HPCWE: High-Performance Computing Applied in Wind Energy

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SC20 – The International Conference for High Performance Computing, Networking, Storage and Analysis

Agenda

- Project Information
- Challenge: Dynamics at different scales
- Objectives
- Use Cases 1, 2 and 3
- Summary

Project information

High-Performance Computing in Wind Energy (HPCWE)

HPCWE main goal is to establish an EU-Brazil strategic partnership in wind energy applications.

Start date: June 2019, 24 months duration

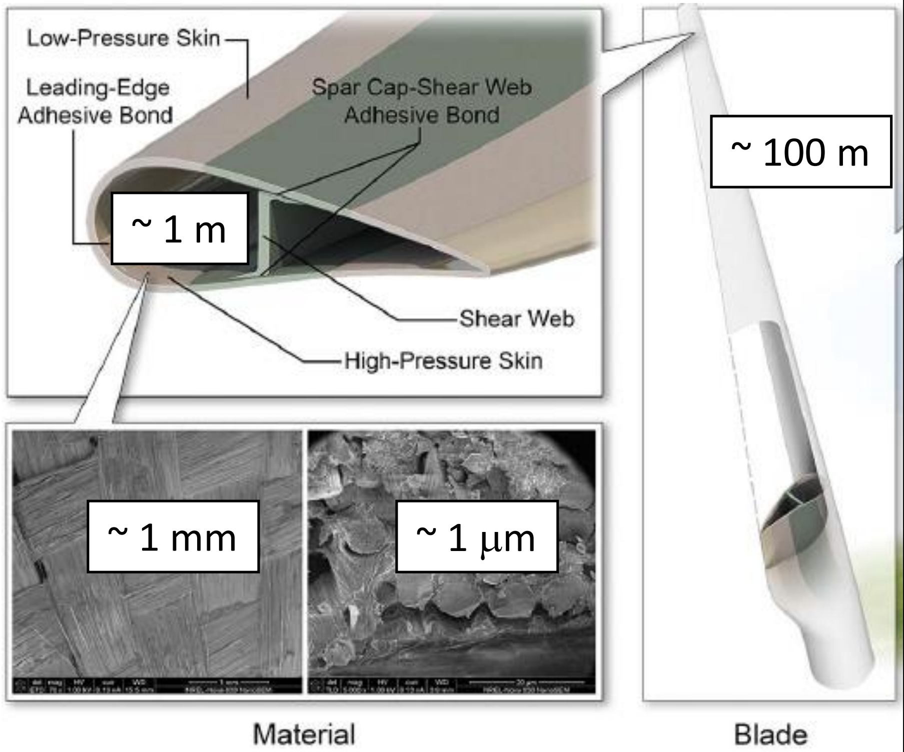
EU contribution: approx. 2 Million Euros, match funding from Brazilian research council

The role of HPCWE is to coordinate the action of universities, companies and consultancies with complementary expertise and to build and test beyond-state-of-the-art HPC strategies for the numerical simulation of wind flow in wind energy exploitation.

Partners of HPCWE

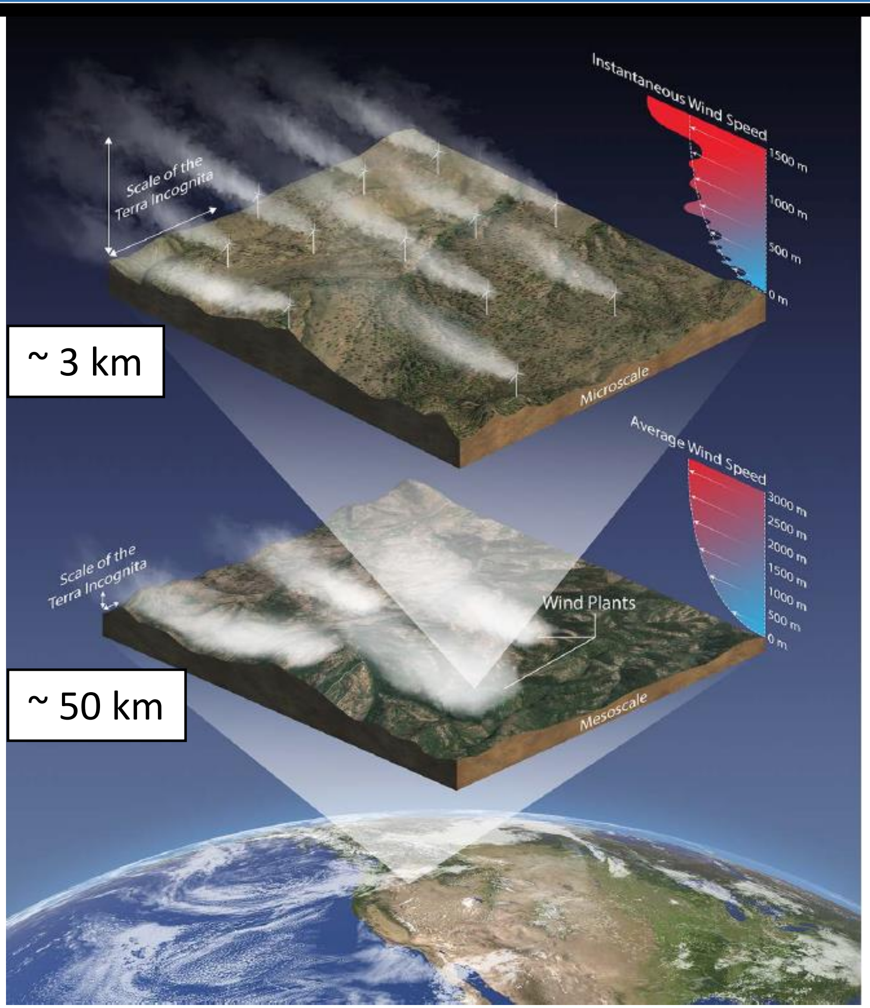
11 partners including **2 HPC centers, 7 top academic institutes and 2 leading enterprises from six European countries and Brazil**

Challenge: Dynamics at different scales



Simulation of blade dynamics

Wind turbine simulations



Mesoscale to microscale

Uncertainty quantification (wind turbine / farm)
Data reduction (wind turbine / farm)

Veers et al., Science 366, 443 (2019)

Why HPC?

- Evolving technology:
  - ◆ Bigger/taller/data driven machines
  - ◆ More complex conversion from wind to electric energy
  - ◆ Larger windfarms - wind power plants (e.g. intra-array wakes)

- Evolving market: offshore, global, new regions, repowering
  - ◆ Towards site specific power curves
  - ◆ Multidimensional power curves
  - ◆ Extreme conditions (negative shear …)
  - ◆ Digital Twin Concept / Digitalization
  - ◆ Energy integration

} Simulation!

– Fast
– Accurate
– Efficient

Objectives

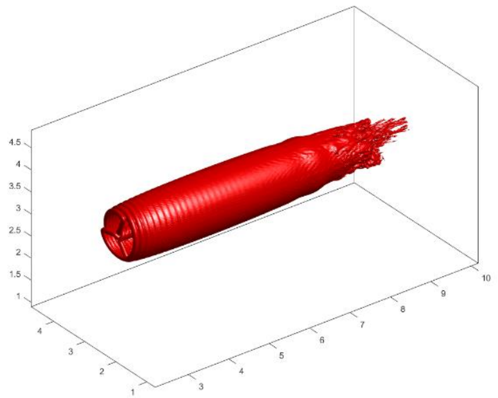
Having in mind the challenges of the application of HPC on wind flow simulations, the specific objectives of the HPCWE consortium are:

- efficient use of HPC resources in wind energy simulations
- accurate integration of the meso- and microscale simulations
- reduction of I/O data in optimization
- establishment of an EU-Brazil network

Use Cases

In order to test and evaluate the new models and algorithms developed by the consortium, three use cases have been selected

- Benchmark vs existing industry and standard solutions
- Show the added value of using HPC over current solutions

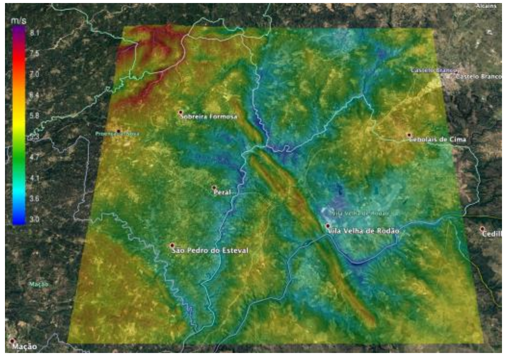


Efficient use of HPC resources in simulation of flow around a wind turbine

Use Case 1: Validation of algorithms and codes for flow around a wind turbine

Optimal hybrid solution for wind resources

Use Case 2: Validation of algorithms and codes for optimization



Effective scale-integration in wind energy beyond state-of-the-art

Use Case 3: Validation of algorithms and codes for scale integration

Use Case 1 – Wind turbine

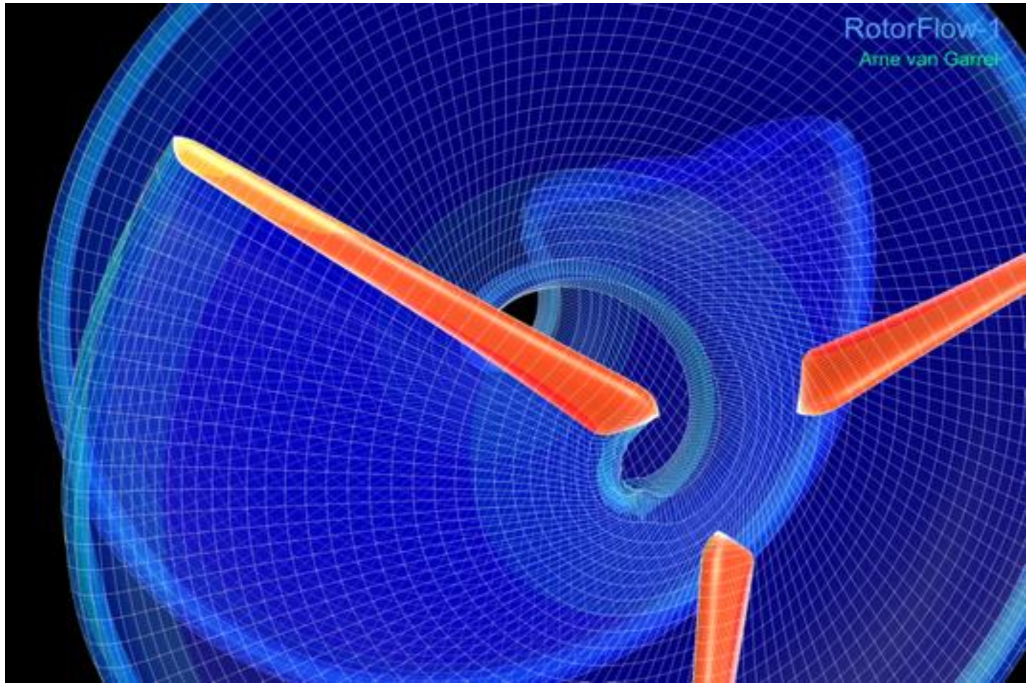
Efficient use of HPC resources in simulation of flow around a wind turbine

