Diagnostics for Tropical Cyclone prediction : from the S2S scale to the mesoscale

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PISSARO

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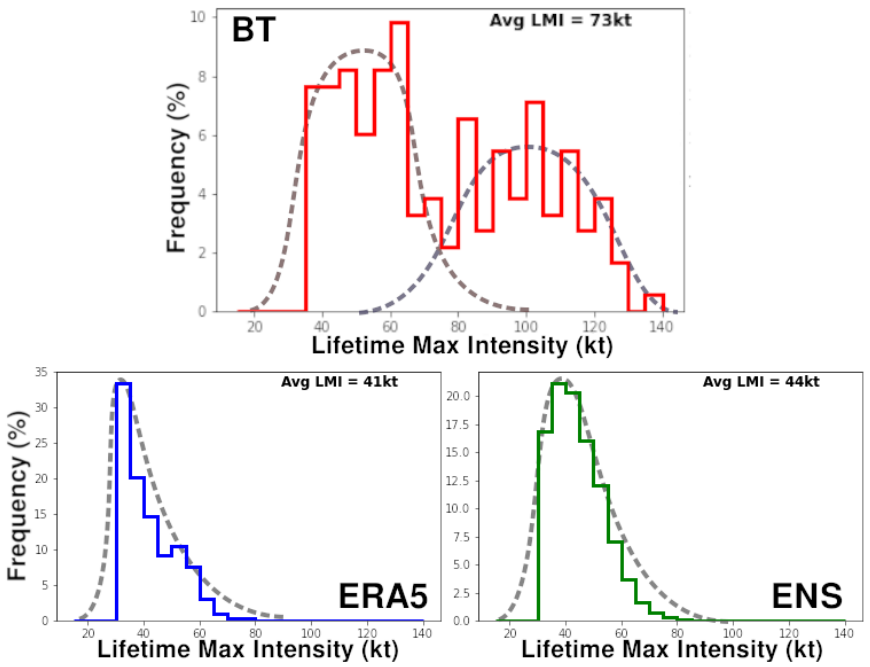
Tropical cyclones : Observations vs Forecasts

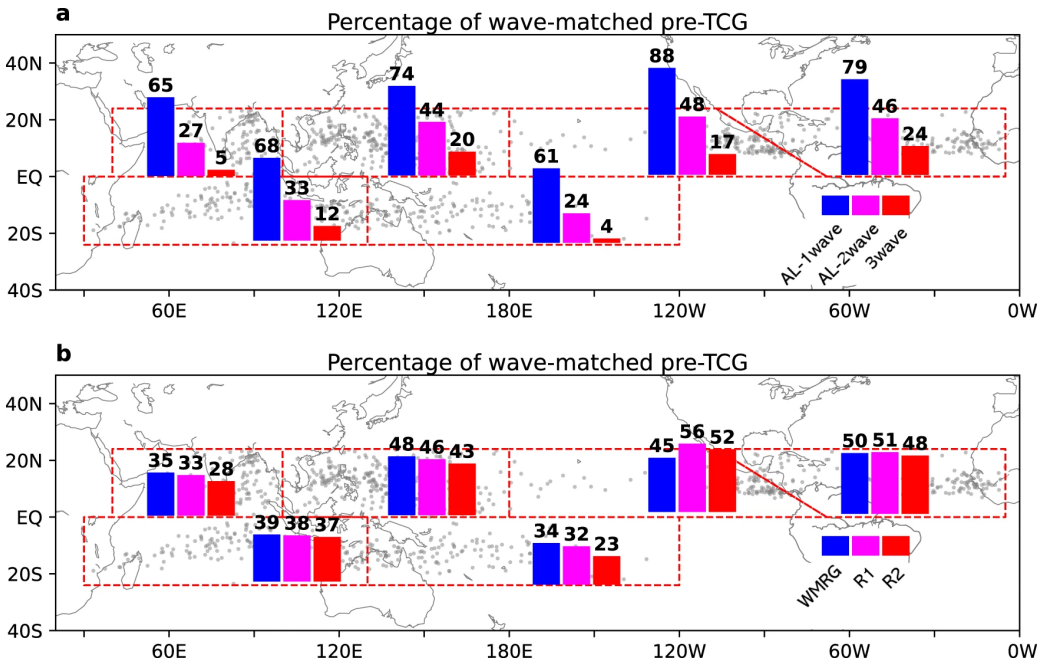


- TC intensity in the Southwest Indian Ocean :
  - IBTracks : Two modes of TC intensity
  - Global Forecast : too weak TCs missing the second mode
  - Same for ERA5 (lack of resolution, missing mechanism leading to rapid intensification...).
- Forecast at kilometric horizontal resolution are now able to simulate deep TCs, rapid intensification and eye wall replacement cycles.
- However, the skill of the trajectory forecast remains driven by the large scale model.

Diagnose the uncertainty of the TC environment & the most probable scenarios

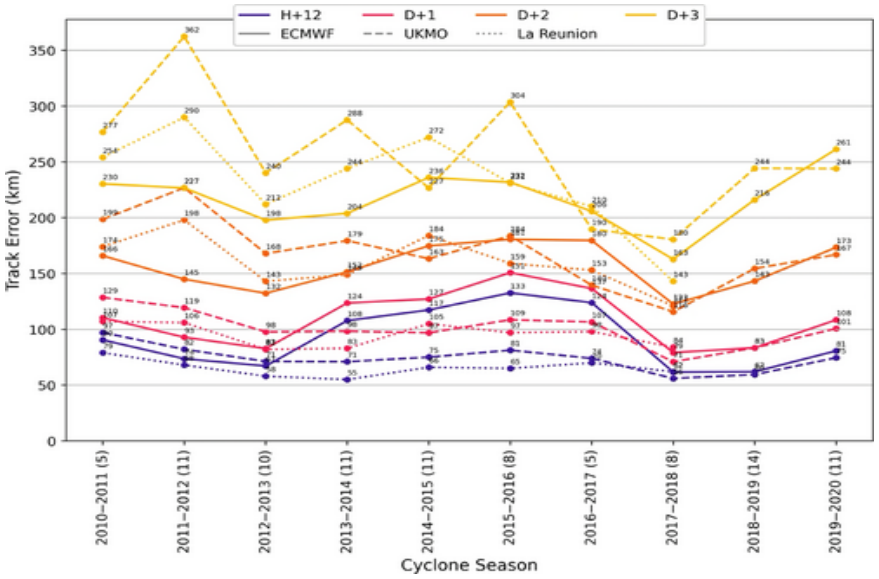
- For longer range forecasts, only the large scale environment shows some predictability.
- Even for short range forecasts, the accuracy of the TC environment forecast is crucial to get both a good track and a good intensity prediction.

