RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
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METEO FRANCE

Tropical Cyclones hazards and impacts (wind/rainfall/swell/surge)

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RA I Training Course on Tropical Cyclones – 11th session

September 2023

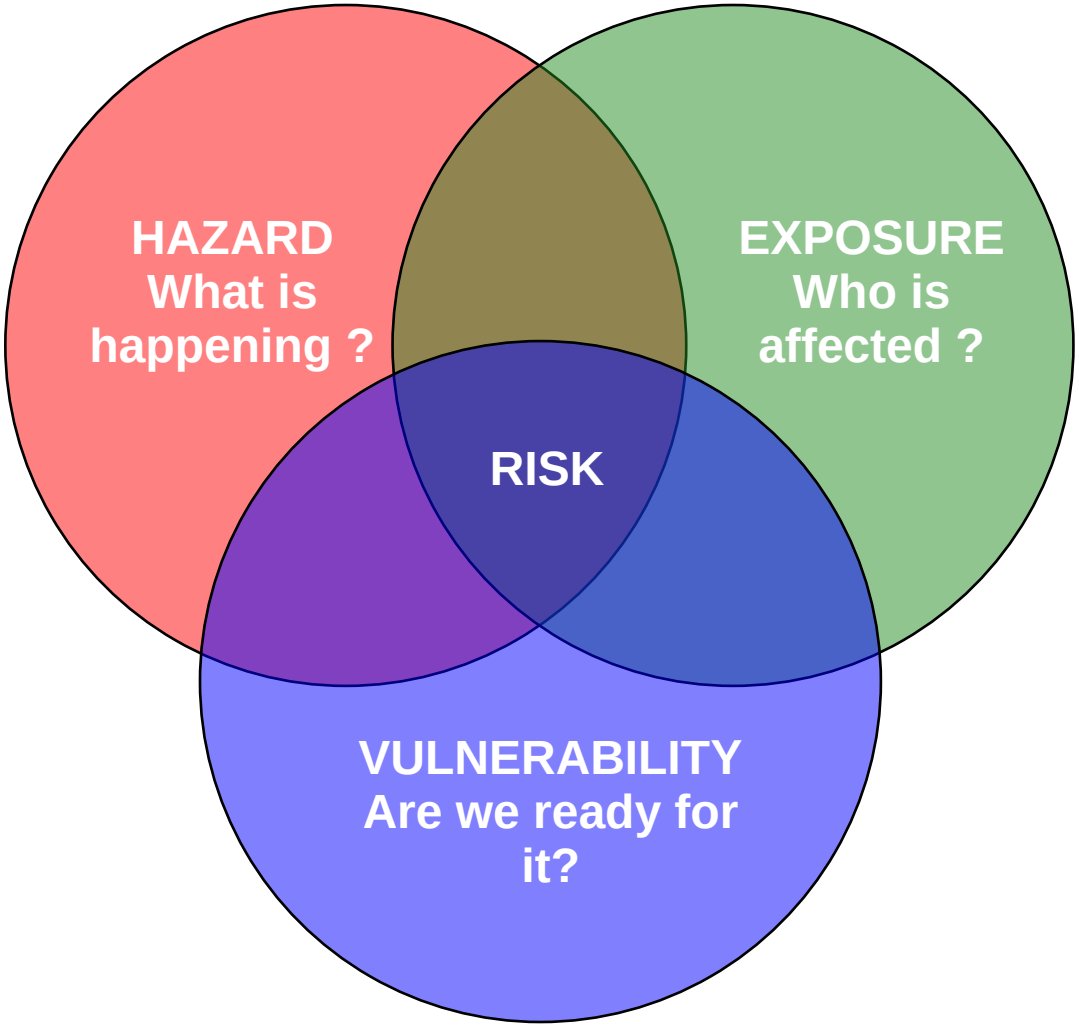
Impact forecast

Goal : Limit the consequences (Impacts) of the cyclone

- Good forecast of the meteorogical parameters (Hazard)

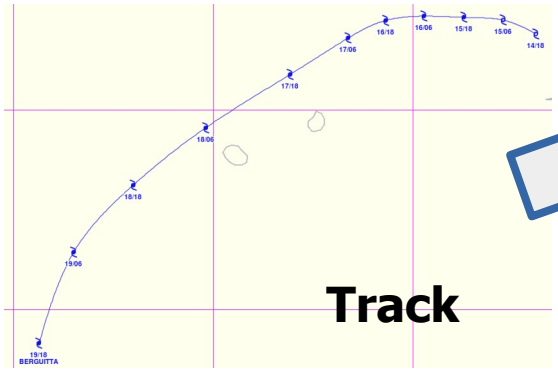
But also :

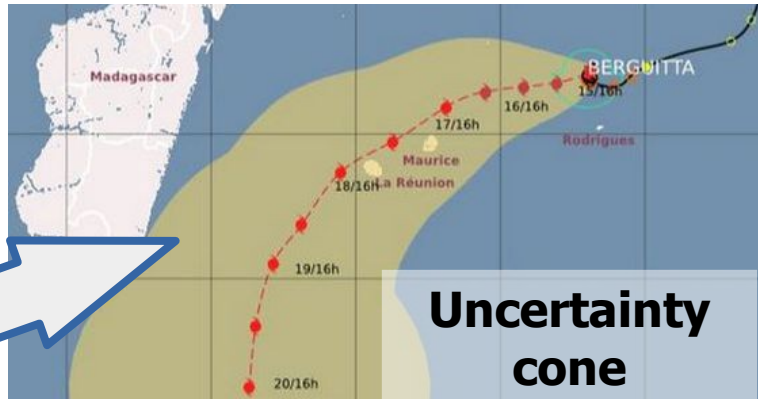
- Give messages adapted to each user
- Forecast the consequences the user will face

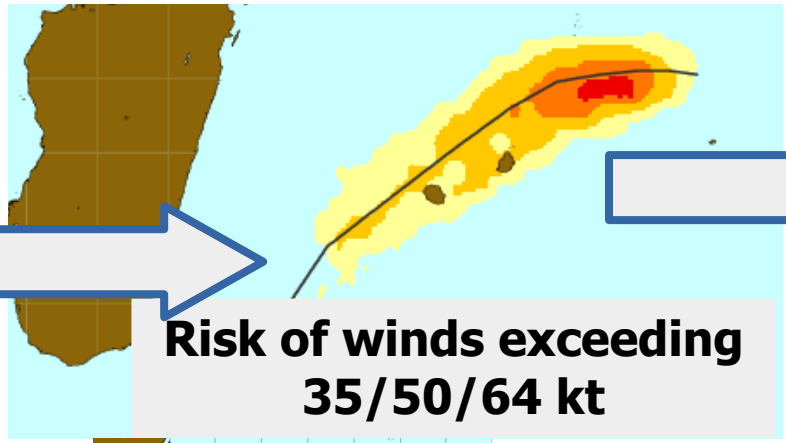


Impact forecast

Gradual evolution of the RSMC products towards impact based







?

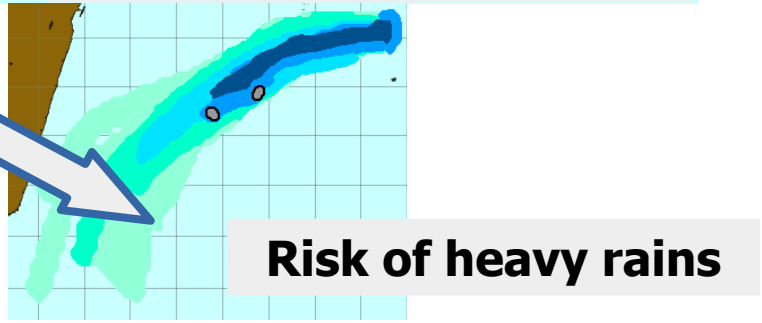
Intensity

Voici les intensités et positions prévues de ce système dépressionnaire au cours des prochains jours:

CYCLONE TROPICAL,
Centre positionné le 15/01 à 21h locales Mayotte, par 17.7 Sud / 61.3 Est.

CYCLONE TROPICAL INTENSE,
Centre positionné le 16/01 à 21h locales Mayotte, par 17.7 Sud / 59.3 Est.

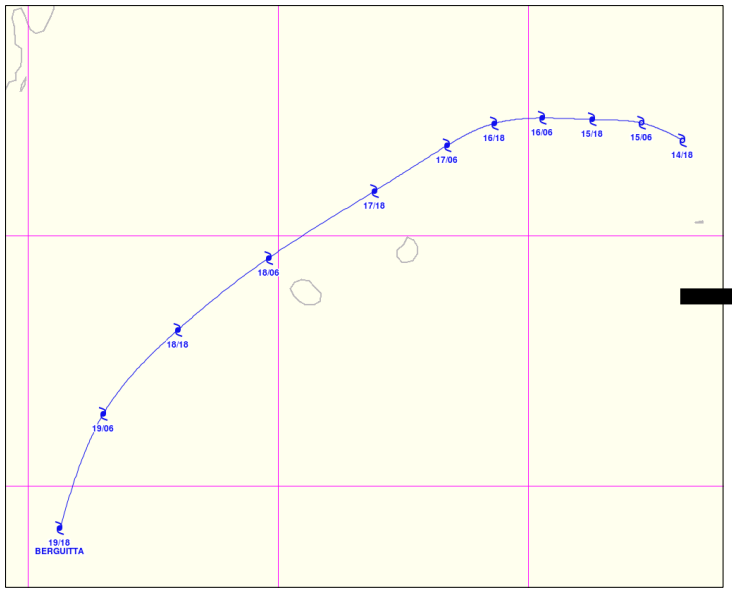
CYCLONE TROPICAL,
Centre positionné le 17/01 à 21h locales Mayotte, par 19.1 Sud / 56.9 Est.



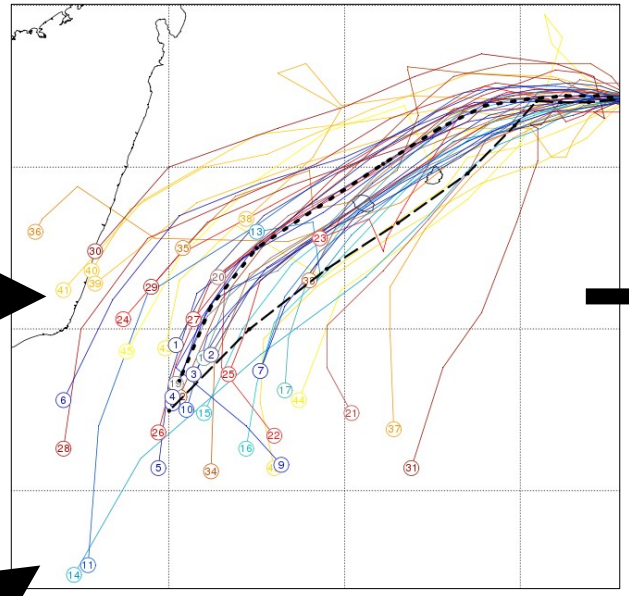
Tools : SpiCy Products

New RSMC probabilistic products

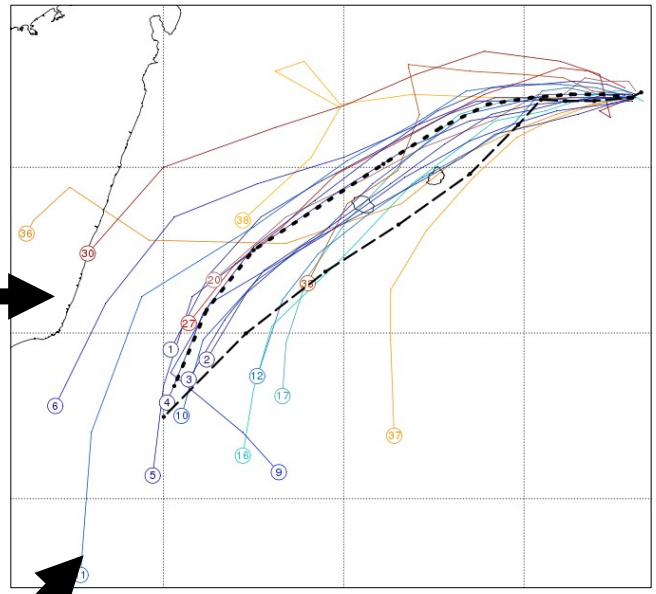
- Goal is to have at disposal probabilistic forecast consistent with RSMC forecast.



RSMC forecast



Alternative climatological scenarios



Alternative SPICY scenarios

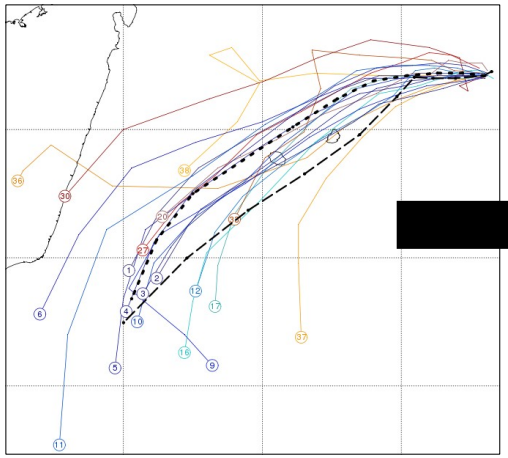
RSMC Climatological errors

ECMWF Ensemble forecasts

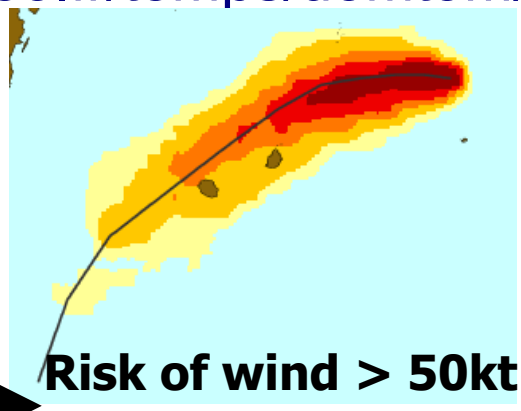
Tools : SpiCy Products

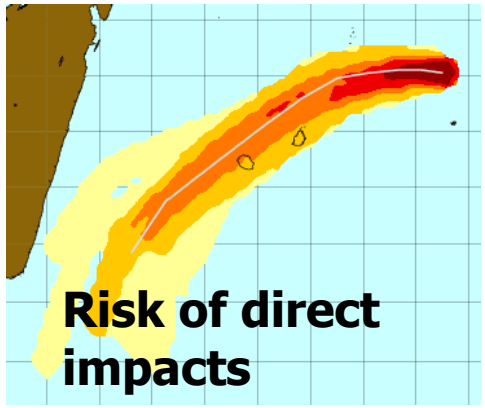
Products available here :

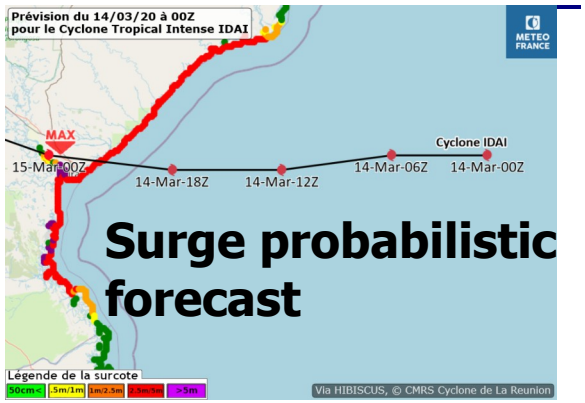
- http://www.meteo.fr/temps/domtom/La_Reunion/meteoreunion2/prod_spicy/multipdf.pdf
- http://www.meteo.fr/temps/domtom/La_Reunion/meteoreunion2/HIBISCUS_GP/

