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Tackling today's wind resource assessment challenges with high-fidelity modelling

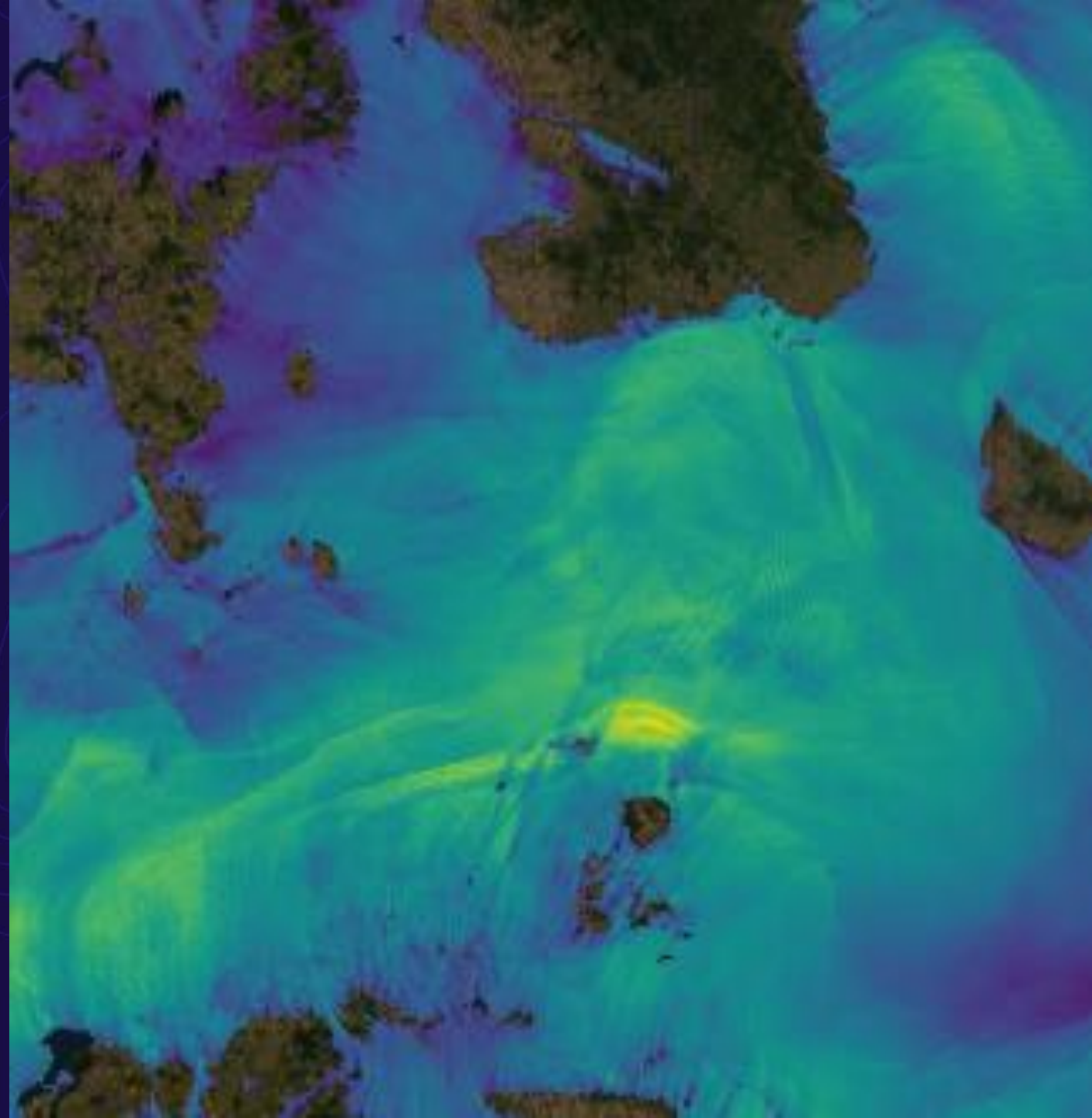
Remco Verzijlbergh

Peter Baas

Many Whiffle colleagues

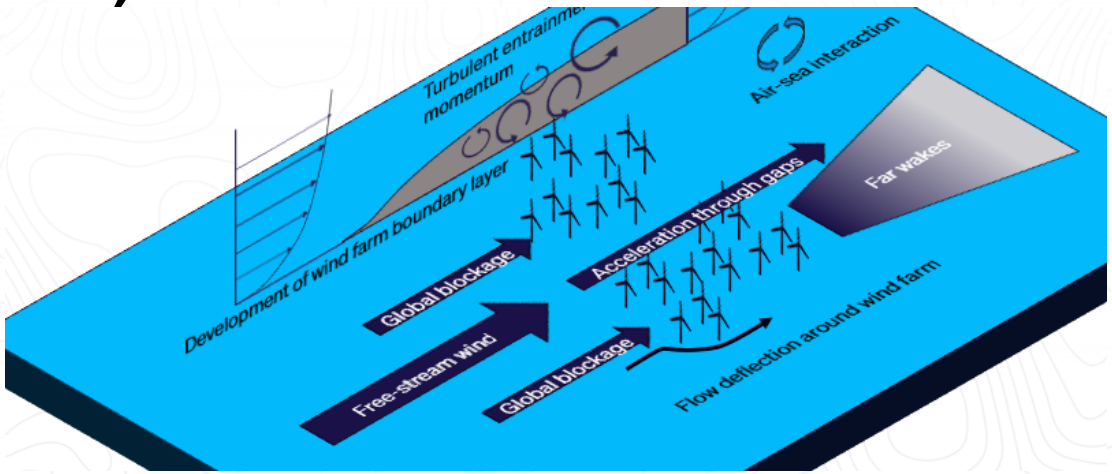
Wind Europe 2025

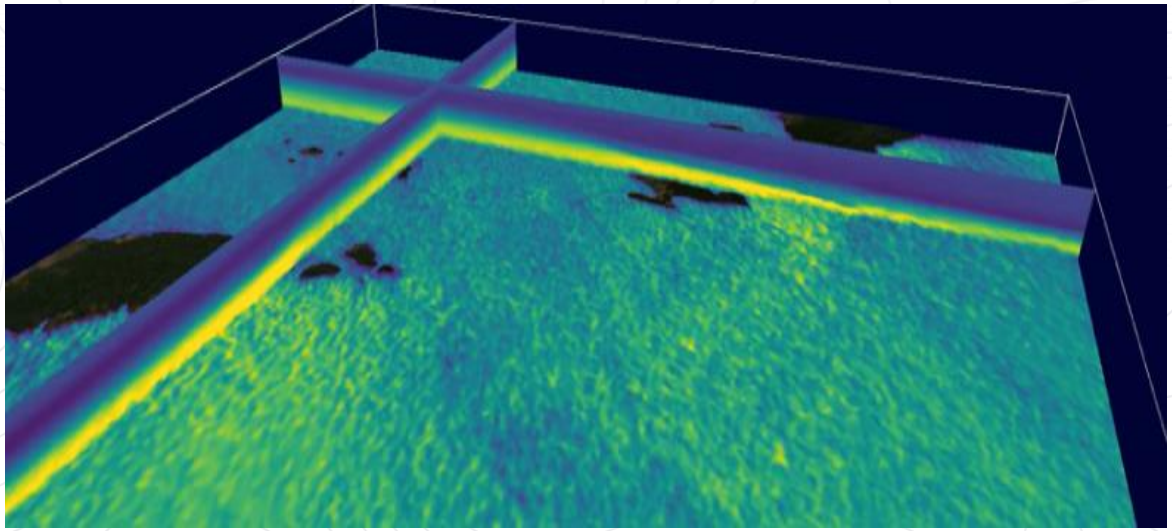
Copenhagen



The idea: a quick and fun talk, lots of nice visuals

✅ Advanced terrain representation – Accurately modelling surface roughness, forestry, and elevation effects.
✅ Meso-scale to micro-scale transition – Capturing site-specific flow dynamics beyond traditional downscaling.
✅ Wake modelling with LES – Resolving turbulence, shear, and flow recovery at turbine-relevant scales.
✅ Beyond CFD & flow cases – Why high-fidelity physics-based modelling is the way forward.





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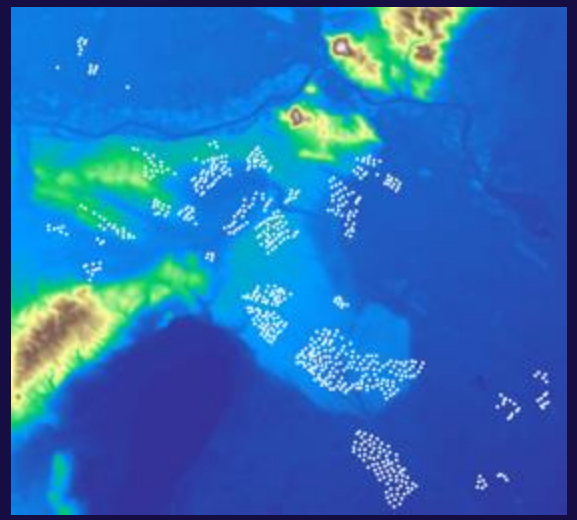
Three challenging and relevant cases for the European wind energy industry

Southern Baltic

- Southern Baltic, including Arkona basin and Oresund
- True multi-scale sites: from macro to micro

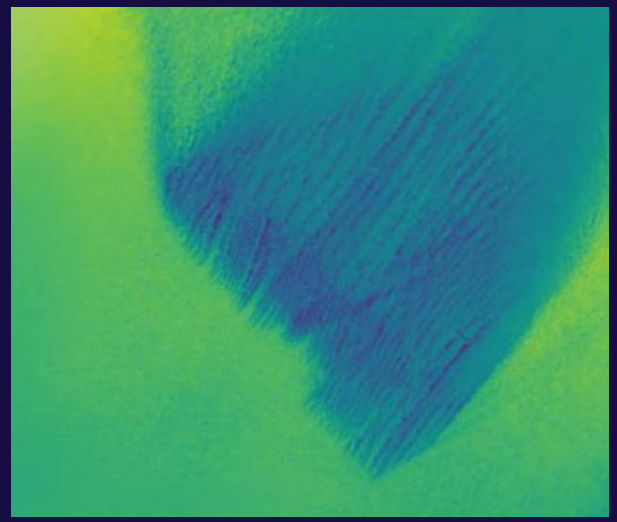
Austria Gap Flow

- North-east side of the Alps
- ~75% of all Austrian wind energy

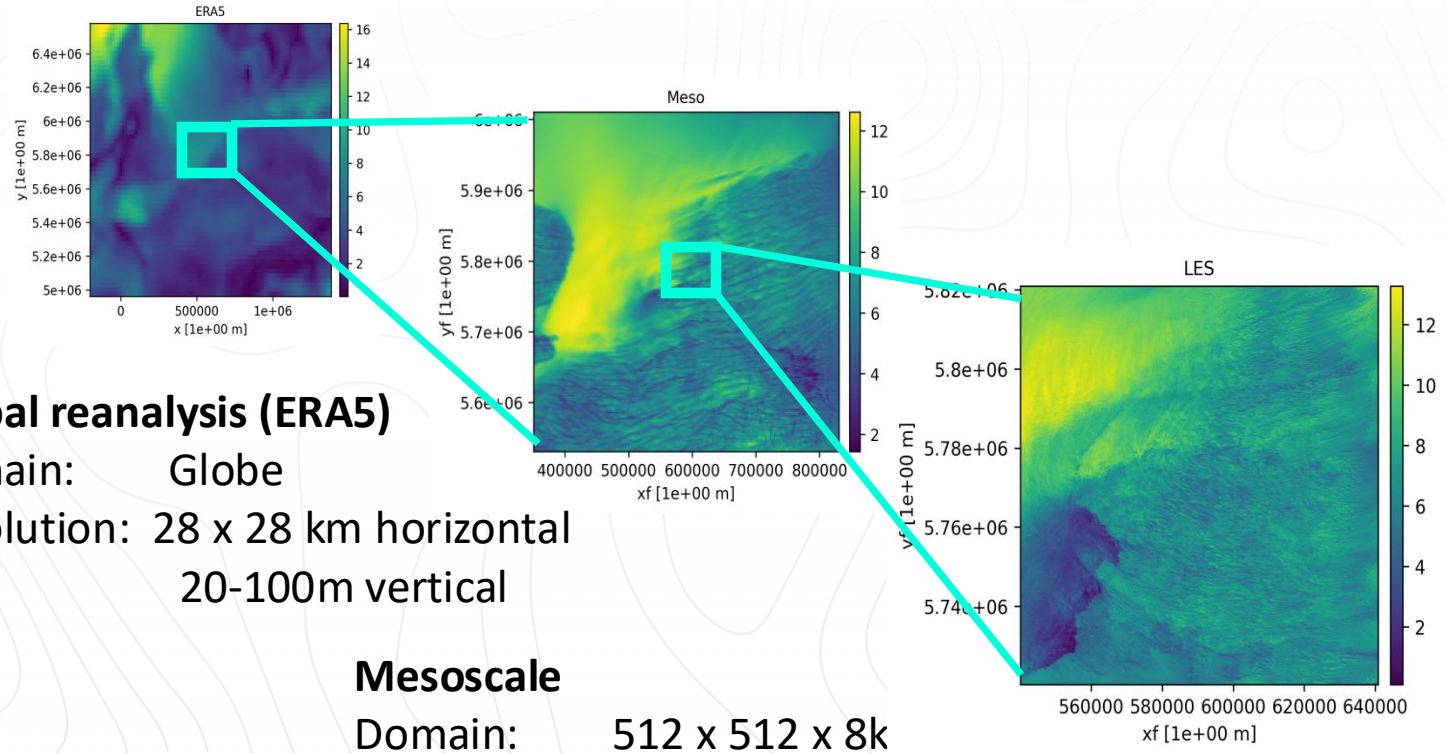


North Sea Cluster

- **Borssele offshore cluster**
- **~ 10 GW in multiple wind farms**



Our standard LES set-up



Global reanalysis (ERA5)
Domain: Globe
Resolution: 28 x 28 km horizontal
20-100m vertical

Mesoscale
Domain: 512 x 512 x 8k
Resolution: 2 x 2 km horizontal
25-100m vertical

LES
Domain: 100km x 100 km x 4km
Resolution: 100 x 100 m horizontal
25-100m vertical

Physics modules of:
- ✓ Wind turbines
- ✓ Vegetation
- ✓ Mountains
- ✓ Buildings
- ✓ Clouds and thermodynamics
- ✓ Precipitation
- ✓ Surface energy balance
- ✓ Soil moisture
- ✓ Radiation
- ✓ Aerosols

Compute on NVIDIA GPUs
- Using different types of GPUs
- Typically, a few hours runtime per simulation day

