9th WindSim User Meeting

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AEP Optimization

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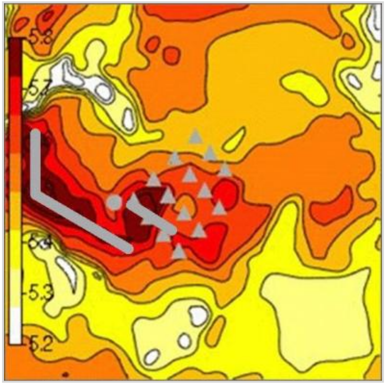
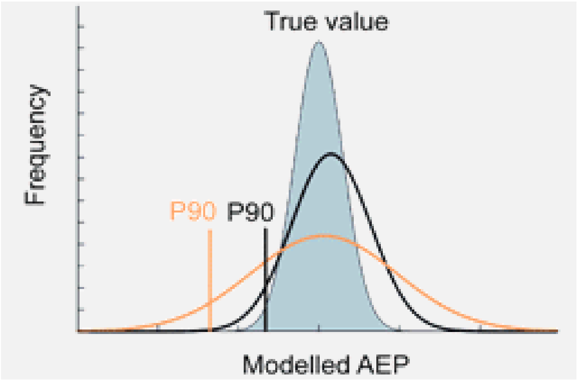
Value proposition – Designing profitable wind farms

- Accurate wind characterization with CFD technology increases the value of wind projects
    - Increased Annual Energy Production, AEP
    - Reduced maintenance costs
    - Better financing, higher P90



10% AEP increase (Torrild, Denmark, 2002)

Correlations; Production log – inflow and turbulence (Chieti, Italy, 2005)

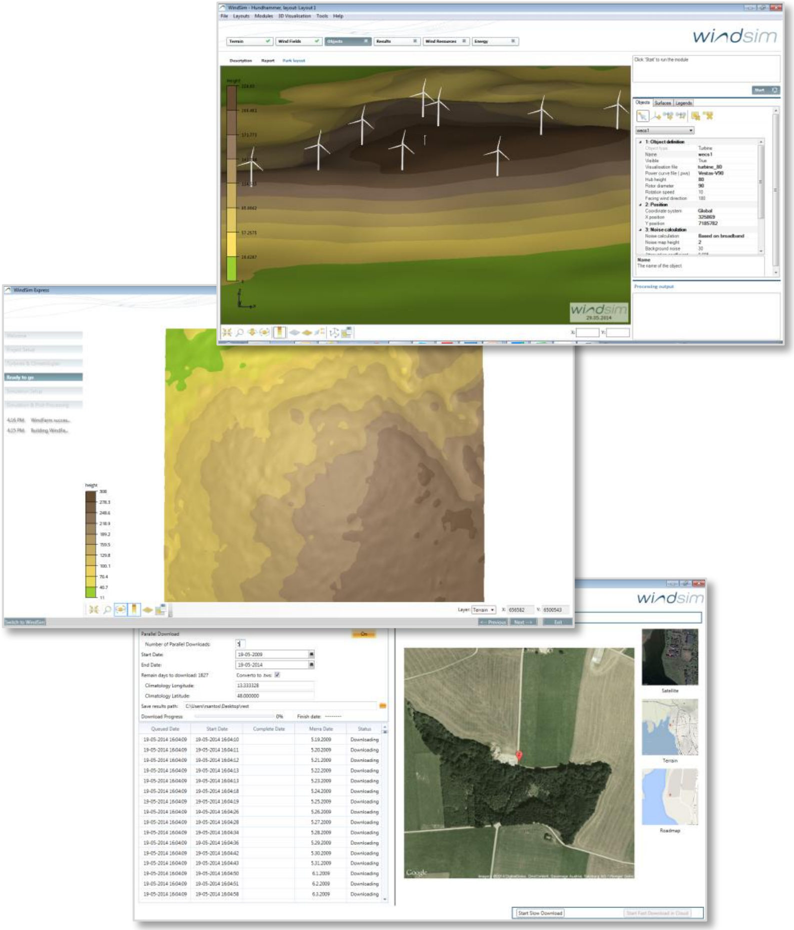


Financiers might ask for CFD, but in general the uncertainties is set by consultants according to their experience

Software suite

Software:

- WindSim
- WindSim Evaluation
- WindSim Express/WindSim Express Cloud
- WindSim Park Optimizer
- WindSim Power Forecasting



Tools:

- WindSim Terrain Editor
- WindSim Reanalysis Data Downloader
- WindSim RSCT (Remote Sensing Correction Tool)
- MCU (Multiple Core Utilization)

Wind project time span

Pre-construction | Construction | Post-construction

Screening

Virtual Wind Data
Measurement Campaign Design
Wind Data Analysis (MCP)

Micro-siting
Site Suitability
Park Optimization

Bankable AEP assessment
Due diligence

Post Construction Assessment
Power Forecasting
Operations

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WS Express/WS Express Cloud

WS Power Forecasting

WS Reanalysis Data Downloader

WS Park Optimizer

Authors – Acknowledgements

This presentation is partly based on two papers published at EWEA 2014

Downscaling MERRA Mesoscale Data for the Generation Microscale Wind Fields Using CFD

