whiffle

Challenging atmospheric flows

as modeled by the Whiffle LES model

Remco Verzijlbergh

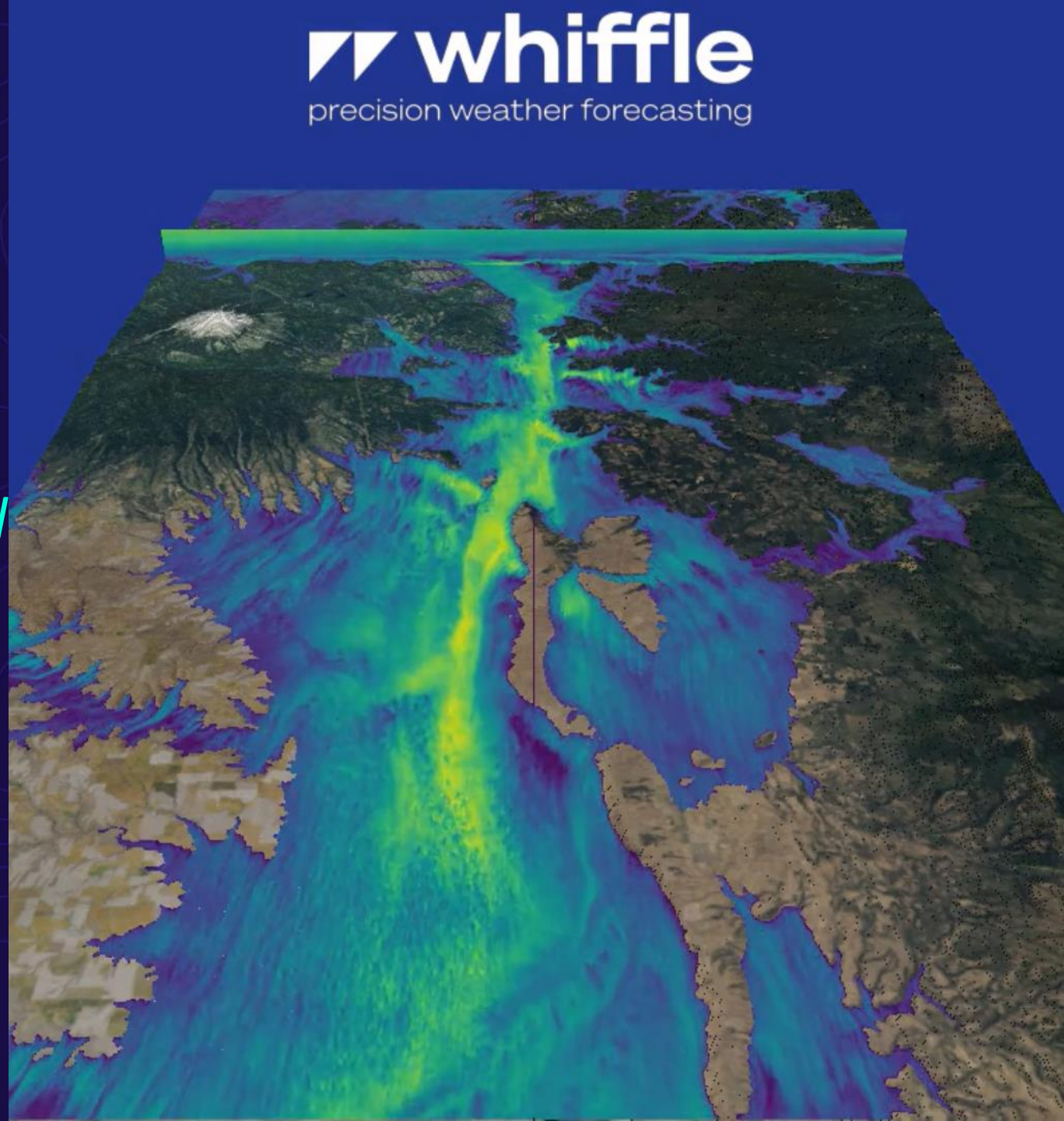
Peter Baas

Many Whiffle colleagues

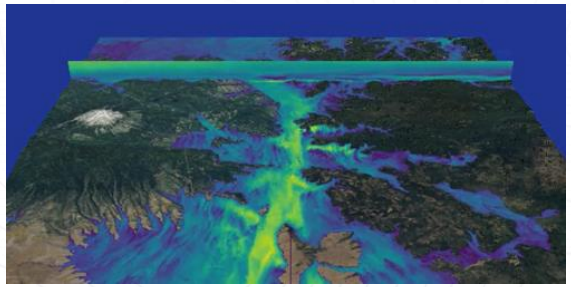
ACP Resource & Tech

2024-10-01

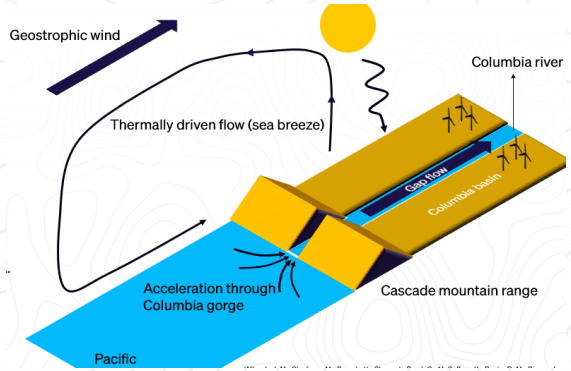
Phoenix, AZ

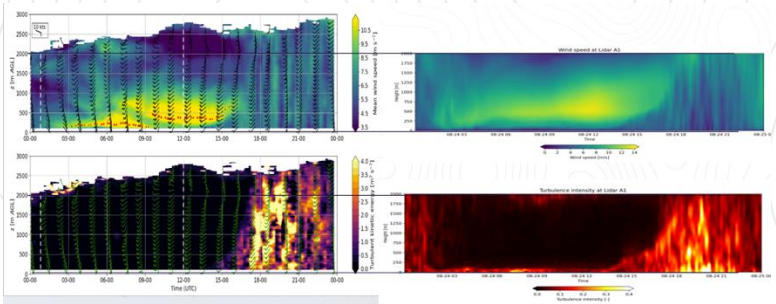


The idea: a quick and fun talk, lots of nice visuals



- ✓ **Show** the power of a high-fidelity atmospheric simulation model
- ✓ **Explain** relevant atmospheric physics
- ✓ **Qualitatively compare** with observations and/or other modelling efforts
- Not an extensive validation study
- Not a full-blown scientific assessment





whiffle

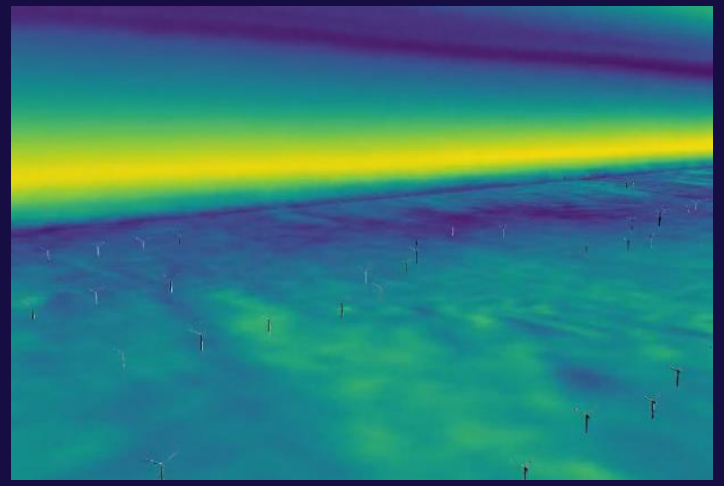
Three challenging and relevant cases for the US wind energy industry

West Coast Gap Flow

- 6GW+ wind energy in Columbia river basin
- Extensively measured and modelled site (Wilczak et al, 2019)

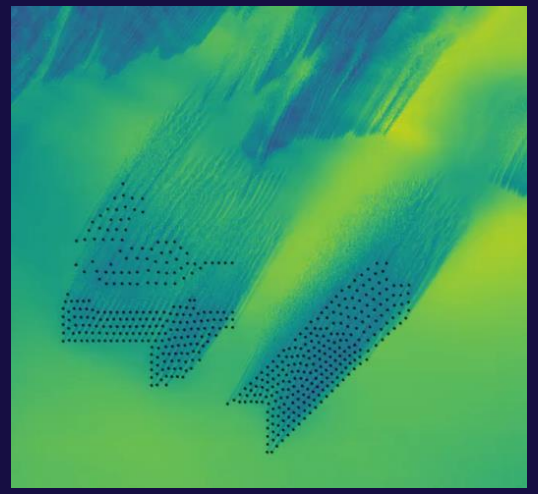
Oklahoma, Low Level Jet

- Great plains, known for jets, home to many GW of wind farms
- AWAKEN measurement campaign



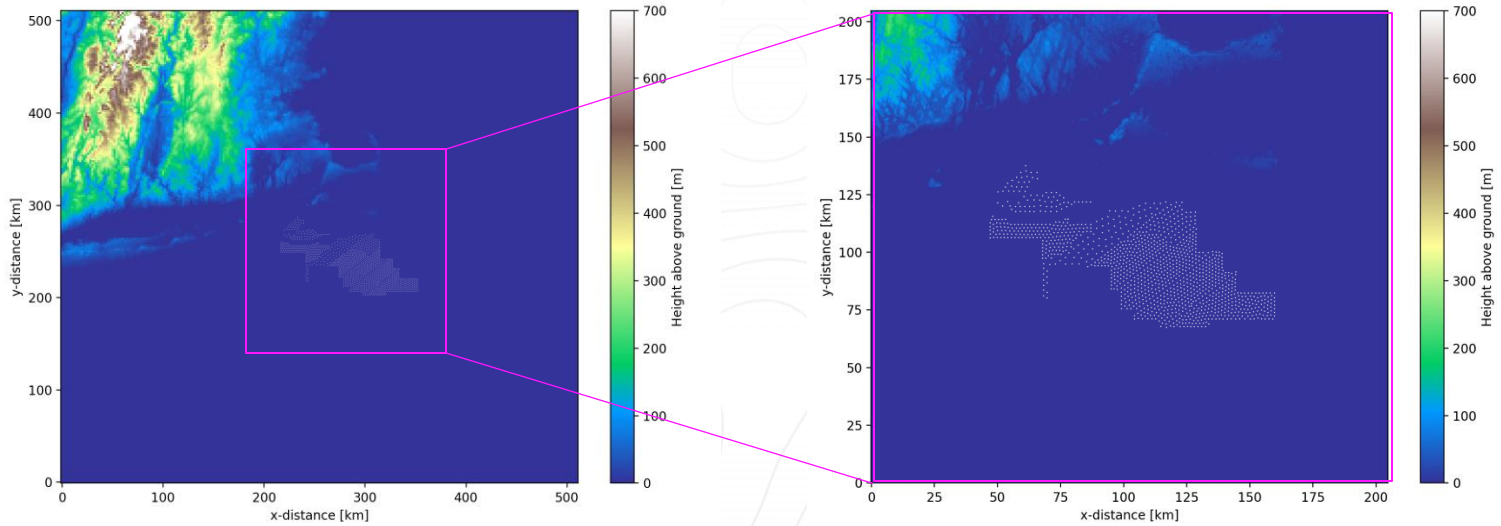
East Coast Offshore Megacluster

- **Partial build-out of the Vineyard cluster**
- **~ 6GW**



whiffle

LES set-ups



Mesoscale
Domain: 512 x 512 x 8km
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