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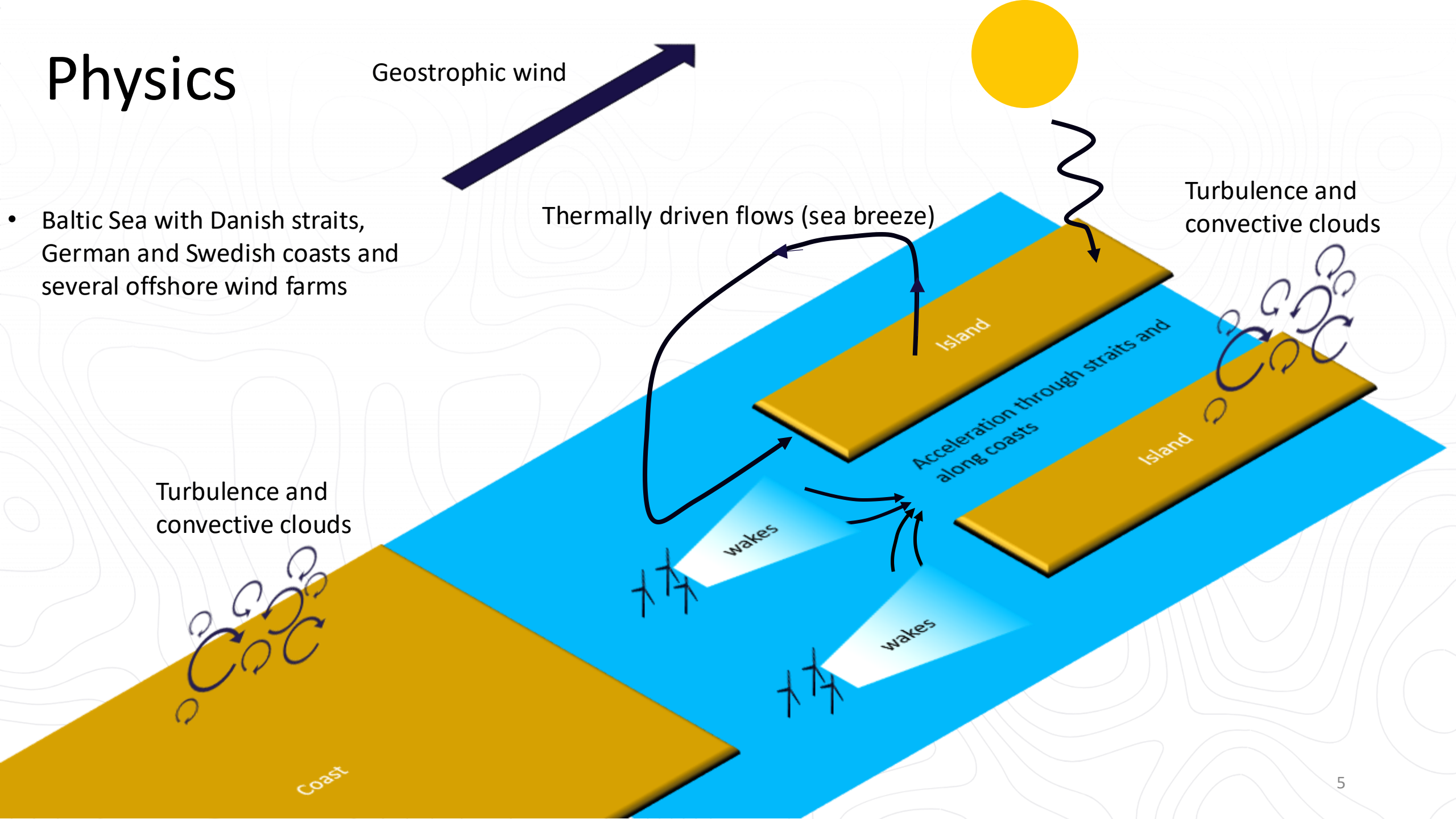
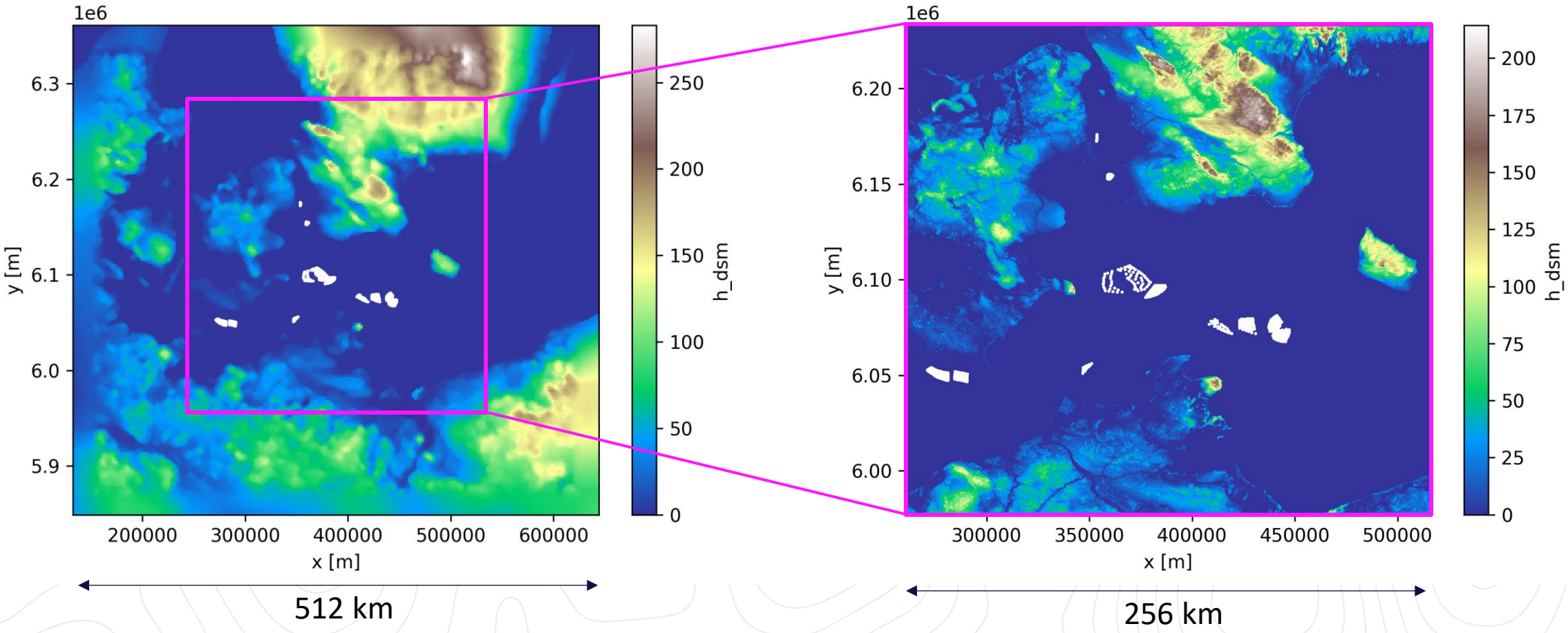
Southern Baltic

Physics

- Baltic Sea with Danish straits, German and Swedish coasts and several offshore wind farms



Mesoscale and LES domains



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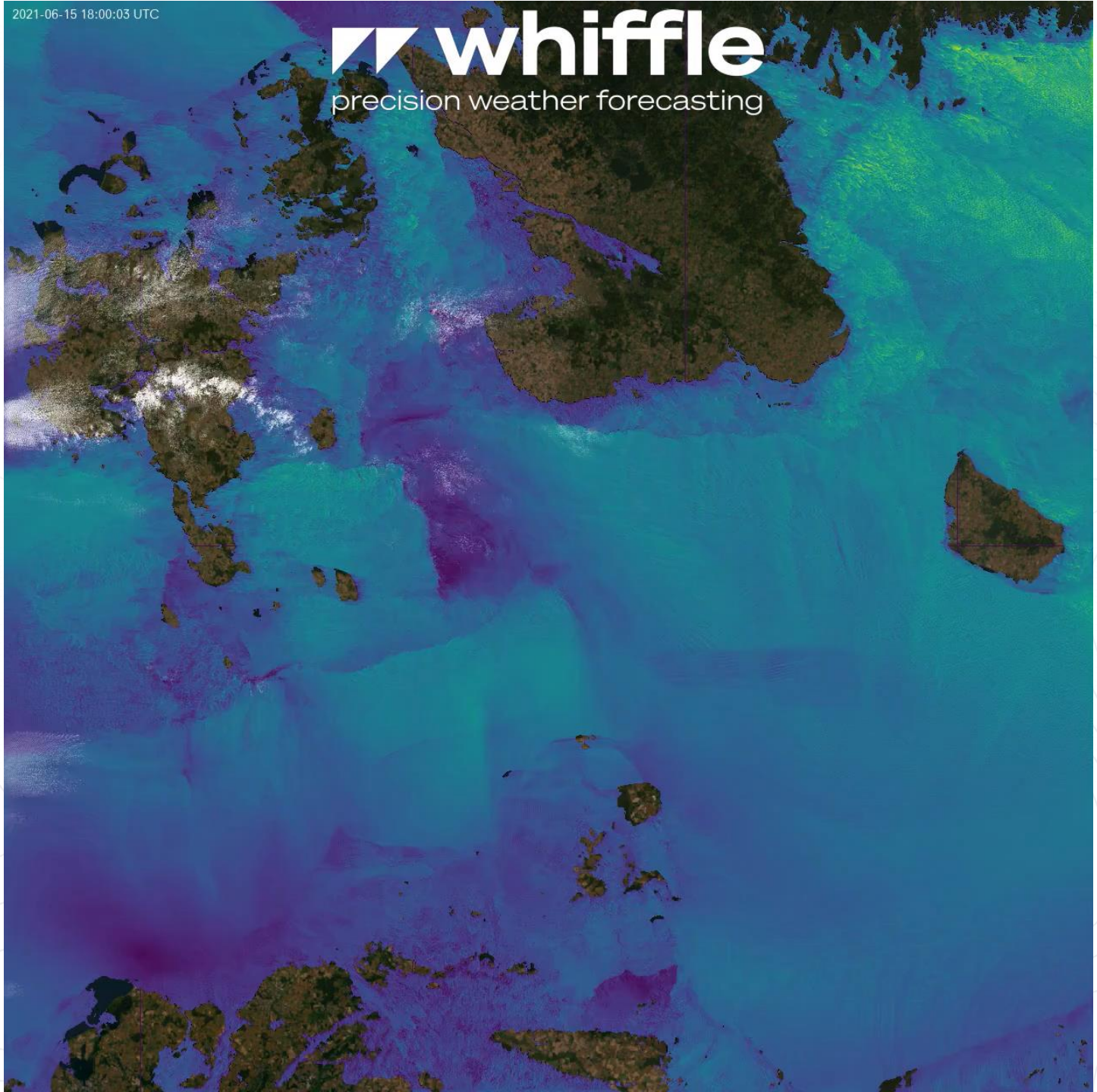
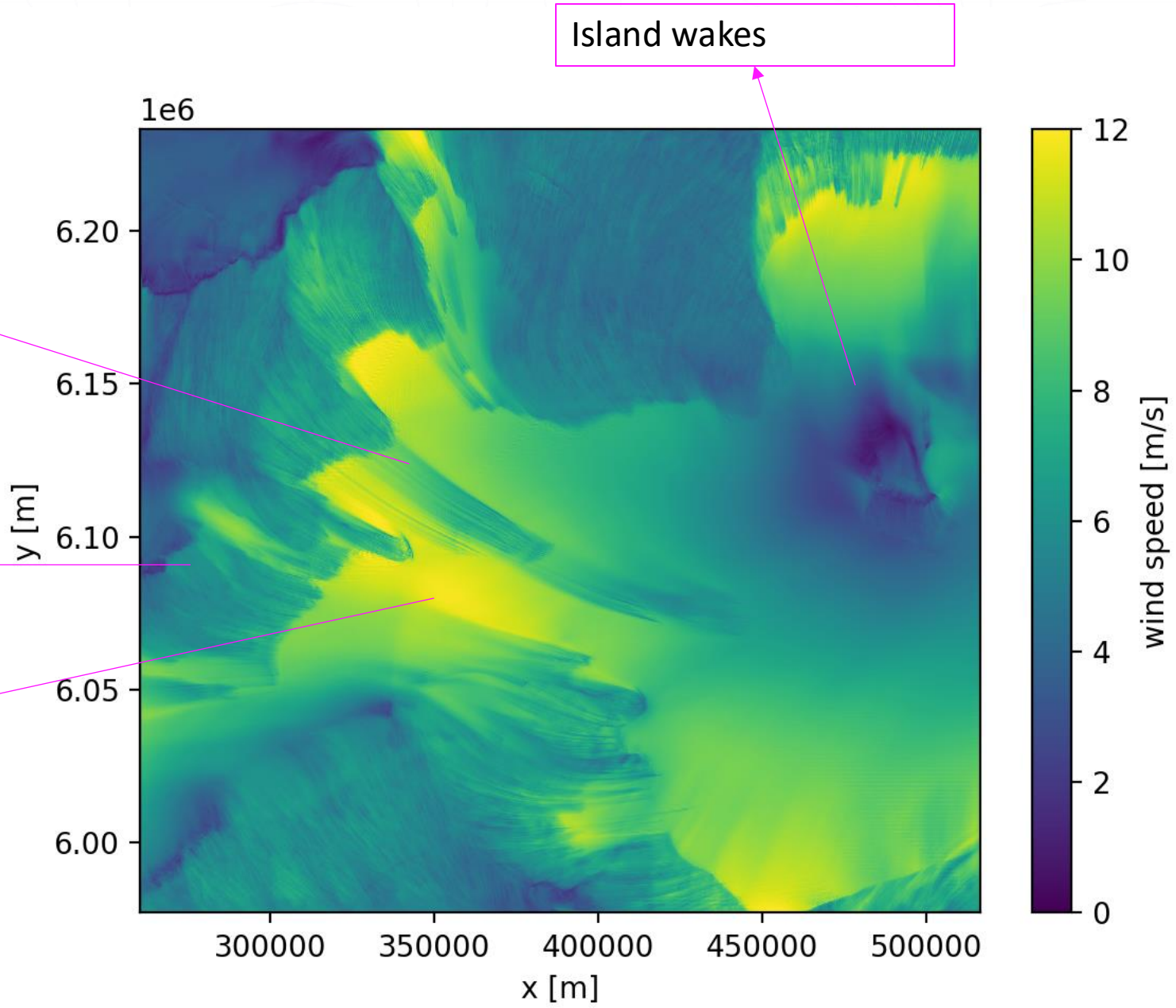
Click here to watch video: https://youtu.be/DQHU_kHF1zU