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From reanalysis data to park optimization

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Objectives – AEP optimization based on reanalysis data

- Check the potential AEP increase in existing wind farms by changing the layout
  - Calculate a reference AEP based on the existing layout and reanalysis data
  - Calculate a hypothetical AEP based on an optimized layout and reanalysis data
  - Find the increased AEP ($AEP_{hypothetical}$ - $AEP_{reference}$)

- As an alternative to the conventional technique of deploying multiple tall met masts and waiting one or several years for this data, we propose the use of mesoscale reanalysis model output statistically and dynamically downscaled using computational fluid dynamics (CFD)

- Before turning to the AEP estimation, lets examine the advantages with reanalysis data and the challenges involved in the downscaling procedure

Reanalysis data – Advantages & Application

• Despite the inherent challenges involved (i.e., coarse resolution, model sensitivities to physical parameterizations, etc.), incorporation of mesoscale reanalysis data into the wind resource assessment process offers a number of unique advantages and opportunities for application

Advantages:

- Provides decades worth of quality controlled, historical meteorological data (i.e. wind, temperature, moisture, etc.)
- Provides realistic wind speed and direction time series for any location on the globe and at any height if downscaled properly
- Reduces dependency on expensive measurement campaigns

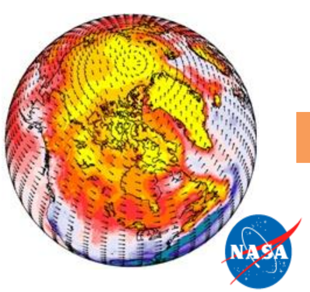
Application:

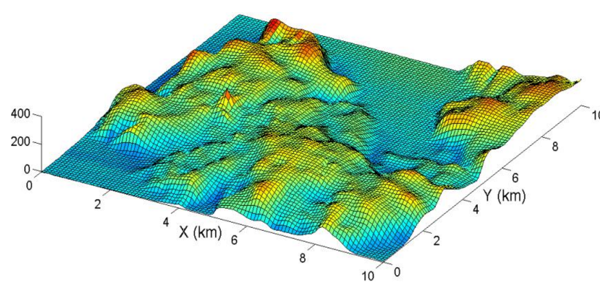
- Early identification of potential site for wind farm projects
- Reference dataset for long term correction (MCP)
- Help measurement campaign design, lower the investment risks of tall and well instrumented met mast
- Early optimization of the layout and other early stage wind farm planning

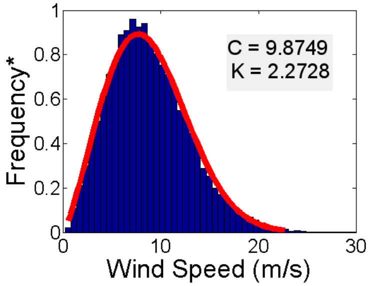
Downscaling MERRA data using CFD

• In this study, modeled meteorological data from NASA's "*Modern-Era Retrospective analysis for Research and Applications*" (MERRA) reanalysis dataset was used to scale CFD simulations carried out by the WindSim model. The major components of the downscaling procedure are:

- Multiple MERRA grid points are utilized
- An in-house height correction is applied to each MERRA grid point to improve wind speed representativeness
- A horizontally stretched grid is required in the region close to each MERRA point to minimize erroneous terrain speed-up near climatology point







Downscaling meso-scale wind data; MERRA, CFD, Virtual climatology at turbine position

Sites and accuracy

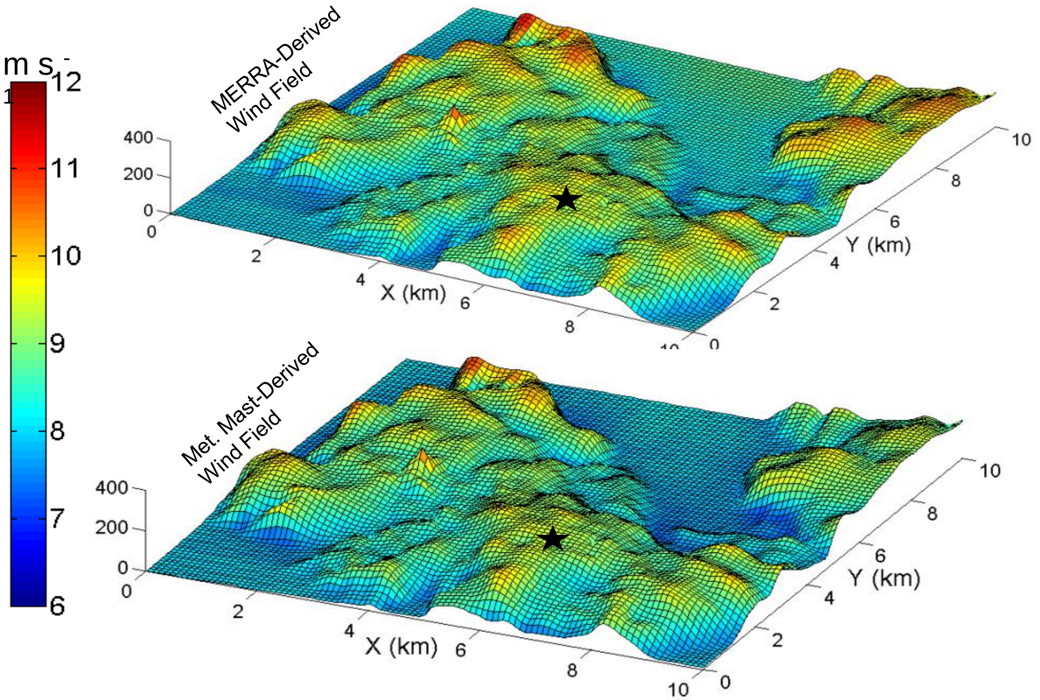
The validity of the downscaling methodology was verified against 7 sites of varying atmospheric stability and terrain characteristics. At each site, virtual climatologies were compared to measured wind climatologies with respect to vertical profile, speed and direction distribution, and time series. At sites where energy production data were available, AEP validations were carried out.

