Satellite-Based Analysis in Tropical Cyclone Forecasting

Uses of Dvorak, Microwave and Scatterometer

by

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Satellite-based Analysis of Tropical Cyclone

Outside of the Atlantic Basin:

(No aircraft reconnaissance)

Primary means of evaluating tropical cyclones

--Synoptic data (scarce)
--Radar (localized)

(still)
Dominated by visual and infrared satellite imagery

Outline of Talk

What do you need from Satellite reconnaissance?

--Position

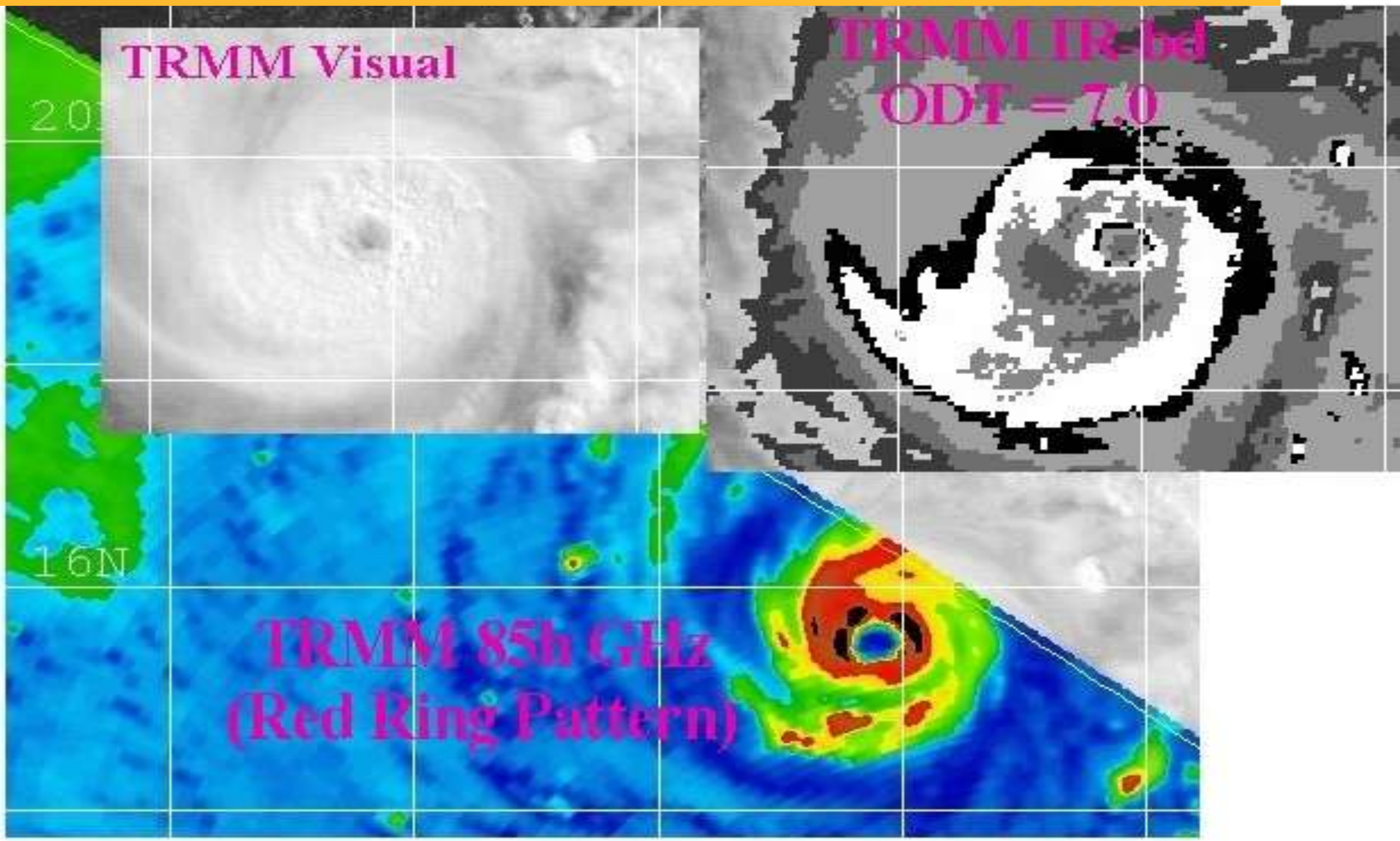
--Intensity/Change of Intensity

--Structure

--Genesis (plus dissipation)

**Need for more than one technique (e.g. IR Dvorak) to do a good analysis

Three views of Super Typhoon Podul
125-140kts



Traditional Satellite Imagery **Use of Dvorak Satellite Intensity Technique (Infrared and Visual)

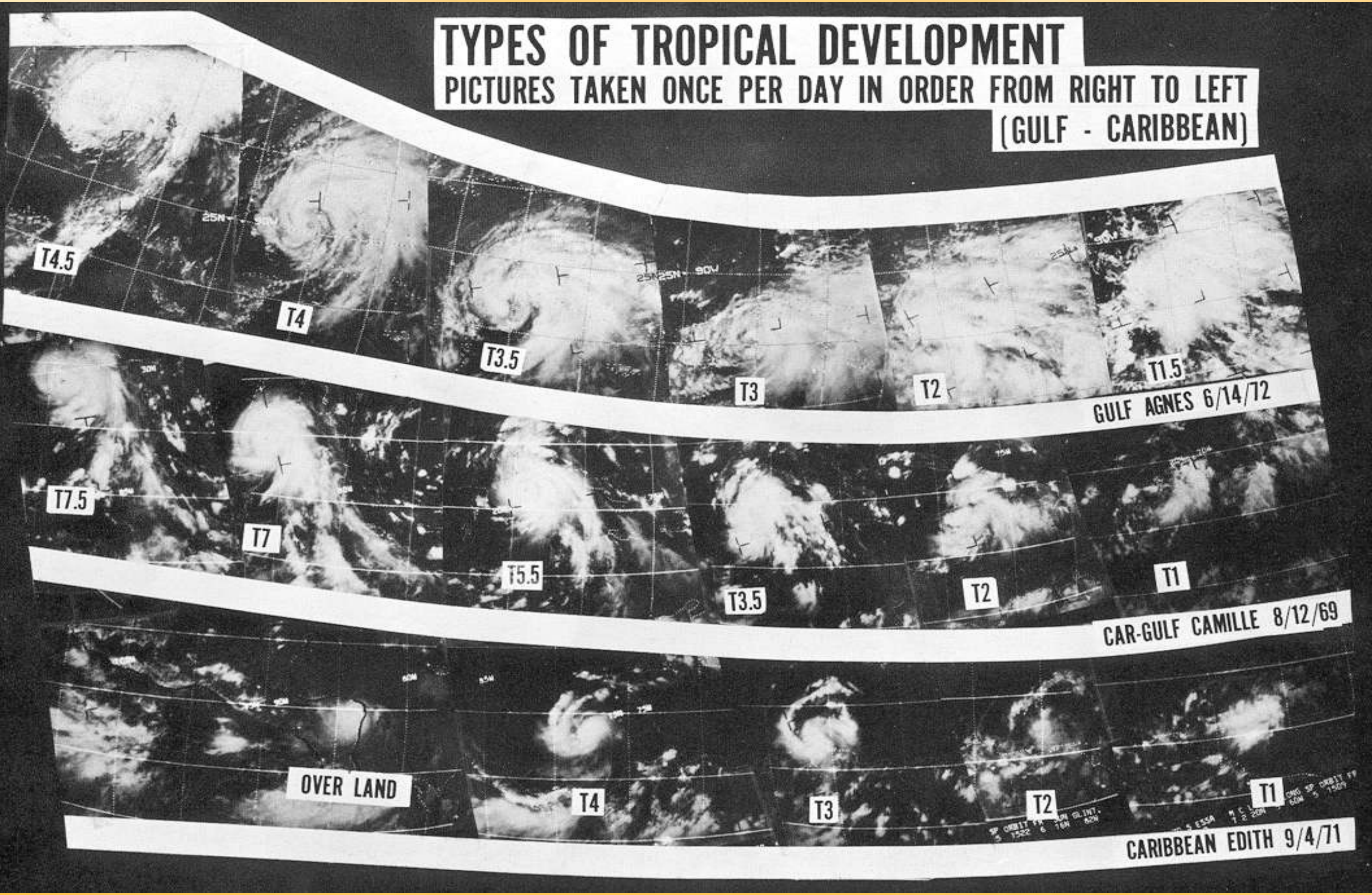
- Visual (higher resolution and animation)
  - Is the low level visible, obscured by clouds?
  - Eye or overshooting tops near an apparent center
  - Watch out for mid-trop circulations and outflow boundaries
- Infrared (24hr view, Temp at the top)
  - Good for well developed systems (no shear)
  - Very difficult in early stages, shear, multi-vortices , heavy mid-upper level clouds, etc etc etc.

What is the Dvorak Technique?

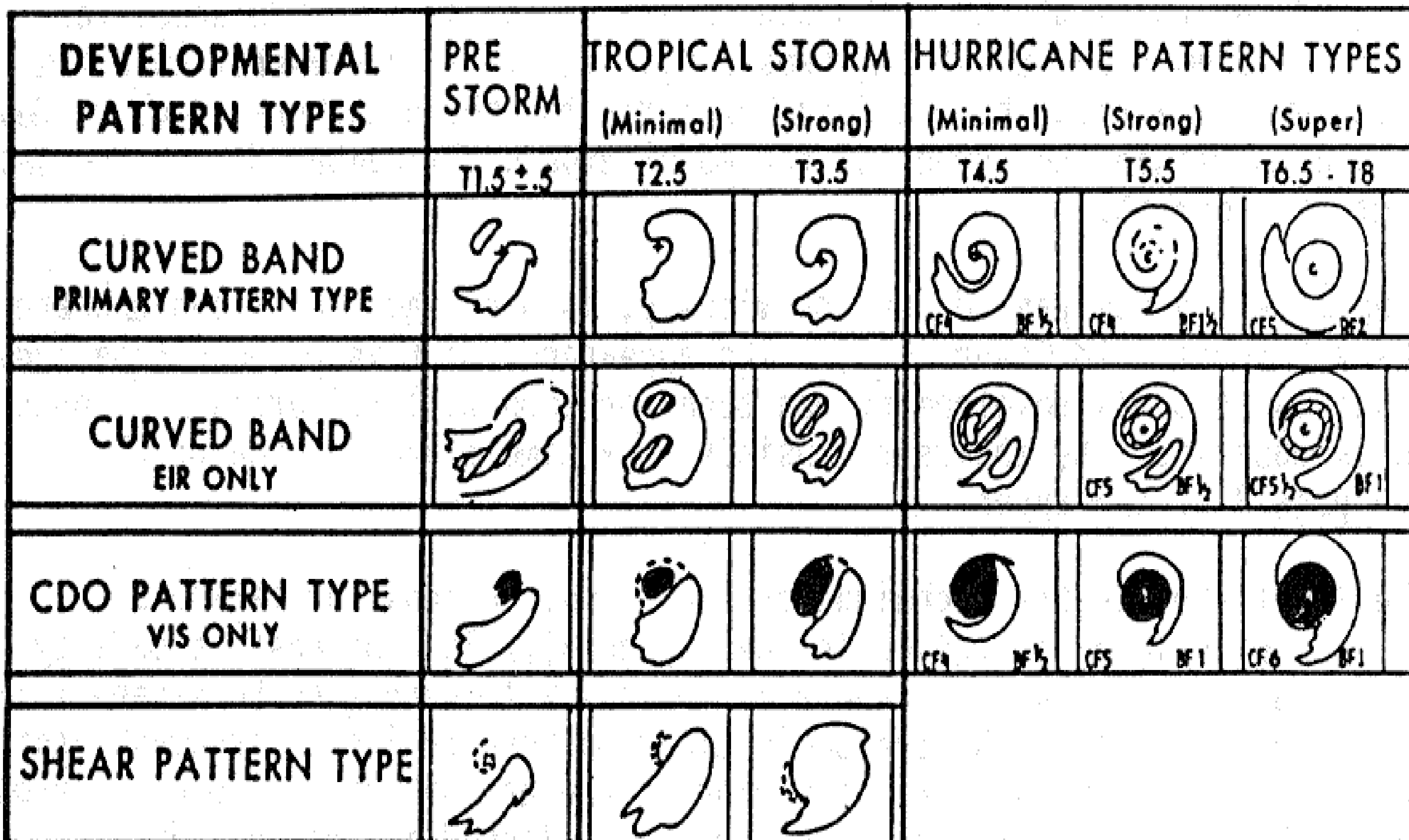
- A statistical method for <u>estimating</u> the intensity of tropical cyclones from satellite imagery
- Can use both Infrared and Visible imagery (maybe MI and SCAT can help)
- Based on a "measurement" of the cyclone's convective cloud pattern and a set of rules

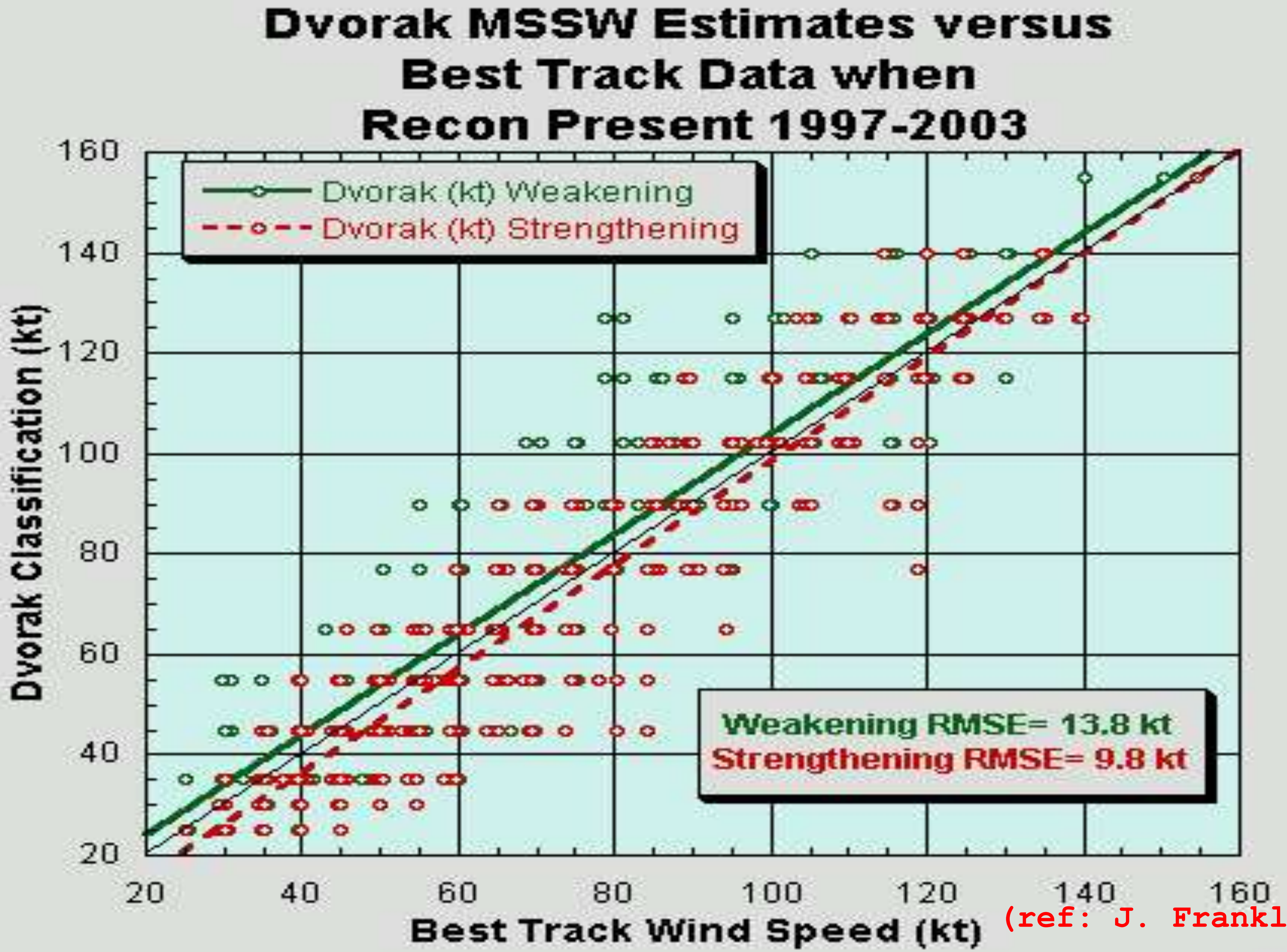
**This technique DOMINATES all others for identifying TC intensity (primarily the IR) in the TC Warning Centers

Dvorak Cloud Patterns



Dvorak Technique Cloud Patterns





Dvorak MSSW Estimates versus
Best Track Data when
Recon Present 1997-2003
Dvorak (kt) Weakening
Dvorak (kt) Strengthening
Weakening RMSE= 13.8 kt
Strengthening RMSE= 9.8 kt
Dvorak Classification (kt)
Best Track Wind Speed (kt)
20
40
60
80
100
120
140
160

(ref: J. Frankl

Chip Guard’s Summary of Why Dvorak Works

Contains the basic ingredients to ‘make’ a Tropical Cyclone

- **VORTICITY**
- **SHEAR**
- **CONVECTIVE VIGOR**

Dvorak Technique
(problem areas)

- From the late 70s
- Updates still based on initial premise
- Primary tool for intensity, outside of aircraft reconnaissance
- Often little ground truth to ‘correct’
- Many documented situations where Dvorak is suspect

THE DVORAK TECHNIQUE
(Is there room for improvement?)

- Visual technique developed in mid 1970s
- IR technique developed in late 70s/ early 80s
  - Animation not part of technique—but since adapted for better positioning
  - Not designed for 'midget-type' TCs, 'Truck Tire eyes,
  - Not designed for TCs originating as monsoon depressions (i.e. large trough in sheared environment), ST & ET systems
  - Only "sees" clouds
  - Becoming 'automated', but still takes a <u>real long</u> time to learn to do well
  - Embedded IR procedure has very large variability
- Ref: 2006 BAMS article, AMS Tropical Conf proceedings

Dvorak Technique

- Even when technique ‘works’, many errors
  - Easy to do, but difficult to do correctly
  - Many times junior forecaster/analyst (with little extensive experience…NEED 2 seasons, minimum)
  - Use of spiral band curvature <u>over used </u>(easy)
  - TC Forecaster is often not the satellite analyst
    - Requires communication and questioning for Forecaster to understand the difficulty
    - What is the forecaster’s experience with Dvorak?

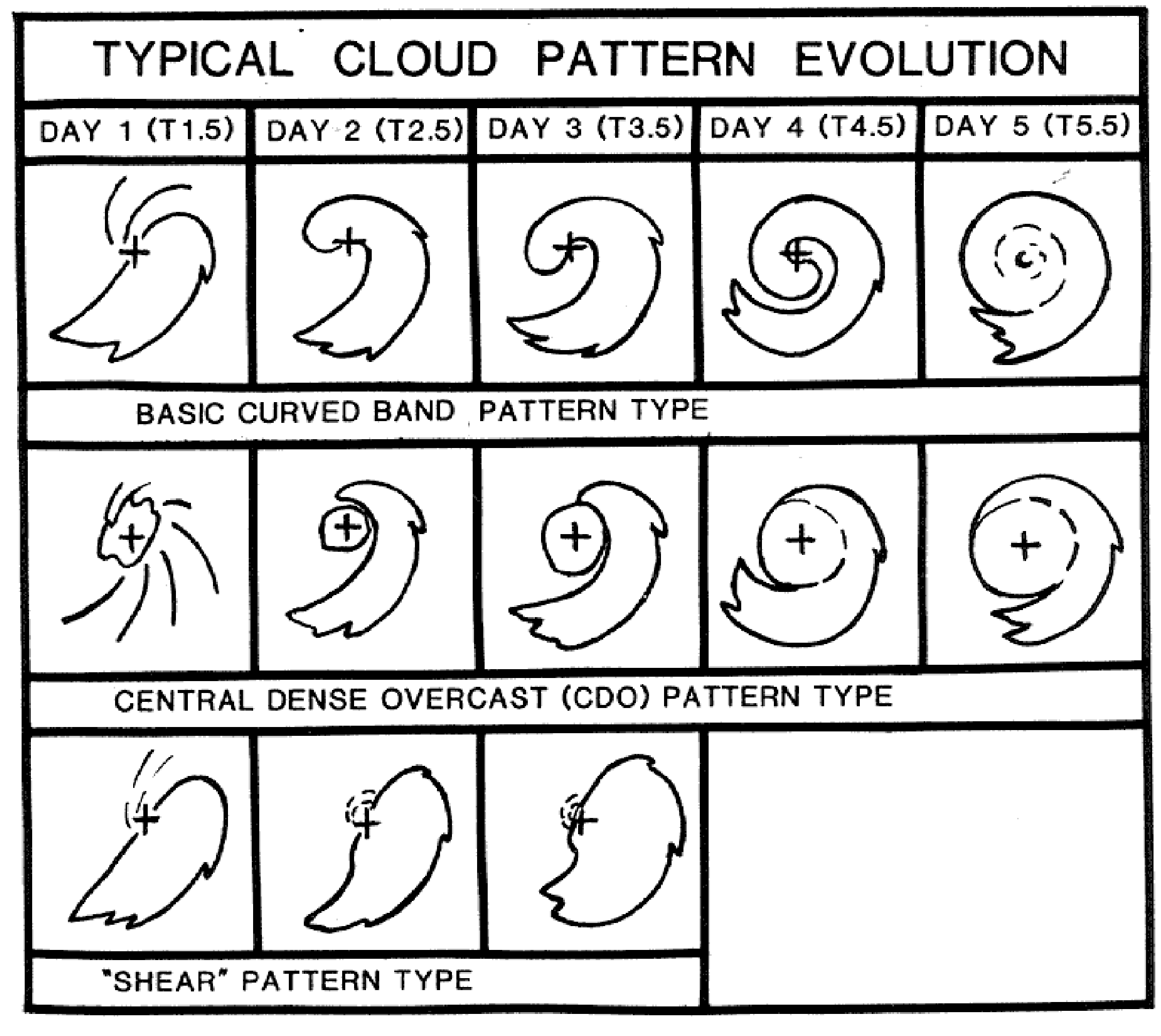
Positioning Difficulties (#1)

Cloud System Center

SBC

CDO

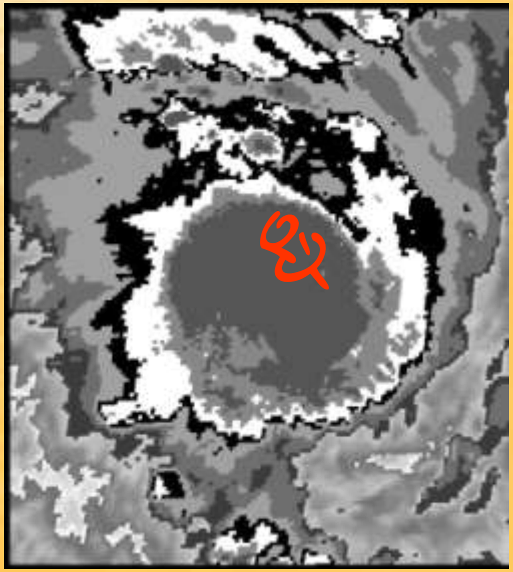
Shear



Positioning Difficulties

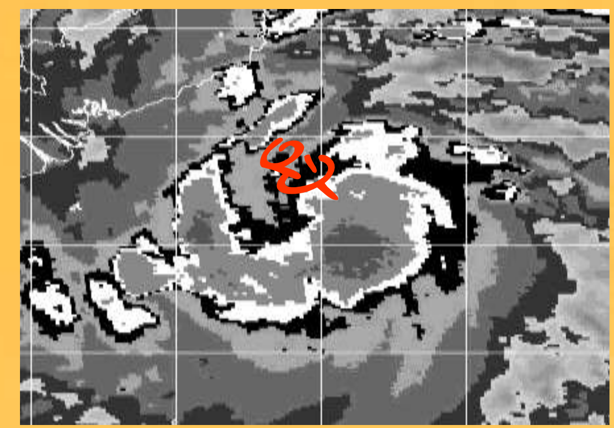
Embedded Center (Difficult) - IR

- Look for a warm spot.
- Look toward the edge with the tightest temperature gradient.