Results highlight 1: wind speed map



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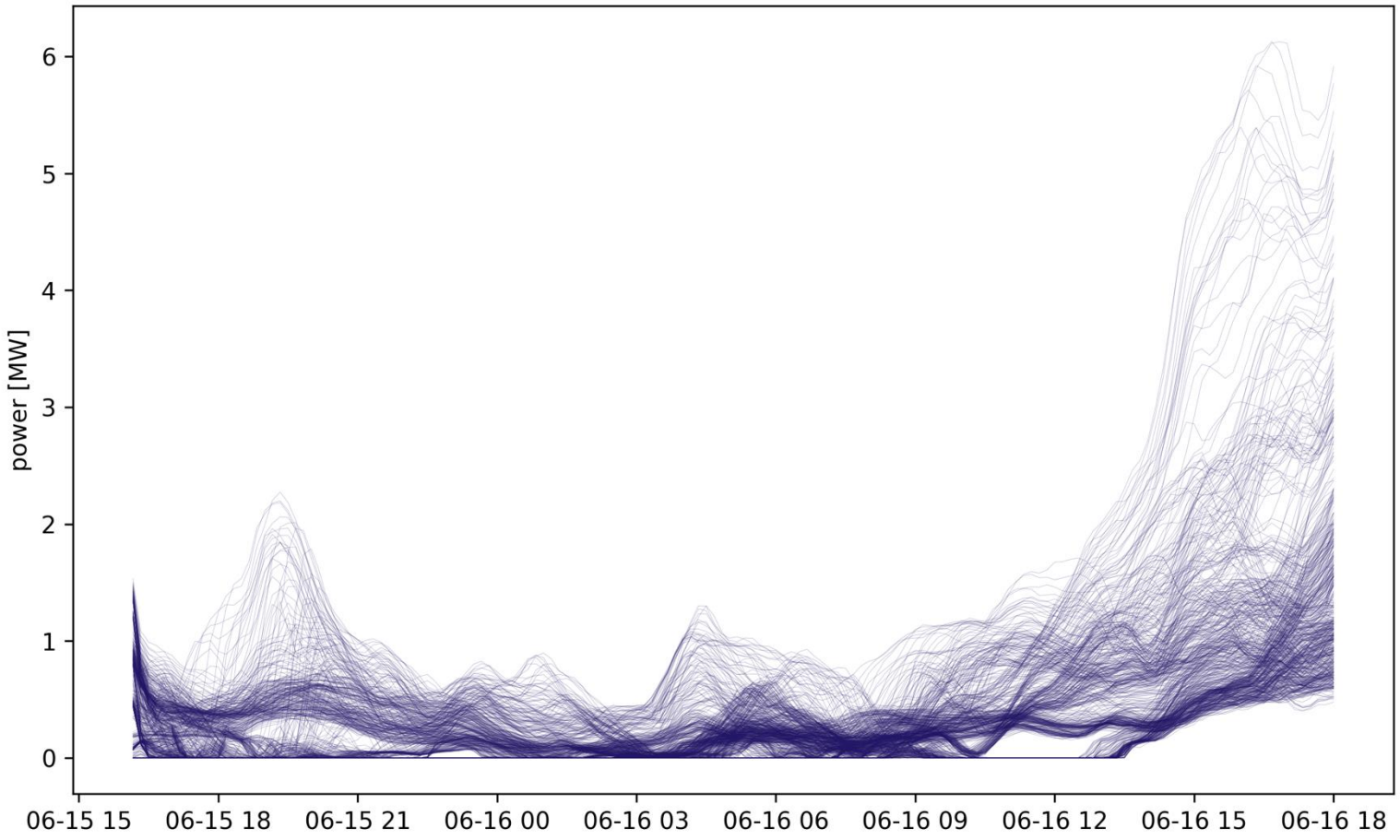
Results highlight 2: power per turbine



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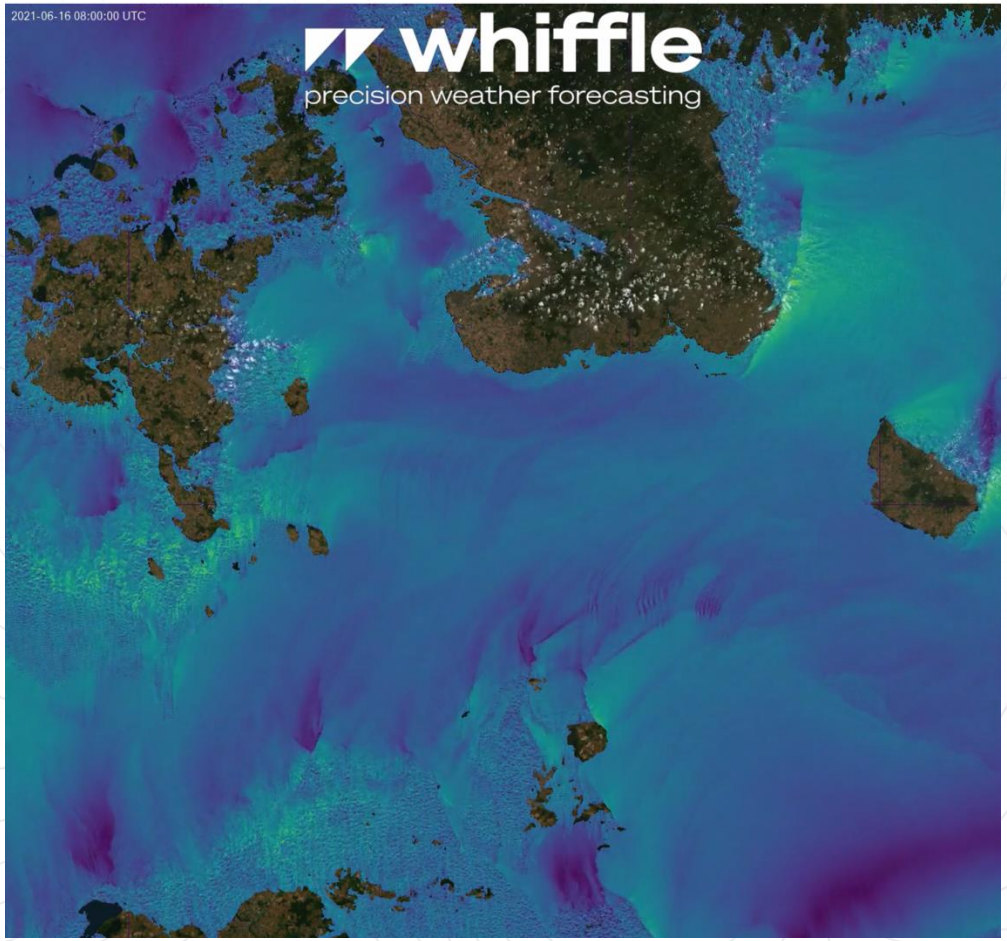
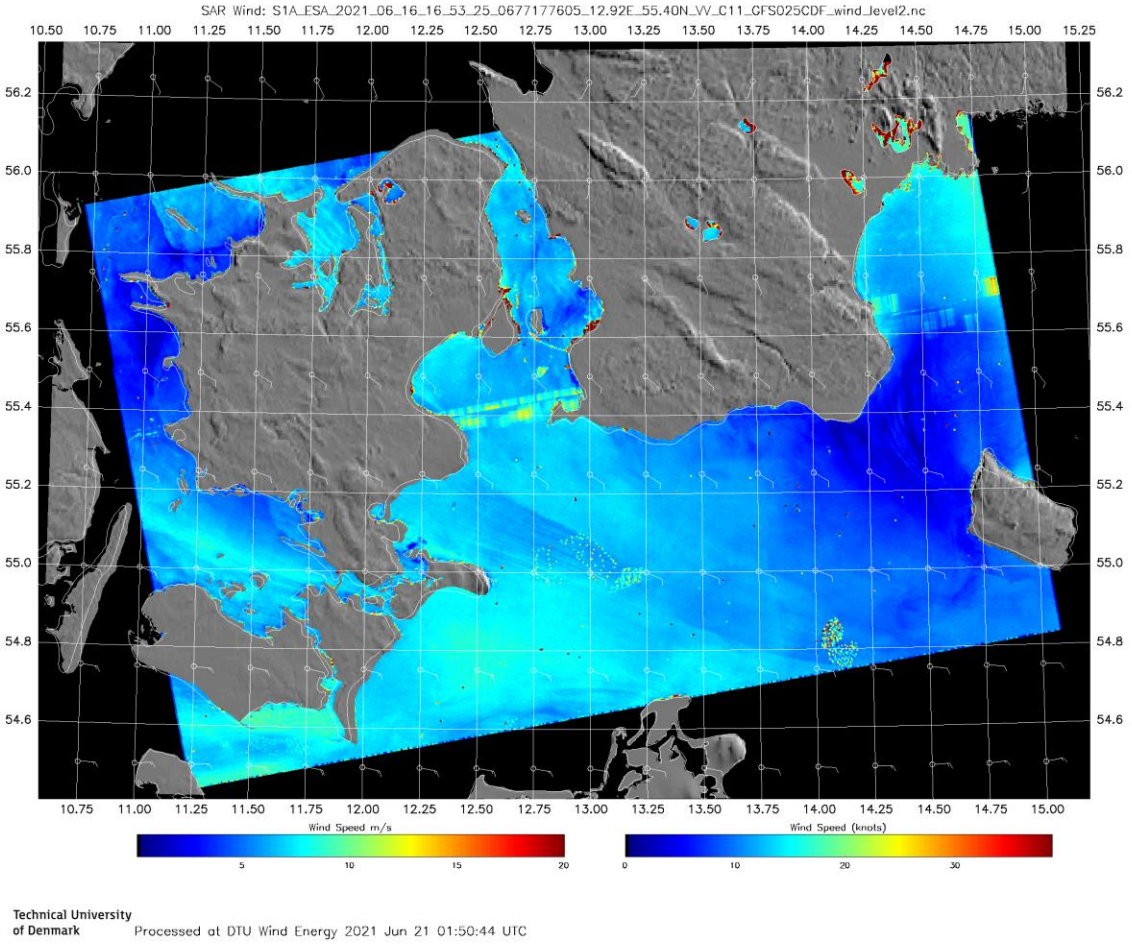
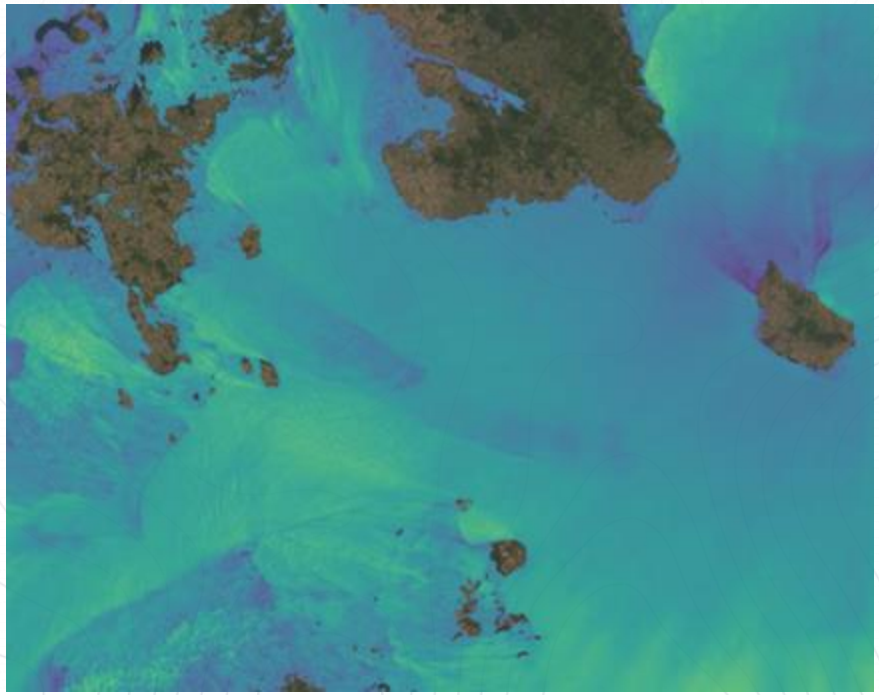
Comparison with observations



Comparison with observations





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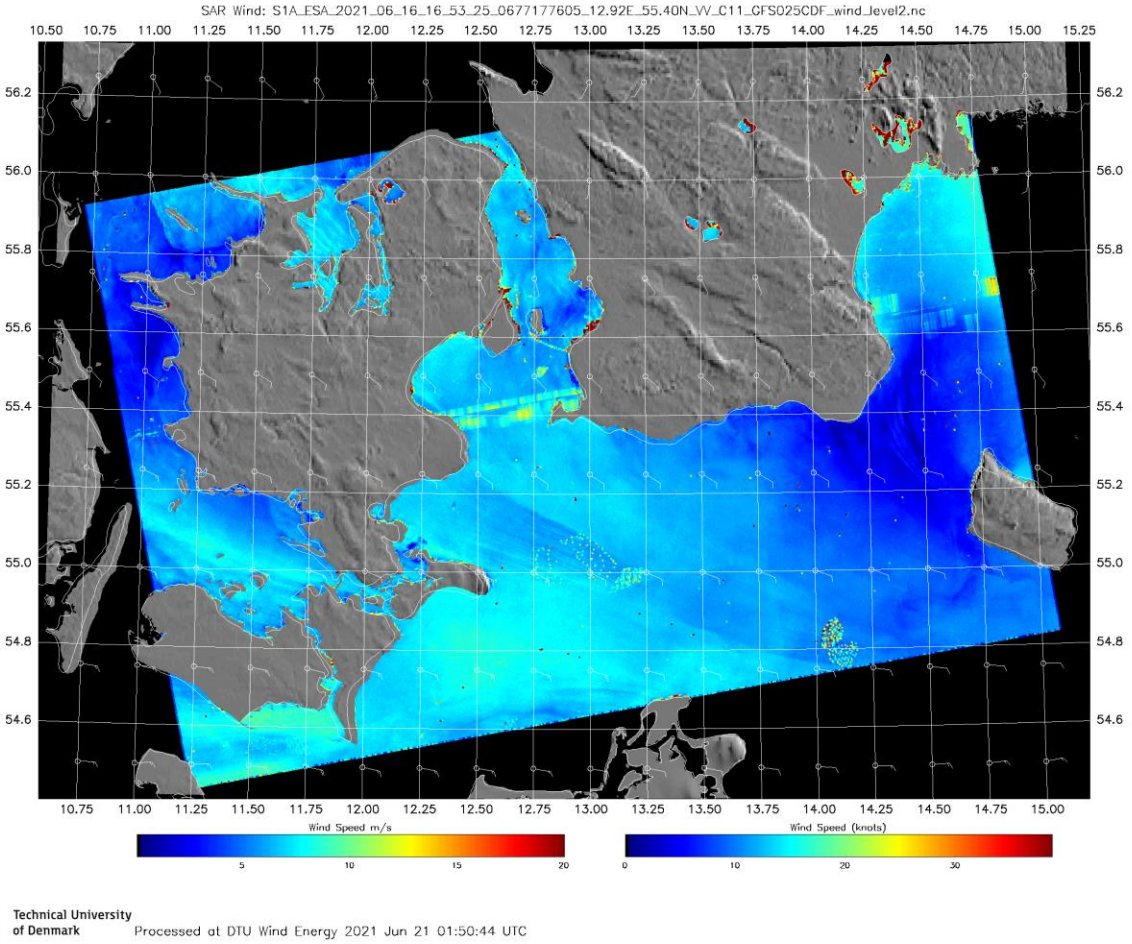
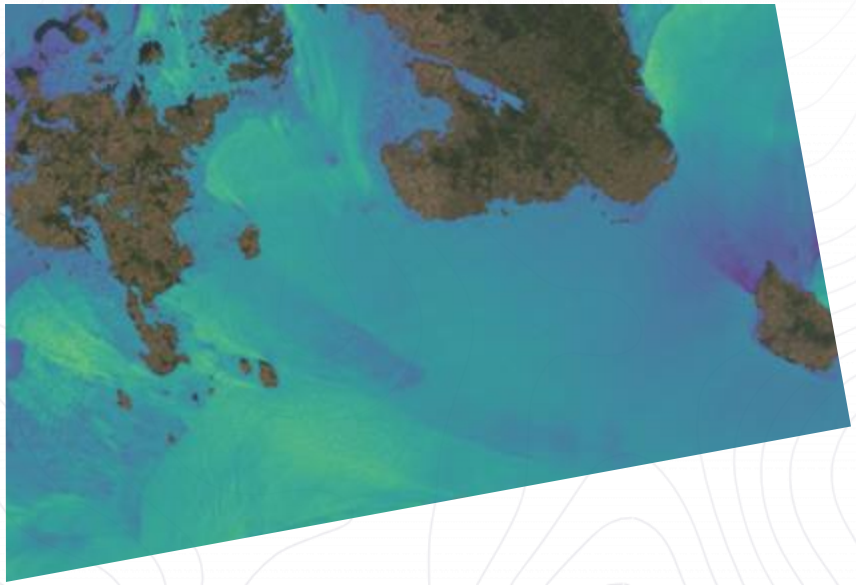
Comparison with observations