Focus on blades aeroelasticity / wind turbine

- Fluid-Structure Interaction (FSI)
- Flow around blade
- Flow around wind turbine

Benchmark/db: Existing virtual wind turbine models (NREL 5MW/15MW, Avatar 10MW)

Model Architectures: Nektar-Sharpy ++
Twente-LES
WInc3D
N3D
OpenFOAM

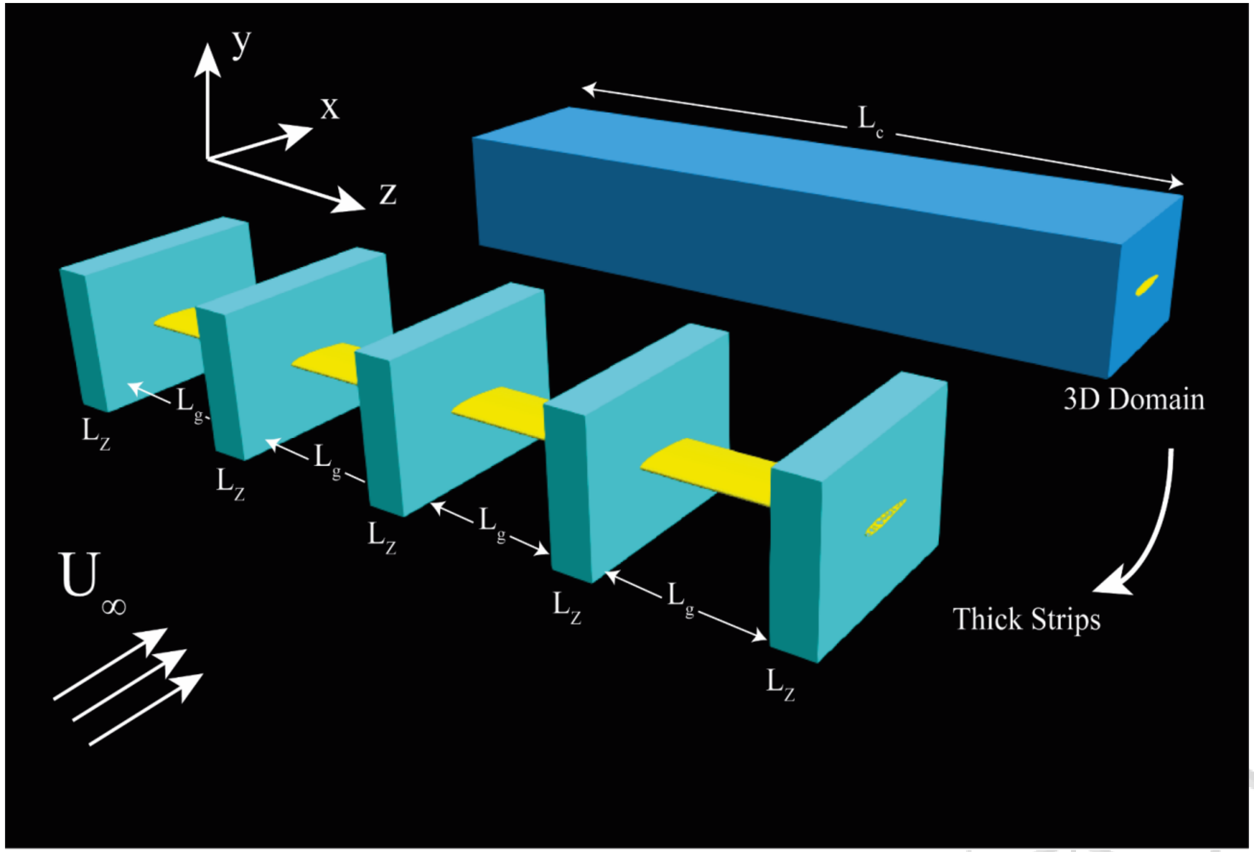


AVATAR wind turbine from http://www.eera-avatar.eu/home/index.html

Use Case 1 – Wind turbine

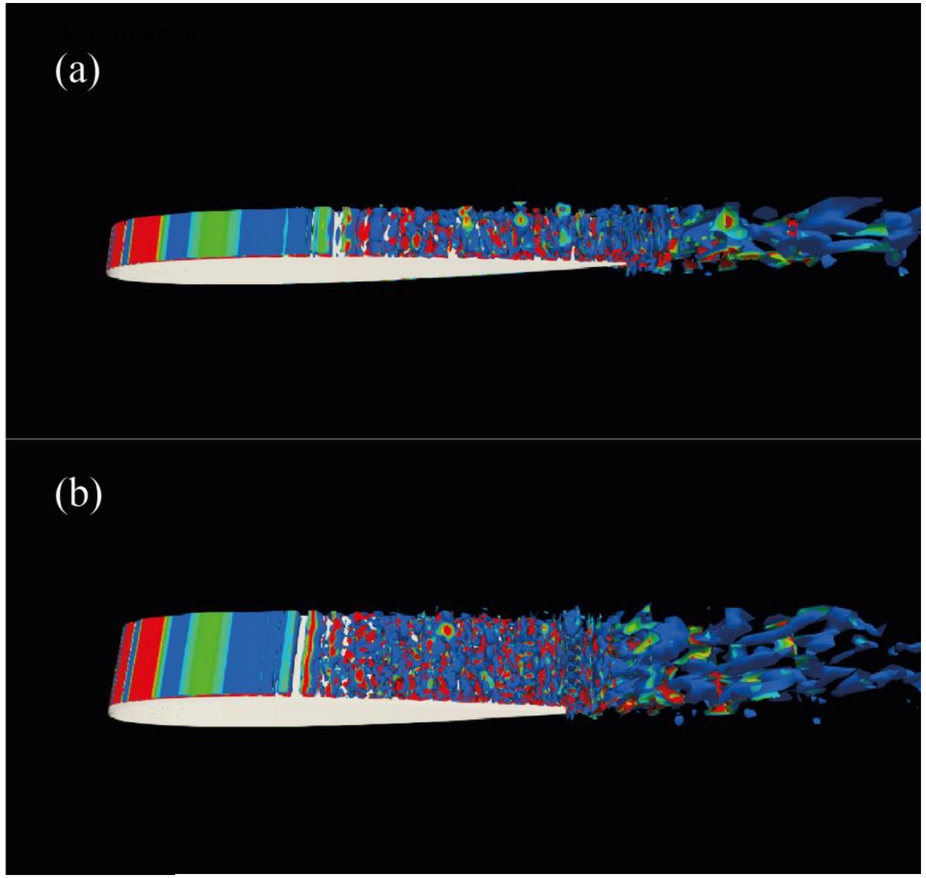
Implicit LES and aeroelastic coupling

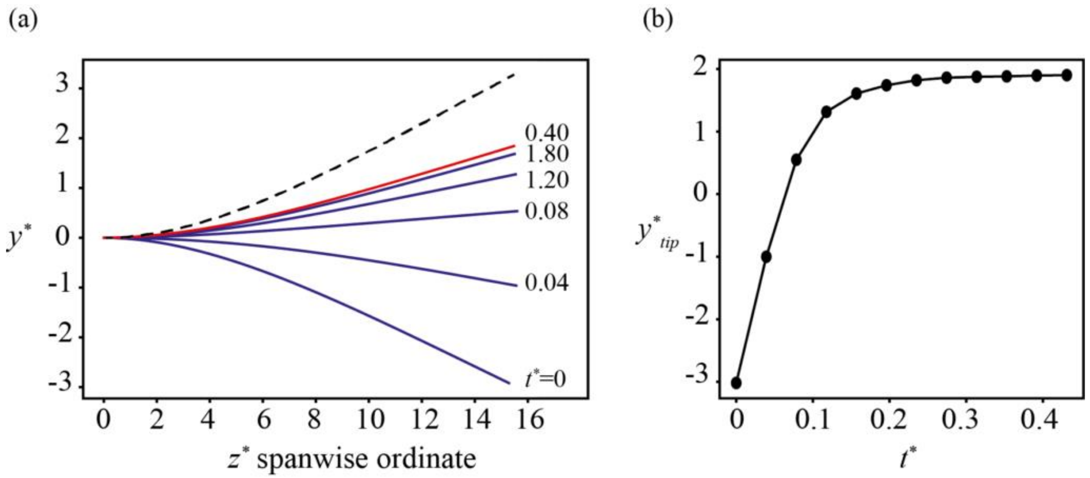
- 3D domain is split into series of smaller domains, thick strips
- Each strip has a thickness Lz in spanwise direction, which enables capturing the local 3D effects
- Strips connected via structural dynamics, which is obtained from solving geometrically non-linear high deformation beam equation



