Understanding processes leading to surface gusts by modeling windstorms at very high resolution

Florian Pantillon, Sophia Brumer, Jean-Pierre Chaboureau, Juan Escobar, Wahiba Lfarh, Nicolas Maury, Joris Pianezze, Philippe Wautelet

Laero Laboratoire d'Aérologie

Université de Toulouse

cnrs

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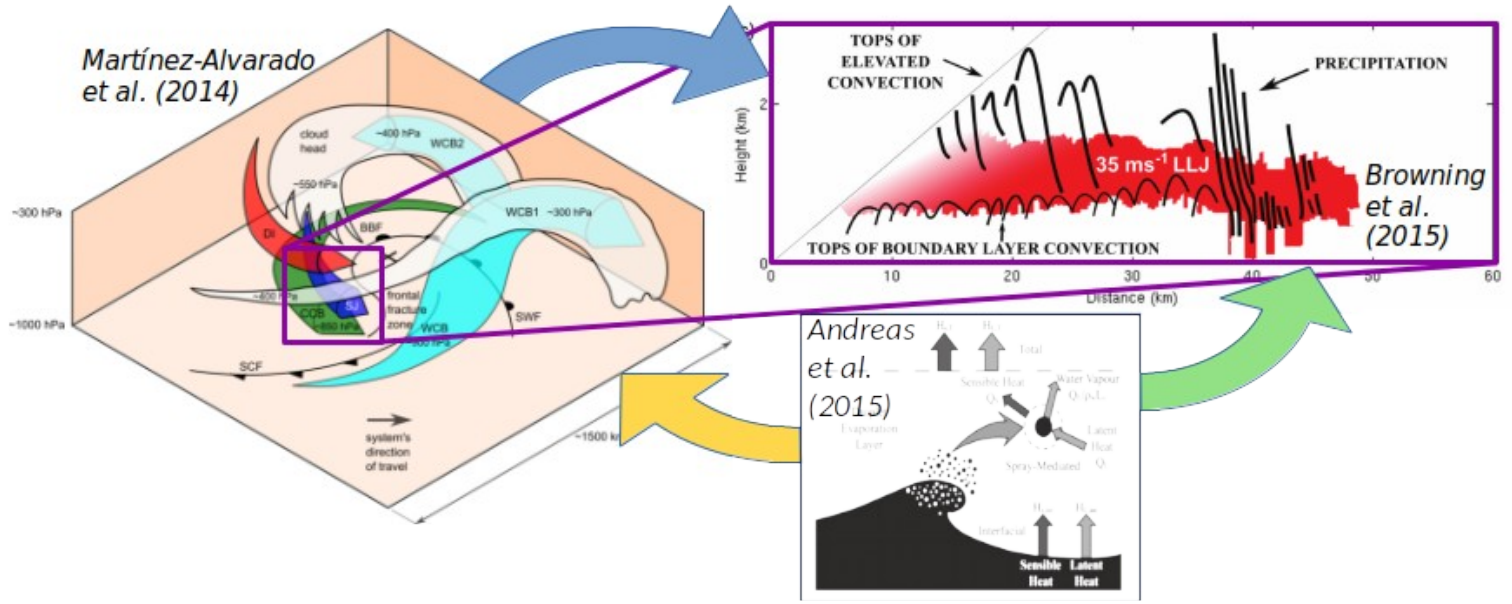
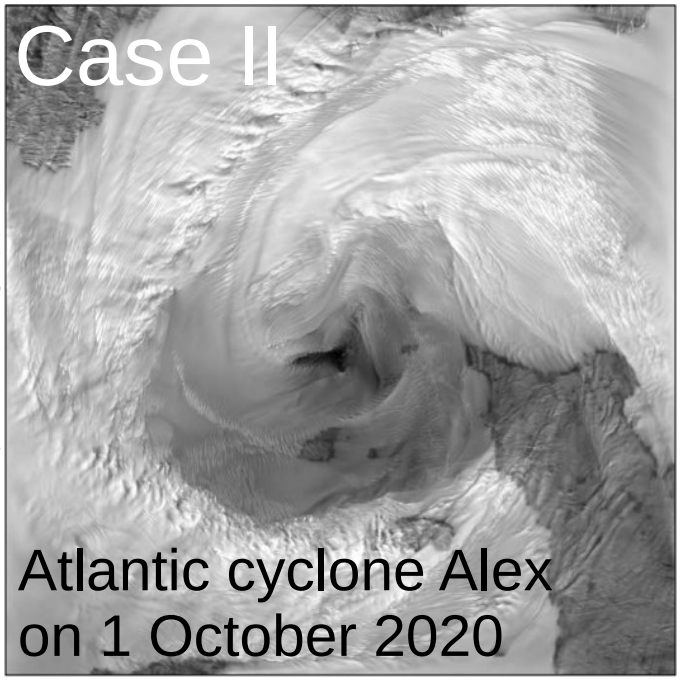
Project anr© JCJC “WINDGUST” (2022–2025)



1. **Characterize the fine-scale processes responsible for the formation of wind gusts**
2. **Quantify the sensitivity of wind gusts to the representation of surface processes**
3. **Explore the feedback of local processes on extratropical cyclone dynamics**

