Tropical cyclones structure / Structure des systèmes tropicaux

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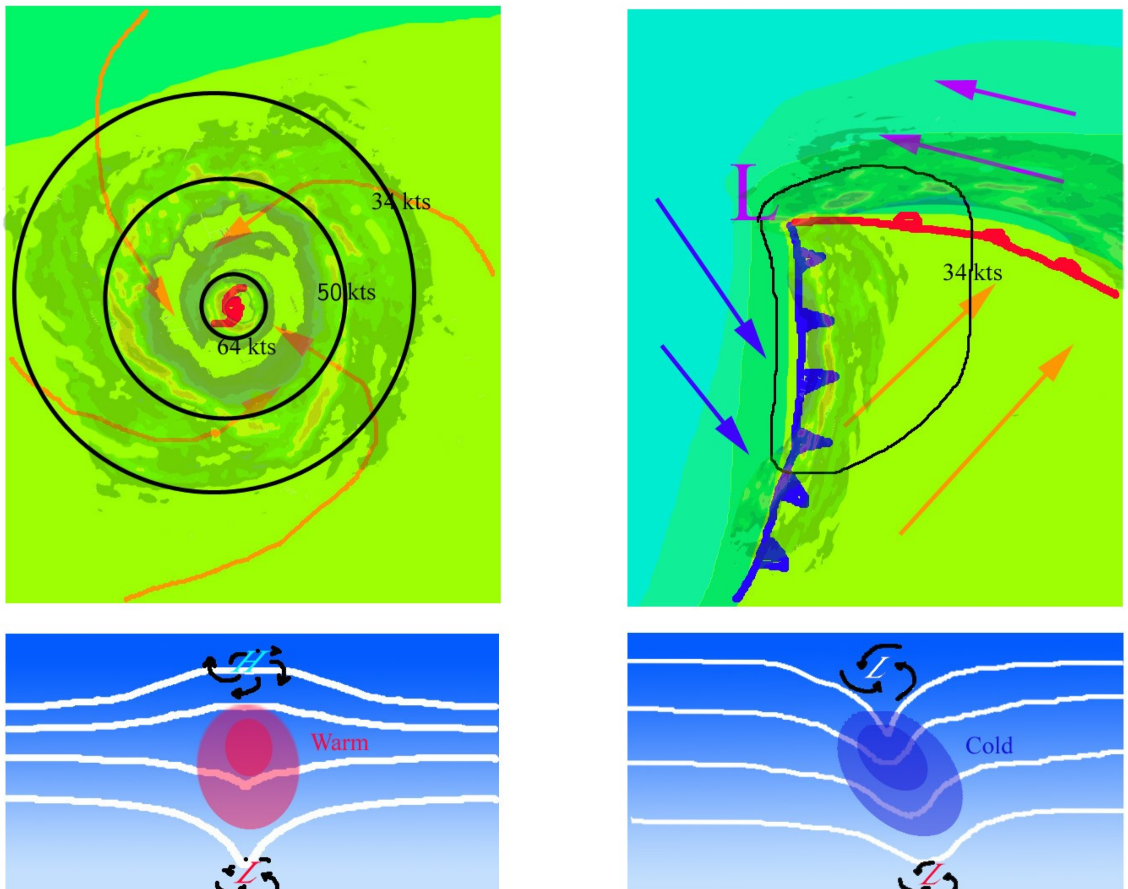
WMO RA1 TC Training

Tropical cyclone structure

1. Introduction
2. Primary and secondary circulations
3. Wind/Pressure relationship
4. ERC, Eyewall Replacement Cycle
5. TC intensity

TC structure
What is a TC ?

- Tropical cyclones are **warm core**, **non frontal, low pressure** system **over sea** with a **closed and organized circulation**



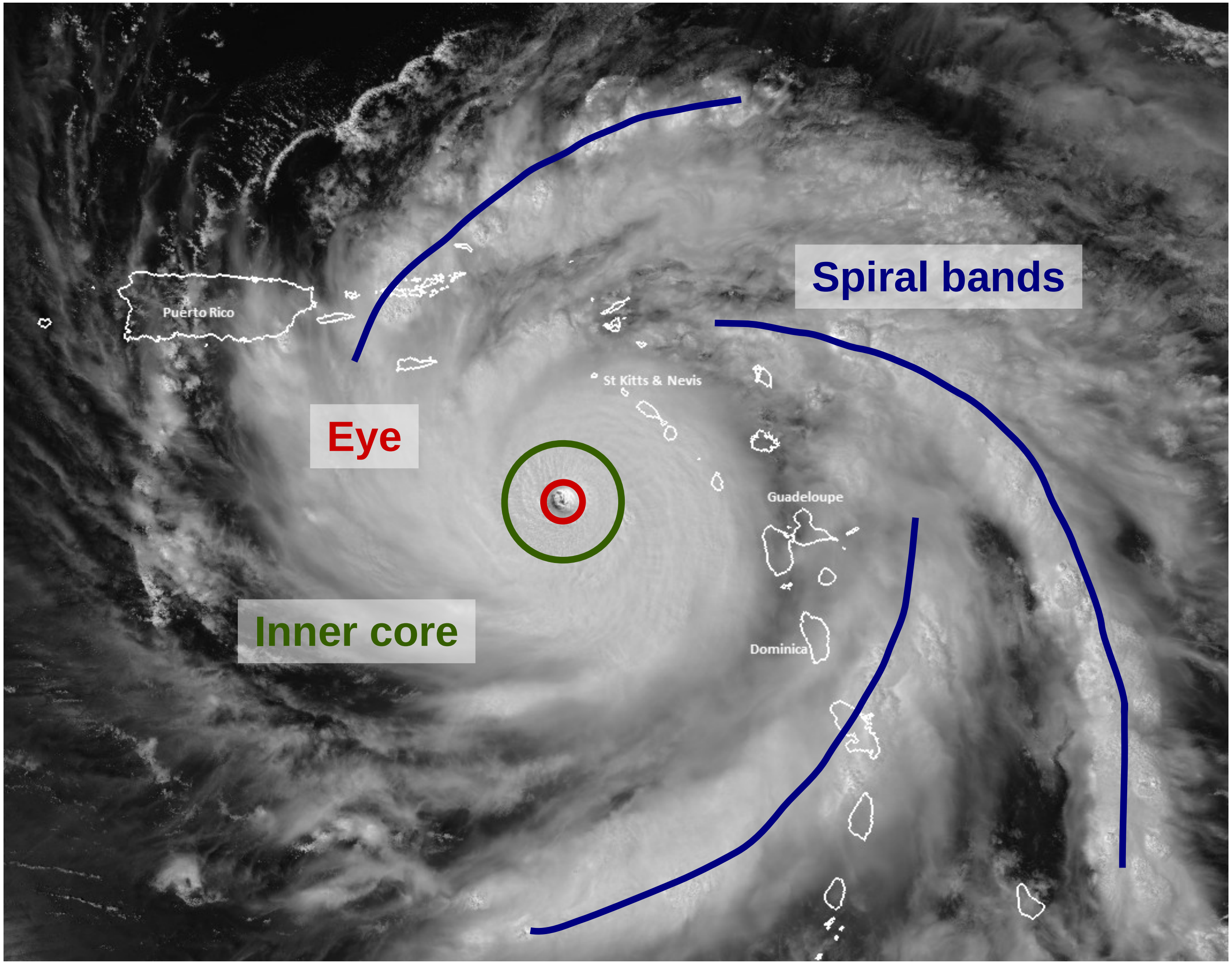
Tropical Cyclone

Extratropical Cyclone

Merrill 1993

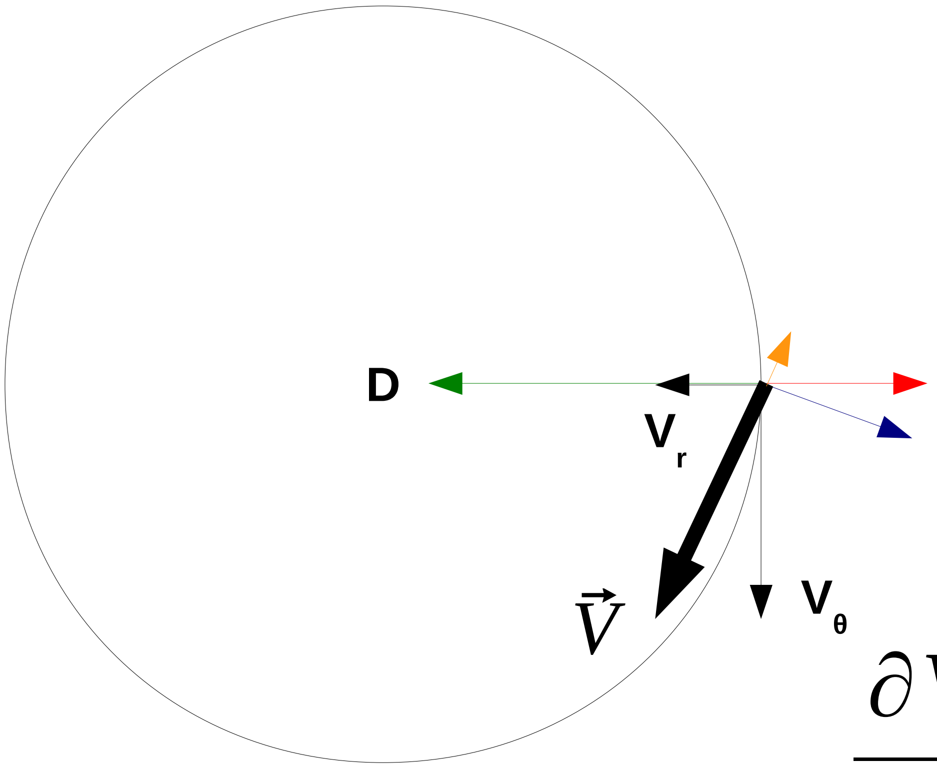
- Warm core
  - Warm (humid) air mass
- Non frontal
  - Weak gradients
  - No baroclinity
    - Central symmetry
    - Isolines // Wind

TC structure
What is a TC ?



Hurricane Maria 2017, North Atlantic

TC structure
Cyclostrophic vs geostrophic balance



Wind $\vec{V}$

Tangential wind V_θ (**primary circulation**)

Radial wind V_r (**secondary circulation**)

Pressure gradient (P)

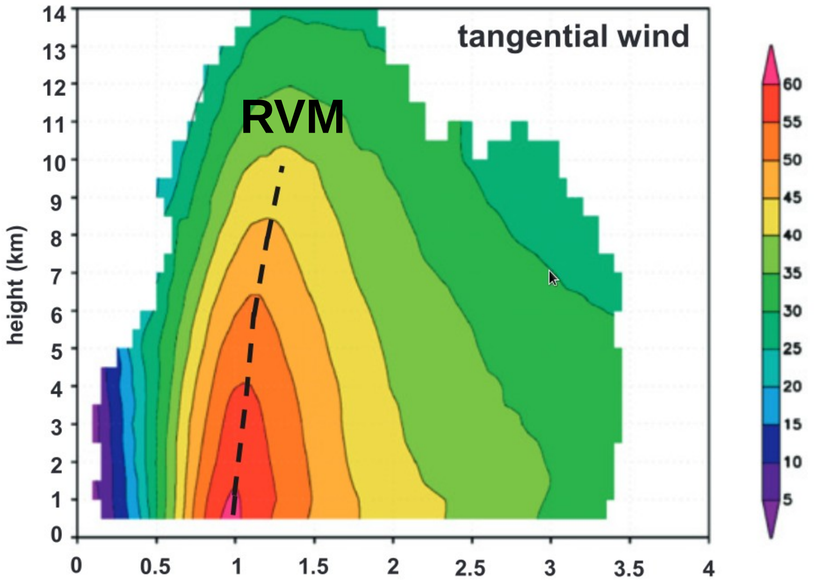
Friction (F)

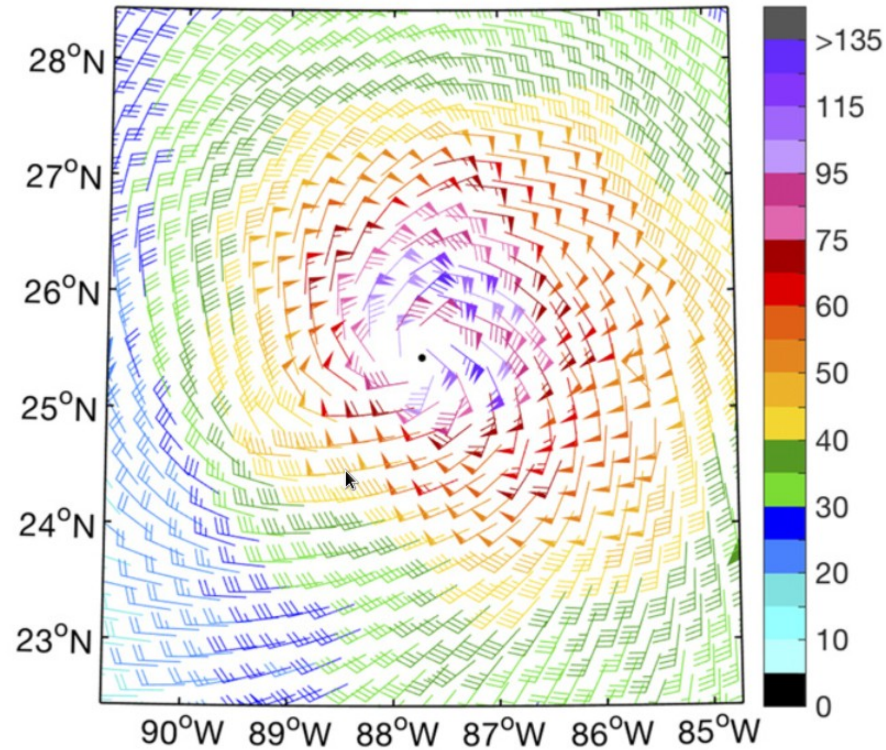
Coriolis force (f)

Centrifugal force

$$\frac{\partial V_r}{\partial t} = \frac{V_\theta^2}{r} + fV_\theta - \frac{1}{\rho}\frac{\partial P}{\partial r} + F_\theta = 0$$

TC structure
Primary circulation





Katrina 28/08/05

- Maximum winds near the surface
- Asymmetries : Movement, Shear, Intensity, Friction (land), Environnement..

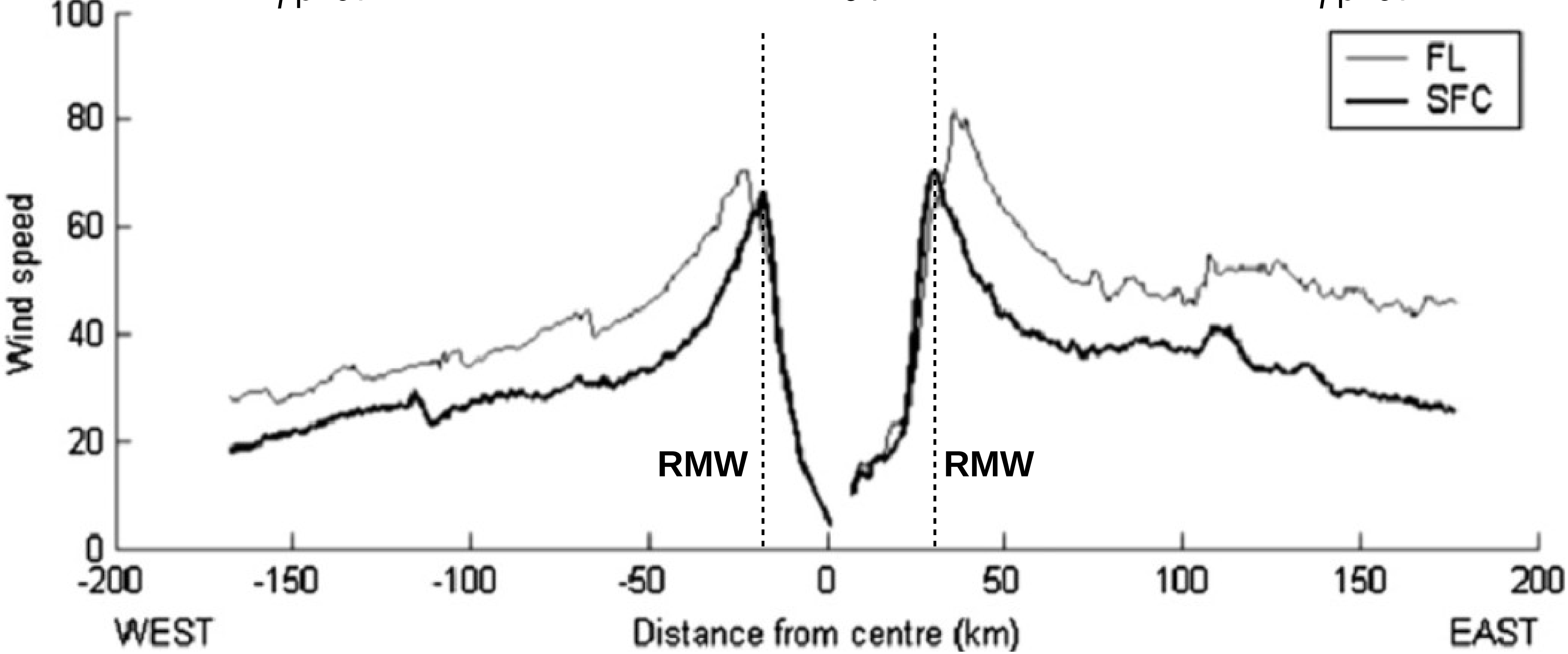
TC structure
Primary circulation

Geostrophism $$V=\frac{1}{f\rho}\frac{\partial P}{\partial r}$$

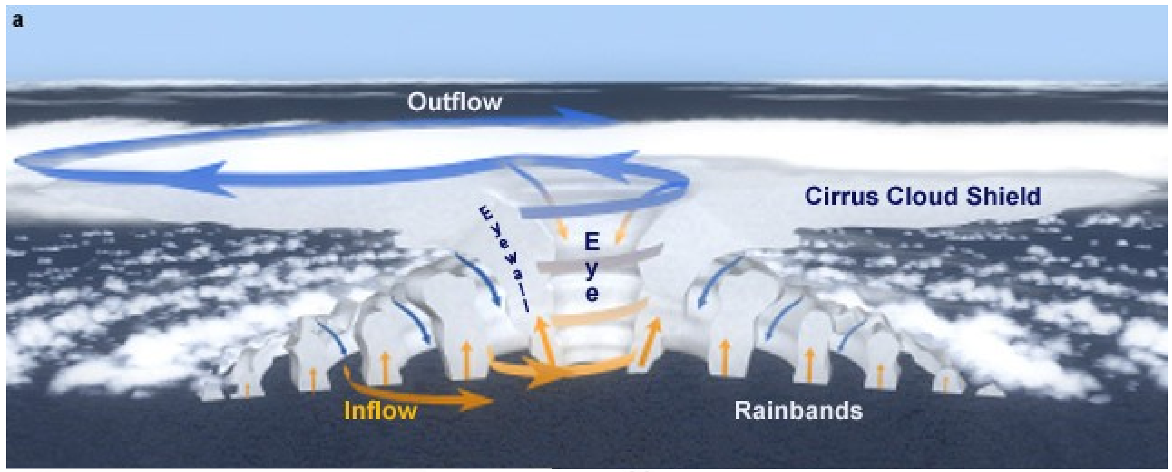
Cyclostrophism $$V^2=\frac{r}{\rho}\frac{\partial P}{\partial r}$$

