An object-based method to study the life cycle of mesoscale convective systems (MCS) and their environment from cloud-resolving AROME-France simulations

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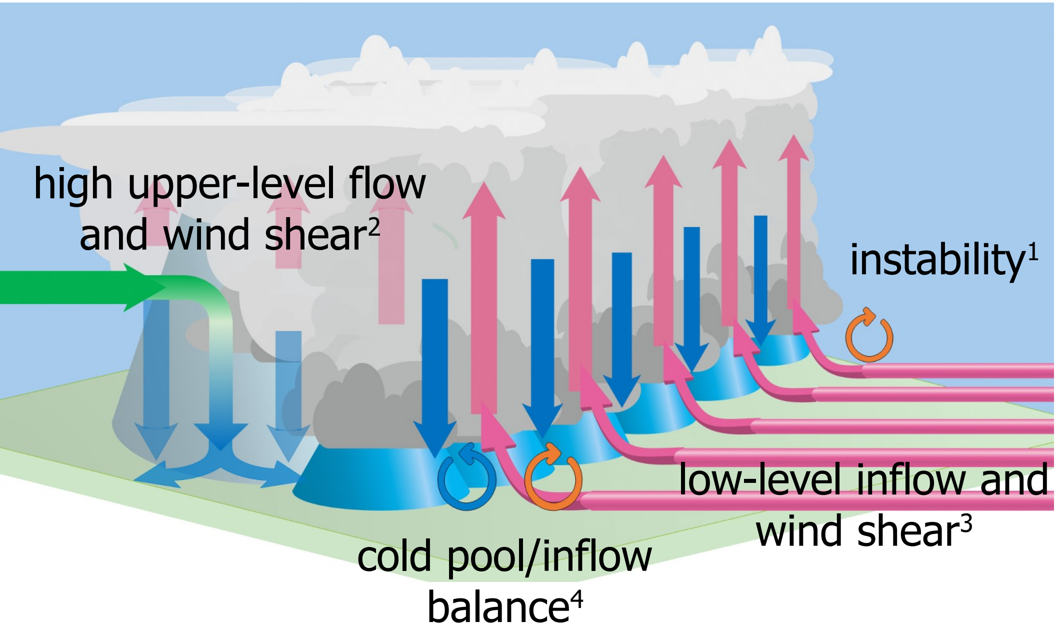
12th European Conference on Severe Storms – Utrecht, Netherlands – 17 to 21 November 2025

The environment favouring MCS initiation and maintenance has been widely studied in the Central United States



[1] Jirak & Cotton (2007), Coniglio et al. (2007)

[2] Coniglio et al. (2006, 2007, 2010)

[3] Gale et al. (2002), Jirak & Cotton (2007), Coniglio et al. (2010)

[4] RKW theory (1988)

Such studies are rare in western Europe (except for the Mediterranean MCSs)

European MCSs are frequent, can be severe, and remain difficult to predict

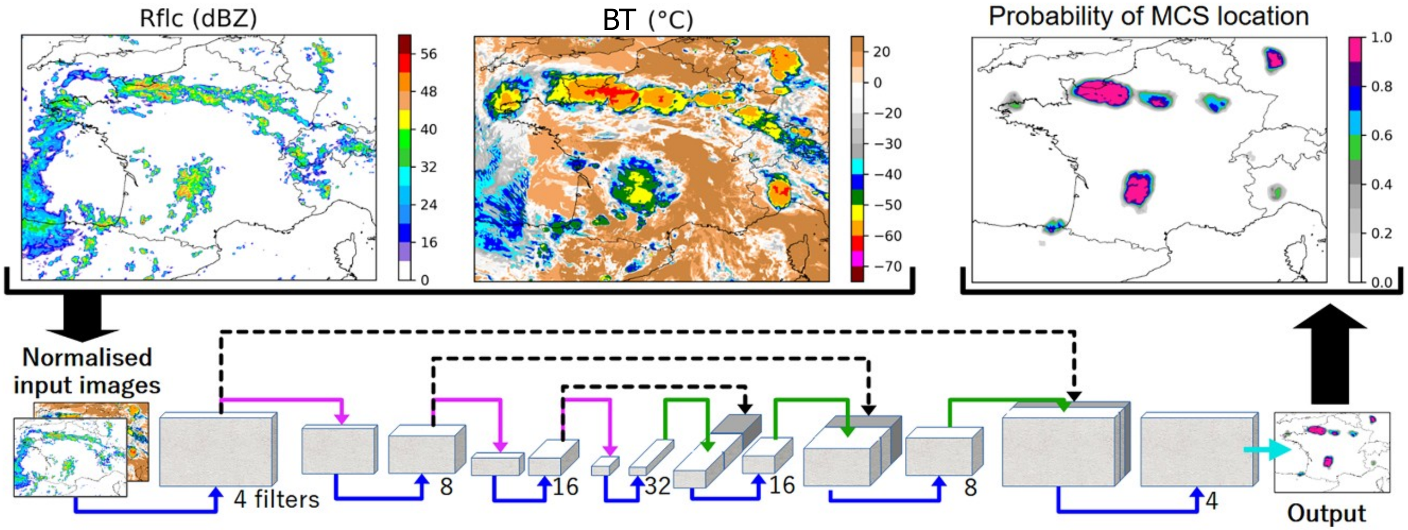
Purpose: document the life cycle of MCSs and their environment in France

