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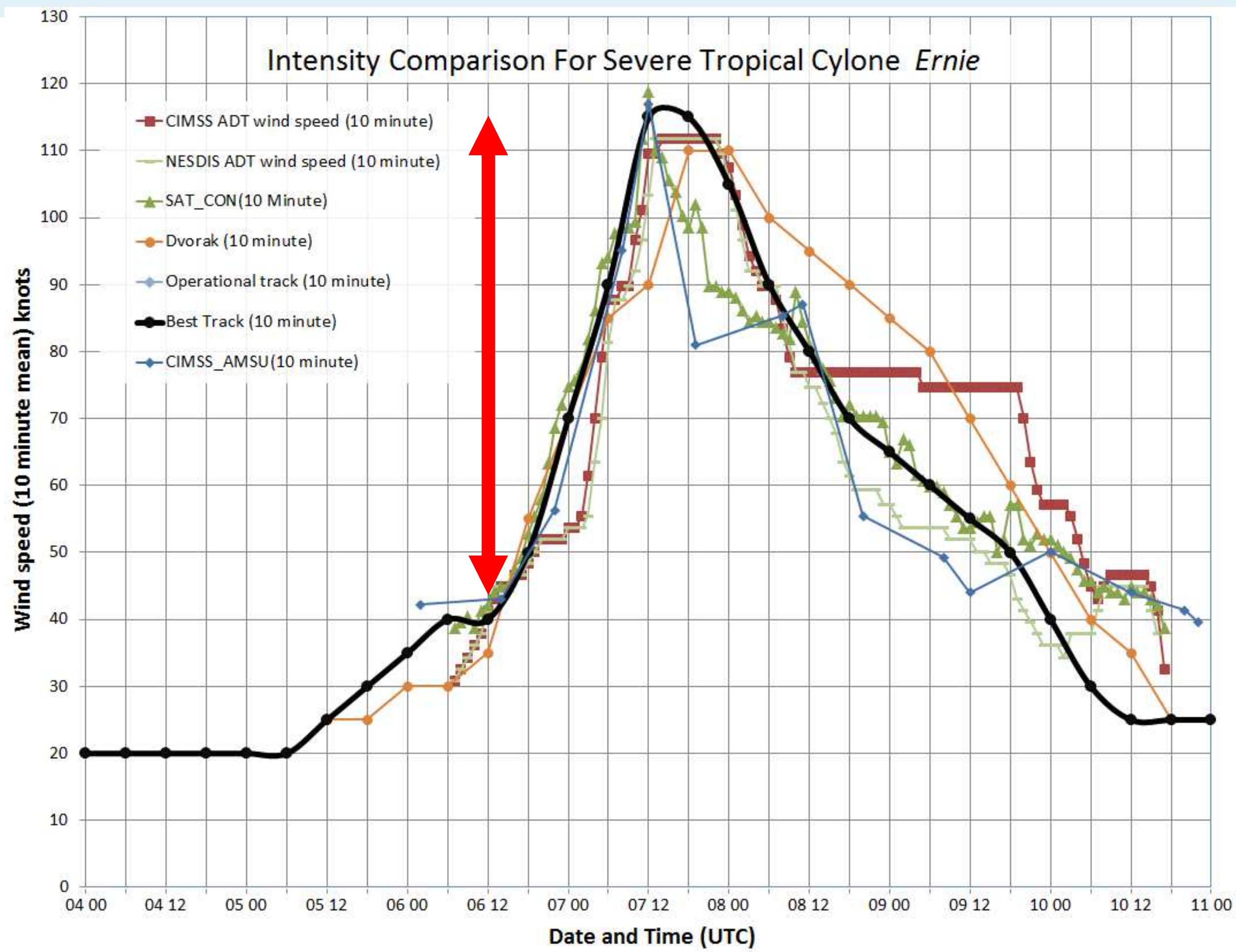
Intensity forecasting
TCs can change intensity rapidly

TC Ernie 2017 Rapid Intensification



40-115kn and DT 2.5 to 7.0 kn in 24 hours!

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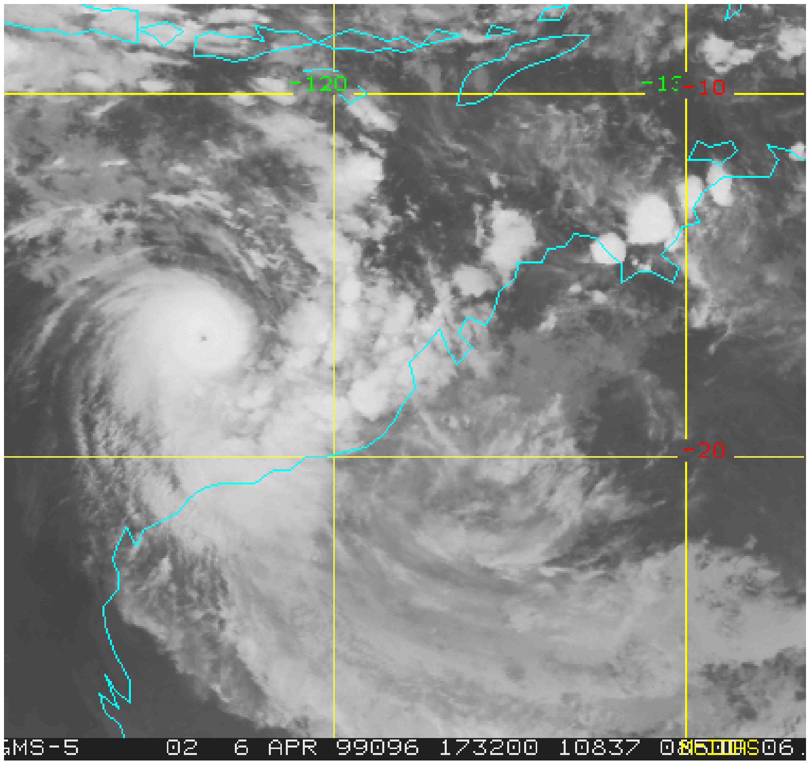
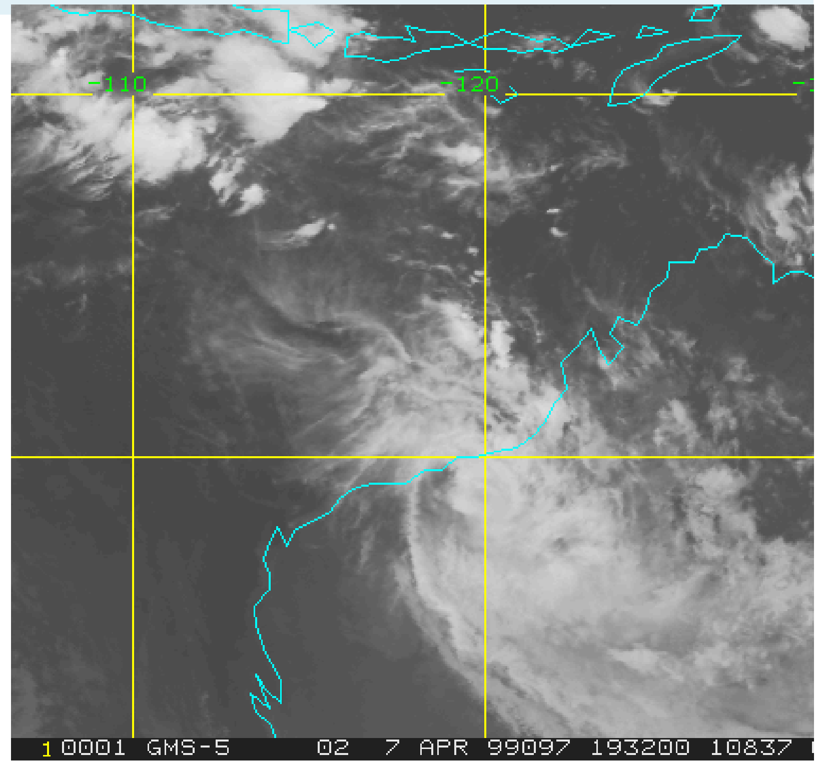
TCs can change intensity rapidly

Gwenda 1999 Rapid Weakening





Cat 5 (120 kn) to Cat 2 (55 kn) in 24 h!

and Cat 4 (90kn) to low (30kn) in 11 h

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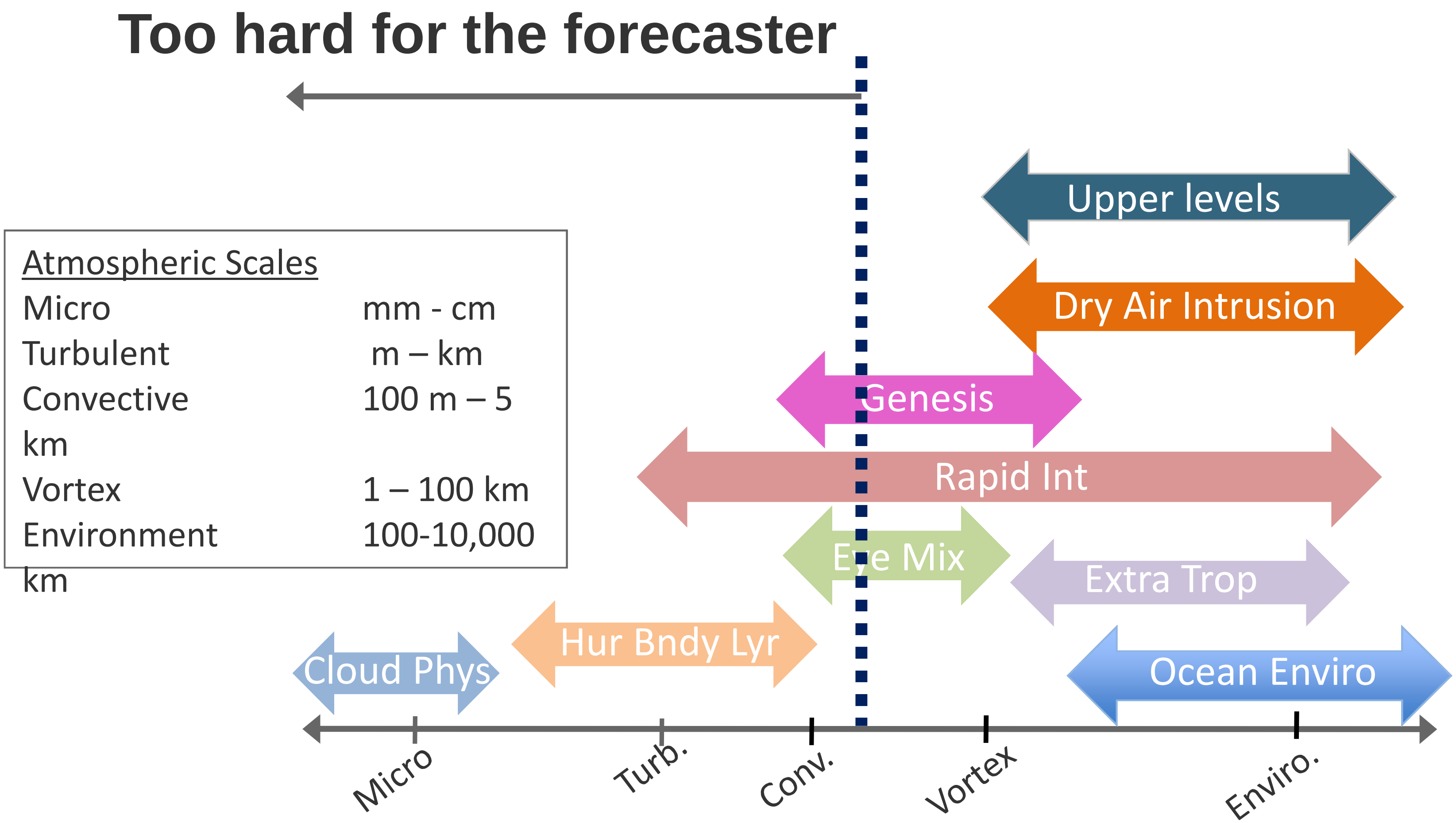
Intensity changes on different scales



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Critical elements

1. Good Analysis and environment assessment
2. Persistence (esp. for first 12h)
3. Changes in the environment (NWP) Conceptual Models
4. Objective outputs:
   statistical-dynamical(STIPS/SHIPS),
   NWP trends & consensus (future); RI index
5. Existing policy- consistency "forecasting in honey"

⇒ Combining Subjective Vs Objective
⇒ Picking Rapid Intensification/weakening

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What intensifies TCs?

Strong Radial Inflow (moisture, heat, angular momentum)

- Moving along the coast esp where it is hilly

Increased Upper-level Outflow

Decrease in Wind Shear

Warm Sea Surface Temperature

Moistening of low-mid levels -heavy precipitation

=>>evidenced in the patterns of the convection and increased low-level relative vorticity

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What weakens TCs?

Movement Over Land

Strong Vertical Wind Shear

Dry air intrusion (coming into the circulation)

Restricted Outflow

Cool SSTs

Slow moving TCs (cooler SST by mixing)

Fast TC Motion (> 20 kn)

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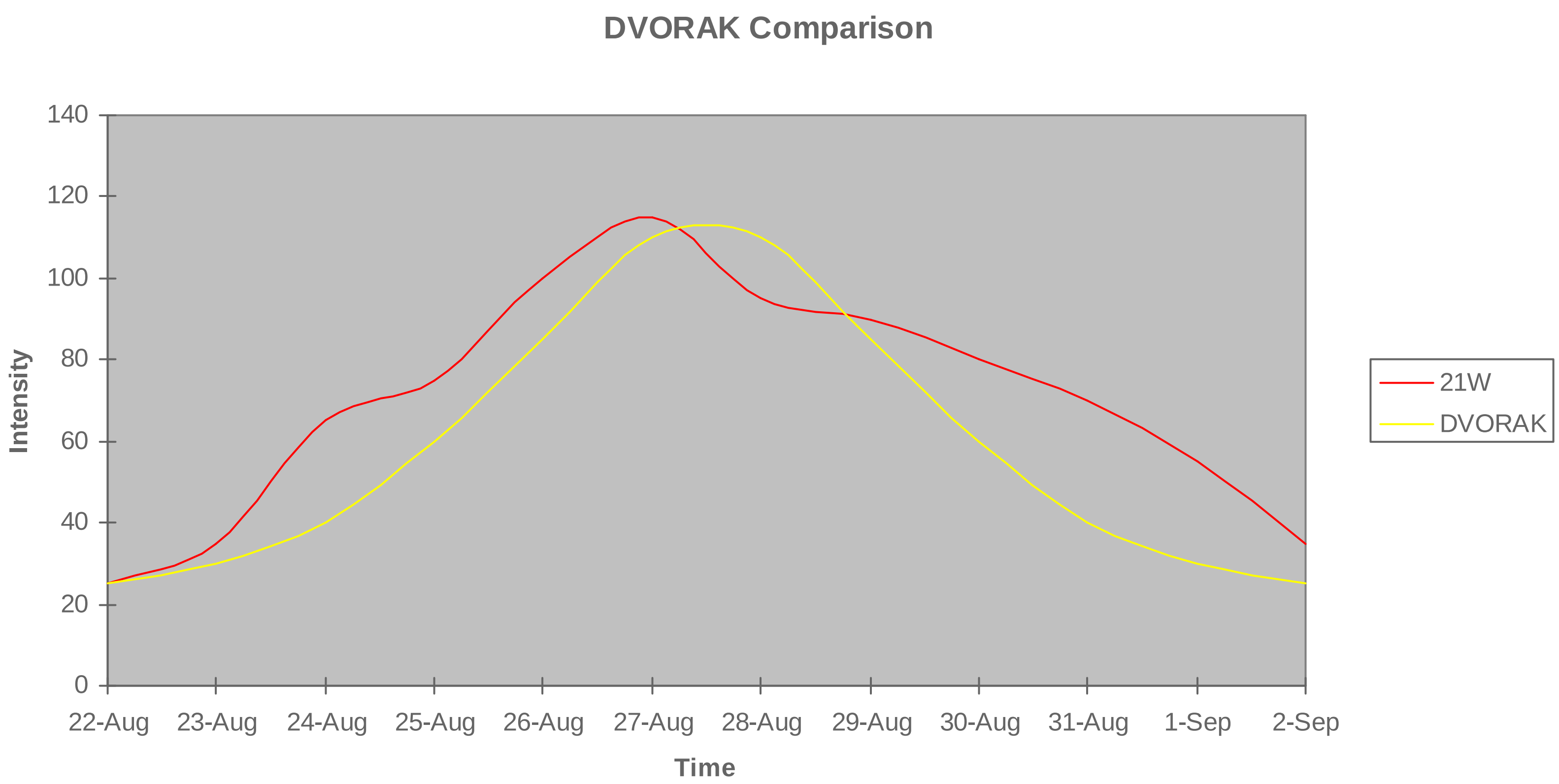
Traditional Forecaster framework in Dvorak T-no. changes

Slight 0.5/day; standard T1.0/day; rapid T1.5+/day



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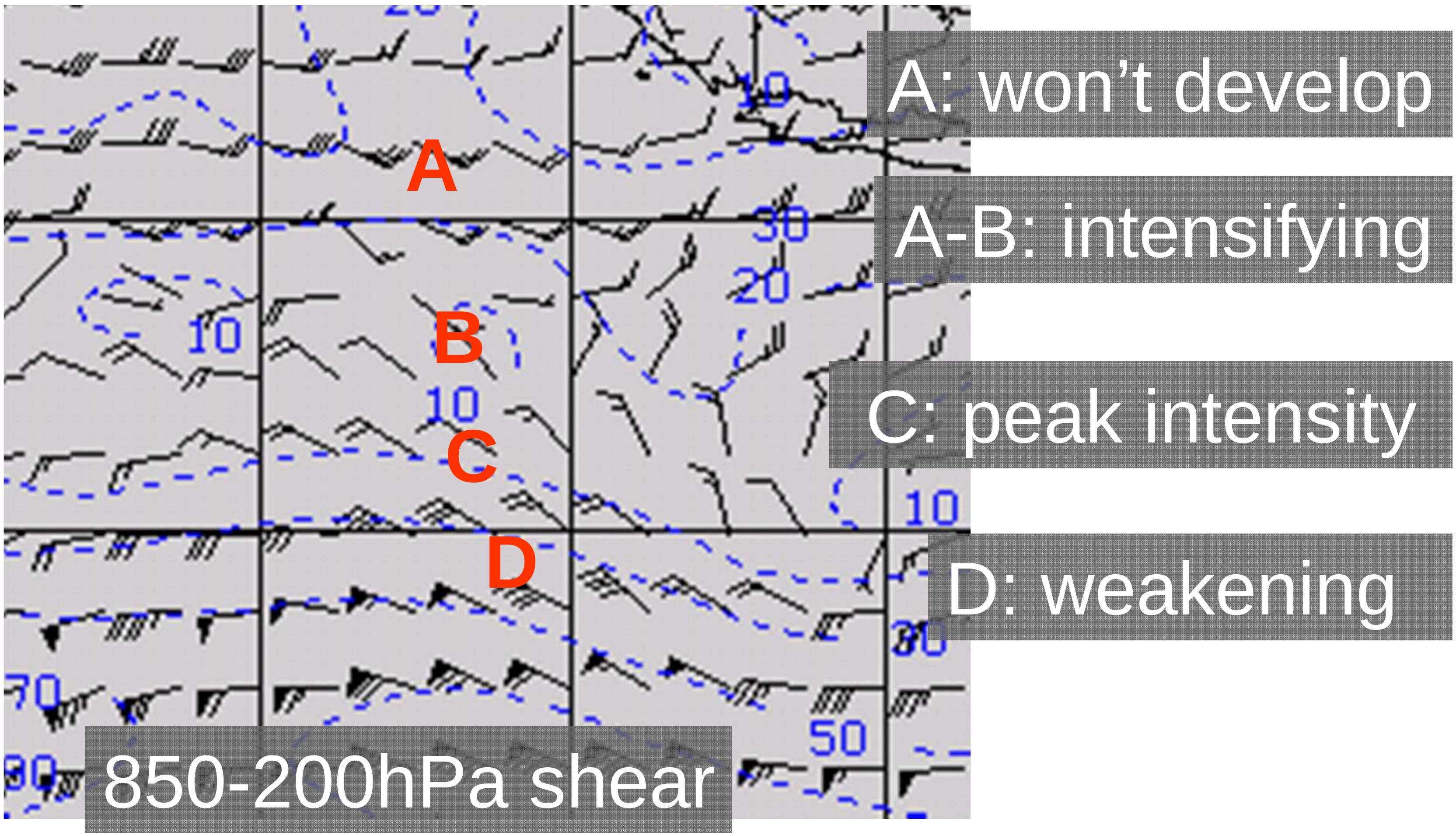
Subjective Approaches

Shear: dominant influence in Aust/Pac

What intensity changes would you expect A-D?



