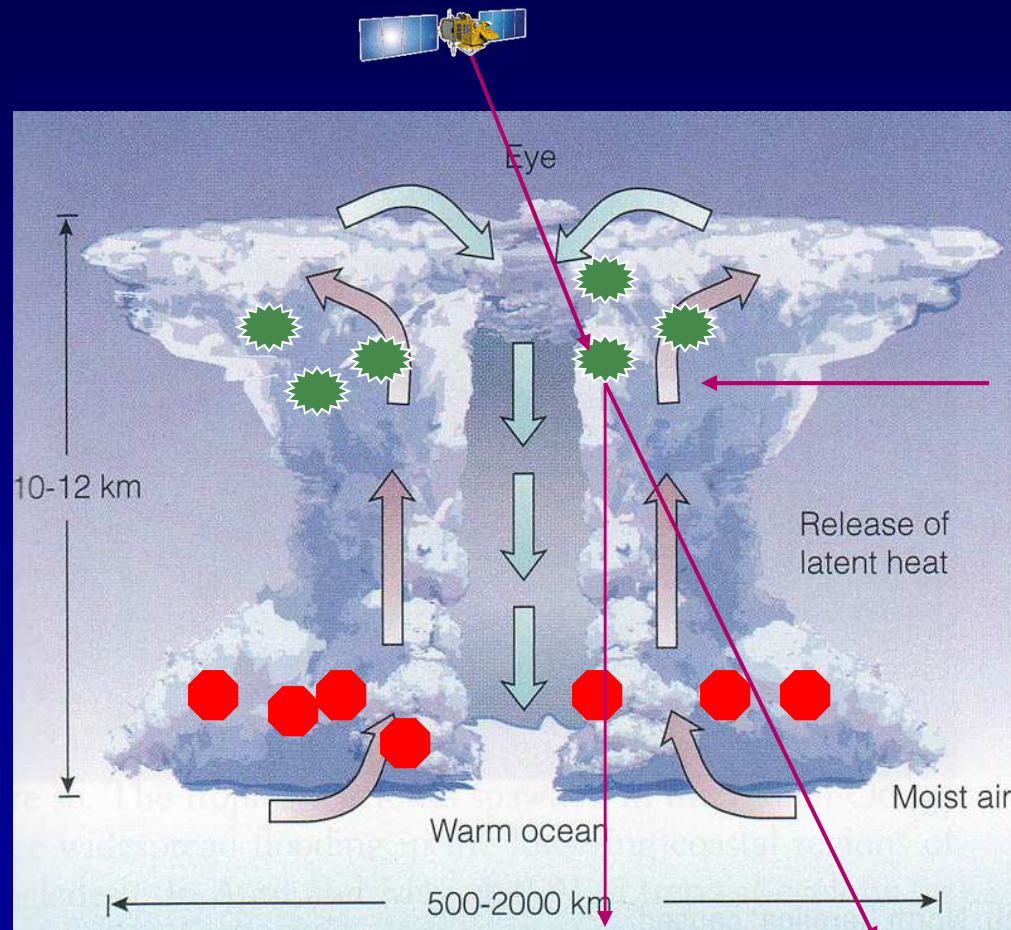
Parallax Error in Center Fixing

- Satellite-derived position error exists, potentially up to 20 km (~10.8 n mi) from actual position
- Occurs due to conical viewing angle and/or viewing geometry of the satellite
- Higher parallax error in 85-GHz images since scattering hydrometeors produce a signature much higher in the eyewall at 85 GHz than at 37 GHz

85-GHz Parallax

Ice Crystals

Raindrops



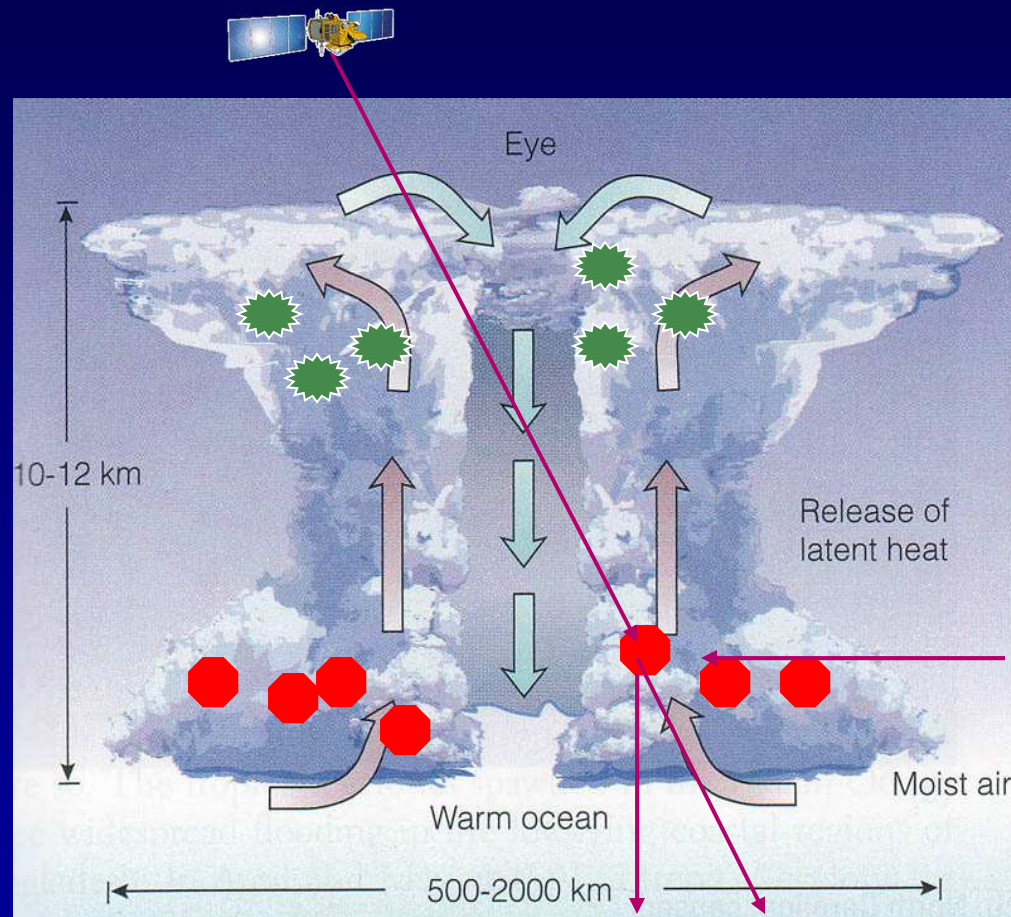
Effective
Level of
hydrometeors

85 GHz
Parallax

37-GHz Parallax

Ice Crystals

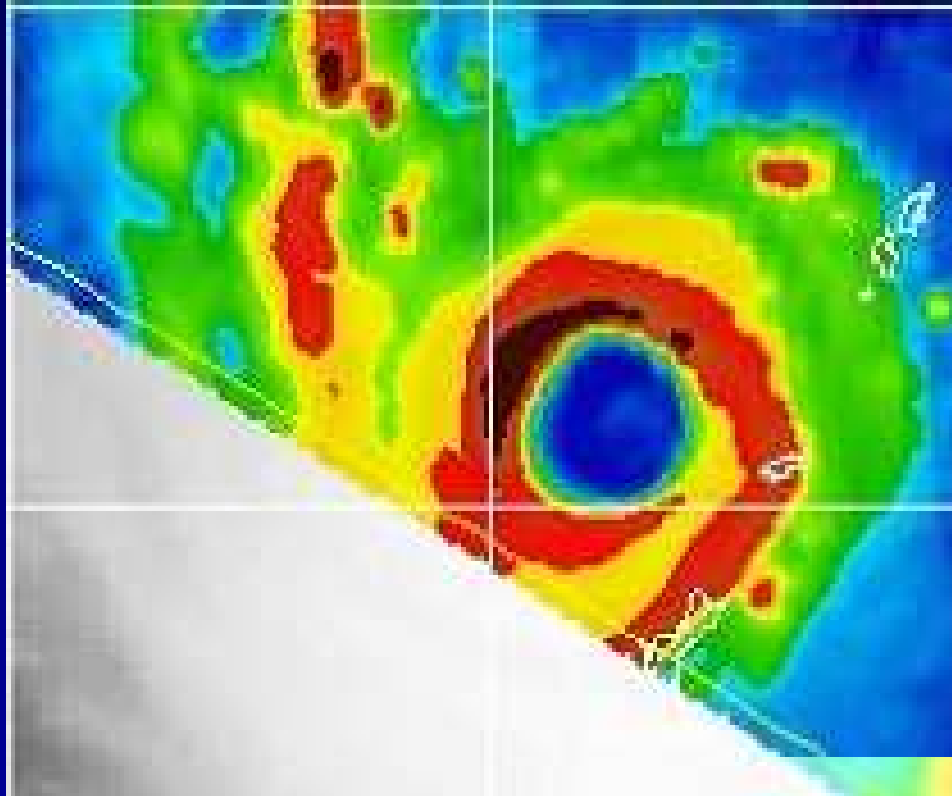
Raindrops



Effective
Level of
hydrometeors

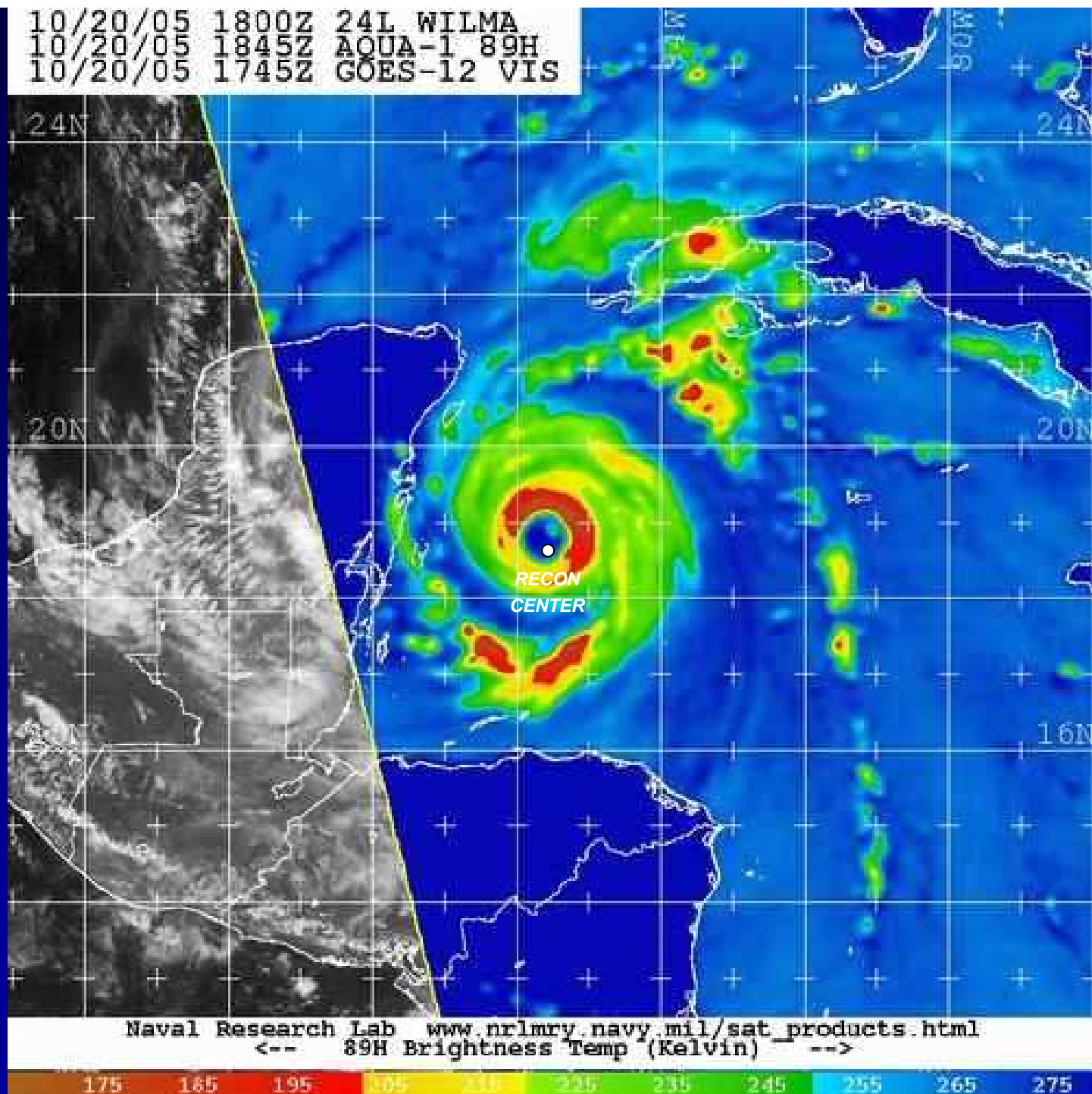
X Y
37 GHz
Parallax

Eye Size Example



85 N

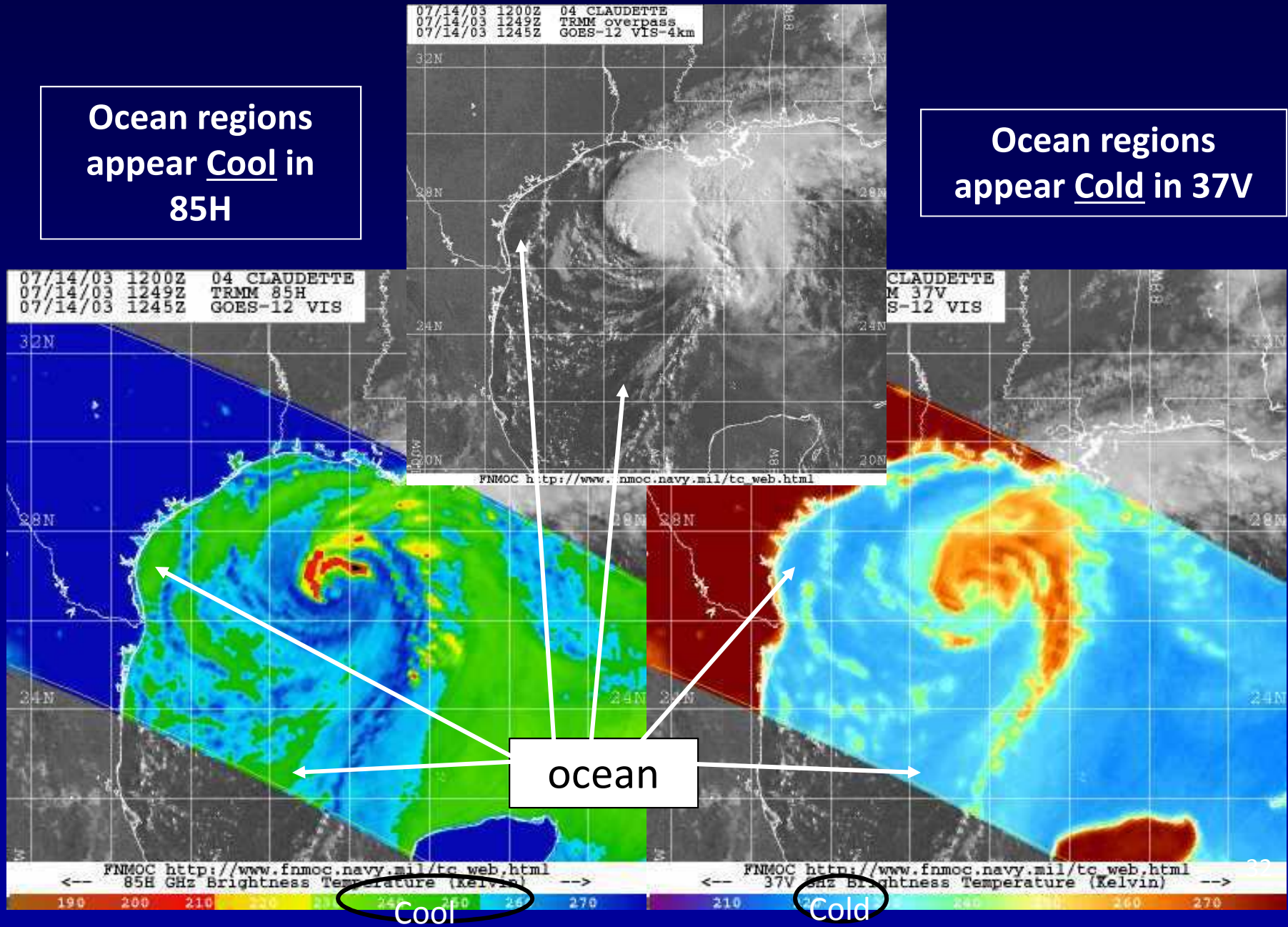
10/20/05 1800Z 24L WILMA
10/20/05 1845Z AQUA-1 89H
10/20/05 1745Z GOES-12 VIS



Single Frequency Interpretation

**Ocean regions
appear Cool in
85H**

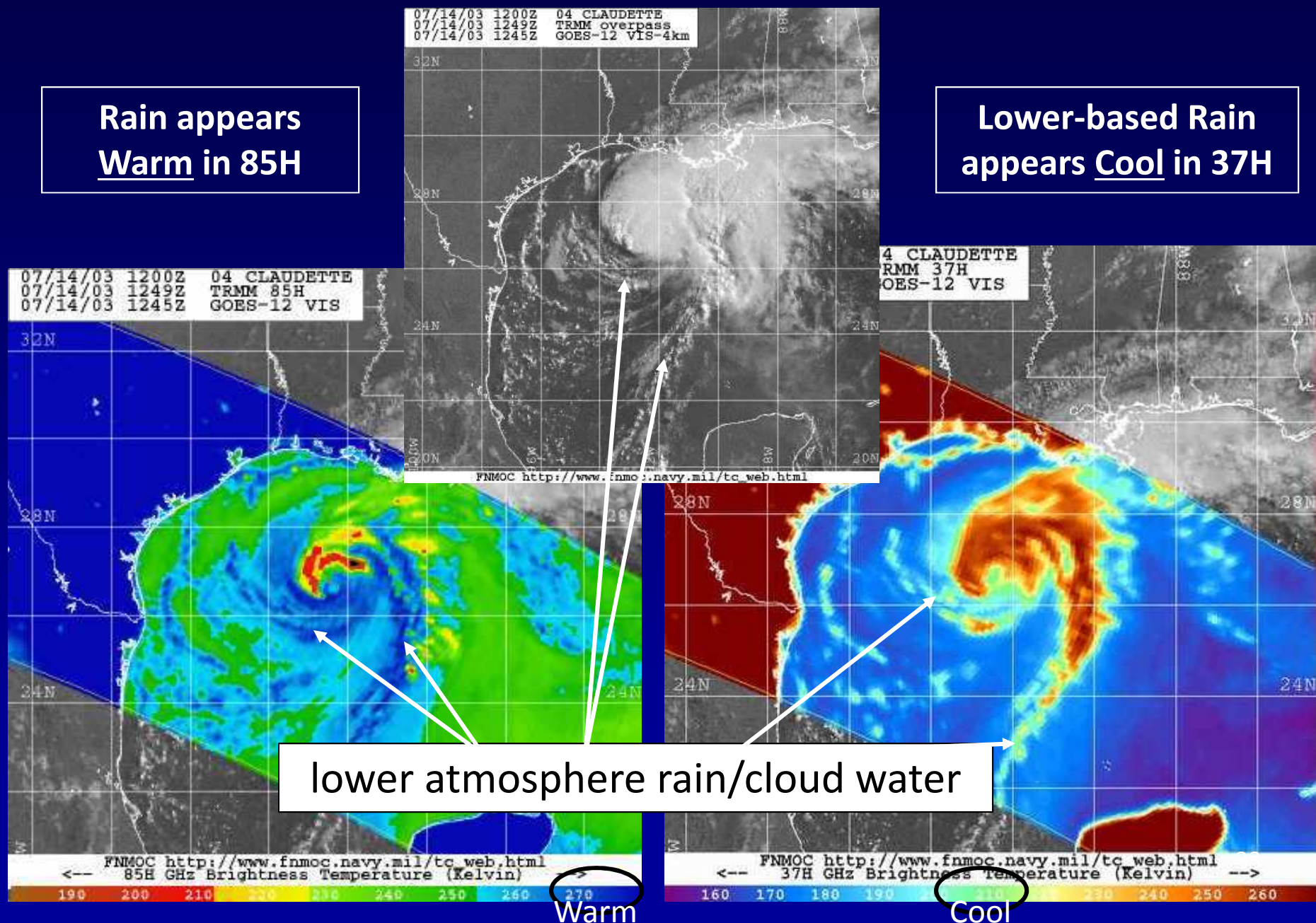
**Ocean regions
appear Cold in 37V**



Single Frequency Interpretation

Rain appears
Warm in 85H

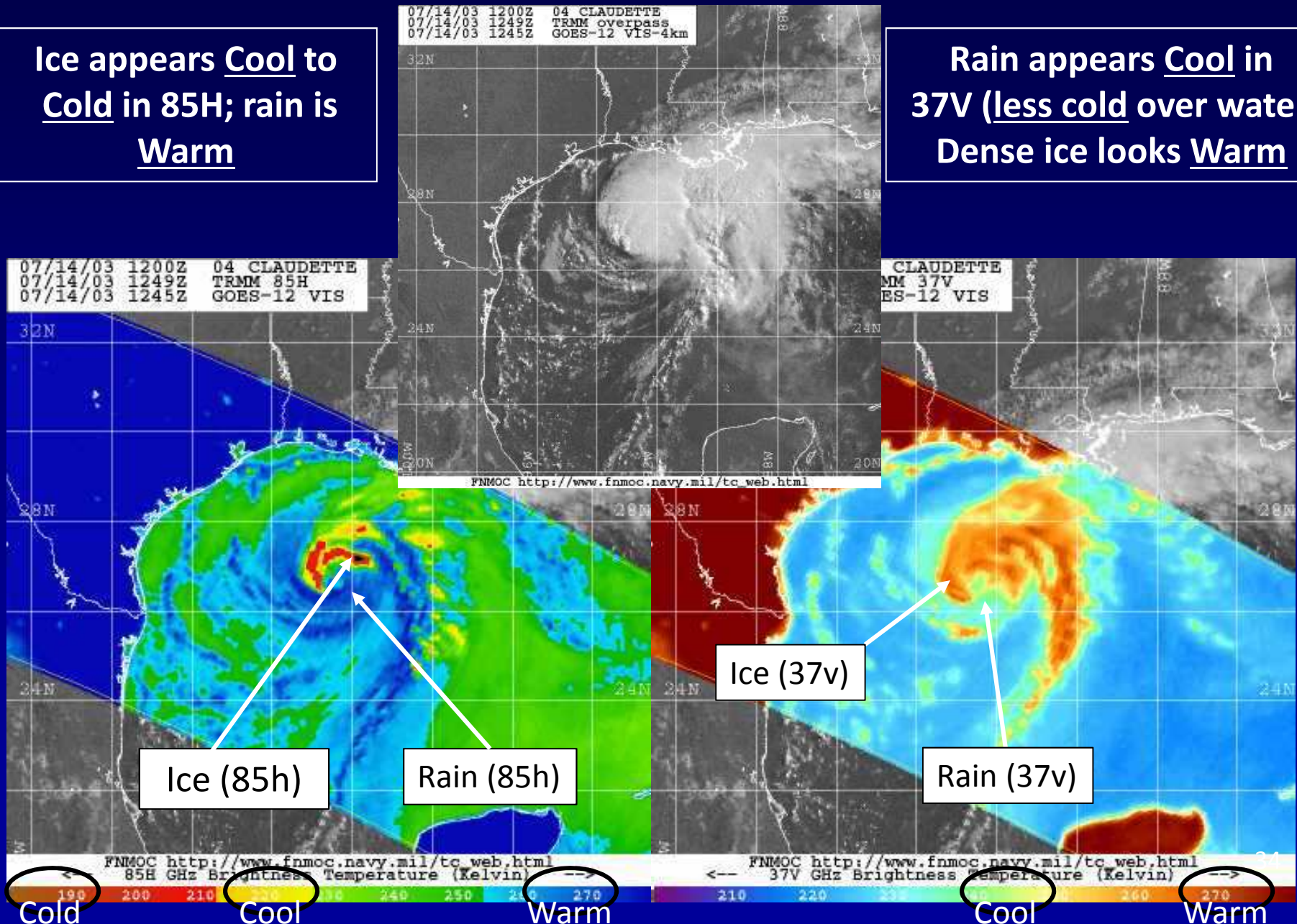
Lower-based Rain
appears Cool in 37H



Single Frequency Interpretation

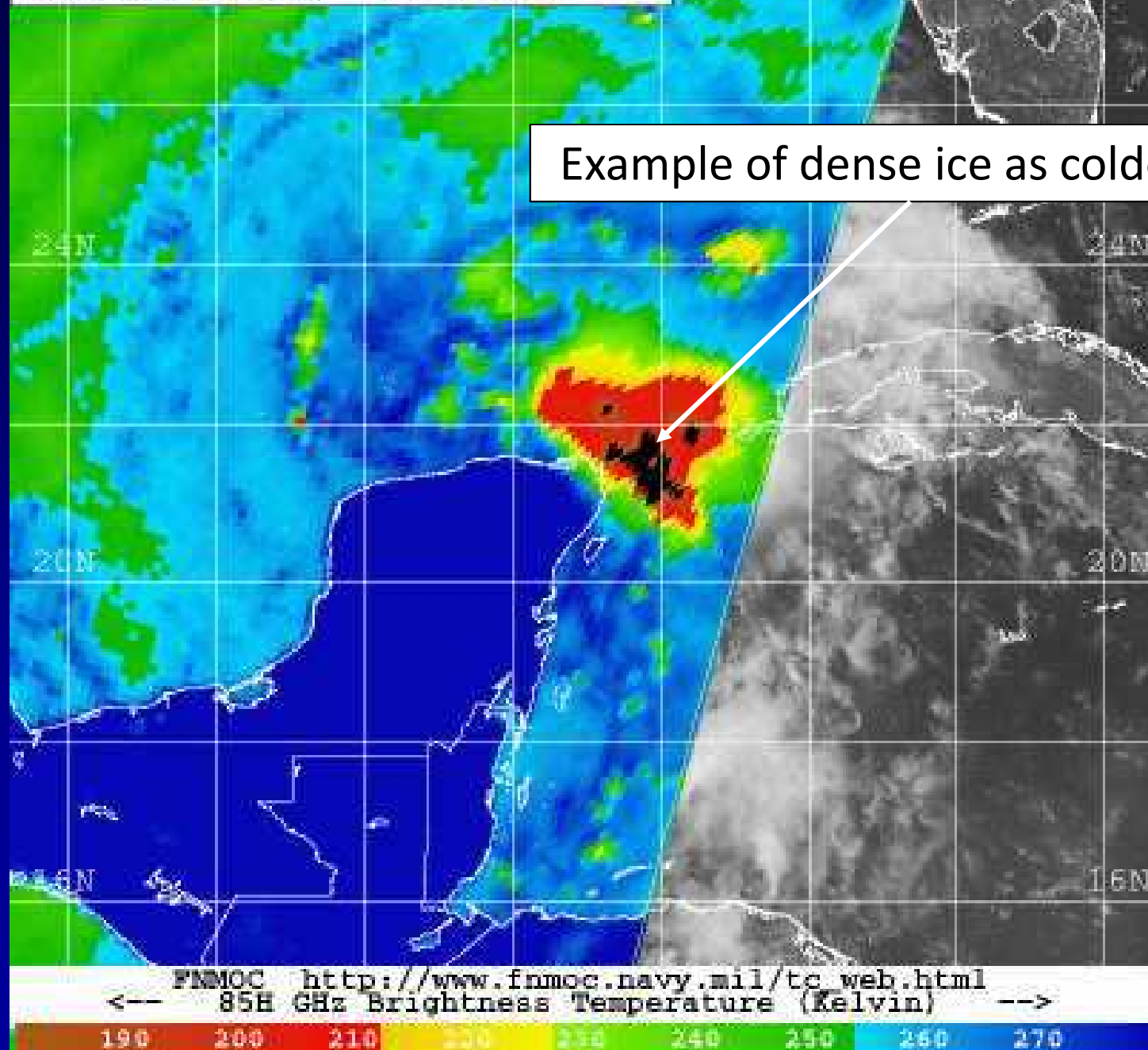
Ice appears Cool to
Cold in 85H; rain is
Warm

