Investigating the predictability of Mediterranean cyclones

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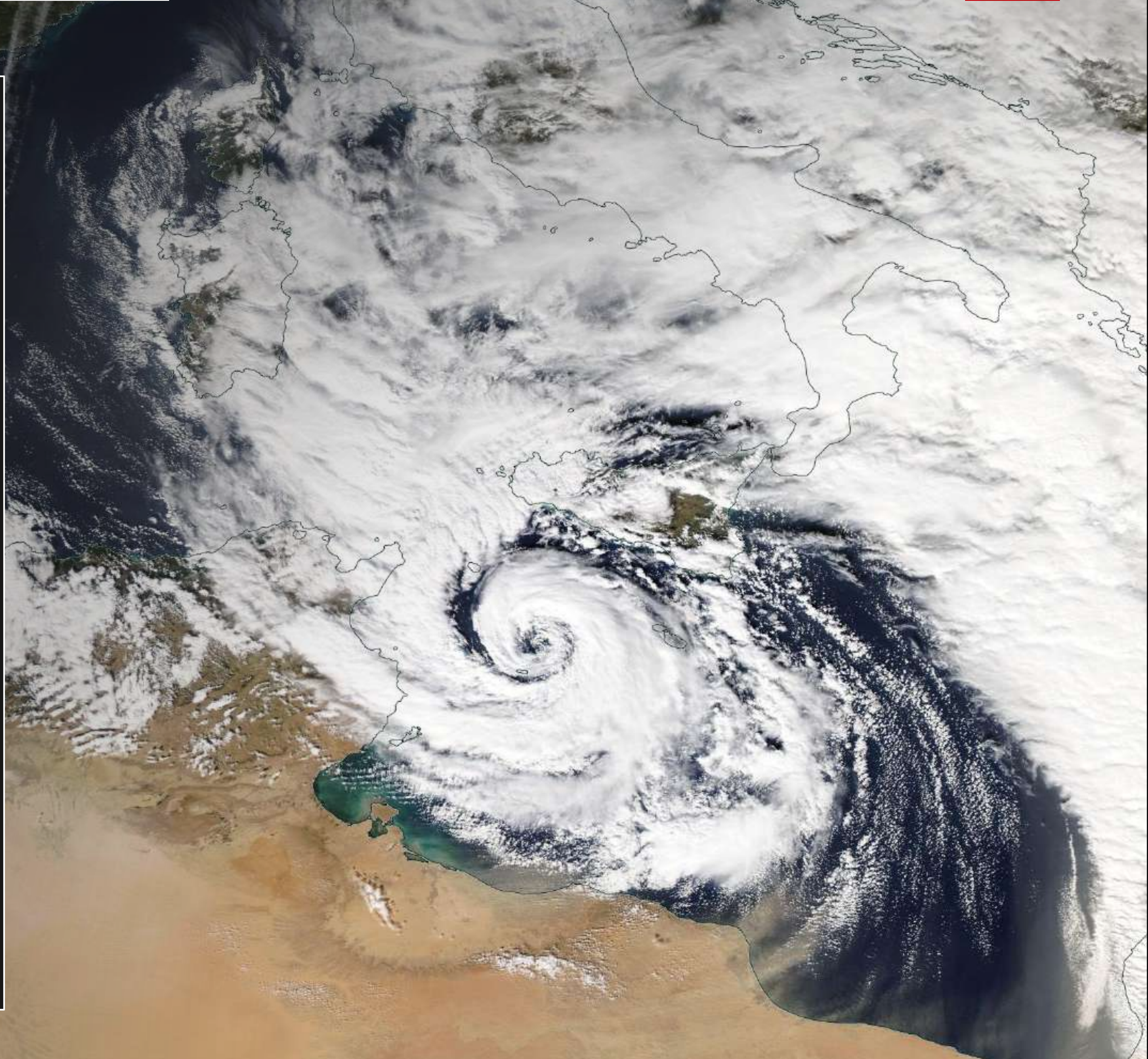


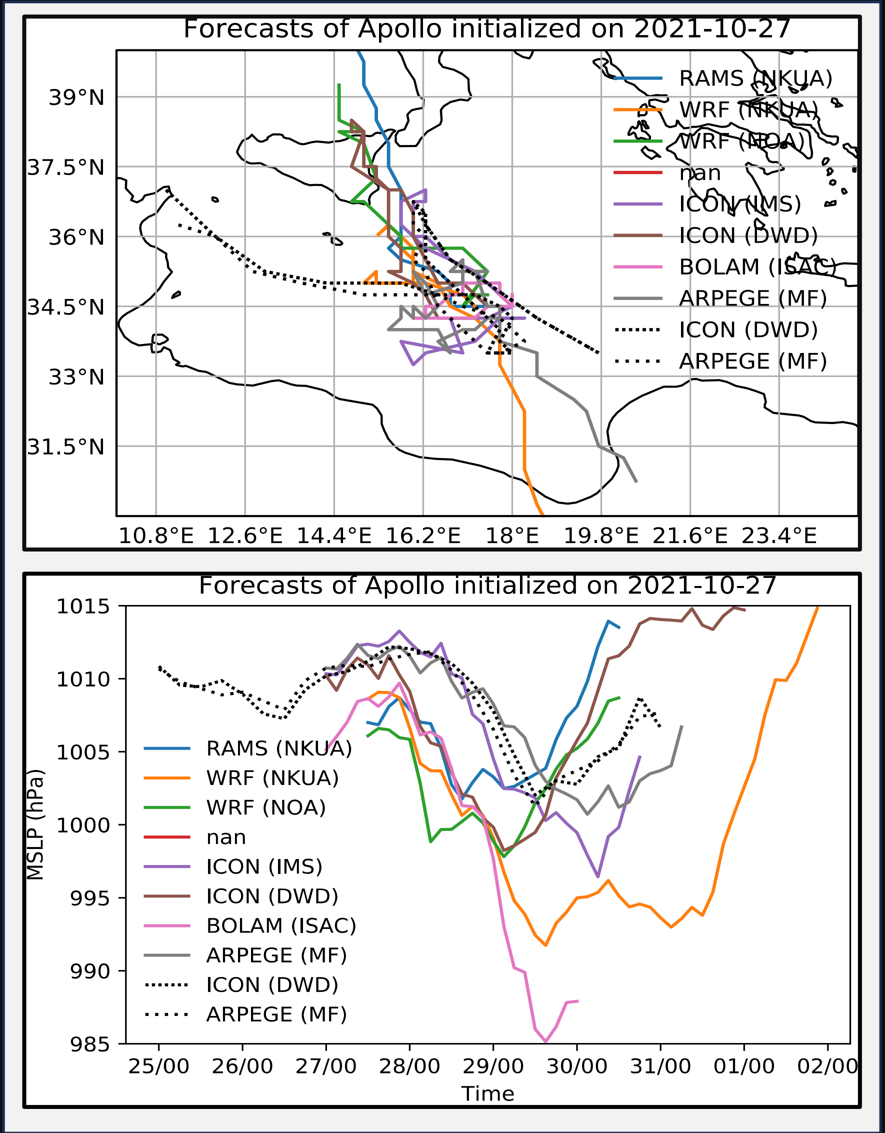
- Medicane Qendresa (2014) - Captured by Aqua/MODIS: https://worldview.earthdata.nasa.gov/

