Downscaling with the WRAPP methodology: clustering of meteorological situations and microscale CFD modeling

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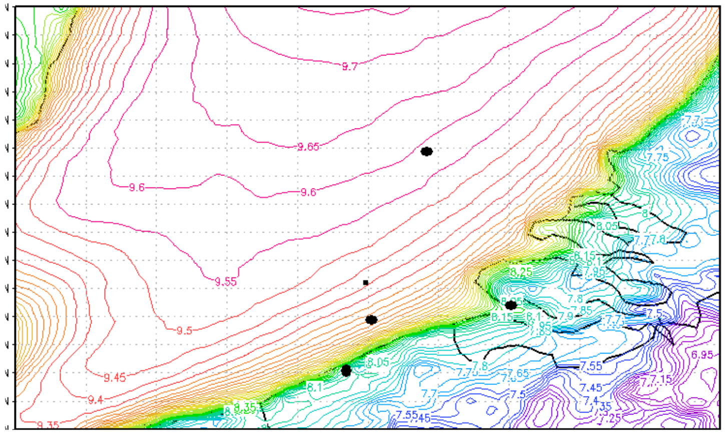
SUMMARY

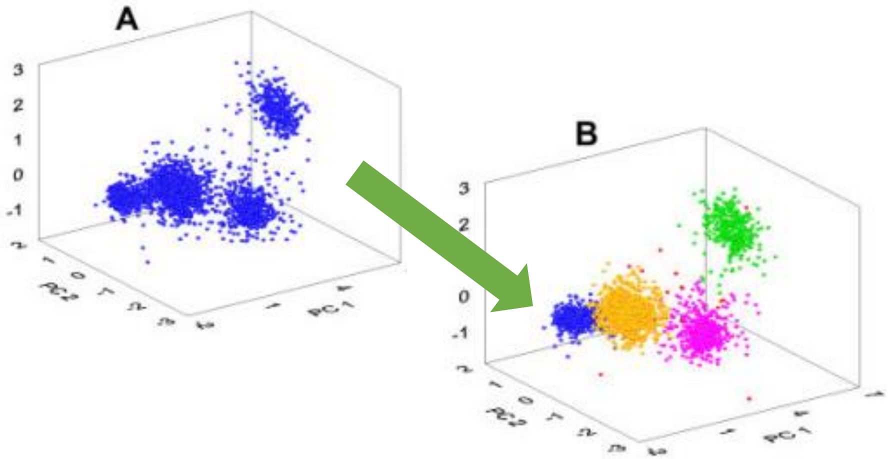
1. Introduction: the WRAPP methodology
2. Improving the clustering step
3. Micro-scale simulations
4. Perspectives within the HPCWE project

1. INTRODUCTION: THE WRAPP METHODOLOGY 1/2

- Need for **accuracy** in wind energy production assessment
  - Impact on financing conditions
  - Important industrial stake
- Increase in turbine and farm size results in increased **wake losses**
  - One of the largest source of uncertainties in AEP evaluation, espacially for offshore wind farms
  - Standard tool: engineering and simplified CFD models
    ⇒ often little to no account for interactions with ABL and **thermal stability**
- EDF has developed the WRAPP methodology to chain **mesoscale** modelling with CFD **micro-scale** simulations