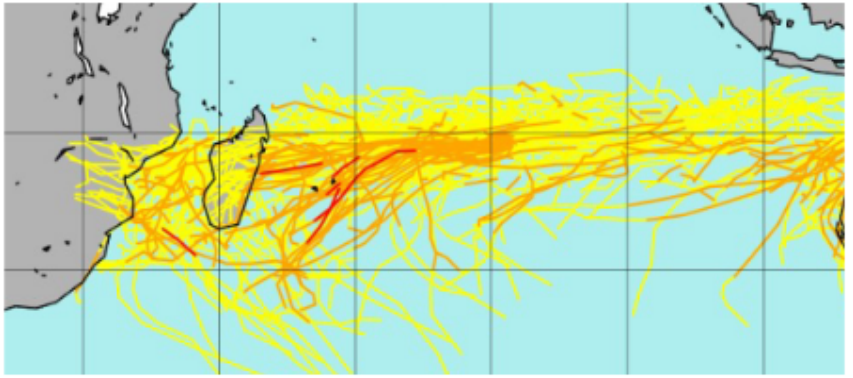
Feng et al. 2023



Tracks of tropical cyclones at different leadtime

Emerton et al. 2024





- A short lead time, RSMC trajetory is better
- In the range of ECMWF/ UKMO at day+2
- Lower than ECMWF/ UKMO at Day+3

- Forecast Tracks are key to monitor TC activity but there was a need of tools allowing scenario based forecast
- PISSARO project :
  - Provided link between research and forecast
  - Explore how the Ensemble forecast can be used to get scenario informations

Outline

1) Linking tropical cyclone to large scale environment
   - ⇒ Cyclogenesis indices
   - ⇒ Equatorial waves monitoring and clustering
2) Tropical Cyclone tracks clustering
3) TC-oriented diagnostics within ensemble high resolution forecast
4) Wrapping of all this with seamless weather briefings

Large-scale environment of Tropical Cyclones

TC indices for S2S forecasting

- An alternative to direct tracking of cyclonic systems in the extanded range forecast: **use of TC indices based on large-scale fields**.
- Historically developed as indicator for low resolution climate models
- Indexes ~ tools for representing zones of potential activity, i.e. suspect areas where tropical cyclones may develop.

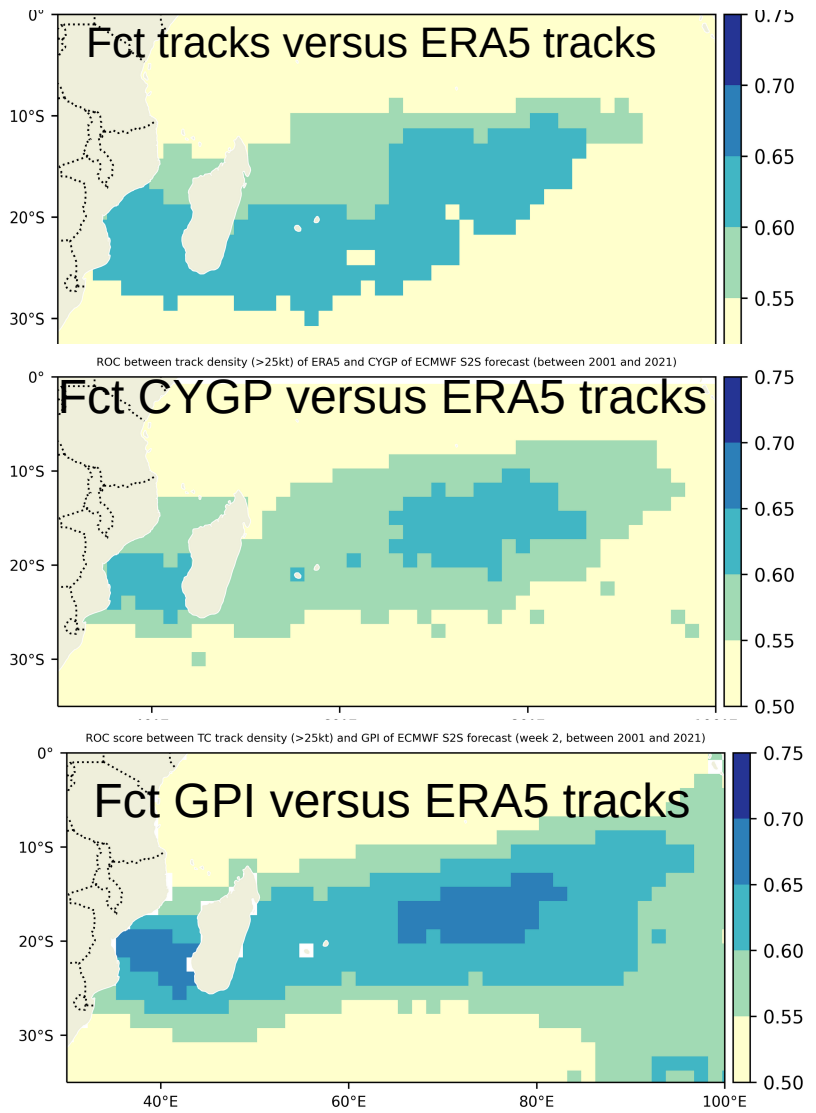
- Two indices have been computed from weekly forecast mean :
  - the **CYGP** (Cyclogenesis Potential, Royer, 1998)
  - the **GPI** (Genesis Potential Index, Emanuel and Nolan, 2004)

$$CYGP = \beta_1 . \underbrace{|f| . \left(\zeta_r \frac{f}{|f|} + 5 \right)}_{vorticity} \underbrace{(V_{shear} + 3)^{-1}}_{shear} . \underbrace{\max(P_c^* - 3, 0)}_{heat}$$

$$GPI = \beta_2 . \underbrace{|\zeta|^{3/2}}_{vorticity} . \underbrace{(1 + 0.1 V_{shear})^{-2}}_{shear} . \underbrace{\left(\frac{H}{30} \right)^3 . \left(\frac{V_{pot}}{70} \right)^3}_{heat}$$

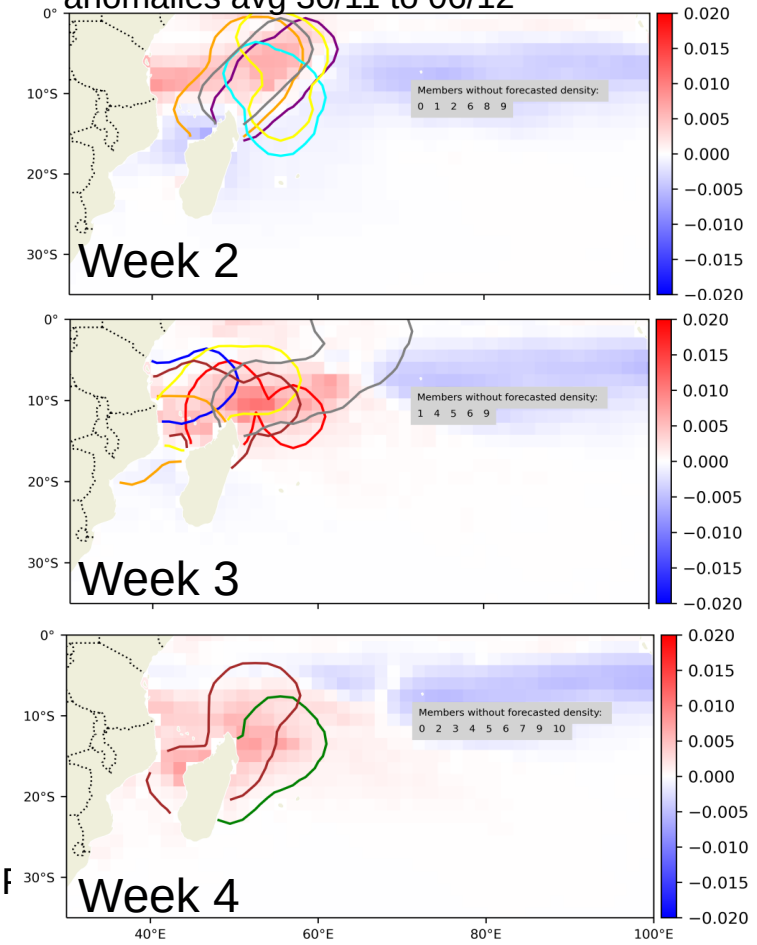
TC indices for S2S forecasting – Week 3

- ROC-Type score (Weigel et al. 2011) of Week3 forecast against ERA5 for TC track density
- At Week 3, the GPI provides an added value compared to TC tracks from the same forecast
- Anomaly of GPI may be even more informative (work in progress)
- ⇒ There is information in the extended range for forecast in the large-scale environment of TC (vorticity, divergence, shear)