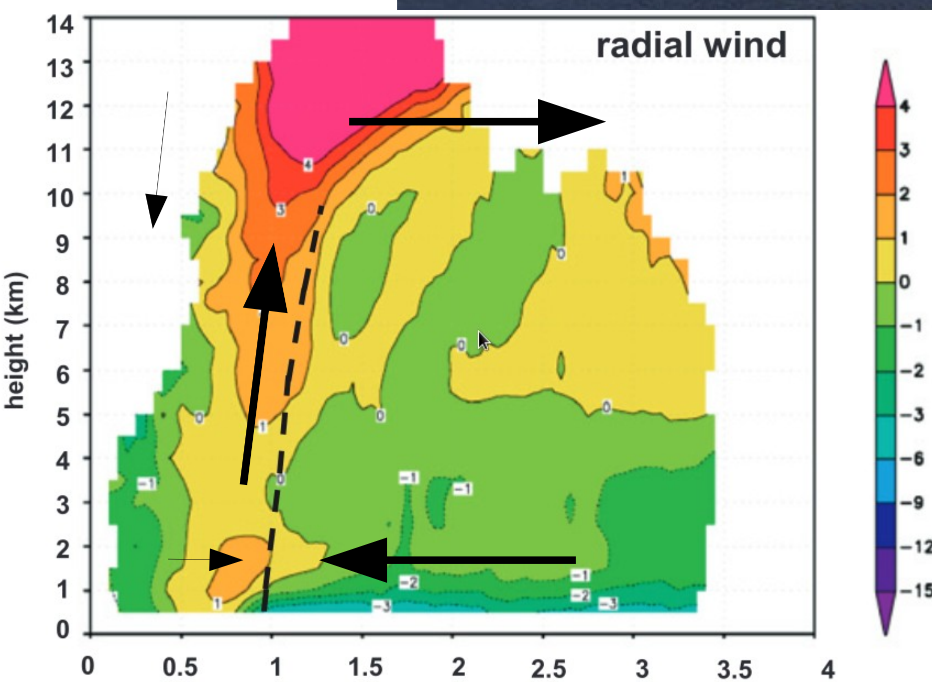
Géostrophism $$V=\frac{1}{f\rho}\frac{\partial P}{\partial r}$$

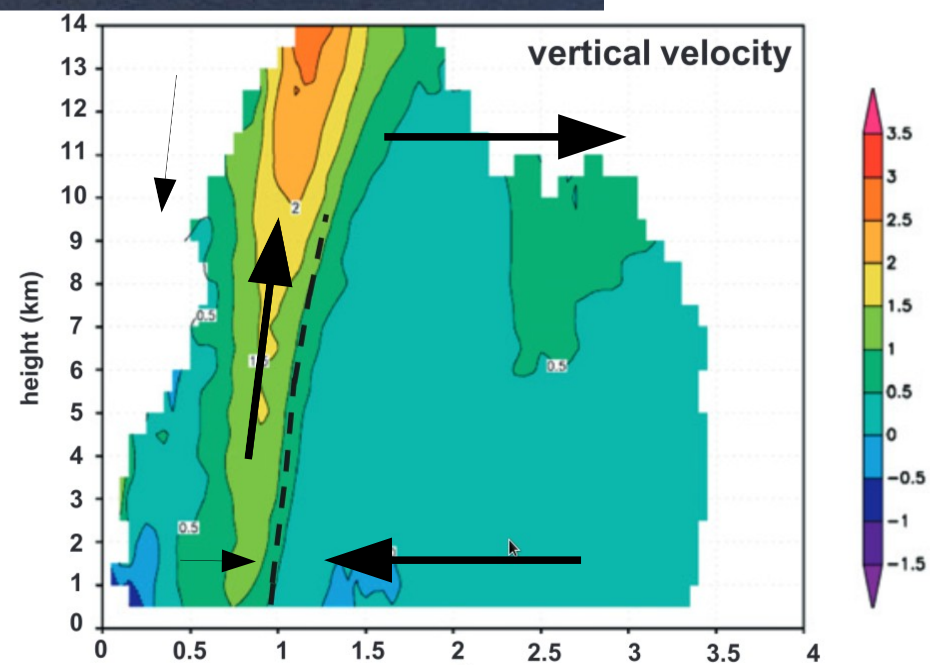
(a)



TC structure
Secondary circulation







TC structure
Eyewall

- When V_θ becomes too strong (Supergradient wind), pressure gradient is not able to balance the other forces (max 5-10hPa/km).

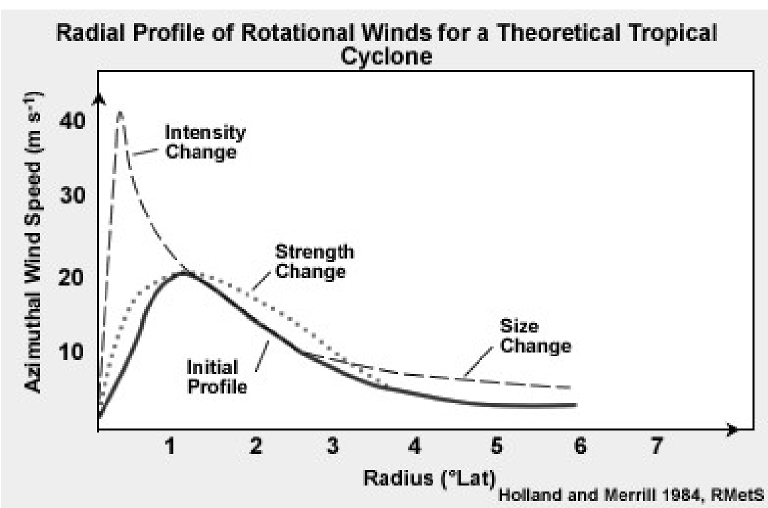
$$\frac{\partial V_r}{\partial t} = \frac{V_\theta^2}{r} + fV_\theta - \frac{1}{\rho}\frac{\partial P}{\partial r} > 0$$

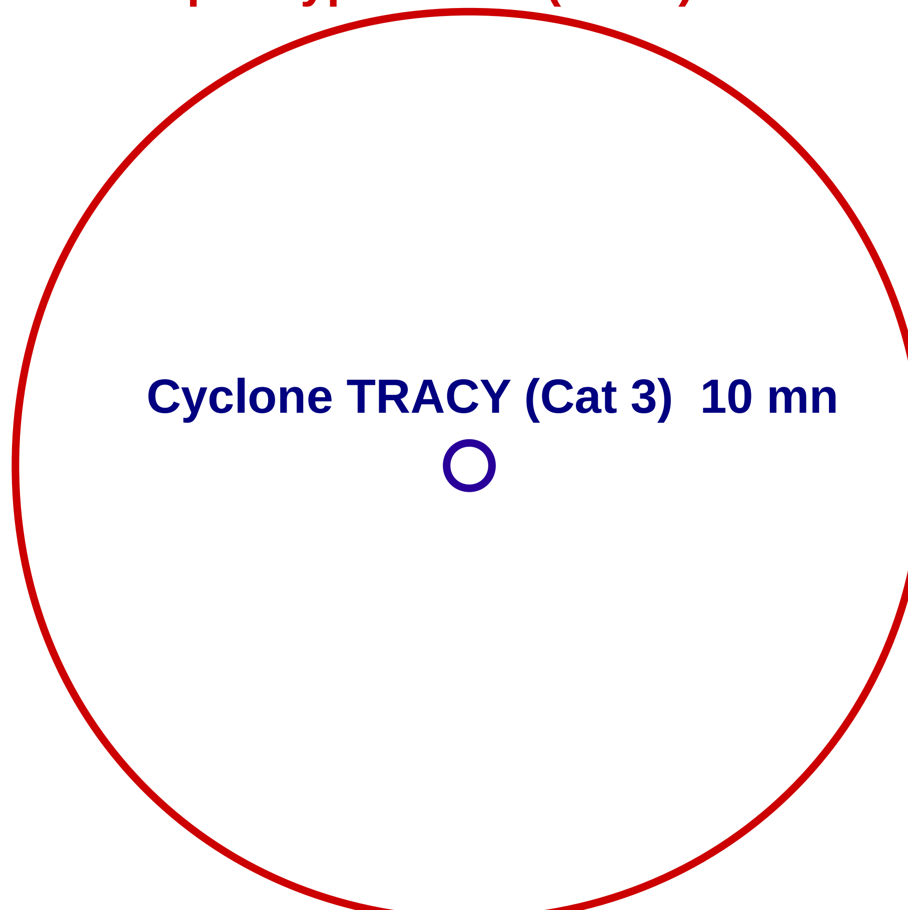
- V_r increases
  - — V_r is negative so the inflow slows down.

    → Convergence → Updrafts → More convection → Building of the eyewall

TC structure
Size

- Size ≠ Intensity
- Size matters for the impacts (swell, storm surge, rainfalls, winds...)

