Parameters driving the intensity of Tropical Cyclones

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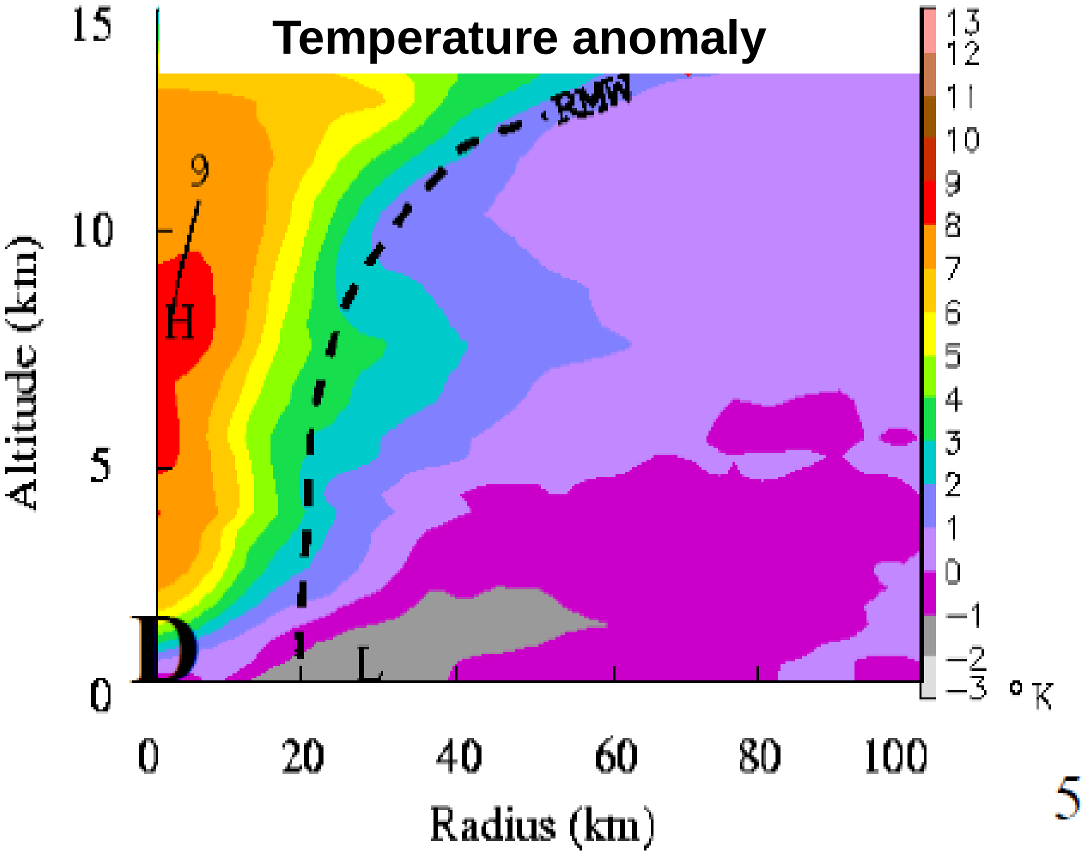
RA I Training Course on Tropical Cyclones – 11th session
September 2023

Warm core



Minimal central pressure (MSLP) is directly related to the warm temperature anomaly above. With the hydrostatic assumption → the pressure represents the weight of the atmosphere above

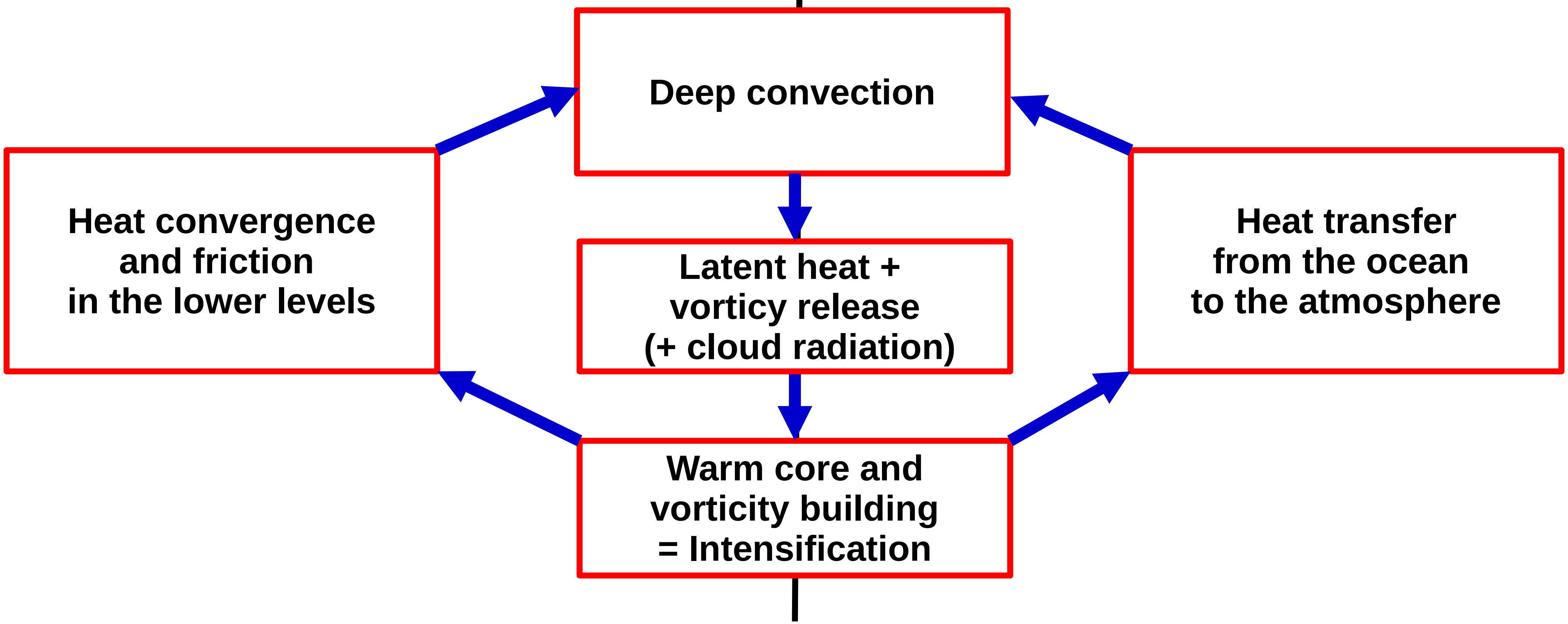
$$P_{sea} = P_{top} + \int_{sea}^{top} \rho(z)\, g\, dz$$

This anomaly is created by the release of latent heat in the deep convection and subsidence in upper troposphere

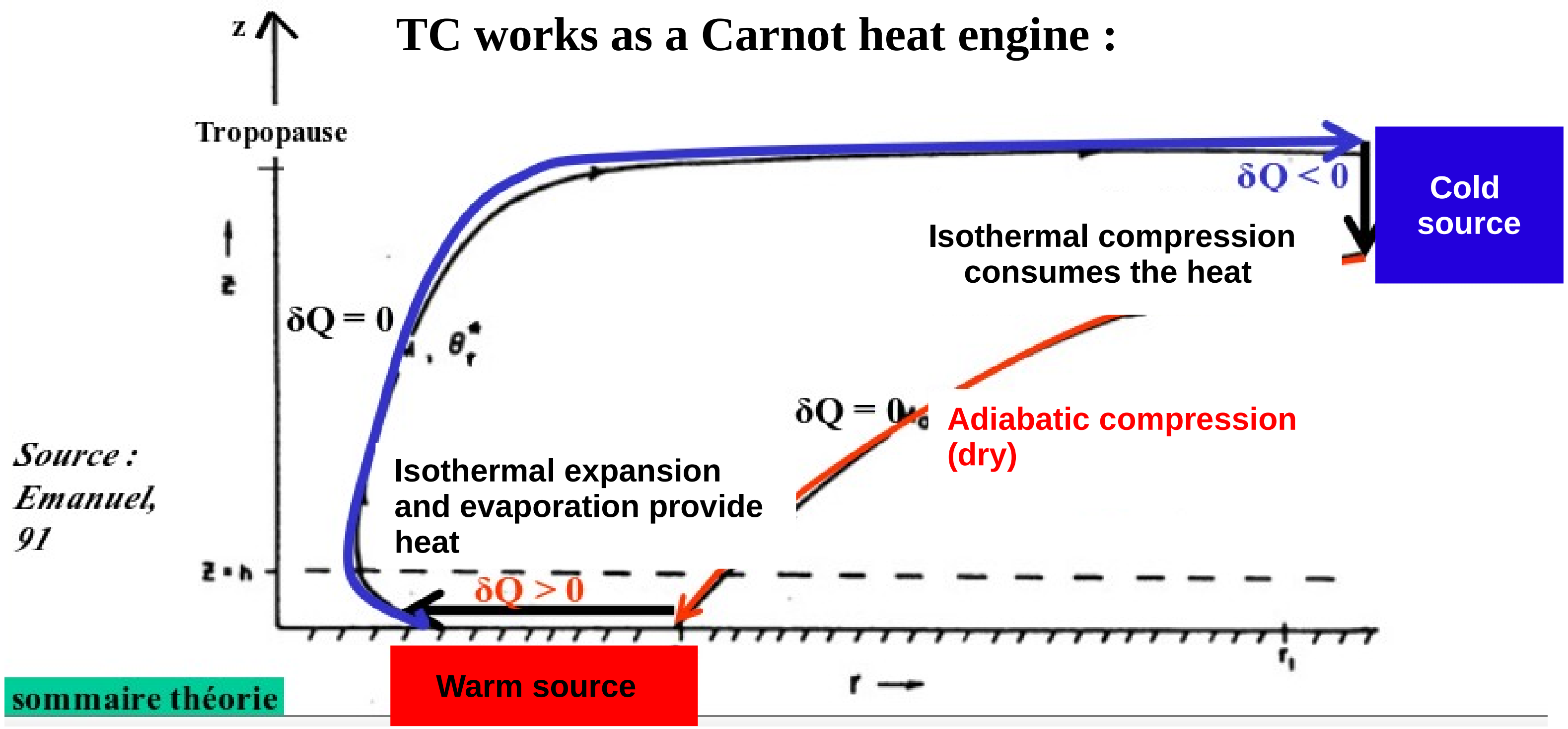
What drives TCs ?

CISK
Conditional Instability of the Second Kind
Driver : friction

WISHE
Wind-Induced Surface Heat Exchange
Driver : ocean



Cyclone = Heat engine



TC transfers heat from the ocean to the upper atmospher producing a side work : the wind

The efficiency of such a heat engine is given by :

$$e = 1 - \frac{T_{froide}}{T_{chaude}} = 1 - \frac{T_{Tropo}}{SST}$$

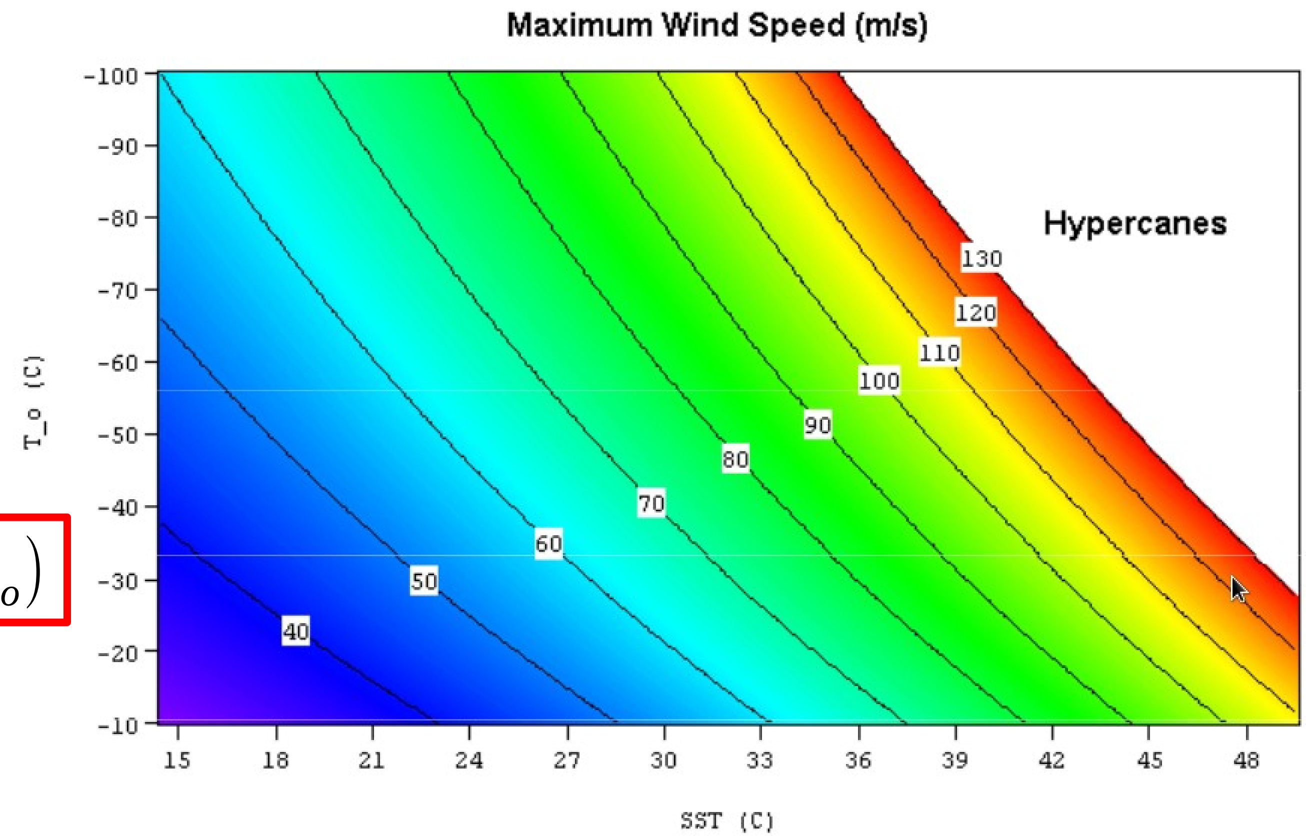
1. Oceanic parameters

Theoretical Maximum Potential Intensity (MPI)

$$V_{maxpot}^{2} \sim SST\, e \left[\frac{C_k}{C_d} \left(s_0^{*} - s_b \right) \right]$$

Parameters related to the exchanges of heat/energy in the boundary layer

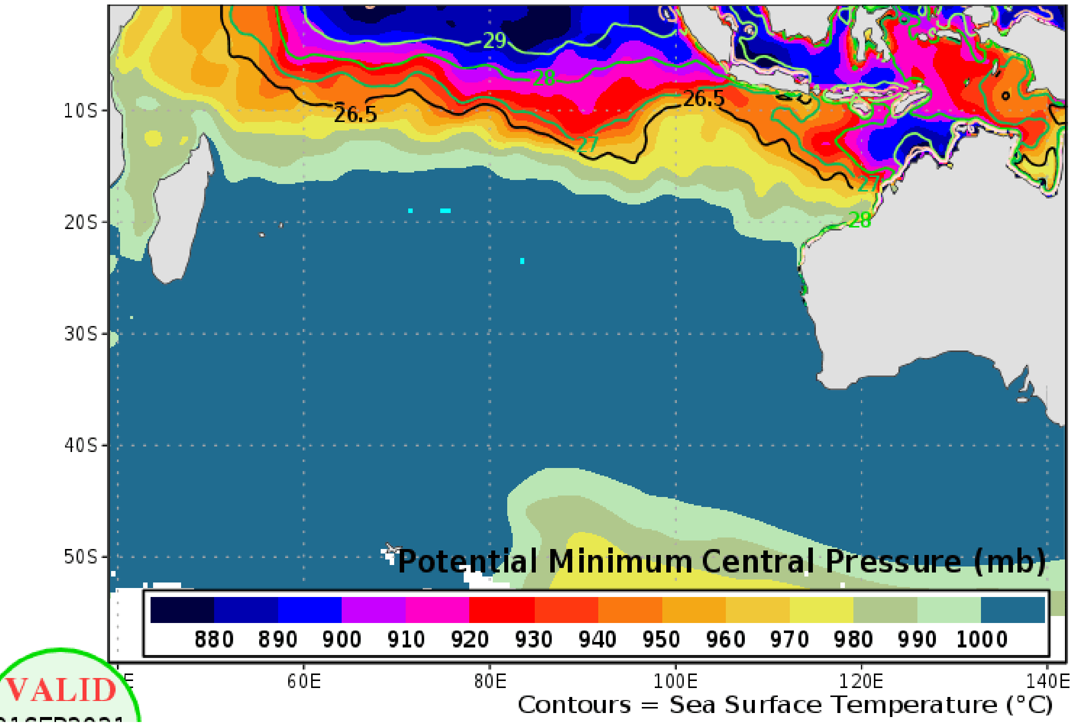
$$MPI = V_{maxpot}^{2} \sim \left(SST - T_{tropo} \right)$$

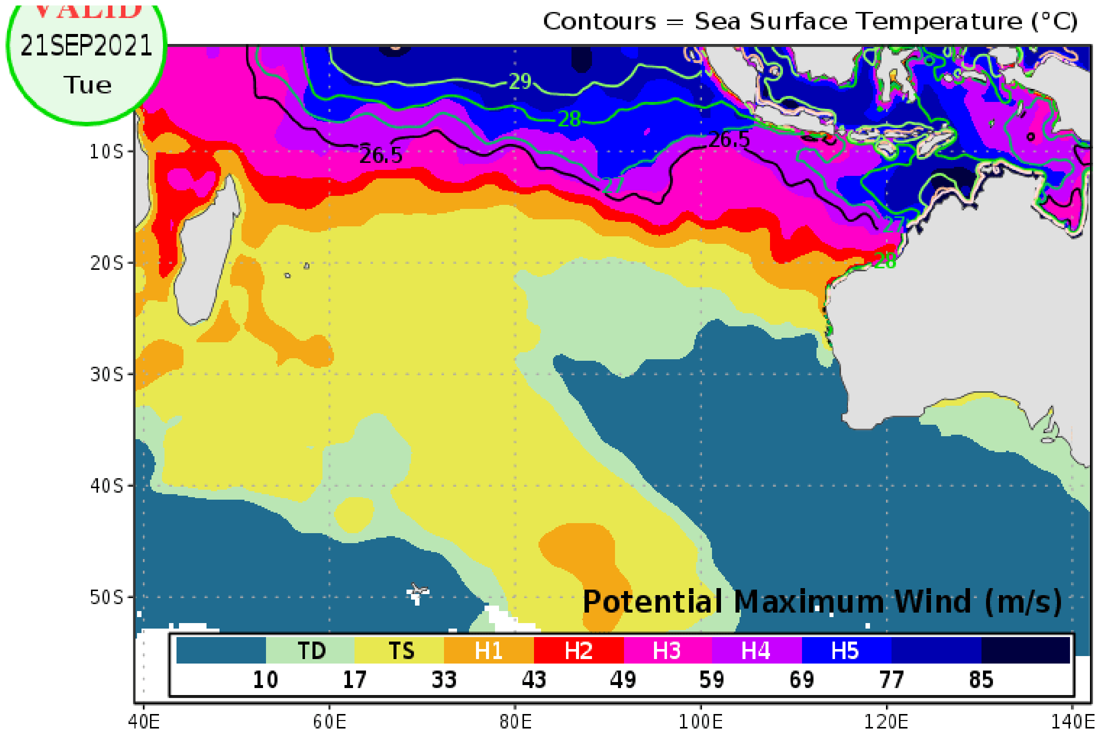


Sea Surface Temperature (SST) is a major factor driving the potential intensity a tropical cyclone can reach.