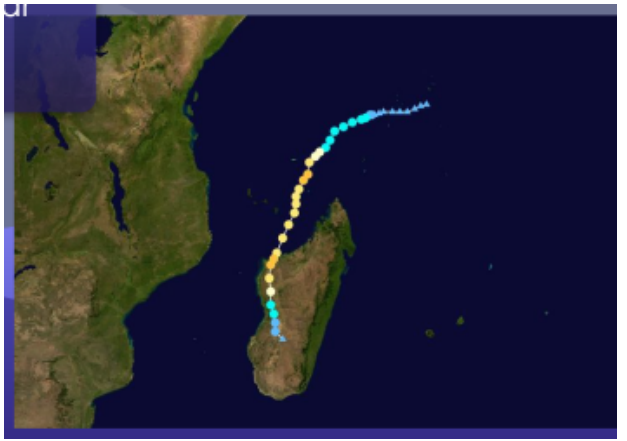


An example with forecast of TC Belna (2-14 Dc 2019)

Ensemble forecast Track density and GPI anomalies avg 30/11 to 06/12



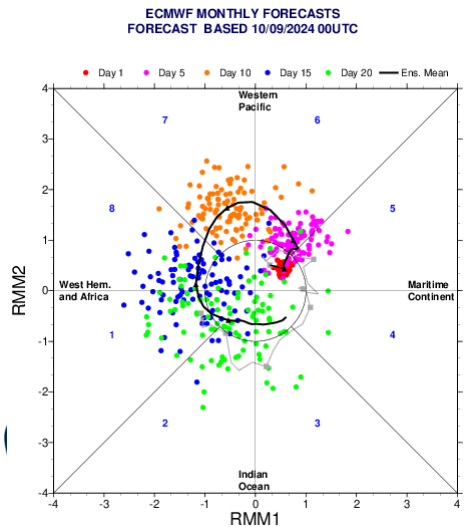
- TC Belna
  - Cat.3 TC, Max wind ~ 185 km/h
  - Hit Madagascar
  - Considerable loss (9 deaths, 25 Millions dollars damages)



- On this particular case, the forecast for week 2 shows a high track density in the genesis area
- With increasing leadtimes (week 3, 4), the GPI anomaly keeps a stable signal while track density vanishes
- Strong potential for using GPI anomaly for long leadtimes ⇒ linked to large-scale drivers

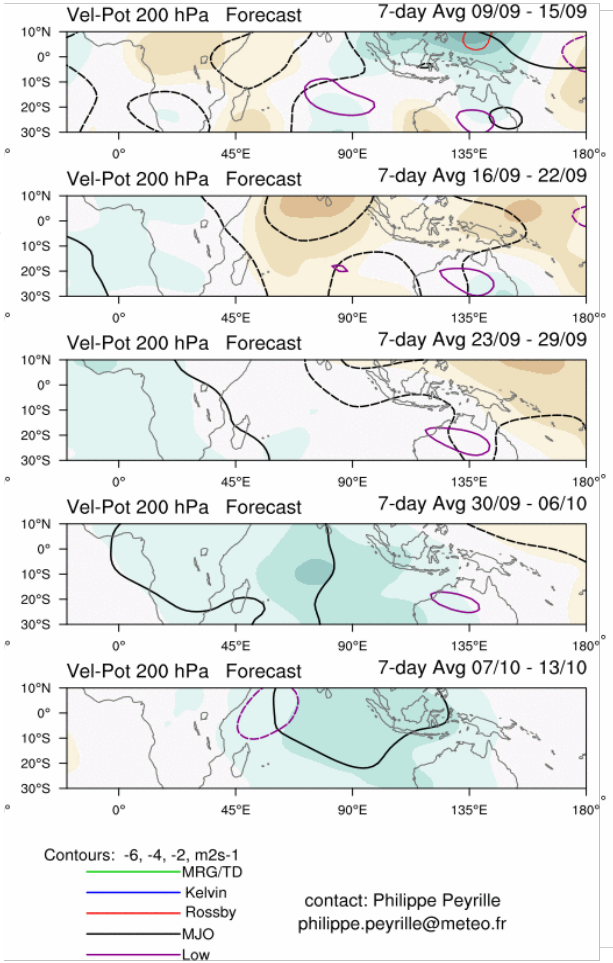
Equatorial waves monitoring

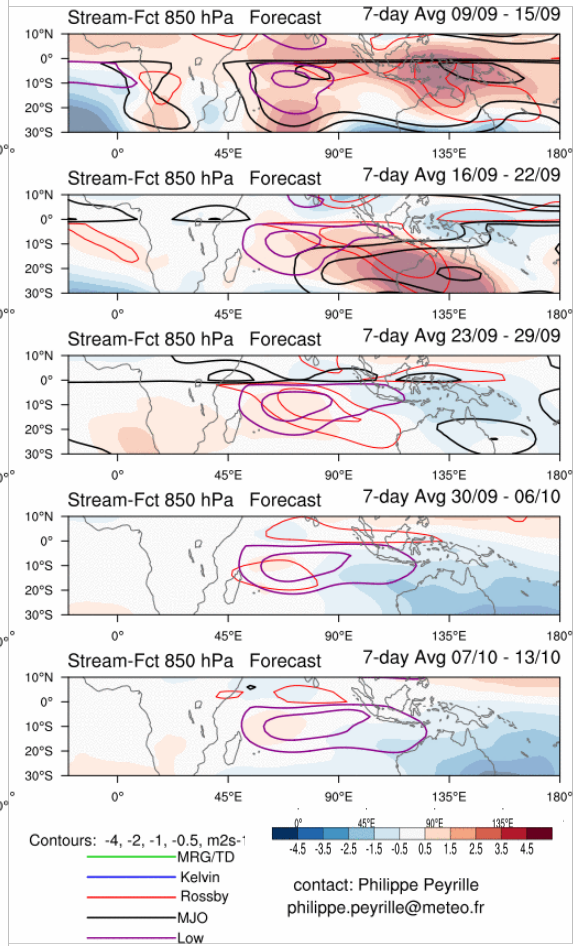
- Based on MISVA website : freely accessible real-time monitoring of equatorial waves
- https://misva.aeris-data.fr (more details on the poster in the poster room)
- Basic diagnostic : anomalies + CCEW contributions