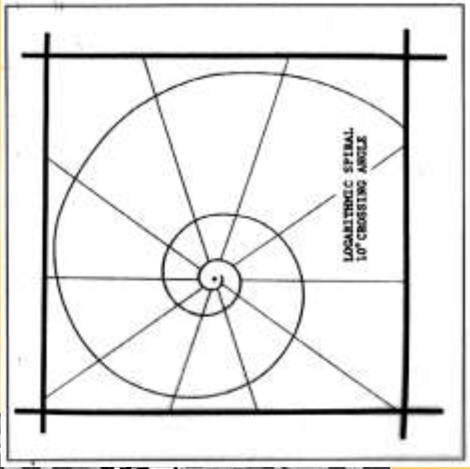


Spiral-Band Curvature IR or Vis (Often Difficult)

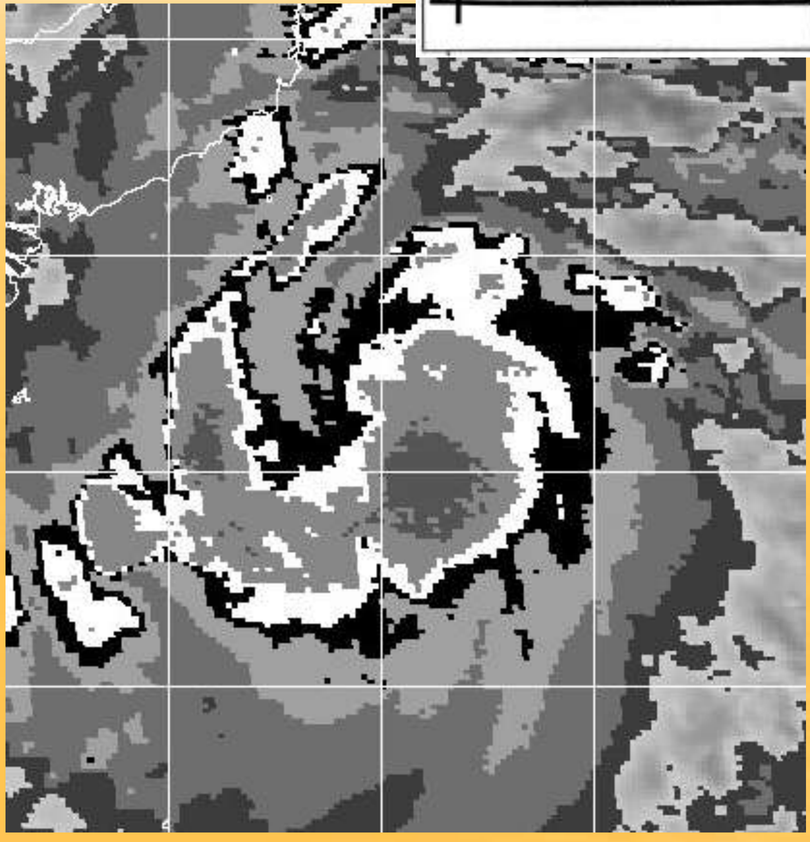
- Use the LOG10 spiral overlay.
- Place it so the curve lies as close as possible to the connective bands.
- Follow the curve to the center.

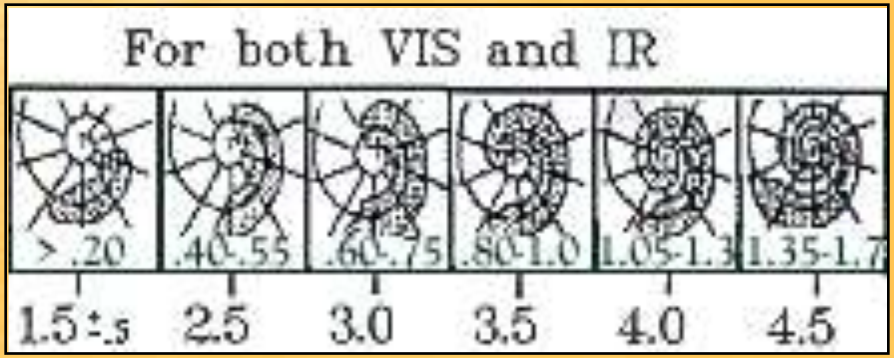


Too much Spiral Band Curvature (SBC)

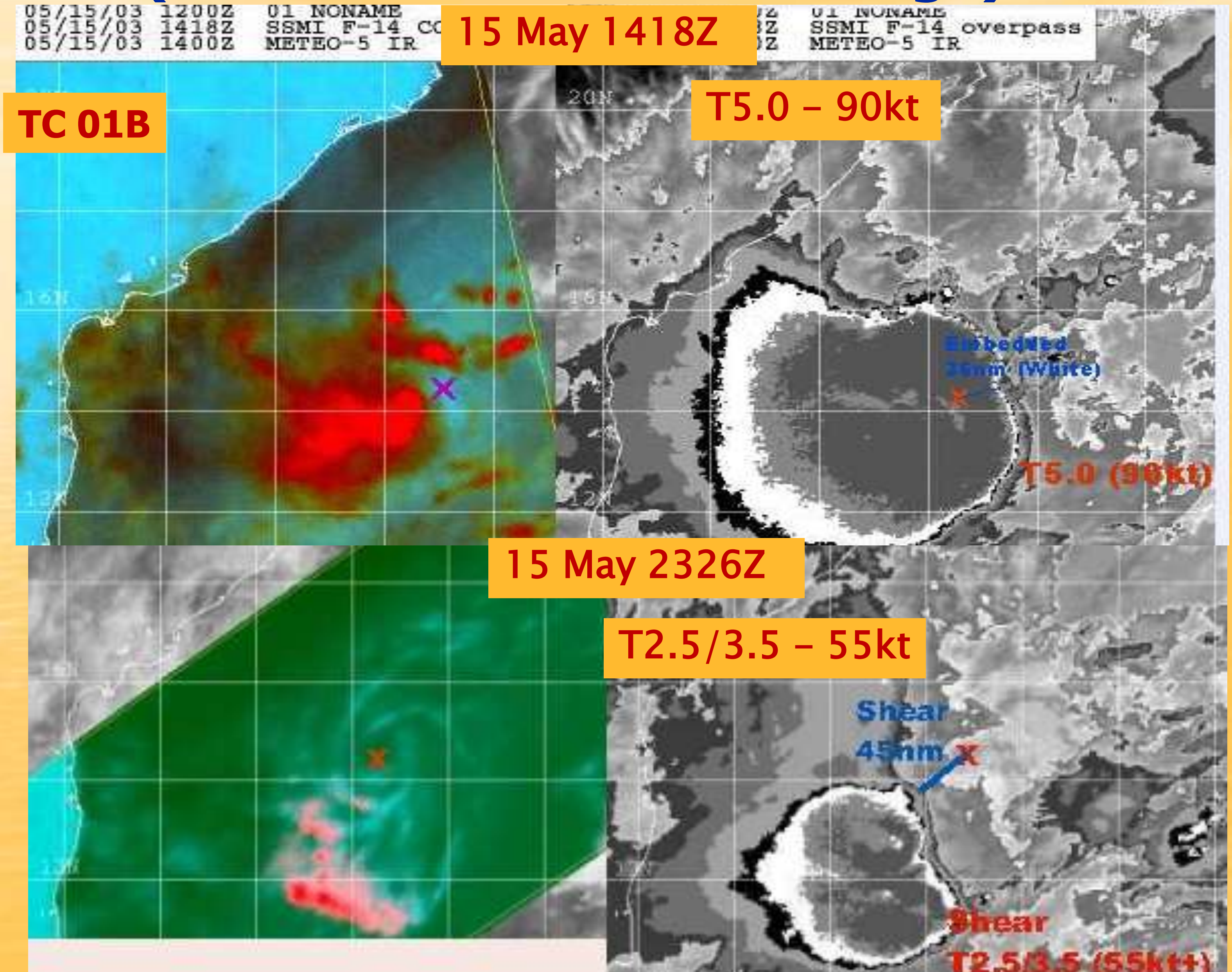


- Use a LOG10 spiral overlay.
- The spiral should lie along the axis of the of the band, and roughly parallel the inside edge of the band.
- Measure the arc length.





Do you remember this embedded IR Techniques (use with MI Multi-Coverage)



Comparison between JTWC and JMA (non-agreement between TC centers)

- 1′ vs. 10′
- Modification to high end scale (based on an observation study by Koba, et al. 1991)
- See T# correspondence (however, satellite interpretation of definition of T# is the <u>same</u>)

Comparison of Dvorak Intensities JTWC vs. JMA

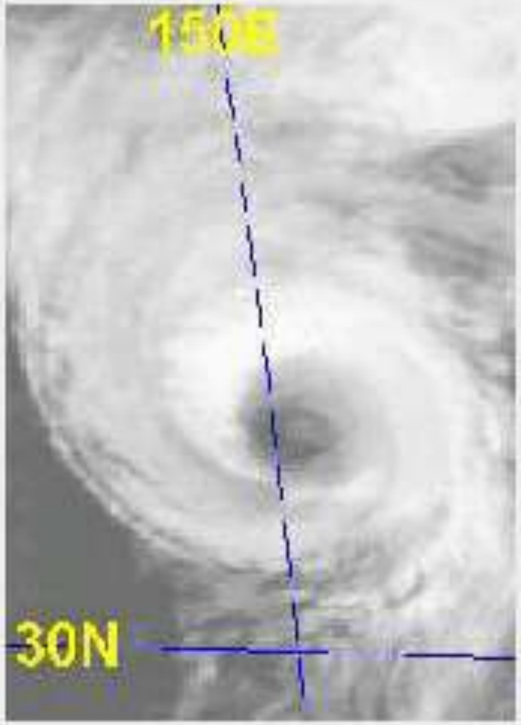
(Conversion to 1

T Number	JTWC (1min)	JMA (10min) →	10′ to 1′
2	30	30	33.6
2.5	35	35	39.2
3	45	45	50.4
3.5	55	55	61.6
4	65	65	72.8
4.5	77	70	78.4
5	90	77	86.2
5.5	102	85	95.2
6	115	93	104.7
6.5	127	100	112.0
7	140	107	119.8
7.5	155	115	128.8
8	170	122	136.6

Mark Lander’s ‘Truck’ Tires

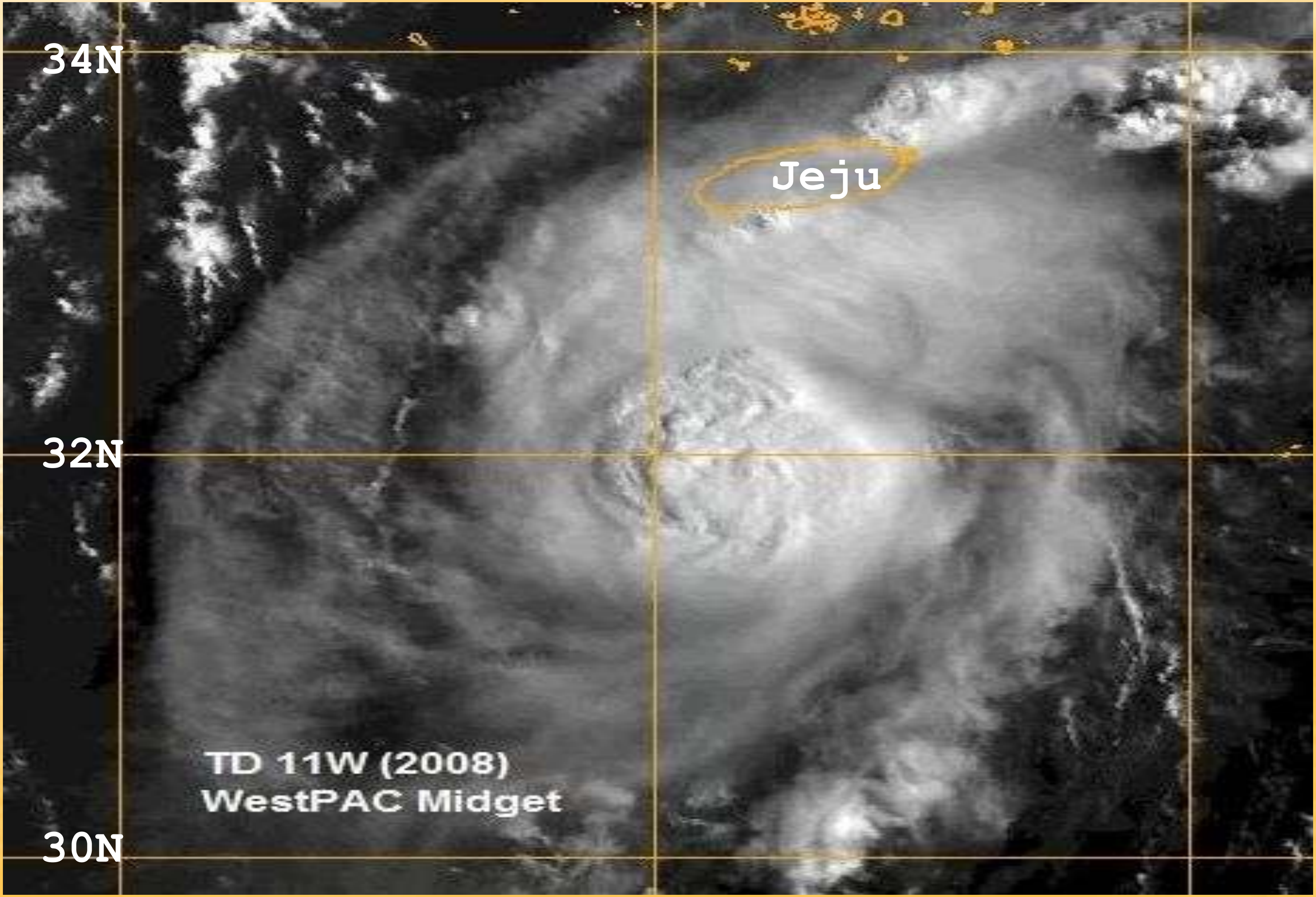
06 AUG 0230Z

07 AUG 0130Z

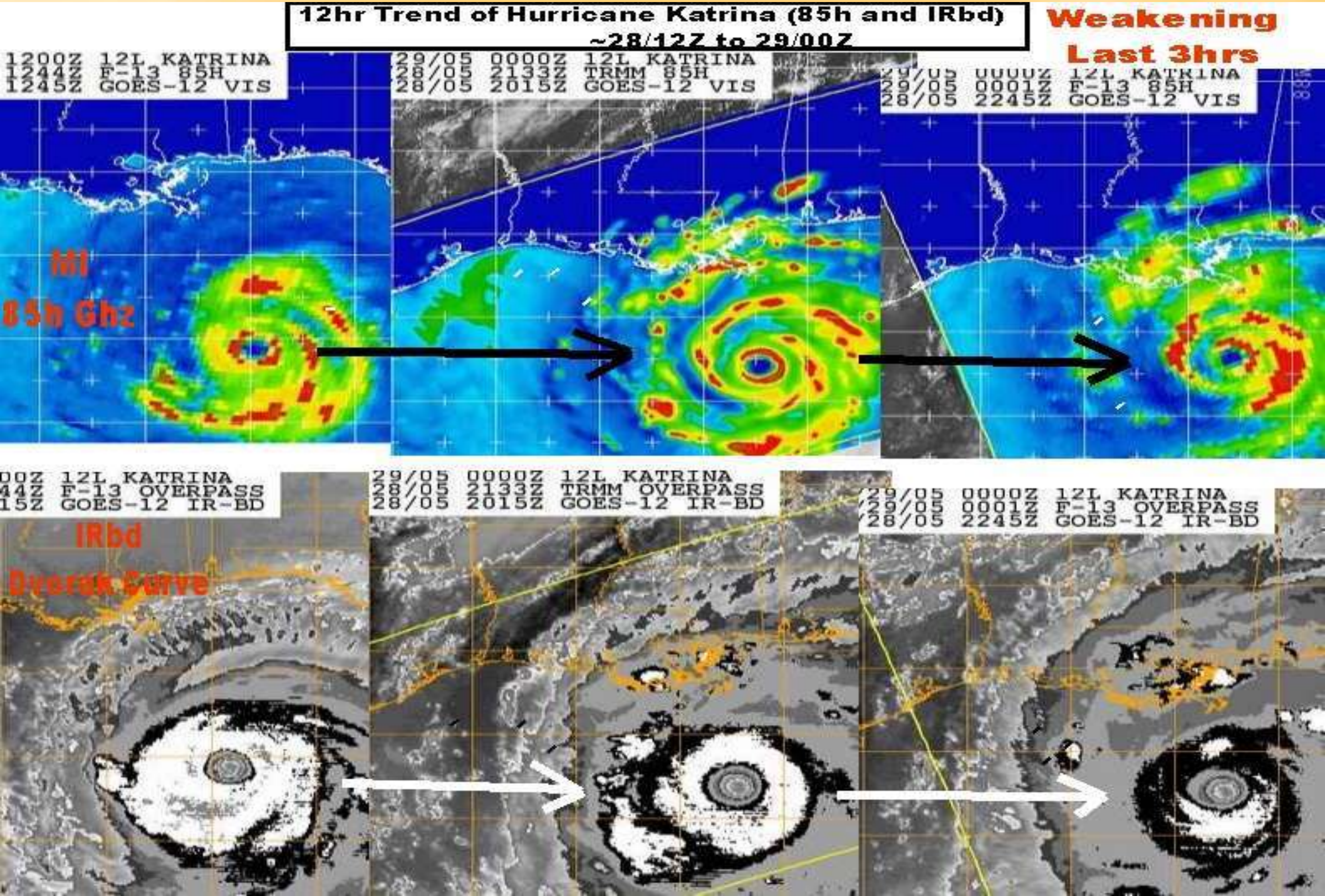


08 AUG 0130Z

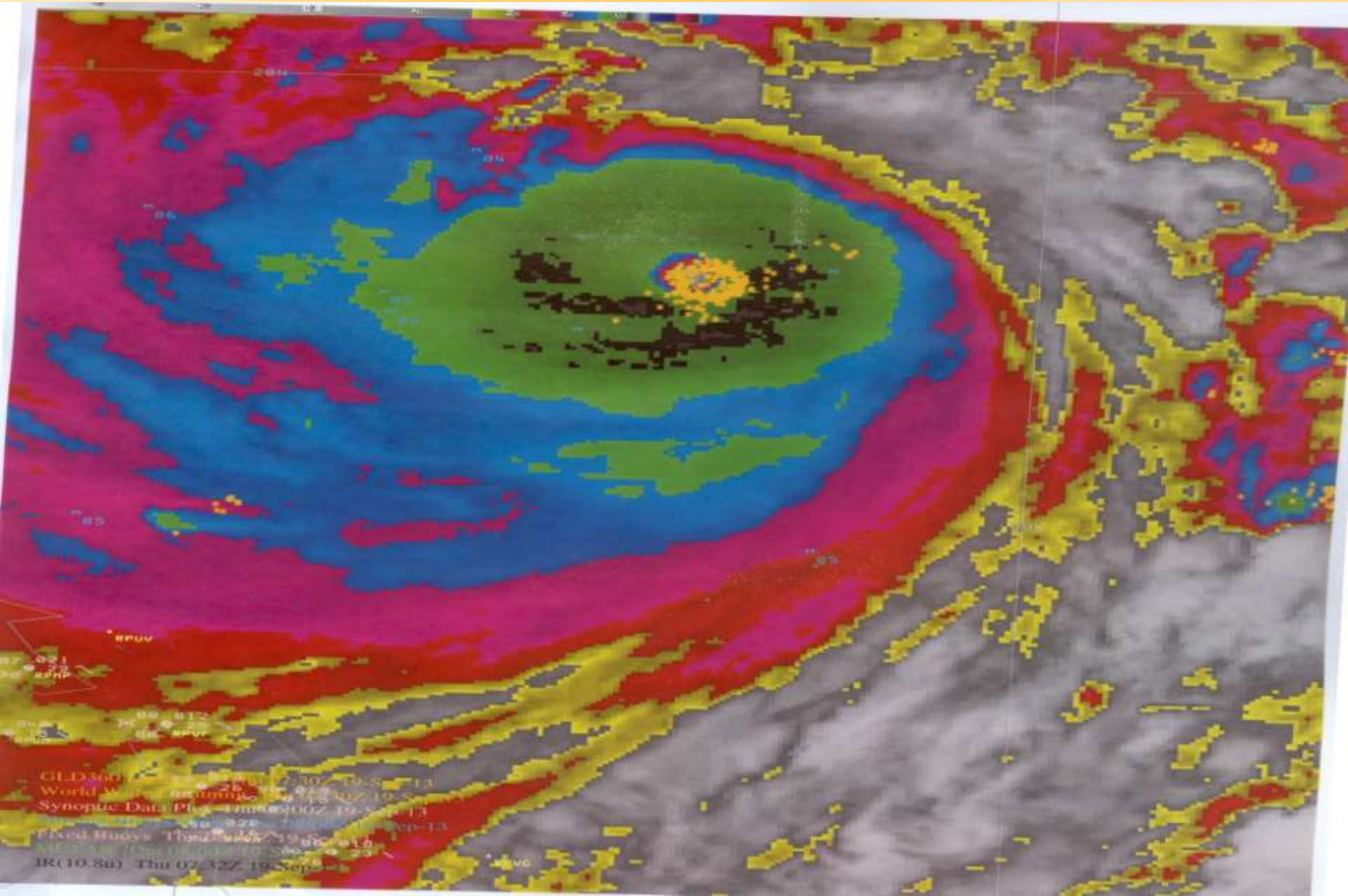
Midgets



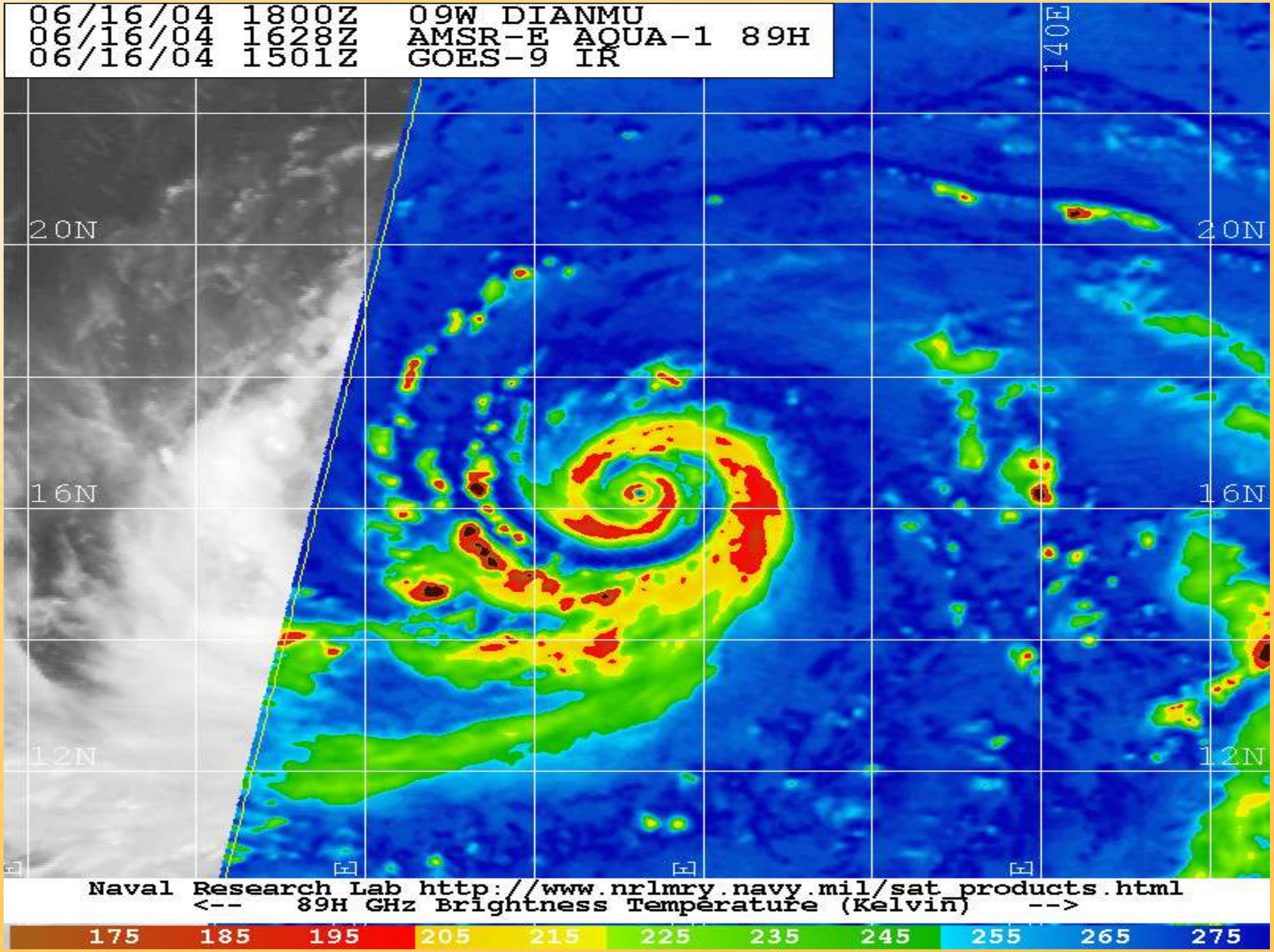
Eye-Wall Replacement Cycle



TY Usagi Rapidly Intensifying (RI) Lightning in Eye-Wall



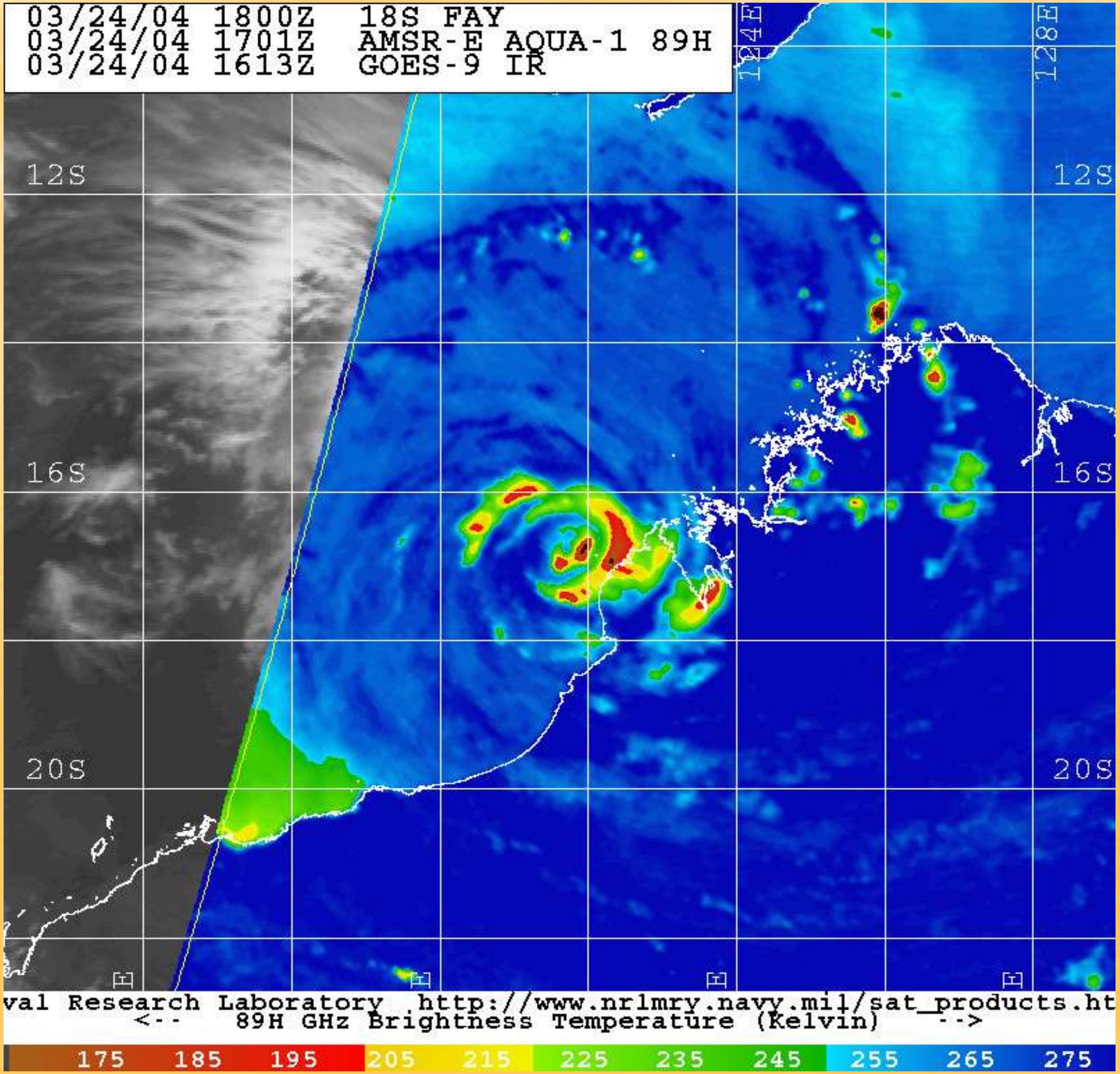
Perhaps we need to (finally) add a Microwave Procedure?



