Modelling Mediterranean cyclones across scales

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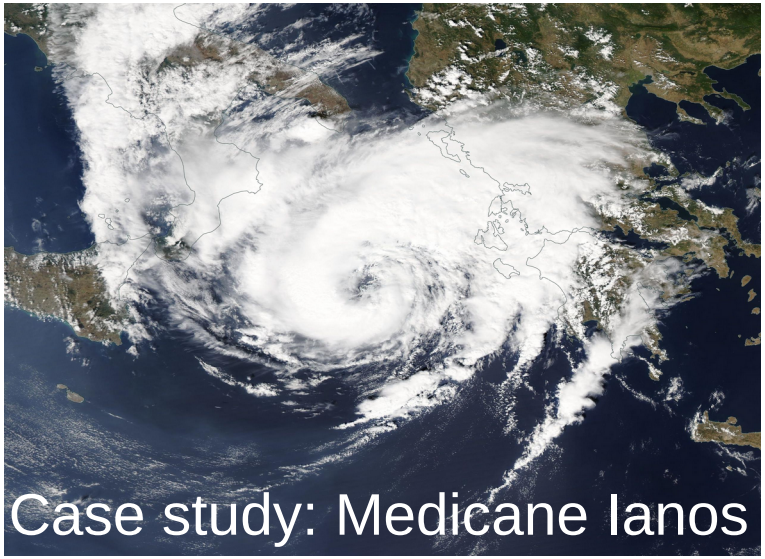
Which scales are we talking about?

Part I: O(1–10 km)



Case study: Medicane Ianos

Part II: O(0.1–1 km)

Case study: cyclone Adrian

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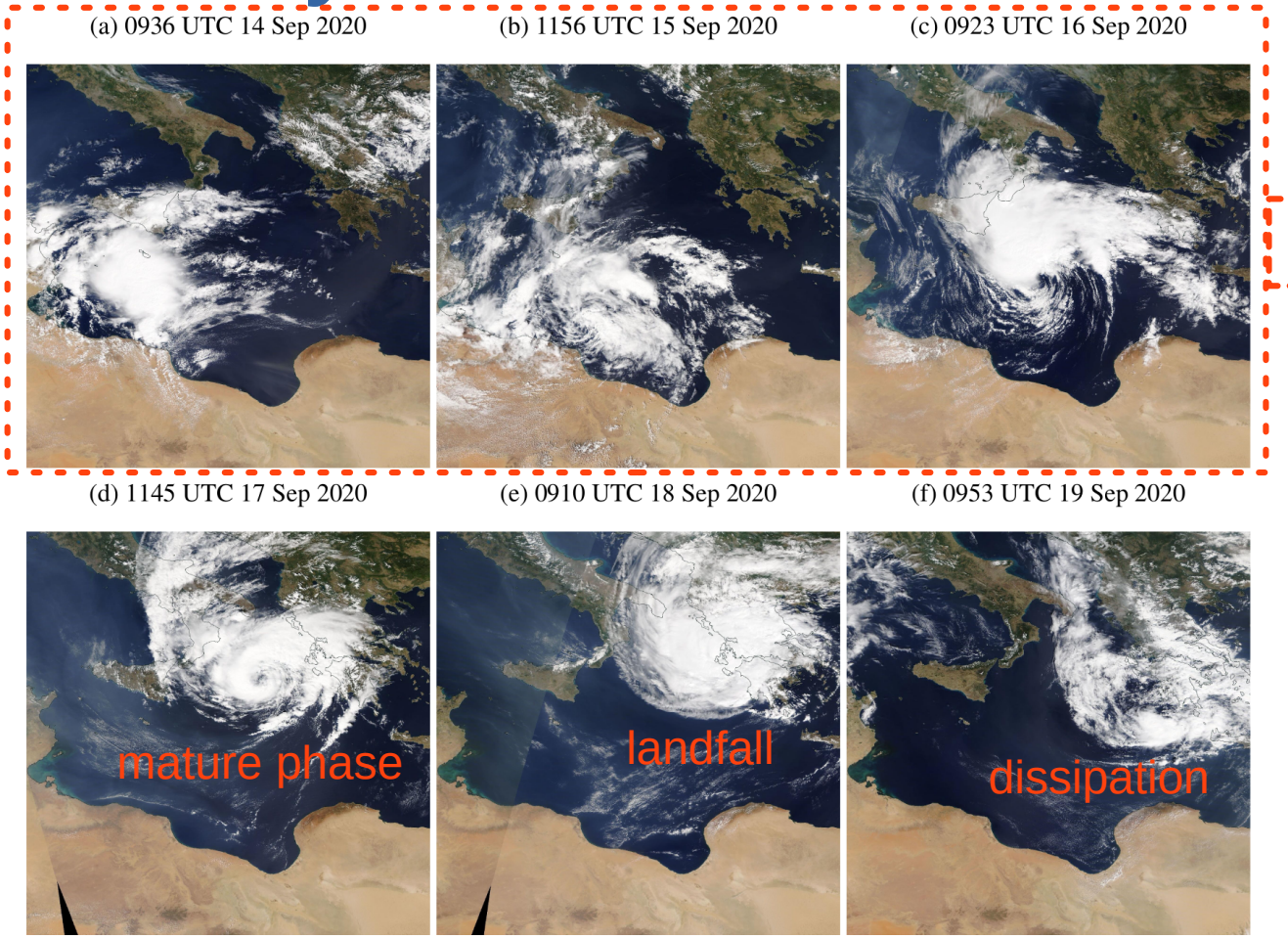
The life cycle of medicane Ianos



cyclogenesis

visible imagery from MODIS instrument aboard AQUA and TERRA satellites
https://worldview.earthdata.nasa.gov/

Model intercomparison project

15 meteorologists from **5** European countries
EU *COST Action MedCyclones* *https://medcyclones.eu/*

5 meteorological models with **10** standard configurations
BOLAM, Méso-NH, MetUM, MOLOCH, WRF

1 common framework
Same domain, same horizontal resolution, same initial and lateral boundary conditions