1. INTRODUCTION: THE WRAPP METHODOLOGY 2/2

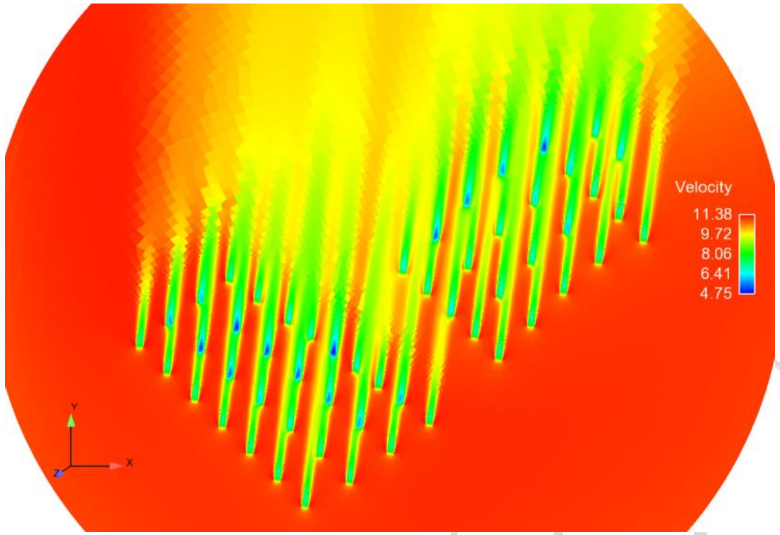




Meso-scale simulations with WRF (thousands to tens of thousands)

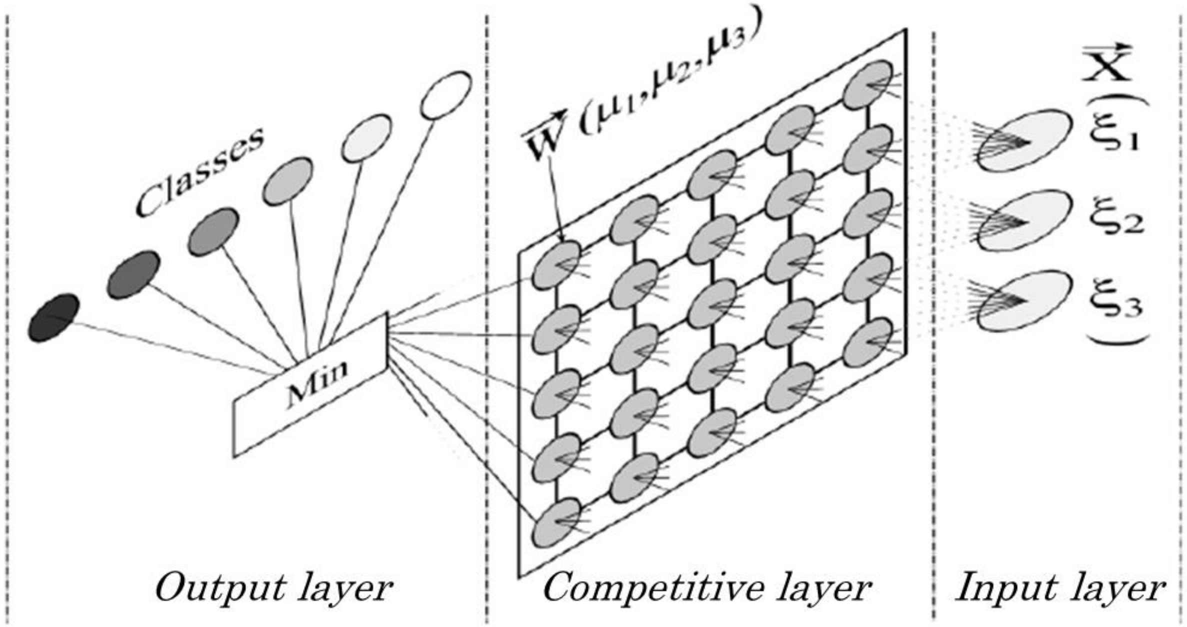
Clustering

Micro-scale CFD simulations with Code_Saturne (hundreds)