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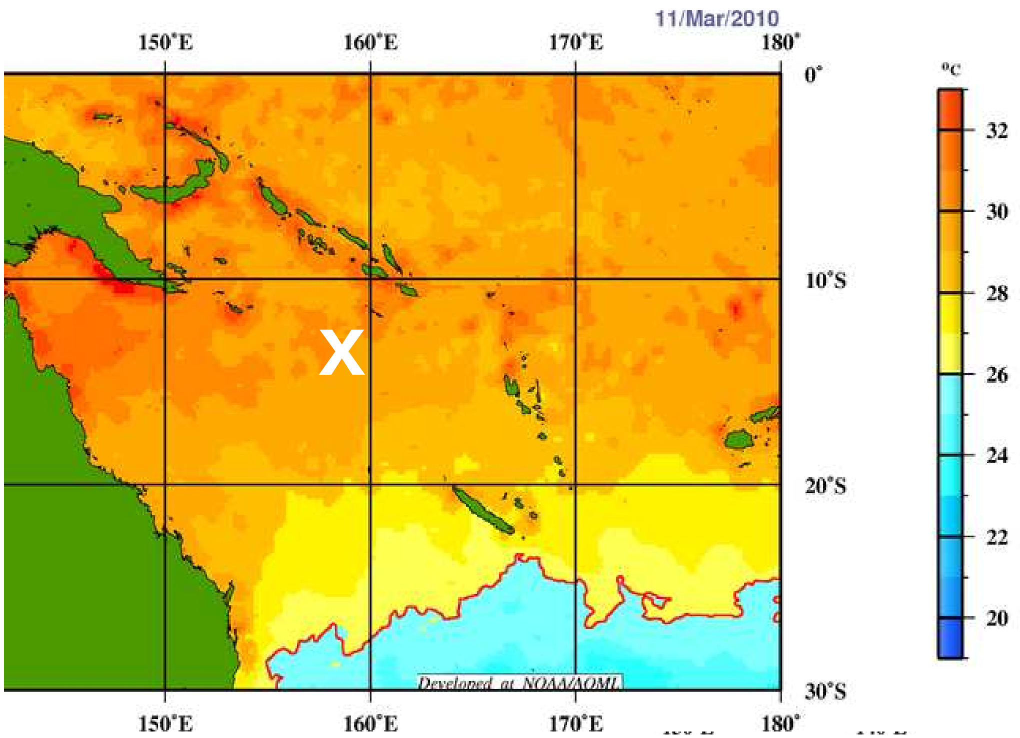
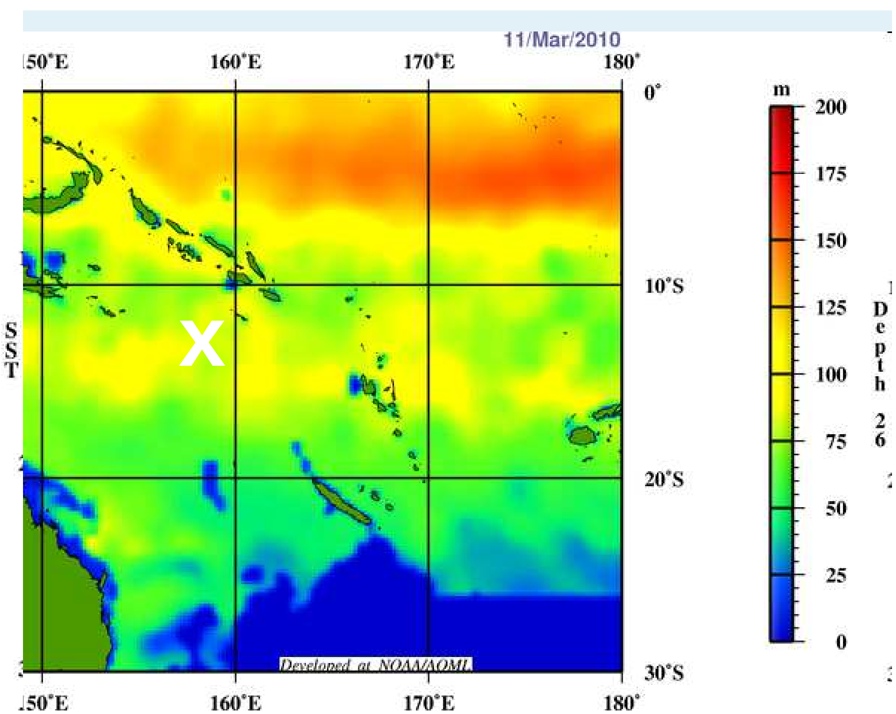
Subjective Approaches: SST weakening due to own slow motion





Pre-Ului on 11 March : 30C SST 13S158E on 17 Mar
26C isotherm at 75m

In Deep Ocean

Subjective Approaches: SST

moving over cooler waters/upwelling

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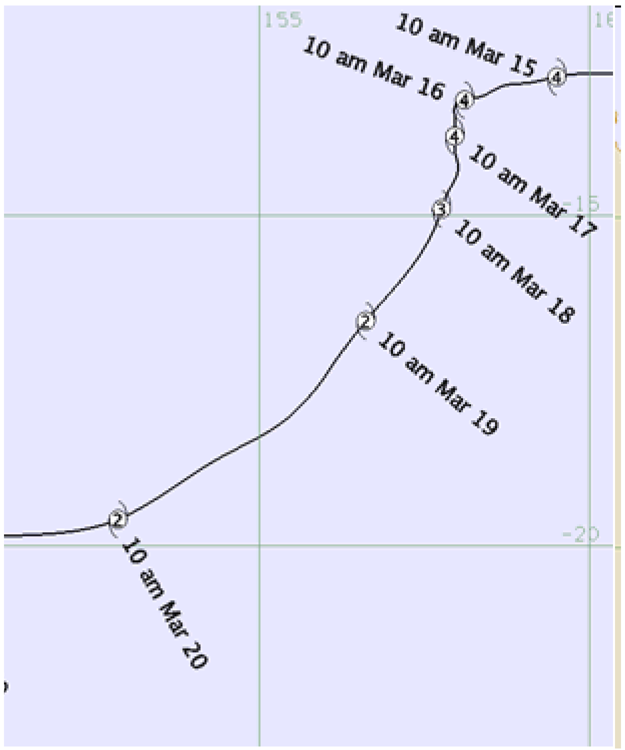

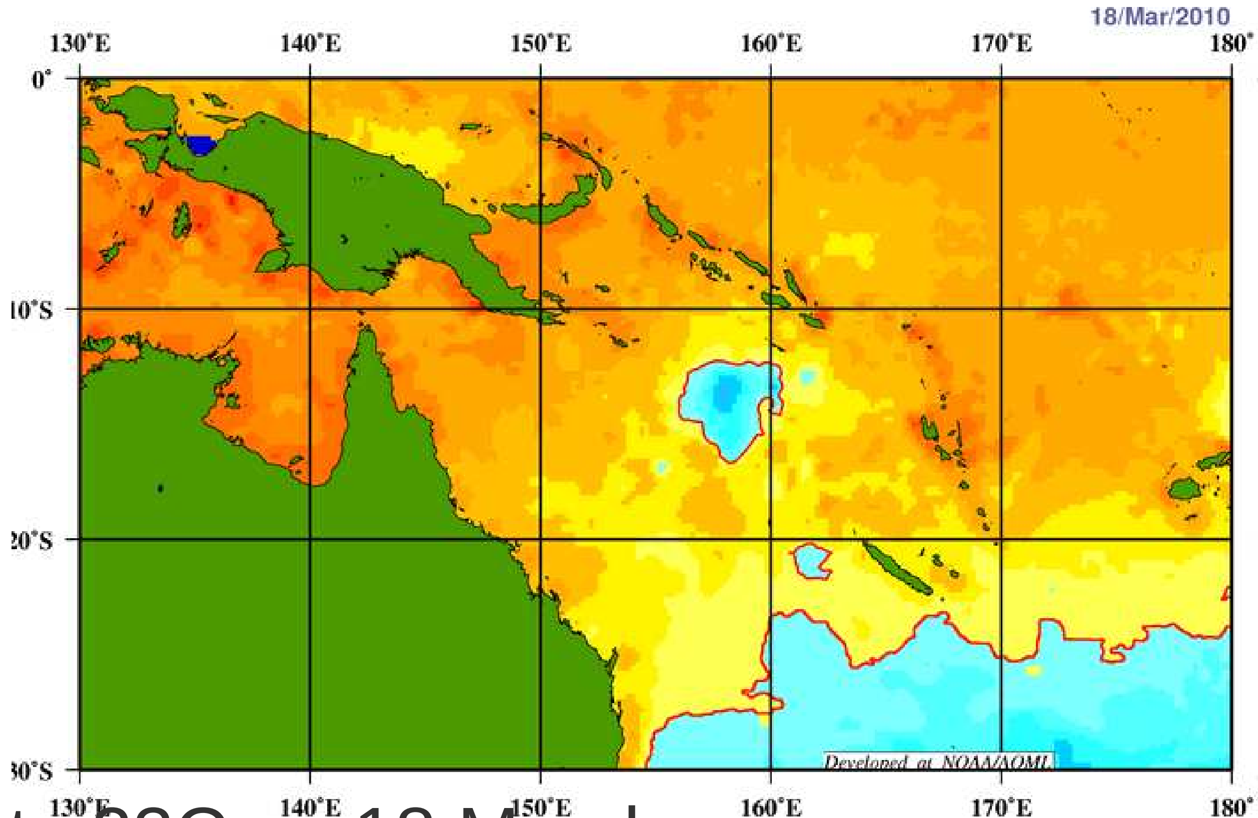

Waters cooled to 23C on 18 March
Ului: weakened from cat 4 to cat 2 17-19 March 2010
Moving at 2 knots 15-18 March

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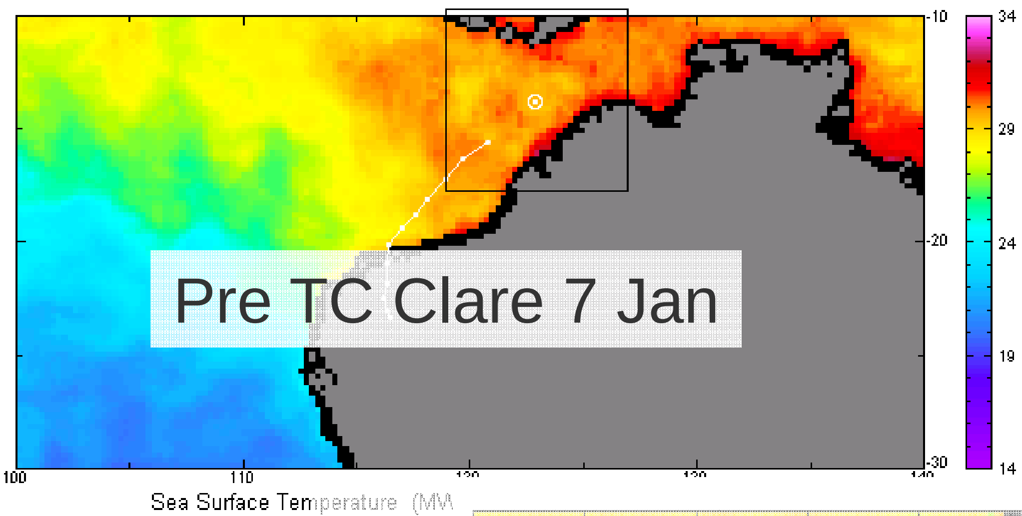
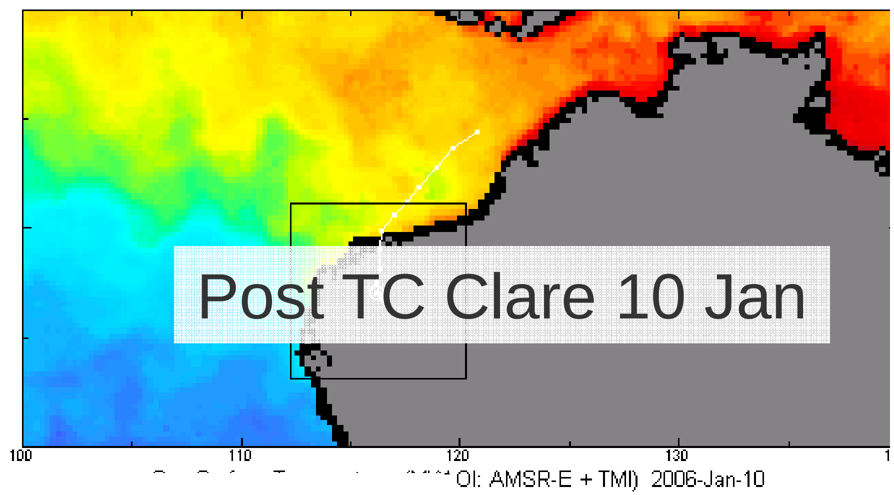
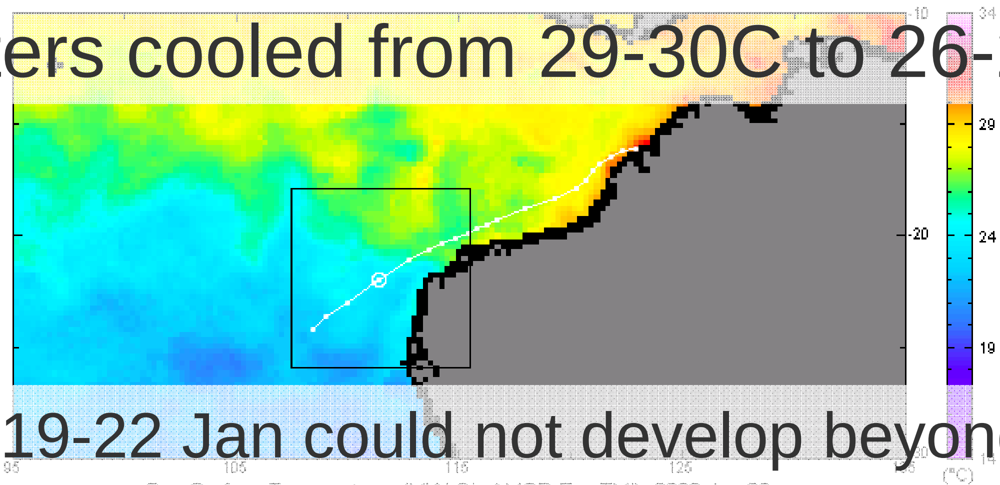
Subjective Approaches: SST

TC Daryl limitation to cat 2





Waters cooled from 29-30C to 26-27C



Daryl 19-22 Jan could not develop beyond Cat 2 despite favourable environment

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Subjective Approaches: SST

TCs moving < 5kn consider upwelling

Upwelling related to motion, intensity, size
Cooling is rapid 12-24h for VSCS roughly 2+C for area of roughly storm force winds (rules of thumb)
Absolute SSTs most critical

- cooling from 31 to 29C not that significant
- Threshold of 28C for VSCS, 26C for CS rule of thumb

Depth of 26C isotherm also a factor – consider OHC
Difficult forecasting challenge given so many variables.

Subjective approaches: Landfall

Standard Decay rate + topography?

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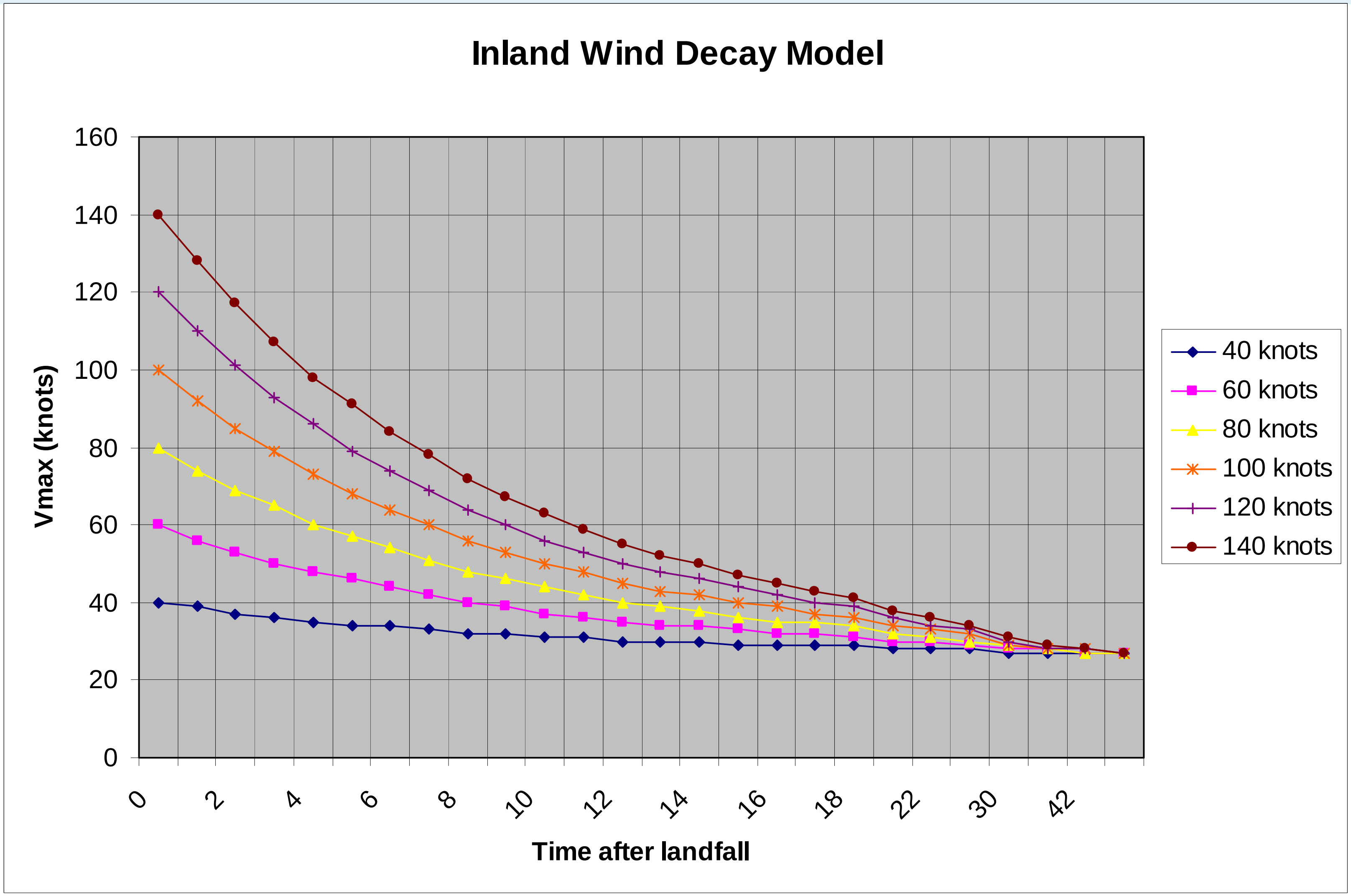
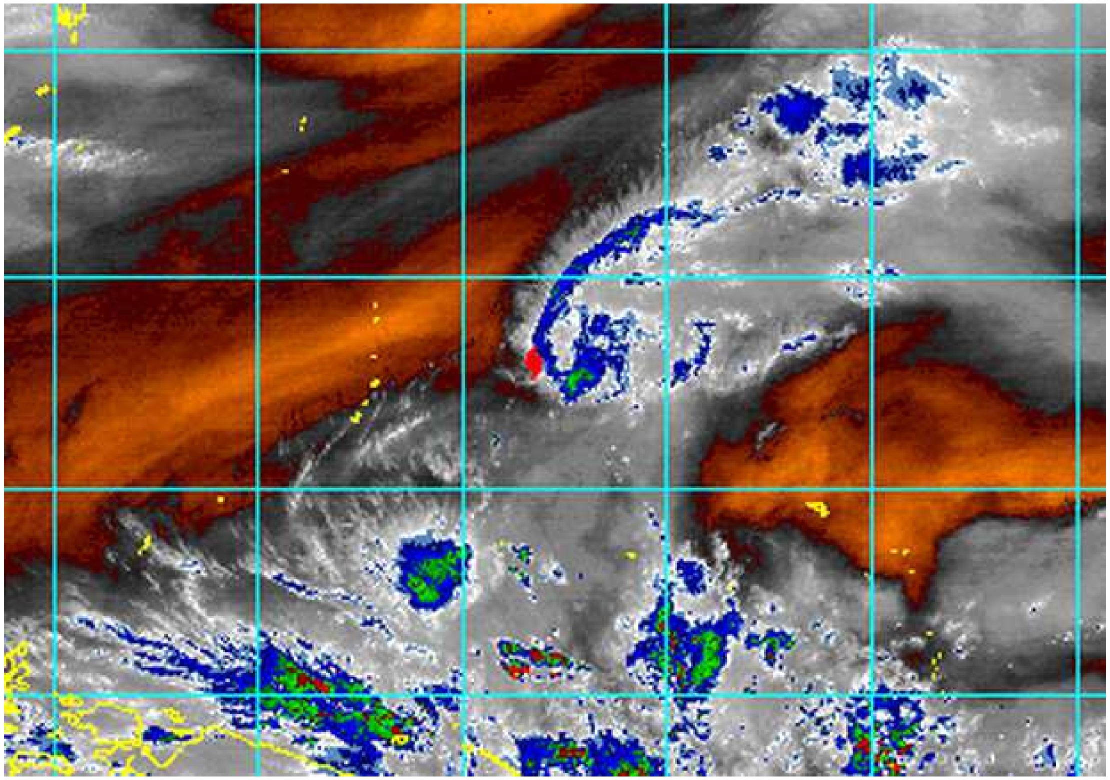


Dry air intrusion: need to look at with shear

Higos (WP Feb 2015)
http://rammb.cira.colostate.edu/products/tc_realtime/loop.asp?product=16kmgwvp&storm_identifier=WP022015&starting_image=2015WP02_16KMGWVP_201502090232.GIF&ending_image=2015WP02_16KMGWVP_201502110232.GIF



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Subjective intensity changes: Cyclonic Storm approaching

What environmental factors should I look be looking at to determine the forecast intensity?