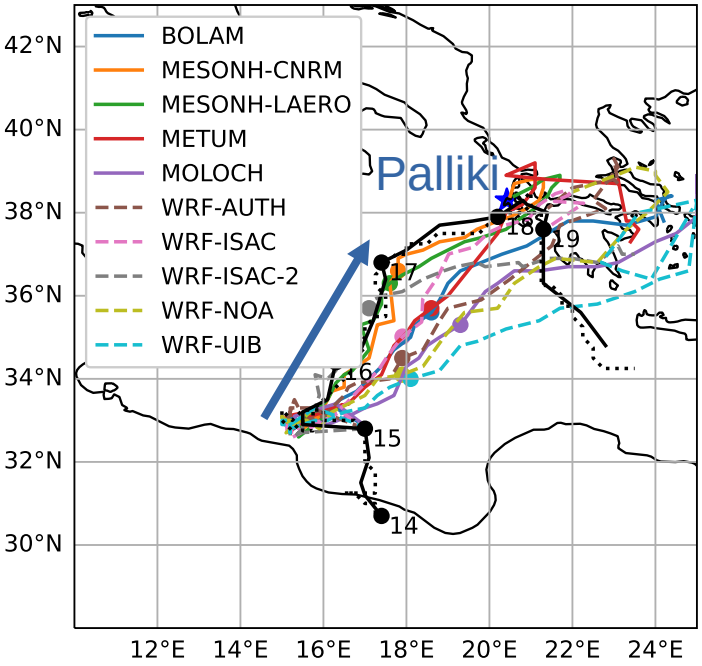
Control simulations
Initialization: IFS analysis
Resolution: Δx=10 km

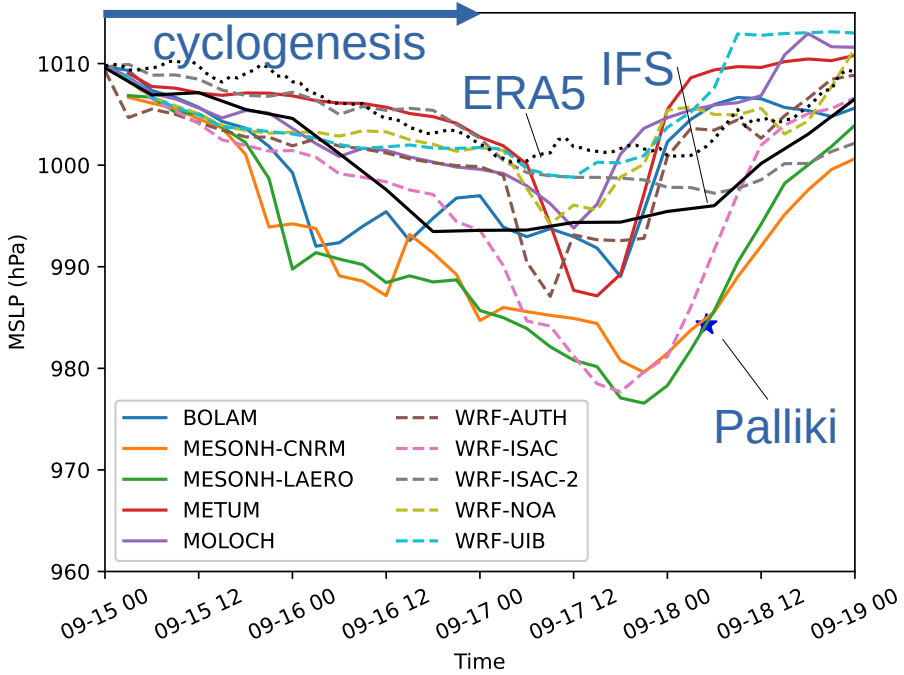
Sensitivity test 1
initialization: ERA5 reanalysis
Resolution: Δx=10 km