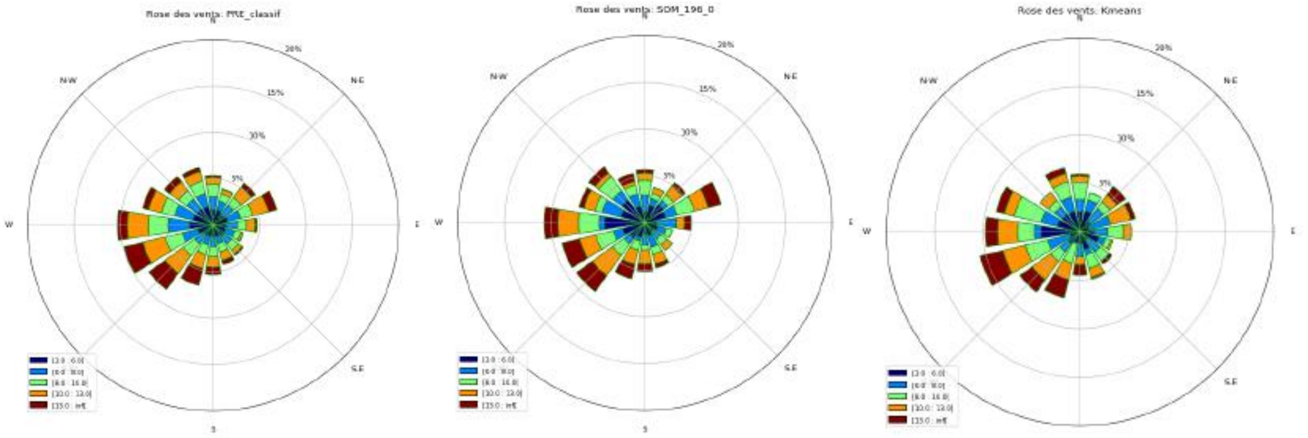
2. IMPROVING THE CLUSTERING STEP 1/3

- Originally, the methodology was developed around a **k-means** clustering, but, for comparison purposes, a preliminary study has been performed with a **SOM** approach (Self-Organizing Map)
  - Encouraging results with SOM
  - Performance benchmark
  - Sensitivity analysis on clustering parameters.
- What are we comparing?
  - K-means: based on a pre-defined number of classes k, whose centres (=means) are randomly initialized; cycles between an
    - **Assignment step**: assign each observation to the cluster with the nearest mean
    - **Update step**: recalculate the means for observations in each cluster.
  - SOM: based on a neural network of pre-defined size, topology and dimension, linked to the input data; cycles between
    - Choosing a **winner** (best matching unit): for each iteration t, an observation X(t) is picked at random, and the closest neuron wins;
    - Updating the map: the winner‘s statistical weight is updated, as well as its neighbours‘. This is modulated through an **activation function**; various such functions can be used.