Upper levels - divergence

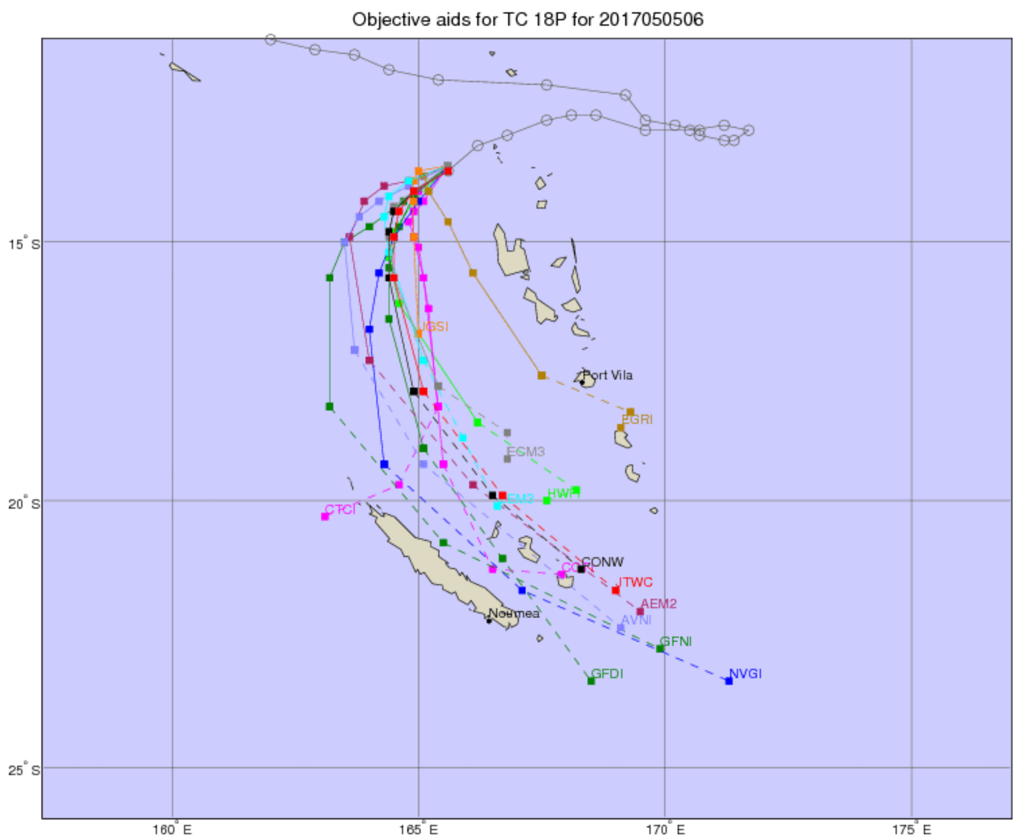
Wind shear

SST and OHC – speed of movement

RH 600hPa

When it will hit land

*also intensity and trend



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Intensity forecasting still tricky but…

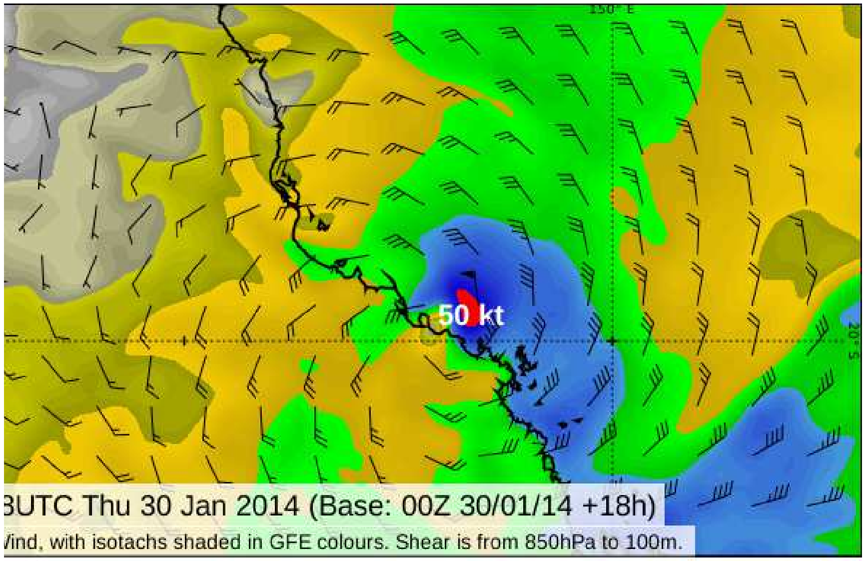
Inputs: manual (+- DT/24h); Objective Aids: S5XX, S5YY;

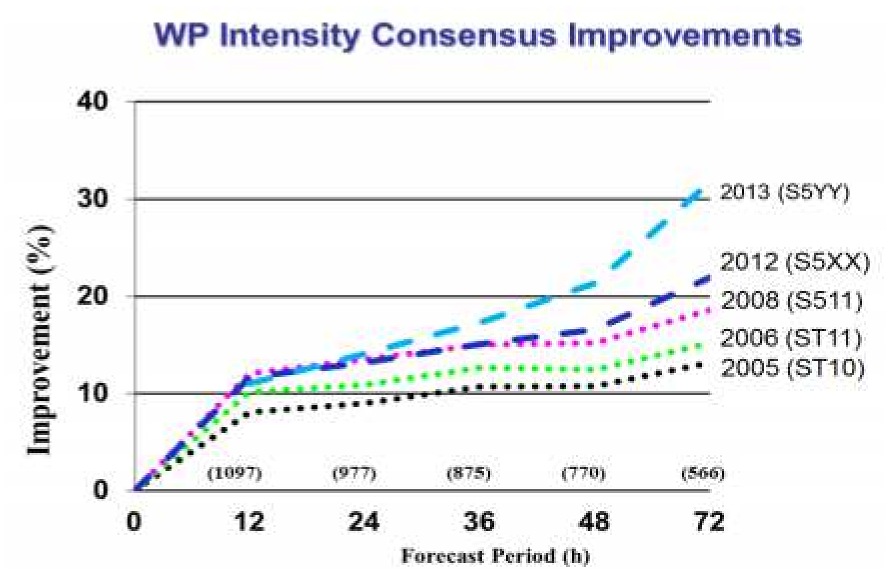
Models: esp. HWRF (ensembles not yet that useful)

model sfc wind patterns

Recognition of satellite signatures for rapid changes

Basic process remains same.





Source: Sampson&Knaff, IWTC

http://www.wmo.int/pages/prog/arep/wwrp/new/documents/Topic2.7_AdvancesinIntensityGuidance.pdf

Objective Intensity Guidance: S5XX and SFYY

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S5XX has been better in SH and IO but S5YY expected to be better now.

S5YY

LGEN/DSHN – SHIPS/LGEM using NAVGEM

- LGEA/DSHA – SHIPS/LGEM using GFS track and wind fields, and NAVGEM thermal fields
- CHIPS
- GFDN
- COAMPS-TC
- HWRF

WARNING ACRONYMS!!!!!

S5XX: From STIPS (no LGEM)

Source: Sampson&Knaff, IWTC
http://www.wmo.int/pages/prog/arep/wwrp/new/documents/Topic2.7_AdvancesinIntensityGuidance.pdf

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Intensity forecasting: Rapid Intensification (RI) index

SHIPS: gives probability of a 30kn/24h intensity based upon 9 predictors.
Calibration
~15-20% consider R
~ 30% RI is definite.
Fluctuations in output
IMD calibration differs

Source: B. Sampson

RII Predictors

1. Previous 12 h max wind change (persistence)
2. Maximum Potential Intensity – Current intensity
3. Oceanic Heat Content
4. 200-850 hP shear magnitude (0-500 km)
5. 200 hPa divergence (0-1000 km)
6. 850-700 hPa relative humidity (200-800 km)
7. 850 hPa tangential wind (0-500 km)
8. IR pixels colder than -30^{o}C
9. Azimuthal standard deviation of IR brightness temperature

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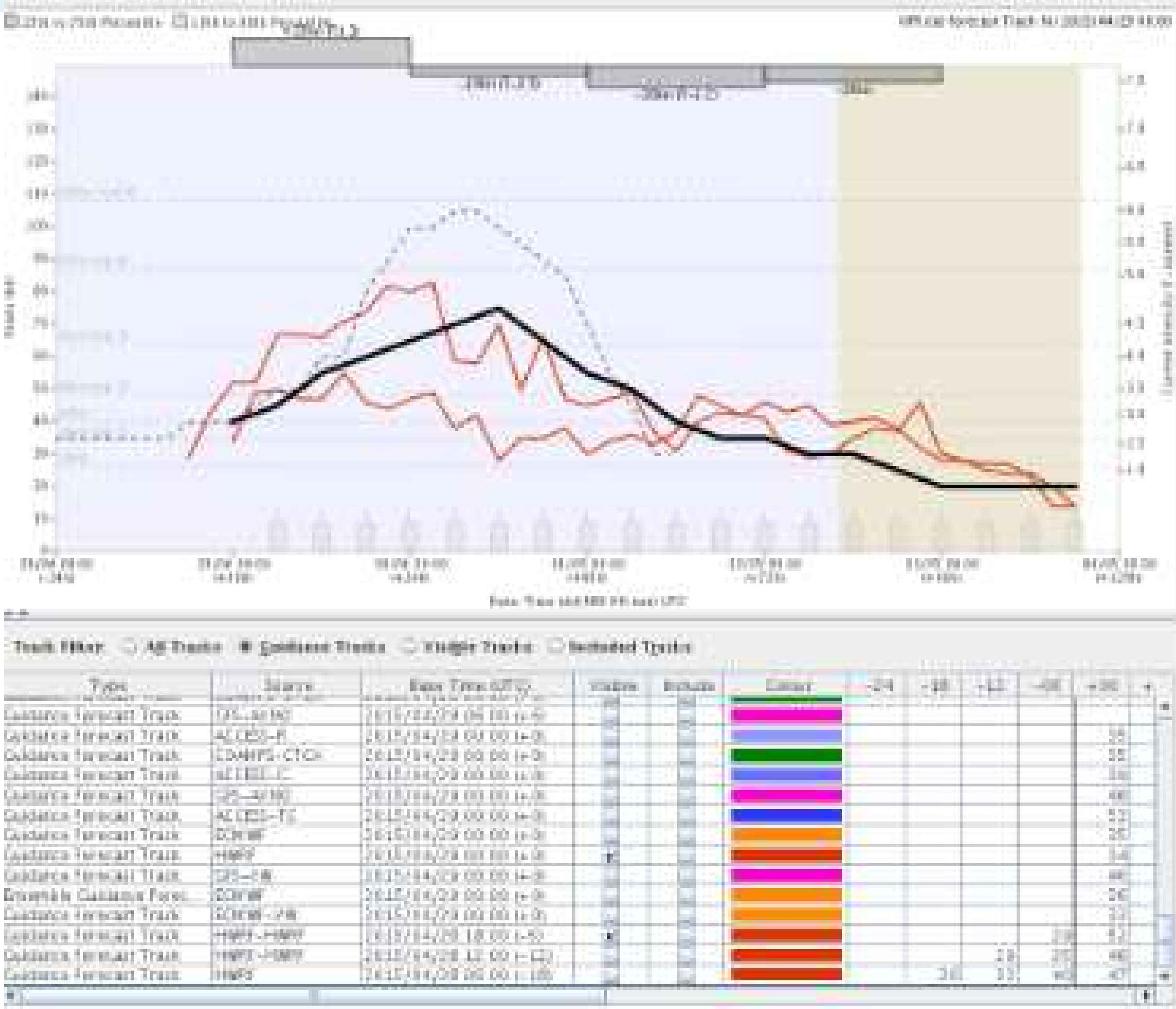
Intensity forecasting : visualising

Intensity plots make it easier for comparison



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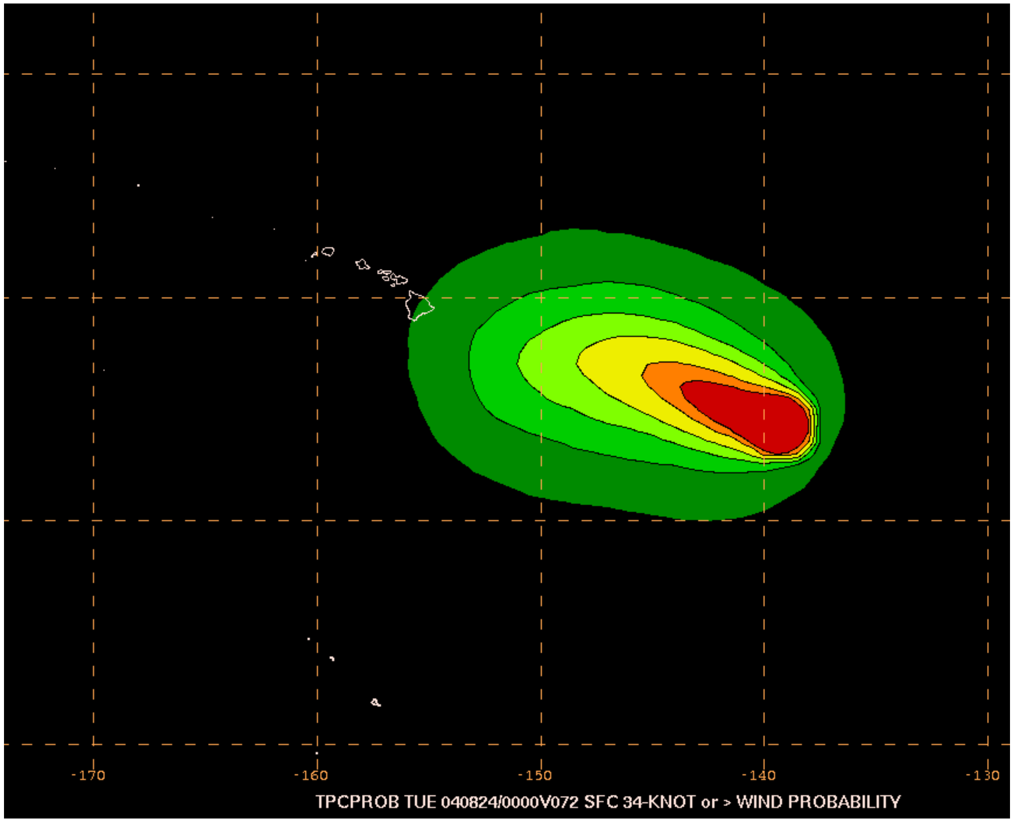
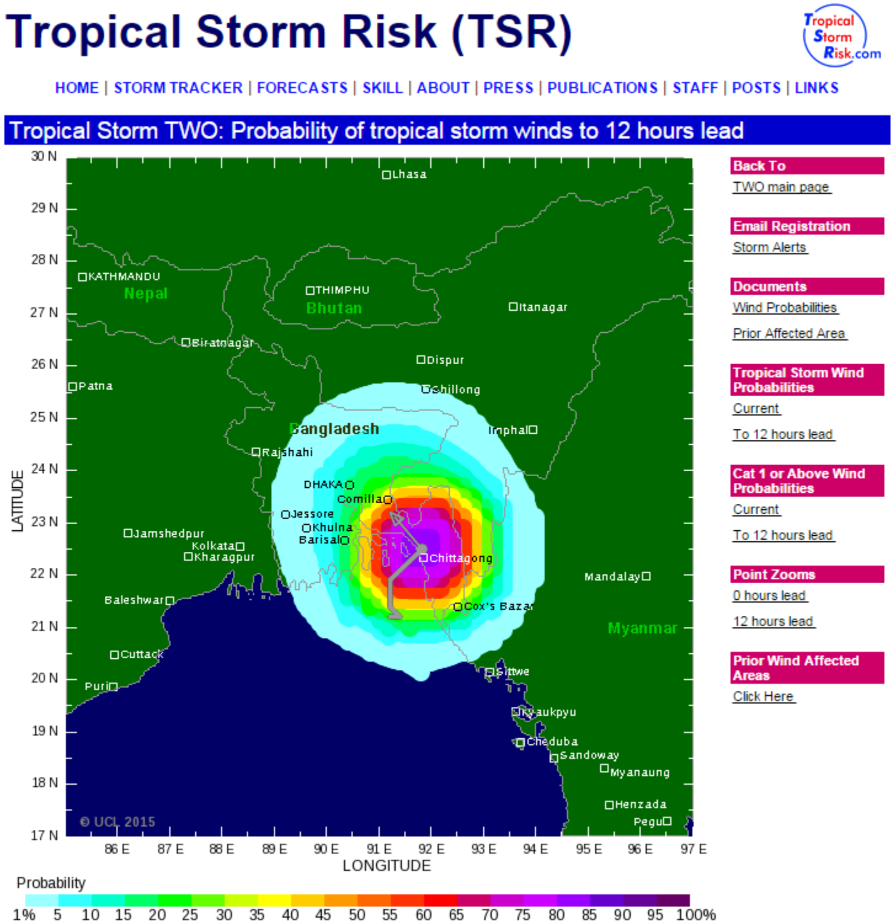
Moving to probability of impact – more info than peak intensity

http://www.nhc.noaa.gov/refresh/graphics_ep3+shtml/083822.shtml?tswind120#contents
http://www.tropicalstormrisk.com/
Coming: http://rammb.cira.colostate.edu/products/tc_realtime/season.asp?storm_season=2018





34 kt Cumulative

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Rapid Intensification: 30kn/day OR T1.5+/day

The difficult forecast - Will it? When?

Most SevTCs undergo RI at some stage (from 50+ kn)

RI index uses upper-level divergence, wind shear, previous 12h intensity change, inner-core symmetry Recognising pre-cursor signals in imagery

microwave patterns (often ‘blob’ stage in IR/Vis)

Low level organisation (37GHz vorticity) plus convection (85GHz)

Kieper, M., and H. Jiang, 2012: Predicting tropical cyclone rapid intensification using the 37 GHz ring pattern identified from passive microwave measurements. Geophys. Res. Lett.,39, L13804,doi:10.1029/2012GL052115.

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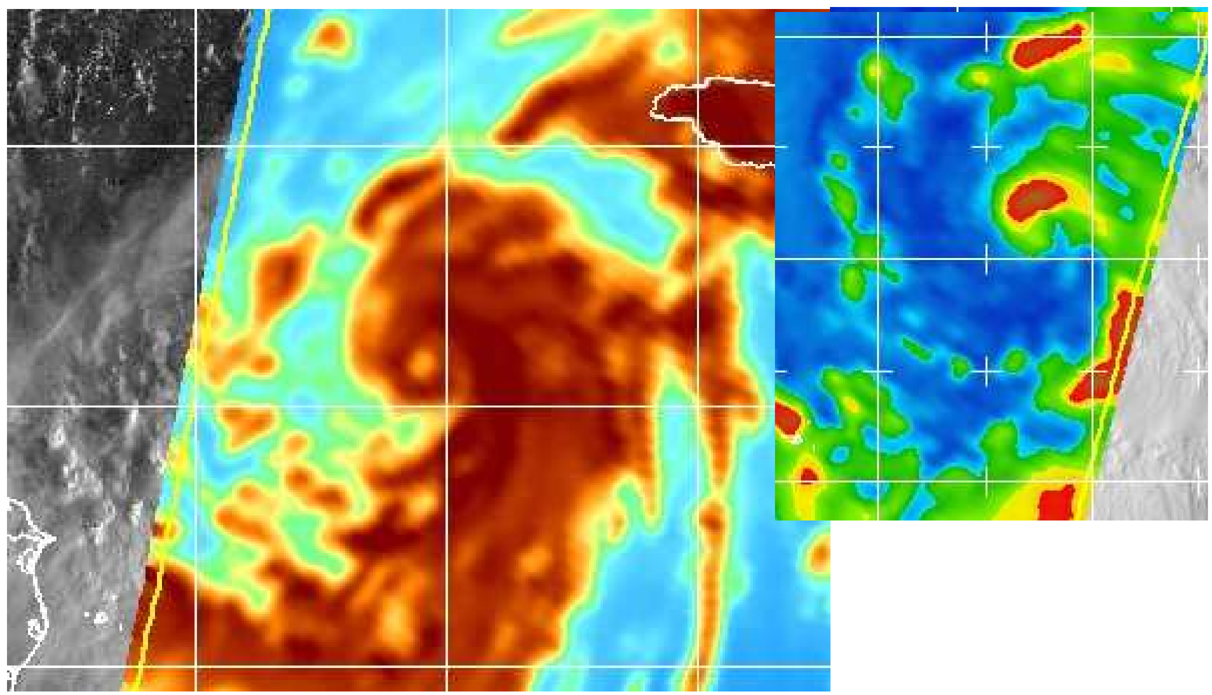
Rapid Intensification: microwave patterns

Recognising microwave patterns (often ‘blob’ stage in IR/Vis)

Low level organisation (37GHz vorticity) plus convection (85GHz)

Wilma, 2005 at 65kn then intensified 95kn/24h

Windsat imagery highest resolution in 37GHz



Kieper, M., and H. Jiang, 2012: Predicting tropical cyclone rapid intensification using the 37 GHz ring pattern identified from passive microwave measurements. Geophys. Res. Lett.,39, L13804,doi:10.1029/2012GL052115.

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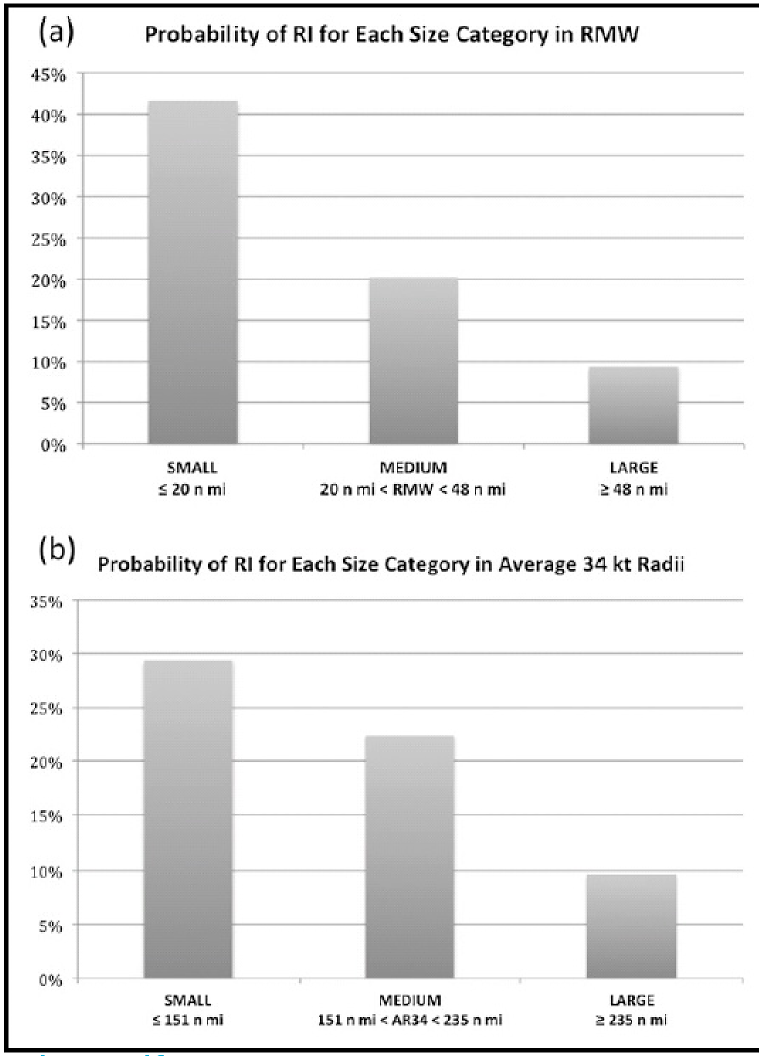
Rapid Intensification:
Small systems more likely to change intensity faster

Probabilities for rapid intensification (RI) for three storm size categories as defined by:

Upper: radius of maximum winds

Lower : average radius of gale-force (34-kt) winds



Fogarty and Zhang, IWTC VIII 2014
http://www.wmo.int/pages/prog/arep/wwrp/new/documents/Topic4.pdf

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Special cases:
Small (Midget) TCs R34 <60nm

Spin (up and down) faster > more likely to undergo RI

'vulnerable' to subtle environmental changes

Analysis: Dvorak underestimates (vis)?; AMSU resolution limitation; use microwave pattern (not objective!)