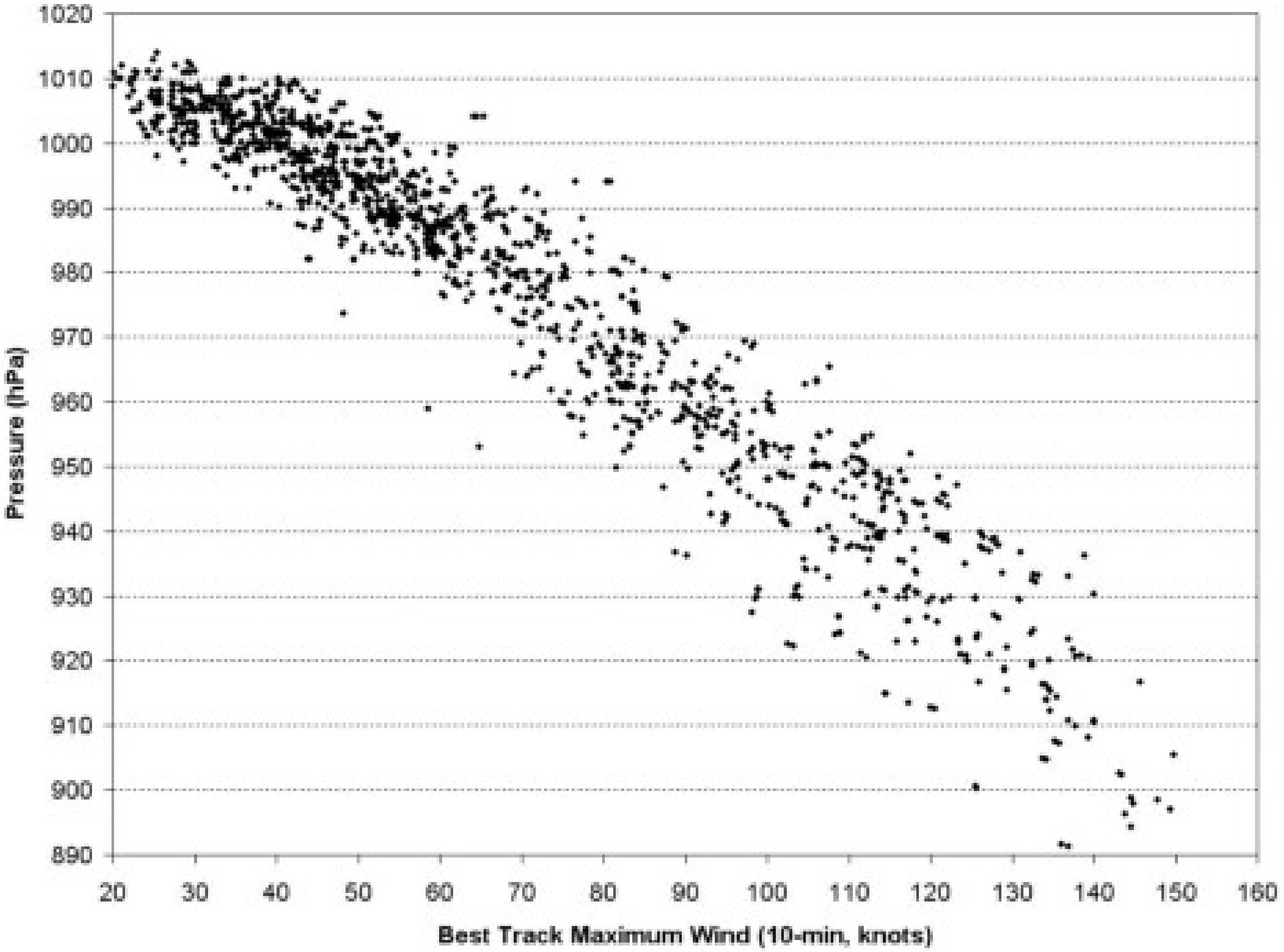




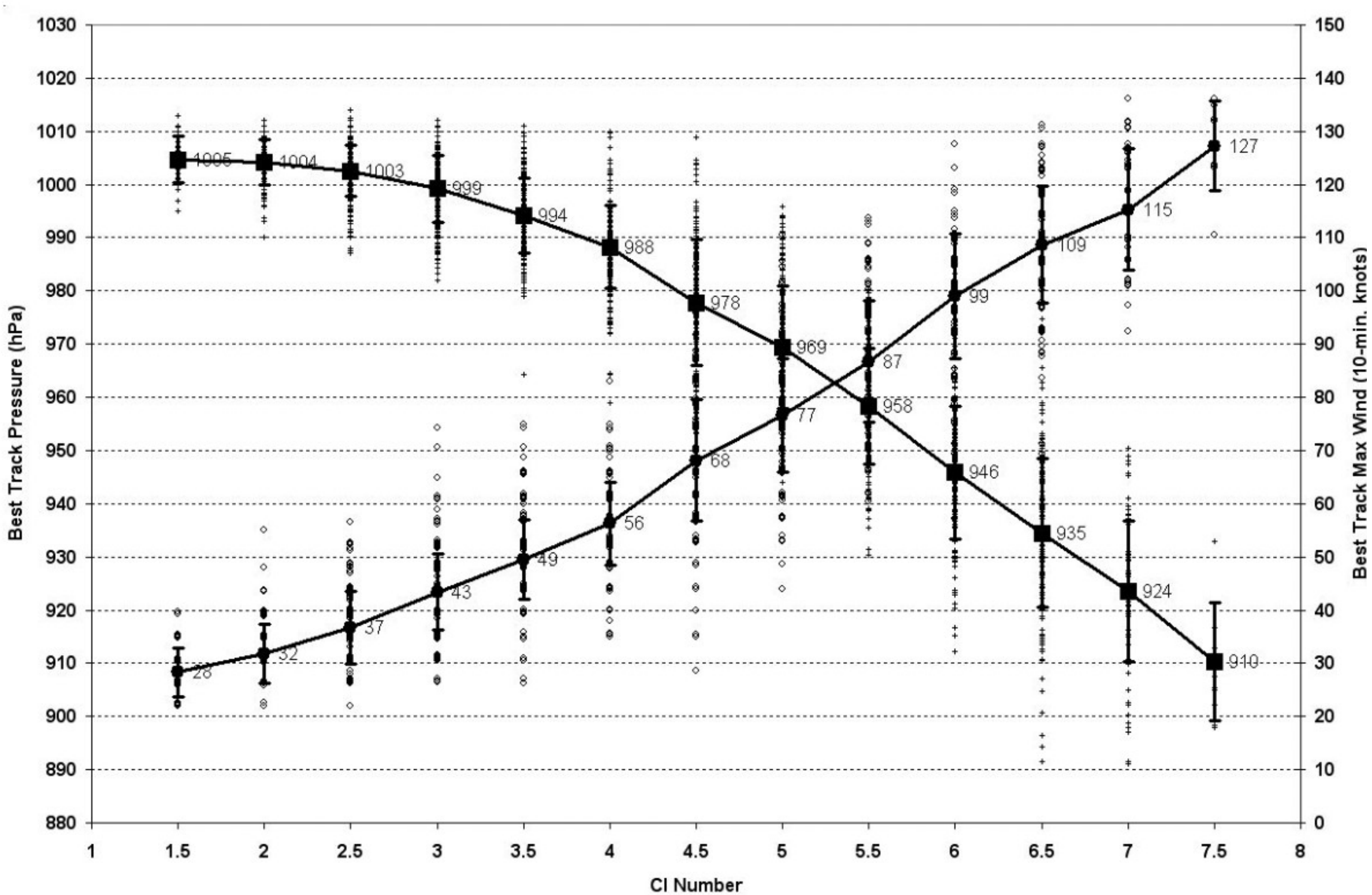
Windfield exceeding 50kt

TC structure
Wind / Pressure relationship

- Courtney Knaff 2009



TC structure
Wind / Pressure relationship



TC structure
Wind / Pressure relationship

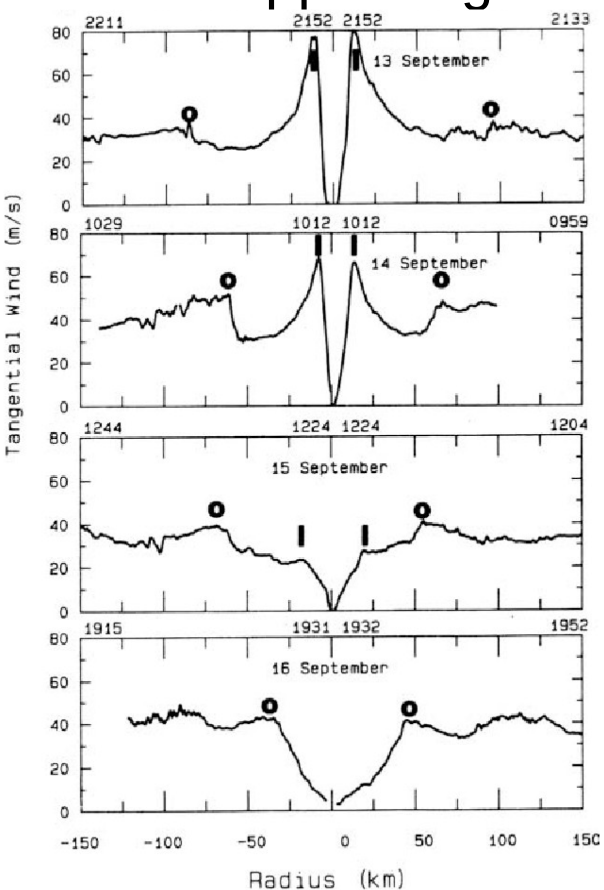
- P_{min} Courtney Knaff 2009 takes into account :
  - — Environmental pressure (P_{min} ↑ if P_{envi}↑)
  - — Size (P_{min} ↑ if Size↓)
  - — Latitude (P_{min} ↑ if Lat↓)
  - — Motion speed (P_{min} ↑ if Speed↑)

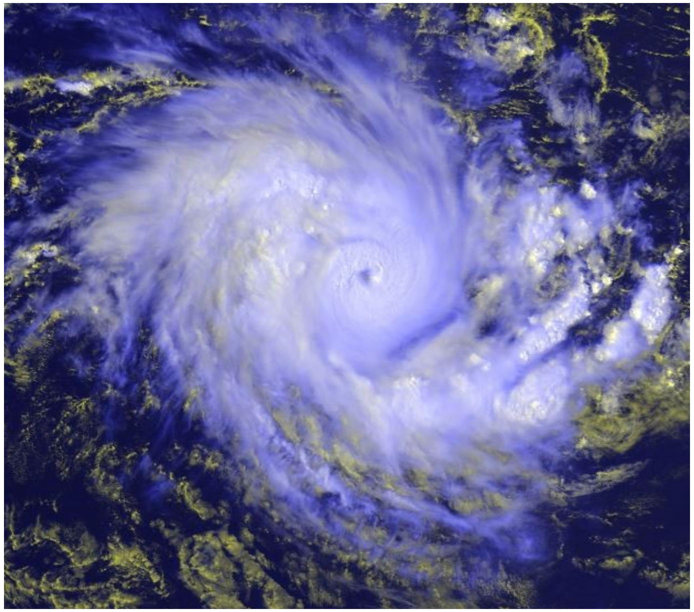
- But its doesn't take into account RMW
  - — (P_{min} ↑ if RMW↑)

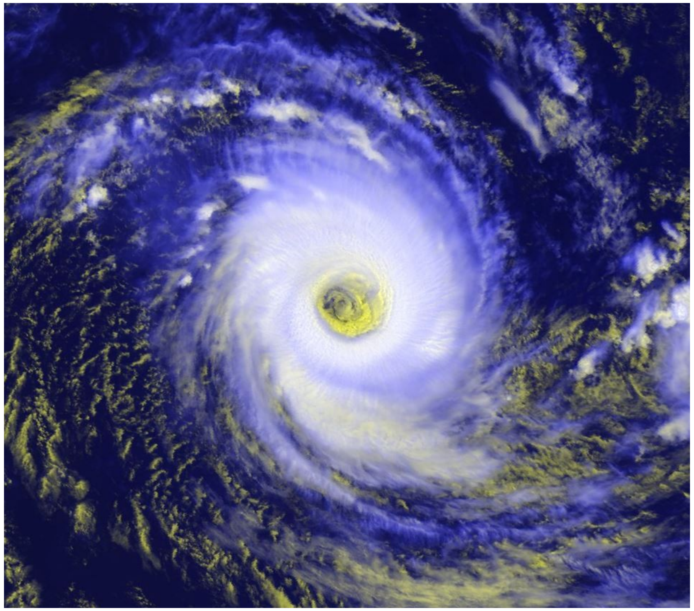
CI	*Latitude*	R_{34} *nm*	ΔP *(Eqn 7) hPa* motion 5 knots	motion 15 knots
1.0	12	60	-2.8	-1.3
		150	-8.5	-8.8
	25	60	-3.4	-1.2
		150	-12.8	-13.8
1.5	12	60	-5.0	-3.3
		150	-9.3	-8.6
	25	60	-6.6	-4.2
		150	-13.3	-12.8
2.0	12	60	-5.0	-3.3
		150	-9.3	-8.6
	25	60	-6.6	-4.2
		150	-13.3	-12.8
2.5	12	60	-7.4	-5.6
		150	-10.8	-9.6
	25	60	-9.8	-7.4
		150	-15.0	-13.7
3.0	12	60	-13	-11
		150	-15	-14
	25	60	-17	-14
		150	-20	-18
3.5	12	60	-19	-17
		150	-21	-19
	25	60	-24	-21
		150	-27	-24
4.0	12	60	-23	-20
		150	-24	-22
	25	60	-28	-25
		150	-30	-28
4.5	12	60	-34	-31
		150	-36	-33
	25	60	-40	-37
		150	-42	-39
	12	60	-42	-39
		[illegible]	[illegible]	[illegible]

TC structure
ERC Eyewall Replacement Cycle

- Building of a secondary maximum wind / eyewall in a convective band (SEF)
- Progressive contraction of this outer eyewall over the inner one.
- Disappearing of the inner eyewall



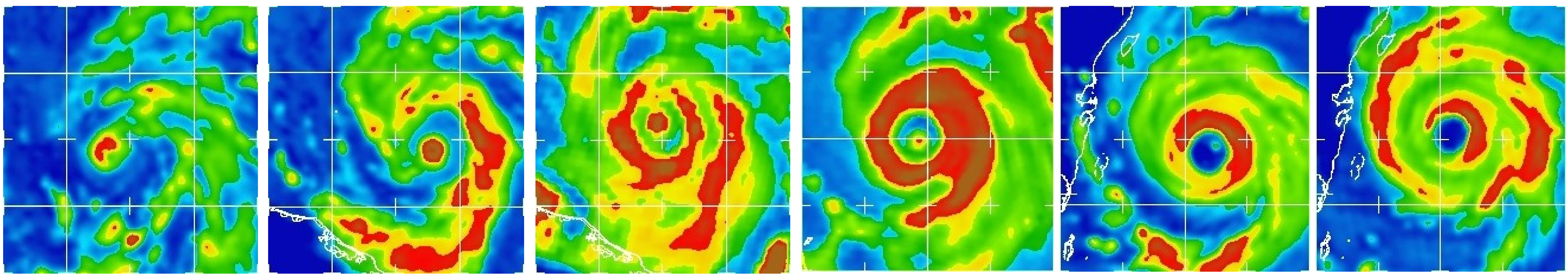




Cebile's evolution in 48h (2018)

TC structure
ERC : WILMA (Atlantic)

975hPa / 75 kt ++ | 892hPa / 150 kt + | 885hPa / 155 kt - | 892hPa / 135 kt - | 917hPa / 130 kt - | 924hPa / 130 kt -



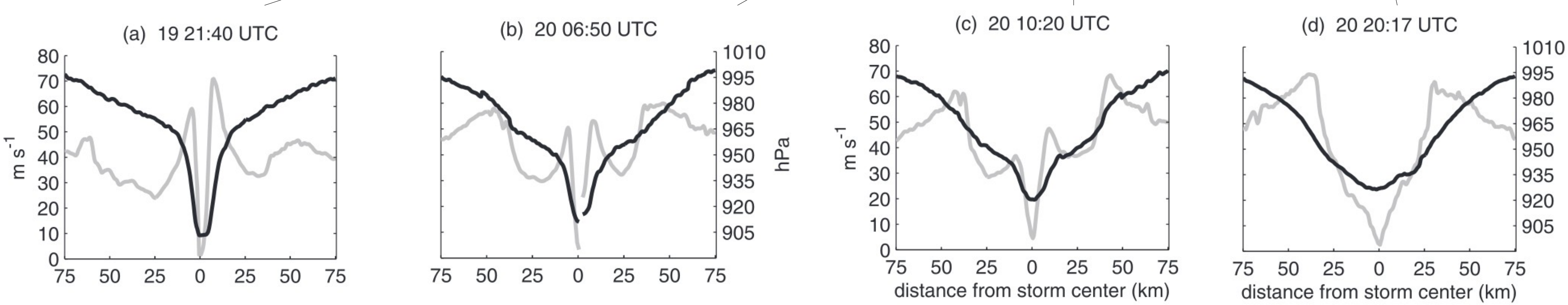
18 1857Z | 19 0709Z | 19 1400Z | 20 0113Z | 20 1845Z | 21 0056Z