Context - Predictability -

Why is it an important challenge in the Mediterranean?

- The Mediterranean region is densely populated
- Short living systems (harder to capture with NWP)
- Some cases can intensify quickly, into strong extratropical or tropical-like cyclones

Example with Medicane Apollo (2021)
→ High uncertainty in both track and intensity



Comparison of different NWP systems
for a forecast of Medicane Apollo
- MedCyclones DynForMed Initiative -

Strategy - Systematic evaluation -

In the Mediterranean, previous works on predictability focussed mainly on case studies

How to systematically investigate the predictability ?

1. Need of a reference -> Tracking a large number of cyclones in reanalysis (ERA5, 1979-2021)

2. Use of ensemble (re)forecasts (IFS, 2001-2021)

3. Characterise the predictability, firstly for all the dataset, then for specific categories of cyclones

   -> What are the processes involved in the loss of predictability (baroclinic vs diabatic) ?

Reference dataset

Inputs for the tracking (algorithm developed at the CNRM and adapted for the Mediterranean, close to Sanchez *et al.*, 2018)

- ➢ Vorticity at 850 hPa
- ➢ Horizontal wind 850 hPa and 700 hPa

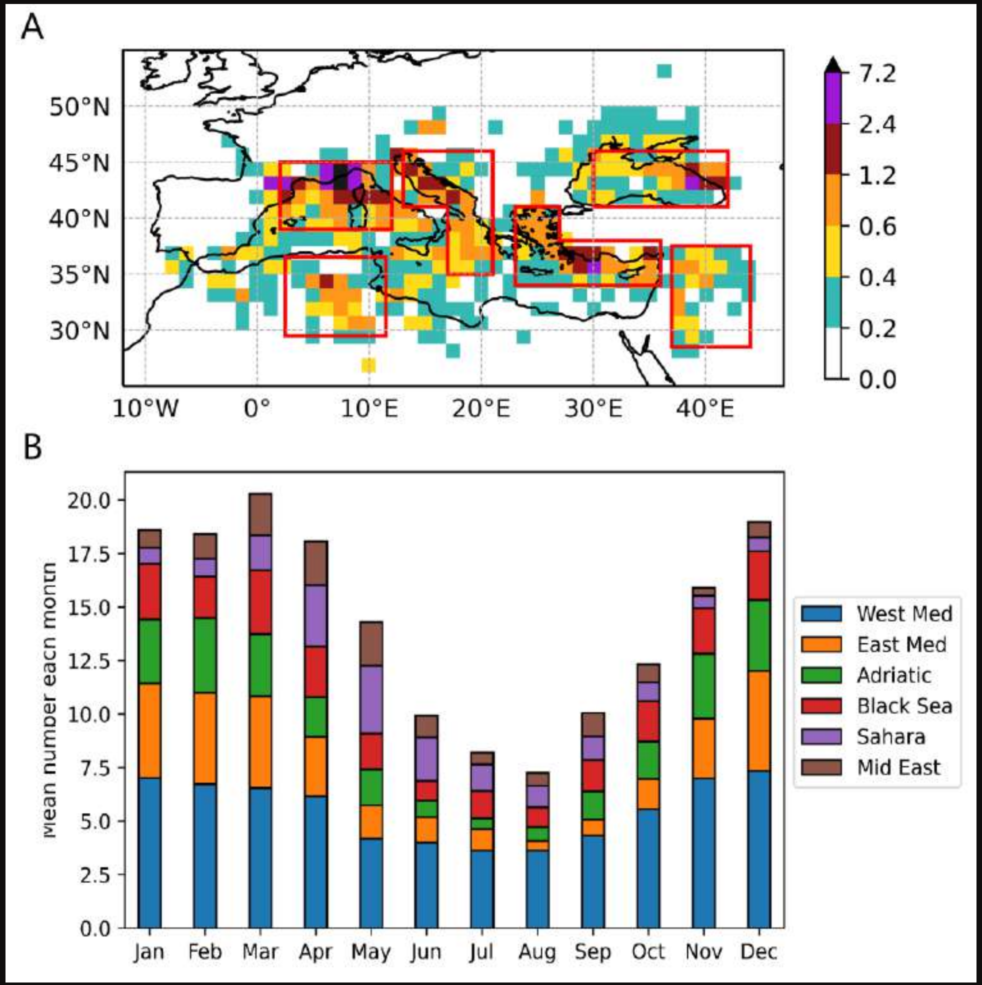
- ❑ 12 000 cyclones tracked in ERA5
  Only for the Mediterranean region, 1979-2021