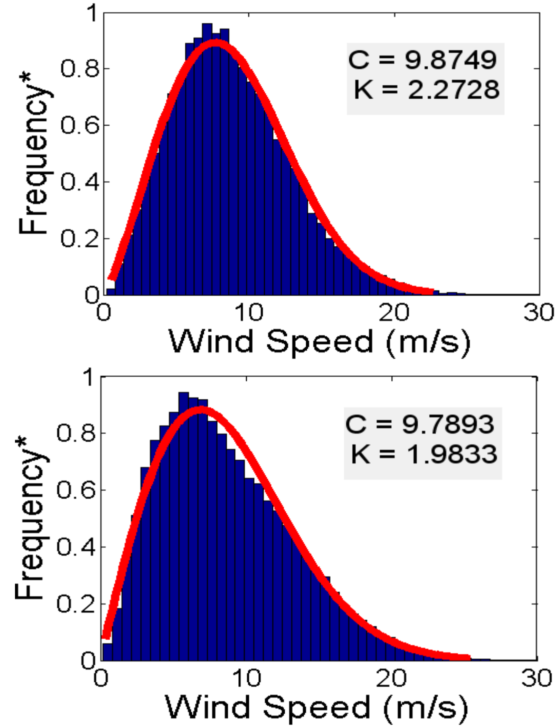
Case	Surface Characteristics	Stability % (Neutral/Stable/Unstable)			Mean Wind Speed % Error*
1	Complex-Coastal/Smooth	16	73	11	+2.51
2	Flat/Forested	8	59	33	+4.90
3	Very Rugged/Forested + Fields	21	51	26	+15.86
4	Small Hills/Smooth	28	36	36	+6.24
5	Small Hills/Forest + Grassland	21	50	29	-10.83
6	Small Trenches/Low vegetation	12	49	39	-6.72
7	Offshore	22	54	24	-1.33

*Description of cases and percent errors of virtual climatology versus met mast mean wind speed measurement. *Heights of wind speed validation are respective of sensor height*

Wind validation I

At each site, virtual climatologies were compared to measured wind climatologies with respect to average wind speed ….