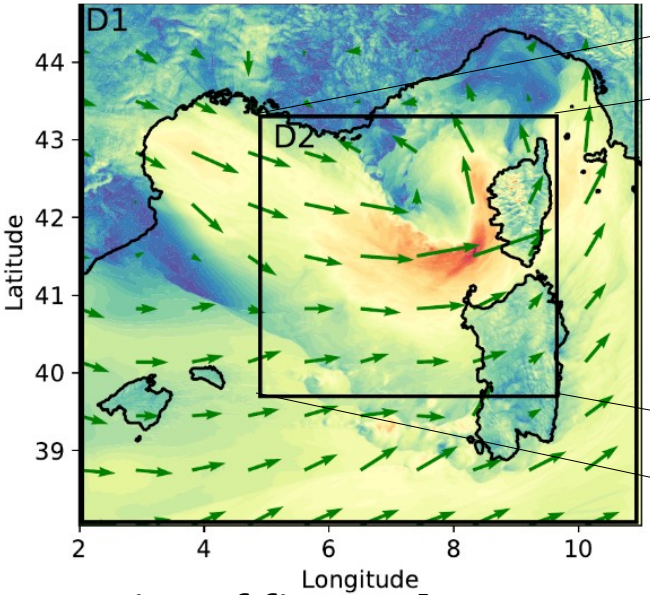
Two case studies



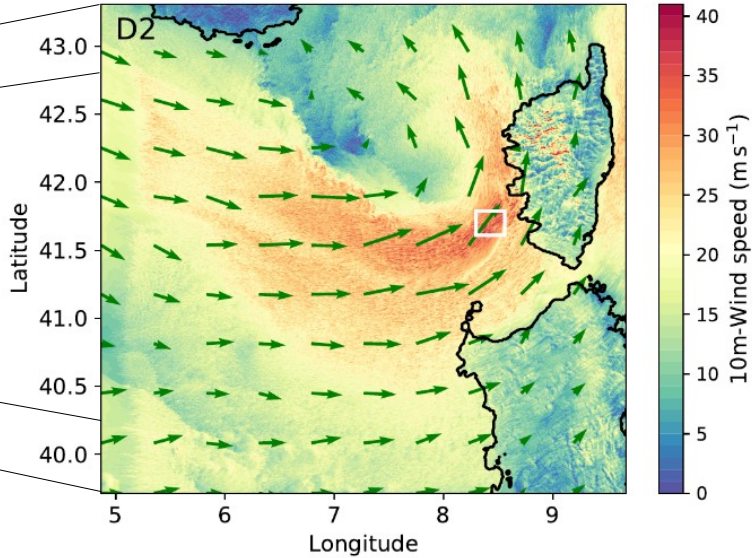
Numerical simulations with the research model

Meso-NH
mesoscale non-hydrostatic model

Mesoscale simulation Δx=1km



Large-Eddy Simulation (LES) Δx=200m



Representation of fine-scale processes

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

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

florian.pantillon@cnrs.fr

Low-level winds associated with cold conveyor belt

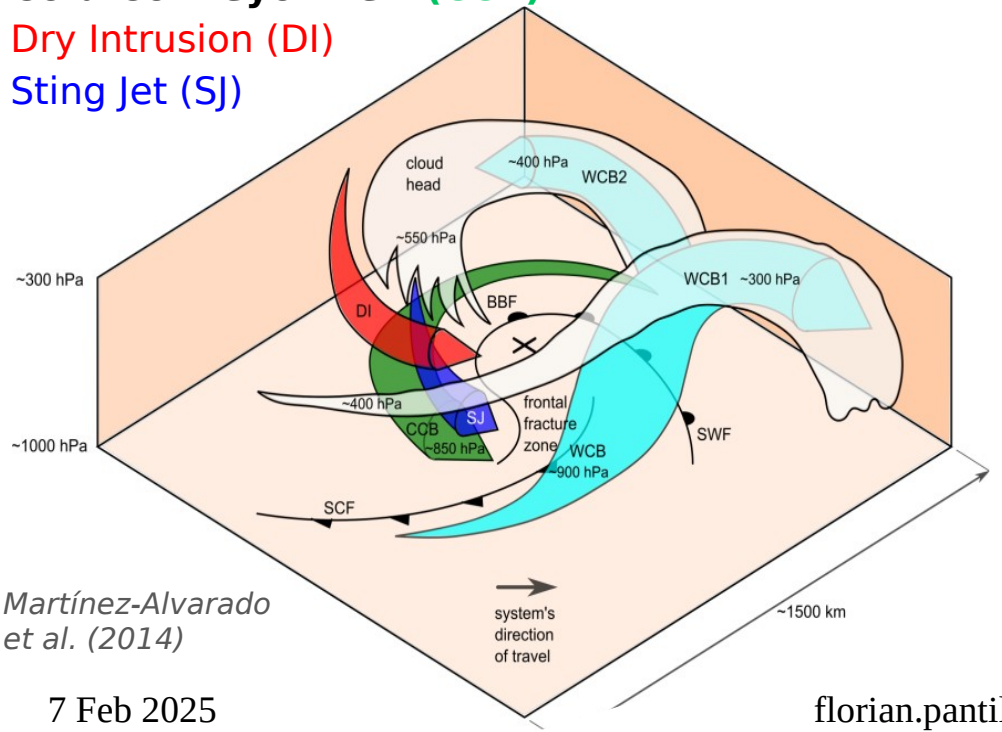
CONCEPTUAL PICTURE

Warm Conveyor Belt (WCB)

Cold Conveyor Belt (CCB)

