WEATHER FORECASTING

RENEWABLE ENERGY FORECASTING WITH GPU BASED LARGE EDDY SIMULATION

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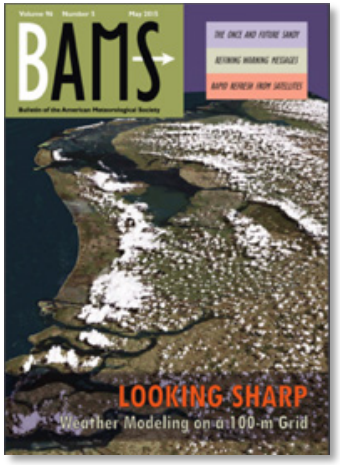
WITH CONTRIBUTIONS FROM
THE WHIFFLE TEAM

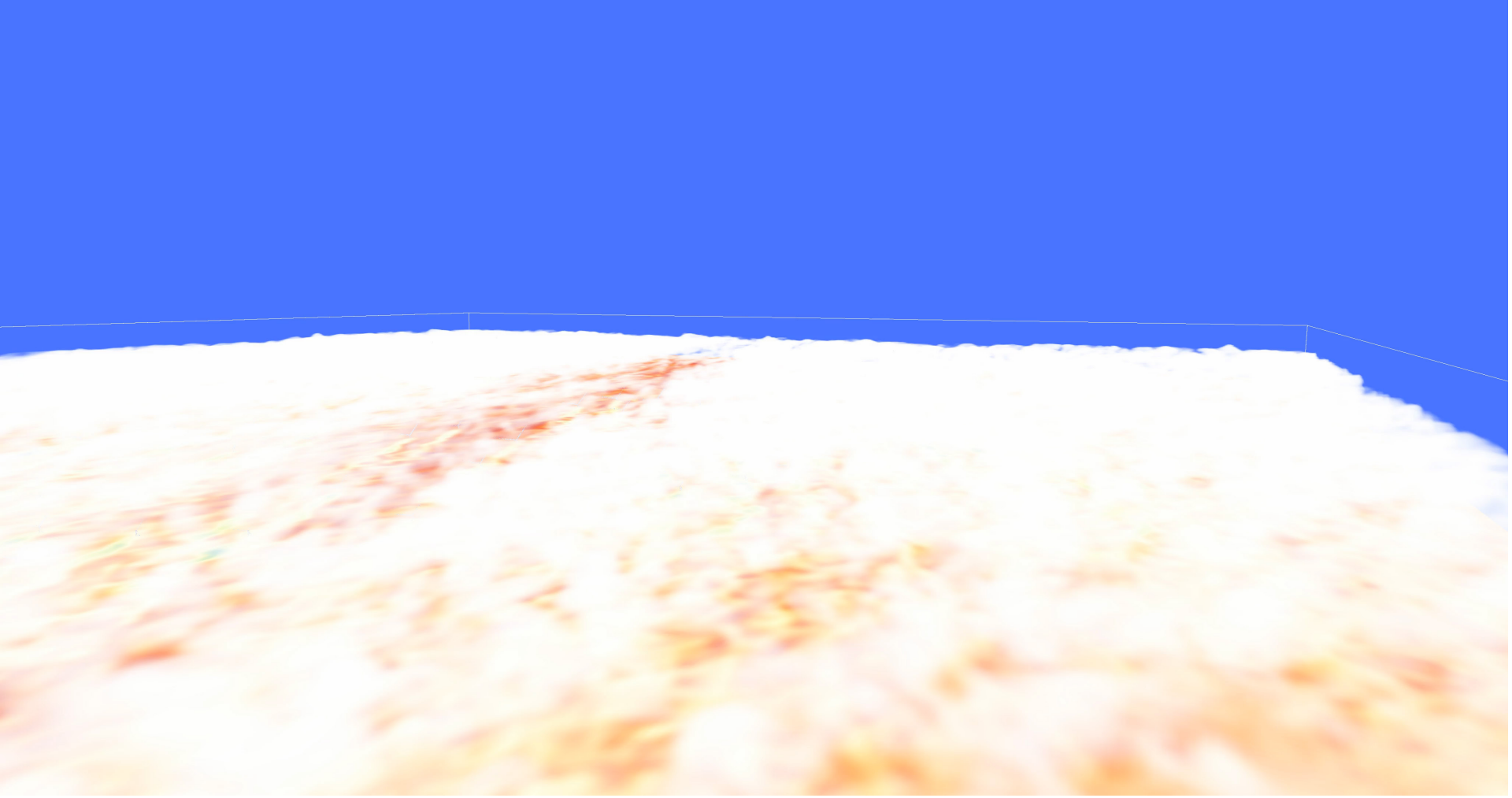
Whiffle Weather Forecasting

- TU Delft spin-off founded in 2015.
- Currently 25 FTE, of which 14 FTE R&D.
- Started with focus on wind energy forecasting
- Scale-up since 2022



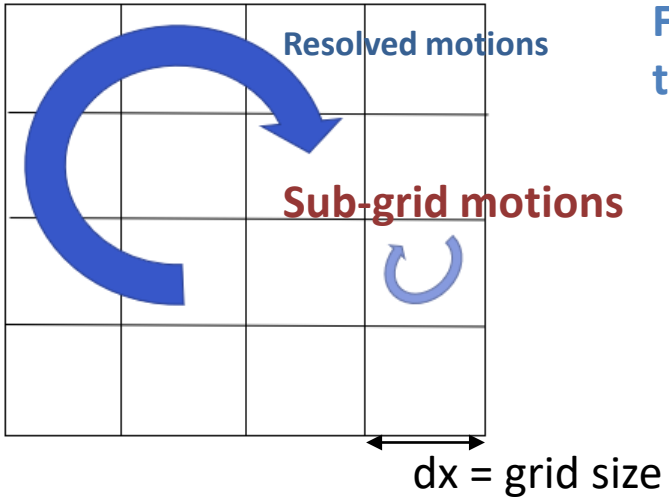
Outline

- LES vs. NWP
- Offshore and onshore wind farm forecasting
- Solar forecasting
- Statistical post-processing
- Future opportunities and challenges



The energy spectrum of turbulent flow in Large Eddy Simulation (LES)