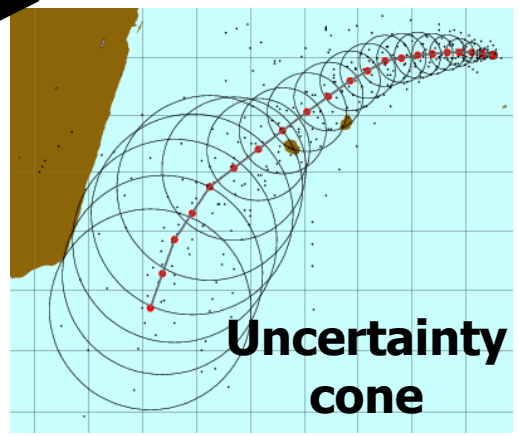


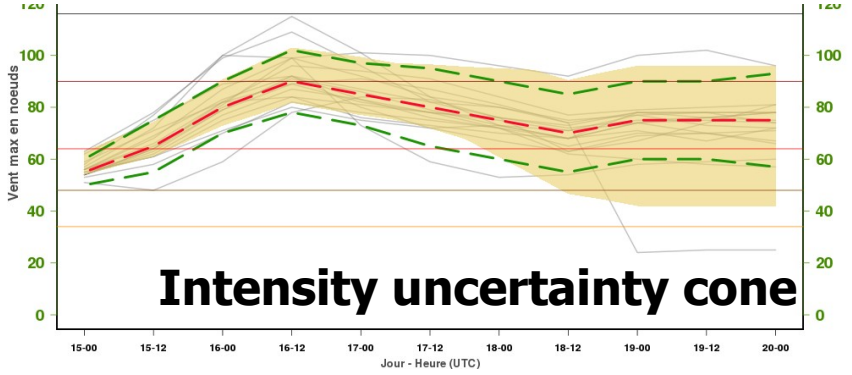
Alternative SPICY scenarios







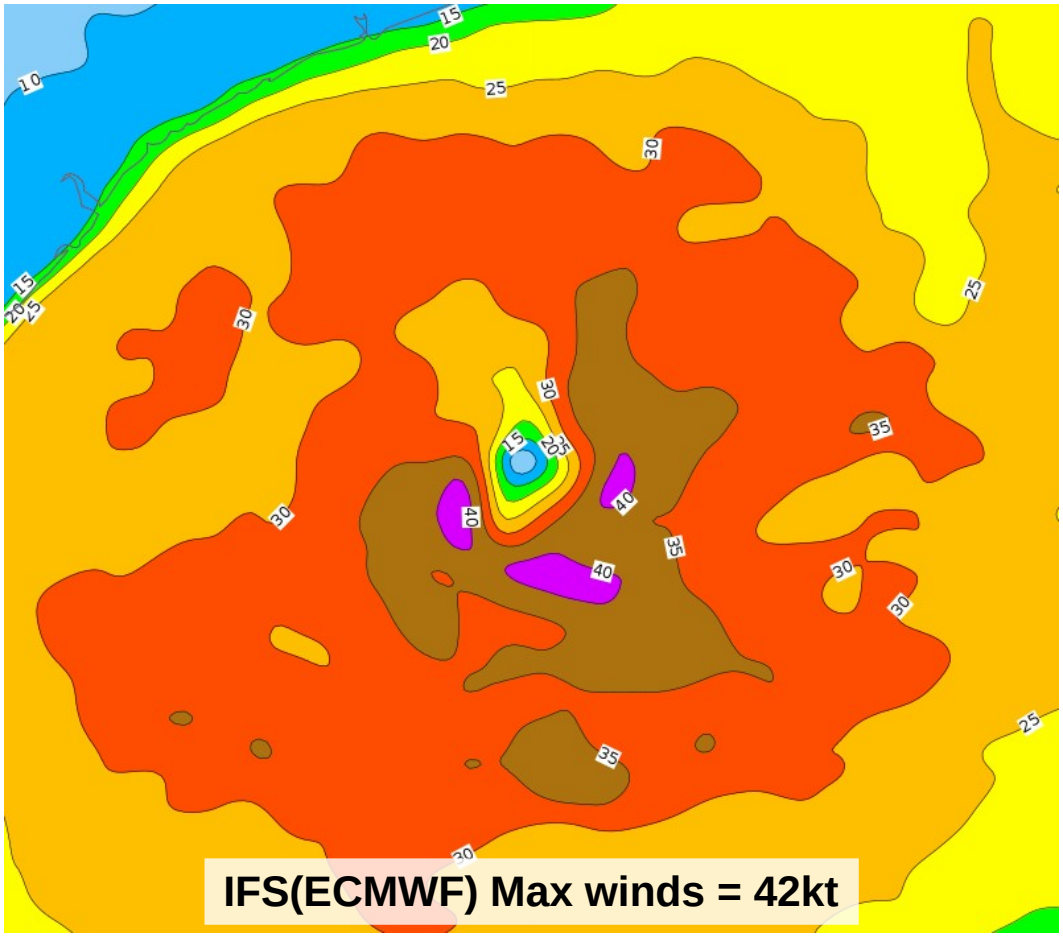


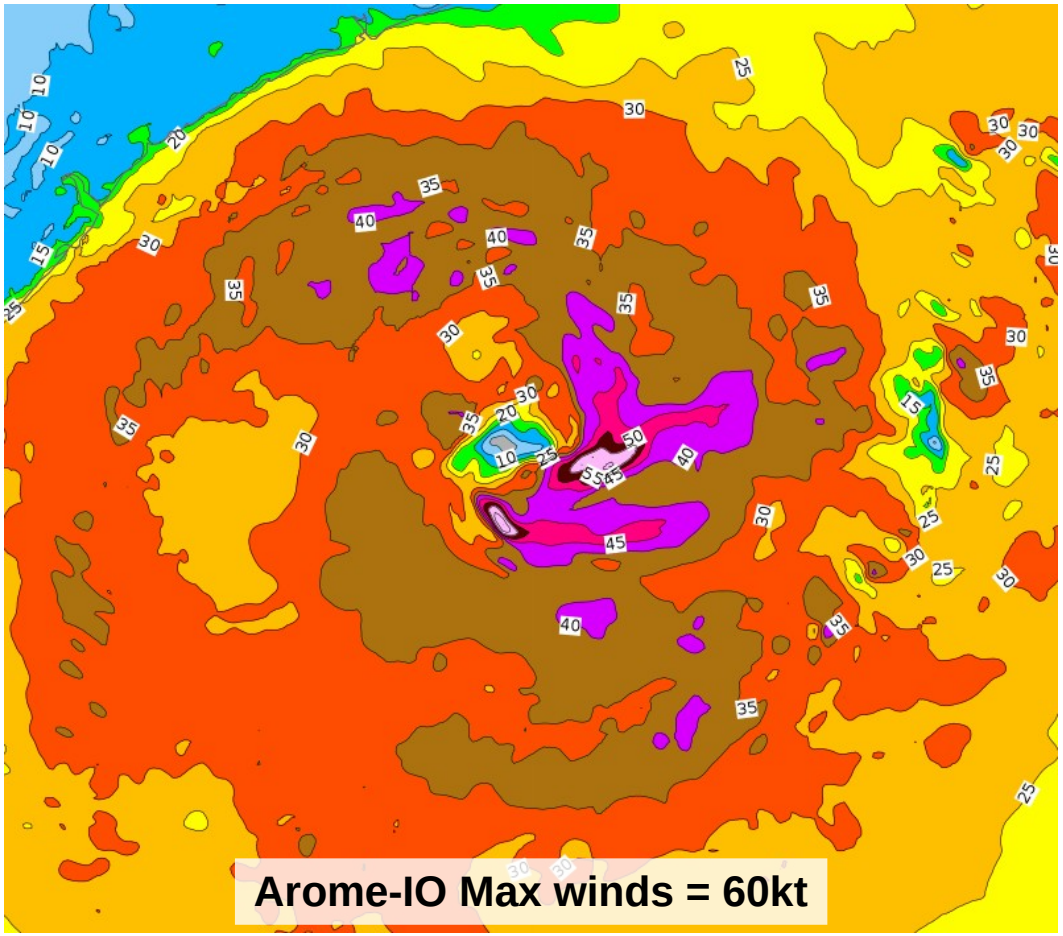


Tools : numerical models

Need of high resolution models like Arome-IO

Freddy's windfield 10/03 00Z

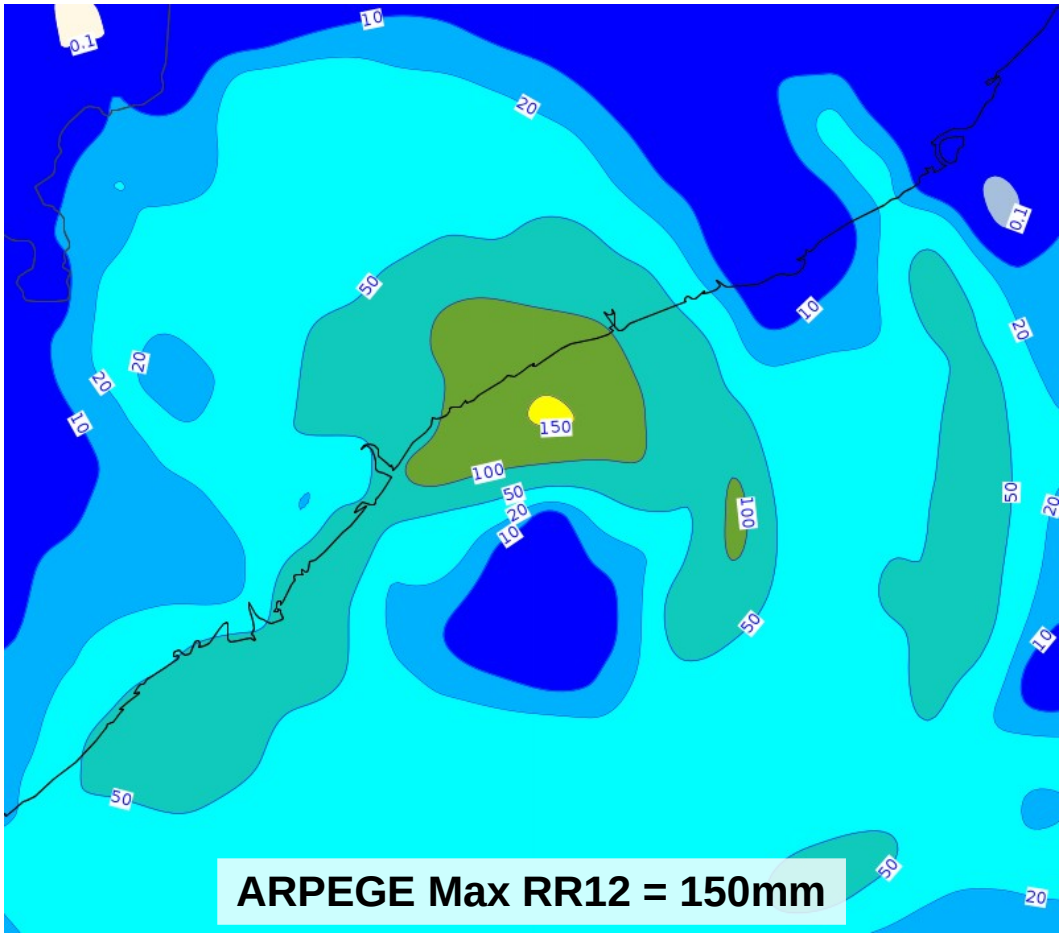


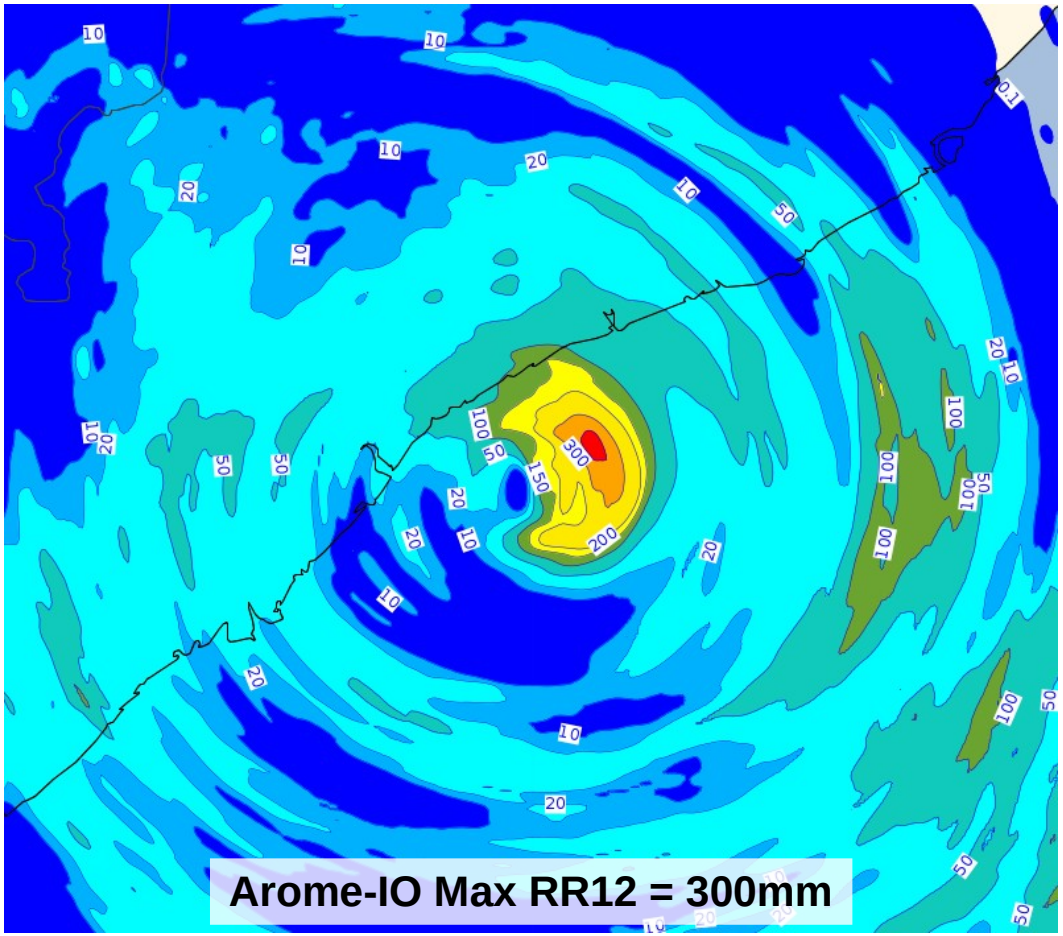


Tools : numerical models

Need of high resolution models like Arome-IO

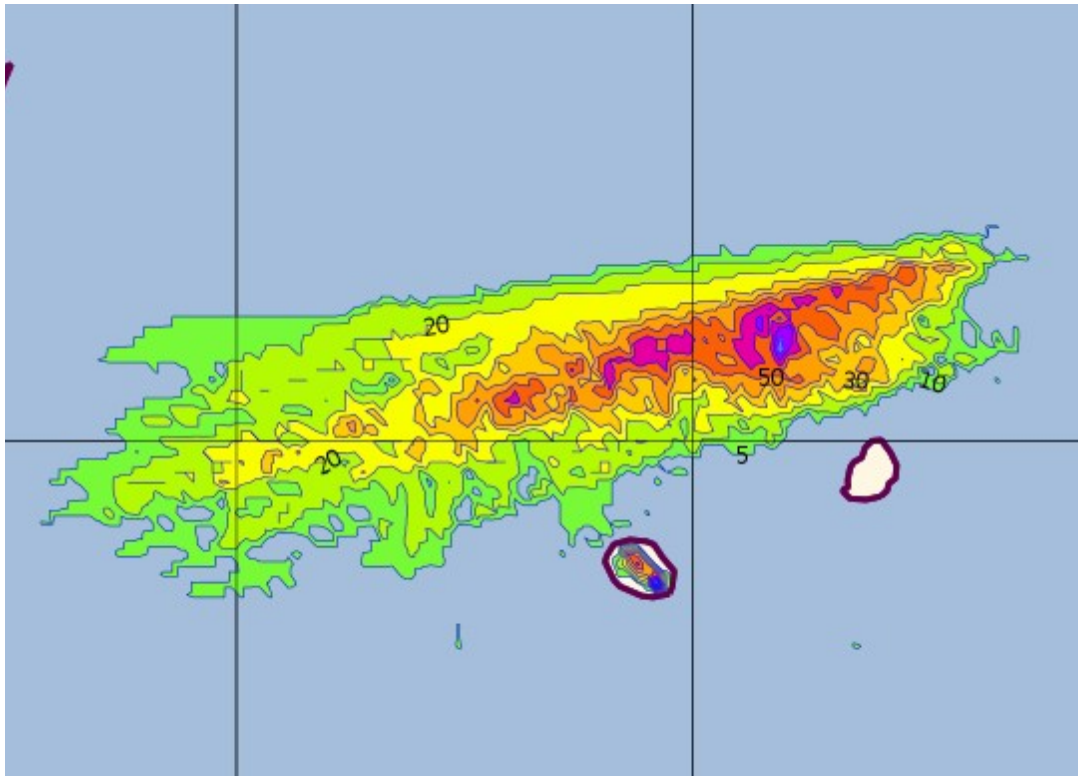
Freddy's rainfall 11/03 00-12Z



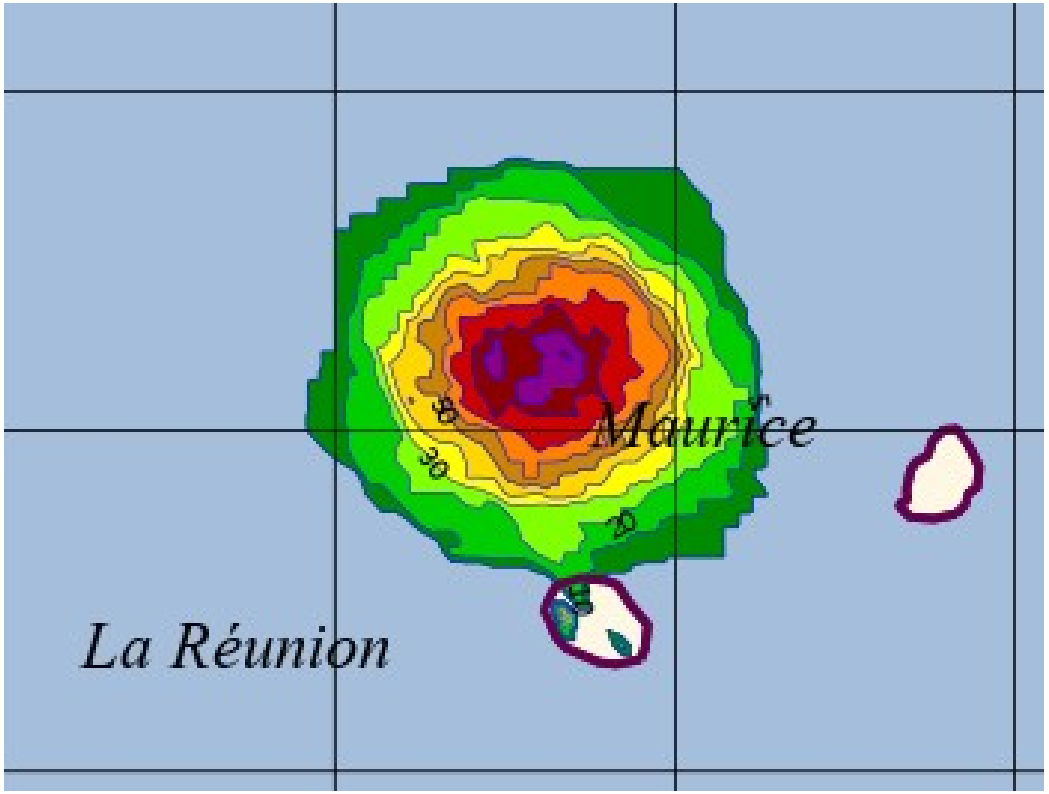


Tools : numerical models

Future PE-Arome Late 2023

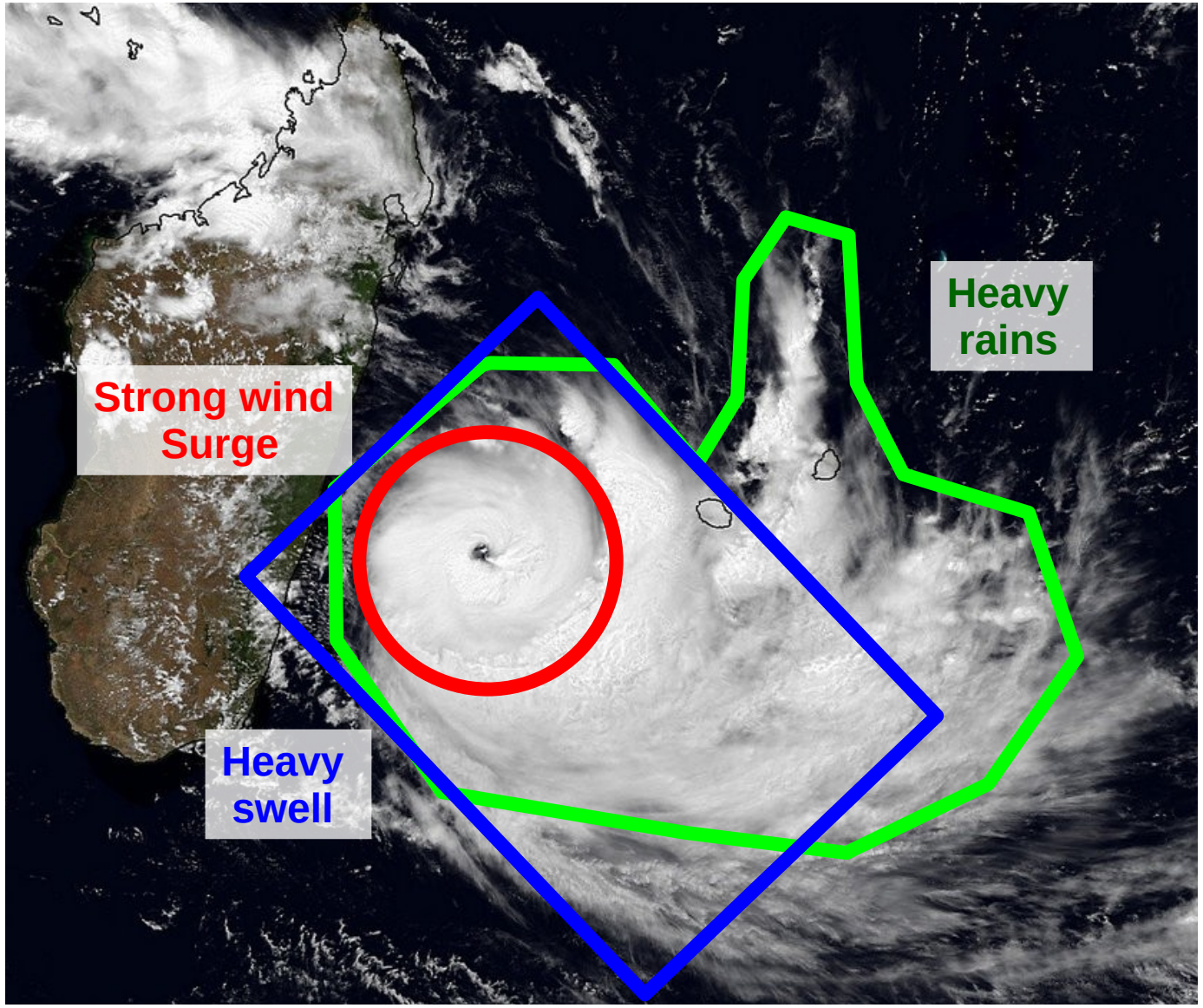


PEARO Probability of RR exceeding 100mm in 24h during FREDDY

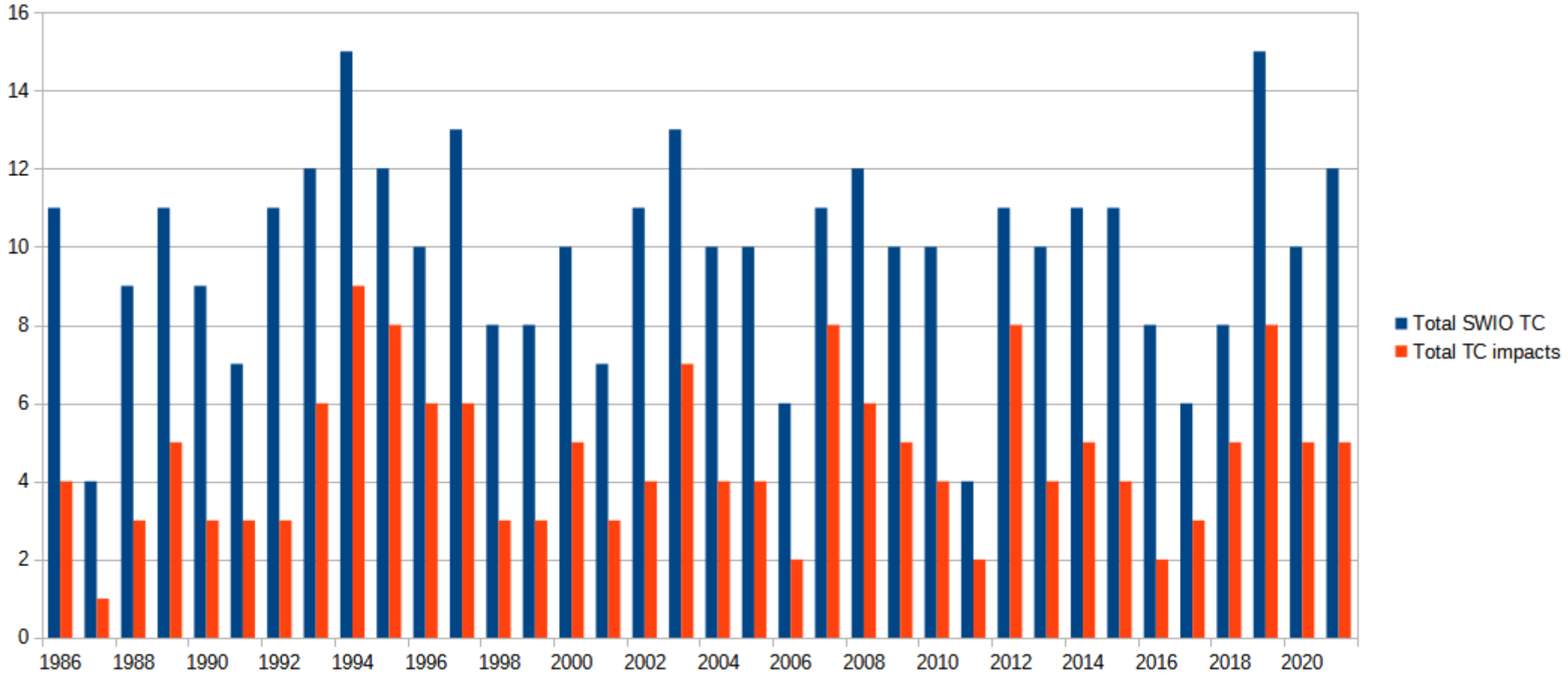


PEARO Probability of gusts exceeding 150km/h during FREDDY

Tropical Cyclones hazards



Impact Climatology

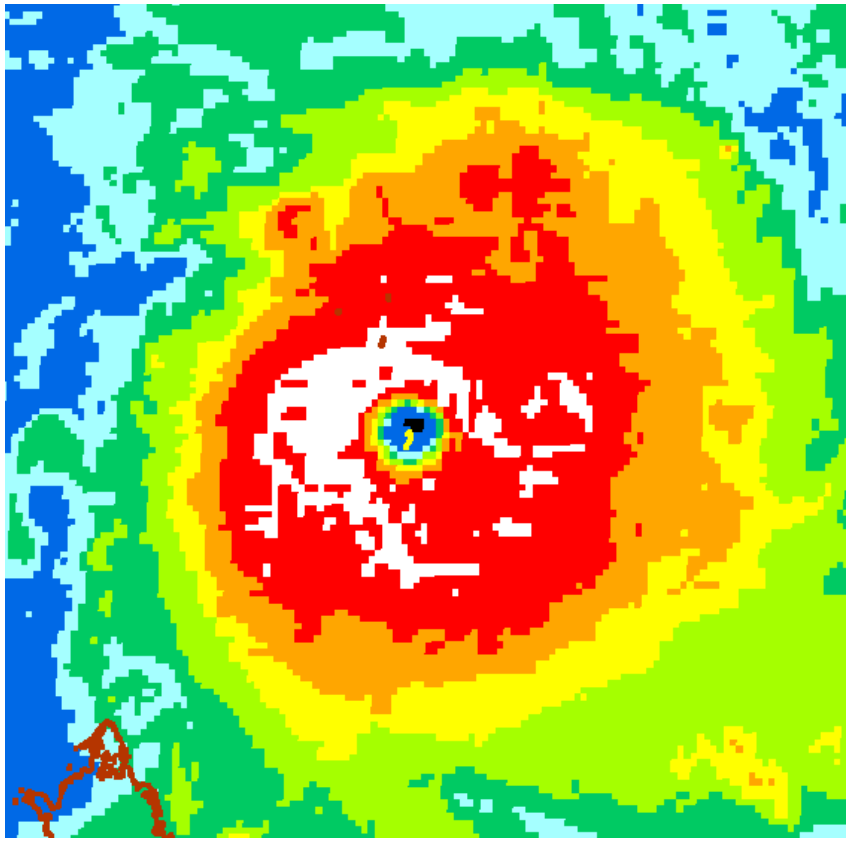


4 to 5 TC impacts (±2) every season (Heavy rains/Destructive winds/..)
45 % of all TC activity each season

1. Wind

Wind damage

VITC Fantala and Farquhar island



Wind damage

VITC Fantala and Farquhar island