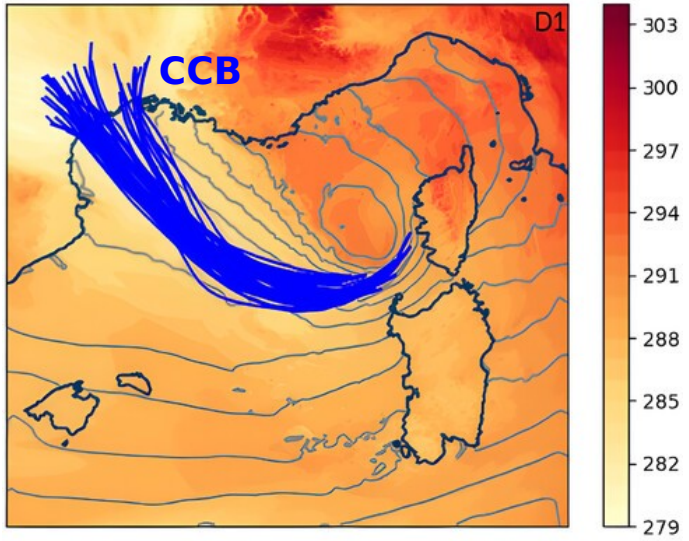
Dry Intrusion (DI)

Sting Jet (SJ)



Martínez-Alvarado et al. (2014)

Mesoscale simulation Δx=1km



Trajectories where **winds > 40 m/s** at 15:15 UTC

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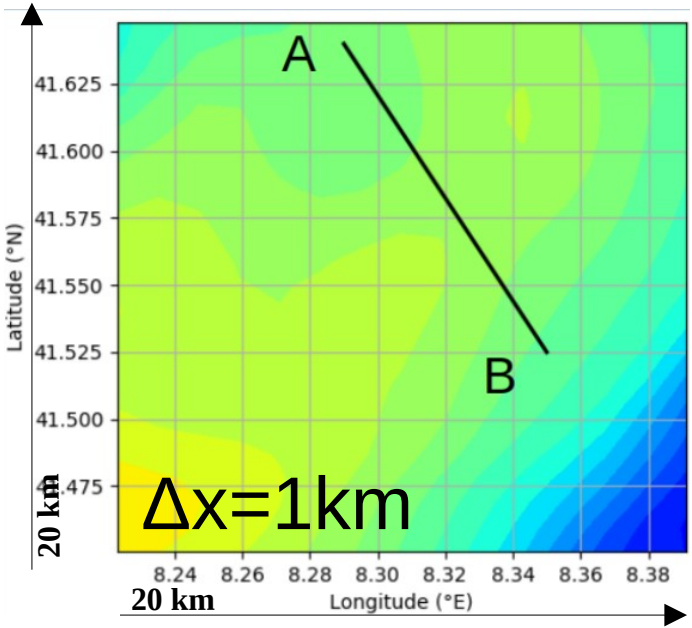
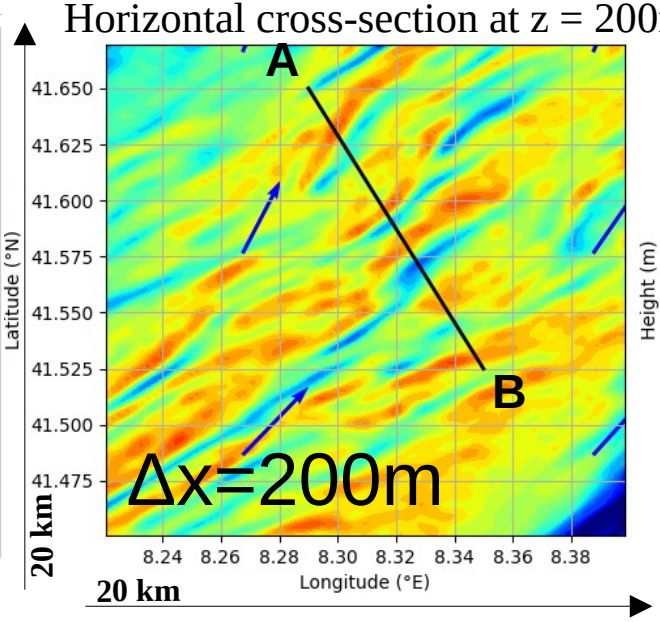
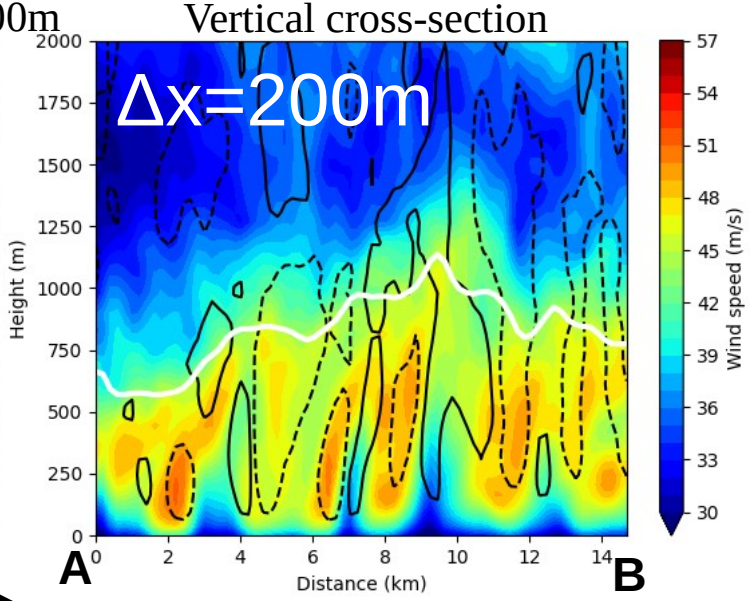
Zoom in on the strong wind area



Horizontal cross-section at z = 200m



Vertical cross-section



Wind structures approximately aligned with mean wind
= roll vortices transporting momentum downward

