OFF SHORE PLAN

Towards a high-resolution offshore wind Atlas - The Portuguese Case

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Presentation outline :

- Introduction
- Mesoscale modelling features to improve the wind resource characterization
- Development of the new offshore wind Atlas: Model calibration - *Step I*
- New offshore wind Atlas: Atlas Validation - *Step II*
- Final Remarks

Introduction

Introduction

- **Offshore wind energy** is a key contributor towards the **decarbonisation** of several **electrical power systems**.

- A **reliable offshore wind resource assessment** is a **crucial step to establish a strategic plan for the exploitation of marine renewable energies**. Although:
  - ➢ experimental measurement campaigns may not be cost effective, especially for deep offshore regions, and these data are, typically, collected inside a limited spatial and time window,
  - ➢ while wind observations inferred through satellites still present large amounts of missing/poor quality data and low spatial/temporal resolution .

- **To achieve this goal**, without resort to an extensive and costly network of anemometric stations or buoys, **it becomes necessary to use the so-called mesoscale numerical models**.

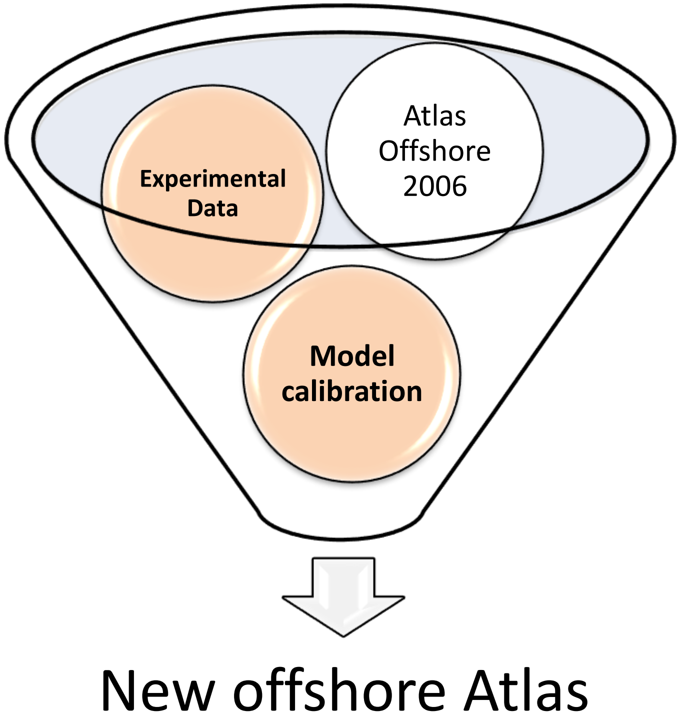
- These models have the **ability to describe important atmospheric phenomena for wind power** purposes such as the atmospheric turbulence, stratification, and sea-land-breeze processes.

Introduction

- The first offshore wind Atlas for Portugal was produced in 2006.

- The **improvements** observed in the **numerical simulation field**, the **lack of measurements to validate** the previous Atlas, **required a new offshore wind Atlas** to support the spatial planning of marine energy sources for the maritime area of Continental Portugal.

- In **this work presents**:
  1. a high spatial resolution (1x1 km) **offshore wind resource Atlas for Portugal**
  2. the **mesoscale model calibration steps**.



Mesoscale modelling features to improve the wind resource characterization

- *Meteorological boundary and initial conditions*
- *Atmospheric parameterizations*
- *Data assimilation*

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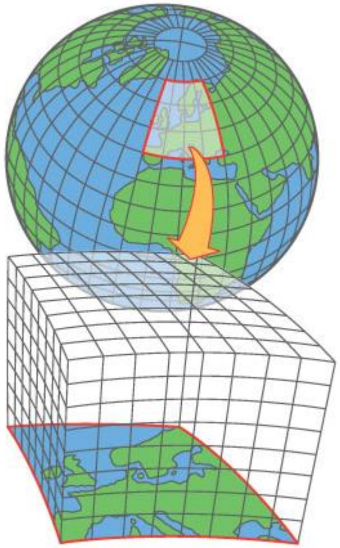
- *Meteorological boundary and initial conditions (IBC)*



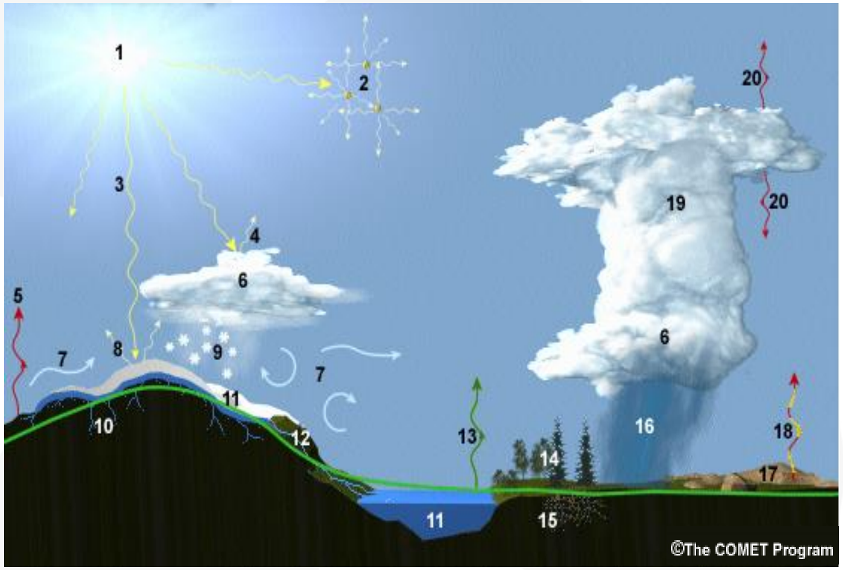
Source: www.csc.fi

- **Data from global model present low spatial and temporal resolutions for local effects characterization**:
  - Spatial Res.: > 25 km;
  - Temporal Res.: > = 1 h (typically 6 h).
- Data from global models essential for feeding mesoscale models:
  - **Initial and border conditions**

Main characteristics of the most common applied IBC products.