Use Case 1 – Wind turbine

Implicit LES and aeroelastic coupling



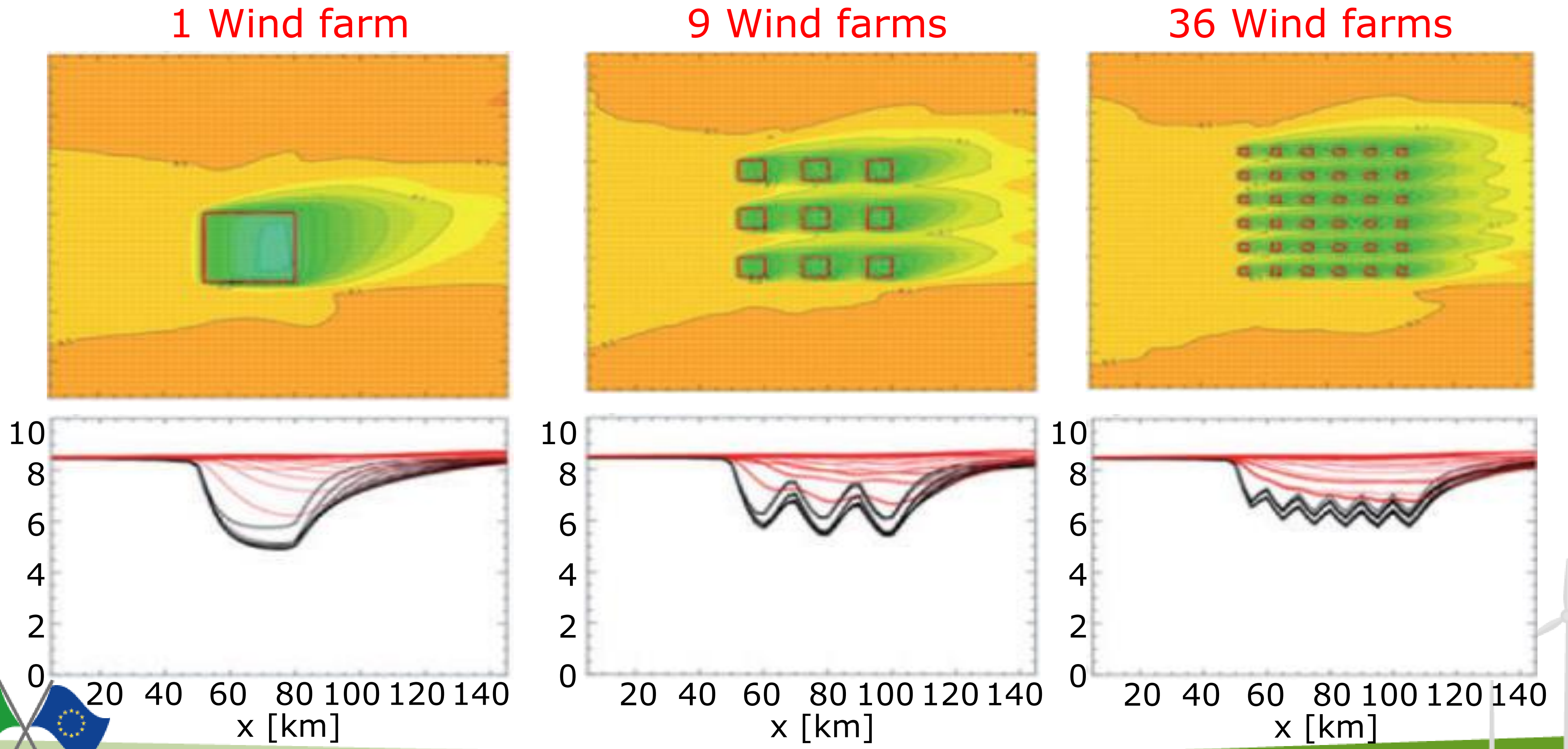


Q-criterion showing vortex formations

Results from WP1

Use Case 1 – Wind turbine

Scale integration meso- and microscale



Results from WP1

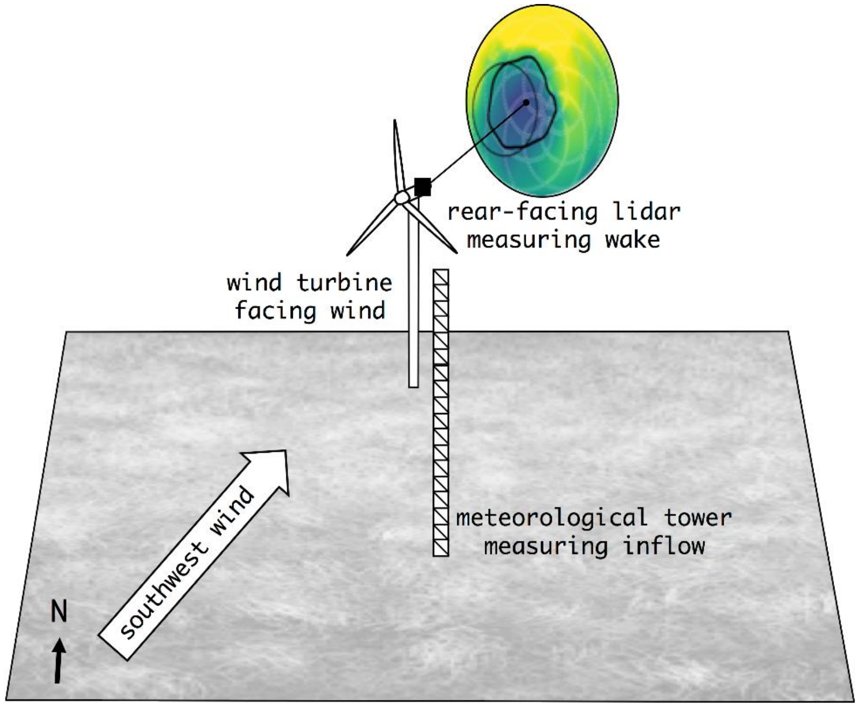
Use Case 1 – Wind turbine

Verification, Validation and Uncertainty Quantification

Code	N3D	Nektar++	OpenFOAM	WInc3D
Origin	Kindly provided by UNOTT, based on open-source code Semtex	ICL, open-source, with module kindly provided by UNOTT	Open-source	ICL, open-source
Test case origin	Kindly provided by UNOTT	Kindly provided by UNOTT	Internal development	Internal development
Test case	Single wind turbine	West Denmark + wind turbine	-Wakebench, NREL -Two in-line turbines, experiments from NTNU Norway	Wakebench, NREL
Numerical method	Spectral element	Tensor product based finite element method	Finite volume method	Finite difference method
Scalability	~100	100+ thousand ranks	Up to 5 thousand	100+ thousand ranks
Discretization	High order	High order	Up to second-order	Sixth-order in space and third-order in time
Wind turbine model	Single C_p, ADM	Single C_p, ADM	- Single C_p, ADM - BEM, ADM - BEM, ALM	BEM, ALM
Suitability	-	+	++	++

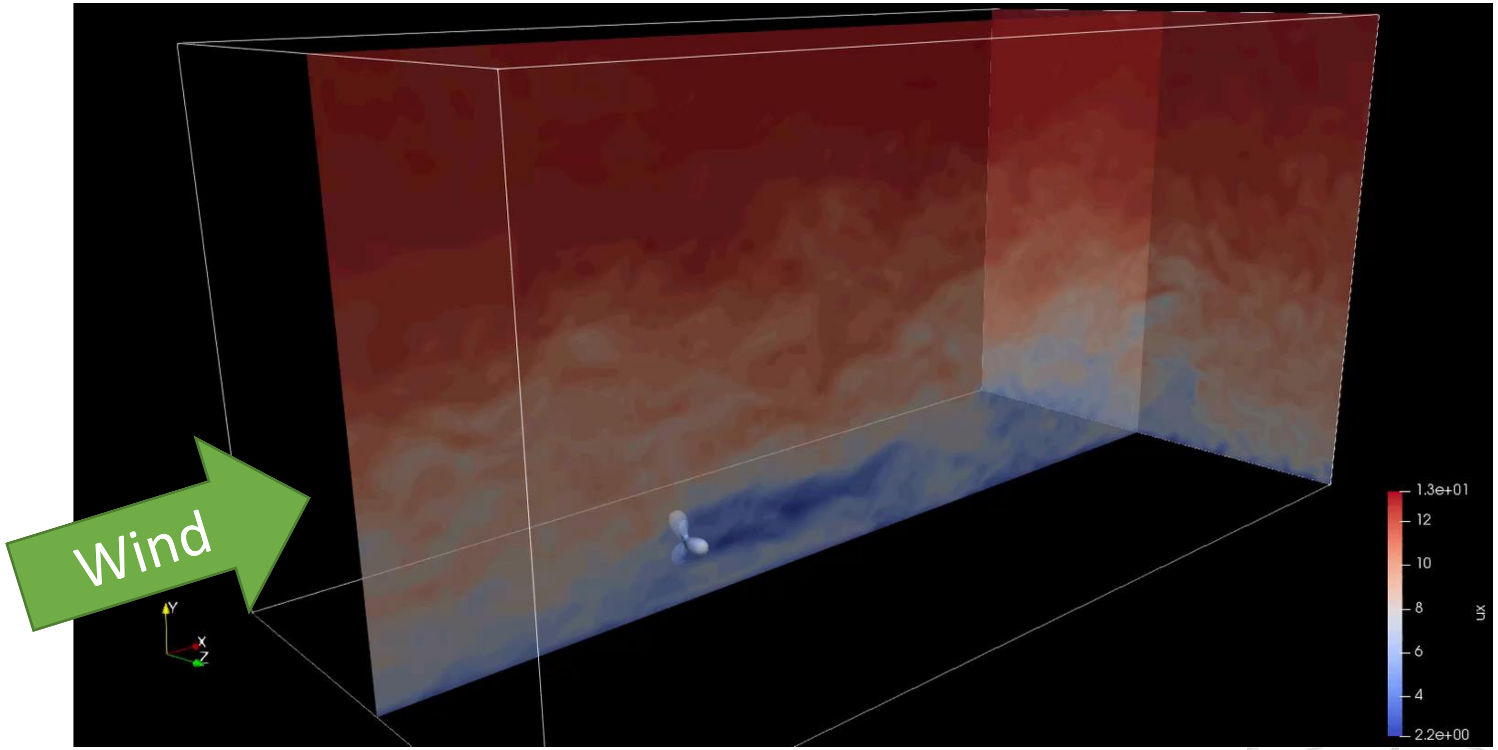
Use Case 1 – Wind turbine

Verification, Validation and Uncertainty Quantification



SWiFT benchmark case, which is included in the International Energy Agency (IEA) Wind Task 31.

https://wakebench-swift.readthedocs.io/en/latest/



LES simulation with WInc3D. Wind turbine modeled using the actuator line model.