2. IMPROVING THE CLUSTERING STEP 2/3

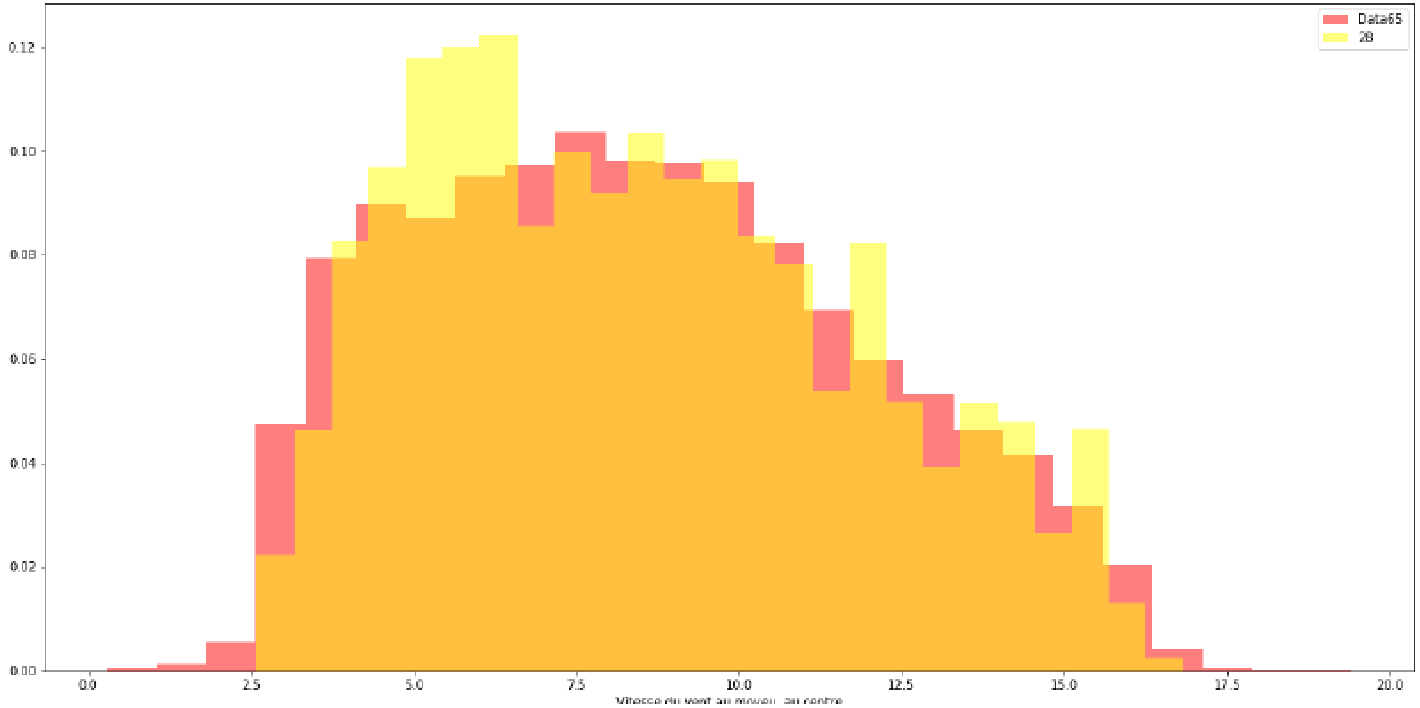
- Extensive dataset based on nudged **WRF computations**:
  - 20138 observations, corresponding to 2.5 years met mast measurements on a French offshore site;
  - Truncated variable number (65) for efficiency reasons:
    - Five interest points are considered;
    - Data observed at 4 different heights for each point;
    - Extraction of meaningful data (velocity, wind direction, Richardson numbers…)
- Comparison of several implementations of SOM and a k-means implementation:
  - The SOM implementations are based on a **14x14 2D** neural network, and differ by the choice of initialization and neighbouring range;
  - **200** clusters for k-means.
- Comparison to pre-clustering data.
  - Check for **distorsions** of initial values;
  - Analysis of velocity, wind rose and energy production.
  - Satisfying performance on **average** velocity and energy production;



Wind rose: pre-clustering data, best-performing SOM and k-means

2. IMPROVING THE CLUSTERING STEP 3/3

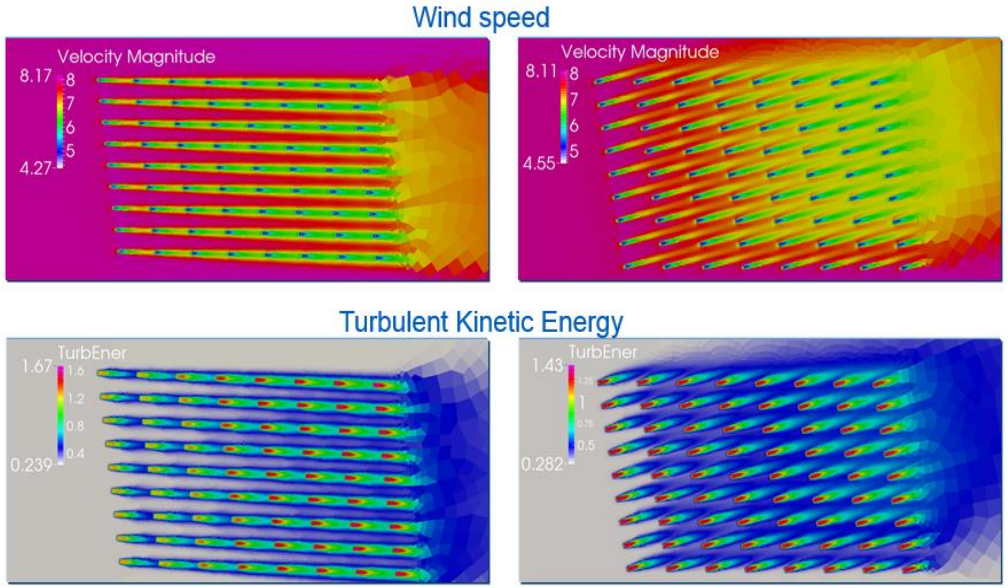
- Comparison to pre-clustering data, cont‘d.
  - Significant **compensation effects** due in part to „erasure“ of extreme data points;
    ⇒ unknown impact on micro-scale computations
  - SOM can obtain better results than k-means but requires fine-tuning the **hyper-parameters**;
  - Increasing the **number of clusters** reduces the distorsion.
    ⇒ what is the optimal number of clusters? Potential interest of Bayesian coresets or Data Squashing approaches to reduce the number of clusters?