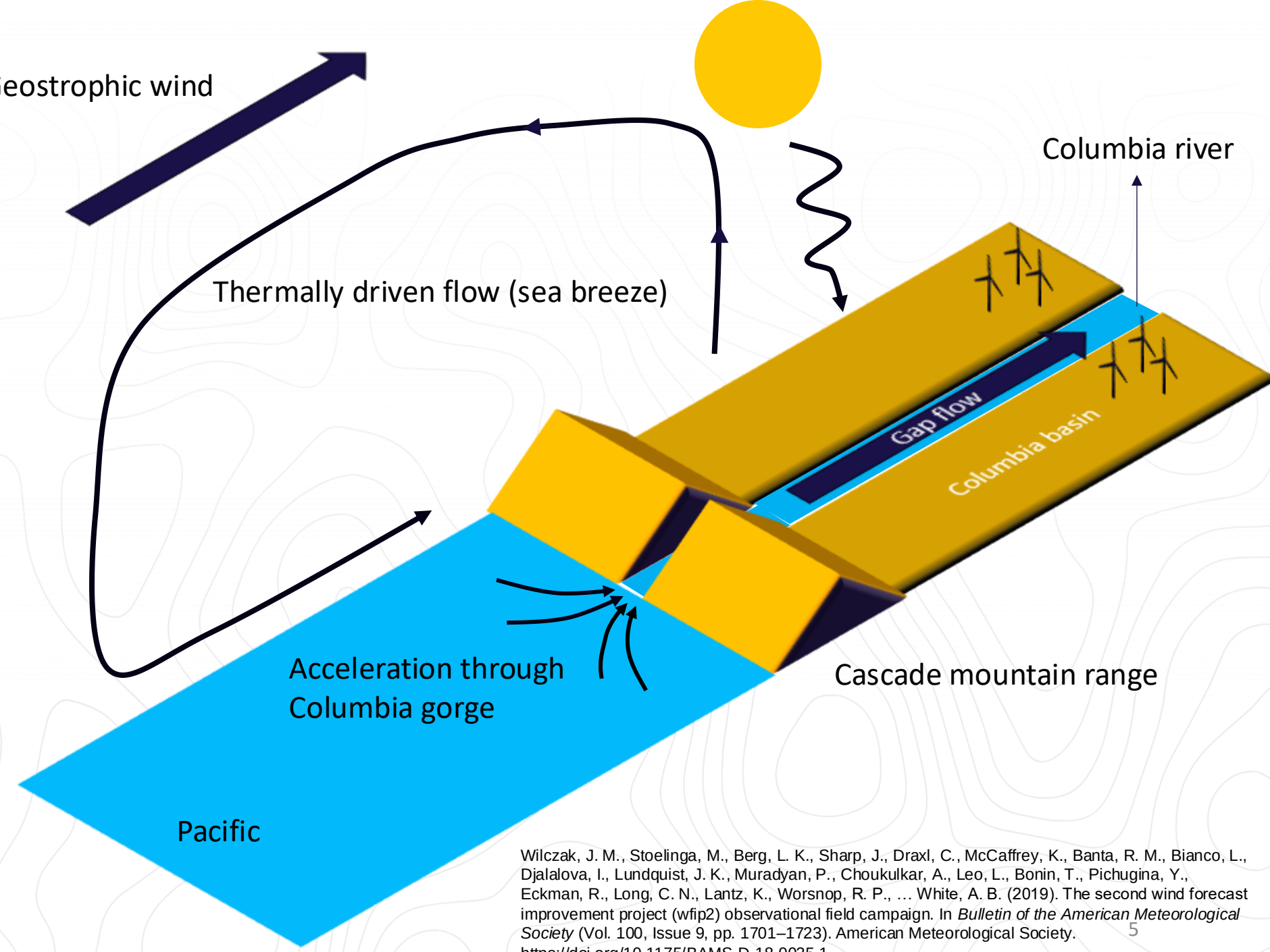
whiffle

whiffle

West Coast Gap Flow

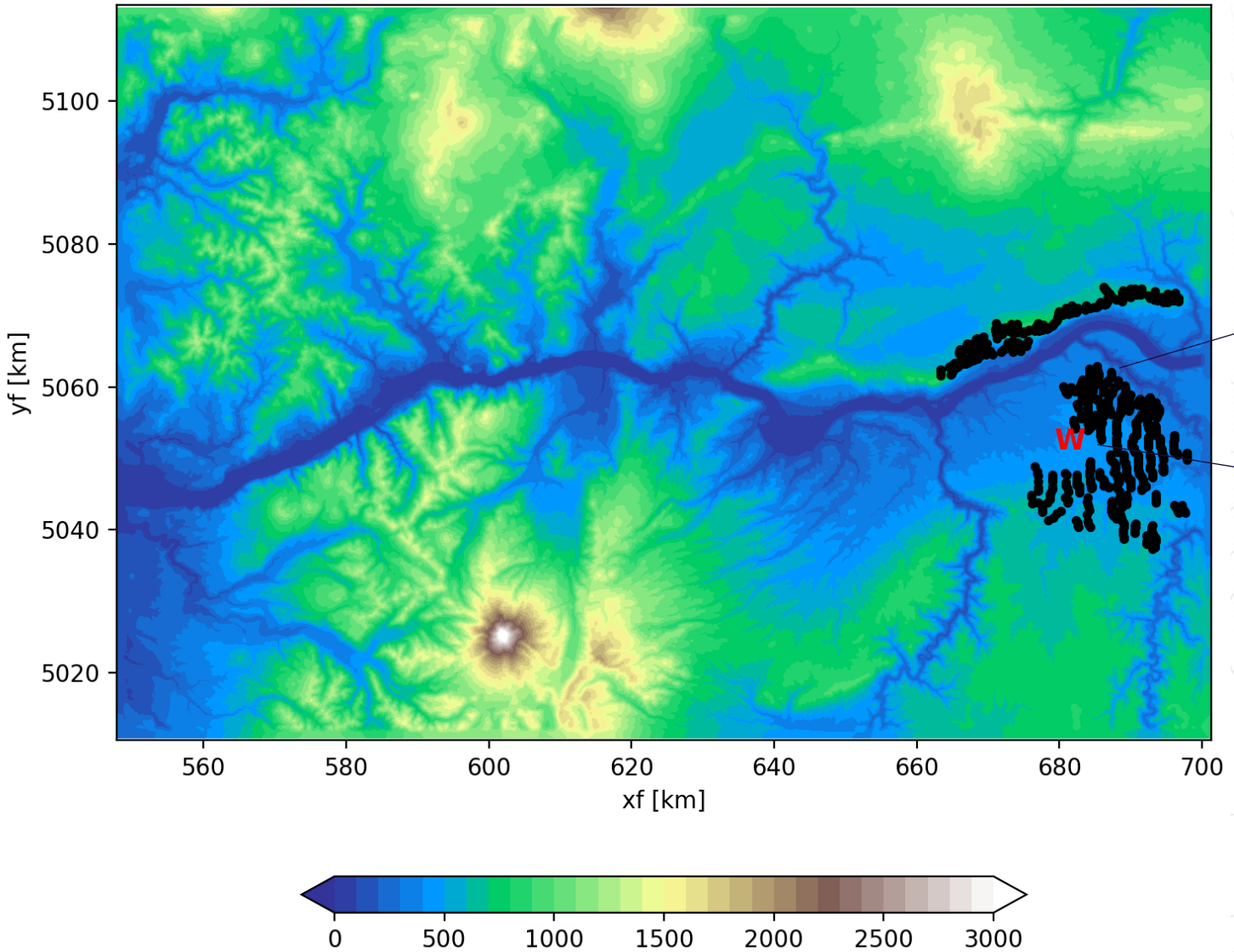
Physics

- Columbia Gorge
- Well-measured and studied site (Wilczak et al, 2019)
- Cold pools, mountains waves, mountain winds, …



Wilczak, J. M., Stoelinga, M., Berg, L. K., Sharp, J., Draxl, C., McCaffrey, K., Banta, R. M., Bianco, L., Djalalova, I., Lundquist, J. K., Muradyan, P., Choukulkar, A., Leo, L., Bonin, T., Pichugina, Y., Eckman, R., Long, C. N., Lantz, K., Worsnop, R. P., … White, A. B. (2019). The second wind forecast improvement project (wfip2) observational field campaign. In *Bulletin of the American Meteorological Society* (Vol. 100, Issue 9, pp. 1701–1723). American Meteorological Society. https://doi.org/10.1175/BAMS-D-18-0035.1