- ❑ The Gulf of Genoa is the main hotspot

- ❑ Cyclones also detected over arid areas (Sahara or Middle East)

- ❑ A strong seasonal cycle is observed

- ❑ Consistent with composite tracks from Flaounas et al. (2023)



A. Probability for a cyclone in its mature stage to be found in a 1.25° box (annual mean)
B. Seasonal cycle for each area of (A)

Methods - Storm Severity Index -

Investigate the impact of Mediterranean Cyclones

Collaboration with the University of Helsinki
(Special thanks to Joona Corner and Victoria Sinclair)

We compute the SSI in a framework close to Leckebush et al., 2008, with a radius of 1000 km around the cyclone centre:

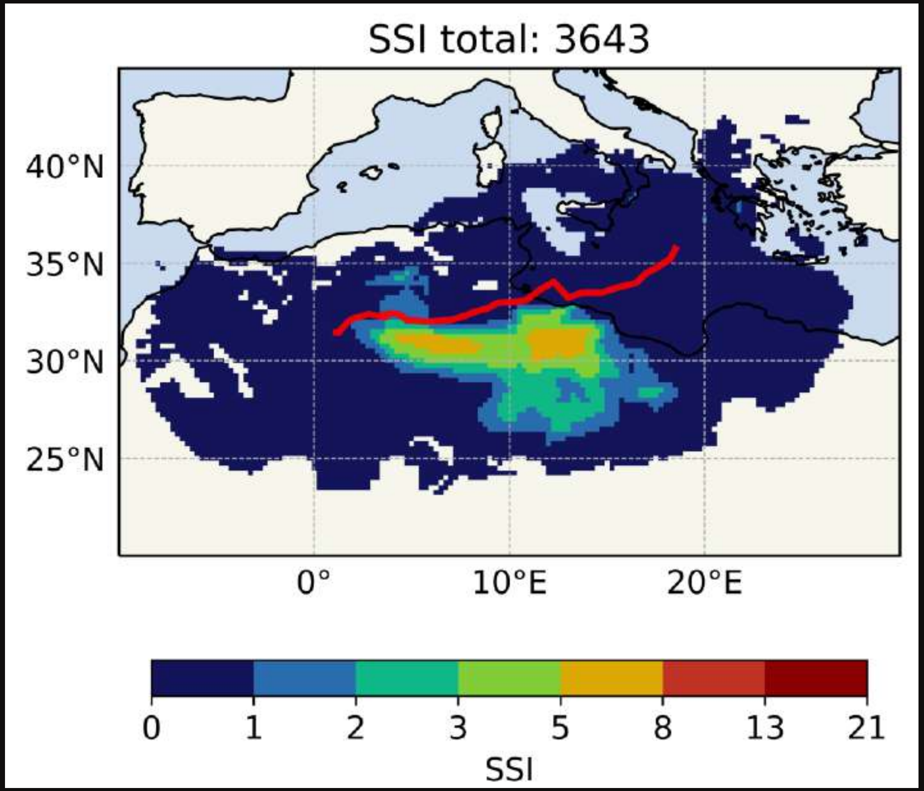
$$SSI_{Total} = \int_{t0}^{tmax} \sum_k \max\left(0, \frac{v_k}{v_{98}} - 1\right)^3 A_k \; dt$$

$$With\ A_k = \frac{A_{gridpoint}}{A_{eq}}$$

$Where\ v_k$ is the wind gust at the grid point k

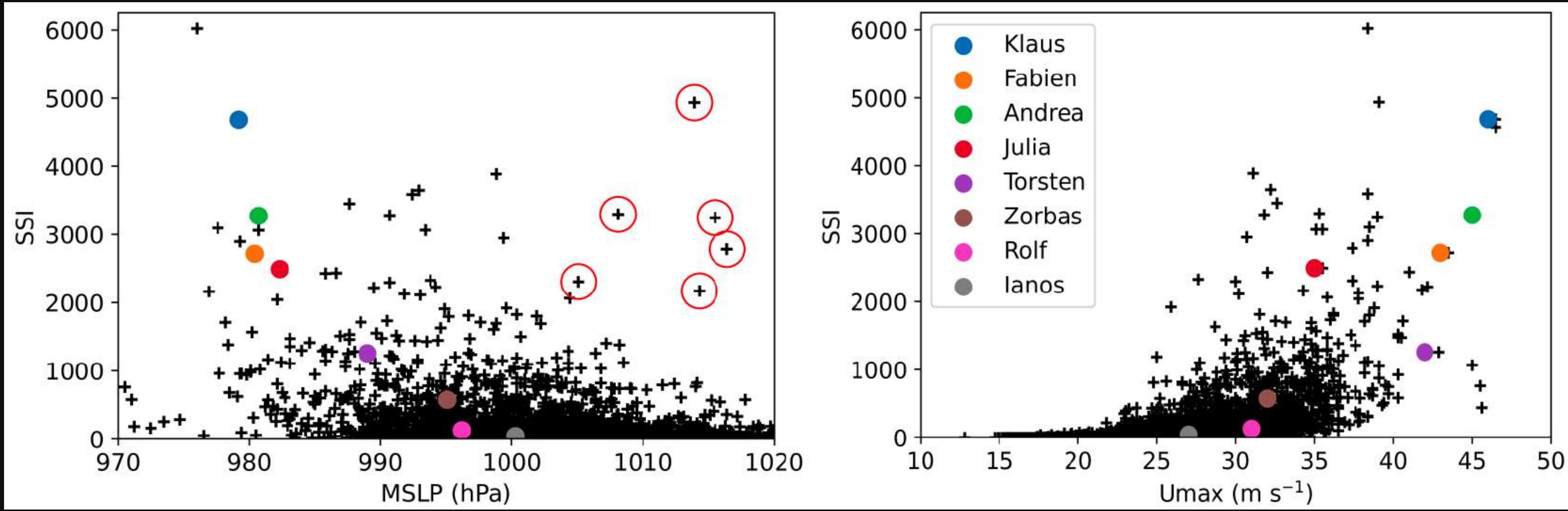
v_{98} is the 98^{th} percentile of the wind gust distribution (at k)