Highlight the ingredients responsible for MCS initiation and maintenance in France, with applications in nowcasting

An object-based study in France

- Period: days associated with **watches** issued by Météo-France for severe convection in **2018-2022**

- MCS objects detected from reflectivity and infrared brightness temperature (BT)… by a **CNN** (U-Net)
  - … in **AROME-France** non-hydrostatic 24 h simulations (starting at 0600 UTC)
    → consistent 3D description of the environment

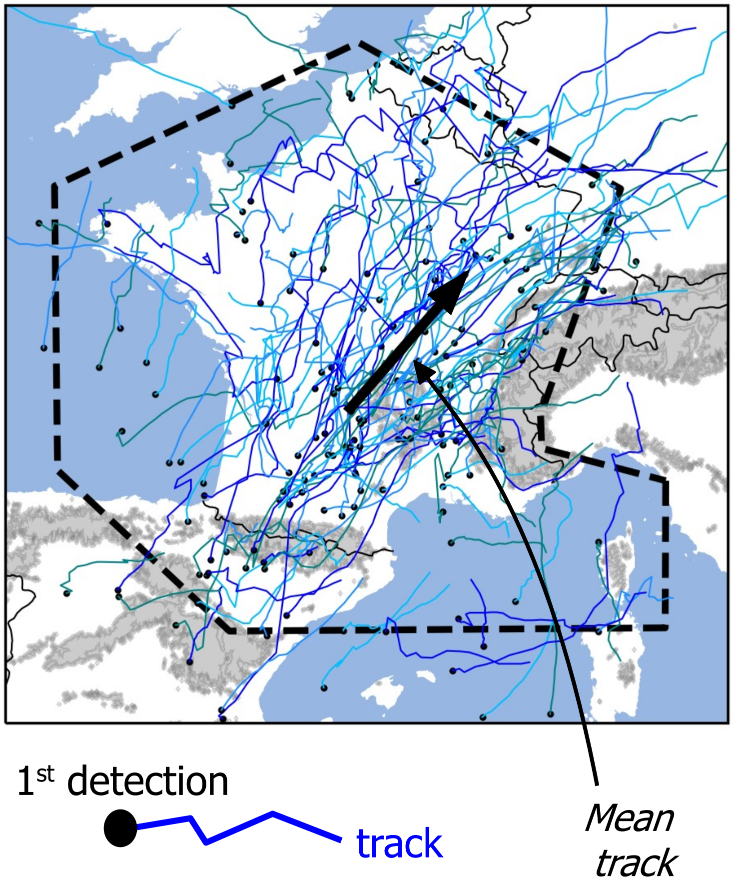


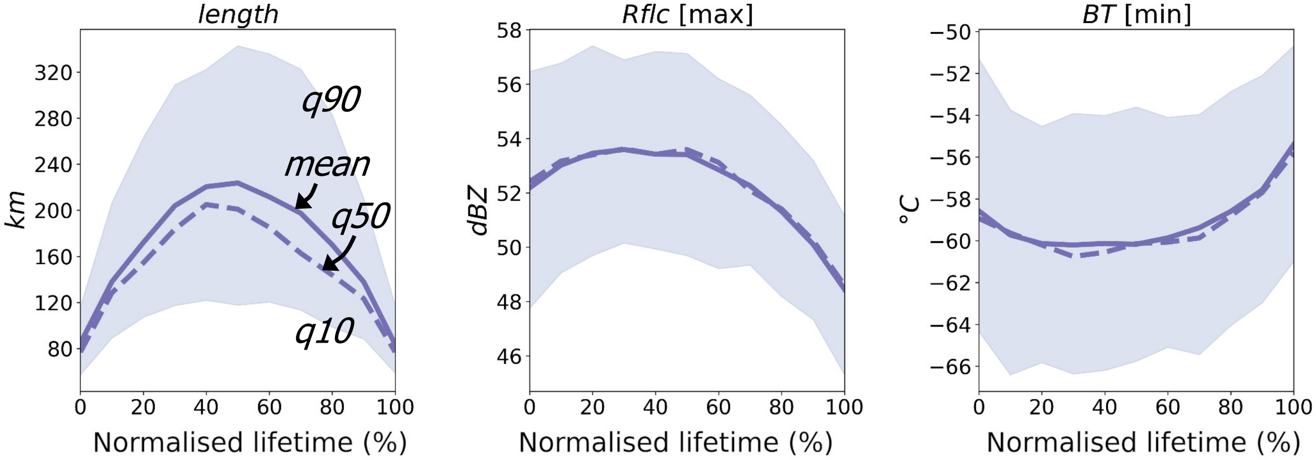
→ MCS objects defined by an optimised threshold (see Arnould et al., 2025)

- MCS objects are tracked over time. We only keep reliable tracks (objects > 100 km for at least 3 h). Stationary Mediterranean MCSs are filtered in this presentation.