LES domain

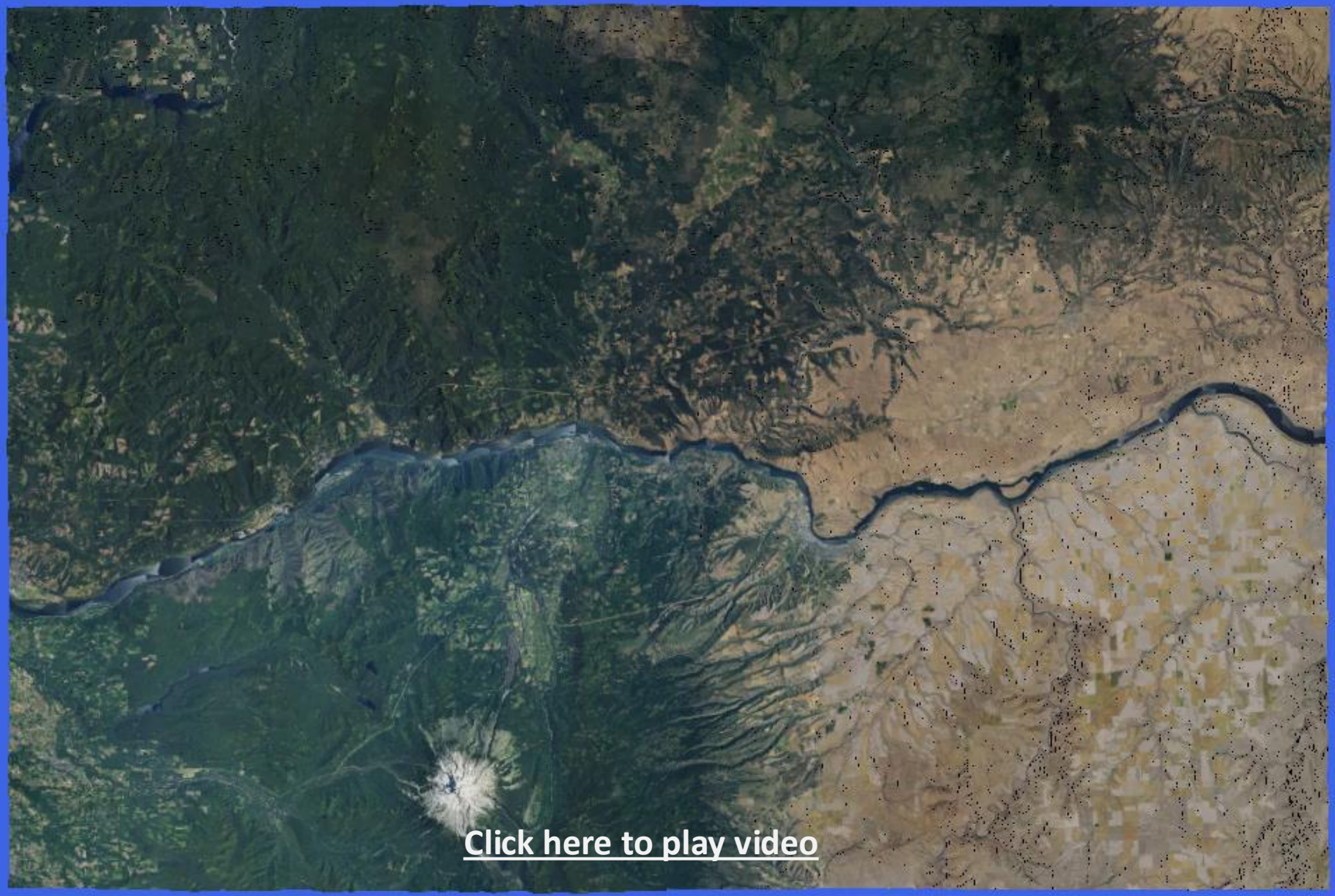


Black dots: All turbines included with actuator disk model

Red W: Location of the Wasco measurement station

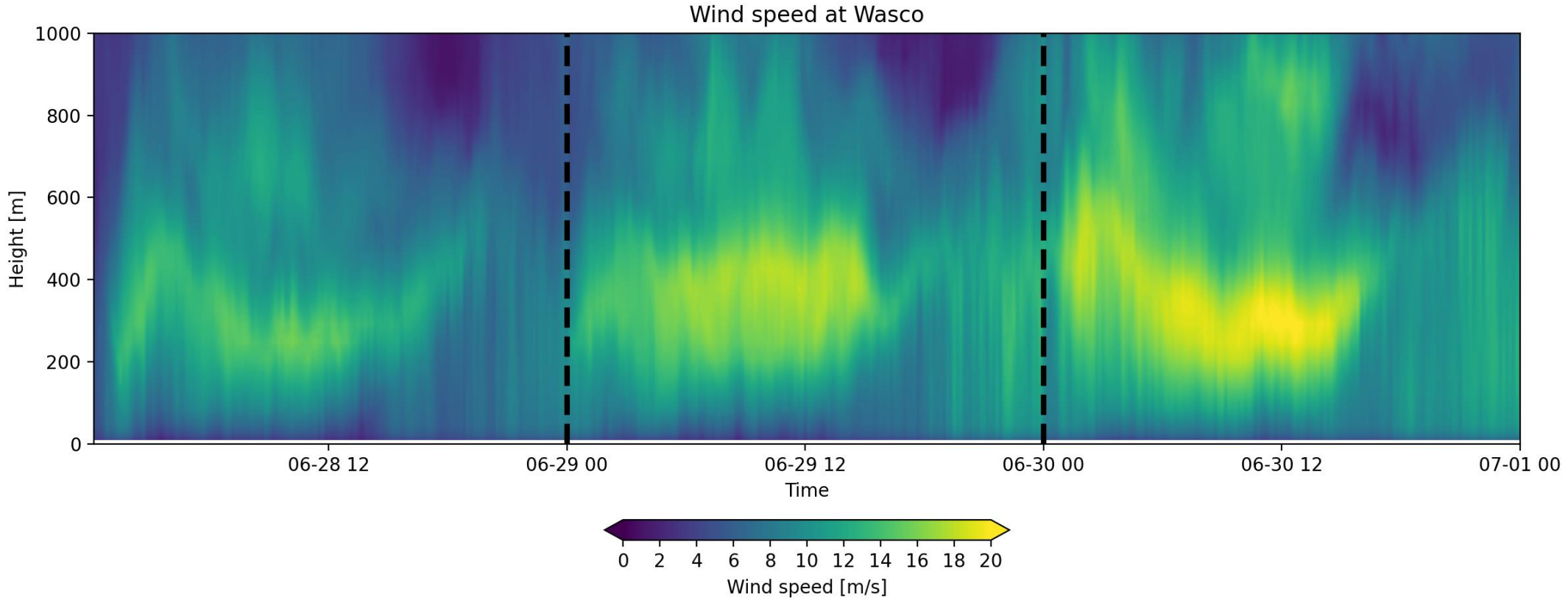
2016-06-28 16:30:00 PDT

whiffle
precision weather forecasting

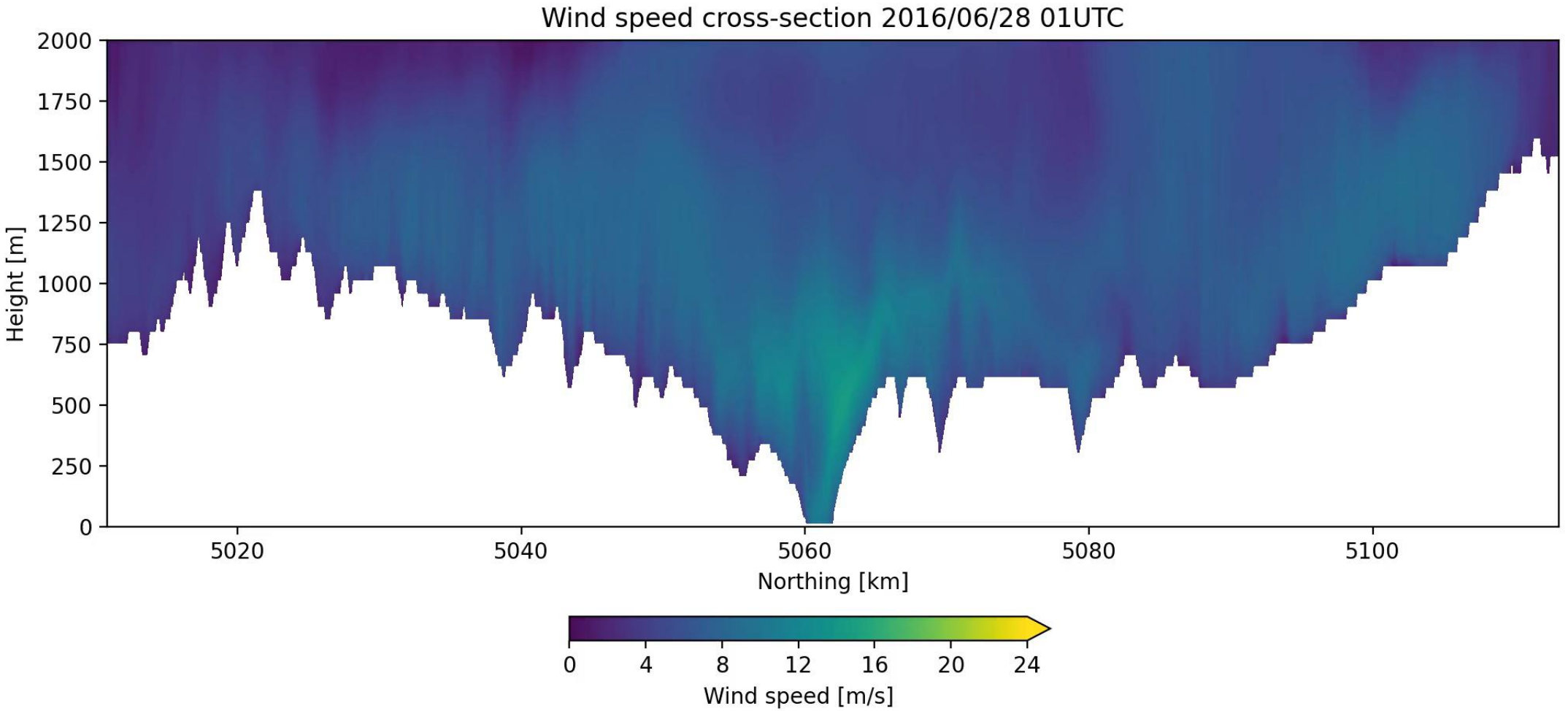


Click here to play video

Results highlight 1: gap flows with strong diurnal cycles

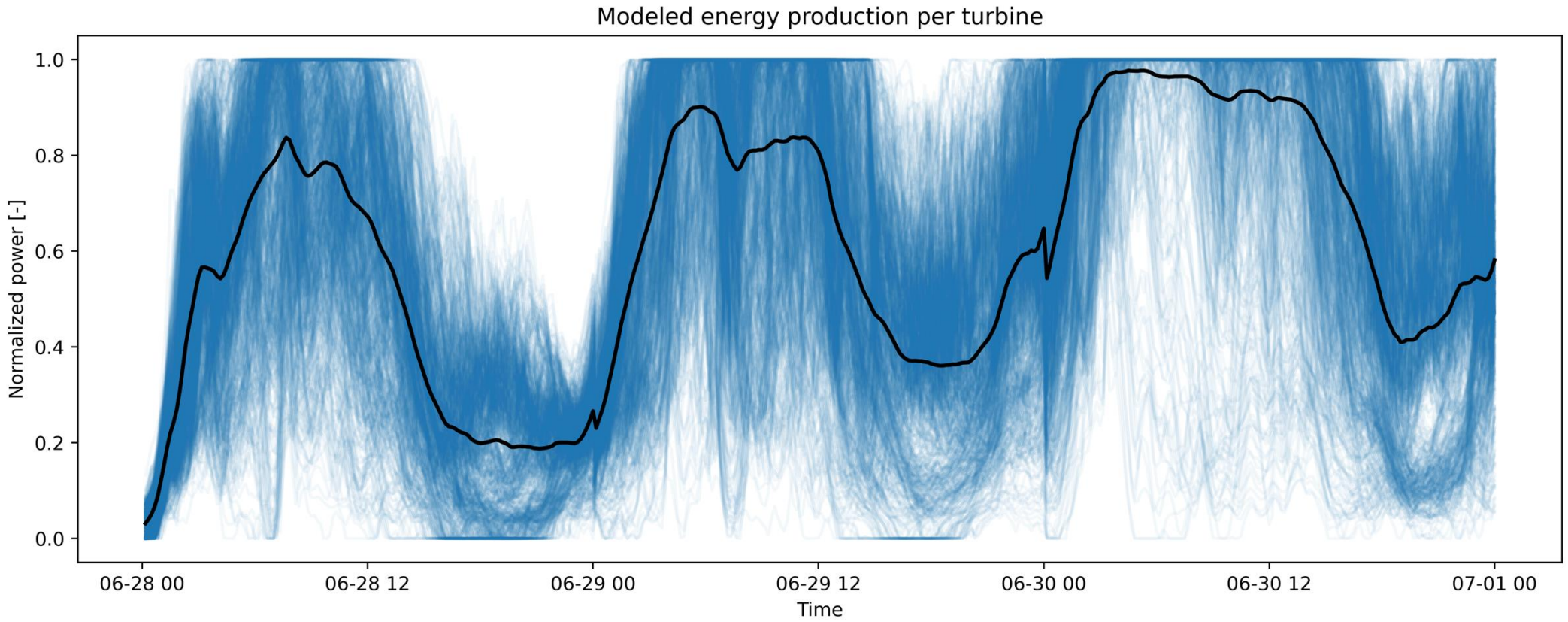


Results highlight 2: Strongly varying wind maximum



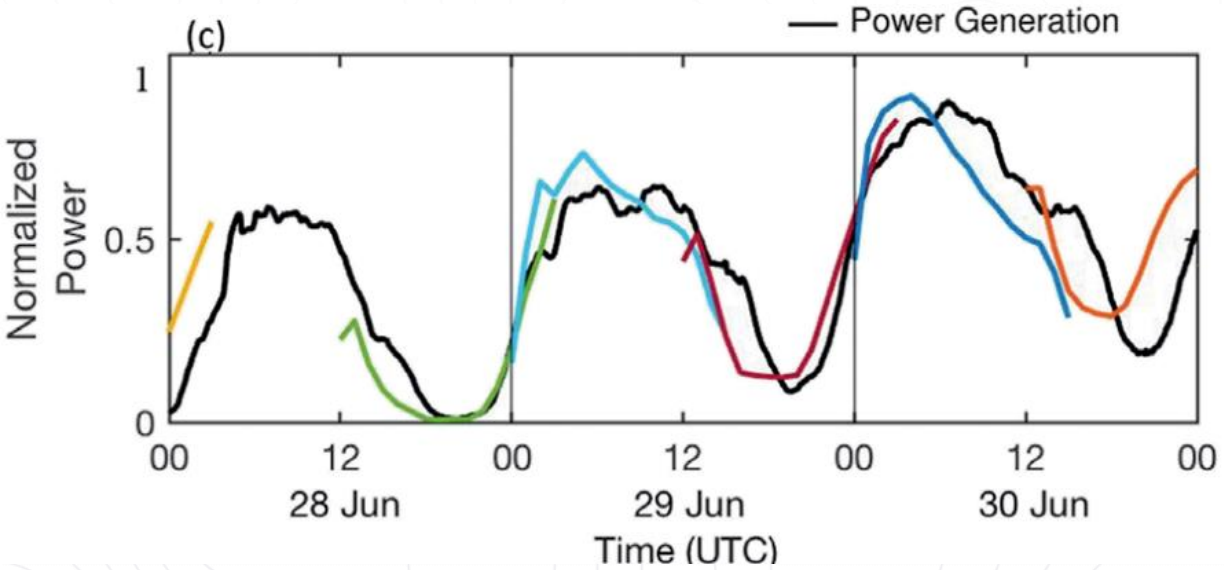
whiffle