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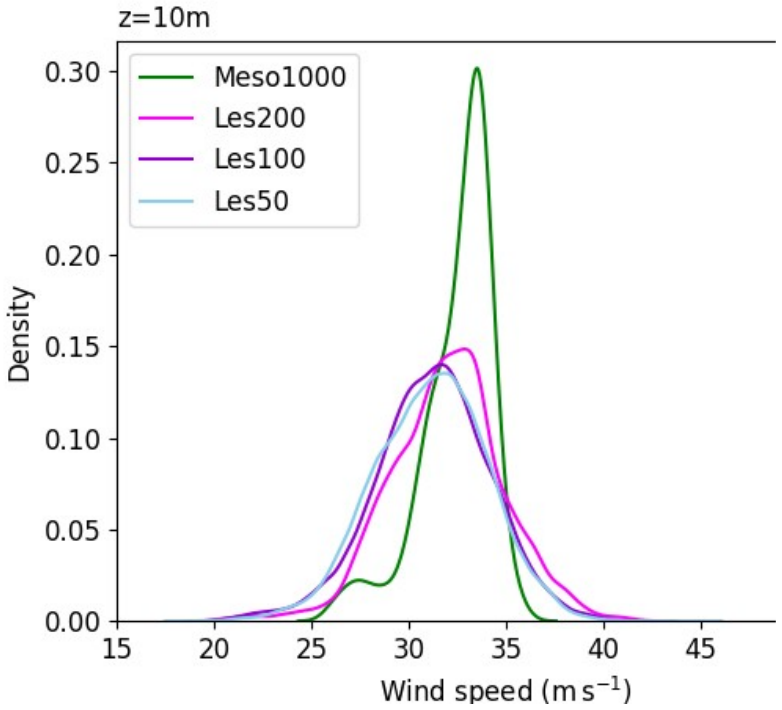
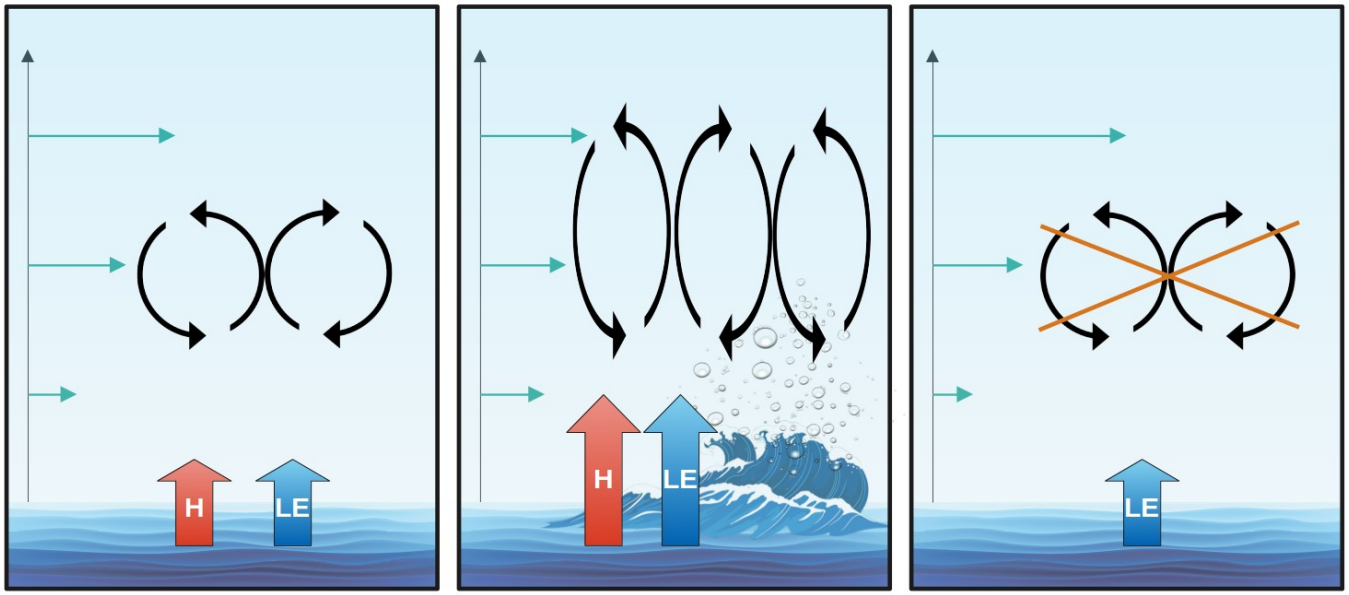
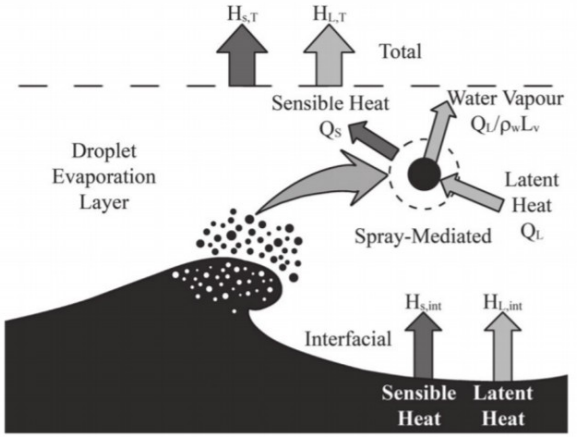
Impact of resolution on near-surface winds



- Large-eddy simulation Δx=200m close to Δx=100m and Δx=50m
- Mesoscale simulation Δx=1km misses tails of distribution but overestimates average wind vs. large-eddy simulations