Use Case 1 – Wind turbine

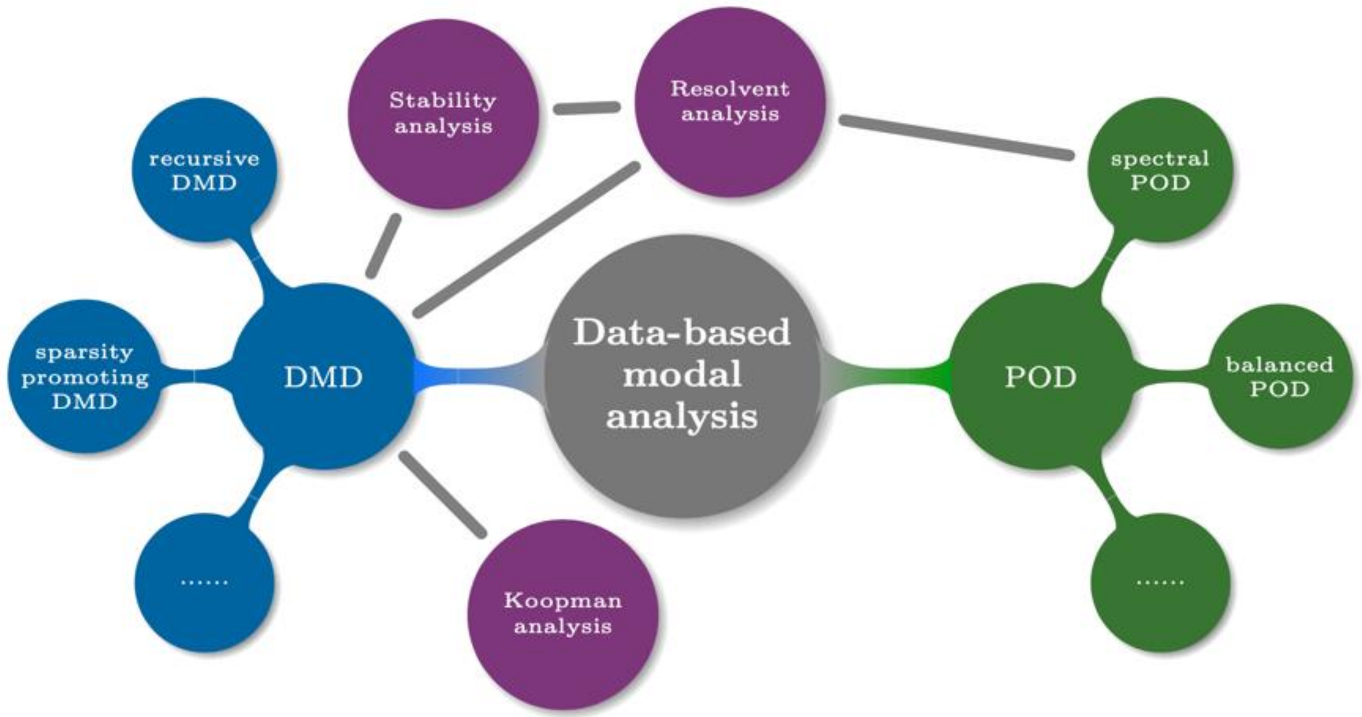
Verification, Validation and Uncertainty Quantification

- HPC resources
  - Vulcan cluster, 2 nodes with 40 cores of Intel Xeon Gold 6138 @ 2.0GHz (Skylake) processors
  - OpenFOAM utilizes fewer resources than WInc3D
    - 55% of the WInc3D computing time when considering main run only
  - WInc3D using a different inflow BC is currently being investigated

	Main run [CPU-hours]
WInc3D - main	505.1
OpenFOAM	255.1

Use Case 1 – Wind turbine

- Detailed wind farm simulations generate upwards of 100TB of data.
  - Even on modern supercomputers this is difficult to handle
- HPCWE: Development of algorithms to reduce data
  - Compressing the relevant physics in limited amount of data



Results from WP1
Results from WP1

Use Case 1 – Wind turbine

- Codes used in WP1

Code	Roles in HPCWE
Nektar++/SHARPy (open source)	Wall resolved fluid and structure interactions at the scale of wind turbine blade.
UTwente_LES	Identifying the bottlenecks for the actuator line model at wind farm scale, reducing the computational overhead and providing recommendations.
WInc3D (open source)	Data reduction studies; comparison against other solvers, demonstrating the ability for actuator line model to be used on large HPC system.
N3D (open source)	Big data analytics in wind energy.
OpenFOAM (open source)	Used in the Verification, Validation and Uncertainty Quantification framework and by the Brazilian partner USP.

Use Case 2 – Complex Terrain

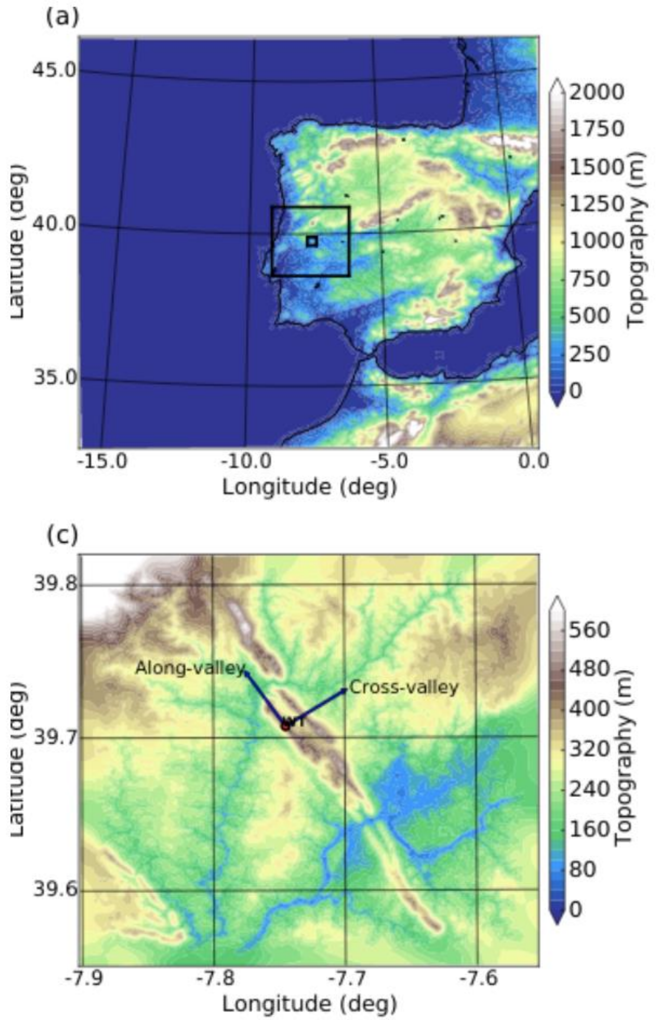
Optimal hybrid solution for wind resources

Musti-scale modeling exercise

- Meso - Microscale integration in complex terrain
- Improve modeling chain across 1km frontier (grey zone)
- Flow modeling in complex terrain
- Initialization exercise
- Wind conditions spatial - vertical structure

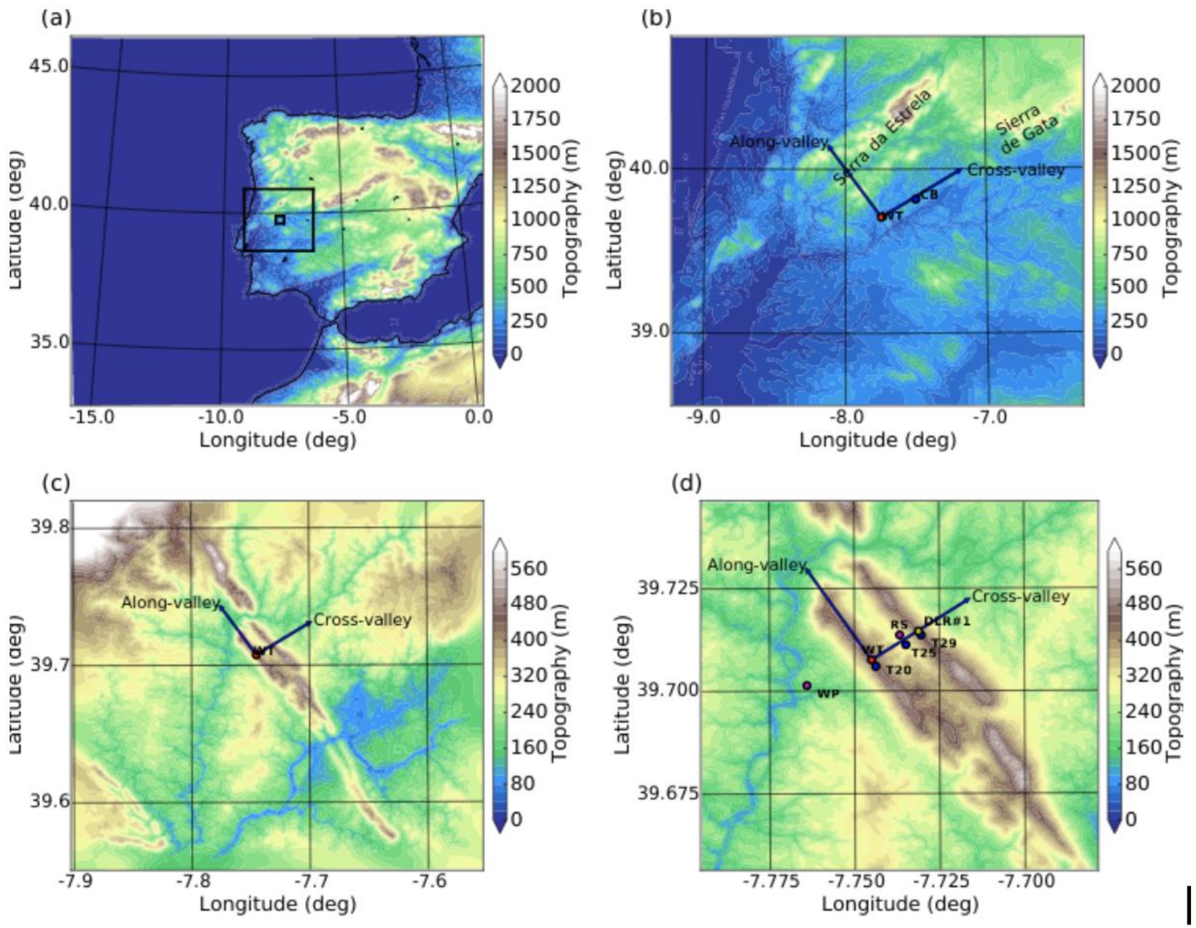
Site: Perdigao Portugal, First-class multi-instrumented campaign