Building of the outer eyewall

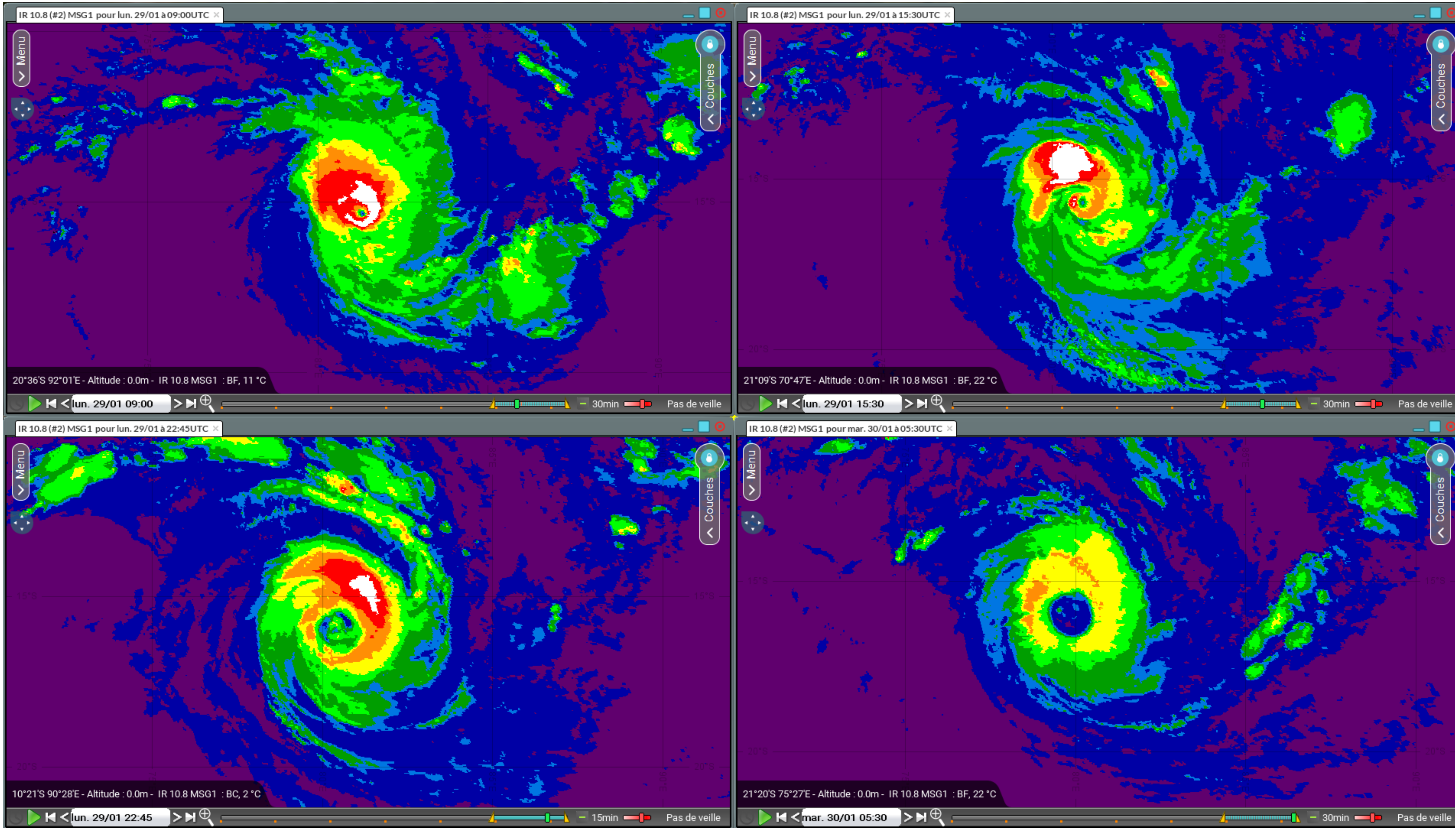
Weakening of the inner eyewall

V_{max} is on the outer eyewall

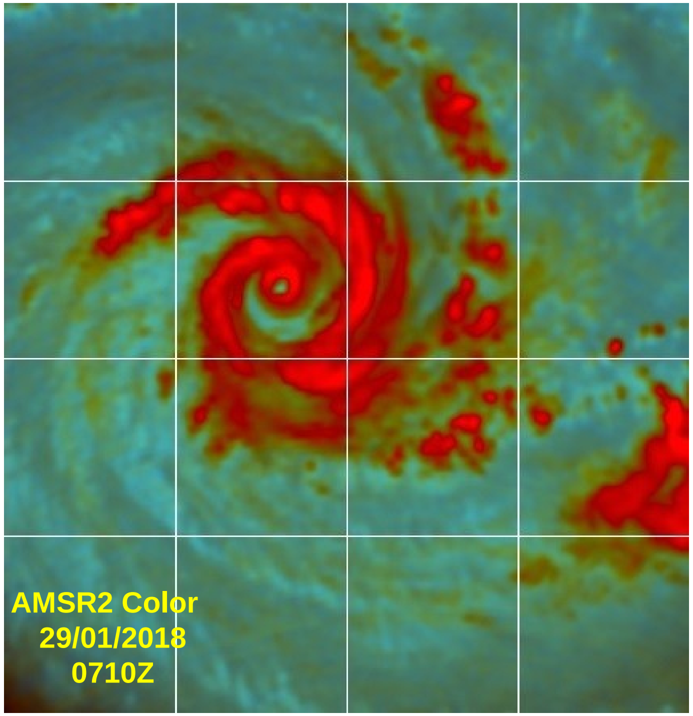
Inner eyewall disappear

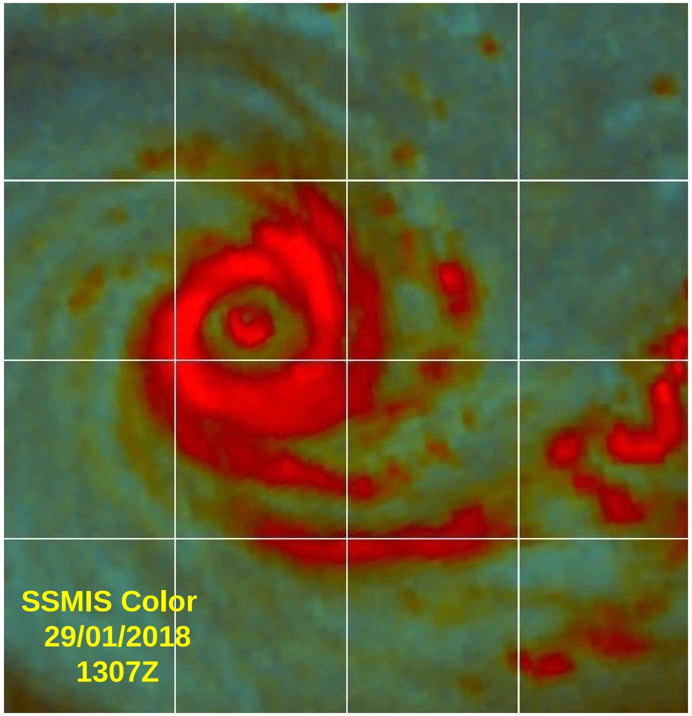


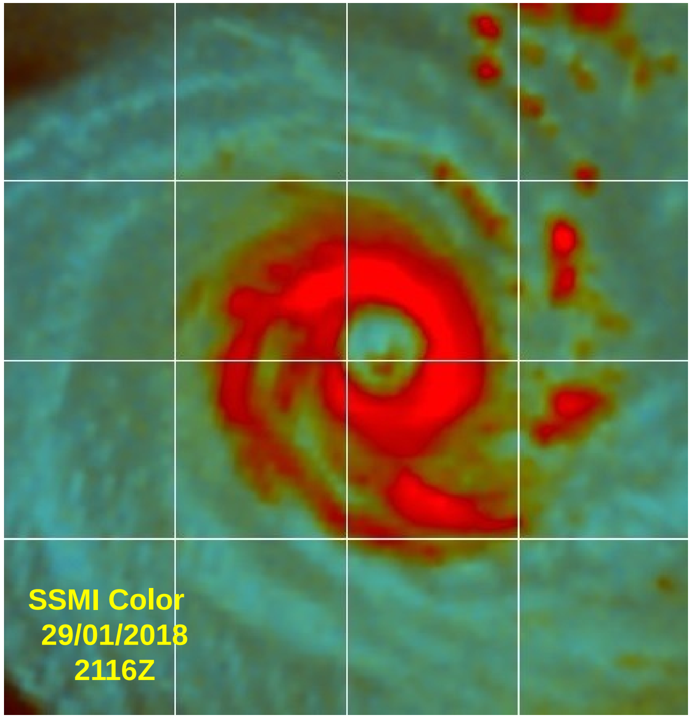
TC structure
ERC : CEBILE



TC structure
ERC : CEBILE







Building of the outer eyewall and a secondary wind maximum

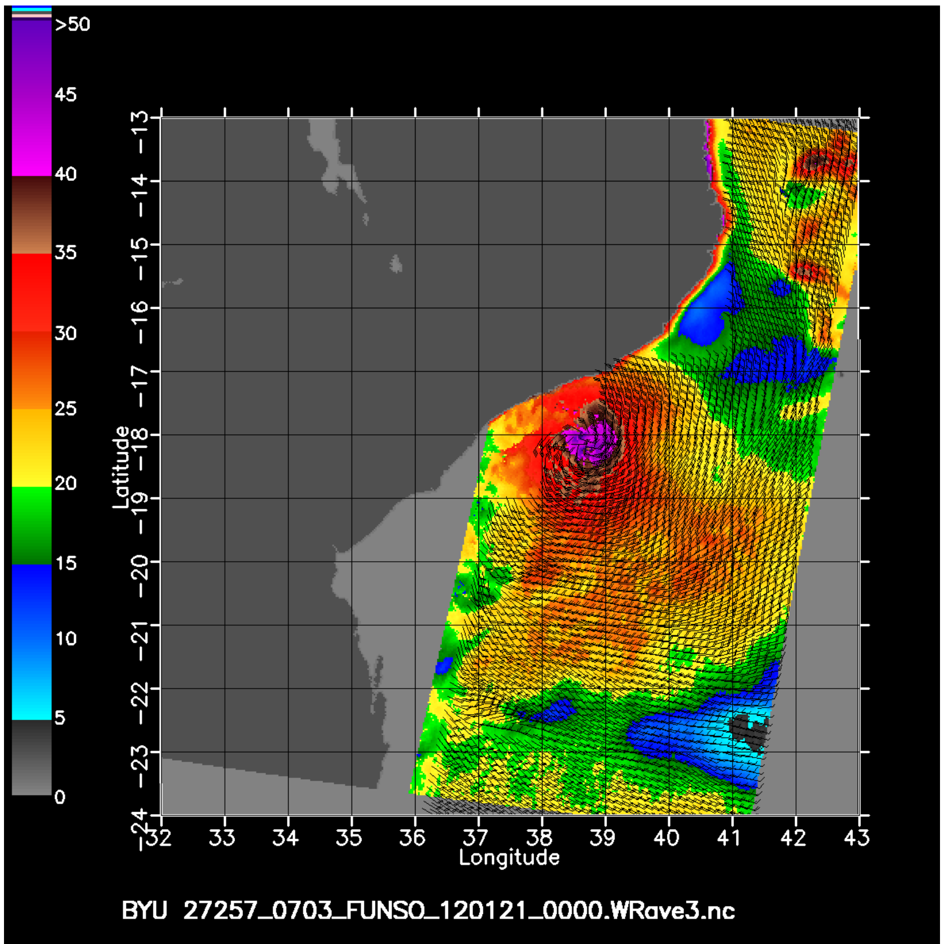
Weakening of the inner eyewall

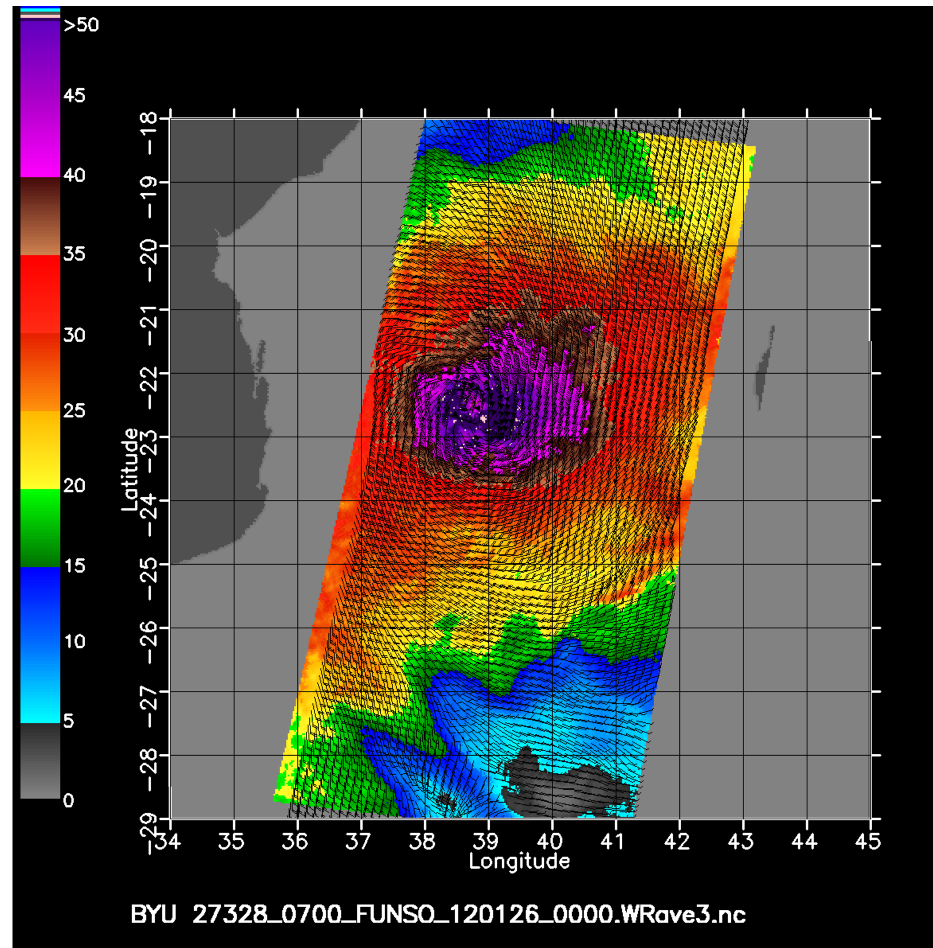
Vmax is on the outer eyewall

Inner eyewall disappear

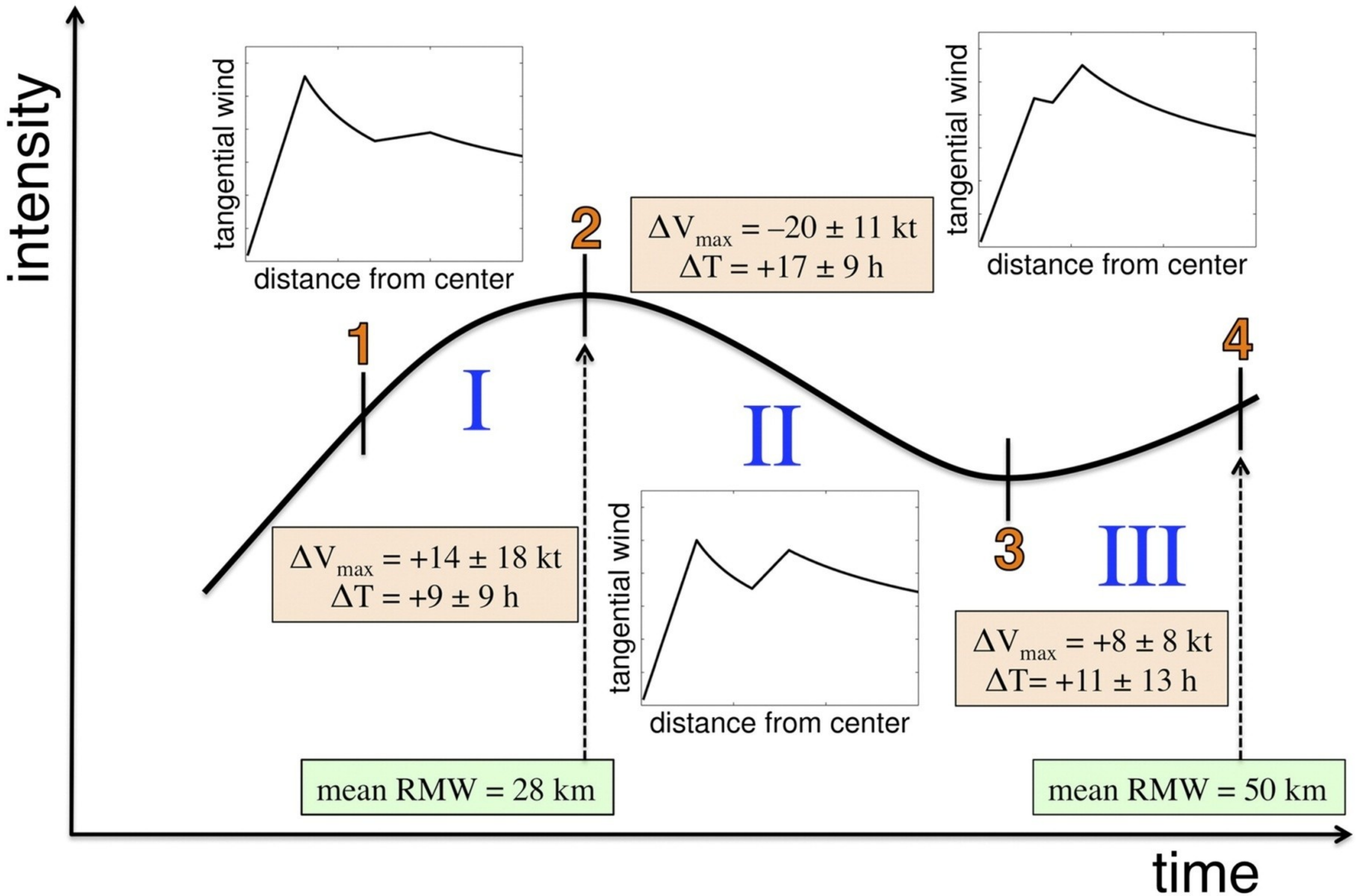
TC structure
ERC

- Expansion of the windfields (Funso 2012) :





TC structure
ERC



TC structure
ERC

- Poorly understood mechanism
- Very likely for the most intense cyclone

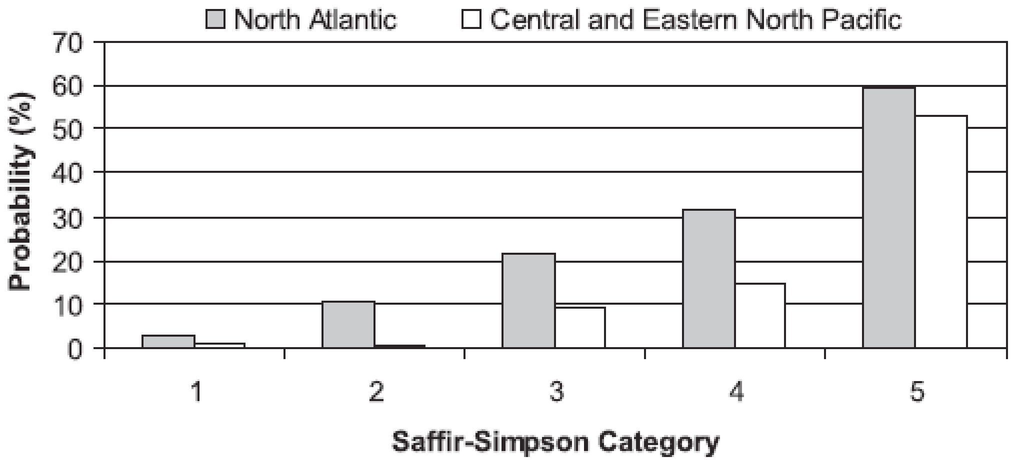
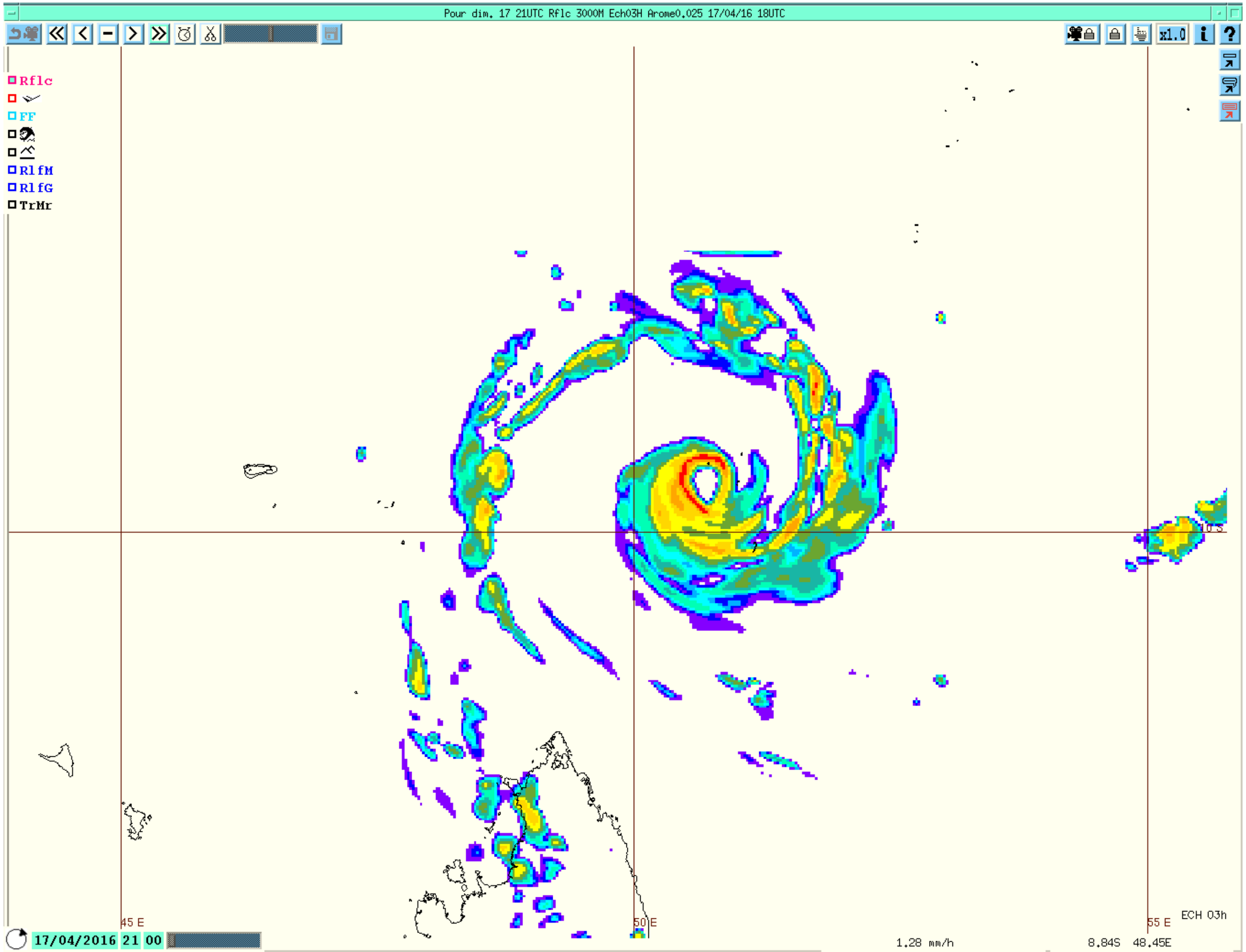


FIG. 6. Climatological probability, based on counts, of secondary eyewall formation as a function of current intensity (grouped by Saffir–Simpson category). The values reflect the climatological probability, for any time that a hurricane is over water, that secondary eyewall formation is imminent.