Spatial distribution and MCS life cycle

153 tracks





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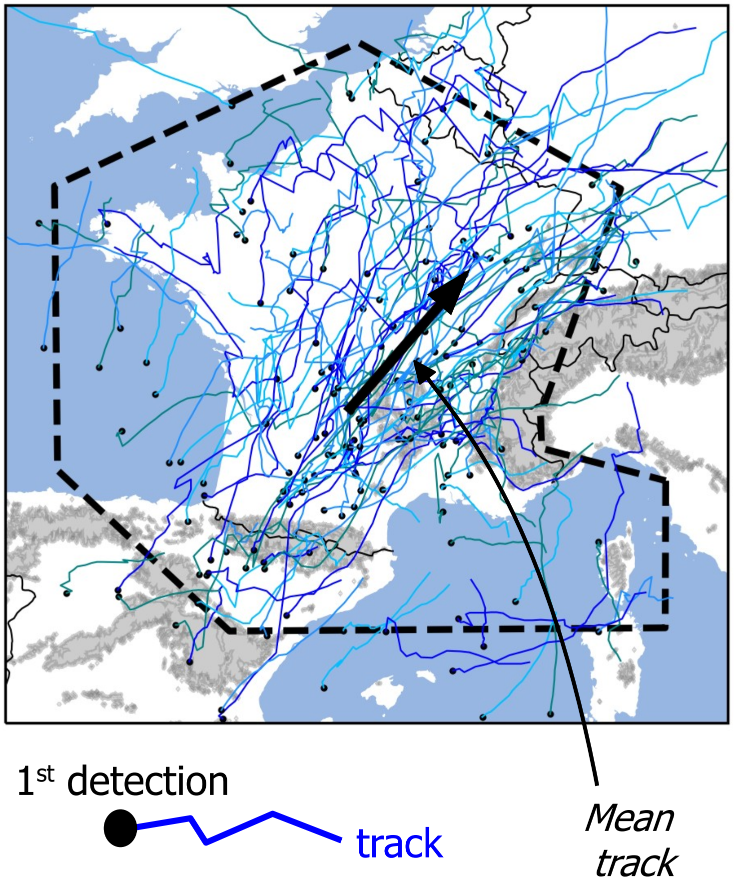
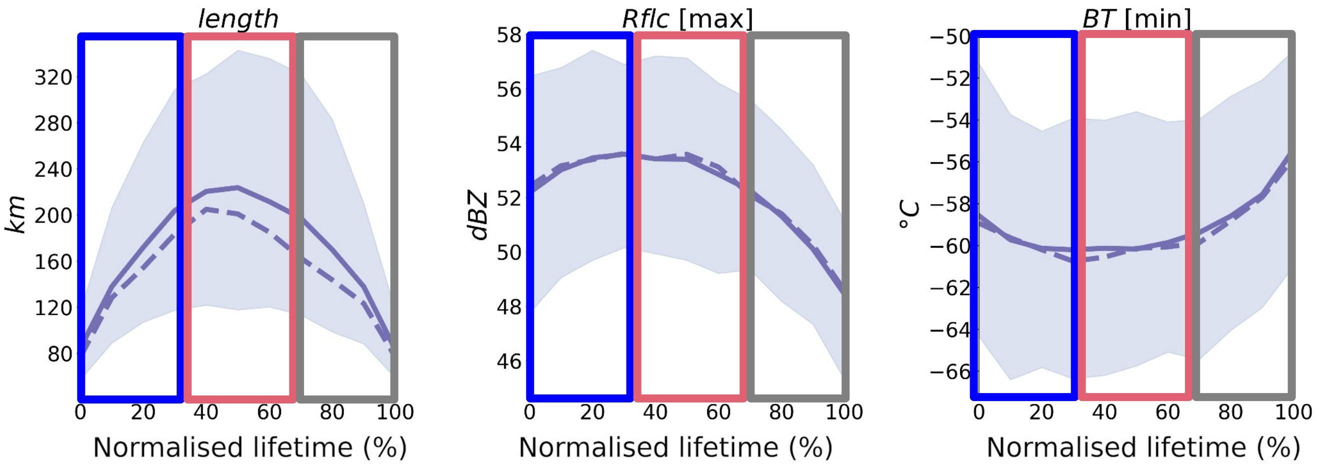