Beyond resolution: sensitivity to air-sea exchanges

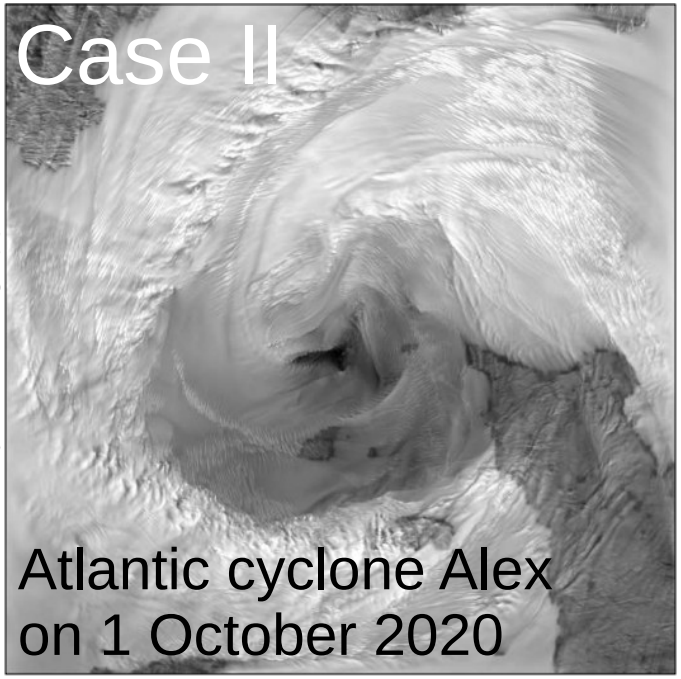




Accounting for **sea spray** increases **surface heat fluxes** *(Andreas et al. 2015)*

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

Two case studies

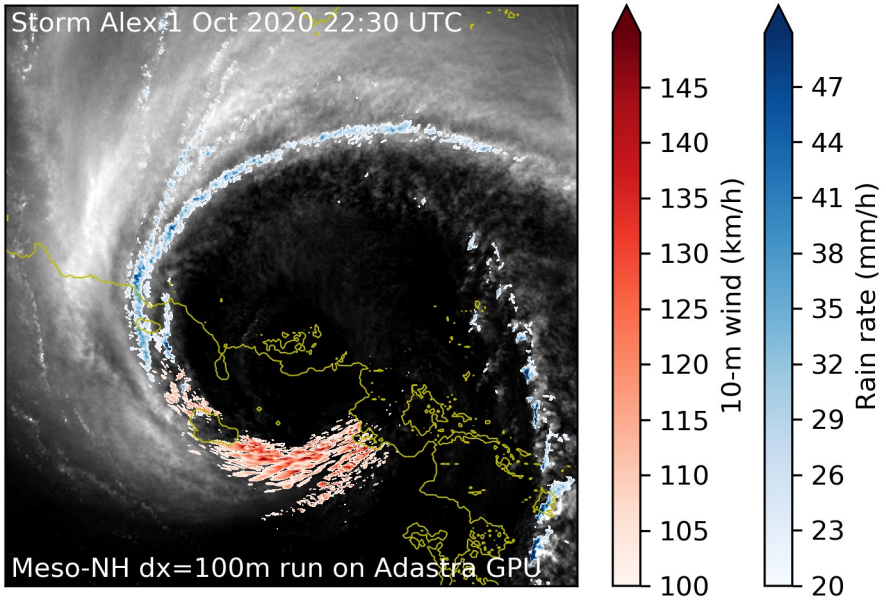


Numerical simulations

Meso-NH
mesoscale non-hydrostatic model

- Mesoscale simulation Δx=1.6km
- Large-Eddy Simulation Δx≥100m

Thanks to porting of code on GPU



Video here! https://youtu.be/Zh90yTck9g4

Low-level winds associated with 3 different airstreams

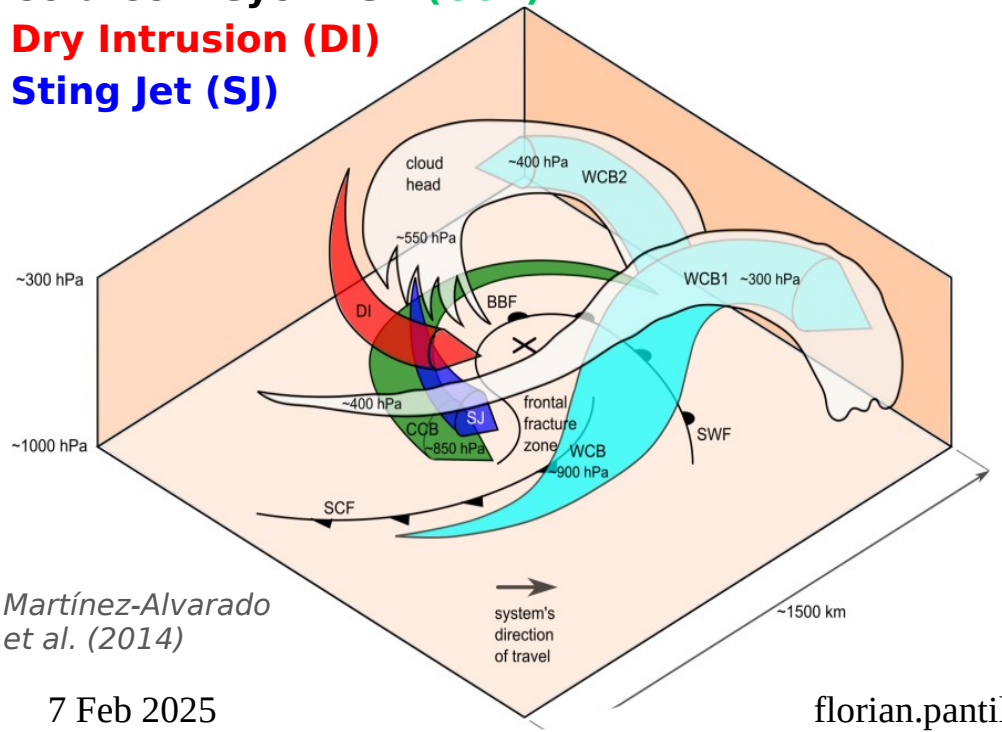
CONCEPTUAL PICTURE

Warm Conveyor Belt (WCB)