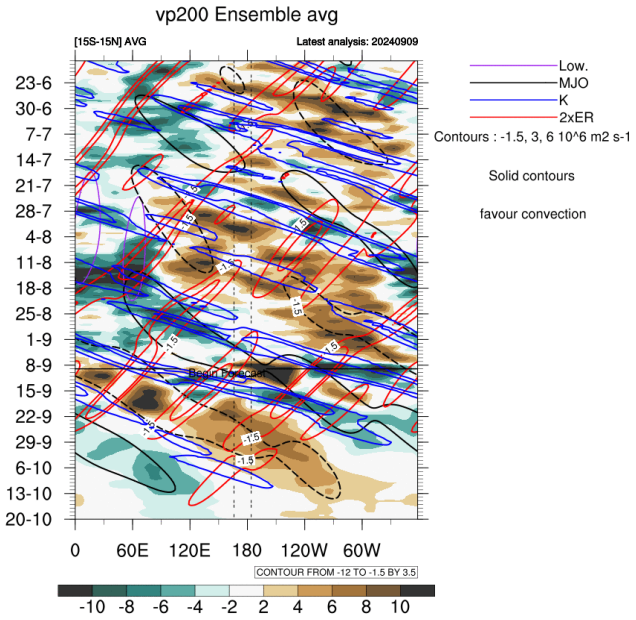
200 hPa Velocity Potential

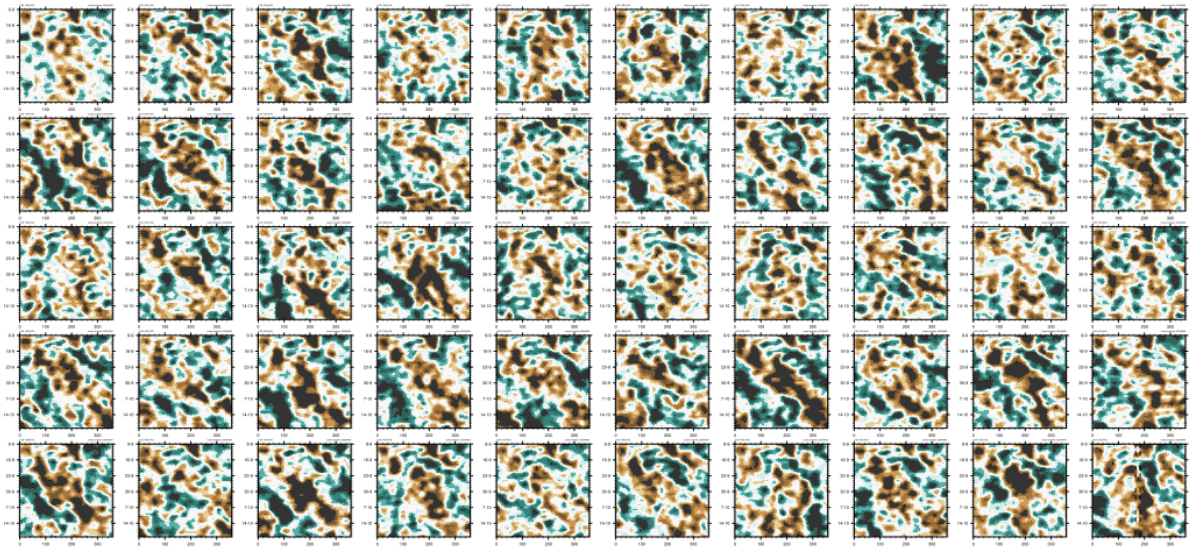
850 hPa streamfunction



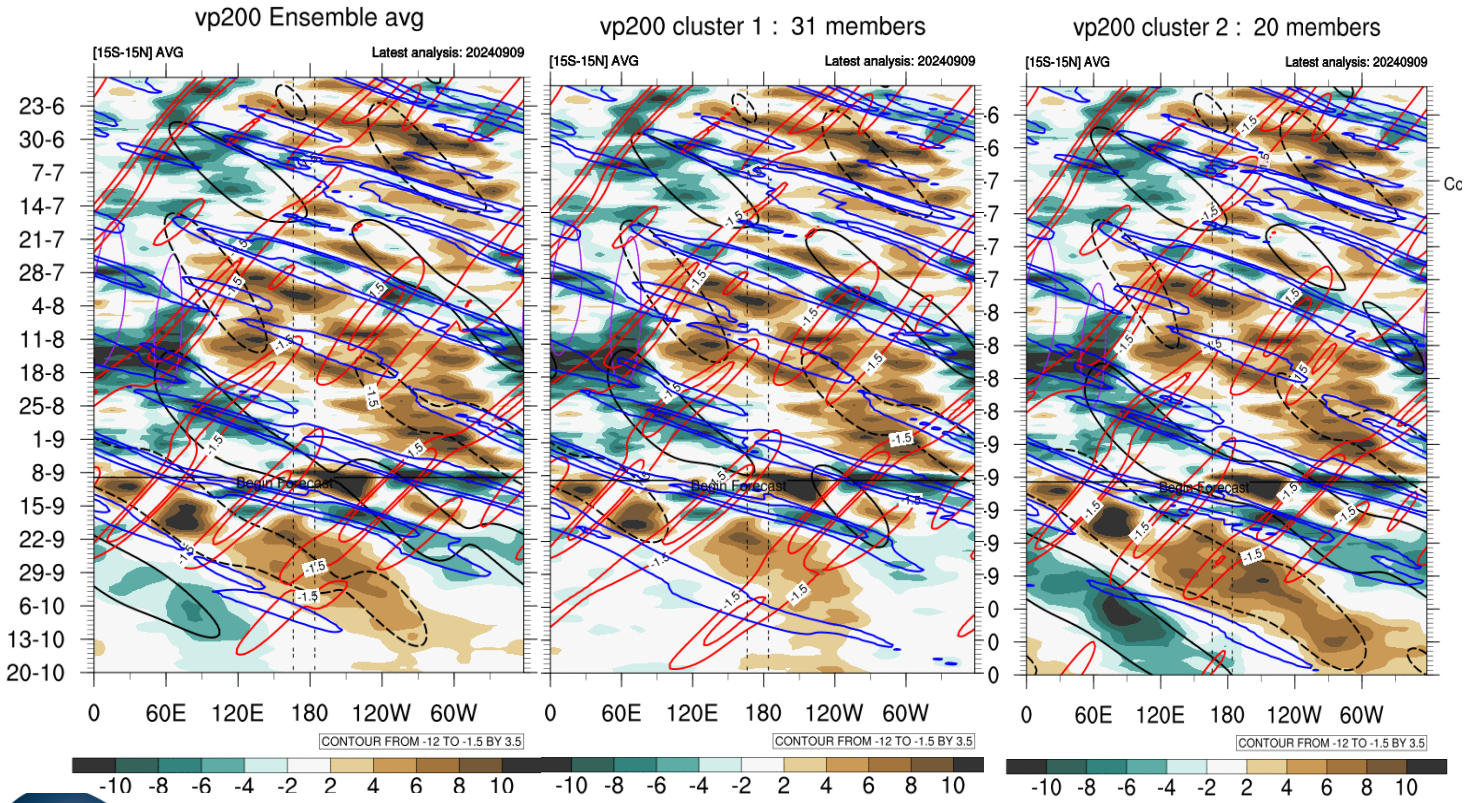


Ensemble mean vs all members, 200 hPa velocity potential

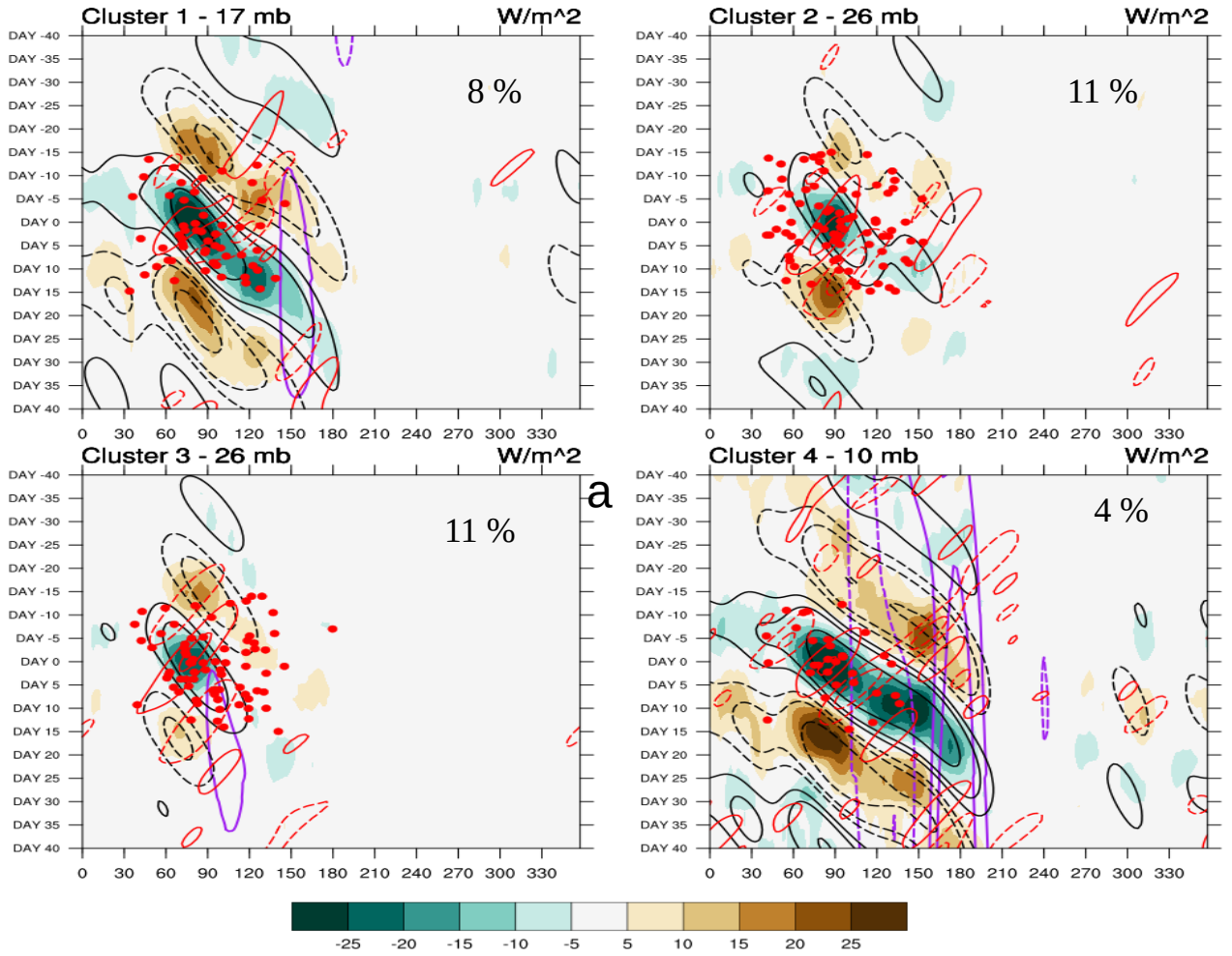




Clustering 200 hPa Velocity Potential hovmollers



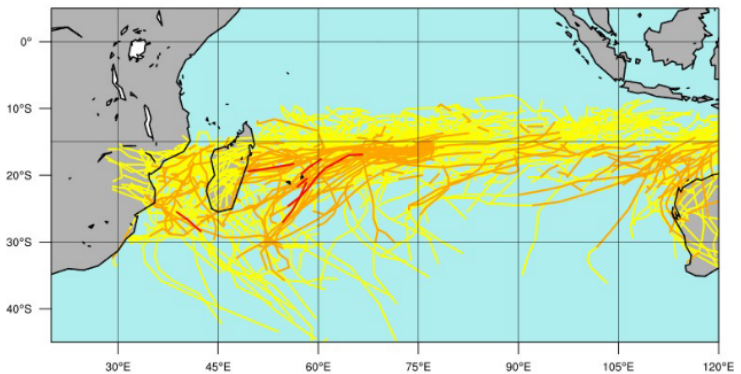
Clusters vs cyclogenesis



- Each cluster has a connection with cyclogenesis with fast modes promoting less TC but more localized in the divergent / convectively active area of the MJO
- We have developped a clustering approach based on hovmollers for the forecast

Track scenarios

5 week TC tracks from extended range forecast



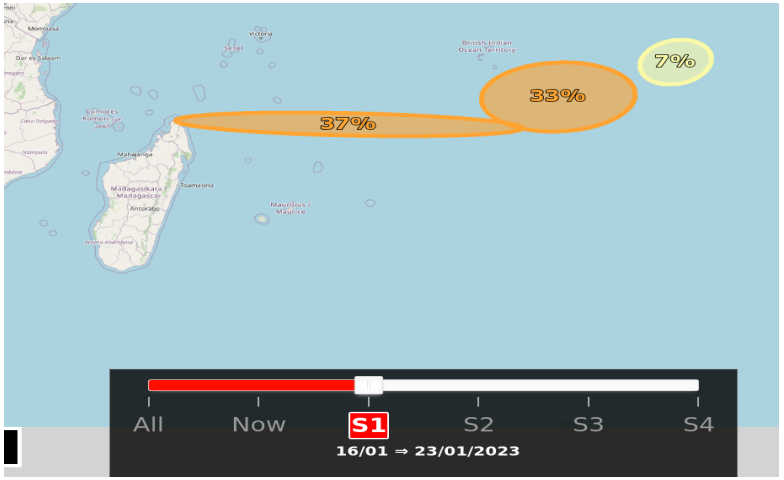