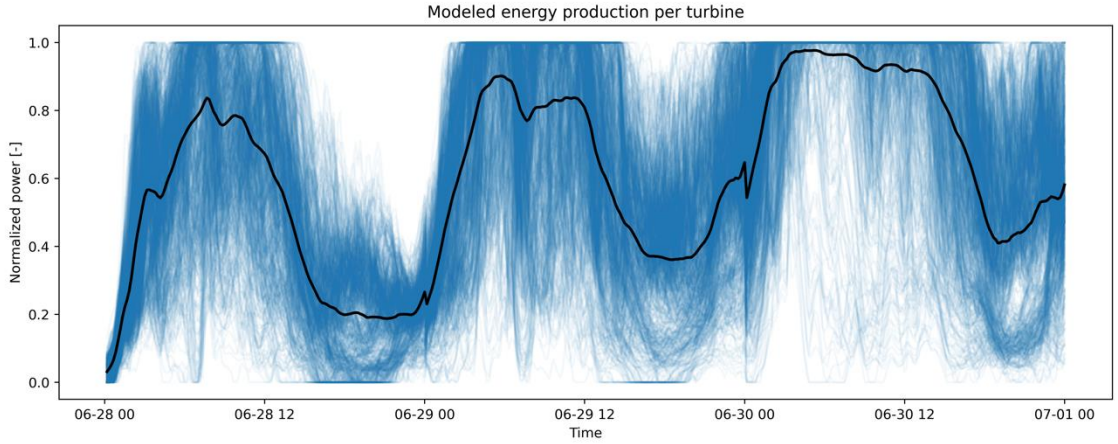
Results high-light 2: power time series

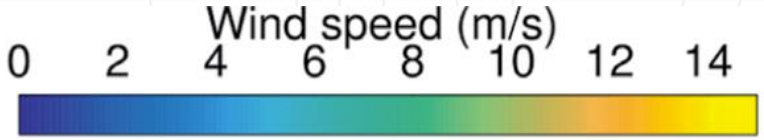


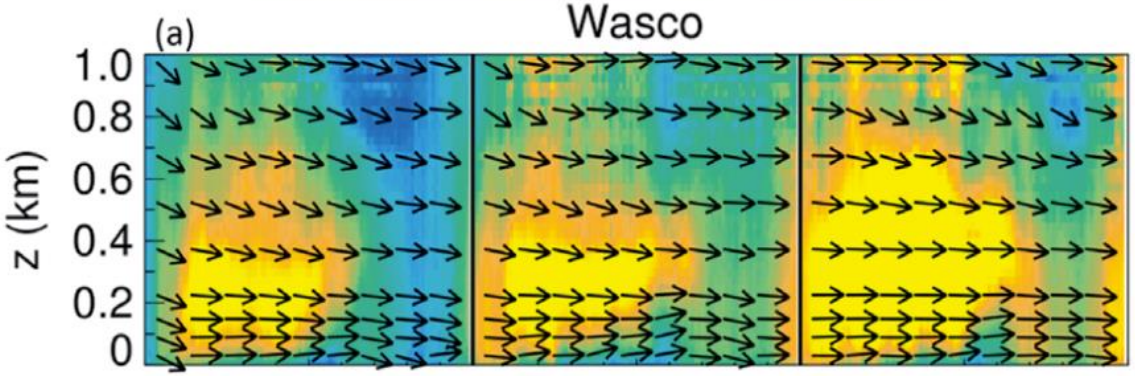
whiffle

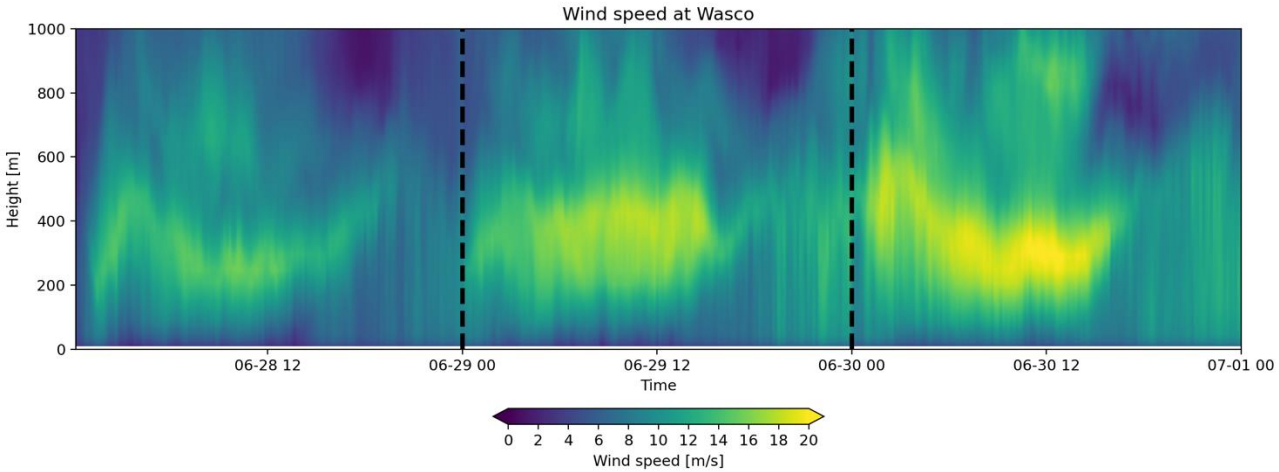
Comparison with observations











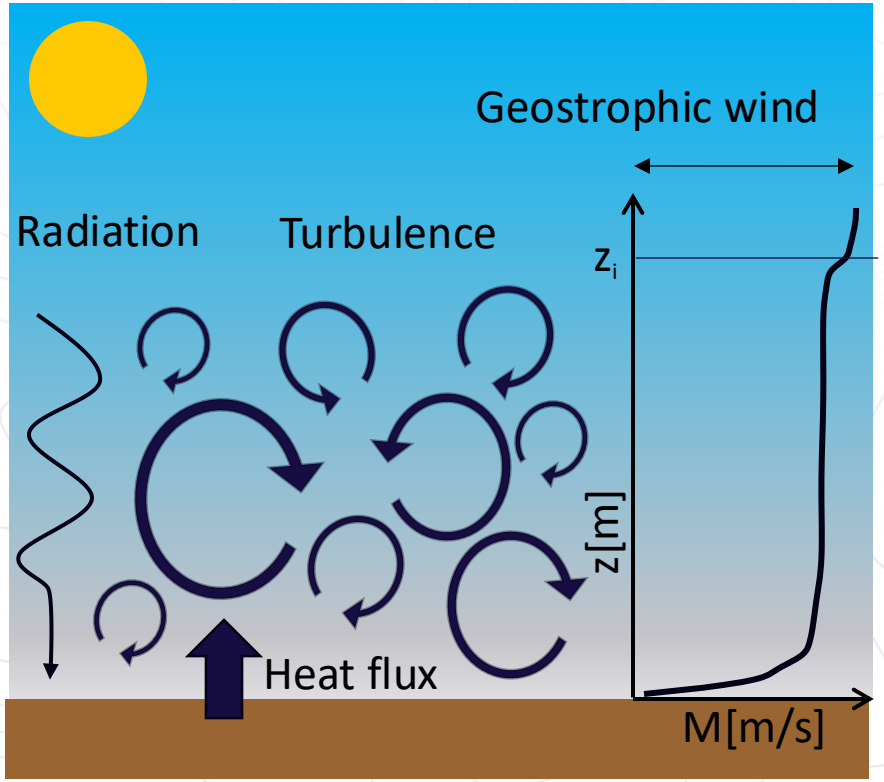
whiffle

whiffle

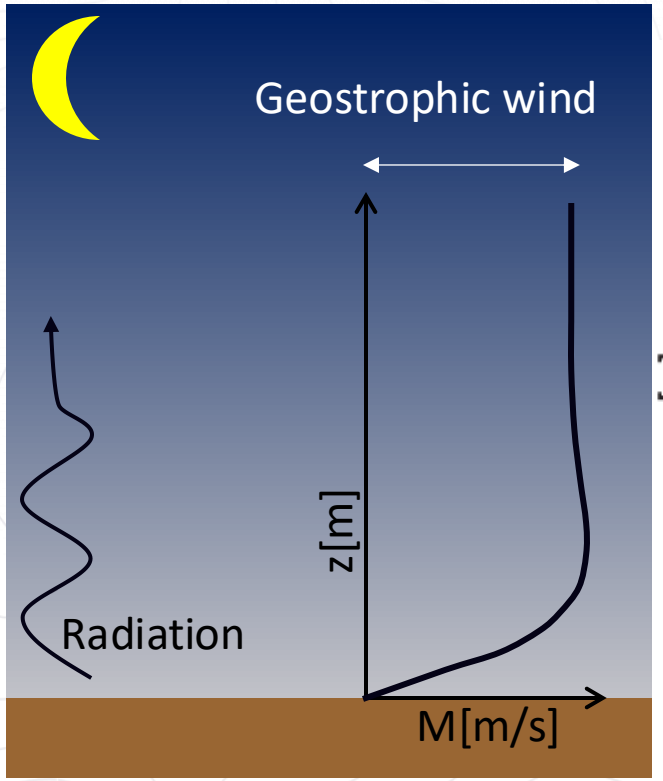
Low Level Jet

Physics

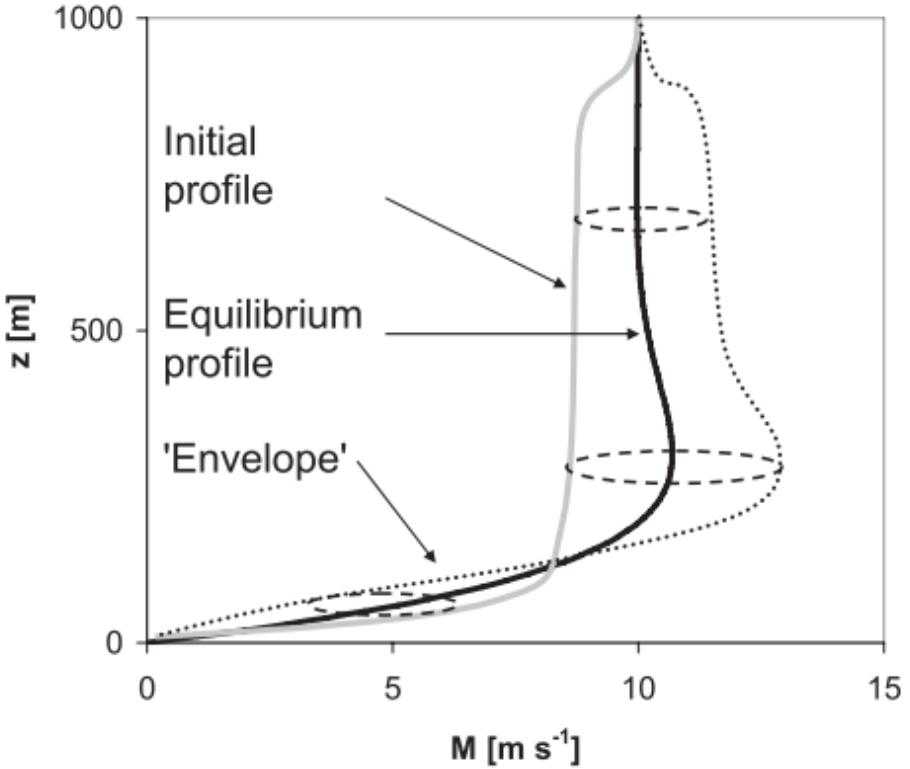
Turbulent transport of momentum



Turbulence decays and layer decouples. Wind accelerates



Inertial oscillation around equilibrium profile [2]