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



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

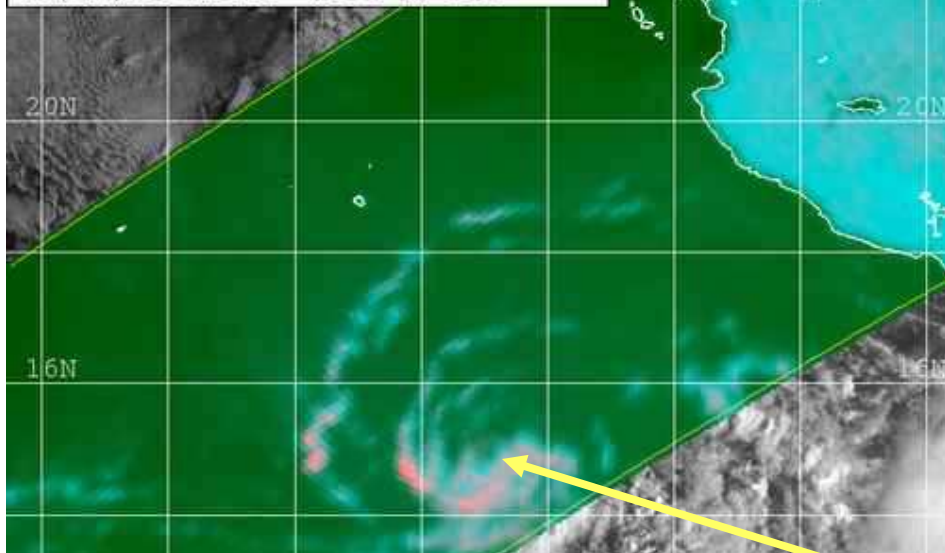
Example of dense ice as coldest T_b



Color Composite Imagery

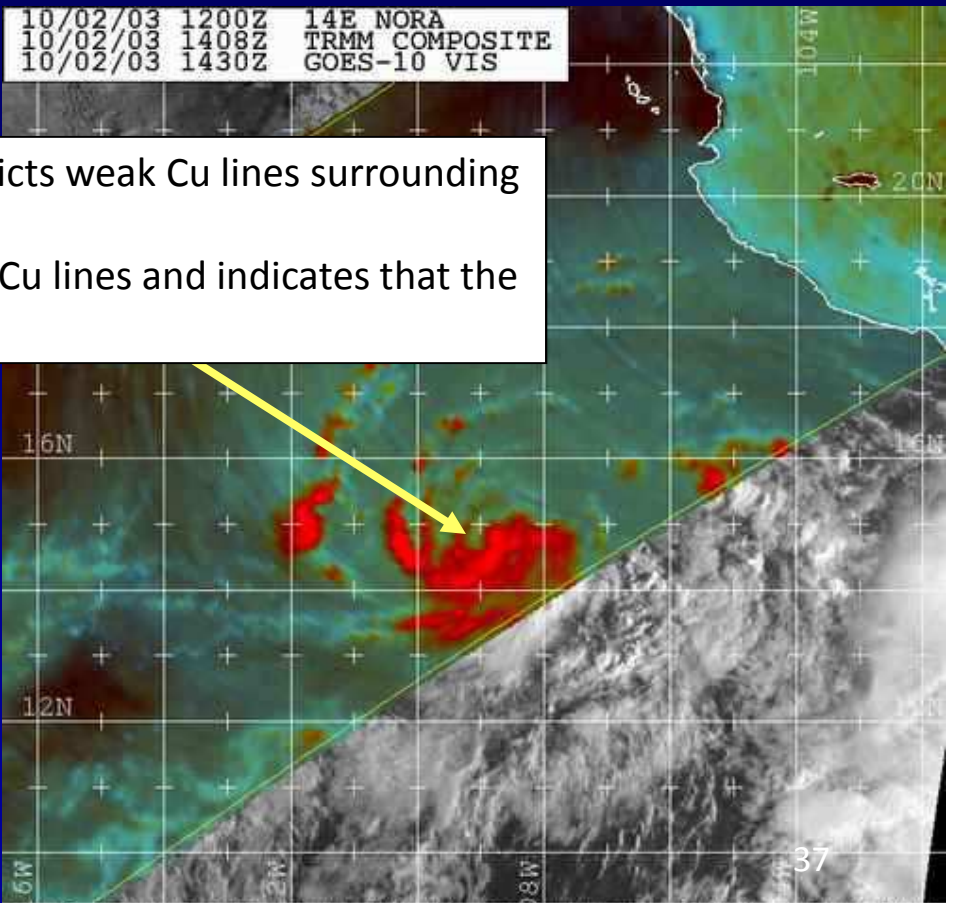
- Significant ambiguities (convection/sea surface, land features) exist when interpreting single frequency 85/37-GHz images
- Polarization Correction Temp (PCT) and color composite images correct T_b in regions of little or no clouds or rain (low emissions) to approximately the surface air temperature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

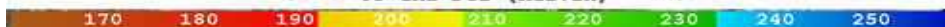


- 37-GHz PCT (37H/37V composite) depicts weak Cu lines surrounding the LLCC
- 85-GHz PCT fails to define the weaker Cu lines and indicates that the center may be further south

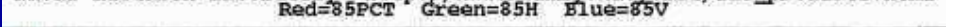
10/02/03 1200Z
10/02/03 1408Z
10/02/03 1430Z



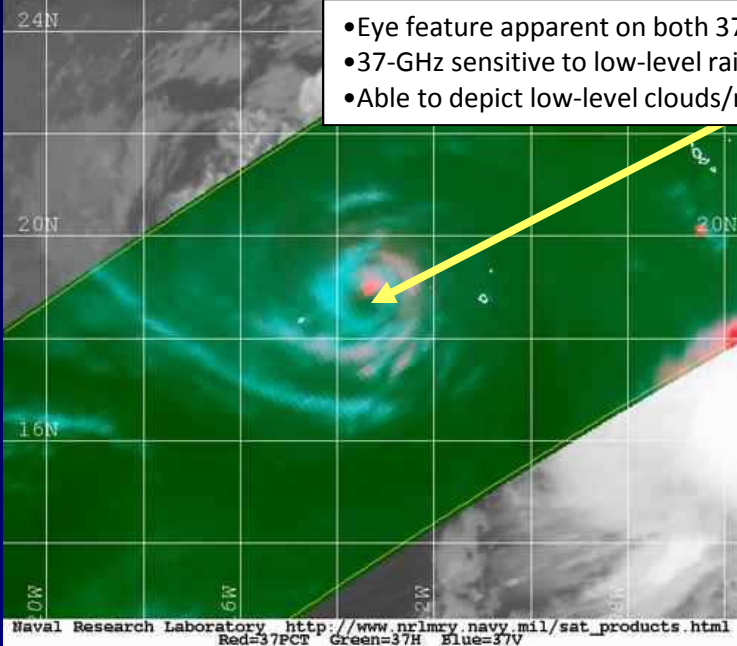
Naval Research Laboratory http://www.nrlmry.navy.mil/sat_products.html
85 GHz PCT (Kelvin)



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

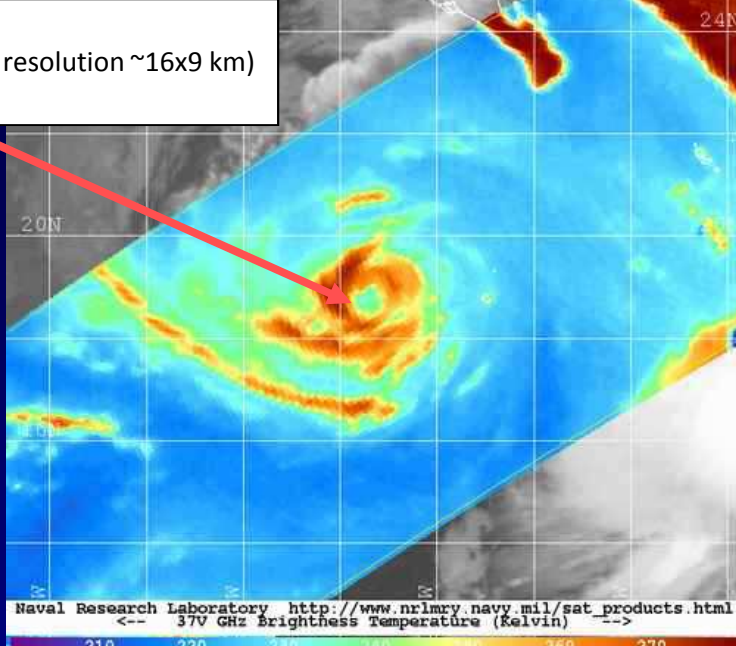


10/05/03 1200Z 14E NORA
10/05/03 1258Z TRMM COMPOSITE37
10/05/03 1230Z GOES-10 IR

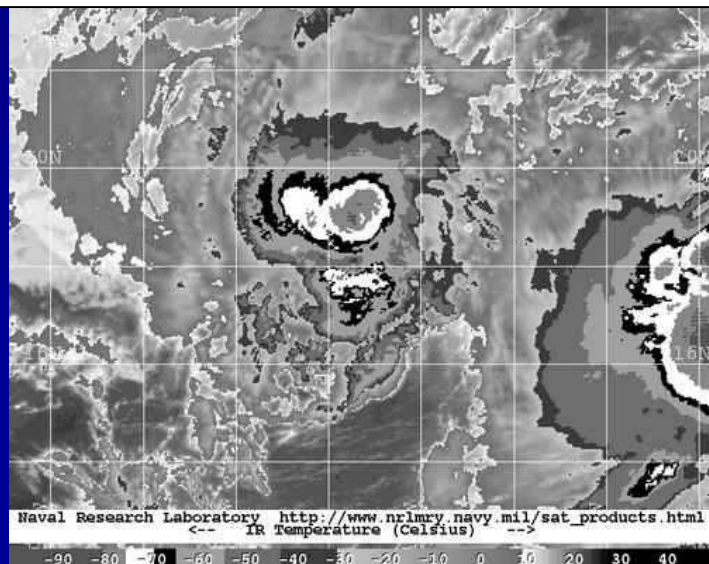


- Eye feature apparent on both 37-GHz images
- 37-GHz sensitive to low-level rain (high spatial resolution $\sim 16 \times 9$ km)
- Able to depict low-level clouds/rainbands

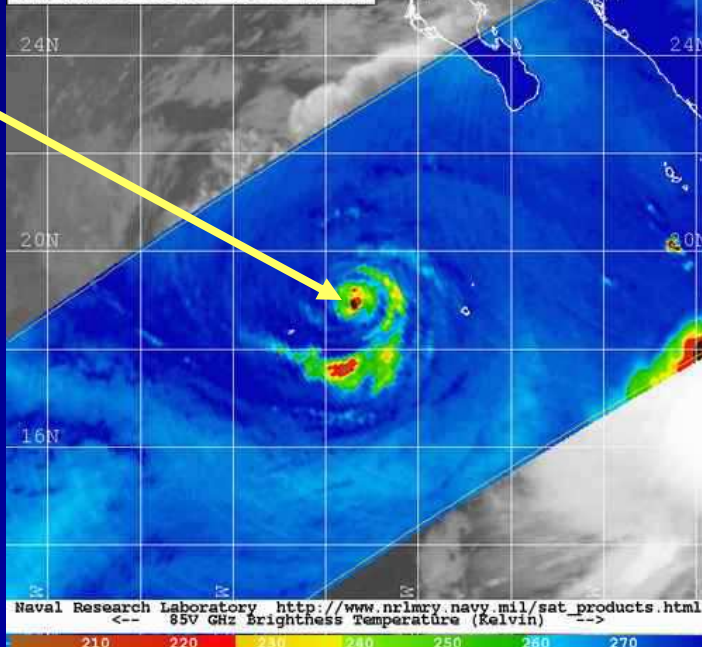
10/05/03 1200Z 14E NORA
10/05/03 1258Z TRMM 37V
10/05/03 1230Z GOES-10 IR

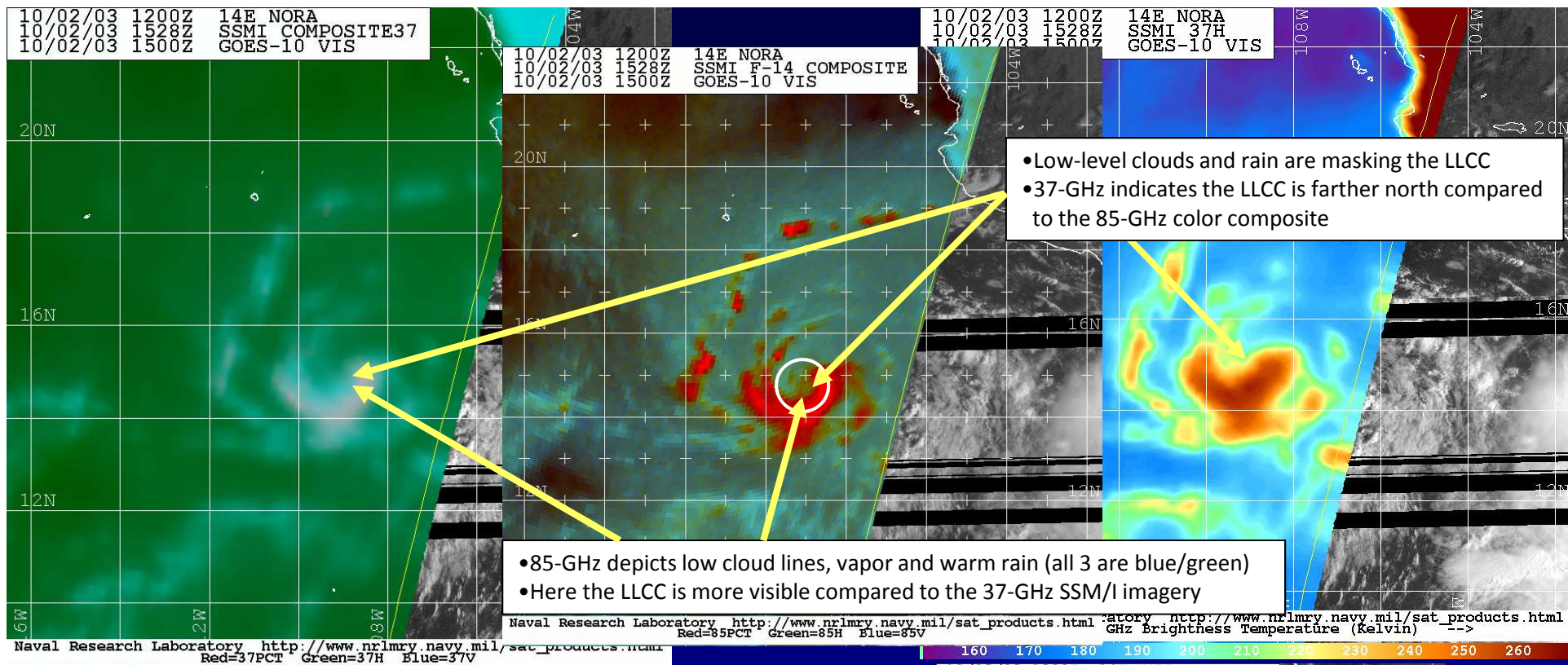


- Unable to detect eye in 85-GHz (CDO feature depicted instead)
- 85-GHz sensitive to large ice particles in deep convection
- Low-level clouds “wash out” beneath heavy rains

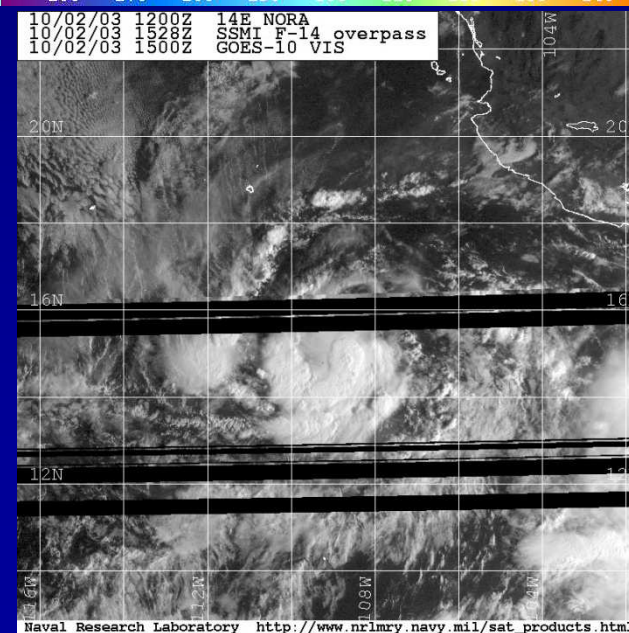


10/05/03 1200Z 14E NORA
10/05/03 1258Z TRMM 85V
10/05/03 1230Z GOES-10 IR

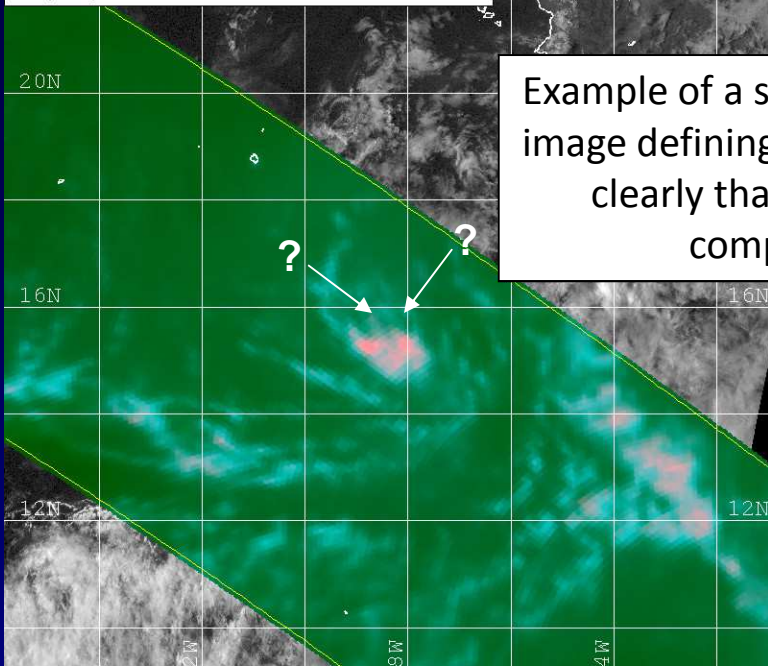




- 85-GHz color composite helps verify the possible solution seen on the 37-GHz color composite
- 37-GHz SSM/I and SSMIS spatial resolution is coarser (37x28 km) than the 37-GHz TRMM
- As a result, during relatively weak stages of a TC, SSM/I and SSMIS 37GHz H/V are difficult stand-alone images to interpret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



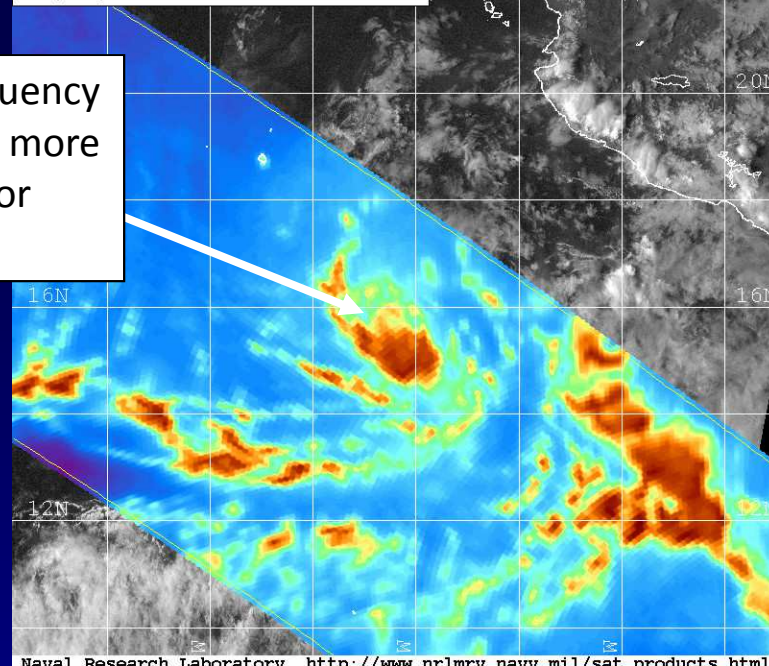
10/02/03 0000Z 14E NONAME
10/01/03 2316Z TRMM COMPOSITE37
10/01/03 2300Z GOES-10 VIS



Naval Research Laboratory http://www.nrlmry.navy.mil/sat_products.html
Red=37PCT Green=37H Blue=37V

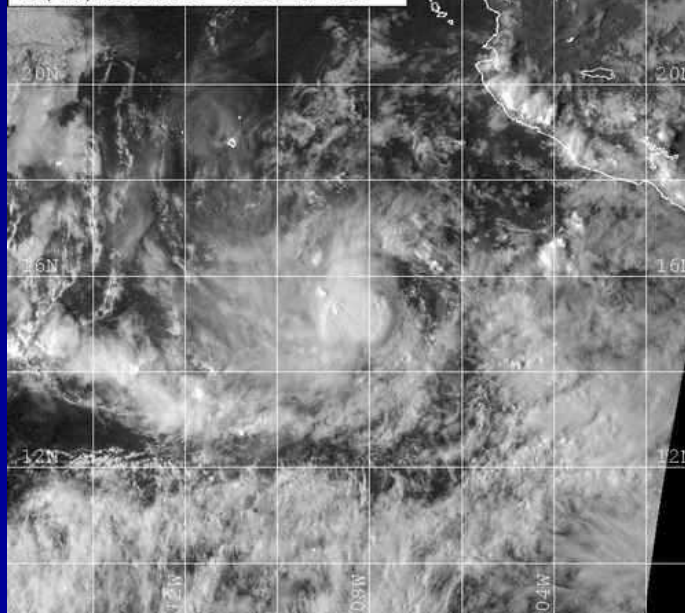
Example of a single frequency
image defining the LLCC more
clearly than the color
composite

10/02/03 0000Z 14E NONAME
10/01/03 2316Z TRMM 37H
10/01/03 2300Z GOES-10 VIS



Naval Research Laboratory http://www.nrlmry.navy.mil/sat_products.html
-- 37H GHz Brightness Temperature (Kelvin) --

10/01/03 2316Z TRMM overpass
10/01/03 2300Z GOES-10 VIS

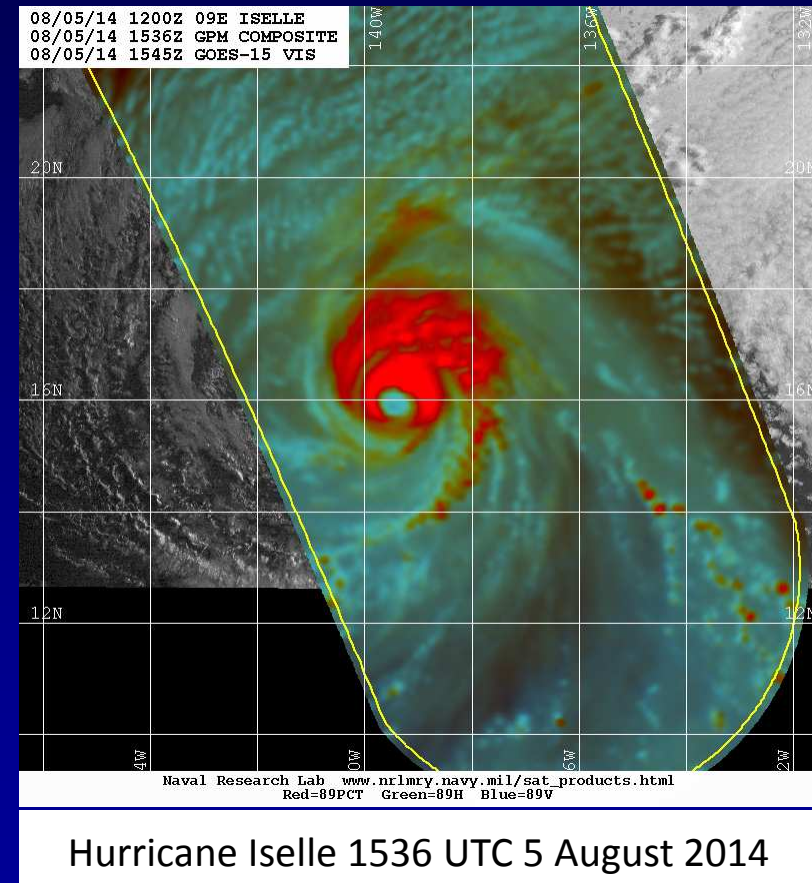


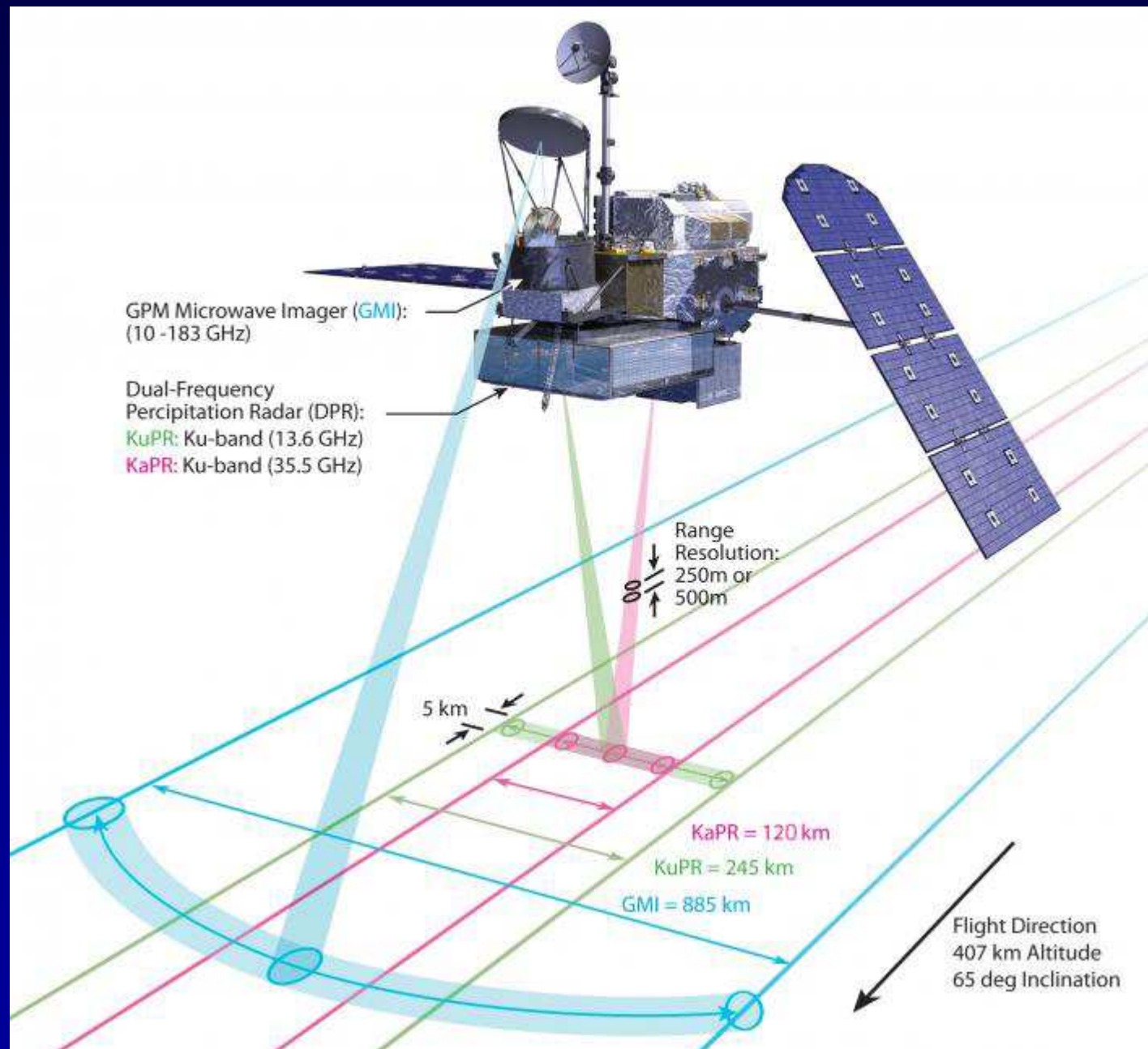
Naval Research Laboratory http://www.nrlmry.navy.mil/sat_products.html

Spaceborne Radars

GPM – Global Precipitation Measurement Mission

- Follow-on to TRMM launched 27 February 2014
- Passive radiometer and dual frequency radar
- Radiometer has 885-km wide swath with 13 channels
 - ~ 6-km resolution footprint at 89 GHz
- Higher-inclination orbit (65°) than TRMM, so less low latitude coverage





GPM Data Swaths – Courtesy NASA

Access to Online Microwave Imagery

NRL Tropical Cyclone Webpage

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

Privacy Policy Disclaimer **NRL Tropical Cyclone Page** Development Team

2016 Season Storms
[All](#) [Active](#) [Year](#)

Atlantic
 East Pacific
 Central Pacific
 West Pacific
 Indian Ocean
 Southern Hem.