Genesis problem: models can miss them; non-MJO linked

RI starts earlier (30 knots) than for larger TCs (50 knots)

more likely to intensify at night (respond to nocturnal cloud-top cooling)

More common in Aust basis than elsewhere?

- Low-latitude/high SST

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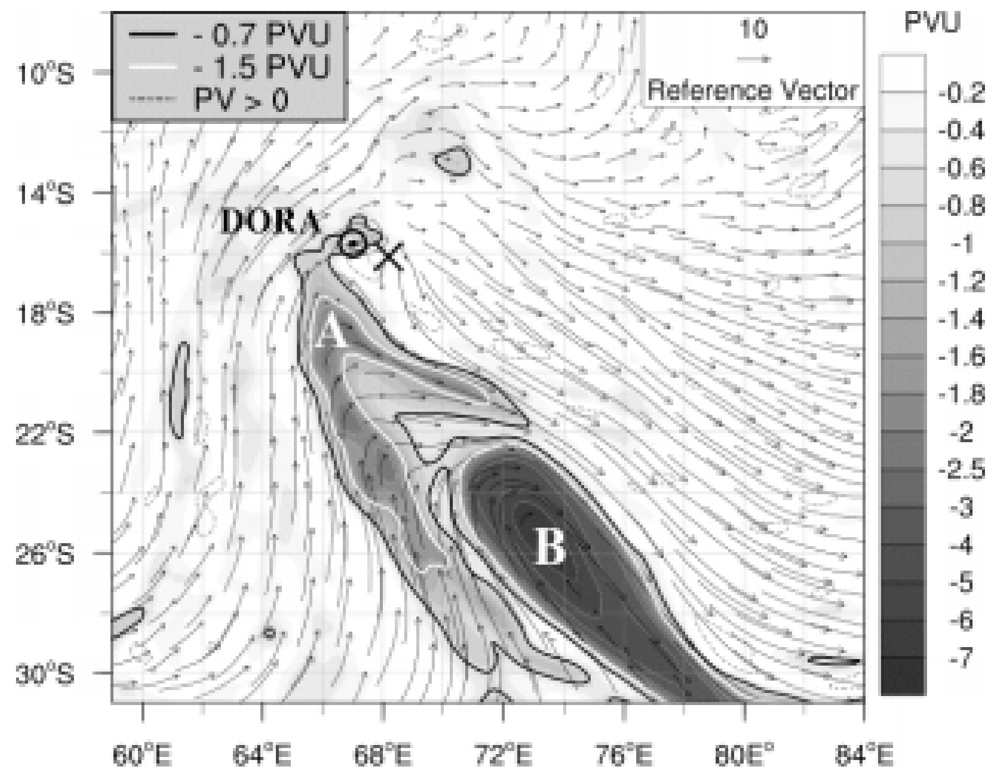
Rapid Intensification from bursts in convection caused by:

Upper trough interactions: increase in divergence;

Downstream energy dispersion (Rossby) – difficult

Warm Air Advection



TC Dora (Southern Hemisphere)
200hPa Winds, PV shaded, x position

Leroux, IWTC VIII 2014

http://www.wmo.int/pages/prog/arep/wwrp/new/documents/T2.5_IntensityChangeExternalInfluences_MDLeroux_7dec2014.pdf

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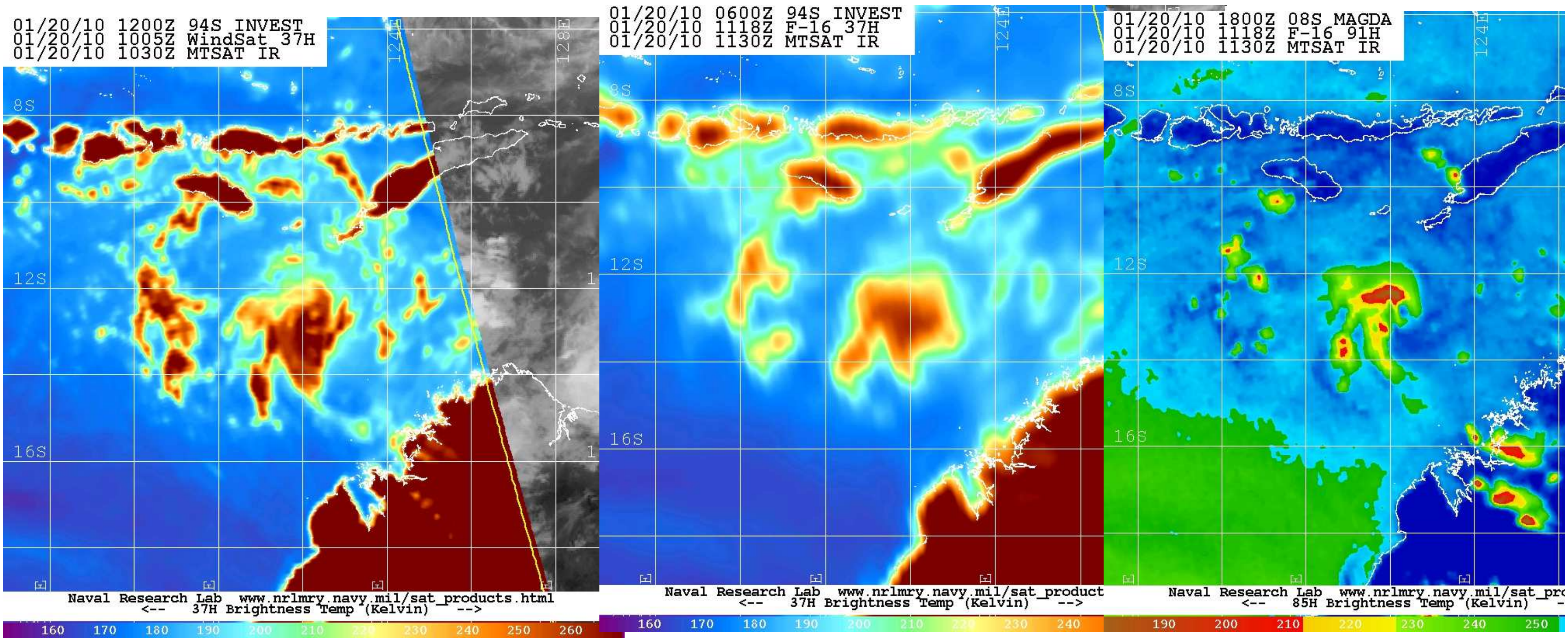
Resolution in the imagery Windsat has highest resolution to detect change in low levels



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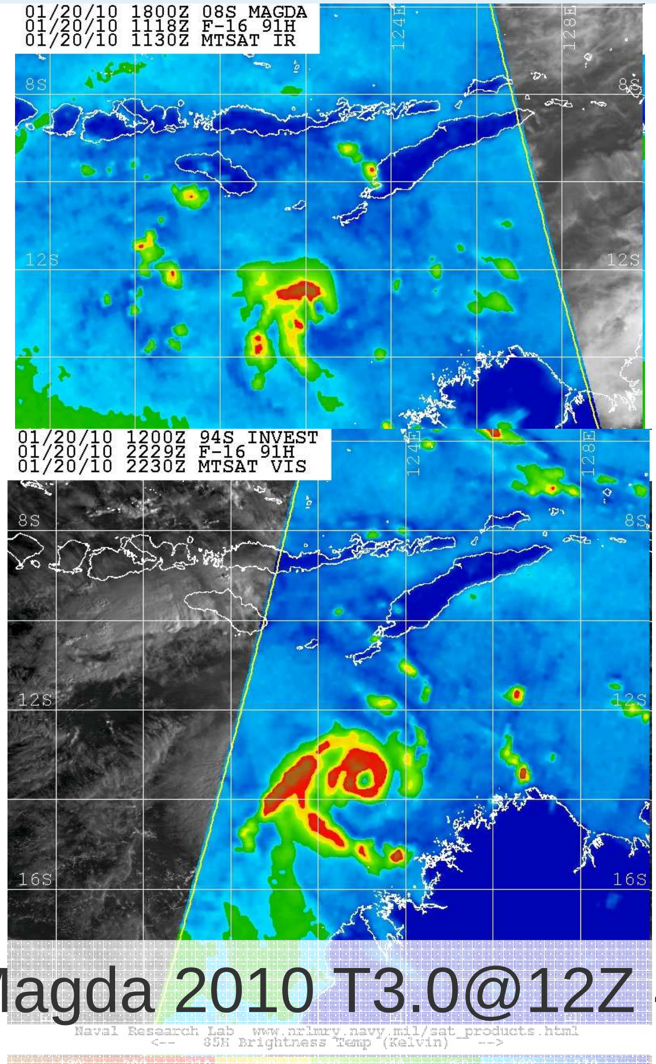
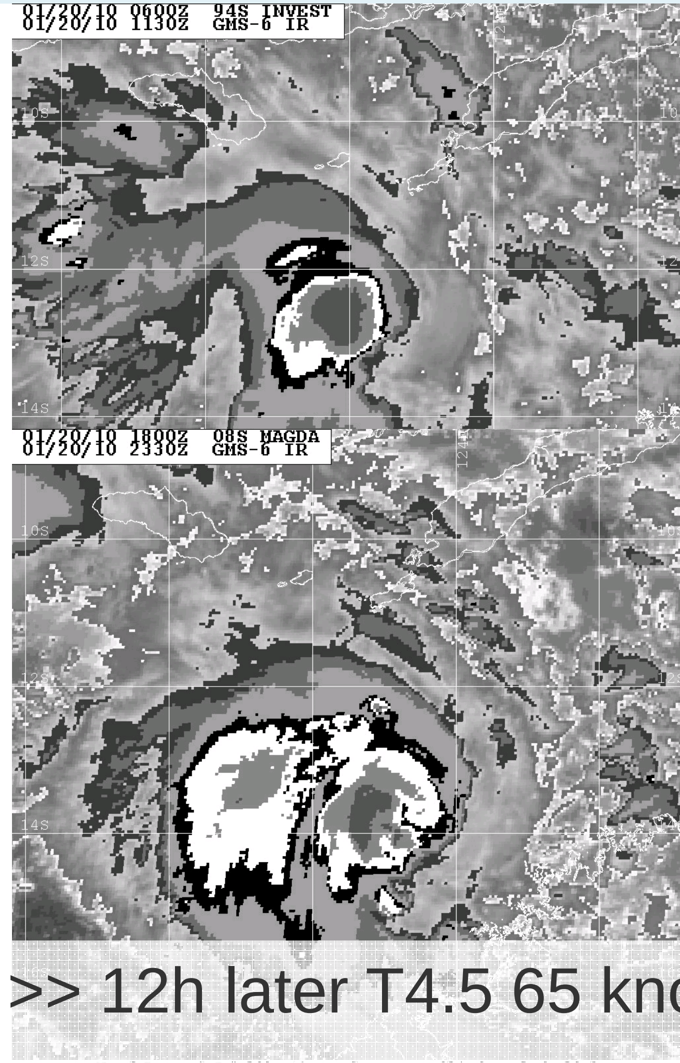
Rapid Intensification of Midgets seen on microwave before IR/Vis





Magda 2010 T3.0@12Z 45 knots >> 12h later T4.5 65 knots

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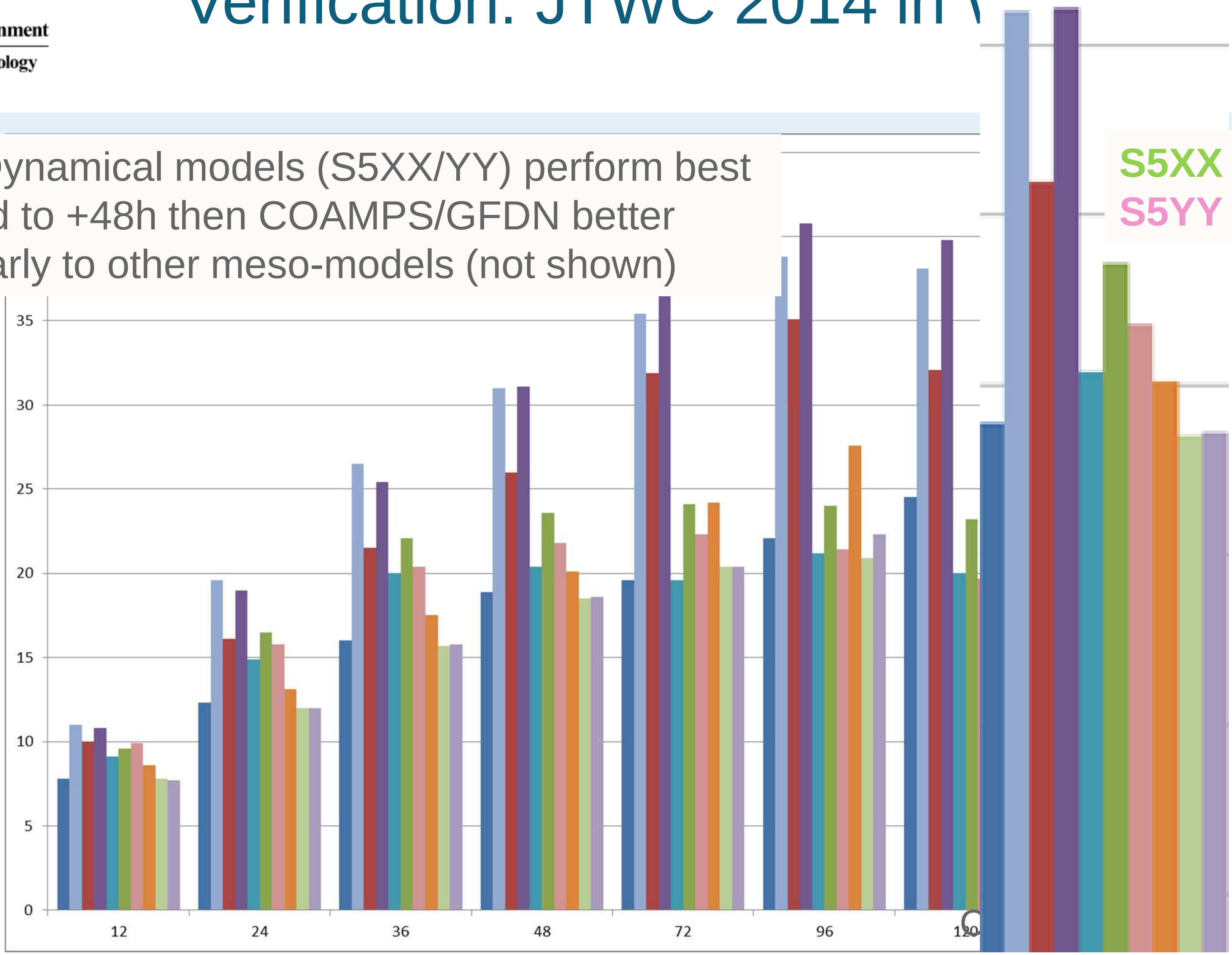
Intensity Forecasting NWP Verification: JTWC 2014 in WPAC

Statistical-Dynamical models (S5XX/YY) perform best
HWRF good to +48h then COAMPS/GFDN better
GFDL similarly to other meso-models (not shown)



HWRF improvements

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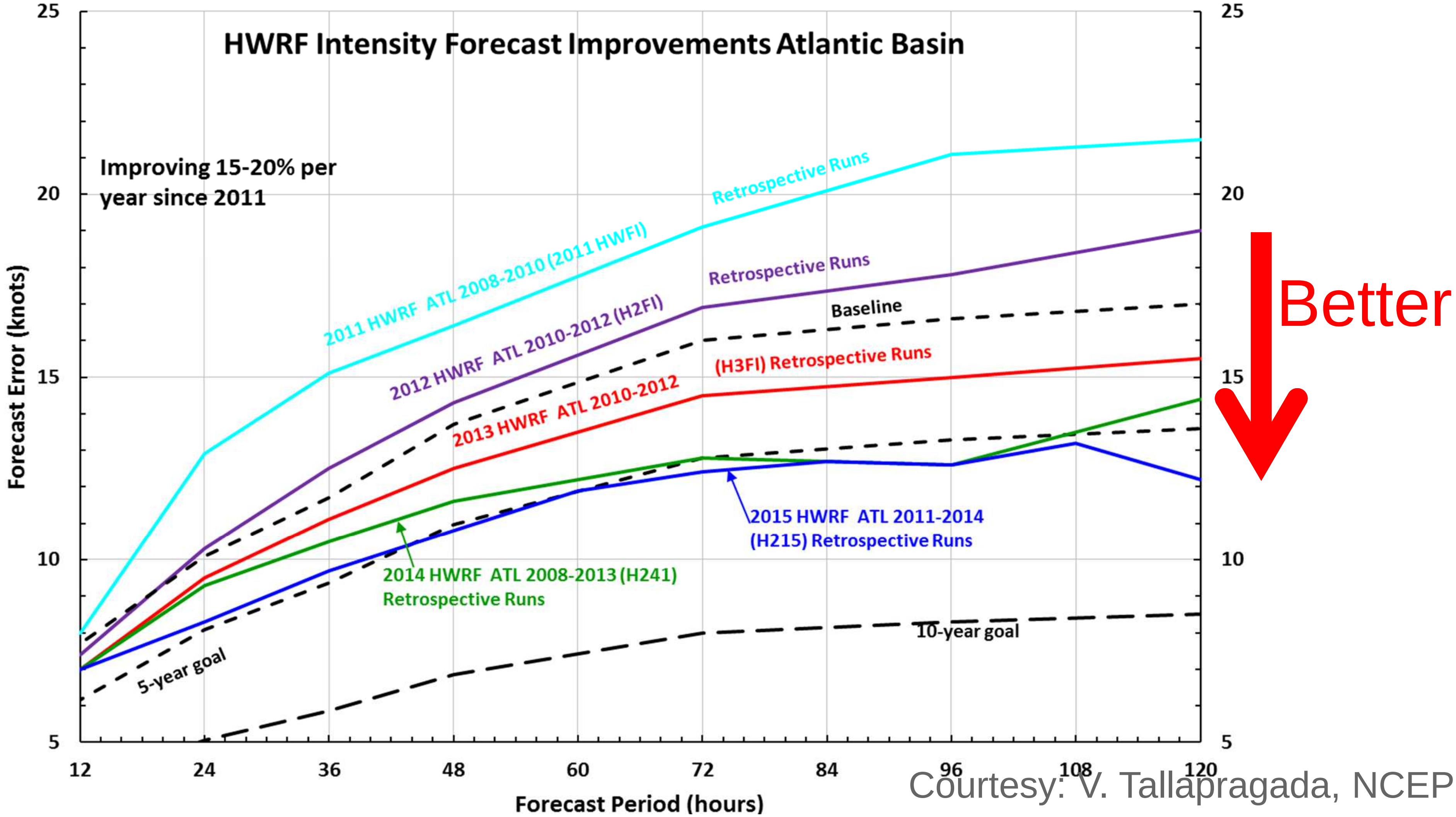

Courtesy: V. Tallapragada, NCEP

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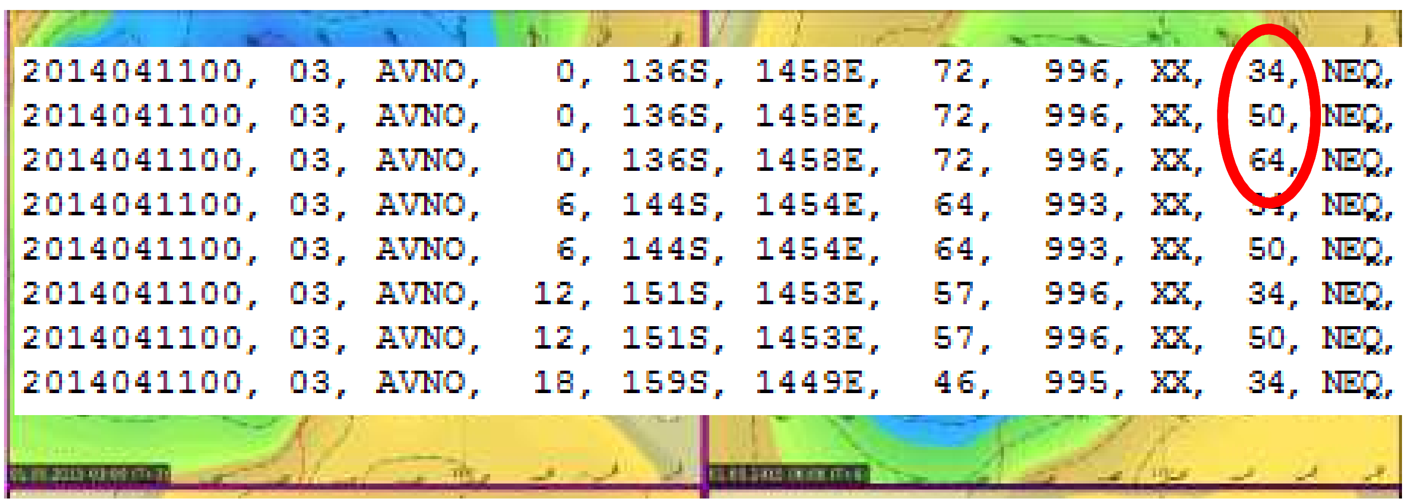
Structure forecasting – the poor cousin