Dataset	Time res. (hours)	Assimilation system	Horizontal res. (Lat. X Lon.)	Vertical levels
NCEP-R2	6	3D-Var	2.50° x 2.50°	28
CFSR	6	3D-Var	0.50° x 0.50°	64
ERA-Interim	6	4D-Var	0.75° x 0.75°	60
GFS	6	3D-Var	0.25° x 0.25°	64
FNL	6	3D-Var	1.00° x 1.00°	52
ERA-5	1	4D-Var	0.28º x 0.28º	72

- *Atmospheric parameterizations*

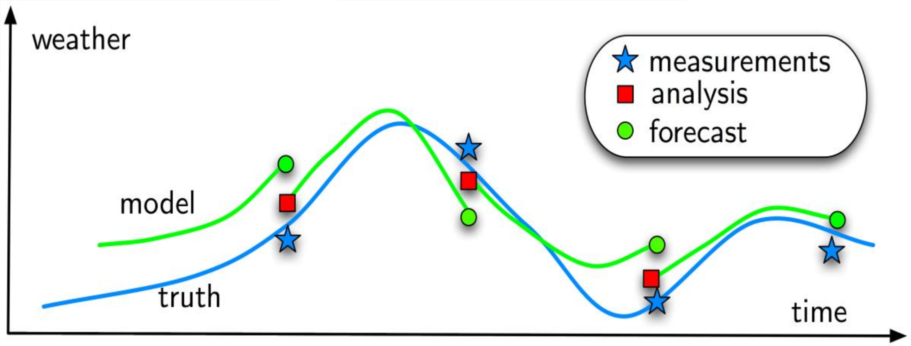


Source: The COMET program (adapted).

- Mesoscale models solve the Navier-Stokes equations.

- **Numerical parameterizations** enable to close the equations using approximations in the simulation to describe the physical processes:
  - *Planetary boundary layer*
  - *Cloud microphysics*
  - *Cumulus*
  - *Radiation processes*
  - *Etc. …*

- *Data assimilation schemes*



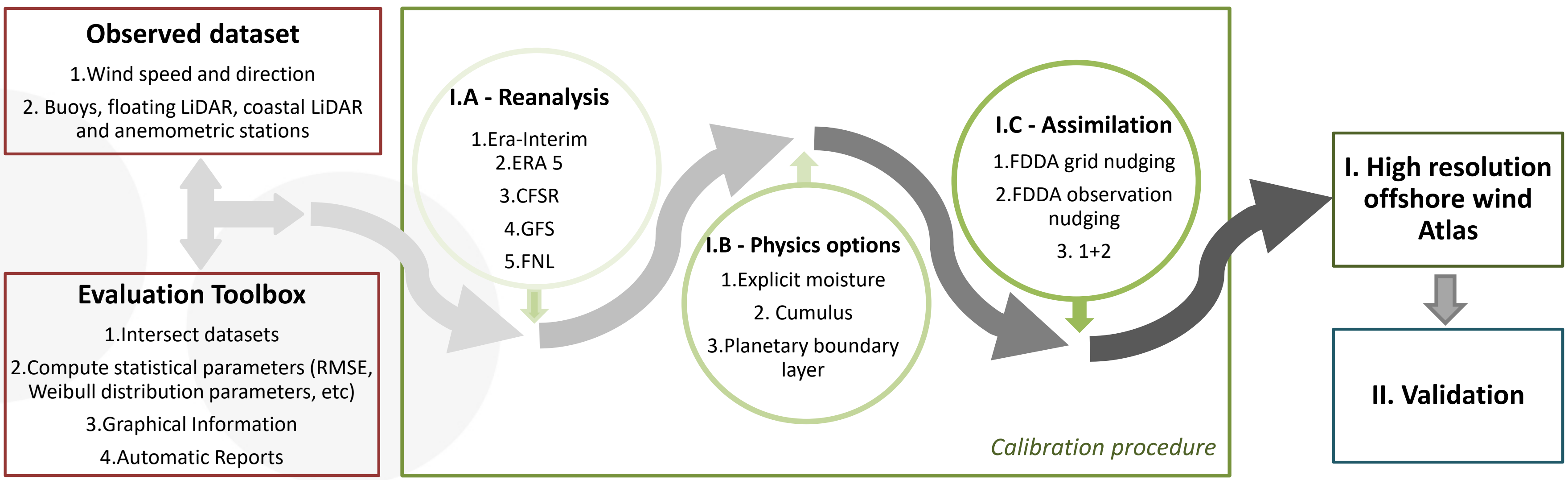
Source: pedagotech.inp-toulouse.fr

- **Assimilation**: numerical technique that combine observed meteorological data with a "first guest" product derived from the numerical prediction model.
  - Equations and parametrizations of the model assure the atmospheric dynamic consistency;
  - Observations keep the model close to the real conditions compensating the deviations associated with the model physics.

- Most relevant parameters in the assimilation schemes:
  - Influence radius - R;
  - Time window - T;
  - Nudging coefficient - G.