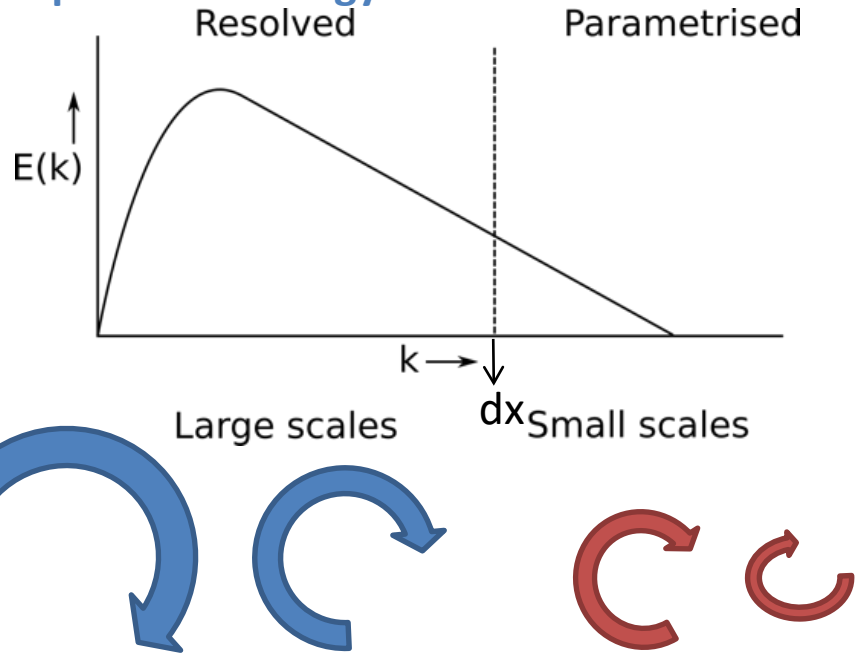
Large Eddy Simulation



Model grid in *physical space* showing schematically the turbulent motions *(eddies)*

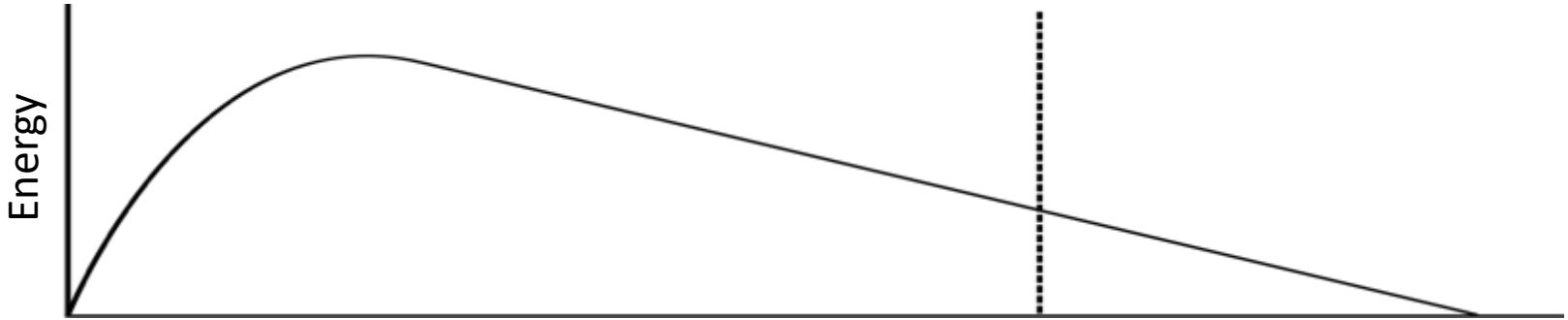
Fourier transform

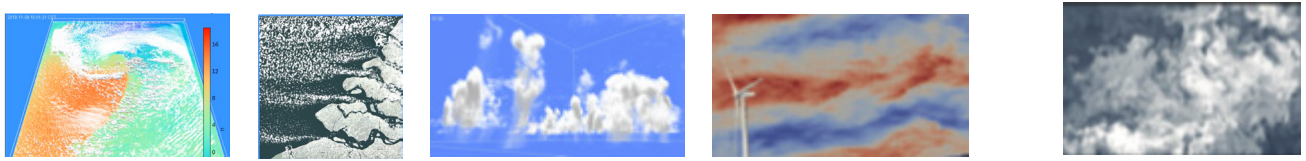
A turbulent spectrum: energy as function of wavenumber



In *spectral space* the energy of different eddies peaks around a certain size

The energy spectrum of turbulent flow in Large Eddy Simulation (LES)





Flow dependent

Flow independent

LES resolves all relevant physical processes and only parametrizes homogeneous turbulence

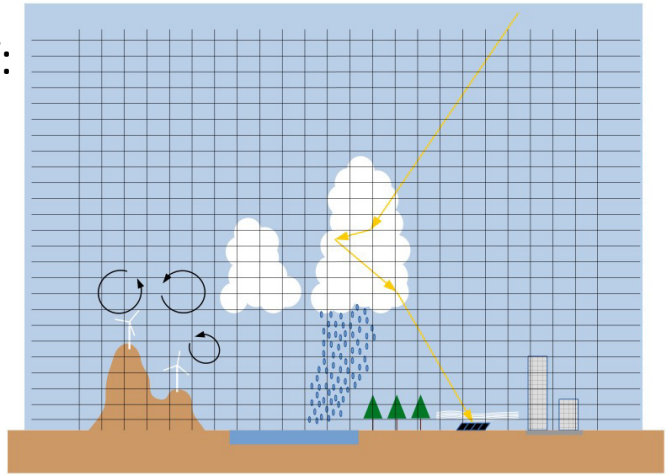
Physics parameterizations in NWP and LES

***Parametrization:* expressing the sub-grid processes in terms of resolved quantities**

The LES grid is fine enough to resolve turbulence, clouds and the surface. *"Assume less, compute more"*

Explicit modelling of:

- Wind turbines
- Canopies
- Buildings
- Turbulence
- Clouds / fog
- Surface energy balance