- It is generally difficult for the forecasters to efficiently analyse the raw tracking of the IFS EPS (medium and extended range).

  Quoc-Phi Diong, Adrien Colomb, Mike Payet

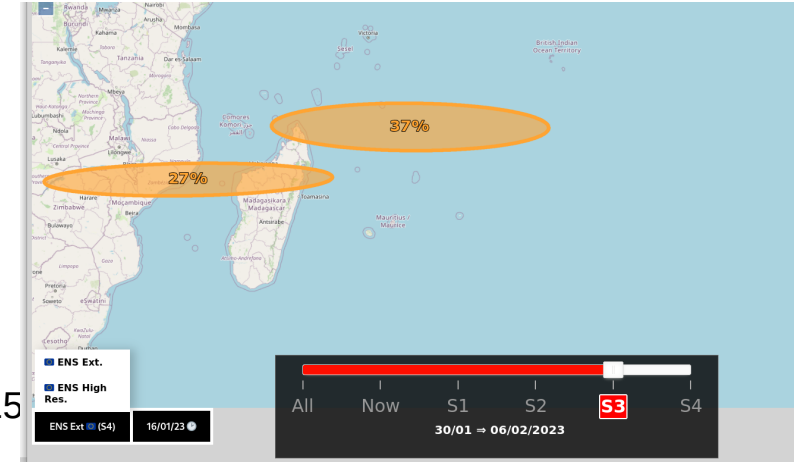
- Needs for a classification :
  - pre-defined classes – basin dependant
  - automatic classification - portable method

CYPHER : Automatic classification of cyclogenesis and tracks

CYclone PatH clustERing

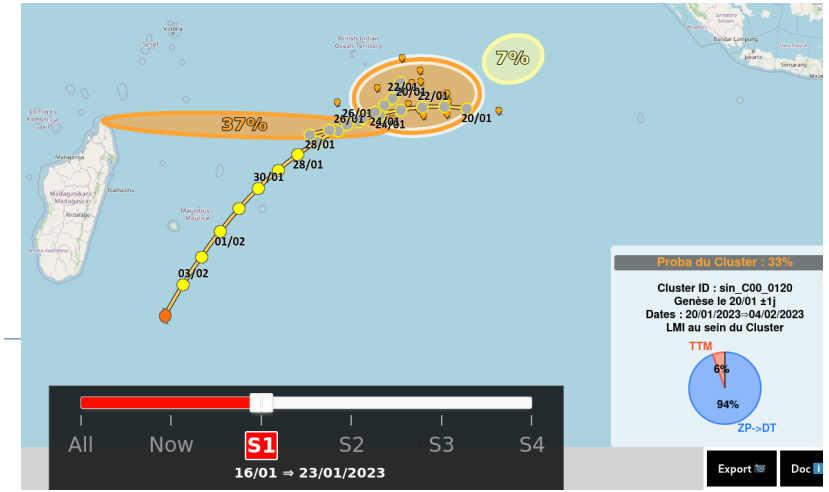


- ***Using the 50 members of the IFS-EPS or the 100 members of the monthly forecast :***
  - Clustering of the genesis points origin spatio-temporal criteria (latitude, longitude and date) using DBSCAN clustering and ECMWF cyclone trackers
    ⇒ **cyclogenesis clusters**.