Development of the new offshore wind Atlas: Model calibration - *Step I*

- *Methodology*
- *Data*
- *MM5 model configuration*
- *Results*



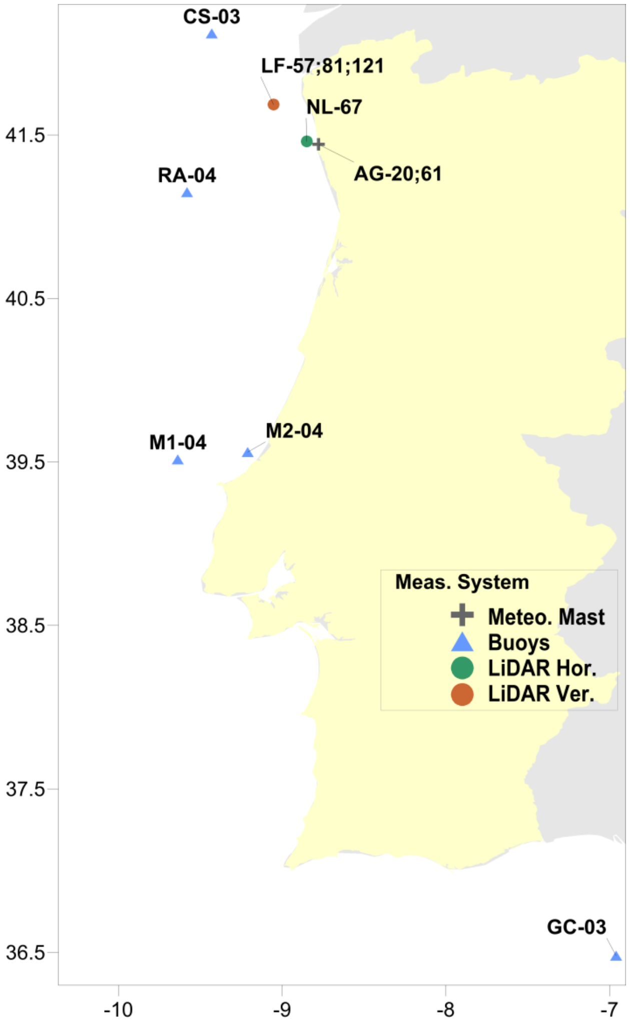
- **Numerical Mesoscale Model** → Fifth-generation Mesoscale Model - **MM5**.
- Evaluation Toolbox → developed to compute the common statistics metrics (*e.g.*, RMSE, bias, Pearson correlation, Weibull distribution parameters, etc.).
- The model calibration is performed through sensitivity tests using the common statistics metrics and hourly simulated/observational data.

Data – Calibration step

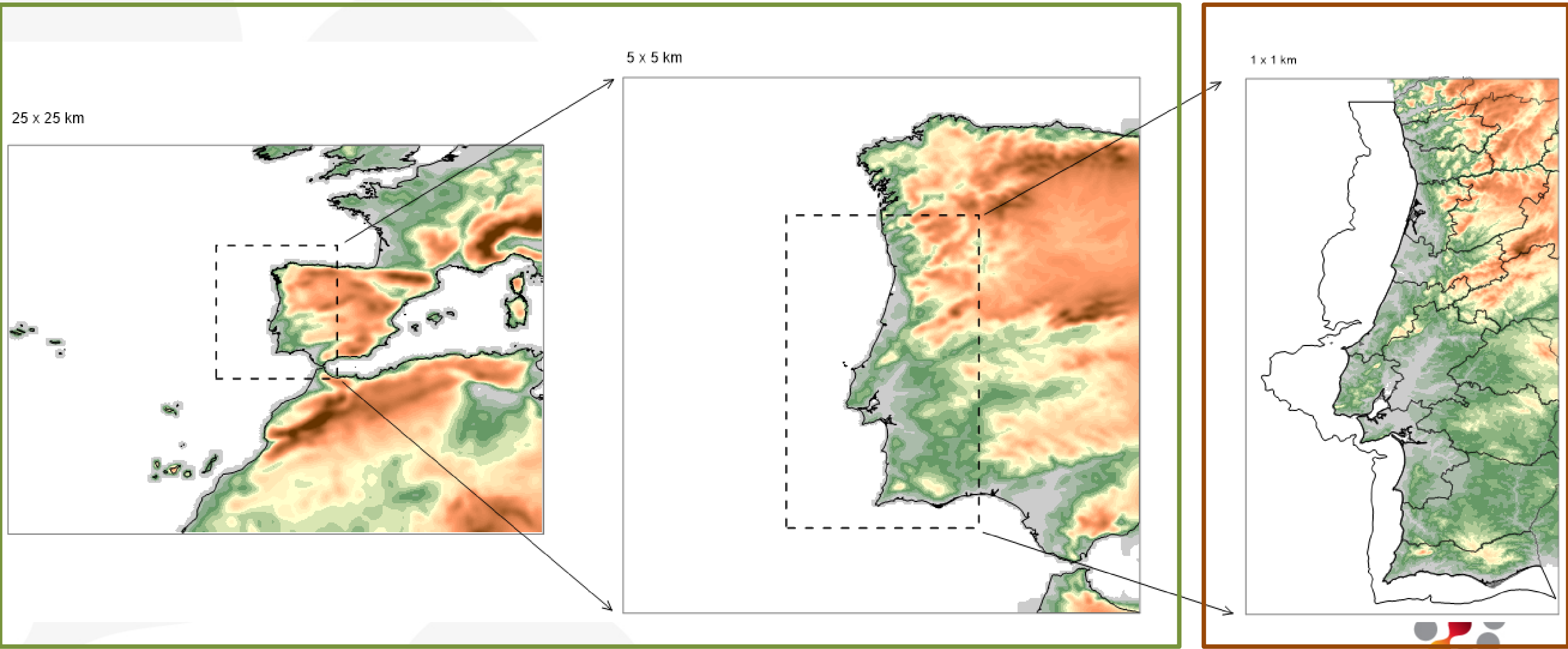
- Observed data used during the calibration step:
  - LNEG database (*e.g.*, FP7 NORSEWind and DEMOWFloat);
  - Buoys publicly available (Instituto Hidrográfico, Puertos del Estado.

- Assimilation data:
  - Satellite → *Global blended ocean wind – scatterometer* and *radiometer* combined with *ECMWF forecasts*.

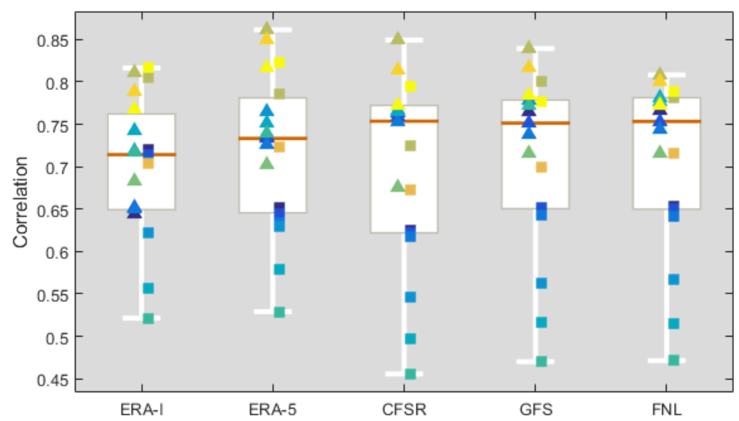
- Calibration period:
  - **Summer**: 01-08-2014 a 01-09-2014
  - **Winter**: 29-12-2014 a 29-01-2015