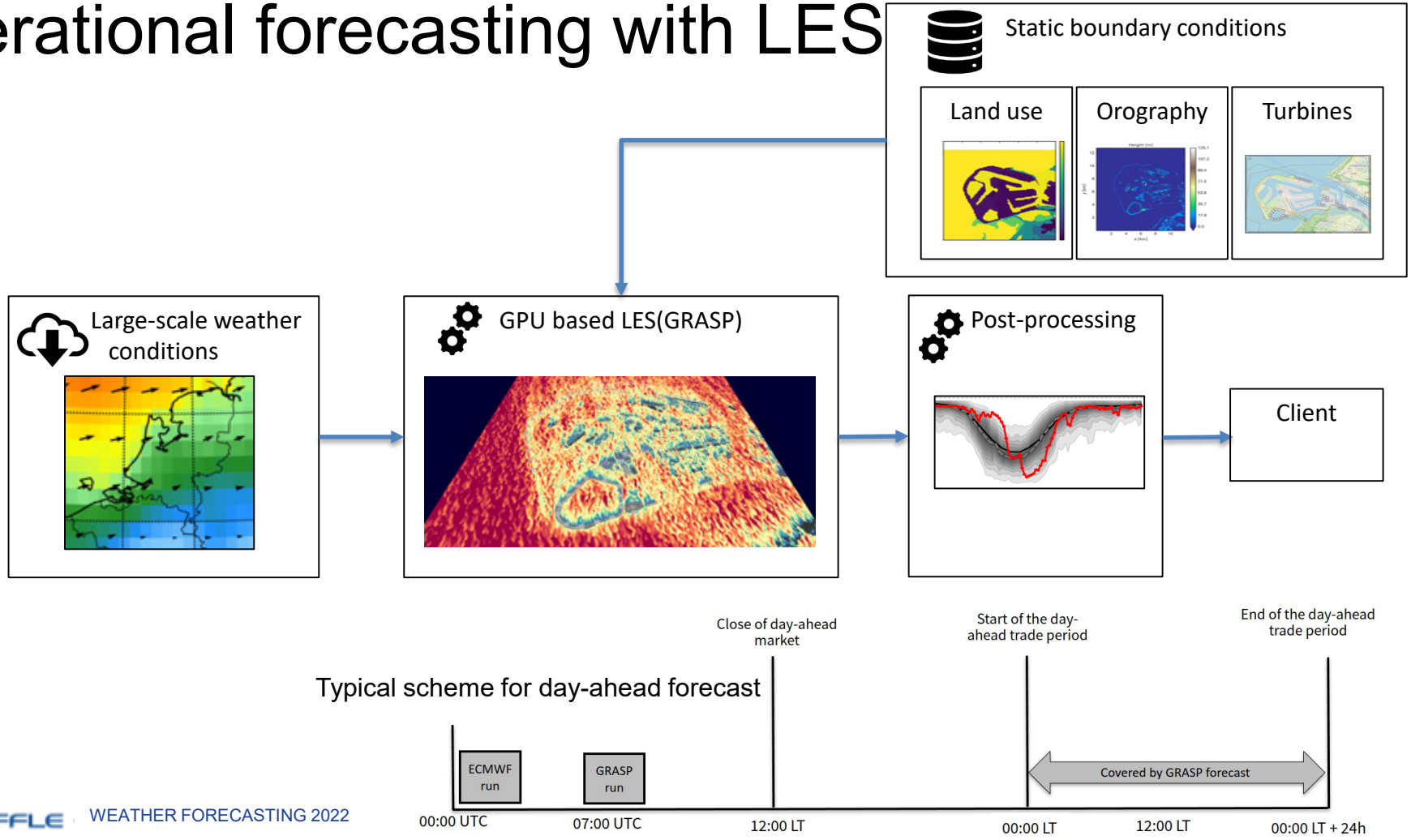


Typical processes that are parameterized in ~~NWP*~~ LES:

- ~~Turbulence~~
- ~~Large-scale clouds~~
- ~~Convective clouds~~
- ~~Surface drag~~
- Radiation
- Precipitation

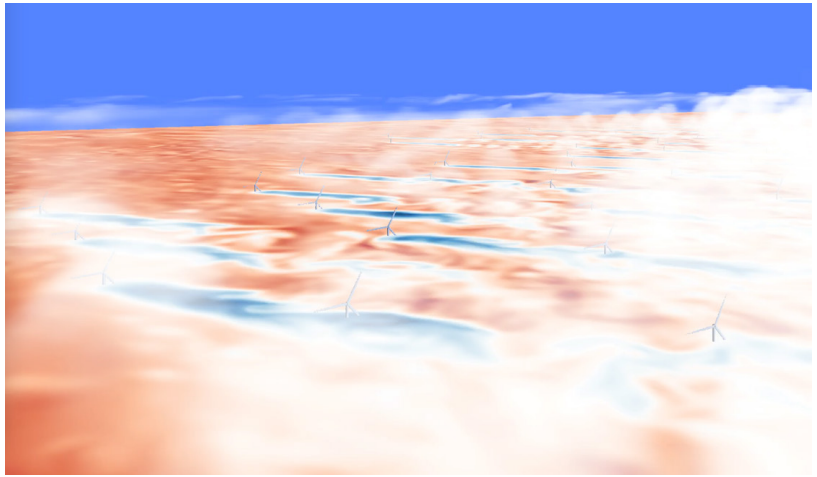
* See for example https://www.ecmwf.int/en/elibrary/18714-ifs-documentation-cy45r1-part-iv-physical-processes