Sensitivity test 2
Initialization: IFS analysis
Resolution: Δx=2 km

→ ***look for robust response!***

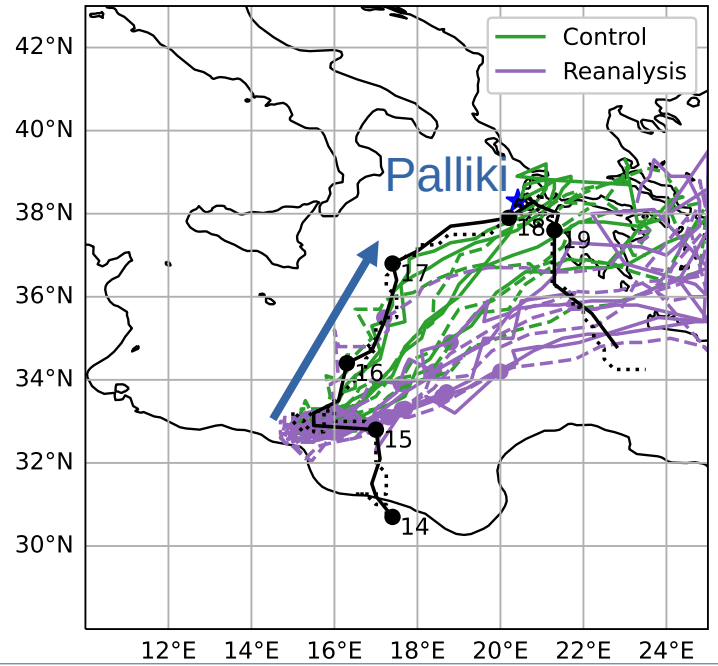
Results from control simulations

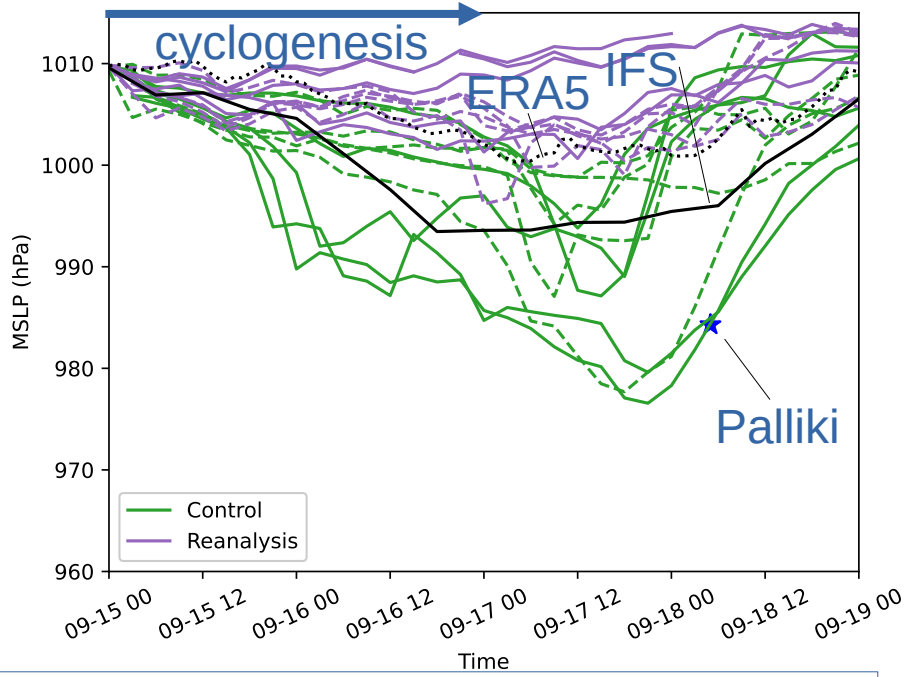




→ ***large spread in track (southeastward shift) and intensity (too weak)***

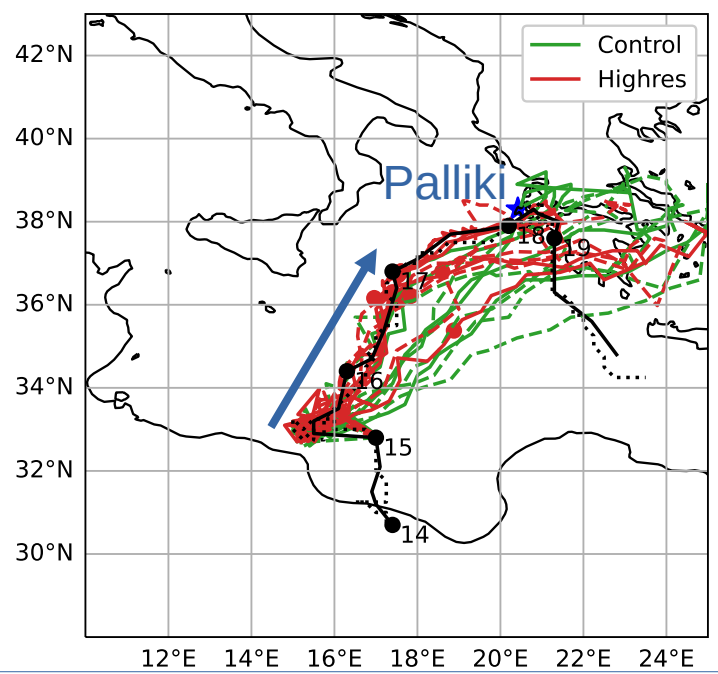
Sensitivity to initial conditions

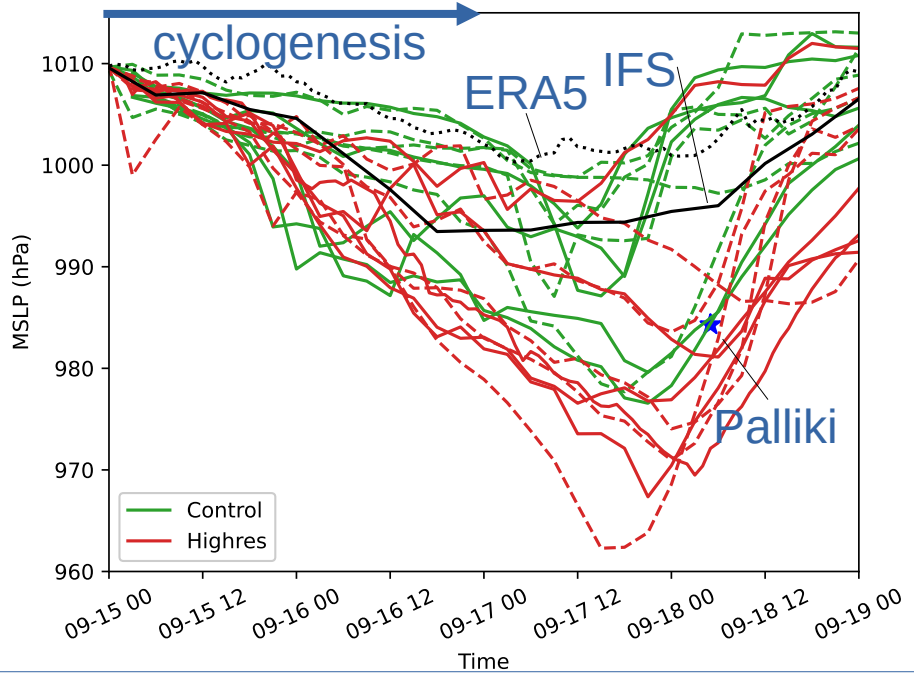




→ ***cyclogenesis poorly predicted using ERA5***

Sensitivity to horizontal resolution

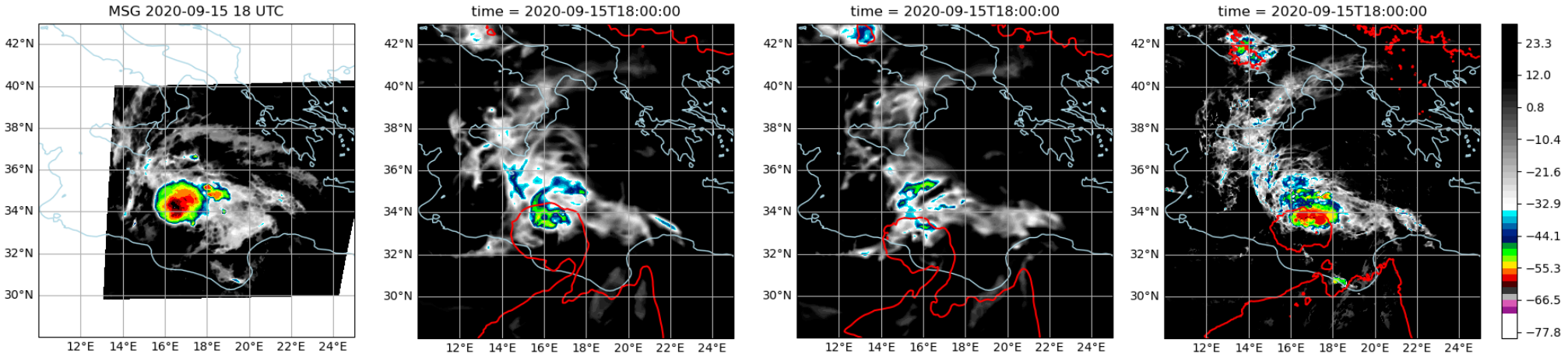




→ ***improved track with explicit representation of deep convection***

Representation of convection (t+18h)