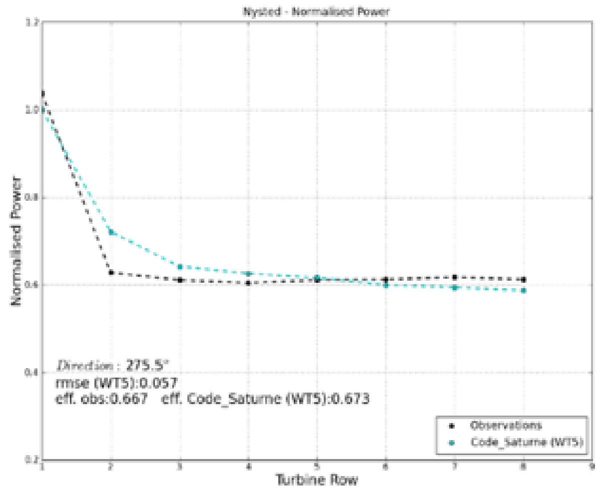
Velocity distribution at hub height: pre-clustering (red), best-performing SOM SOM with 784 clusters (yellow) and k-means (blue).

3. MICROSCALE SIMULATIONS: VALIDATION 1/2

- CFD computations performed with **Code_Saturne**
  - Open source CFD code developed by EDF;
  - Includes an atmospheric module;
  - The WT are modelled through the **actuator disk** approach.
- The WRAPP approach has been tested against **field data**:
  - Stand-alone Code_Saturne: validation against experimental data
    - From the **Nysted** farm: calculated efficiency within 8% of actual data.
    - From the **Horns Rev** farm : calculated efficiency within 8 % of actual data.