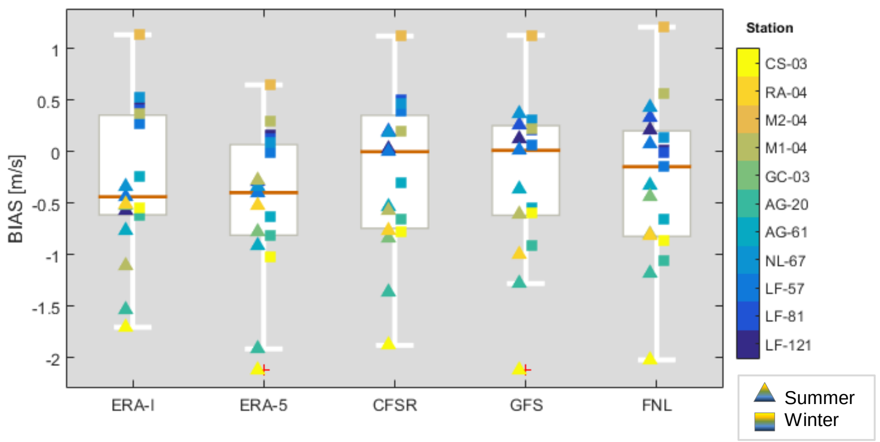


- **3 domains using a one-way nesting technique.**
- **Spatial resolution** : 25x25km, 5x5km e 1x1km (until 300 m bathymetric).
- Simulations were configured *i)* to restart every day, *i.e.*, runs continuously only 24 hours, and *ii*) for recording data every hour.



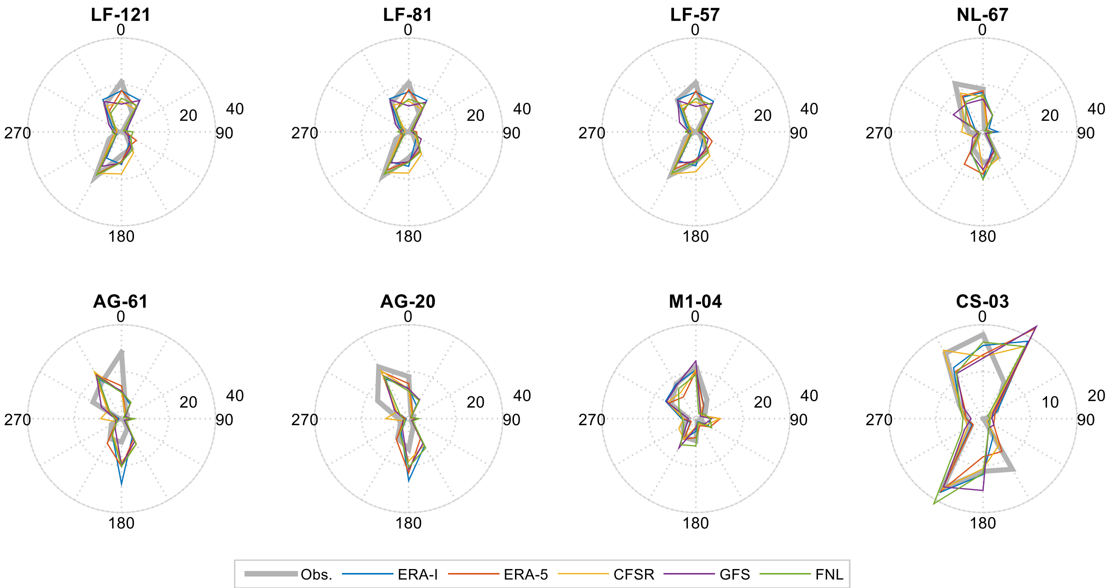
- **I.A** - Identification of the **most adequate meteorological initial and boundary conditions**
    - *5 products were tested: FNL, ERA-Interim, CFSR, GFS e ERA-5.*



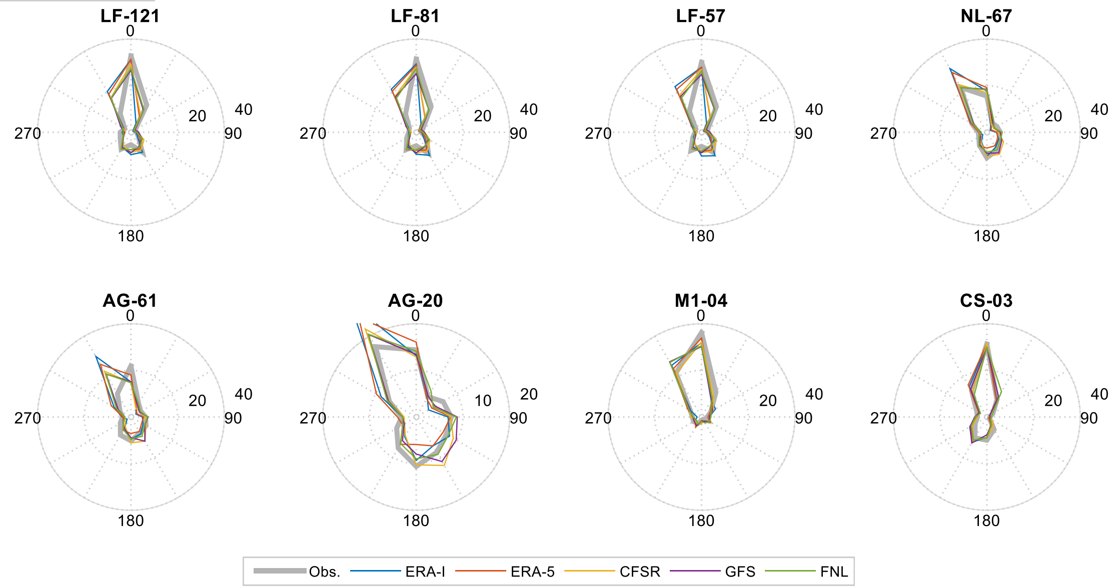


- Overall, the recent **ERA-5 (ECMWF) product presents the best performance** in the statistical parameters analysed.