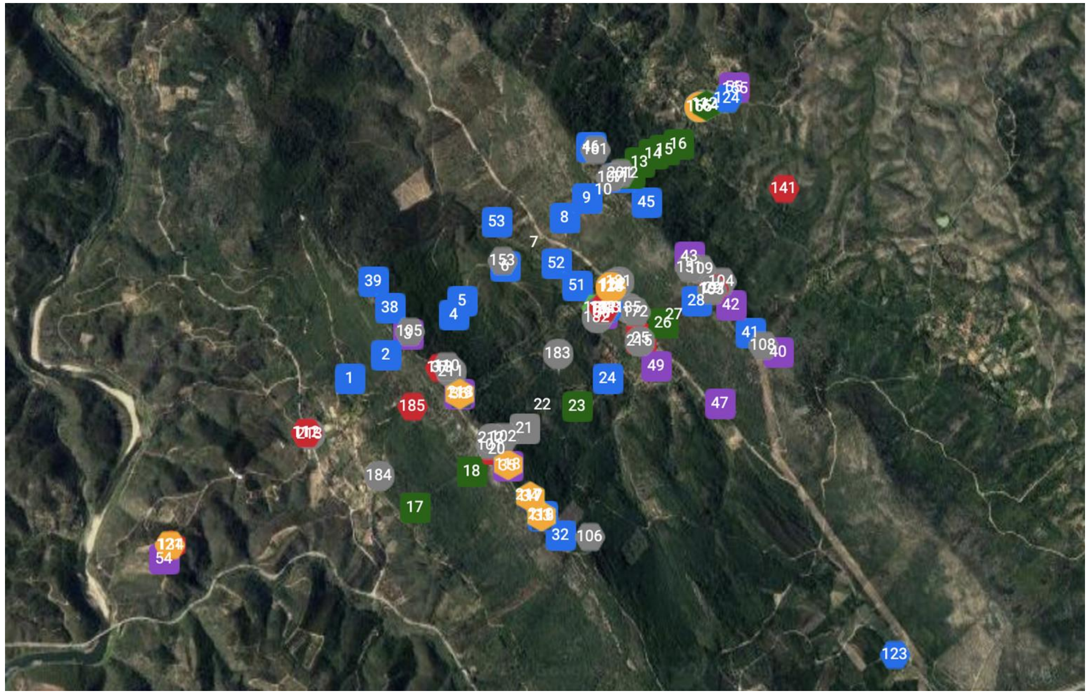
Model Architecture: WRF (Mesoscale) + LES
EWP-WRF
WRF + Code_Saturne (WRAPP)



Results from WP3

Use Case 2 – Complex Terrain



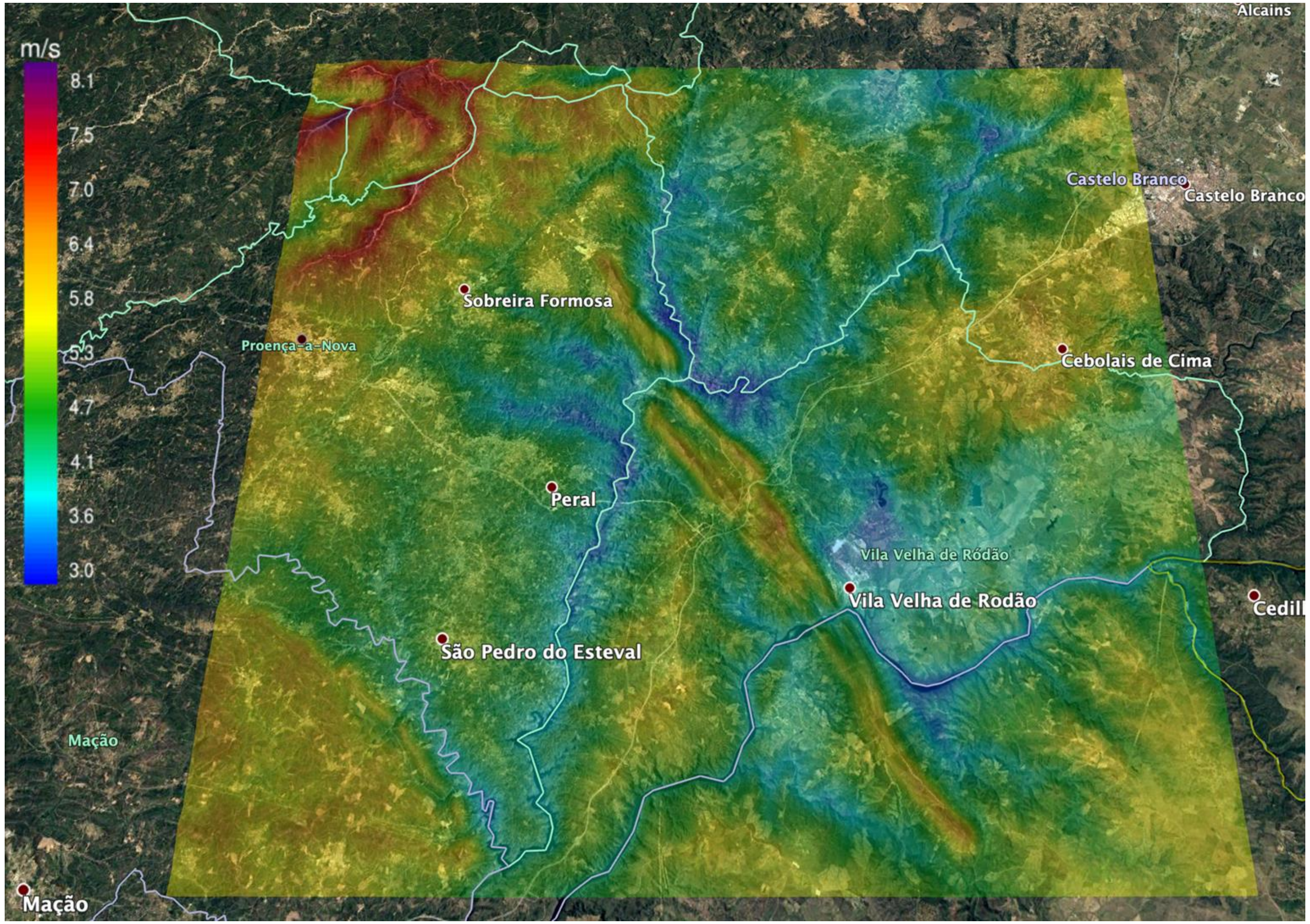


Position of the instrumentation at the Perdigão site

Use Case 2 – Complex Terrain

Average Long-term Wind Speed at 100m height

WRF Model
Standard Parameterizations (No LES)
Spatial Resolution: 100m
Period: 2000-2019



Results from WP3

Use Case 2 – Complex Terrain

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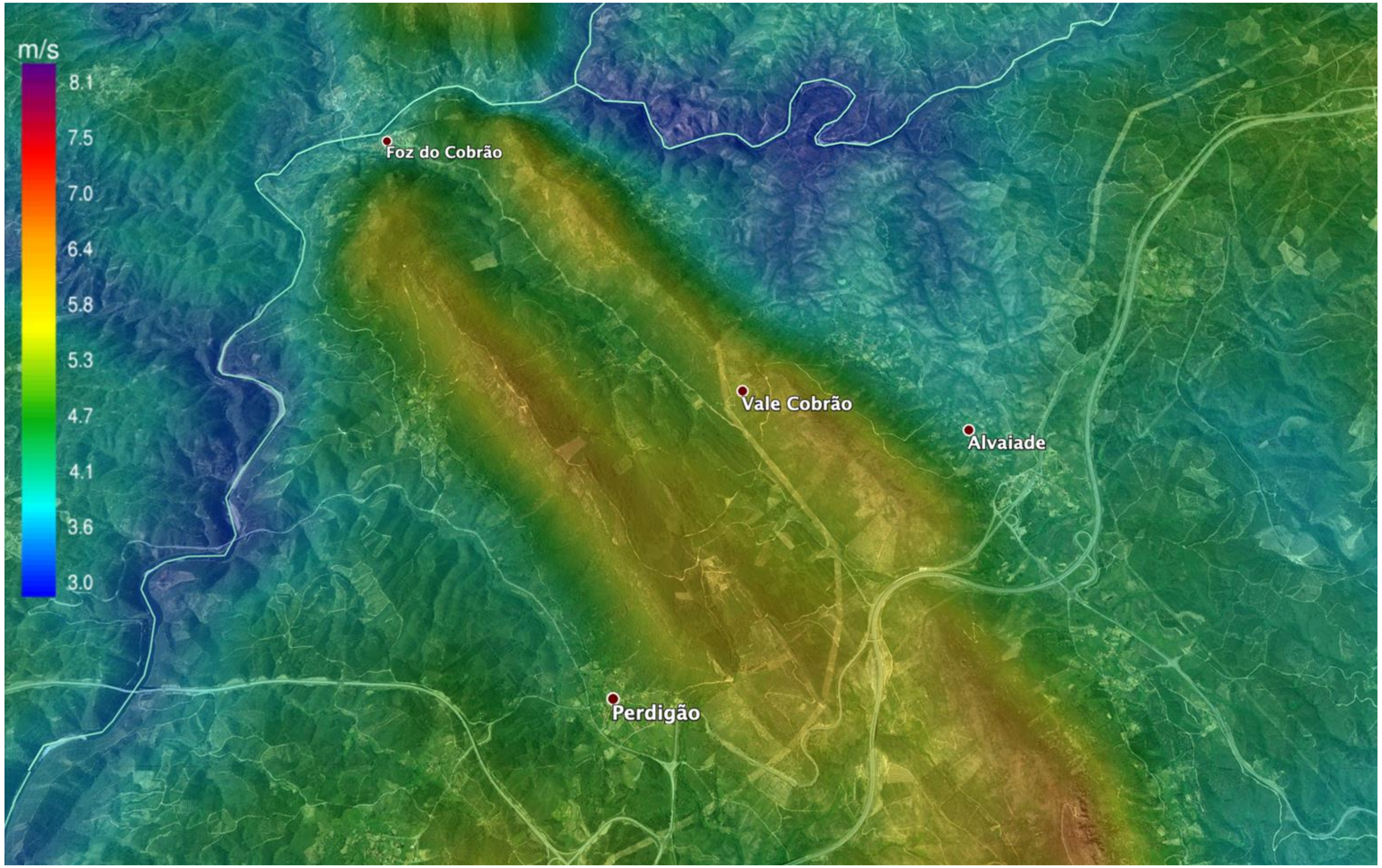
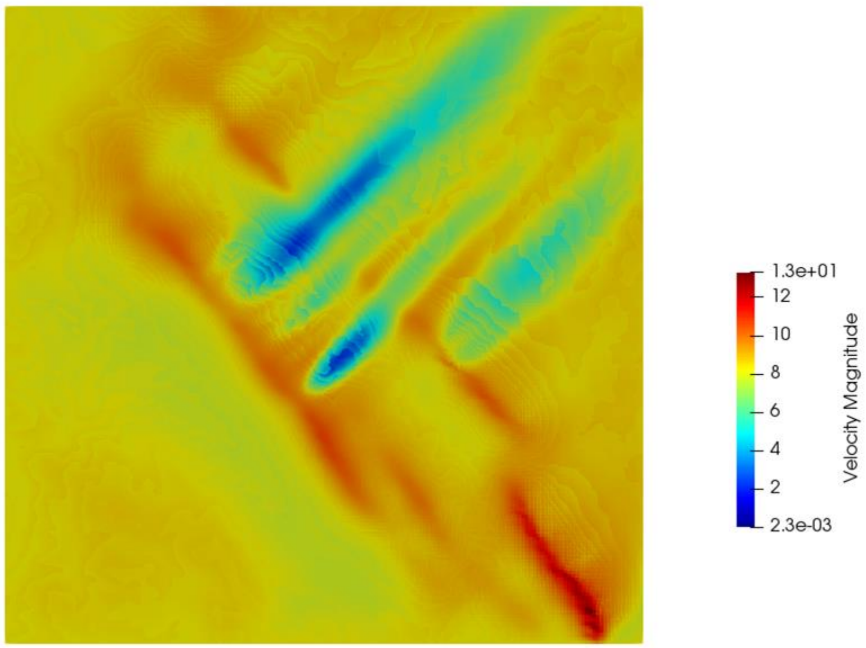
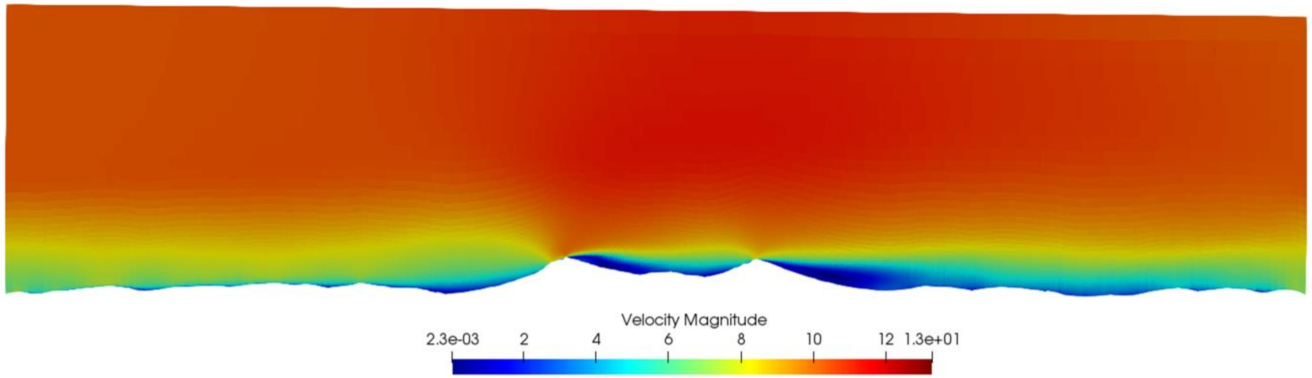