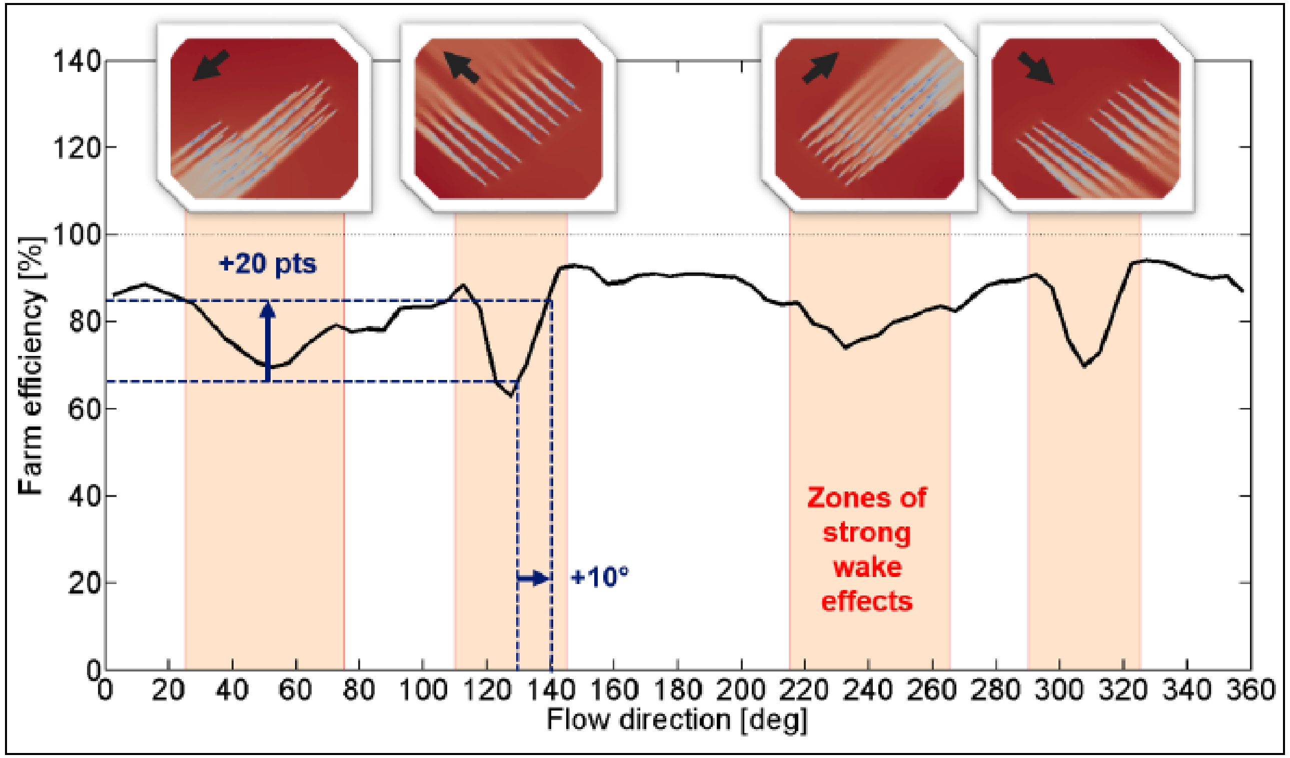
Nysted farm: wind speed and TKE calculated at hub height for directions 278° (left) and 263° (right).



Nysted farm: comparison of the measured and computed values of normalized power along the turbine row for a direction of 278° and 275.5 ° respectively.

3. MICROSCALE SIMULATIONS: VALIDATION 2/2

- The entire WRAPP chain has been tested on the **Thortonbank wind farm**:
  - Offshore farm in the Belgium North Sea
  - **SCADA** data available.
- Methodology:
  - Outsourced WRF simulation;
  - Filtering of the SCADA data;
  - SOM clustering
  - Interpolation of WRF wind profiles to define CFD BC
  - CFD simulations.
- Initial result:
  - ⇒ Wake losses overestimated by about **2 %**
- Large part of the difference can be traced back to:
  - The difference between WRF results and real meteorological conditions: correcting with experimental data yields a wake overestimation of **less than 1 %**;
  - The **stand-by WT effect**: some selected data points have up to 8 WT on stand-by, i.e. not producing any wake ;
  - The relatively **small number of clusters**.