Operational forecasting with LES



Offshore wind farm forecasting

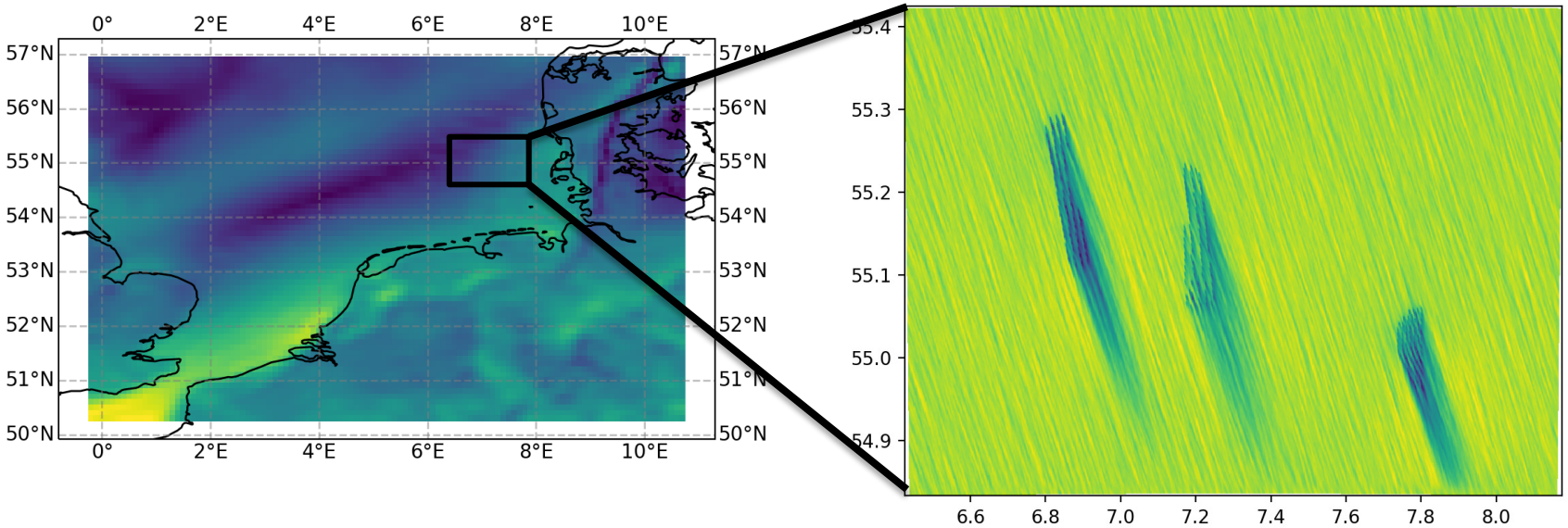
- Turbines are part of the atmospheric model as actuator disks
- LES well proven method for representing turbulent mixing inside the wind farm
- Wakes effects in relation to atmospheric stability



Offshore wind farm forecasting

ECMWF

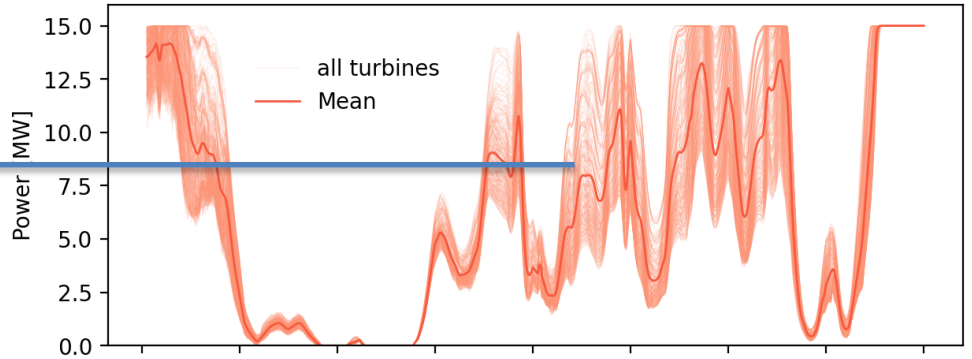
GRASP LES



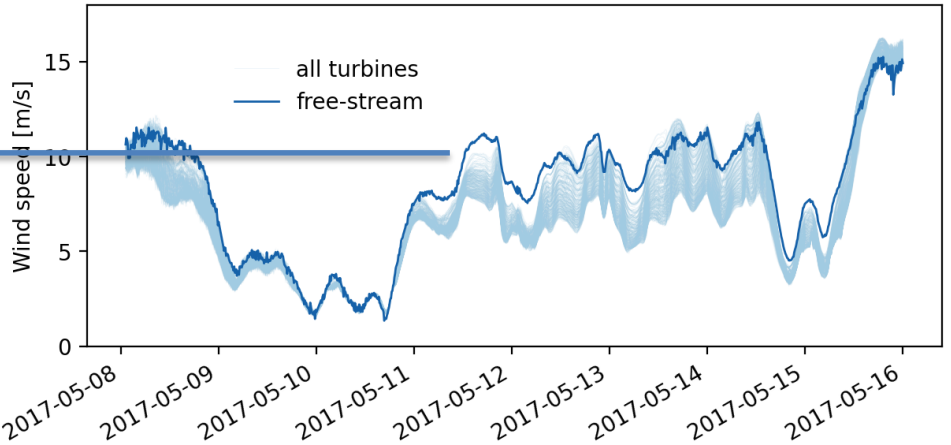
Example forecast of wind farms in German bight.
Hourly average 100m wind speed

Offshore wind farm forecasting

60% difference between waked and first row turbines



Small wind speed variations cause huge power swings

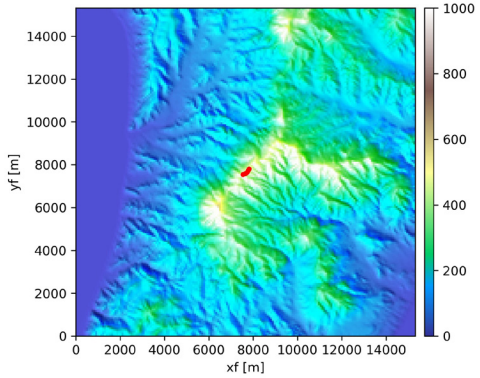


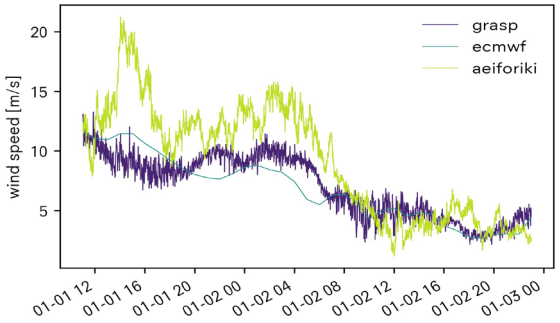
Verzijlbergh, R. A. (2021). Atmospheric flows in large wind farms. *Europhysics News*, *52*(5), 20–23. https://doi.org/10.1051/epn/2021502