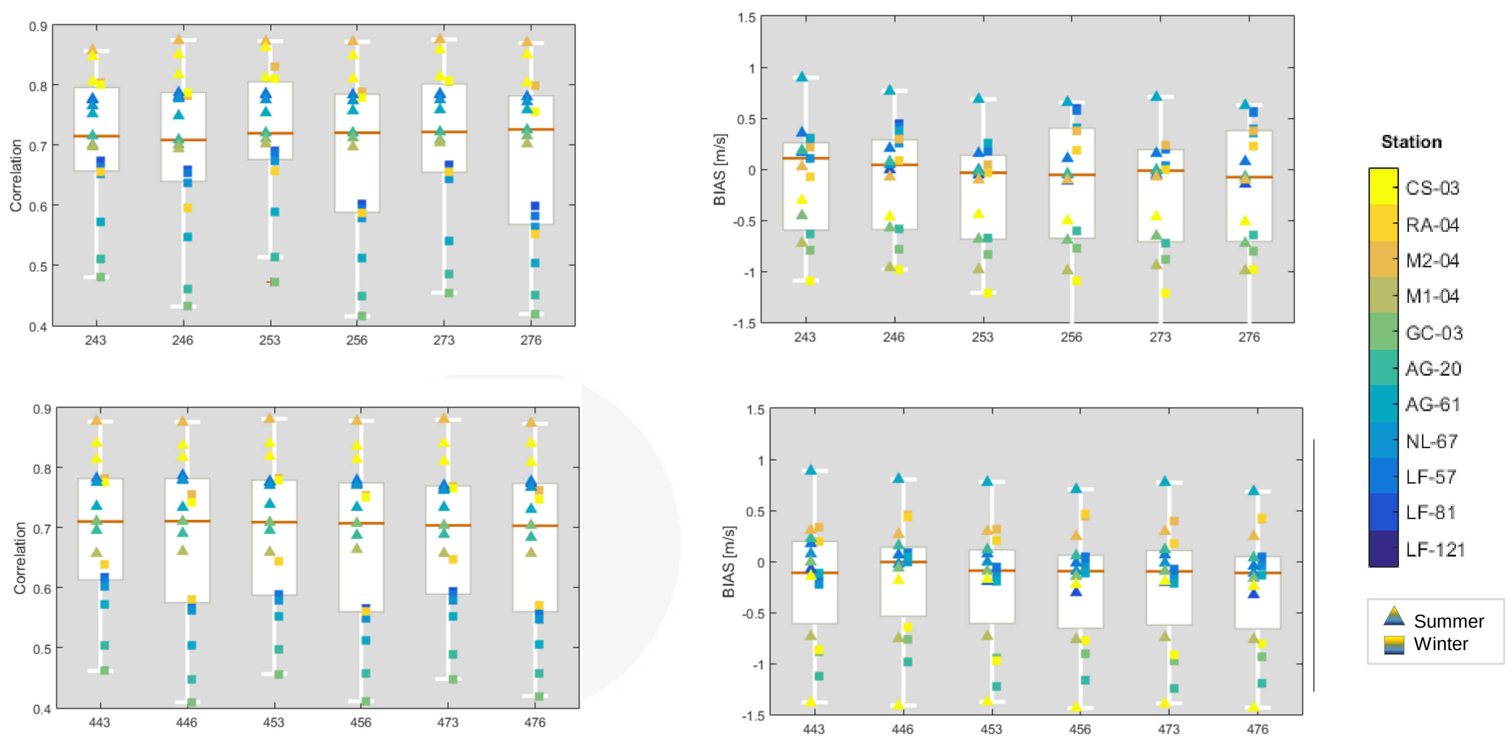
- **Power density rose**



- **Wind rose**

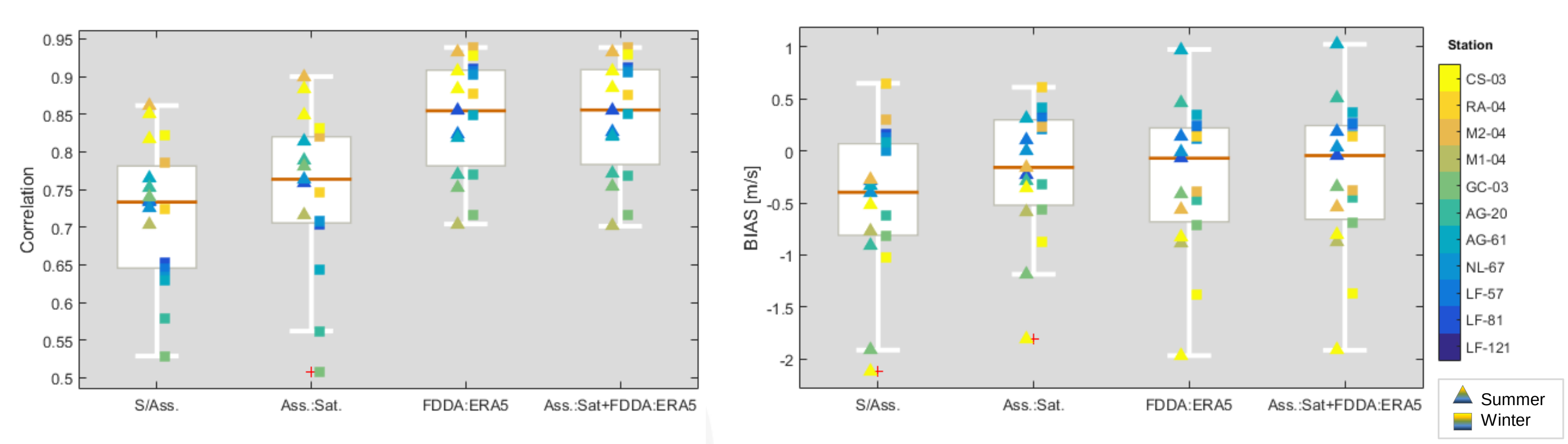


- **I.B** - Identification of the **most adequate physical parameterizations**:
  - *27 different set of parameterizations were tested: Microphysics - IMPHYS (3), PBL - IBLTYP (3), and cumulus- IUCUPA (3).*