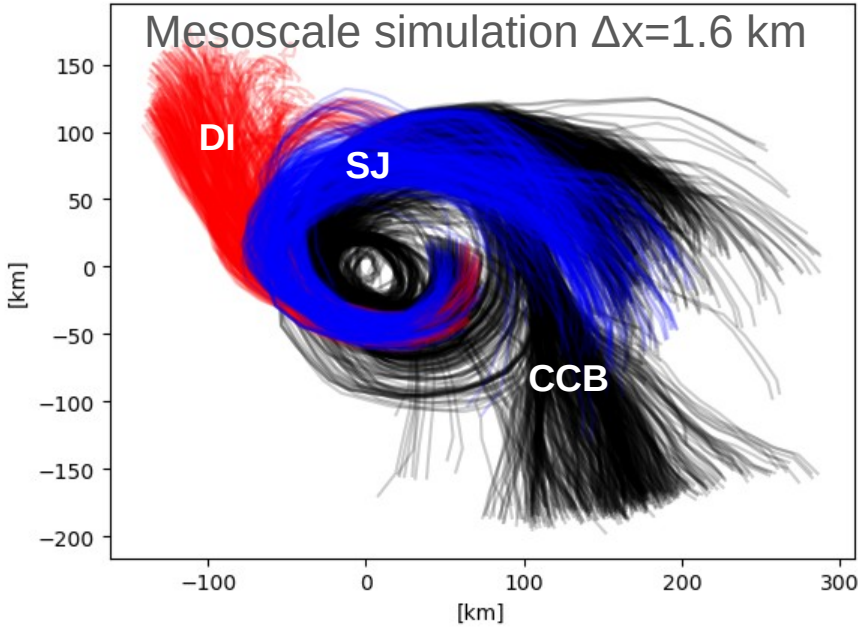
Cold Conveyor Belt (CCB)

Dry Intrusion (DI)

Sting Jet (SJ)



Martínez-Alvarado et al. (2014)



Cyclone-centered trajectories
where **winds > 35 m/s** at 22:30 UTC

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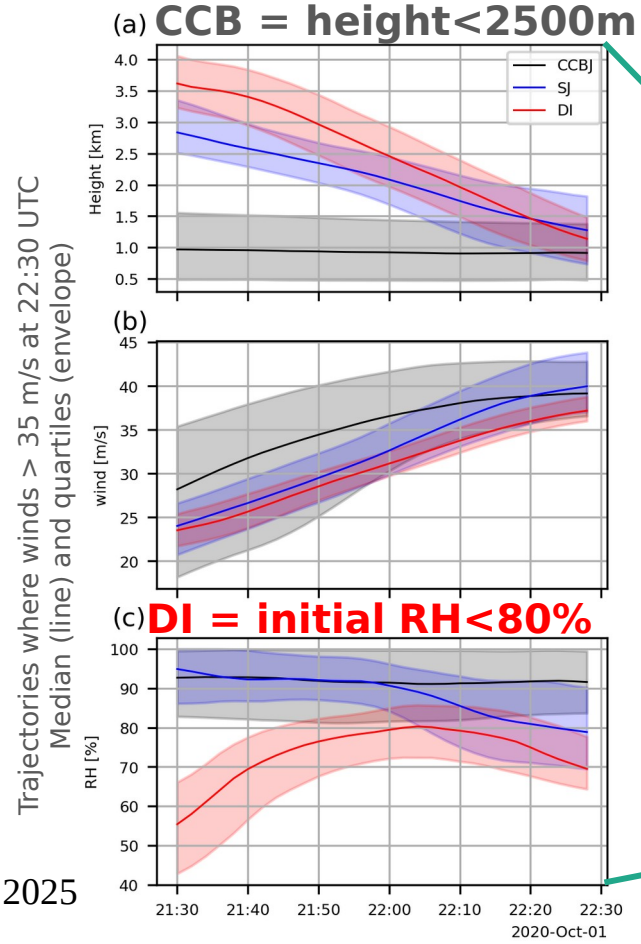
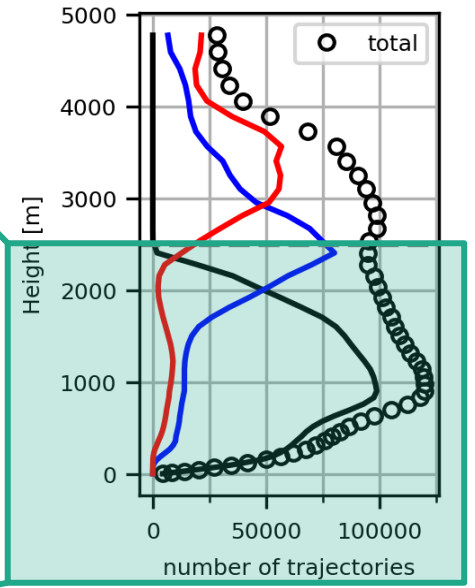
Insights into airstreams @ Δx=200m