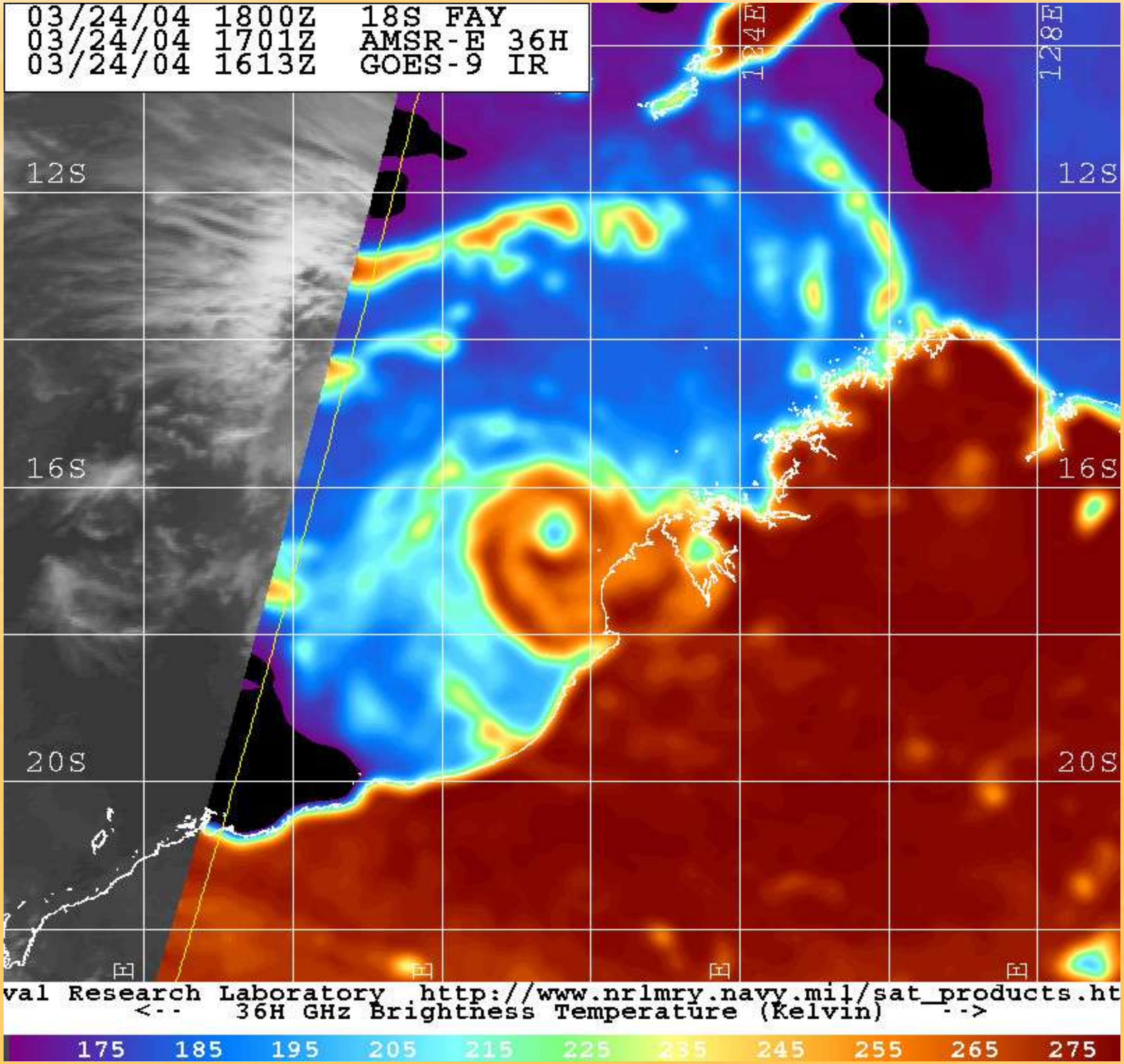
ADVANTAGES OF USING 85 GHz AND 37 GHz Microwave Imagery

- 'Sees' through clouds
- Positioning of TCs in difficult situations (especially in EARLY stages of development)
- View of convective rain bands is more DIRECTLY related to intensification of the TC
- Less delay in seeing *changes* in intensification
- Lower altitude of TRMM/WindSAT has increased resolution in BOTH 85 and 37 GHz
- Can (should be) still use <u>in conjunction</u> with existing techniques (e.g. IR Dvorak and Scatterometer data)

Some times the 87 GHz Imagery is not enough: Where's the Eye of the Storm?



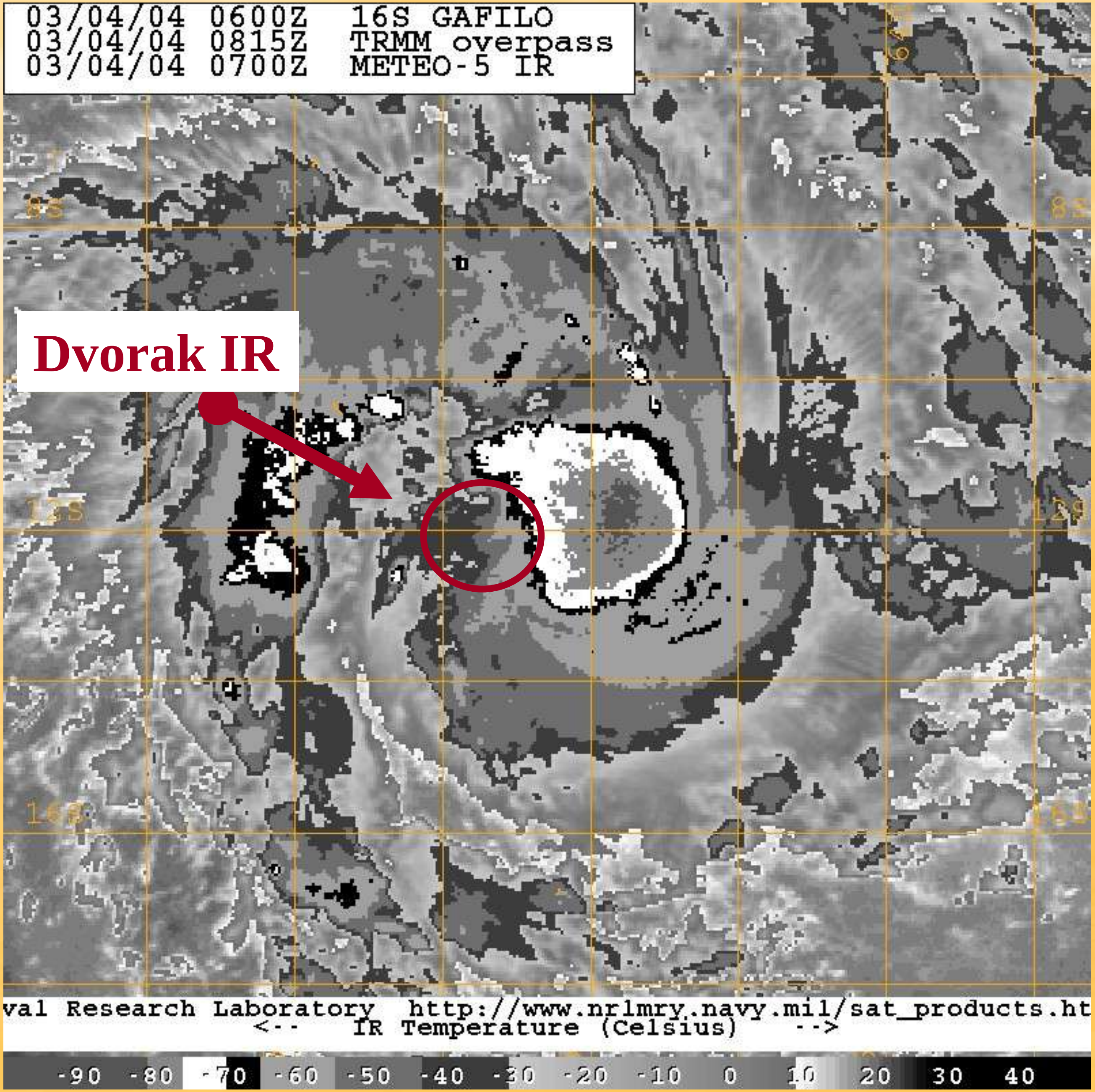
Another case for Using the 37 GHz: Eye Revealed



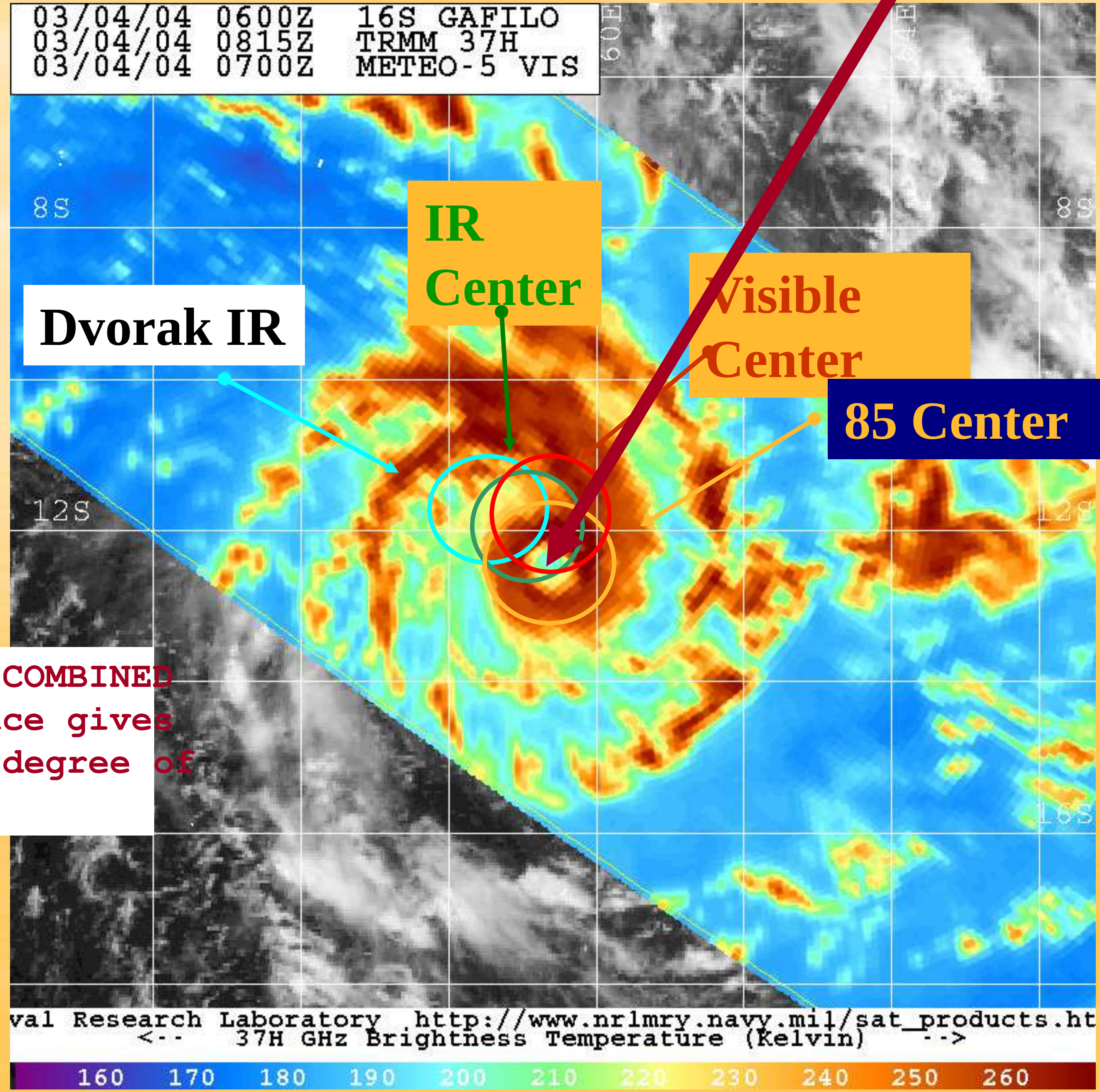
Use of Microwave and Dvorak

- Positioning is often superior to Vis/IR
- Problems
  - Frequency of passes (and correspondence to other data)
  - Resolution
  - Some interpretation
  - (still) No current intensity technique (partial by CIMSS, Univ of Wisconsin)

Where's the Center? Need help for Dvorak IR

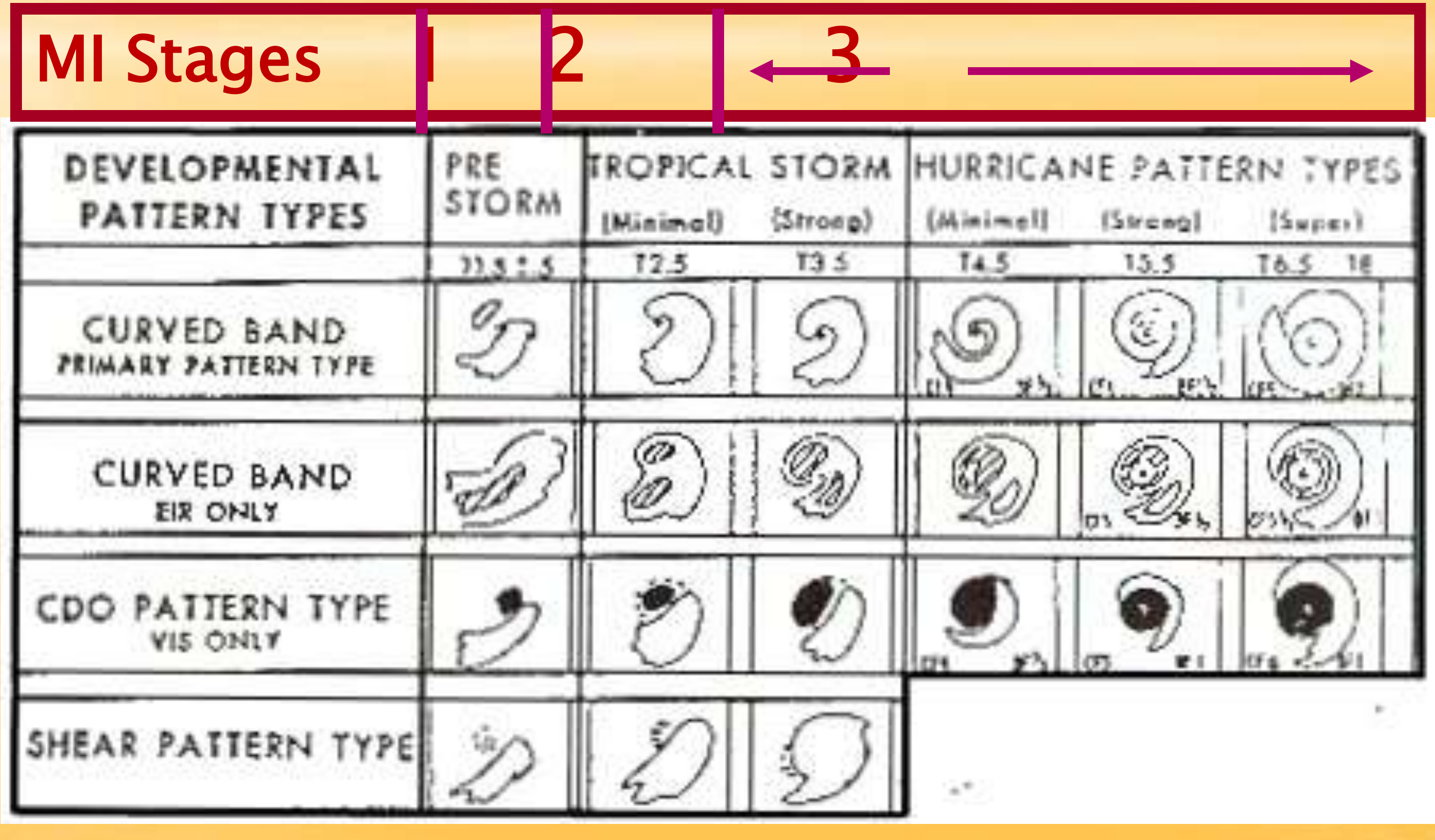


Now, where's the Center? TMI 37 GHz**



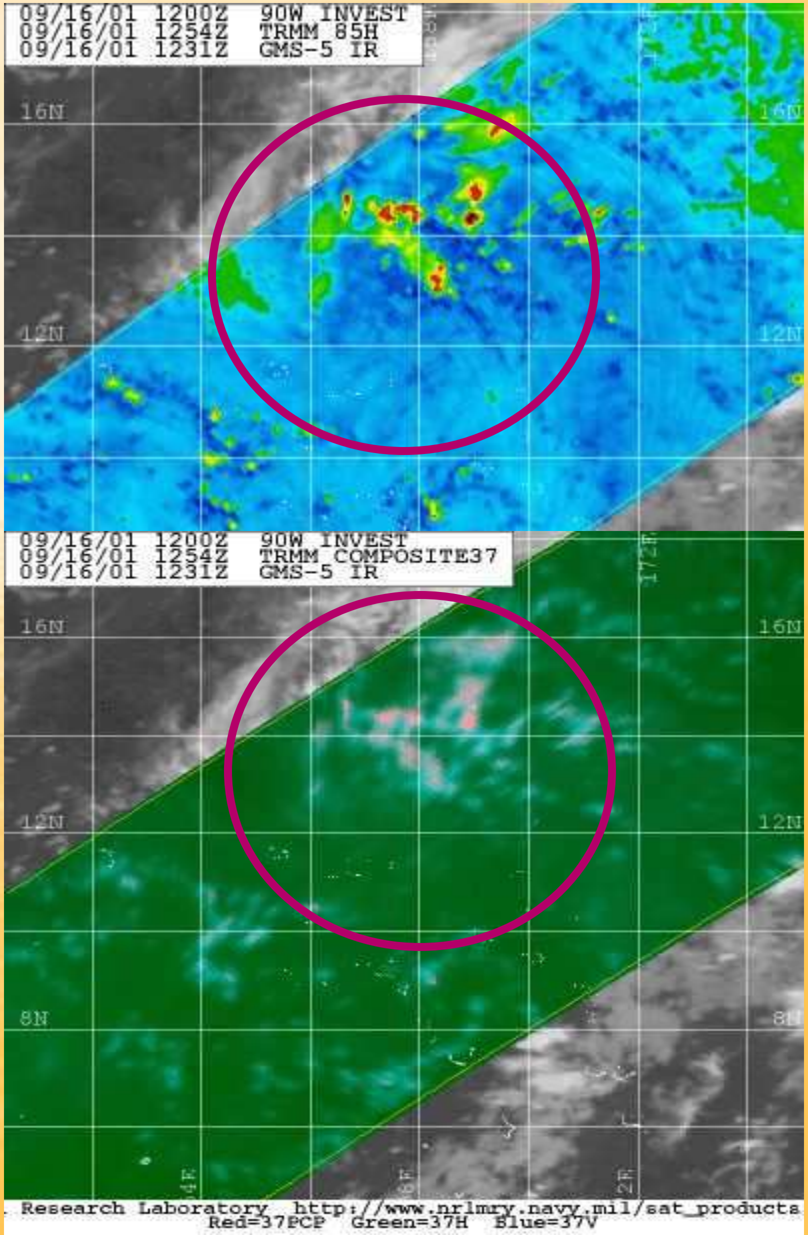
Actually, COMBINED Reconnaissance gives the highest degree of Confidence

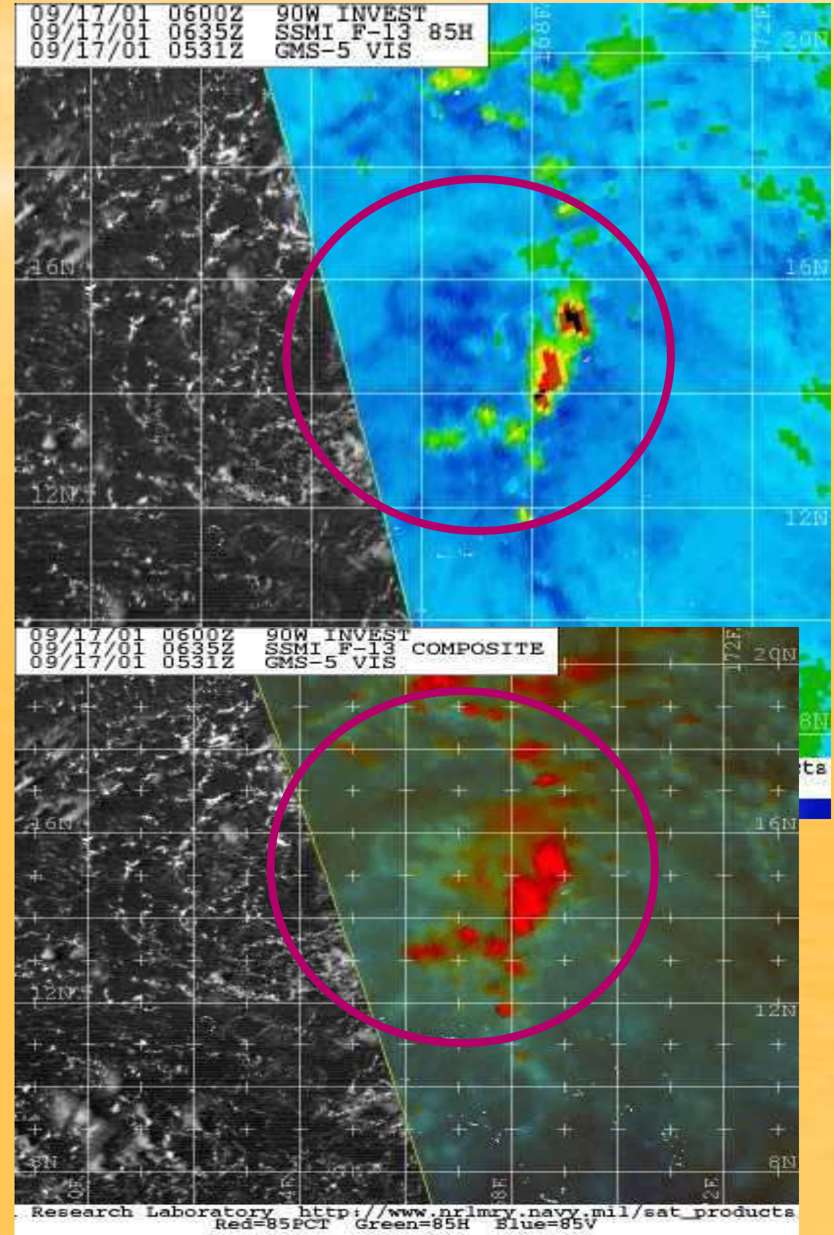
Comparison of Dvorak patterns with first 3 MI Stages in a TC Life Cycle



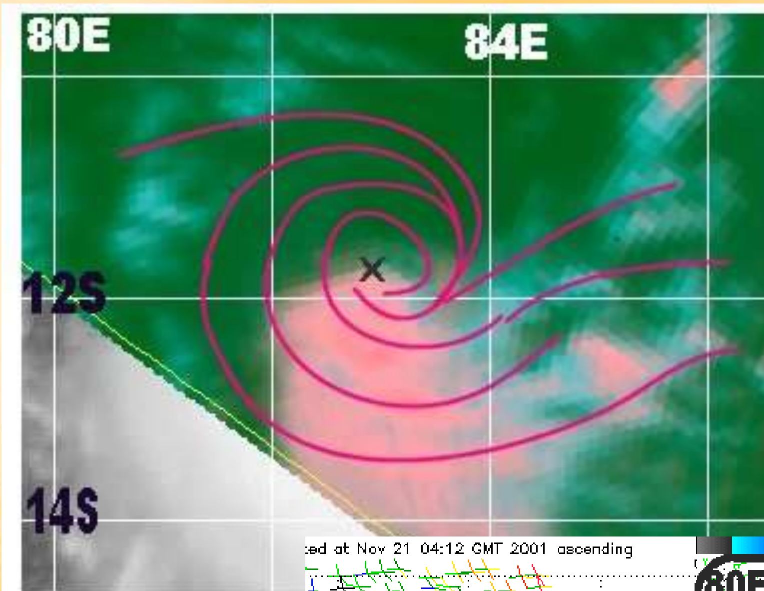
(Pre-Typhoon Francesco < = 25kts)