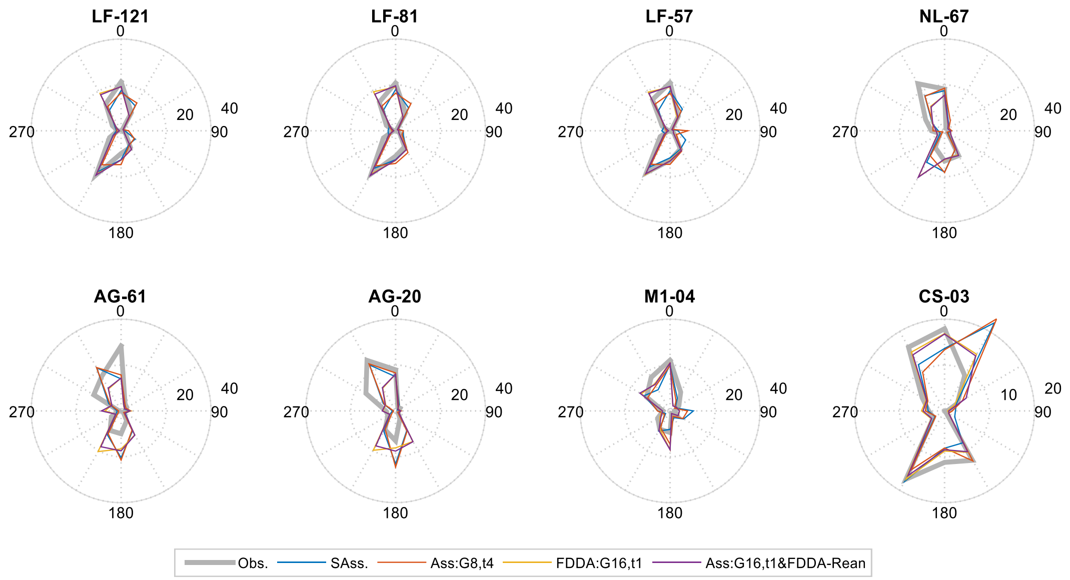
- The sensitivity tests for the atmospheric parameterization showed **small differences among the different options tested.**

- **I.C** - Identification of the **most adequate assimilation scheme and data**:
  - *Several sensitivity tests (e.g., nudging, obs-FDDA) were implemented to identify the most adequate assimilation scheme, parameters (G, T and R) and dataset.*



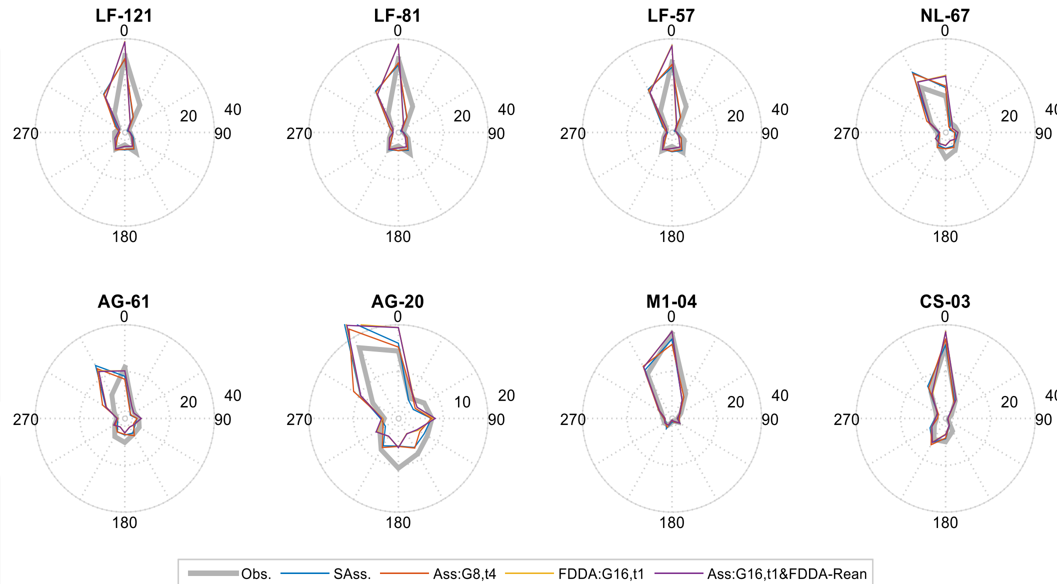
- Using the **four-dimensional data assimilation (FDDA) scheme significant improvements were found.**

- **Best performance** was achieved with the **data assimilation based on information inferred by satellite** in the ocean **coupled with data from ECMWF reanalysis ERA-5** project.

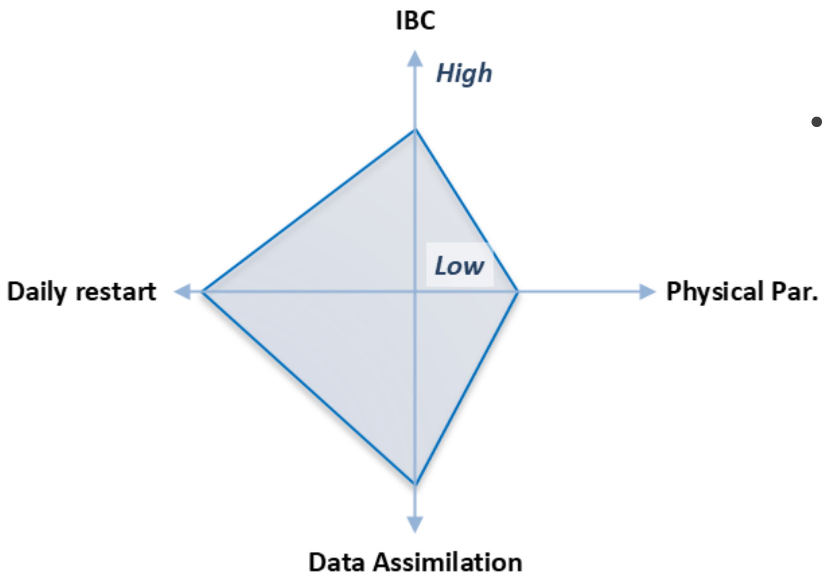


- <u>Power density rose</u>

- <u>Wind rose</u>



- More than 100 sensitivity tests were performed using the MM5 model.