Proportions in boundary layer

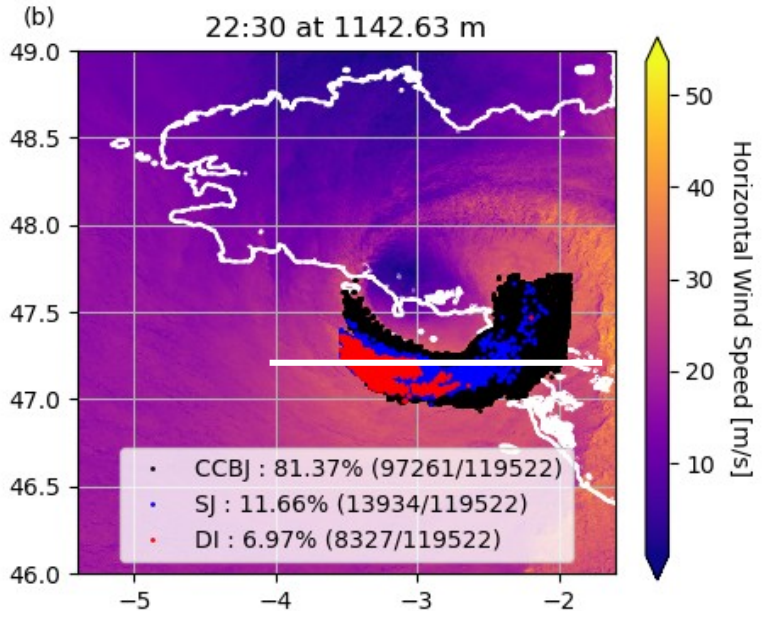
CCB~80% **SJ**~14% **DI**~6%

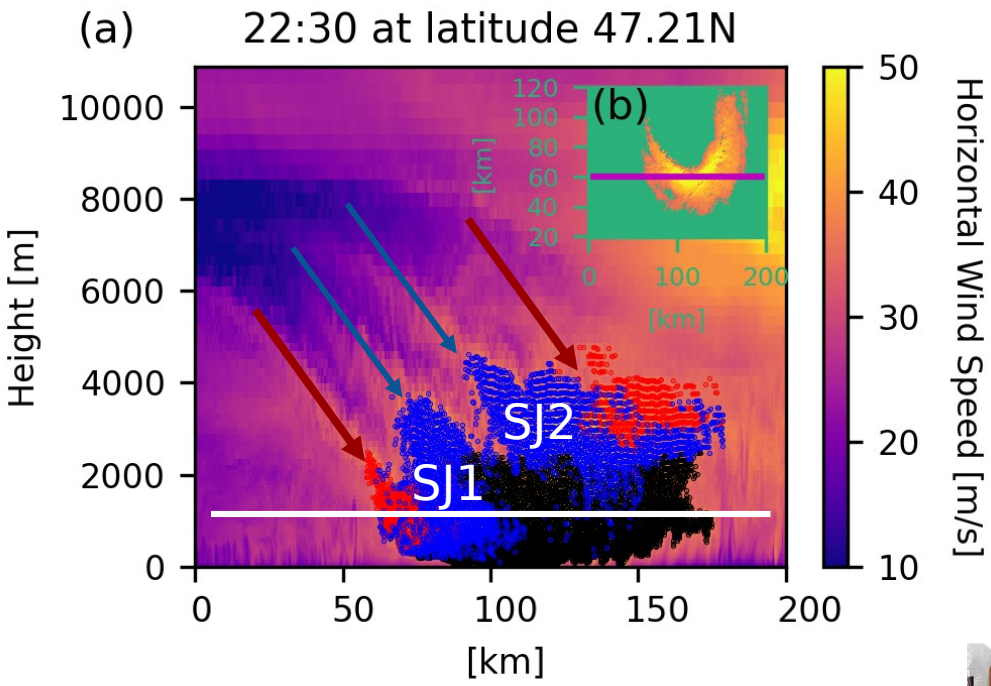


florian.pantillon@cnrs.fr

Two branches of the sting jet in the cloud head

- **SJ1** descends deep toward the surface
- **SJ2** remains above the boundary layer
- Also two **DI** branches behind and above the SJ





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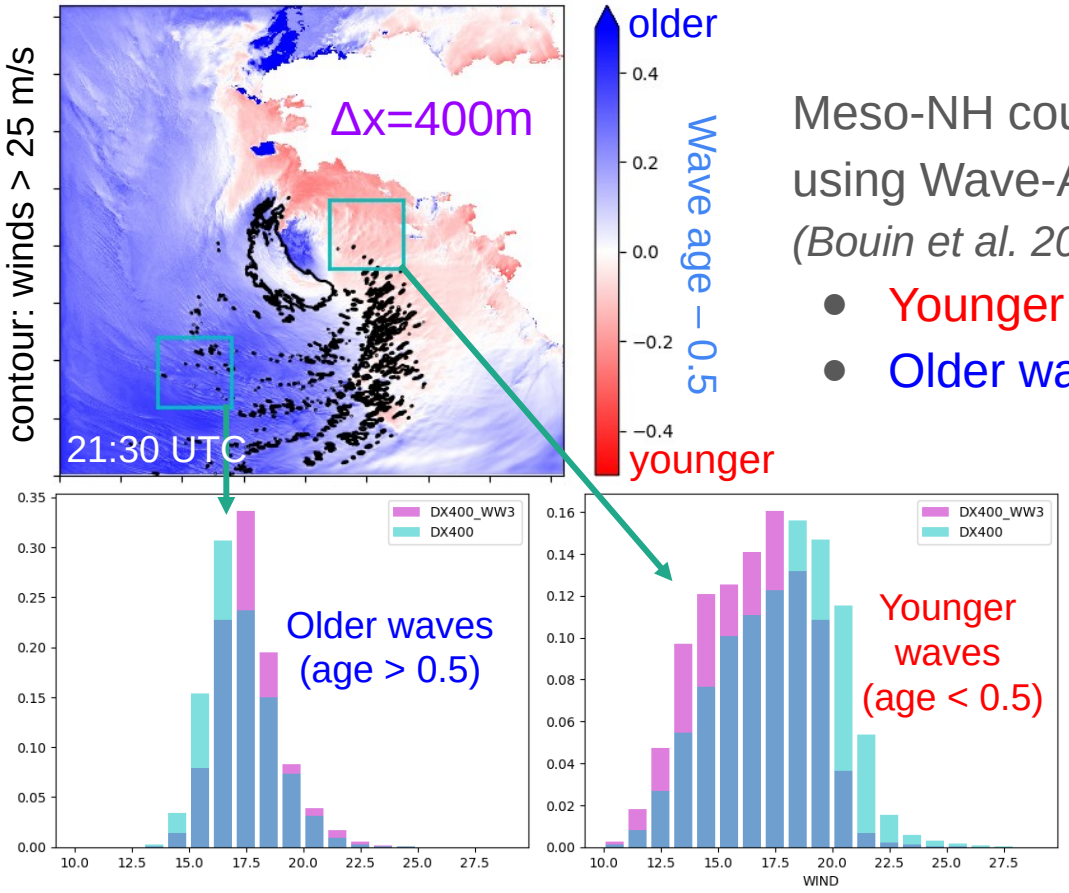
Beyond resolution: wave impact on near-surface winds