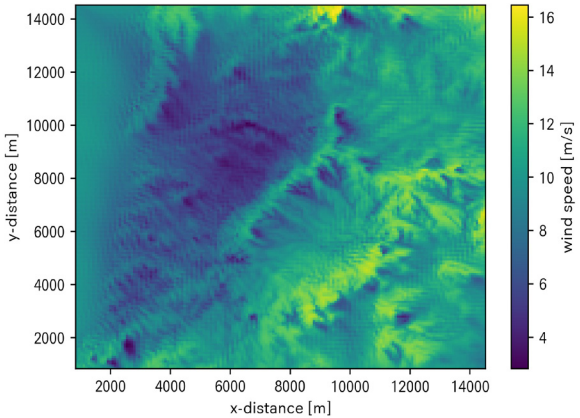
Onshore wind farm forecasting

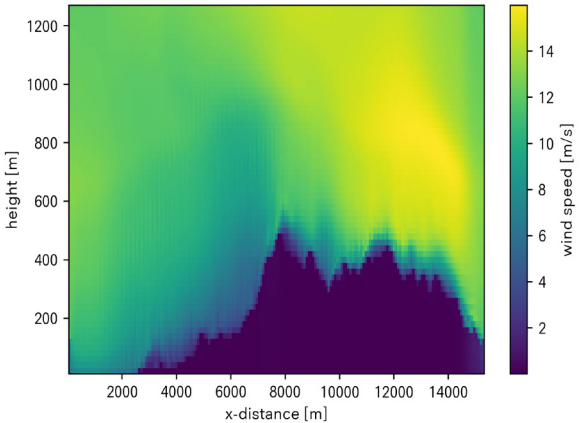
- Represents terrain in high detail (mountains, canopies, buildings..)
- Captures small-scale atmospheric phenomena (turbulence, low clouds, low-level jets)

Case study of wind farm on Rhodes. From top left in clockwise direction: 1. terrain height. 2. Example forecast time series 3. Horinzontal wind speed ma