16 Sep 1200 – 2 days before 17 Sep 0600 – 1 day before

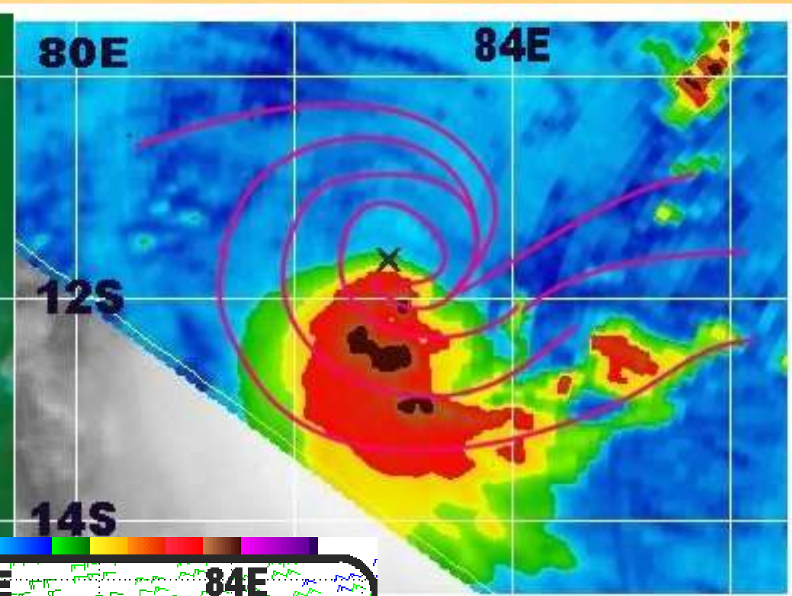




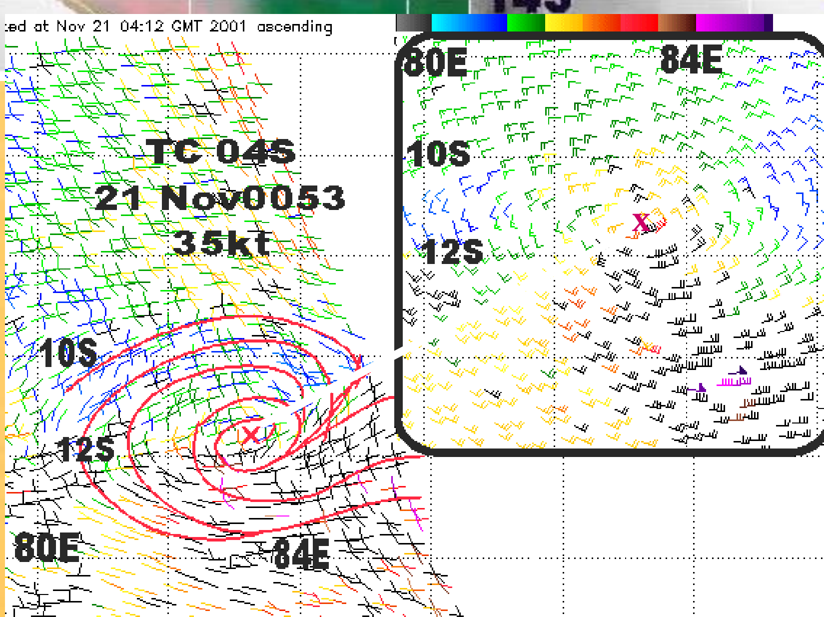
Stage 2 – Shear pattern (35kts)



37color



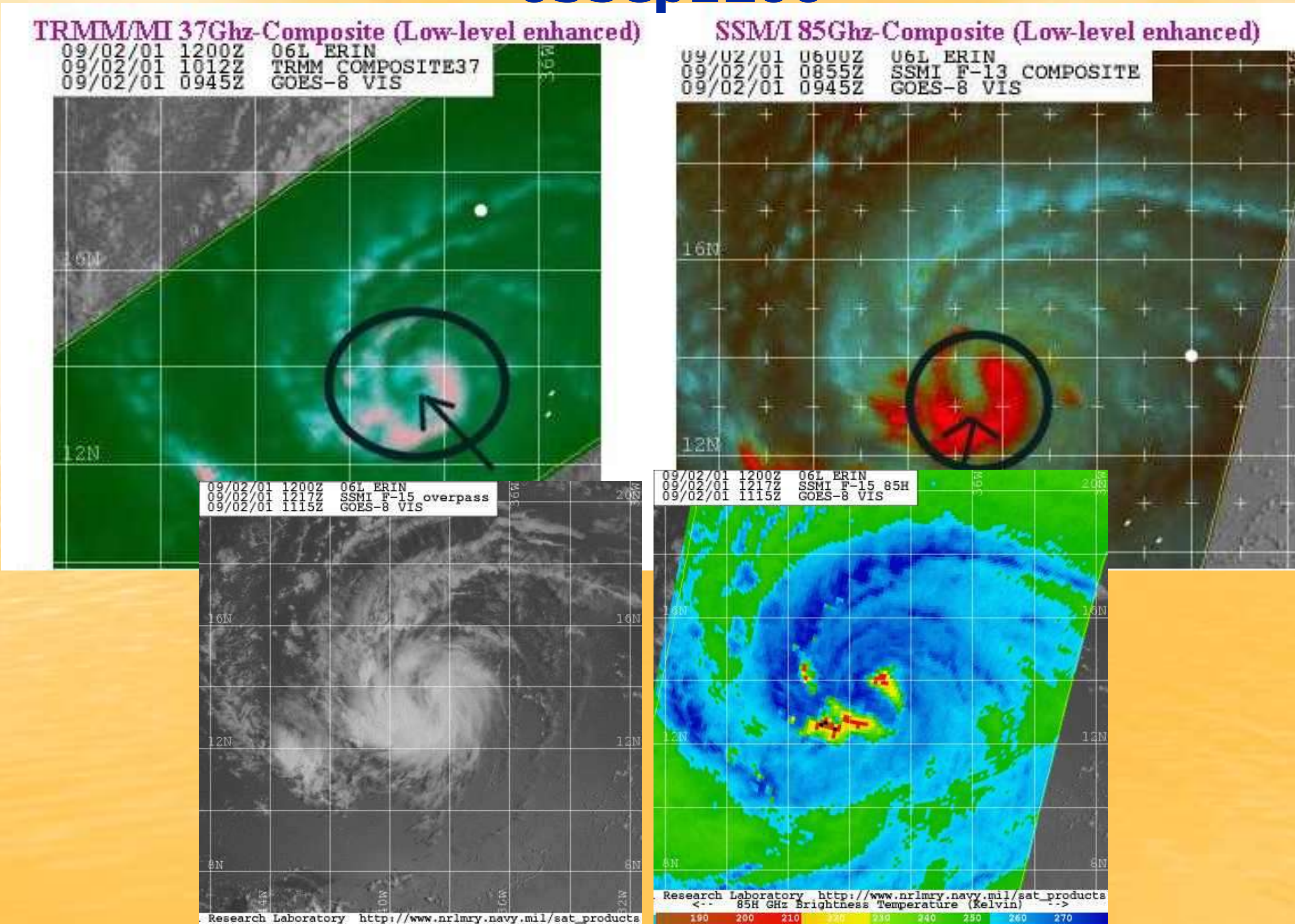
85h



QuikSCAT Ambiguity

Each system may require a varied set of microwave imagery to best bring out the best features

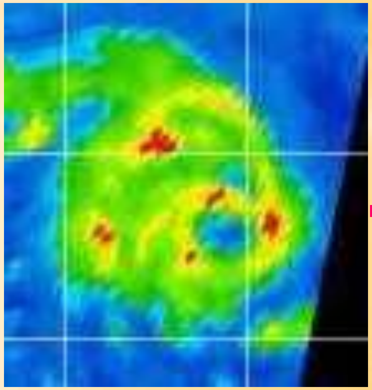
Tropical Storm Erin (06L) 45kts-- Stage 2 03Sep1200



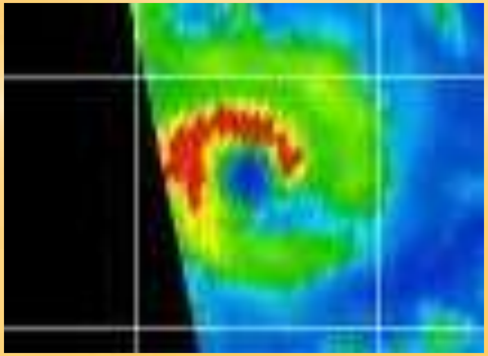
Possible ways to Supplement the Dvorak Analysis with Microwave Imagery

– Provide for an integrated positioning technique (spiral band curvature and shear)
- Precision in use of embedded IR technique
- TC life cycle supplement (in MI)
- Early genesis identification (pre-T#1)
- Identifying both potential 'rapid' and 'delayed' intensification scenarios ('MET')
- Identification of 'peaking' and 'MET' changes
- Intensities during Extratropical Transition and dissipation scenarios
- Integration with 'other' techniques, including use of AMSU, Scatterometer, AODT, etc..

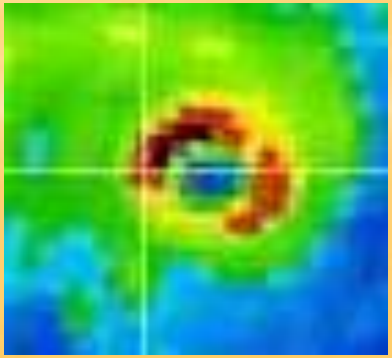
EVALUATIONS OF CAT5/SUPER TYPHOONS (85h) VIEWS: Time changes in red inner eyes



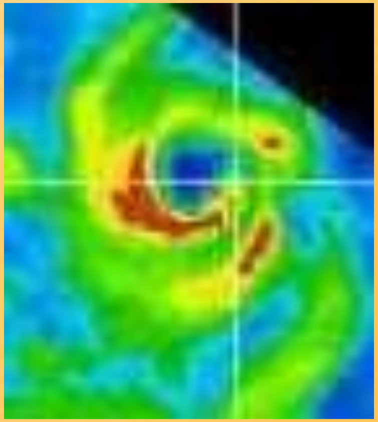
TC Susan 70kt -26hr



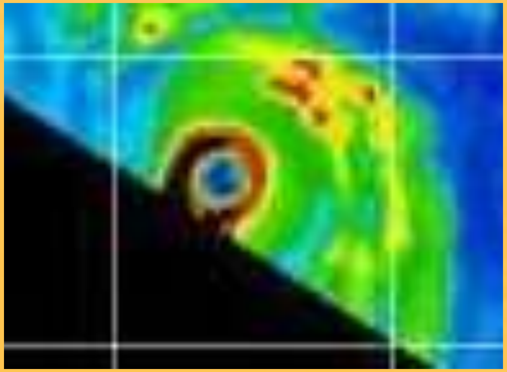
TC Susan 95kt -13hr



TC Susan 120kt -06hr



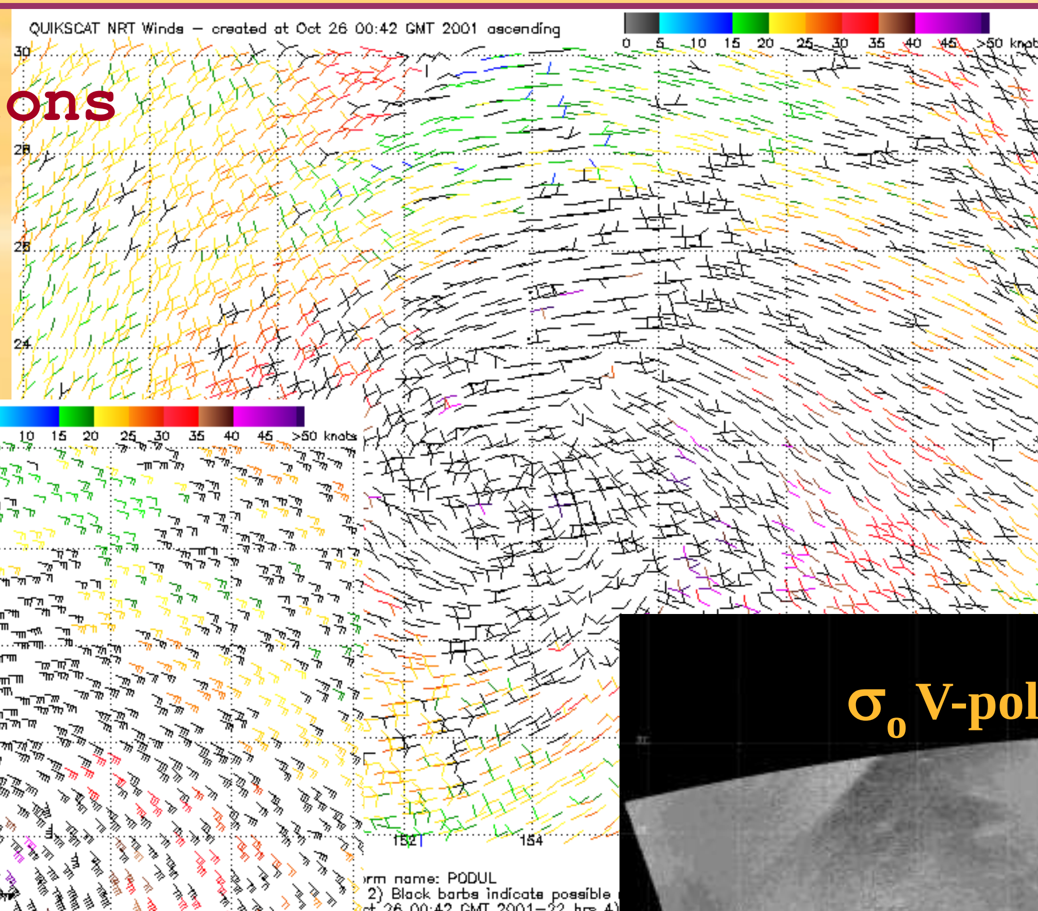
STY Zeb 95kt -24hr



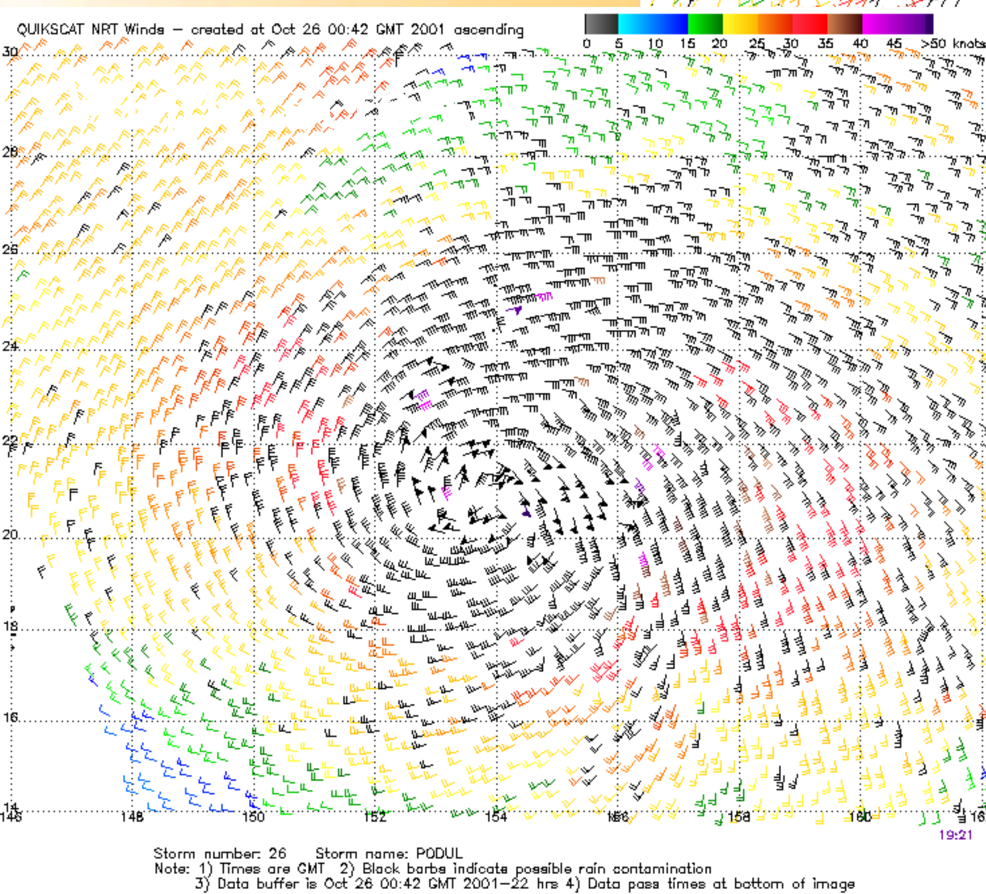
STY Zeb 140kt -00hr

3-views of Scatterometer

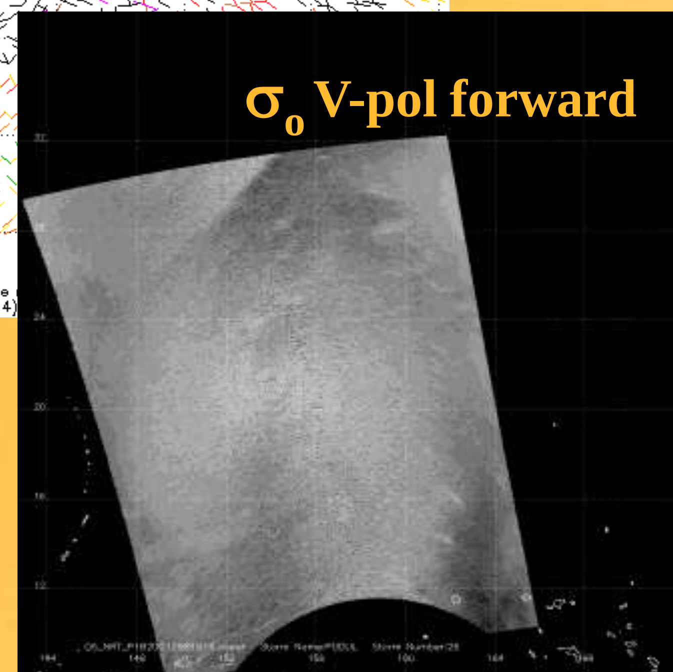
Ambiguity Solutions



Wind Vectors



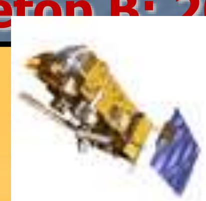
NRCS



Scatterometer Platforms

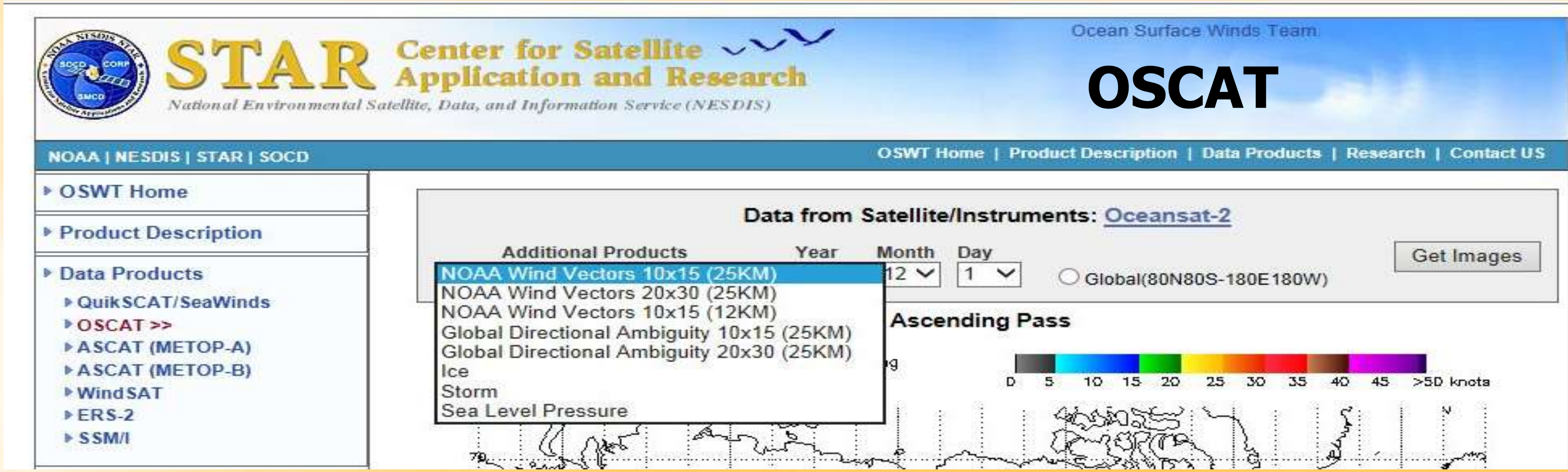


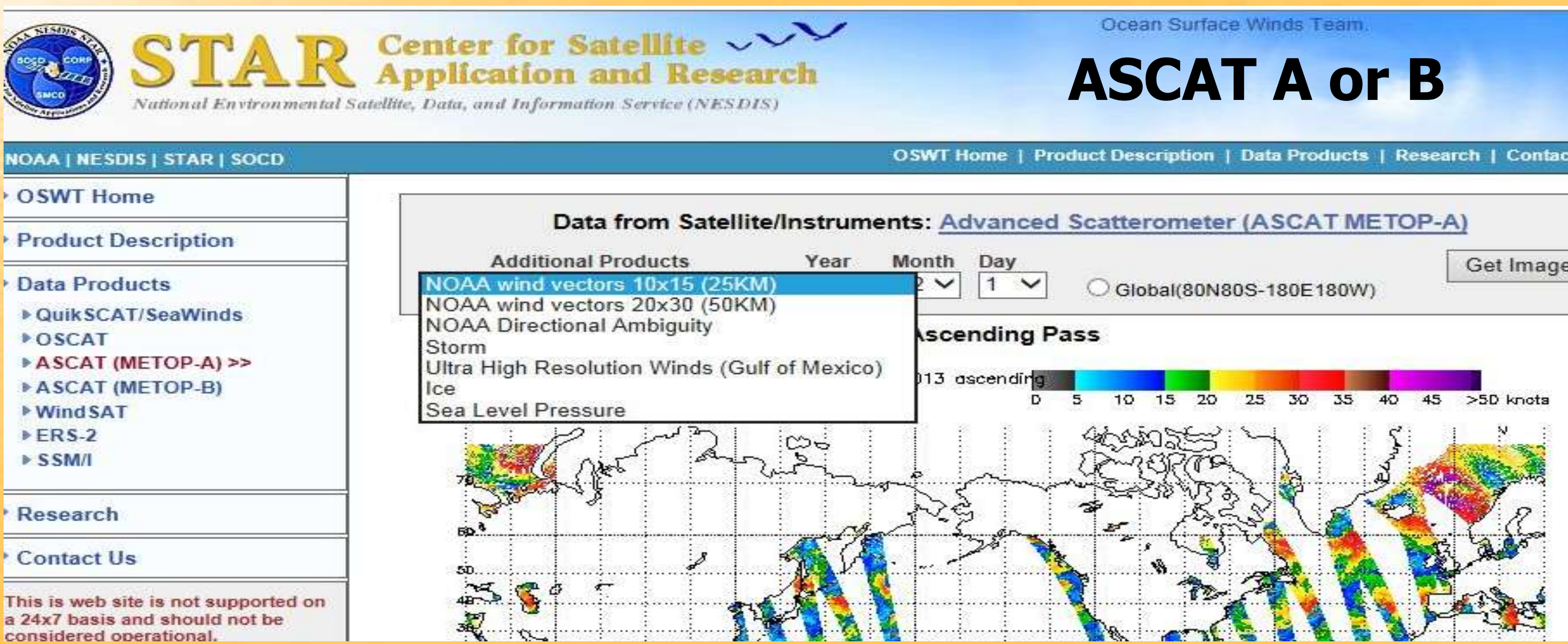
	ASCAT Metop A: 2006-	OSCAT Oceansat-2: 2009-	QuikSCAT 1999 - 2009
Frequency	**5.3 GHz (C)**	**13.5 GHz (Ku)**	**13.4 GHz (Ku)**
Geometry	**6 Fan Beams**	**2 Rotating Pencil**	**2 Rotating Pencil**
Polarization	**VV**	**HH inner / VV outer**	**HH inner / VV outer**
Altitude	**817 km**	**720 km**	**803 km**
Sun-Sync Orbit / Repeat	**101 min / 29 days**	**99 min / 2 days**	**101 min / 4 days**
Incidence Angles	**25° – 53° 34° – 64°**	**49° / 57°**	**46° / 54°**
Swath	**550km 700km-gap 550km**	**1400 km / 1836 km**	**1400 km / 1800 km**
to Launch	****Metop B: 2012**	**Oc [illegible] 2016**	**?**