Meso-NH coupled with wave model Wavewatch III using Wave-Age-dependent Stress Parameterisation *(Bouin et al. 2023)*

- Younger waves in SJ, DI, CCB, WCB regions
- Older waves behind storm (cold sector)

Coupled model vs. Meso-NH only

- Younger waves
  winds **decrease**
- Older waves
  winds **increase**

PDF of wind speed (m/s)

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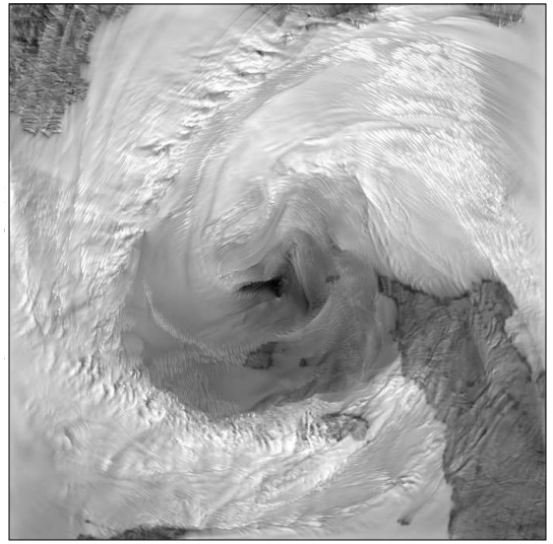
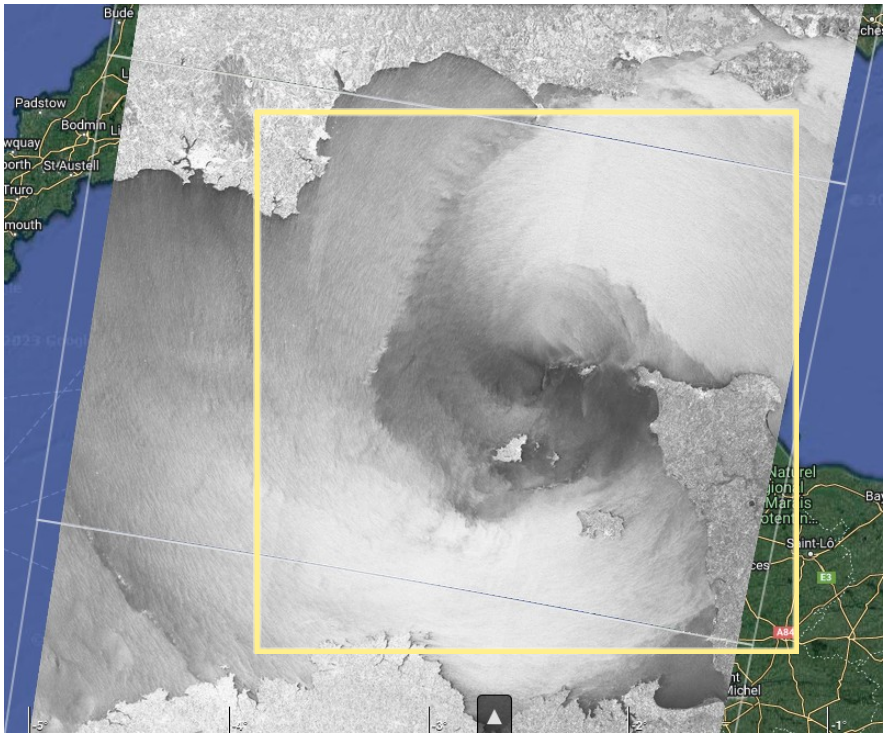
Are fine-scale wind structures realistic? SAR!

Storm Alex on 02 Oct 2020



10m wind Meso-NH Δx=100m



Synthetic aperture radar (SAR) observations

https://ovl.oceandatalab.com/

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Understanding processes leading to surface gusts by modeling windstorms at very high resolution

Large-eddy simulations (hectometric resolution) with the Meso-NH research model on GPU

Escobar et al., 2024. https://doi.org/10.5194/egusphere-2024-2879

Mediterranean cyclone Adrian

Vertical momentum transport in **cold conveyor belt**

- driven by **roll vortices**
- controlled by **surface heat fluxes**

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

Lfarh et al., 2024. https://doi.org/10.1029/2023JD040191

Atlantic cyclone Alex

Two branches of **sting jet**

→ only one descends to the surface

Contrasted response of **wave coupling**

→ wind decrease in cloud head

Brumer et al., in prep.

Surface winds depend on accurate representation of

- **fine-scale processes** → *requires very high resolution*
- **air-sea exchanges** → *needs obs to constrain models*