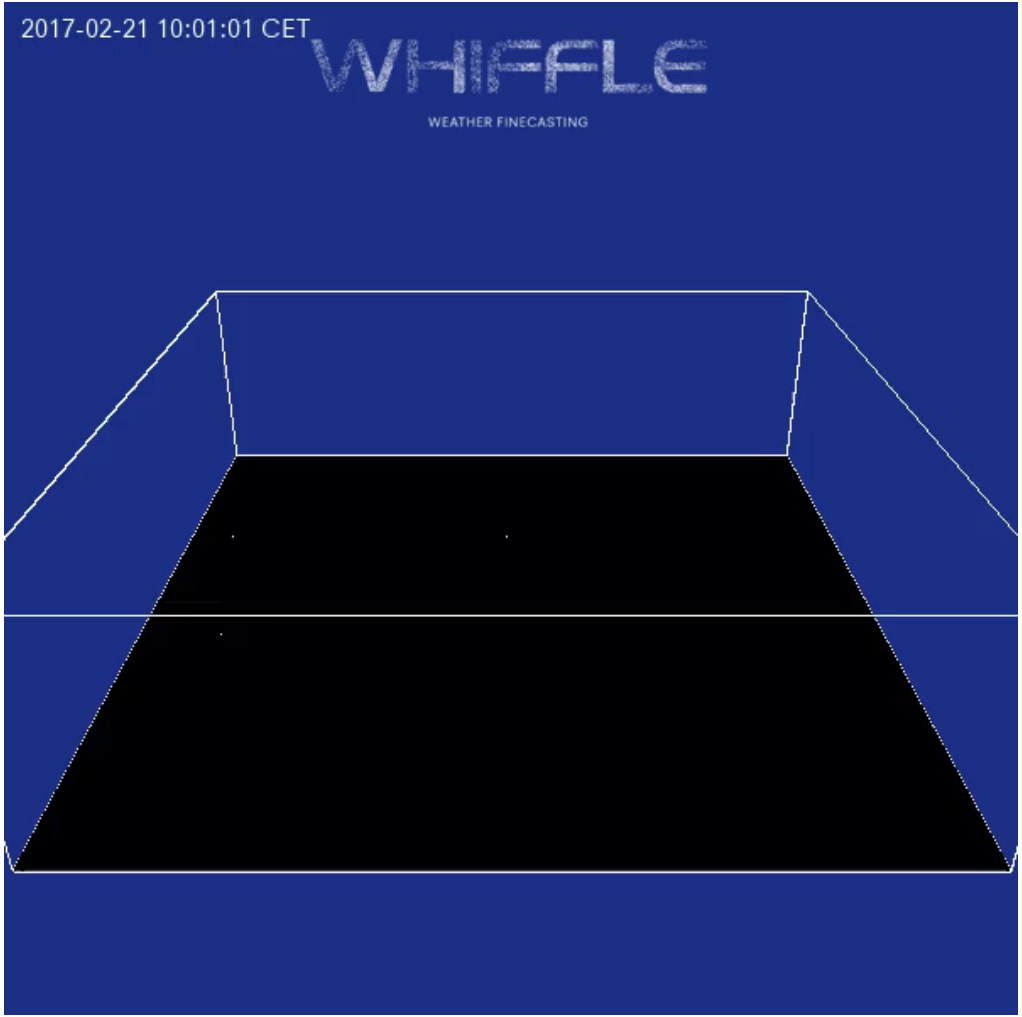




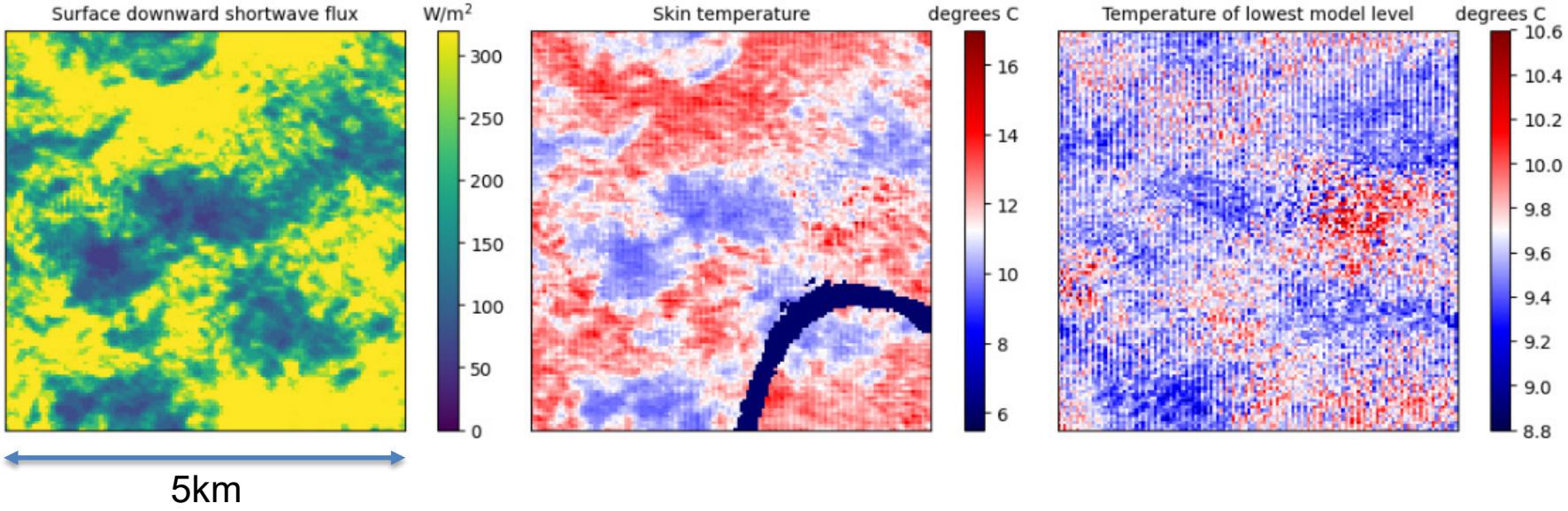


Solar forecasting

- New radiation scheme based on ECRad/ RRTMG
- Implementation uses a smart column