Scatterometer Sites NOAA/NESDIS

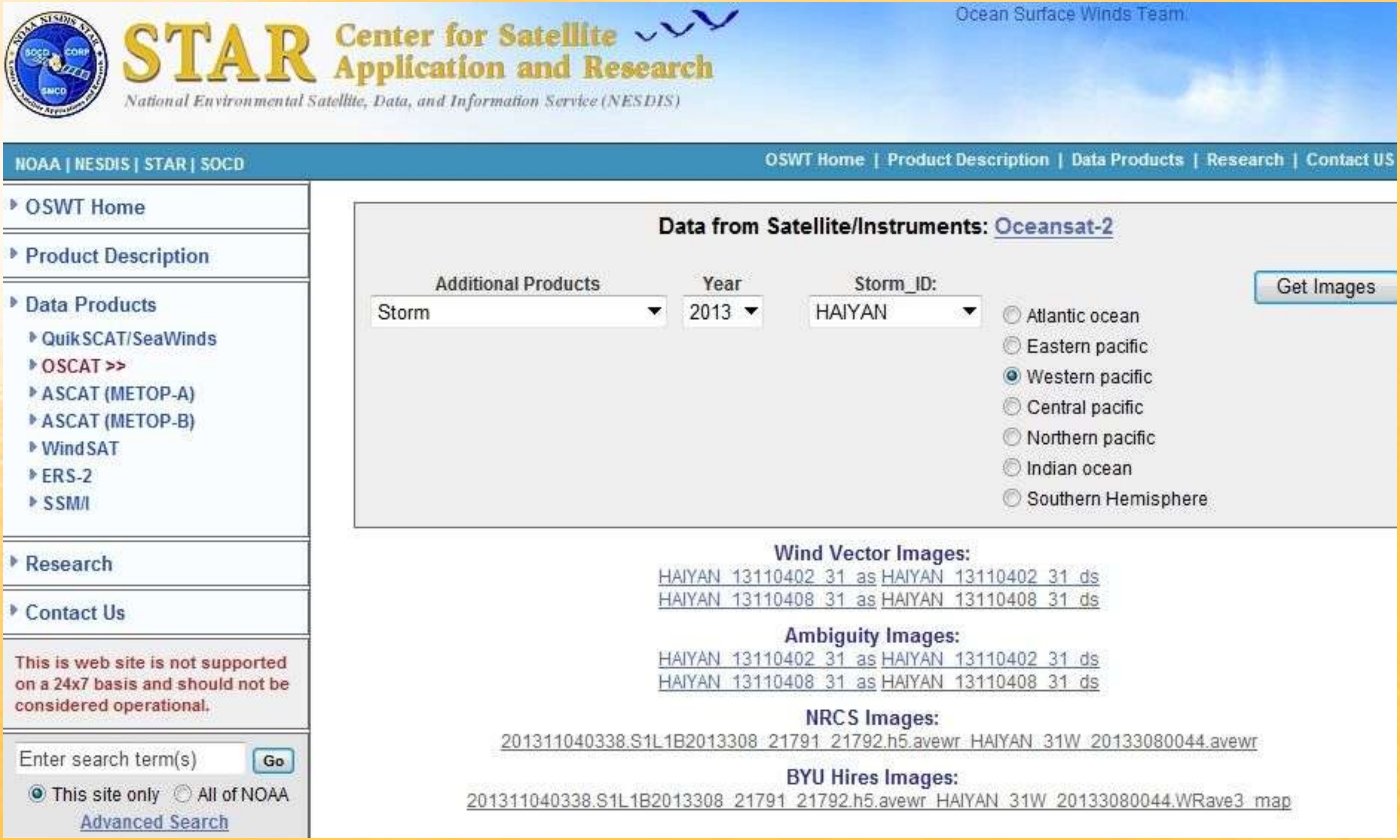
http://manati.star.nesdis.noaa.gov/datasets/OSCATData.php





Scatterometer Sites NOAA/NESDIS

Storm Pages (ASCAT and OSCAT)



Scatterometer Sites: KNMI

http://www.knmi.nl/scatterometer/ascat_osi_25_prod/ascat_app.cgi

OSI SAF
Ocean and Sea Ice

Ocean and Sea Ice SAF

Wind Processing Centre

GO TO OSI SAF CENTRAL WEB SITE

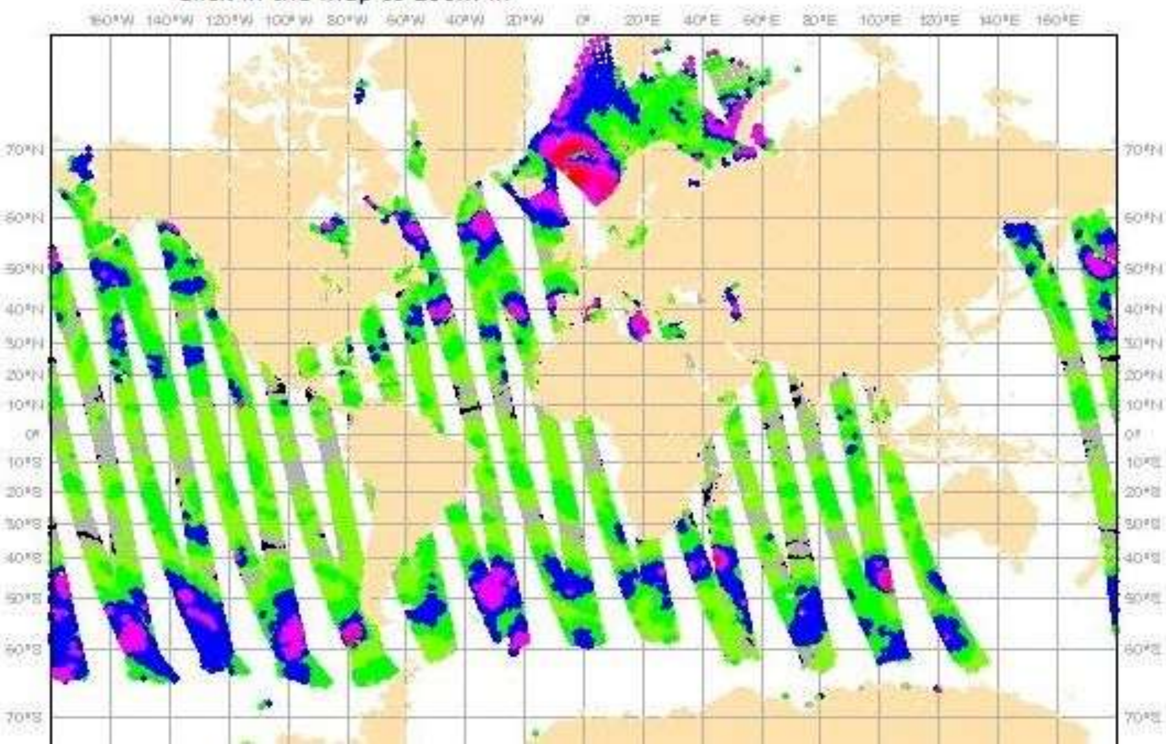
Updated @ 2013-12-01 12:33 utc

OSI SAF ASCAT-A 12.5-km product

ASCAT12, status: operational

Ascending passes

Click in the map to zoom in



Select view

- Monitoring information
- Buoy validations
- Ice maps
- Data from previous day

Background information

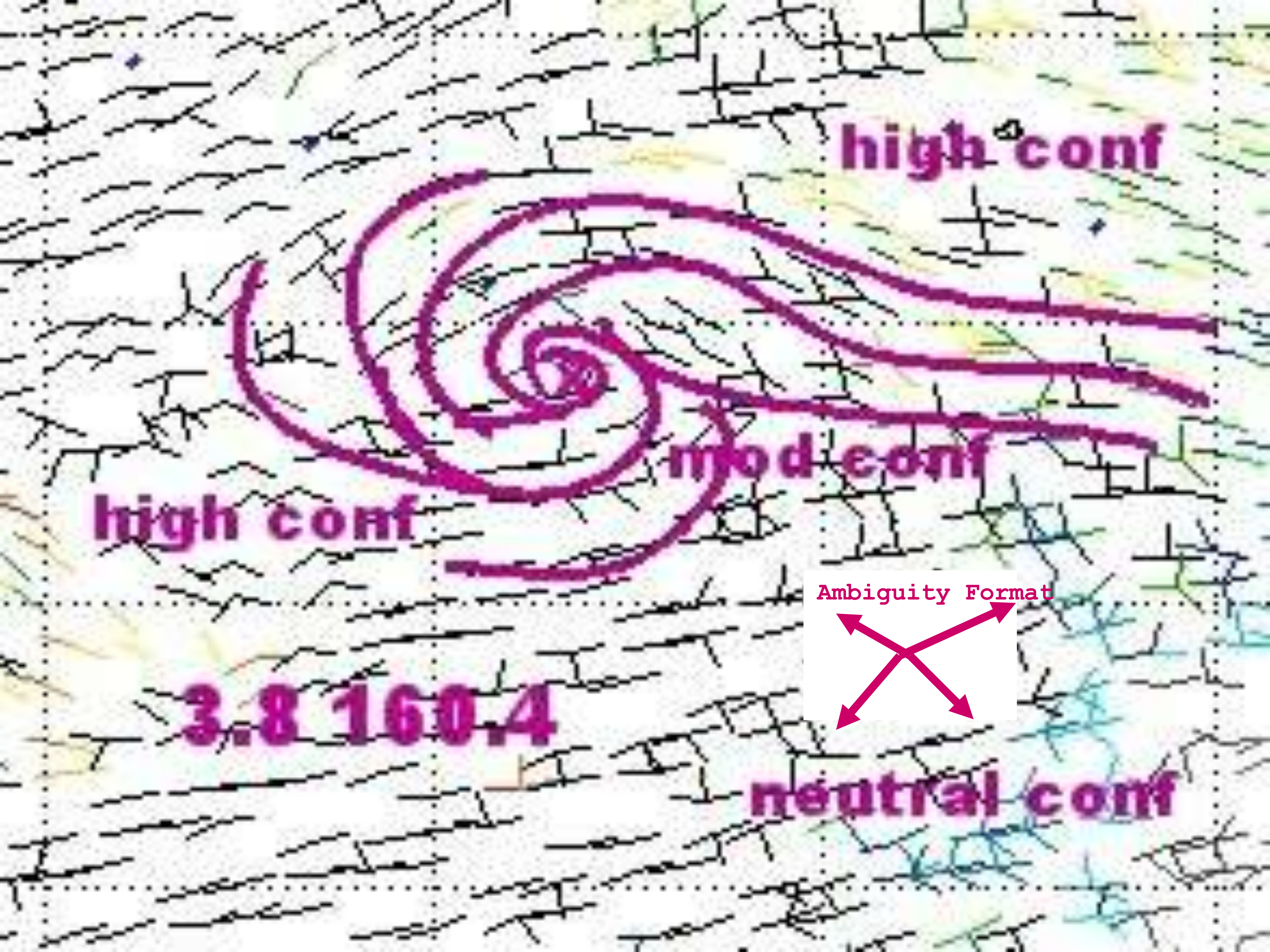
- Modifications/anomalies
- Description of plots
- Access to products
- Acknowledgements
- ASCAT Product User Manual
- ASCAT 12.5-km Validation report
- Home OSI SAF Wind Centre

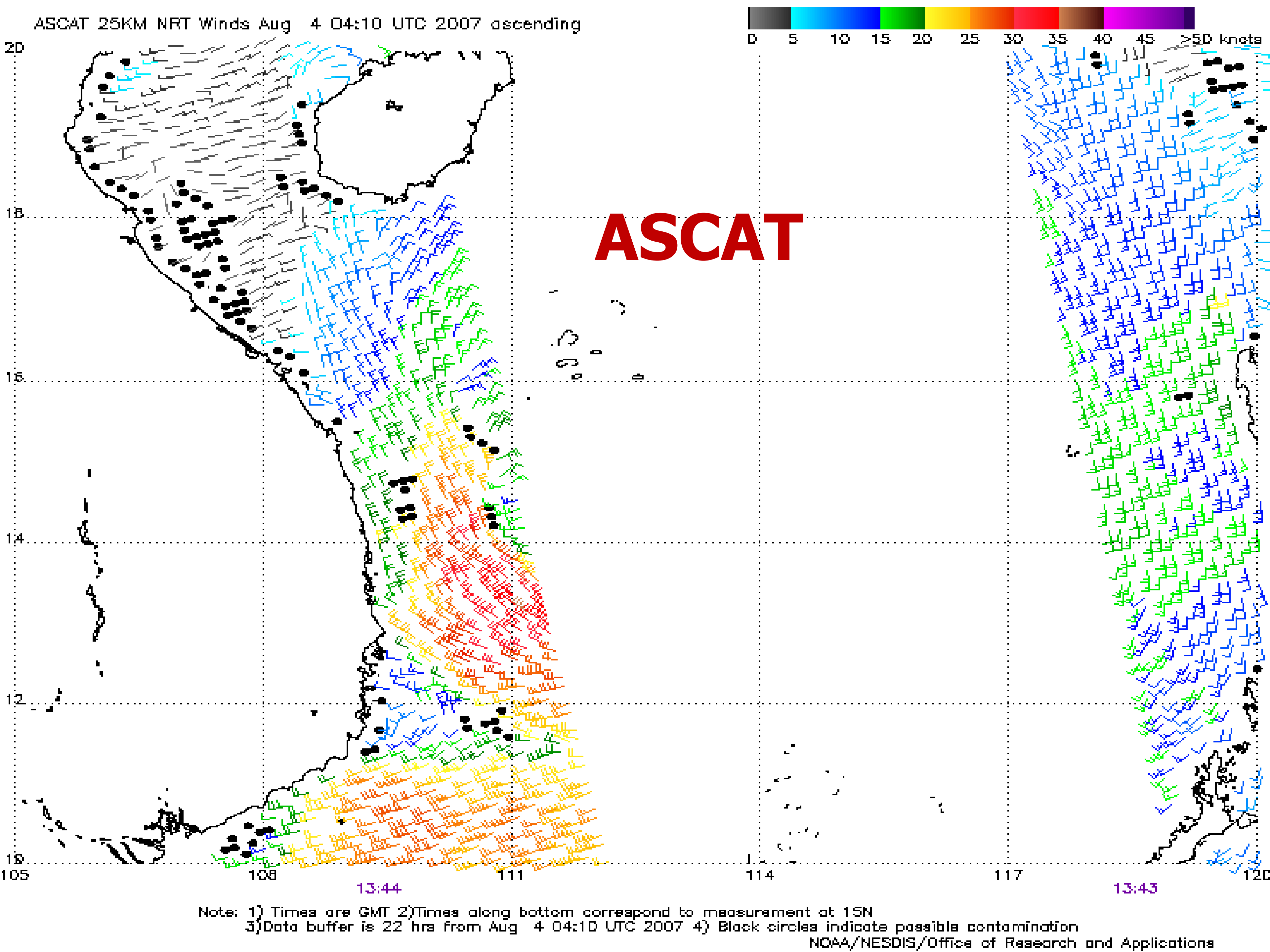
OSI SAF Wind Products

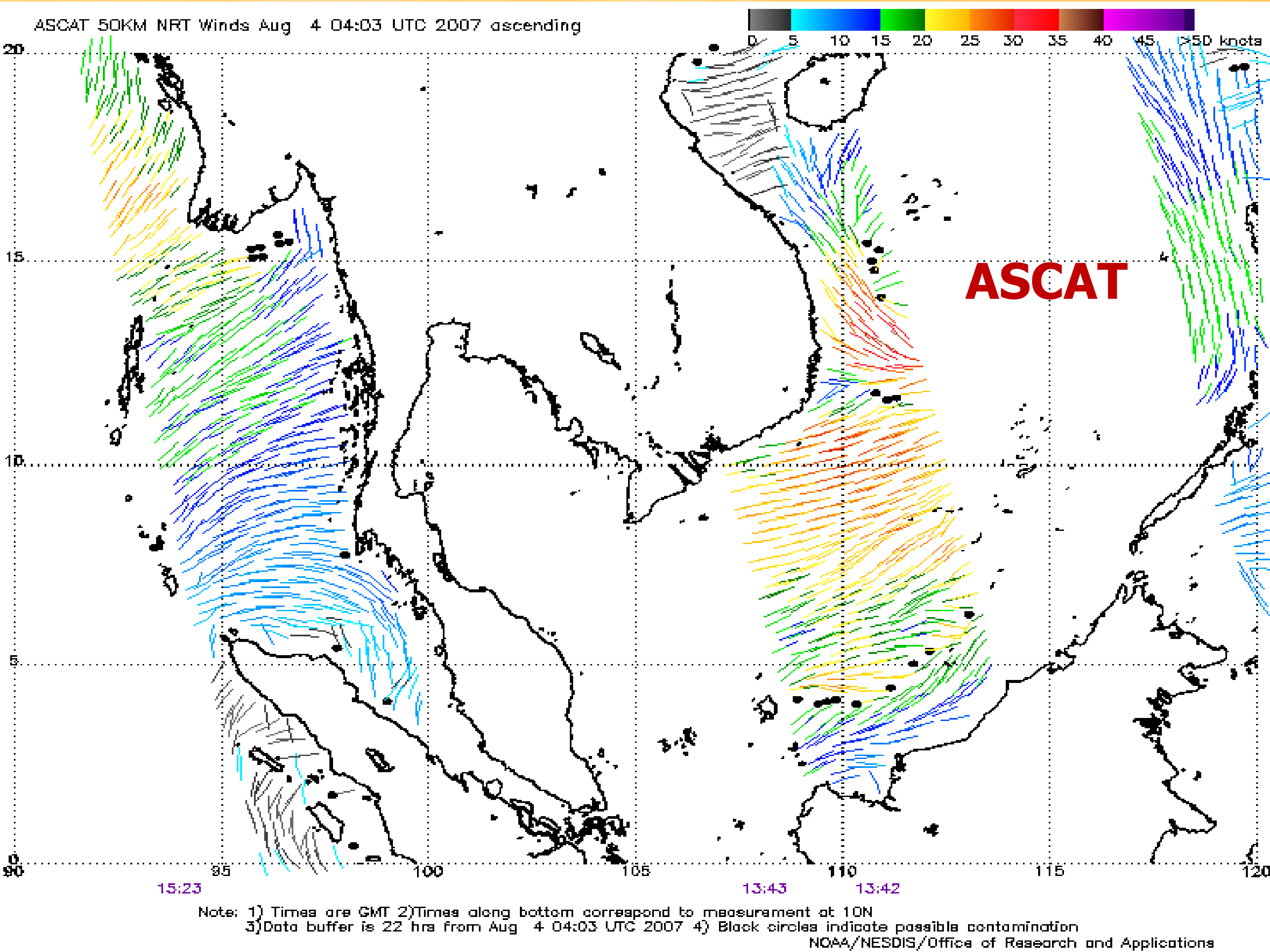
- ASCAT-A 25-km winds
  Operational status
- ASCAT-A Coastal winds
  Pre-operational status
- ASCAT-B 25-km winds
  Operational status
- ASCAT-B Coastal winds
  Pre-operational status
- Oceansat-2 50-km winds
  Operational status
- QuikSCAT winds
  Discontinued status

Uses of Scatterometer data over Tropical Cyclones (GOALS)

- **Positioning and Motion**
- **Minimum (at least) maximum wind**
- **Structure and Structure Change (Wind Radii)**
- **Genesis and (Surface) Genesis processes**
- **Extratropical Transition and Dissipation**

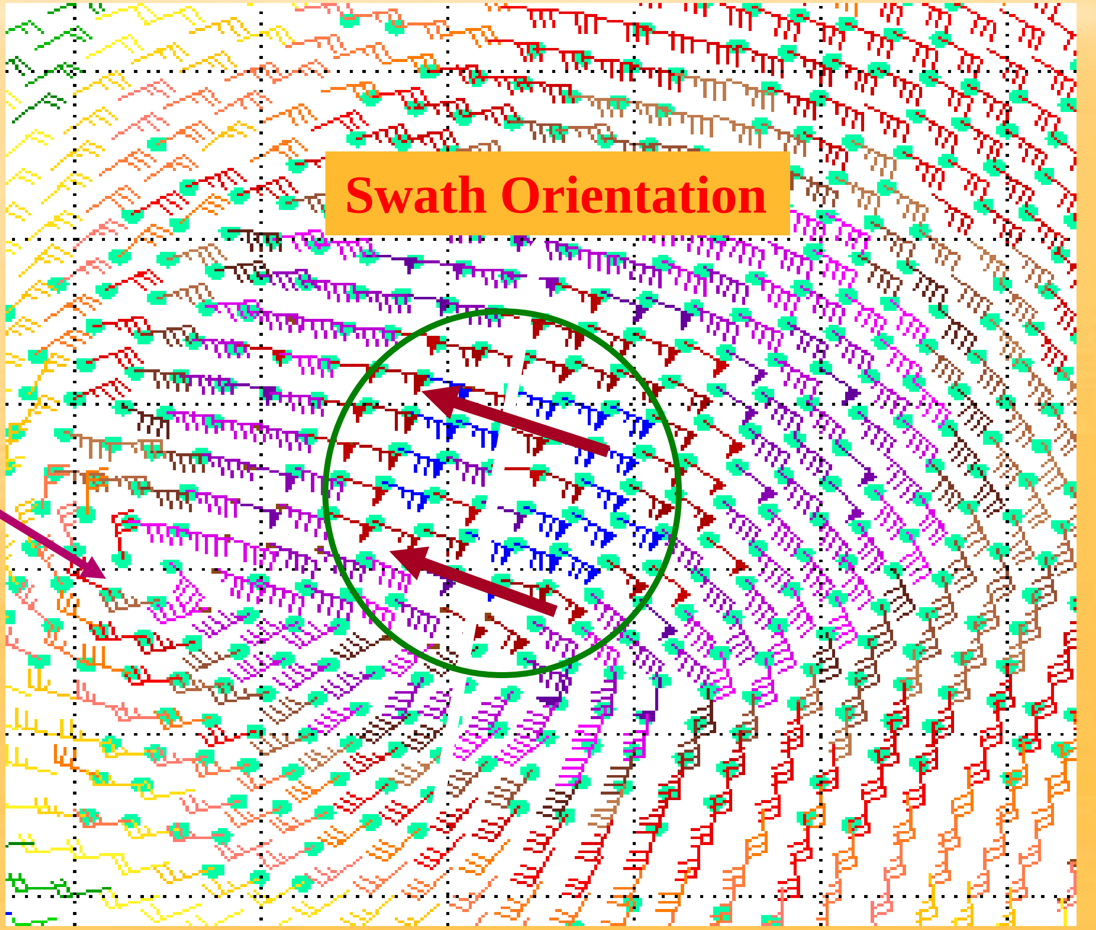

high conf
mod conf
high conf
3.8 160.4
Ambiguity Format
neutral conf


ASCAT 25KM NRT Winds Aug 4 04:10 UTC 2007 ascending
0 5 10 15 20 25 30 35 40 45 >50 knots
ASCAT
20
18
16
14
12
10
105
108
111
114
117
120
13:44
13:43
Note: 1) Times are GMT 2)Times along bottom correspond to measurement at 15N
3)Data buffer is 22 hrs from Aug 4 04:10 UTC 2007 4) Black circles indicate possible contamination
NOAA/NESDIS/Office of Research and Applications


ASCAT 50KM NRT Winds Aug 4 04:03 UTC 2007 ascending
0 5 10 15 20 25 30 35 40 45 >50 knots
ASCAT
20
15
10
5
0
90
95
100
105
110
115
120
15:23
13:43
13:42
Note: 1) Times are GMT 2)Times along bottom correspond to measurement at 10N
3)Data buffer is 22 hrs from Aug 4 04:03 UTC 2007 4) Black circles indicate possible contamination
NOAA/NESDIS/Office of Research and Applications

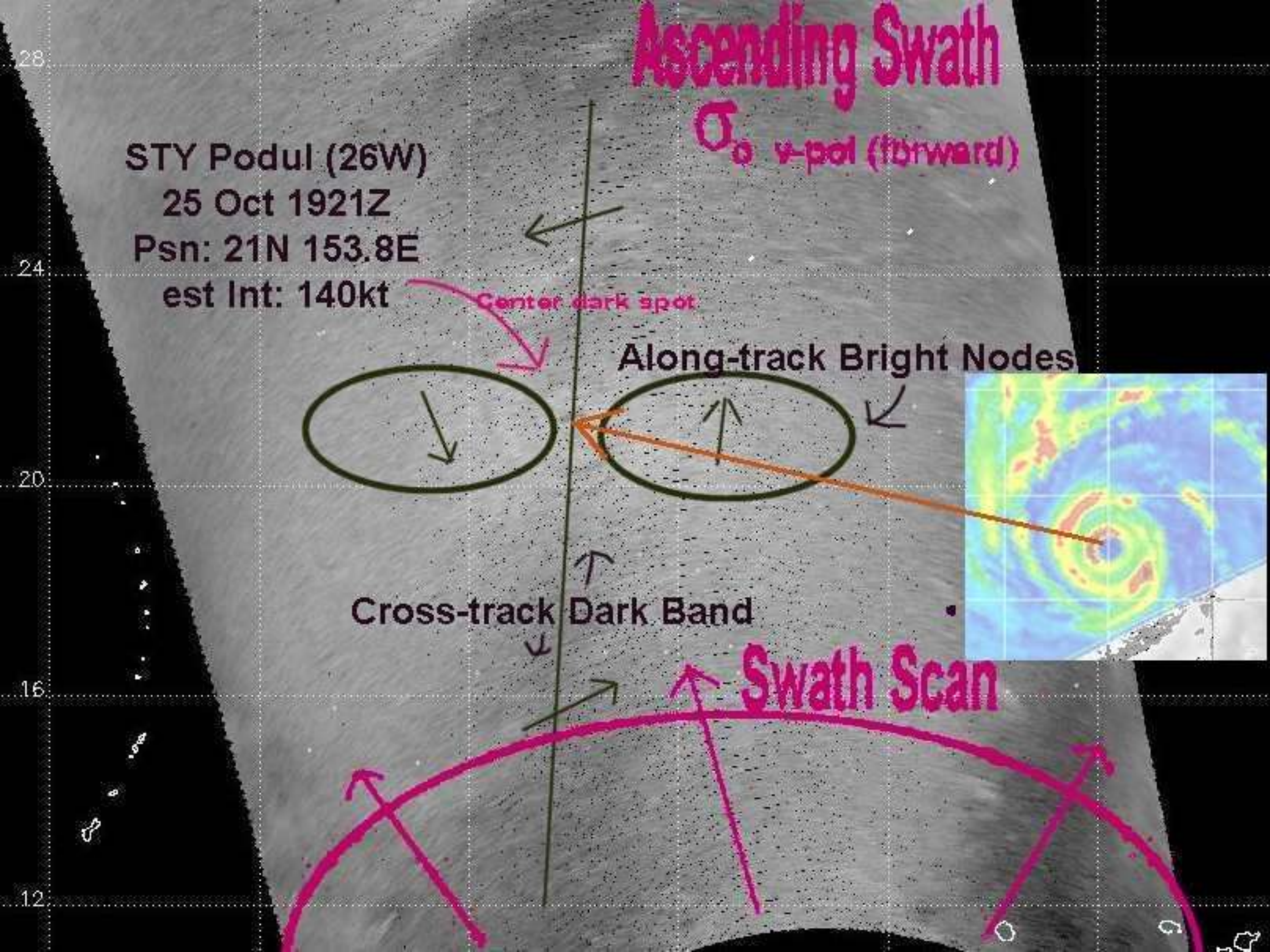
RAIN EFFECTS-Direction selection problem (Rain Blocks--Perpendicular to Swath)