Greater emphasis for future because it affects:

- Watch/warning areas;
- Onset times of gales so preparation activities;
- Wave generation and storm surge;

Analysis – Ascat + model fields

Model guidance graphic and numeric



2014041100,	03,	AVNO,	0,	136S,	1458E,	72,	996,	XX,	34,	NEQ,	136,	101,	83,	100,
2014041100,	03,	AVNO,	0,	136S,	1458E,	72,	996,	XX,	50,	NEQ,	70,	72,	65,	55,
2014041100,	03,	AVNO,	0,	136S,	1458E,	72,	996,	XX,	64,	NEQ,	52,	53,	54,	0,
2014041100,	03,	AVNO,	6,	144S,	1454E,	64,	993,	XX,	34,	NEQ,	104,	93,	37,	86,
2014041100,	03,	AVNO,	6,	144S,	1454E,	64,	993,	XX,	50,	NEQ,	67,	64,	0,	58,
2014041100,	03,	AVNO,	12,	151S,	1453E,	57,	996,	XX,	34,	NEQ,	100,	102,	0,	71,
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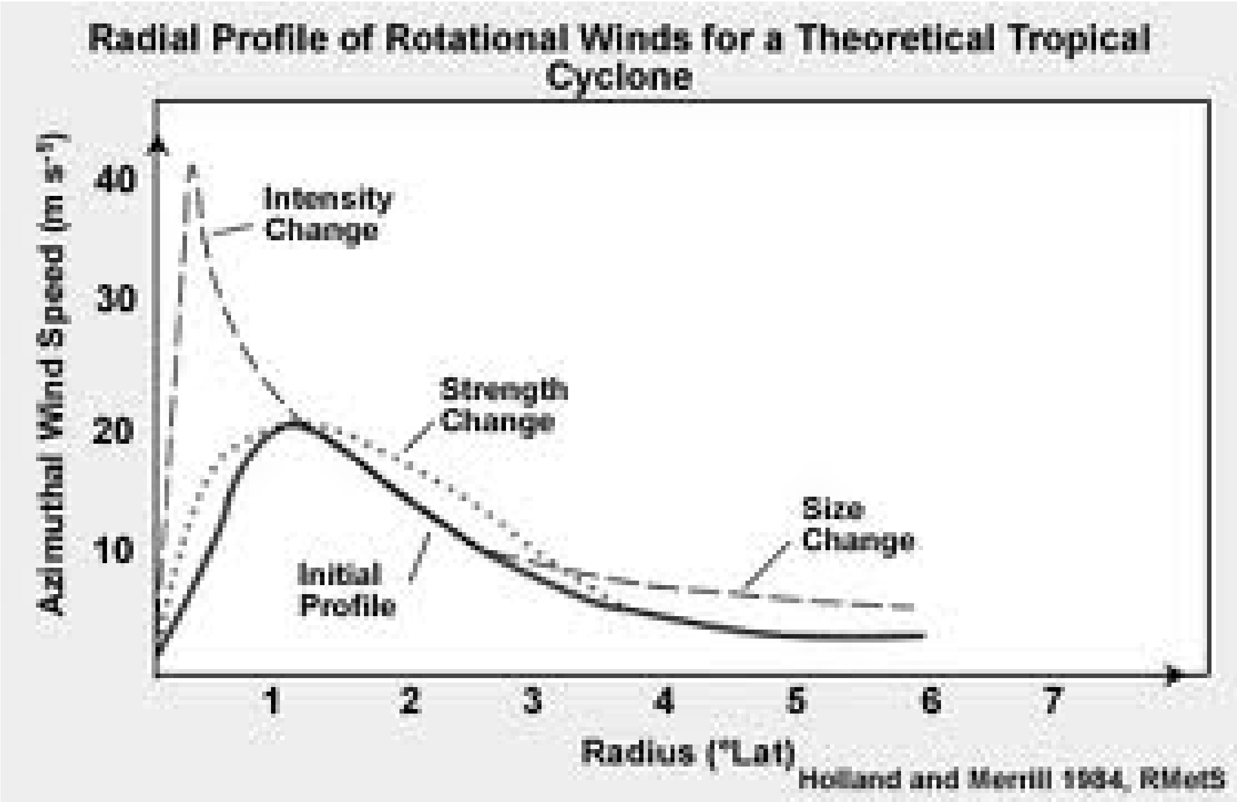
Structure Changes

Environment: monsoon/STR; shear; land, dry air, motion;

Inner core: +eye wall replacement cycles

X Extra-Tropical Transition



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Structure Changes

Question: how would you expect R34 (gale radius) to change:

a. monsoon flow changes?

b. Shear increase?

c. Land interaction?

d. dry air increase?

e. Motion increase?

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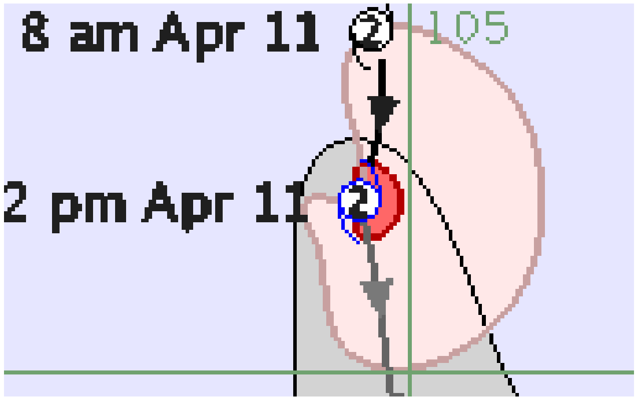
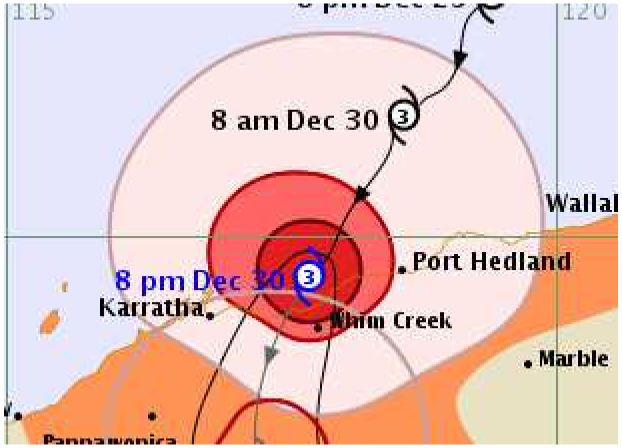
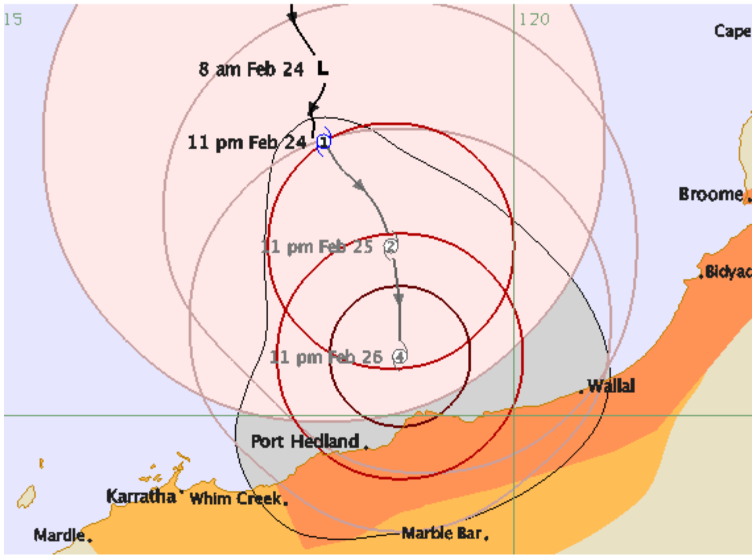
Gale changes







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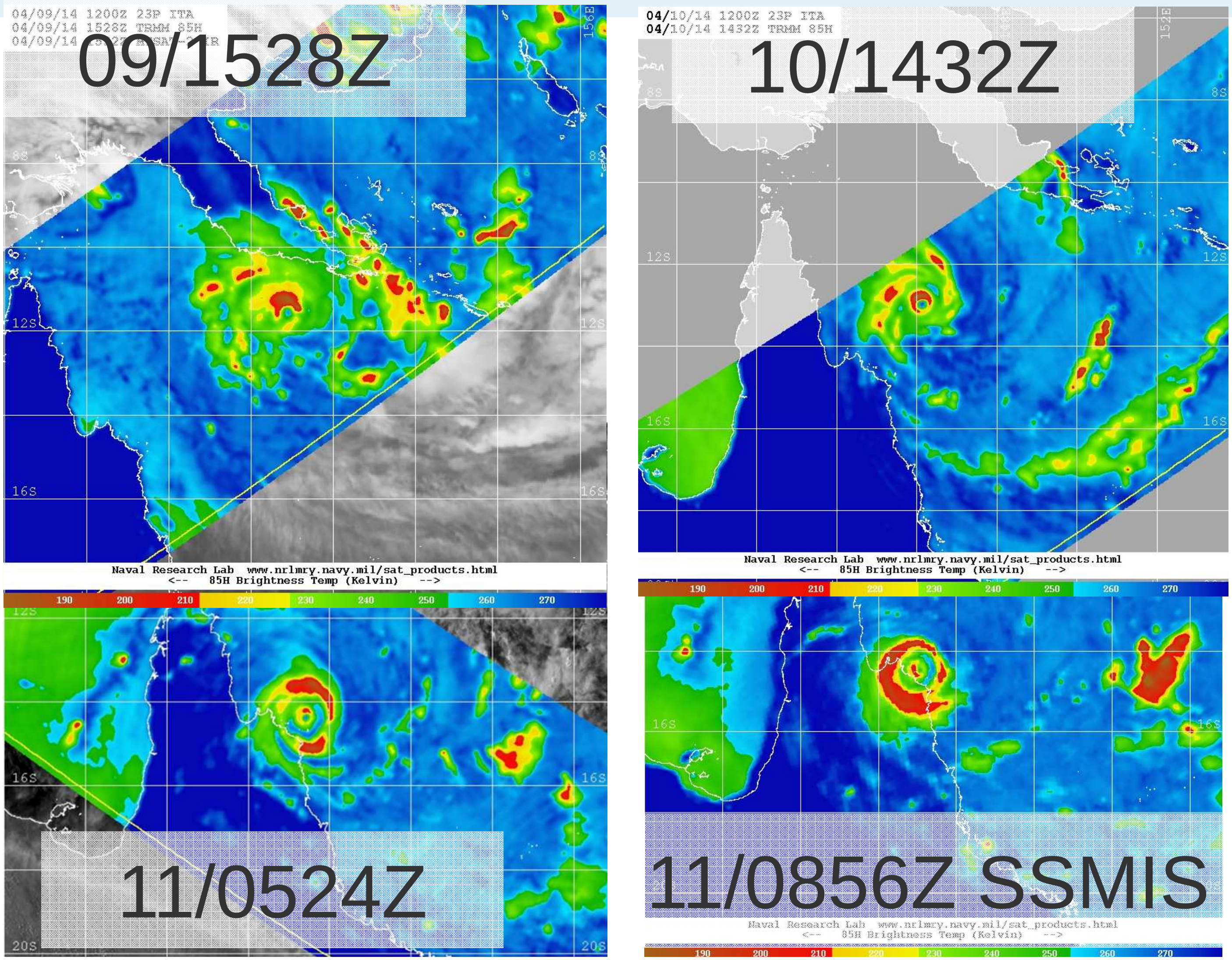
Eyewall Replacement Cycles (ERC) Secondary eyewall formation (SEF)



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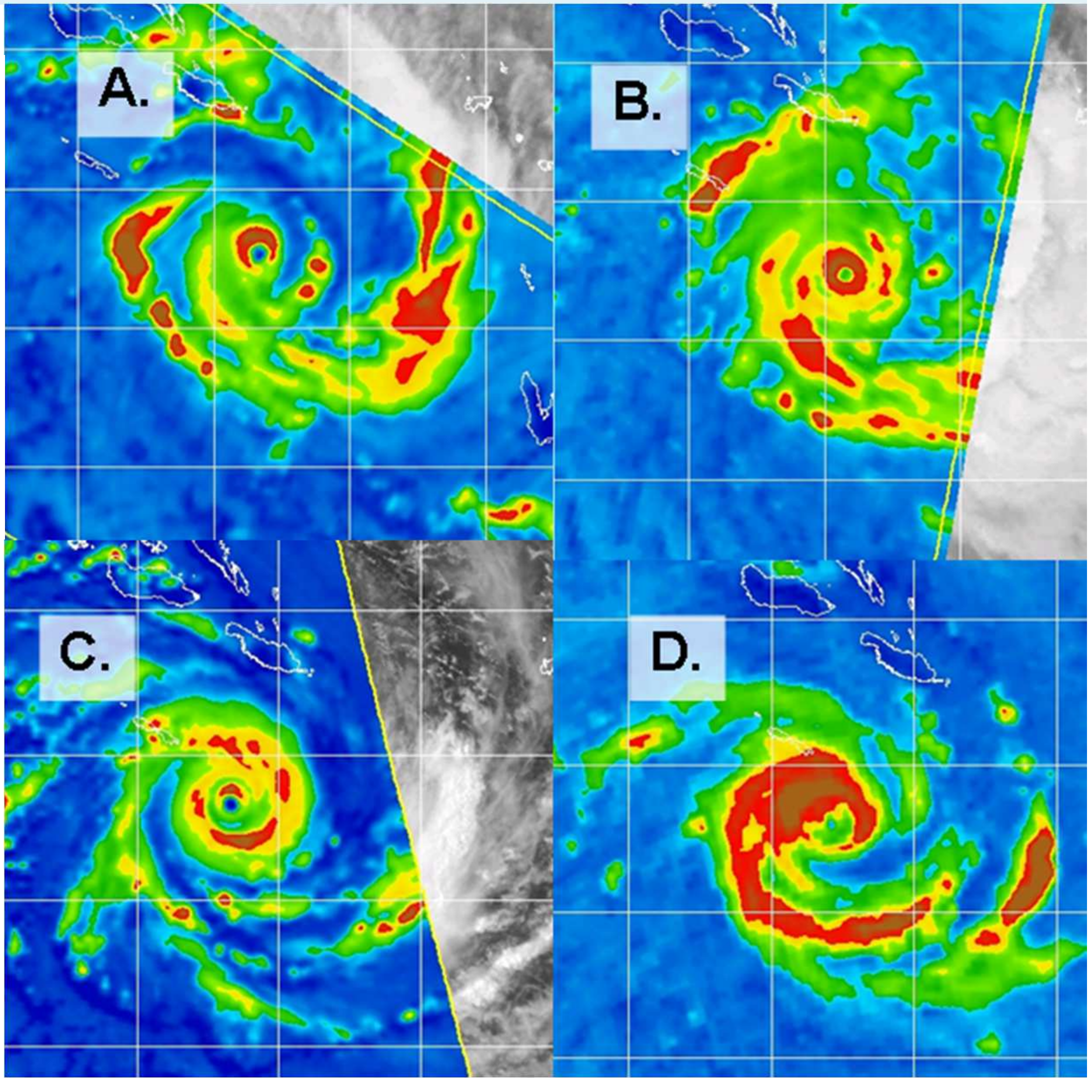
Eyewall Replacement Cycles (ERC)
Secondary eyewall formation (SEF)

Which of these following images suggests the MOST intense system?
Why?

SH system



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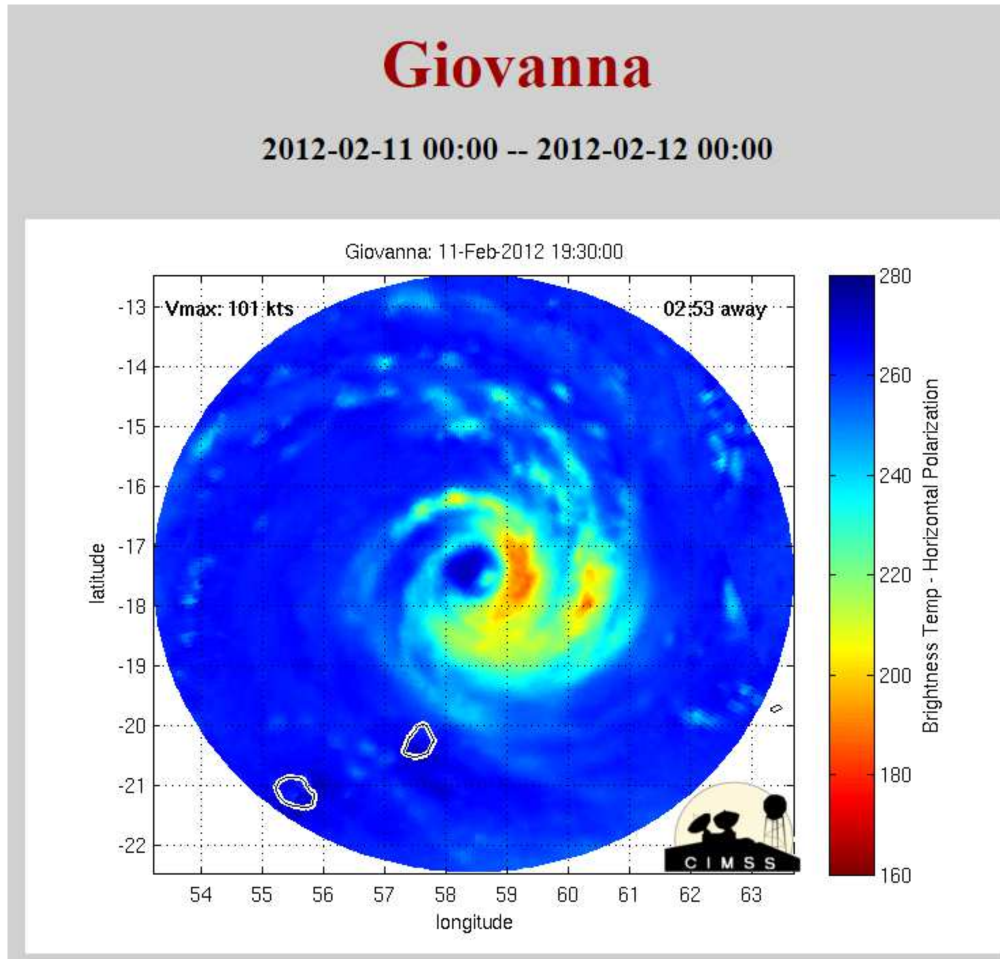
Eyewall Replacement Cycles (ERC) Secondary eyewall formation (SEF)

http://tropic.ssec.wisc.edu/real-time/mimic-tc/2012_12S/webManager/displayGifsBy12hr_02.html



CIMSS Morphed microwave imagery

What do you notice

Yasi
http://tropic.ssec.wisc.edu/real-time/mimic-tc/2011_11P/webManager/displayGifsBy12hr_08.html

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Eyewall Replacement Cycles (ERC) Secondary eyewall formation (SEF)

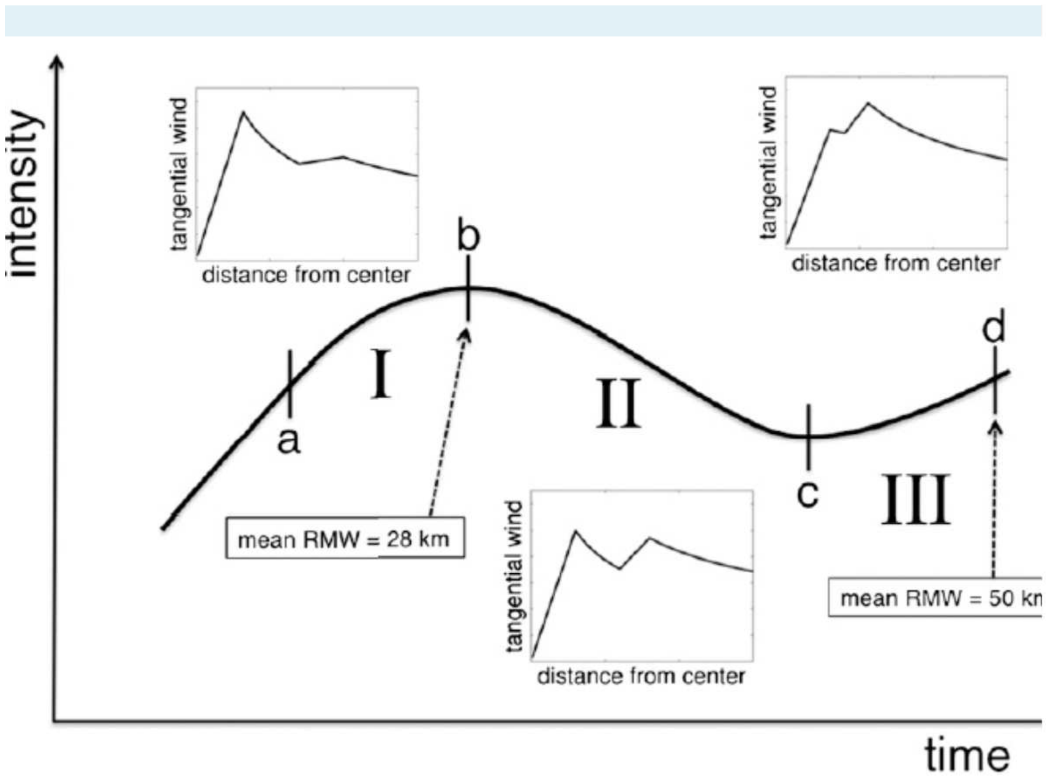
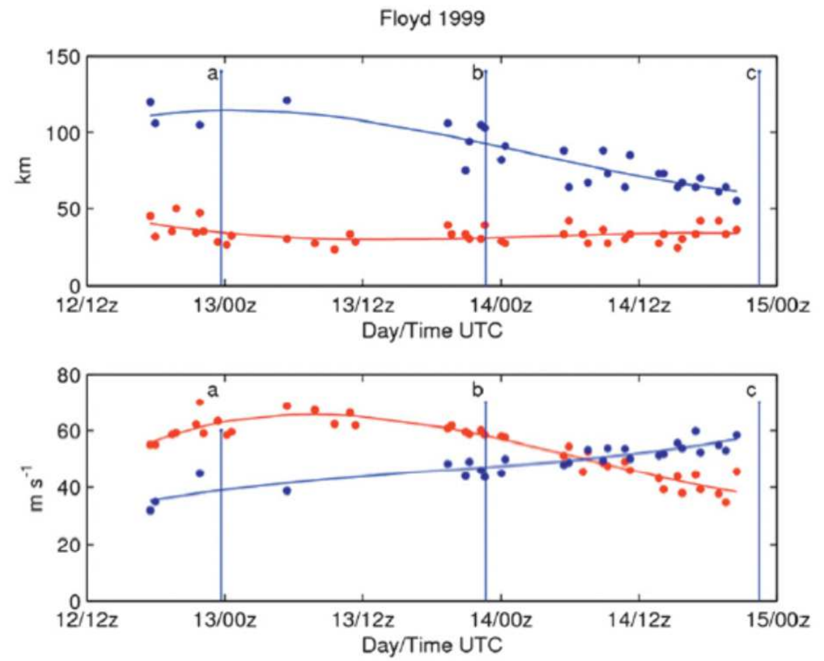