[13S.URIAH](#)
[11P.WINSTON](#)

Latest [Pass_Mosaic](#) [Text](#) [Track](#) [ATCF](#) [Track+Image](#) [WindVectors](#)

Environment [TPW](#) [TPW+NAVGEOM_TPW](#) [TPW+NAVGEOM_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
SSM/I	39														
SSMIS	57														
GMI	50														
AMSR2	97														
WINDSAT	71														
AMSUB	97														

GAC:
 GEO:
 MODIS:
 VIIRS:
 OLS:

11P.WINSTON, TRACK_VIS, 19 FEB 2016 1752Z 18:32:18 UTC (Z)
 Forecast and Graphic by: Naval Maritime Forecast Center/Joint Typhoon Warning Center

Overview [Tutorials: COMET](#)

Latest ATCF Track: smsh112016.16021906.jpg

Latest ir/geo/1km_bw/20160219.1752

(Click product for full sized image)

Satellite Pass Info				
Sensor	Latest	Next (View All)		
SSM/I	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		

Sat_Home [East_Pacific+WestCoast](#) [Global](#) [CONUS](#) [ModelOver](#) [RainRate](#) [CloudTops](#)

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 TCPage Ver: 4.55.14 (11/19/2013)
 Approved for public release by: Superintendent
 Sat Section Head
 Webmaster

NRL TC Page

Archive data
available
(click "year")

Active TCs or
Invest
areas

Forecast Track
from RSMC, if
available

Satellite Pass
Information

Privacy Policy Disclaimer **NRL Tropical Cyclone Page** Development Team

2016 Season Storms
All Active Year

Atlantic
East Pacific
Central Pacific
West Pacific
Indian Ocean
Southern Hemisphere

13S.URIAH
11P.WINSTON

Latest Pass_Mosaic Text Track ATCF Track+Image WindVectors
Environment TPW TPW+NAVDEM_TPW TPW+NAVDEM_850_Winds Wind_Shear COAMPS_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
SSM/I	38														
SSM/IS	57														
GMI	50														
AMSR2	97														
WINDSAT	71														
AMSUB	97														

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

Tutorials: COMET

11P.WINSTON, TRACK_VIS, 19 FEB 2016 1752Z 18:32:18 UTC (Z)

Forecast and Graphic by: Naval Maritime Forecast Center/Joint Typhoon Warning Center

Latest ATCF Track: smsh112016.16021906.jpg

Latest ir/geo/lkm_bw/20160219.1752

(Click product for full sized image)

Satellite Pass Info				
Sensor	Latest	Next (View All)		
SSM/I	02/19 1450 Z, F-15 0941	02/19 1520 Z, F16	0775	
TC_SSM/IS	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	

Sat_Home East_Pacific+WestCoast Global CONUS ModelOver RainRate CloudTops
Training TropCyclones
NexSat VIIRS ColorComposite SSMI-Comp2 Tropics CloudWinds ScatWinds CloudClass

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[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														

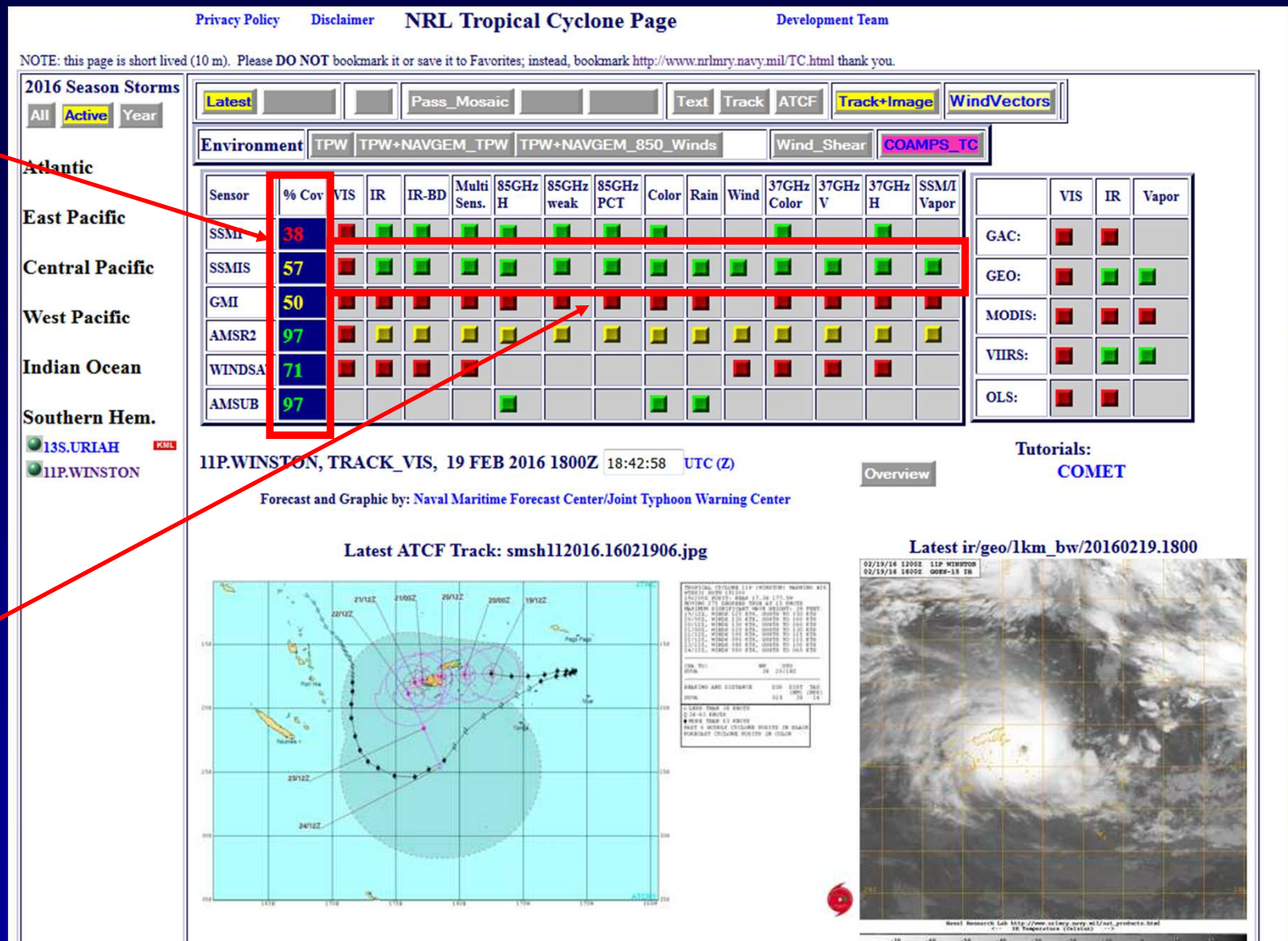
Index of: /SATPRODUCTS/TC/tc15/ATL/11LJOAQUIN/gmi/color/2degreeticks

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[20151012.1506.gpm.x.colorpet_89h_89v.11LJOAQUIN.30kts-999mb-426N-120W.58pc.jpg \(224445\)](#)
[20151012.0001.gpm.x.colorpet_89h_89v.11LJOAQUIN.30kts-999mb-426N-120W.49pc.jpg \(227834\)](#)
[20151010.2321.gpm.x.colorpet_89h_89v.11LJOAQUIN.30kts-998mb-426N-129W.34pc.jpg \(228699\)](#)
[20151010.1516.gpm.x.colorpet_89h_89v.11LJOAQUIN.35kts-992mb-431N-140W.57pc.jpg \(286763\)](#)
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[20151006.0516.gpm.x.colorpet_89h_89v.11LJOAQUIN.75kts-970mb-364N-634W.51pc.jpg \(381709\)](#)
[20151004.2026.gpm.x.colorpet_89h_89v.11LJOAQUIN.75kts-964mb-346N-649W.58pc.jpg \(384604\)](#)
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[20151002.0711.gpm.x.colorpet_89h_89v.11LJOAQUIN.115kts-935mb-230N-747W.36pc.jpg \(408268\)](#)
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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](#)

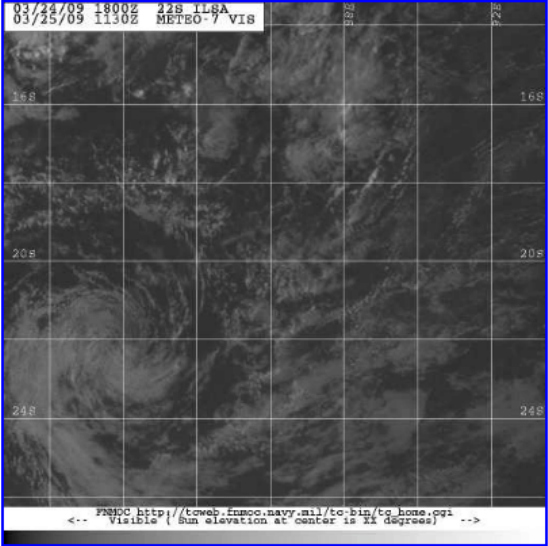
[SSMI](#) [SSMIS](#) [TRMM](#) [AMSU](#) [QuikScat](#) [AMSR](#) [WindSat](#) [MODIS](#) [VIS](#) [IR](#) [OLS](#)

[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).



03/24/09 1800Z 22S ILSA
03/25/09 1130Z METEO-7 VIS

168 168 208 208 248 248

FNMOC http://tcweb.fnmoc.navy.mil/tc-bin/tc_home.cgi
 <-- Visible (Sun elevation at center is 11 degrees) -->

Latest
SSMI: 03/25 0029Z 244
SSMIS: 03/25 0131Z 0
TMI: 03/25 0839Z 678
AMSU: 03/25 0729Z 0
QScat: 03/25 0014Z 570
WSat: 03/25 0038Z 0
AMSR: 03/25 0825Z 496
MODIS: 03/25 0400Z 0

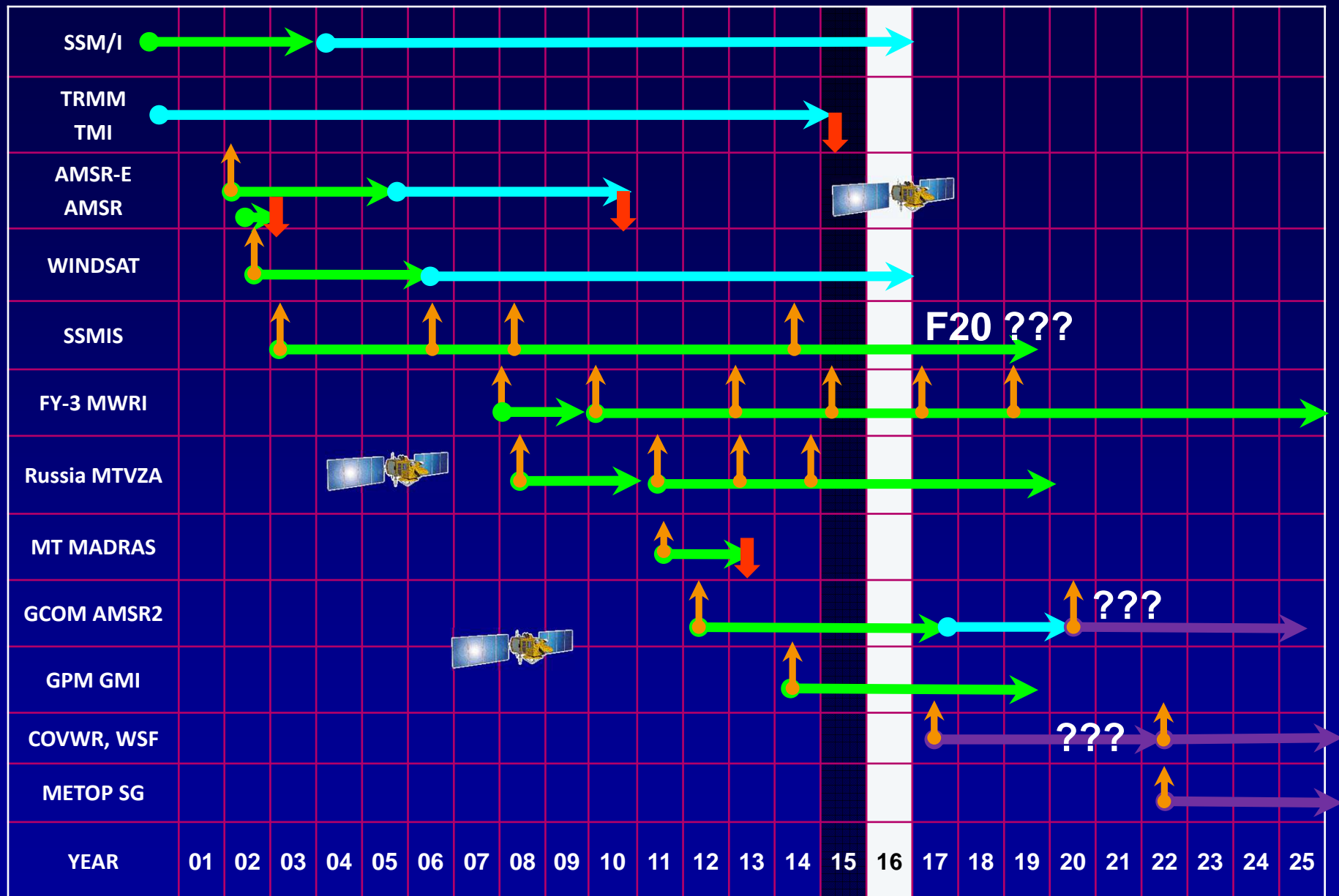
Upcoming Passes (more)
03/25 13:03 F-15 408
03/25 14:07 F-16 138
03/25 15:14 TRMM 76
03/25 11:28 N-15 273
03/26 12:34 QUIK 658
03/26 00:23 WSAT 672
03/25 19:22 AQUA 562
03/26 04:42 TERRA 223

Navy FNMOC TC Webpage

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

Passive Microwave Imager Missions (Courtesy NRL)

Feb 2016



•Launches ↑

•Primary Mission →

•Extended Mission →

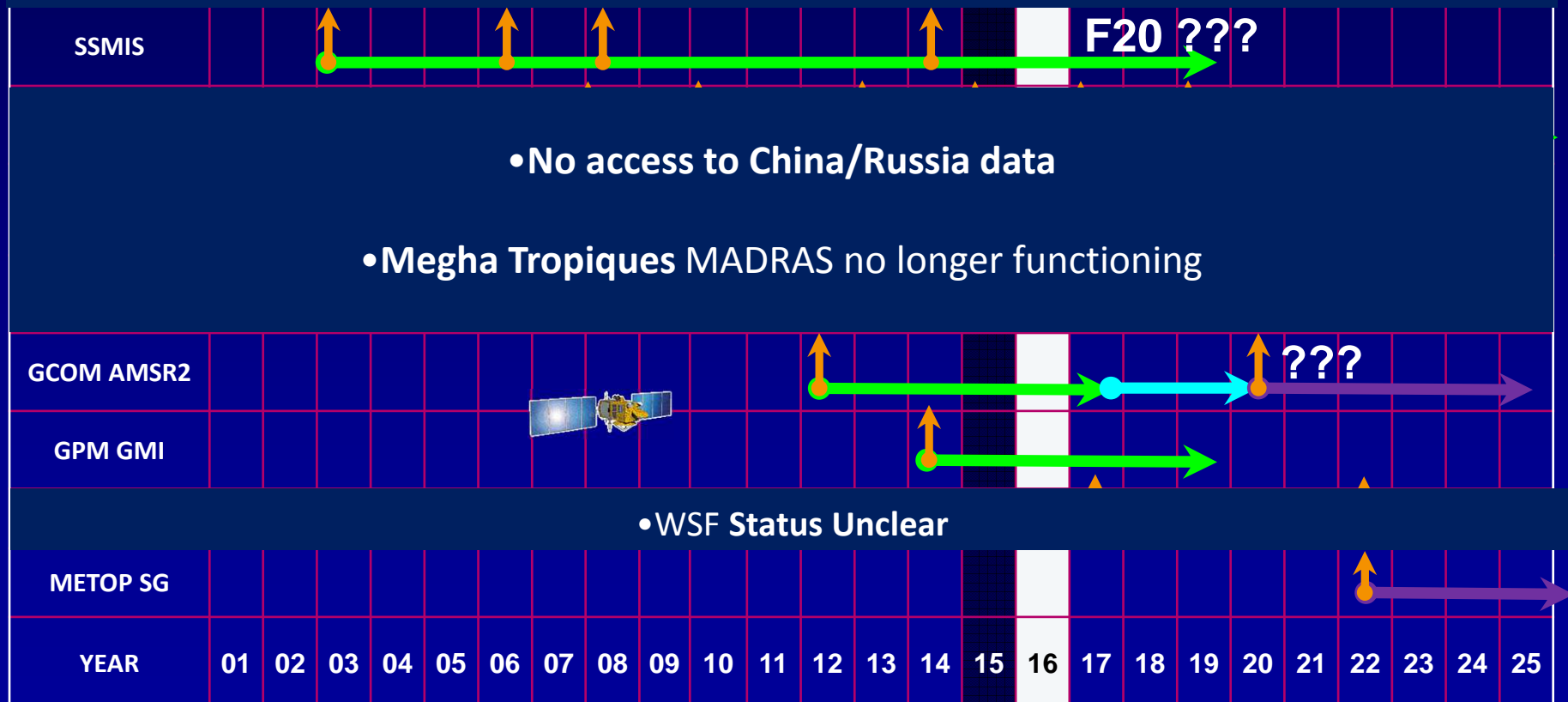
•Future Mission →

•Failures ↓

Passive Microwave Imager Missions (Courtesy NRL)

Feb 2016

- What's left in a few years after
- old R&D satellites fail



- No access to China/Russia data

- Megha Tropiques MADRAS no longer functioning

- WSF Status Unclear

•Launches ↑

•Primary Mission →

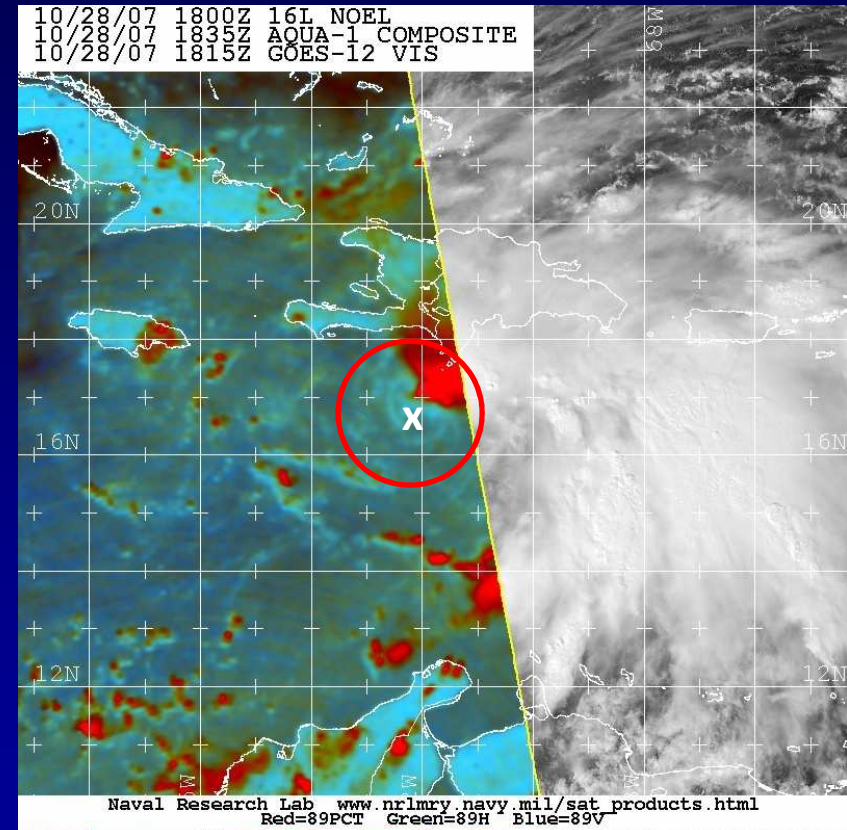
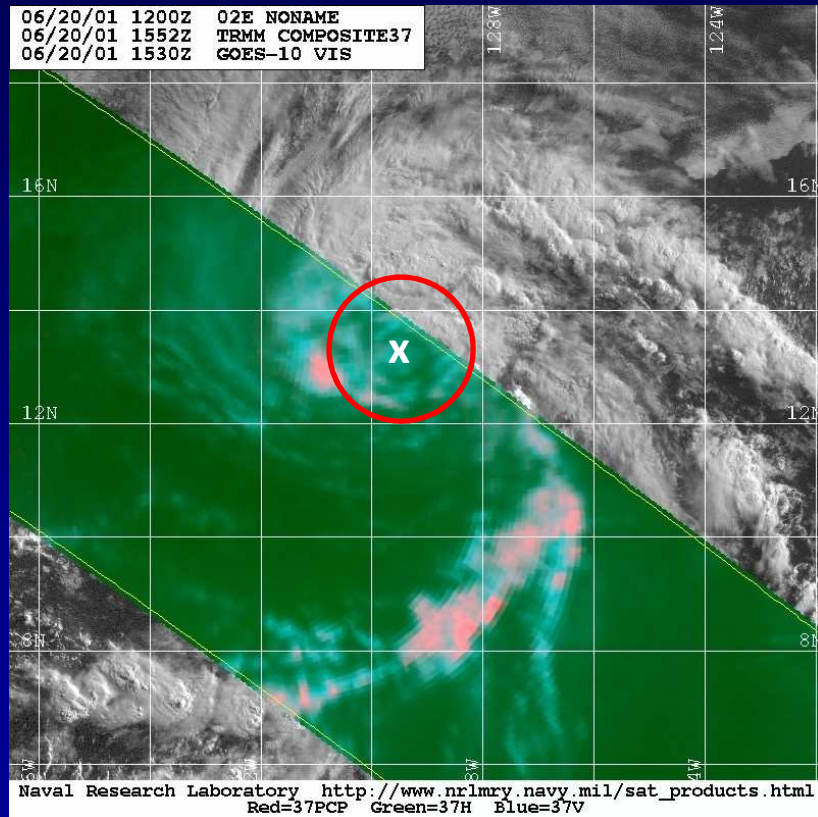
•Extended Mission →

•Future Mission →

•Failures ↓

Tropical Cyclone Positioning Using Passive Microwave Data

Positioning in Microwave Imagery

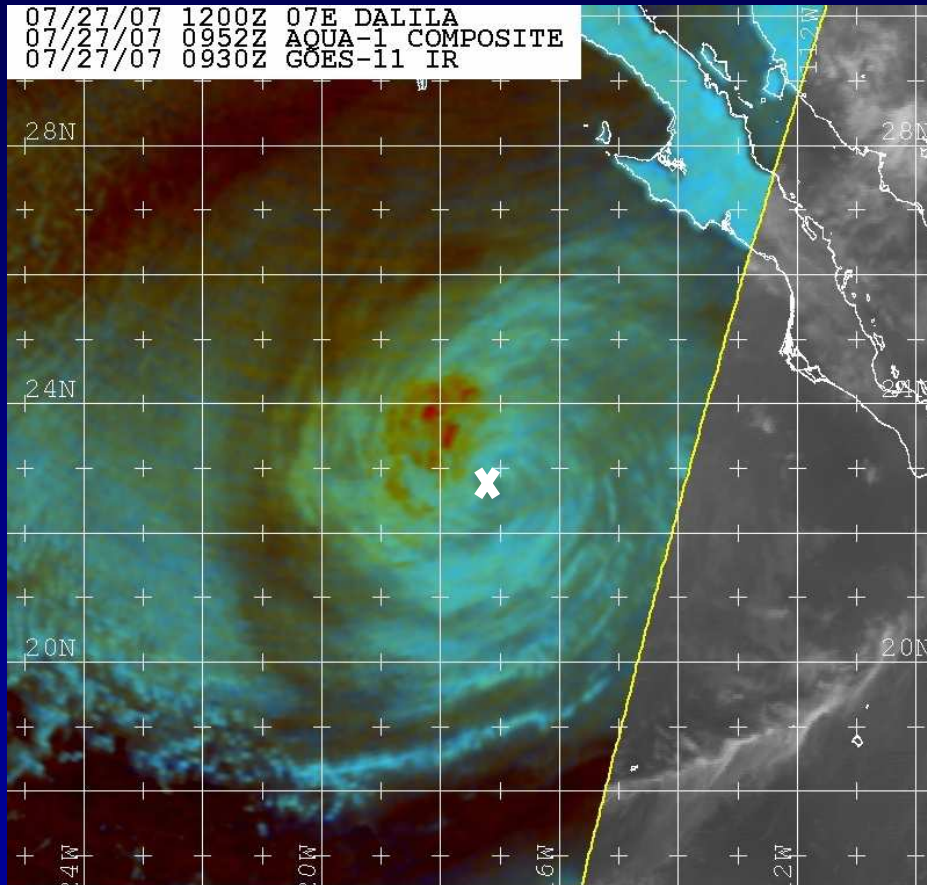


Try to position in the rain-free dry area—out of the convection

Positioning in Microwave Imagery

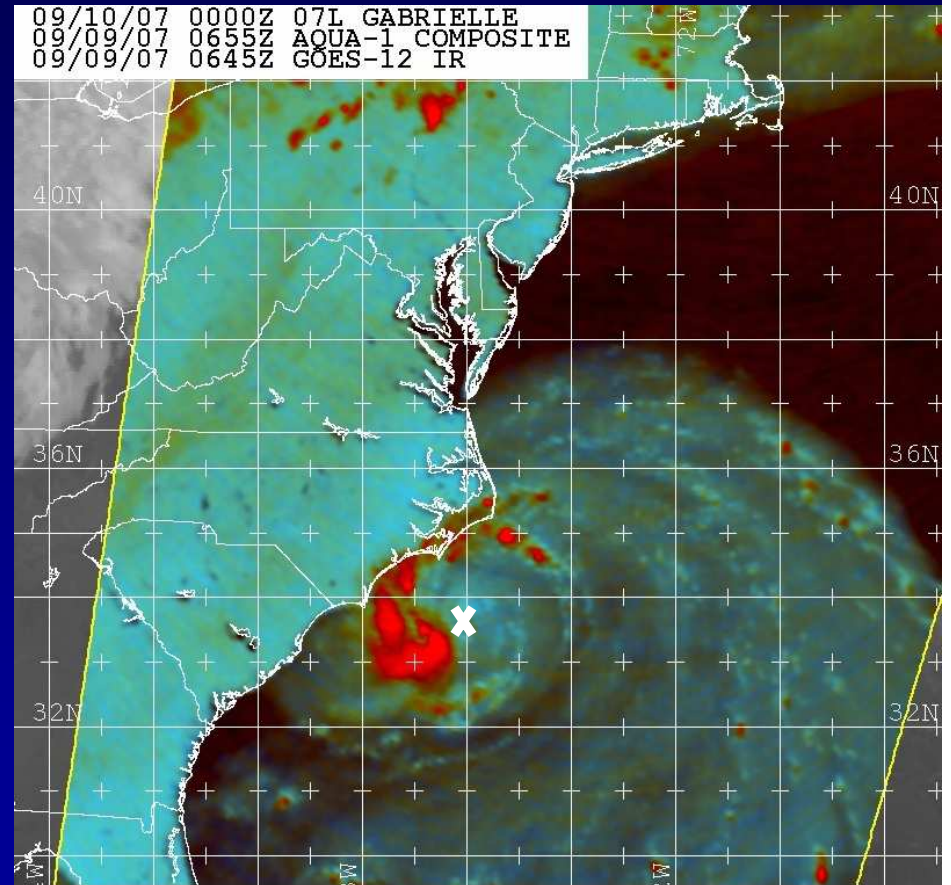
Look for convective free darker areas

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



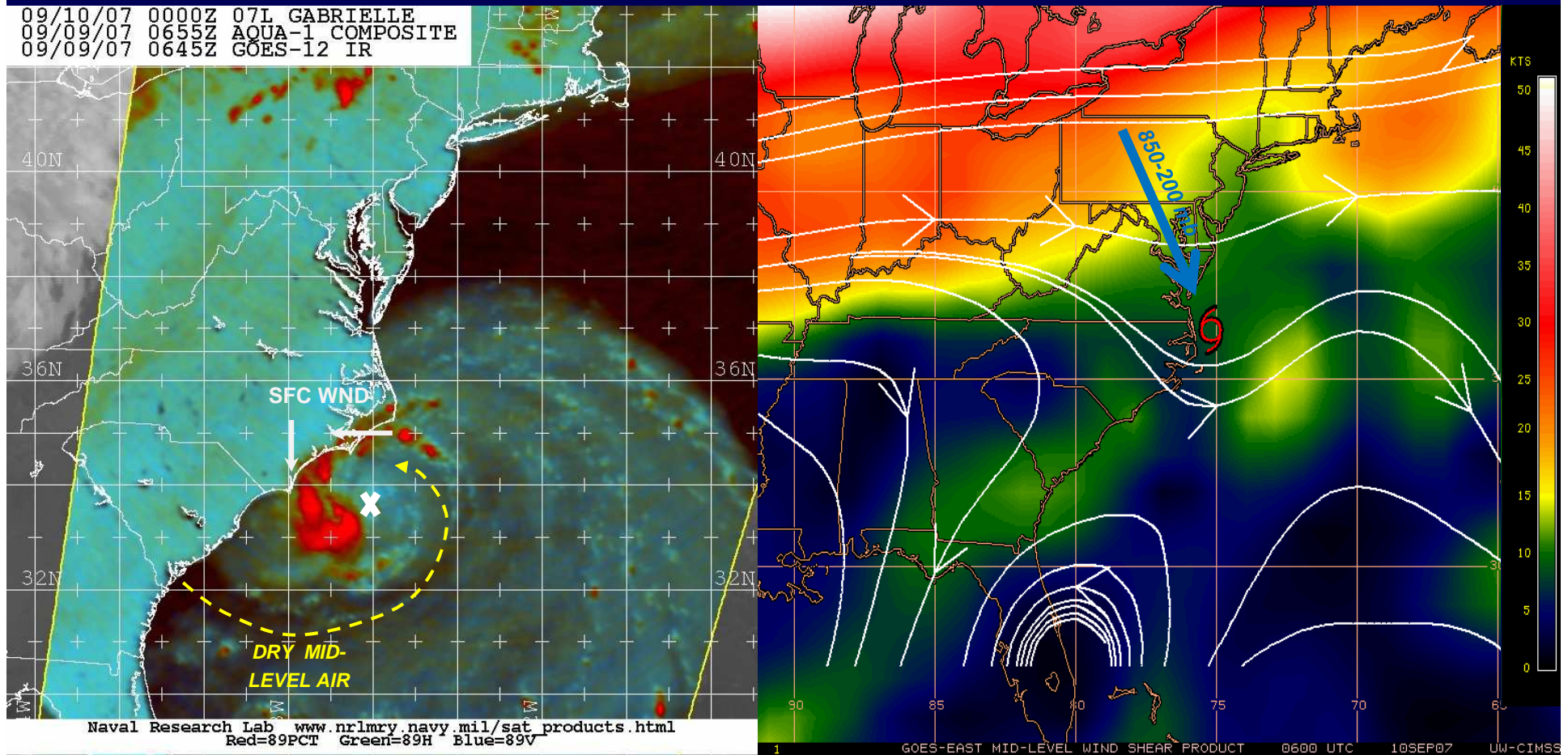
Naval Research Lab www.nrlmry.navy.mil/sat_products.html
Red=89PCT Green=89H Blue=89V