Theoretical Maximum Potential Intensity (MPI)

In operations→ http://wxmaps.org/pix/hurpot :

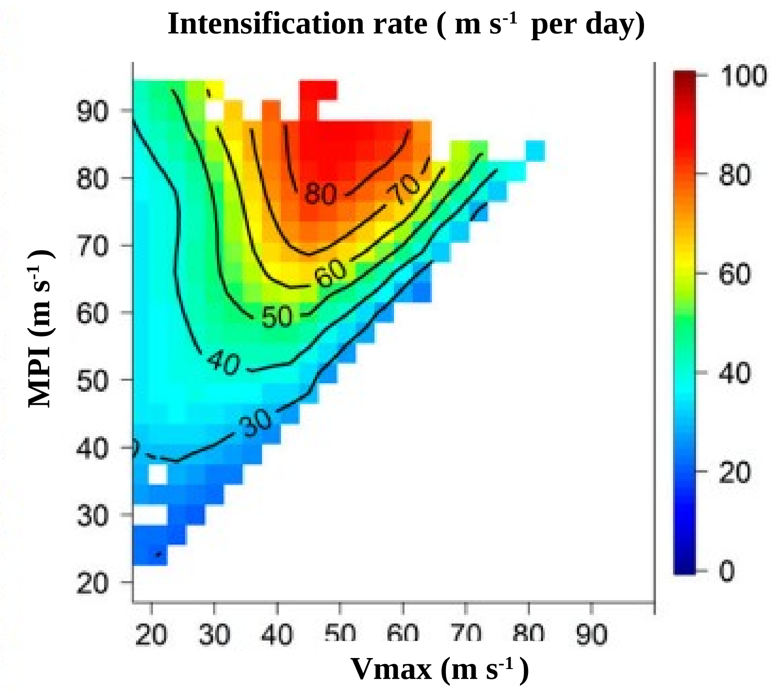


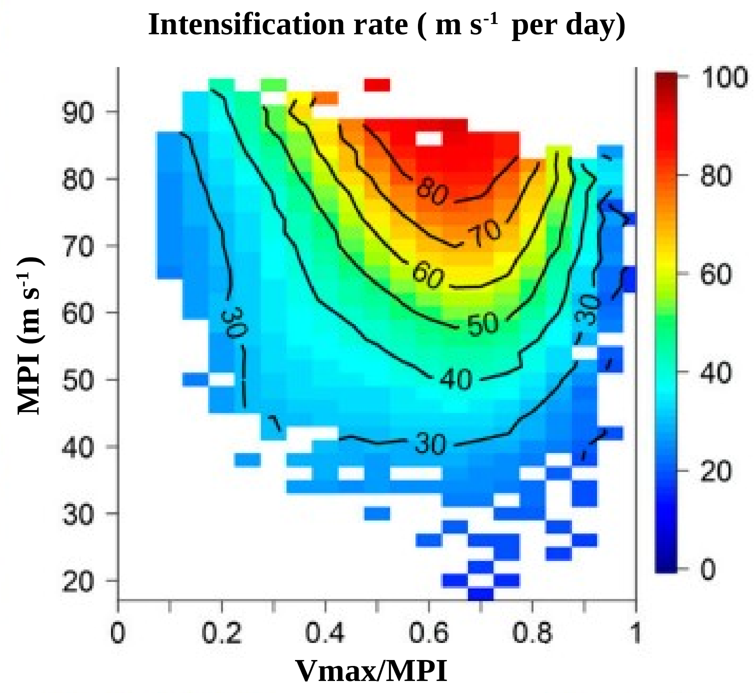


Theoretical Maximum Potential Intensity (MPI)

$$\left.\frac{\partial V_{max}}{\partial t}\right|_{maxpot} \sim V_{max}^2\left(\sqrt{\frac{MPI}{V_{max}}}-1\right)$$

According to : A New Time-Dependent Theory on TC Intensification (Wang et al. 2021)





Sea Surface Temperature (SST) is a major factor driving the intensification rate a tropical cyclone can reach

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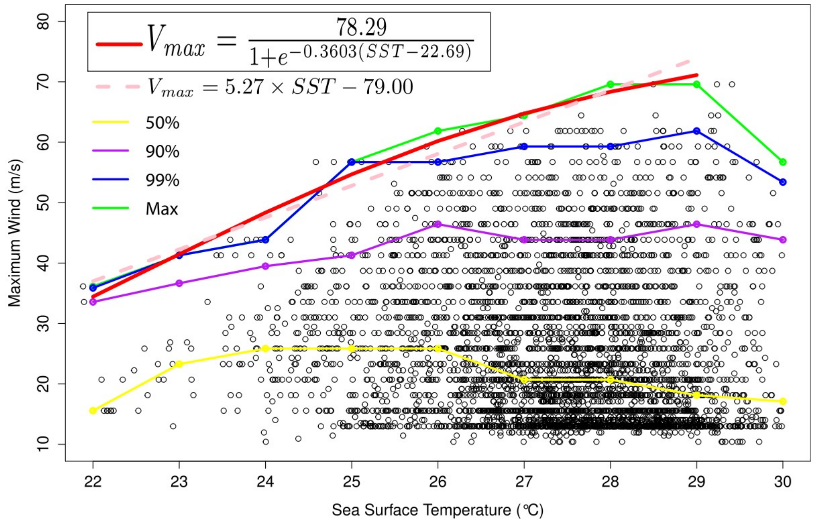
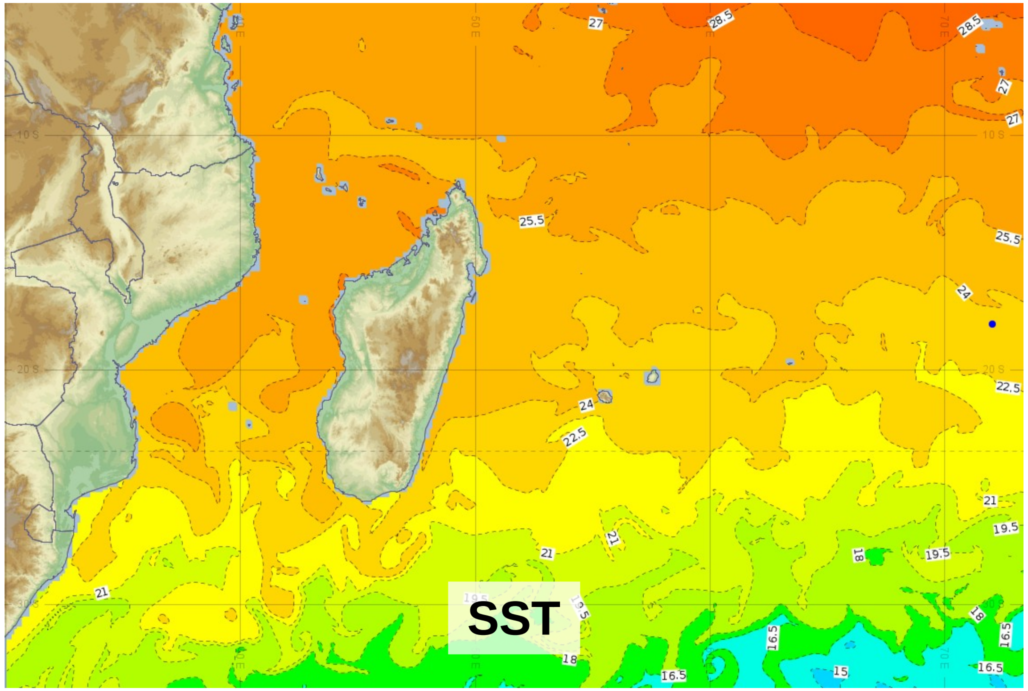
Empirical Maximum Potential Intensity (MPI)

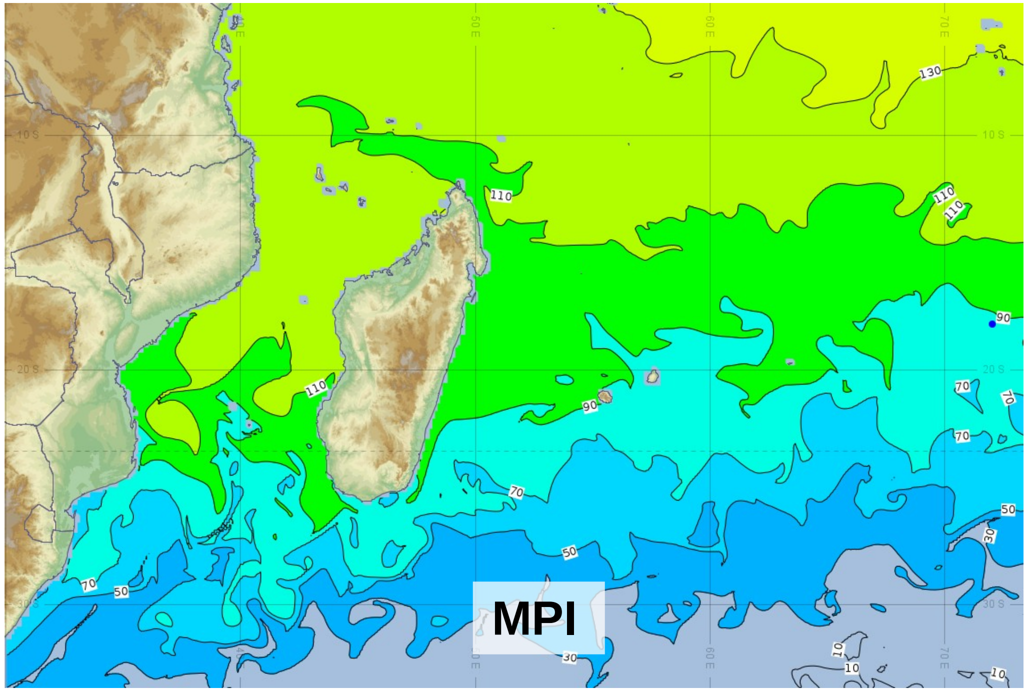


Empirical MPI (*M-D Leroux 2018*) :

$$MPI_{empirical}(m/s) = \frac{78.29}{1+e^{-0.3603(SST-22.69)}}$$

26°C → 117 kt (nearly a VITC)



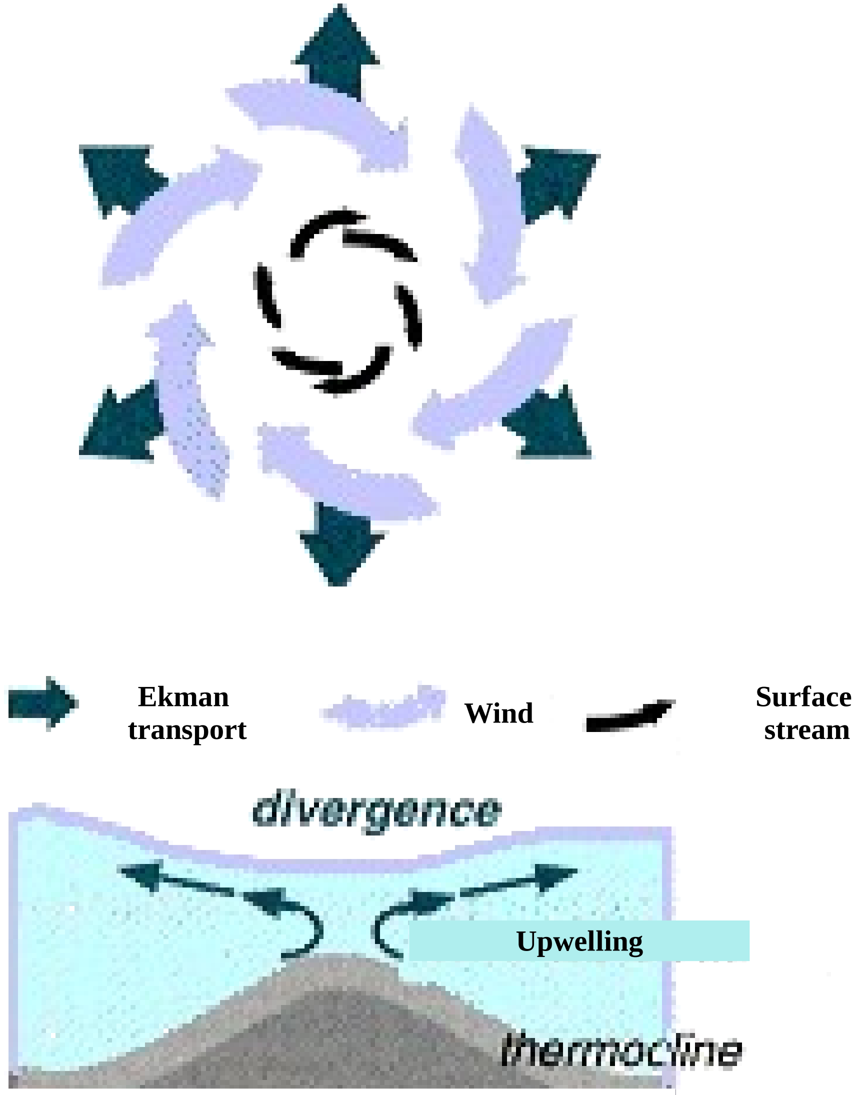


Induced water cooling

Heat transfer only represents **20 %** of the SST decay after a TC

Main explaination :
Ekman pumping and mixing

→ Need to consider also the temperature a few meters below surface



Ekman Pumping

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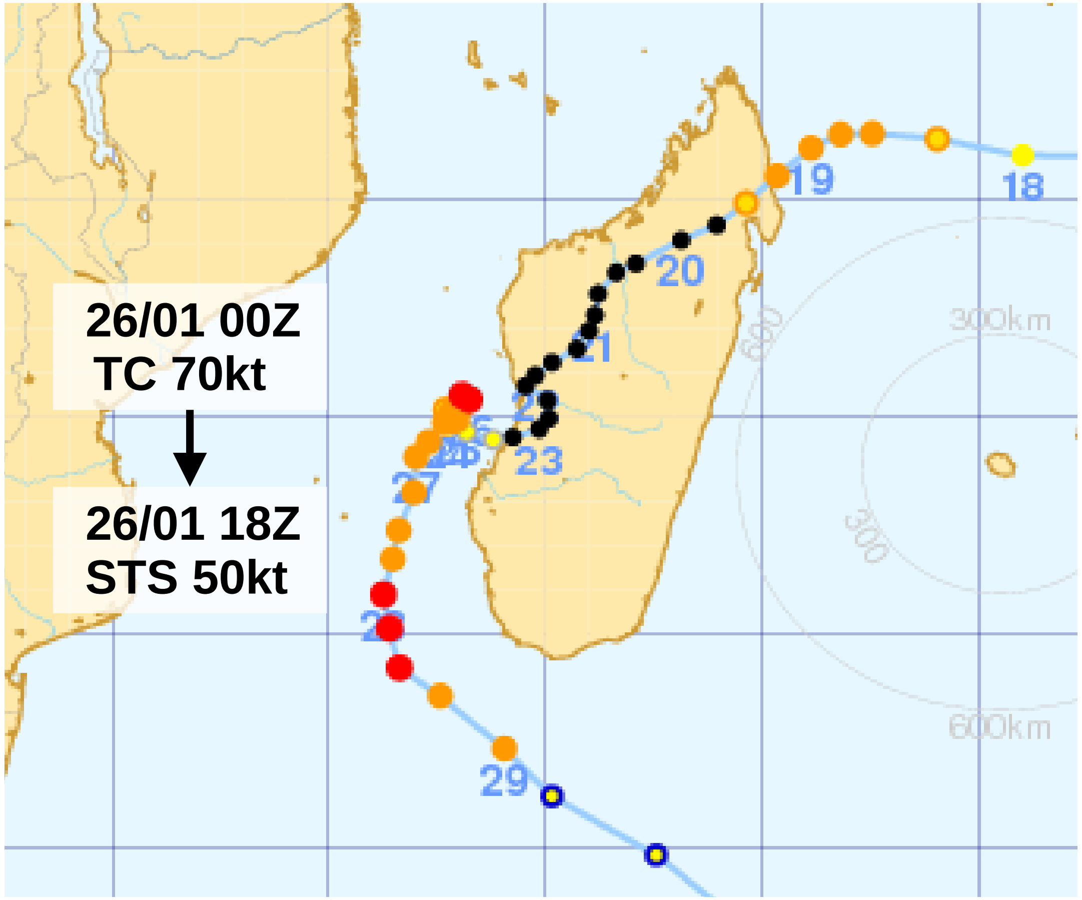
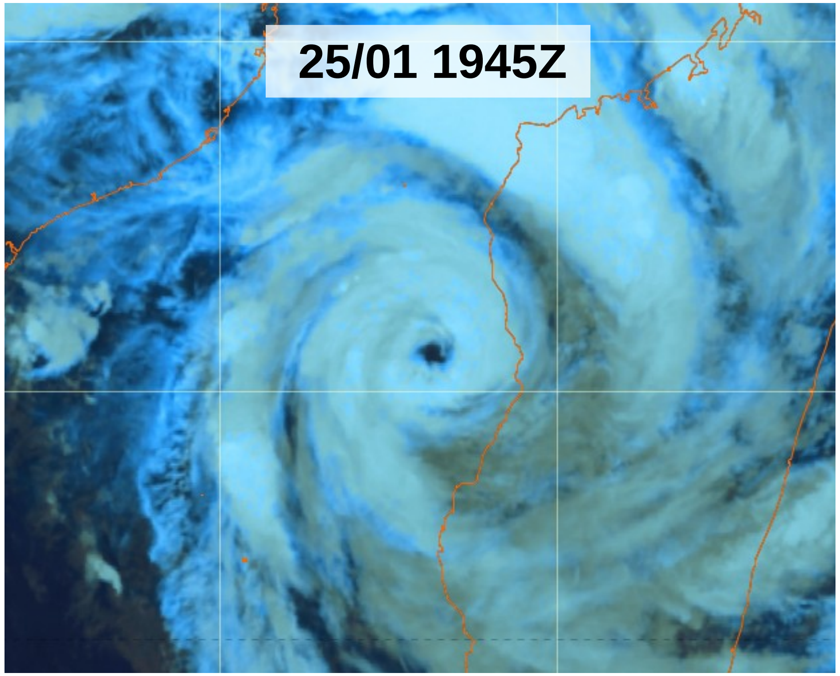
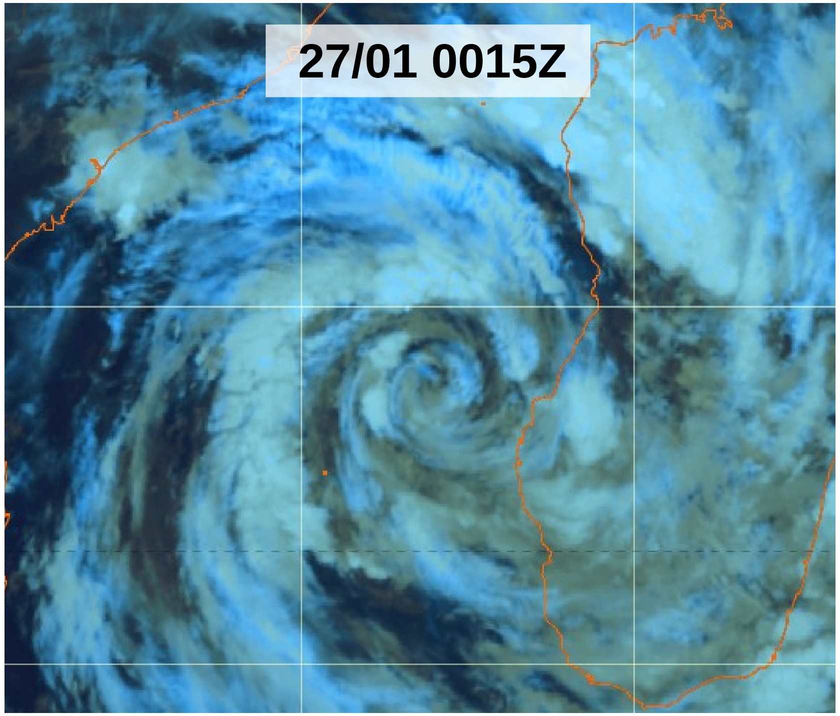
Induced water cooling