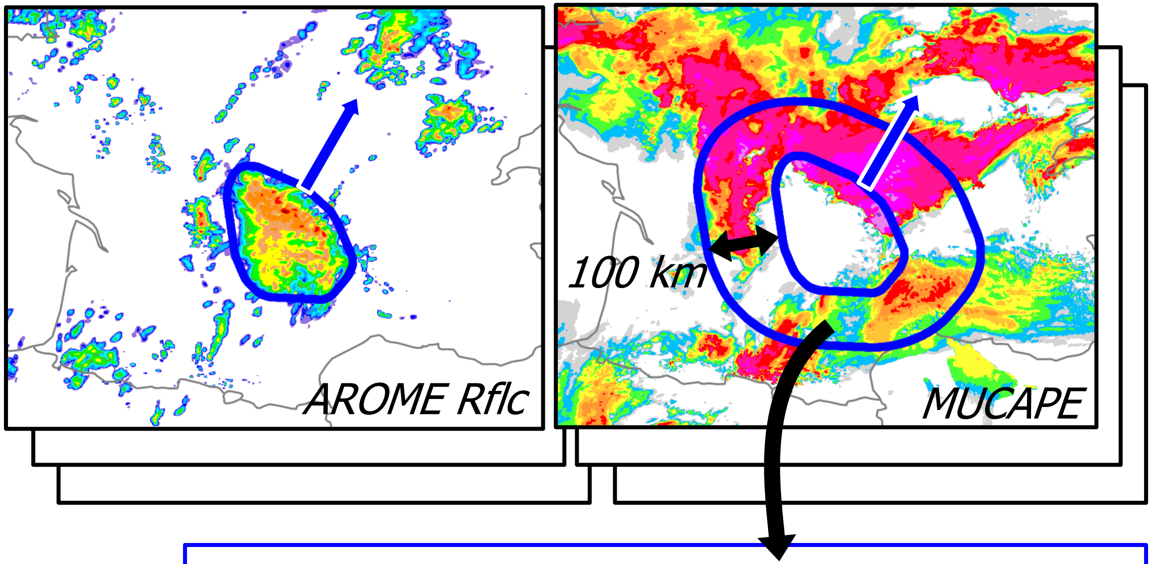
- From a preliminary evaluation, AROME-France realistically reproduces the life cycle of observed MCSs in France

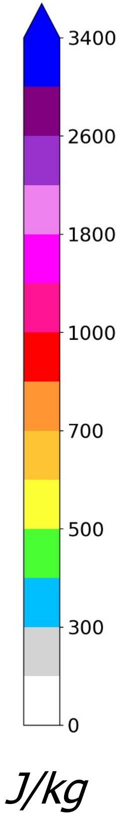
- We characterise changes in the environment during three key stages:
  - **Developing** → represented by **10%** of lifetime,
  - **Mature** → **50%**,
  - **Weakening** → **80%**