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

Effect of Vertical Wind Shear on Center Positioning in Microwave Imagery

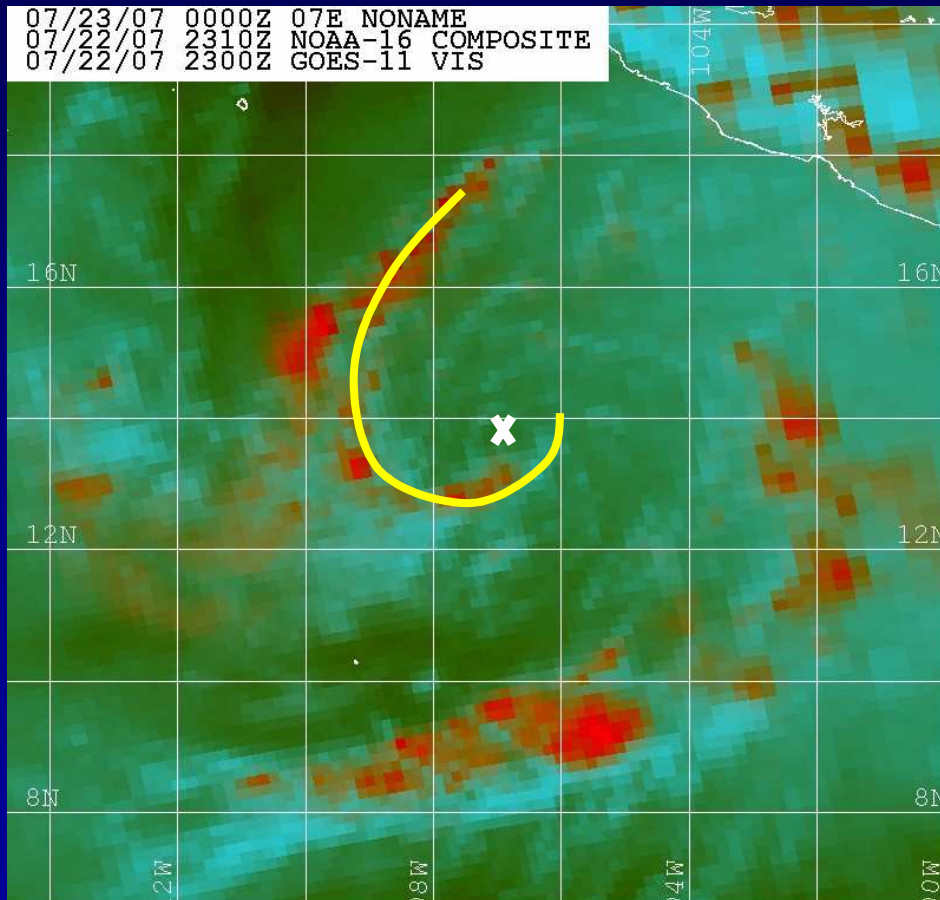


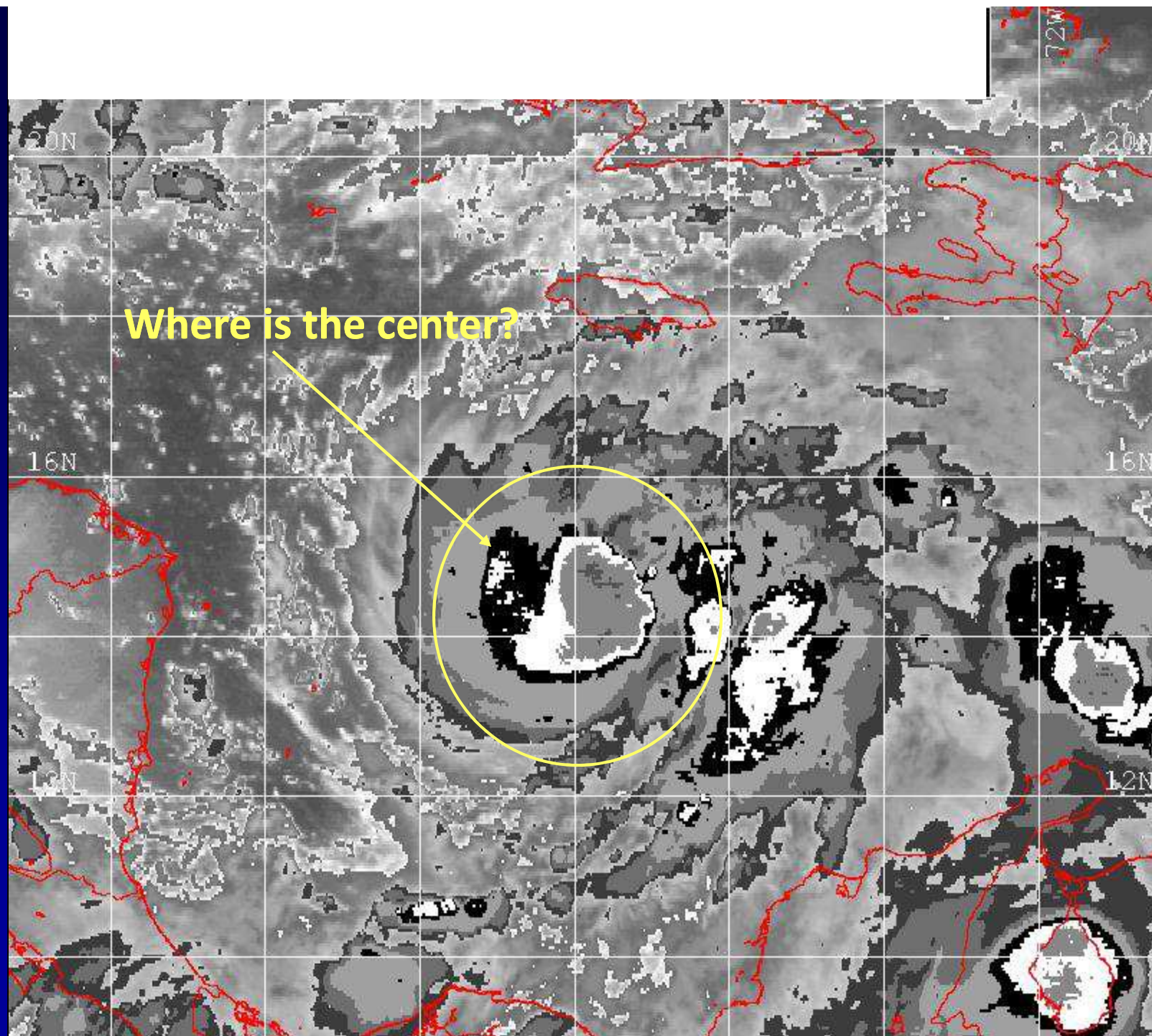
Anticipating the location of the LLCC based on vertical wind shear causing asymmetry in the deep convection pattern helps, **BUT** it can not always be used as an absolute as this case clearly indicates.