CHENESO

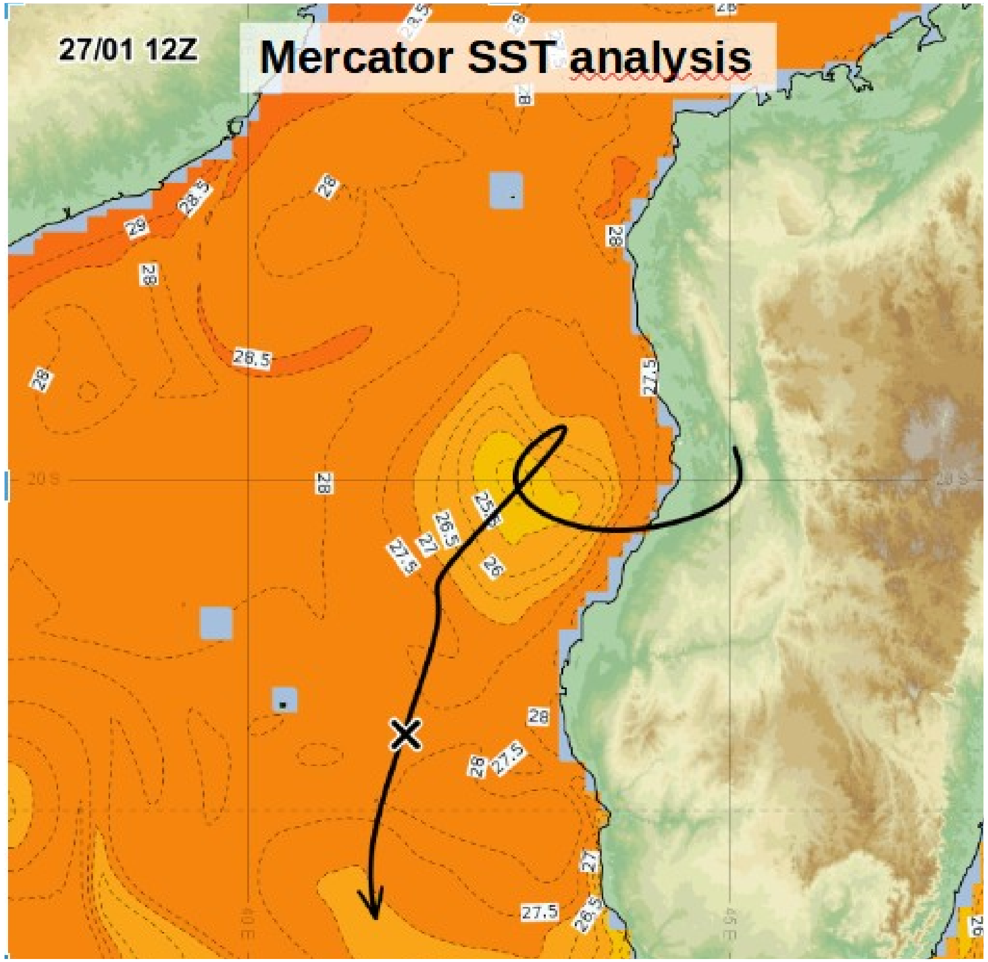


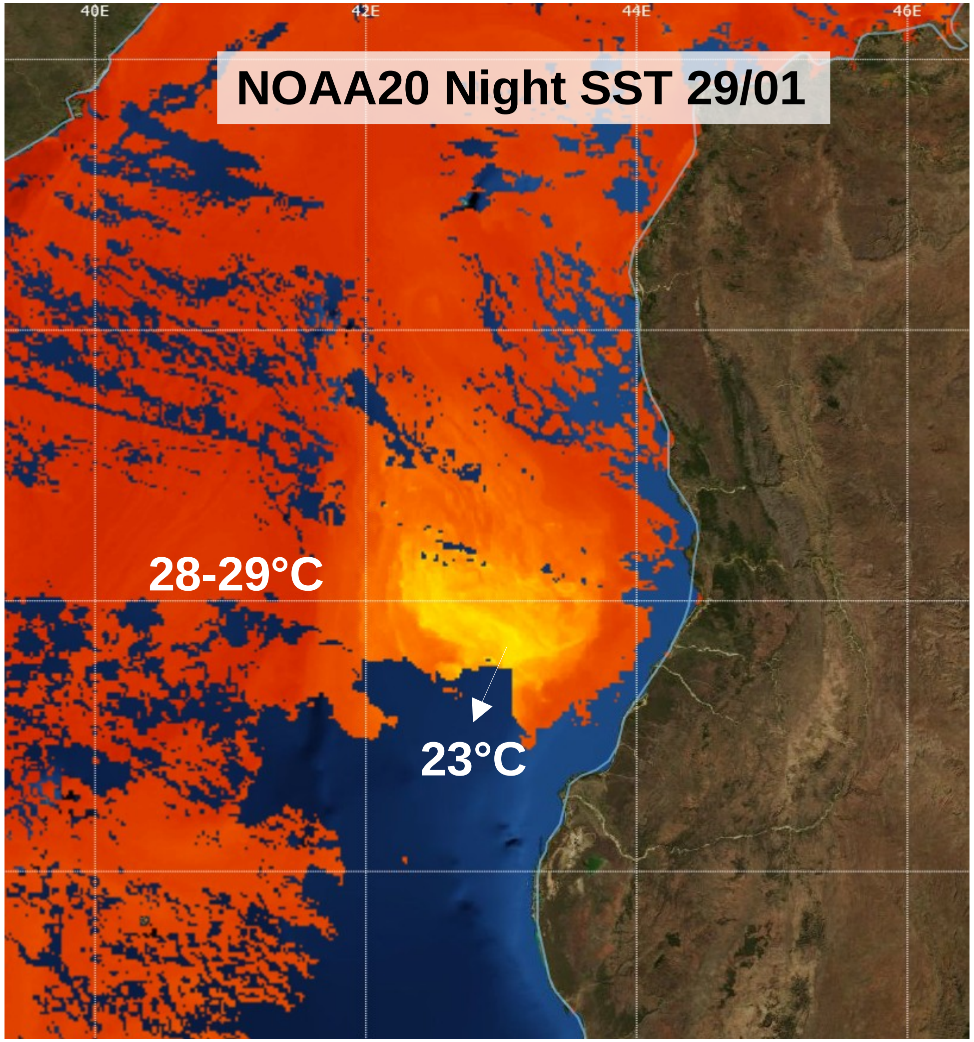




Induced water cooling

CHENESO





SST change → Probably at least 5 °C decay in 24/48h

Oceanic parameters – In operations

Necessary but rarely a limiting factor in tropics

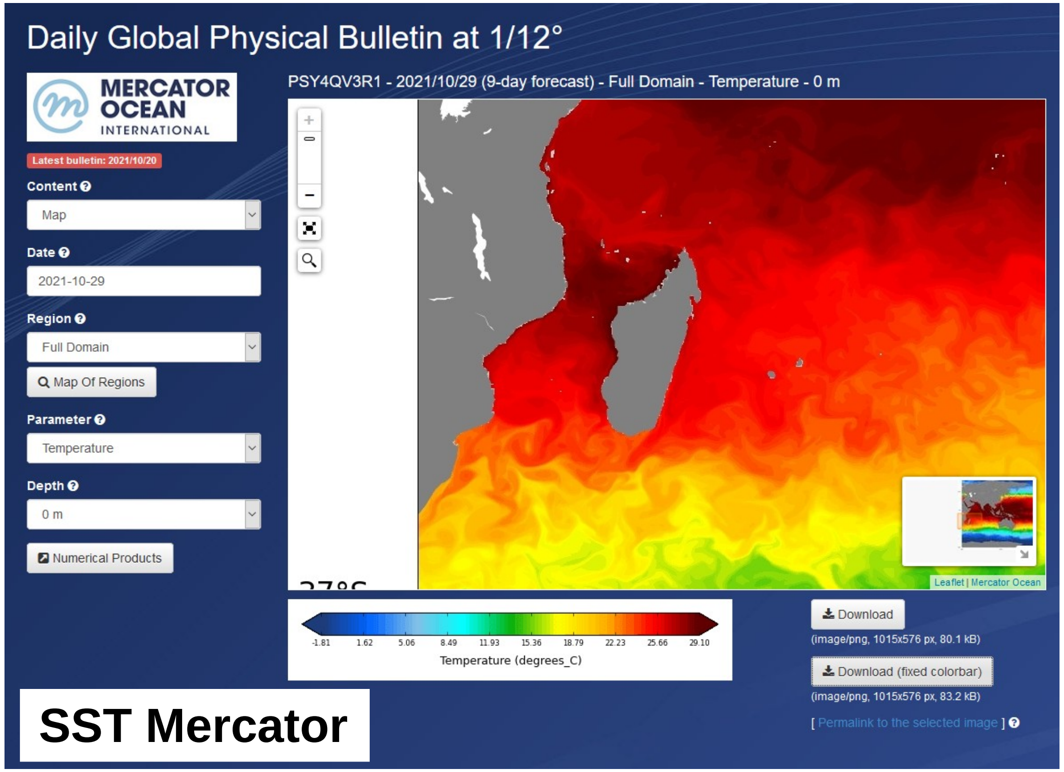
Most important parameters : **SST** and **TCHP**

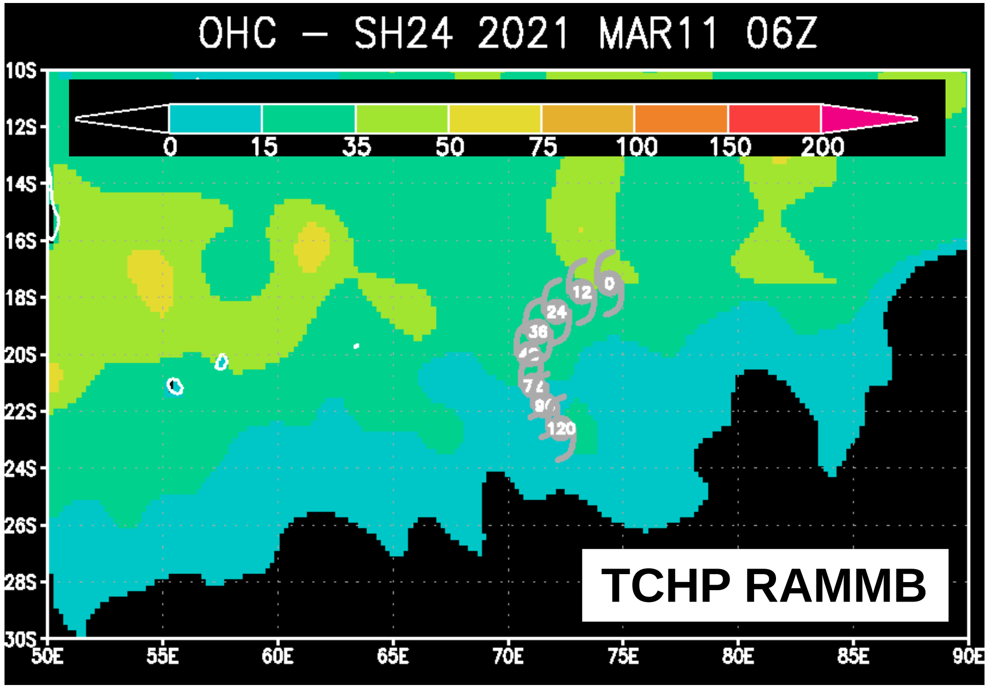
– Tropical Cyclone Heat Potential : Integrated heat content between 0°C and the 26°C isotherm

Websites :

– Mercator (Temperature at 0m and 30m) http://bulletin.mercator-ocean.fr/en/PSY4

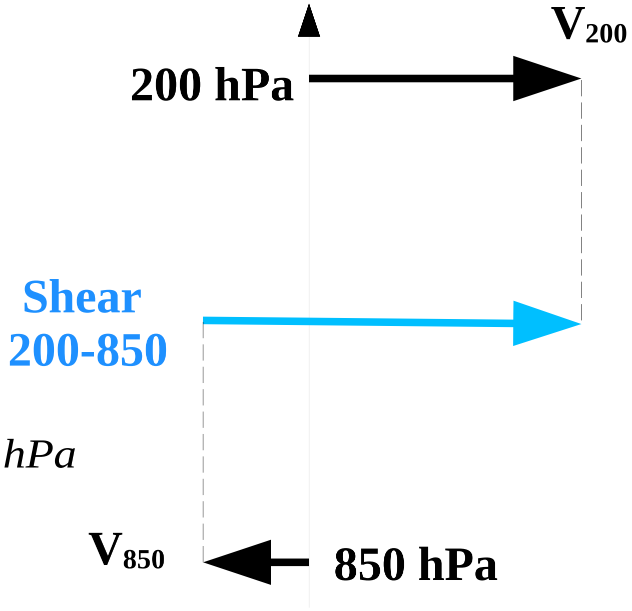
– RAMMB CIRA / NOAA (TCHP) https://rammb-data.cira.colostate.edu/tc_realtime/





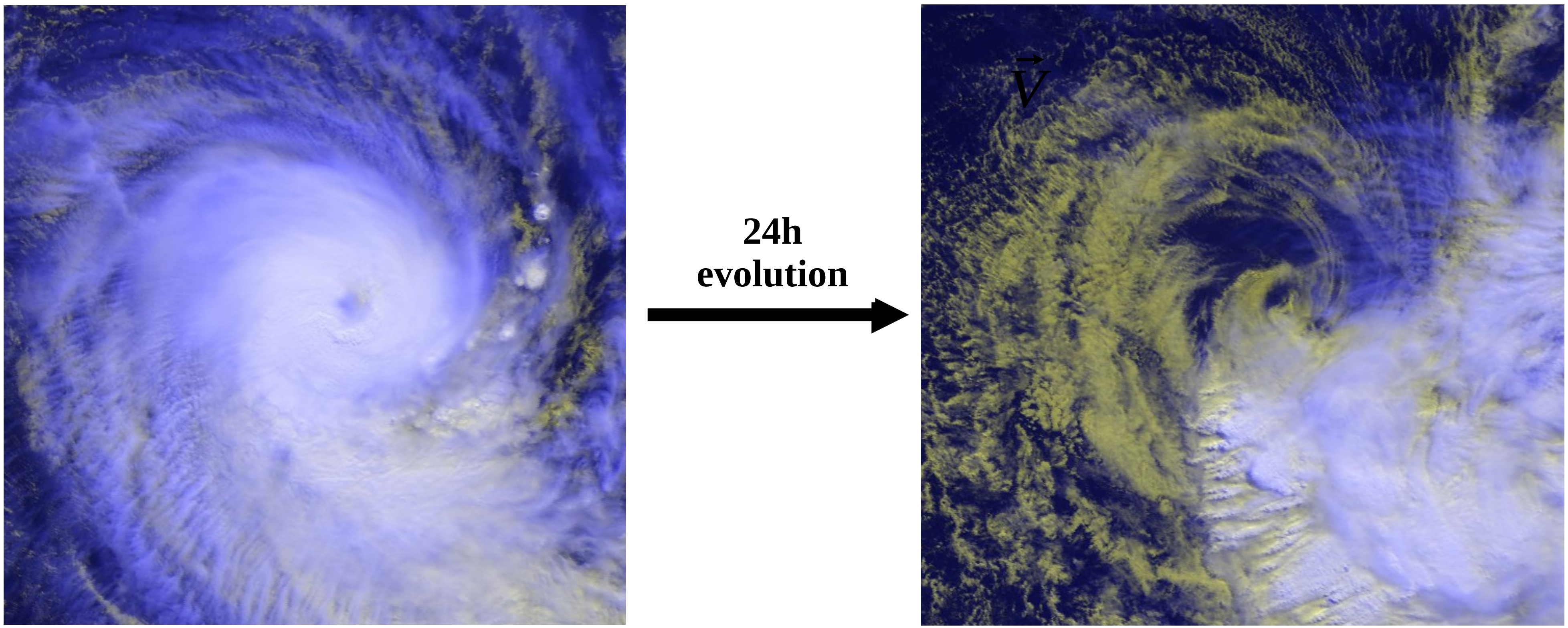
2. Atmospheric parameters

Vertical Wind Shear



Wind difference $\vec{V}_{upper} - \vec{V}_{lower}$, souvent $\vec{V}_{200\ hPa} - \vec{V}_{850\ hPa}$

- Example : TC Lorna in 2019, 30kt NW shear

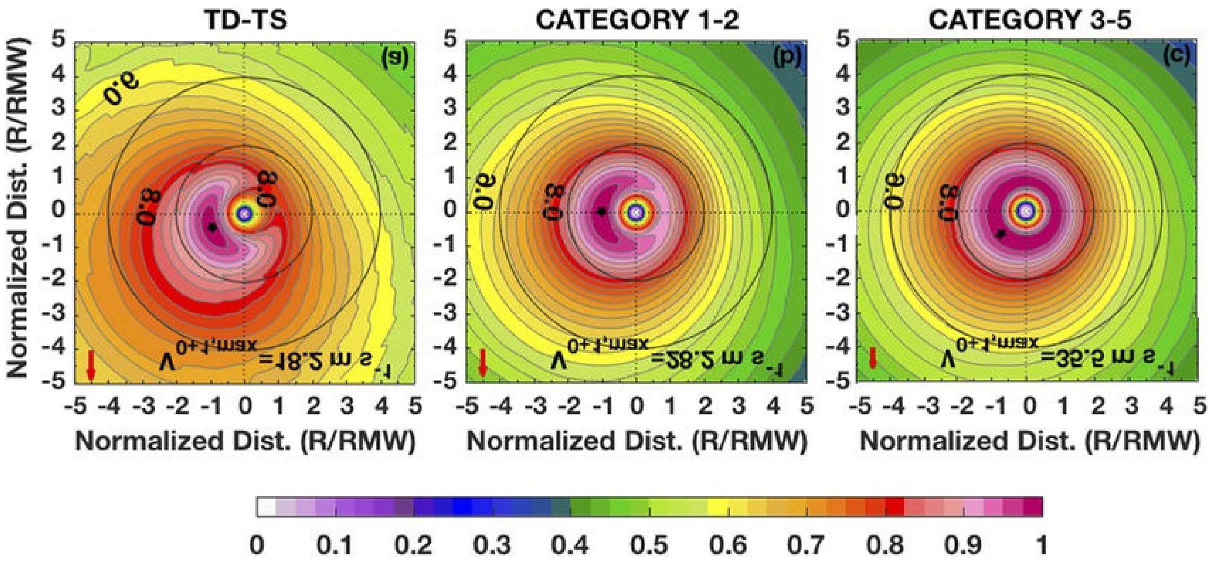


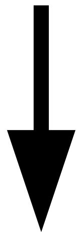
Vertical Wind Shear for mature TCs

1) First consequence of increasing shear : development of asymmetries

- **Maximum Rain/Wind** on the **right** (especially downshear right) of the shear in the **SH**