MSG observation | **Control run** | **ERA5 initialization** | **High-resolution**

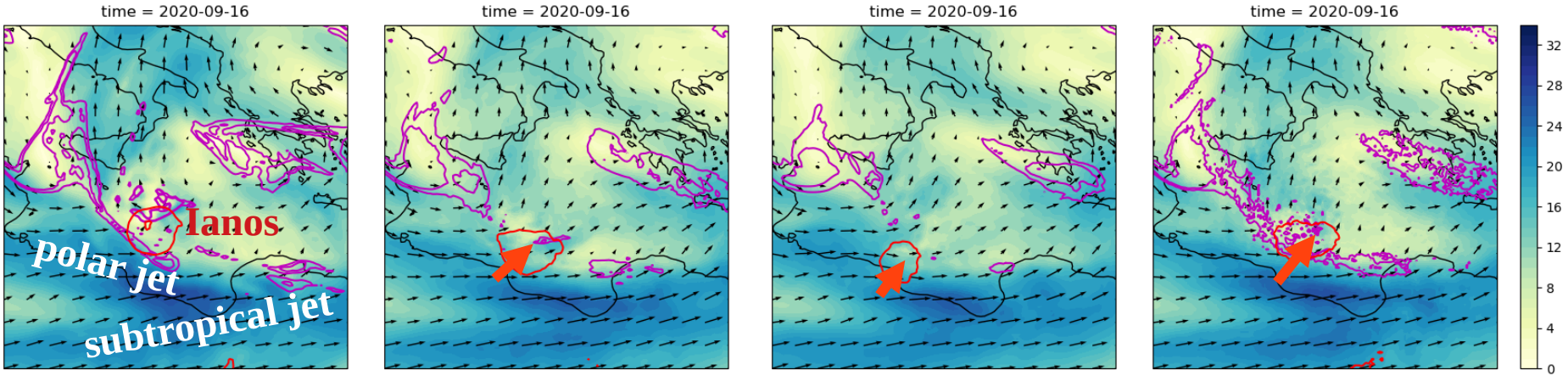


Infrared brightness temperature (in K) observed and simulated by the Meso-NH model

→ ***convective activity much enhanced at high resolution***

Interaction between scales I (t+24h)

IFS analysis | **Control runs** | **ERA5 initialization** | **High-resolution**

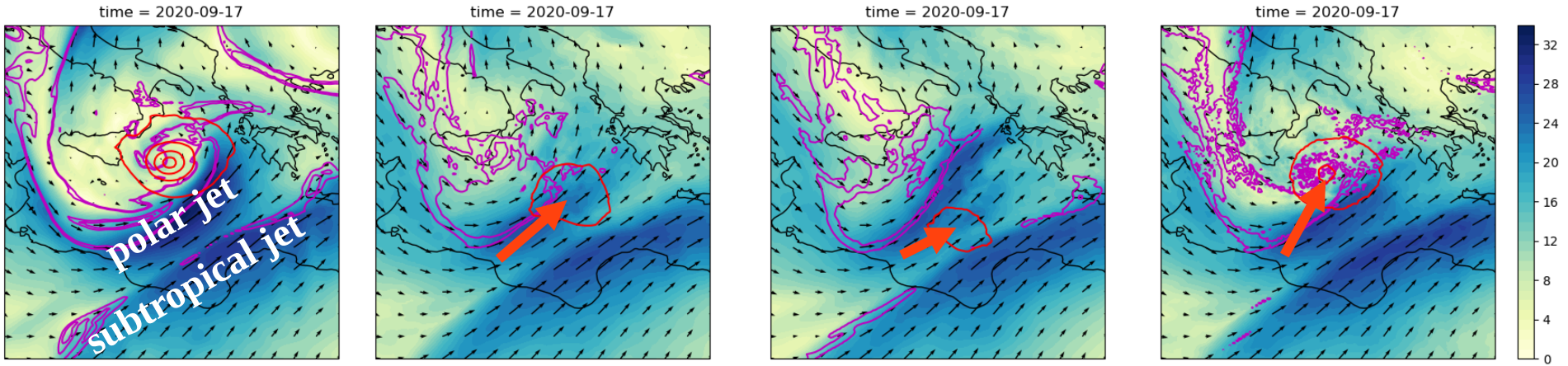


Composites of 300 hPa wind (vectors and shading), 300 hPa potential vorticity (pink contours), MSLP (red contours)

→ ***slight difference in phasing between simulations***

Interaction between scales II (t+48h)

IFS analysis | **Control runs** | **ERA5 initialization** | **High-resolution**



Composites of 300 hPa wind (vectors and shading), 300 hPa potential vorticity (pink contours), MSLP (red contours)

→ ***upscale impact of convection on phasing of cyclone with upper-level jets***

Which scales are we talking about?