Positioning in Microwave Imagery

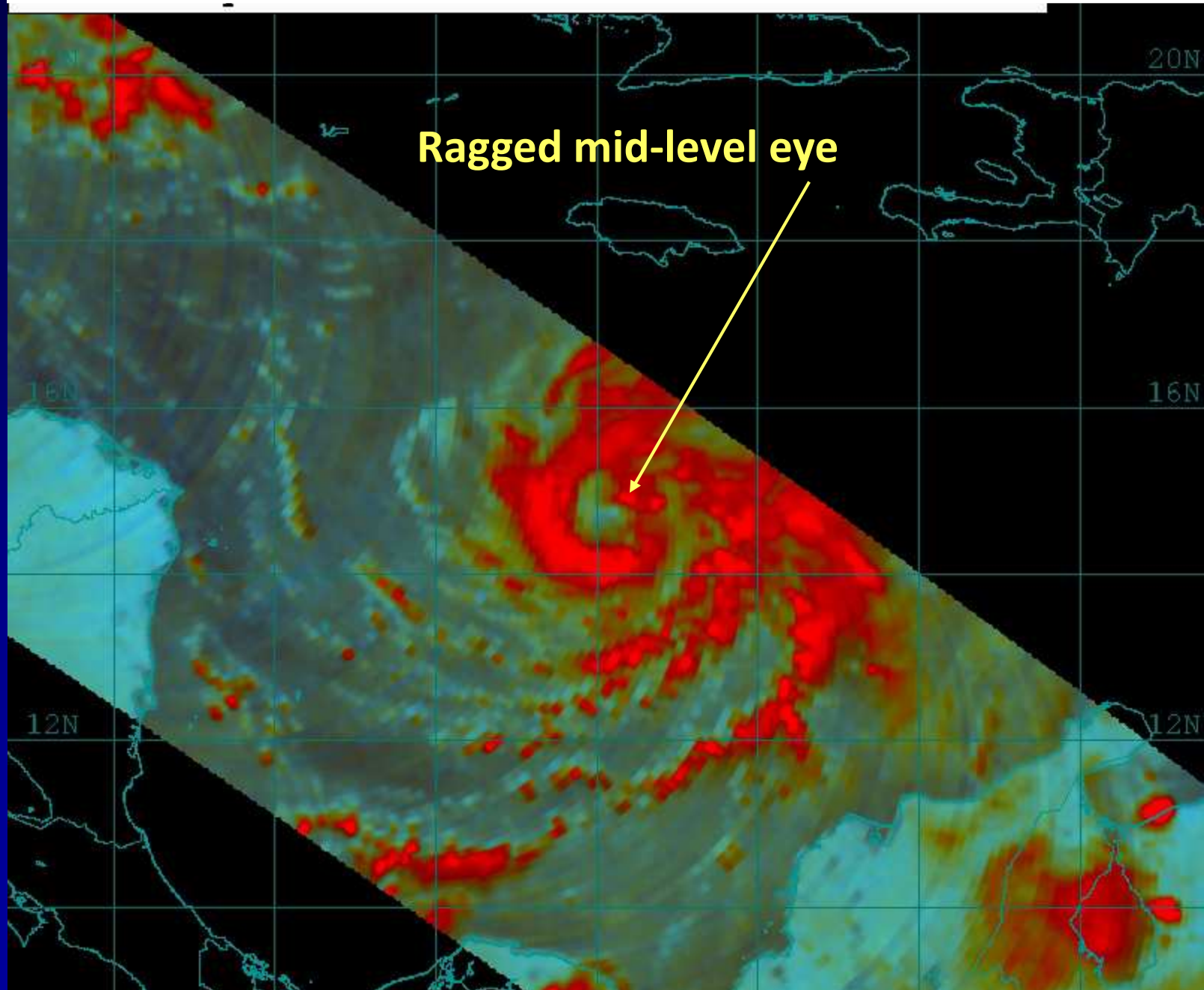
Look for low cloud curvature

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

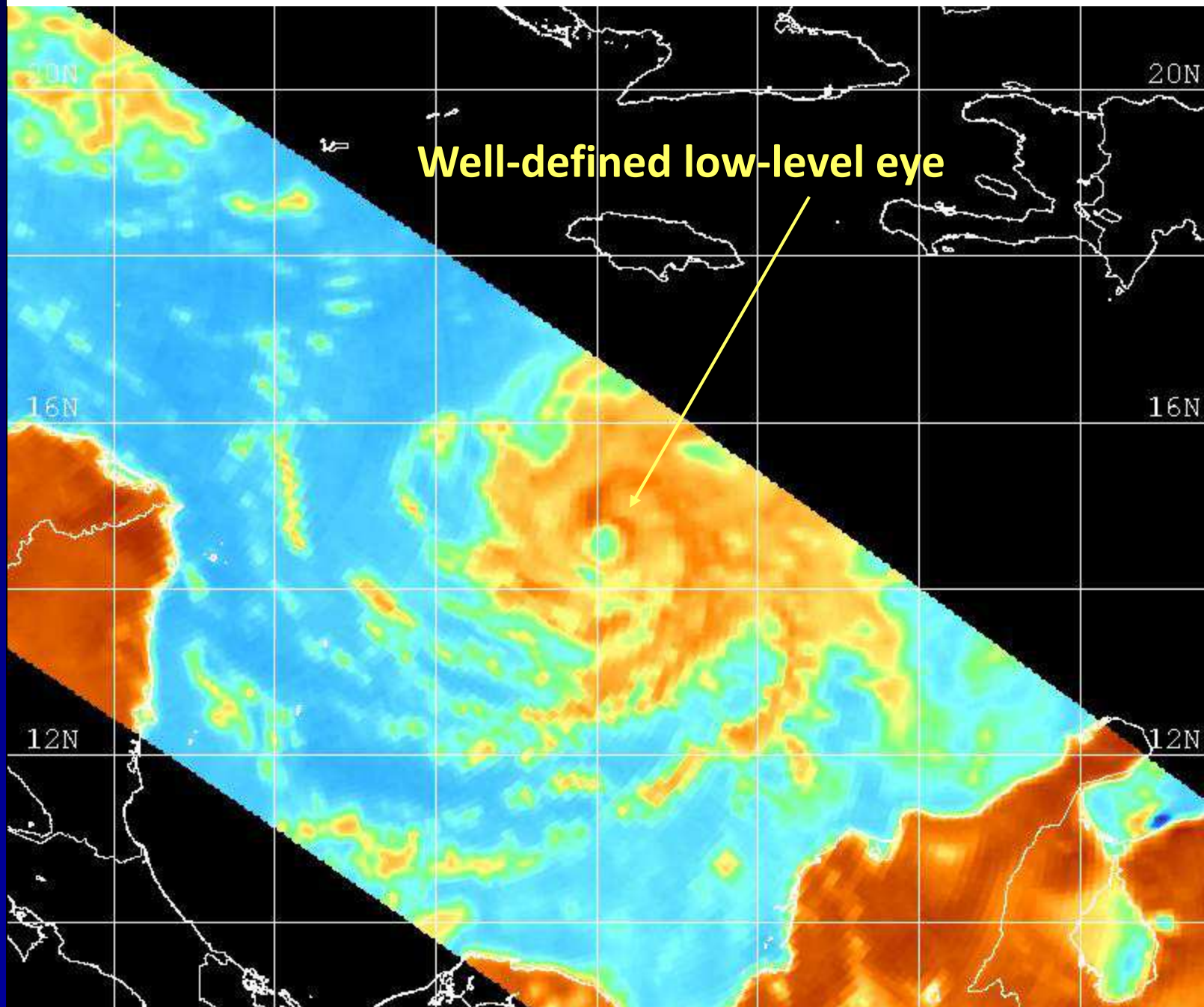




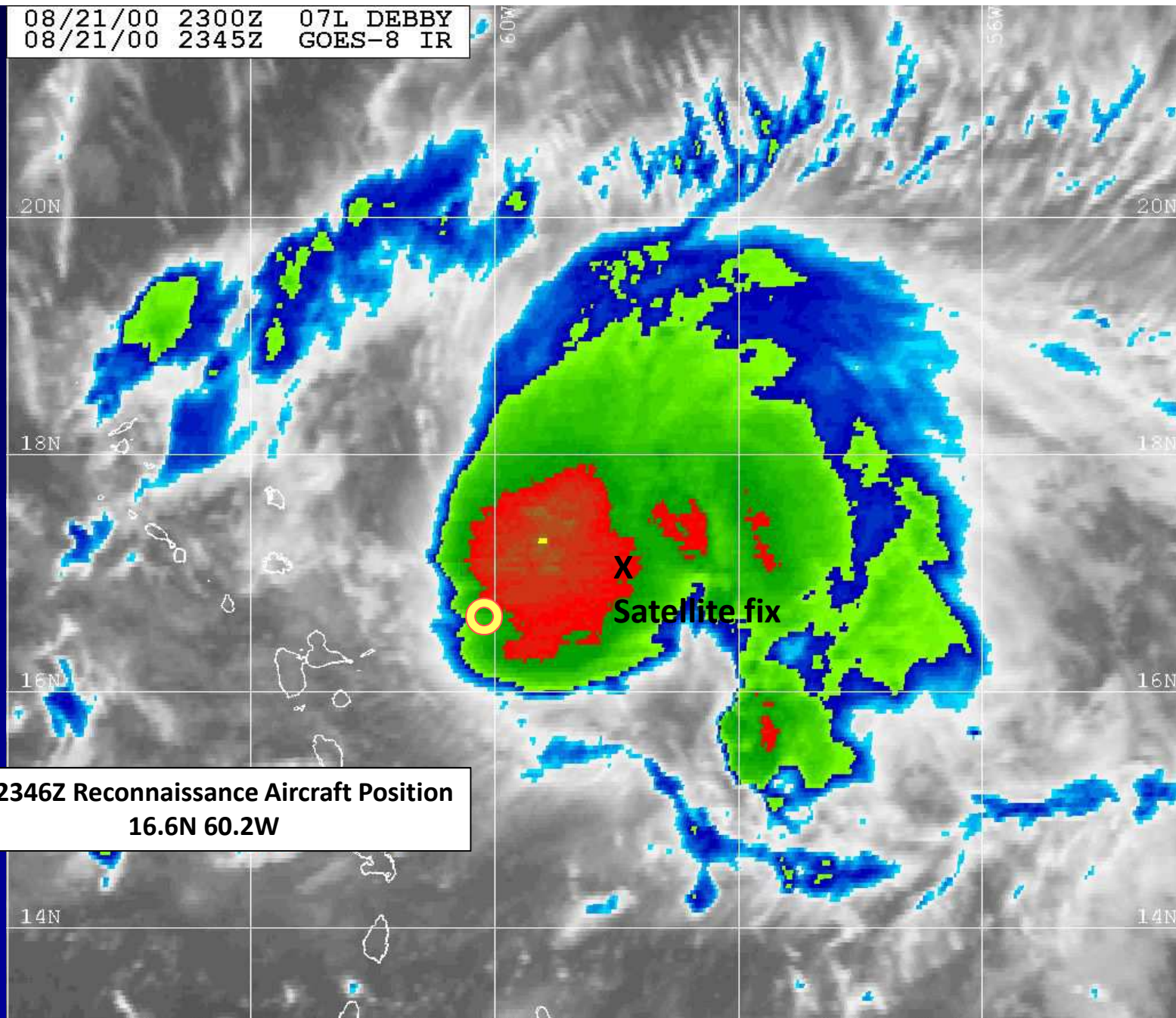
85 GHz Color-Composite Example



37 GHz Example



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

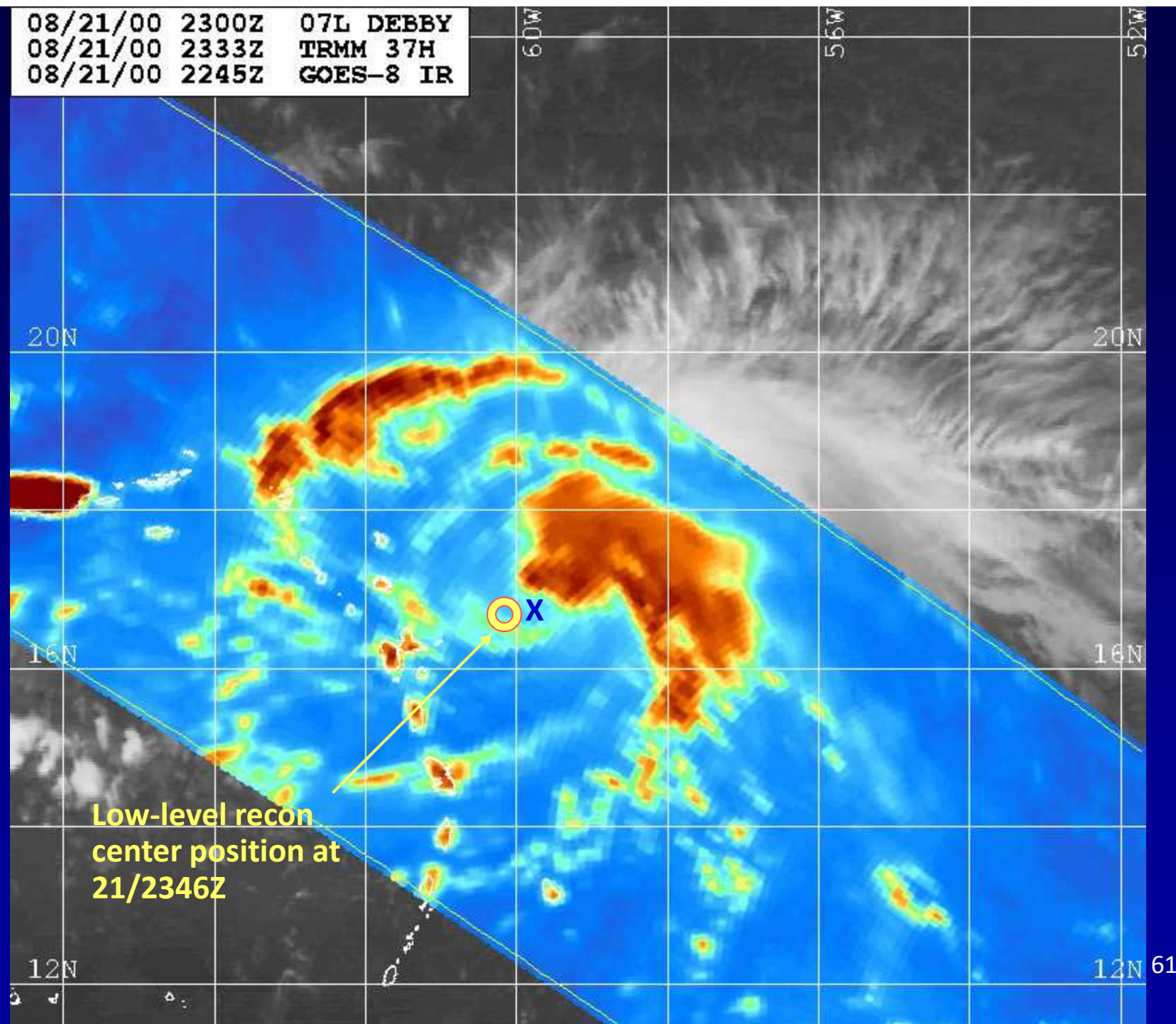


21/2346Z Reconnaissance Aircraft Position
16.6N 60.2W

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

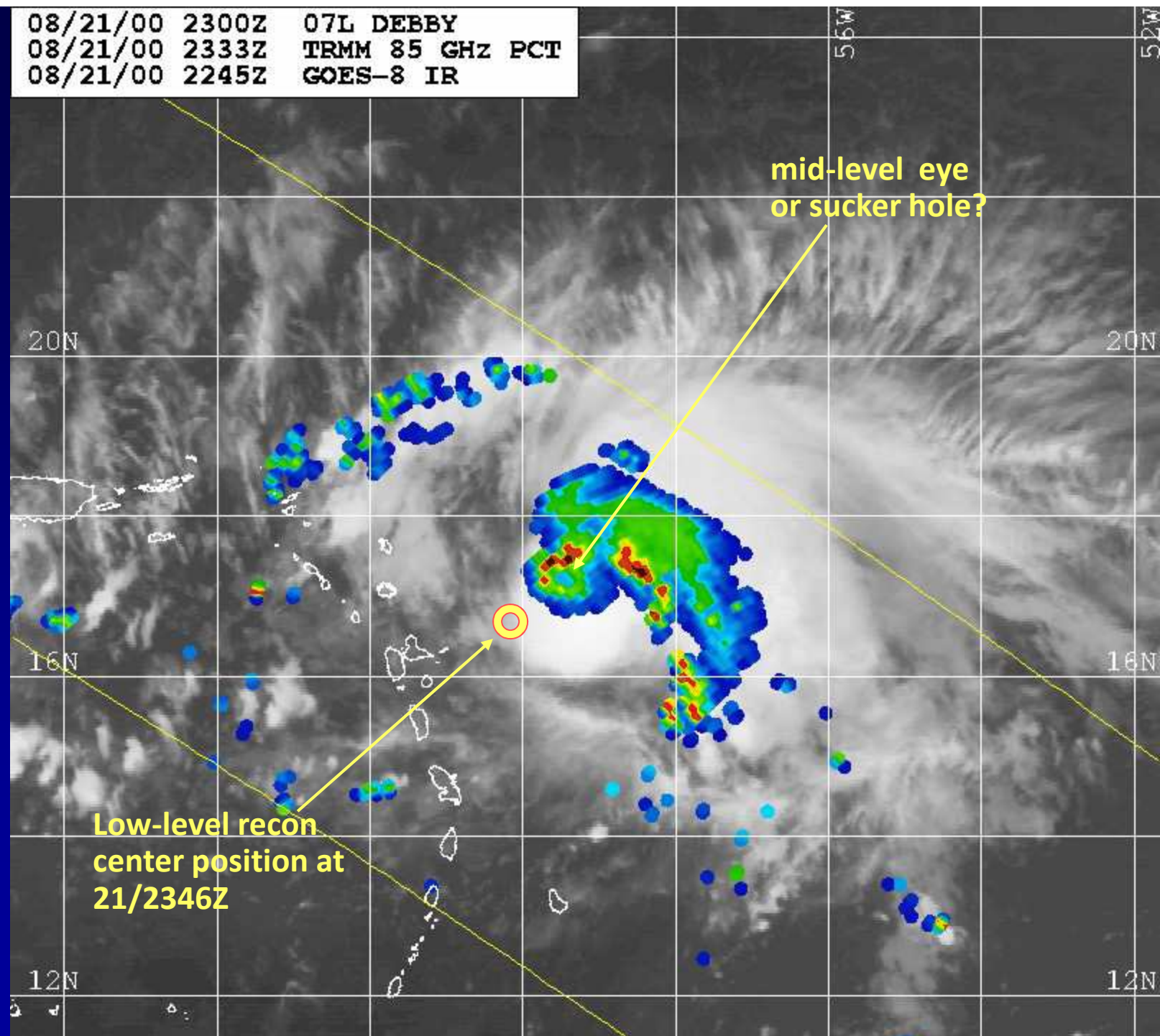
-80 -70 -60 -50 -40 -30 -20 -10 0 10 20

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

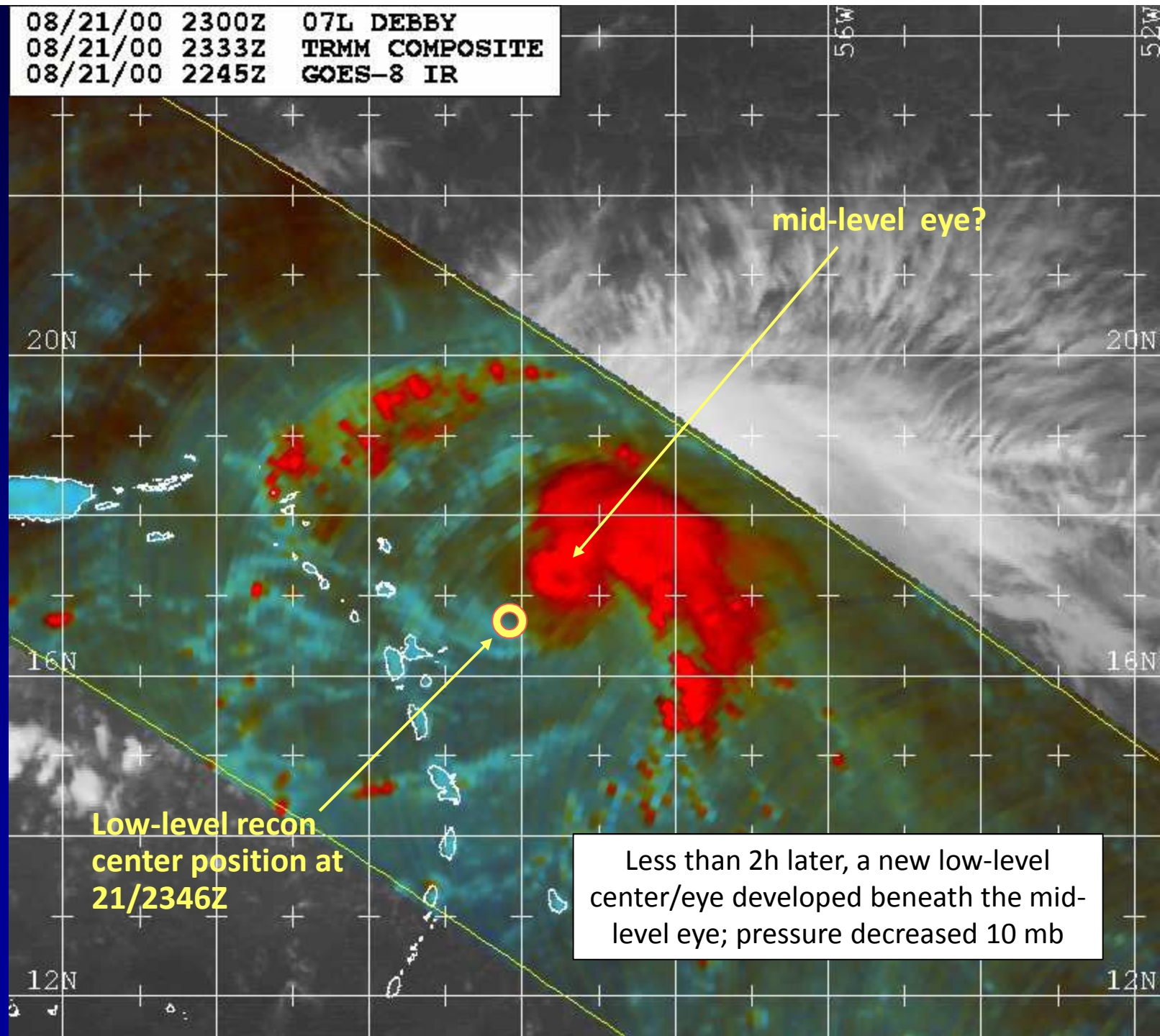


Low-level recon
center position at
21/2346Z

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



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

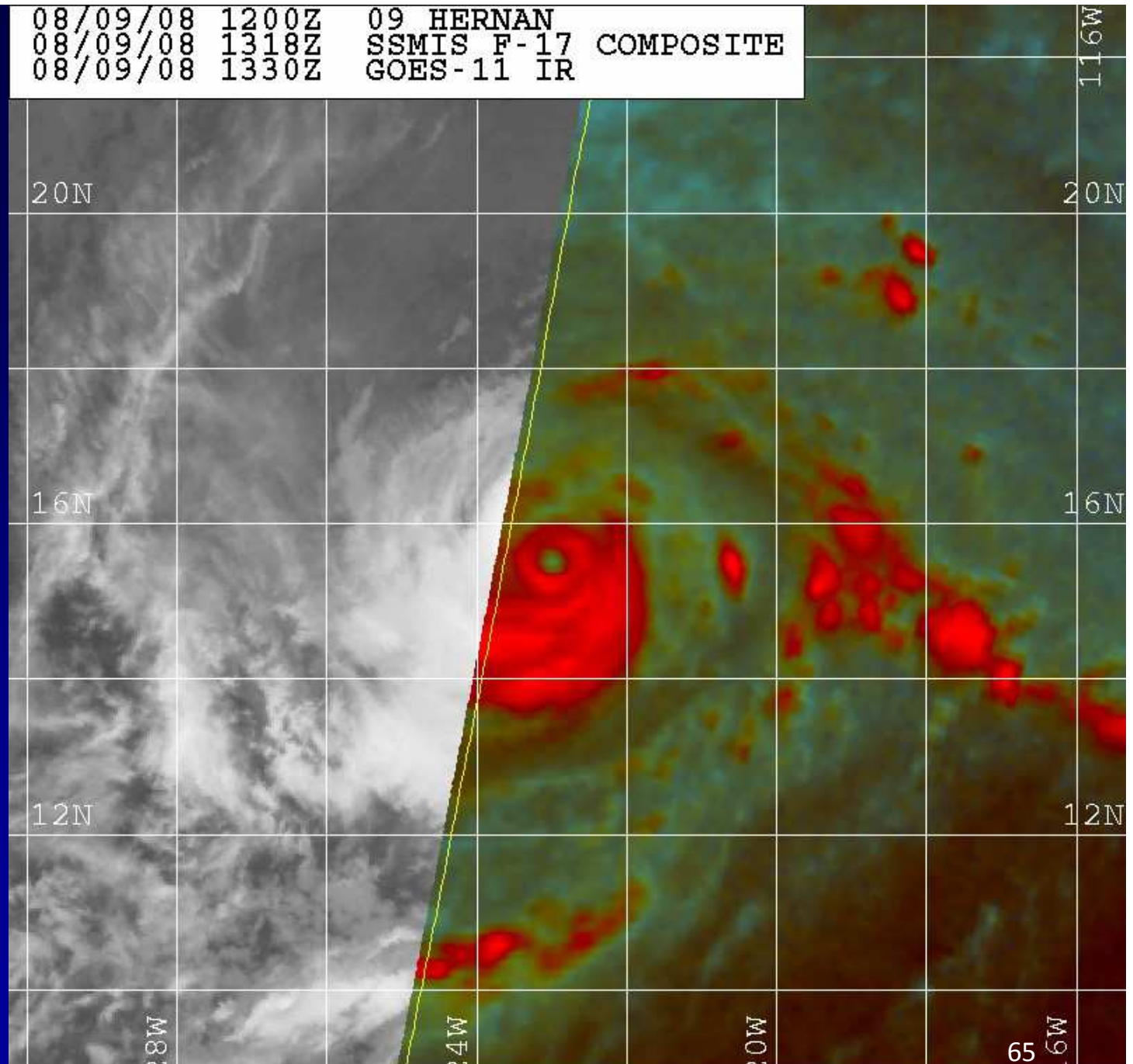


Expanded Use of Microwave Imagery for Tropical Cyclone Analysis

- 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

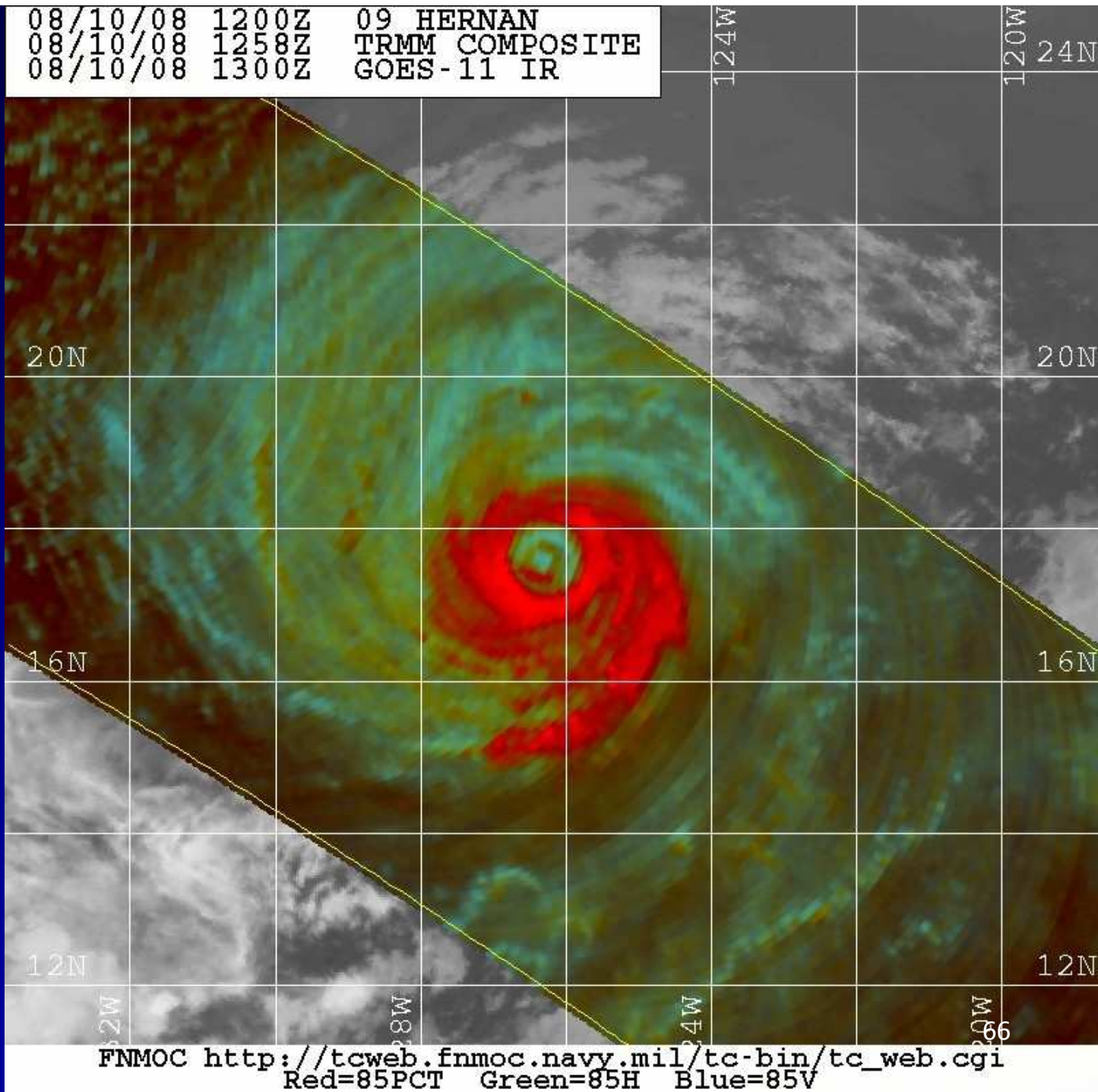
Hernan near
peak intensity
9 Aug 2008

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

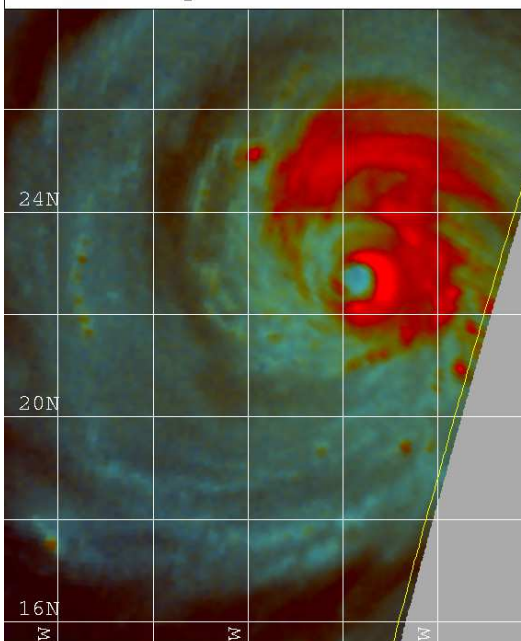


FNMOC http://tcweb.fnmoc.navy.mil/tc-bin/tc_web.cgi
Red=91PCT Green=91H Blue=91V

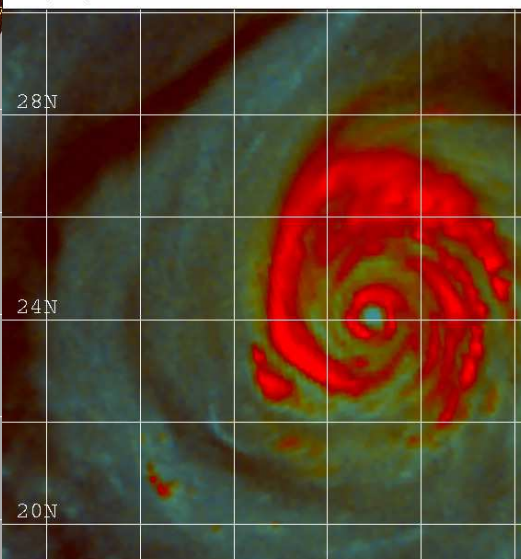
Hernan Eyewall
Replacement
Cycle 24 h later
10 Aug 2008



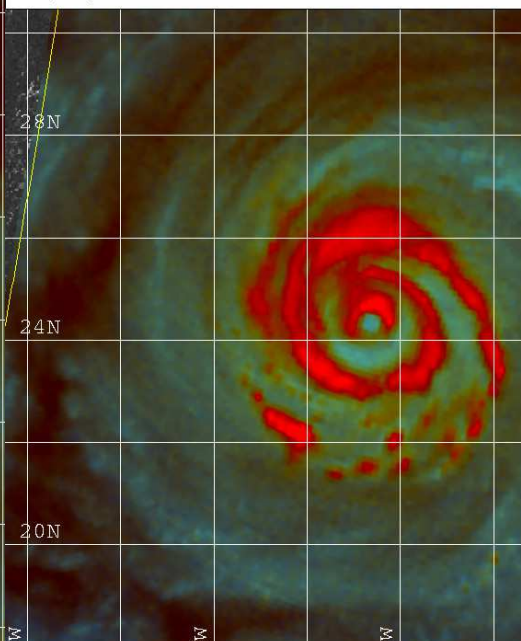
09/18/06 0600Z 08 HELENE
09/18/06 1205Z SSMIS F-16 COMPOSITE
Geostationary Data Unavailable



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

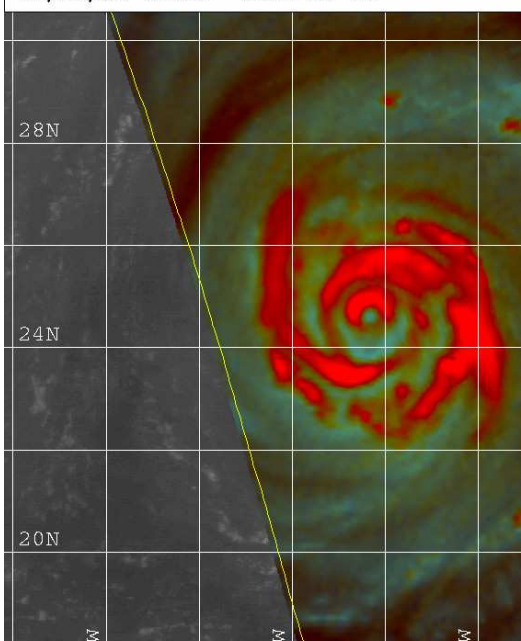


09/19/06 1200Z 08 HELENE
09/19/06 1152Z SSMIS F-16 COMPOSITE
09/19/06 1145Z GOES-12 VIS

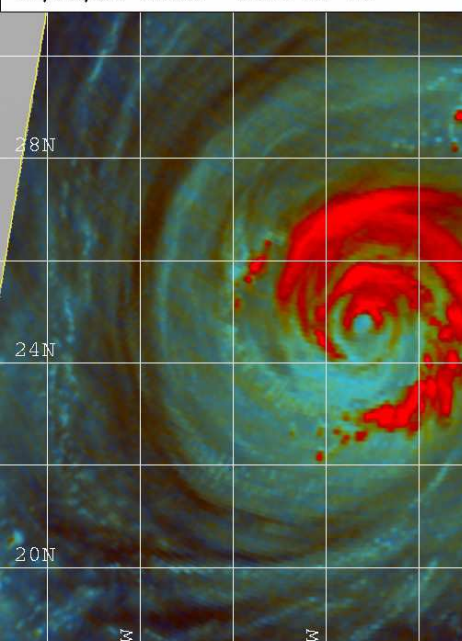


Helene 18-20 Sep 2006

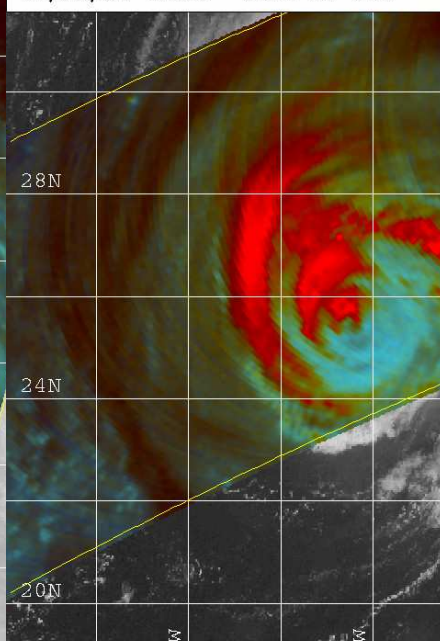
09/20/06 0000Z 08 HELENE
09/19/06 2309Z SSMIS F-16 COMPOSITE
09/19/06 0945Z GOES-12 IR



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

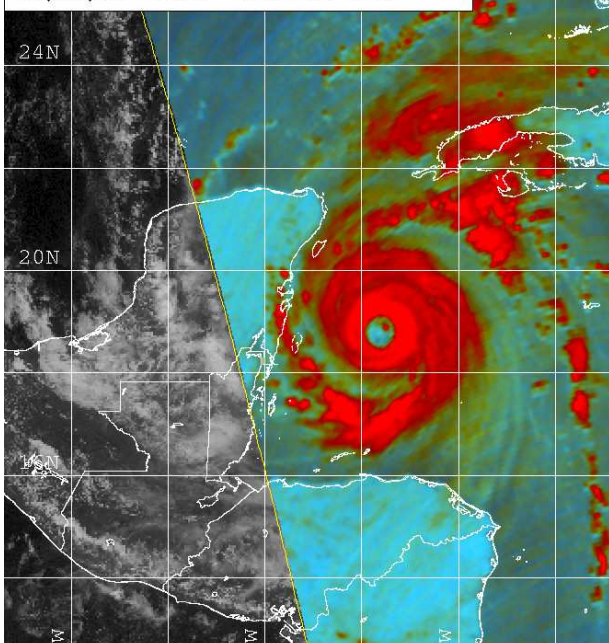


FNMOCC http://tcweb.fnmoc.navy.mil/tc-bin/tc_home.cgi
Red=91PCT Green=91H Blue=91V

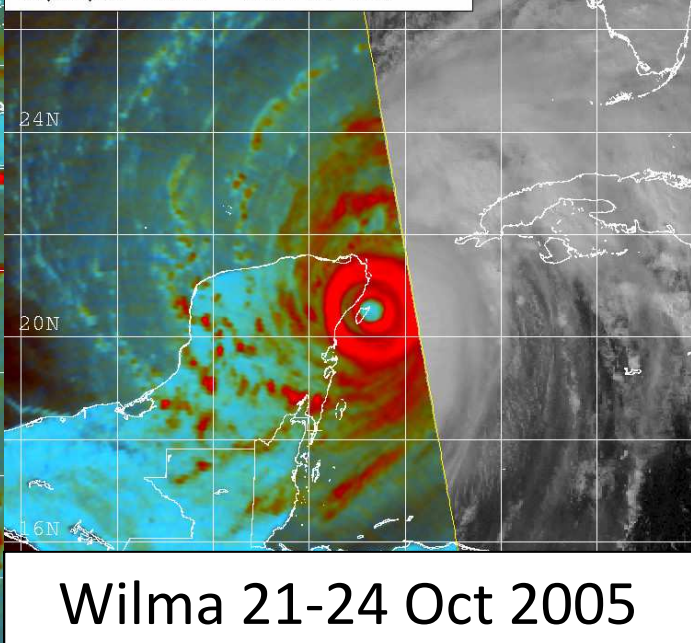
FNMOCC http://tcweb.fnmoc.navy.mil/tc-bin/tc_home.cgi
Red=89PCT Green=89H Blue=89V

FNMOCC http://www.fnmoc.navy.mil/tc_web.html
Red=85PCT Green=85H Blue=85V

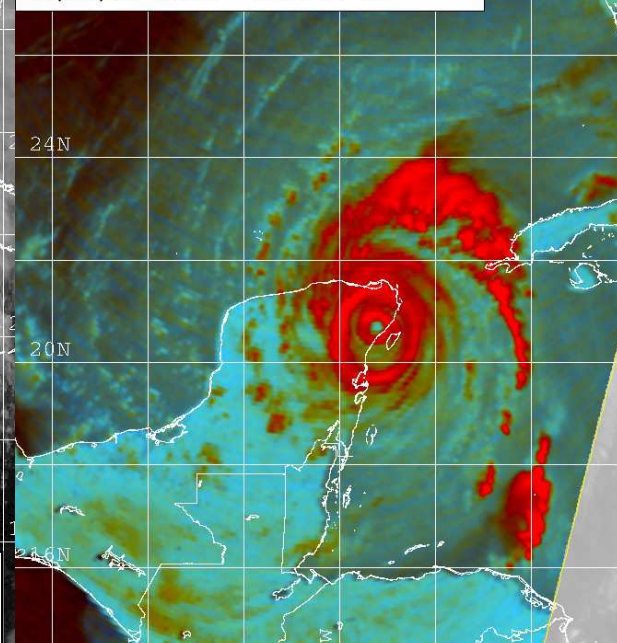
10/21/05 0000Z 24 WILMA
10/20/05 1846Z AMSR-E COMPOSITE
10/20/05 1845Z GOES-12 VIS



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

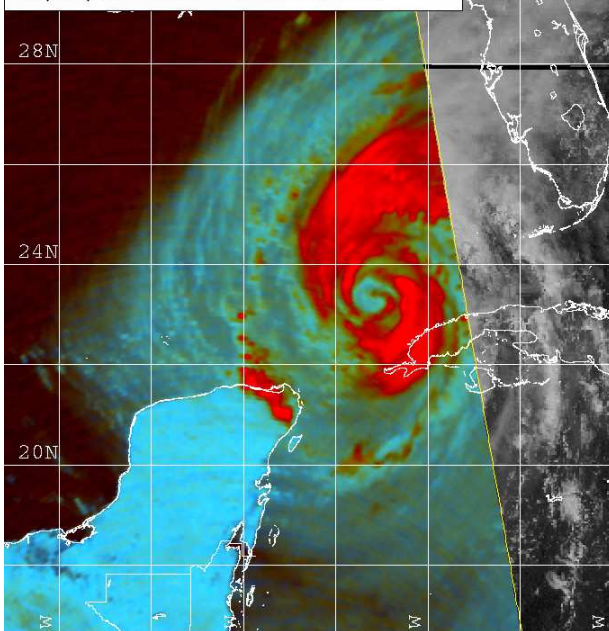


10/22/05 0600Z 24 WILMA
10/22/05 0739Z AMSR-E COMPOSITE
10/22/05 0715Z GOES-12 IR

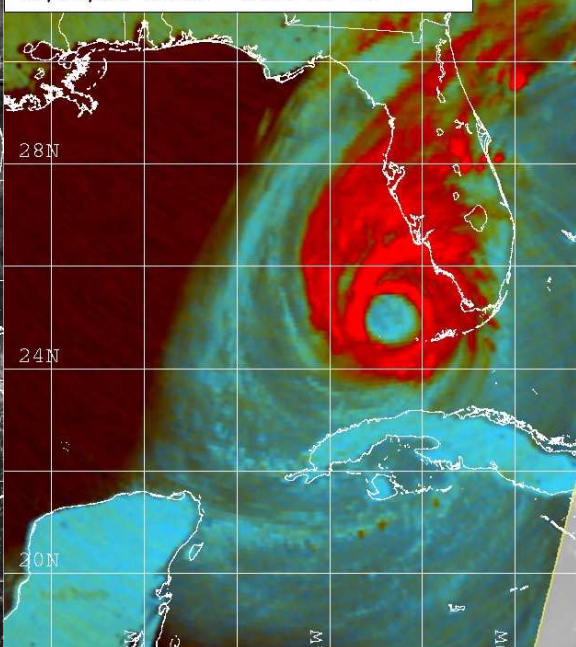


Wilma 21-24 Oct 2005

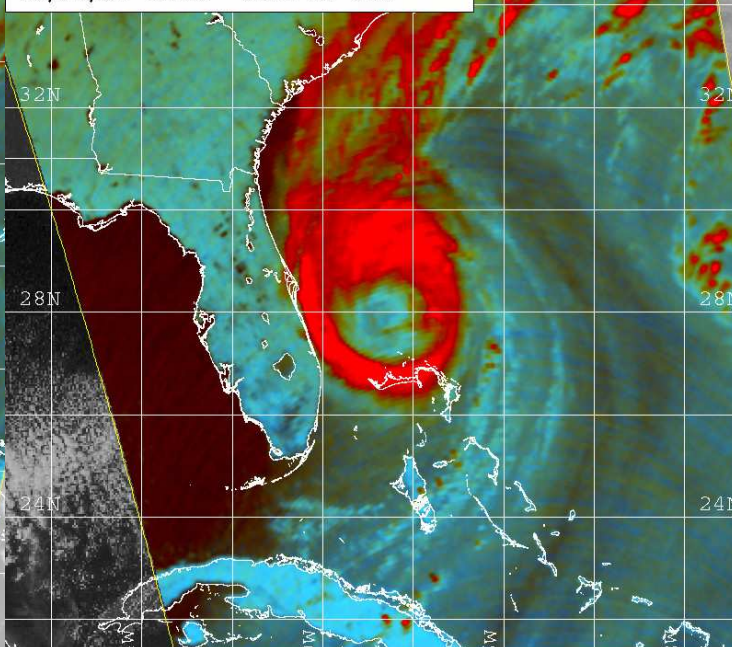
10/23/05 1800Z 24 WILMA
10/23/05 1917Z AMSR-E COMPOSITE
10/23/05 1915Z GOES-12 VIS



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

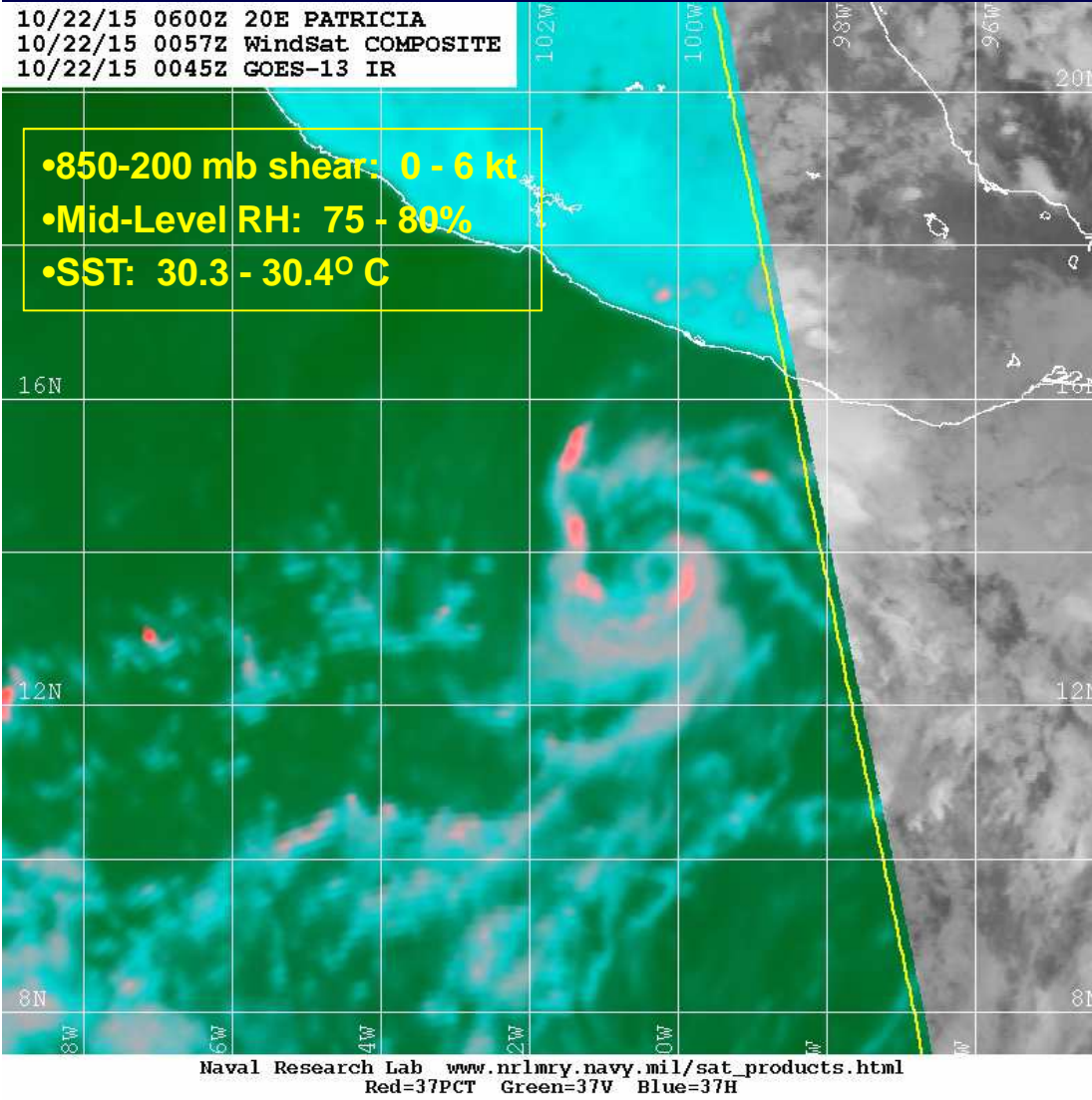


FNMOC http://tcweb.fnmoc.navy.mil/tc-bin/tc_home.cgi
Red=89PCT Green=89H Blue=89V

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

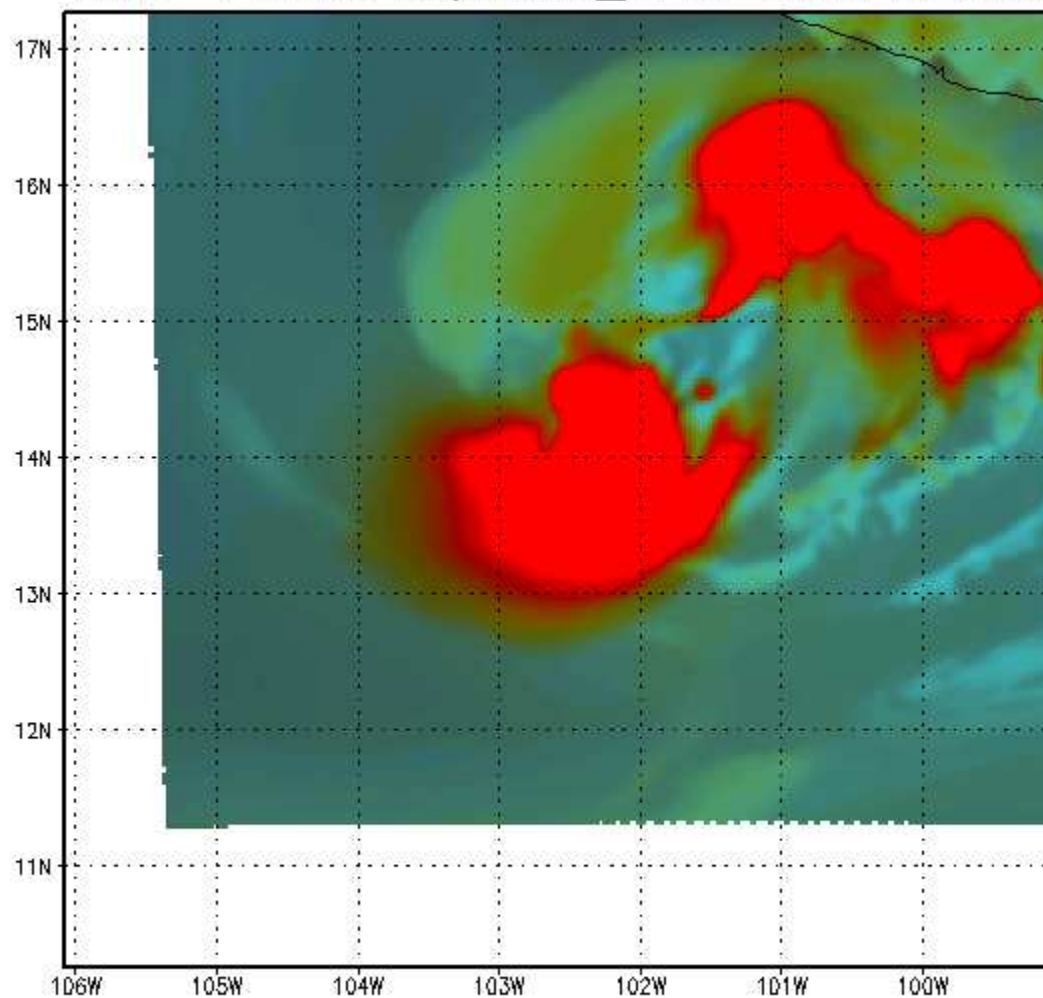
Precursor Structure Before Rapid Intensification



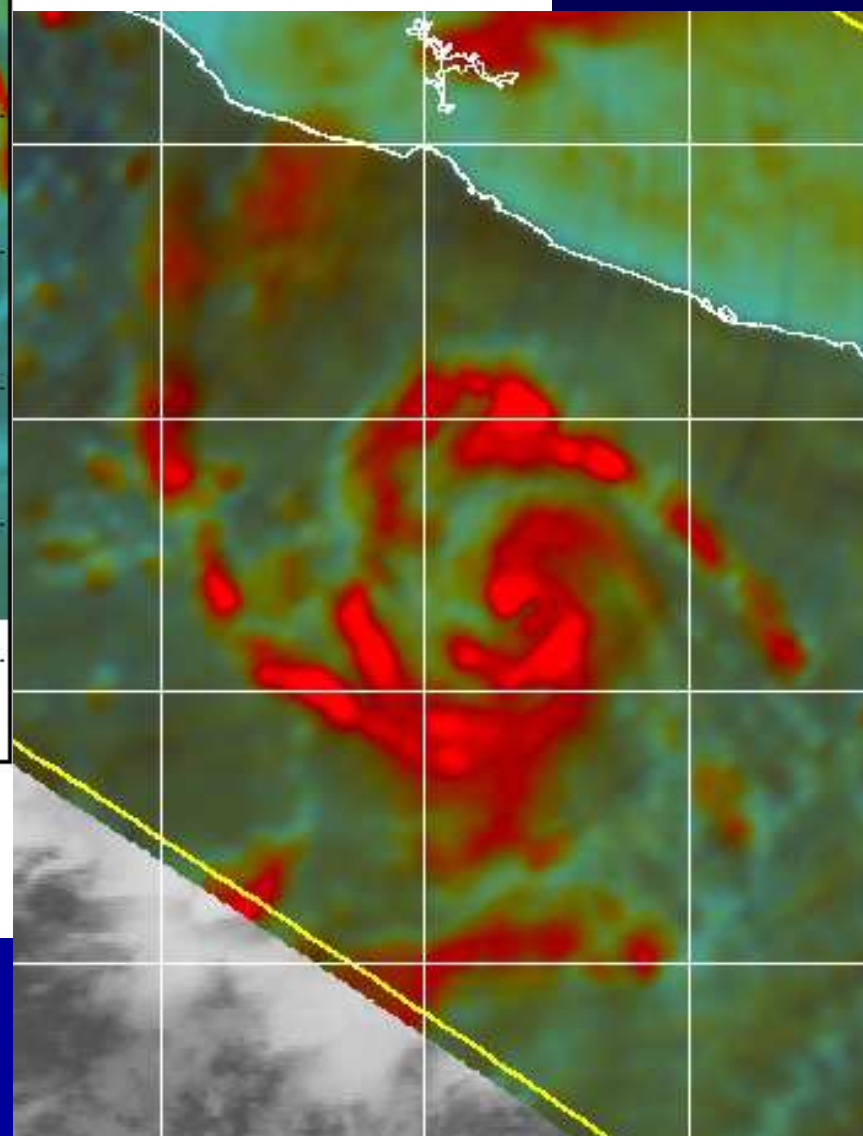
- A closed low-level ring of convection in 37-GHz imagery can be a precursor signal to rapid intensification *IF* other environmental factors (e.g., vertical wind shear) are favorable
- In the case shown here, Patricia strengthened an incredible 90 kt from 60 kt to 150 kt in only 24 hours!