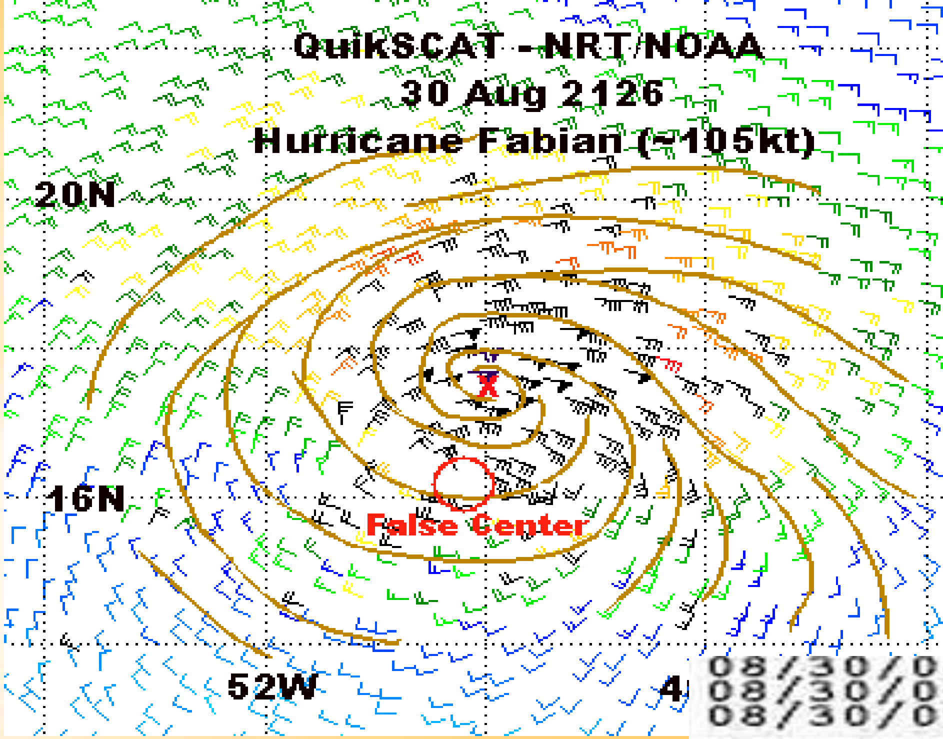
The "Rain Block"

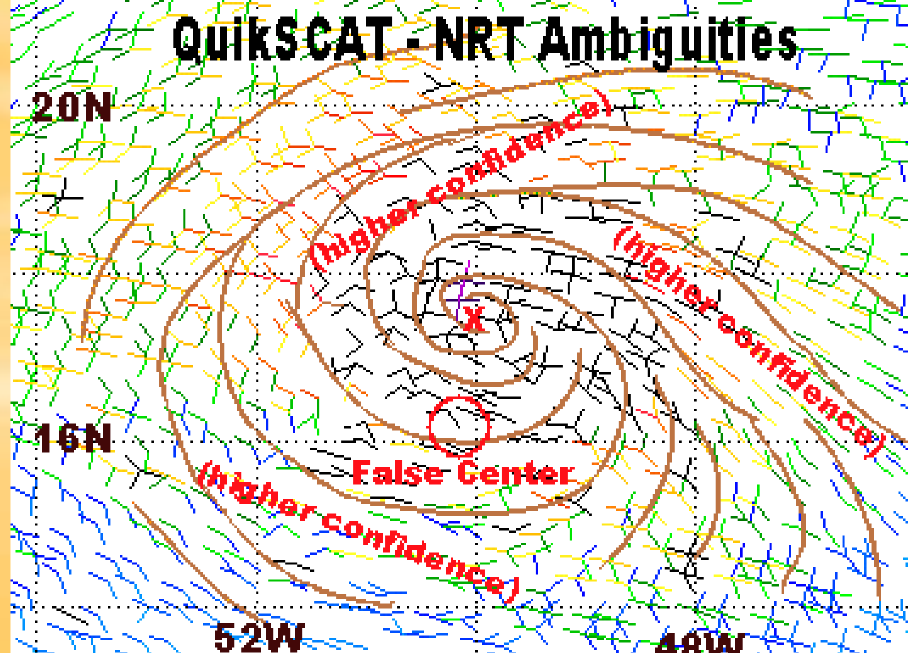


Watch out for "False Center"!

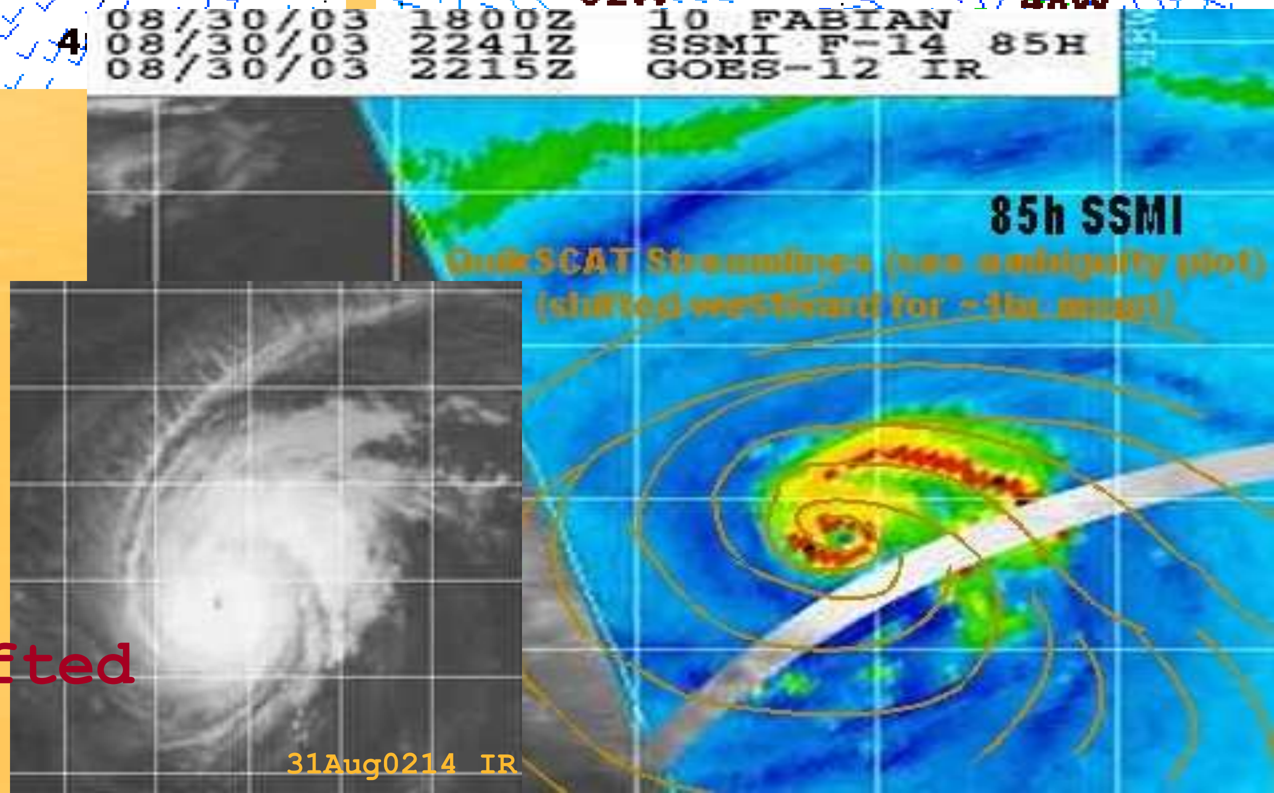
Bad direction *selection*—Speeds are 'good'.


Ascending Swath
σo v-pol (forward)
STY Podul (26W)
25 Oct 1921Z
Psn: 21N 153.8E
est Int: 140kt
Center dark spot
Along-track Bright Nodes
Cross-track Dark Band
Swath Scan
28
24
20
16
12





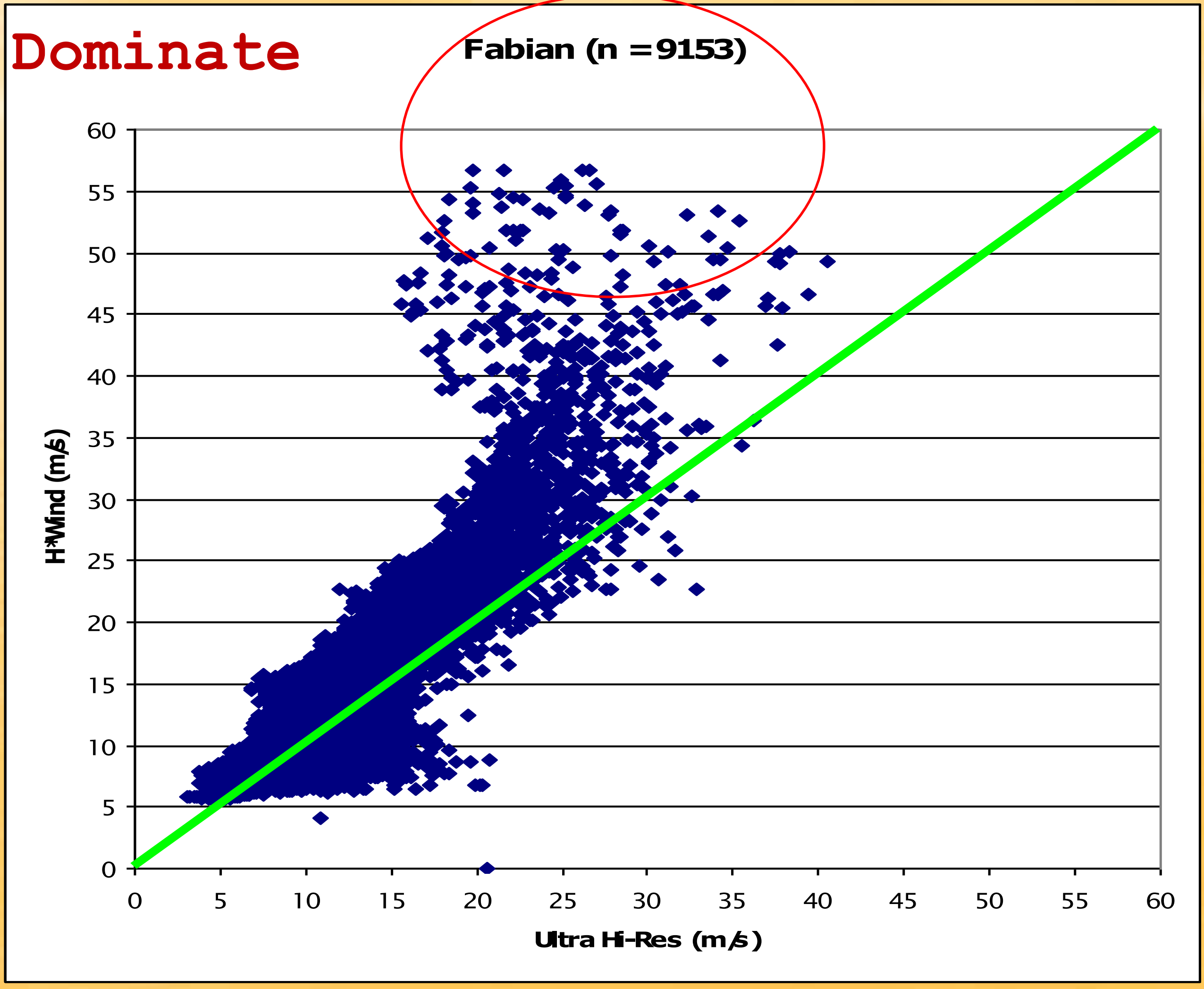
Hur Fabian (10 L) ~17.5N 49.9W 105kt



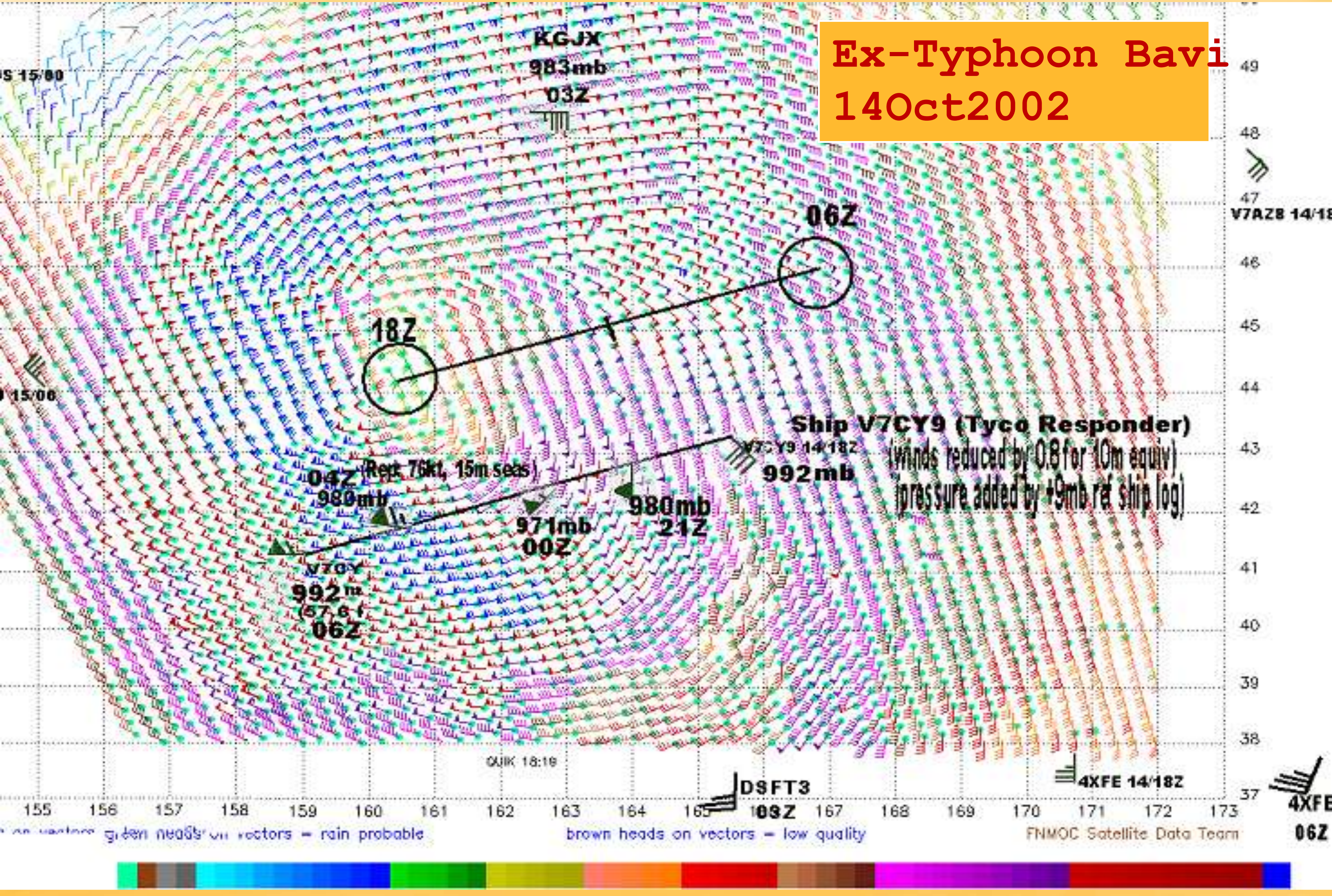
Streamlines shifted westward

Doesn't the scatterometer always read to high?

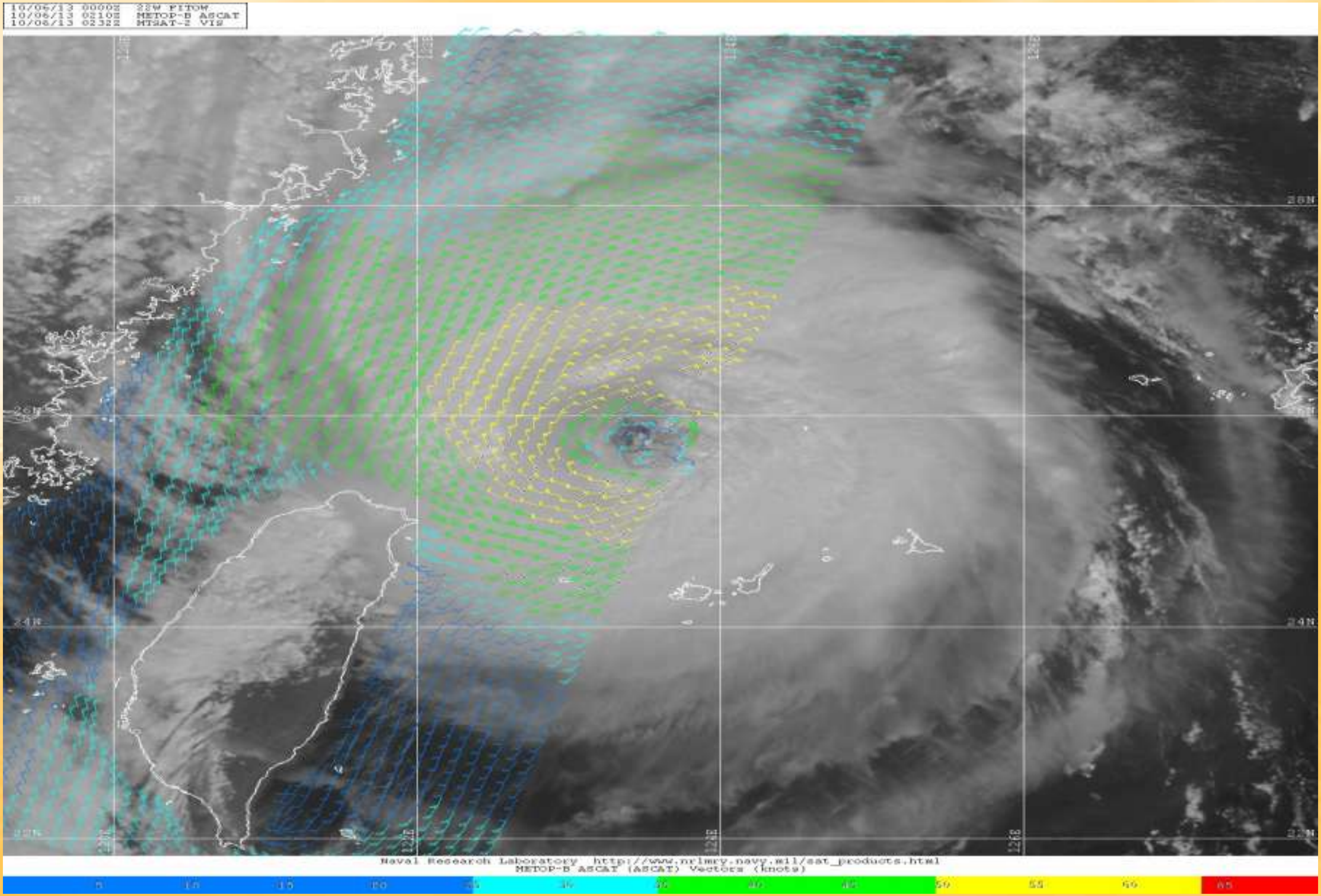
NO! Attenuation and Resolution Dominate

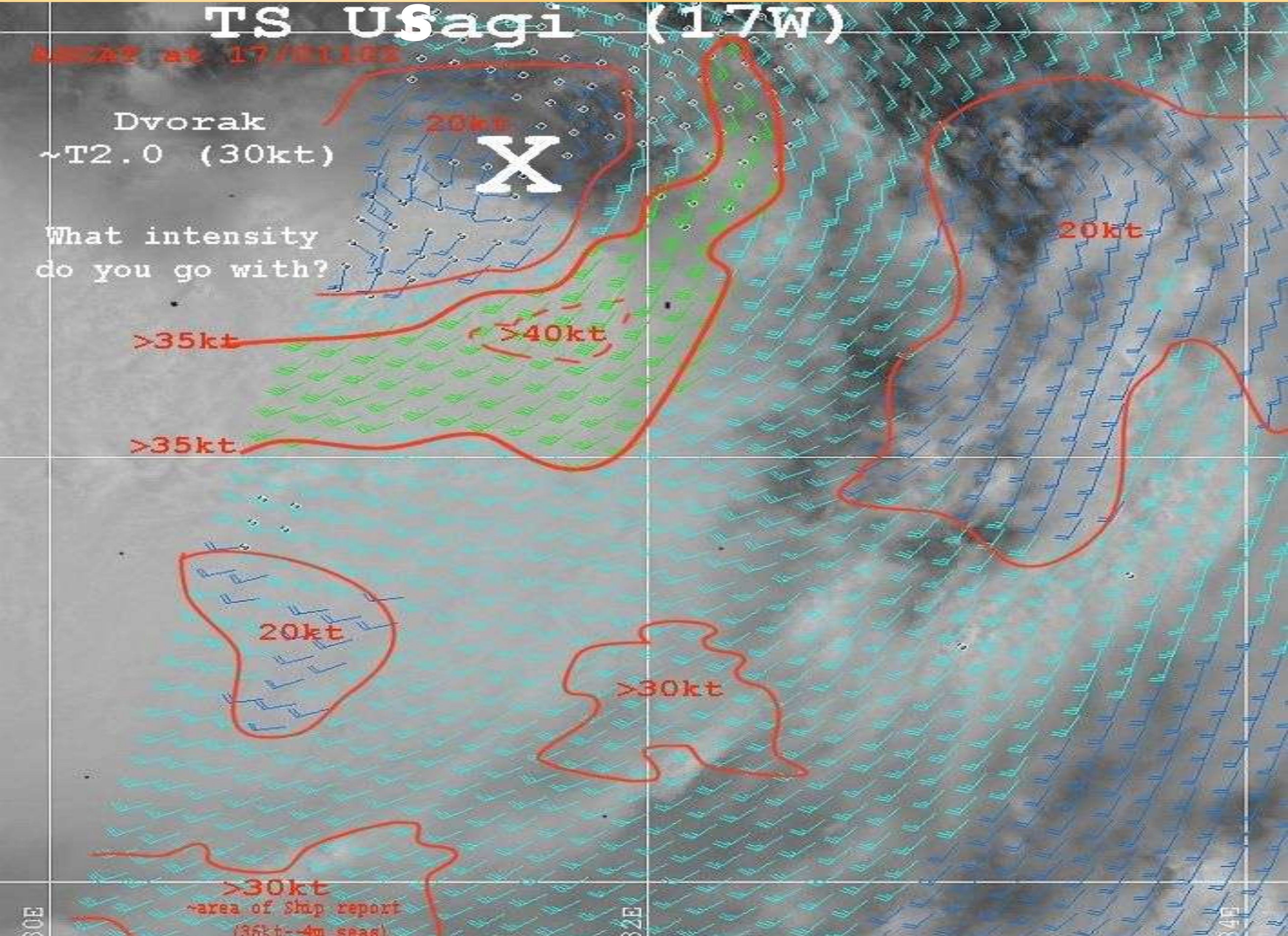


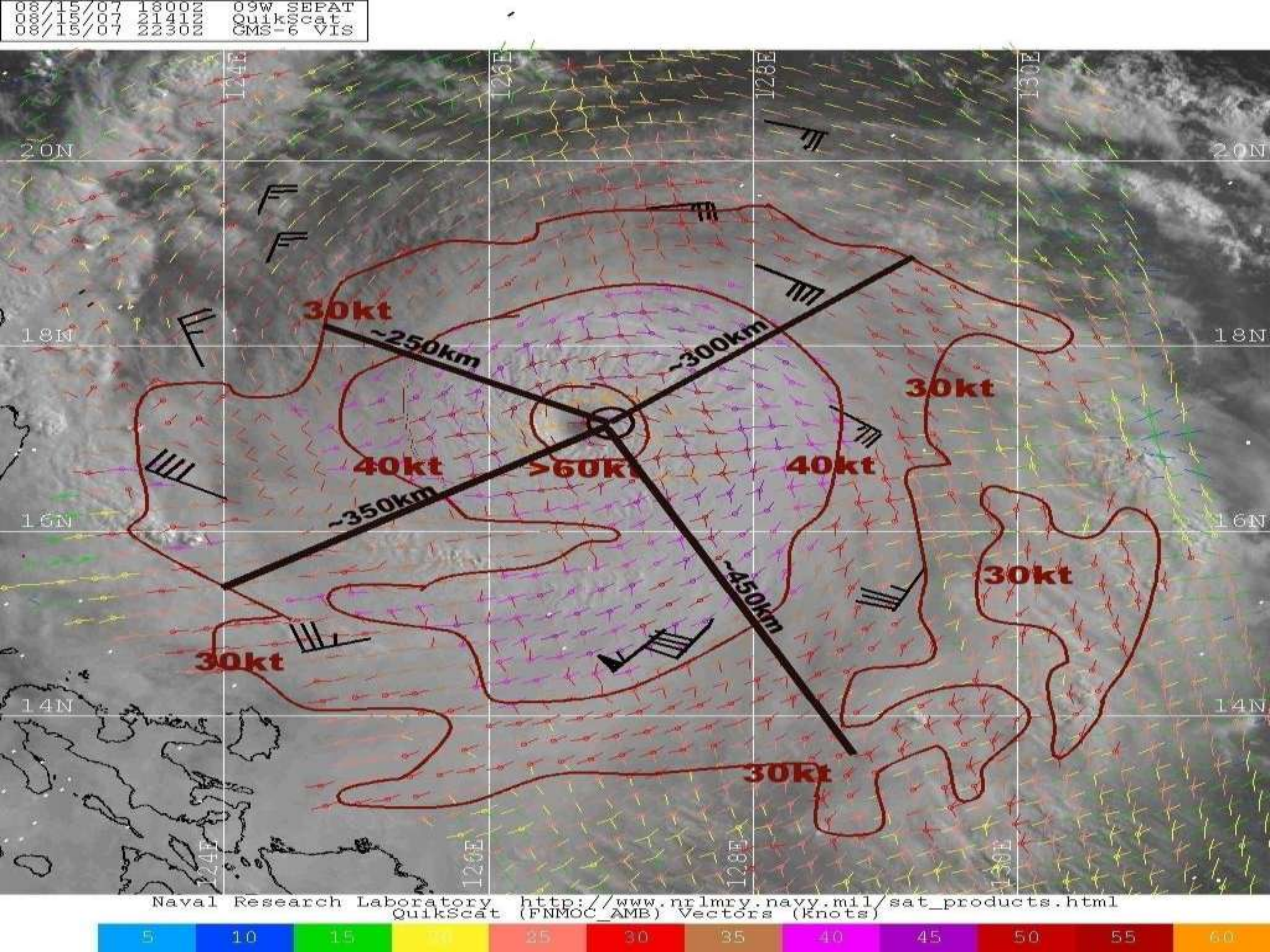
Scatterometer Winds over the Ocean (up to 100 kt!)