Use Case 2 – Complex Terrain





Interim results for cross-section runs - Code_Saturne

Use Case 2 – Complex Terrain

WRF – LES for M20 location
- CFRS
- MERRA2
- ERA5

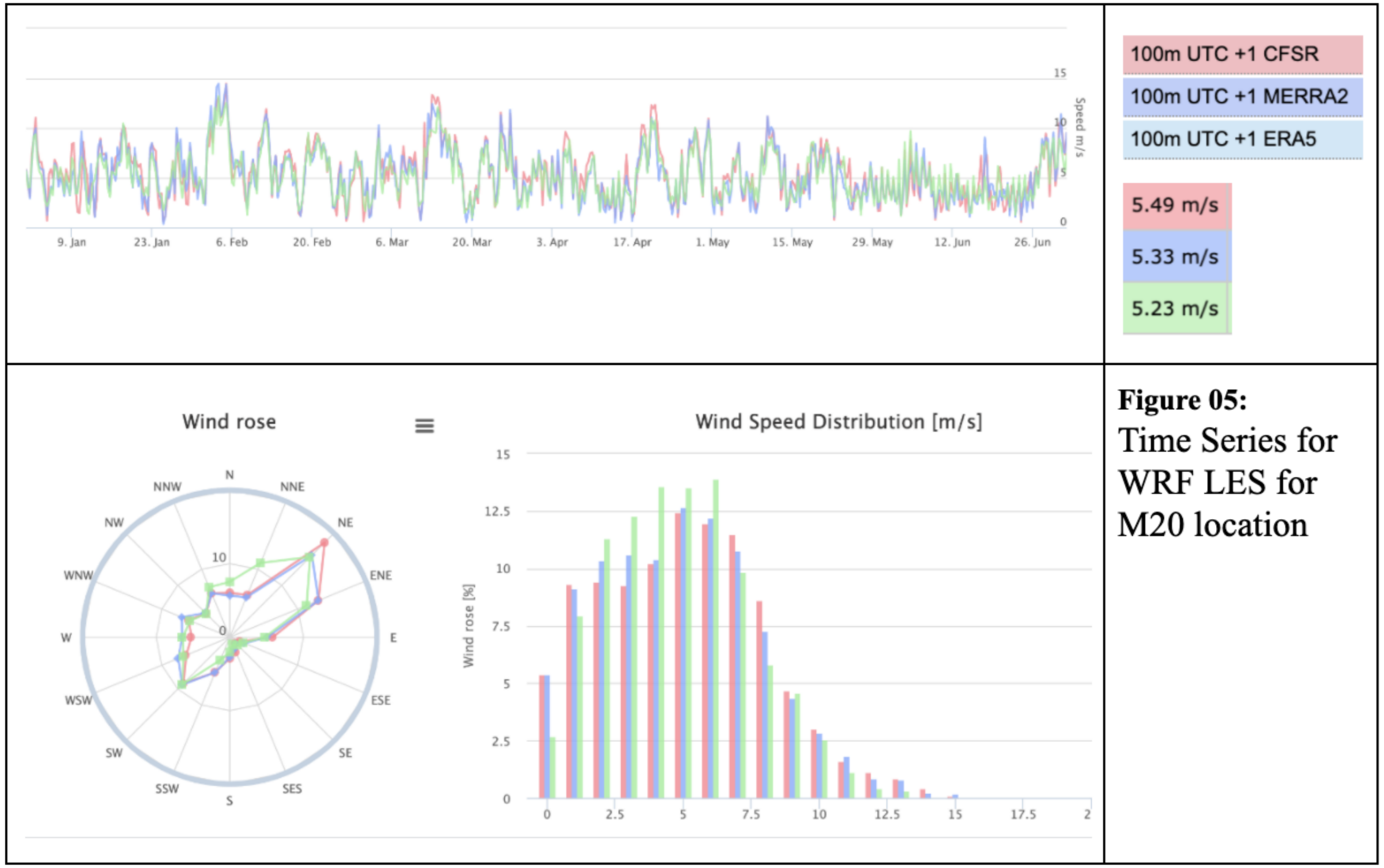
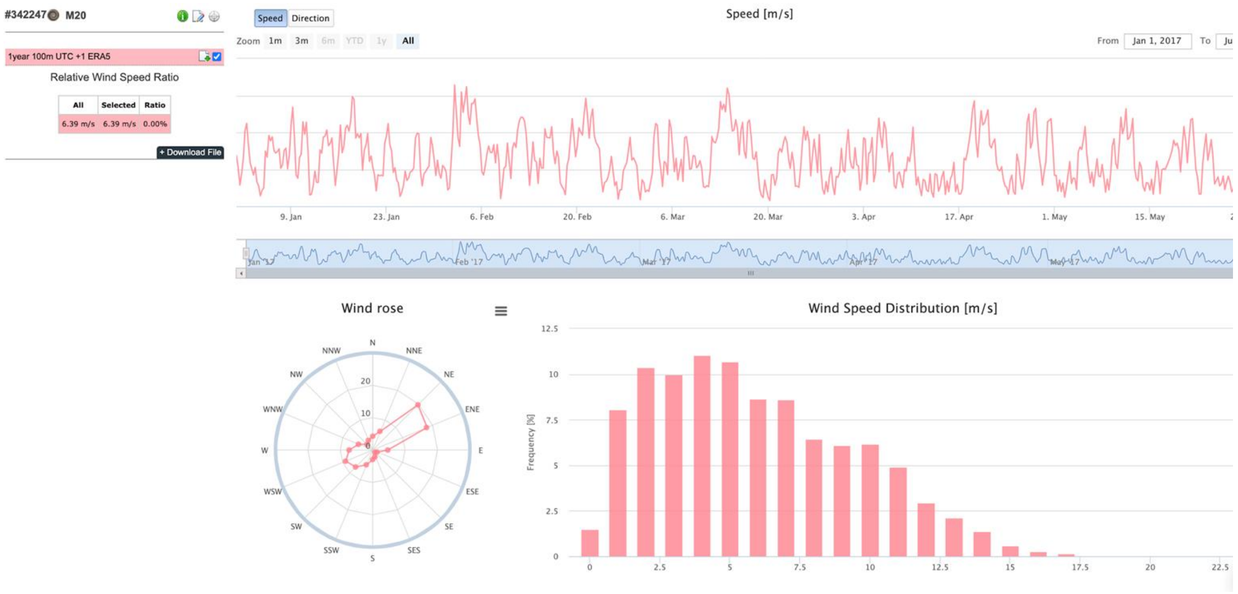
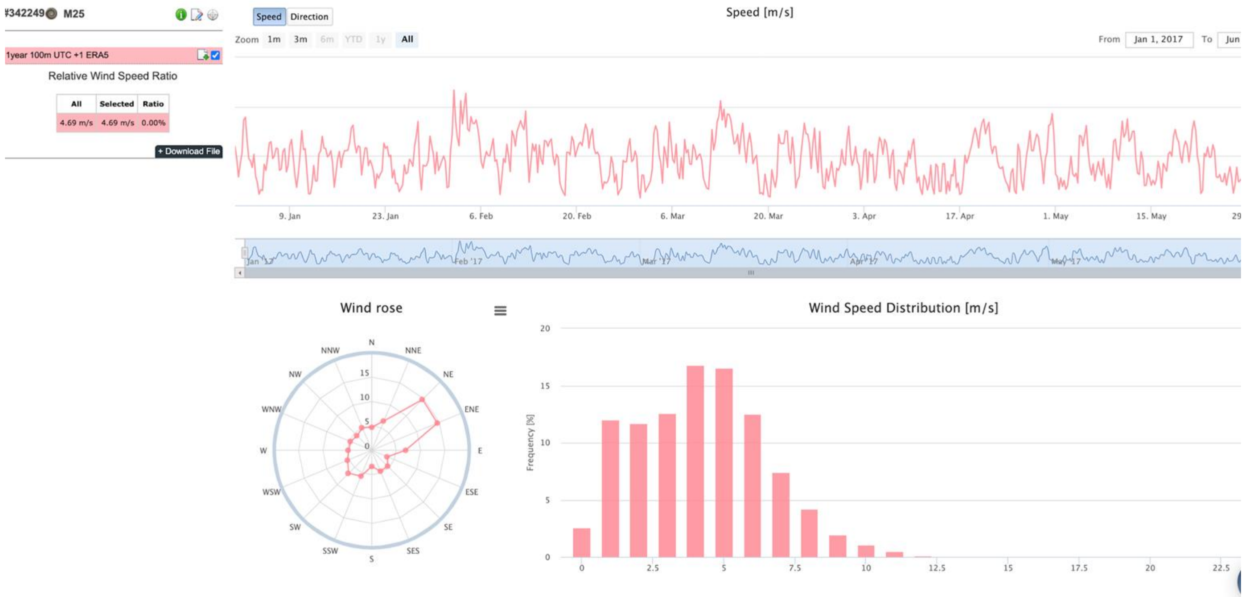