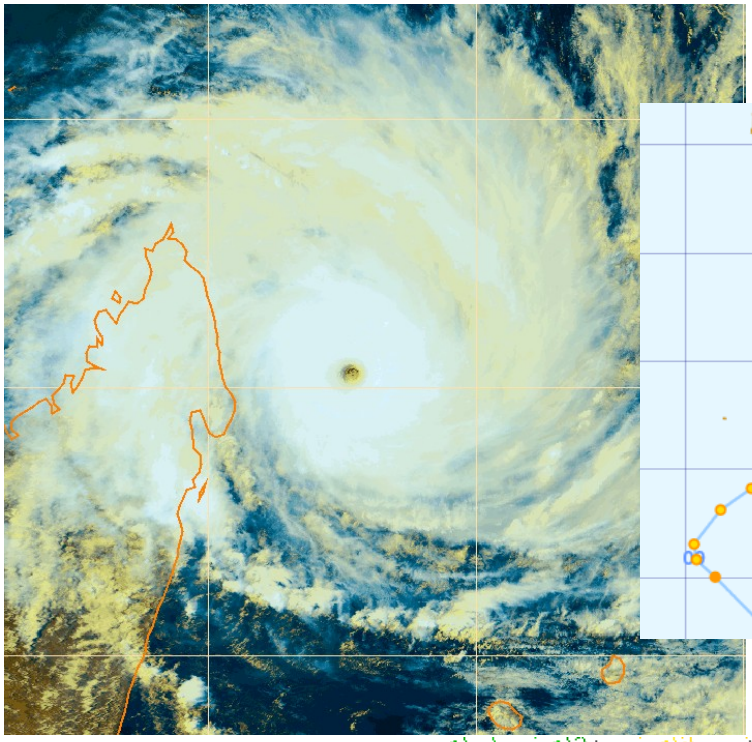
Wind damage

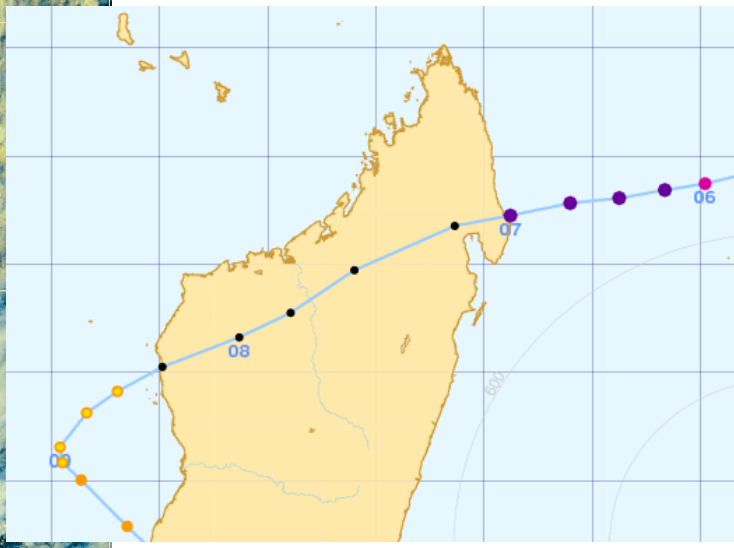
The danger of flying debris

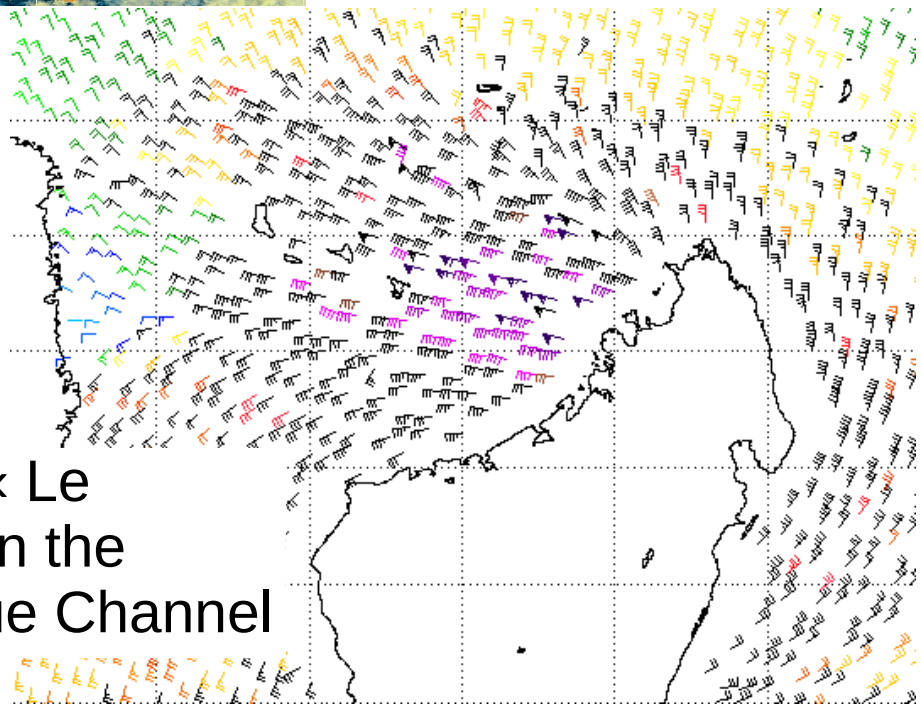
Historical Wind Impacts

GAFILO (2004)

- Landing near Antalaha (Madagascar)



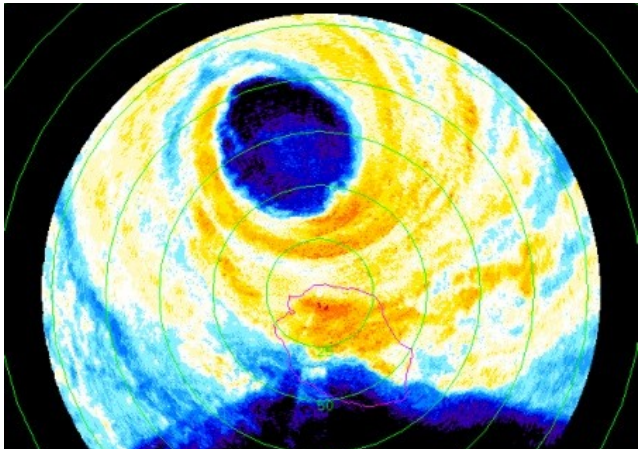


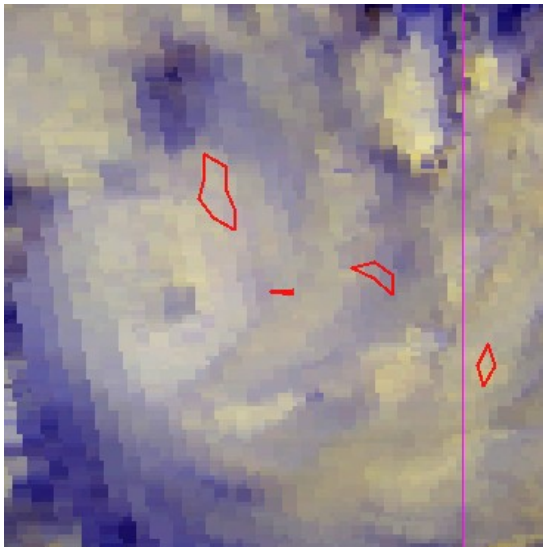


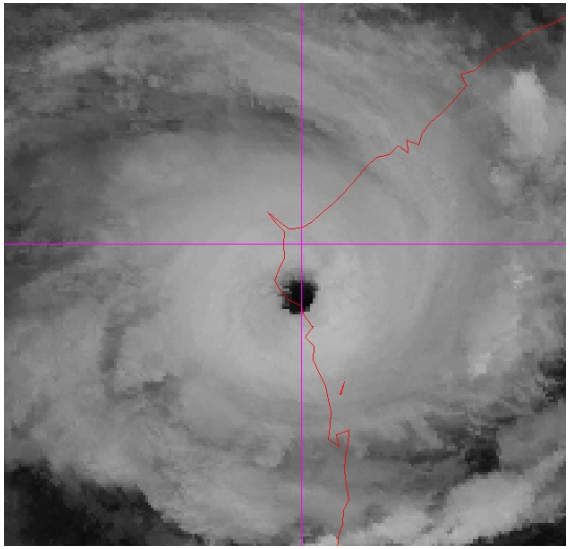
- Sinking of « Le Samson » in the Mozambique Channel

Historical Wind Impacts

ENAWO (2017) / DINA (2002) / ELINE (2000) / HOLLANDA (1994) / KAMISY (1984) / ELINAH (1983) / ….

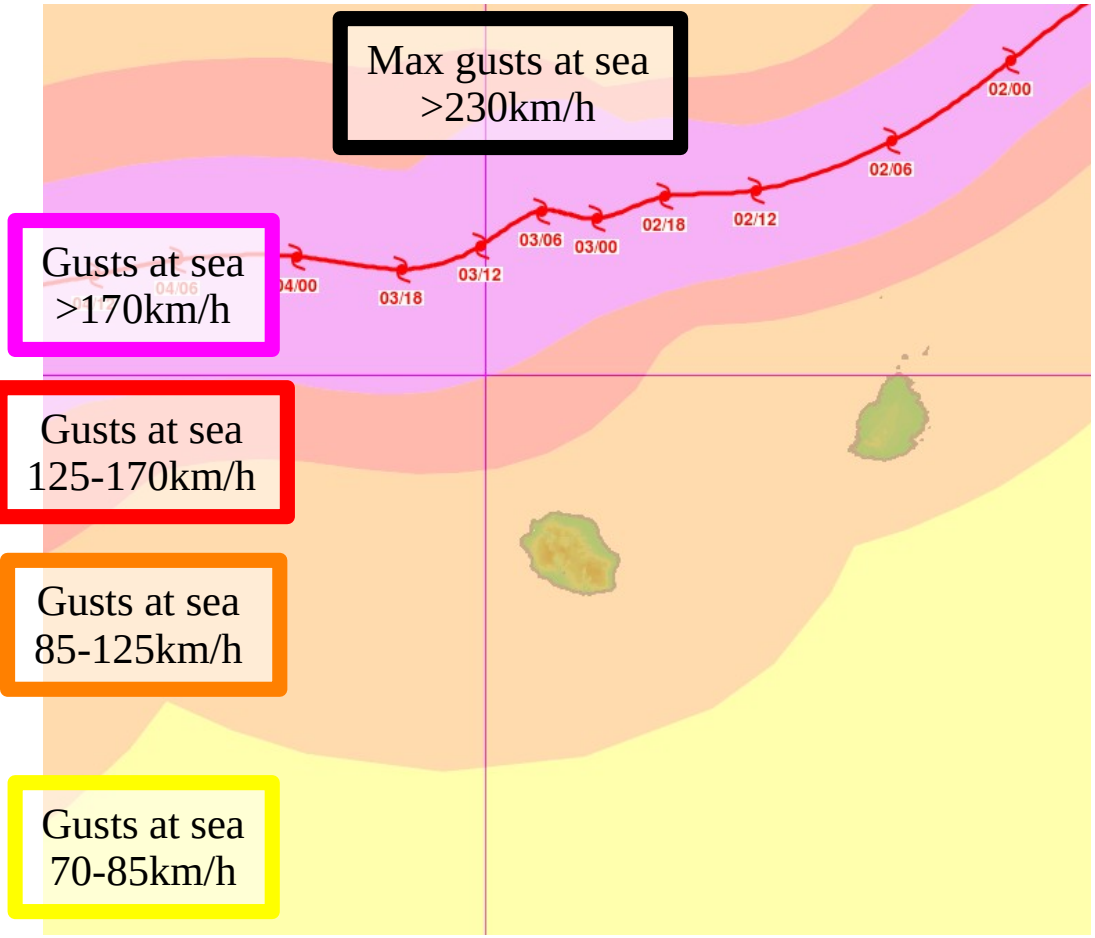




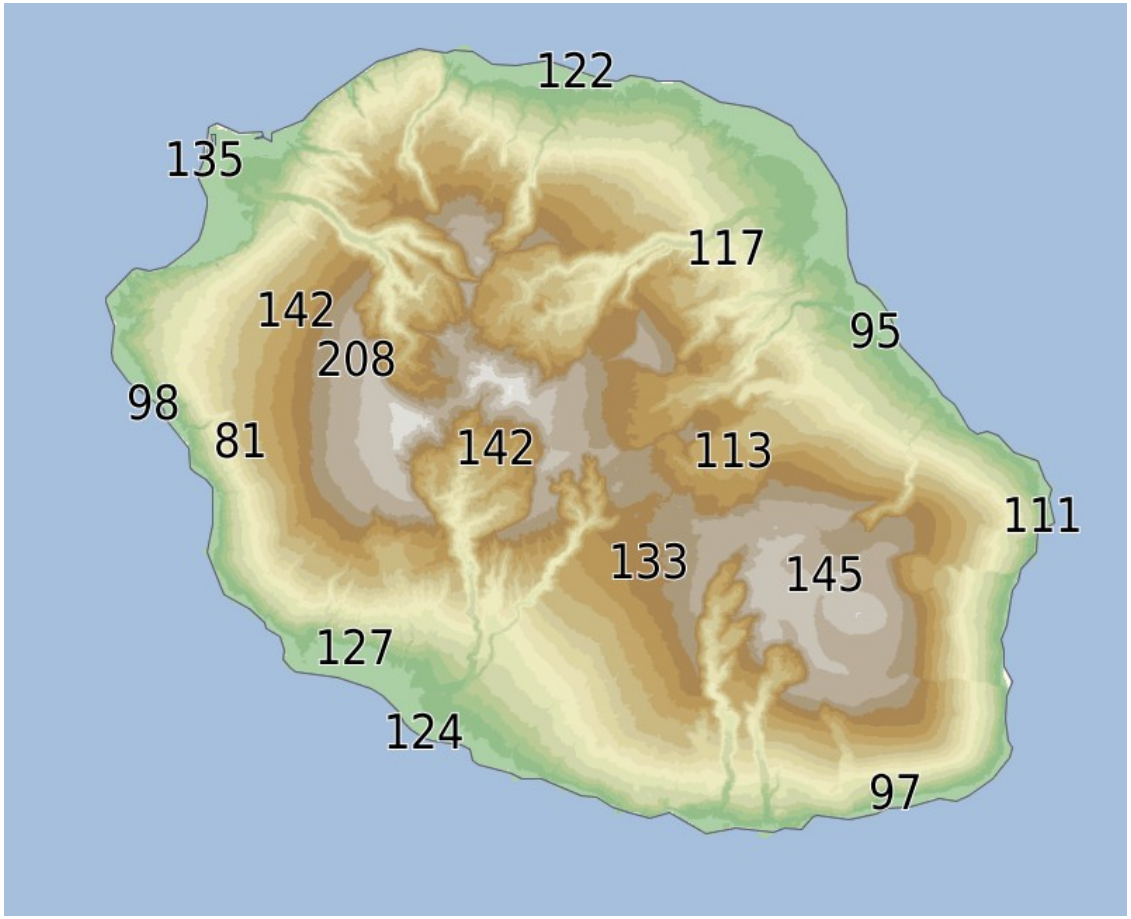


TC Windfield

Batsirai windfield



Maximum gusts observed during Batsirai (km/h)



The strongest winds are confined to a very small part of the TC

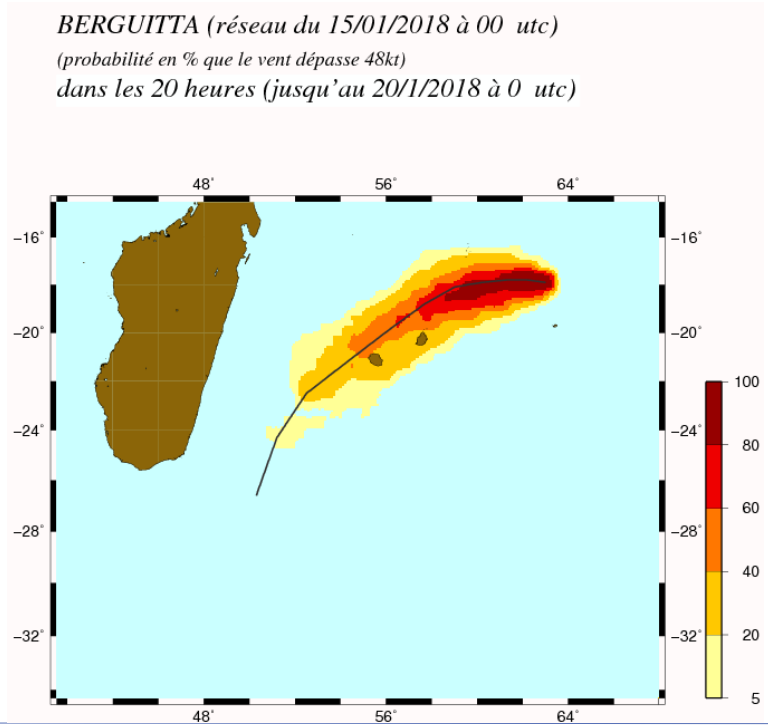
Mountainous areas can experienced lower and stronger winds than over sea

Wind forecast – Mid/Long range (> 2-3 days before)

Challenge :

- Strongest winds limited to a small area → Will the TC come close enough ?
- Wind direction depends on the side of the TC → Will the TC pass N or S ?