FIG. 1. Mean evolution of a hurricane eyewall replacement cycle (ERC). Here the begin
of the ERC (point a) is identified by a persistent coherent secondary wind maximum obse
at flight level. This marks the beginning of the intensification phase (I) of the ERC. During
phase, both the primary (inner) and secondary (outer) wind maxima are increasing and
tracting. During the w
secondary maximum i
is identified when both
exceeded the inner on
(III), the outer wind maximum continues to contract inward while intensifying. The three i

Kossin and Switkowski (2012)

Switkowski et al 2011



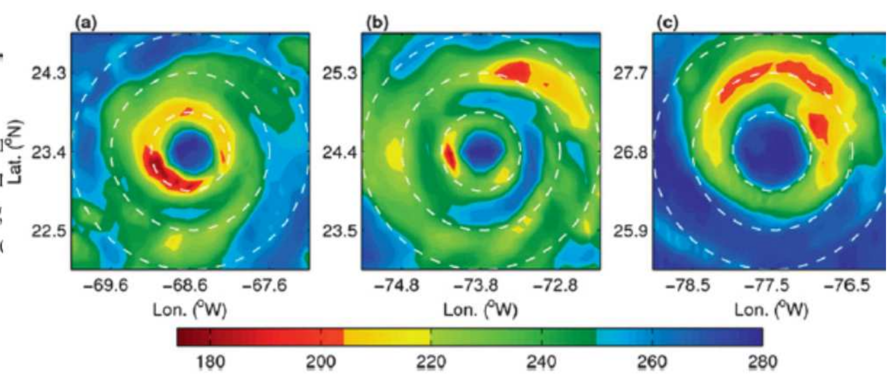


FIG. 6. (top) As in Fig. 5, but for a Hurricane Floyd (1999) ERC. The lettered vertical line
correspond to the times when the inner core was observed by microwave instrumentation

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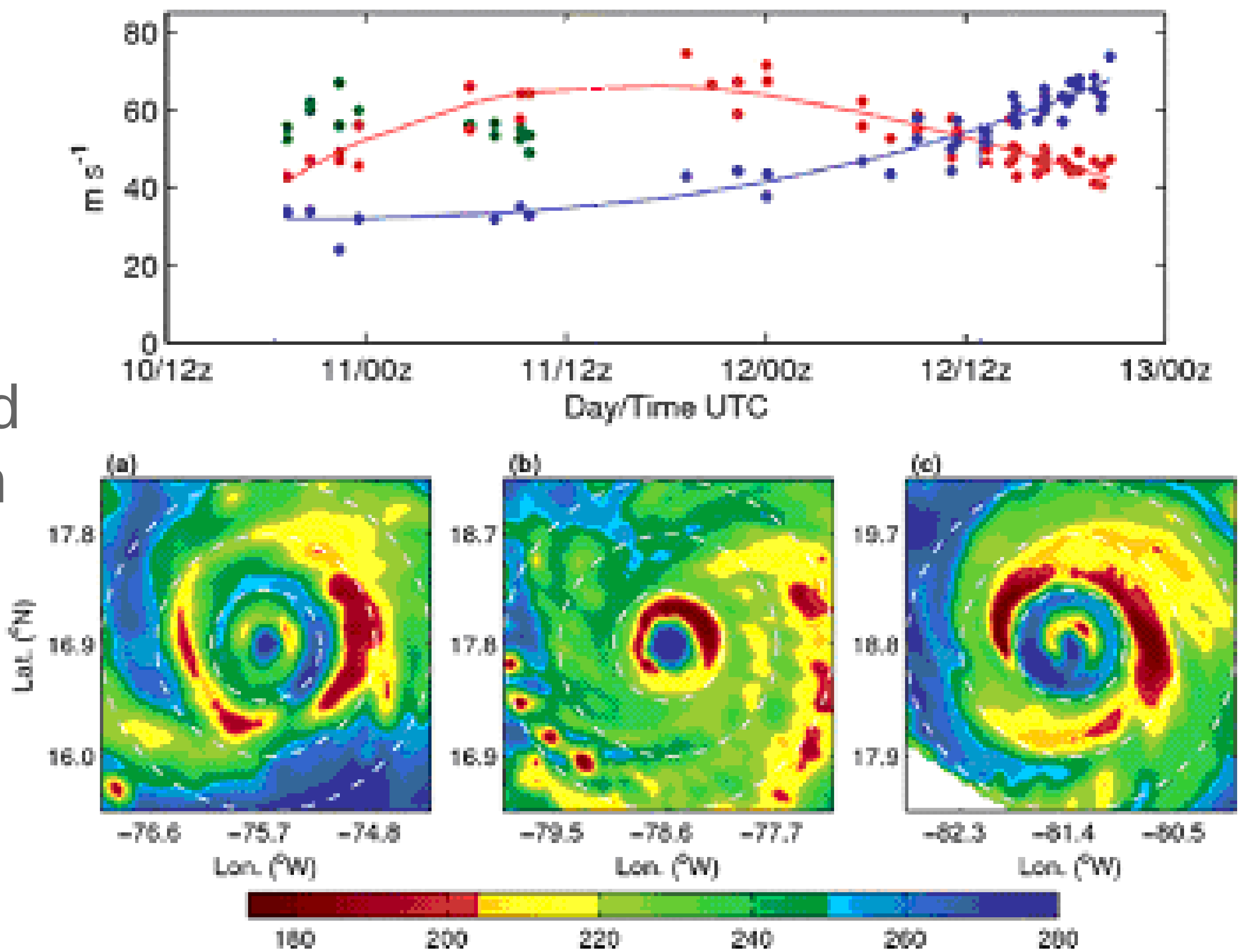
Eyewall Replacement Cycles (ERC) Hurricane *Ivan*

1. Which image has the highest intensity winds?

2. At what times do images at a, b, and c correspond to on the graph?

Red is inner max

Blue is outer max



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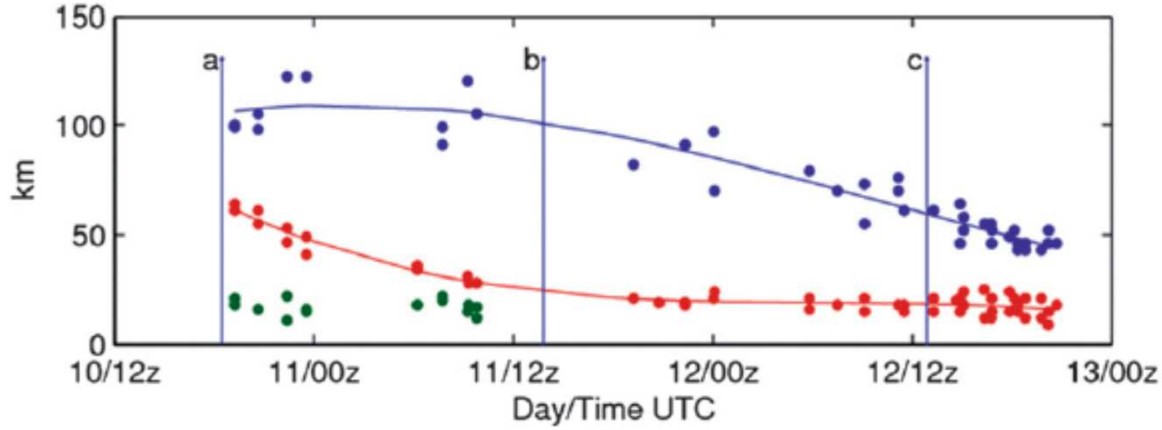
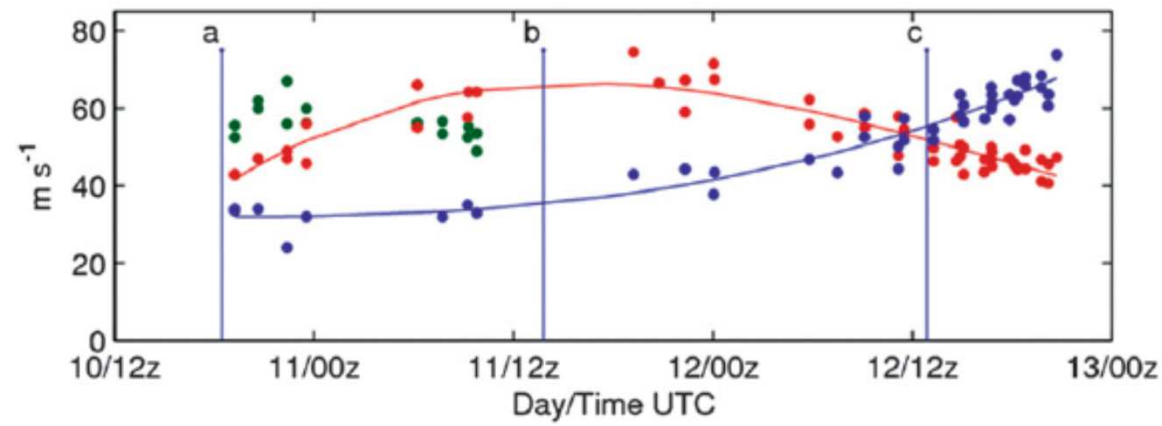
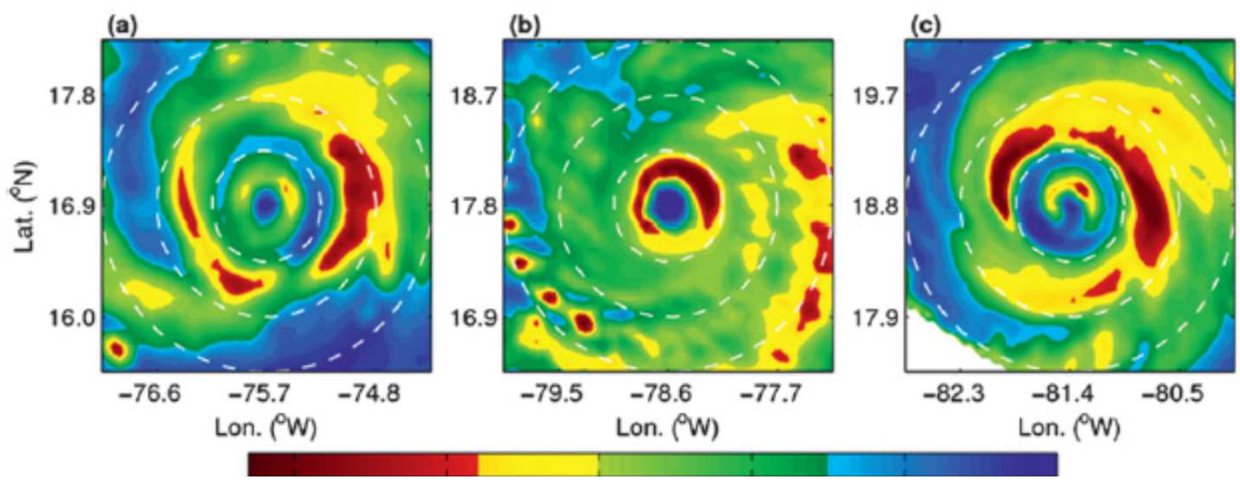
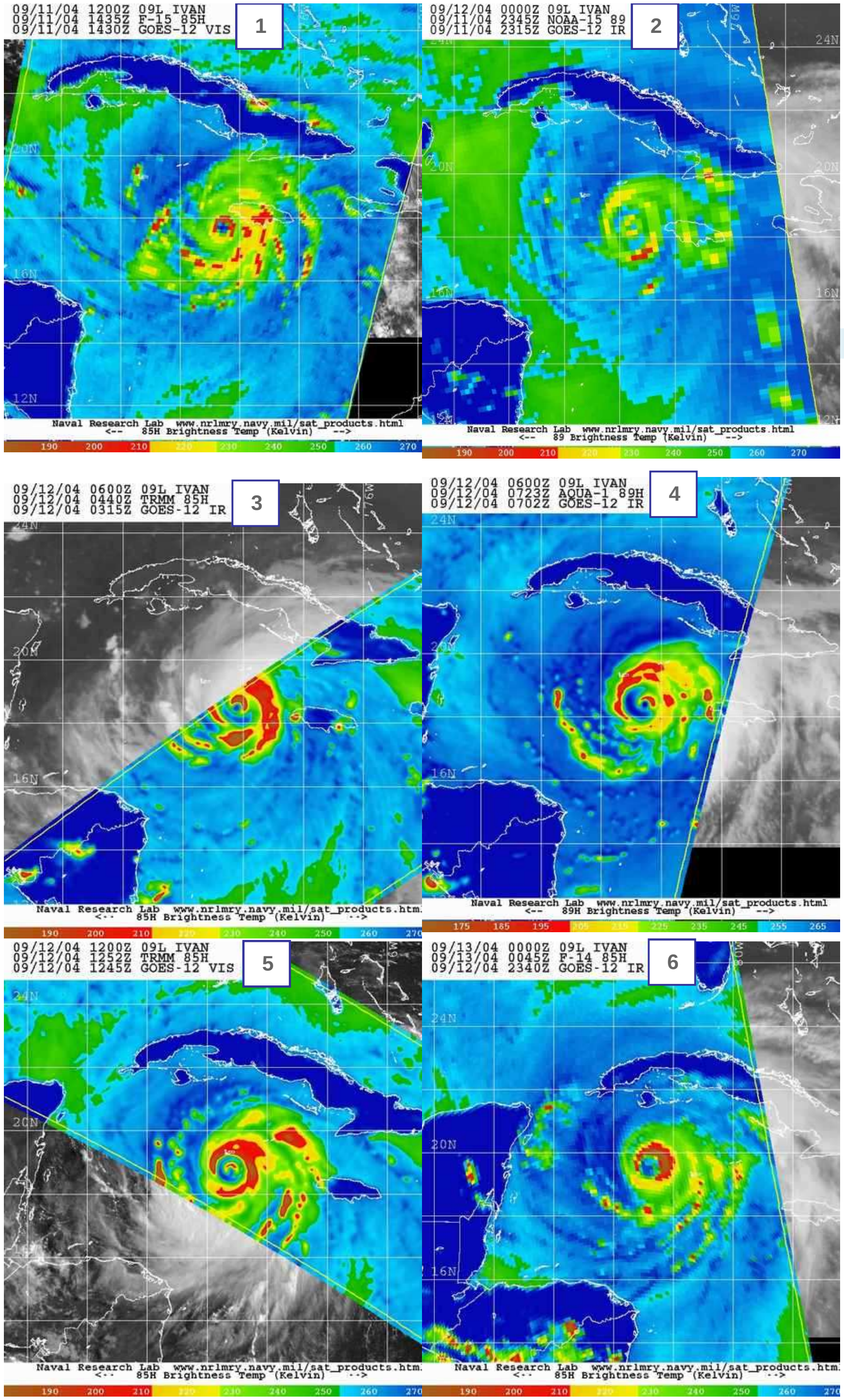
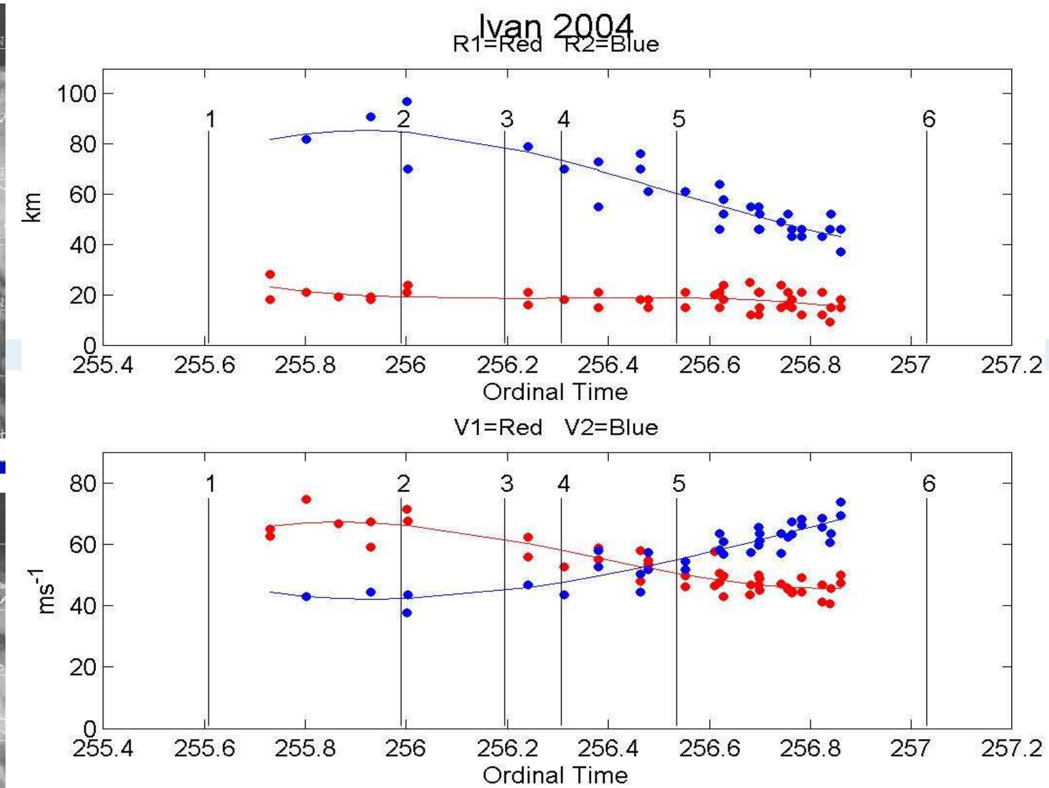
Ivan 2004