A_{eq} is the area of the grid box at the equator



Example of SSI footpath for a case of Mediterranean cyclone (Jan 2004)

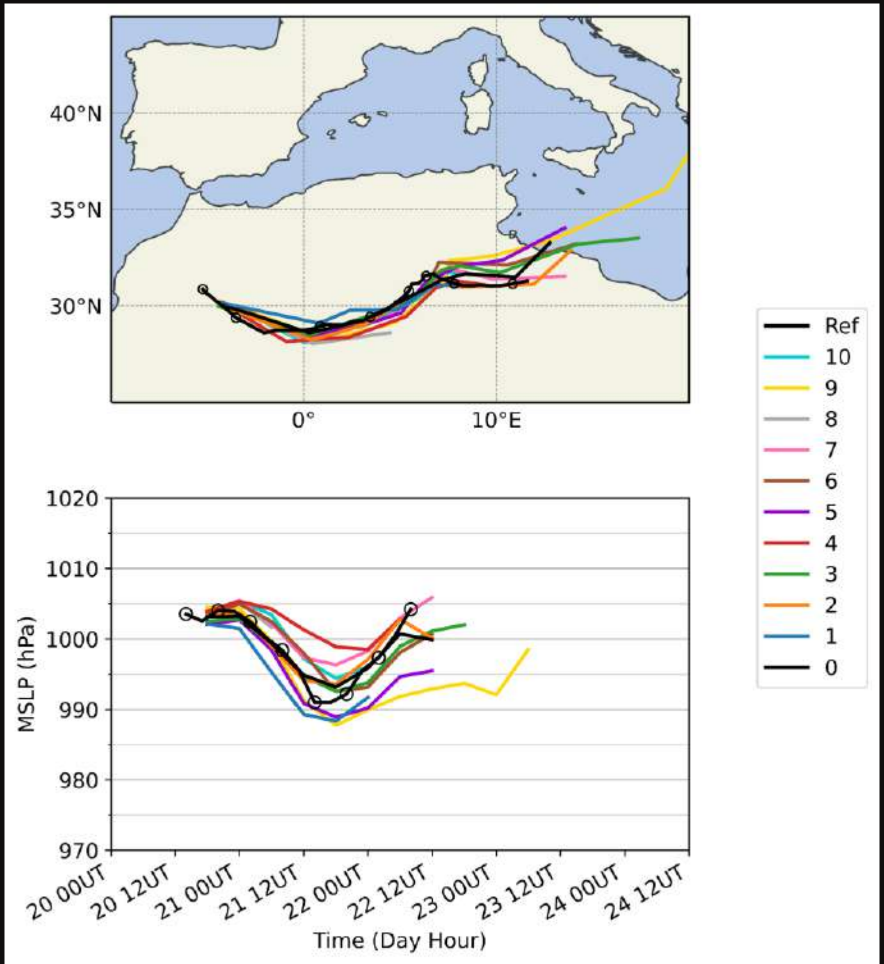
Results - Storm Severity Index -



SSI in function of the mean sea level pressure and of the maximum wind gust in a radius of 1000 km
Cases with SSI > 1500 and MSLP > 1005 hPa are surrounded in red

Suspicious cases with high SSI and high MSLP -> Threshold at 1005 hPa for the final dataset

Methods - Reforecasts -



Tracking of a cyclone in IFS reforecasts
The reference corresponds to ERA5, 0 is the control member

IFS reforecasts (Oct 2001 – Oct 2021):

- 10 + 1 members
- Homogeneous configuration over the whole period
- Ensemble Data Assimilation ERA5 + Singular Vectors
- Horizontal resolution 0.25 °
- 6 h output frequency limited here until 7 days lead time
- Initialisation at 00 h on Mondays and Thursdays

Use of another algorithm (VDG n° 386) to track cyclones in the reforecasts using ERA5 trajectories as a reference