Two methods to describe MCS environment

MCS identification

A field of the environment

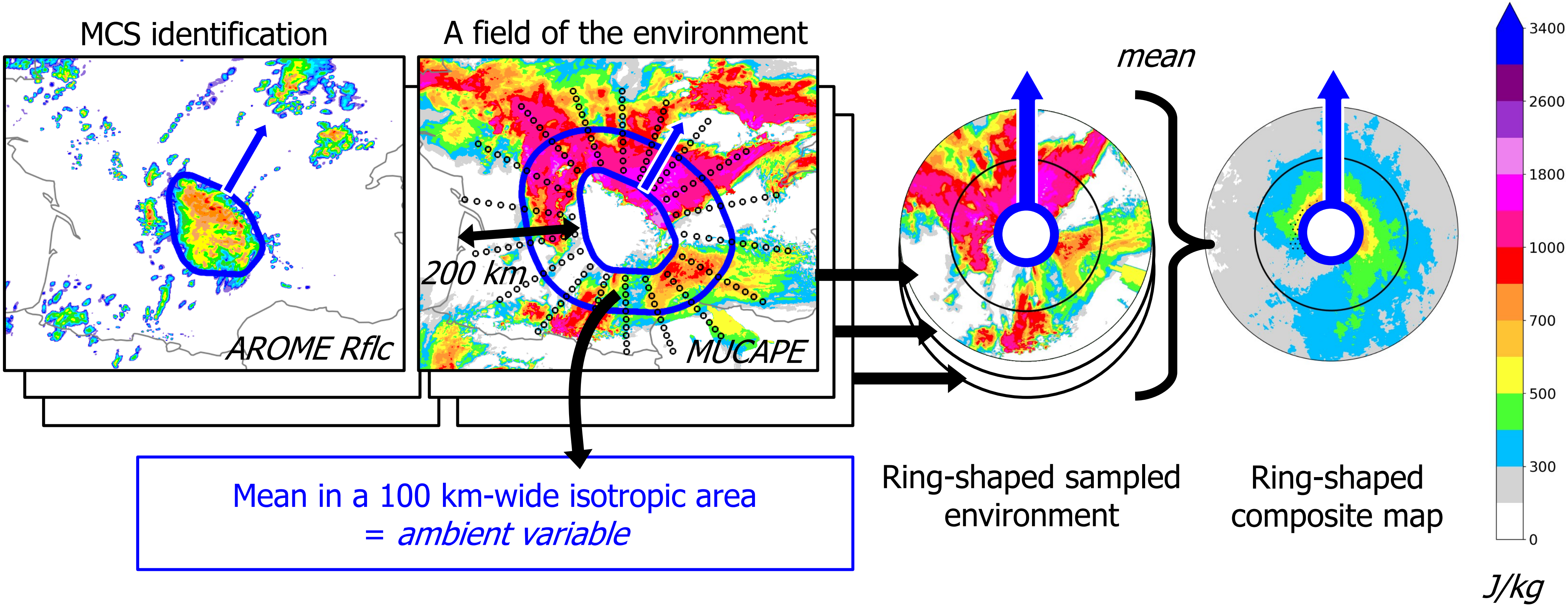




Mean in a 100 km-wide isotropic area
= *ambient variable*

Method 1: bulk analysis

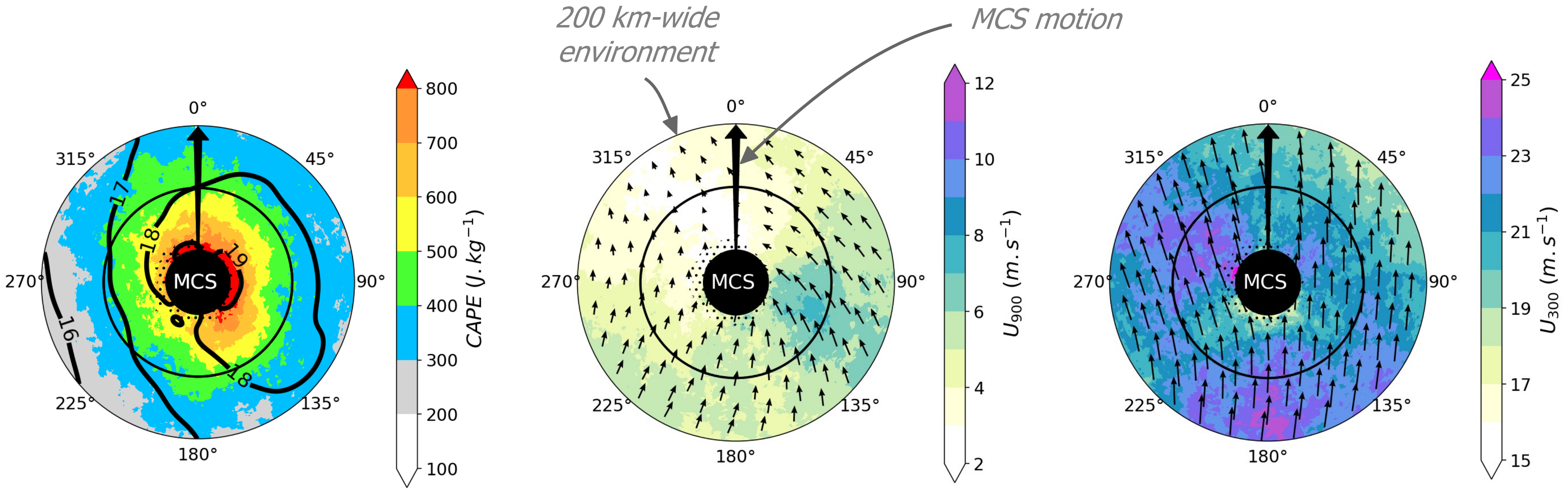
Two methods to describe MCS environment



Method 1: bulk analysis

Method 2: composite mapping analysis

Ring-shaped composite maps of MCSs at developing stage



MUCAPE
θ_w 900 hPa (lines in °C)