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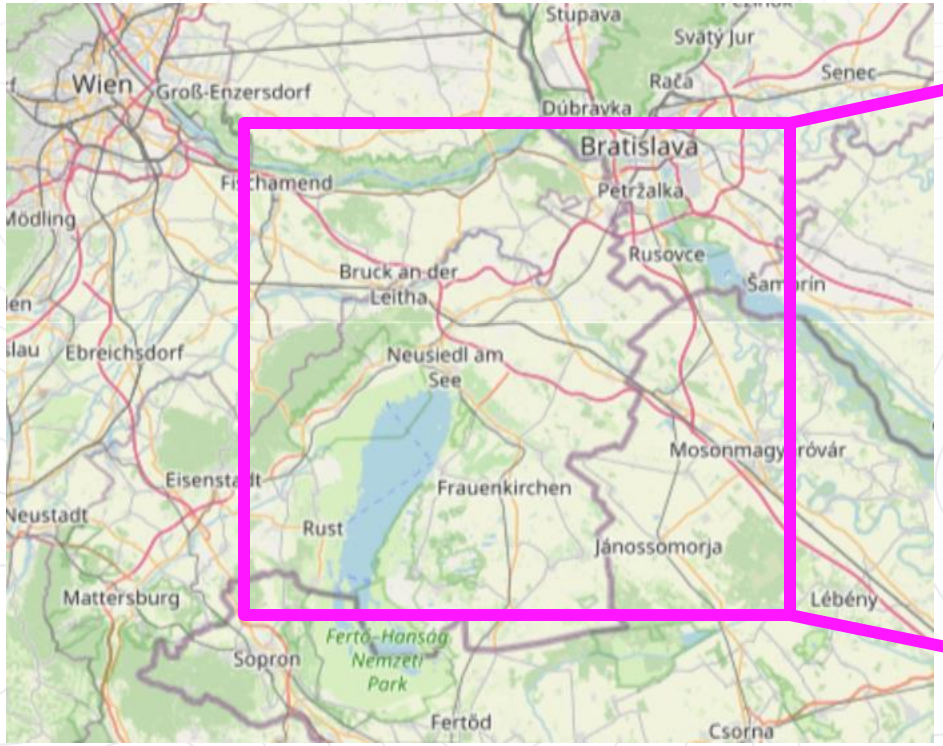
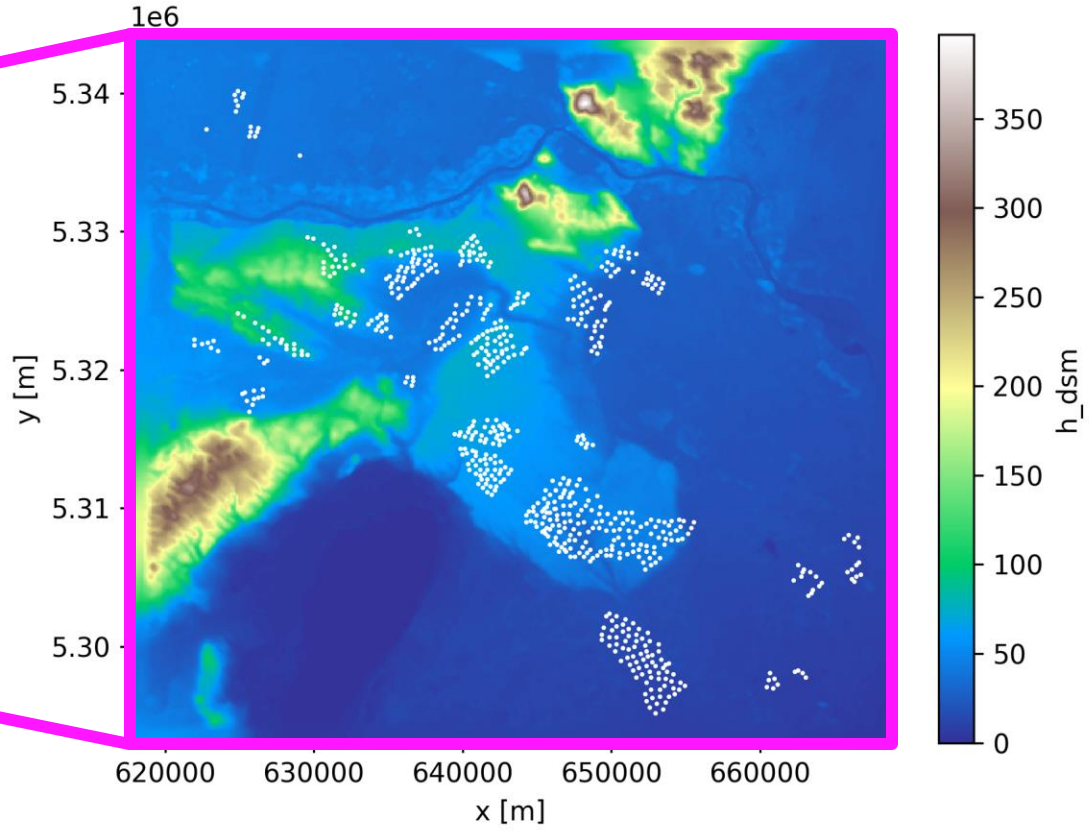
Austria: Gap flows, Mountain waves and Low level jets

Location: Vienna/Lower Austria





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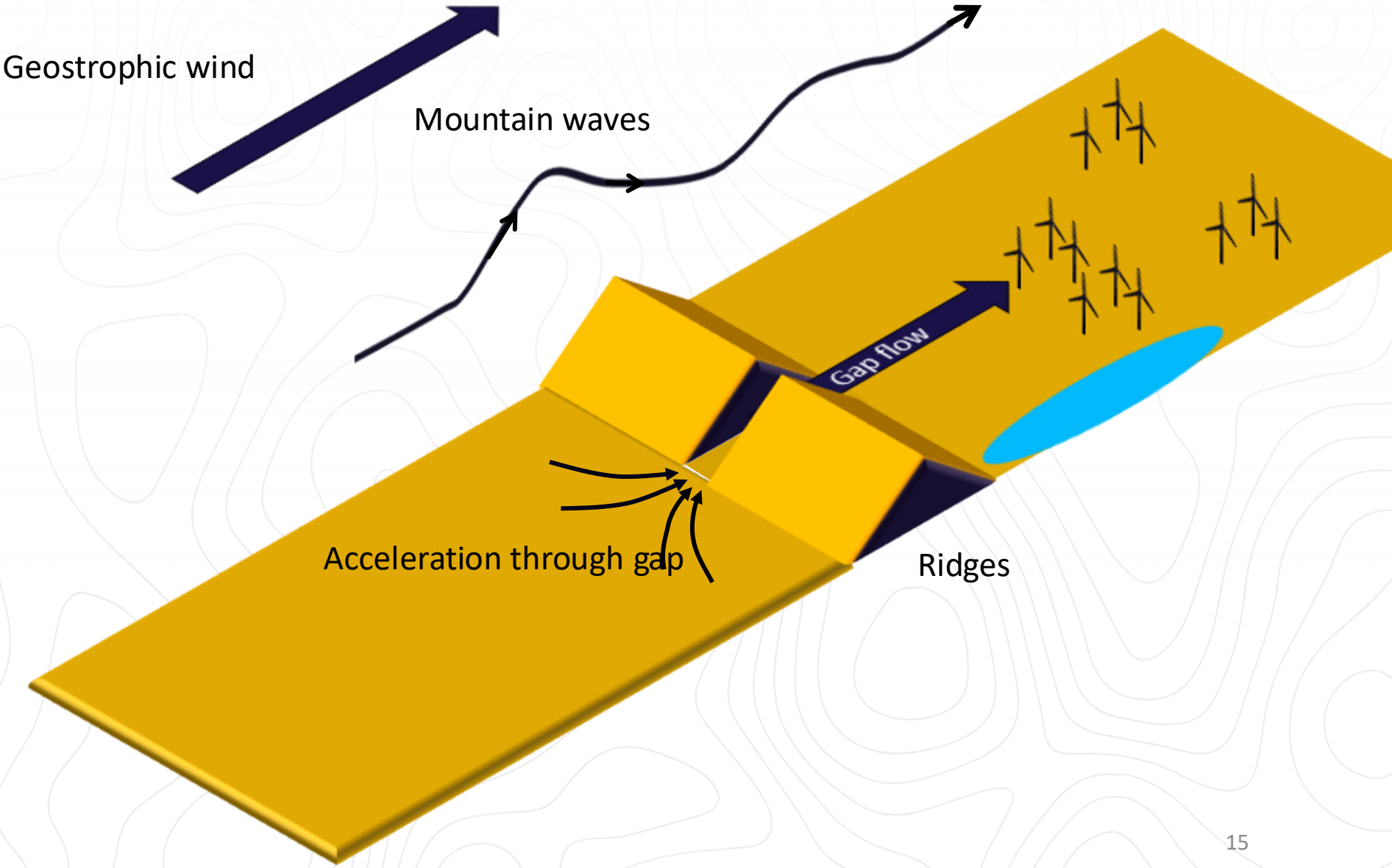
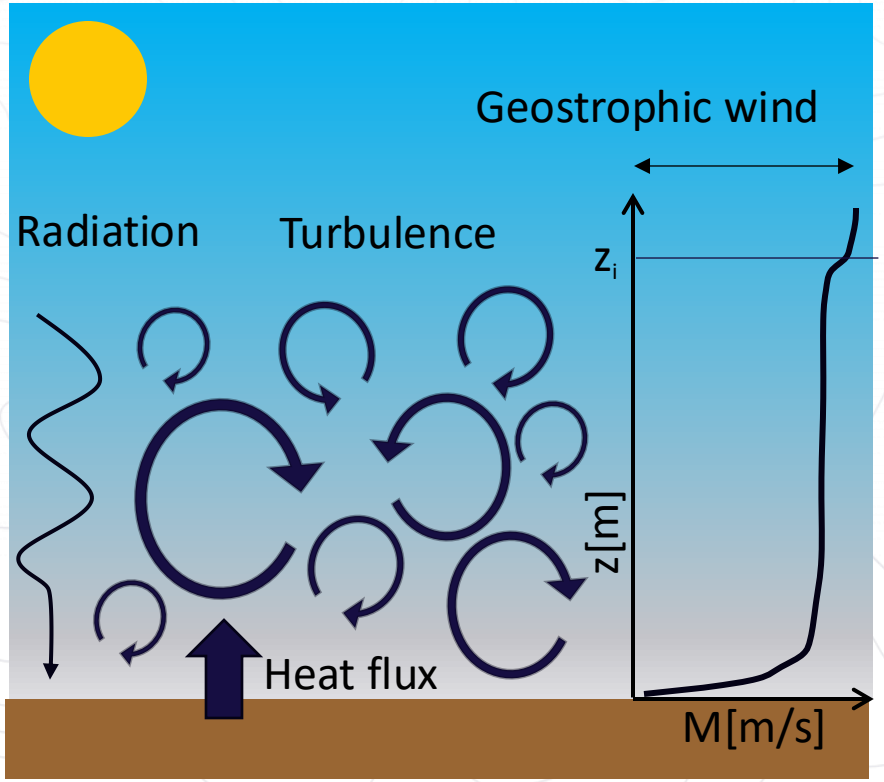
Physics: gap flows and mountain waves