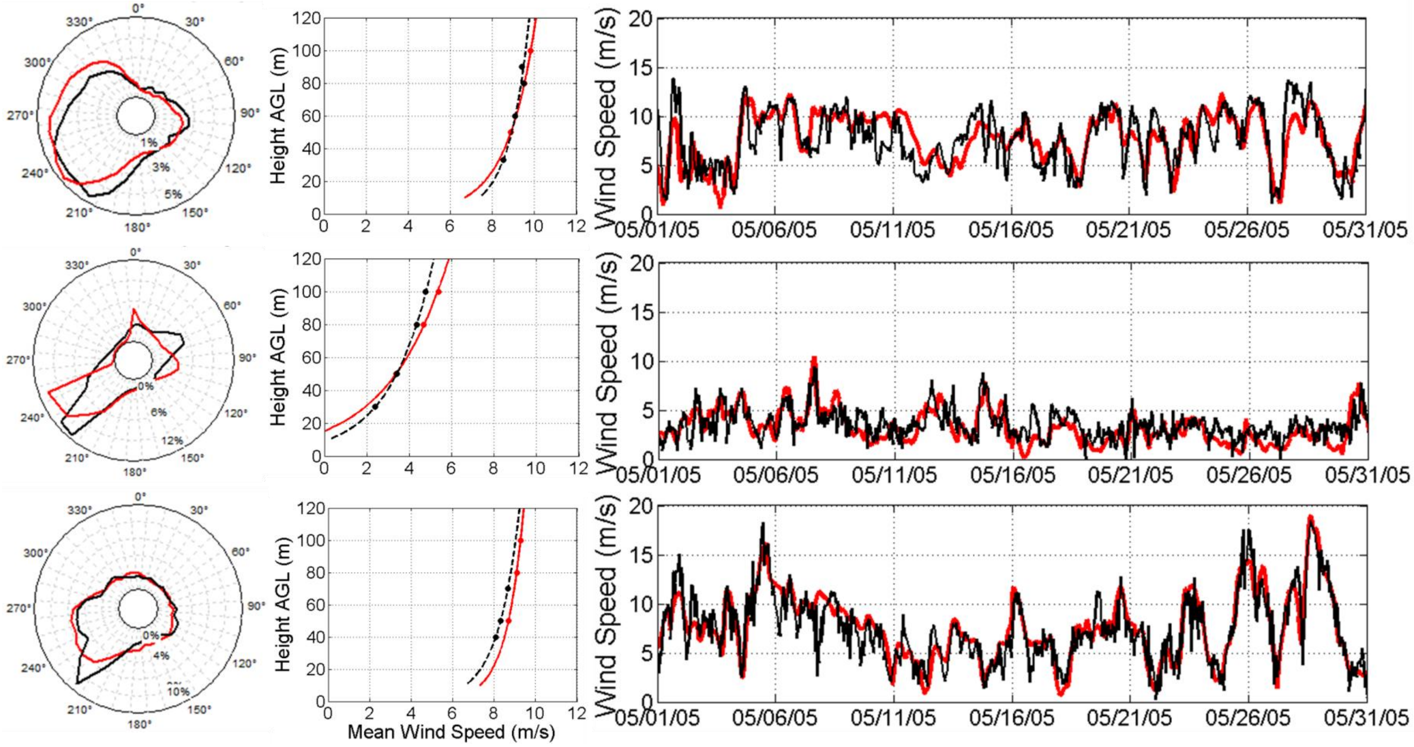




Simulated mean wind speed for Case 1 scaled by measured (bottom left) and virtual climatology (top left) time series. Also, corresponding wind speed frequency distribution for the measurement location, as denoted by the black star, extracted from the model solutions scaled by the measured (bottom right) and virtual (top right) climatology time series

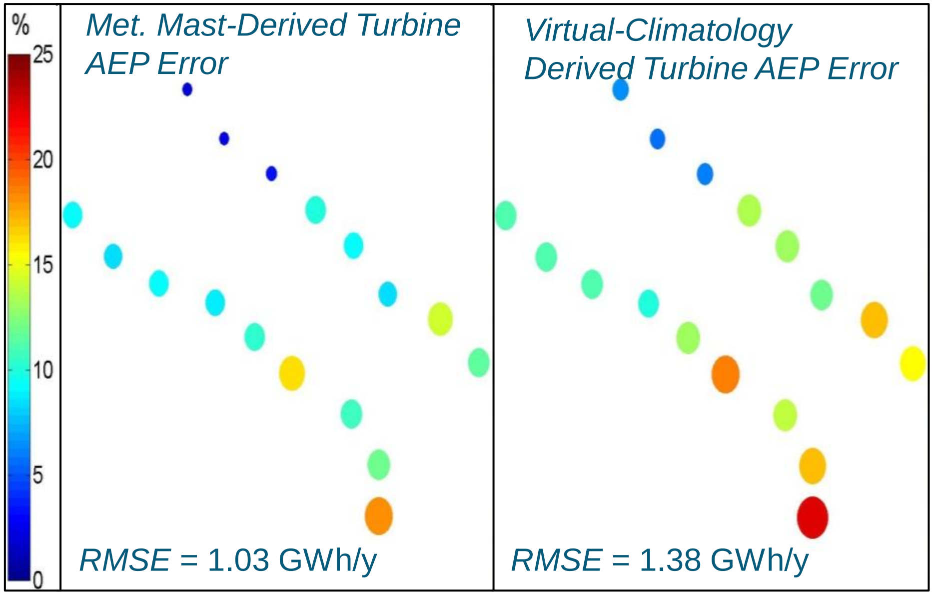
Wind validation II

… and with respect to wind rose, vertical profiles and time series



Comparison of wind rose (left column), mean wind speed profile (middle column), and sample 50m wind speed time series (right column) for met mast location. Red represents virtual climatology and black represents measurements. The three rows correspond to cases 7, 2, and 4 (in order from top to bottom)