Unstable environment with baroclinicity

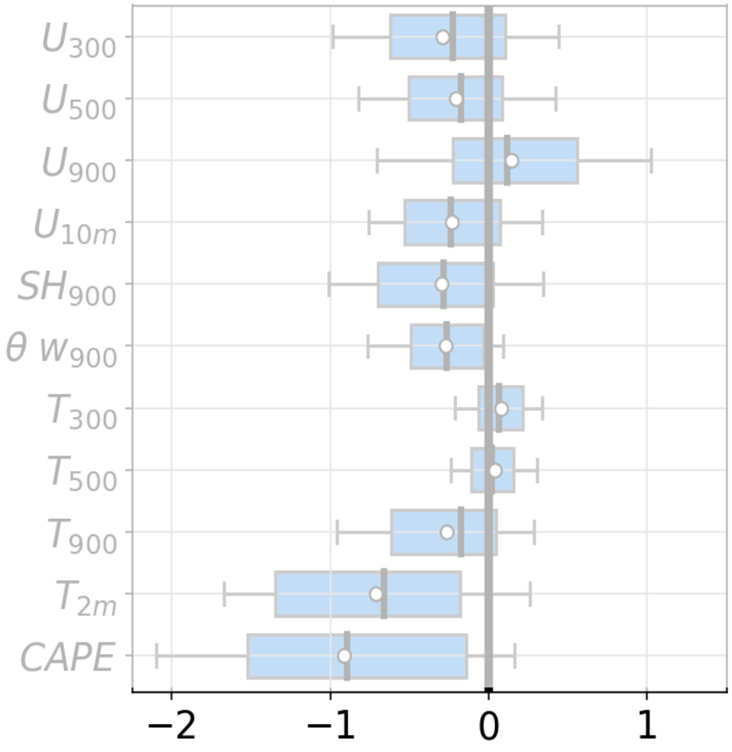
Wind 900 hPa

Low-level wind convergence

Wind 300 hPa

High upper-level flow, max on the left and rear sides

Changes in the environment between developing and weakening stages

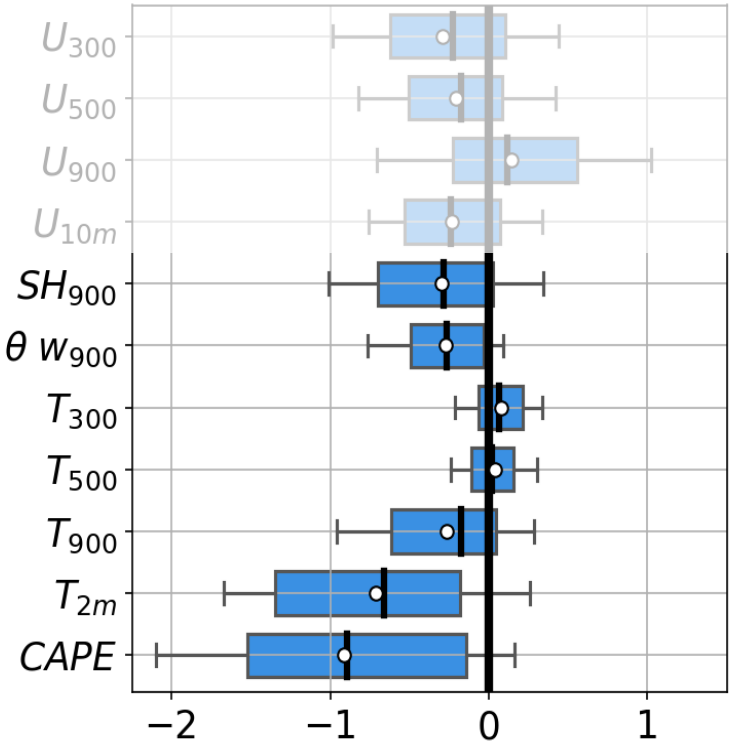


Trends of normalised ambient variables, in units of std
(distribution over 153 simulated MCSs)

- Preliminary study: monotonic evolution of ambient variables
  → we directly compute trends betweend the developing and weakening stages

- Ambient variables are normalised to compare the amplitude of trends

Ambient CAPE: strongest decrease because of low-level cooling and drying
MCSs are advected towards less unstable regions (+ nocturnal cooling)



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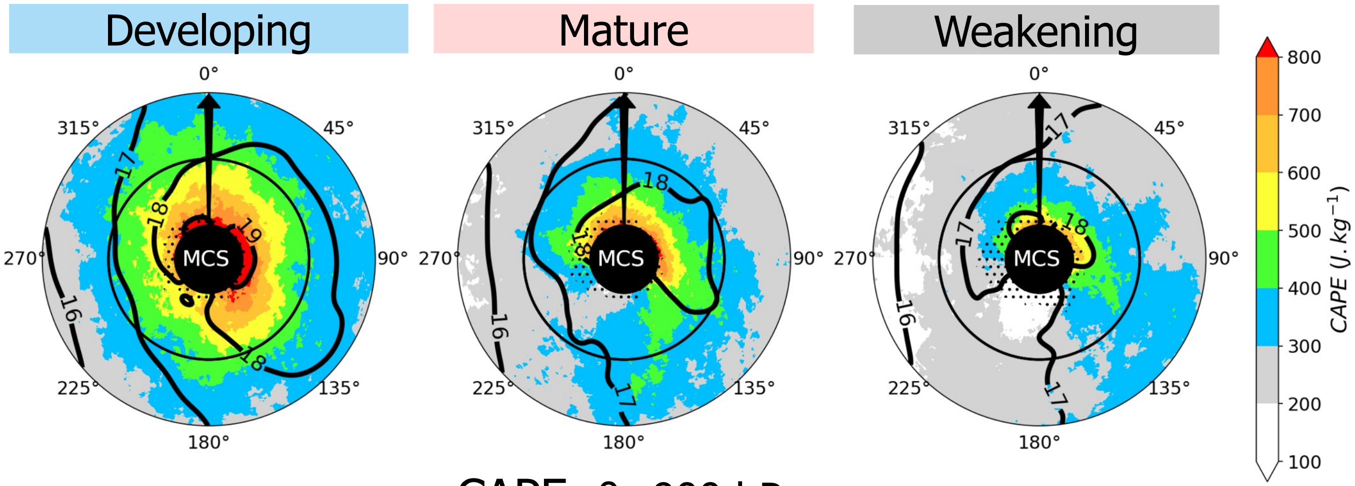
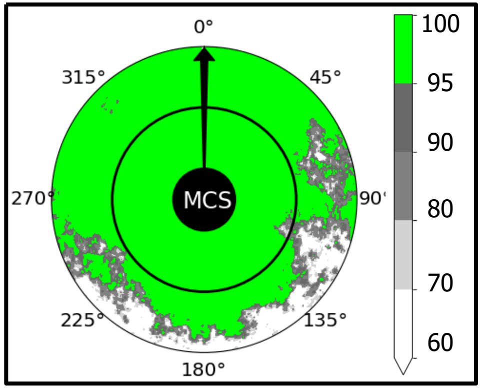
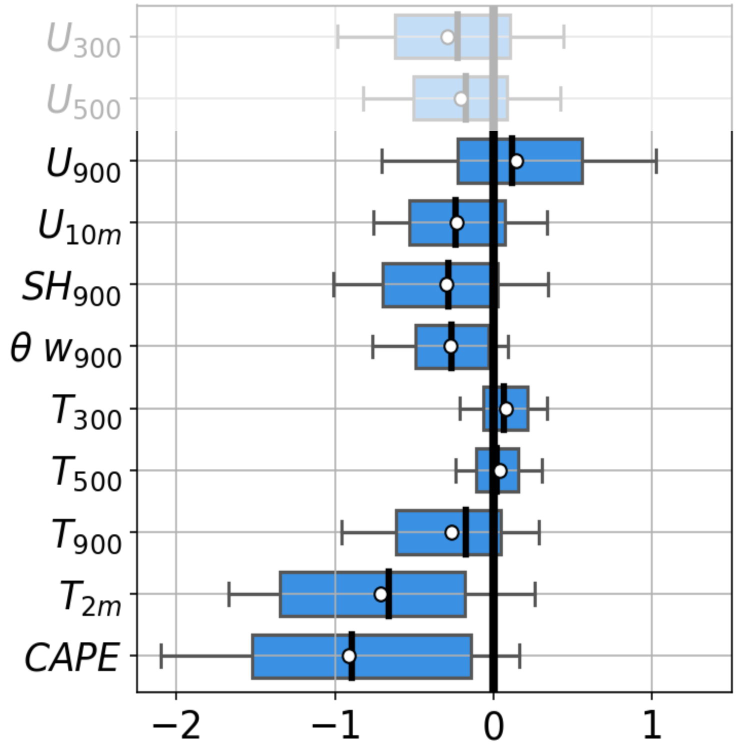