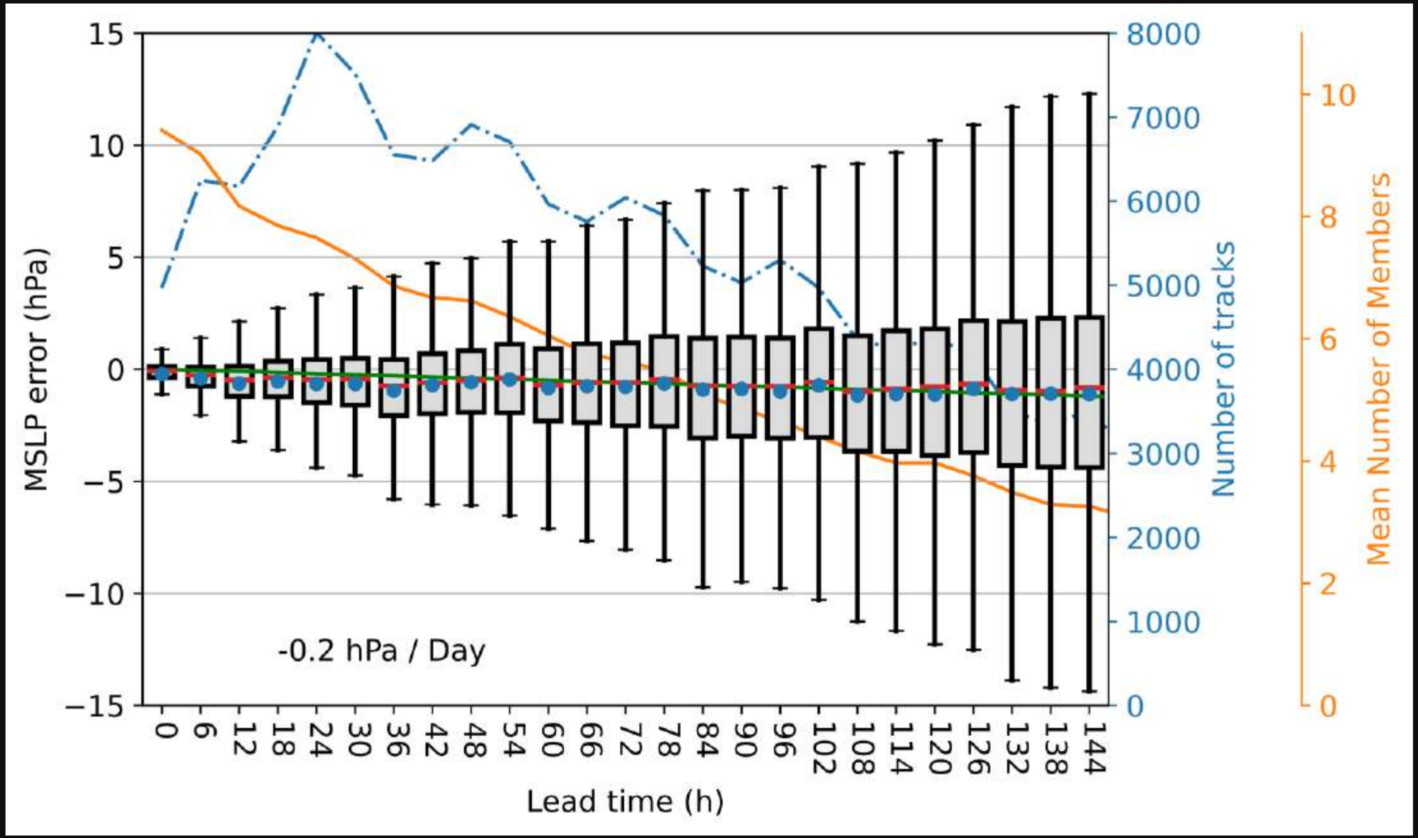
Result: 3853 cyclones (deeper than 1005 hPa) tracked in the ensemble reforecasts

Results - Error in the intensity -

Weak MSLP error growth ~ -0.2 hPa / day
(Using medians of errors distributions)

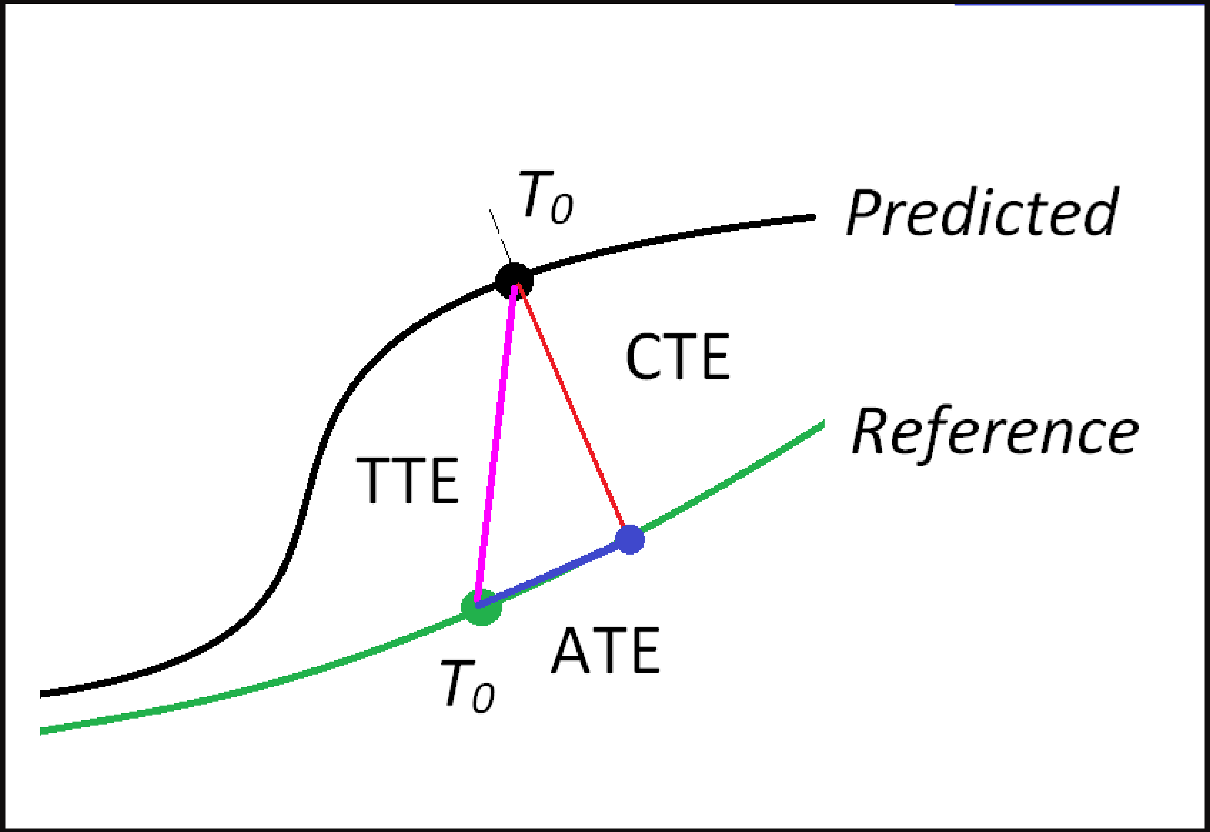
After 4 days of forecasts, 50% of the errors are between +2 hPa and -3 hPa