Simulated Microwave Imagery from HWRF Model Output

HWRF 91GHz: Raymond_17EP 2013102006

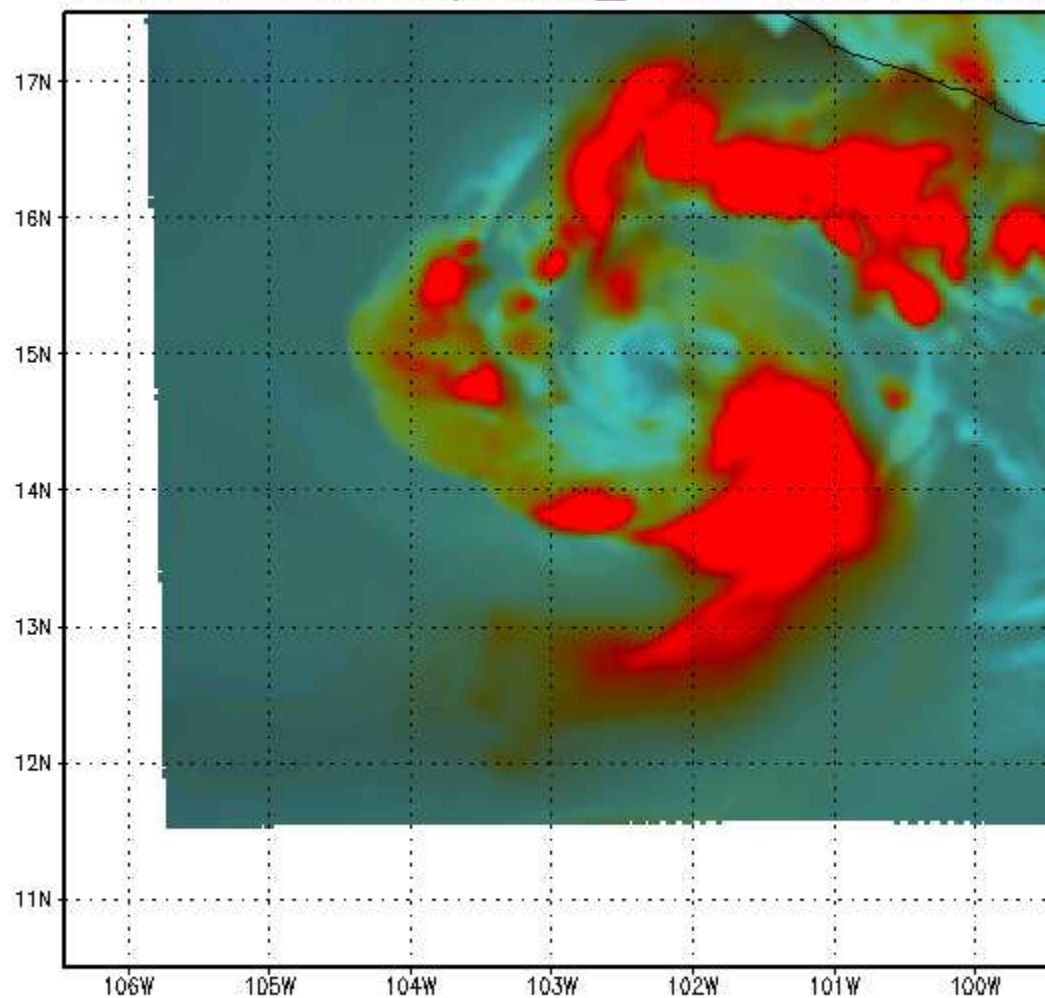


Forecast Valid:
12Z20OCT2013

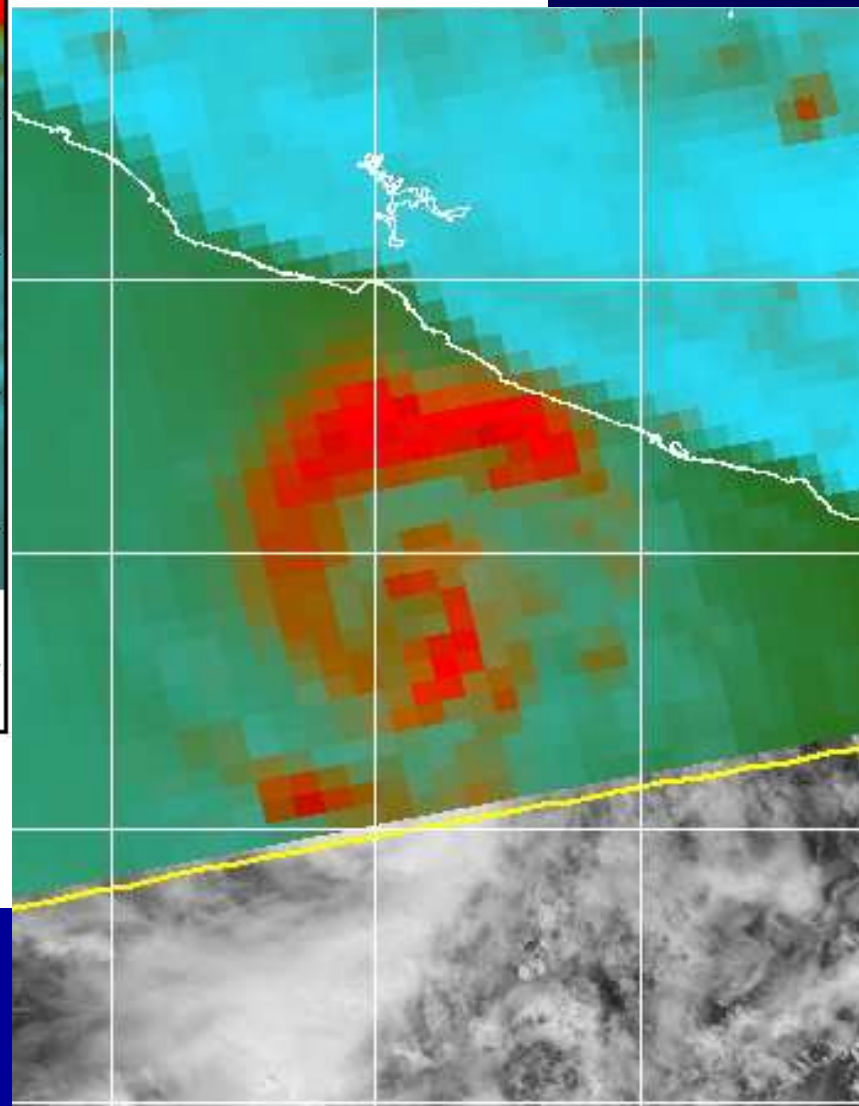


Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed
microwave images (right)

HWRF 91GHz: Raymond_17EP 2013102006

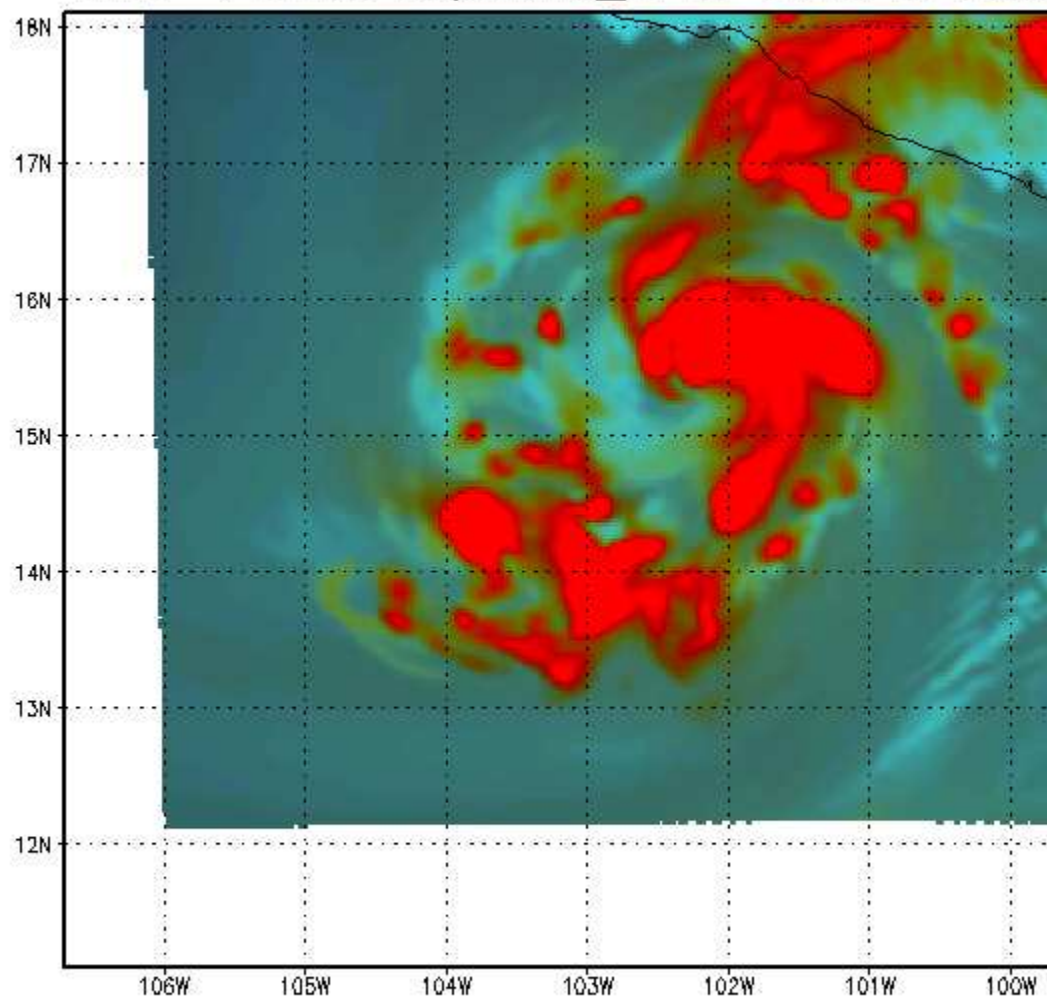


Forecast Valid:
18Z20OCT2013

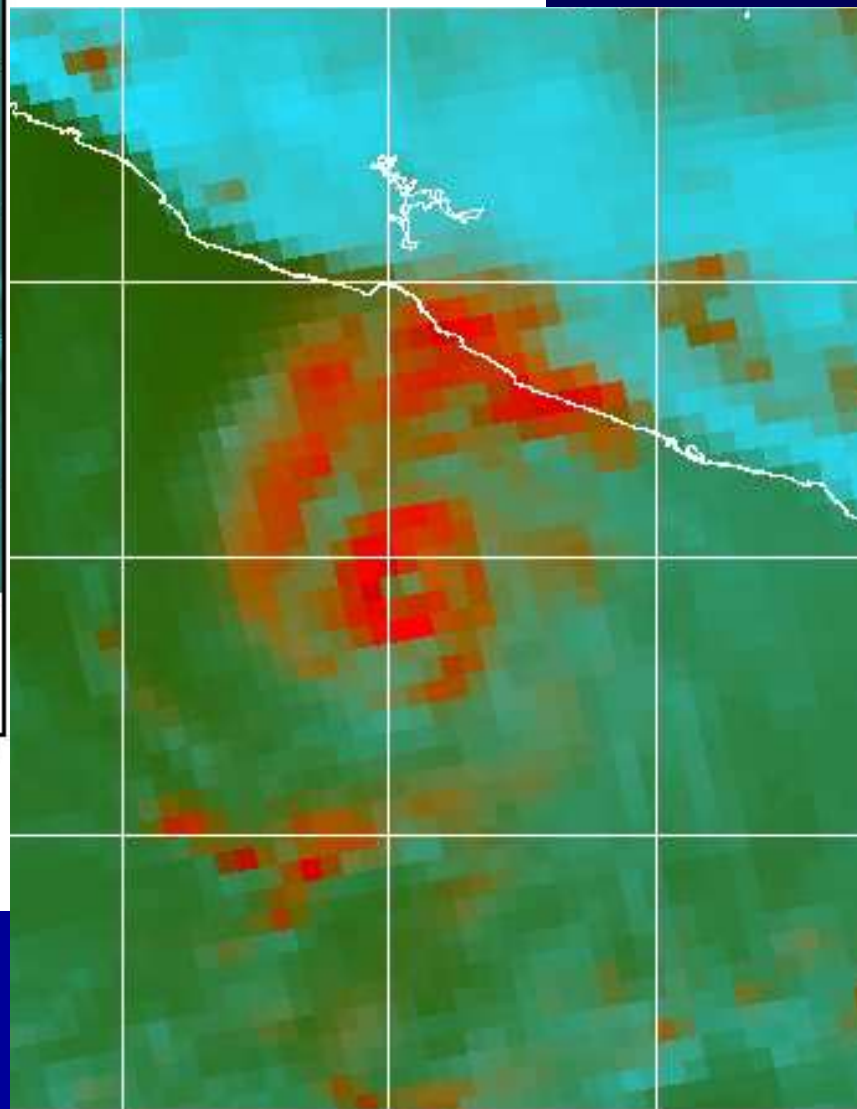


Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed
microwave images (right)

HWRF 91GHz: Raymond_17EP 2013102006

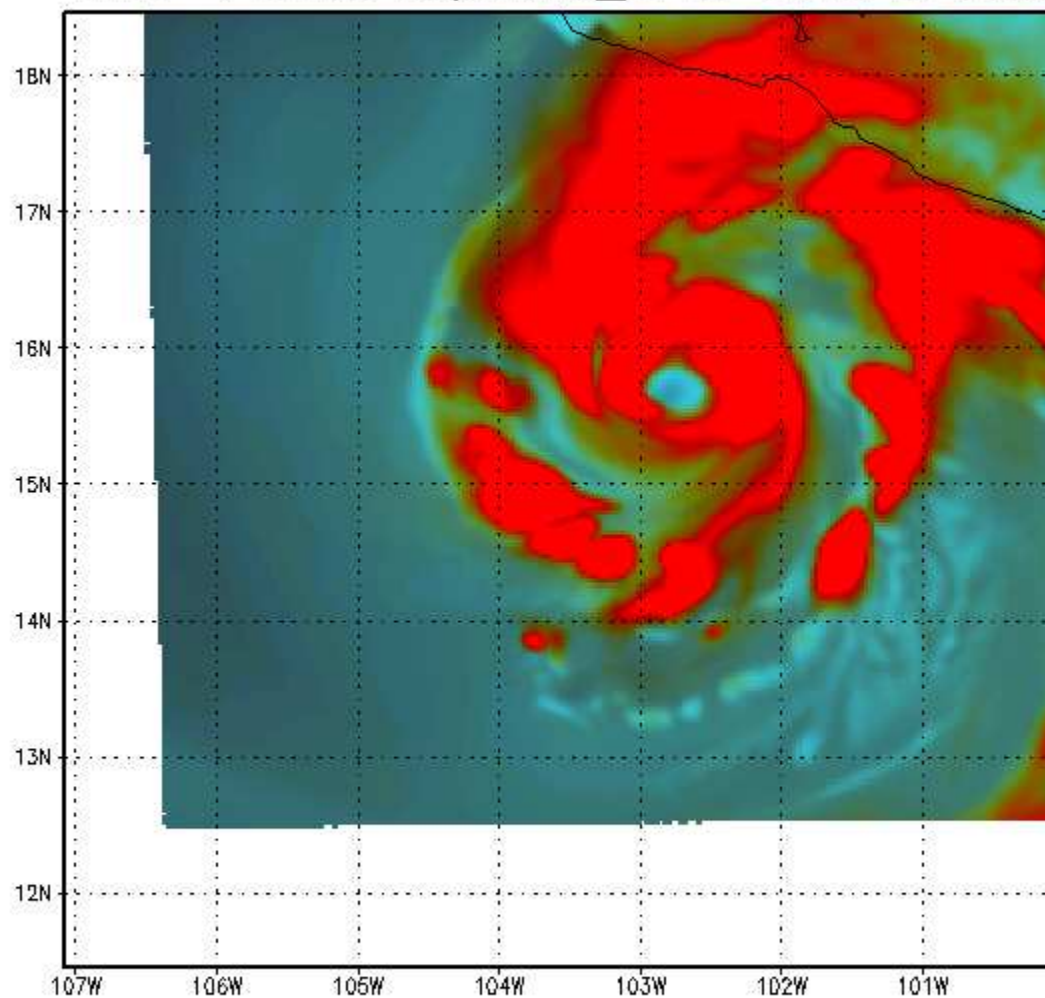


Forecast Valid:
00Z21OCT2013

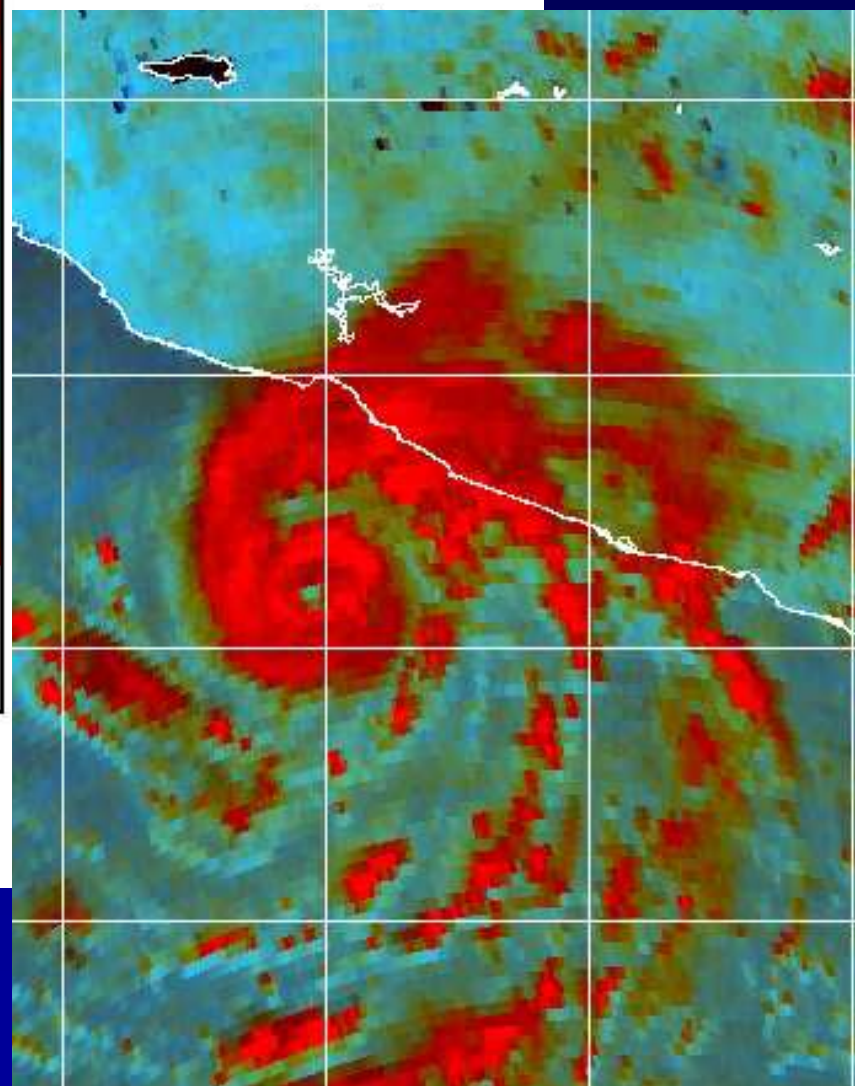


Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed
microwave images (right)

HWRF 91GHz: Raymond_17EP 2013102006

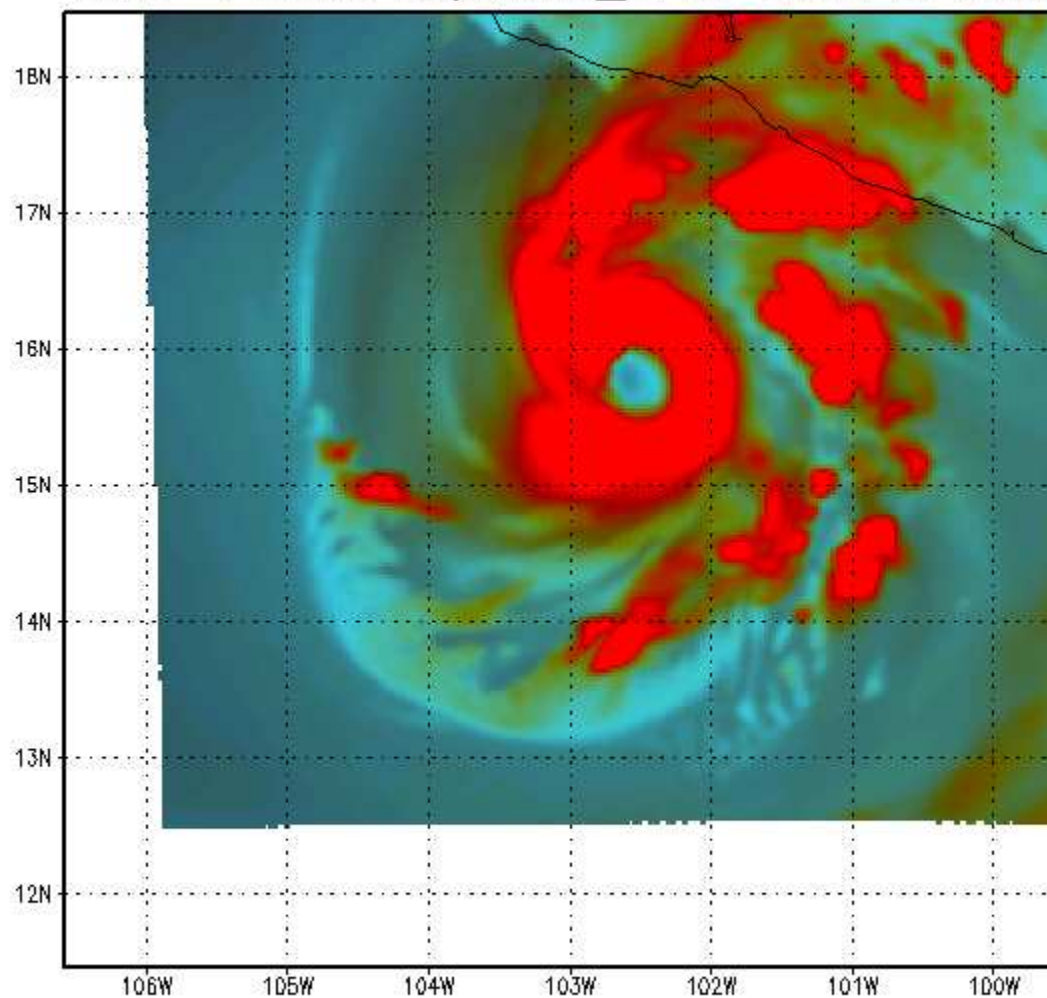


Forecast Valid:
18Z21OCT2013

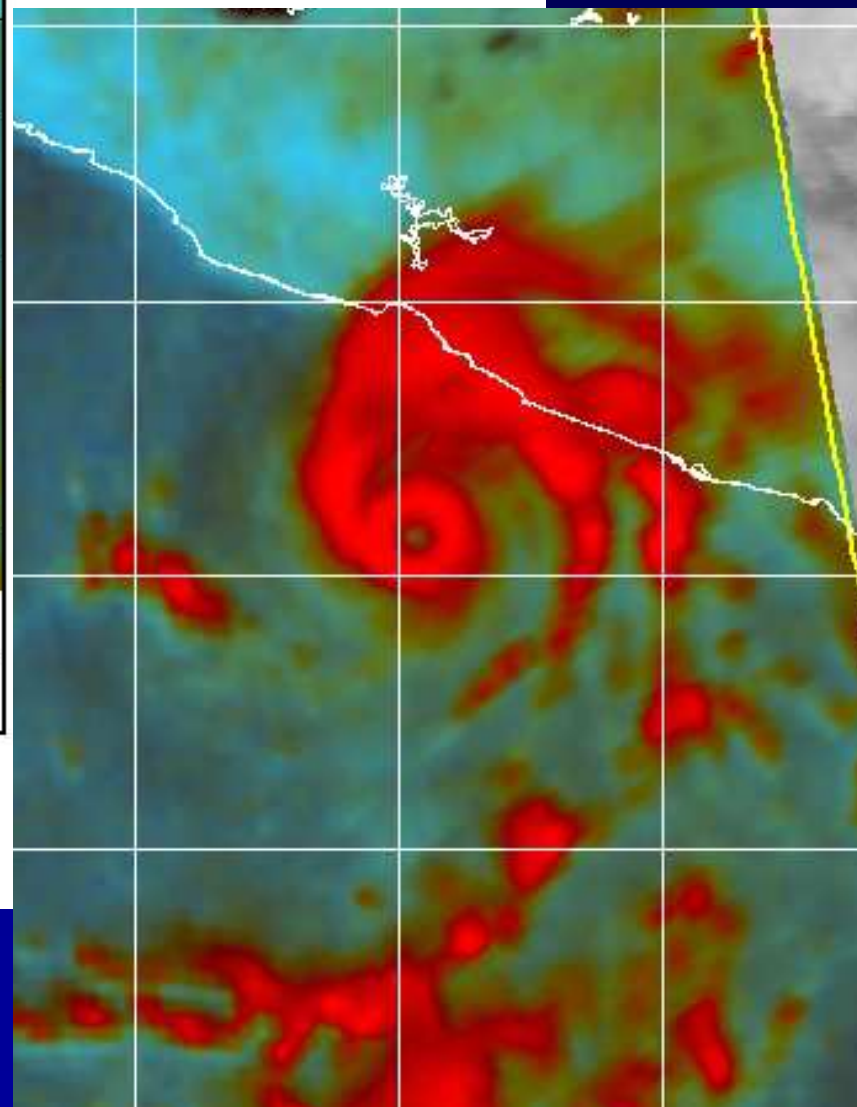


Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed
microwave images (right)