Figure 05: Time Series for WRF LES for M20 location

Use Case 2 – Complex Terrain





WRF - LES for M20 (right) & M25 (left)
C3S ERA5 driving conditions
NEWA Experiment Digital Terrain Model / 10m

Results from WP3

Use Case 2 – Complex Terrain

- Codes used in WP2

code	Roles in HPCWE
Vortex_WRF_LES	The mainstream of mesoscale wind resource assessments (use case 2 and 3), driven by Copernicus C3S ERA5 Reanalysis.
MPAS	A community meteorological model. Potentially the future model for wind resource assessments.
Code_Saturne (open source)	Integration of meso and microscale simulations for wind resource assessment.

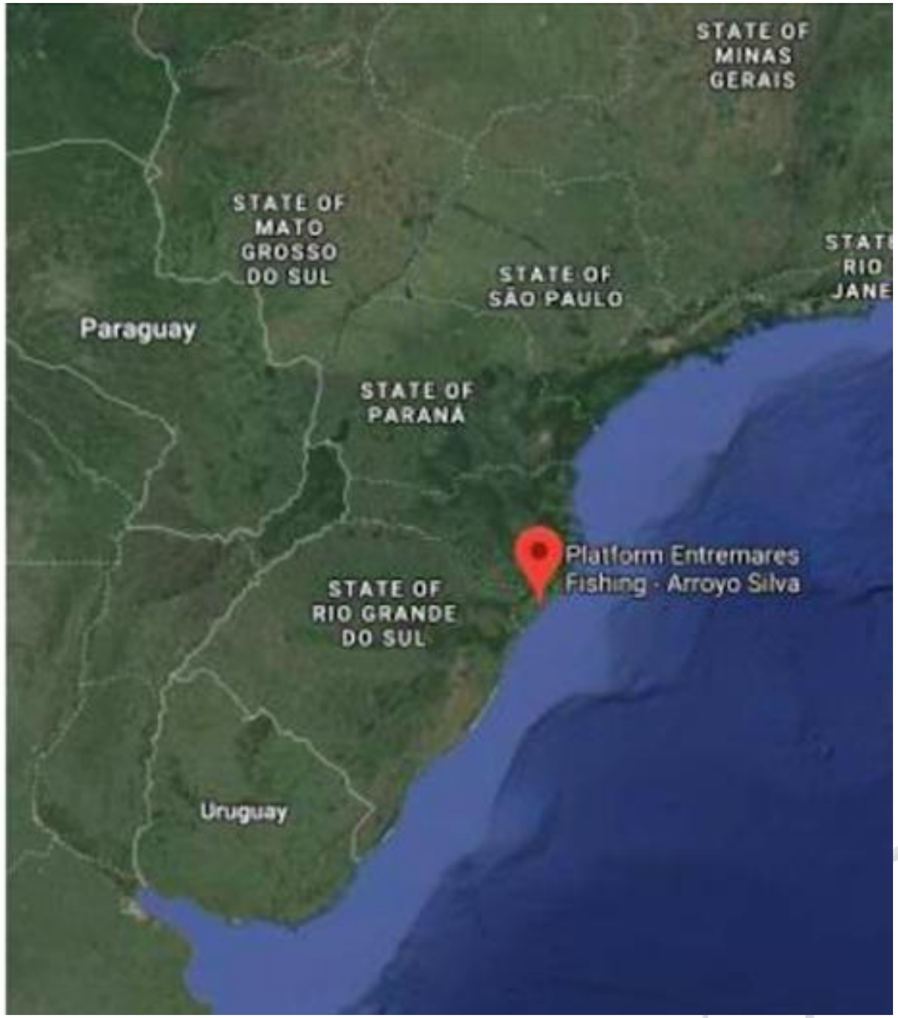
Use Case 3 – Coastal area

Effective scale-integration in wind energy beyond state-of-the-art

Musti-scale modeling exercise
Meso - microscale integration in coastal areas

Site: BOAA Maritime Station, Santa-Catarina - LIDAR

Model Architectures: WRF + LES
EWP-WRF
WRF + RANS (Code_Saturne)

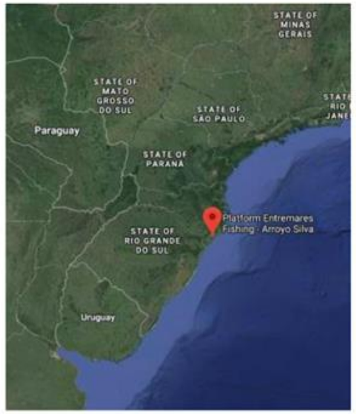


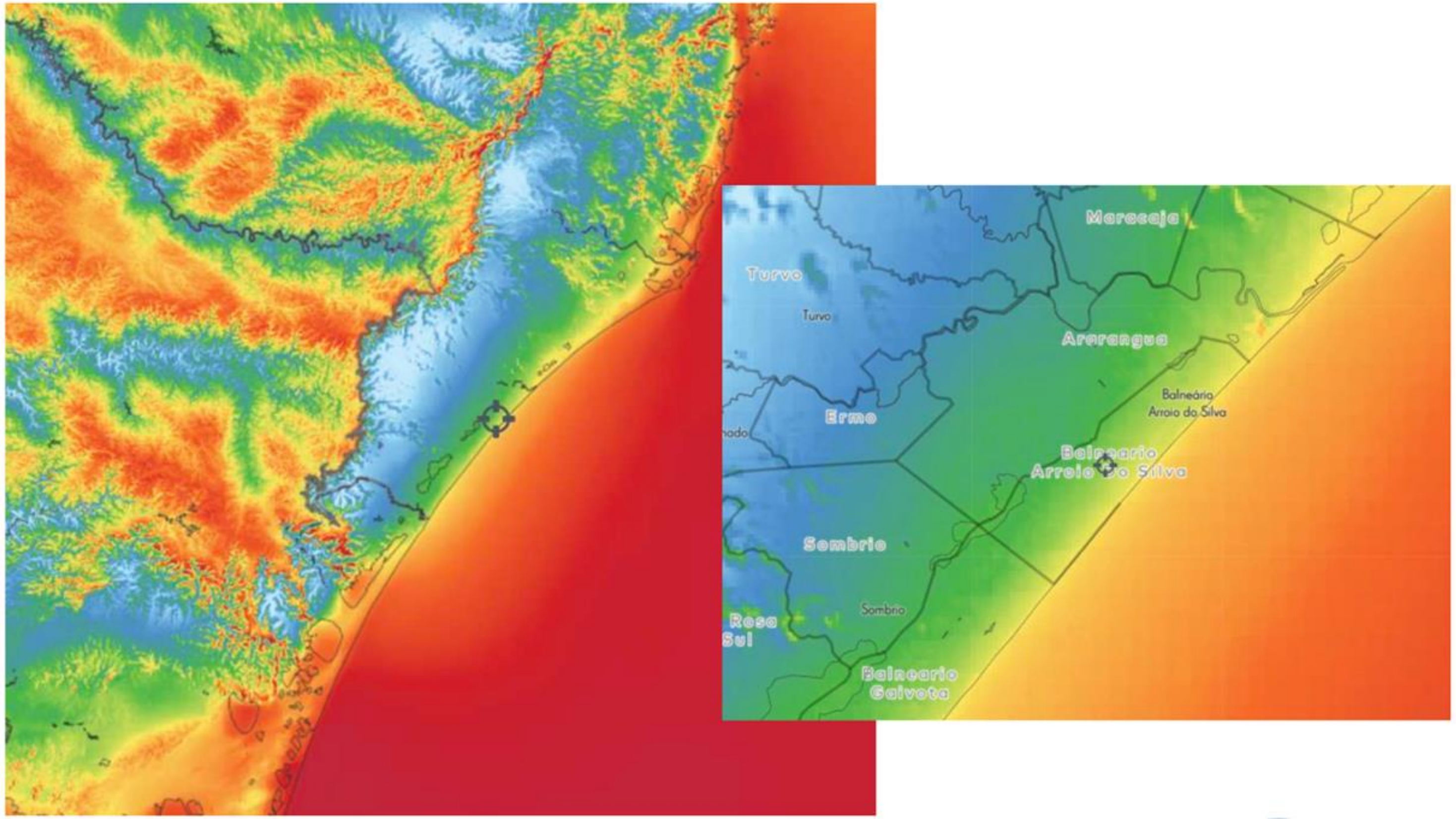
Use Case 3 – Coastal area

(a)

(b)