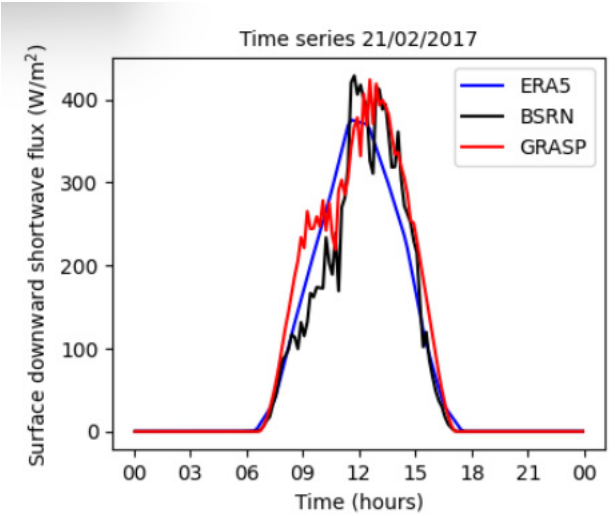
Solar forecasting

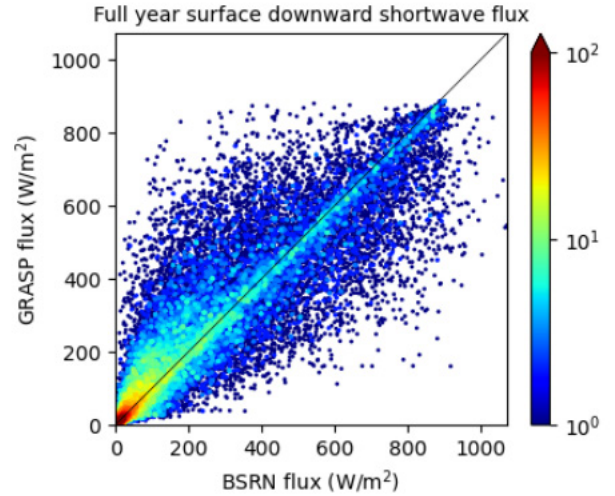


Solar feedback on atmosphere through surface energy balance

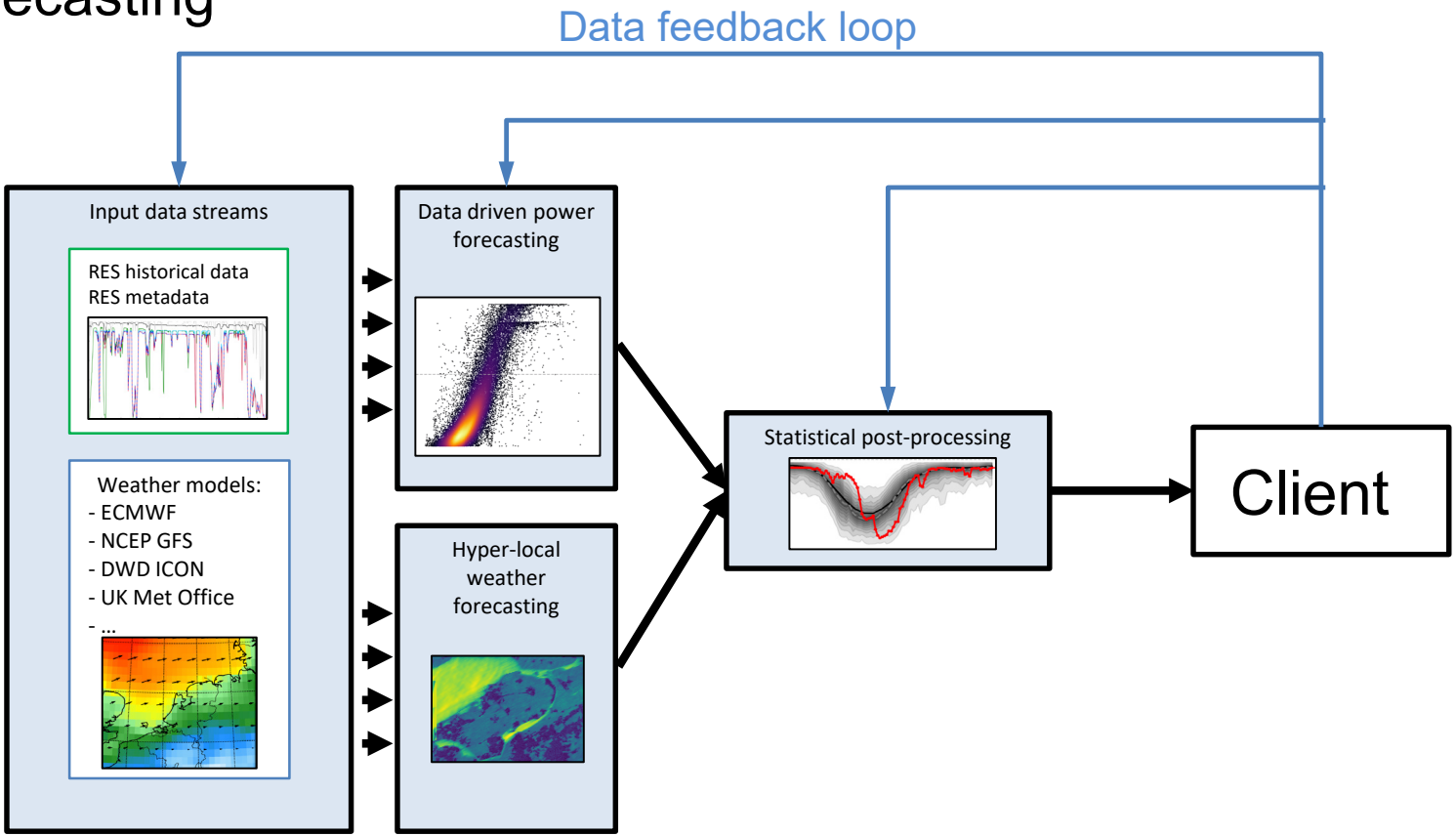
Solar forecasting

- LES gives realistic 3D cloud representations
- Radiative transfer on all columns
- Note the stochastic nature of clouds

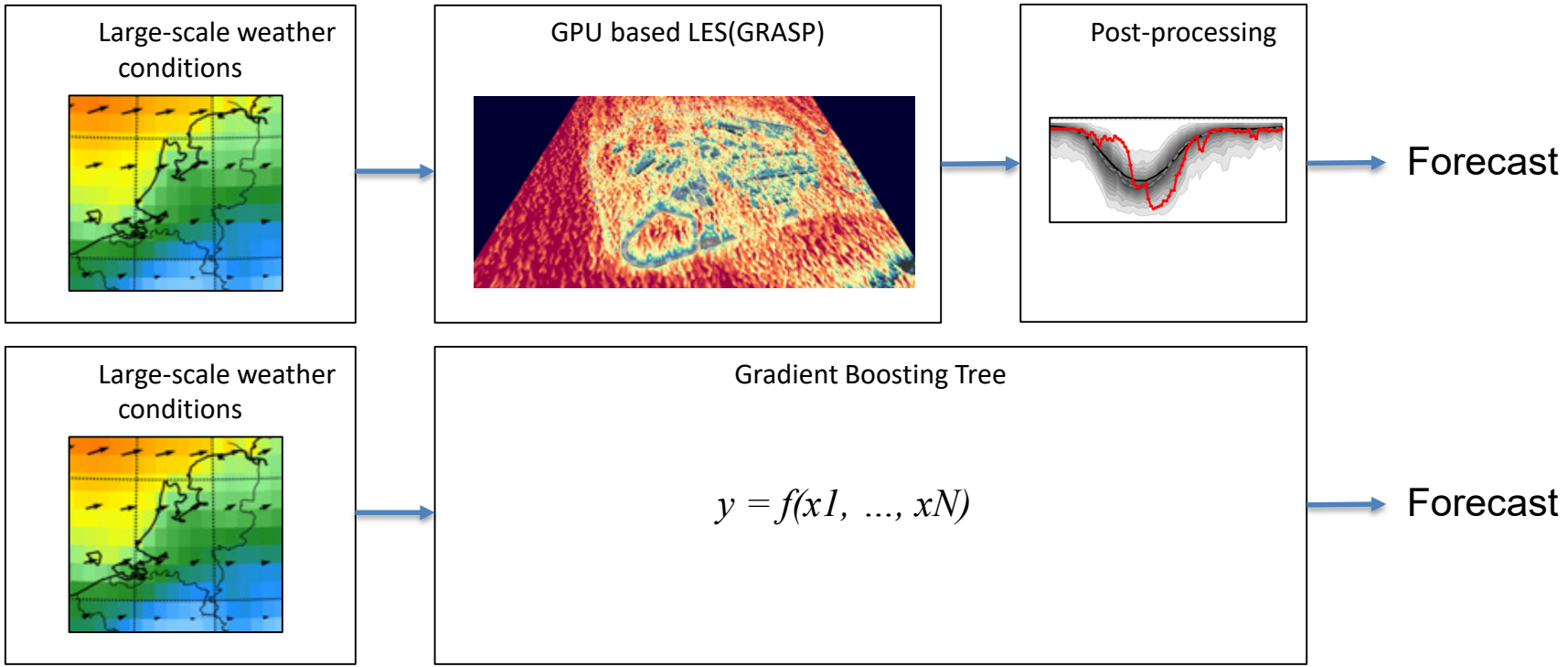




Whiffle combines machine learning and LES for operational power forecasting



How does LES relate to statistical post-processing?

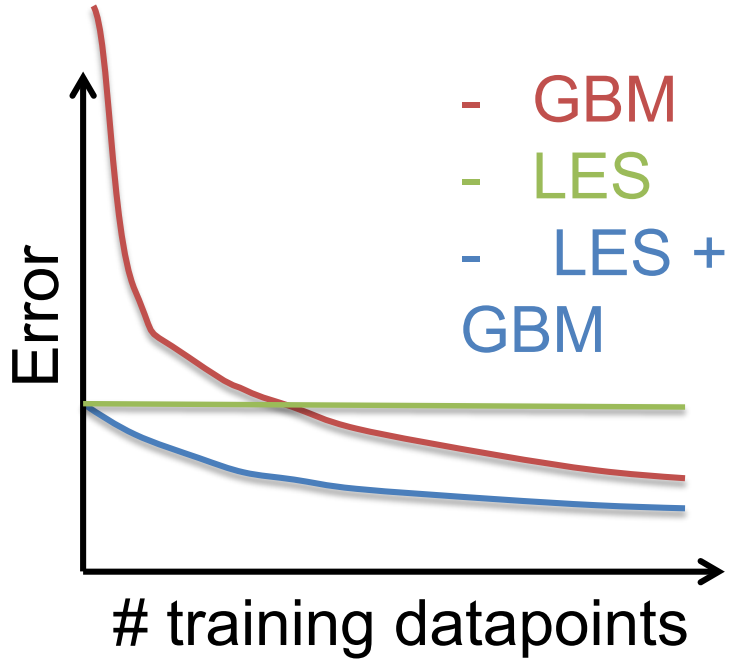


How does LES relate to statistical post-processing?