- Gap flow
- Mountain waves
- Lake effects

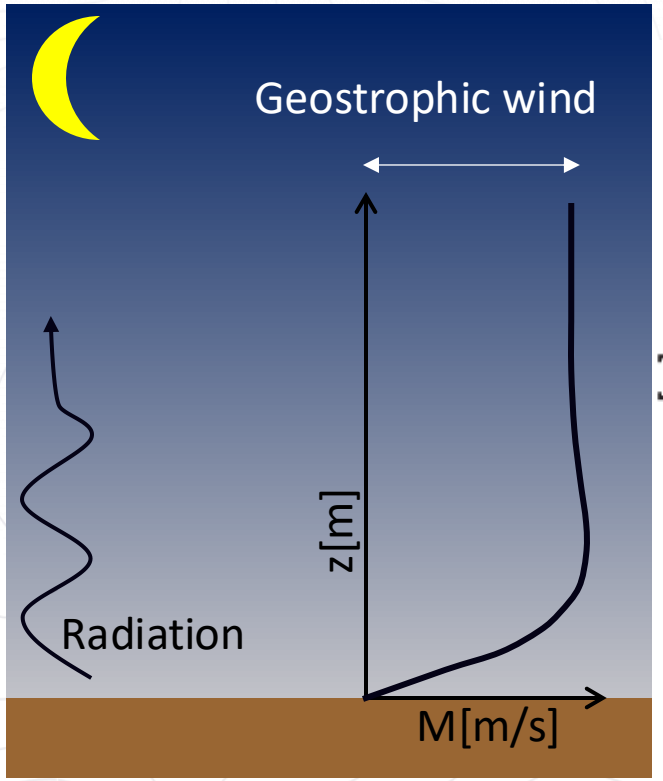


Physics: low-level jets

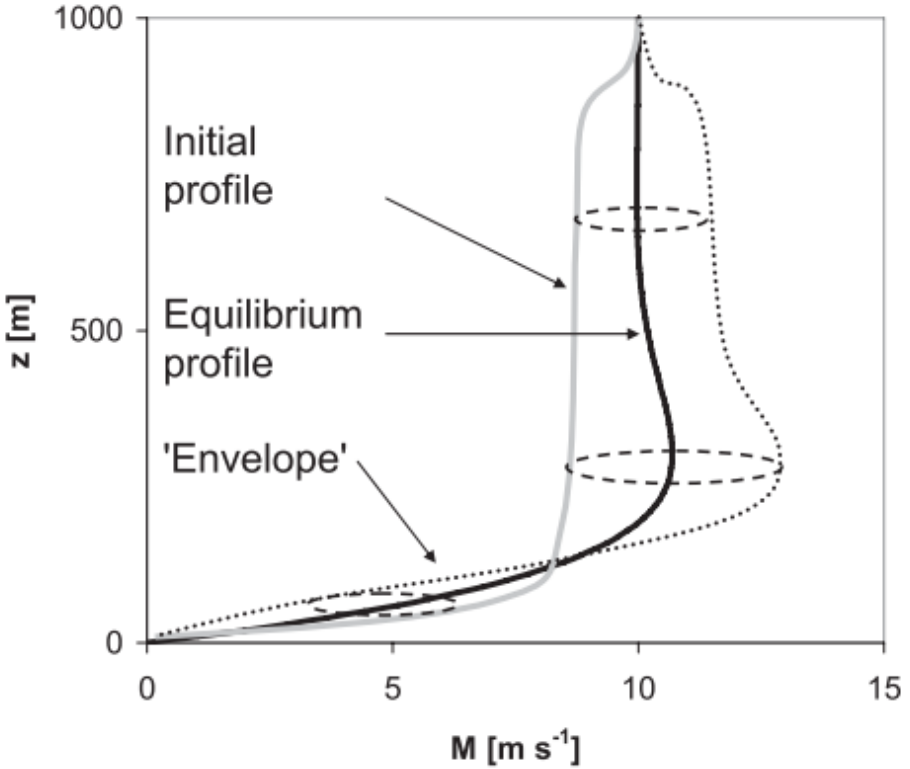
Turbulent transport of momentum



Turbulence decays and layer decouples. Wind accelerates



Inertial oscillation around equilibrium profile [2]



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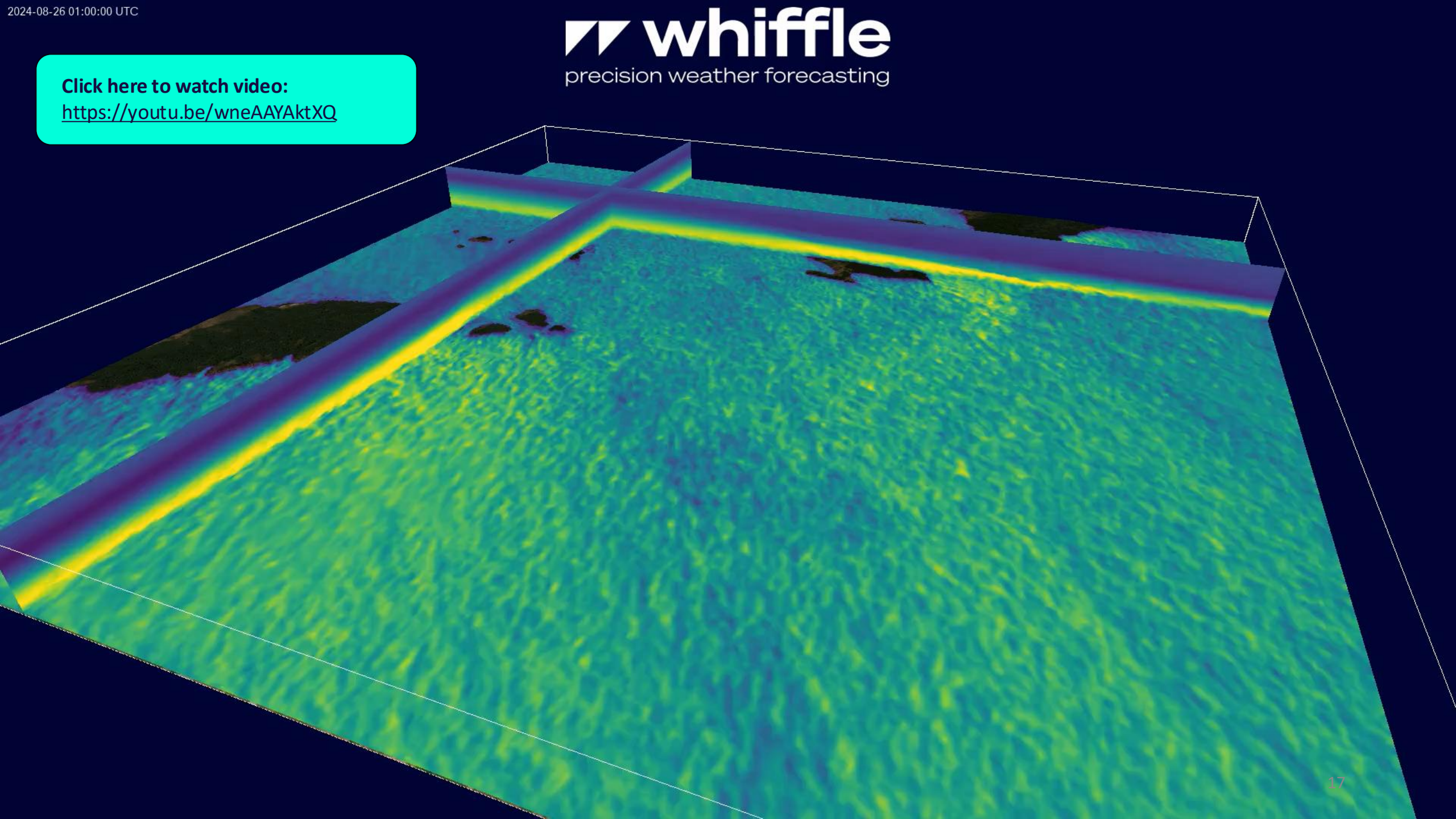
[2] van de Wiel, B. J. H., Moene, A. F., Steeneveld, G. J., Baas, P., Bosveld, F. C., & Holtslag, A. A. M. (2010). A conceptual view on inertial oscillations and nocturnal low-level jets. *Journal of the Atmospheric Sciences*, *67*(8), 2679–2689. https://doi.org/10.1175/2010JAS3289.1


2024-08-26 01:00:00 UTC
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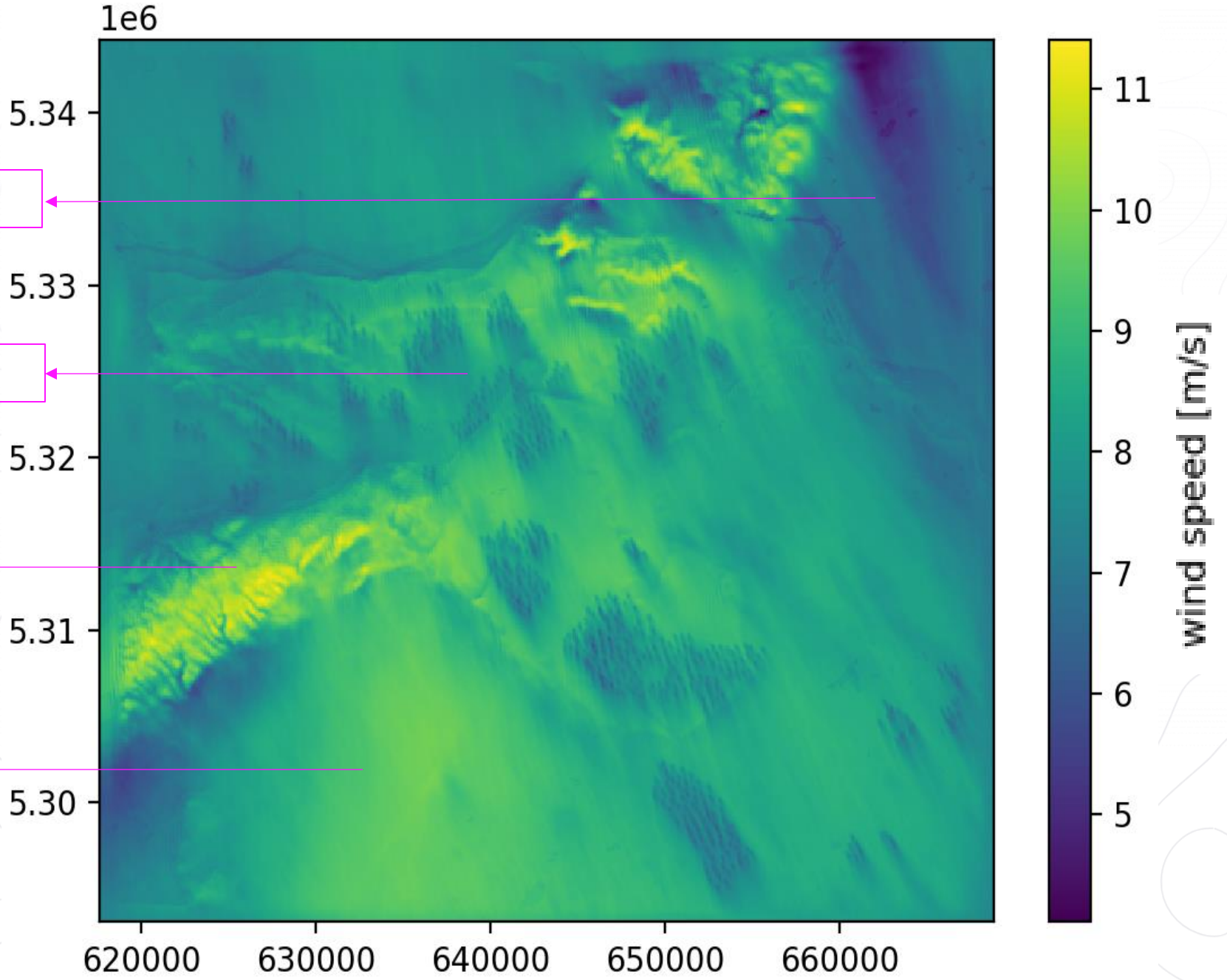
precision weather forecasting
Click here to watch video:
https://youtu.be/wneAAYAktXQ

Results highlight 1: win speed map



Shielding of ridges

Wake effects

Acceleration across ridges

Lake with lower roughness and less turbulence

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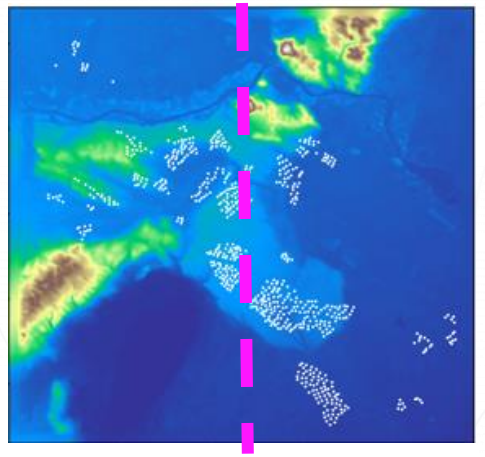
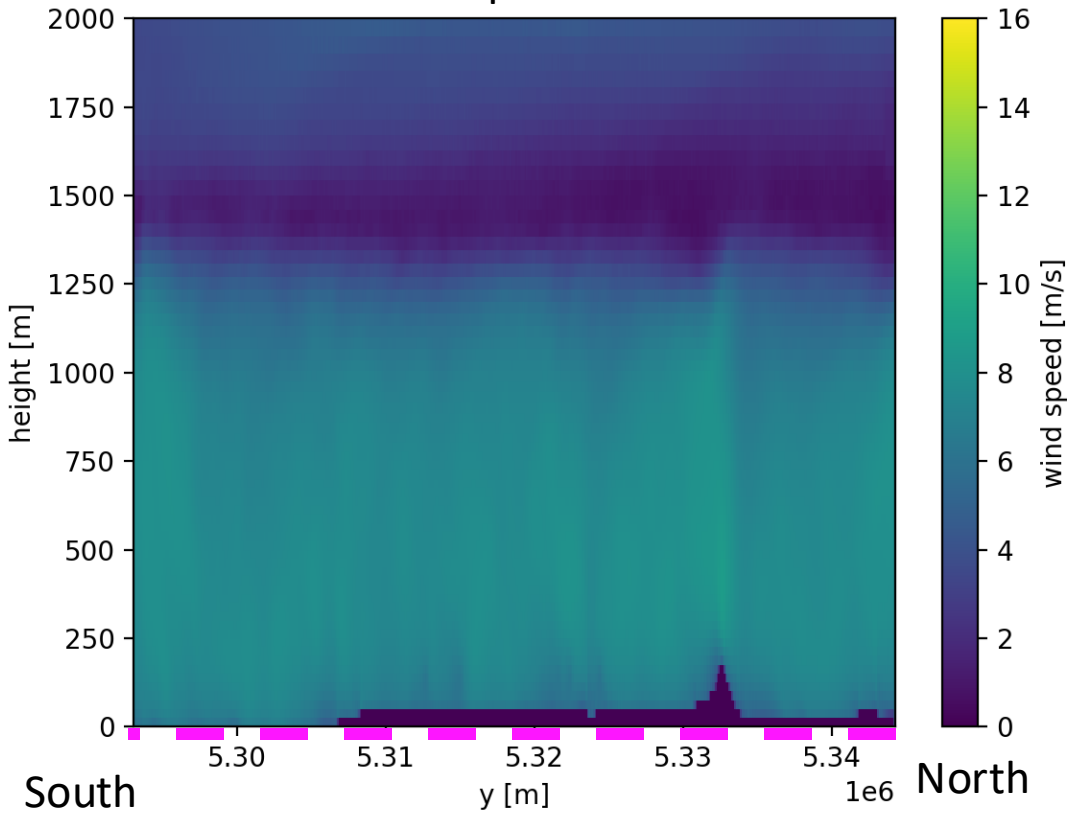
Results high-lights 2: Height profile in north-south cross-section during daytime