Structure—ASCAT-B



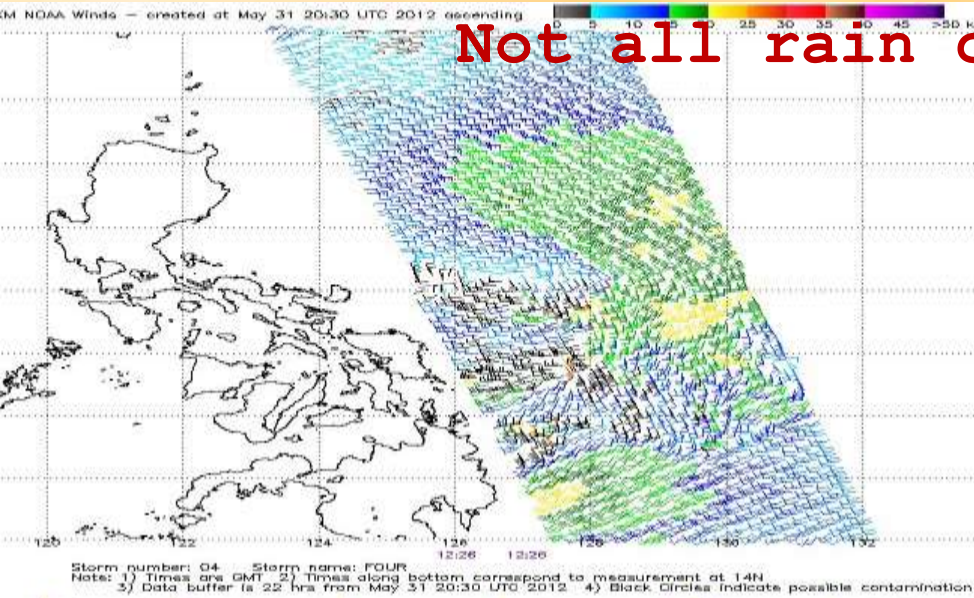

TS Usagi (17W)
Dvorak
~T2.0 (30kt)
What intensity
do you go with?
20kt
>35kt
>40kt
>35kt
20kt
20kt
>30kt
>30kt
~area of Ship report
(36kt-4m seas)

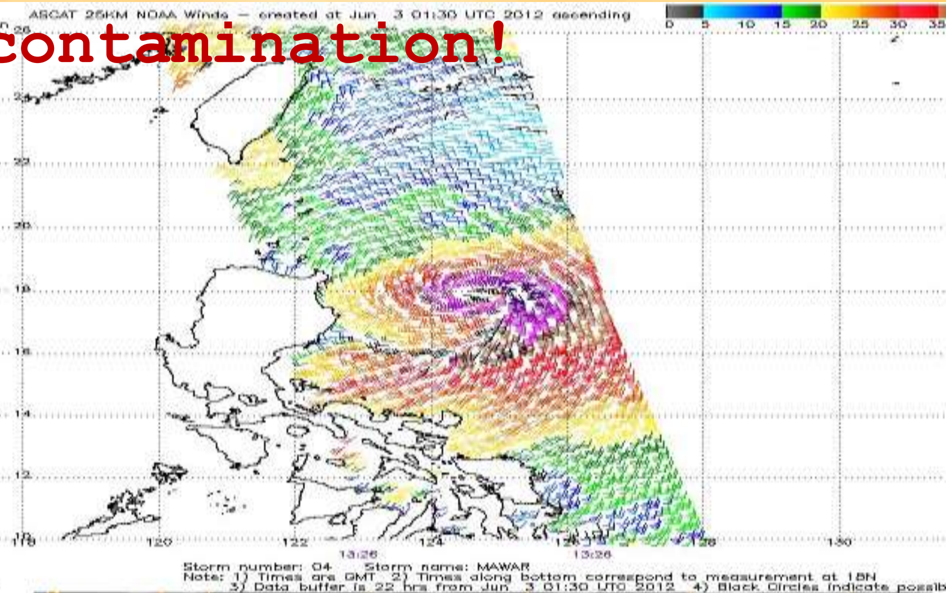


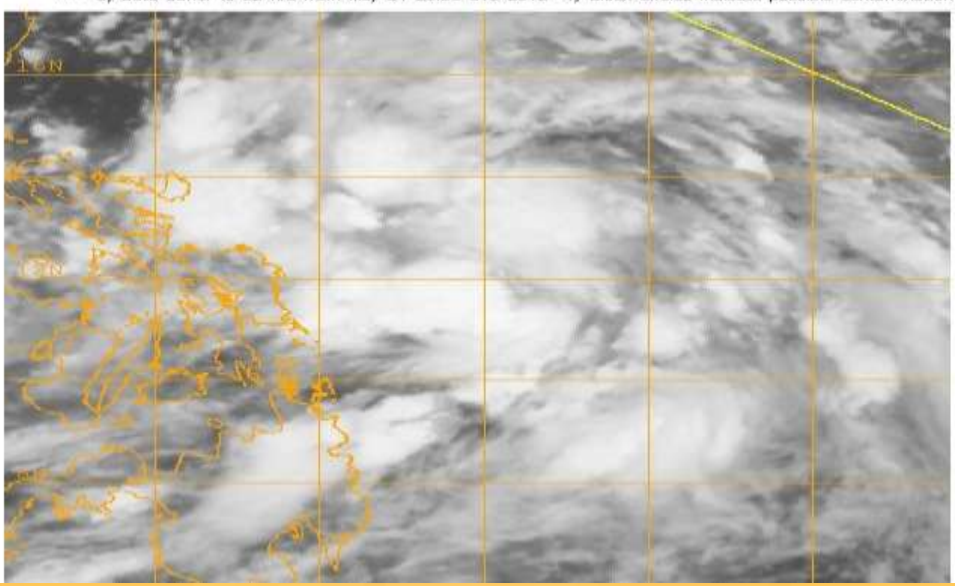
08/15/07 1800Z 09W SEPAT
08/15/07 2141Z QuikScat
08/15/07 2230Z GMS-6 VIS
124E
126E
128E
130E
20N
18N
16N
14N
30kt
~250km
~300km
30kt
40kt
>60kt
40kt
~350km
30kt
~450km
30kt
30kt
Naval Research Laboratory http://www.nrlmry.navy.mil/sat_products.html
QuikScat (FNMOC_AMB) Vectors (knots)
5
10
15
20
25
30
35
40
45
50
55
60

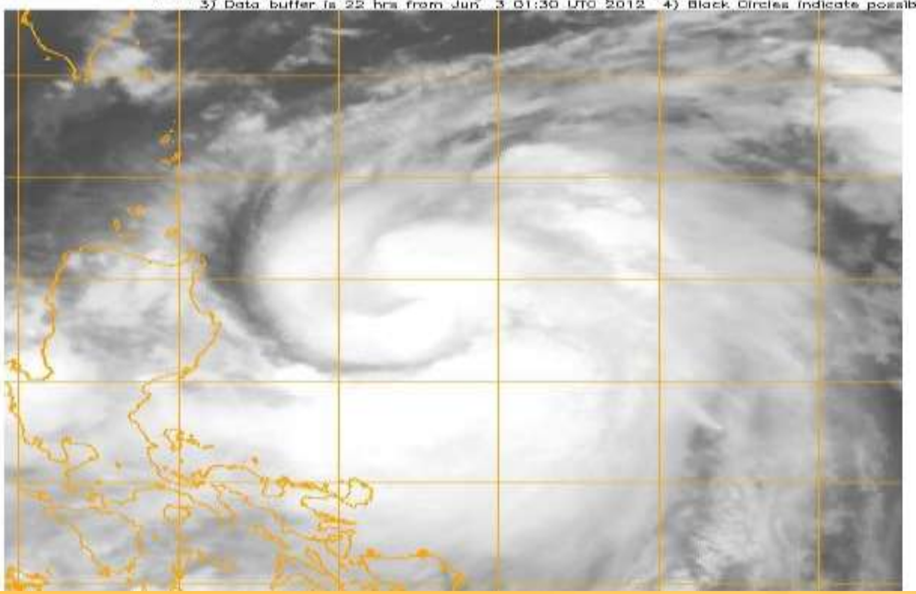
Scatterometer shows development just like the IR

Not all rain contamination!



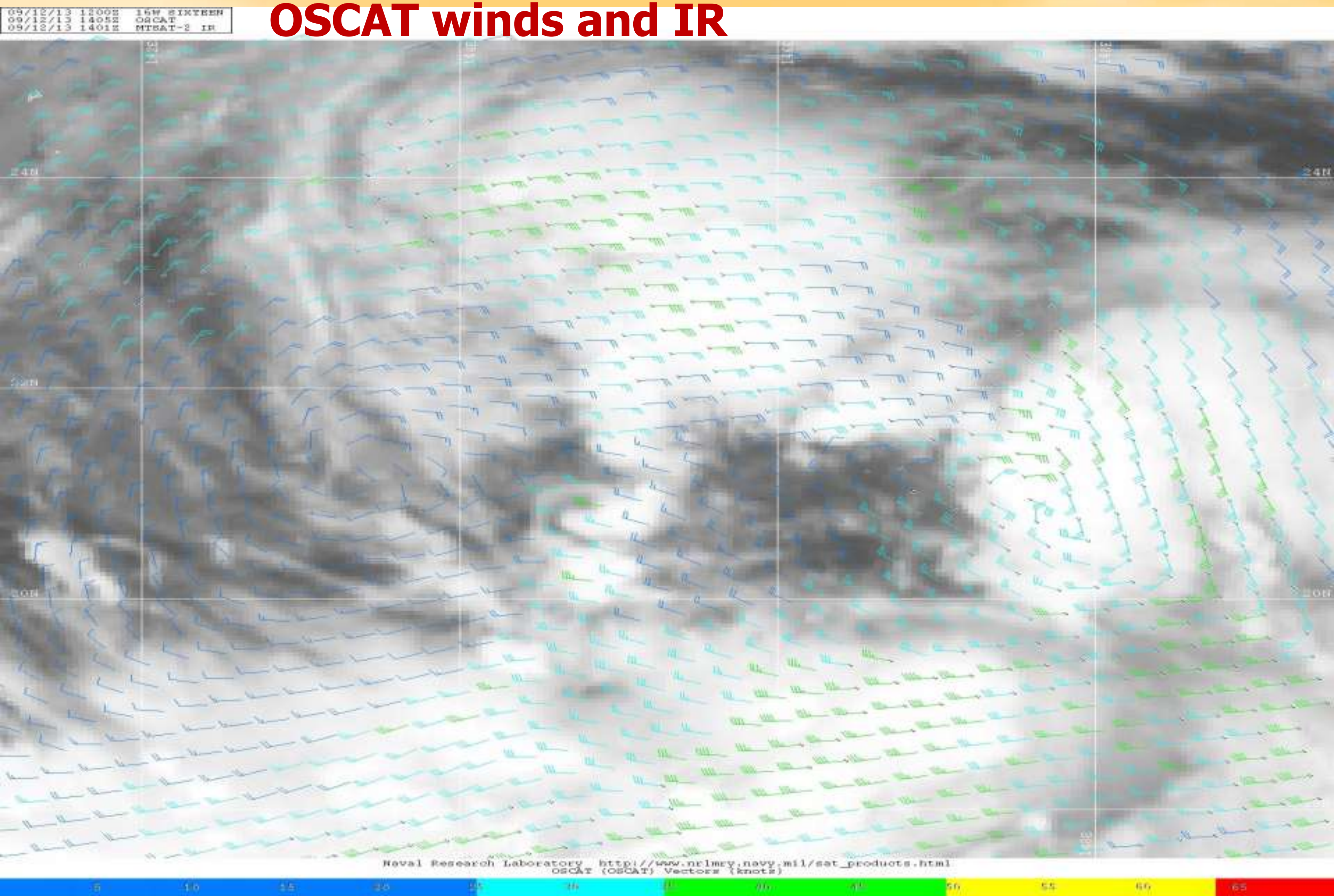






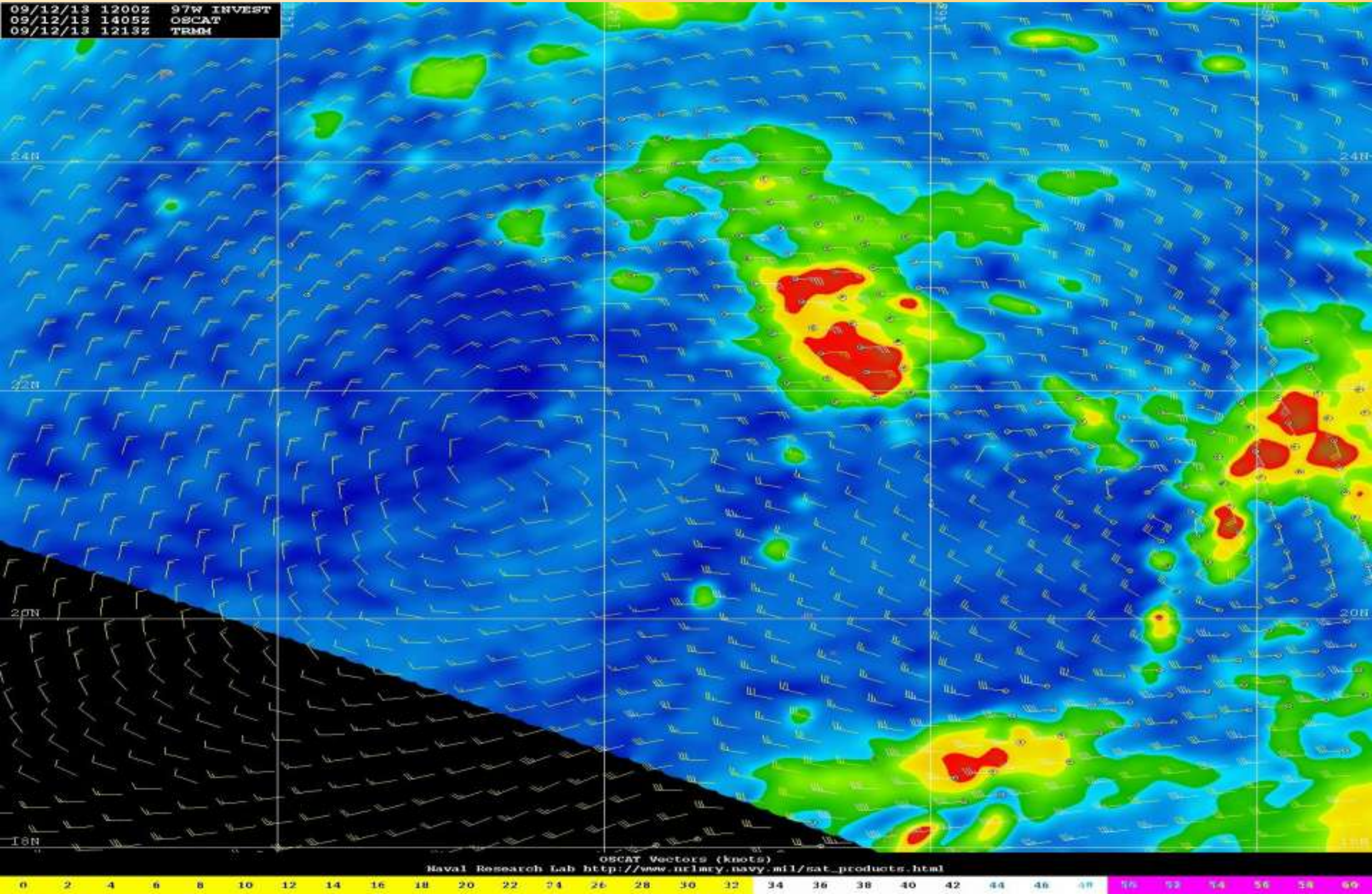
TD developing from Monsoon Circulation 16W (Man-yi)

OSCAT winds and IR

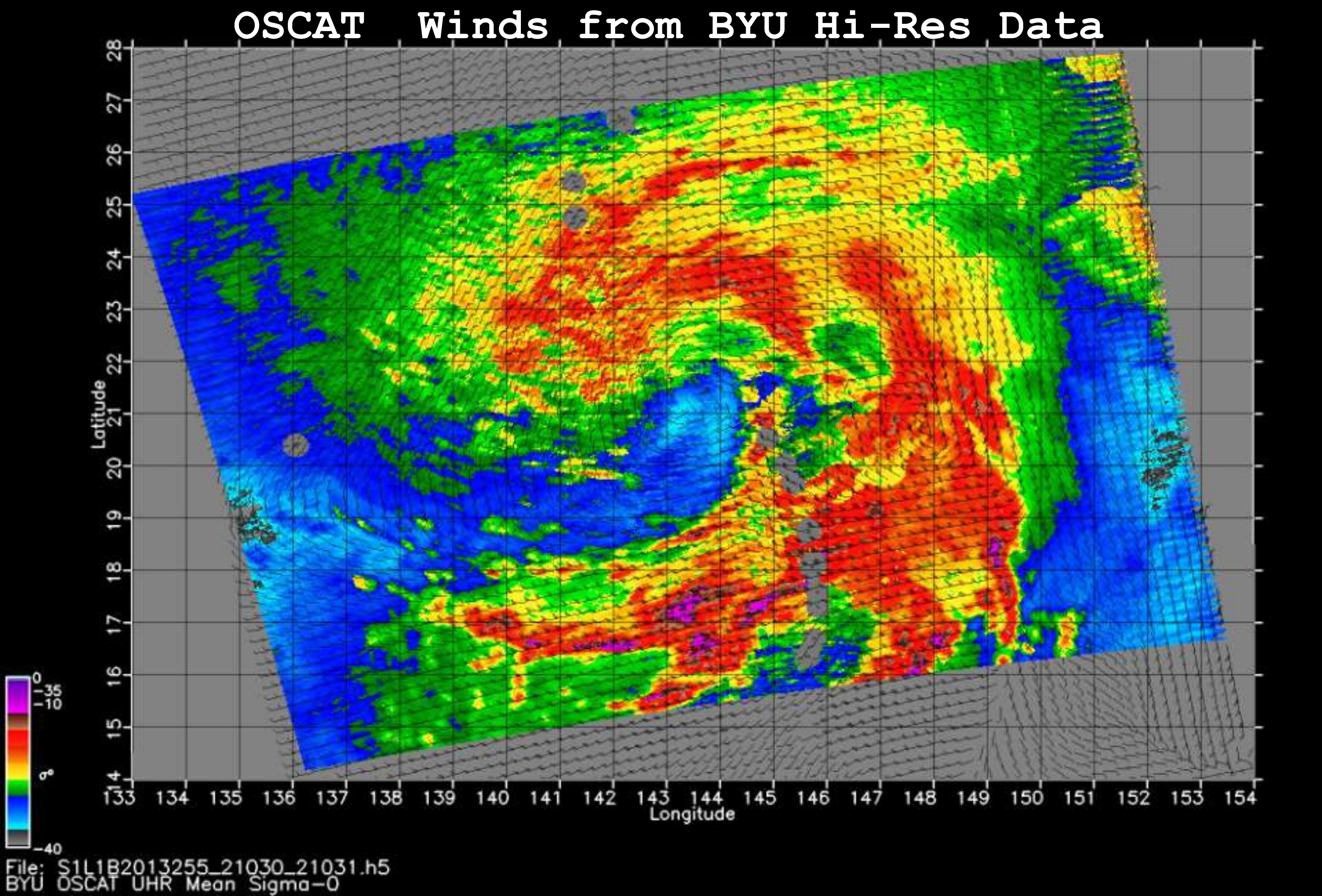


TD developing from Monsoon Circulation 16W (Man-yi)

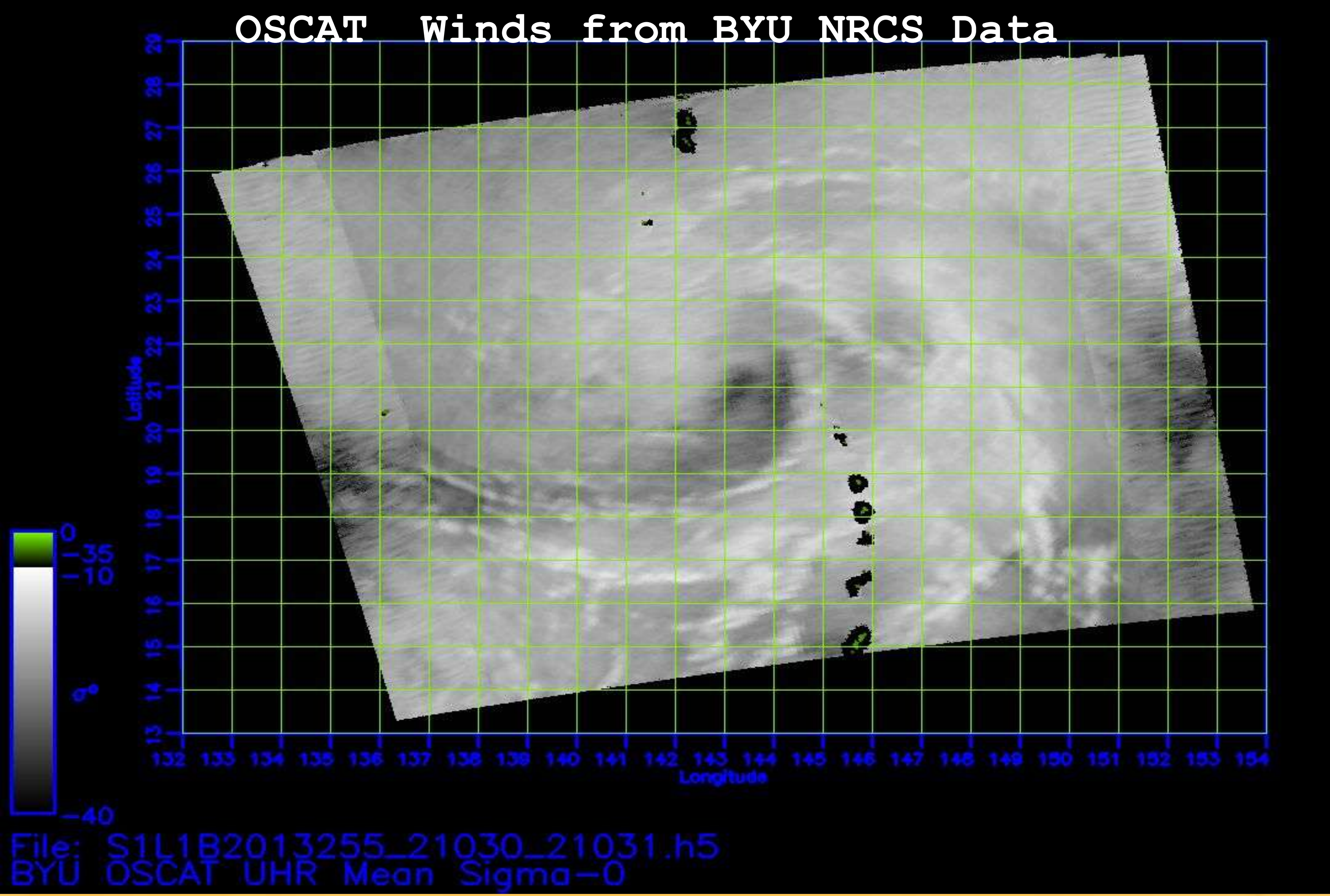
OSCAT winds and TRMM 85h



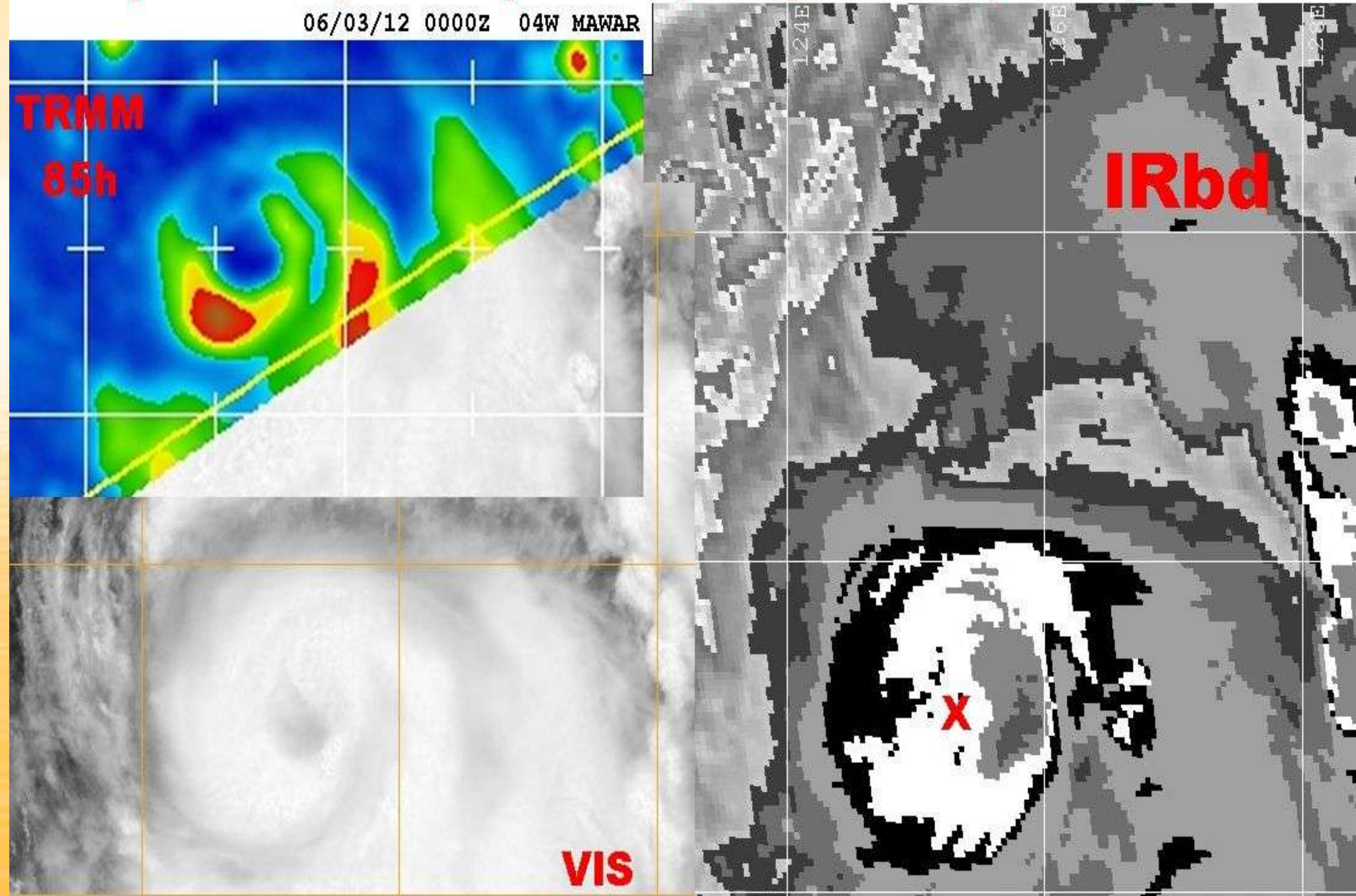
TD developing from Monsoon Circulation 16W (Man-yi)