50 % of the members are lost after 3.5 days



Mean sea level pressure error (hPa) distribution in function of the lead time (h)
Median is in red and mean in blue dot

Methods - Track Errors and Spread -



Track error decomposition, from Leonardo and Colle, 2017

Decomposition of the track error:

- ❑ Total track error (magenta)
- ❑ Along track error (blue)
- ❑ Cross track error (red)

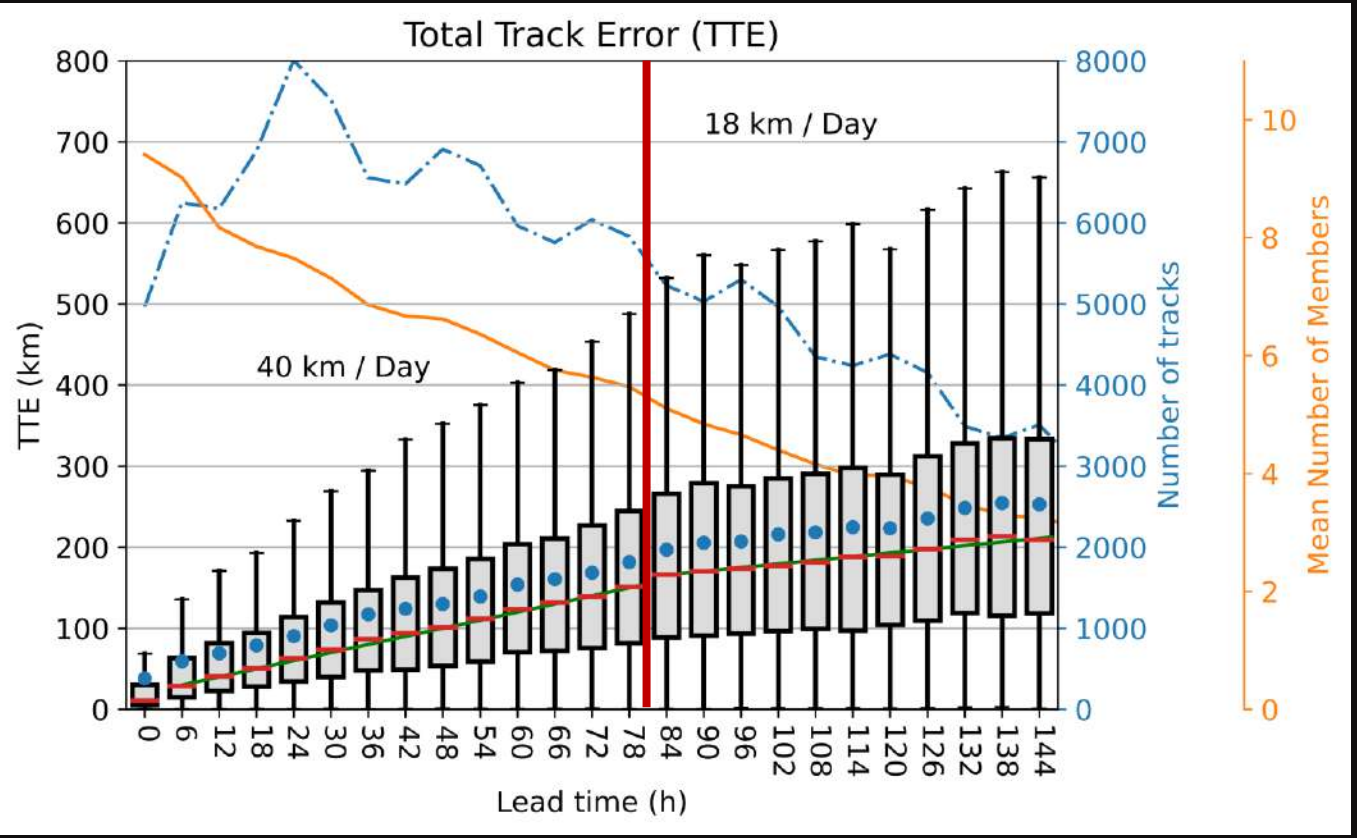
Results - Track Errors -

Error growth for the Total Track Error:
(Using medians of error distributions)