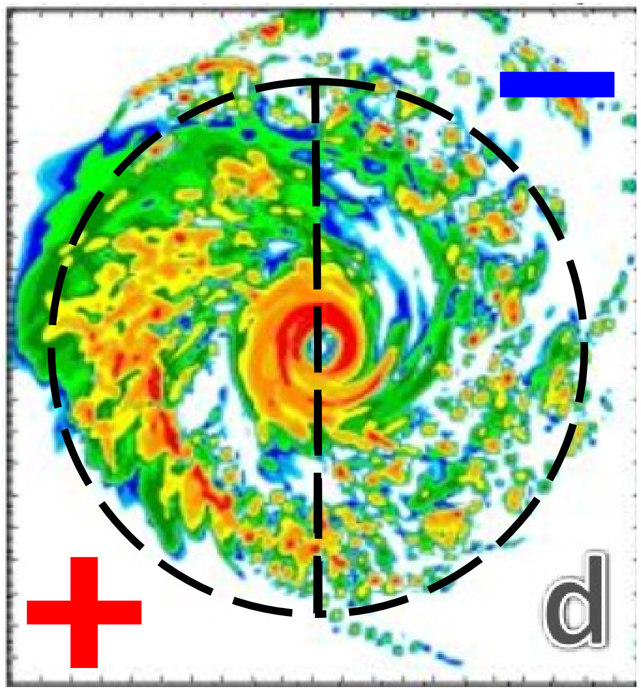
Surface wind





Shear

Precipitations

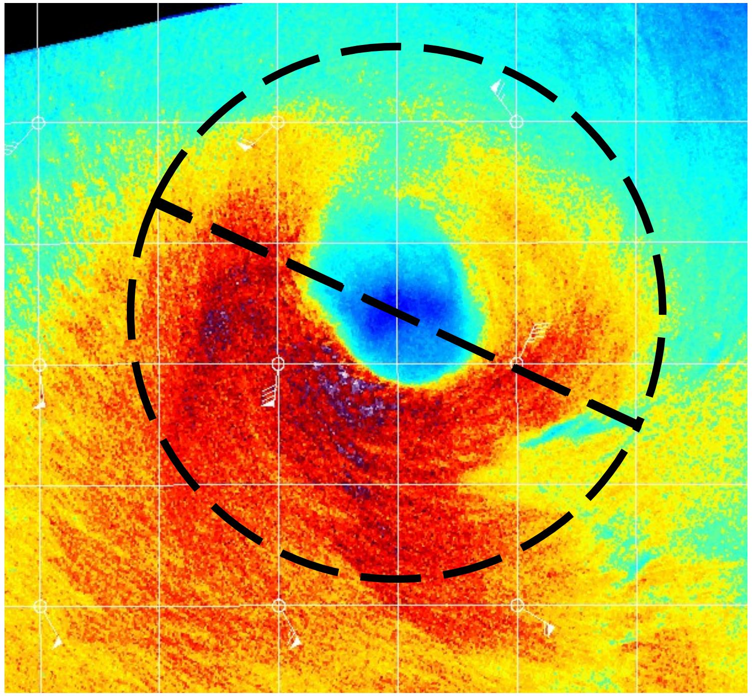


Vertical Wind Shear for mature TCs

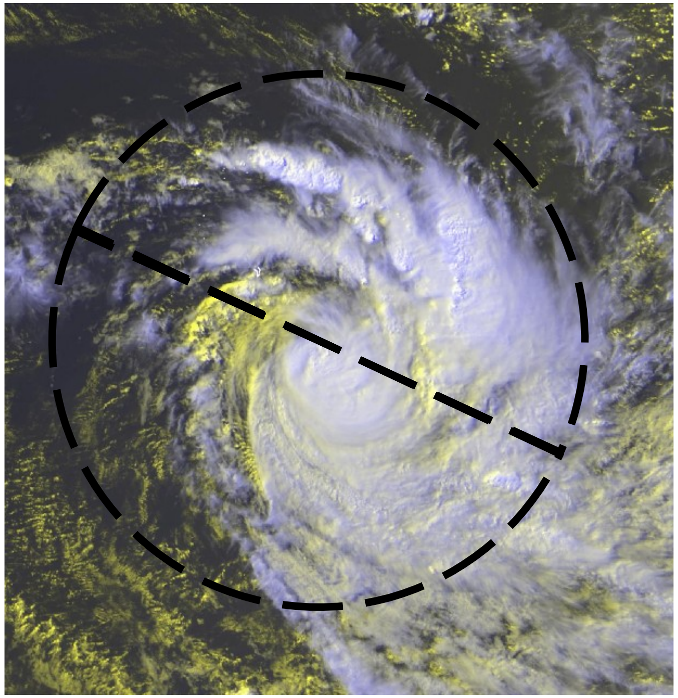
NW Shear

1) Example on TC FABIEN May 2023

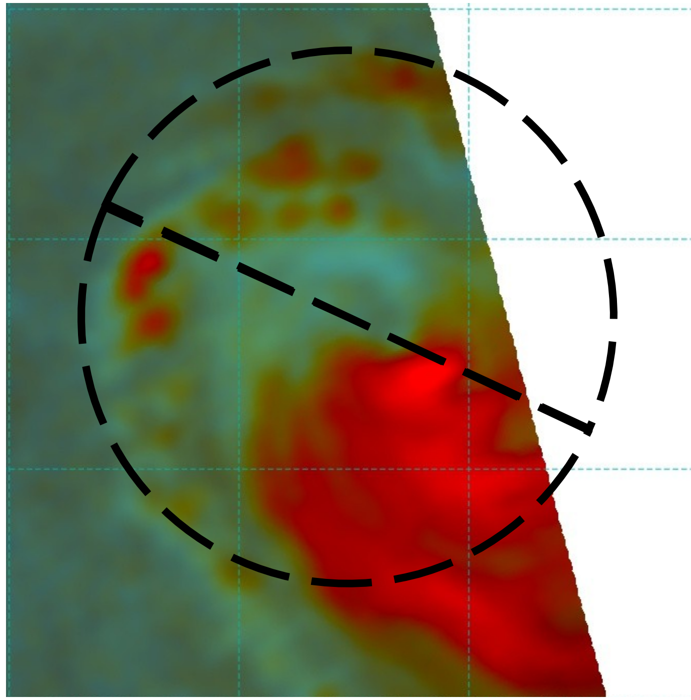
SAR Winds RCM3 17/05 1330Z



MSG2 17/05 11Z



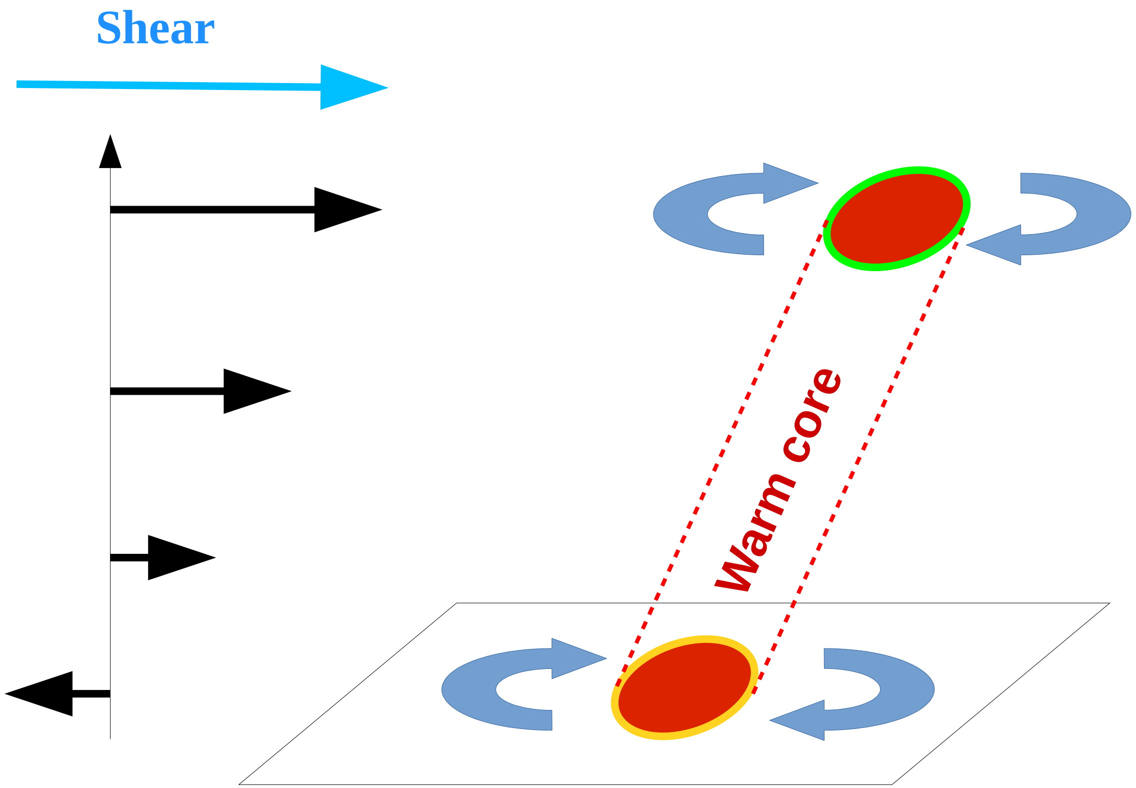
SSMIS F18 17/05 1135Z



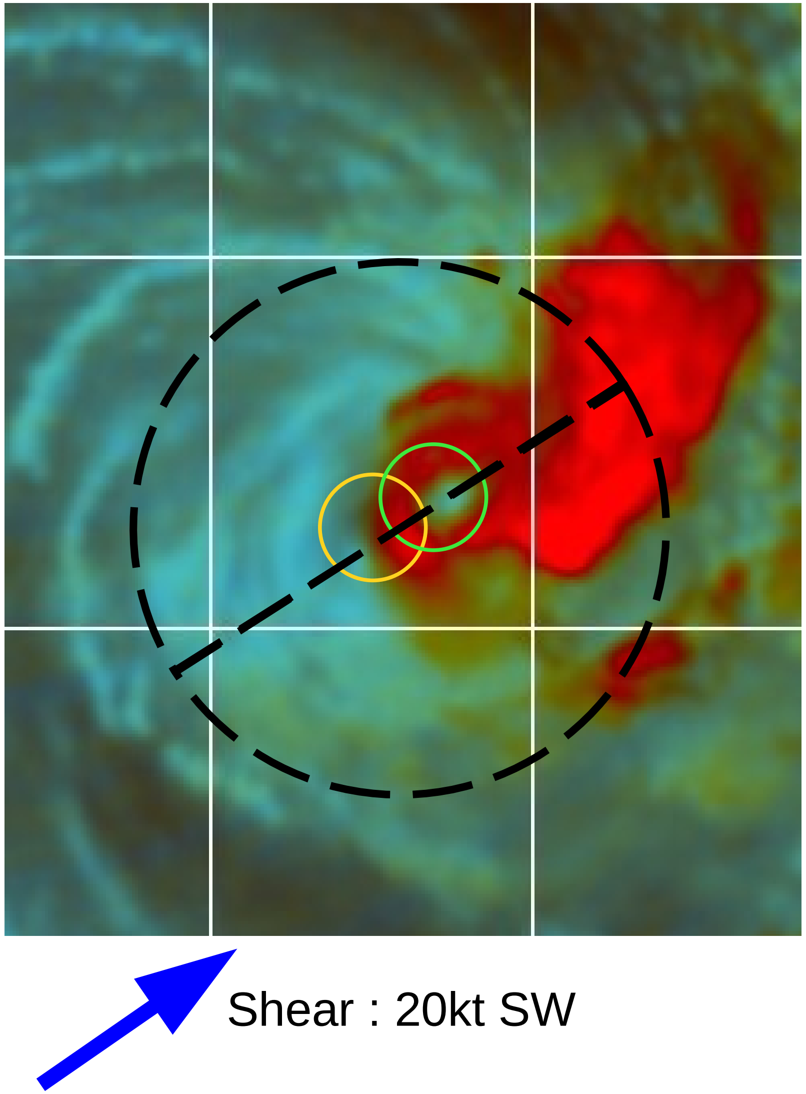
Vertical Wind Shear for mature TCs

2) Second consequence : Tilt

→ Less efficient structure



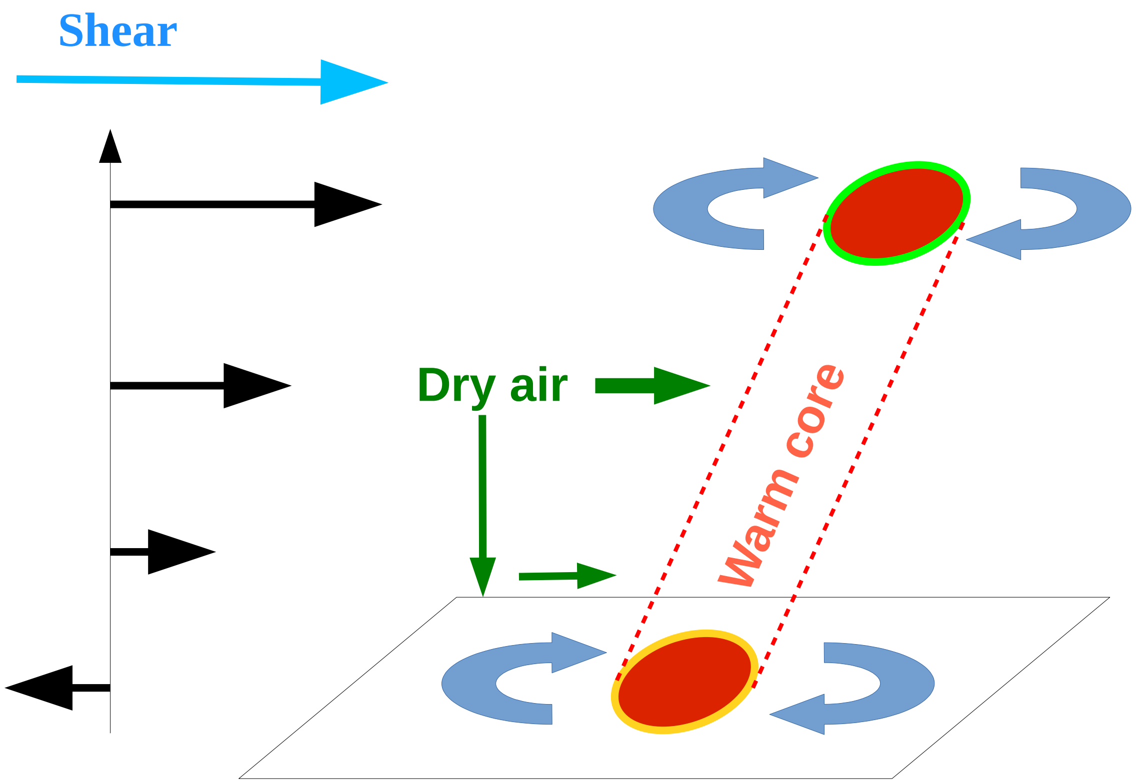
Gelena tilt, 2019



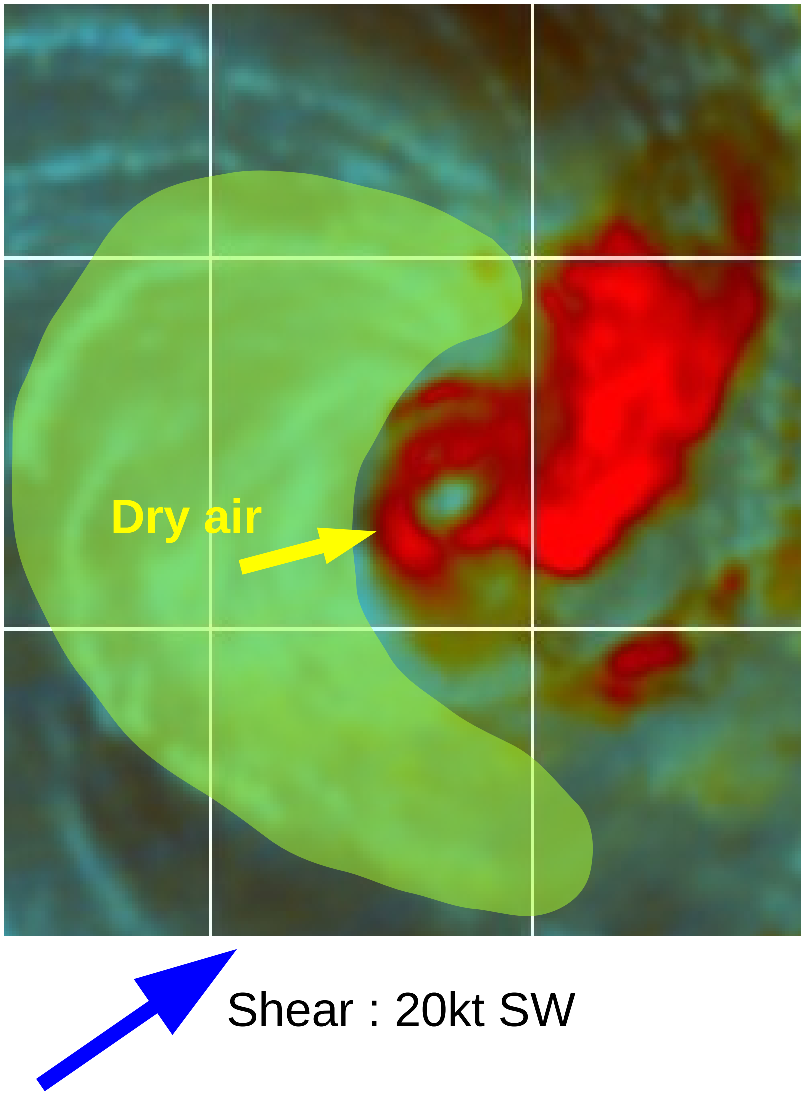
Vertical Wind Shear for mature TCs

3) Third consequence : Dry air entrainment

→ Less instability and energy available



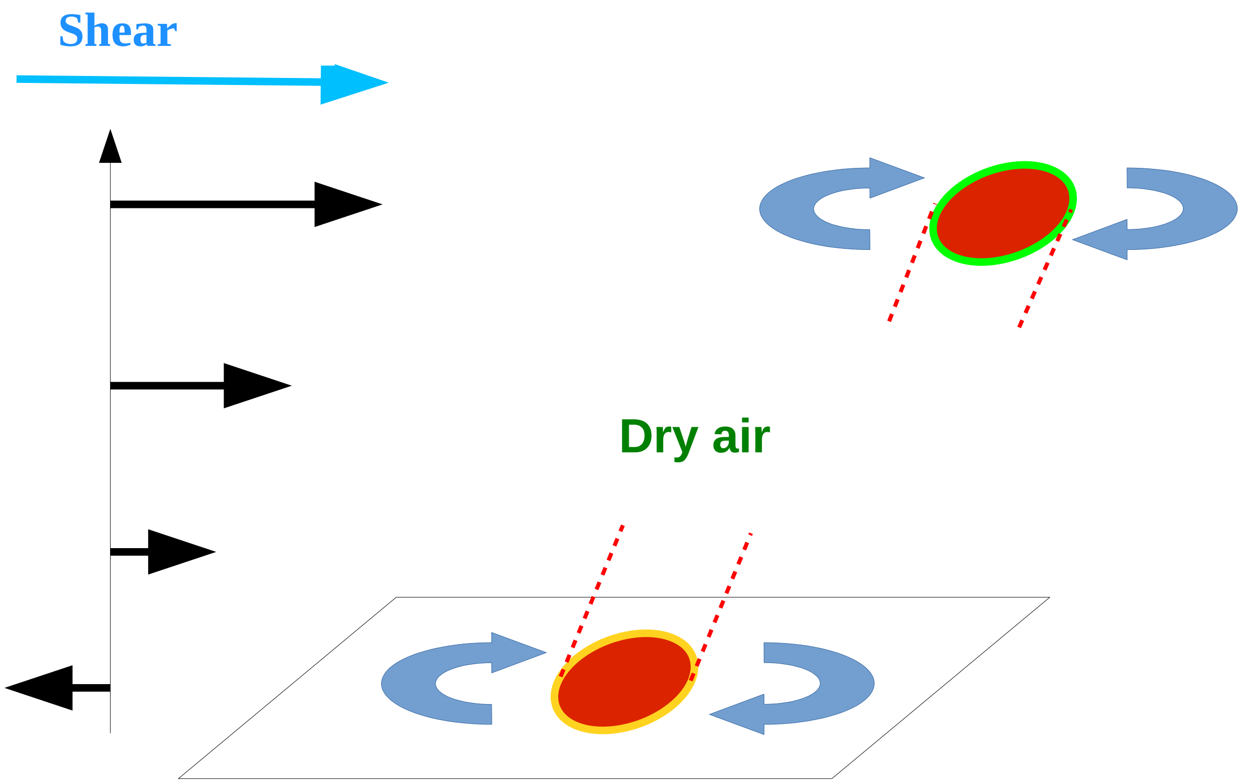
Gelena, 2019

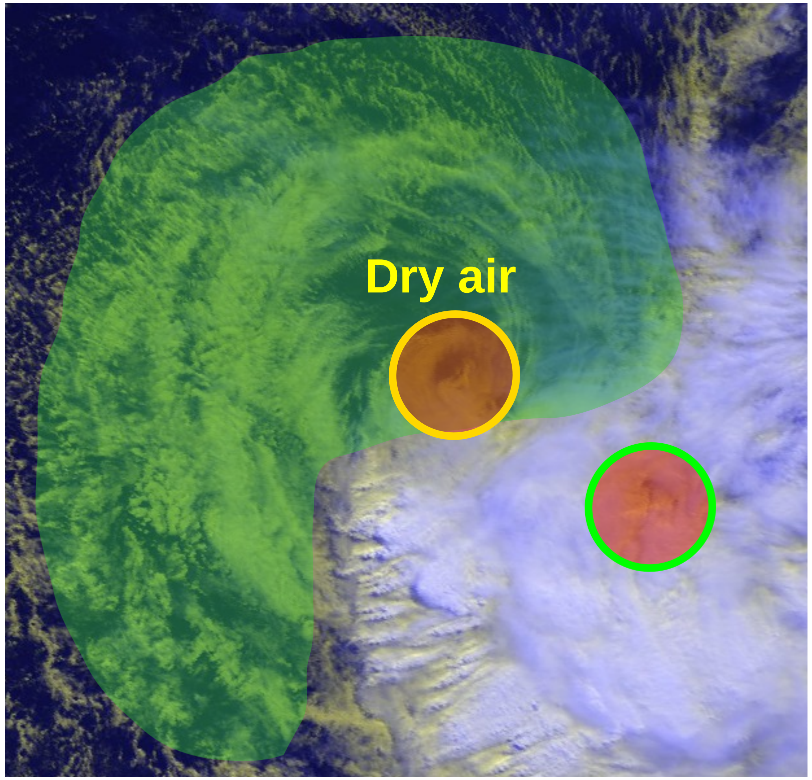


Vertical Wind Shear for mature TCs

4) If the shear is too strong

- Warm core ventilation/disruption → weakening