TD developing from Monsoon Circulation 16W (Man-yi)



Three Views of Typhoon Mawar (04W)
(STS 1203, Mawar)---90kt (1min) or 55kt (10min)



Typhoon Tembin (15W) Comparisons
29 August 2012

Scat Winds in Rain (ASCAT or OSCAT)
- LOW Bias (when actual winds > ~25-30kt)
- More reliable when not cross track (rain bias direction)
- More reliable/confident with consistent pattern

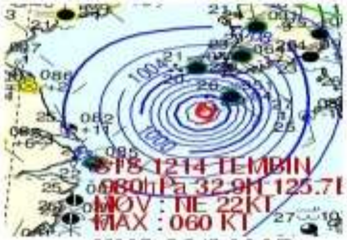
Dvorak in Shear/Extratropical Transition
- Often not representative (non-tropical pattern)
- Does not account for accelerated forward speed
- Often weakens too quickly (when under 100kt)

JMA

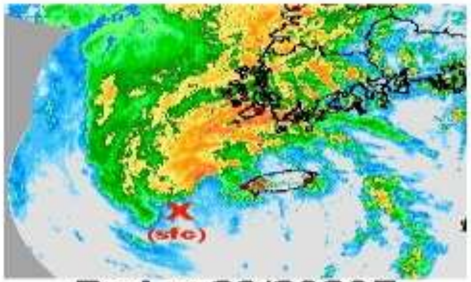
STS 1214 (TEMBIN)
Issued at 21:50 UTC, 29 August 2012

<Analyses at 29/21 UTC>	
Scale	-
Intensity	-
Center position	N32°25'(32.4°) E125°40'(125.7°)
Direction and speed of movement	NNE 30km/h(15kt)
Central pressure	980hPa
Maximum wind speed near the center	30m/s(60kt)
Maximum wind gust speed	45m/s(85kt)

60kt (10min)



KMA 29/2100Z
60kt (10min)



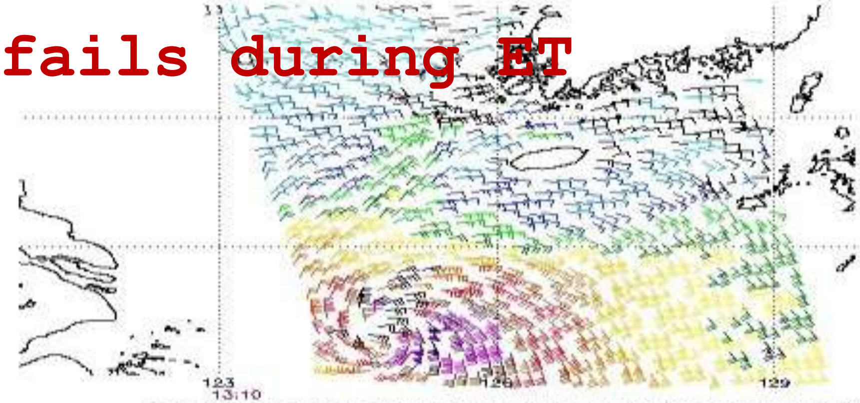
Radar 29/2030Z

WTPN31 PGTW 292100
MSGID/GENADMIN/JOINT TYPHOON WRNCEN PEARL HARBOR HI//
SUBJ/TROPICAL CYCLONE WARNING//
RMKS/
1. TROPICAL STORM 15W (TEMBIN) WARNING NR 044
01 ACTIVE TROPICAL CYCLONE IN NORTHWESTPAC
...D WINDS BASED ON ONE-MINUTE AVERAGE
...RADII VALID OVER OPEN WATER ONLY

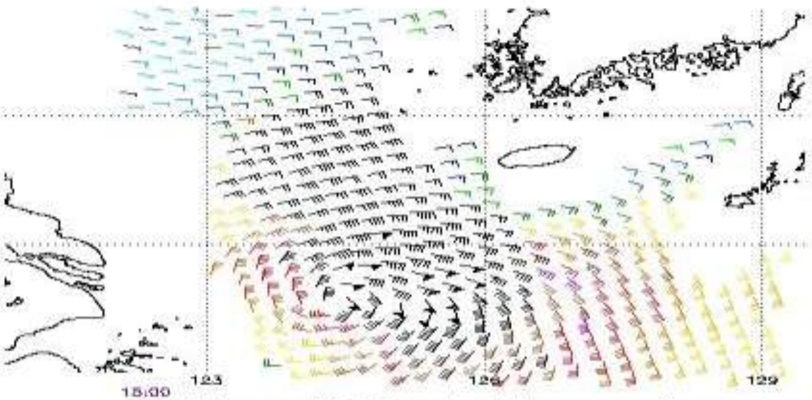
WARNING POSITION:
291800Z --- NEAR 32.4N 125.2E
...MENT PAST SIX HOURS - 015 DEGREES AT 20 KTS
...SITION ACCURATE TO WITHIN 035 NM
...ON BASED ON CENTER LOCATED BY SATELLITE
PRESENT WIND DISTRIBUTION:
MAX SUSTAINED WINDS - 045 KT, GUSTS 055 KT

JTWC 45kt

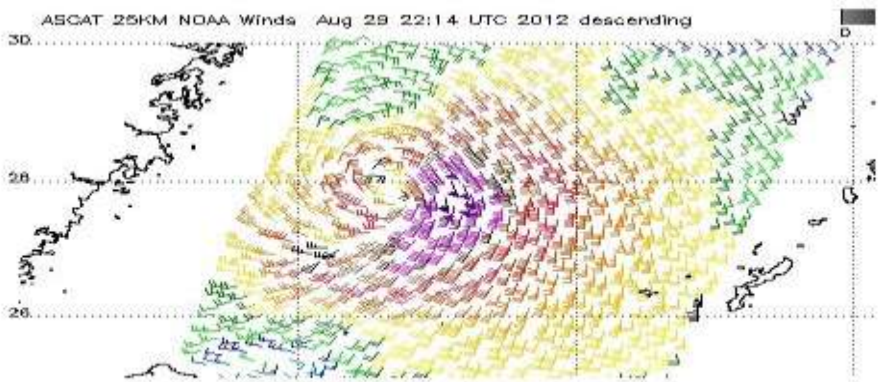
Dvorak often fails during ET



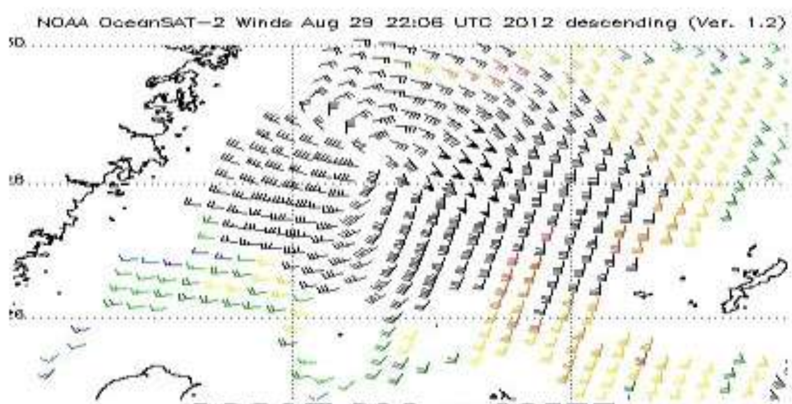
ASCAT 29Aug 1310Z



OSCAT 29Aug 1500Z



ASCAT 29Aug 0154Z



OSCAT 29Aug 0357Z

TC Centers and TC Forecasters

IR Dvorak CANNOT (should not) work by itself

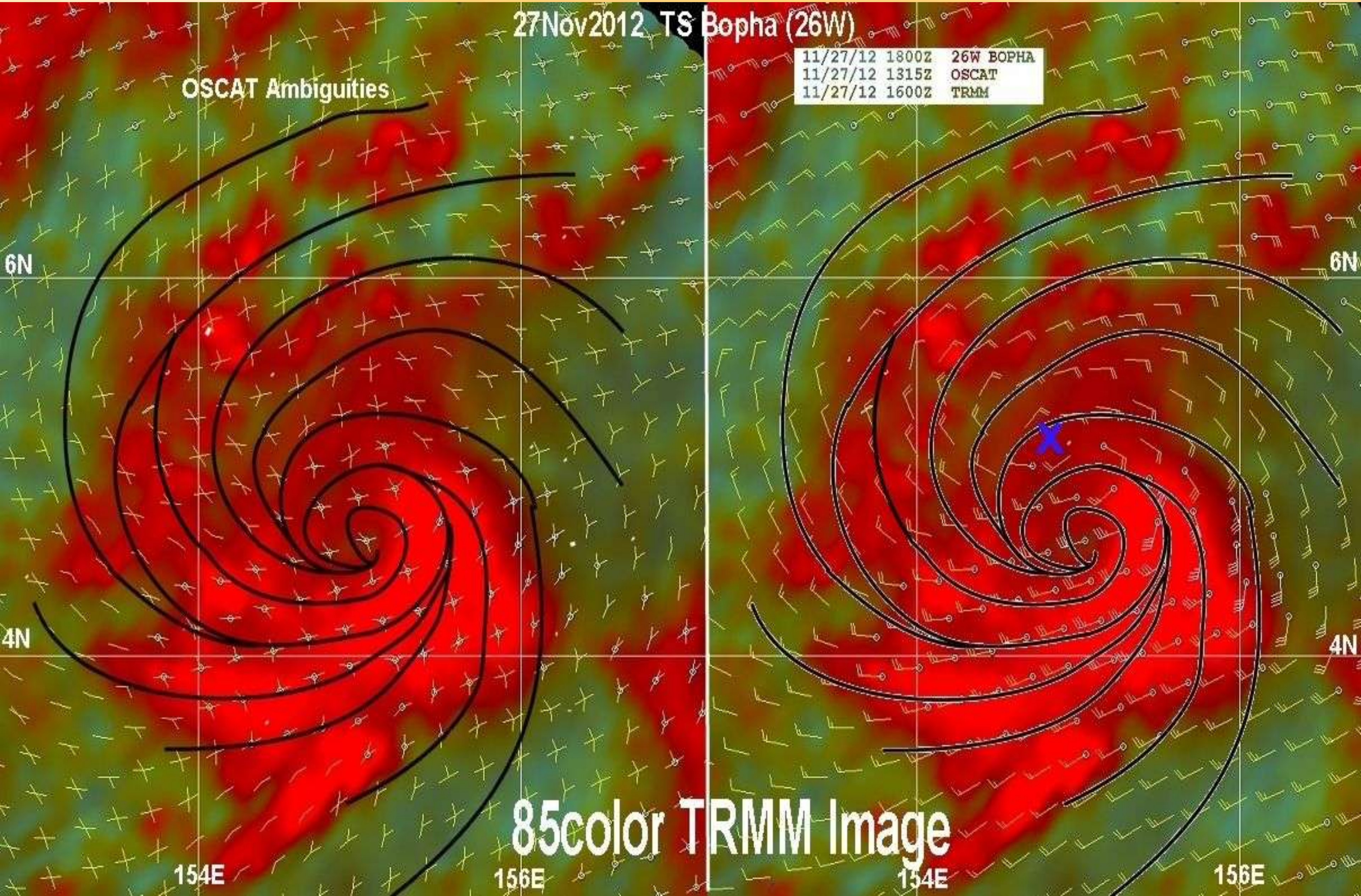
Only an integrated/combined satellite analysis will improve TC Analysis (and Forecasting)

Now is the time: Don’t be ‘low’ and ‘slow’

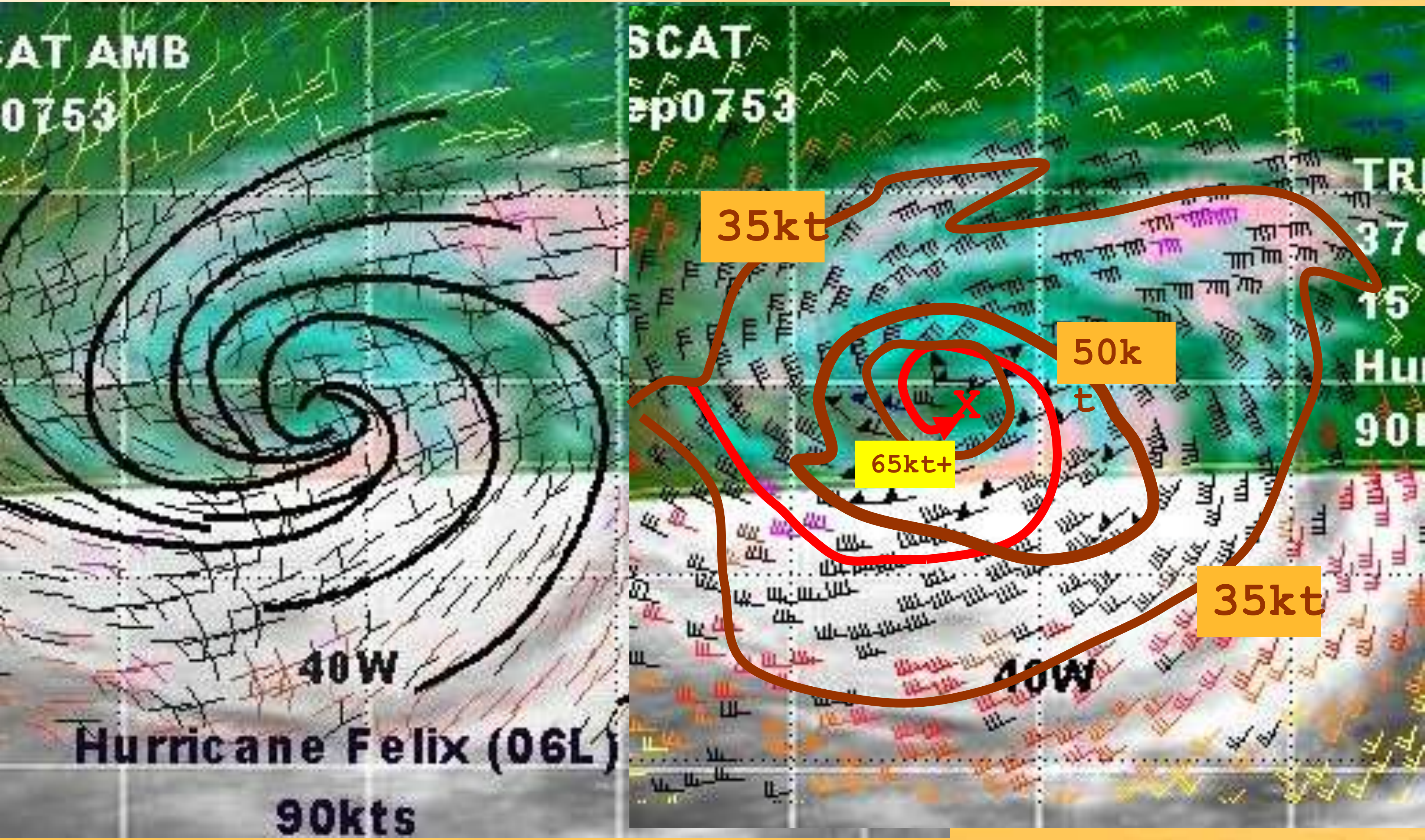
Questions?

EXTRA Slides for Reference

Positioning and Structure



Overlay QuikSCAT winds and ambiguities over MI - 37Ghz imagery



Advantages of 85 GHz

1. Identify peripheral low-level cloud bands, giving information about center of circulation.
2. Distinguish deep (cold) convection (heavy precipitation) from lightly-raining (warm) low cloud features.
3. Identify cirrus-covered eyes.
4. High Spatial Resolution

Limitations of 85 GHz

1. Cold Ocean may “look like” deep convection: Use 85 GHz Color Composite as a correction.
2. Parallax Error (10-20 km).
3. Saturates (no detail) in storm cores, misses structure.

Advantages of 37 GHz

1. Identify cirrus-covered eyes.
2. Resolve detail within the storm core missed by 85 GHz, sometimes can see eyes missed by 85 GHz.
3. Shows regions of low-level clouds/rain.
4. Little Parallax error compared to 85 GHz.

Limitations of 37 GHz

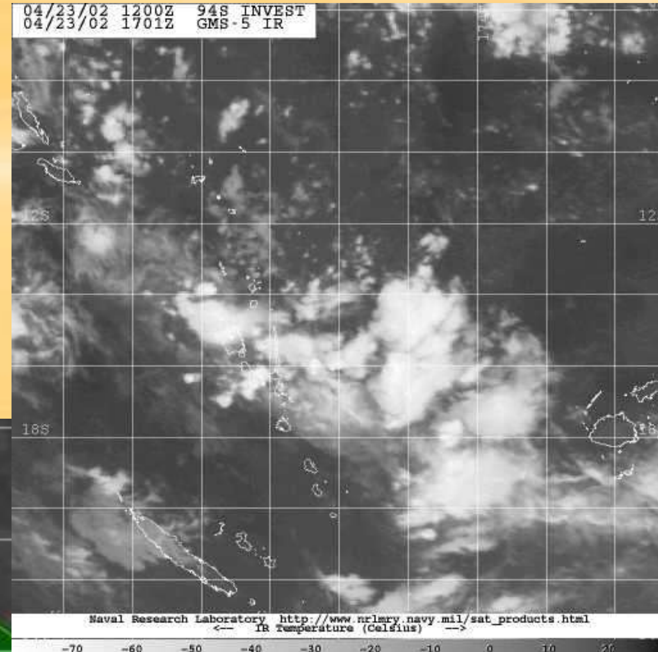
1. Does not show distinguish convection from low clouds bands. Eyes are sometimes poorly defined or not detectable. False eyes are common*.
2. Suffers from poor spatial resolution on SSM/I, SSM/IS, better on TMI, WindSAT and AMSR-E
3. Not available on AMSU-B

Tropical Cyclone Lifecycle in Microwave Imagery

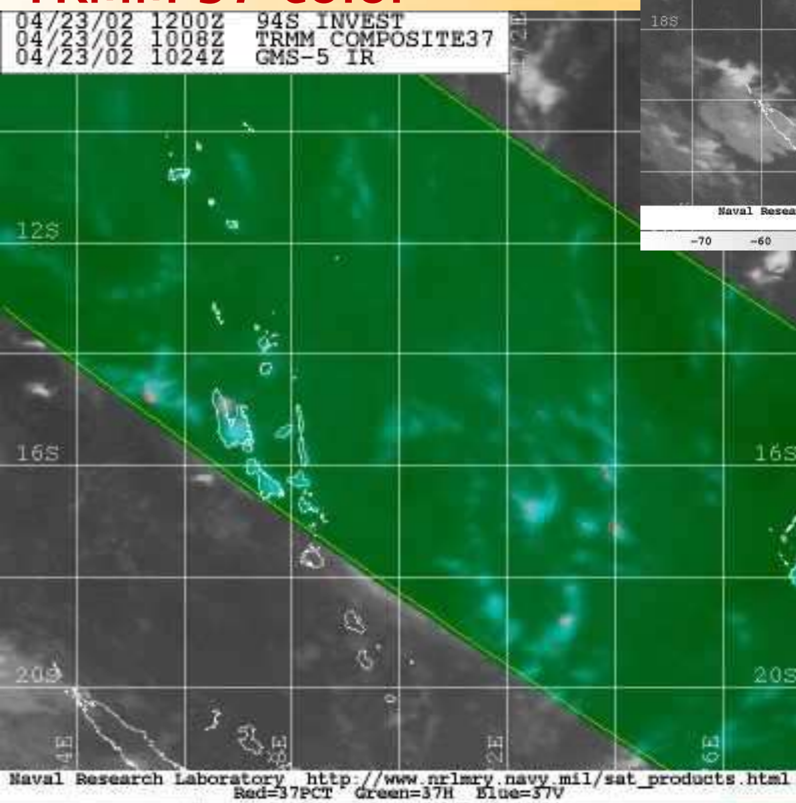
I. TC Genesis Stage ~25-30kt
II. Early Intensification and Development~30-45kt
III. Continued Intensification and Mature Stage
IV. Peaking and Initial Weakening Stage
V. Dissipation and Extratropical Transition

The Beginning?....no classification

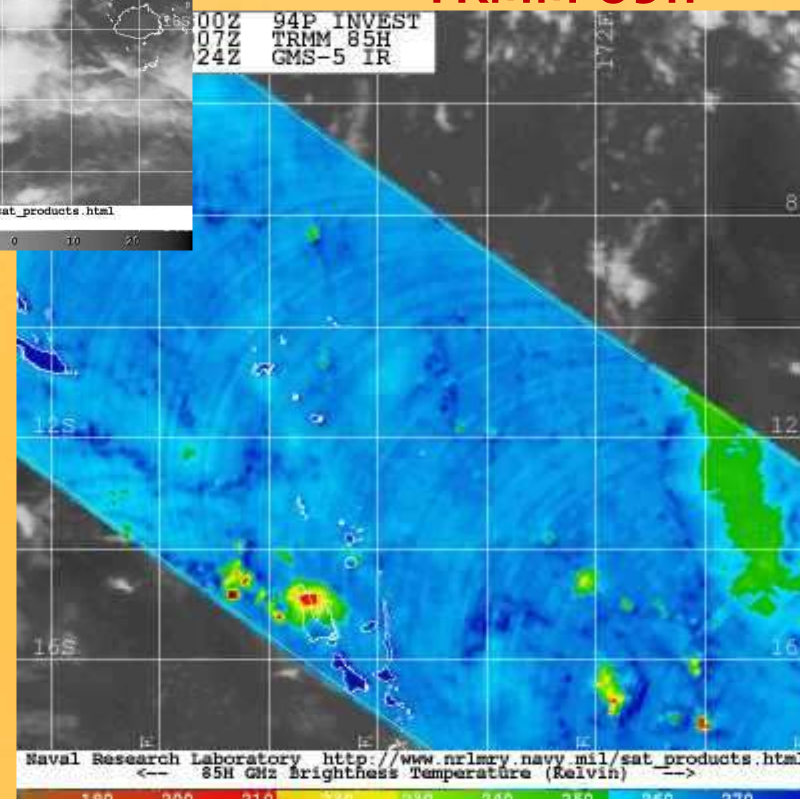
IR



TRMM 37 color



TRMM 85h



Pattern 'C': LLCC present and convection < 250 K forms hooks, claws or broken rings: AVG INTENSITY = 57 kts

(From Cock et al.)