- 40 km / day in the first 78 h
- 18 km / day from 84 h to 144 h

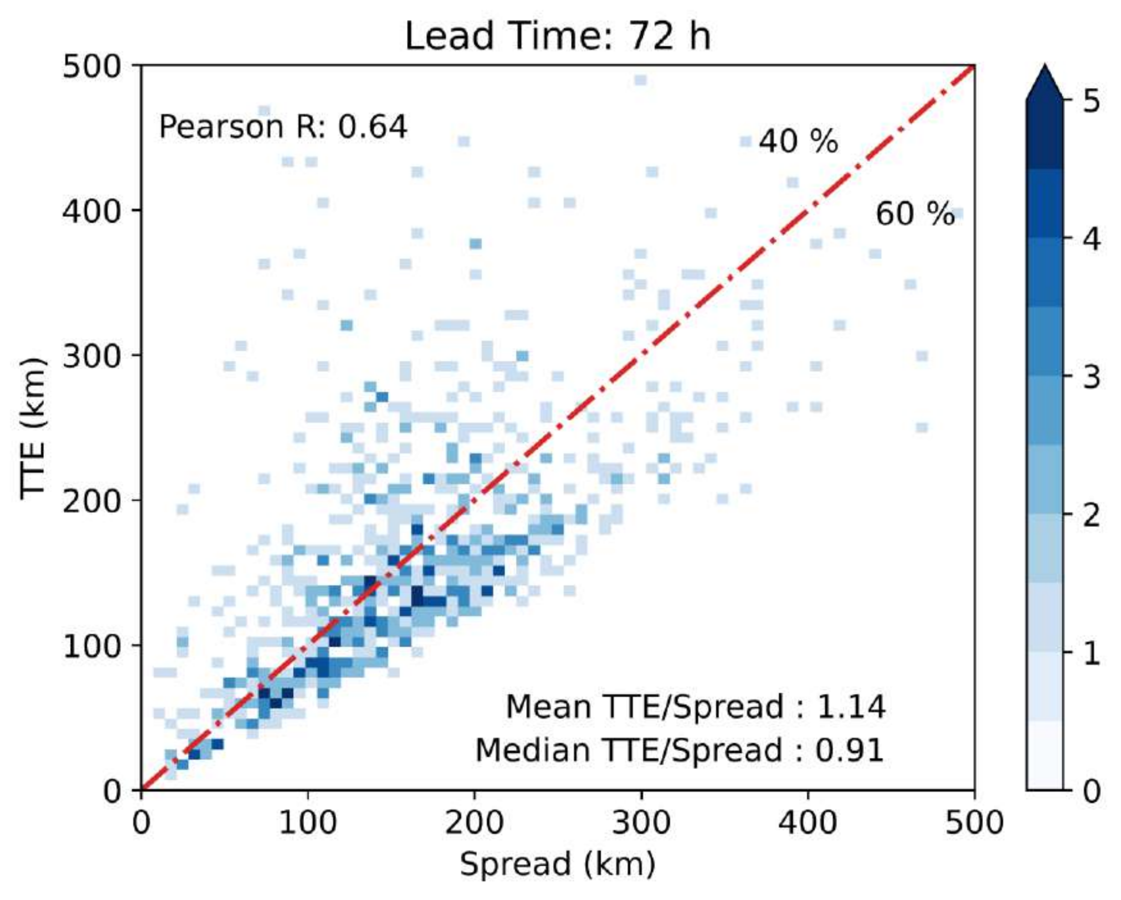
Error for the Along Track Error:
- No systematic bias before 60 h lead time
- Weak and constant error from 66 h to 144 h lead time (-20 km)

Error growth for the Cross Track Error:
- Weak error of about 5 km / day



Total track error (km) distribution in function of the lead time (h)
Median is in red and mean in blue dot

Spread - Skill relationship



Total track error (km) in function of the spread (km)
Density Plot (Number of points in a 7 km square)

Is the ensemble well-calibrated?

- **Comparison** between **Total track Error** (mean of the TTEs of each member) and **Spread** (mean of distance between each pair of members)

- The ensemble seems to be most of the time slightly over-dispersive (TTE < Spread)
- Difference between mean and median of the ratio TTE/Spread -> Some cases are sometimes poorly predicted (TTE >> Spread)

Predictability - Cyclone dynamics relationship

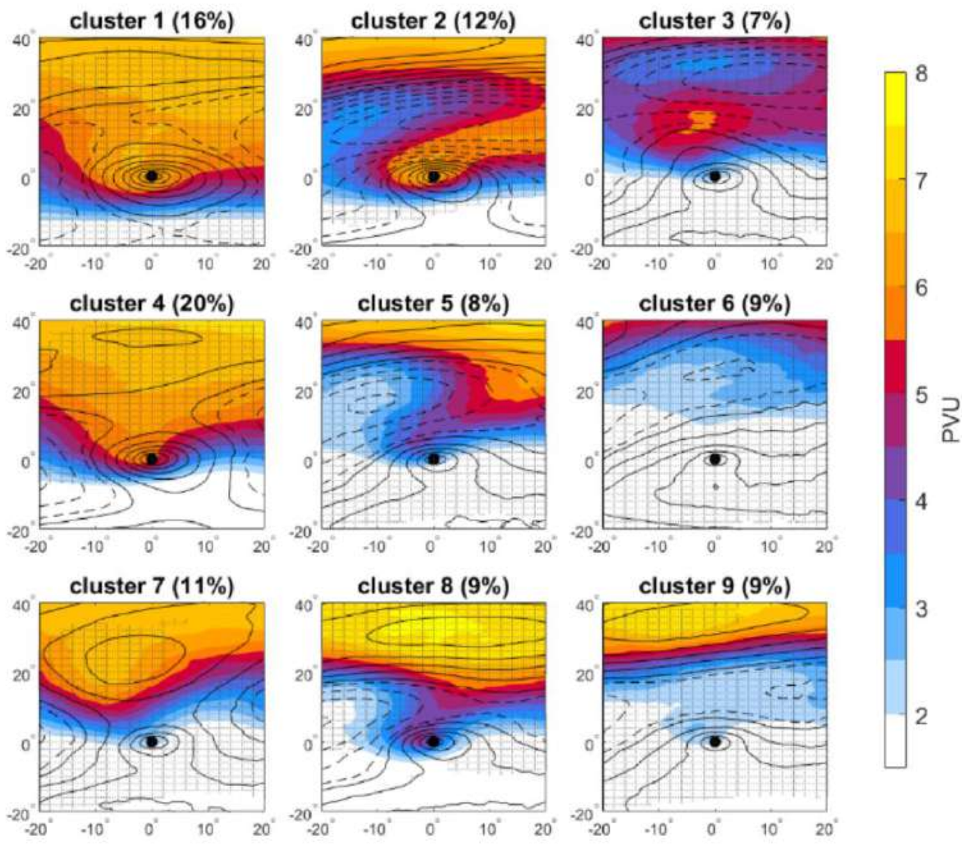


Figure 3: Cyclone-centered cluster composites of upper-level PV (PVU, shading) and SLP (black contours at 2-hPa intervals, dashed over 1015 hPa). Stippling indicates a 99% significance level of the PV field concerning the total cyclone average (Fig. 2a). The mean frequency of each cluster out of all cyclones considered is given in the title.