Use probabilistic information and communicate on uncertainty

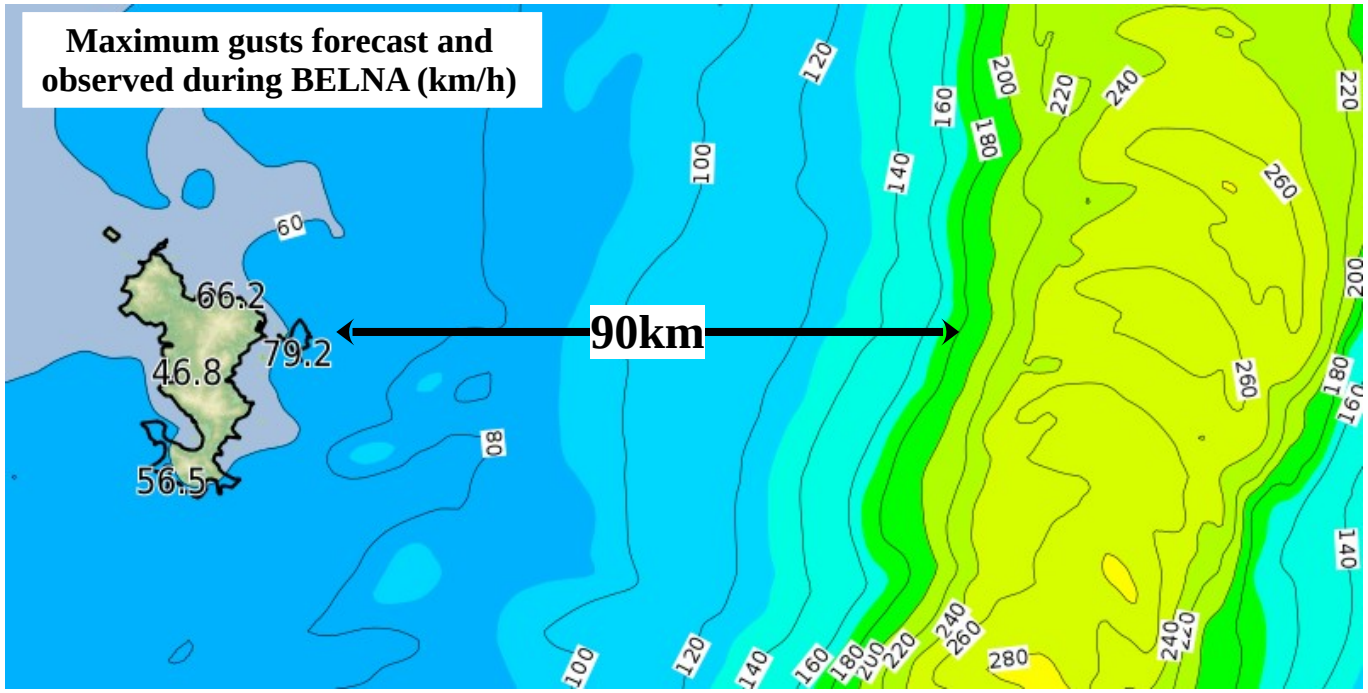


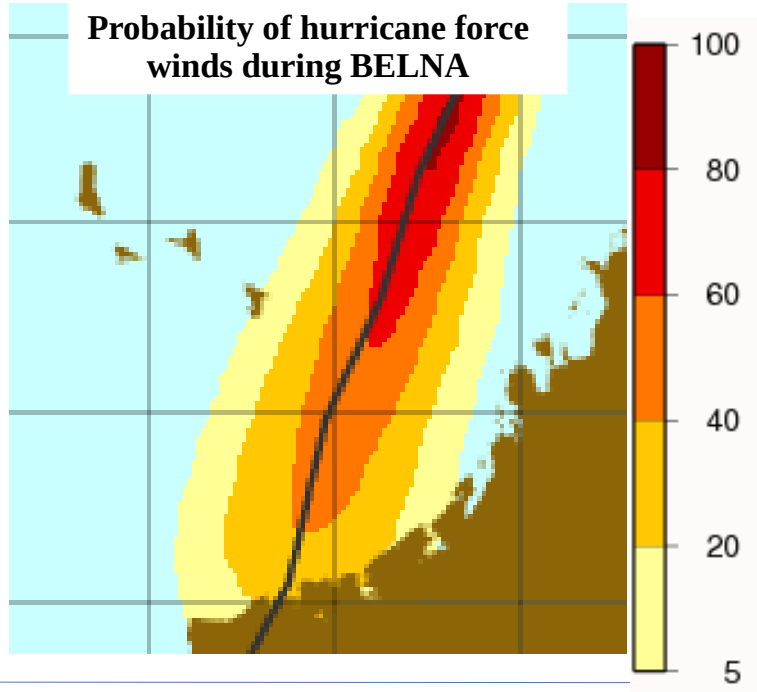
Wind forecast – Short range (1 day before)

Challenge :

- Still uncertainty (90 km mean error at 24h range)
- Take into account effects of topography to give reliable forecast gusts

Use both probabilistic information and high resolution numerical model (Arome IO) if they represent well the TC and its track





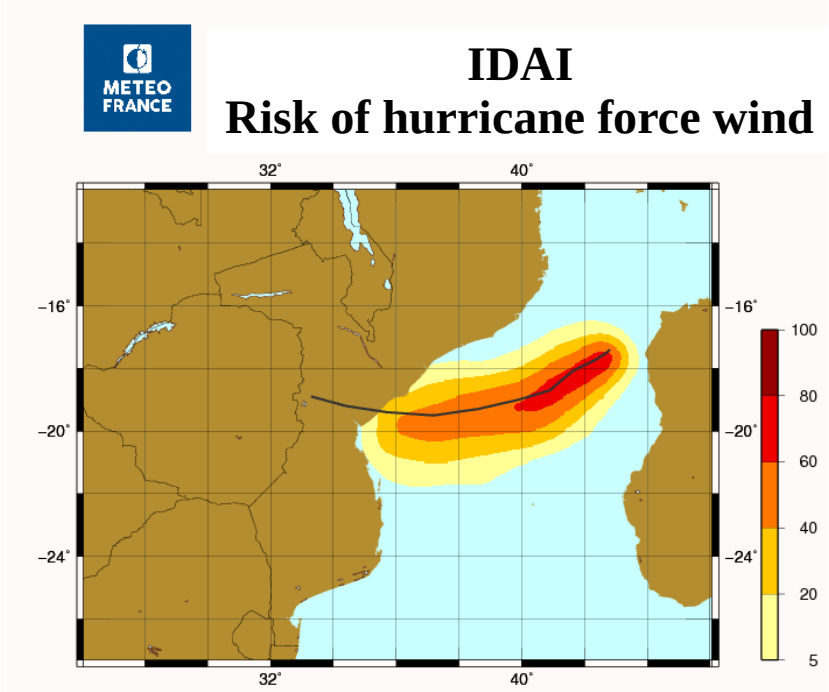
Wind forecast – In operations

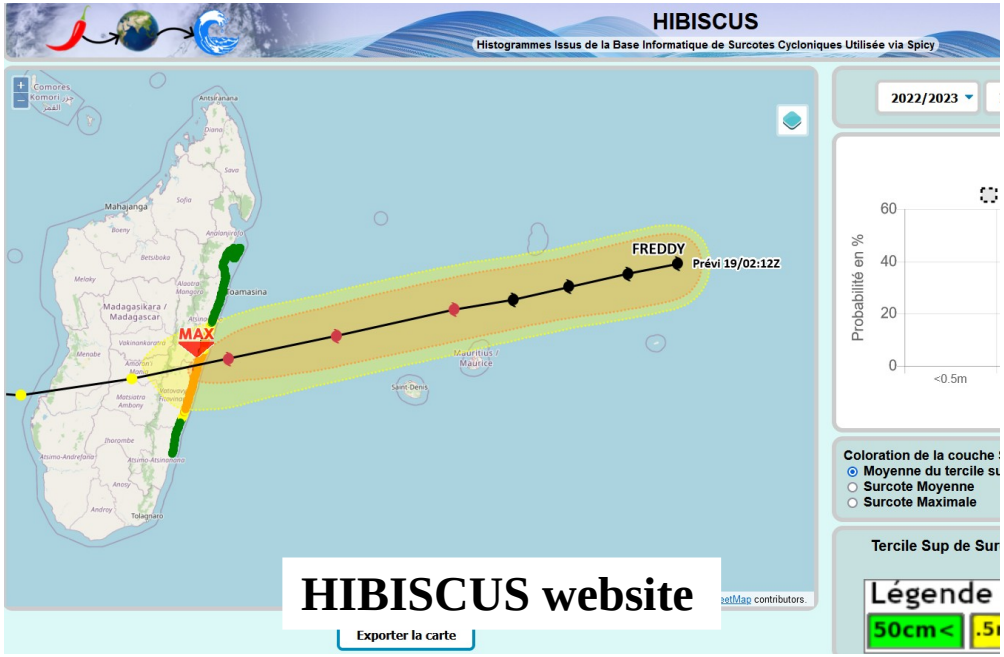
Numerical guidance :

- 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

Official RSMC bulletins / product :

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





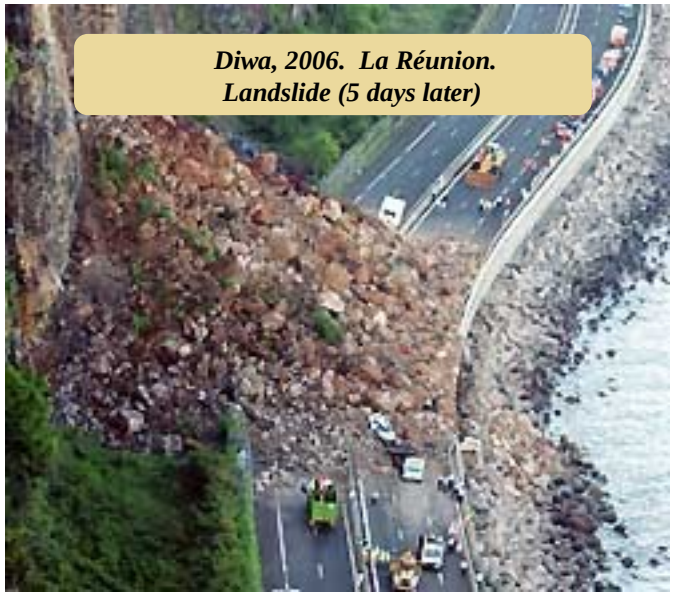
2. Rainfalls

Rainfalls consequences

Beira after IDAI (Denis Onyodi/AP Images)

Deadlier than wind generally

- Floodings
- Landslides
- Lack of drinking water and risk of epidemics



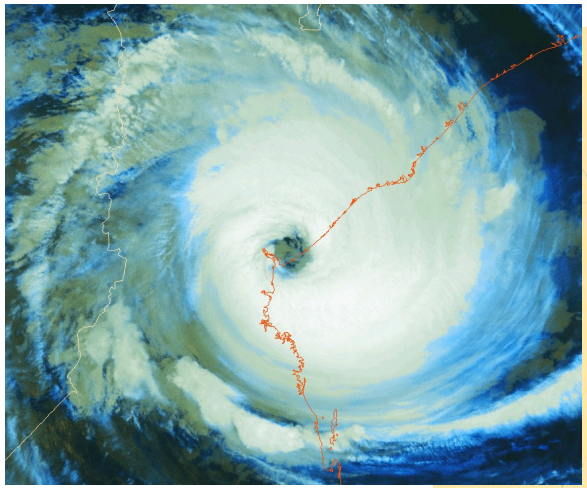
Diwa, 2006. La Réunion.
Landslide (5 days later)

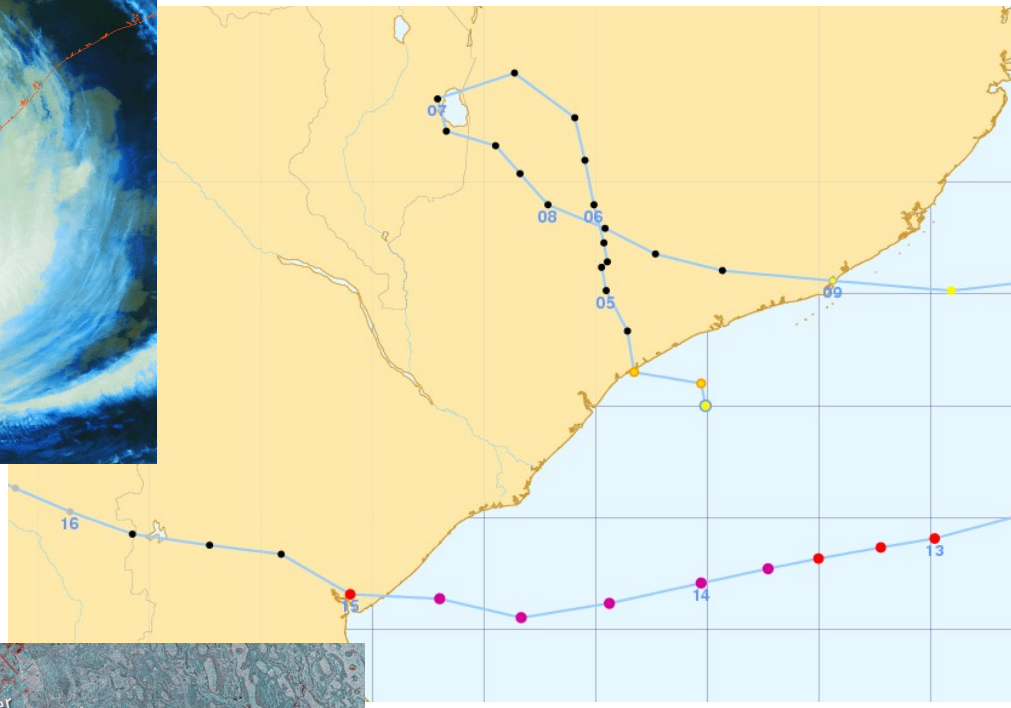
TC Bonita Madagascar, 1996

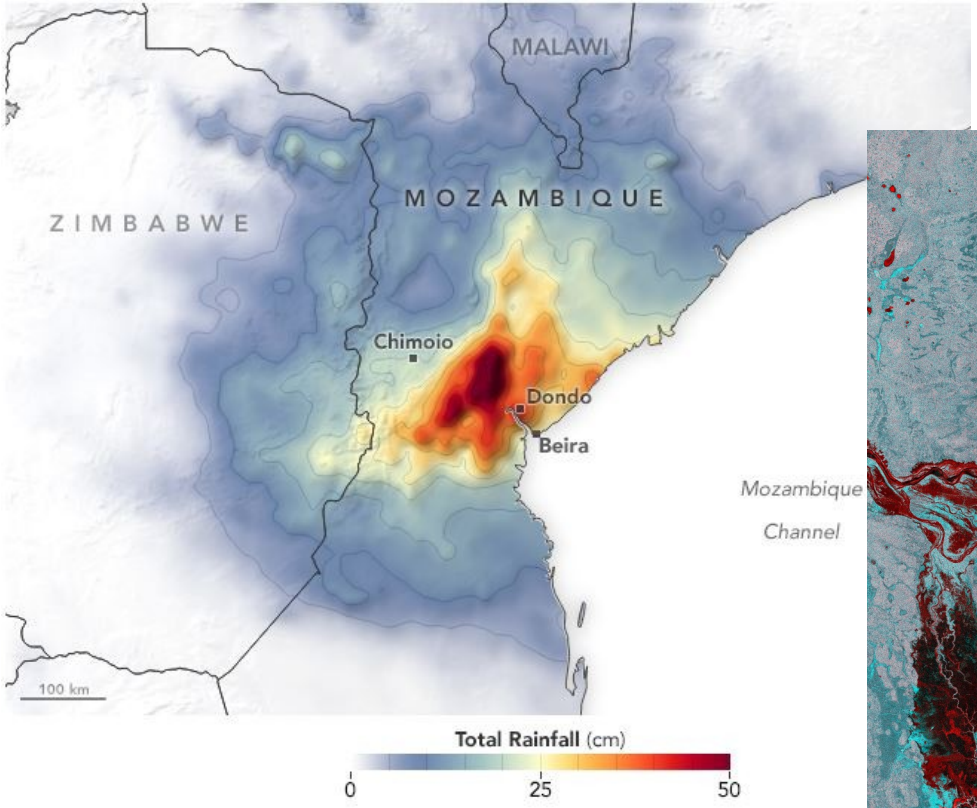
Historical Rain Impacts

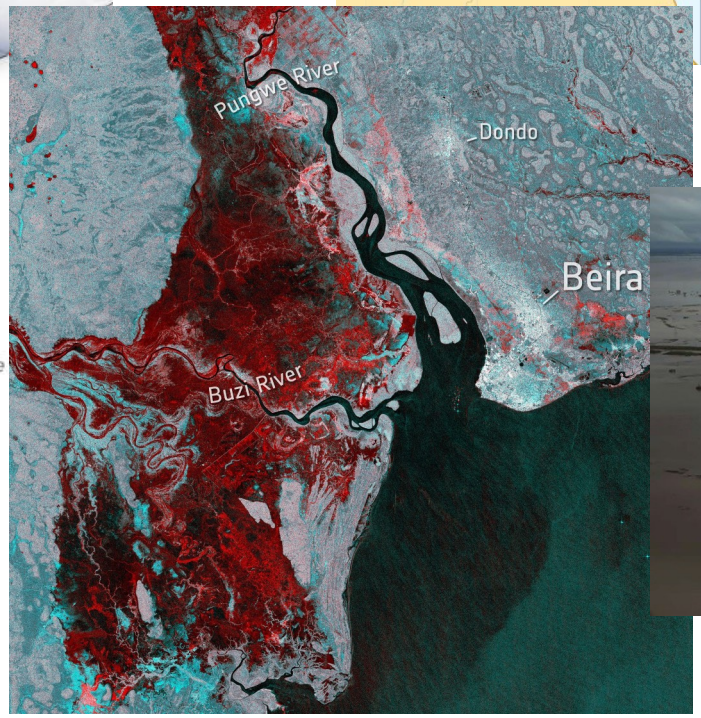
IDAI (2019)

- Landing near Beira (Mozambique)









Historical Rain Impacts

FREDDY (2023)

- Landing near Quelimane (Mozambique)
- Floods in Malawi (morning of 12/03)

Flooding in Nsanje, Malawi, 16 March 2023. Photo: Malawi Red Cross Society

People cross a raging river in Blantyre, Malawi, Monday, March 13, 2023. THOKO CHIKONDI / AP

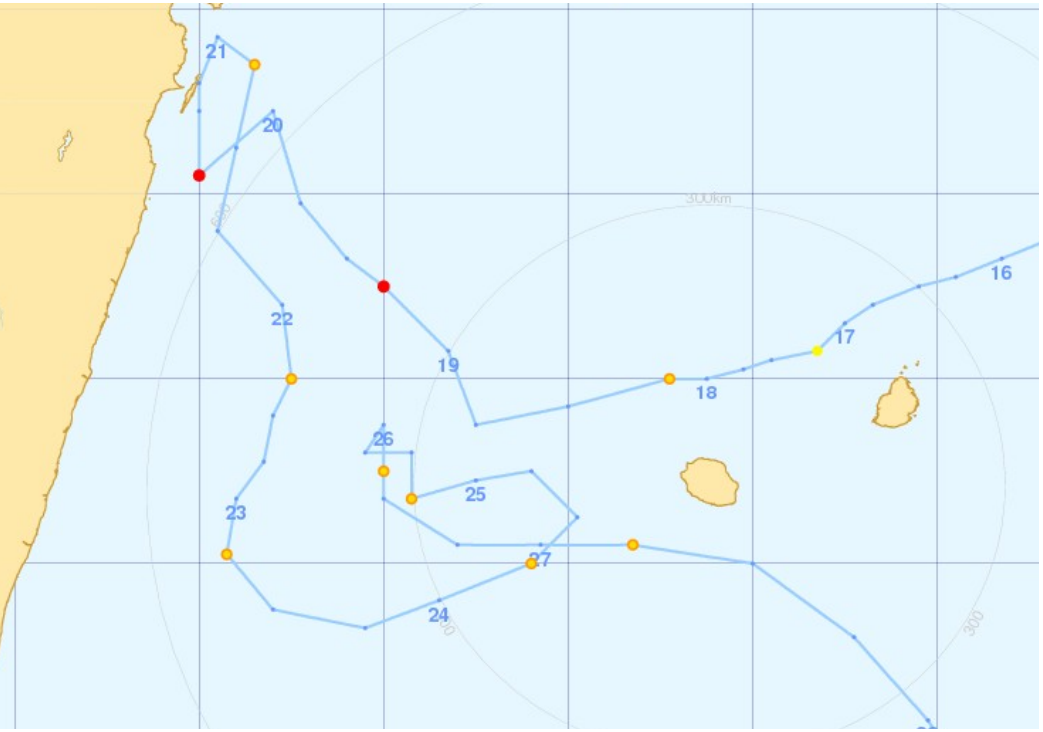
This handout photograph taken and distributed by UNICEF on March 12, 2023 shows people walking along a street damaged by the impact of Cyclone Freddy in the city of Quelimane. ALFREDO ZUNIGA / AFP