Energy validation



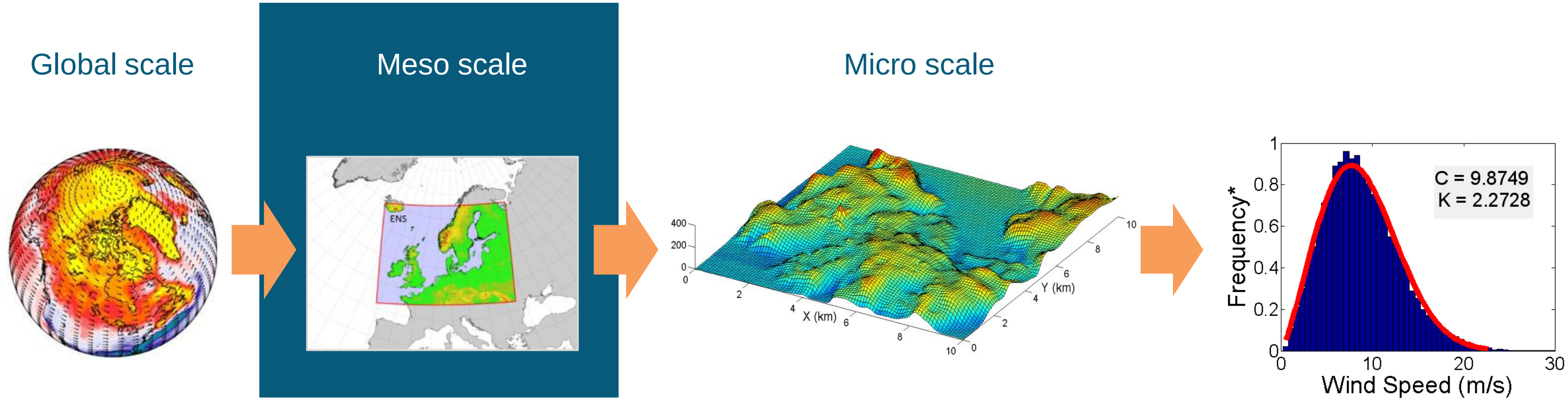
Turbine specific, AEP error of Case 1 when CFD simulation is scaled by 50m met mast measurements (left) and virtual climatology (right). RMSE is computed using historical power production data as truth.

Total Farm Avg. AEP for Case 1	Met. Mast-Derived AEP (GWh/y)	Virtual-Climatology -Derived AEP (GWh/y)
WM 1	165	171
WM 2	170	177
WM 3	165	170

AEP estimates for Case 1 with respect to Wake Model (WM). Observed AEP was approx. 150 GWh/y.

Downscaling Virtual Met Masts (VMM ® MetOffice) using CFD

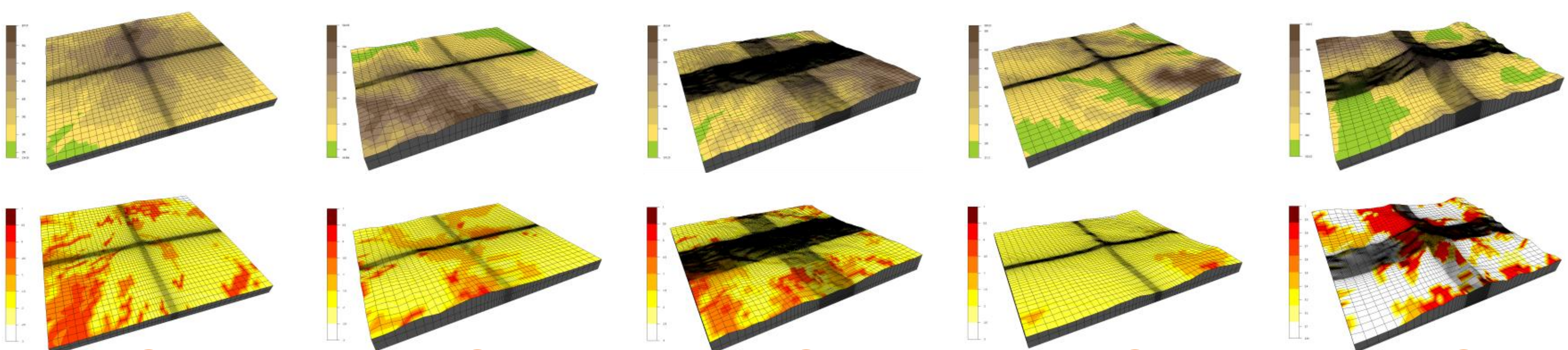
- As opposed to the MERRA data download where the Meso scale was skipped, the downscaling with VMM includes the Meso scale



Downscaling meso-scale wind data; VMM, CFD, Virtual climatology at turbine position

Sites

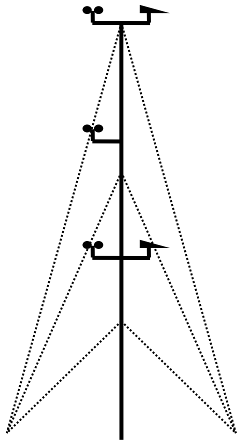
5 sites in complex terrain and complex climatology driven by thermal effects. Elevation difference up to 900m and terrain inclination up to 36 degrees



1 2 3 4 5

Wind measurements available – Validation

- 11 met masts ranging from 40m to 70m
- Calibrated cup anemometers
- Only top sensor used
- Hourly wind speed and direction values from 10 minutes averages
- More than 21 years of cumulative data