whiffle

[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

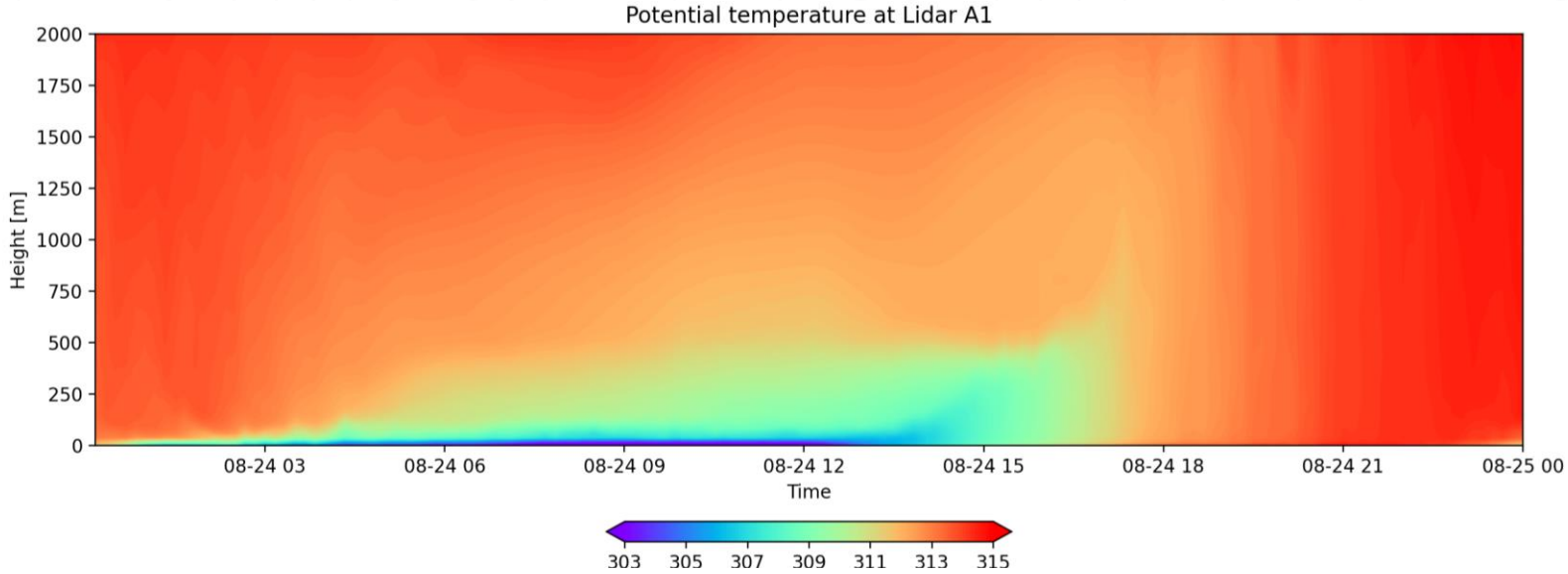
2023-08-23 19:00:04 CDT

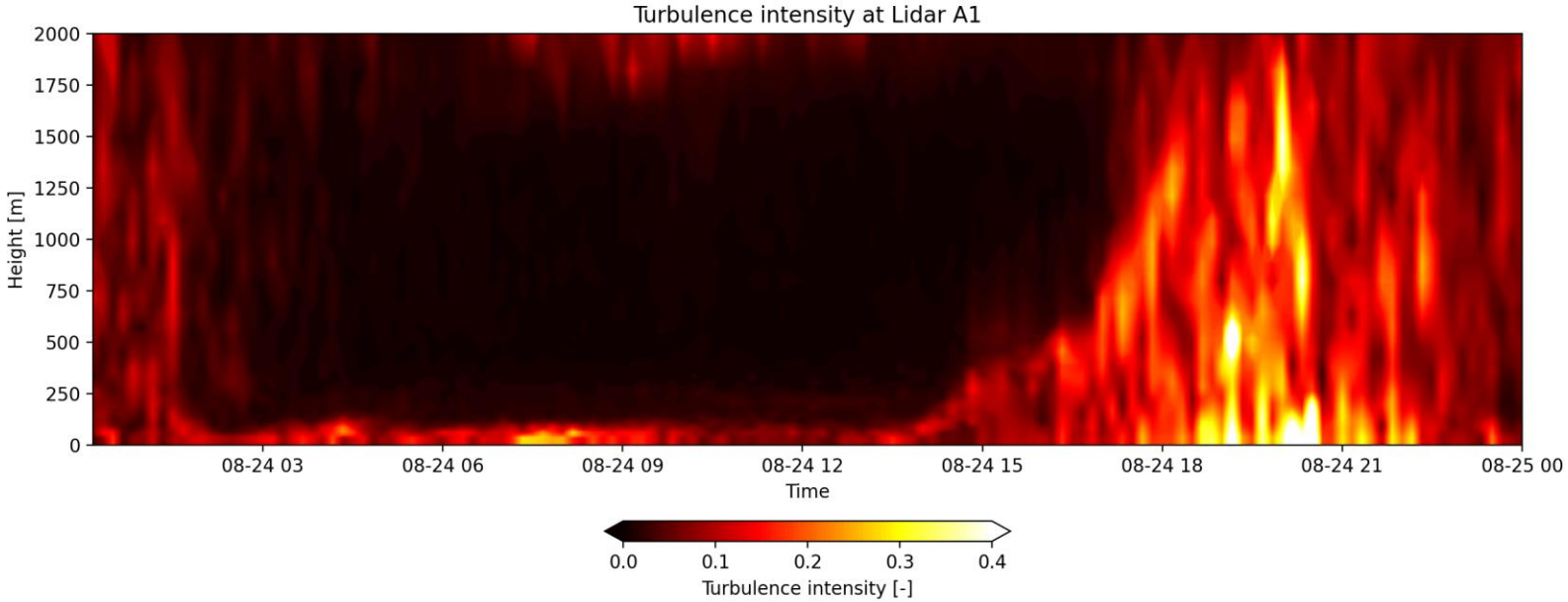
whiffle

precision weather forecasting

Click here to play video

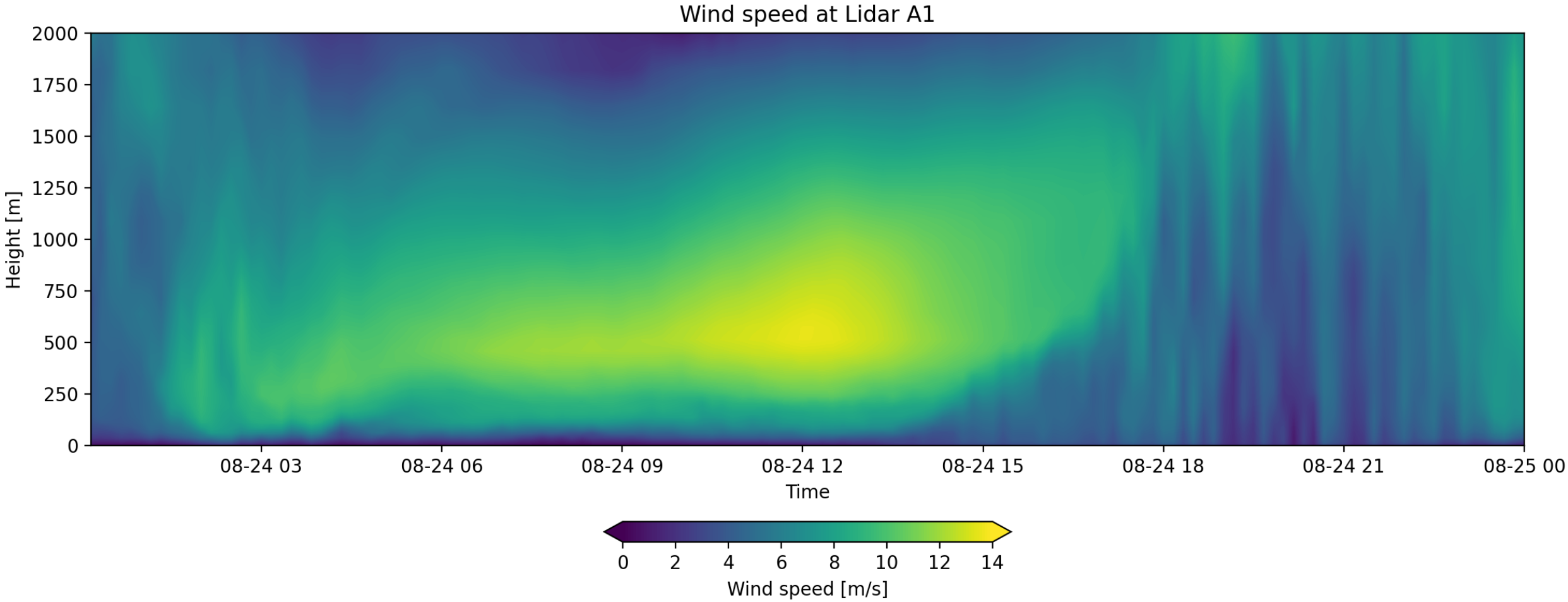
Results highlight 1: temperature and turbulence