- **The highest improvements** in the calibration results were **associate to:**
  - **Daily restart** of the model → prevents the errors propagations during the simulations;
  - **Data assimilation** schemes.

- Based on the previous findings → **long term simulations were performed to obtain the new offshore wind Atlas for Portugal with a spatial resolution of 1km**:
  - Simulated period : 01.01.2015 – 31.06.2018

New offshore wind Atlas: Atlas Validation - *Step II*

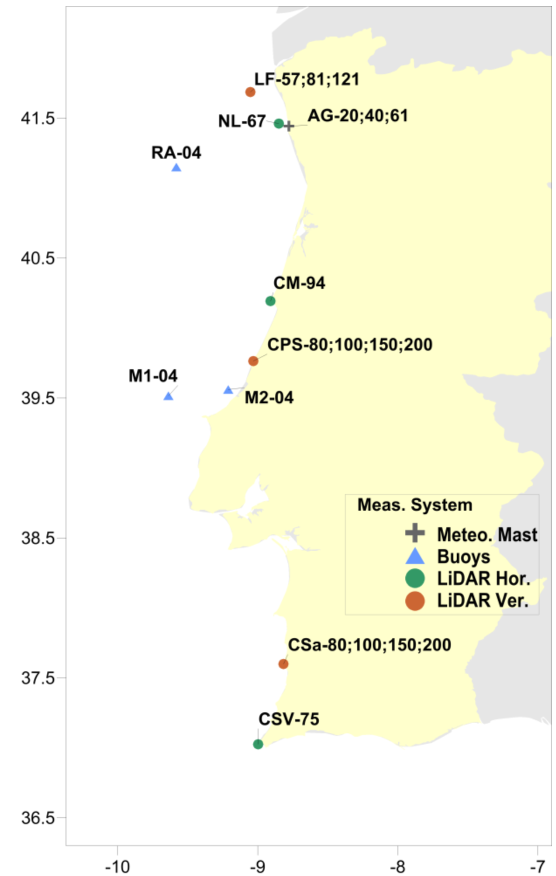
- *Data*
- *Results: validation performance and the new offshore wind Atlas*

Data – Validation step

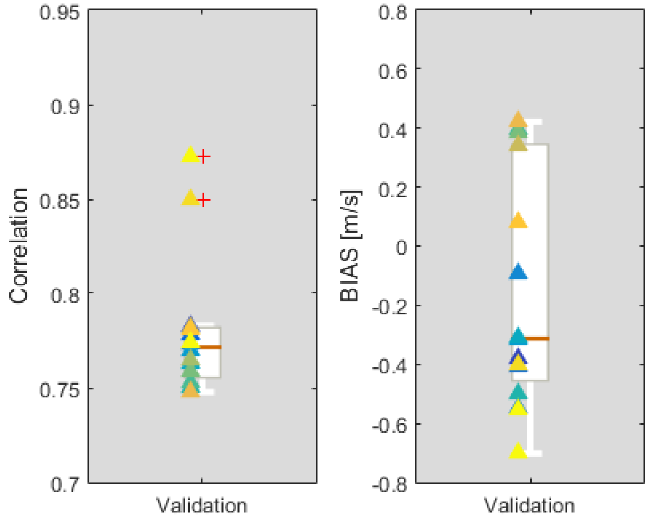
- Short-term experimental measurement campaigns took place to validate the new offshore wind Atlas.
- These campaigns were based on Light Detection and Ranging (LiDAR) systems:

  - **Horizontal LiDAR system:**

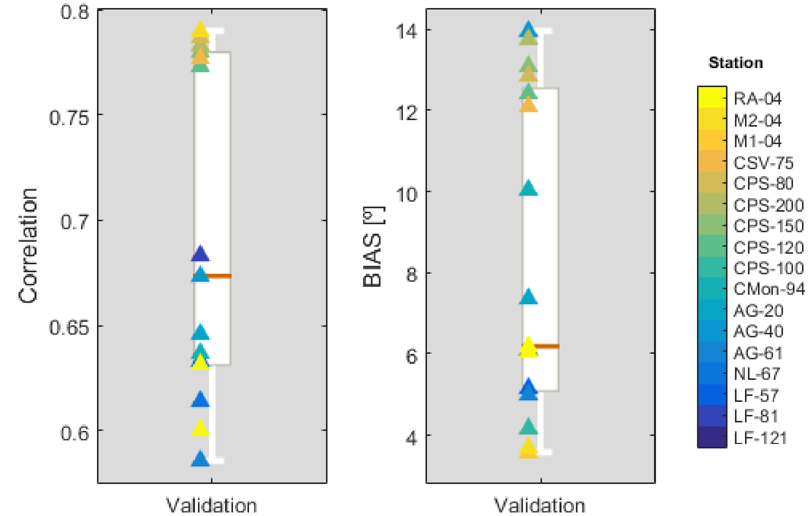
  - **Vertical Lidar system:**



Wind speed results



Wind direction results



- The **average bias error is only -0.14 m/s**, while the median value is -0.29 m/s.
  - Errors showed non-dependency from the measurement height → stratification of the atmosphere was correctly simulated;
- Average wind speed correlation is 0.79, although some measurement points show a correlation of nearly 0.90.
- **Average wind direction bias error is always above 15º**. For some stations, the correlation is only 0.6.