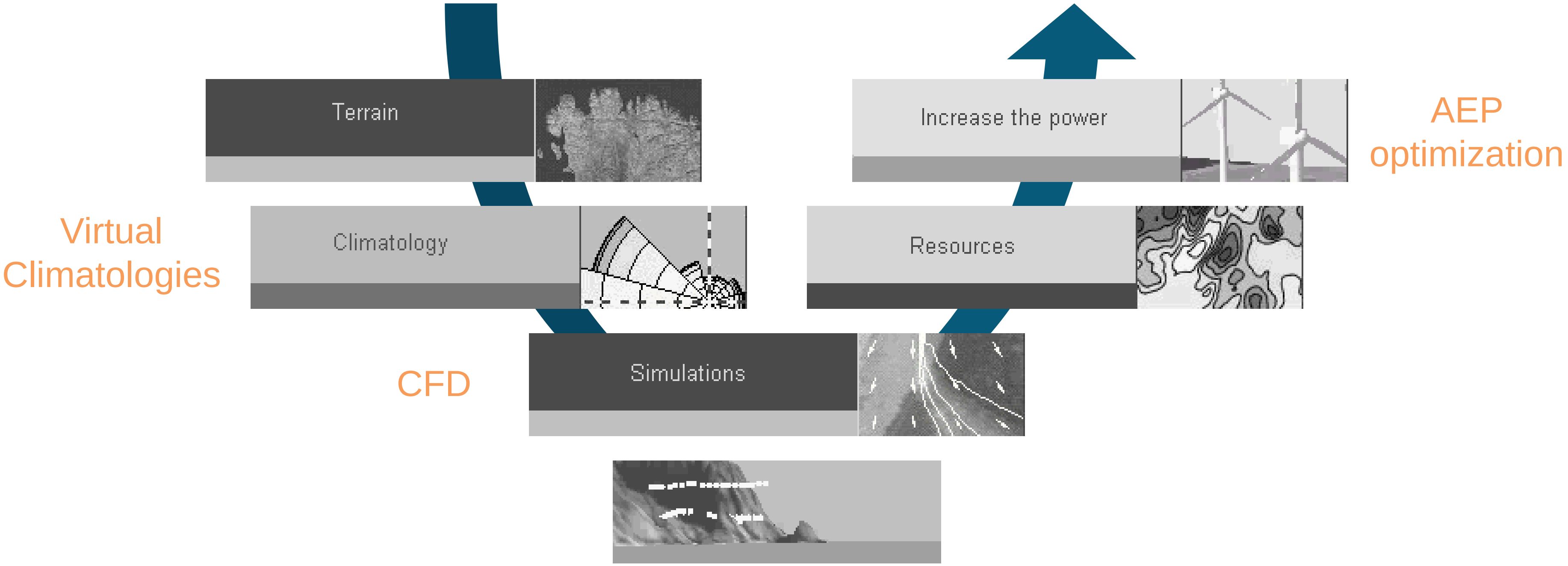
Preliminar analysis shows that CFD downscaling brings to a reduction of 0.4 m/s in standard deviation of errors (uncertainty) and 0.12 m/s in average (bias)

Summary – Downscaling meso-scale wind data using CFD

- We have developed a methodology for generating high-resolution, virtual wind climatologies (i.e., speed and direction time series) for any location around the world and for any height within the surface layer

- The downscaling can be made based on MERRA or with intermediate meso-scale steps like the method of VMMs (Virtual Met Masts)

Micro-siting procedure – Early AEP optimization



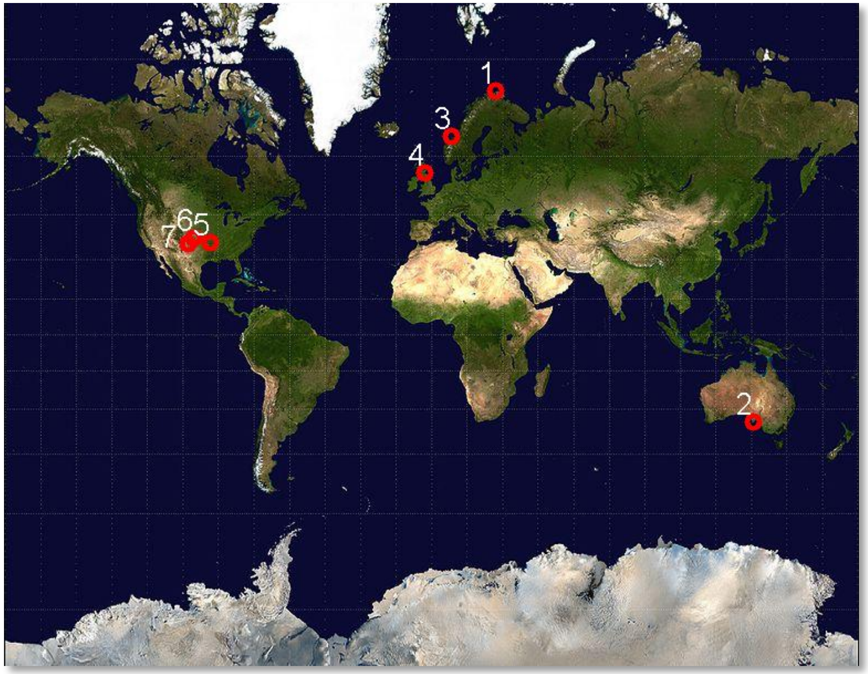
The micro-siting procedure consists of five steps; Terrain, Climatology, Simulation, Resources and AEP optimization