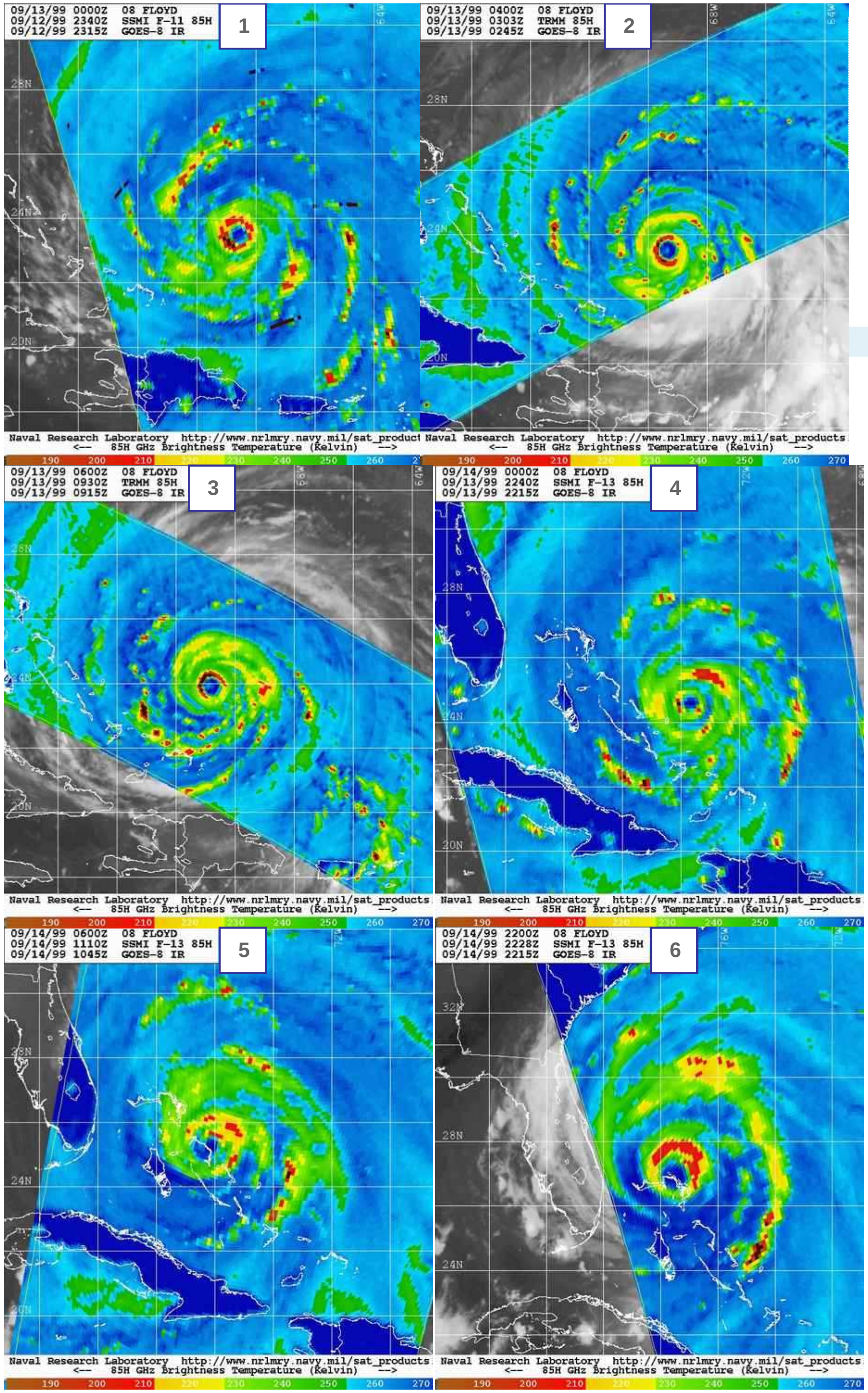


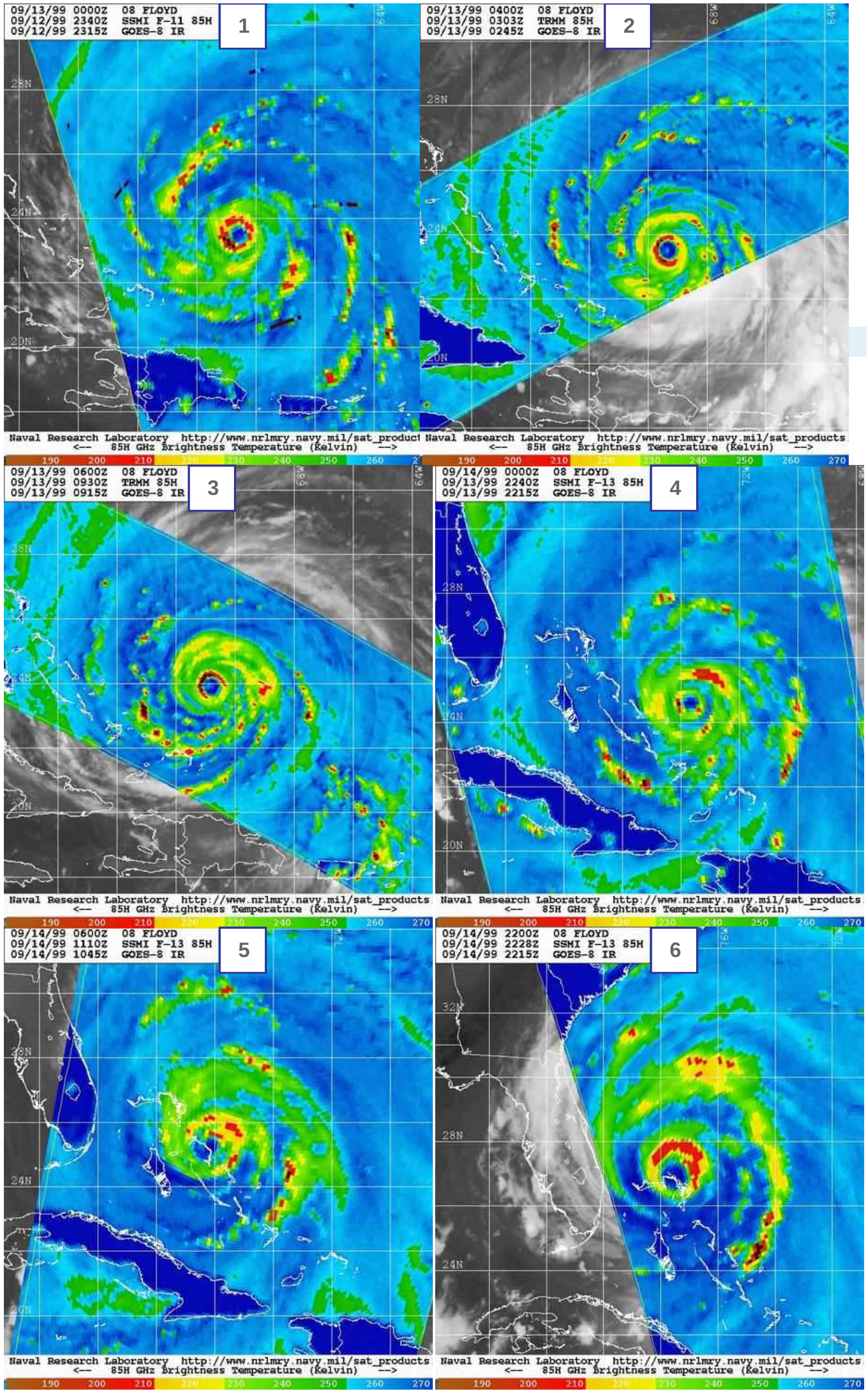


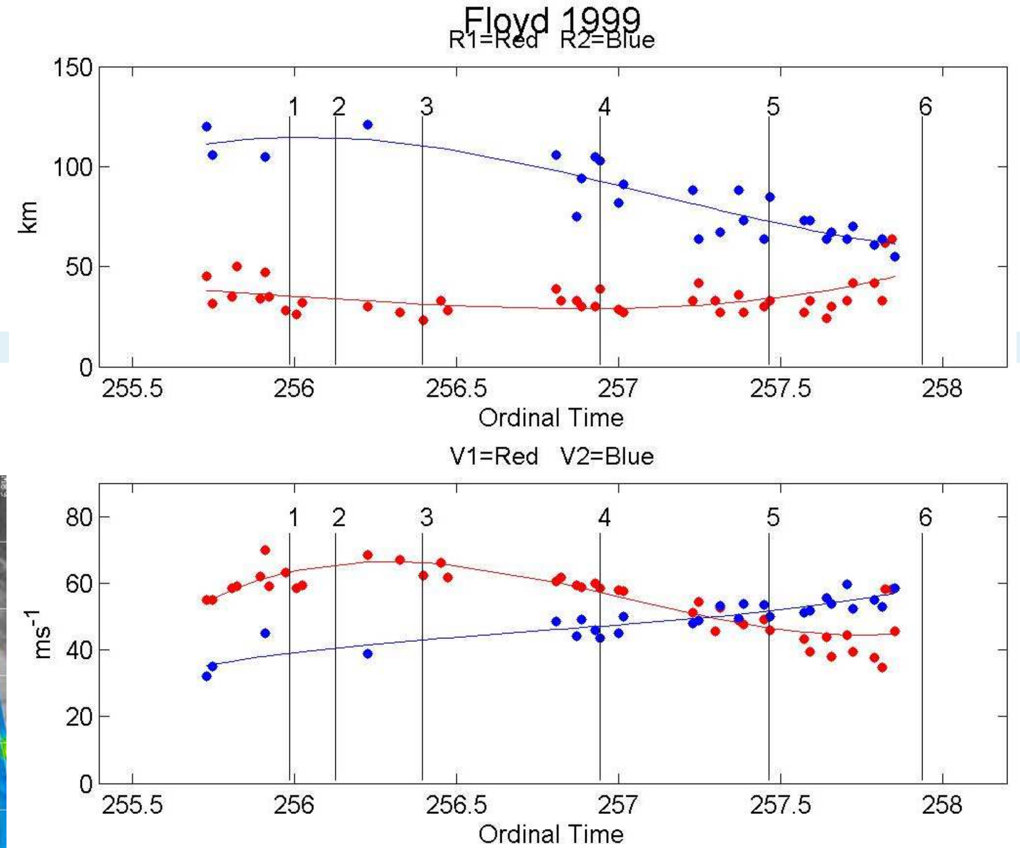


The first swm is detected shortly after the 1st microwave image, where rainbands and cellular convection dominate. The 2nd image indicates that a concentric eyewall formed roughly 9 hours after the 1st image. With the concentric rings present the storm begins to weaken and the swm contracts. Shortly before the 5th image the intensities of the concentric eyewalls are equal.

ERC - Floyd

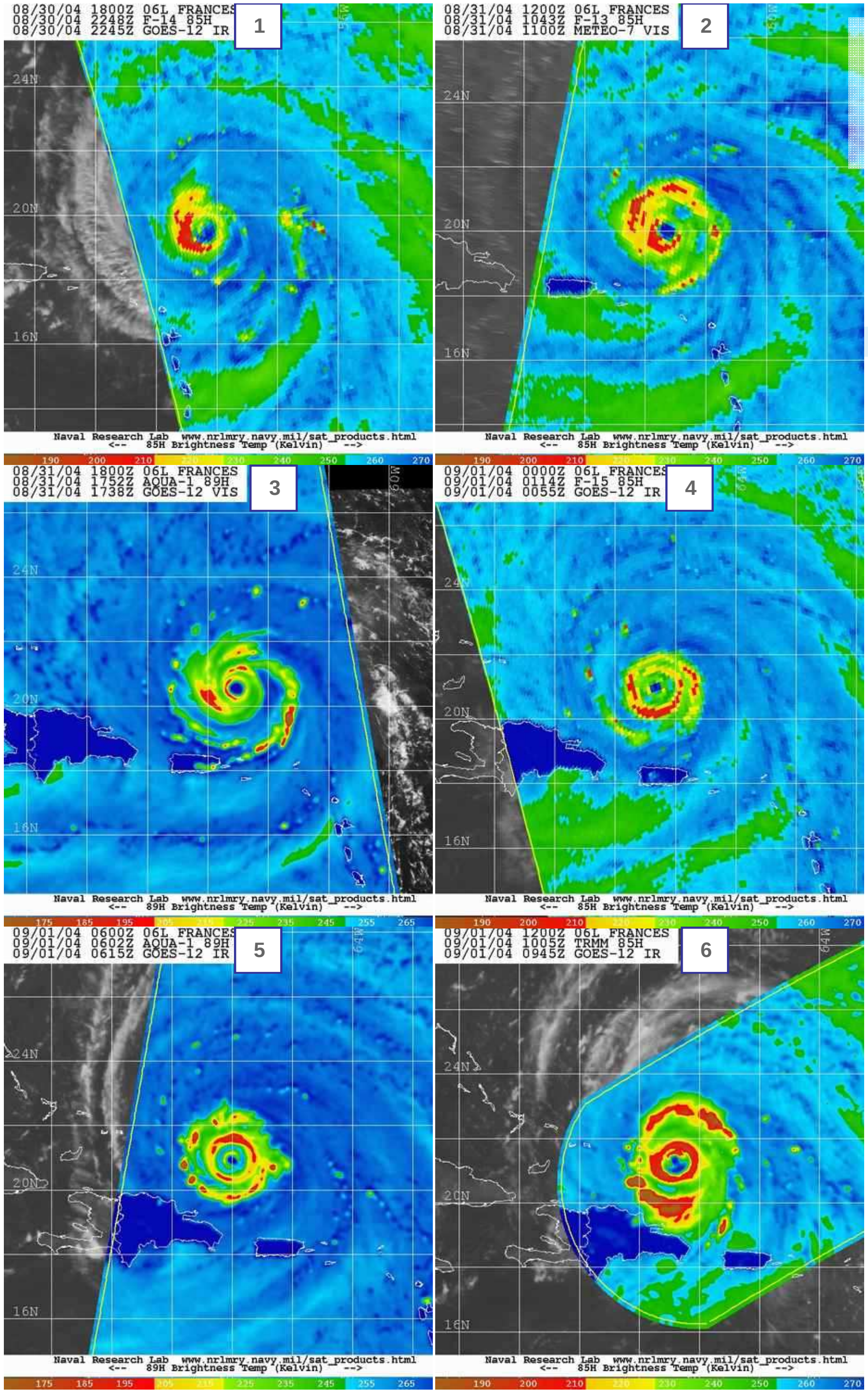

09/13/99 0000Z 08 FLOYD
09/12/99 2340Z SSMI F-11 85H
09/12/99 2315Z GOES-8 IR
1
09/13/99 0400Z 08 FLOYD
09/13/99 0303Z TRMM 85H
09/13/99 0245Z GOES-8 IR
2
09/13/99 0600Z 08 FLOYD
09/13/99 0930Z TRMM 85H
09/13/99 0915Z GOES-8 IR
3
09/14/99 0000Z 08 FLOYD
09/13/99 2240Z SSMI F-13 85H
09/13/99 2215Z GOES-8 IR
4
09/14/99 0600Z 08 FLOYD
09/14/99 1110Z SSMI F-13 85H
09/14/99 1045Z GOES-8 IR
5
09/14/99 2200Z 08 FLOYD
09/14/99 2228Z SSMI F-13 85H
09/14/99 2215Z GOES-8 IR
6
Naval Research Laboratory http://www.nrlmry.navy.mil/sat_products
<-- 85H GHz Brightness Temperature (Kelvin) -->
190 200 210 220 230 240 250 260 270

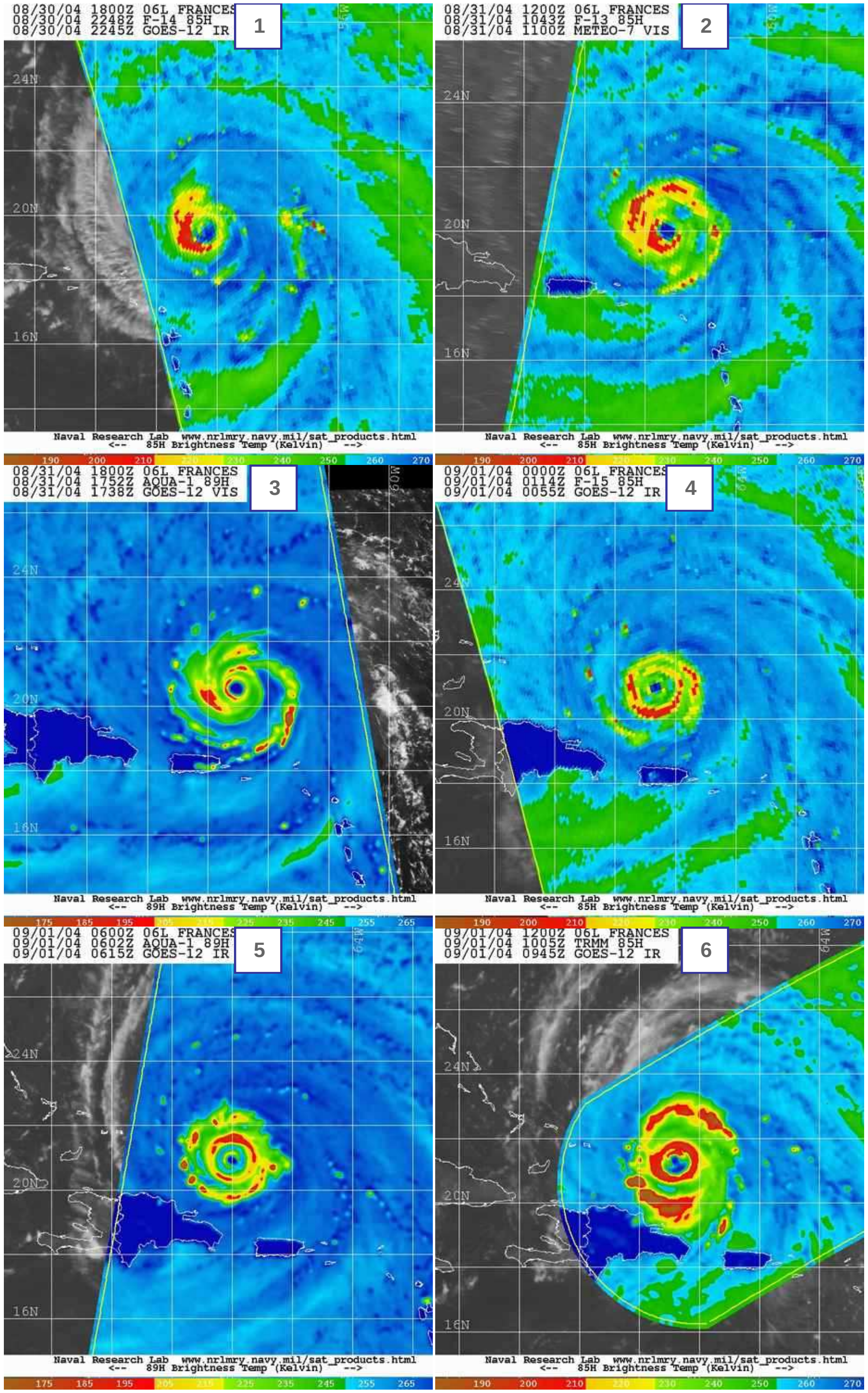


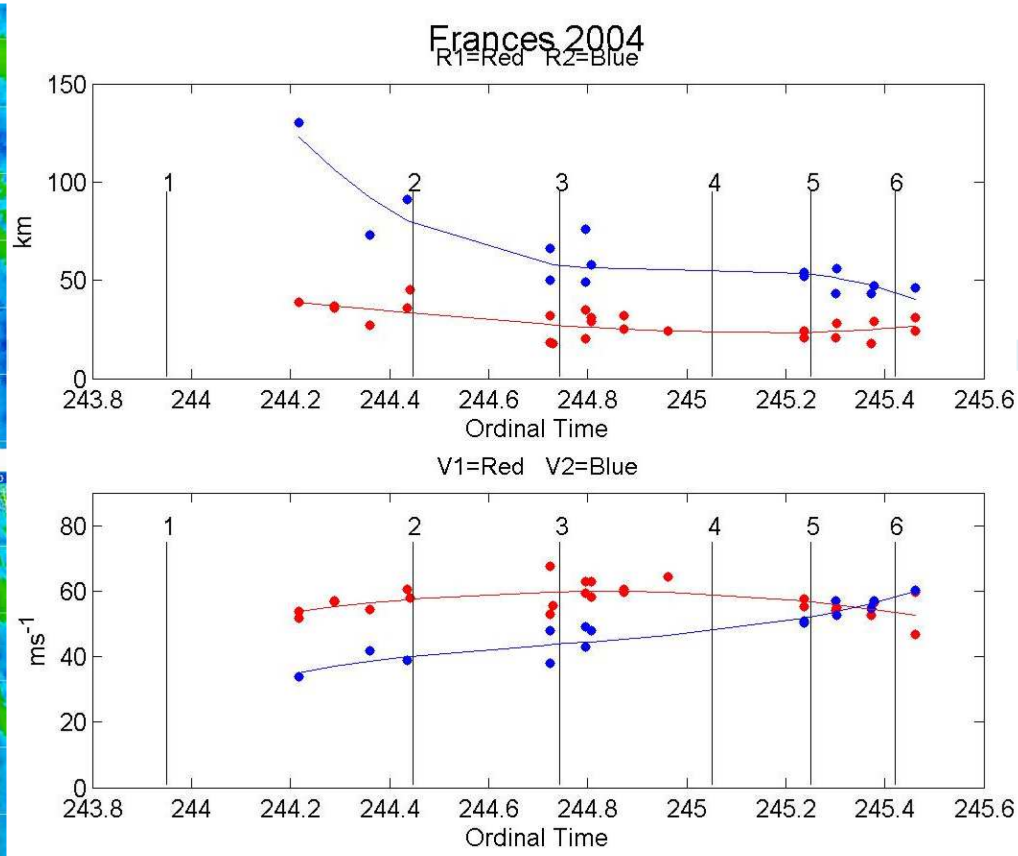


Is this an example of the secondary wind maximum organizing or do I just start this ERC to early? Tough, but the 2nd image looks pretty SEFish