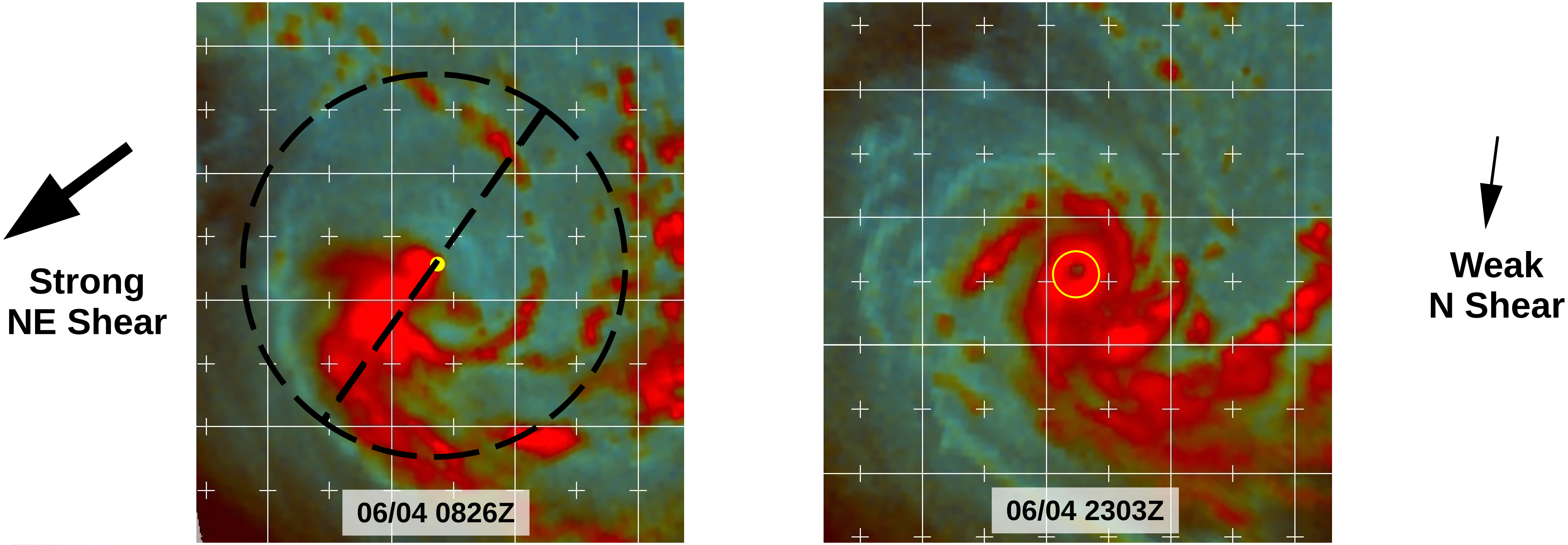


Vortex alignement

On the contrary, decreasing shear is likely to lead to an intensification trough vortex alignment

- Convection increase upshear
- Tilt decrease

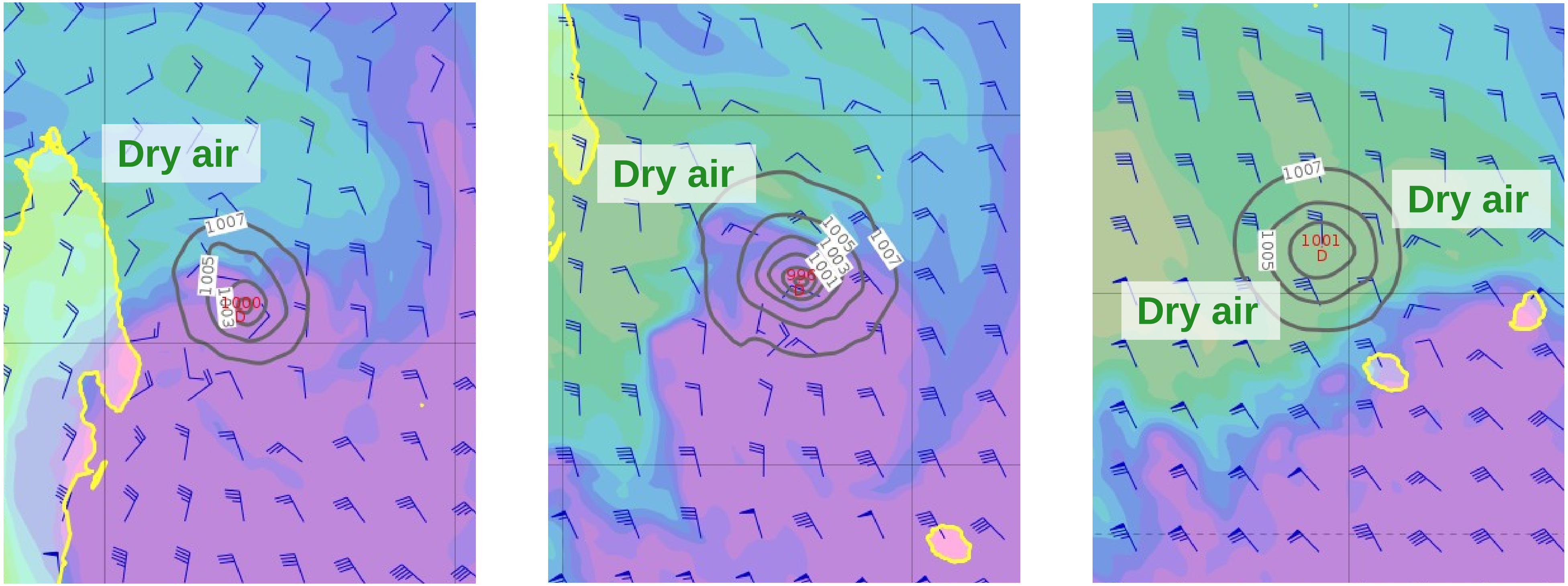
Example : TC ERNIE (South East Indian Ocean) in 2017 (45kt → 120kt in 24h)



Vertical Wind Shear

Complex interaction with TC → But numerical models are quite able to handle the consequences of shear

IFS0.5° - 200 hPa wind + Humidity 500 hPa – 23/04 00Z run

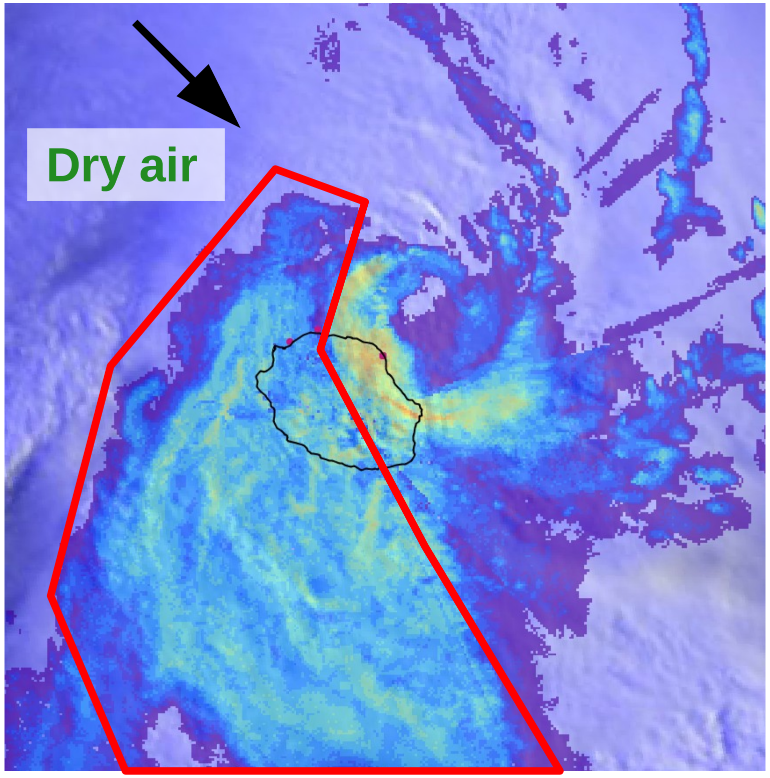


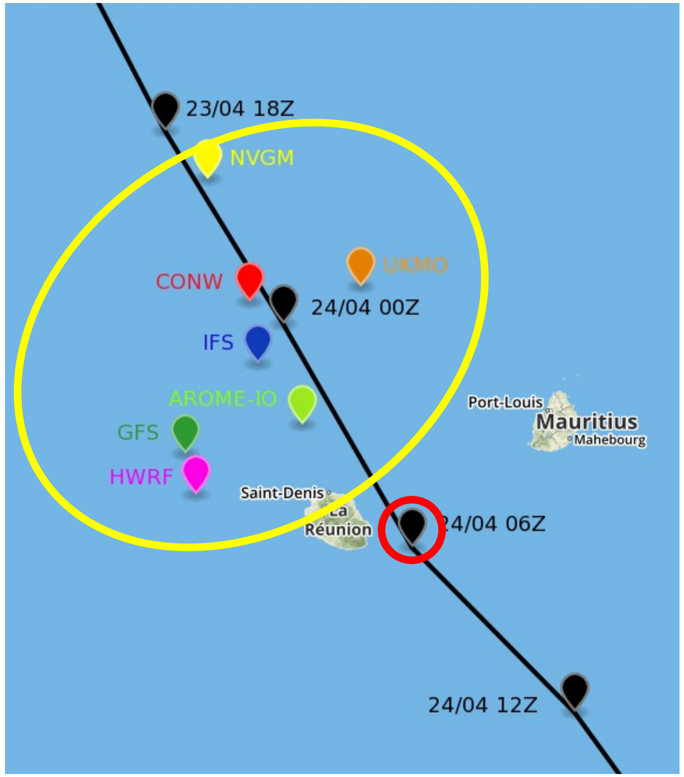
Vertical Wind Shear

But be careful, deep shear (200-850hPa) in not all that matters !

— Importance of the TC motion : FAKIR (April 2018)

- FAKIR was moving at 30 to 42km/h (23kt) in the same direction as the shear

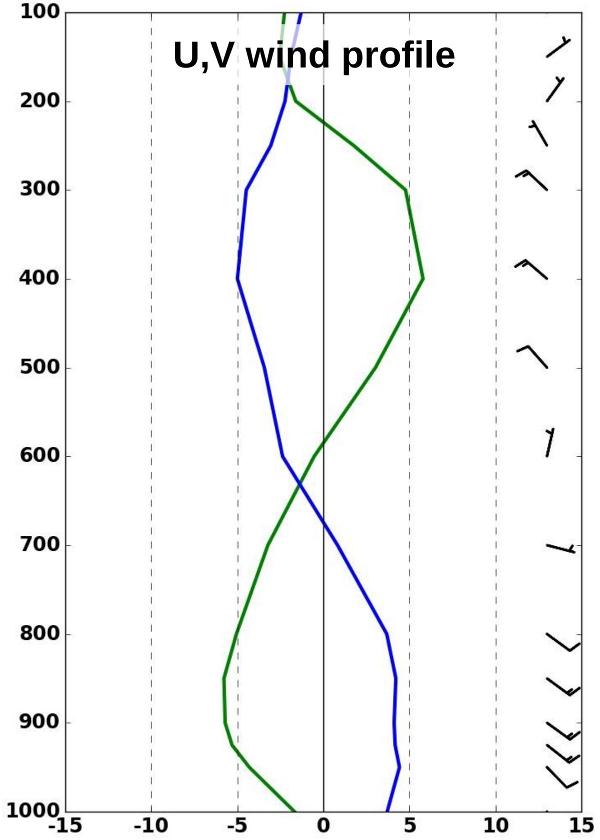


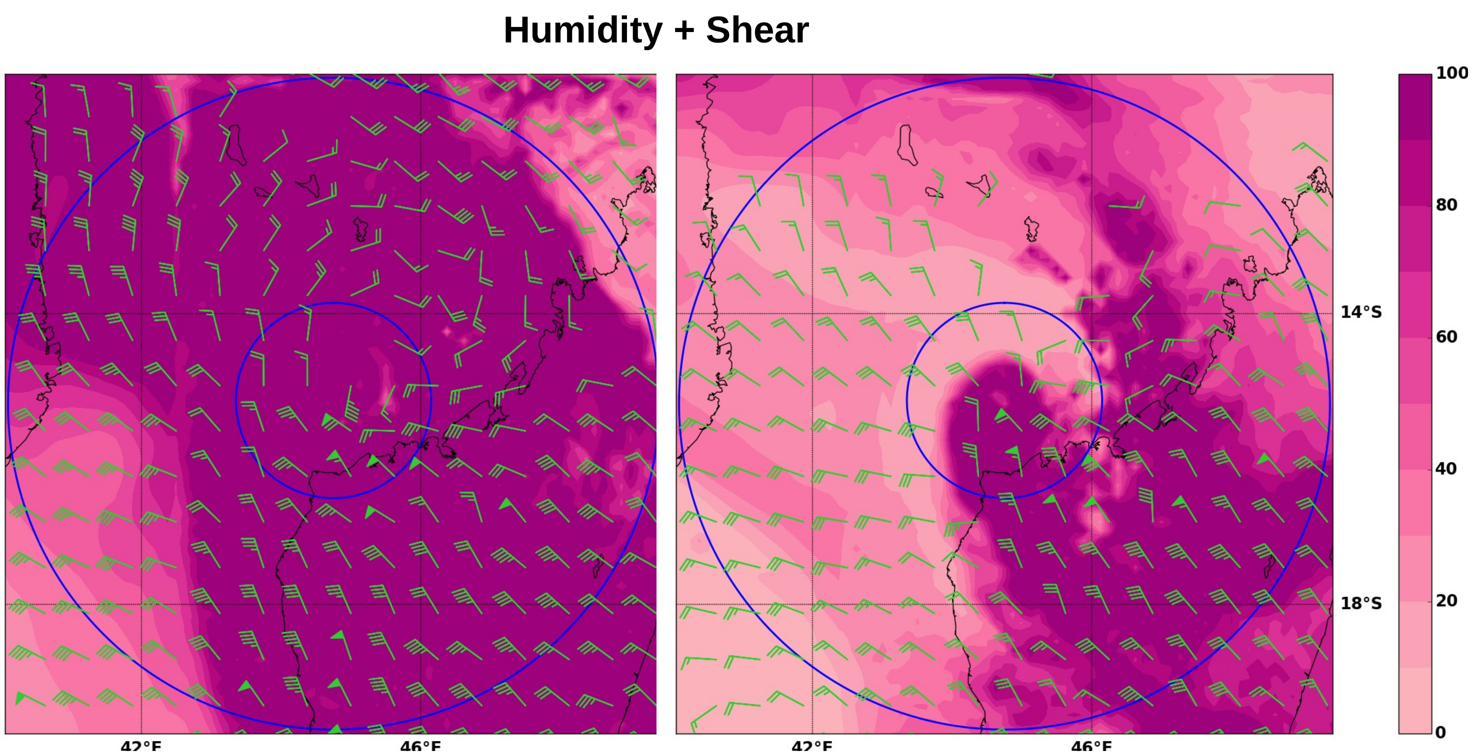


Vertical Wind Shear

But be careful, deep shear (200-850hPa) in not all that matters !