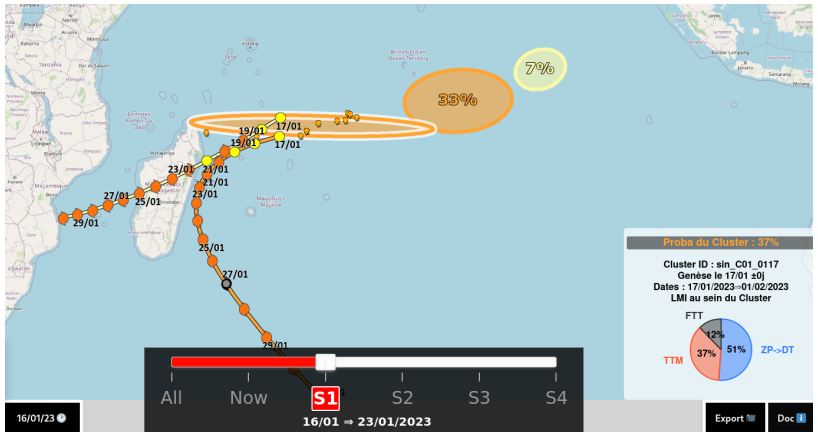


- An interactive web page has been developed for the forecasters
  - an easier navigation between the objects (clusters, mean scenarios and associated
  - ensemble members) and accessibility to their characteristics

CYPHER : Automatic classification of cyclogenesis and tracks

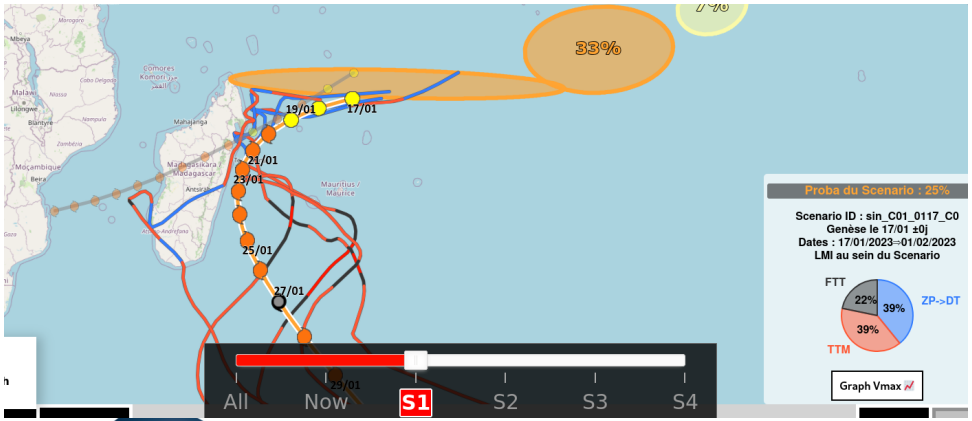


- For each cyclogenesis cluster, each TC tracks is summarized by five (lat,lon) points.
- They are grouped by similarity using hierarchical agglomerative classification.
- A Ward linkage method with a fixed distance criterion is applied to automatically determine the final number of **track clusters**.



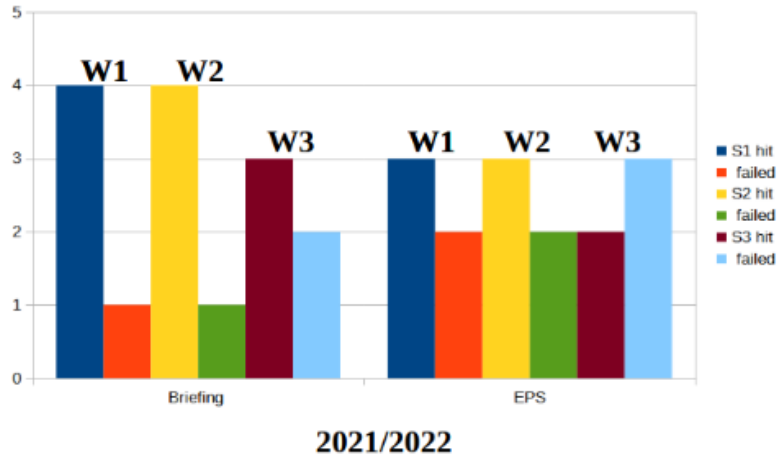
- This provides a scenario view associated with probability that feed the forecaster
- The cluster mean trajectory is accessible with
  - TC intensity (circles)
  - TC probability (width / color of trajectory)

CYPHER : Automatic classification of cyclogenesis and tracks

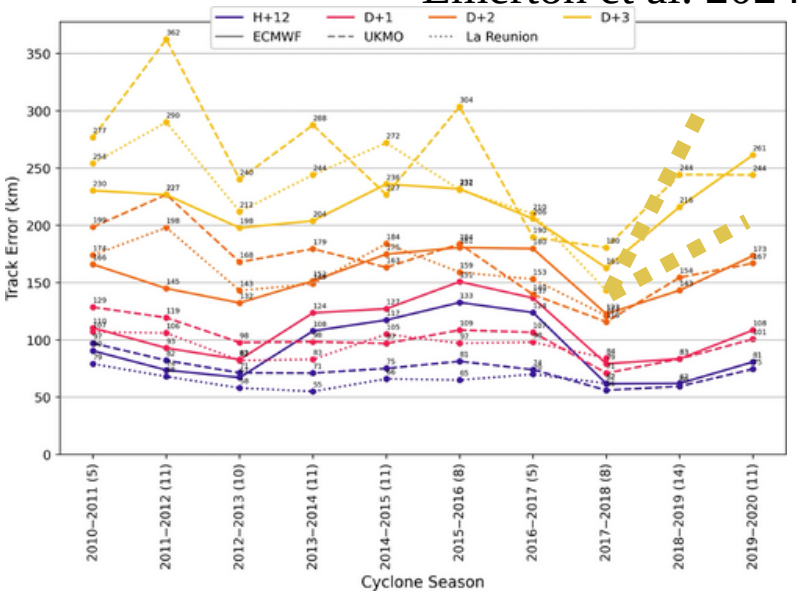


- Individual trajetories are still accessible grouped by their genesis area
- This is a key product for operational purposes

A last powerful (human) diagnostic : weather briefings



Emerton et al. 2024



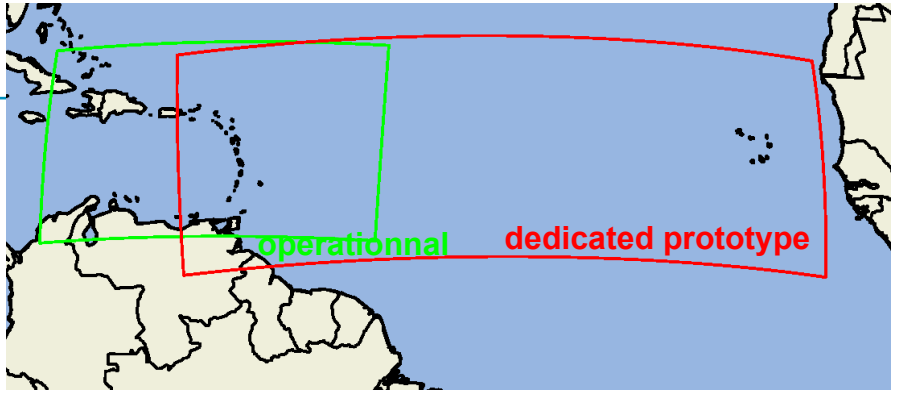
- Bassin-wide score for on 2021 / 2022 compares raw EPS forecast to expertized forecast after briefing
- ⇒ expertized discussions bring an added value to numerical forecast