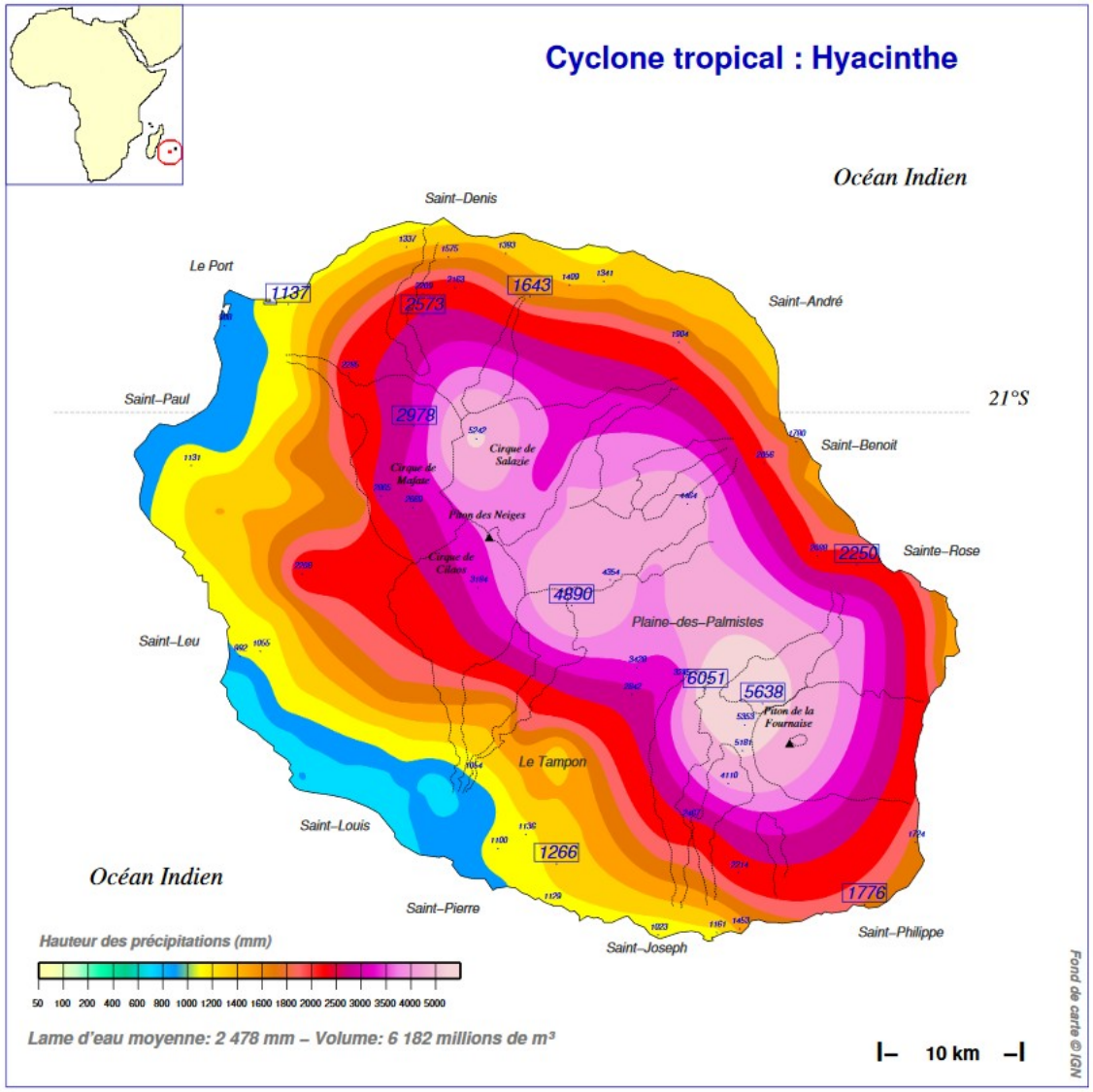
Historical Rain Impacts

HYACINTHE (1980)

- **W**orld **R**ecord rainfall in La Reunion

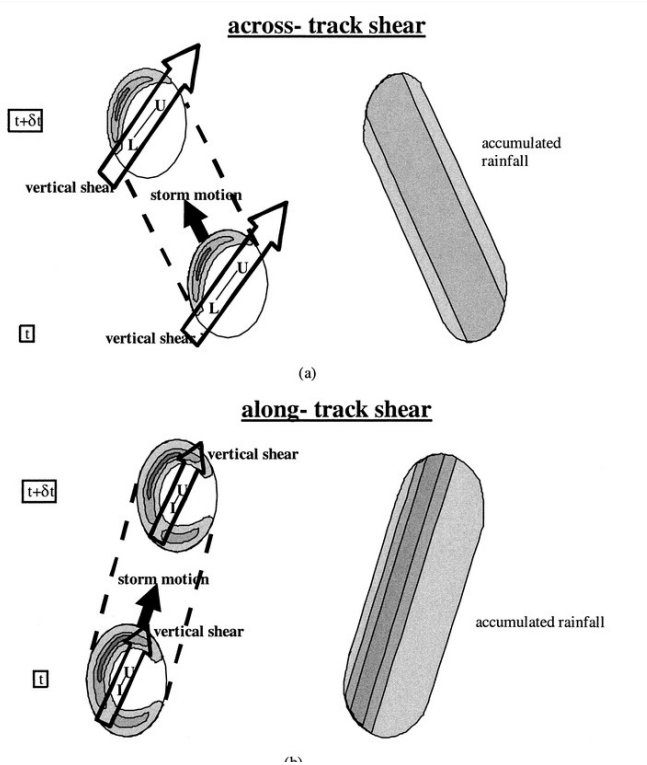
  6083mm in 15 days





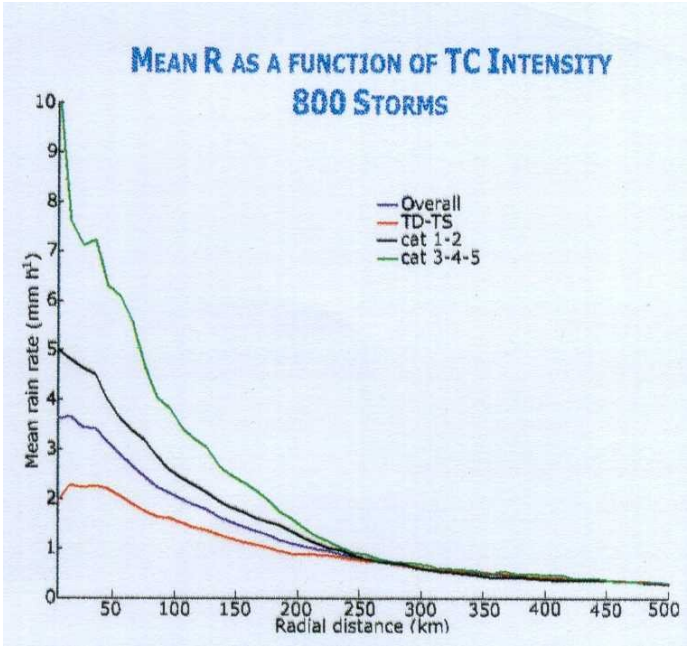
TC rainfall

From Rogers et al. (2003)



It depends on many parameters interacting at the same time:

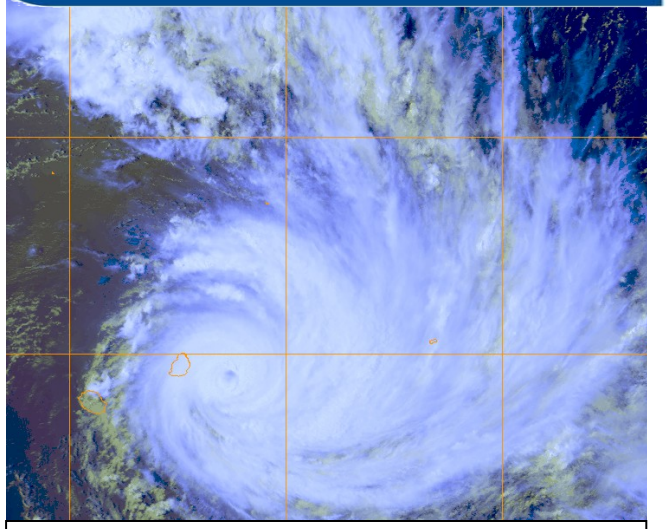
- Cyclone structure and environment (shear / dry air / ..)
- Track and motion speed
- Topography



Compact cyclone

Litanne 13/03/1994 at 12h53 UTC

Broad and asymmetric cyclone

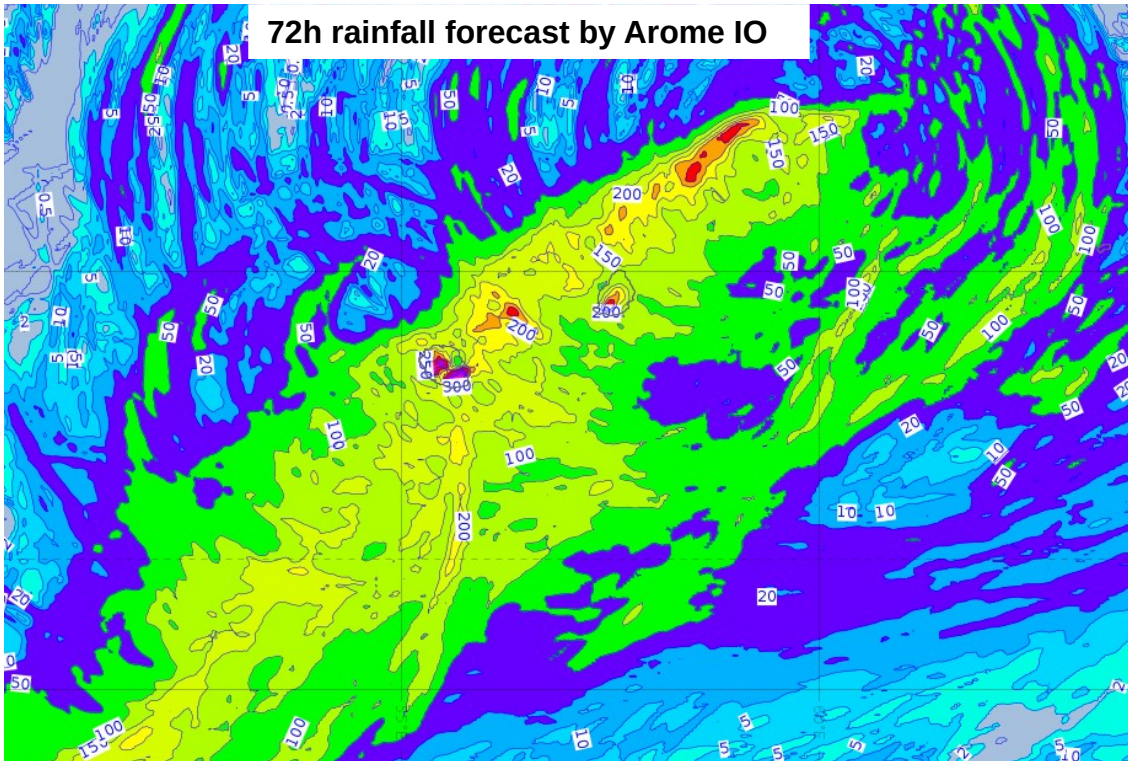


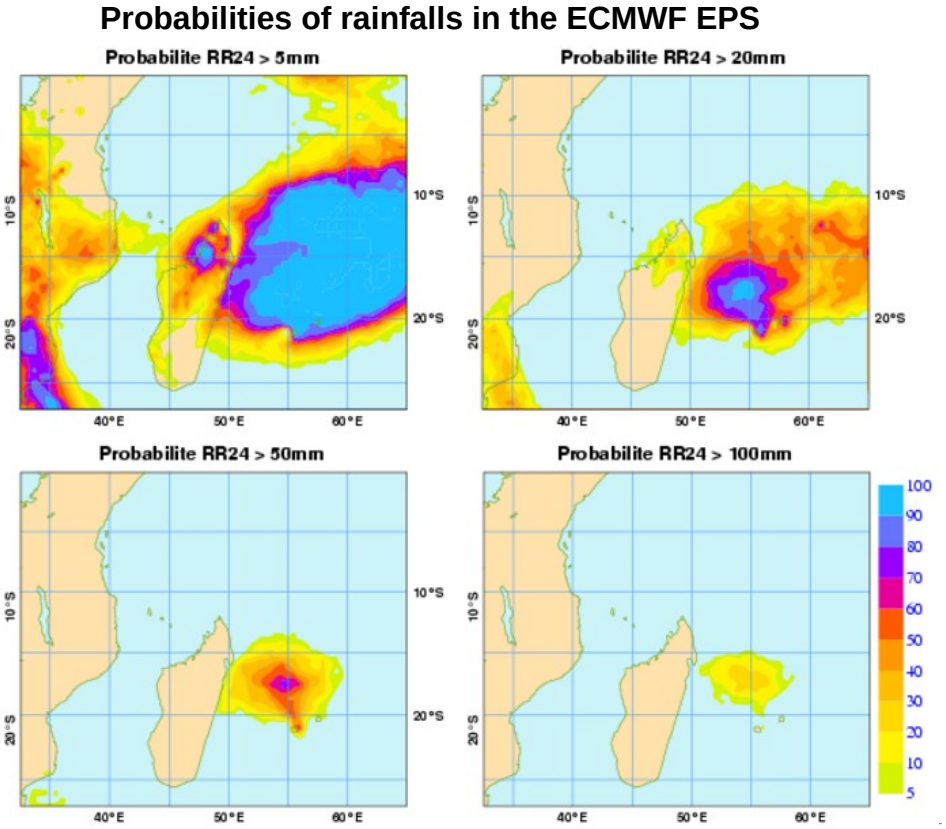
Anacelle 11/02/1998 at 10h32 UTC

Rainfall forecast – Mid/Long range (> 2-3 days before)

Challenge : Very uncertain forecast highly depend on its precise track and structure

Use probabilistic forecast and eventually deterministic guidance in agreement with the official forecast **to assess the uncertainty and identify the most exposed areas. It is often too early to forecast reliable quantities.**



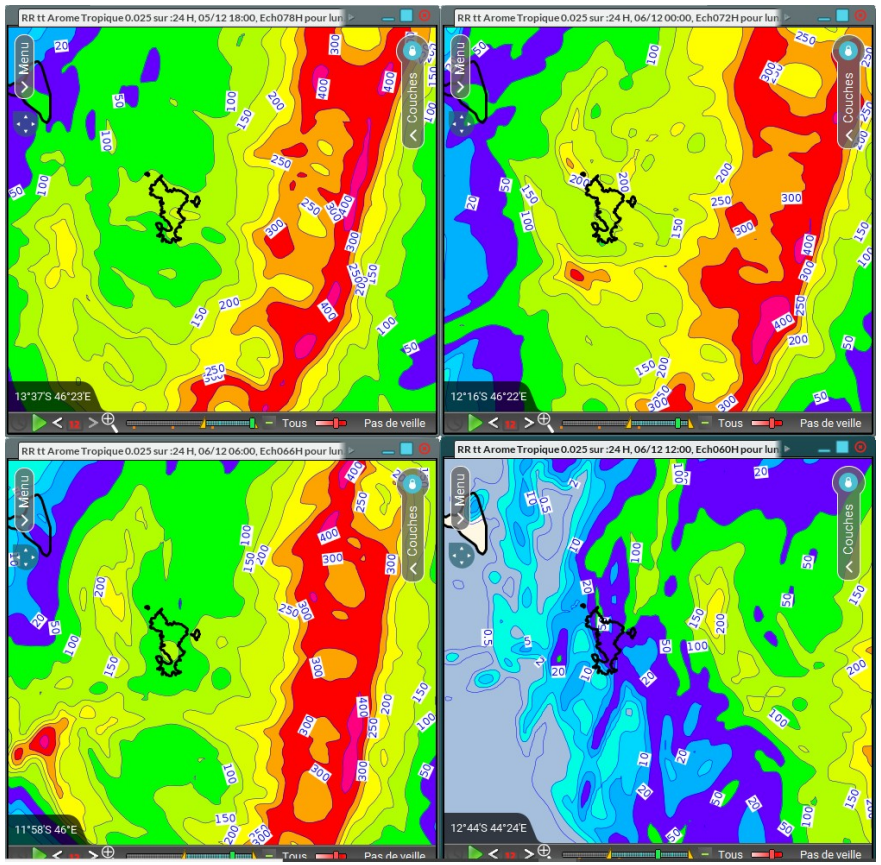


Rainfall forecast – Short range (1 day before)

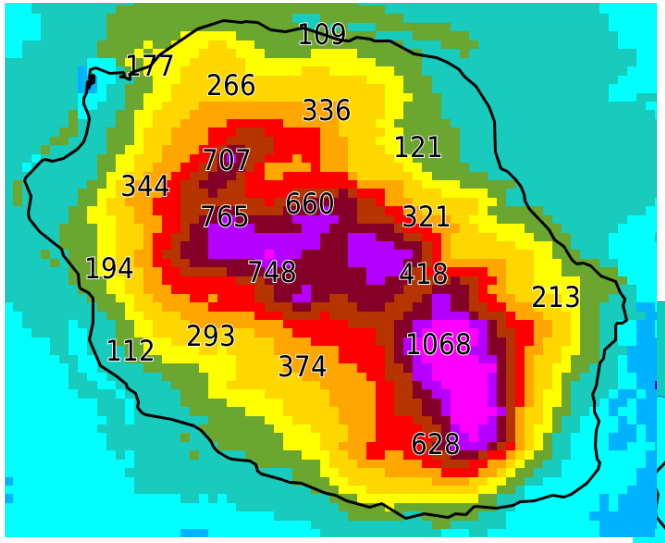
Challenge : Still uncertain especially within spiral bands far from the inner core

Use probabilistic forecast and several run high resolution model (Arome IO) to assess a range of possible total rainfalls.