LES uses known laws of physics…

… but is not perfect…

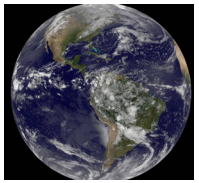
…so post-processing still helps.



Current and future research

- Fine-tuning heterogeneous conditions
- Multi-GPU large domain LES
- Micro-physics
- Data assimilation
- Coupled atmosphere-ocean-wave
- Ensembles

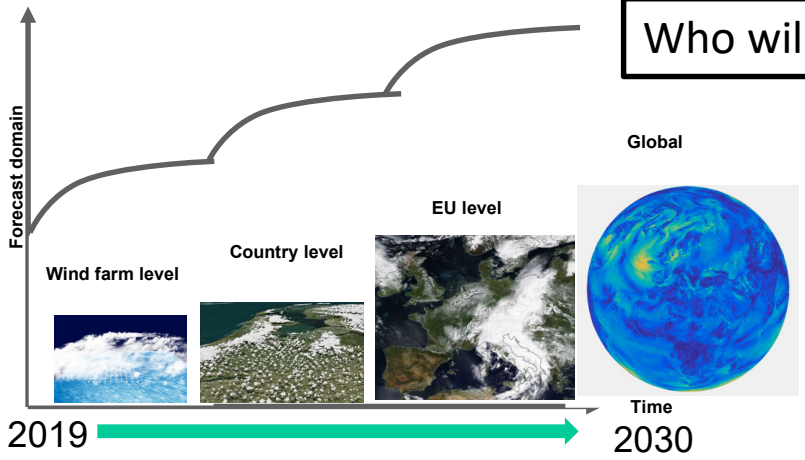
The future of numerical weather prediction



Next generation weather model:

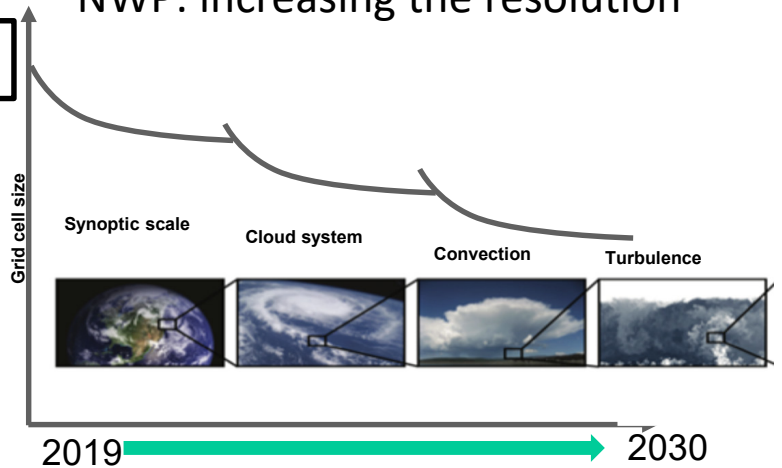
- Turbulence and cloud resolving (= LES !)
- Uses big data and massive computational power
- Supports energy transition and climate adaptation

LES: scaling up the domain size



Who will be first?

NWP: increasing the resolution



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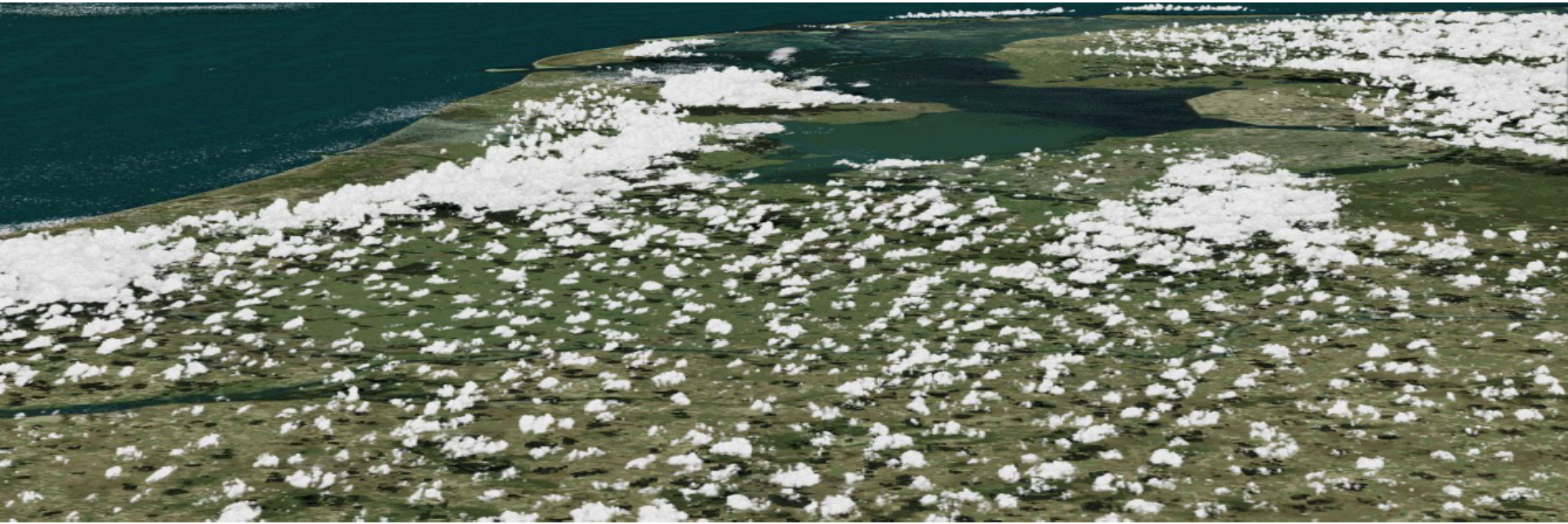

Cloud field of an LES run over the Netherlands using 256 GPUs

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