CAPE, θ_w 900 hPa

Confidence (%) that the CAPE is different between the developing and weakening stages
(Wilcoxon signed-ranked test)



Changes in low-level flow are not pronounced



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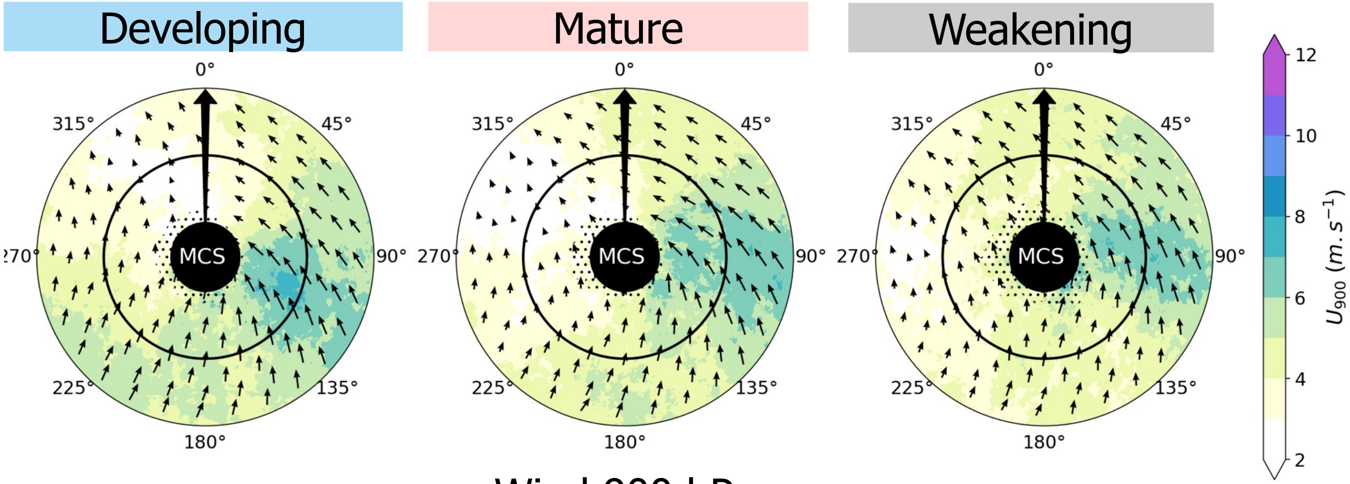
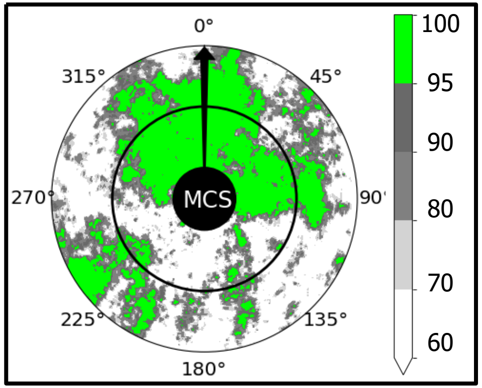
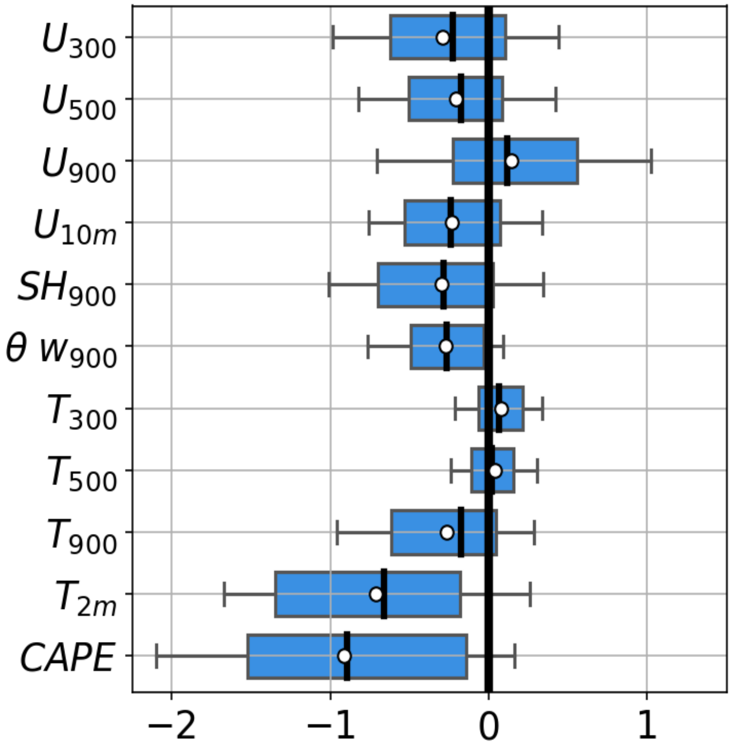