- The maximum level of the VWS can be at another level (300,400 or even 500hPa)
  - Hellen (March 2014), rapid weakening due to a mid-level shear (400-850hPa)





200hPa : Shear <15kt

400hPa : Shear ~30kt + Dry air

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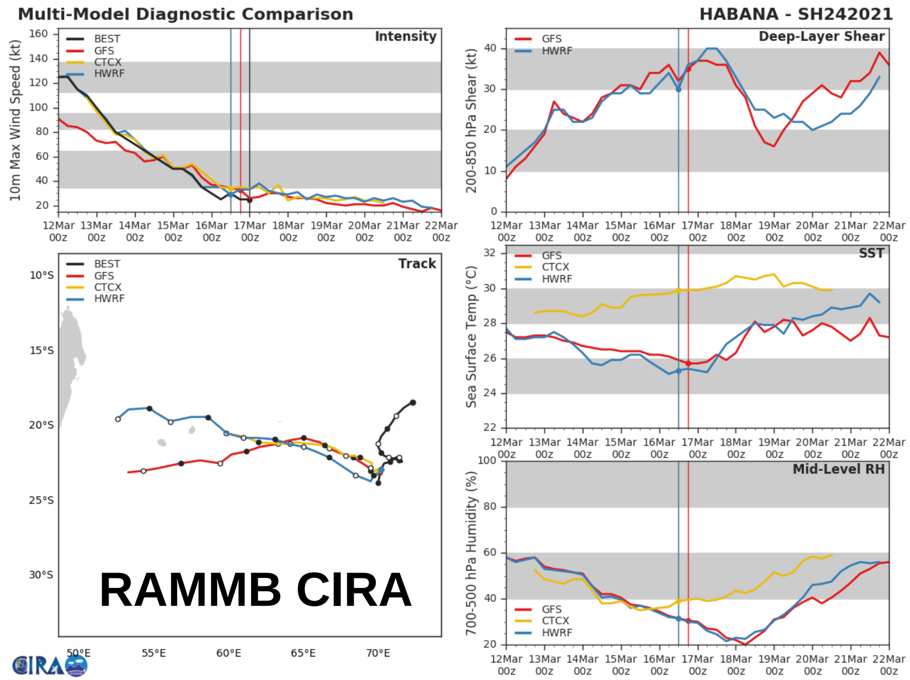
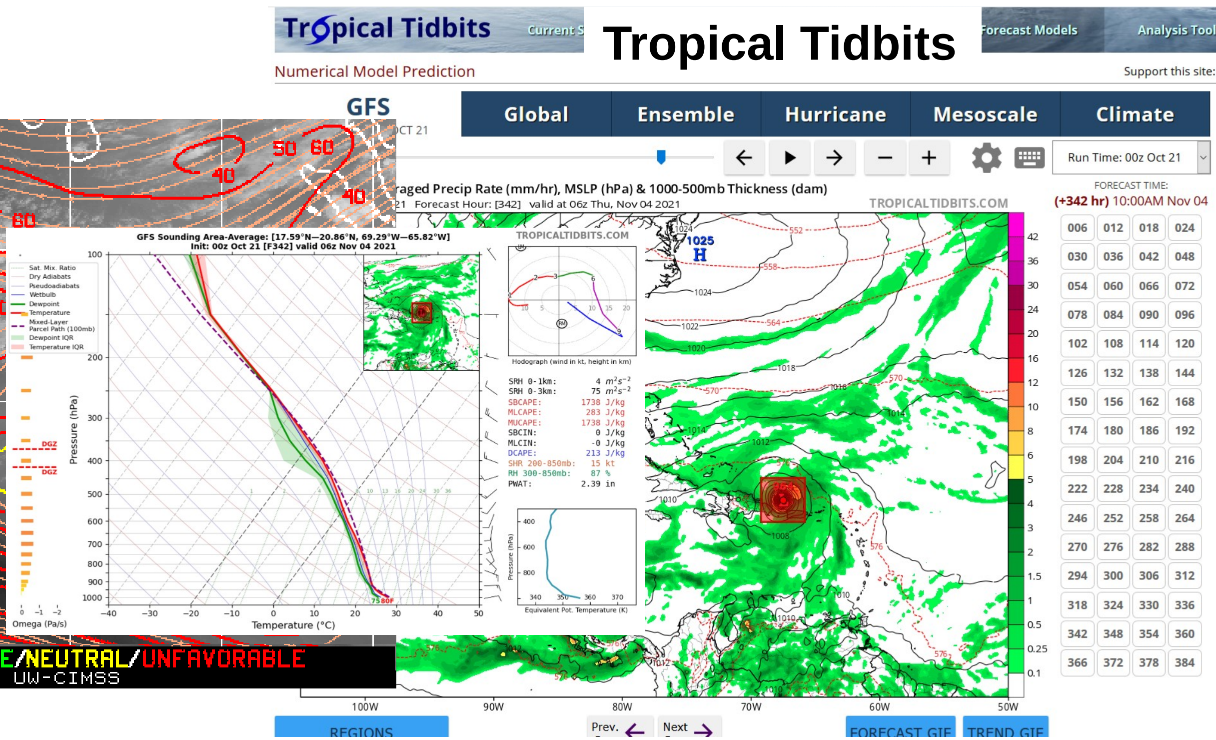
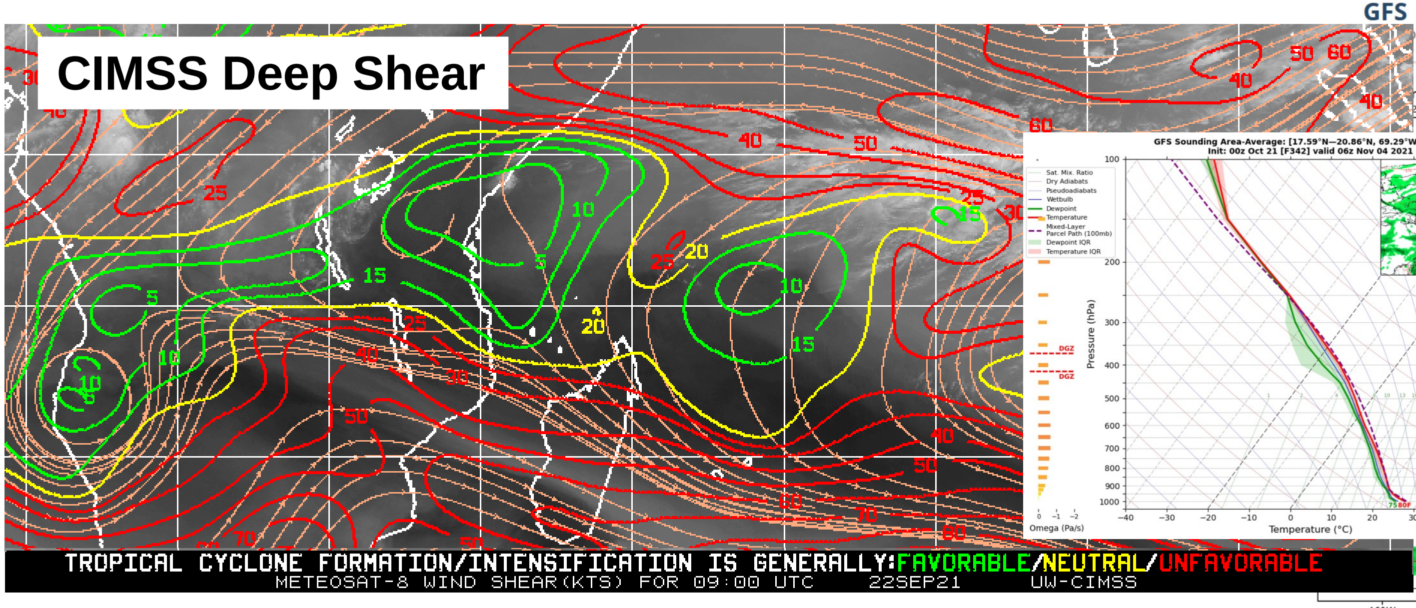
Vertical wind shear – In operations

- Windy / Tropical Tidbits (IFS/GFS/HWRF)
- CIMSS (Deep and Mid Shear) http://tropic.ssec.wisc.edu/real-time/windmain.php?&basin=indian&sat=wm5&prod=shr&zoom=&time
- RAMMB CIRA TC realtime



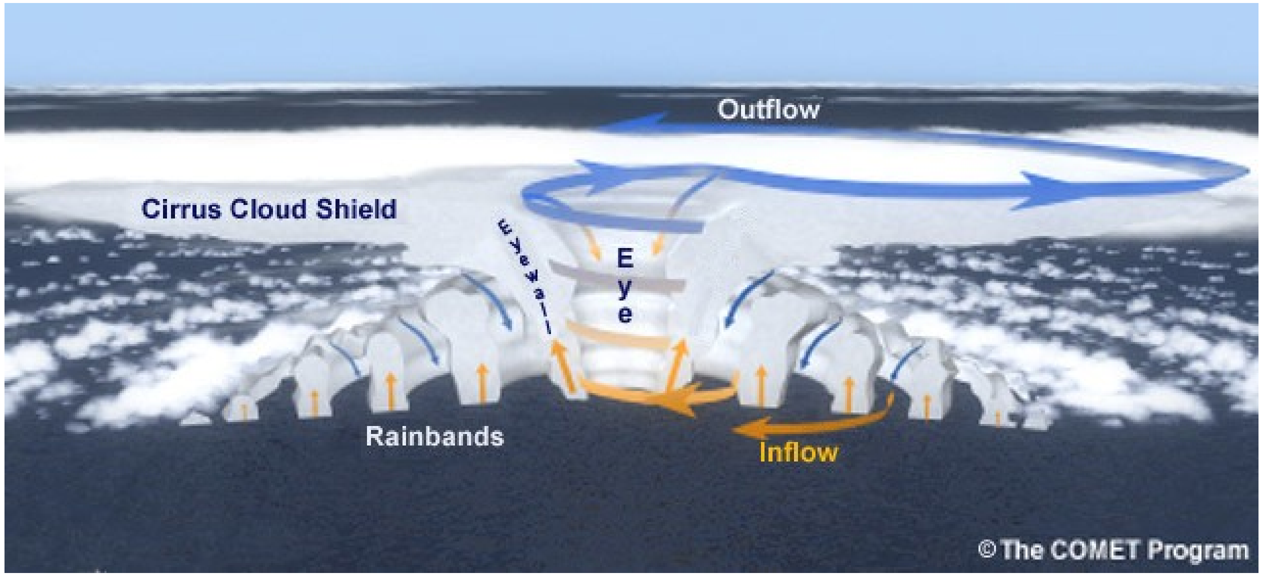


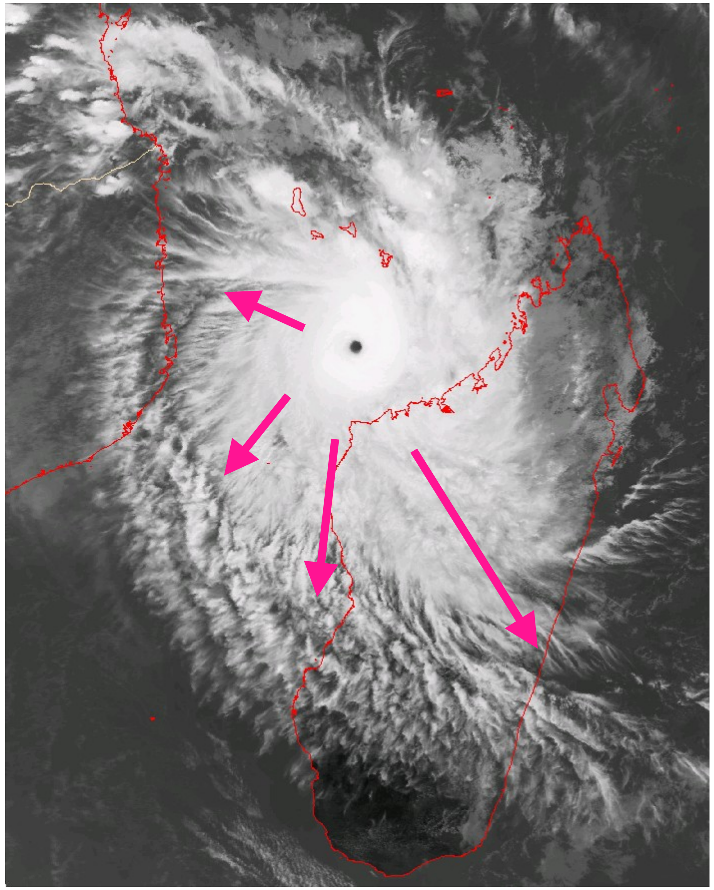


Upper divergence

Wind field divergence in the high troposphere (150-200hPa) near a cyclone

- Accelerate the secondary circulation
- Increase the efficiency of the heat transfer



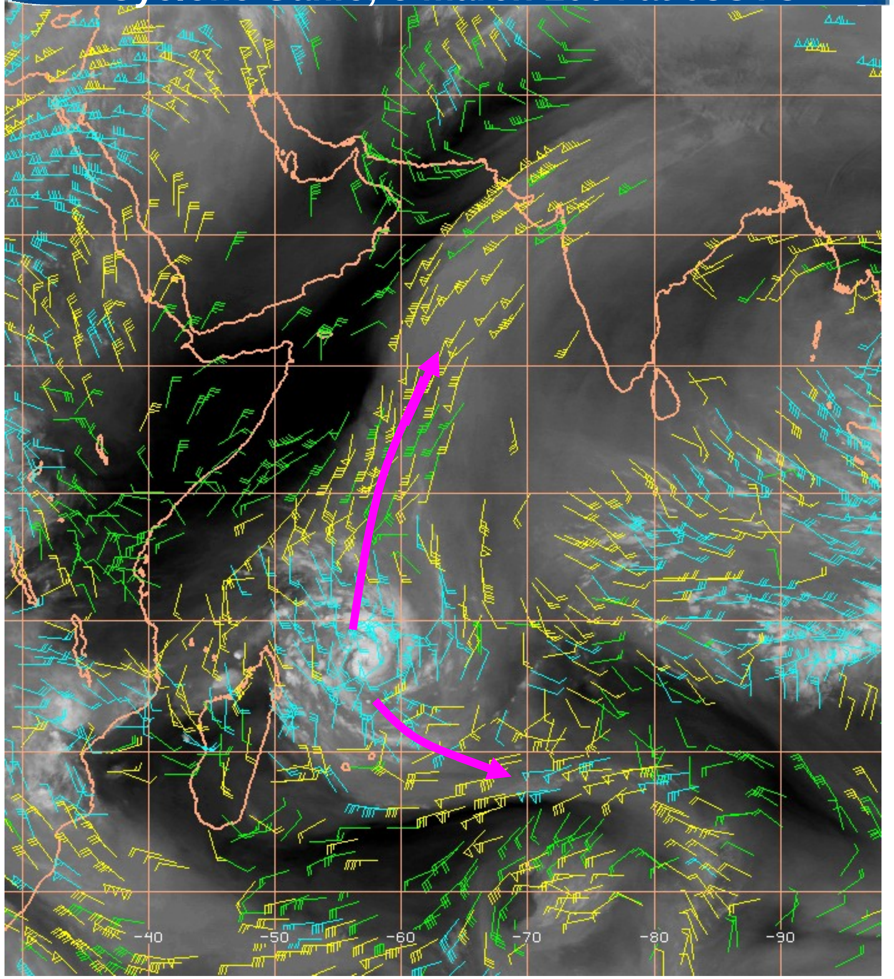


Strong synoptic upper divergence are frequently associated with rapid intensification

Upper divergence

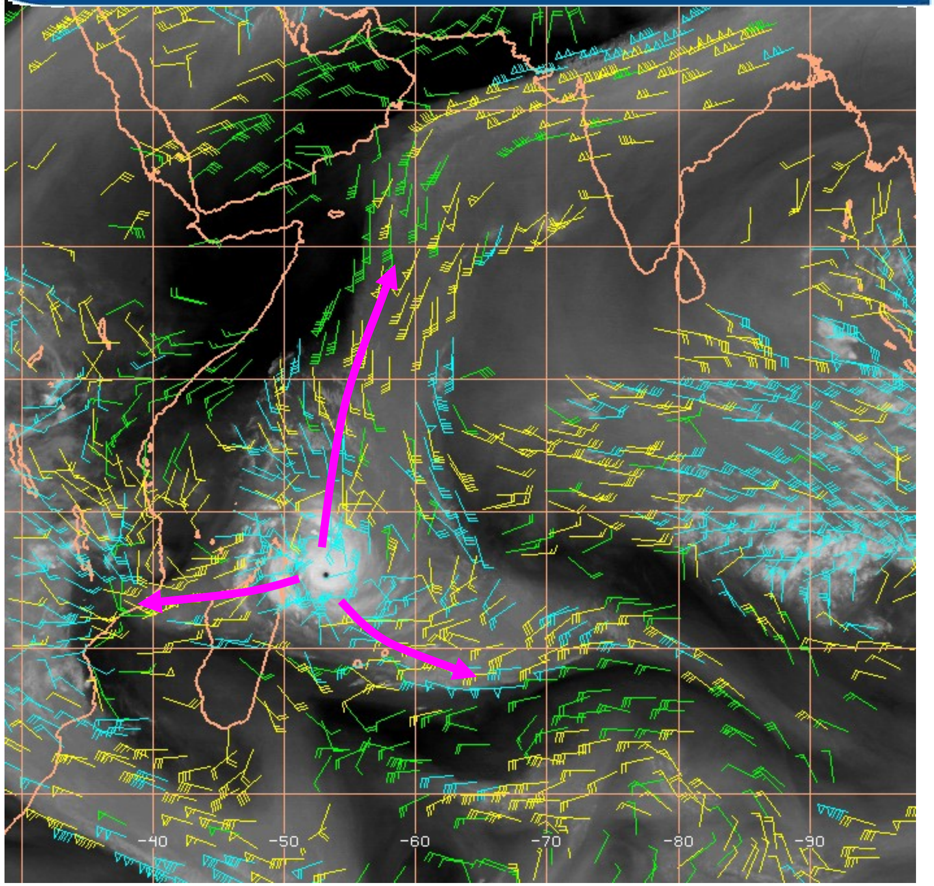
Outflow channels

Cyclone *Gafilo*, 5 march 2004 at 03UTC



Cyclone *Gafilo*, 6 march 2004 at 09UTC

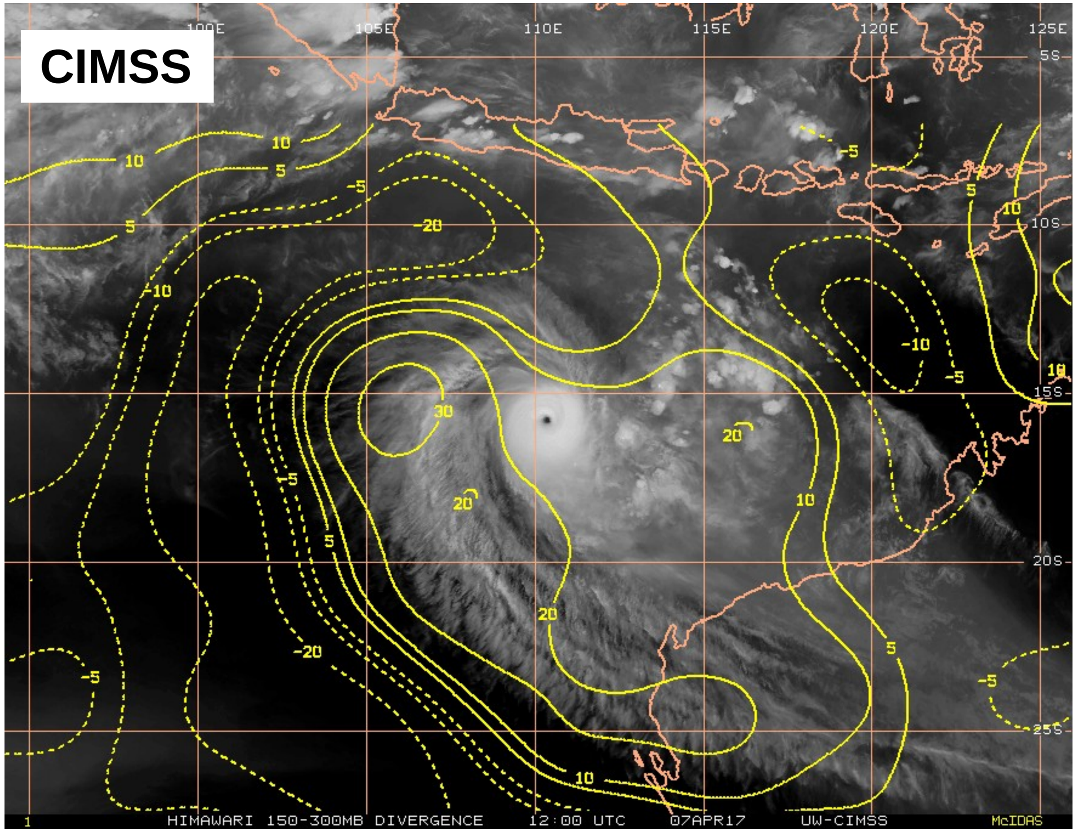
60 hPa deepening in 24h in bestrack



Upper divergence – In operations

- Windy (Wind 150hPa)
- CIMSS http://tropic.ssec.wisc.edu/real-time/windmain.php?&basin=indian&sat=wm5&prod=dvg&zoom=&time