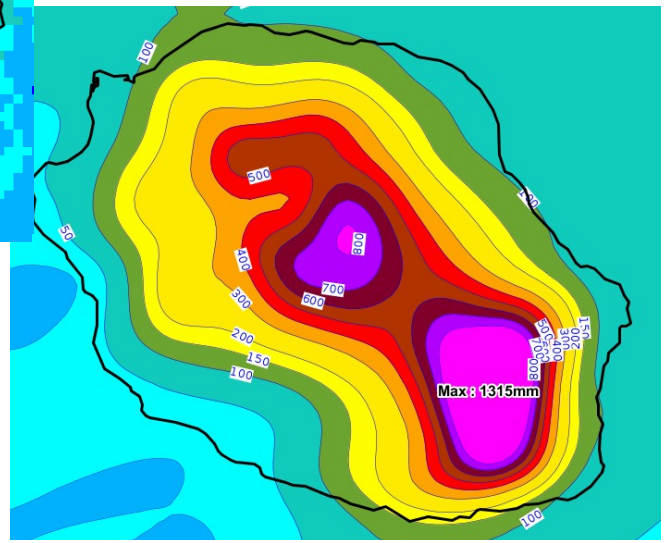
RR24h of 4 consecutive runs - BELNA



BATSIRAI



RR24h observed



RR24h forecast by Arome IO

Rainfall forecast – In operations

Numerical guidance :

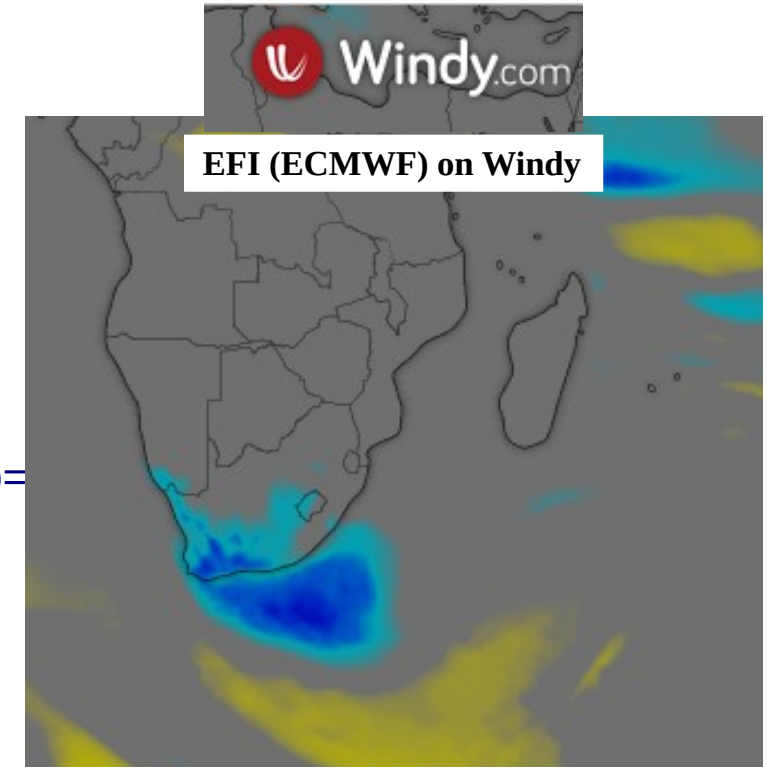
- Meteociel (AROME IO) in French
  https://www.meteociel.fr/modeles/arome.php?ech=3&mode=1&map=60
- RSMC La Réunion Extranet
  https://pro.meteofrance.com/page/index/affiche/id/76436
- ECMWF (Extreme Forecast Index EFI + Rain forecast) :
  https://charts.ecmwf.int
- Windy (EFI + Accumulated rainfall)

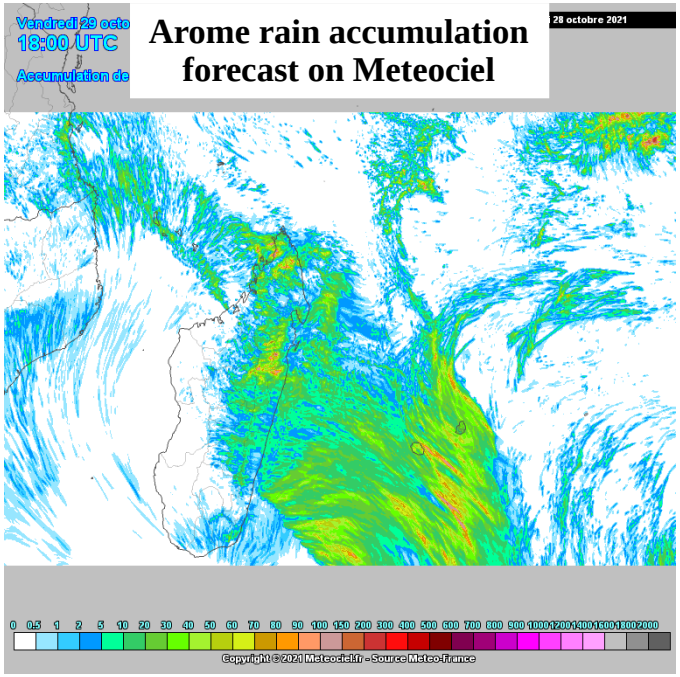
Official RSMC bulletins :

- WTIO 30 / WTIO 31

IN TERMS OF EXPECTED IMPACTS, HEAVY RAINS ARE STILL TO BE EXPECTED ON THE ISLANDS OF THE COMOROS ARCHIPELAGO IN THE MARGIN OF THE STORM THAT CAN REACH 100 TO 200MM IN 24H, UNTIL TOMORROW SATURDAY. THE GUSTS SHOULD REMAIN MODEST OF ABOUT 60 KM/H.
FOR TANZANIA, WITH THE WEAKENING OF THE JOBO SYSTEM AT THE LANDING, THE IMPACTS COULD REMAIN LIMITED IN TERMS OF WIND BUT HEAVY RAINS ARE EXPECTED AT THE LANDING ZONE. FROM SUNDAY, WE CAN EXPECT TO HAVE ACCUMULATIONS THAT CAN REACH 250/300M IN 24H, THAT IS TO SAY QUANTITIES EQUIVALENT TO THE MONTHLY ACCUMULATION FOR A MONTH OF APRIL.

WTIO30





3. Swell

Swell damage

BEJISA swell

COLINA (Jan. 93) swell
H1/3 6,1m Ste-Marie Hmax 9,4m

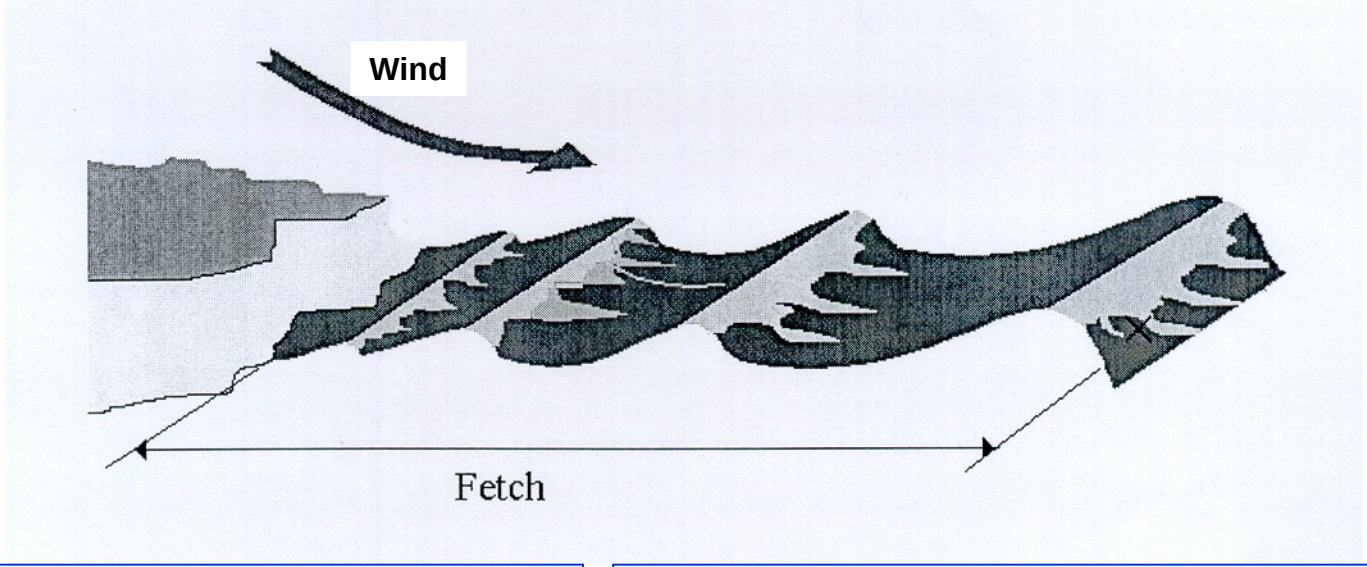
GAMEDE swell
H1/3 7,0m Pte du Gouffre Hmax 11,7m

Wave formation

Duration : time during which the wind blows on the generating area

Wave characteristics depend on :

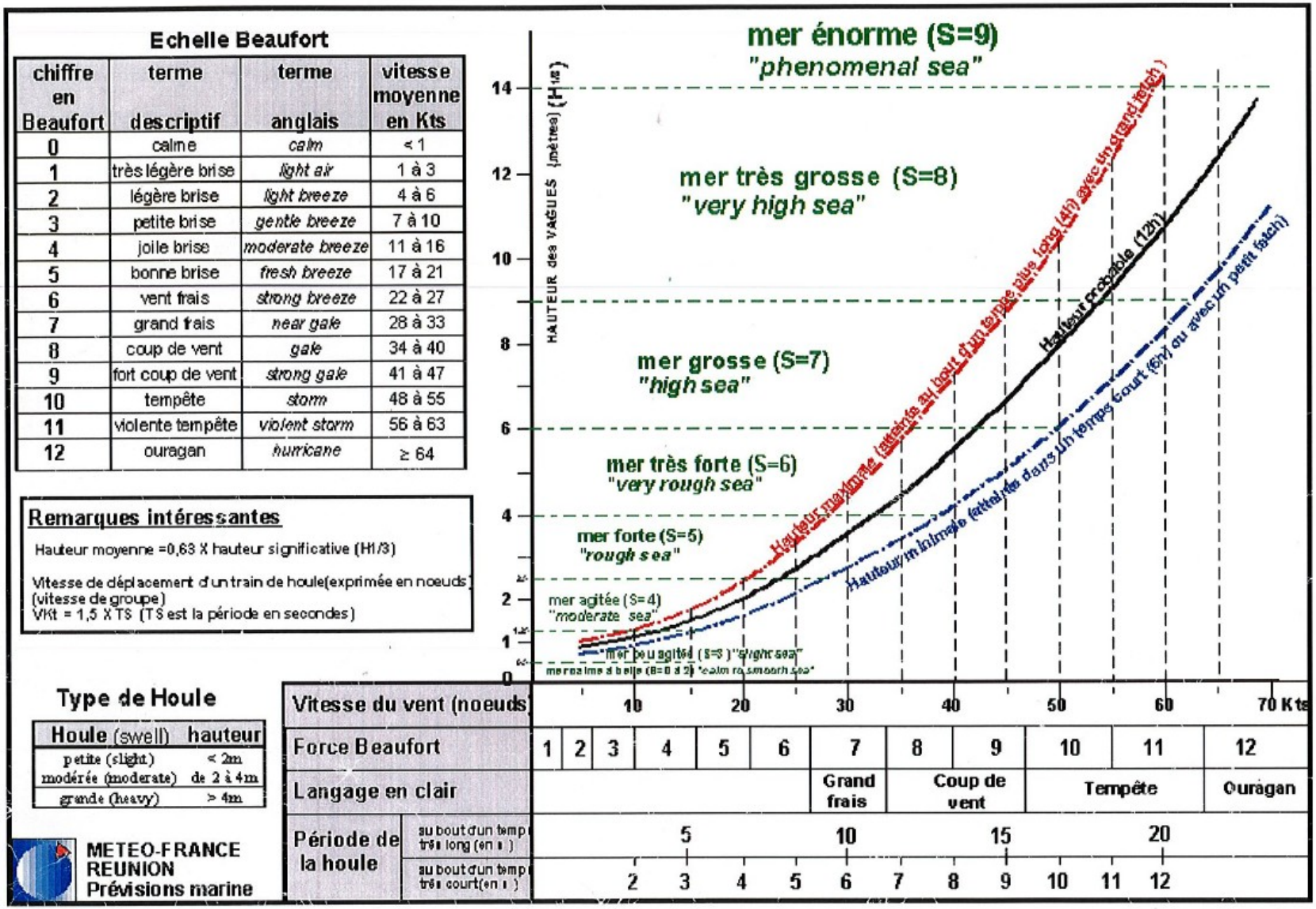
- Wind speed
- Duration
- Size of the generating area (Fetch)



FETCH : Length of the generating area

H1/3 : significant height : mean height of the third highest waves

Wave formation



Echelle Beaufort

chiffre en Beaufort	terme descriptif	terme anglais	vitesse moyenne en Kts
0	calme	*calm*	< 1
1	très légère brise	*light air*	1 à 3
2	légère brise	*light breeze*	4 à 6
3	petite brise	*gentle breeze*	7 à 10
4	jolie brise	*moderate breeze*	11 à 16
5	bonne brise	*fresh breeze*	17 à 21
6	vent frais	*strong breeze*	22 à 27
7	grand frais	*near gale*	28 à 33
8	coup de vent	*gale*	34 à 40
9	fort coup de vent	*strong gale*	41 à 47
10	tempête	*storm*	48 à 55
11	violente tempête	*violent storm*	56 à 63
12	ouragan	*hurricane*	≥ 64

Remarques intéressantes

Hauteur moyenne =0,63 X hauteur significative (H1/3)

Vitesse de déplacement d'un train de houle(exprimée en noeuds) (vitesse de groupe)
VKt = 1,5 X TS (TS est la période en secondes)

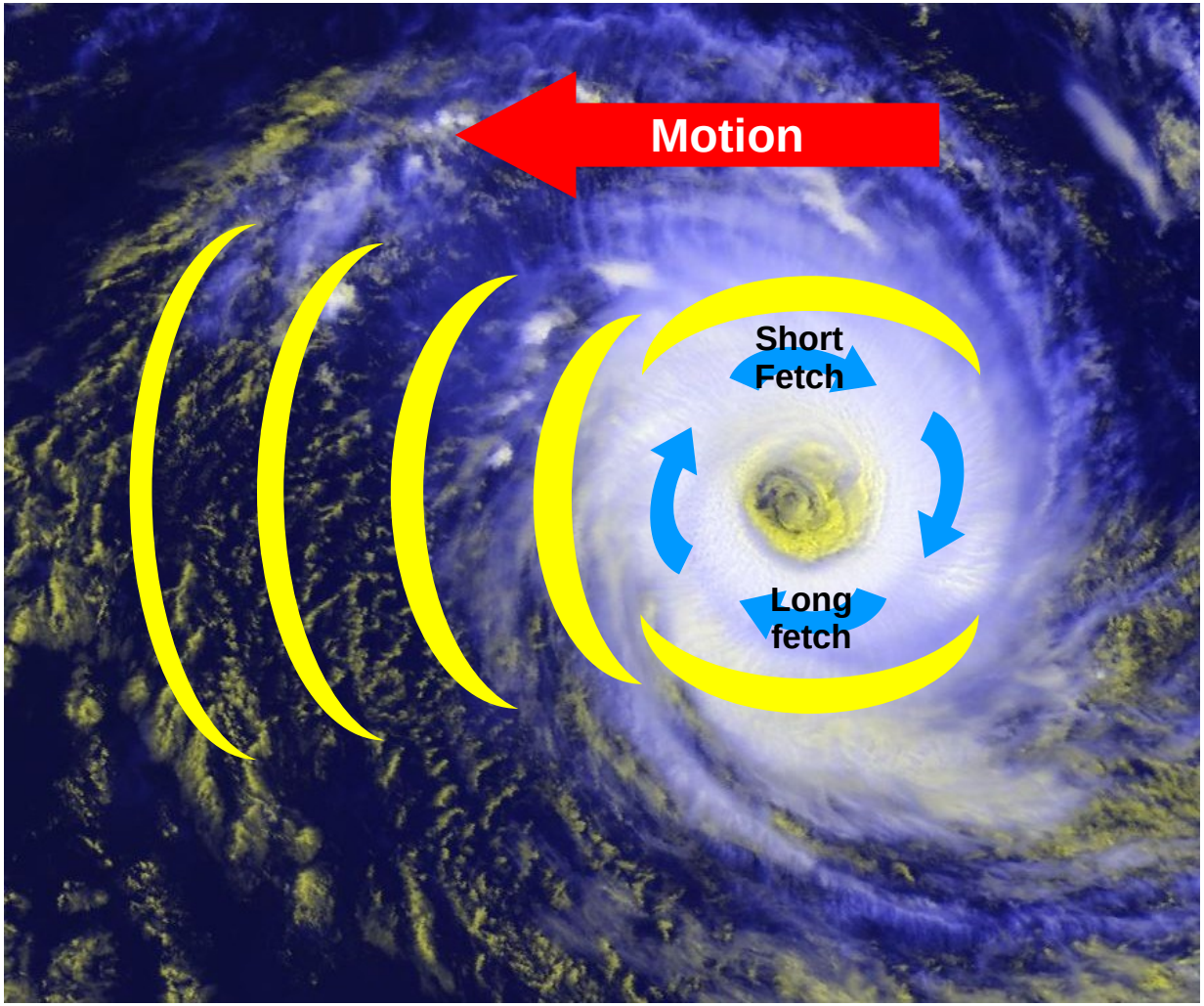
Type de Houle

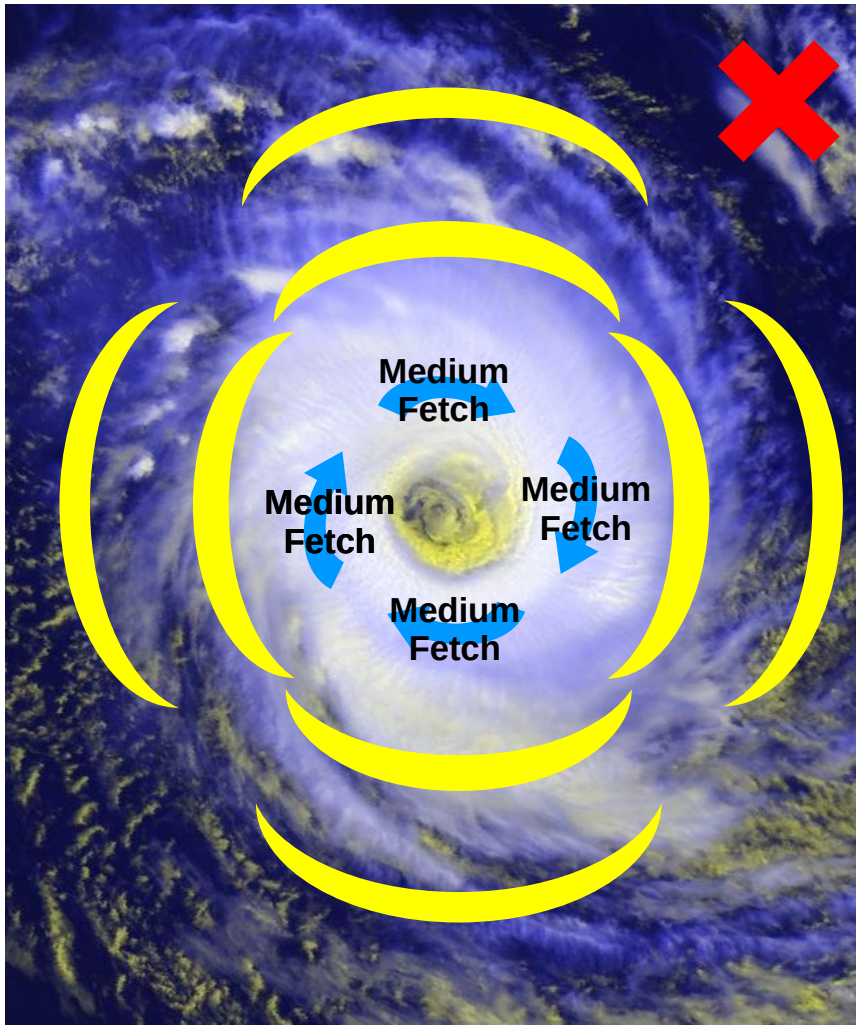
Houle (swell)	hauteur
petite (slight)	< 2m
modérée (moderate)	de 2 à 4m
grande (heavy)	> 4m

Vitesse du vent (noeuds)		10			20			30			40		50		60		70 Kts
Force Beaufort	1	2	3	4	5	6	7	8	9	10	11	12					
Langage en clair							Grand frais	Coup de vent		Tempête		Ouragan					
Période de la houle — au bout d'un temp très long (en s)					5			10			15			20			
Période de la houle — au bout d'un temp très court (en s)	2	3	4	5	6	7	8	9	10	11	12						