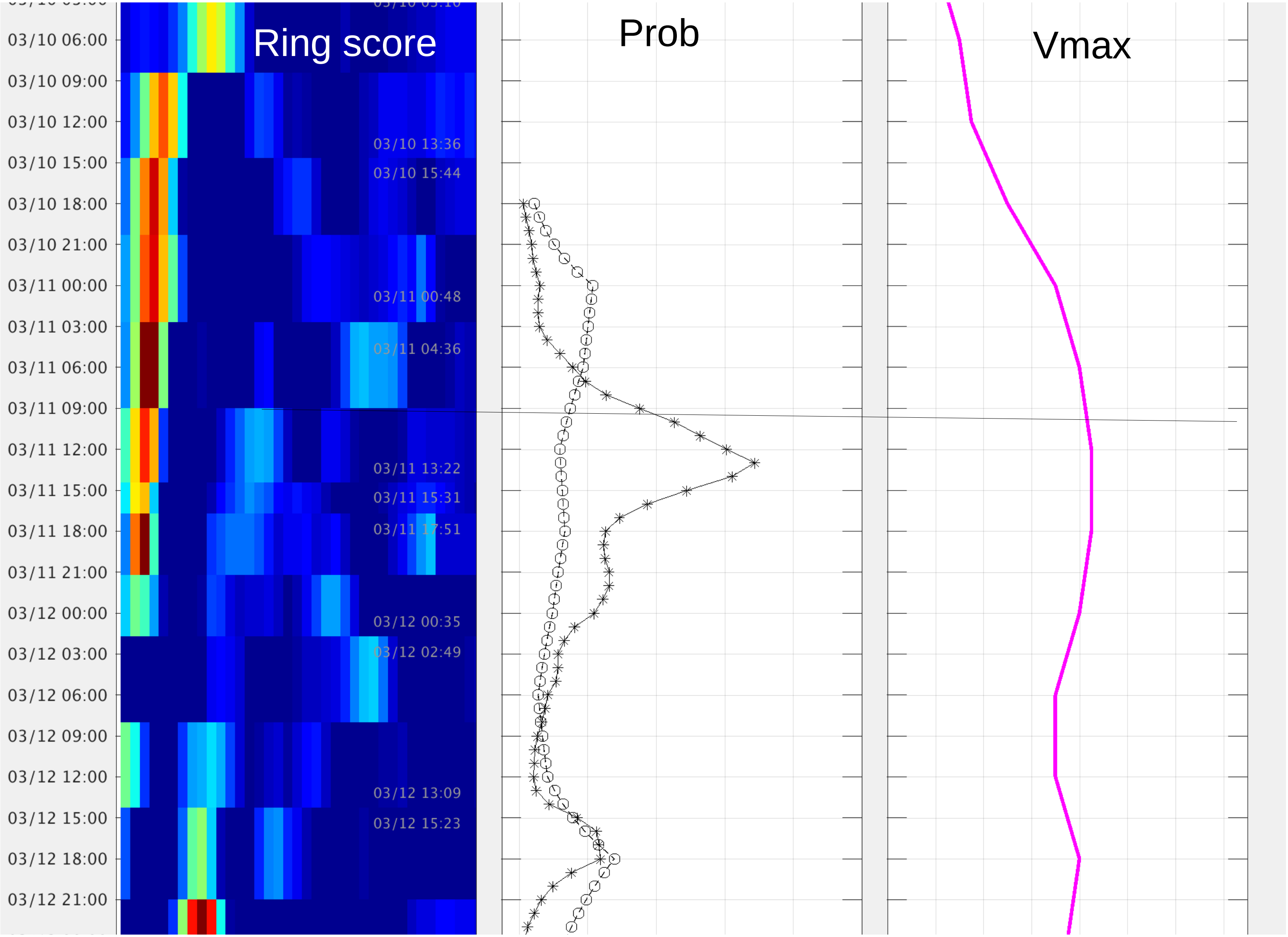
TC structure
ERC

- Arome IO able to simulate an ERC but ...

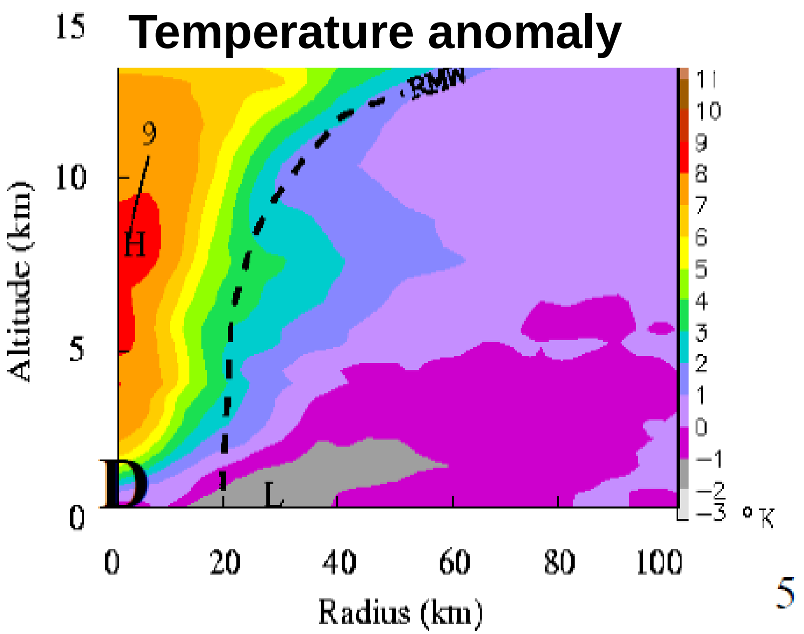


TC structure
ERC : MPERC

- MPERC
- Cas IDAI



TC Intensity
Warm core

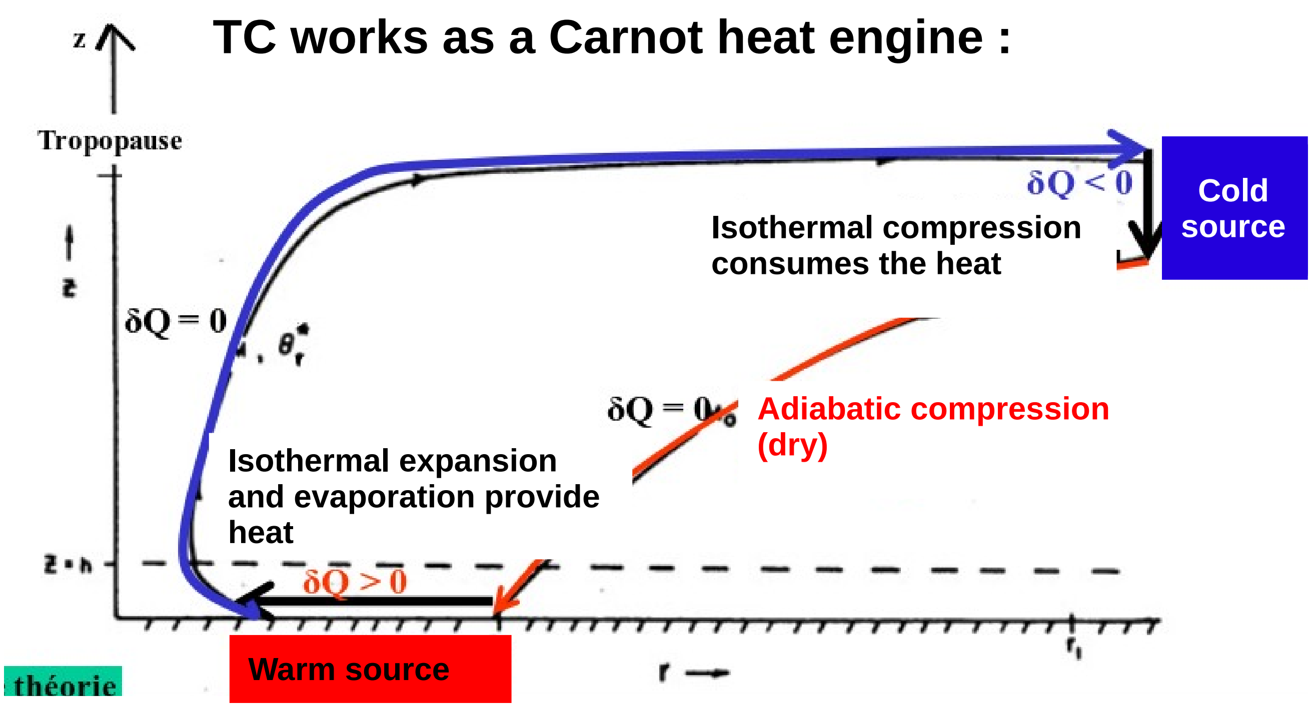


- With the hydrostatic approximation, the pressure is the weight of the atmosphere above.

$$P_{sea} = P_{top} + \int_{sea}^{top} \rho(z)\, g\, dz$$

- This anomaly is created by the latent heat release in the eyewall and the adiabatic compression in the eye.

TC Intensity
WISHE/Carnot Cycle



- TC transfer heat from the oceans to the upper atmosphere
- The efficiency of such a heat engine is given by

$$e = 1 - \frac{T_{cold}}{T_{warm}} \approx \frac{1}{3}$$

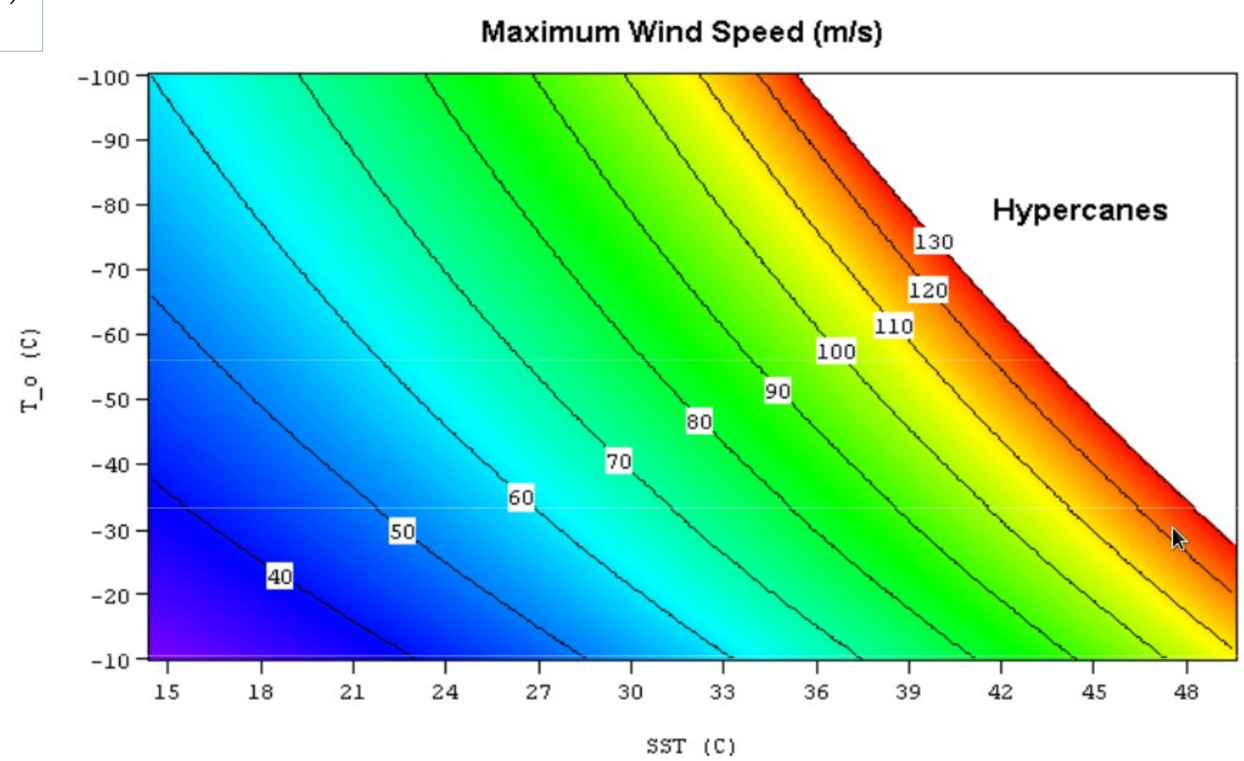
TC Intensity
MPI : Maximum Potential Intensity

- Given some assumptions, the efficiency can be related to intensity :

$$V_{max}^{2} \sim e \frac{C_k}{C_d} \left(k_0^{*} - k \right)$$

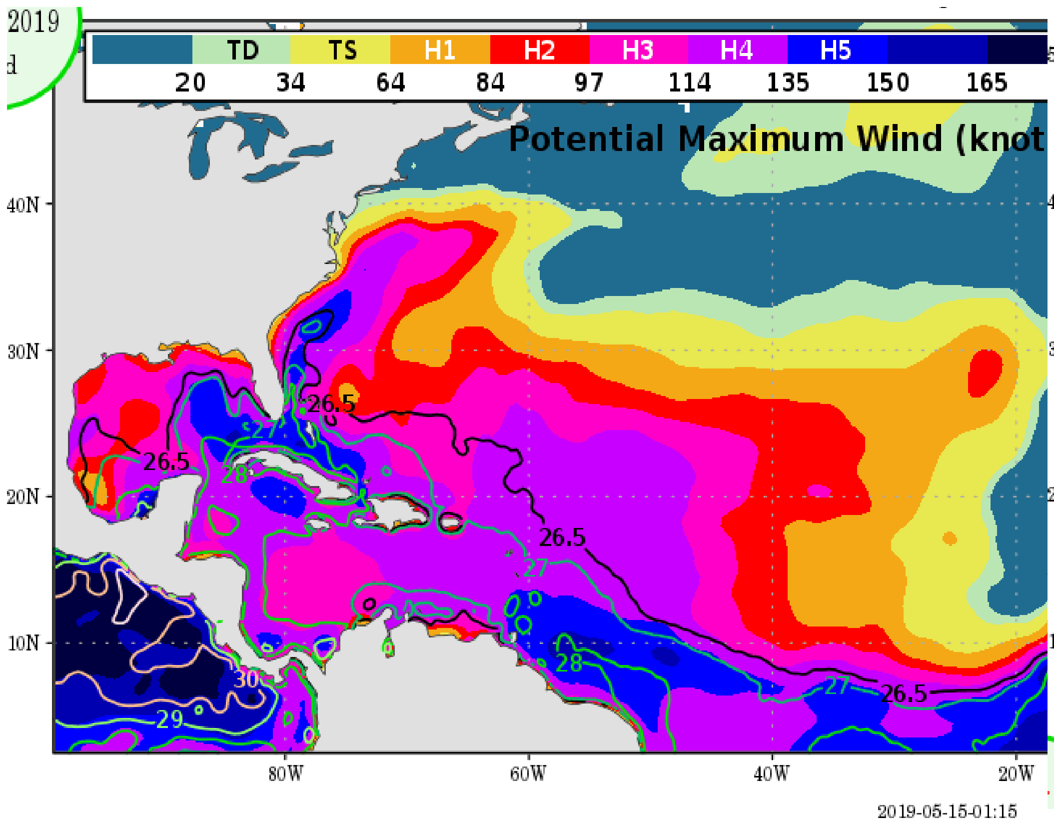
Parameters related to the exchanges of heat/energy