Ernie (2017)



Rapid intensity changes

Usual intensity changes

- ±1.0 in 24h Dvorak number
- Between 10 and 25kt

Rapid Intensificaiton (RI) / Rapid weakening (RW) :

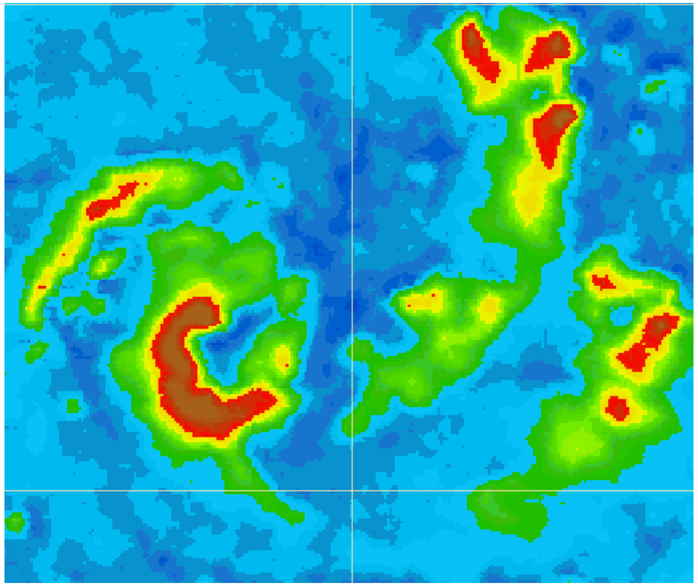
- ±30kt in 24h

Favorable factors for rapid intensification :

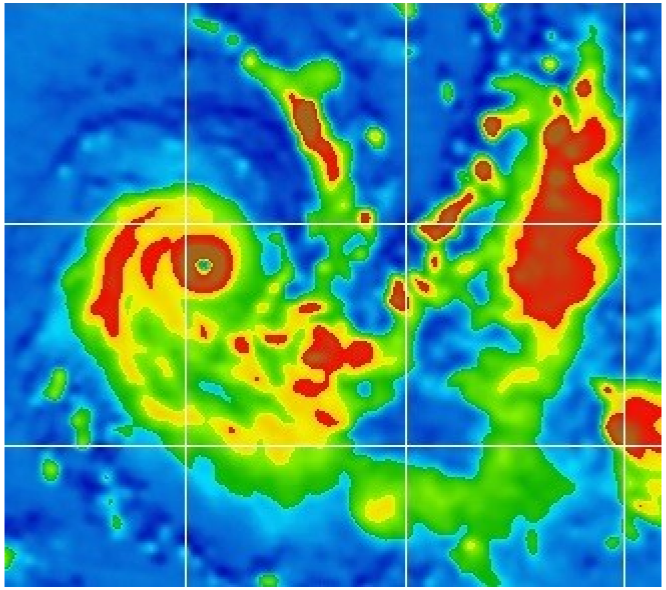
- Small size (more efficient)
- Hot tower near the RMW
- Strong upper divergence and MPI

Favorable factors for rapid weakening over sea

- Small size (less inertia)
- Strong change in the environment (Shear, SST,...)



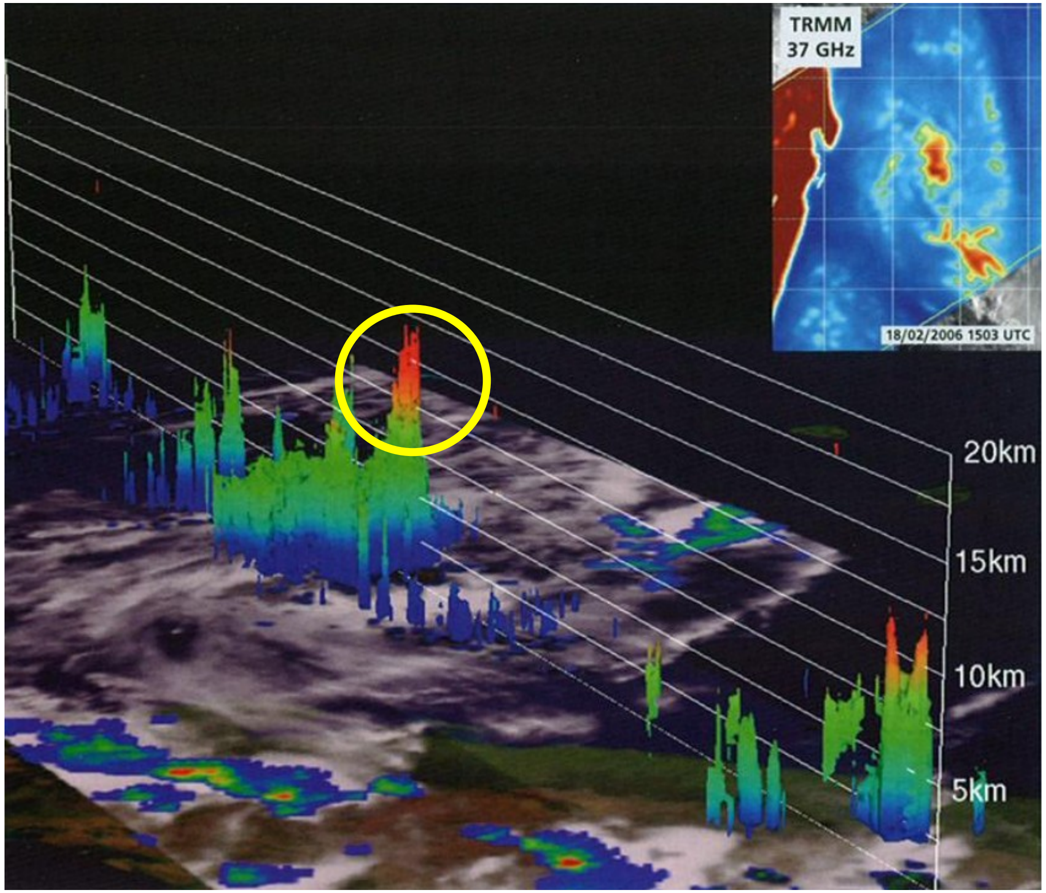
Ambali (2019)
Evolution in 19h
45kt → 120kt

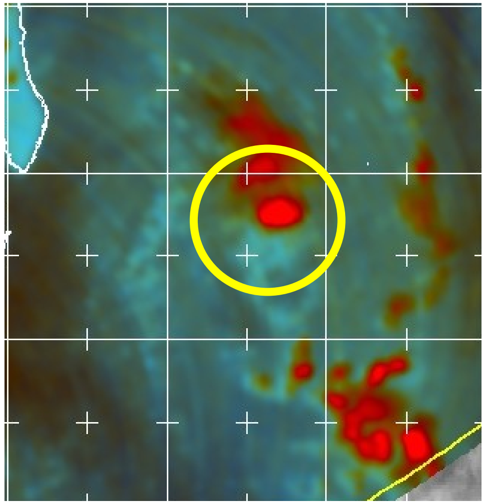


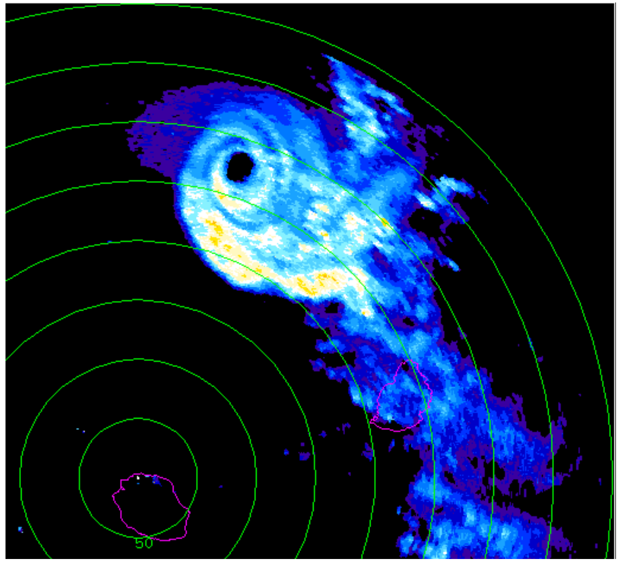
Hot towers

« Super cumulonimbus » which releases very high quantity of latent heat, creating vorticity. If it happens near the RMW, it can trigger a rapid intensification.

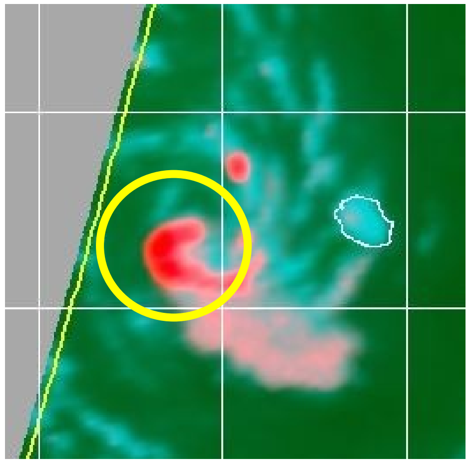
- STS 9 (2006), +25kt in 24h







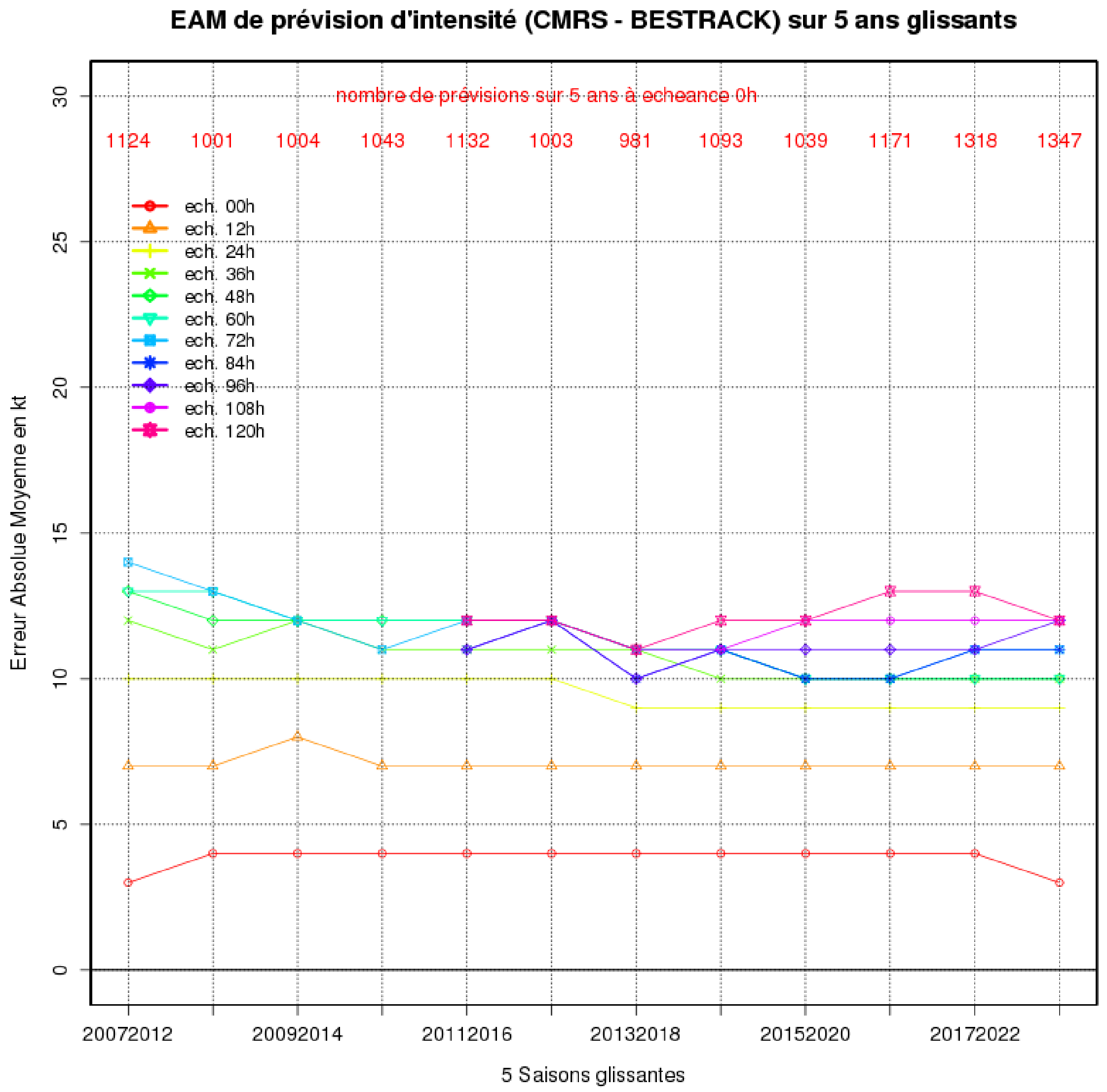
- Carlos (2017), +38kt in 36h



3. Intensity forecast

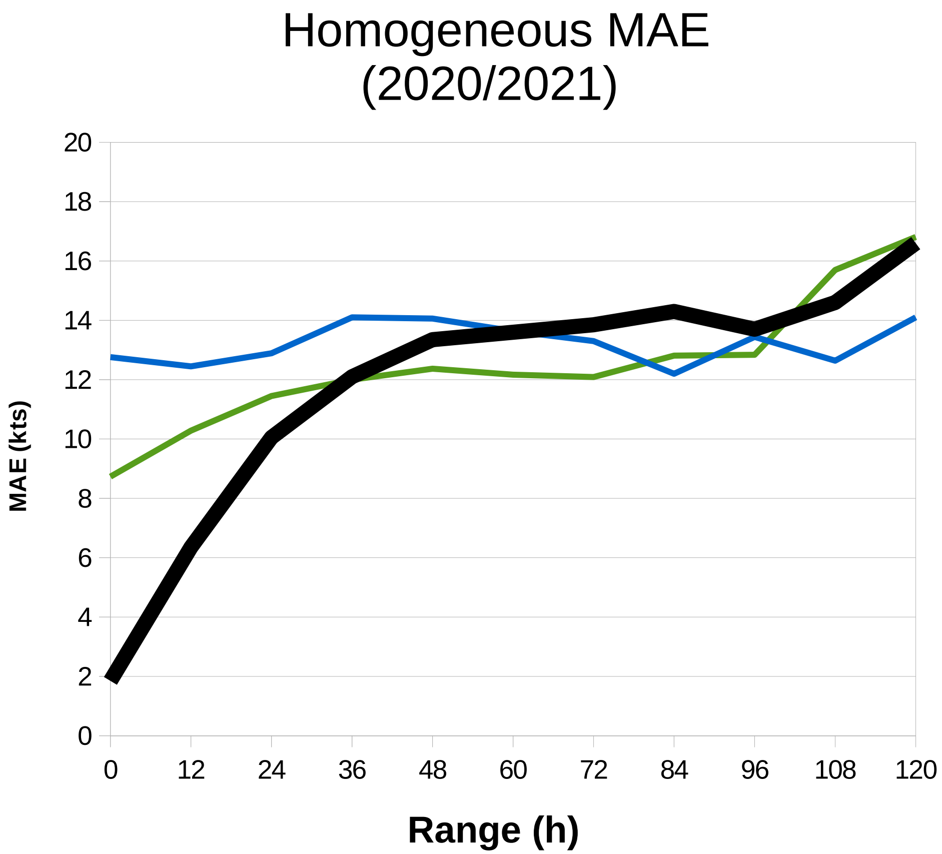
RSMC La Réunion forecast errors

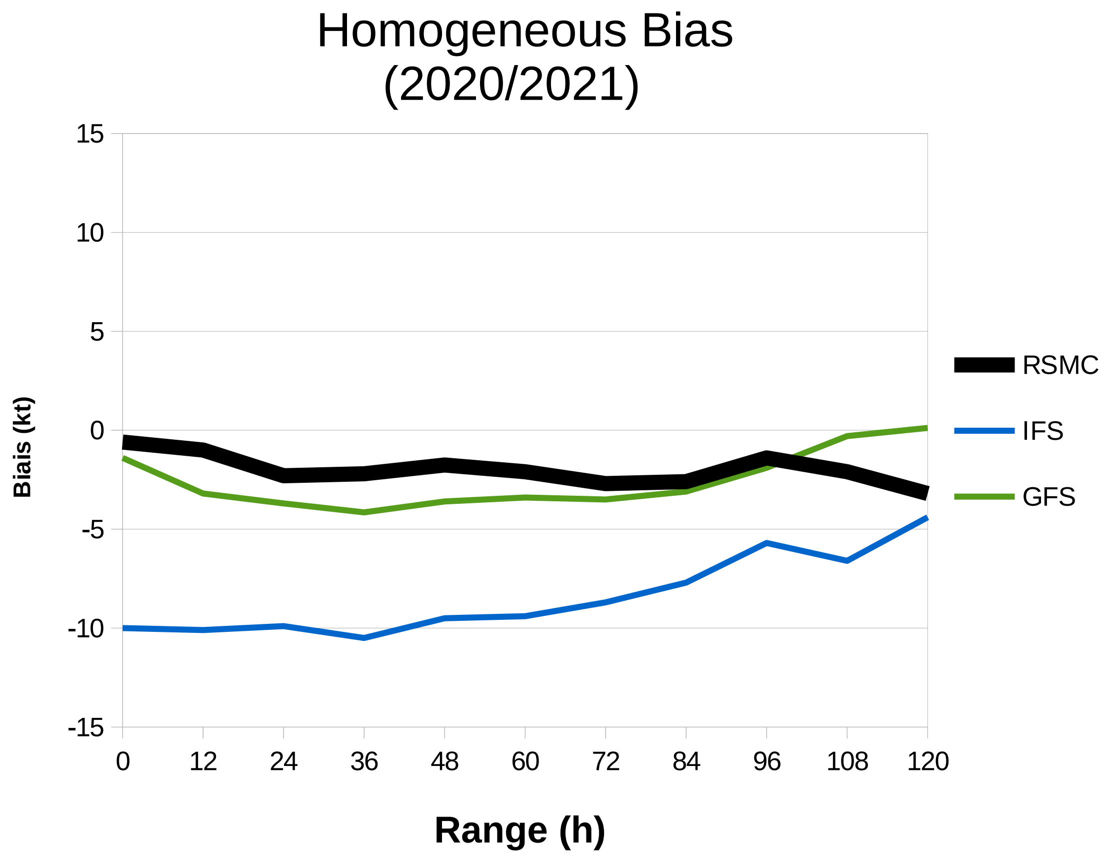
Mean Absolute Error (MAE) between the forecast and the bestrack