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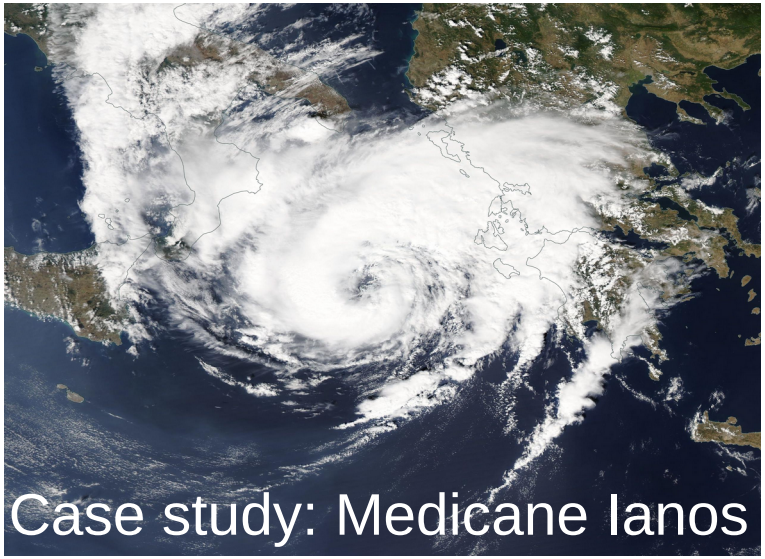
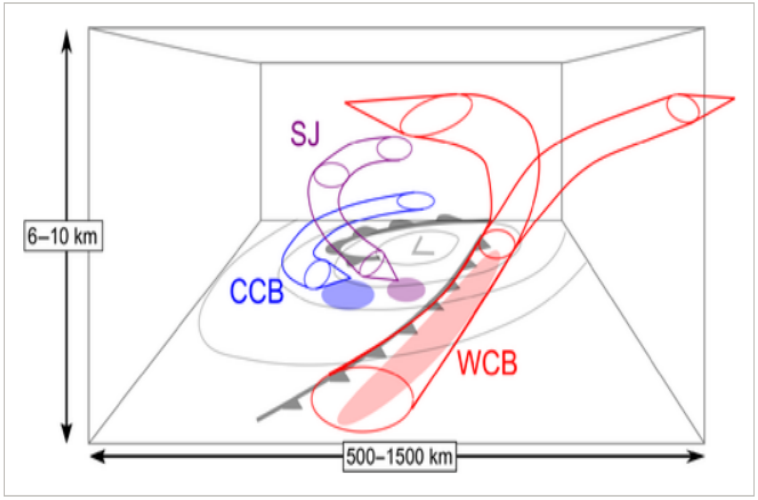


Case study: Medicane Ianos

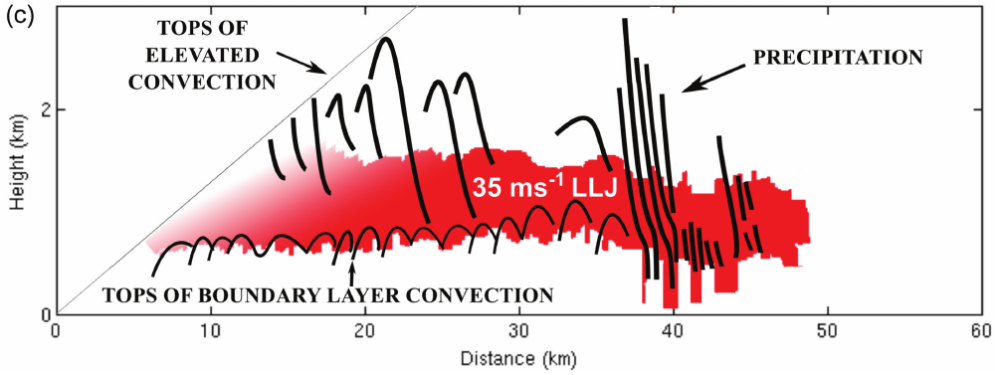
Part II: O(0.1–1 km)

Case study: cyclone Adrian

Project anr® JCJC “WINDGUST” (2022-2025)



Clark and Gray (2018)



Browning et al. (2015)

Mesoscale dynamics of midlatitude cyclones O(10–1000 km) ✓

Downscale →

← Upscale

Fine-scale dynamics leading to wind gusts ? O(0.1–1 km)

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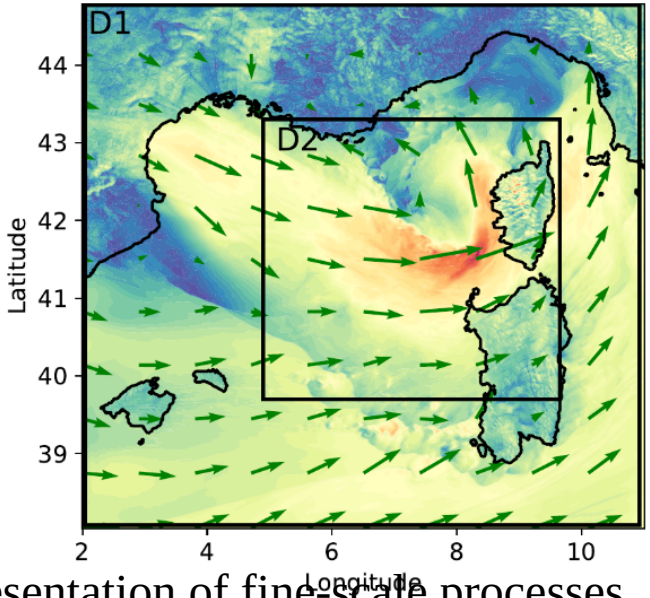
Case study: Mediterranean cyclone Adrian (aka Vaia)

Small but intense cyclone on 29 October 2018 over the northwestern Mediterranean
Extreme winds, heavy precipitation and storm surges (Davolio et al. 2020)
→ *PhD thesis of Wahiba Lfarh (2020–2023), co-supervised by Jean-Pierre Chaboureau*

Numerical simulations with the research model

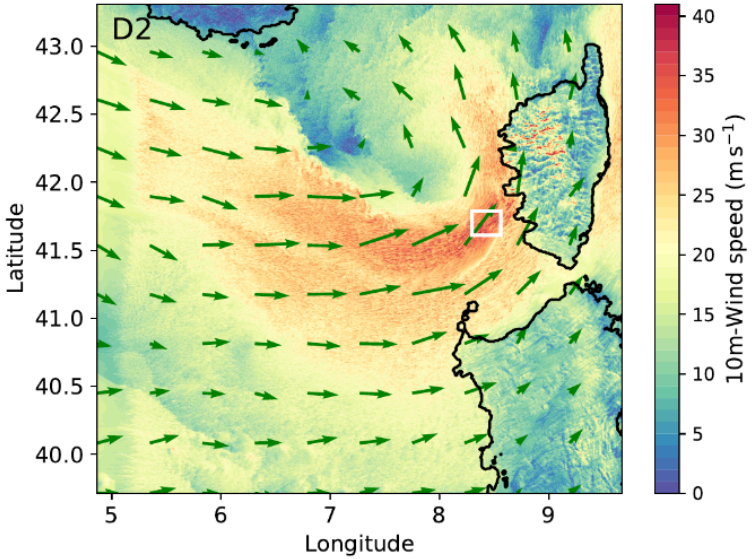
Mesoscale simulation Δx=1km (a)