Use Case 3 – Coastal area





Interim results for average long-term wind speed at 100m height - WRF

Results from WP3

Use Case 3 – Coastal area

WRF for BOAA Maritime Station
- MERA2
- ERA5

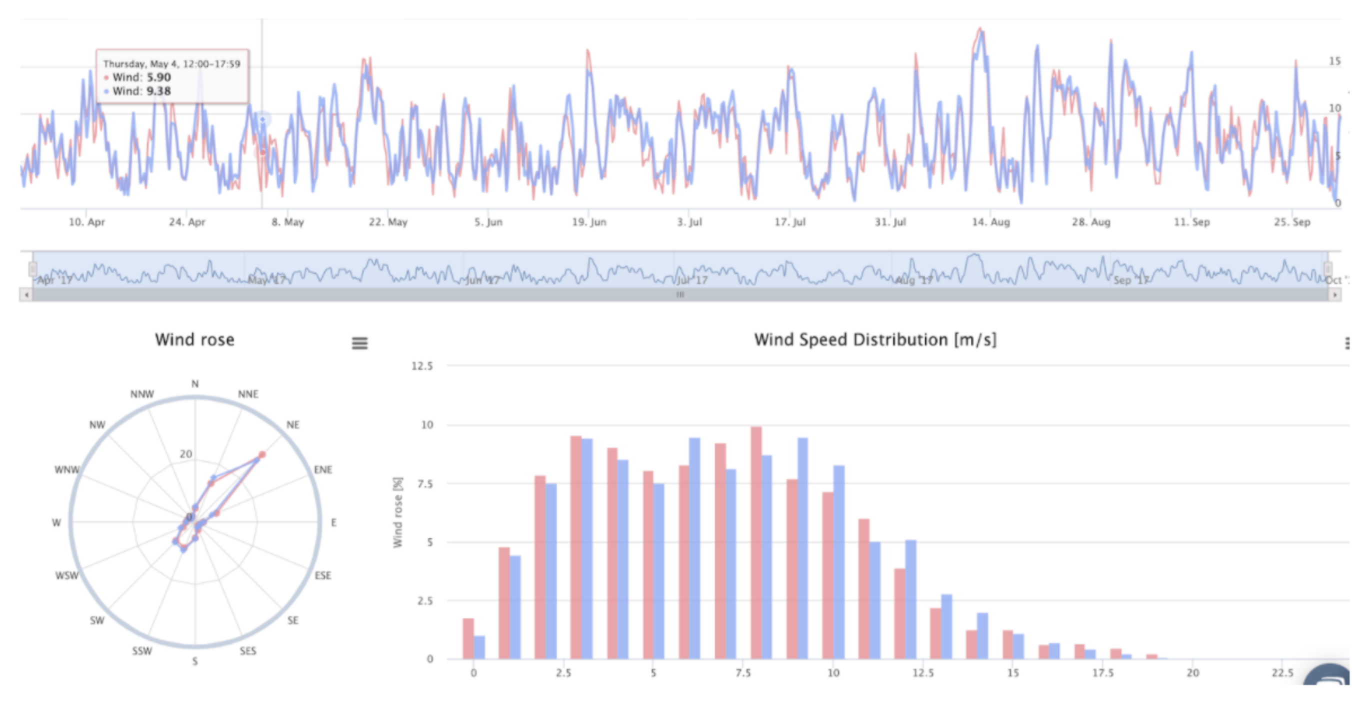
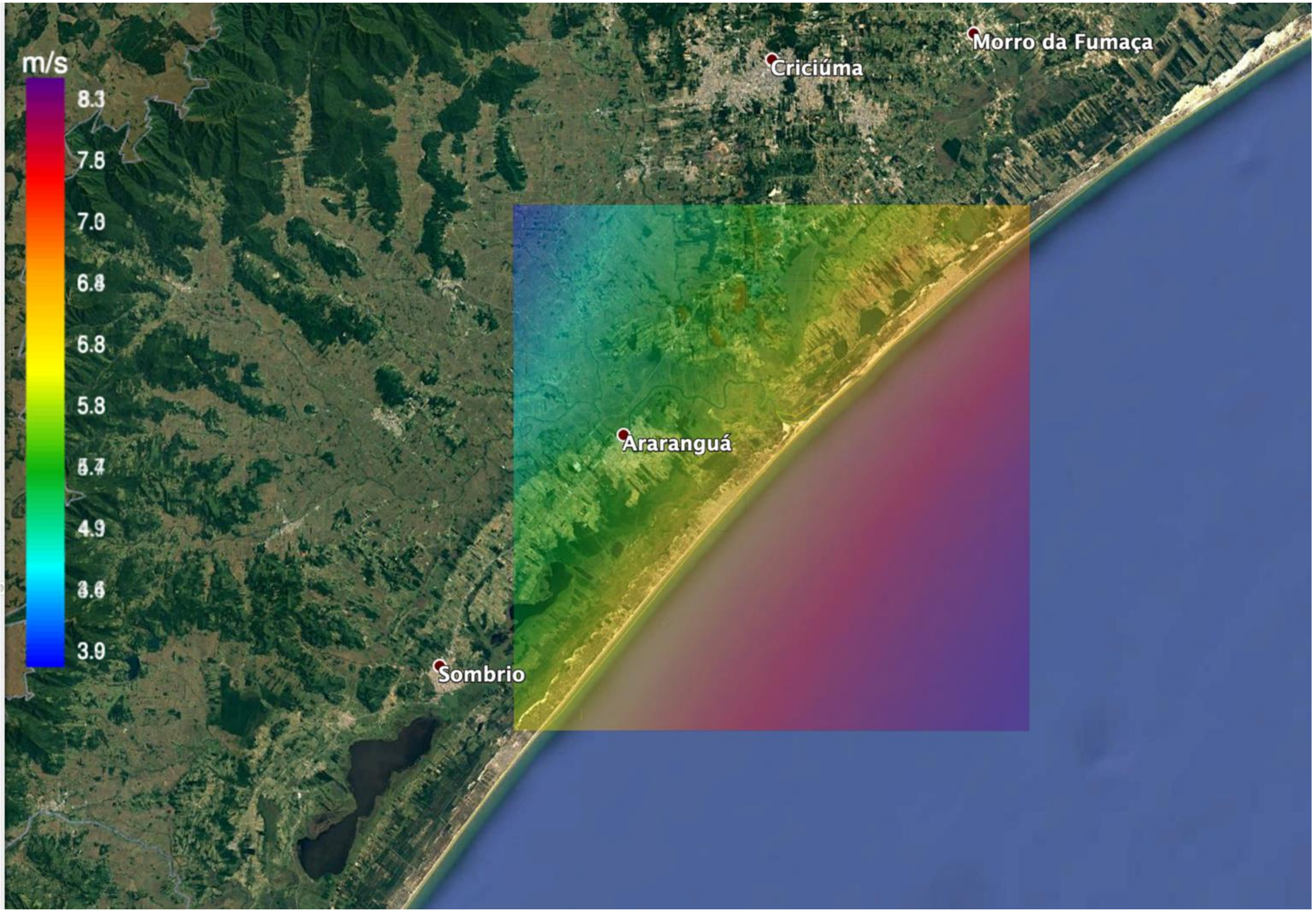


Figure 7:
Time Series for WRF at 3km resolution using MERA2 and ERA5 Reanalysis data

Use Case 3 – Coastal area

Average Long-term Wind Speed at 100m height

WRF Model
Standard Parameterizations (No LES)
Spatial Resolution: 100m
Period: 2000-2019



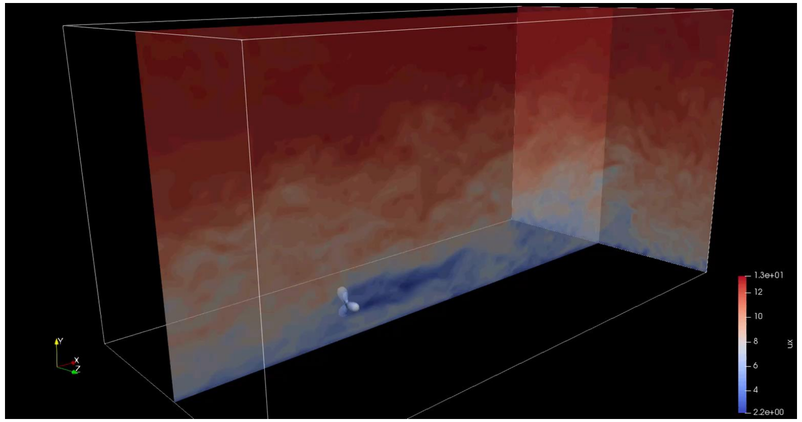
Use Case 3 – Coastal area

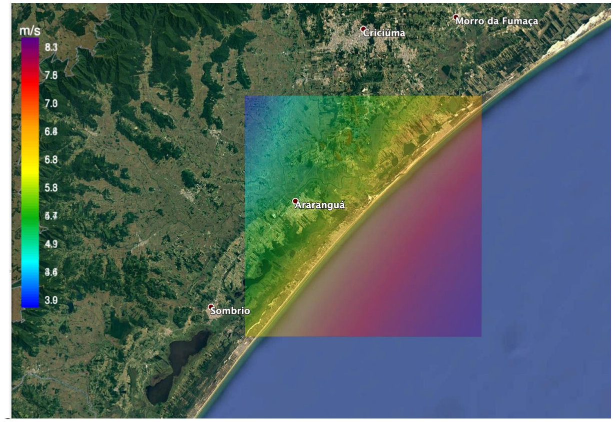
- Codes used in WP3

code	Roles in HPCWE
EWP	Module to account for flow effects of wind farms that can be embedded into mesoscale meteorological simulation platforms.
Vortex_WRF_LES	The mainstream of mesoscale wind resource assessments (use case 2 and 3), driven by Copernicus C3S ERA5 Reanalysis.

Summary

HPCWE is promoting the use of high-performance computing in Wind Energy applications in both Europe and Brazil



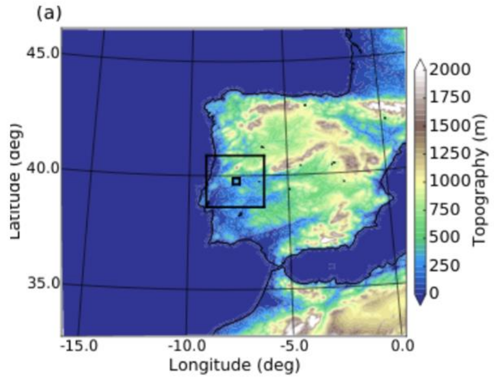


Three Use Cases

- Wind turbine model
- Onshore wind farm site in Portugal
- Coastal wind farm site in Brazil

Four main objectives

- efficient use of HPC resources in wind energy simulations
- accurate integration of the meso- and micro-scale simulations
- reduction of I/O data in optimization
- establishment of an EU-Brazil network



Results from WP1 and WP3

Thank you

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