RSMC La Réunion forecast errors

RSMC forecast errors vs models forecast errors (Saison 2020-2021)





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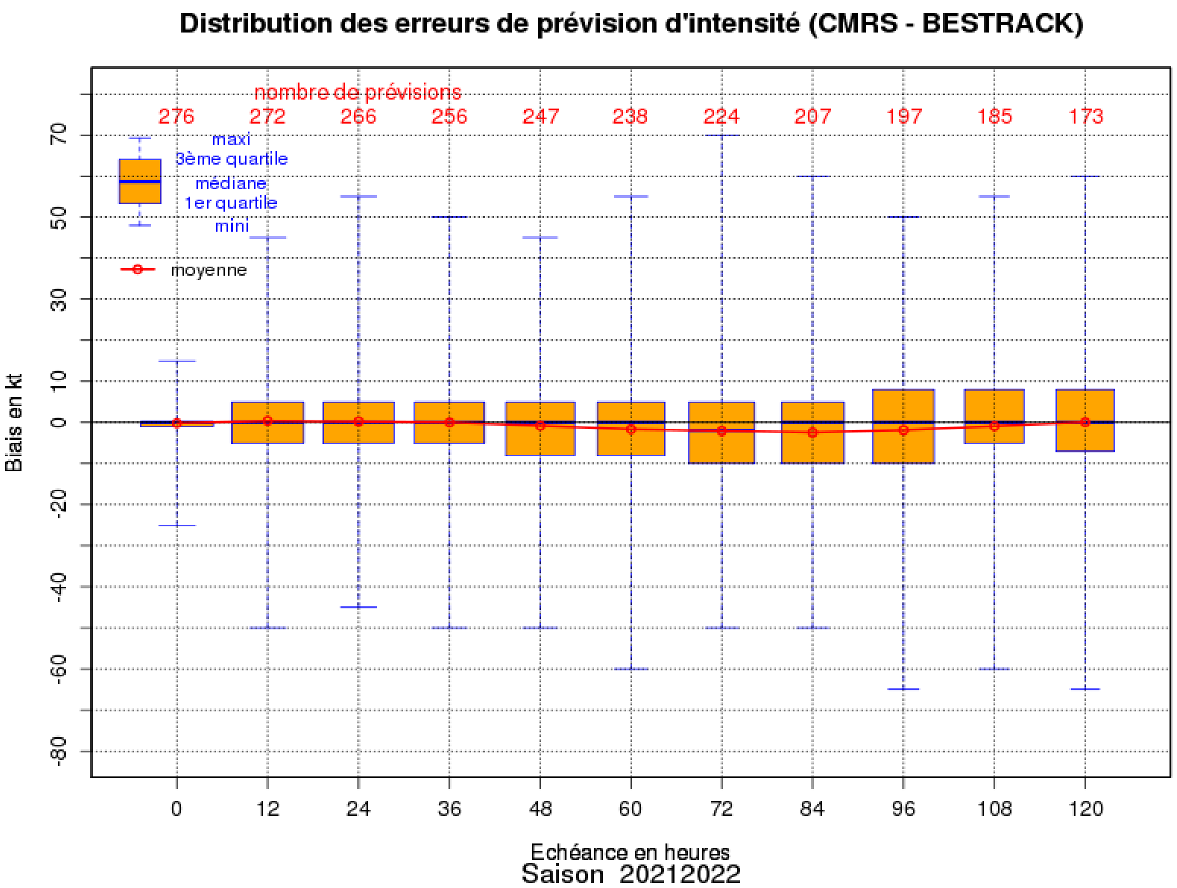
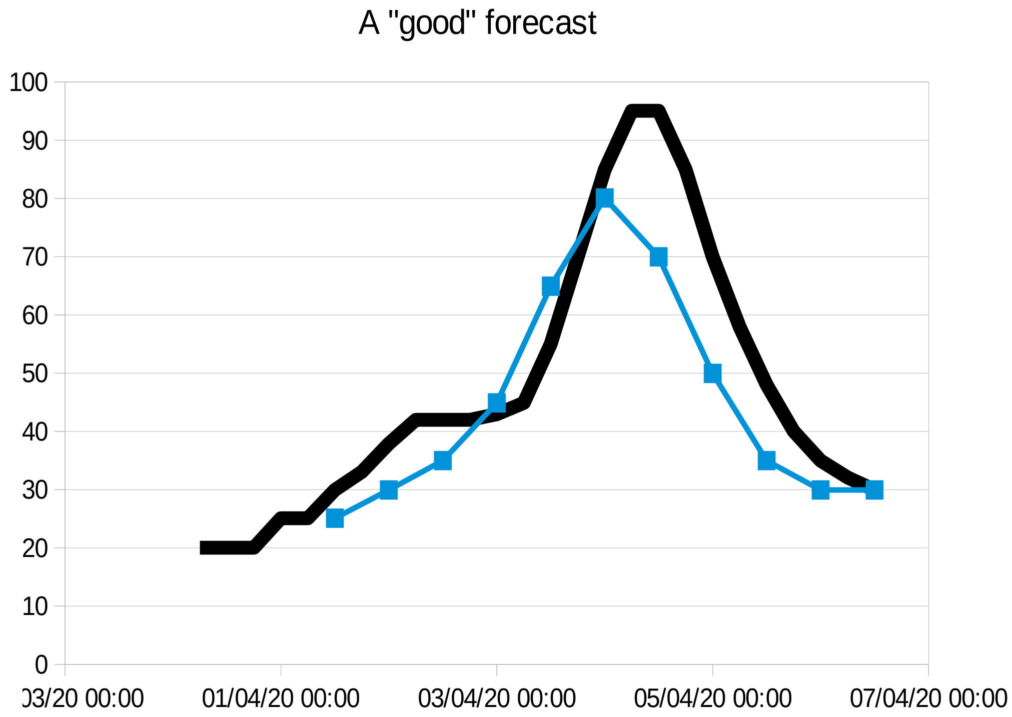
RSMC La Réunion forecast errors

The quality of each forecast is uneven





Types of errors :

- Bad initial analysis
- Rapid changes
- Temporal shift
- Underestimation of the peak intensity

How to make a(n intensity) forecast

1) Analysis of the current location/intensity/structure
2) First track forecast guess
3) Subjective assessment on the environmental conditions along the track (Oceanic, upper levels, ...)
4) First intensity forecast guess
5) Comparison with the available numerical guidance
6) Adjustment the intensity forecast
7) Verification if the track forecast is still consistent

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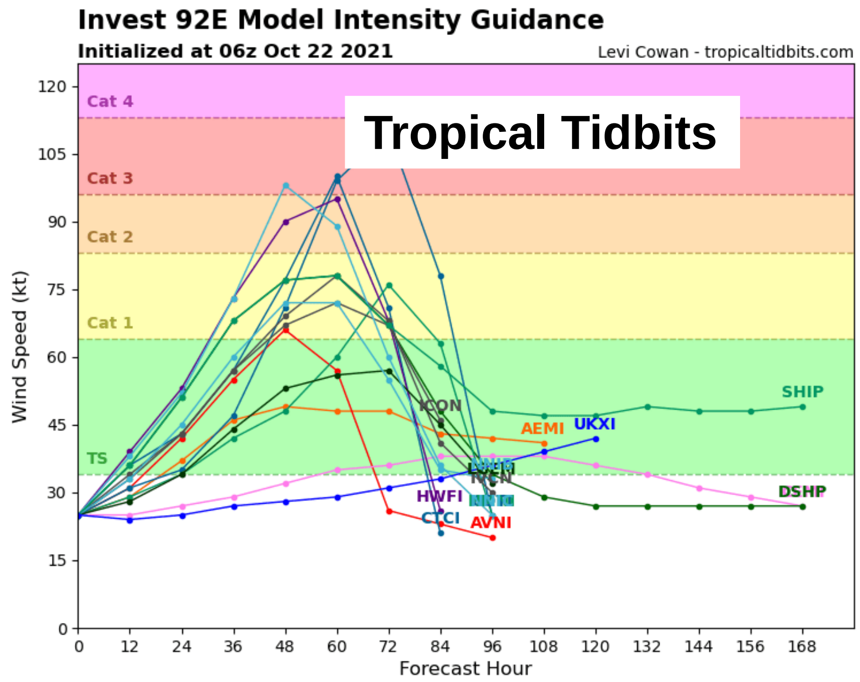
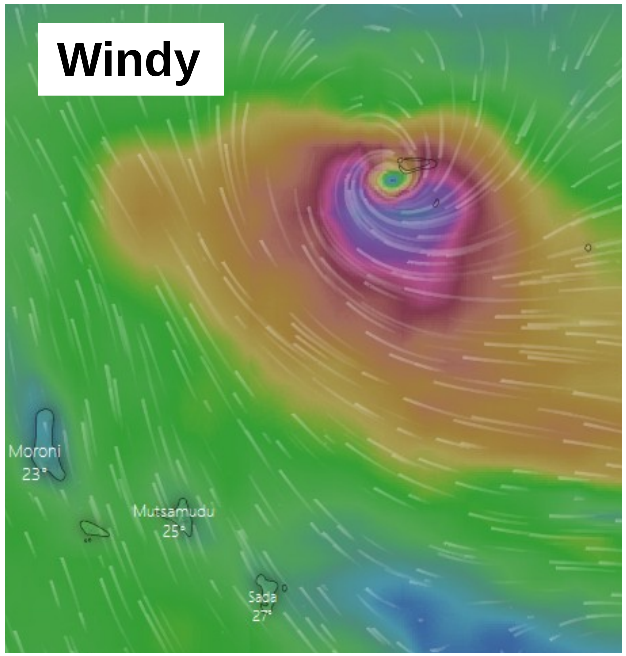
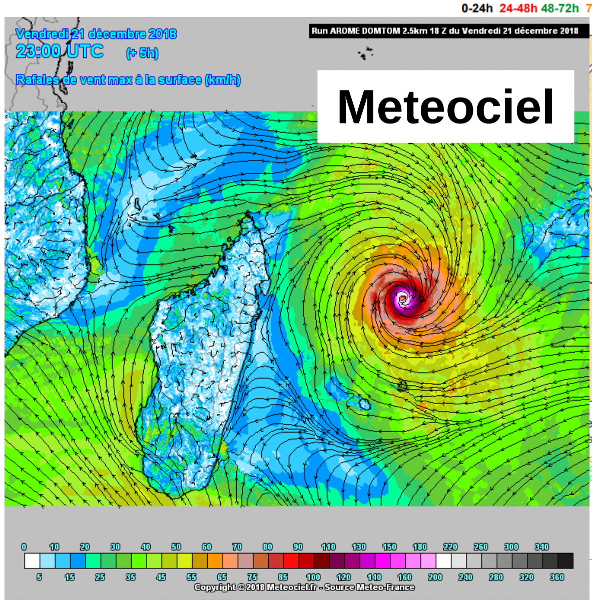
Intensity forecast – In operations

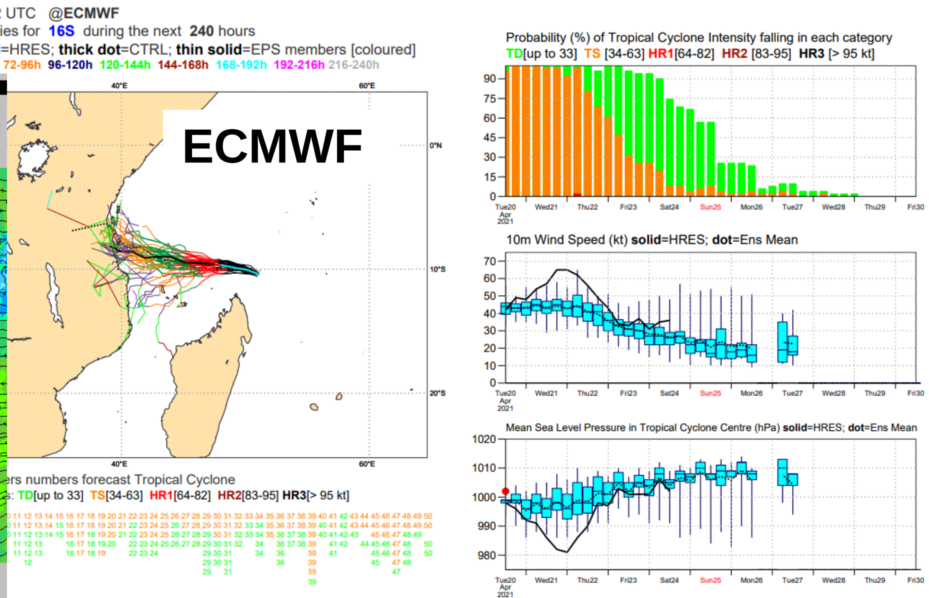
Numerical guidance :

- Windy / Tropical Tidbits / RAMMB CIRA TC realtime
- ECMWF (IFS/EPS)
  https://www.ecmwf.int/en/forecasts/charts/tcyclone/
- Meteociel (AROME IO) in French
  https://www.meteociel.fr/modeles/arome.php?ech=3&mode=1&map=60
- RSMC La Réunion Extranet
  https://pro.meteofrance.com/page/index/affiche/id/76436









RÉPUBLIQUE FRANÇAISE
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METEO FRANCE

WTIO 30
WTIO 31

Intensity forecast – In operations

Official RSMC bulletins / product :

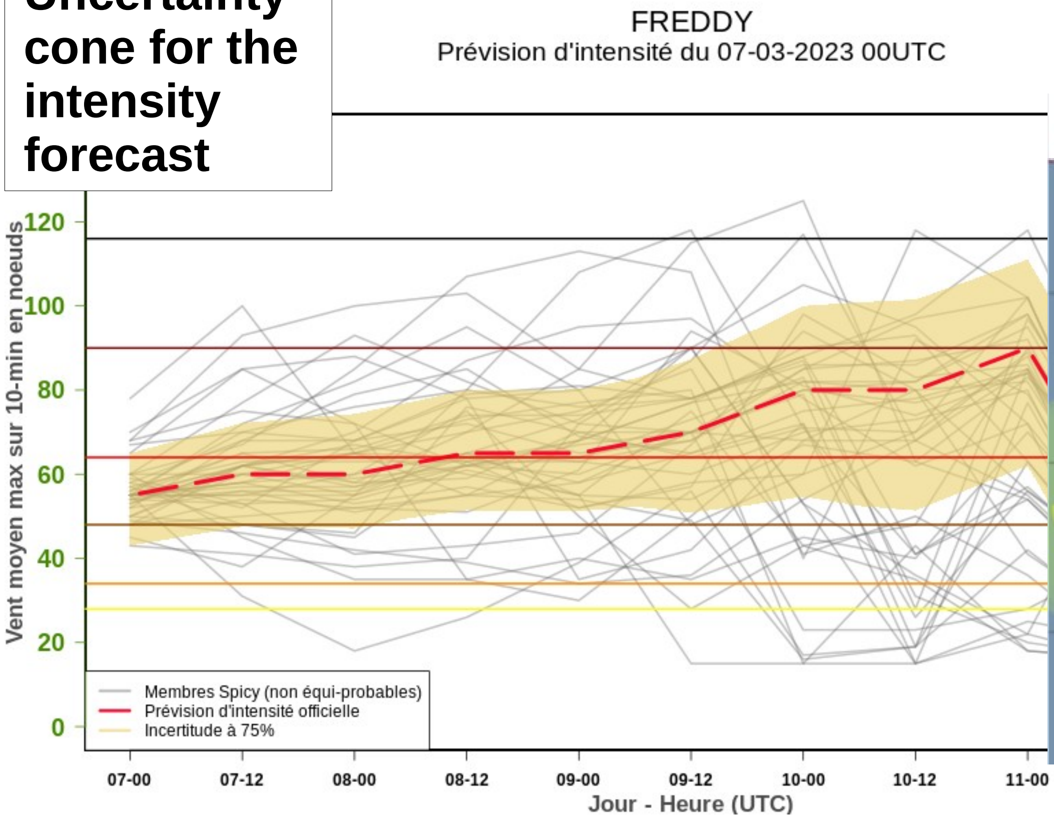
- http://www.meteo.fr/temps/domtom/La_Reunion/webcmrs9.0/
- http://www.meteo.fr/temps/domtom/La_Reunion/meteoreunion2/prod_spicy/multipdf.pdf

1.B FORECASTS:
12H: 2019/12/08 00 UTC: 11.5 S / 46.9 E, VENT MAX= 085 KT, TROPICAL CYCLONE
24H: 2019/12/08 12 UTC: 12.8 S / 46.5 E, VENT MAX= 095 KT, INTENSE TROPICAL CYCLONE
36H: 2019/12/09 00 UTC: 14.1 S / 45.9 E, VENT MAX= 105 KT, INTENSE TROPICAL CYCLONE
48H: 2019/12/09 12 UTC: 15.8 S / 45.5 E, VENT MAX= 105 KT, INTENSE TROPICAL CYCLONE
60H: 2019/12/10 00 UTC: 17.3 S / 44.7 E, VENT MAX= 075 KT, OVERLAND DEPRESSION
72H: 2019/12/10 12 UTC: 19.0 S / 44.3 E, VENT MAX= 045 KT, OVERLAND DEPRESSION

2.B LONGER-RANGE OUTLOOK:
96H: 2019/12/11 12 UTC: 21.9 S / 44.0 E, VENT MAX= 025 KT, OVERLAND DEPRESSION
120H: 2019/12/12 12 UTC: 23.8 S / 45.2 E, VENT MAX= 020 KT, OVERLAND DEPRESSION

ENVIRONMENTAL CONDITIONS REMAIN CONDUCIVE FOR A QUICKER DEVELOPMENT IN THE NEXT HOURS : WARMER WATERS AND NO WIND SHEAR. TOMORROW, BELNA TRACKS BETWEEN TWO UPPER LEVEL RIDGES WHICH COULD BOOST ITS OUTFLOW. A POTENTIAL EYEWALL REPLACEMENT CYCLE COULD ALSO OCCUR. FROM MONADY EVENING, THE INTENSITY FORECAST IS MUCH MORE UNCERTAIN FOLLOWING THE FORECASTED LANDFALL.

Uncertainty cone for the intensity forecast



Forecast map