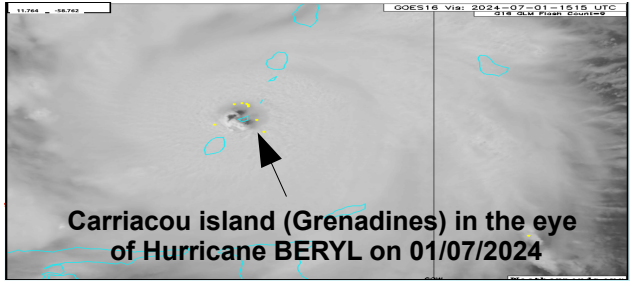
Diagnostics for high resolution convective permitting models

AROME EPS design

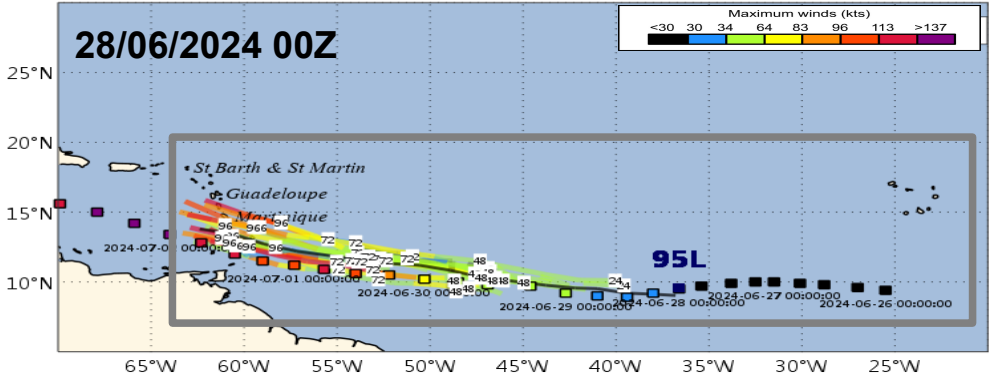
- AROME : 2.5 km resolution
- Experimental protocol with larger domain than usual
- 15 perturbed members + 1 ctrl member derived Peturbed global Arpege (Meteo-France) model
- (SPPT for perturbations)
- AROME is run for 120 h

  ⇒ test TC-oriented diagnostic (Large scale at TC feature)





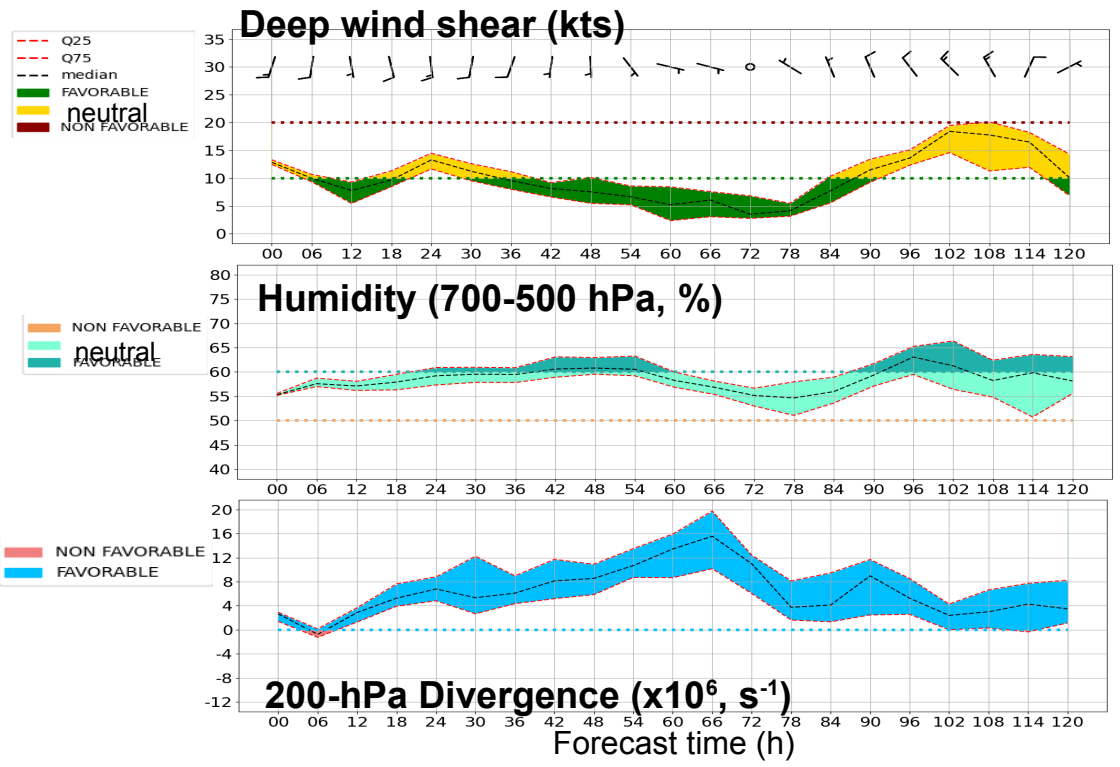
AROME EPS prototype



Environment of TC BERYL (2024)

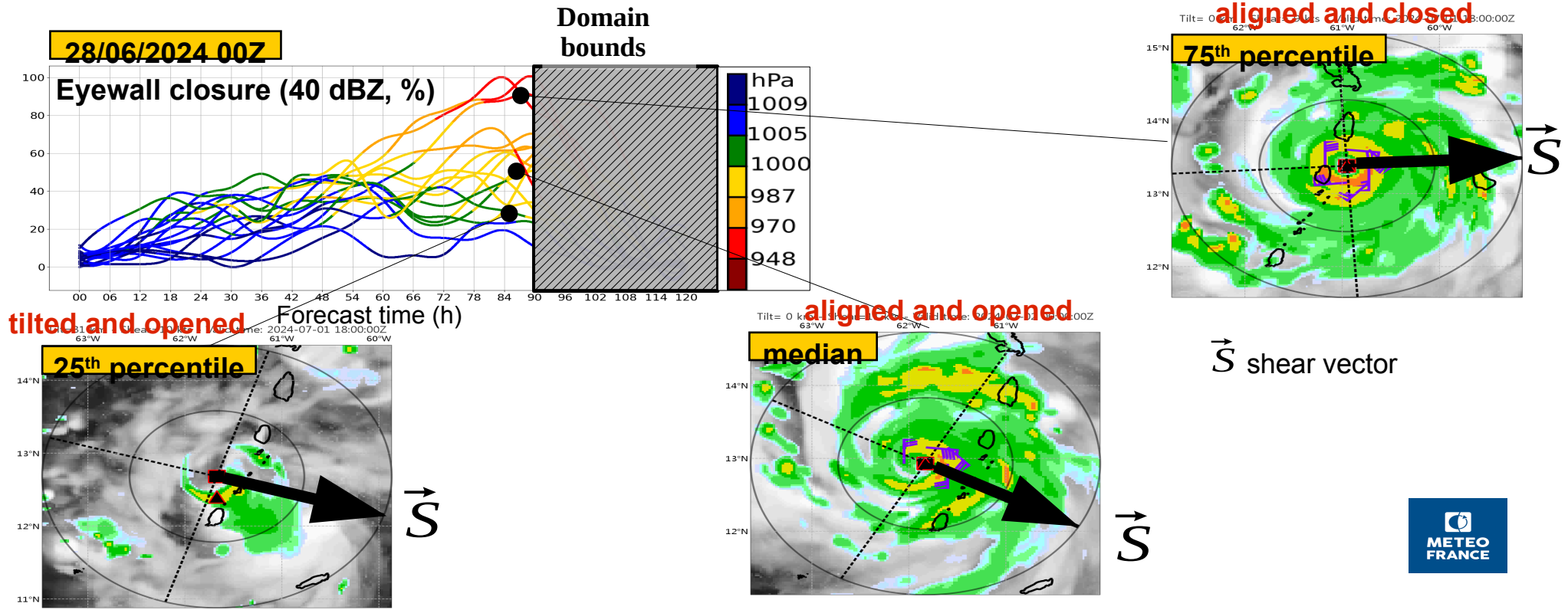
- TC are tracked among the forecasts and indices are computed, centered on the identified TC (r=200-800 km)

- For large-scale indices :
  - BERYL was evolving within a very favorable **environment** :
    - low vertical wind shear,
    - high relative **humidity**
    - good **divergence**/outflow aloft,...