Representation of fine-scale processes

- **Deep convection**: explicit
- **Shallow convection:** parameterized
- **Turbulence:** parameterized

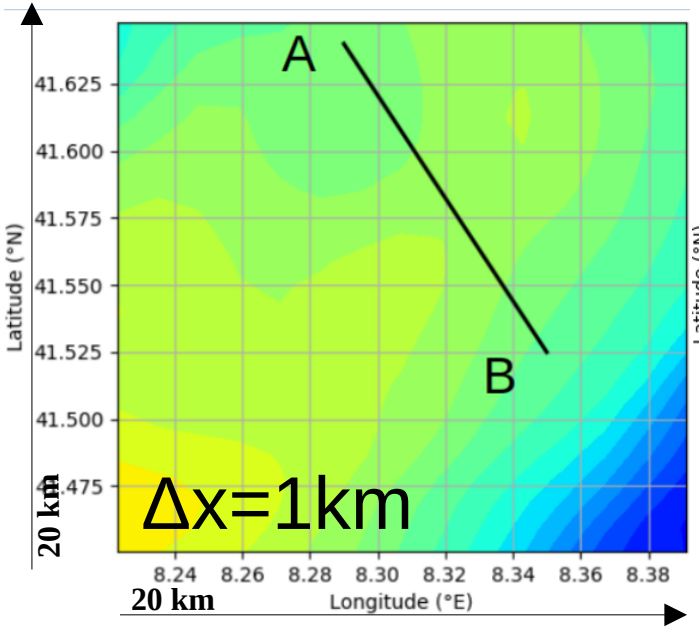
Large-Eddy Simulation (LES) Δx=200m (b)



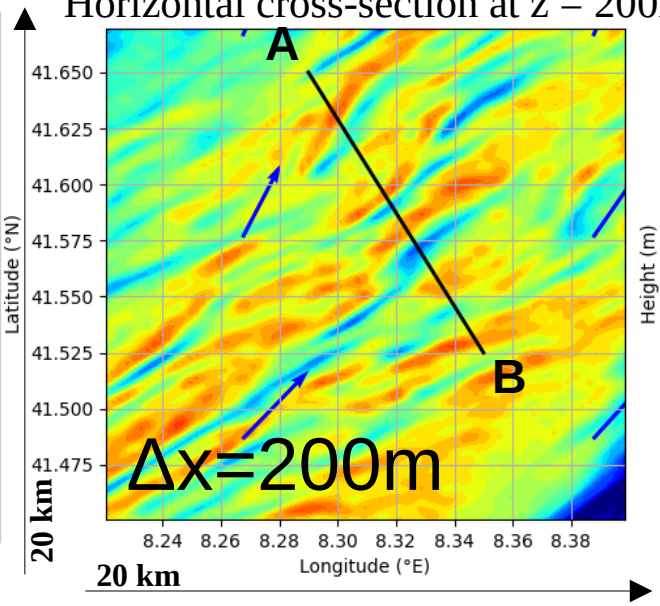
Representation of fine-scale processes

- **Deep convection:** explicit
- **Shallow convection:** explicit
- **Turbulence:** partly explicit (most energetic eddies)