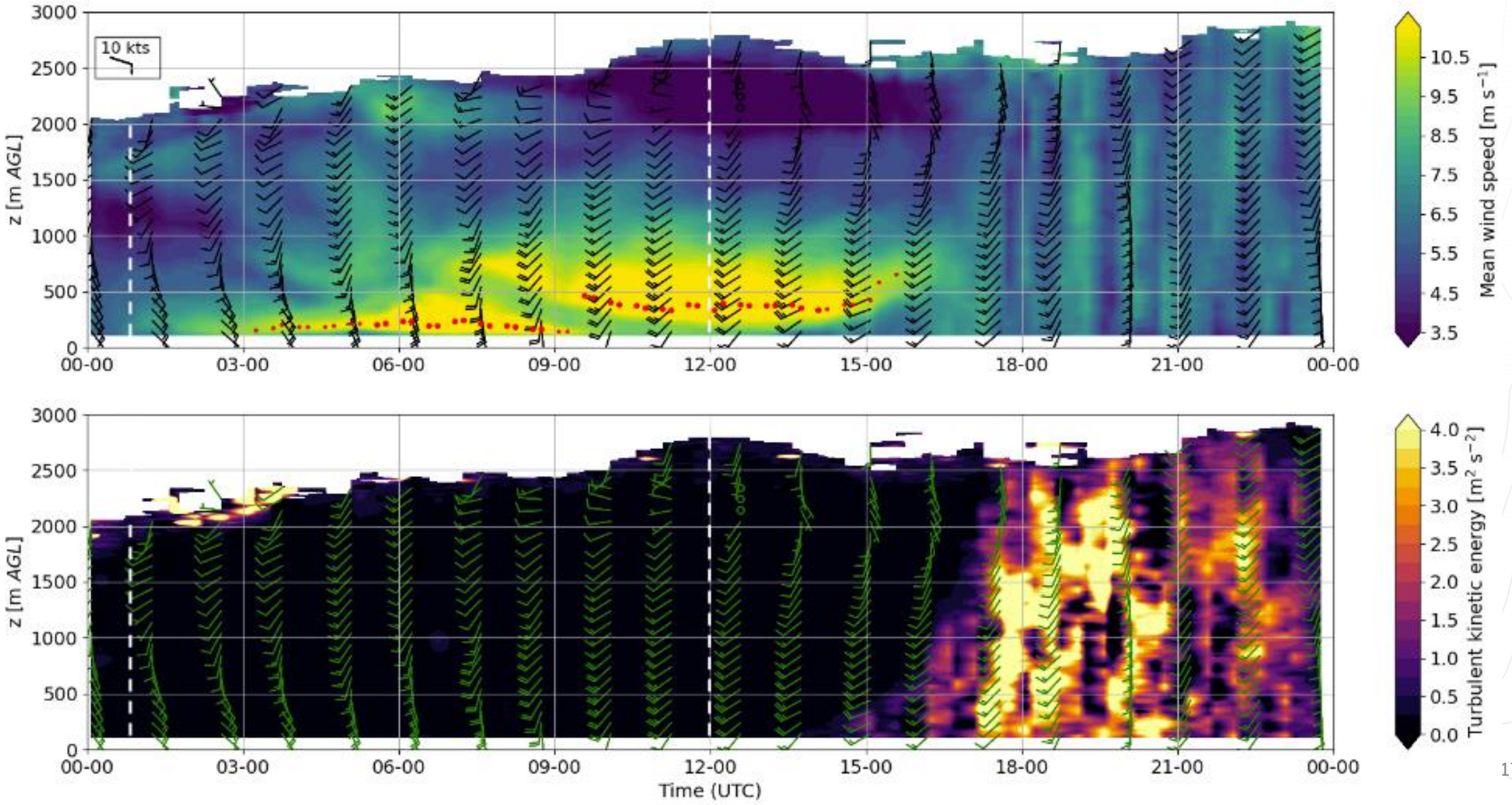


whif

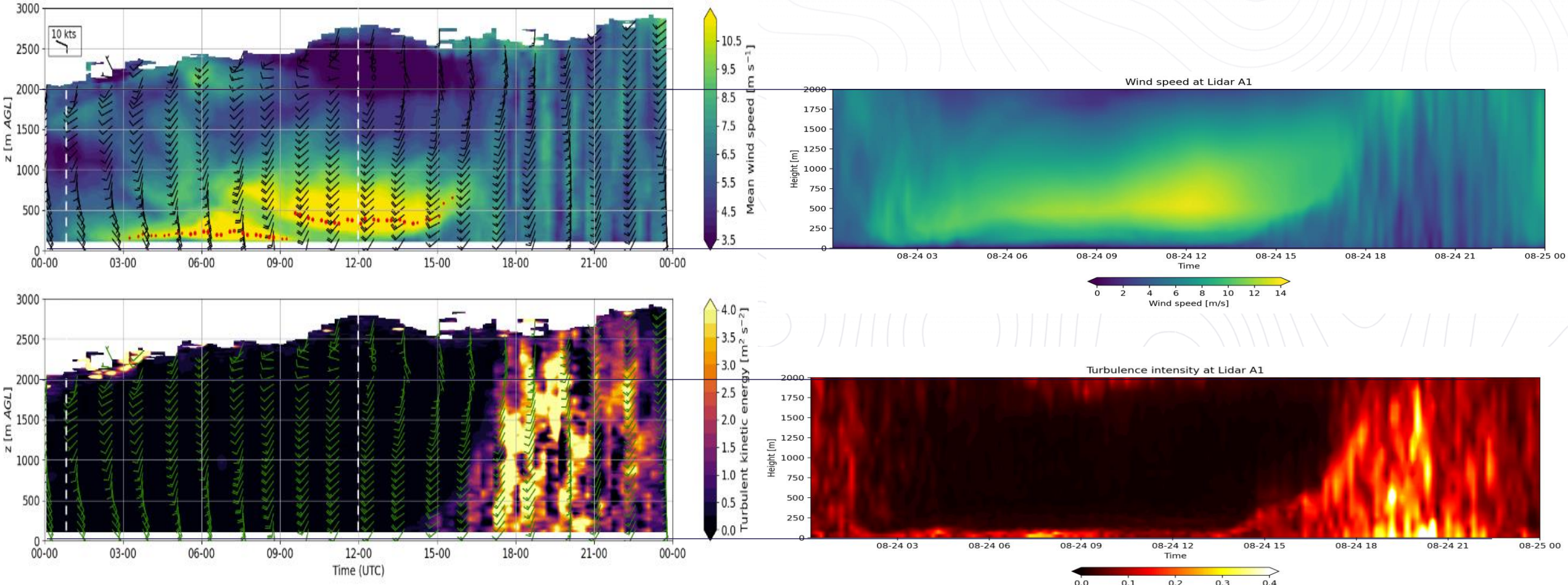
Results highlight 2: Wind speed



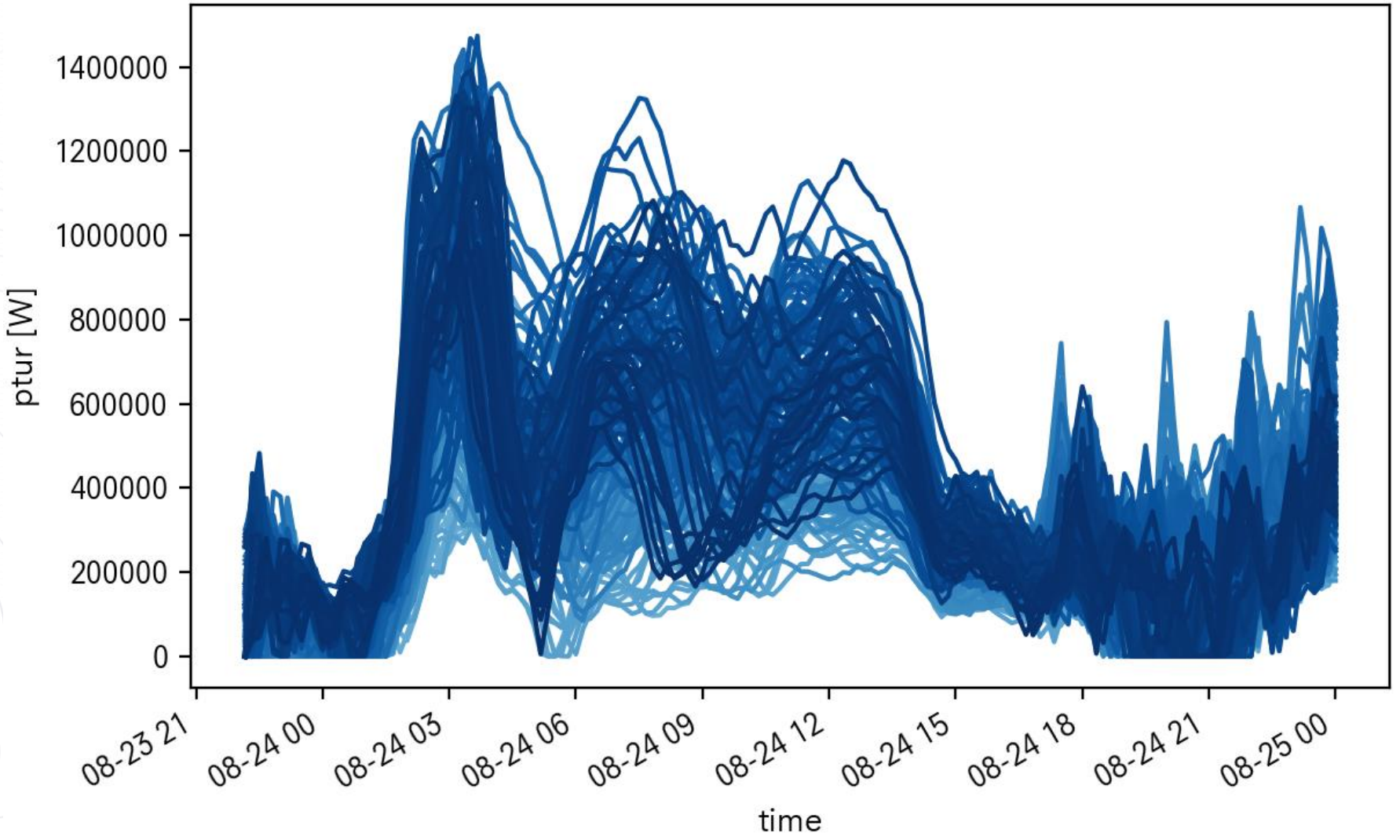
Observations from the AWAKEN campaign



Comparing the observations from the AWAKEN campaign with the model results



Results highlight 3: Power time series



whiffle

More AWAKEN data?

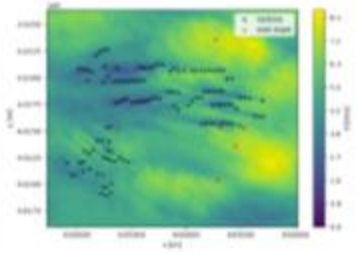
Exposing Atmospheric Flows in the AWAKEN Field Experiment with a Year-Long Open LES Dataset

Remco Verzijlbergh, Pim van Dorp, Peter Baas and Mikko Folkersma

Key features

1. Full year, 100m resolution, meso-scale coupled large eddy simulation (LES).
2. Actuator disk representation of turbines providing SCADA-like electrical power, wind speed and wind direction.
3. Terrain following wind fields at several heights for understanding flow patterns.

Wind flow field



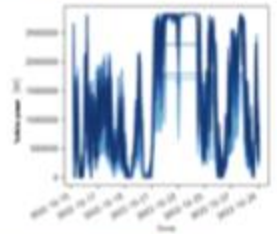
Large eddy simulation to complement measurements: Get insight into complex atmospheric flows.

Download the full dataset here:

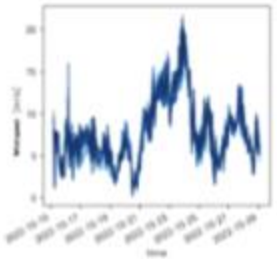
RESOURCE &TECH

AMERICAN CLEAN POWER

Virtual SCADA data



Virtual LiDAR data



References
https://www.nrel.gov/wind/awaken.html

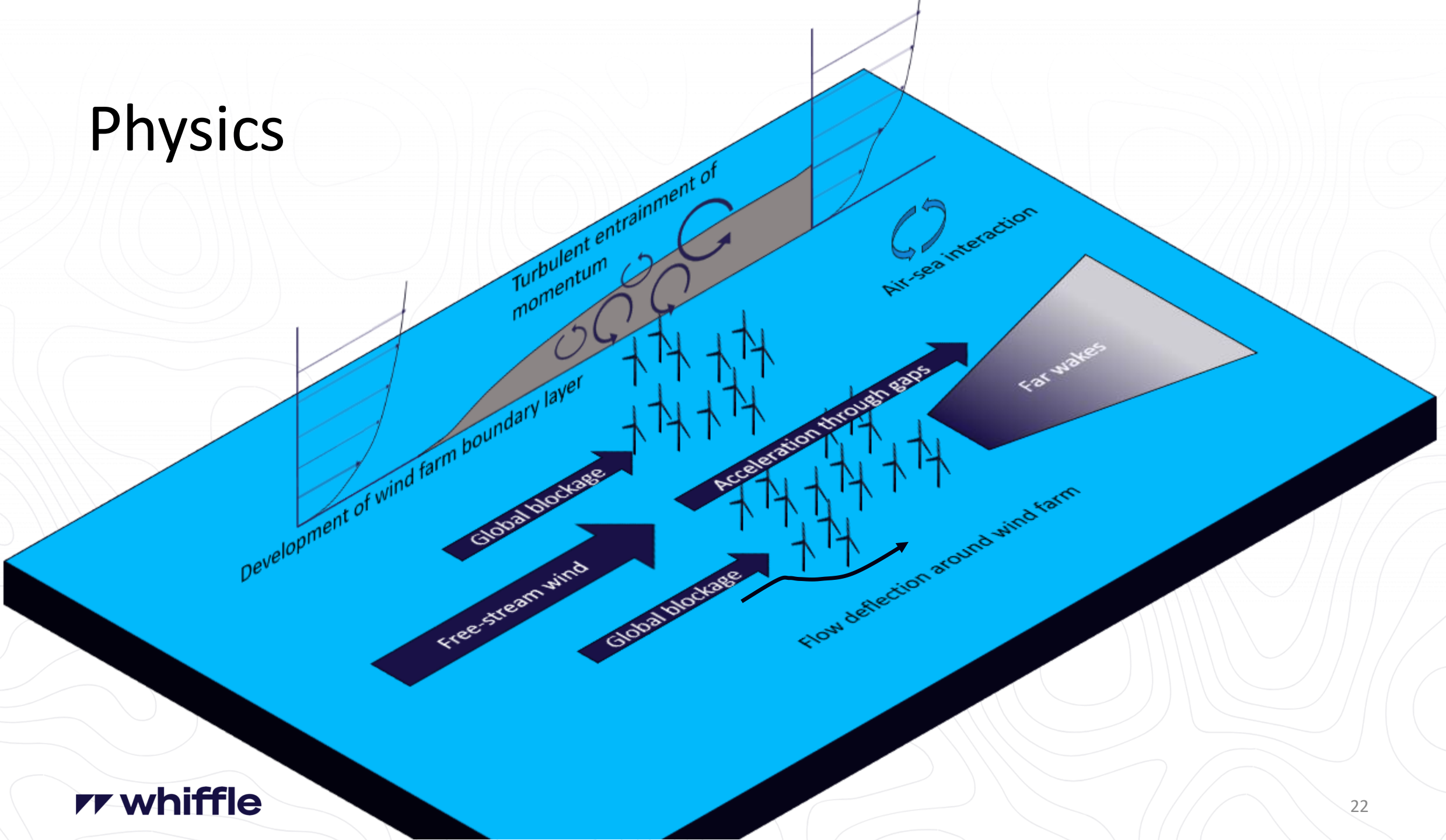
Contact Info
remco.verzijlbergh@whiffle.nl