HWRF 91GHz: Raymond_17EP 2013102006

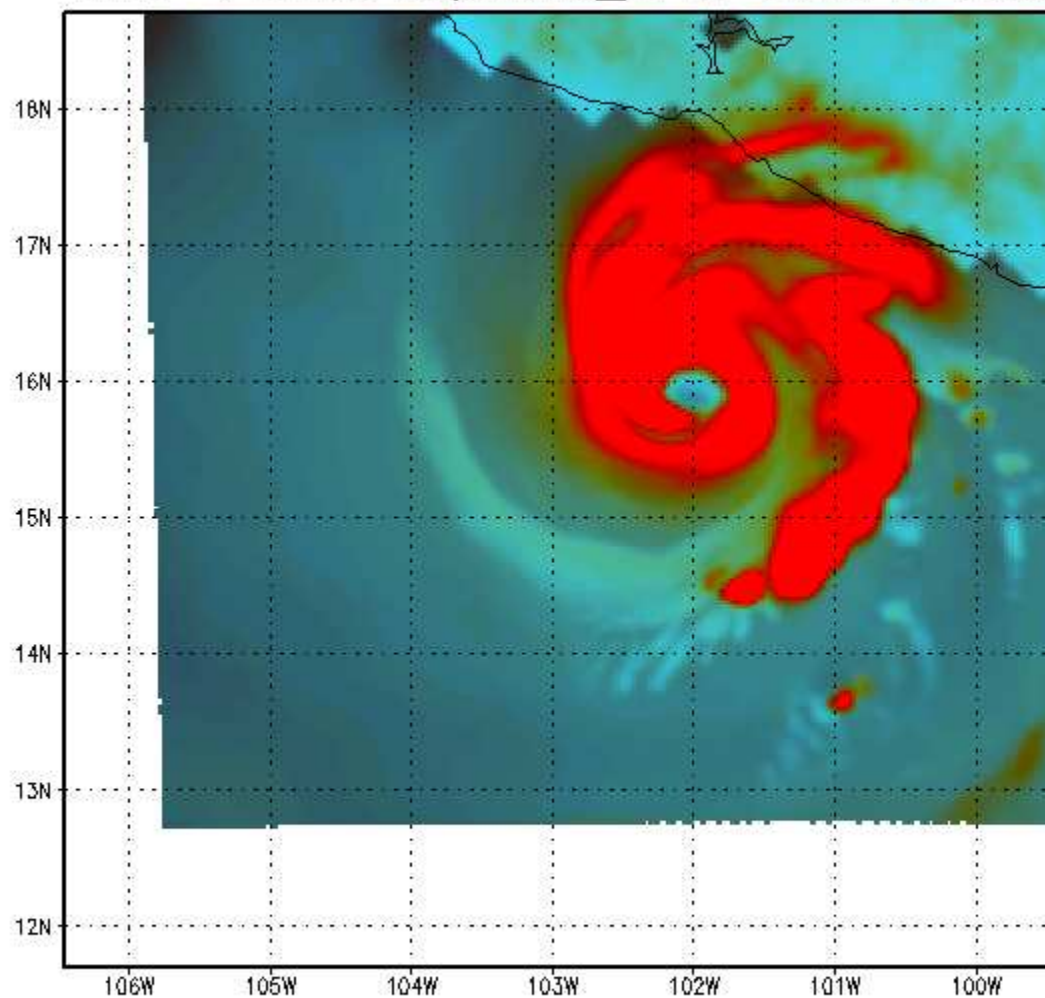


Forecast Valid:
00Z22OCT2013

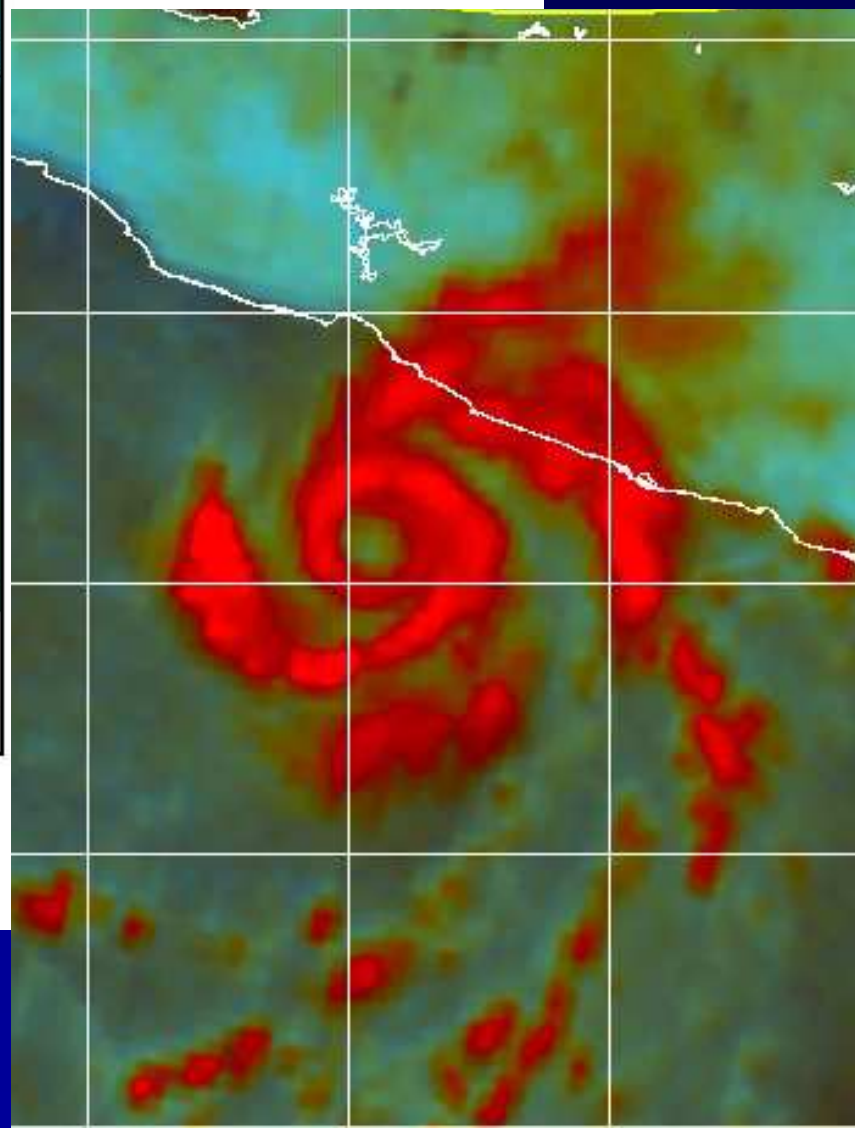


Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed
microwave images (right)

HWRF 91GHz: Raymond_17EP 2013102006

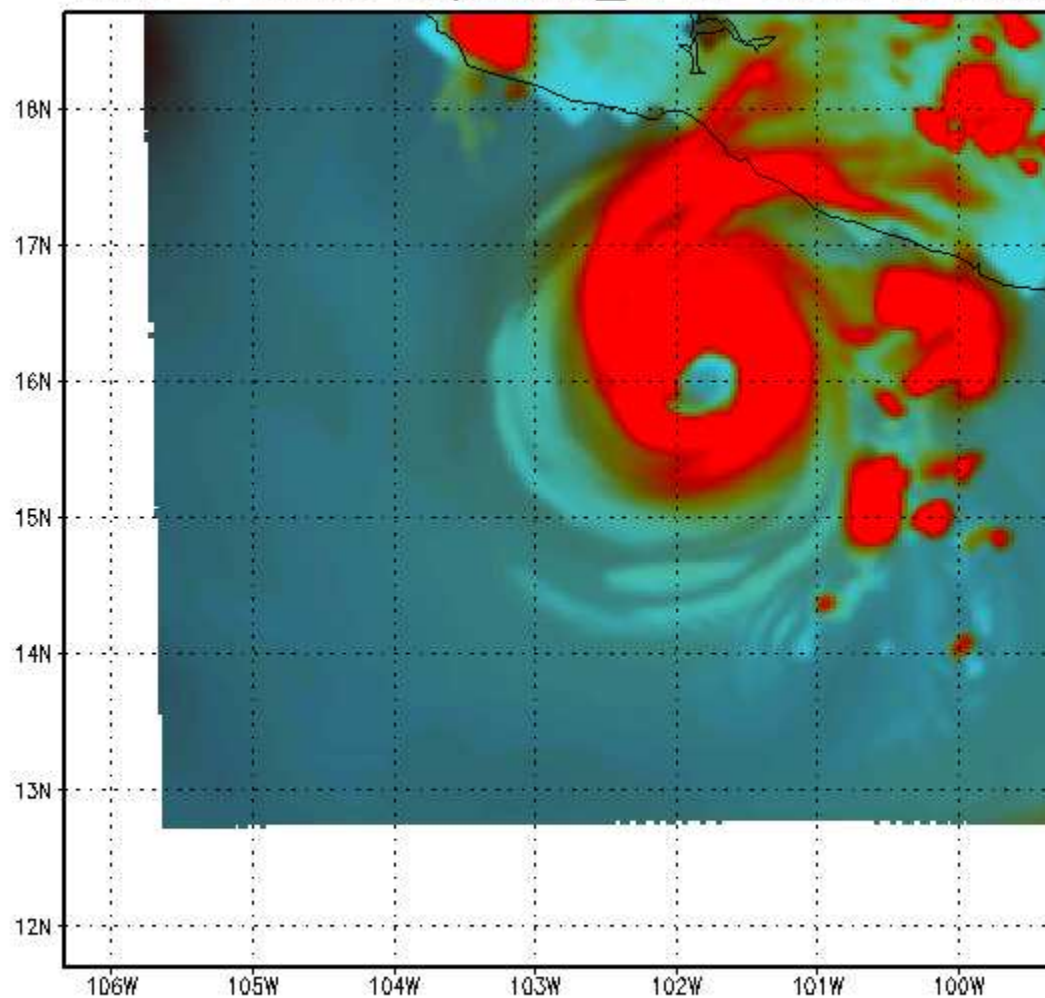


Forecast Valid:
18Z22OCT2013

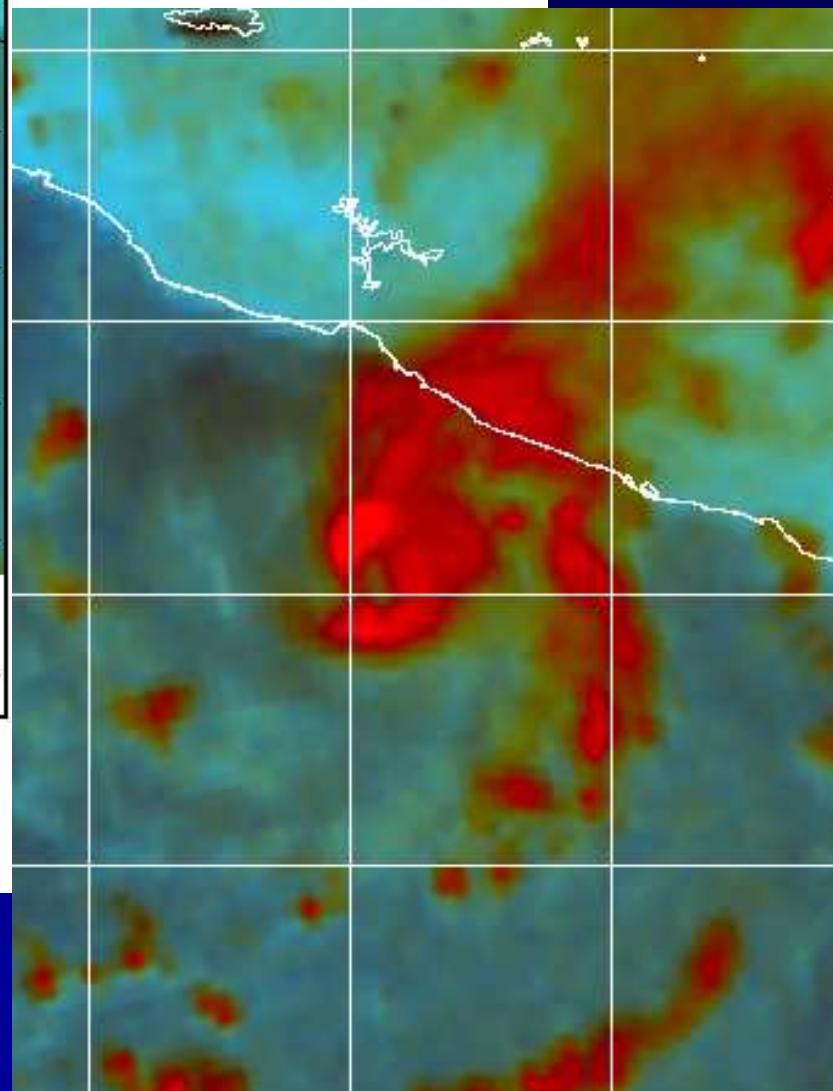


Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed
microwave images (right)

HWRF 91GHz: Raymond_17EP 2013102006

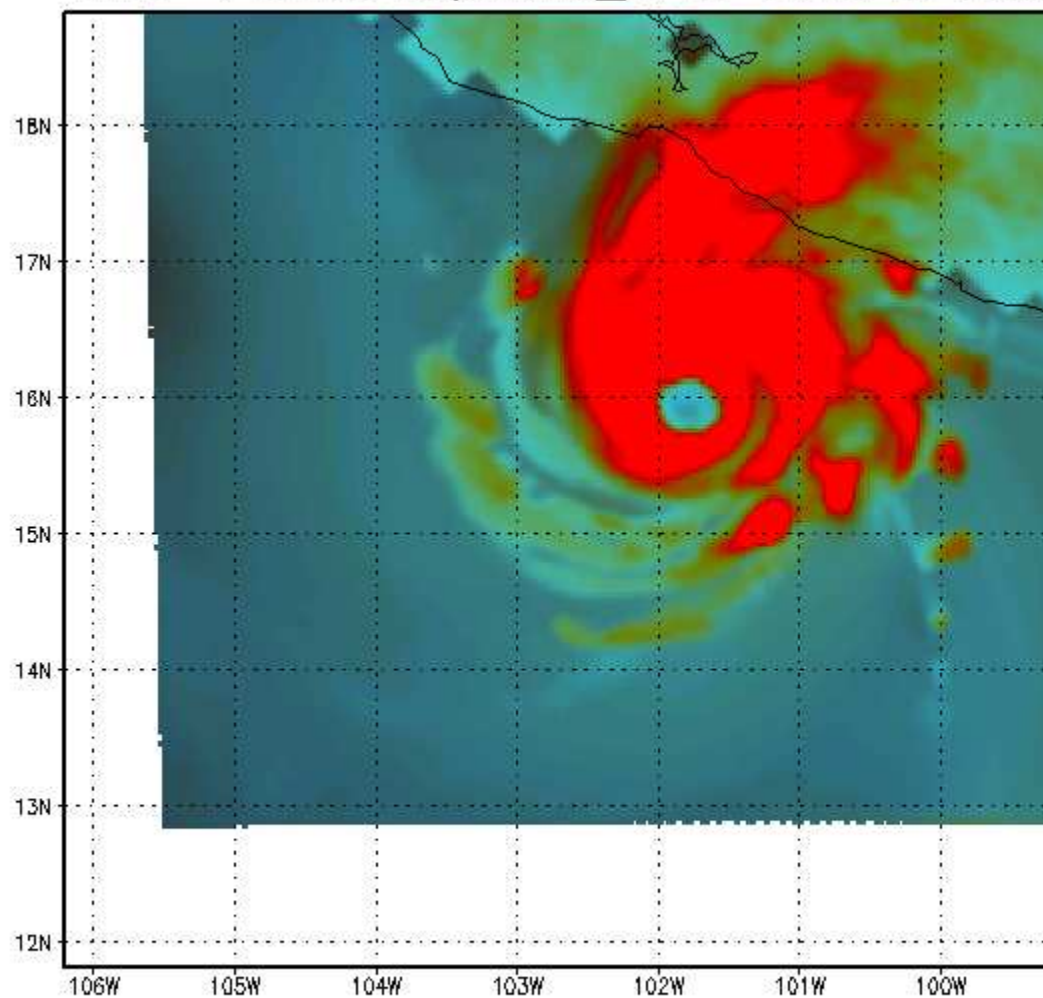


Forecast Valid:
00Z23OCT2013

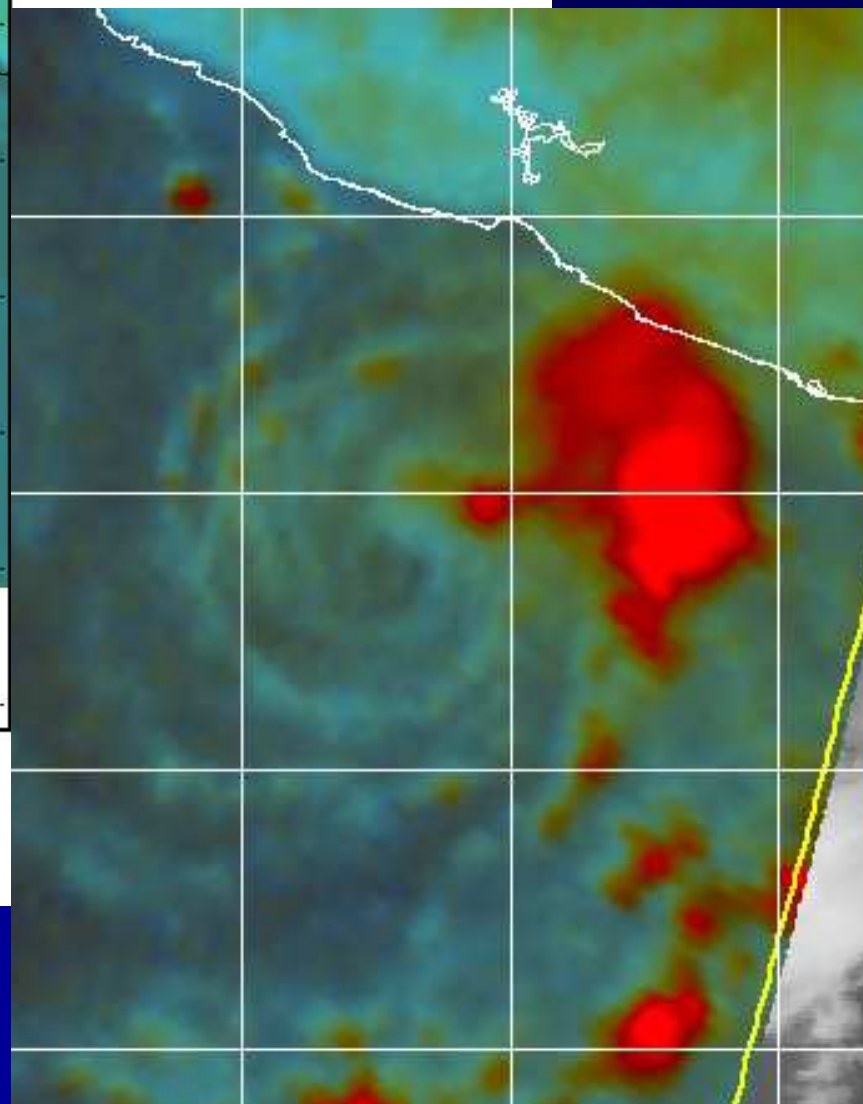


Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed
microwave images (right)

HWRF 91GHz: Raymond_17EP 2013102006

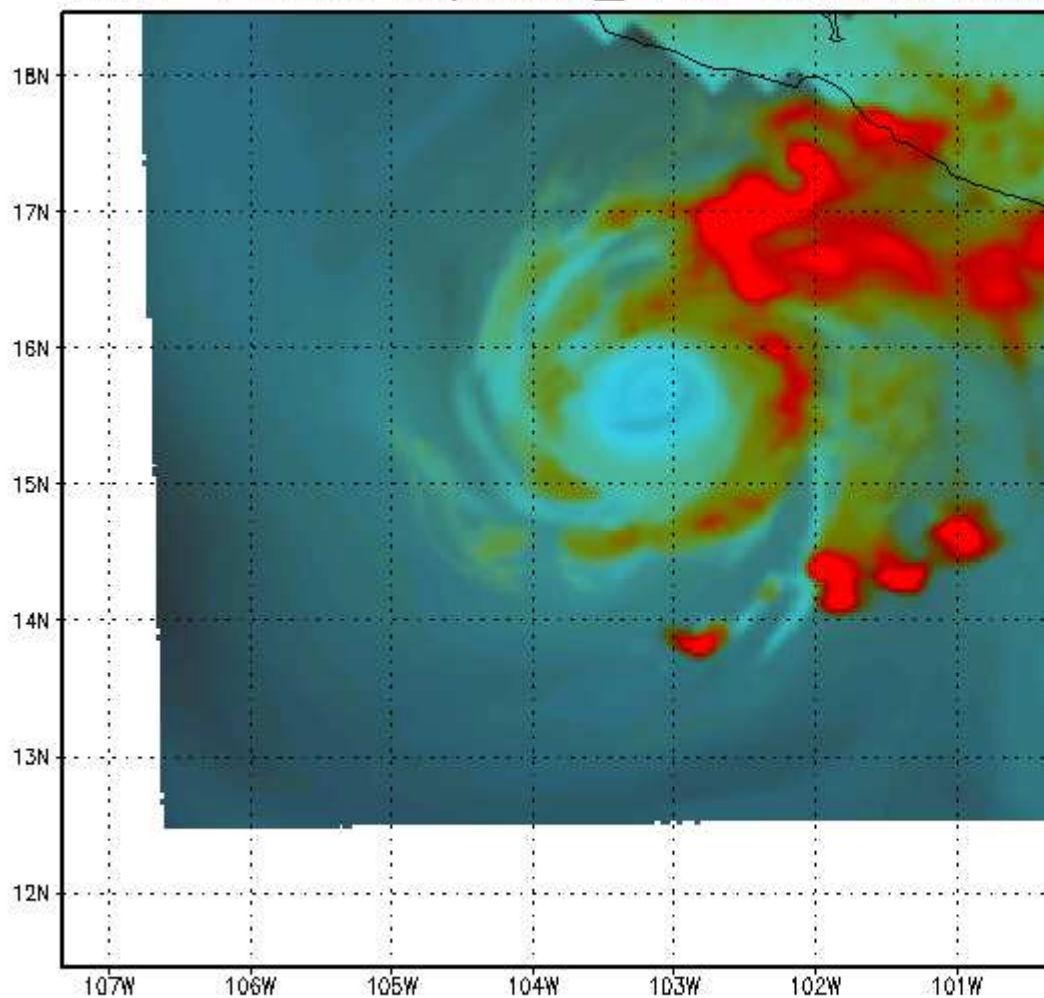


Forecast Valid:
12Z23OCT2013

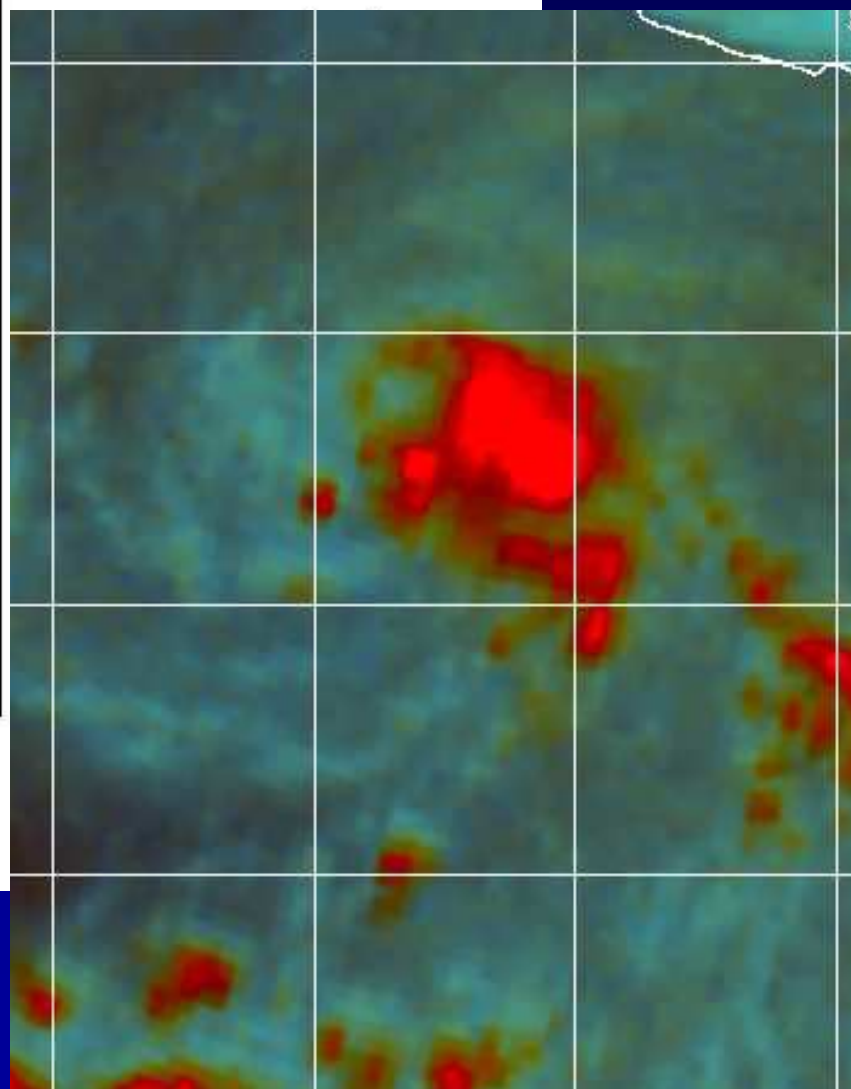


Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed
microwave images (right)

HWRF 91GHz: Raymond_17EP 2013102006

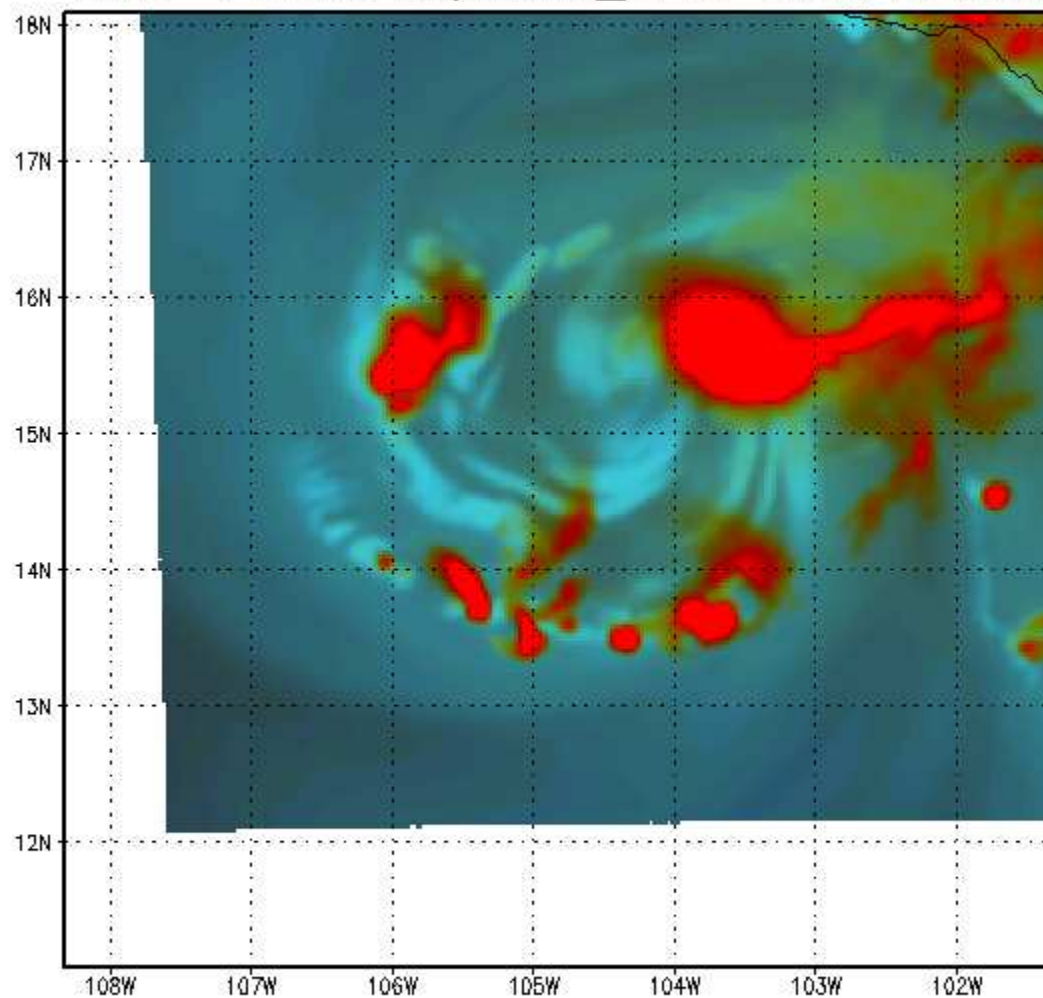


Forecast Valid:
12Z24OCT2013

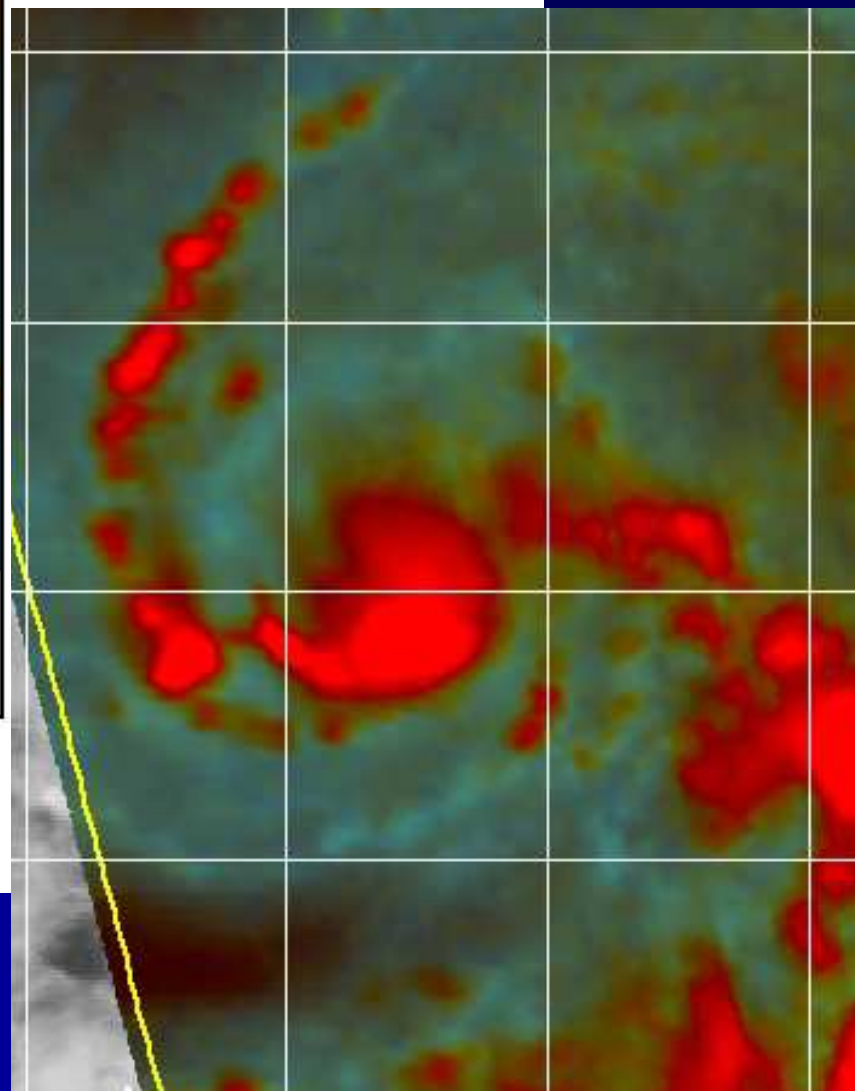


Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed
microwave images (right)