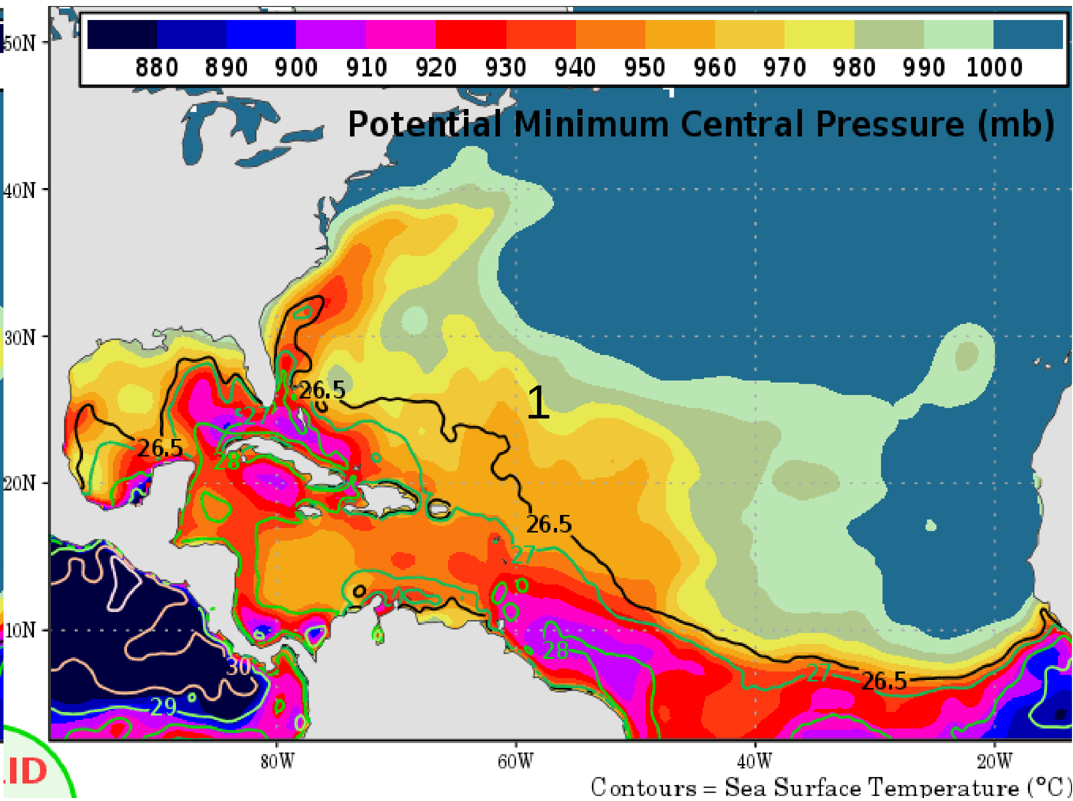
$$V_{max}^{2} \sim \left(1 - \frac{T_{tropo}}{SST} \right)$$



TC Intensity
MPI

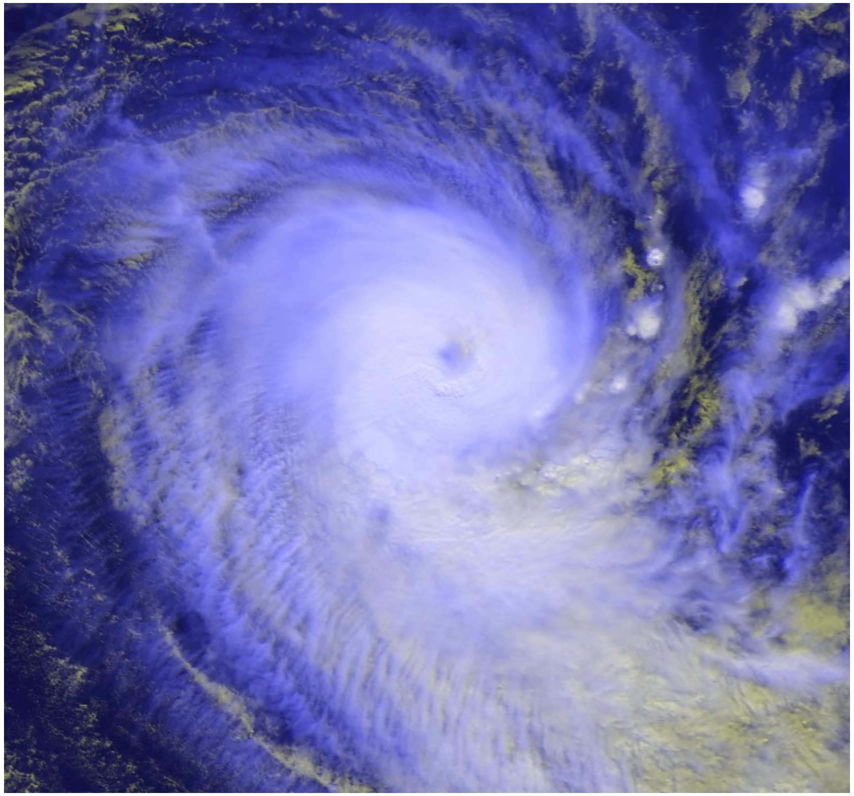
- Realistic theoretical MPI :

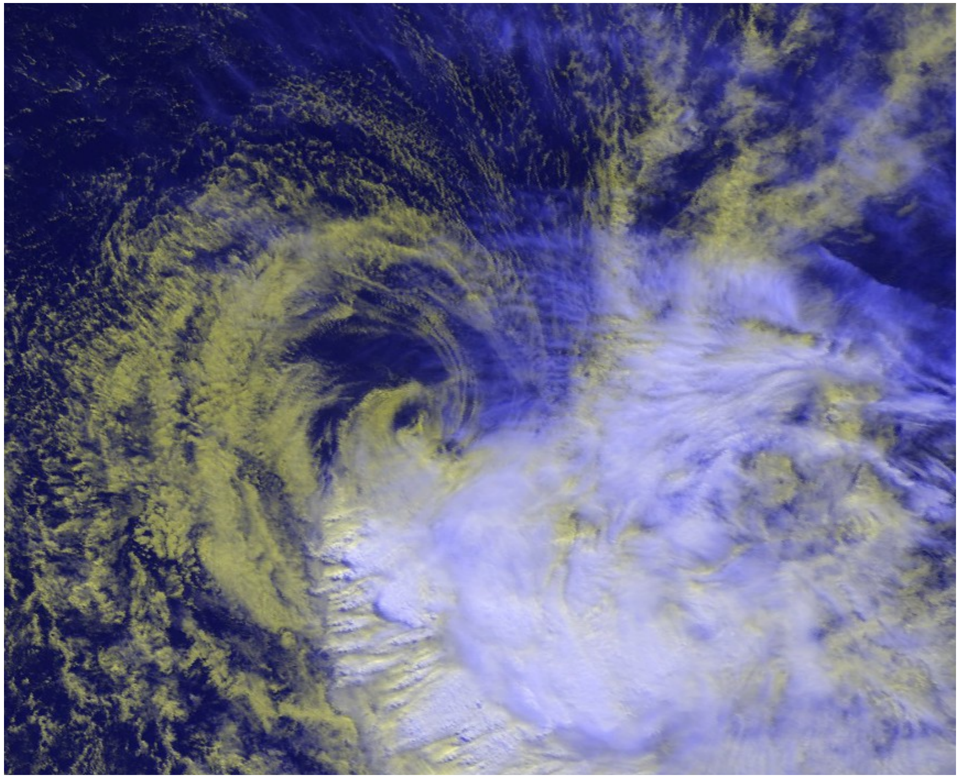




TC intensity
Vertical wind shear (VWS)

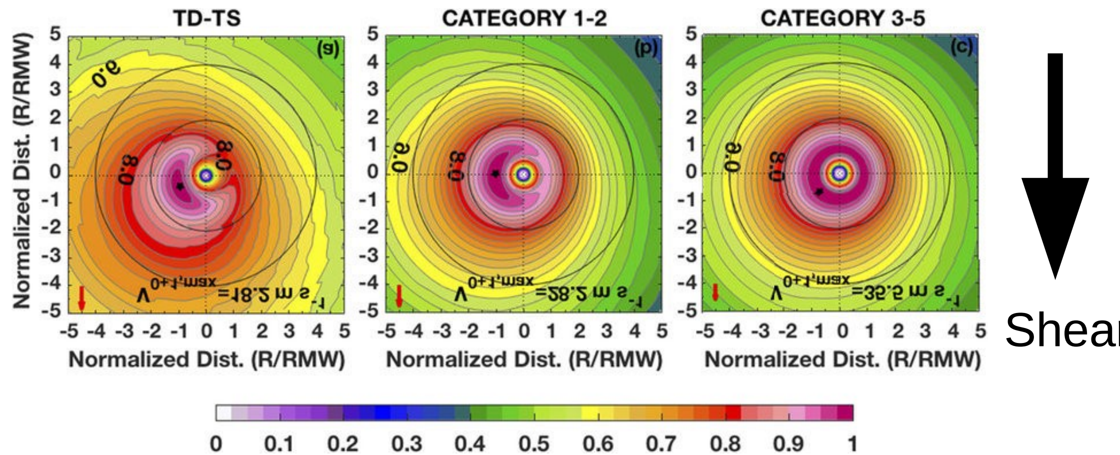
- Shear (VWS) : Wind difference ($V_{altitude}$-V_{ground}), often V_{200}-V_{850}
- Lorna 2019, 30kt NW shear, 24h change :

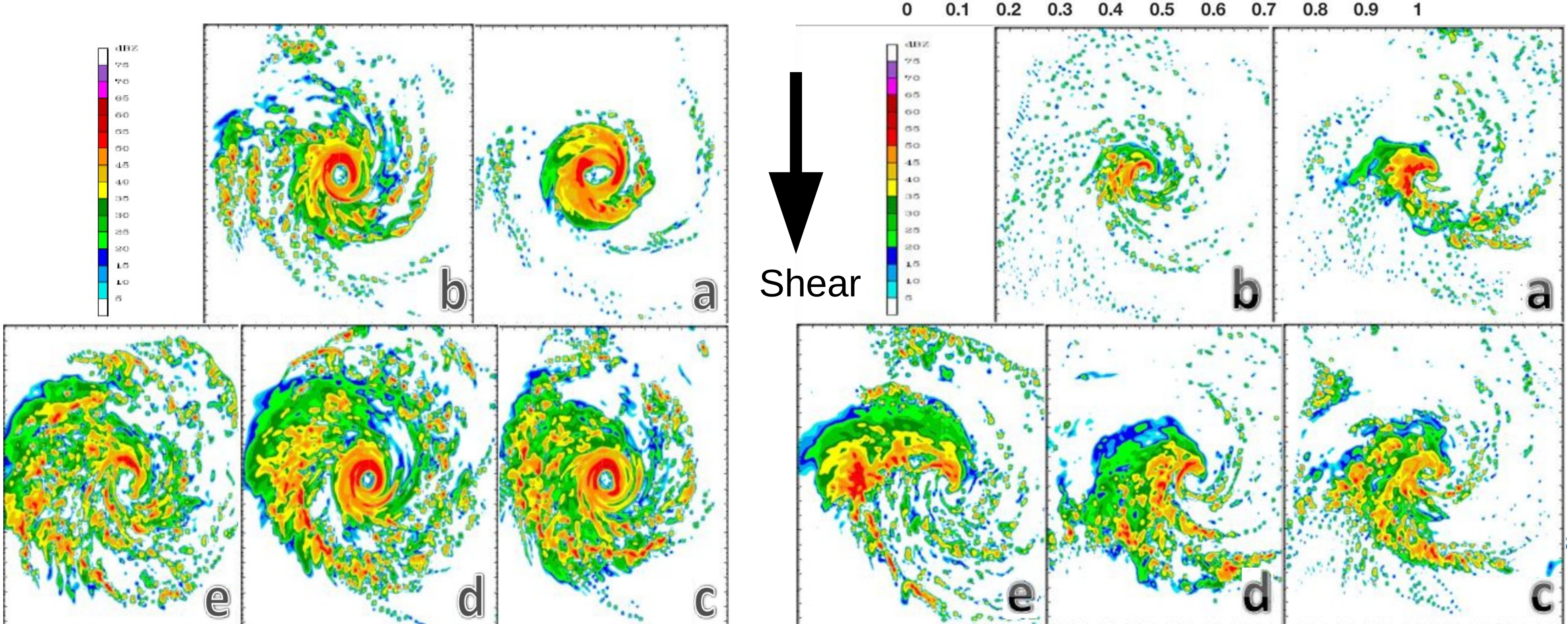




TC intensity
Vertical wind shear (VWS)

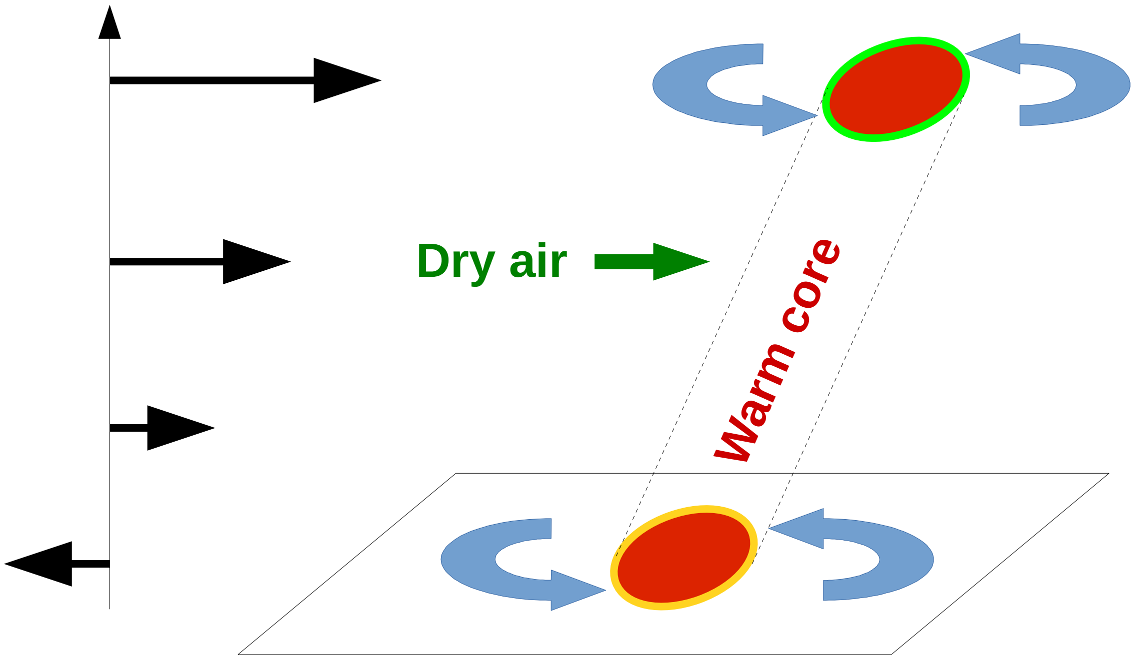
- Shear organizes convection and creates asymmetries
- **RR/Wind maximum** on the **right** (left) side **of shear** in the **South hemisphere**(NH)



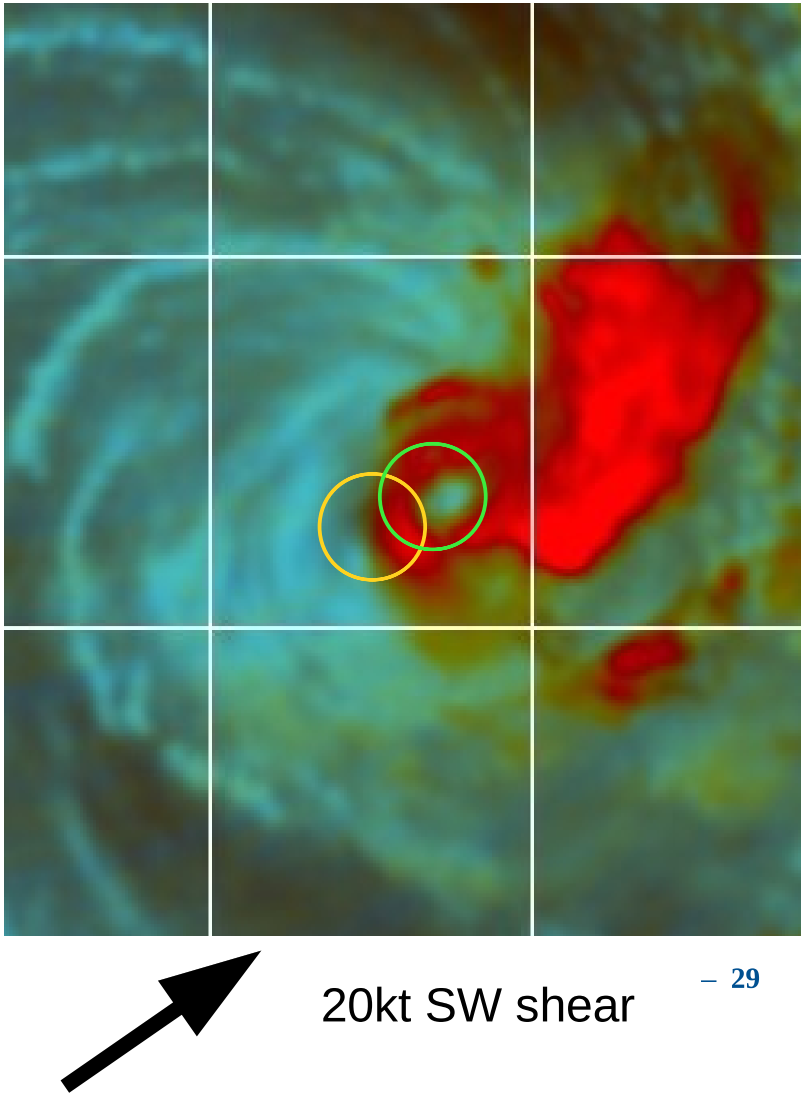


TC intensity
Vertical wind shear (VWS)