Potential intensification of TC BERYL (2024) : local structure metric

- The **closure** of the eyewall by deep convection + a vertically **aligned vortex** are excellent **precursors** for a faster intensification.
- For this run, a more likely **scenario** is at least a **strong cat2** hurricane but AROME EPS was suggesting that rapid intensification (RI) was not ruled out.



Conclusions

- Within PISSARO project, we developed a whole methodology / tools to forecast TC activity from subseasonal scale to short lead times with a scenario approach

- Large Scale environment monitoring : brings a significant information on TC activity sometimes far beyond week 3
- Main source of predictability : equatorial waves, the MJO yes, but also Eq. Rossby wave and the low interannual frequency. ⇒ Key diagnostics are the CCEW filtering contributions and clusters of 200 hPa velocity

- Clustering of TC genesis and trajectories : great diagnostic to derive a useful information for the forecaster ⇒ now available over all sectors
- At shorter scale (leadtimes < 2 days) convective permitting forecasts help determine the TC features ⇒ TC oriented diagnostic show great potential

Thank you !

Take home messages

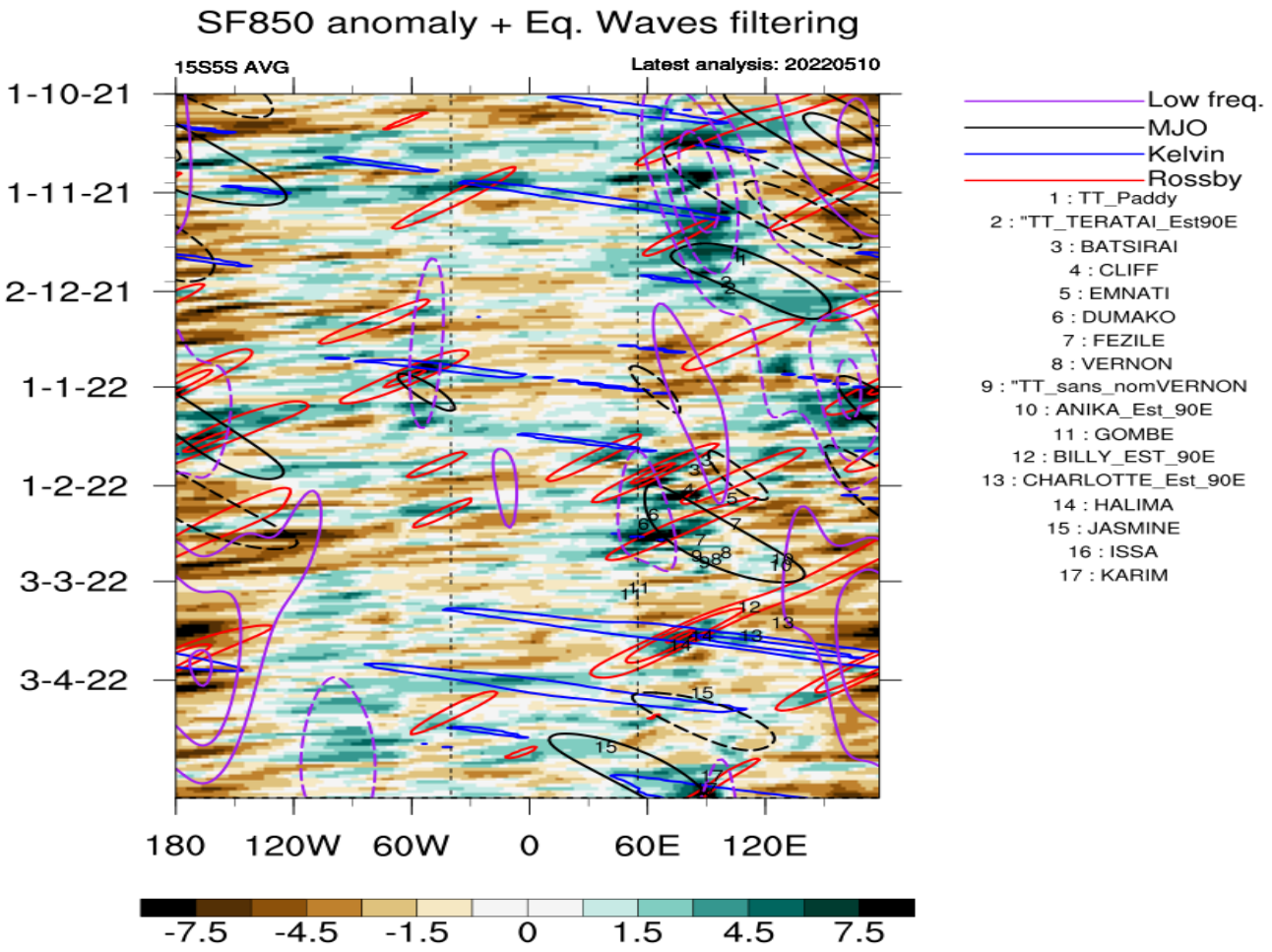
- There is informations in the forecast at large scale to link with TC activity
  - Cyclogenesis indices are a useful way to diagnose the environment for TC
  - Equatorial waves monitoring too, with informations far beyond the RMM
    - Contributions on vorticity, humidity, upper-level divergence
    - Clustering for scenario at large scale
- Clustering Cyclogenesis areas and tracks provides a scenario with associated proabilities within the ensemble

Development of TC metrics in Arome EPS

- Implementation of **environmental** predictors and local **structures** metrics (*DeMaria et al, 1994; Hazelton et al, 2021*) in AROME EPS.
- These parameters are « **tracked** » for each member and forecast time from AROME EPS.

- **SHRD** = Deep wind shear (**850-200** hPa) averaged between r = 200-800 km.
- **SHRS** = Shallow wind shear (**850-500** hPa) averaged between r = 200-800 km.
- **RHMD** = Mid-level Relative Humidity (**700-500** hPa) averaged between r = 200-800 km.
- **DIV200** = Upper-level Divergence (200 hPa) averaged between r = 200-800 km.

- **TMVM** = Vertical vortex Tilt (layer between 2km and 5km height).
- **TPMA** = MAX(z) of inner-core temperature anomaly between $T_{0\text{-}15km} - T_{200\text{-}300km}$.
- **CLDE** = Eyewall closure by convection (> reflectivity radar threshold, %).


SF850 anomaly + Eq. Waves filtering
15S5S AVG
Latest analysis: 20220510
1-10-21
1-11-21
2-12-21
1-1-22
1-2-22
3-3-22
3-4-22
180
120W
60W
0
60E
120E
-7.5
-4.5
-1.5
0
1.5
4.5
7.5
Low freq.
MJO
Kelvin
Rossby
1 : TT_Paddy
2 : "TT_TERATAI_Est90E
3 : BATSIRAI
4 : CLIFF
5 : EMNATI
6 : DUMAKO
7 : FEZILE
8 : VERNON
9 : "TT_sans_nomVERNON
10 : ANIKA_Est_90E
11 : GOMBE
12 : BILLY_EST_90E
13 : CHARLOTTE_Est_90E
14 : HALIMA
15 : JASMINE
16 : ISSA
17 : KARIM