HWRF 91GHz: Raymond_17EP 2013102006

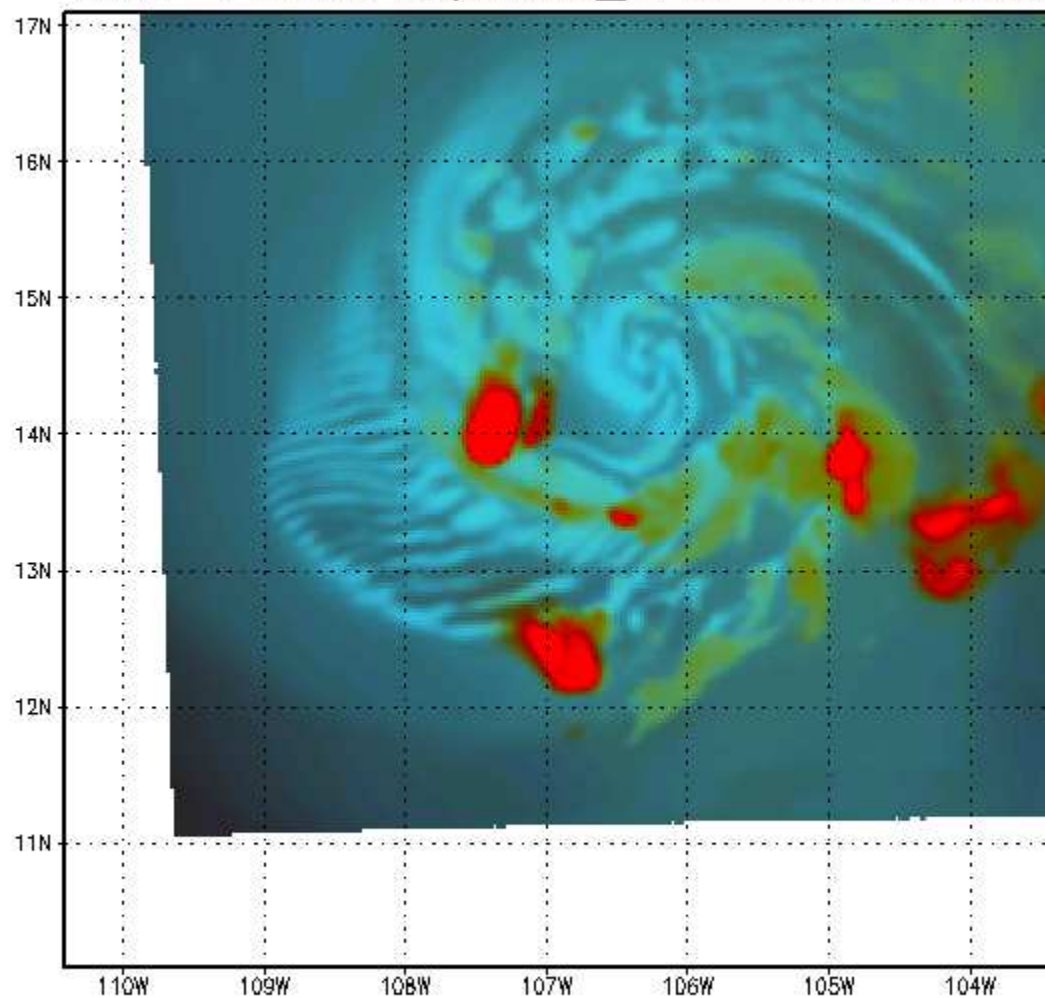


Forecast Valid:
00Z25OCT2013

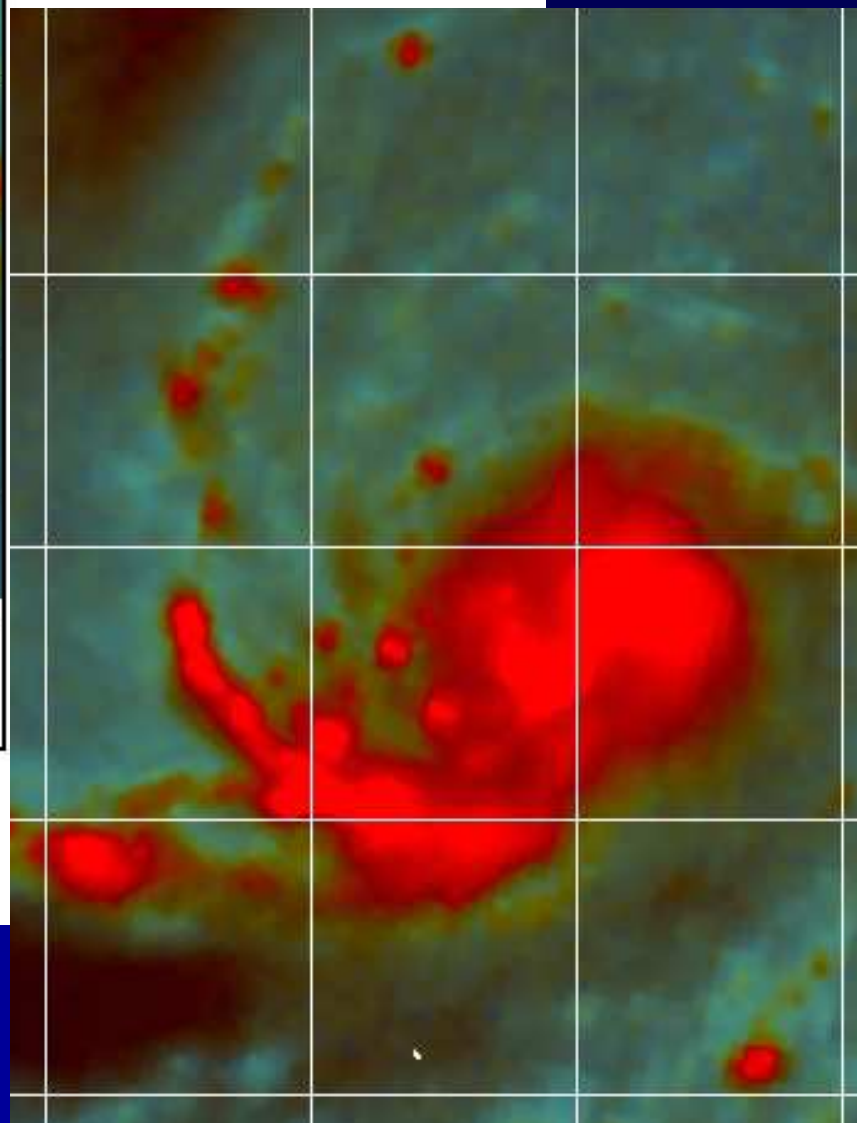


Sample Forecast: Raymond (2013)
HWRF forecast (above) and observed
microwave images (right)

HWRF 91GHz: Raymond_17EP 2013102006



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-1, 2, 3

Launch: 2006, 2012, 2017

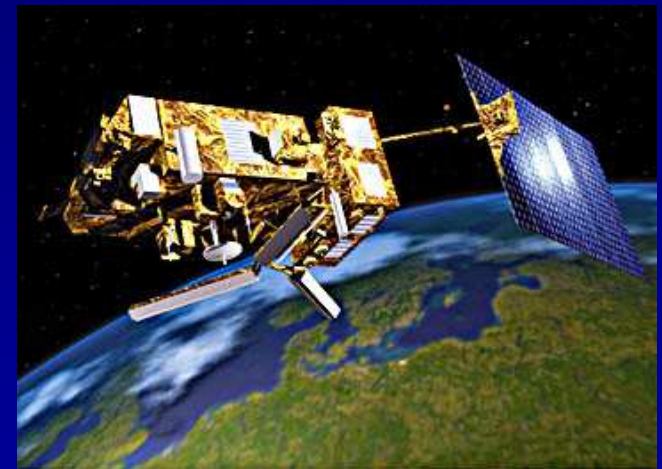
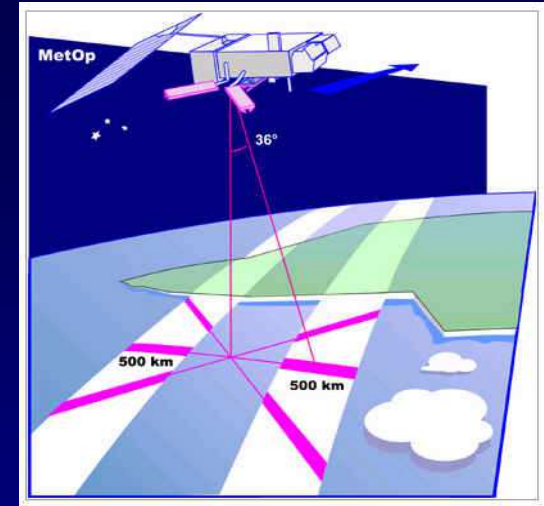
Heritage: ERS-1, 2

Channel: 5.25 GHz, C-band

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

Utility for TC Applications:

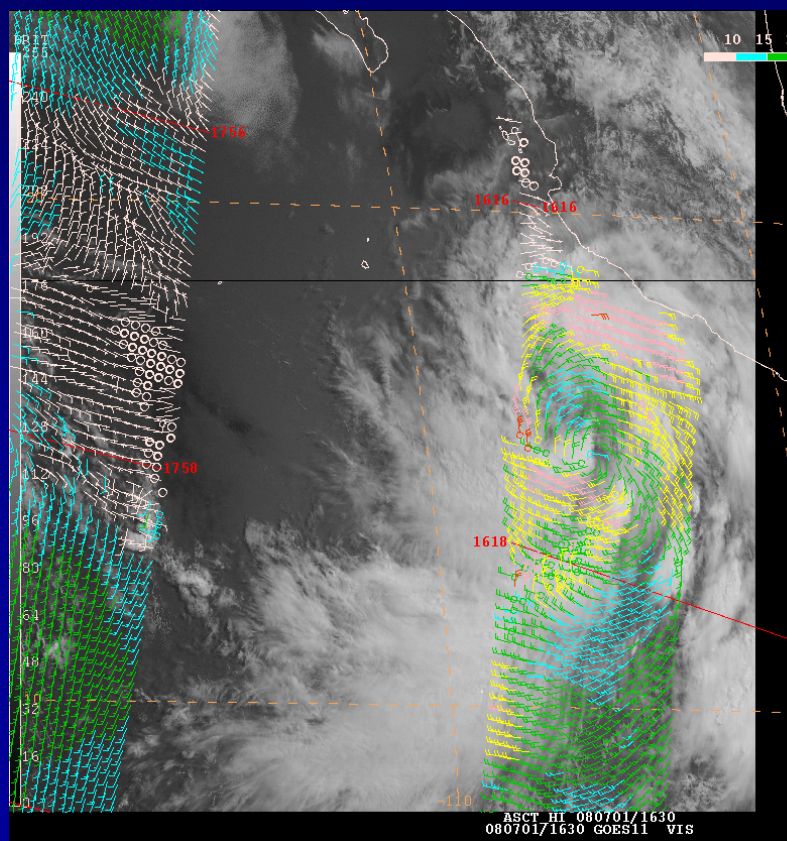
- (1) Only long term operational scatterometer series
- (2) C-band, less rain contamination, larger footprint
- (3) 25- and 50-km wind vector products, good for winds up to gale force (low bias above 35-40 kt)
- (4) Gap in swath center over the tropics is a major drawback for coverage



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

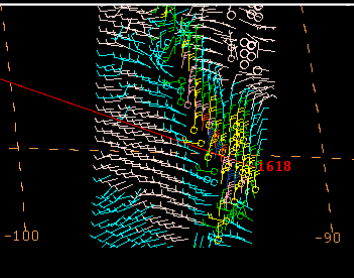


TROPICAL DEPRESSION FOUR-E DISCUSSION NUMBER 1
NWS TPC/NATIONAL HURRICANE CENTER MIAMI FL EP042008
800 PM PDT TUE JUL 01 2008

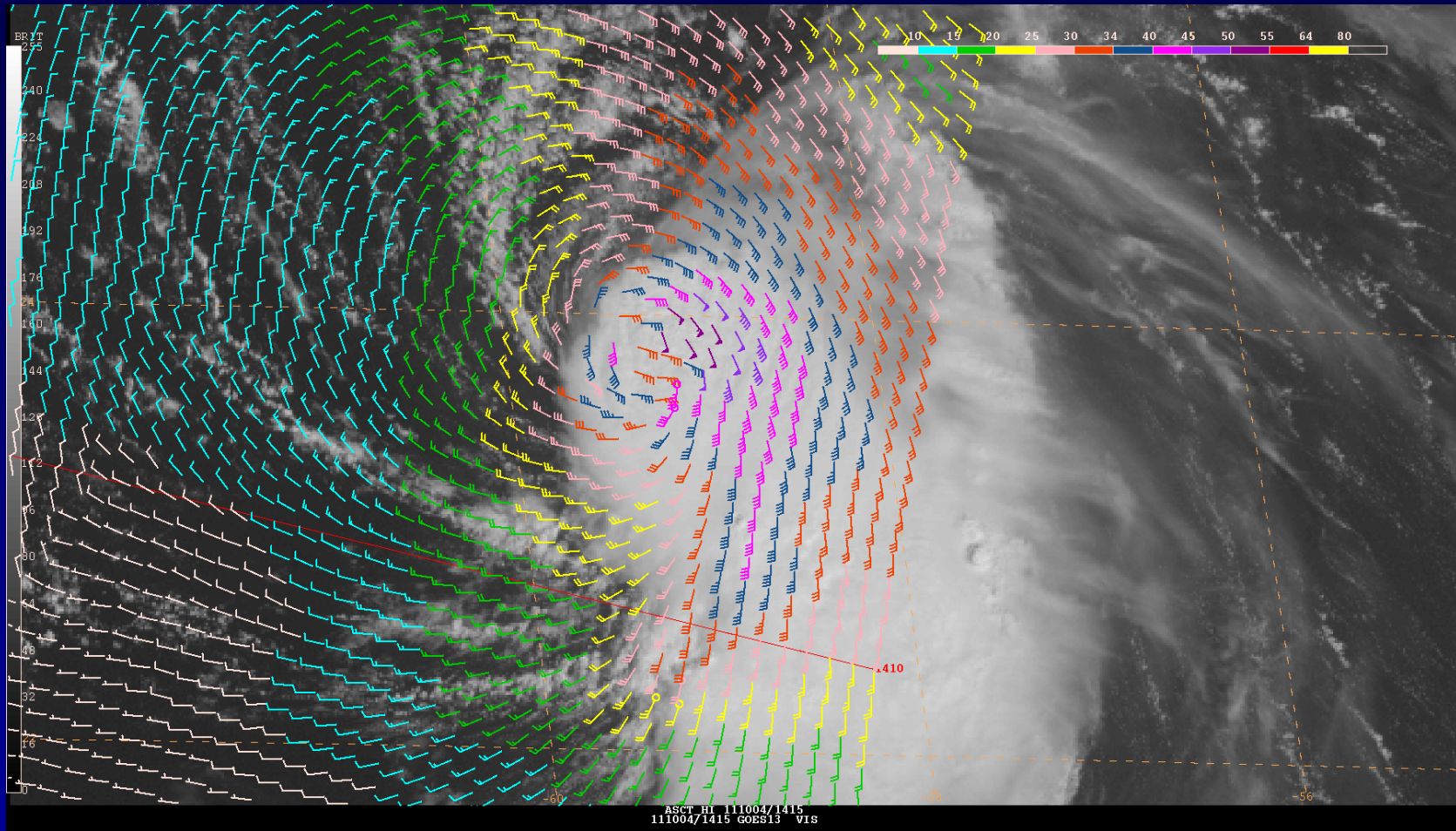
ASCAT DATA AT AROUND 16Z SHOWED THAT THE LOW PRESSURE AREA SOUTHWEST OF MANZANILLO MEXICO HAD A BROAD CENTER ELONGATED NORTH-NORTHWEST TO SOUTH-SOUTHEAST. SINCE THAT TIME...SATELLITE IMAGERY INDICATES THAT THE CIRCULATION AND ASSOCIATED SHOWER ACTIVITY HAS SOMEWHAT CONSOLIDATED AT THE SOUTHERN END OF 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...

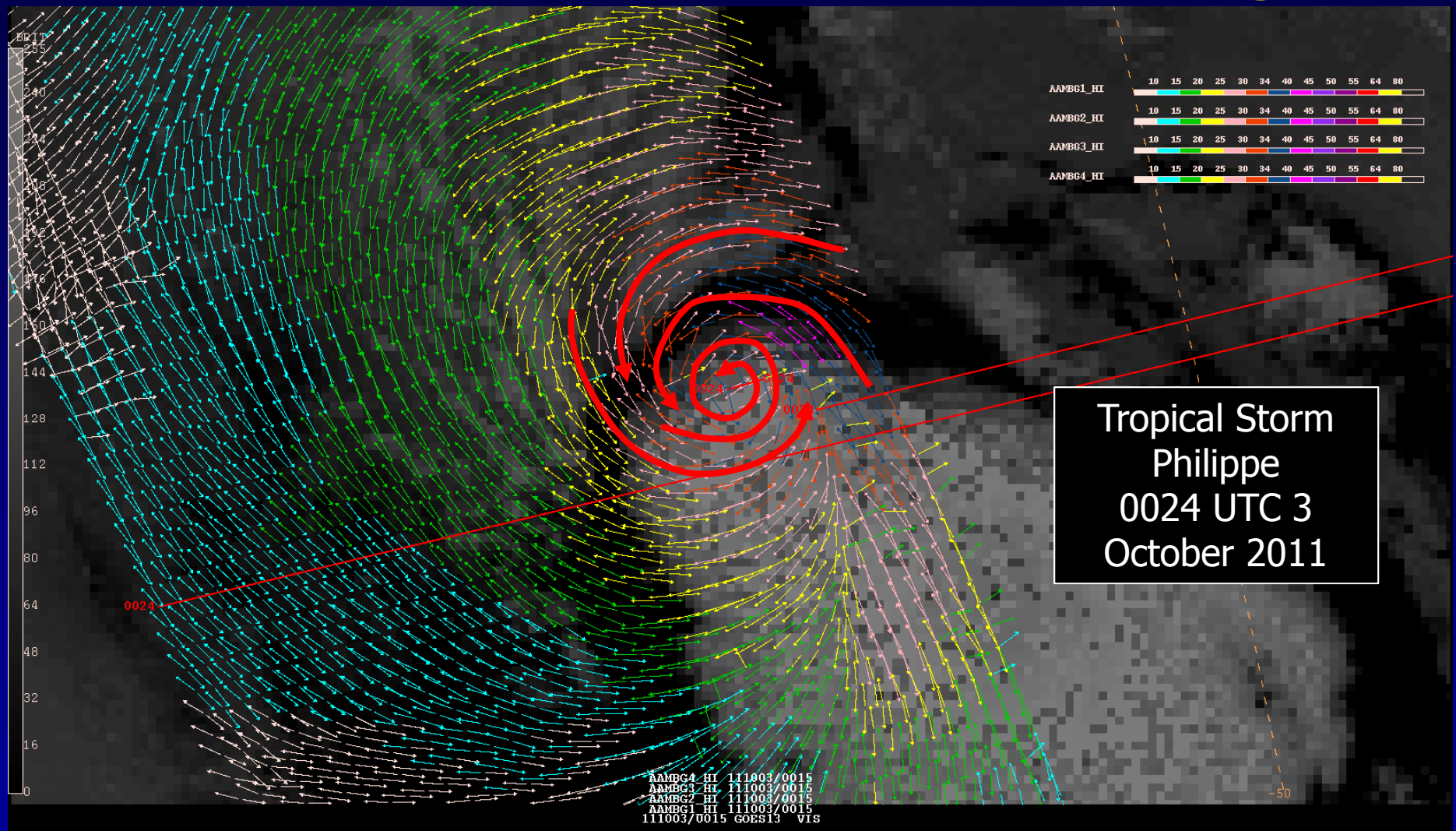


ASCAT Use in TC Intensity Analysis



- 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

RapidScat

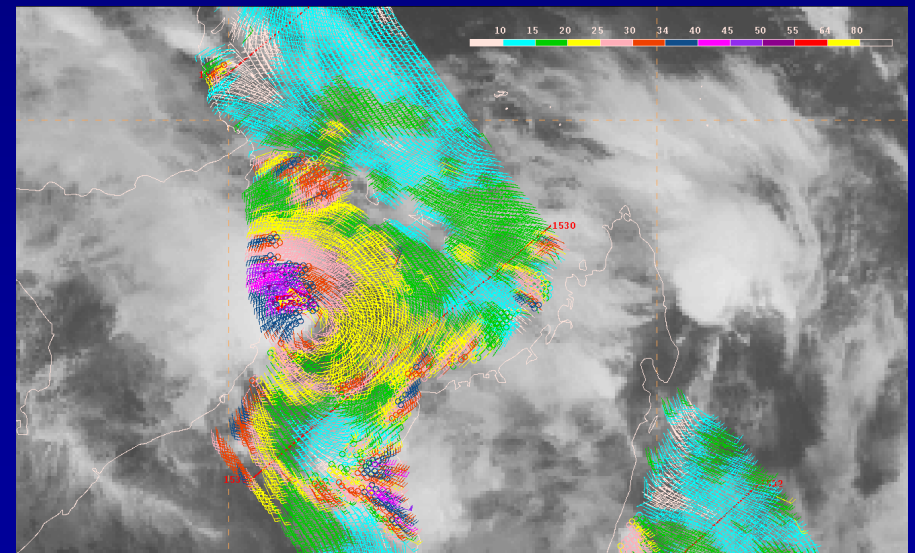
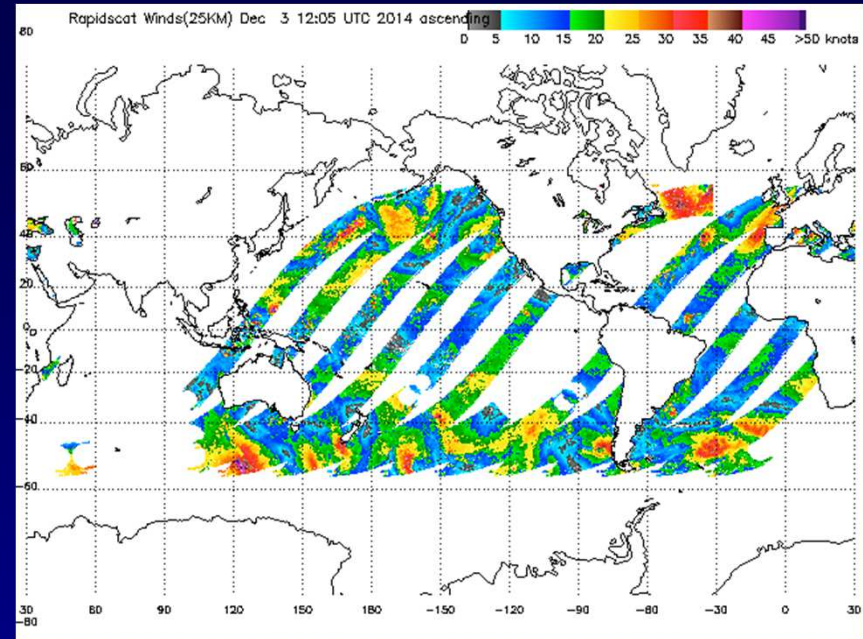
- Instrument built using spare parts from QuikSCAT
- Launched on 21 September 2014 and in orbit on the International Space Station (ISS)
- Ku-band pencil beam configuration
- 800-km wide measurement swath, but varies with altitude of ISS
- Near-real time data available from NESDIS

(<http://manati.star.nesdis.noaa.gov/datasets/RSCATData.php/RSCATData.php>) and on NRL TC page

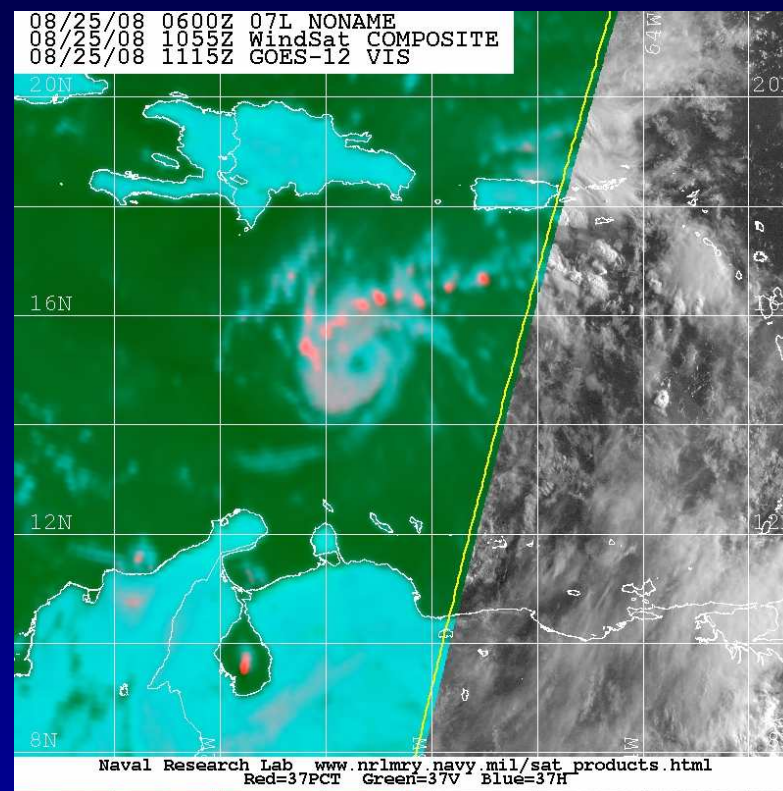
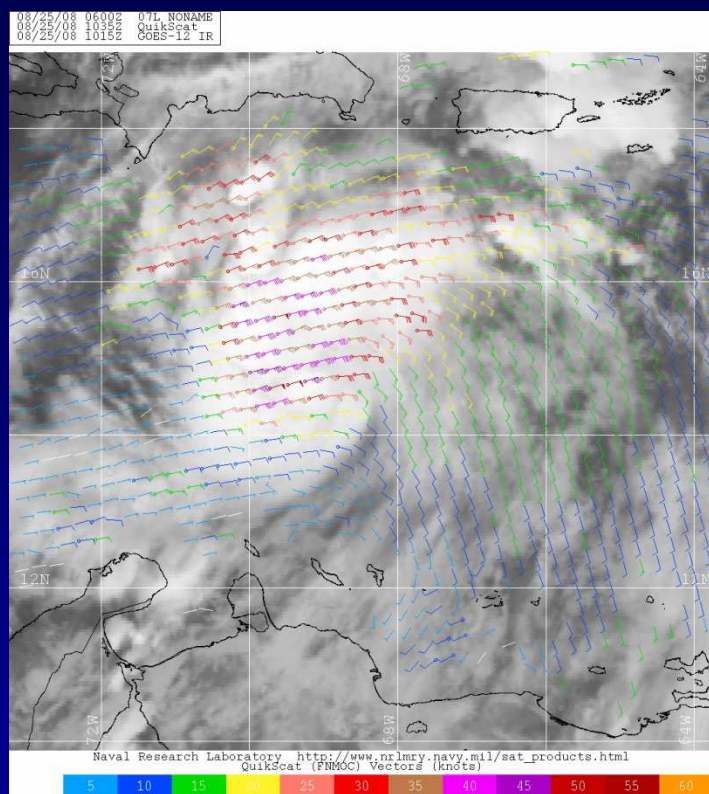


RapidScat

- ISS orbit extends to about 55° latitude, so coverage not optimized in low latitudes
- Ku-band retrievals are quite sensitive to rain, and will be rain inflated a low wind speeds even in the presence of light rain
- Interpretation in TCs is challenging due to rain
- Data will not always be available due to ISS maneuvers and activities (e.g., spacewalks)



Using Microwave Imagery and Scatterometry 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?