- Layout changes can be difficult after completion of the permit process
- Early AEP optimization of the layout

Sites – AEP optimization based on reanalysis data

• In this presentation we comment on the importance of optimizing turbine positions while quantifying potential AEP improvements for a number of existing wind farms

• The wind energy development over the past two decades has been accelerated by the abundance of locations with promising wind resources. These locations have been aggressively sought-out due to their low-risk of inefficiency; nevertheless, future development depends on the exploration of areas with higher-risk wind resource

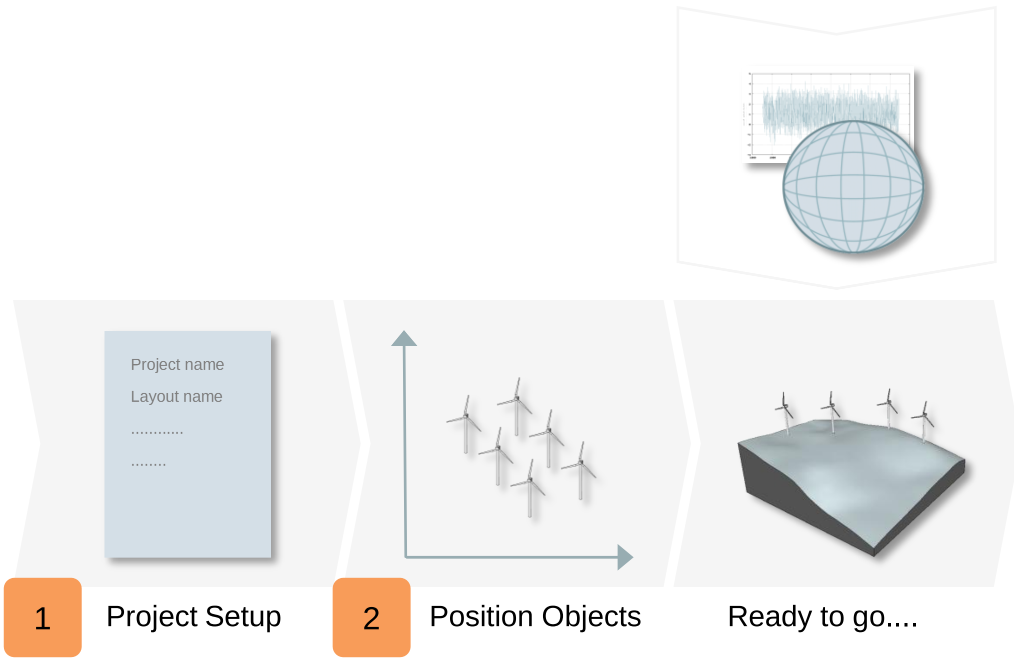


Locations of the seven sites used in this study

• These higher-risk sites are inevitably much more sensitive to pre-construction technical decisions (i.e. turbine layout, hub height, turbine selection, etc.) and accurate wind resource characterization

Tools: Wind Simulations – WS Express/WS Express Cloud

- WindSim Express Cloud addresses the early stage market



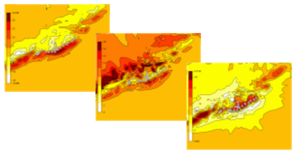
WindSim Express makes CFD based micro-siting a simple three step procedure. First, name your project. Second, load your turbine positions and measurement data. Finally, set the resolution of the numerical model. That's all. WindSim Express automatically download a terrain model of the area of interest and runs the simulations

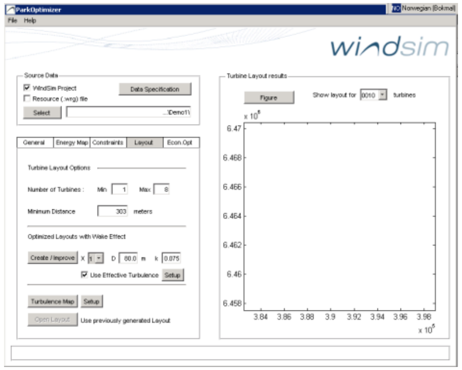
Webinar: https://www.youtube.com/watch?v=TMU33KkmBkQ

Tools: Park Optimization – WS Park Optimizer

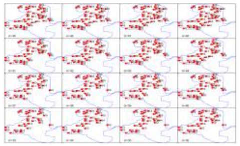
- Based on simulated wind conditions the optimum wind farm size is found taking into account the following constraints:
  - Projects constraints
  - IEC compliance
  - Optimize turbine layouts
  - Optimize wind farm size