- Effect on intensity
  - **Shear + dry air**

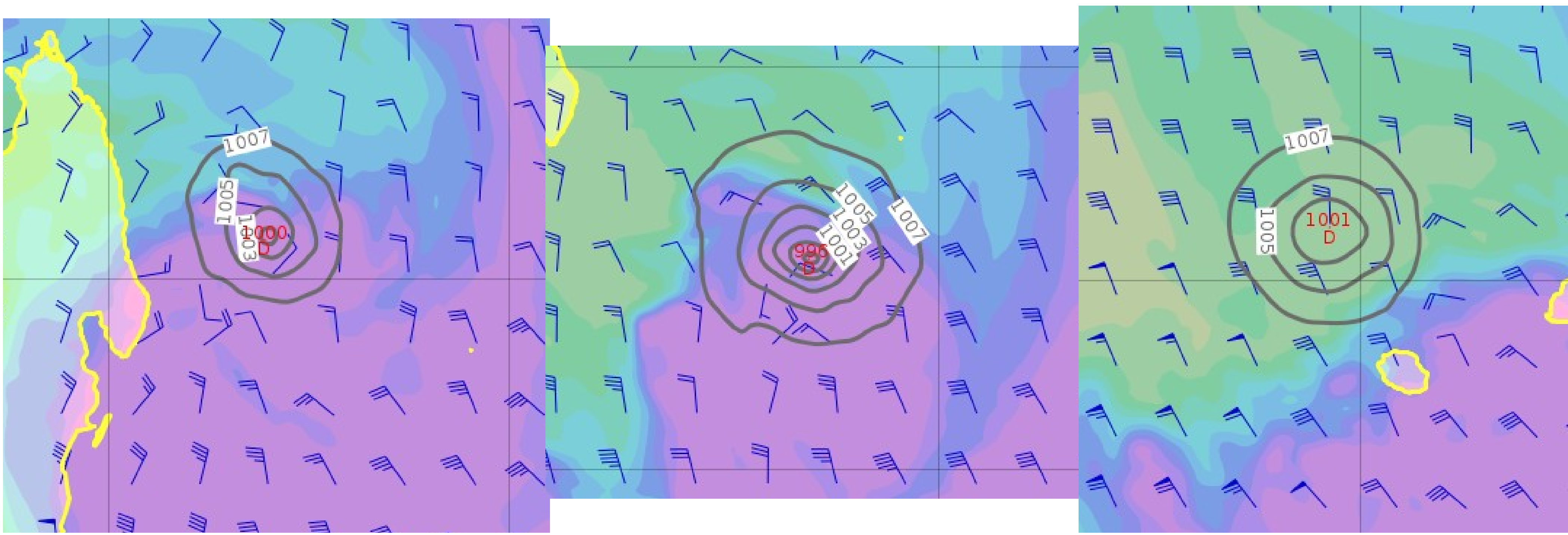


Gelena tilt, 2019



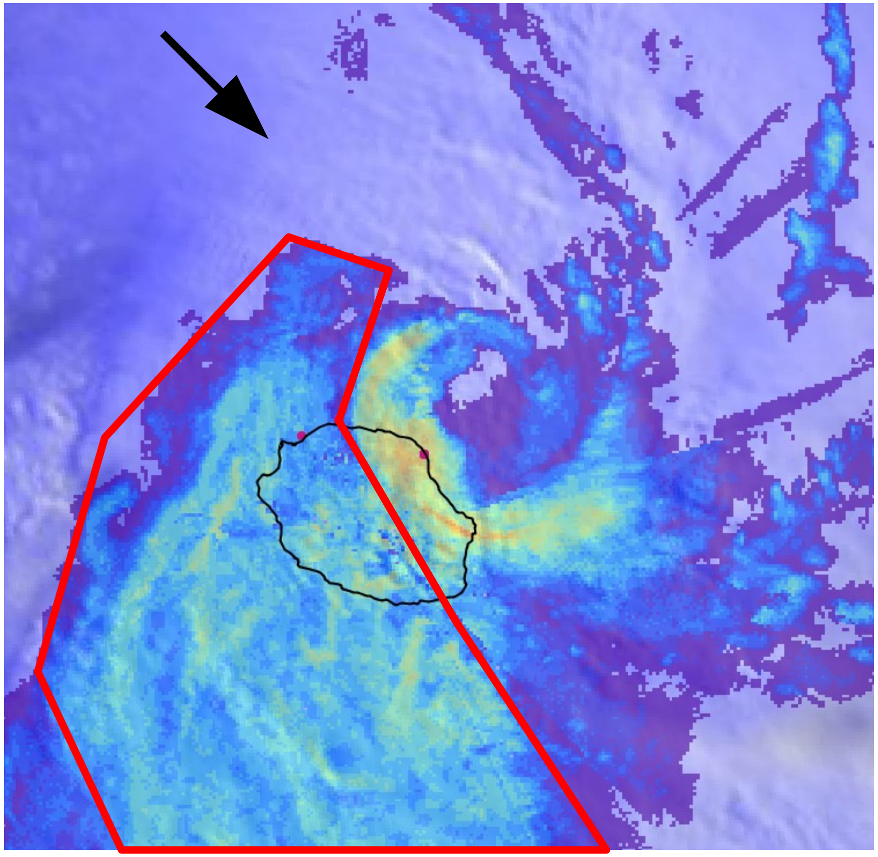
TC intensity
Vertical wind shear (VWS)

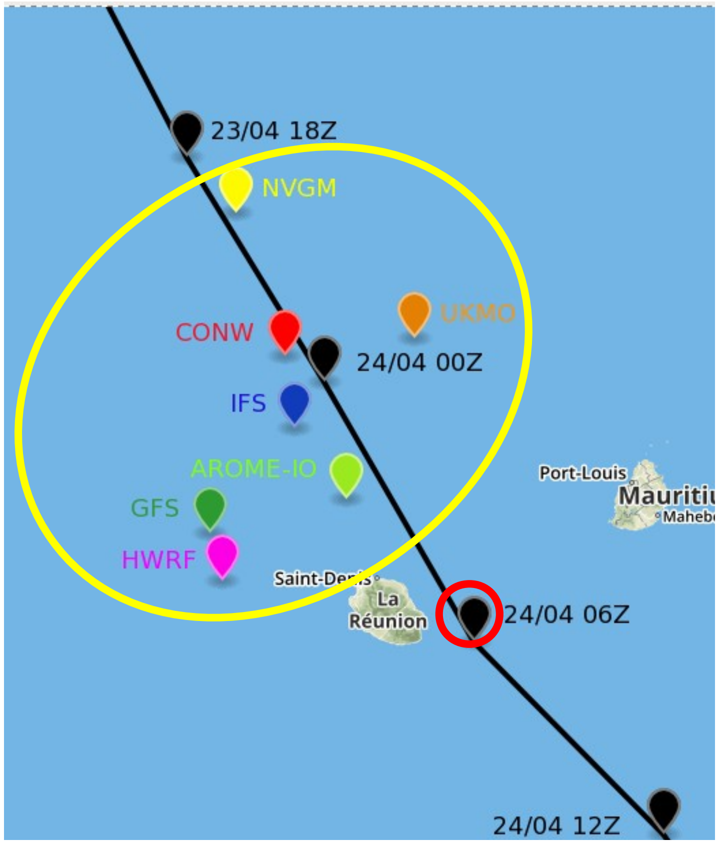
- Complex interaction → Numerical models fairly good to simulate the impact
- IFS0.5° - Wind 200 hPa + Hu 500 hPa – 23/04 00Z run H+30h



TC intensity
Vertical wind shear (VWS)

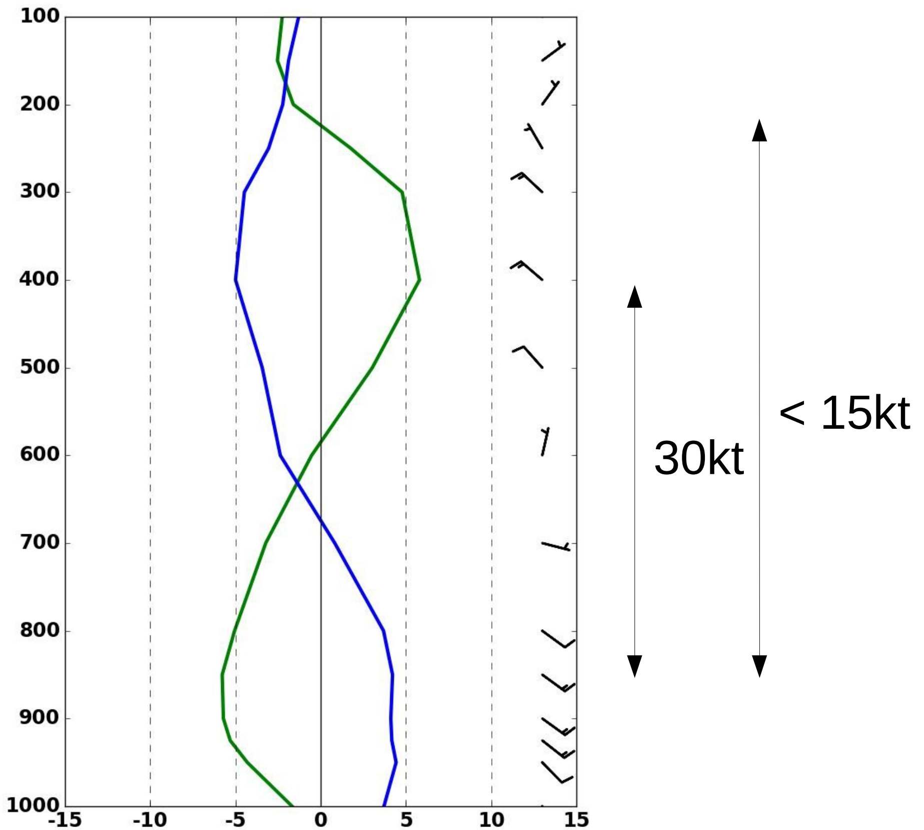
- Be careful, 200-850hPa is not all that matters
  - Motion : Fakir (April 2018)
    - Speed around 30 to 42km/h (23kt) in the same direction as shear

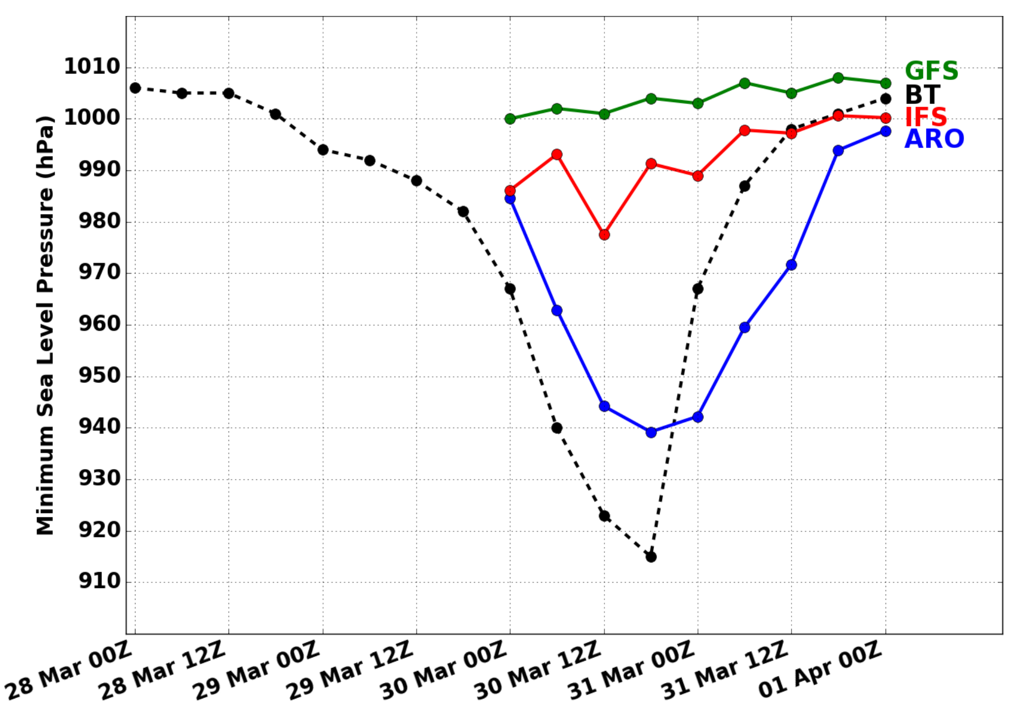




Intensité
Cisaillement vertical de vent

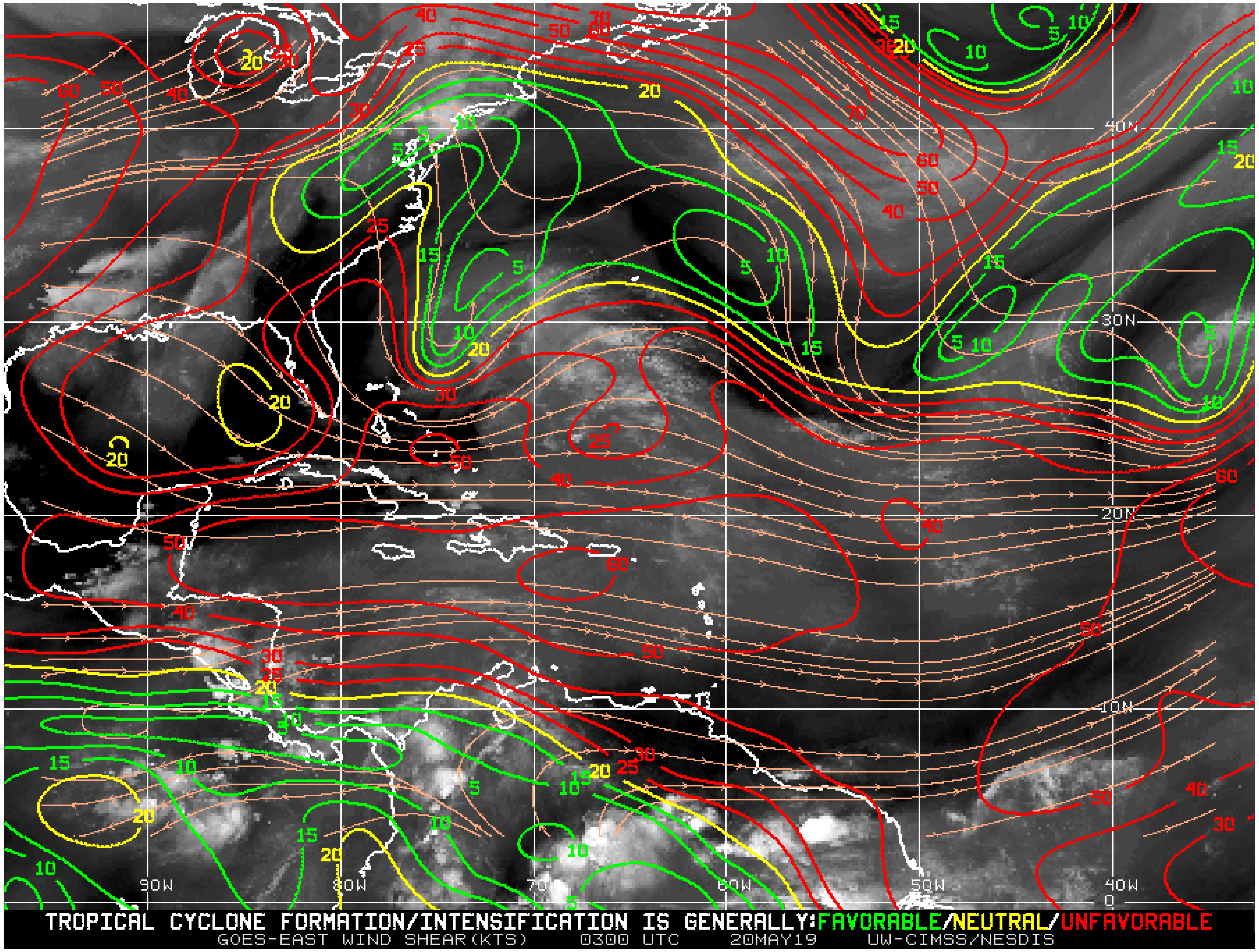
- Be careful, 200-850hPa is not all that matters
  - Max VWS can be lower (300,400 or even 500hPa)
    - Hellen (March 2014)