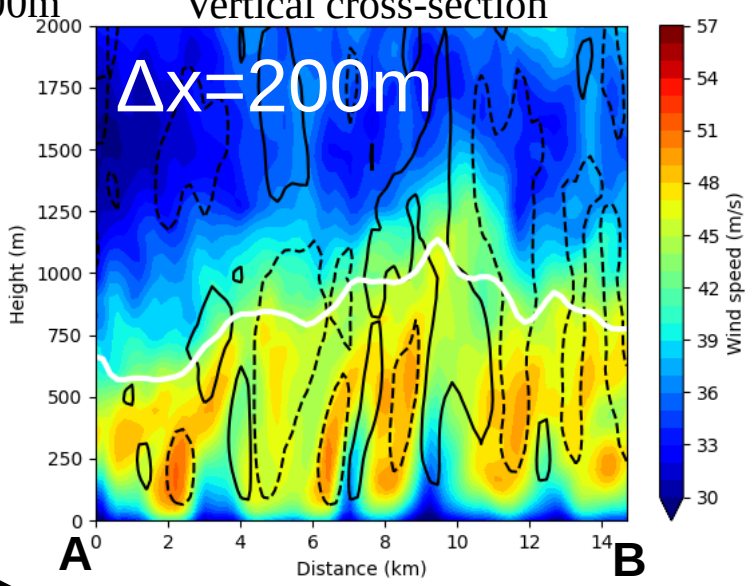
Zoom on the strong wind area



Horizontal cross-section at z = 200m



Vertical cross-section



Wind structures approximately aligned with wind direction

- Width λ≈2400m
- Stronger/weaker winds ~ downward/upward motion

= roll vortices responsible for vertical transport of momentum

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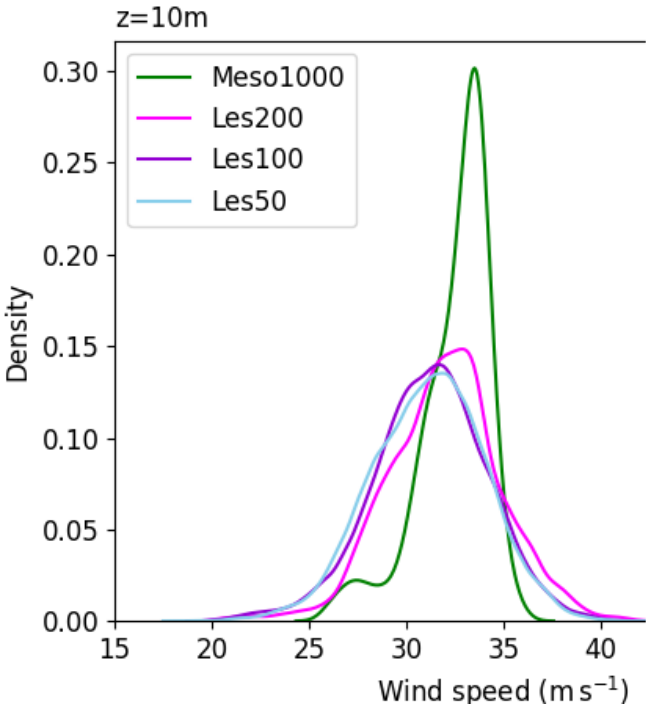
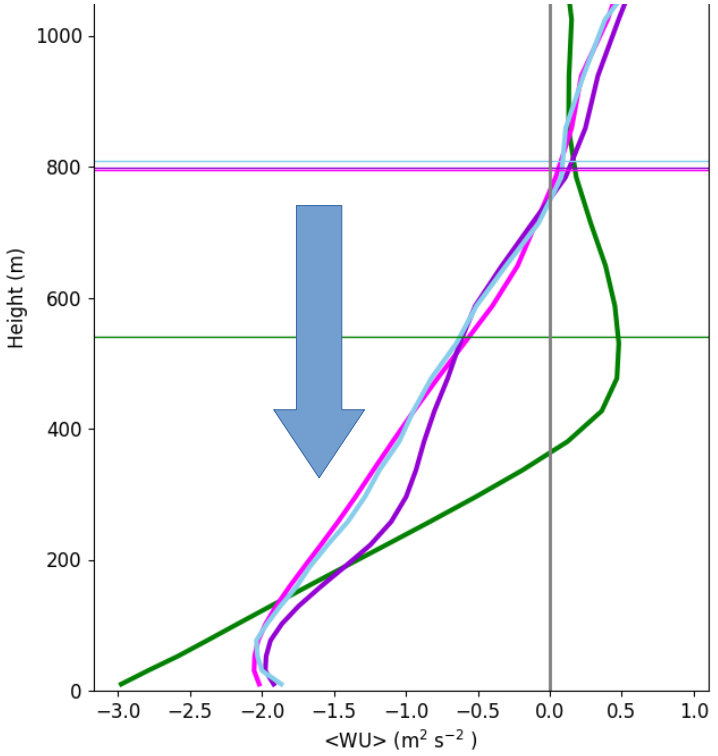
Impact on near-surface winds



PDF of 10-m wind

- Large-eddy simulation Δx=200m close to Δx=100m and Δx=50m
- Mesoscale simulation Δx=1km <u>overestimates</u> vertical momentum transport and near-surface winds vs. large-eddy simulation



Vertical momentum transport

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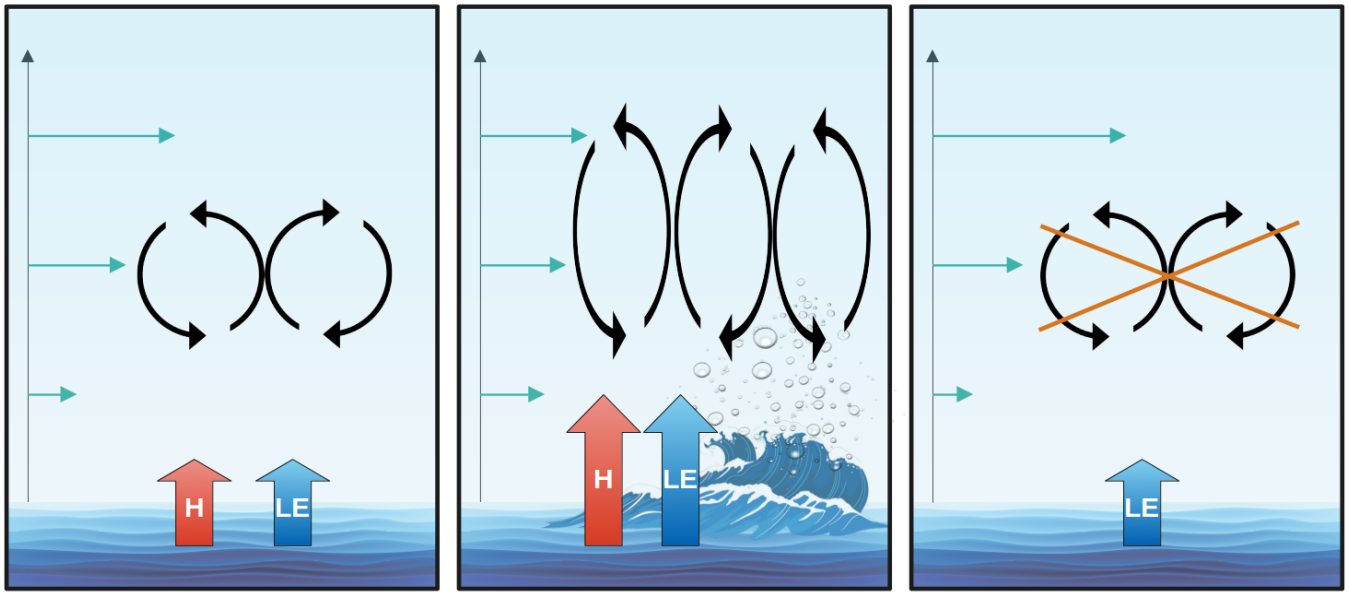
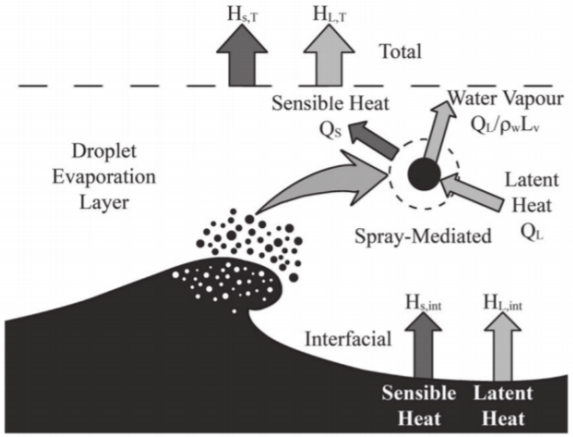
Beyond resolution: sensitivity to air-sea exchanges