Wind 900 hPa

Confidence (%) that the U_{900} is different between the developing and weakening stages
(Wilcoxon signed-ranked test)



Upper-level flow decelerates, especially at 300 hPa (except on the left side)
→ possible reasons: MCSs act as an obstacle and/or are advected away from the jet



Trends of normalised ambient variables, in units of std
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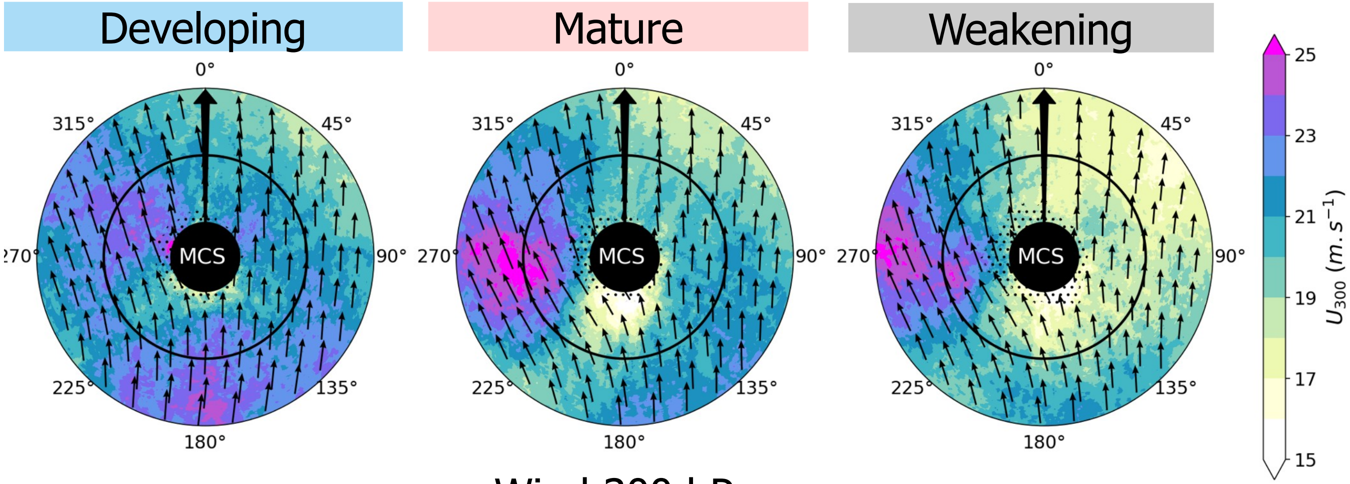
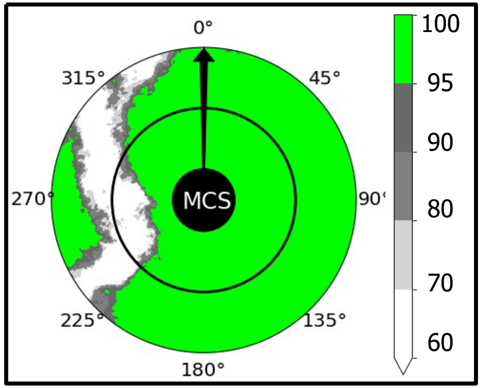


Wind 300 hPa

Confidence (%) that the U_{300} is different between the developing and weakening stages
(Wilcoxon signed-ranked test)



Conclusions

- ~150 MCSs studied in AROME-France simulations between 2018 and 2022
- Two methods to describe changes in the environment during the life cycle of simulated MCSs: (1) ambient variables and (2) ring-shaped composite maps

MCS maintenance in the US	France and surroundings
Instability	**Strongest decrease for CAPE** → cooling and drying at low level, ahead of the MCS In nowcasting: characterise the ambient instability of MCS objects tracked in real time, typically using CAPE forecasts from a recently updated hydrostatic model
Upper-level flow	Small decrease (obstacle effect?) but the impact on the life cycle is not evident
Low-level jet	Small trend (more important for stationary Mediterranean MCSs, not shown here)
Cold pool/inflow balance	*To be studied*

- All details in Arnould et al. (2025), *An object-based method to study the life cycle of mesoscale convective systems and their environment from cloud-resolving AROME-France simulations*
  Quarterly Journal of the Royal Meteorological Society

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