CFD results





Final layout



1 Project constraints

2 IEC compliance

3 Optimize turbine layout

4 Optimize size

Optimization details

- The optimized layout of each wind park was constrained by the IEC standards

- The hub heights corresponded to the real hub heights of each wind farm (i.e. 42 – 82 m above ground level)

- A standard turbine power curve and rotor diameter was used for all cases

- CFD simulations were scaled using virtual climatology data derived from MERRA reanalysis

Optimization results

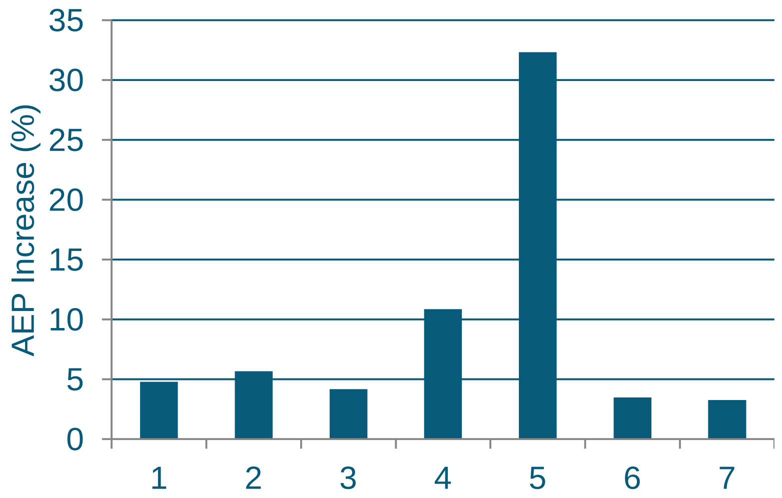
Case	Site	Location	# of Turbines	Original AEP (GWh/y)	Original Wake Loss (%)	Optimized AEP (GWh/y)	Optimized Wake Loss (%)	AEP Increase (%)
1	Kjøllefjord	Northern Norway	17	146	5.13	153	1.85	4.79
2	Cathedral Rocks	Southern Coast of Australia	33	229	4.63	242	3.02	5.68
3	Hitra	West Coast of Norway	23	120	4.01	125	2.55	4.17
4	Black Hill	Eastern Scotland	22	138	10.47	153	3.70	10.87
5	U.S. WF 1	Mississippi River Valley	60	133	2.76	176	2.53	32.33
6	U.S. WF 2	U.S. Great Plains	162	952	2.63	985	3.28	3.47
7	Wildorado	Northern Texas	70	489	5.54	505	3.19	3.27

Summary of the cases and comparison of the power statistics from the original and optimized turbine layouts

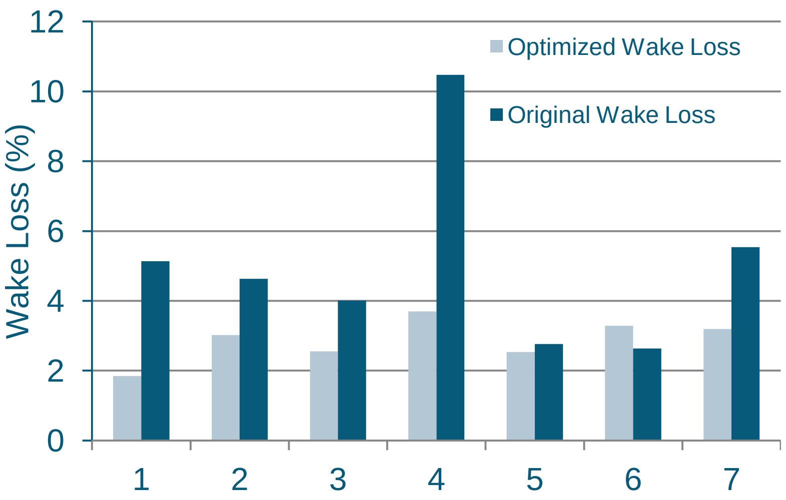
Optimization results

• Demonstrated a methodology based on the use of a global reanalysis dataset (MERRA) which has proven capable of delivering realistic wind fields also in complex terrain

• For the cases investigated, we have found optimized AEP increases ranging from 3% to 32% and wake loss decreases up to 7%



Increase in annual energy production (AEP) after park optimization for each case



Original and optimized wake losses for each case

Summary – AEP optimization based on reanalysis data

- AEP increases of primarily 3 to 10% were achievable through the park optimization process; however, there was an outlier or 32% for Case 5 mainly due to the large area that the original park occupied.

- Wake loss decreases of up to 7% were found; however, for one case (6) wake losses increased slightly despite the fact that overall AEP increased.

- Overall, the magnitude which a wind park can be optimized is closely related to the size of the land area available; in other words, expanding the boundaries of the wind park slightly can significantly improve power production for most cases

- In addition, it was found that the capacity of the park optimizer to produce valuable park layouts strongly depends on the accurate prescription of all relevant geologic, technical, and financial constraints

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