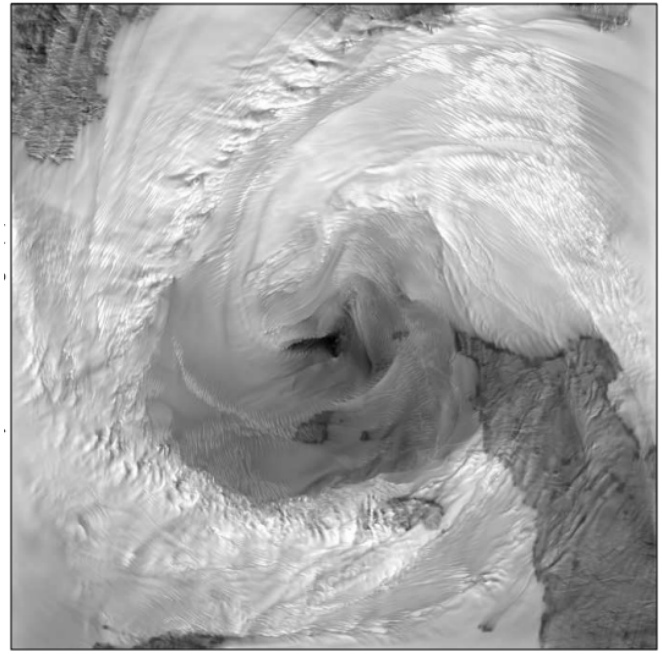
Andreas et al. (2015)

Accounting for **sea spray** increases **surface heat fluxes**

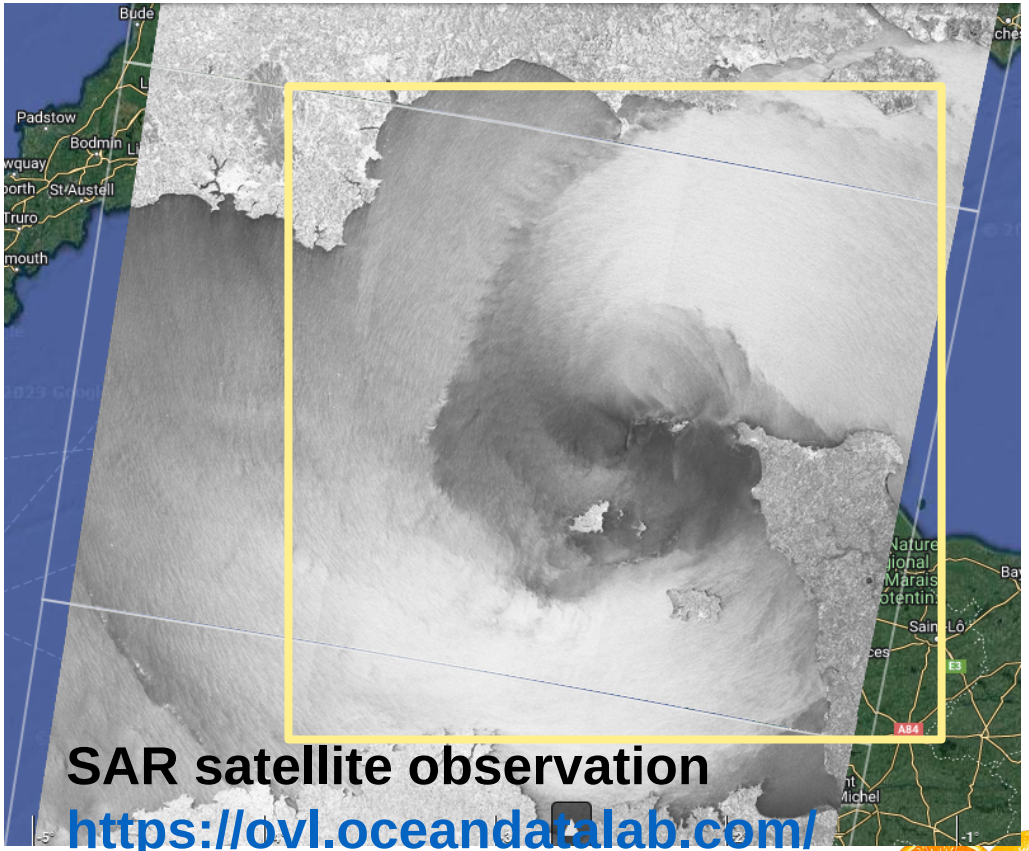
- **Sensible** heat fluxes → stretched rolls + **enhanced momentum transport**
- **Latent** heat fluxes → weak impact

Are fine-scale wind structures realistic?

Windstorm Alex on 02 Oct 2020



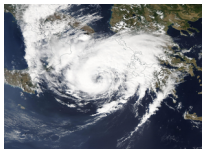
10m wind Méso-NH Δx=100m



SAR satellite observation

https://ovl.oceandatalab.com/

Modelling Mediterranean cyclones across scales



Part I: O(1–10 km)

Model Intercomparison of medicane Ianos

1) **Robust** sensitivity to initial conditions: cyclogenesis hardly captured using ERA5
2) **Robust** sensitivity to horizontal resolution: improved track with explicit convection
3) Crucial interplay between convective and baroclinic processes during cyclogenesis

Pantillon, Davolio et al., in rev.
https://doi.org/10.5194/egusphere-2024-1105

Sanchez et al., in rev.
https://doi.org/10.5194/egusphere-2023-2431

EU COST Action MedCyclones (2020-2024)

Part II: O(0.1–1 km)

Large-eddy simulations of cyclone Adrian

1) Vertical **momentum** transport driven by rolls: overestimated at km resolution
2) Vertical **momentum** transport also controlled by surface heat fluxes: poorly constrained in models due to lack of observations

Lfarh et al., 2023.
https://doi.org/10.1175/MWR-D-23-0099.1

Lfarh et al., in rev.
https://doi.org/10.22541/essoar.169774560.07703883/v1

→ Next step: ESA MEDICANES (2024-2026)