ERC - Frances

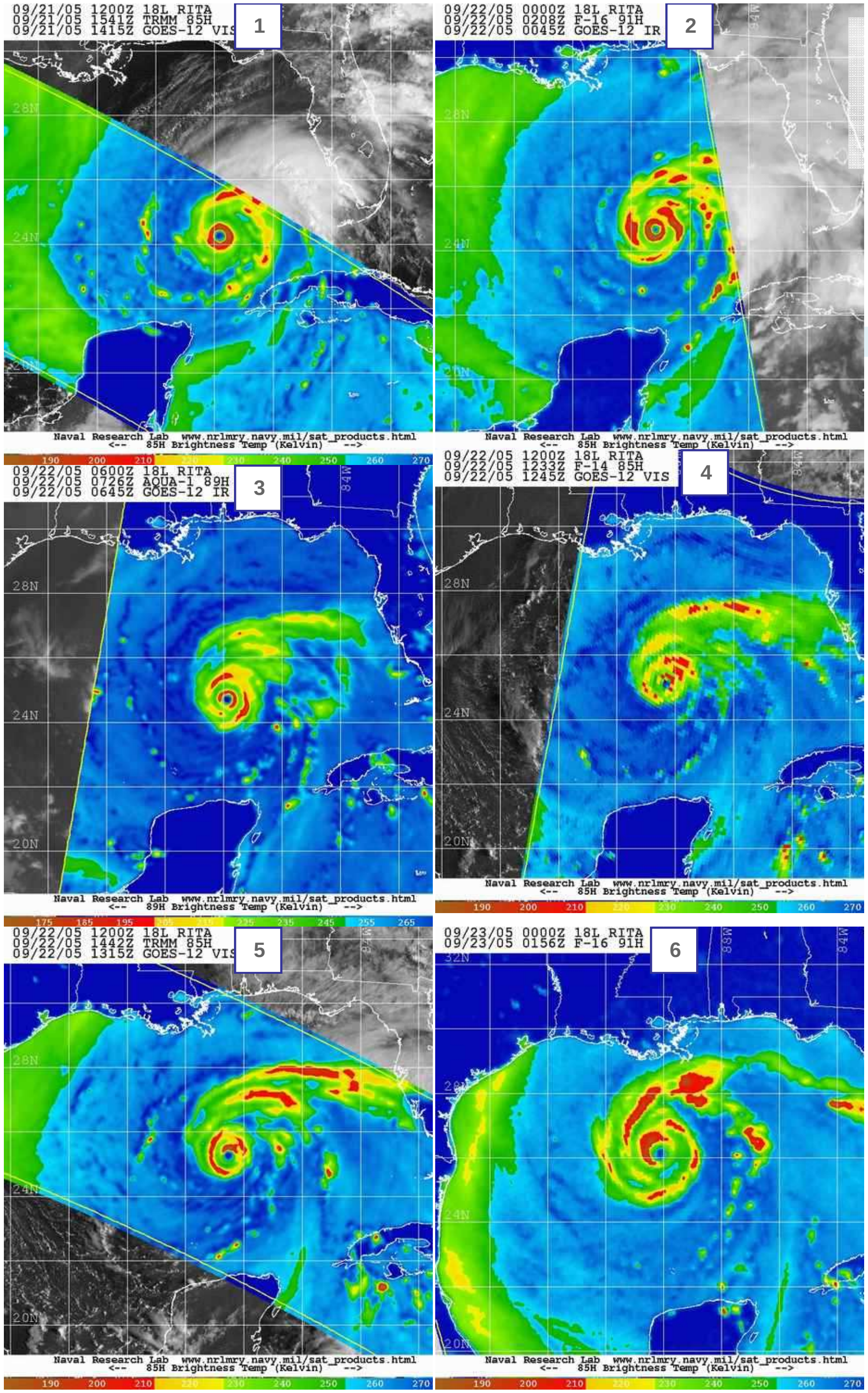

08/30/04 1800Z 06L FRANCES
08/30/04 2248Z F-14 85H
08/30/04 2245Z GOES-12 IR
1
08/31/04 1200Z 06L FRANCES
08/31/04 1043Z F-13 85H
08/31/04 1100Z METEO-7 VIS
2
08/31/04 1800Z 06L FRANCES
08/31/04 1752Z AQUA-1 89H
08/31/04 1738Z GOES-12 VIS
3
09/01/04 0000Z 06L FRANCES
09/01/04 0114Z F-15 85H
09/01/04 0055Z GOES-12 IR
4
09/01/04 0600Z 06L FRANCES
09/01/04 0602Z AQUA-1 89H
09/01/04 0615Z GOES-12 IR
5
09/01/04 1200Z 06L FRANCES
09/01/04 1005Z TRMM 85H
09/01/04 0945Z GOES-12 IR
6
Naval Research Lab www.nrlmry.navy.mil/sat_products.html
85H Brightness Temp (Kelvin)
89H Brightness Temp (Kelvin)

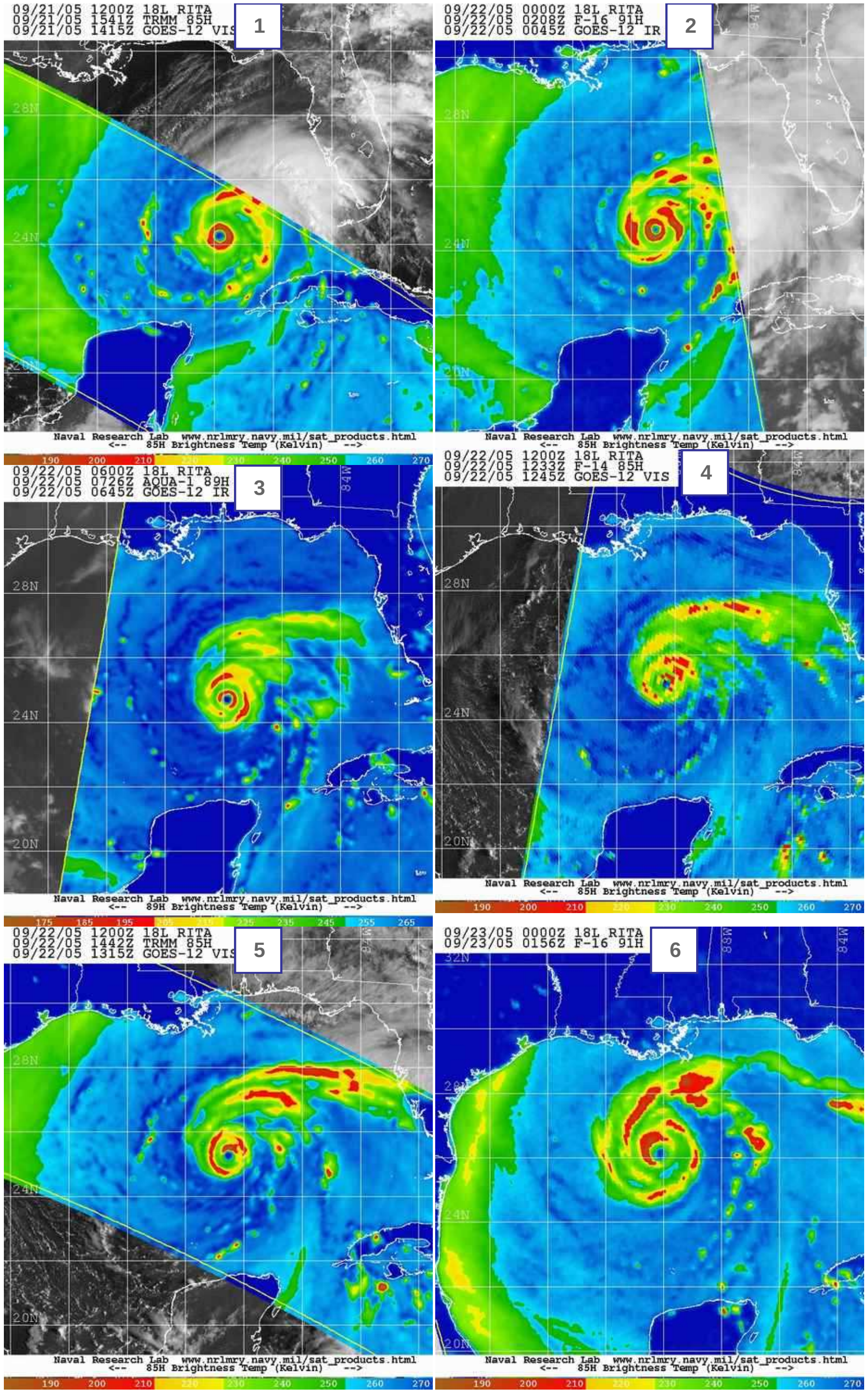


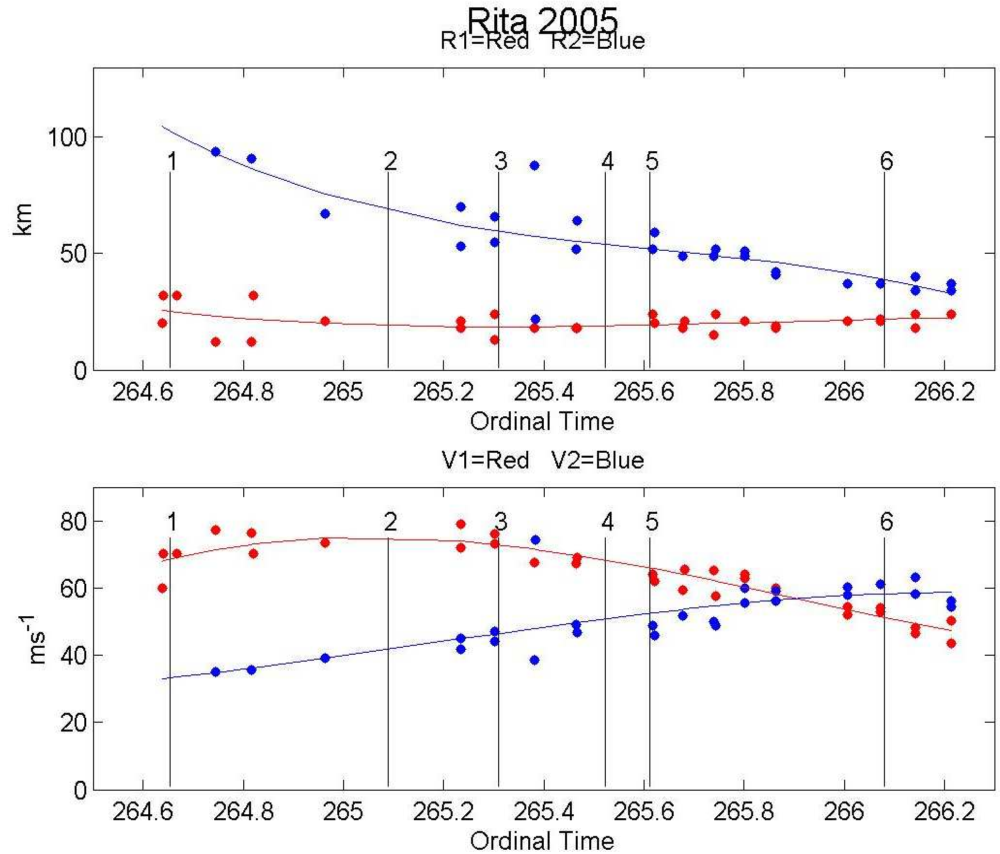


Another example of things organizing before we see the solid concentric eyewalls in image 4. Weakening commences once the outer ring is fully formed.

ERC - Rita


1
2
3
4
5
6
09/21/05 1200Z 18L RITA
09/21/05 1541Z TRMM 85H
09/21/05 1415Z GOES-12 VIS
09/22/05 0000Z 18L RITA
09/22/05 0208Z F-16 91H
09/22/05 0045Z GOES-12 IR
09/22/05 0600Z 18L RITA
09/22/05 0726Z AQUA-1 89H
09/22/05 0645Z GOES-12 IR
09/22/05 1200Z 18L RITA
09/22/05 1233Z F-14 85H
09/22/05 1245Z GOES-12 VIS
09/22/05 1200Z 18L RITA
09/22/05 1442Z TRMM 85H
09/22/05 1315Z GOES-12 VIS
09/23/05 0000Z 18L RITA
09/23/05 0156Z F-16 91H
Naval Research Lab www.nrlmry.navy.mil/sat_products.html





Again, weakening commences once the outer ring is complete. There is a triple wind max at the end of this ERC, the next event happens as this one finishes.

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Summary

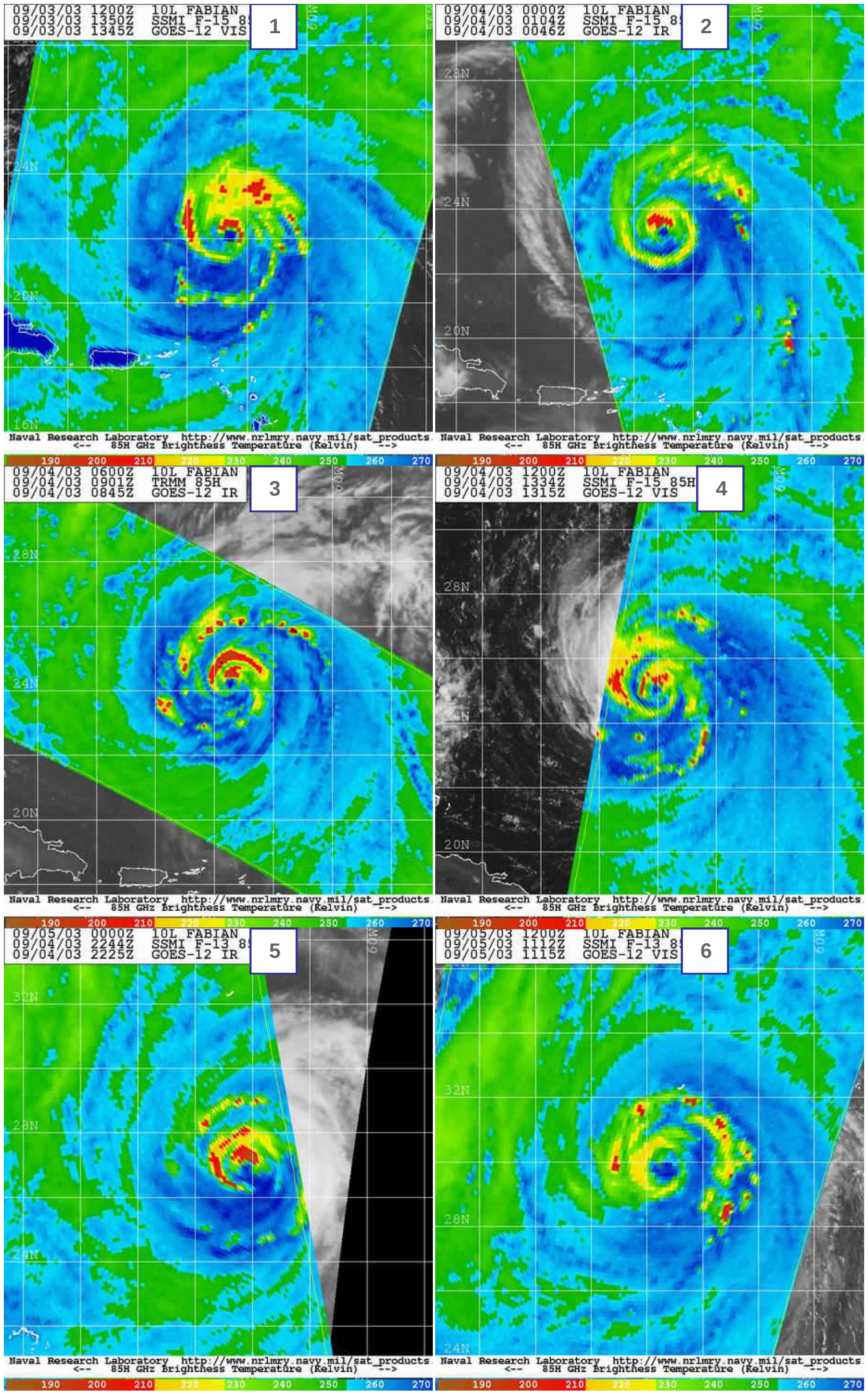
Intensity forecasting based on combination of persistence, subjective assessment of current and forecast environment, statistical-dynamic schemes and NWP trends

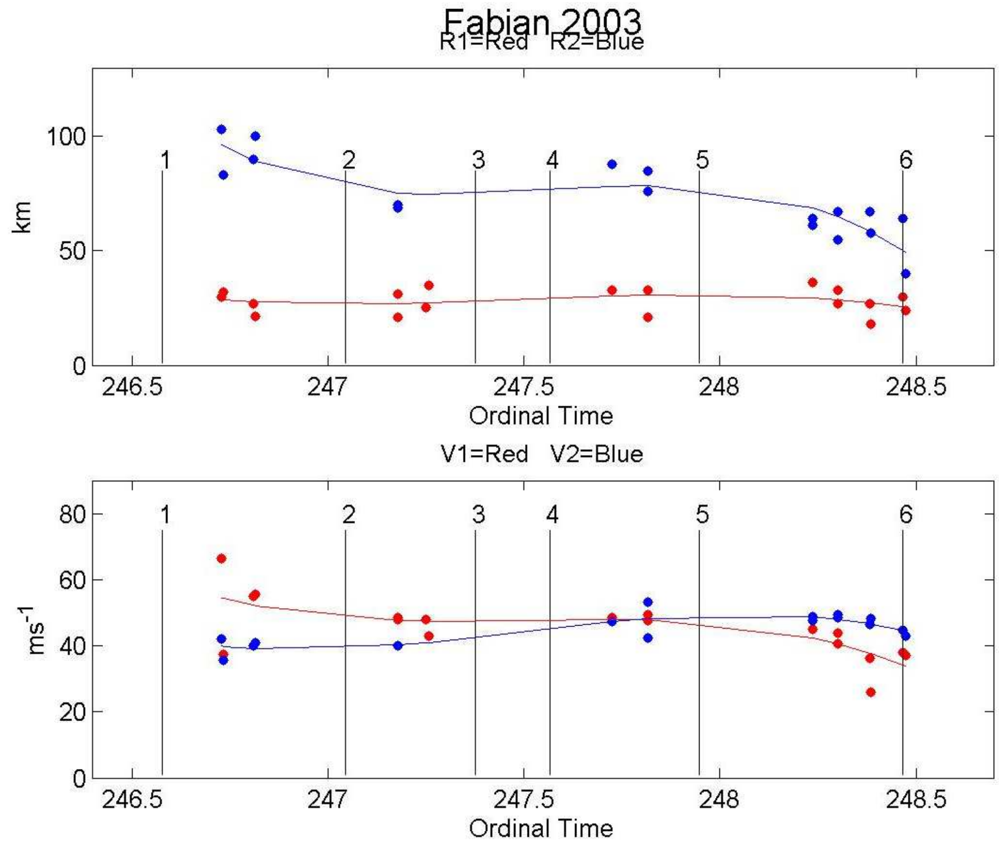
Increasing use of objective consensus techniques – STIPS/LGEM

Dynamical models – are we approaching the threshold for skill over statistical models?

Important to recognise rapid changes

esp for small systems





The microwave images depict a storm struggling to complete an ERC and the evolution plots support this. The ‘pause’ in contraction aligns with the ‘pause’ in weakening.

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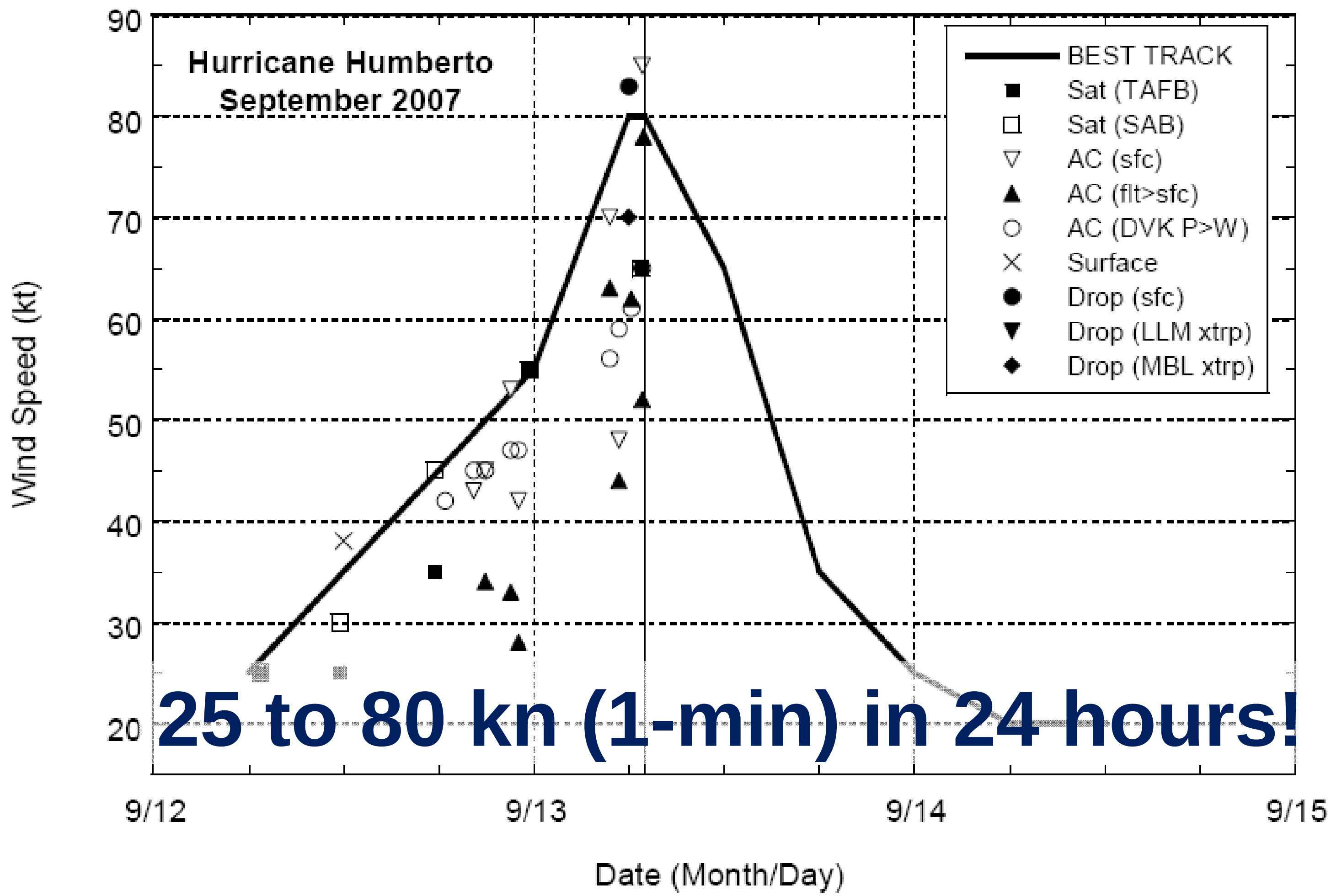
TCs can change intensity rapidly

Humberto 2007 Rapid Intensification



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Intensity and Structure Forecasting

Table 0.4.1. Operational Needs of TC Forecast and Warning Centers (Jim Davidson)

TPC/	JTWC	Australia TCWCs	Operational Need
1	1	2	Guidance for tropical cyclone **intensity change**, with highest priority on the onset, duration, and magnitude of rapid intensification events.

IWTC and US priority http://www.ofcm.gov/ihc13/summary.pdf

Structure forecast: becoming more significant

References from IWTC VIII 2014

Internal influences, Stern & Dunion

http://www.wmo.int/pages/prog/arep/wwrp/new/documents/Topic2.6_IntensityChange_InternalInfluences.pdf

External influences, Leroux,
http://www.wmo.int/pages/prog/arep/wwrp/new/documents/T2.5_IntensityChangeExternalInfluences_MDLeroux_7dec2014.pdf