Extracted from Givon et al., 2023 (submitted)

Reminder: Different classes of Mediterranean cyclones based on Self-Organising Maps of Potential Vorticity structures

- Clusters 1 and 4 show lee cyclogenesis
- Clusters 2, 5 and 8 are Rossby Waves Breaking
- Clusters 3 and 9 are Cut-off lows
- Cluster 7 are daughter lows
- Cluster 6 represent the heat lows

Results - Track error in different categories -

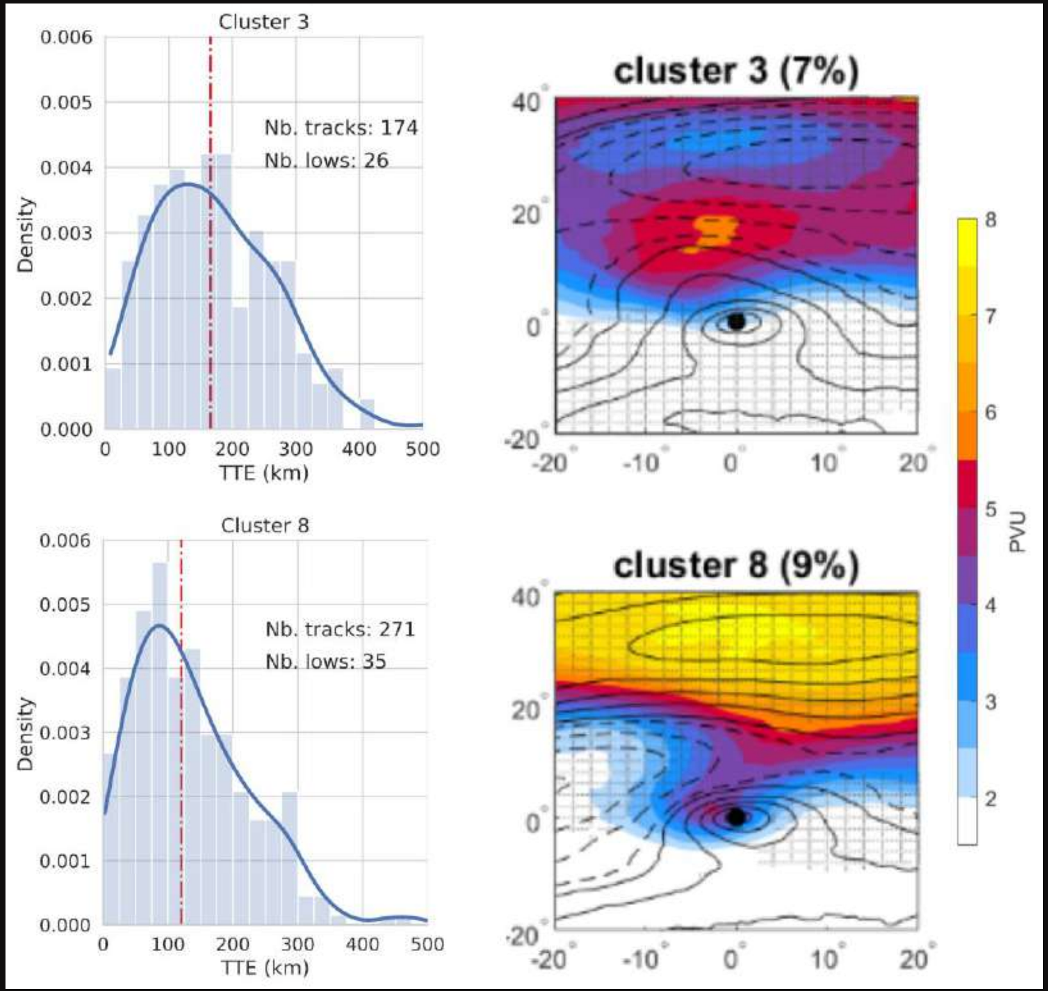
Differences in the Total track error distribution between categories

Medians of the Total track error:

cluster 8 < cluster 3

Higher probability to have smaller errors for cluster 8 than for cluster 3

Seems to indicate a better predictability for RWB-cyclones than for Cut-off lows



Total track error (km) distributions for two categories of Mediterranean Cyclones **at 72h lead time**
The red line indicates the median of the distribution

Take home messages

- ❑ Use of reference (ERA5) and ensemble reforecasts (IFS) to provide a systematic evaluation of predictability
  3854 cyclones tracked (2001-2021)
- ❑ The total track error growth exhibits two phases. In particular using medians of distribution:
  0-78 h ➡ 40 km / day | > 78 h ➡ 18 km / day
- ❑ The IFS ensemble is well-calibrated (a bit over-dispersive),
  Some cases are poorly predicted (TTE >> Spread)
- ❑ Different categories of Mediterranean cyclones show different track error distributions

Perspectives

How to systematically investigate the predictability ? -> What are the reasons for the loss of predictability ?

- ❑ Quantify the predictability using different metrics
  SSI distributions, Spread, MSLP …

- ❑ Testing different categorisations
  Geographical origin, intensity, severity

- ❑ Investigate the reasons for the loss of predictability
  Loss in prediction due to baroclinic processes or to diabatic heating?

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