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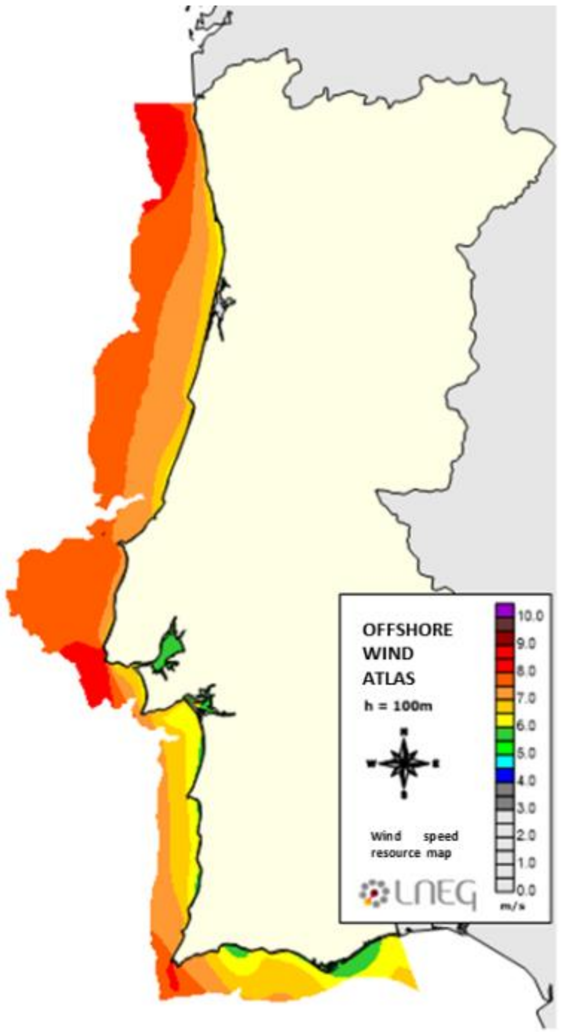
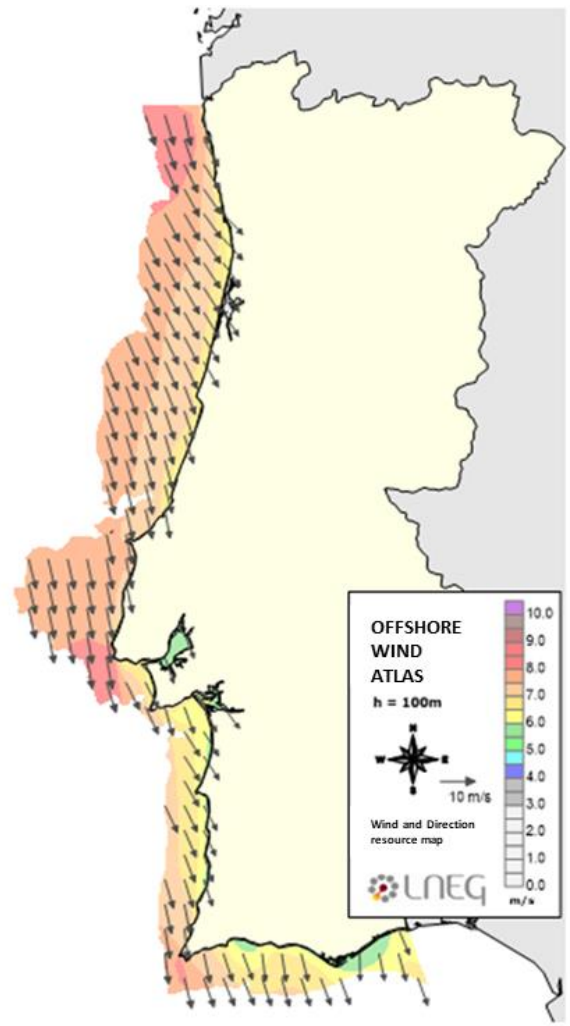
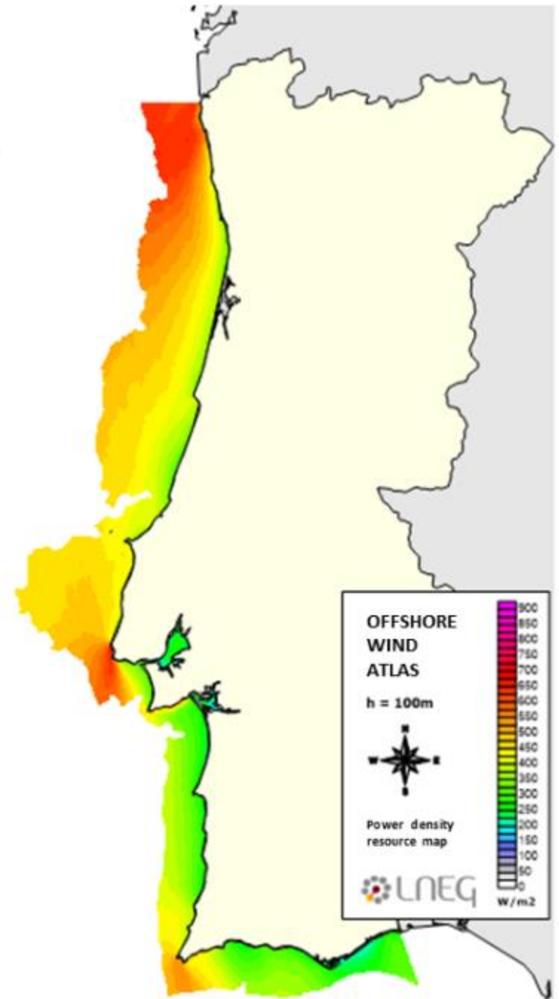
- **Wind speed map**



- **Wind direction map**



- **Power density map**



Final remarks

- This paper presents the calibration procedures and the new offshore wind Atlas for Portugal with a spatial resolution of 1x1km to adequately describe the wind phenomena over the sea and in the cross-border sea/land areas.

- Given the impracticability of studying, in detail, the Portuguese offshore wind potential using experimental data, the only viable way is through numerical mesoscale simulations.

- To overcome uncertainty associated with the use of numerical mesoscale, several sensitivity tests were performed.

- Results show that the calibration procedure is a crucial step to improve the wind speed and direction characterization. The most meaningful improvement was associated with the data assimilation procedure with the observational four-dimensional data assimilation – FDDA, followed by the IBC dataset used.

- On average, the new Atlas shows a bias error equal to -0.14 m/s, and a correlation of 0.79.

- This validated Atlas will support the identification of adequate areas for offshore wind park deployment and allowing to improve the spatial planning of marine energy sources for the maritime area of Continental Portugal.

- Although further research is required to enable its full validation, the adoption of assimilation procedures coupled with the state of art of meteorological IBC presents a promising improvement in the accuracy of the wind resource assessment, especially, at regions where observed wind data are not available.

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- **Acknowledgements**

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