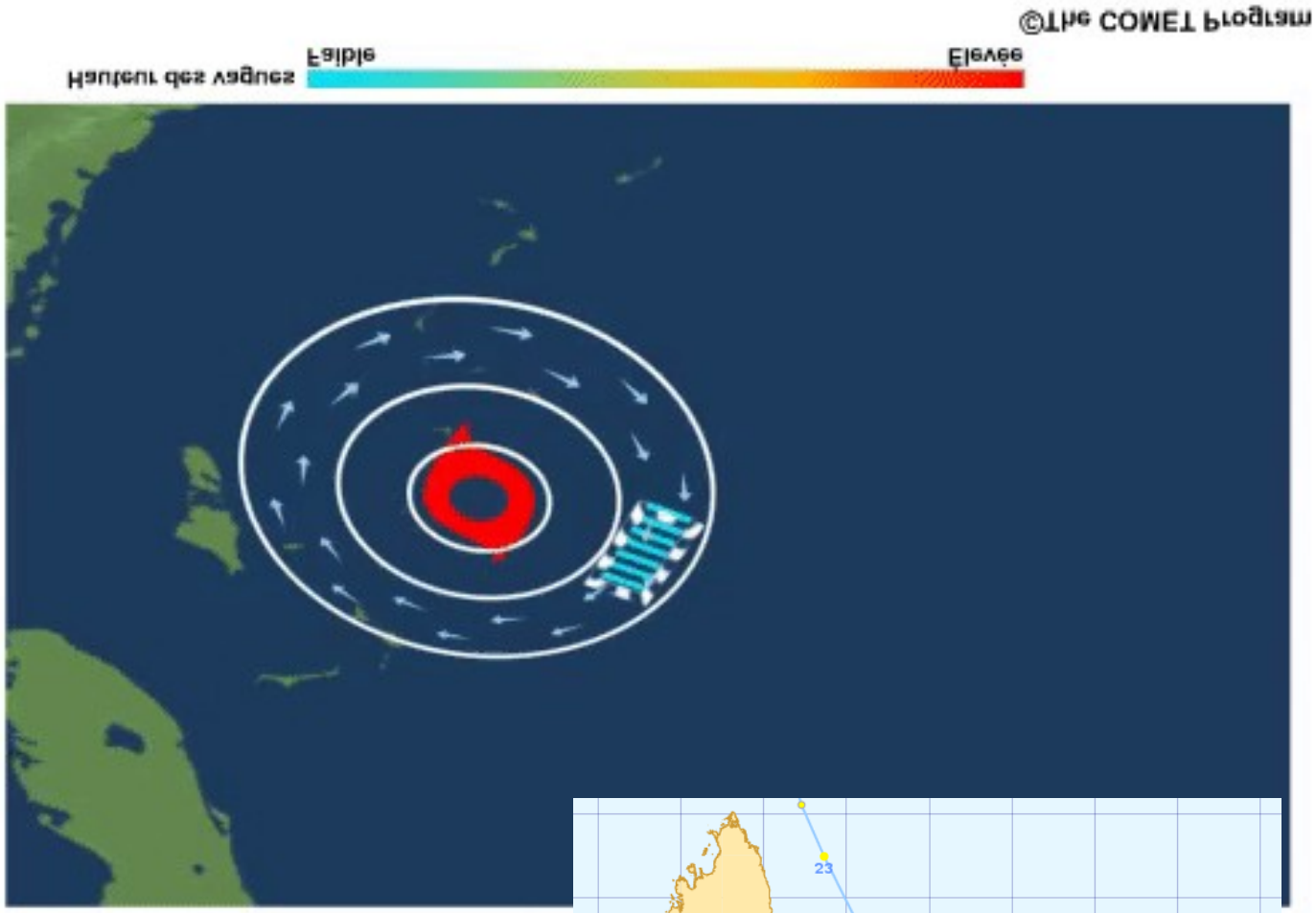
METEO-FRANCE
REUNION
Prévisions marine

Swell generation in a tropical cyclone

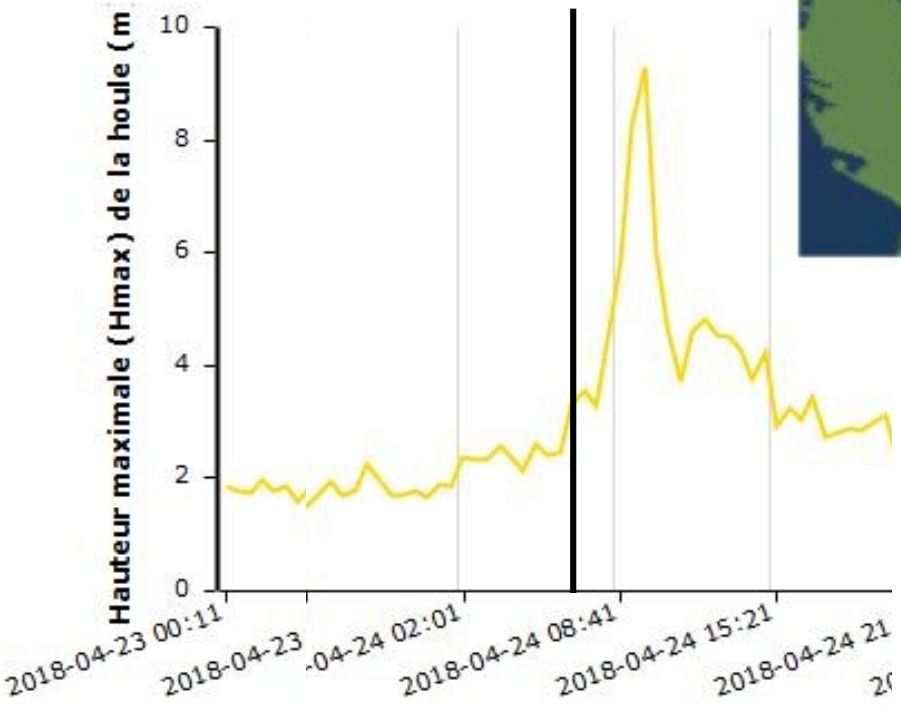




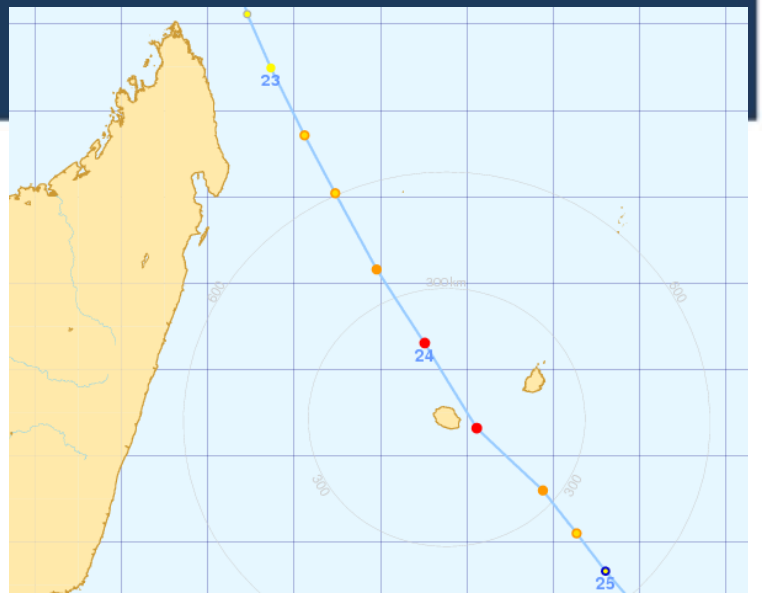
Dynamic Fetch - FAKIR



FAKIR time of arrival



FAKIR, swell measured at la Reunion

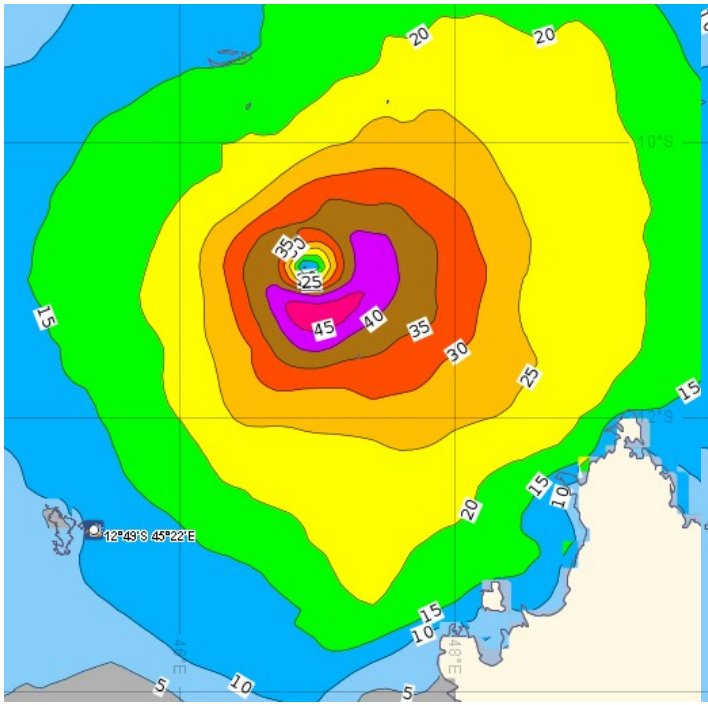


Swell forecast

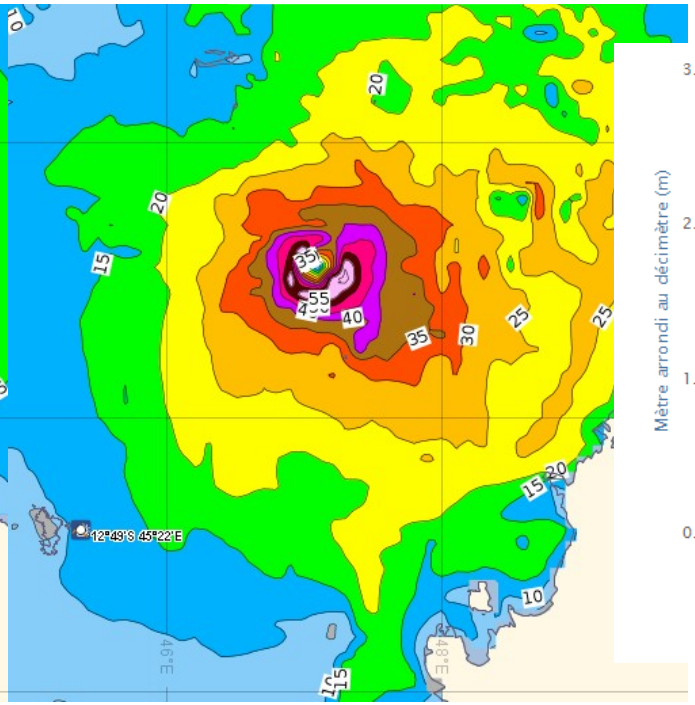
Challenge : Depends on the TC structure especially the extent of Near Gale force (R28) and Gale force (R34) winds and also on the track. Maximum intensity is not that much important.

Use deterministic forecast in agreement with the official track and structure.

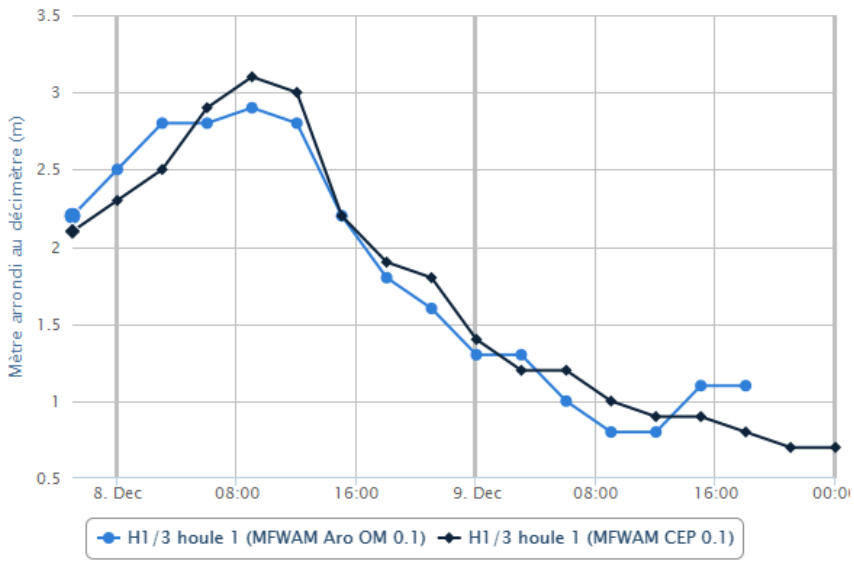
Wind IFS



Wind Arome OI



H1/3 forecast



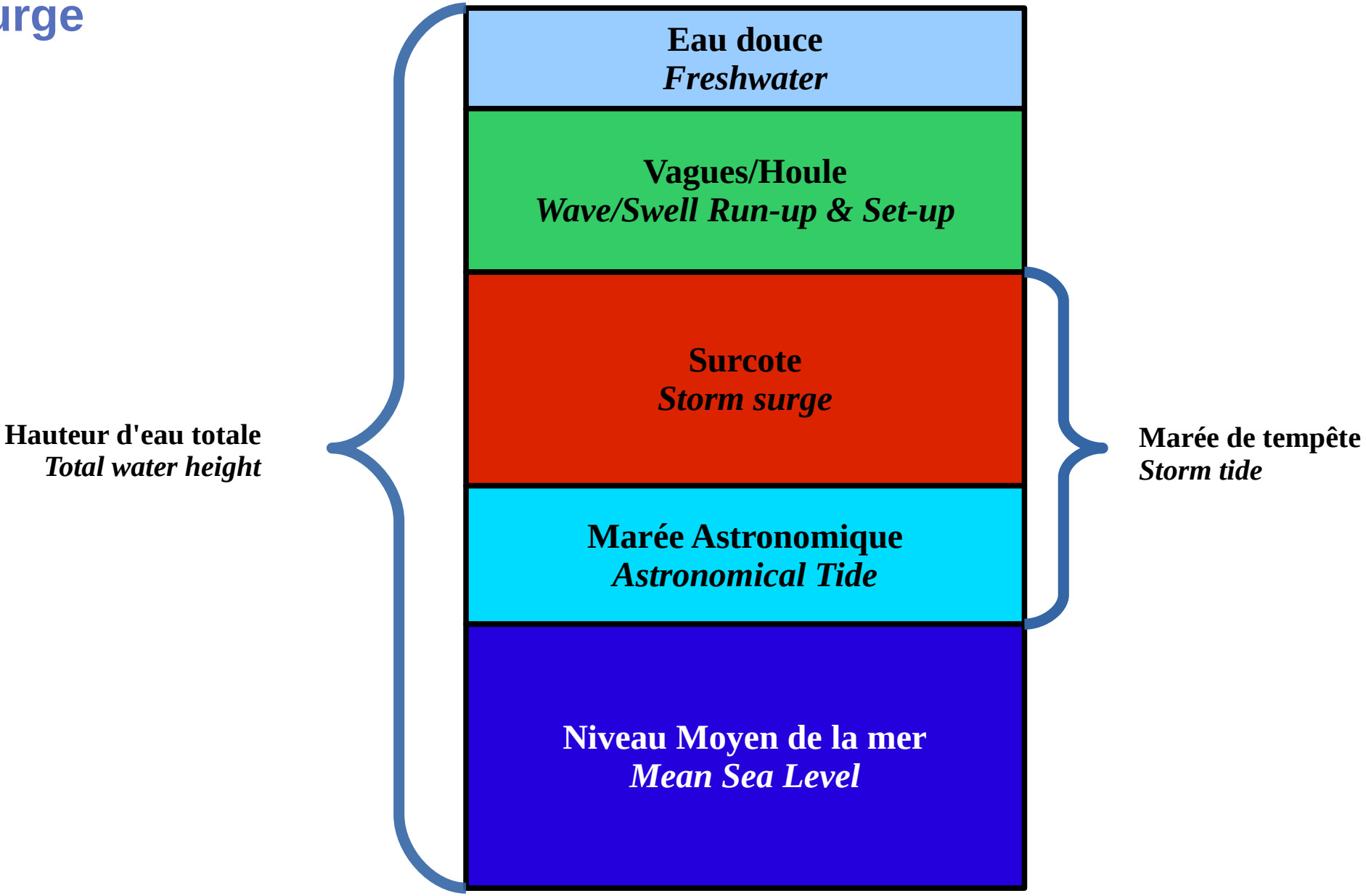
4. Storm surge

Storm surge damage

The deadliest :

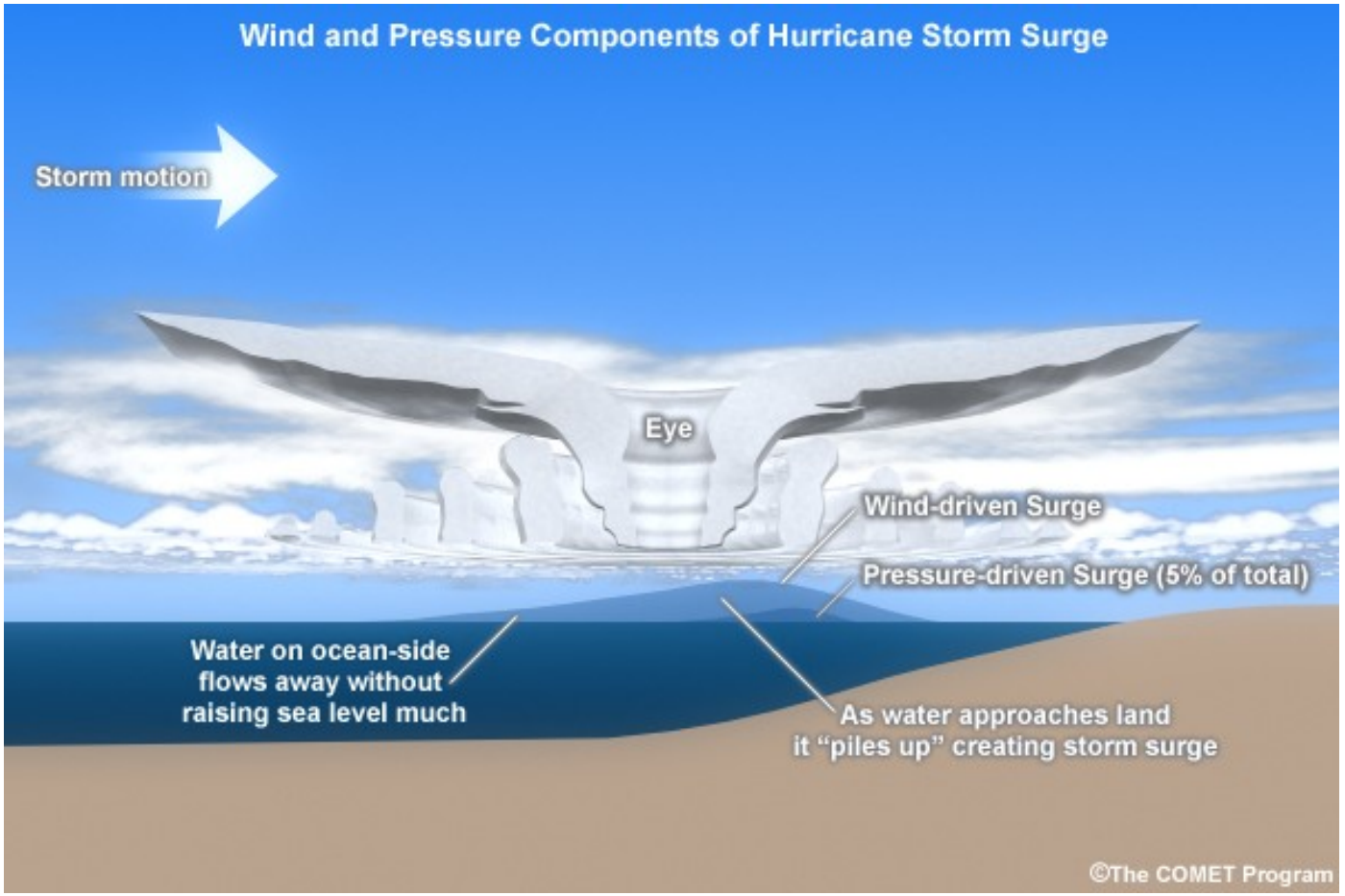
- In November 1970, a 9m surge killed 350 000 people in Bangladesh (Bhola Cyclone).
- In May 2008, NARGIS allegedly caused 138 000 casualties in Burma
- Nicholls, 2003 : Storm surge probably killed 2,6 millions during the last 200 years.