whiffle

whiffle

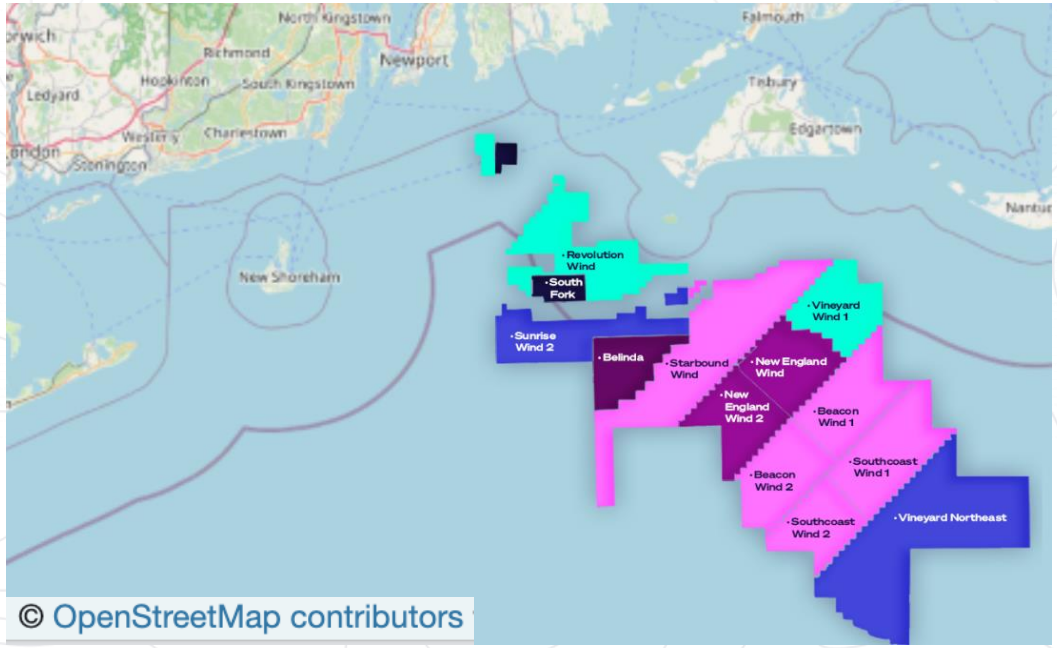
Offshore megacluster

Physics



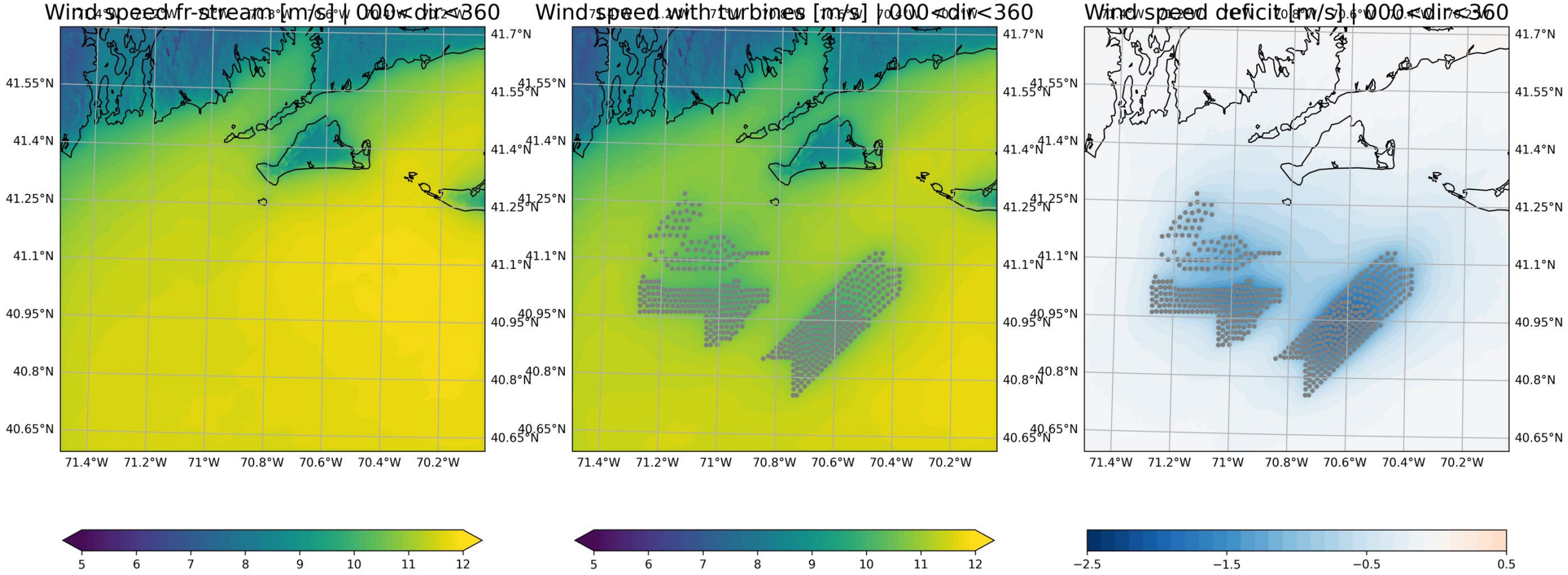
whiffle

Animation

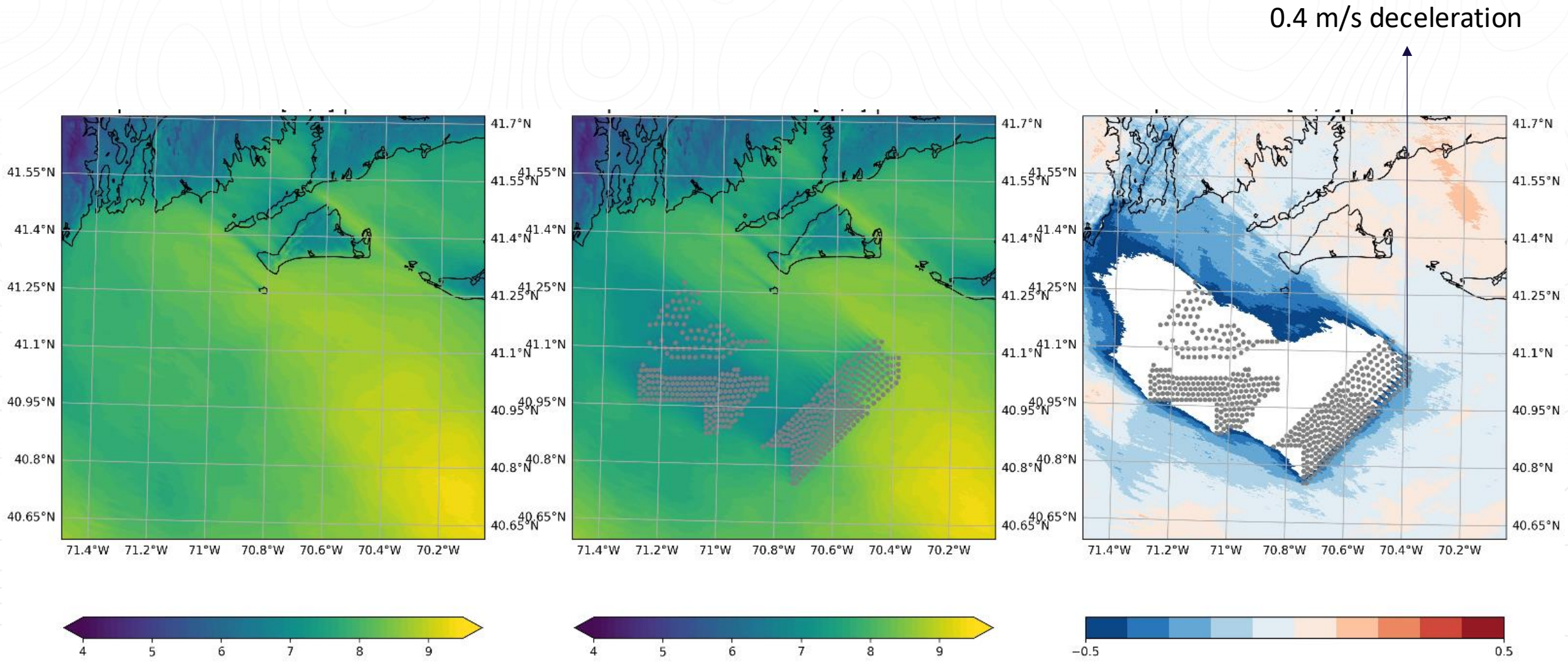


whiffle

Results highlight 1: velocity deficits for different wind directions

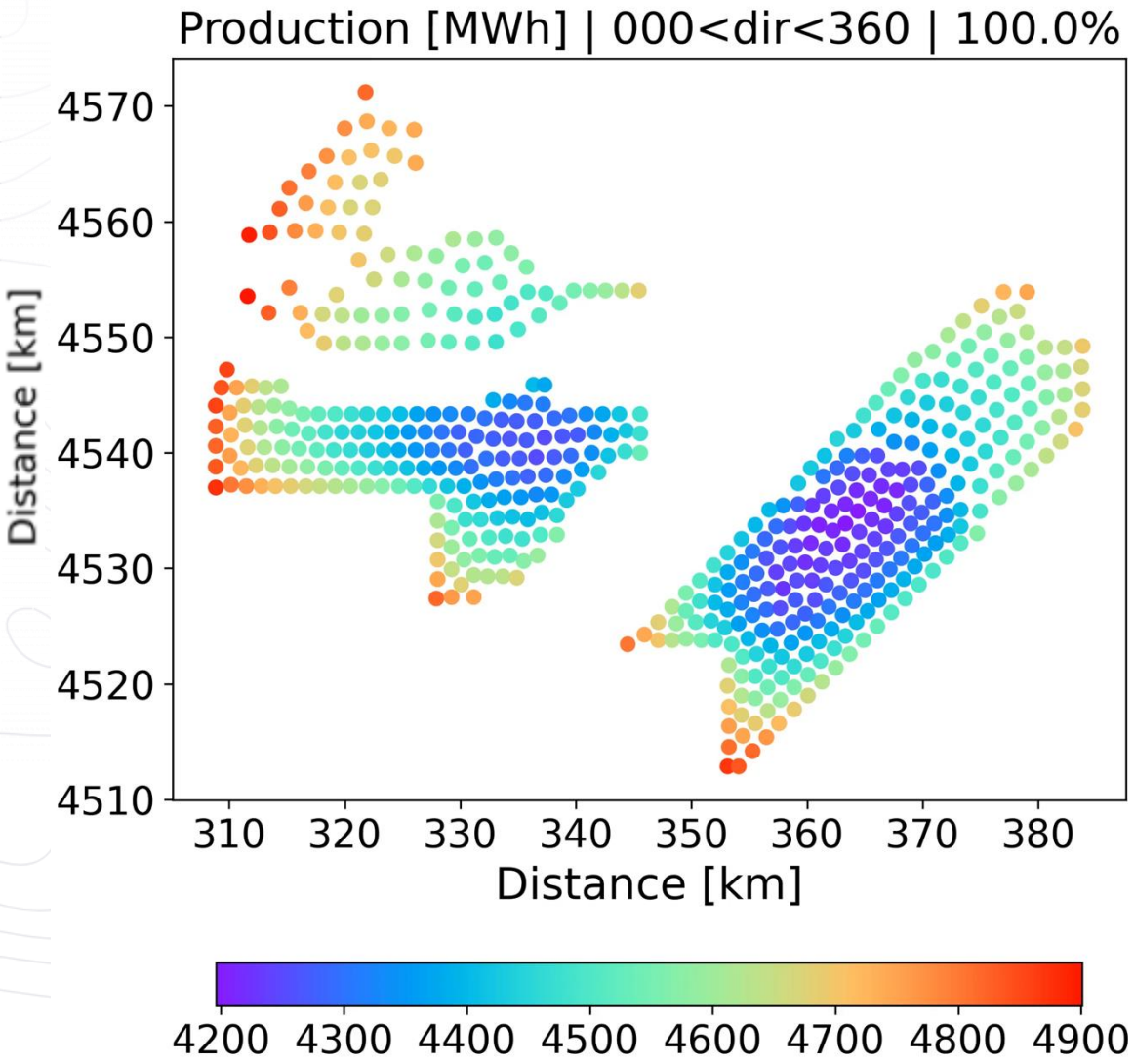


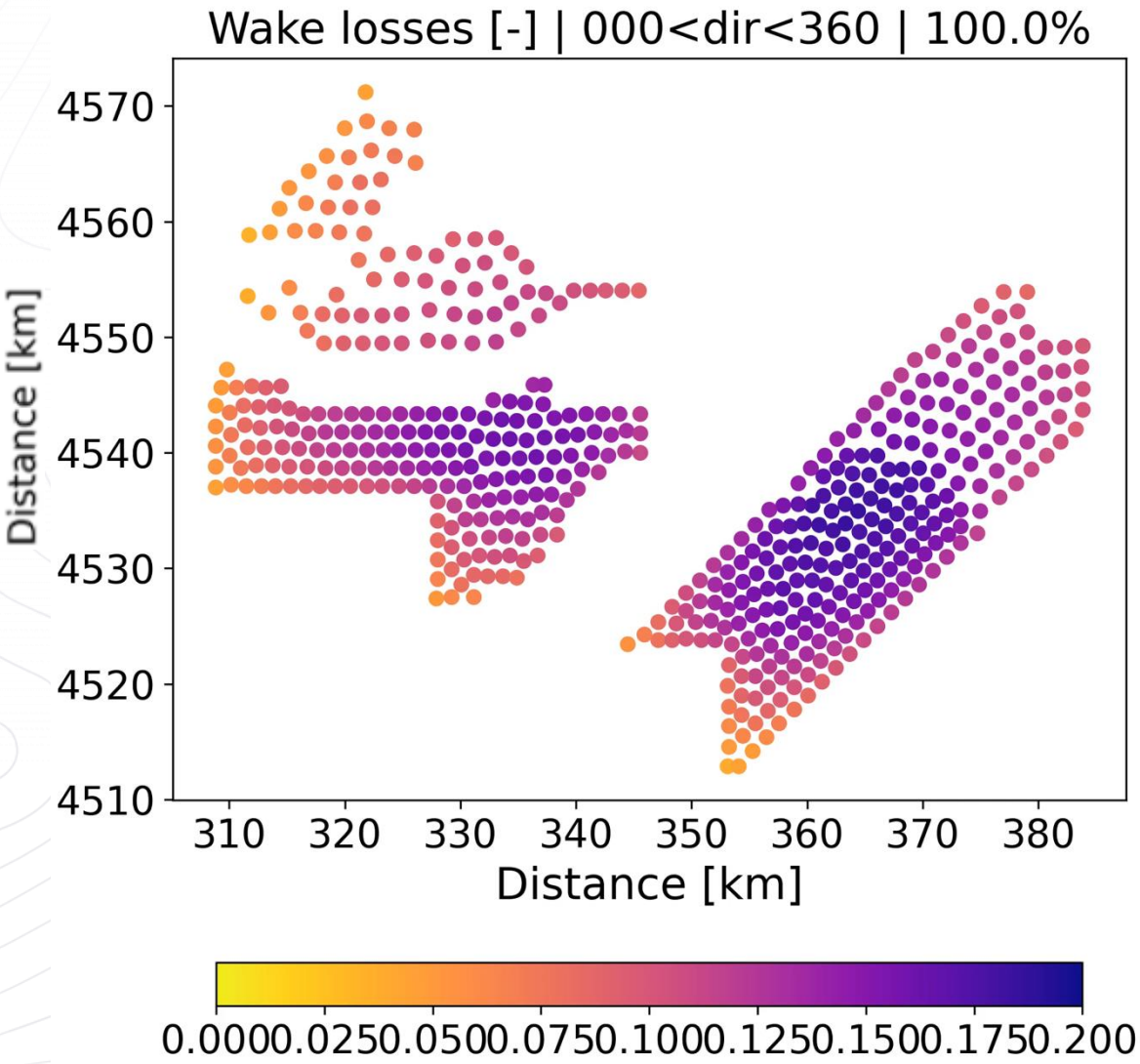
Results highlight 2: zoom in on global blockage



whiffle

Production losses per sector



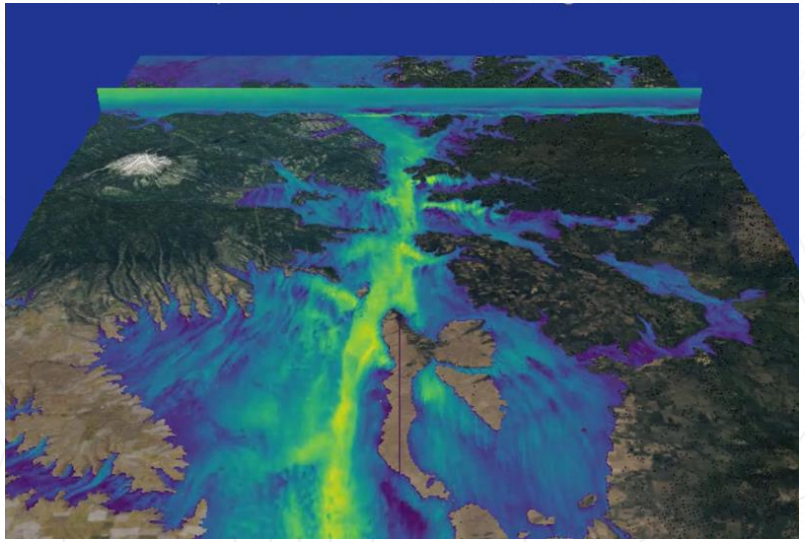


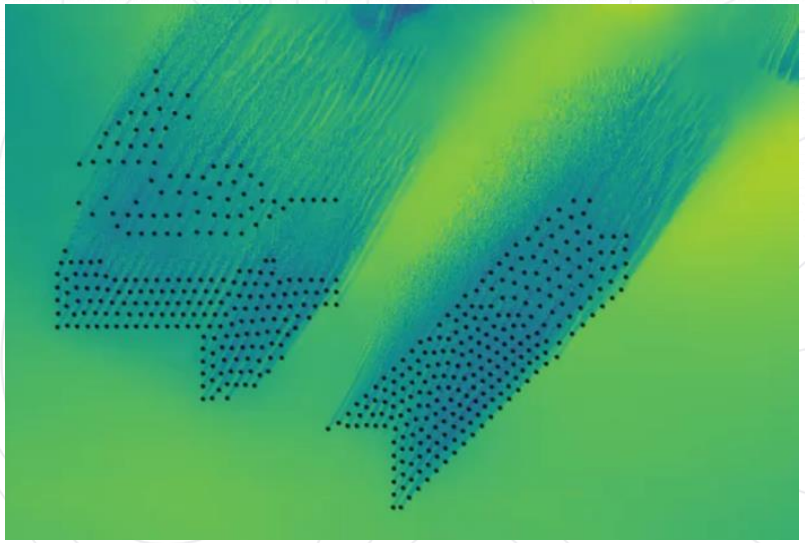
whiffle

Conclusions

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!



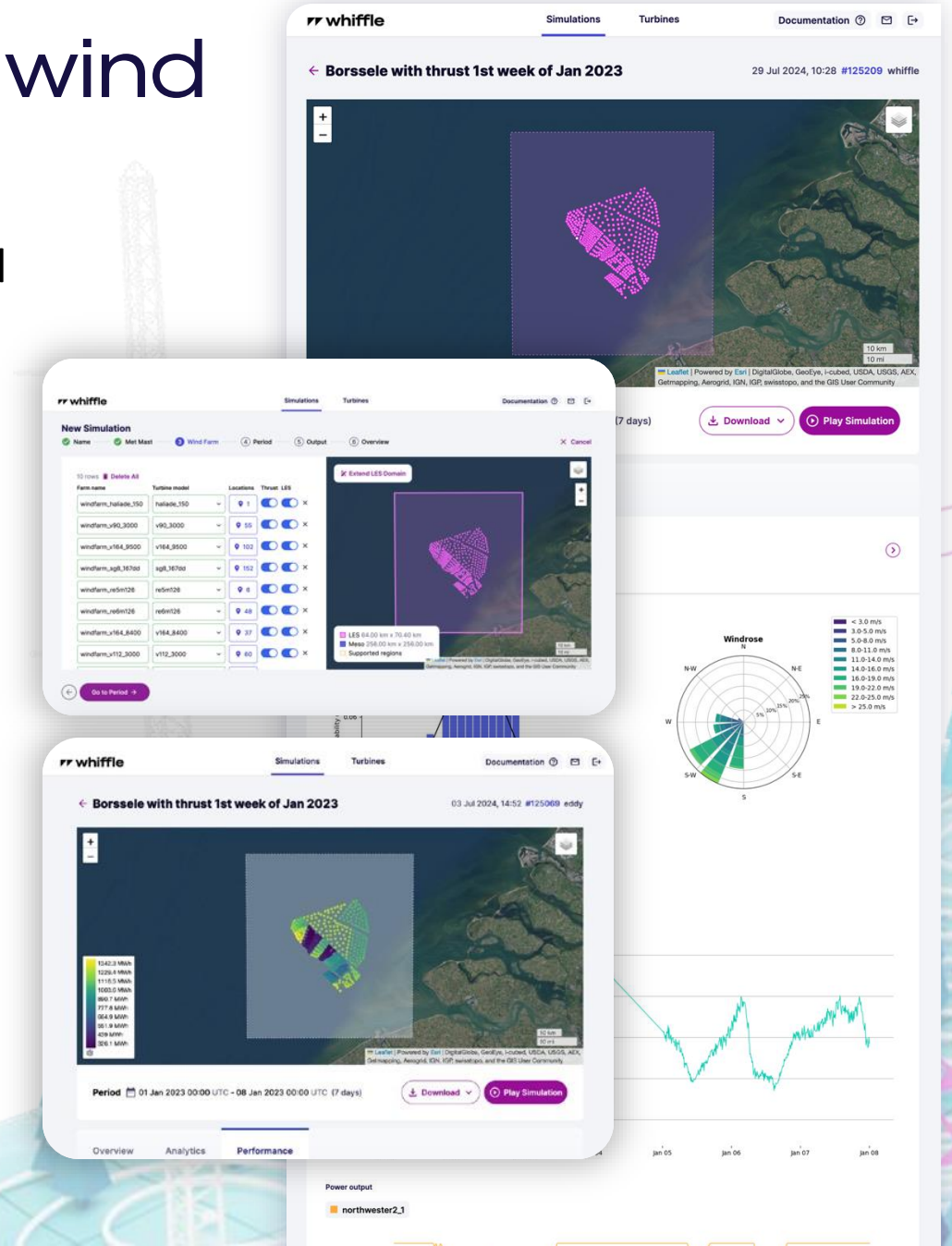


whiffle

Our solution: whiffle | wind

Whiffle Wind is a user-friendly web application that offers easy access to Whiffle's ultra-high-resolution, LES-powered weather model

- Advanced flow and wake modelling
- Simulate entire sites up to 100 x 100 km
- Timeseries for weather and production
- Customizable historical time-periods
- Turbine, met masts and gridded output
- User-friendly output (.csv, .netcdf & .wrg)
- Post-processing and visualization tools