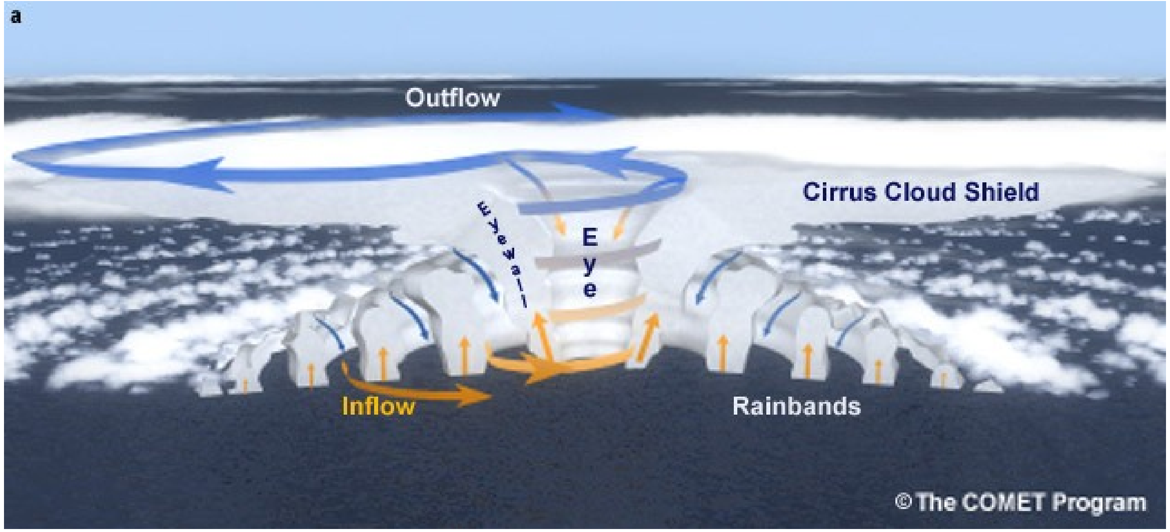
Intensité
Cisaillement vertical de vent

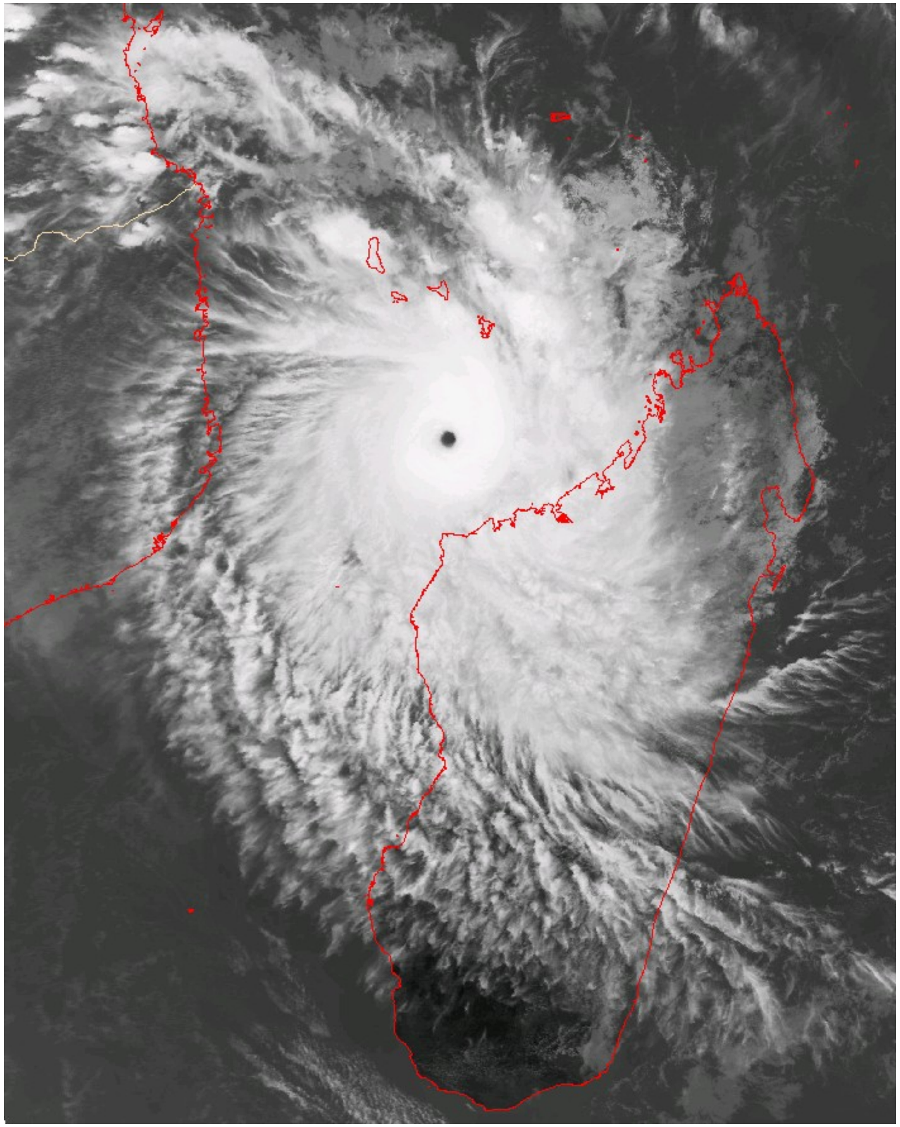
- CIMSS :



TC intensity
Upper divergence

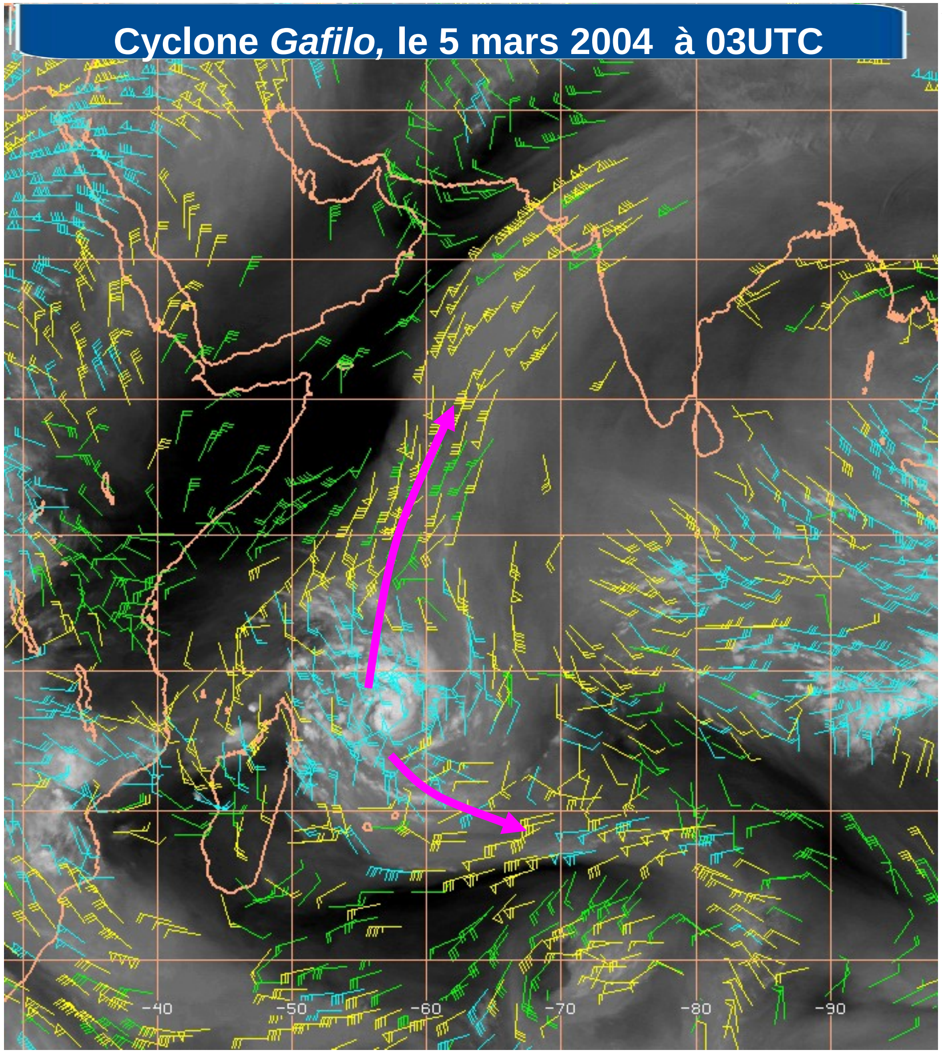
- Accelerates the secondary circulation
  → More efficiency

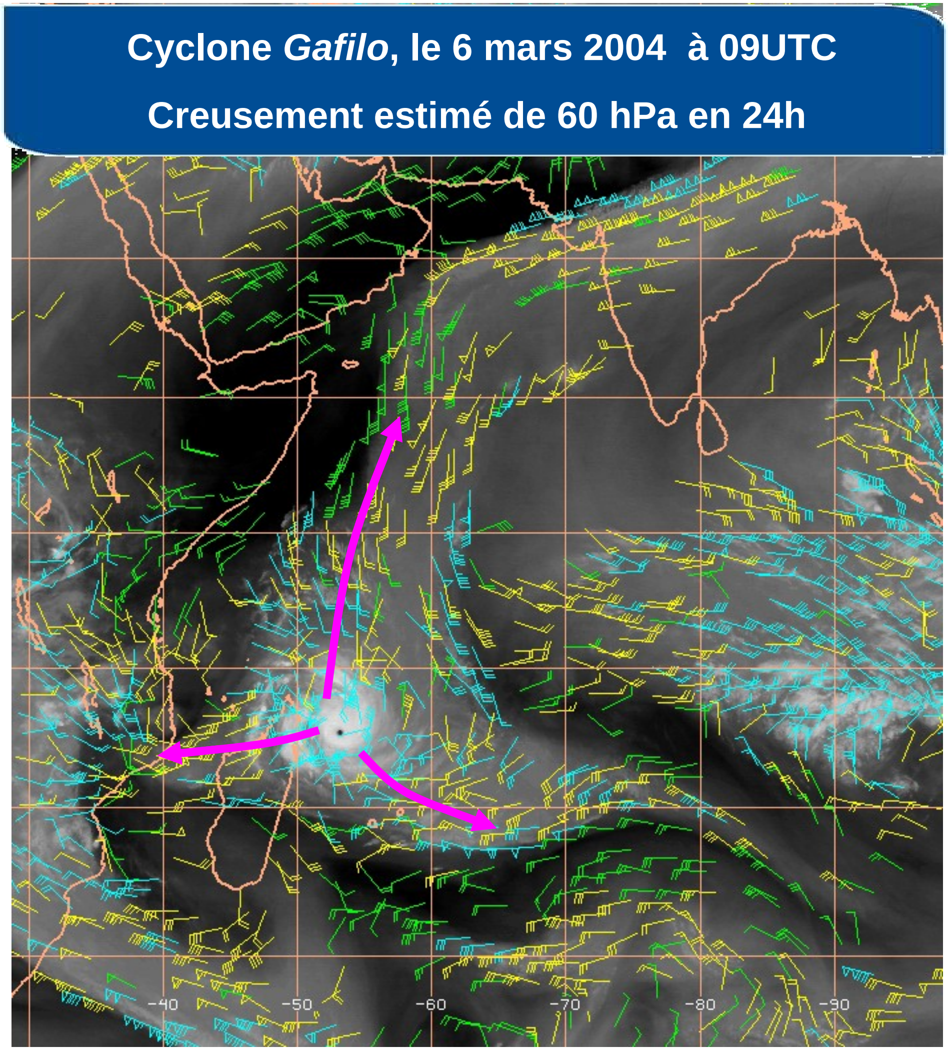




TC intensity
Upper divergence

- Outflow channels (Troughs, Jets…)

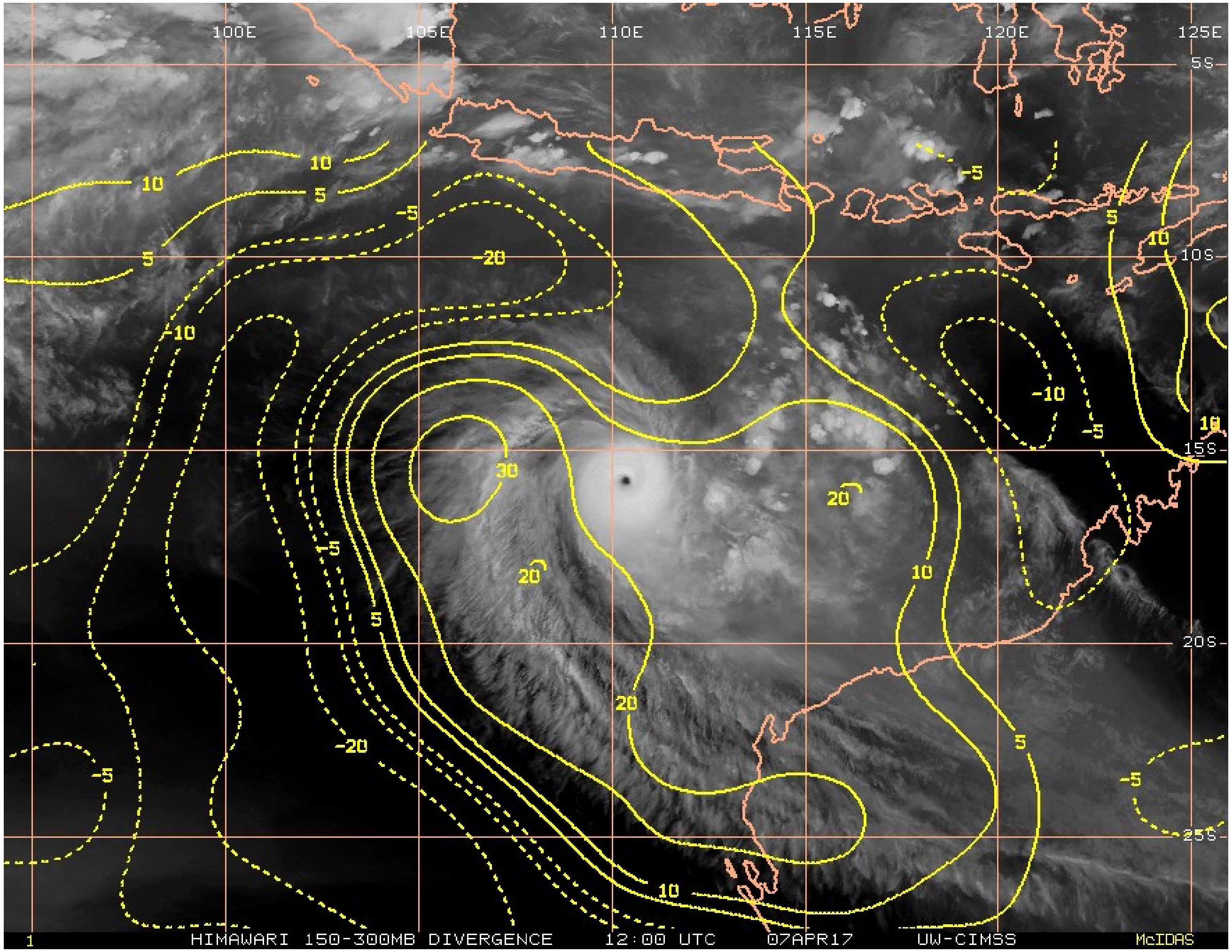




TC intensity
Upper divergence

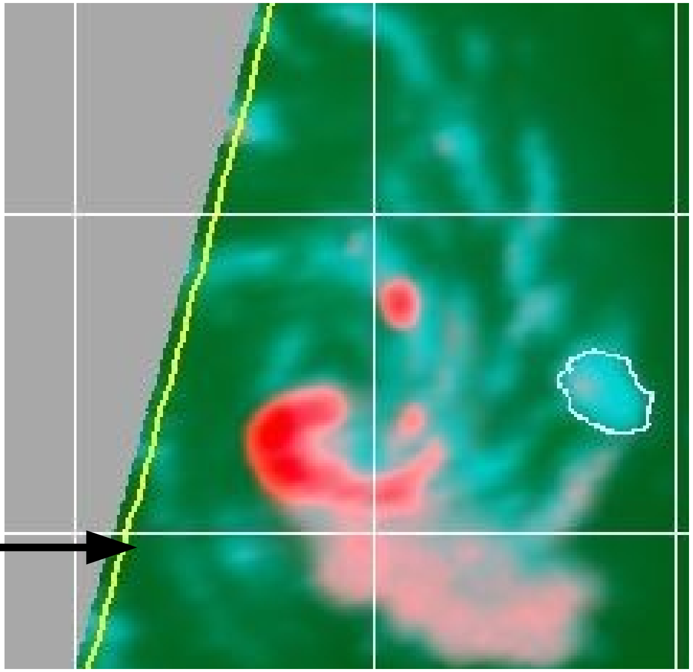
- CIMSS :

Ernie (2017)



TC intensity
Rapid Intensification (RI)

- Usual variations : +1.0 Dvorak T number in 24h :
  — Around 10 to 25kt
- Rapid Intensification (RI) :
  — +30kt en 24h
- Conducive conditions :
  — Small size
  — Rapid environmental changes
- Inner core processes :
  — Hot tower near the RMW
    - Carlos (2017), +38kt in 36h
- Detection : Microwaves



Des questions ?? / Any questions ??