Storm Surge


Eau douce
Freshwater
Vagues/Houle
Wave/Swell Run-up & Set-up
Surcote
Storm surge
Marée Astronomique
Astronomical Tide
Niveau Moyen de la mer
Mean Sea Level
Hauteur d'eau totale
Total water height
Marée de tempête
Storm tide

Surge

Surge = Due to the **wind +** Due to the **low atmospheric pressure**

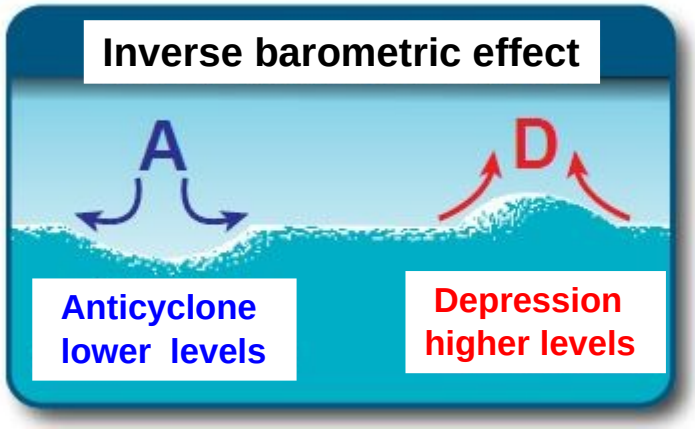


Barometric surge

Surge = Due to the wind **+ Due to the low atmospheric pressure**

- For an intense tropical cyclone for example : 940hPa instead of 1010hPa usually

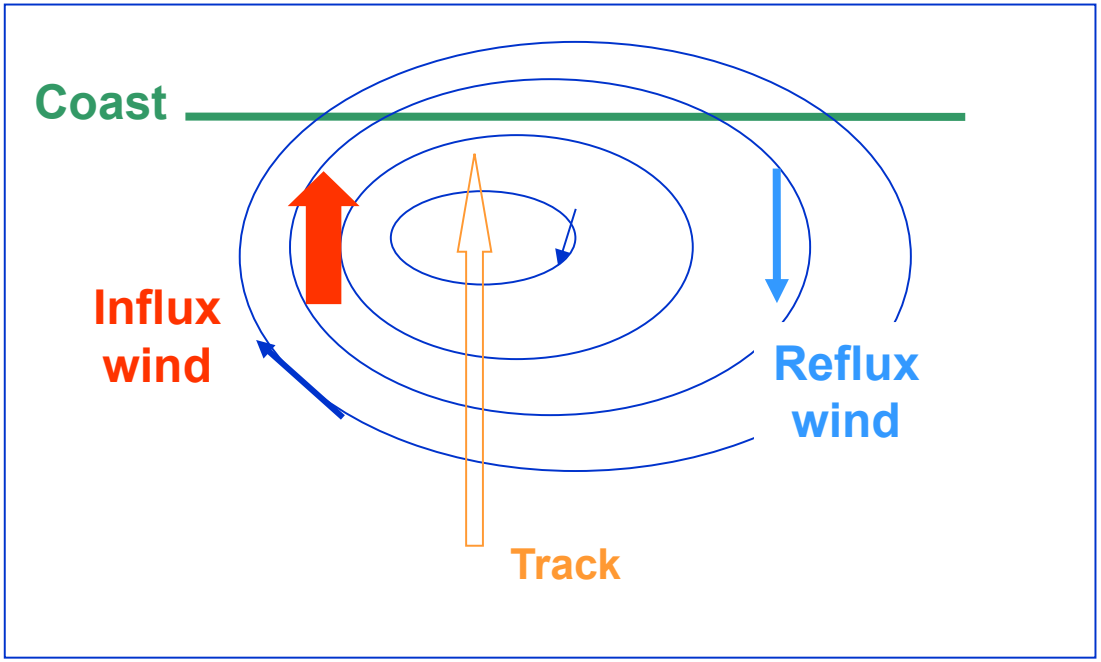
→ **70cm surge**



10 cm for 10 hPa

Wind surge

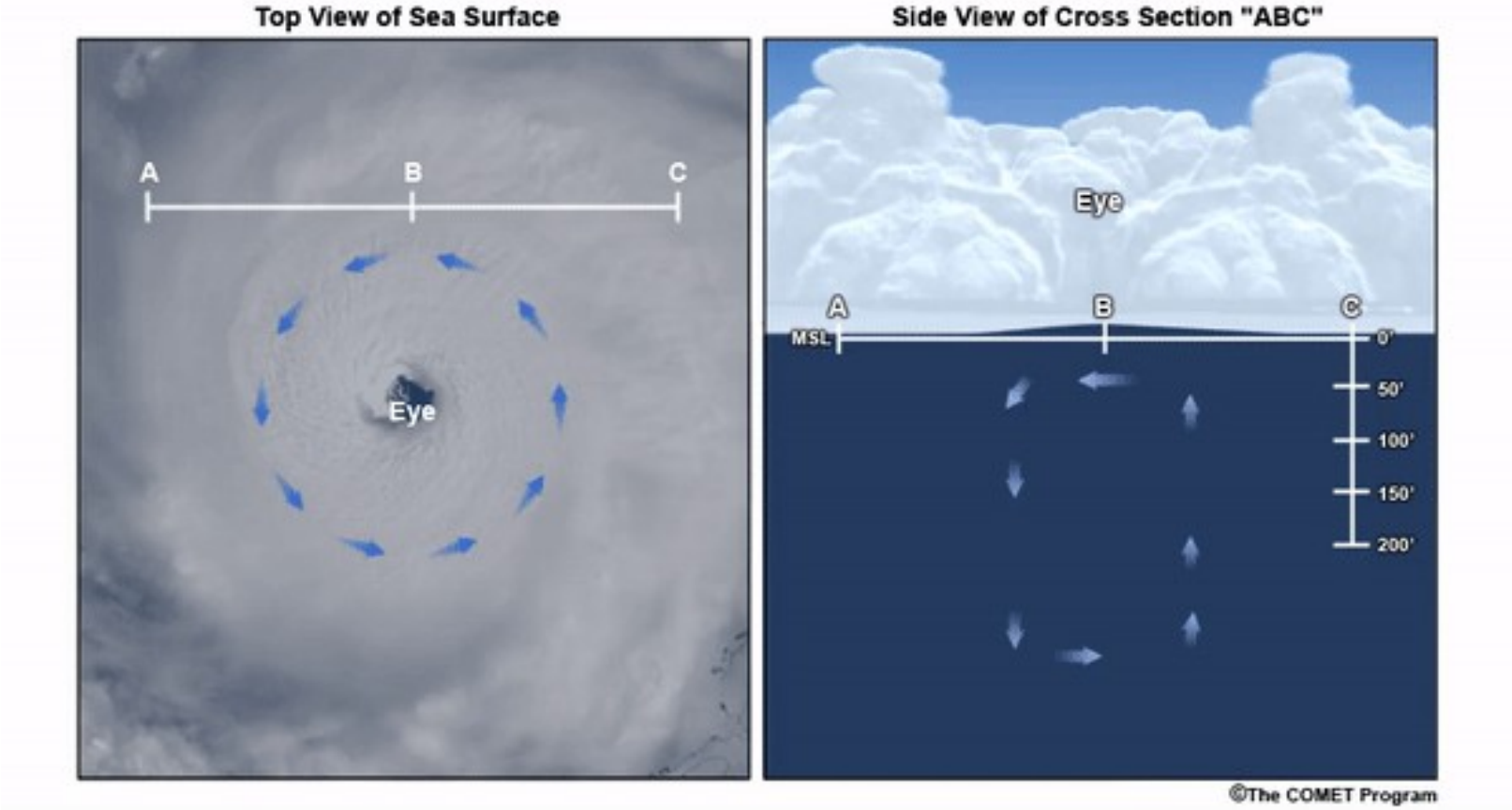
Surge = Due to the wind + Due to the low atmospheric pressure



Wind surge

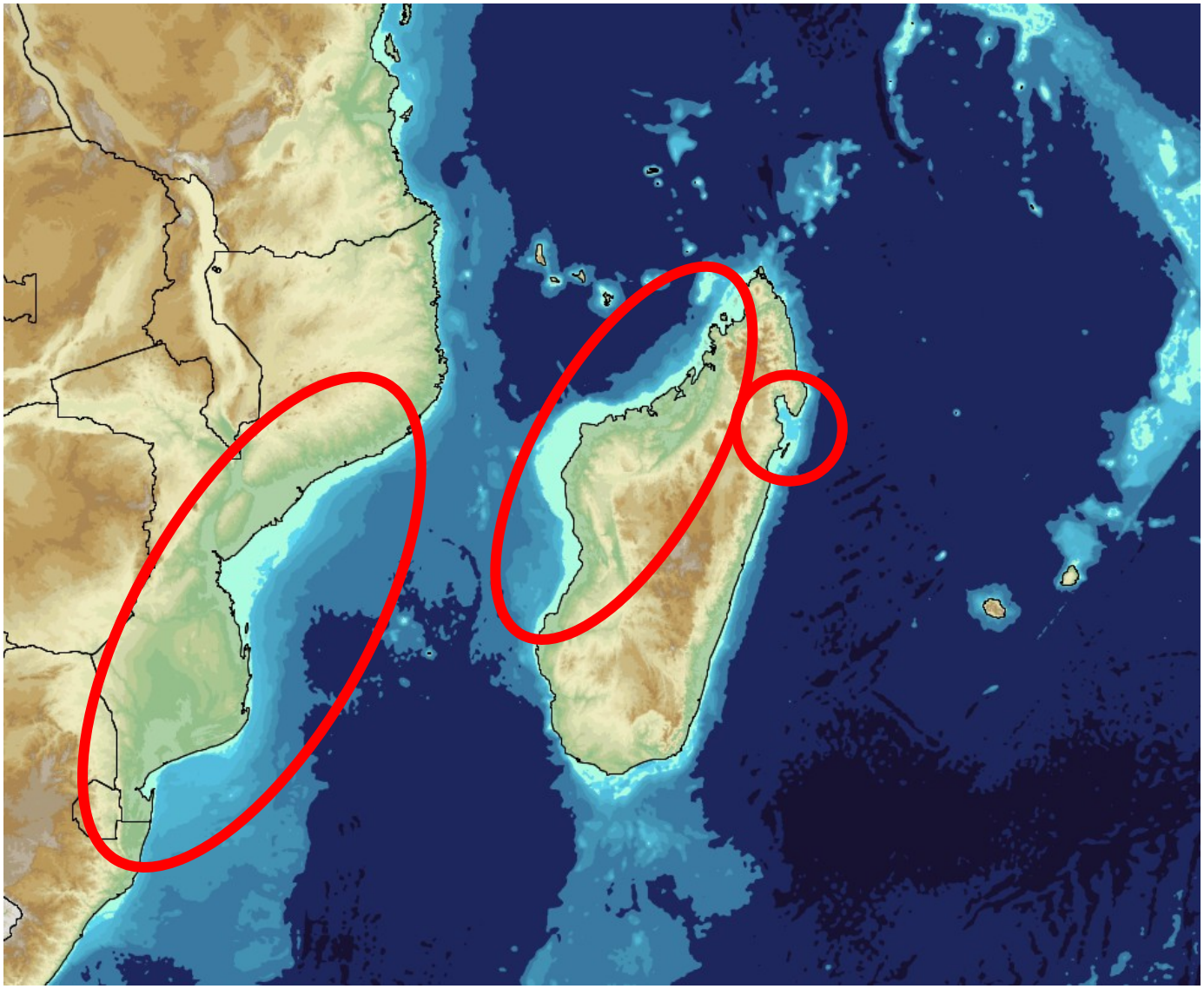
Surge = Due to the wind + Due to the low atmospheric pressure

- Enhanced effect in shallow coastal areas and in the bays bottoms



Area exposed to surge in the South West Indian Ocean

- **Mozambique** (all the coastline especially Beira, Inhambane and Maputo)
- **Madagascar** (Western coast / Antongil bay and Sainte Marie Island area)
- Volcanic islands are generally not threaten by strong surge (steep coasts)
- Complex interactions within lagoons



Historical Surge Impacts

IDAI (2019)

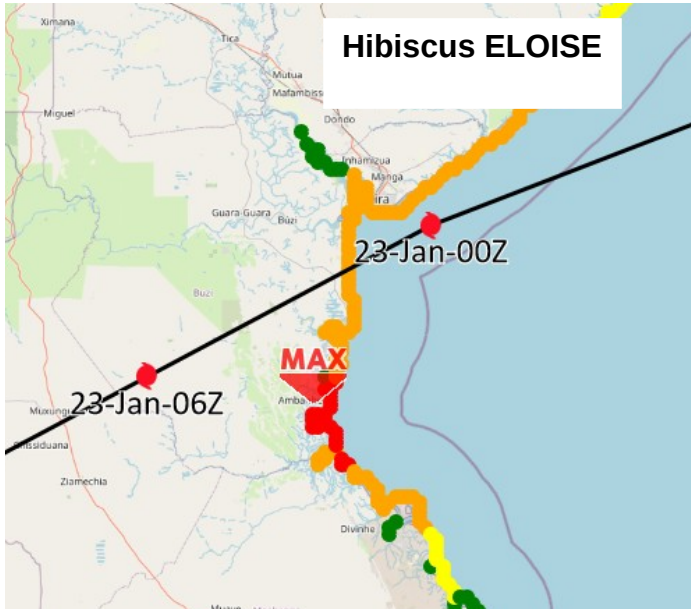
Landfall : 955hPa 90kt

→ at least 4-5m surge in the Pungwe mouth

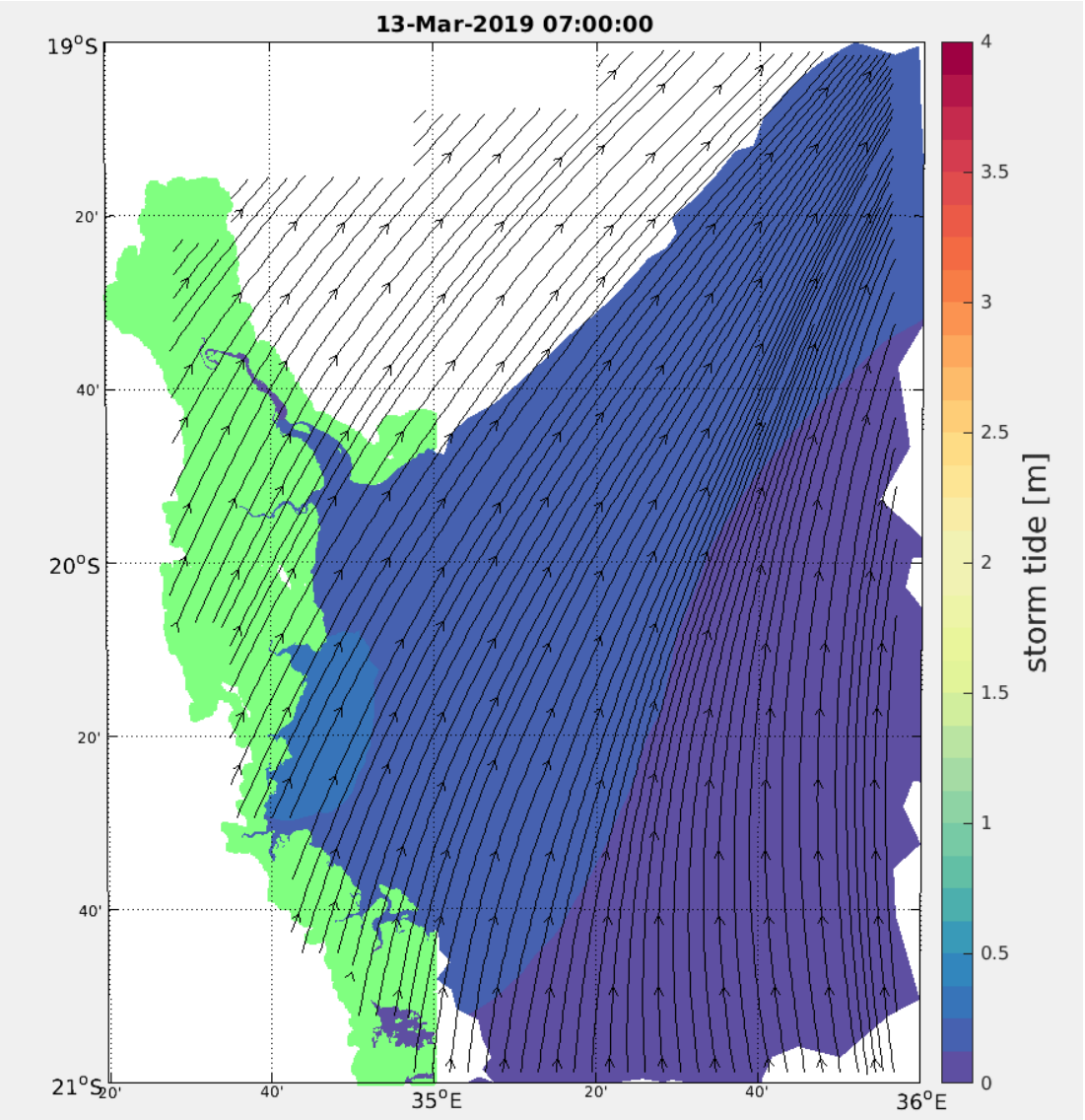
ELOISE (2021)

Landfall : 965hPa 80kt

→ at least 3m surge south of Beira



IDAI surge

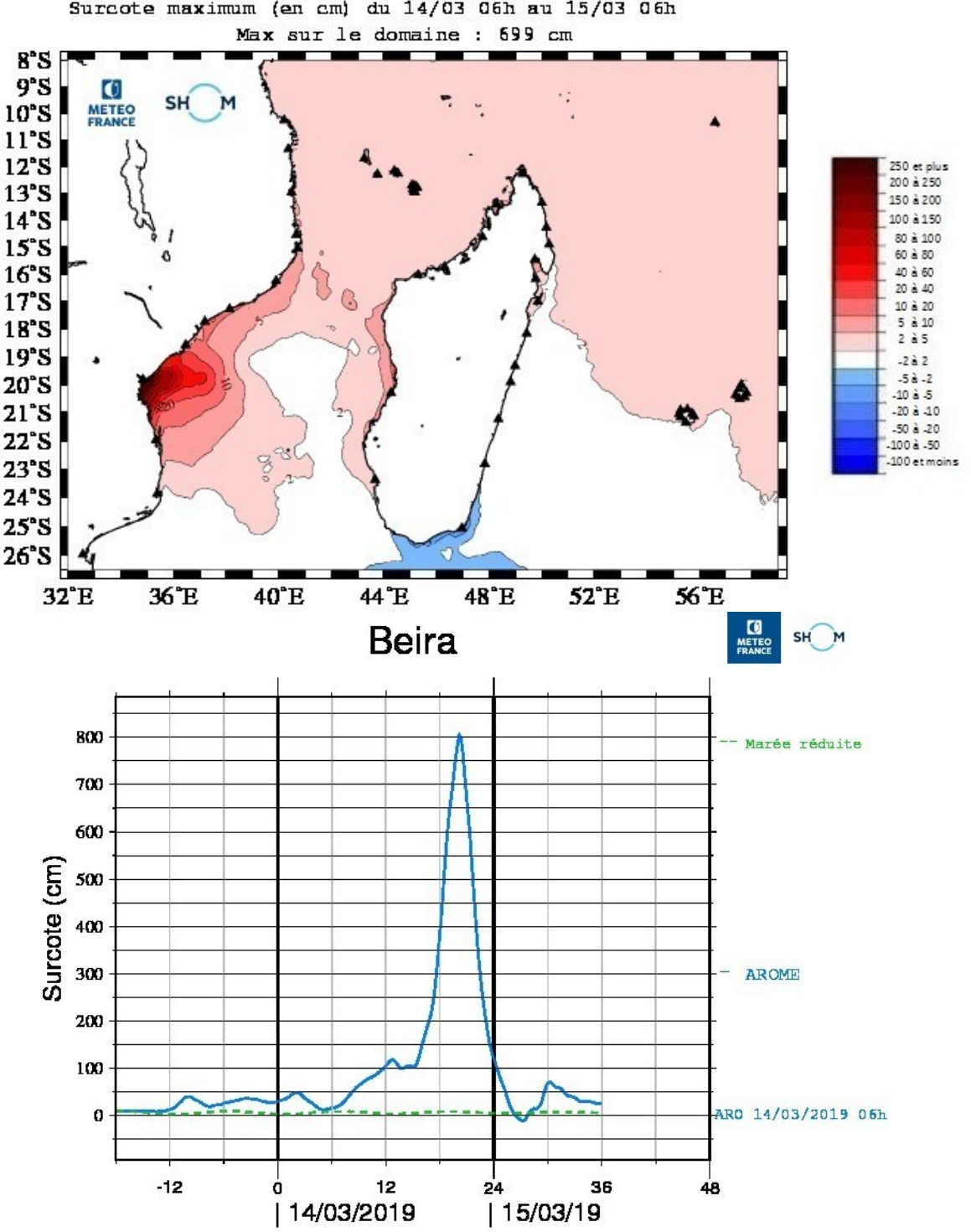


From https://wpringle.github.io/GLOCOFFS/

Surge forecast

Challenge : There are a lot of uncertainties because of

- Minimal pressure / Maximum winds
- TC motion
- TC structure
- Track angle to the coastline
- Bathymetry / Topography (Lagoons, Coral reefs)



Surge forecast – In operations

WTIO30

ON THE CURRENT FORECAST TRACK AND BASED ON FORECAST WINDFIELDS FROM AROME, SOME LIFE-THREATENING STORM SURGE UP TO 3M50-4M IS POSSIBLE AT BEIRA REACHING 5M50-6M IN THE PUNGWE RIVER MOUTH (CAUTION: THIS VALUE DOES NOT TAKE INTO ACCOUNT THE TIDE AND THE WATER RISE FROM THE CYCLONIC SWELL). DUE TO THE DISPERSION IN THE TIMING OF LANDFALL, MAXIMUM OF STORM SURGE MAY HAPPEN IN TUNE WITH THE MAXIMUM OF THE TIDE. IF THE CURRENT TRACK IS CONFIRMED, THIS COULD BE A WORST CASE SCENARIO FOR THE BEIRA AREA.

Official RSMC bulletins :

- WTIO 30 / 31
- http://www.meteo.fr/temps/domtom/La_Reunion/meteoreunion2/HIBISCUS_GP/

Median surge forecast

Couche "Surcote SYSTEME": Valeurs de surcote pour le scénario médian issu de la prévision probabiliste SPICY. Infos sur les autres scénarios dans la jauge.

Légende de la surcote

50cm<	.5m/1m	1m/2.5m	2.5m/5m	>5m

Risk of coastal flooding

Estimation qualitative du risque de submersion côtière à grande échelle sur une grille de 2km², basée sur des données d'altitude, des prévisions probabilistes de surcote et de marée.

Zone inter-marée (Estran)	Risque Faible	Risque modéré	Risque Fort
As usual	Low risk	Moderate risk	Strong risk