- World-wide coverage
- API access possible



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

whiffle

Simulated cloud field over the Netherlands

Thank you

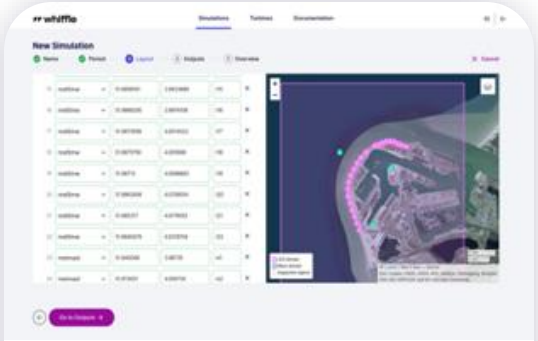
For more information visit www.whiffle.nl

whiffle

Extra material

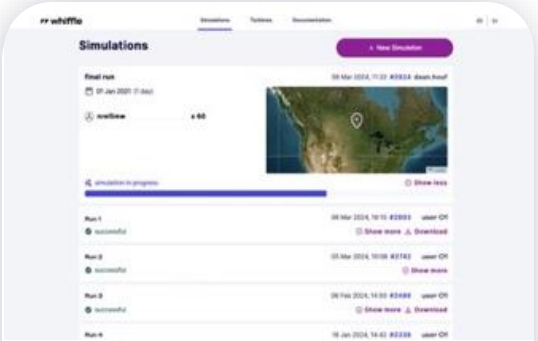
Here you will find additional information (not presented at the Whiffle Tech Talks).

How it works: conduct LES simulations for your wind farm or site with just a few clicks.



Step 1: Provide

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

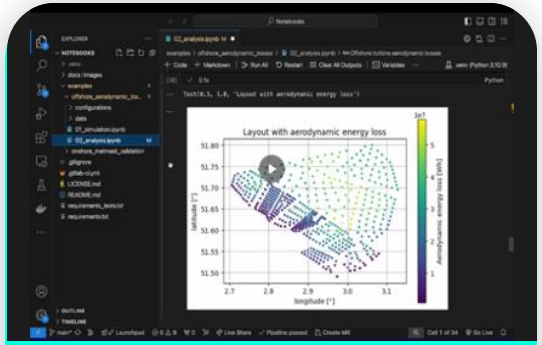


Step 2: Submit

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.

How we work with clients

Free Trial

- Trial account pre-loaded with free credits for running simulations.
- Full use of the Whiffle Wind web app and API.

Professional Plan

- Pay-as-you-use
- Full access to the Whiffle Wind web app and API.
- Dedicated customer service.

Enterprise Plan

- Choose from different credit bundles with discounts
- Full access to the web app and API.
- Dedicated customer service

*Most preferred plan