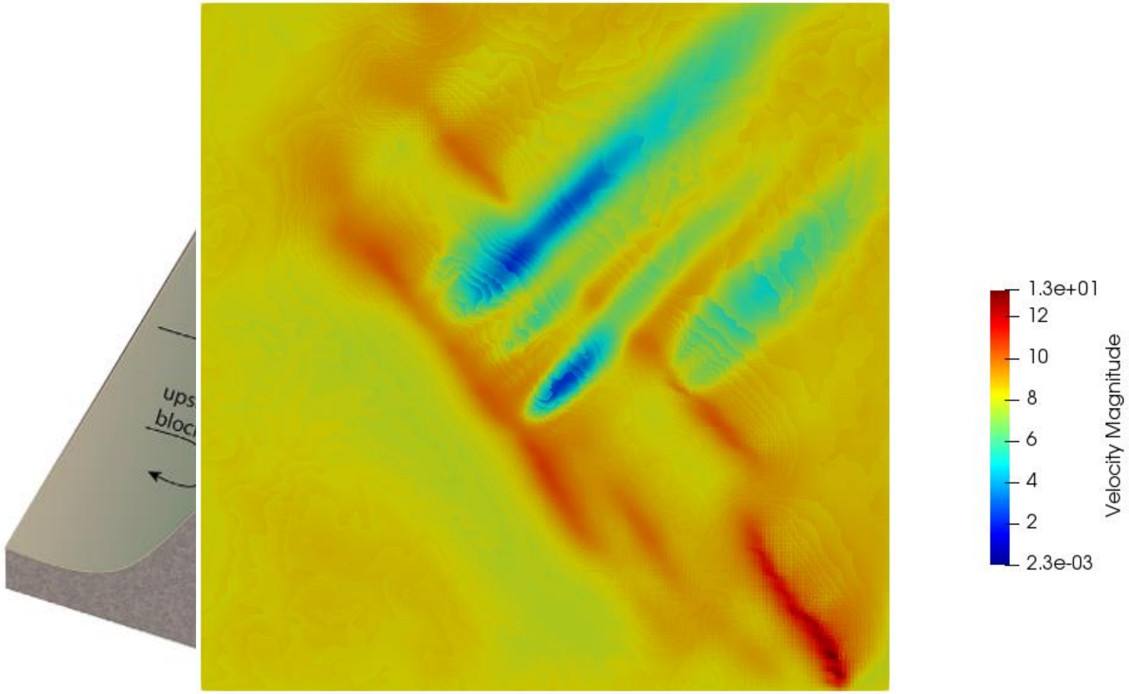


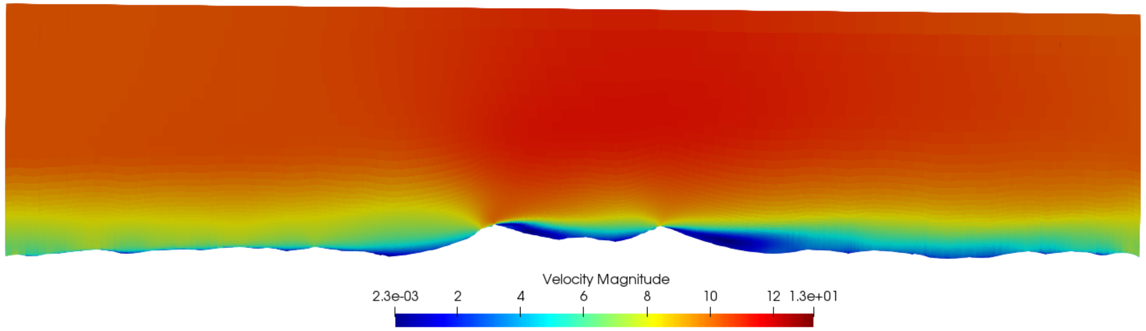
Effect of flow direction on farm efficiency

3. MICROSCALE SIMULATIONS IN HPCWE: PERDIGAO

- Well-instrumented Portuguese site
  - **Complex orography**;
  - NEWA field measurement campaign.
- WRF data to be provided by Vortex;
  - Definition of **input vectors** for the clustering step?
  - Optimal number of classes?
- **Benchmark** with DTU's Ellipsys and comparison to experimental data;
- Preliminary computations finished.

an idealized





H.J.S. Fernando et al., 2018. "The Perdigão: Peering into Microscale Details of M 799-819.

4. PERSPECTIVES

- Within the HPCWE project:
  - Perdigão computations;
  - Brazilian case:
    - Offshore site;
    - 20 years of WRF computations
      ⇒ optimal for a more in-depth study of the **clustering step**.
- In general:
  - The methodology has already been used in an industrial context for EDF Renewables;
  - Further **validation** required
    ⇒ need for high-quality exploitation data over a significant period of time;
  - Impact of blockage effect;
  - Increasing the number of clusters means higher **HPC needs** to perform the micro-scale simulations.

THANK YOU FOR YOUR ATTENTION!