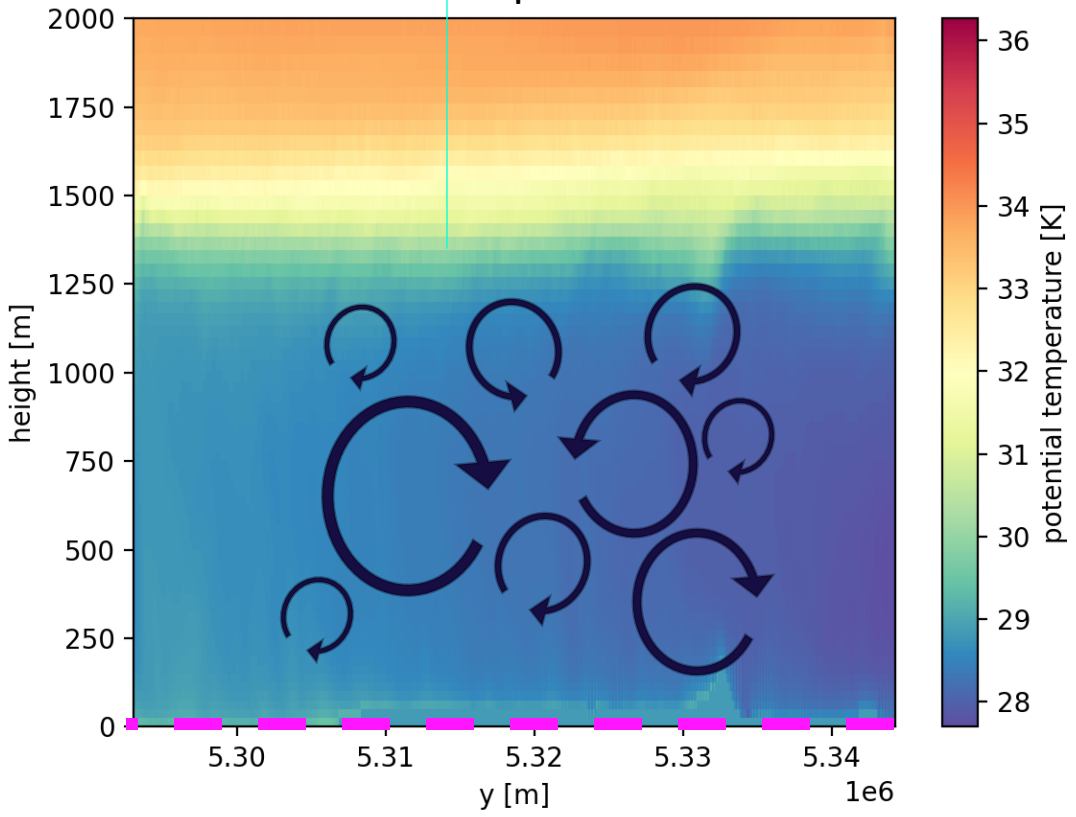
Well-mixed boundary layer

Wind speed



South North

Potential temperature



South North

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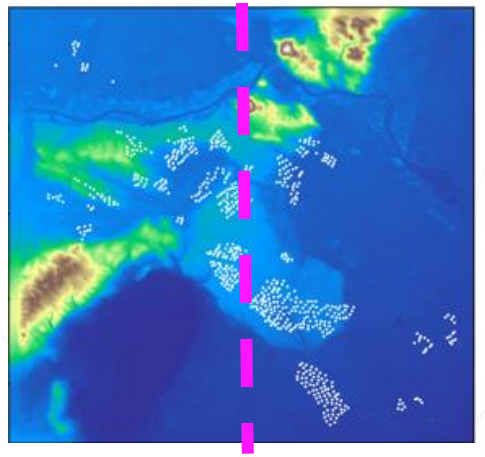
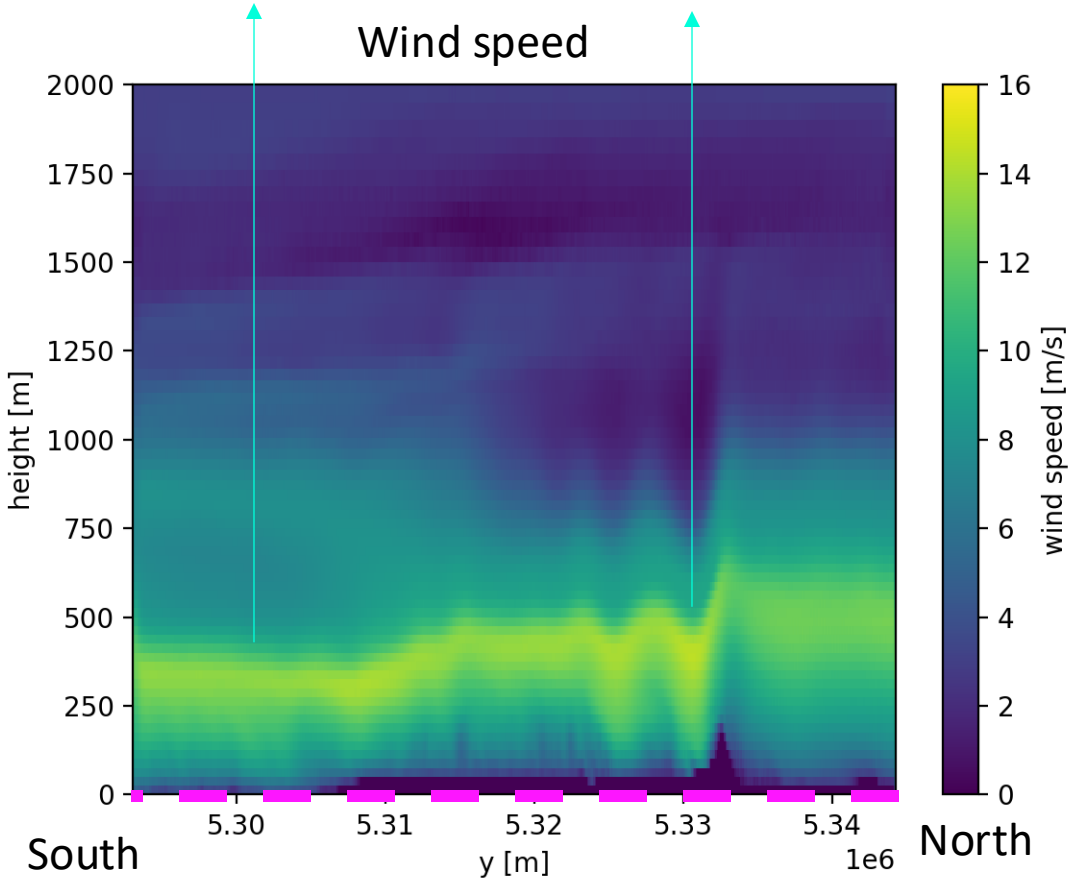
Height profile in north-south cross-section: night

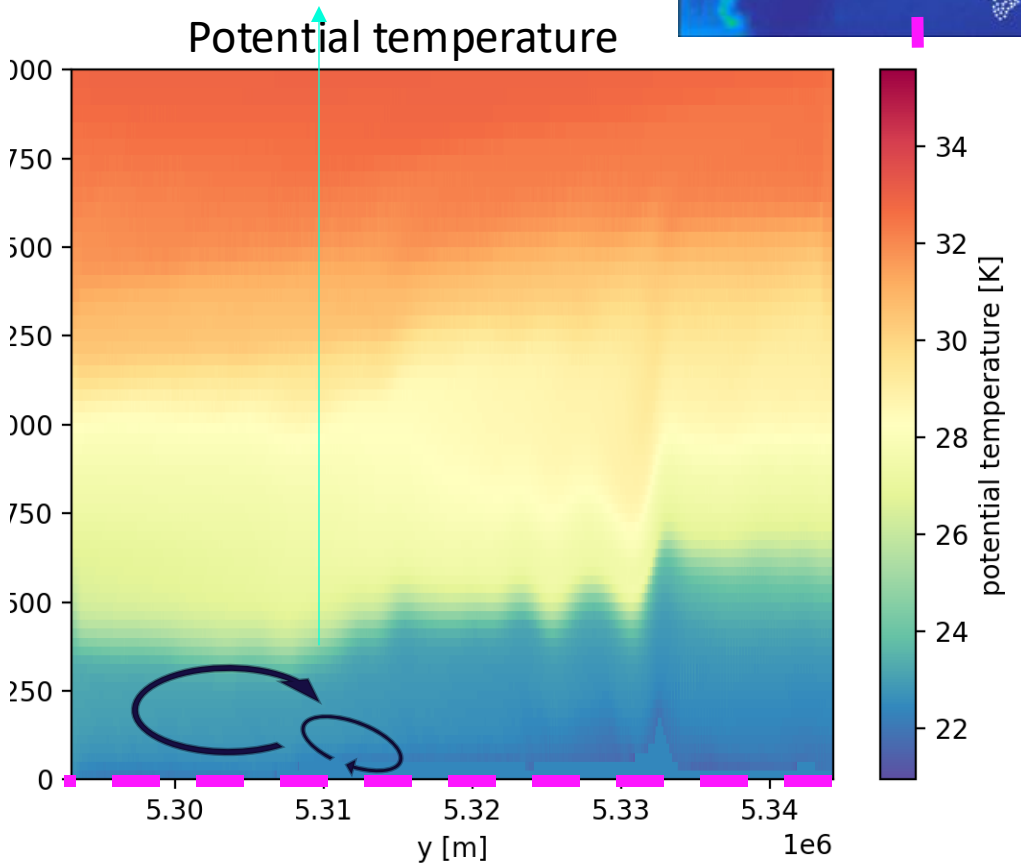


Low-level jet

Mountain waves

Stably stratified layer





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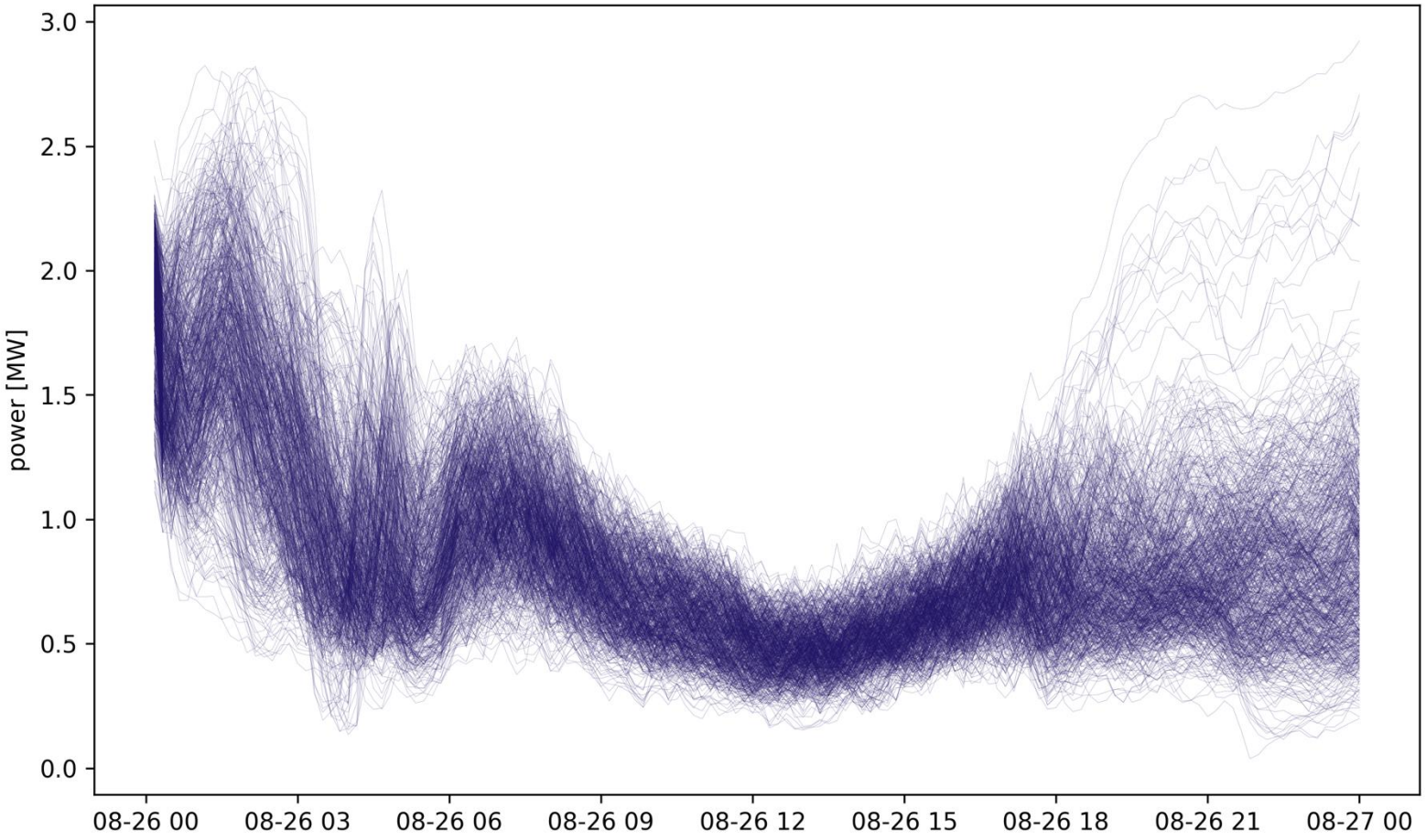
Results highlight 3: Power time series



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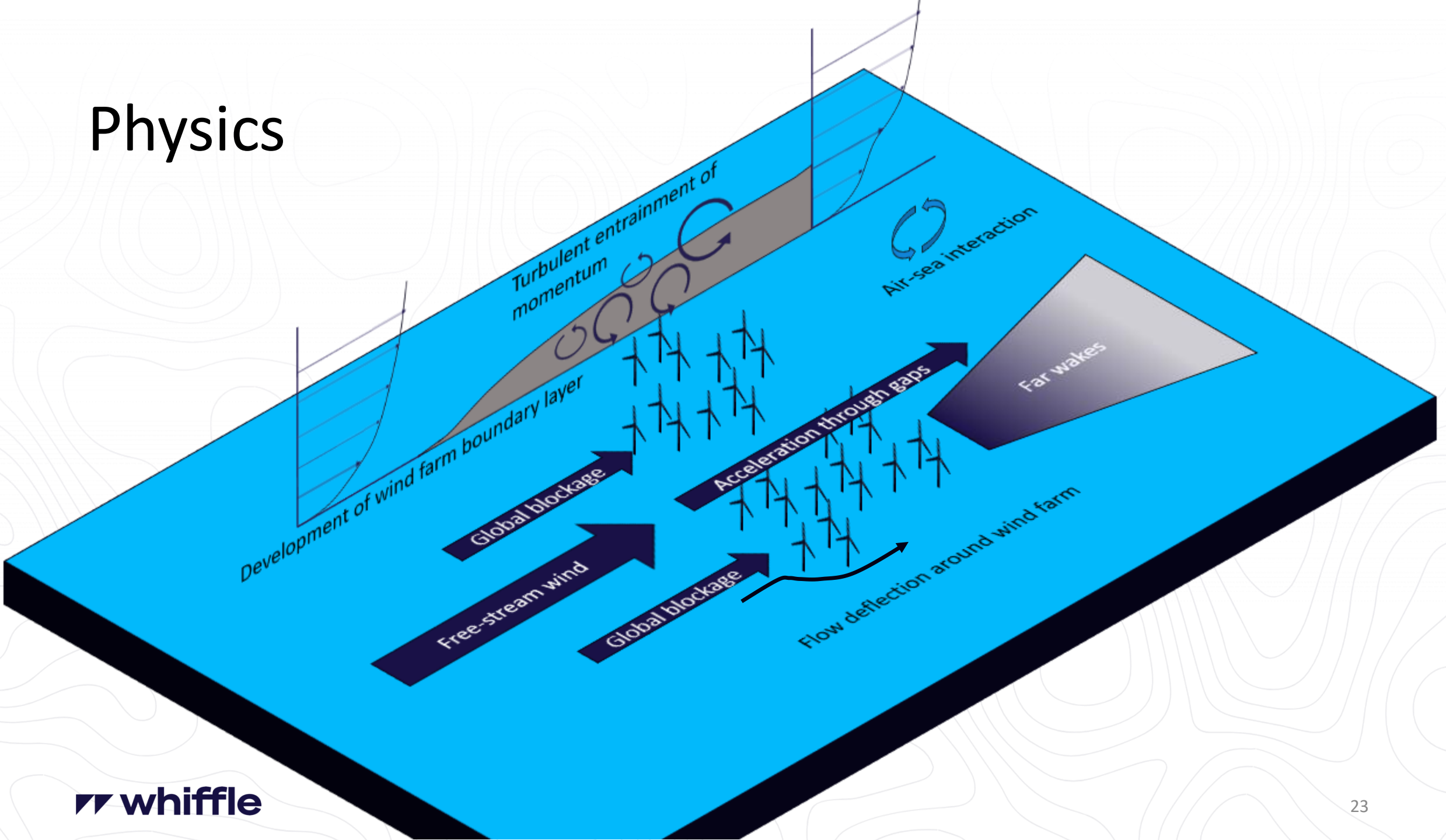
Offshore megacluster

Physics



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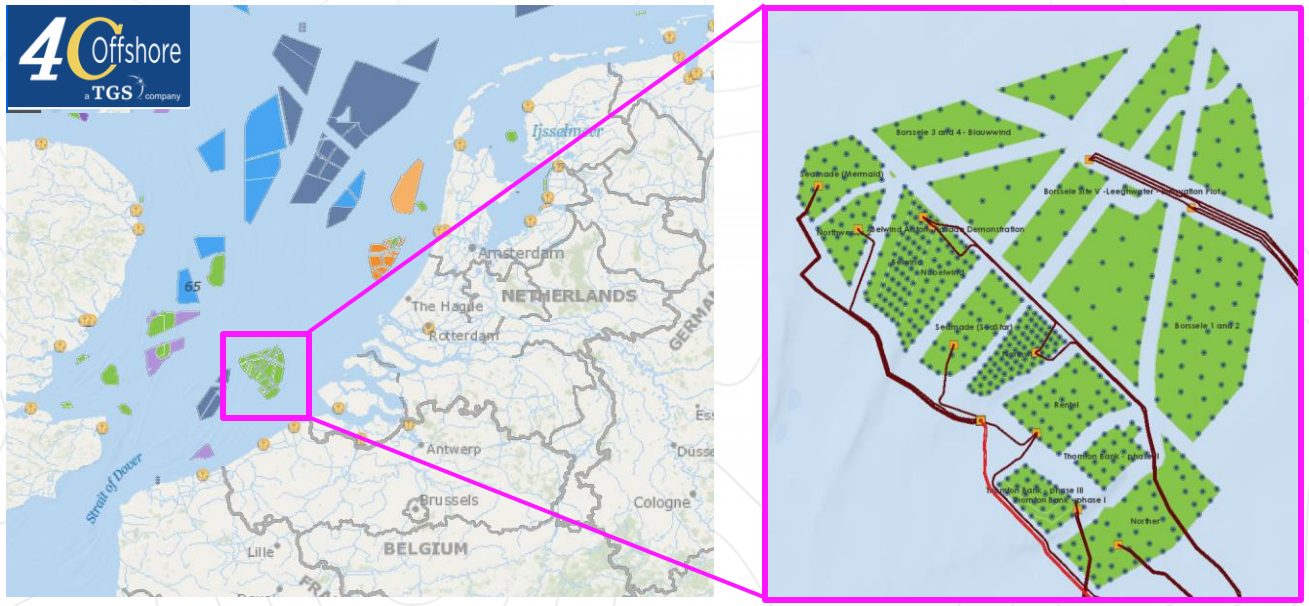
Location: Borssele offshore cluster



Large-Eddy Simulation of the cluster:

- 572 turbines, 3.8 GW
- 767 x 768 x 64 gridpoints (37 million)
- Roughly 1.630.745.395.200 grid-point x time integrations

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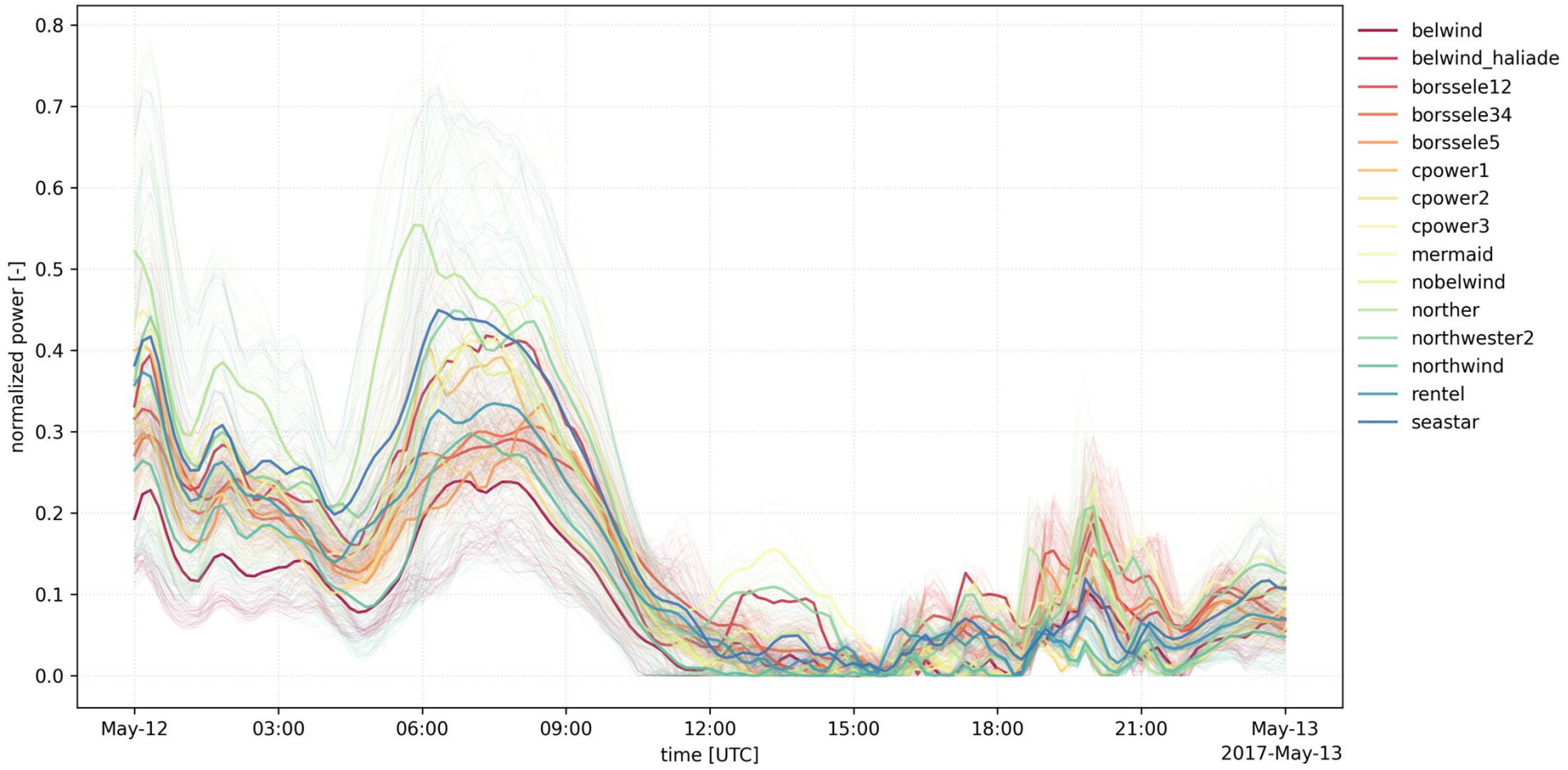
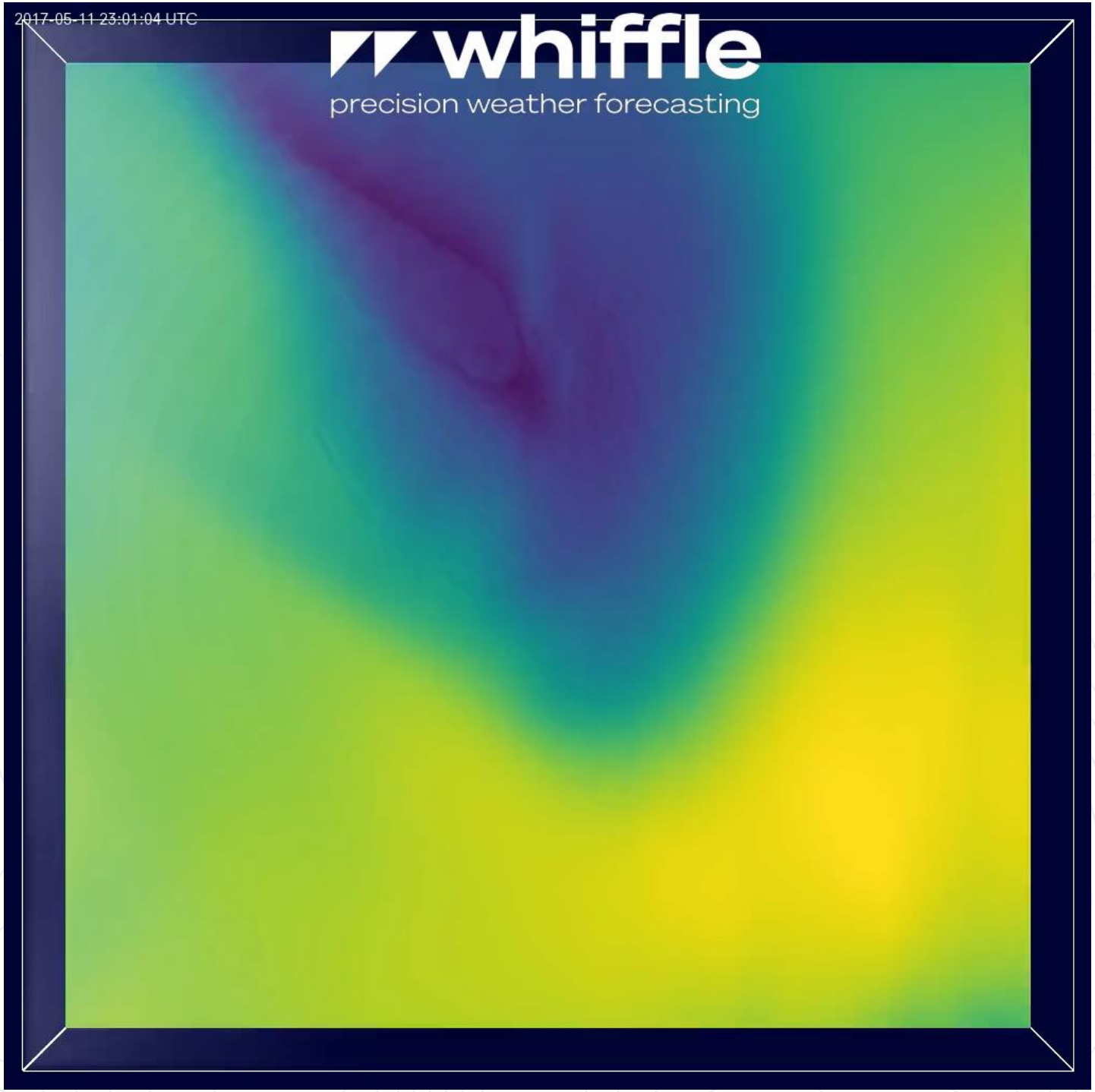
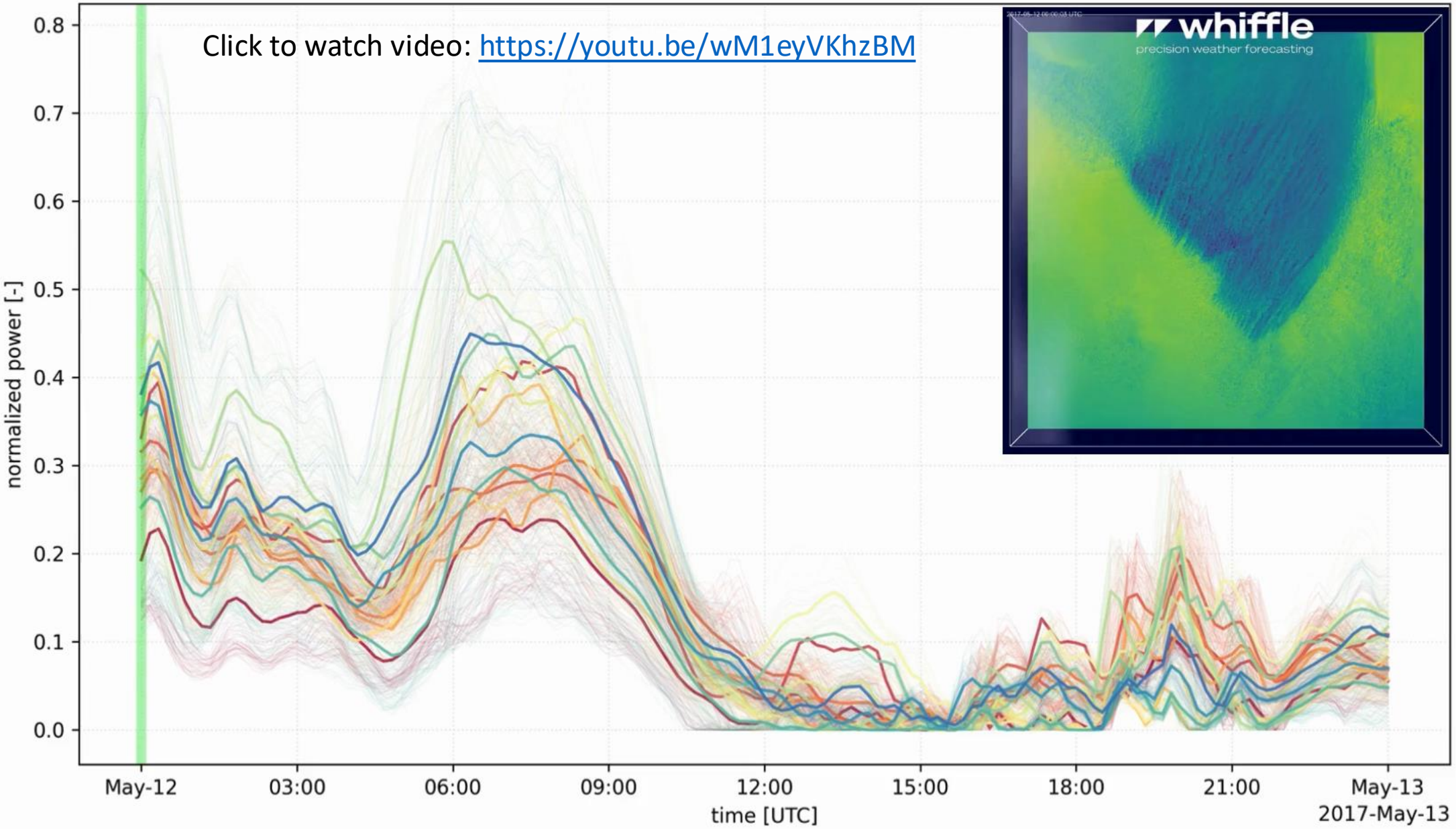
Timeseries of power production



Click here to watch video: https://youtu.be/W_ySSpuoAjc



Click to watch video: https://youtu.be/wM1eyVKhzBM



▶ Illustrative case study: Dutch / belgian offshore cluster

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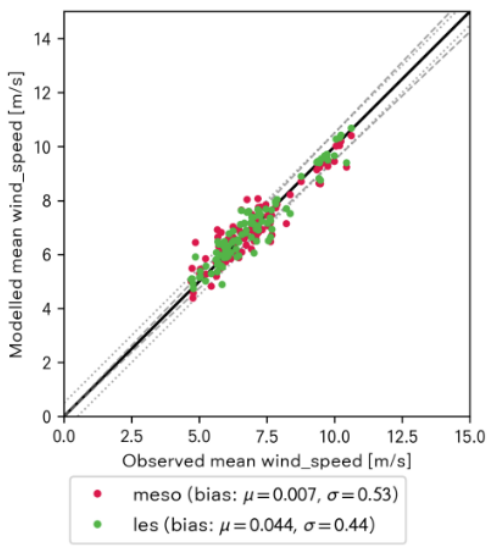
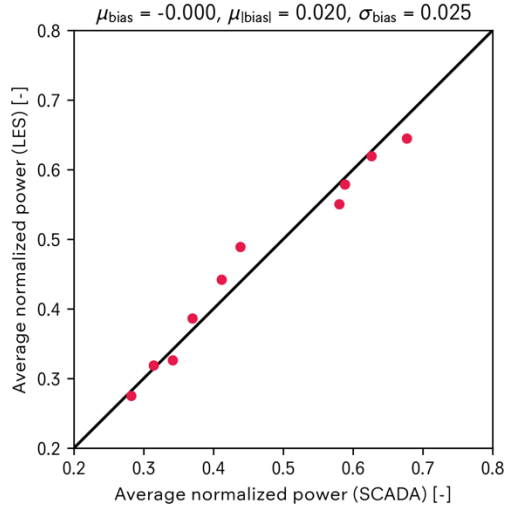
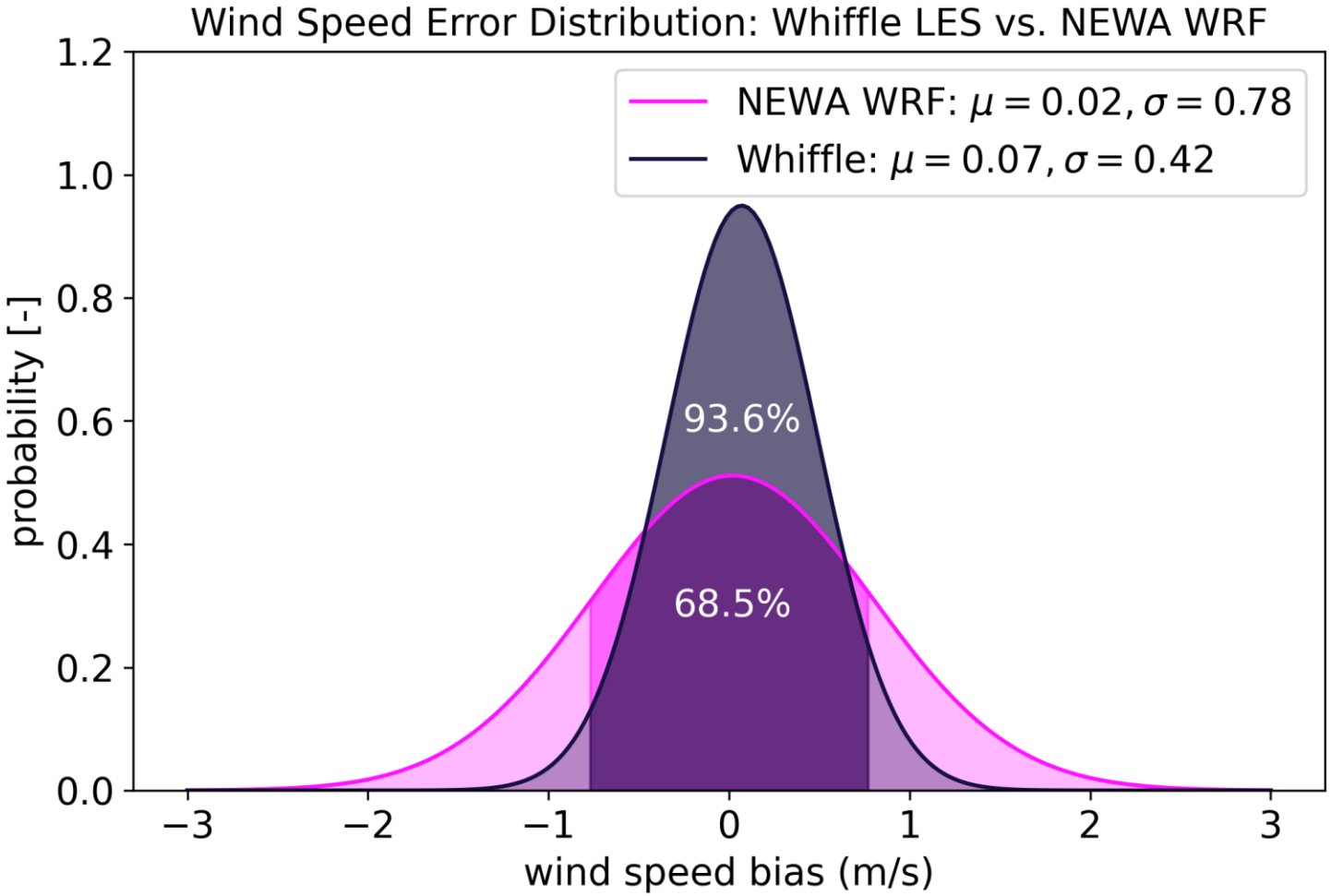
“How good is your model?”

170 site validation campaign with RWE







[Landmark RWE-Whiffle study validates 170 years of LES data, confirming reduced uncertainty in wind speed modelling with Whiffle's meso and micro-scale approach - Whiffle]

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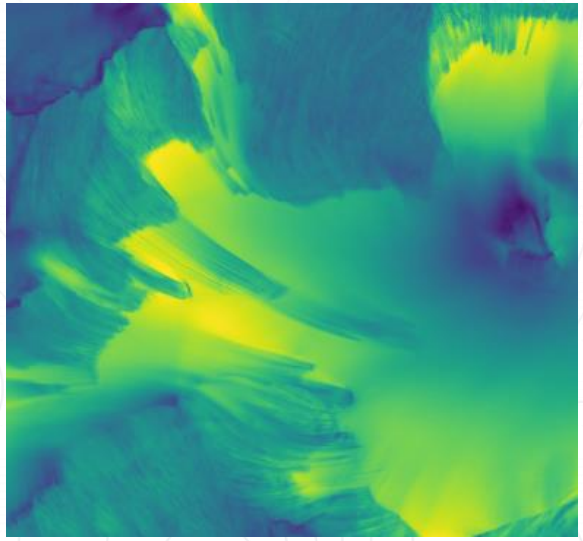
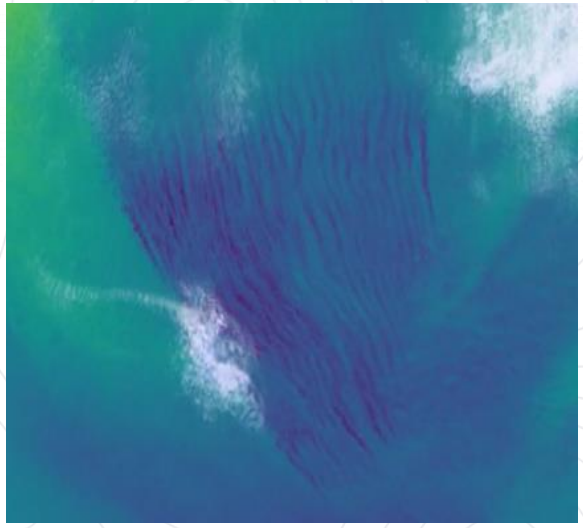
Summary, conclusions and future work

- Full-physics atmospheric LES models *'got what it takes'* to model complex atmospheric flows
- Temperature, turbulence, terrain, vegetation, ….
- We are working on several improvements: surface (and sea) interactions, larger and faster models, …
- The beauty of it all: you can run the model yourself!





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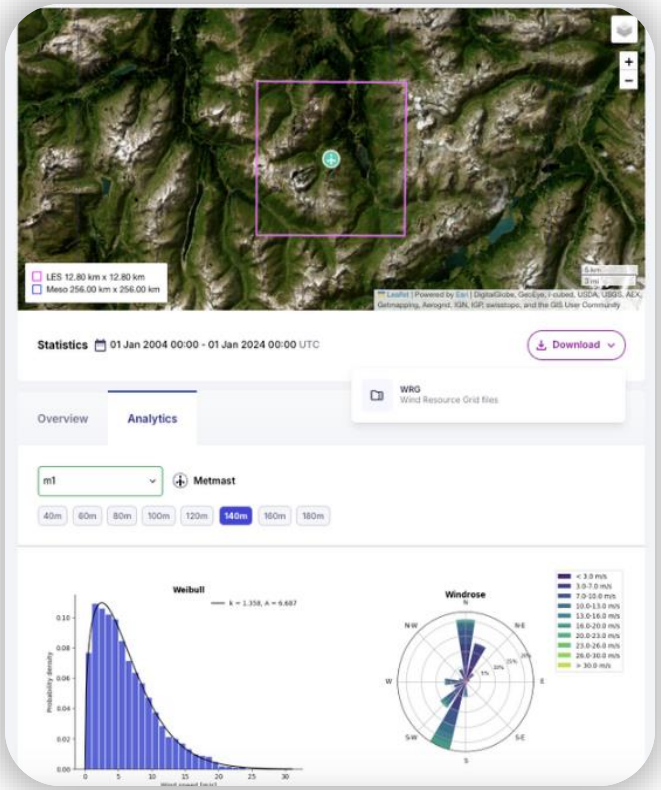
Our solution: whiffle | wind

Whiffle Wind Statistics



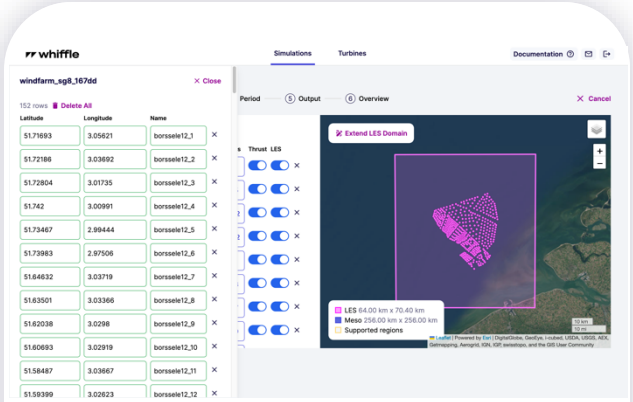
- LES-based long-term statistics for any terrain type, worldwide

Whiffle Wind Time Series

- LES time series data for optimised wind and energy yield modelling

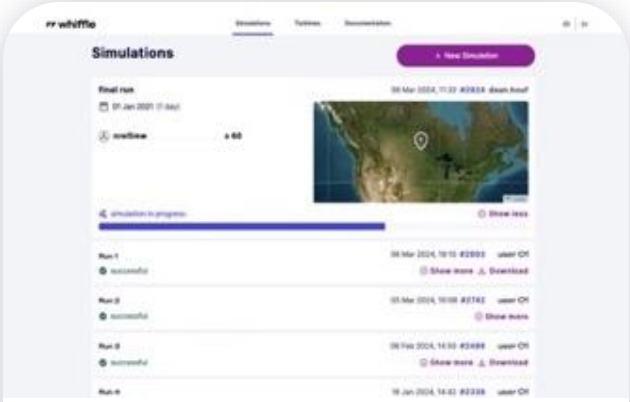
Conduct LES simulations for your wind farm or site with just a few clicks.

whiffle | wind



Step 1: Provide

Input met mast details, turbine type, site layout, and desired simulation period.



Step 2: Submit

Review the output settings, the simulation setup and price, then submit for processing.

Step 3: Retrieve

Explore the results dashboard with wind statistics, time series data, simulation videos and more.

**Whiffle Wind can also be used programmatically with Python thanks to the Whiffle API Client.*

Learn more: whiffle.nl/solutions/whiffle-wind

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Simulated cloud field over the Netherlands

Thank you

For more information visit www.whiffle.nl