Introduction to Offwind tool

Prediction tools for offshore wind energy generation

Offwind Group

(IRIS, SINTEF, VattenFall, LTH, Aalborg Univ, Megajoule, NRG-Soft, NREL, Norsk Vind, Kiel GMbH)

Outline

- Offwind Project specification
- Offwind Code specification
    - Engineering Level
    - Advance CFD Level
- Meso-Scale wind results
- Wind-Wake simulation Results
- Wind-Wave Simulation Results
- Now-Casting

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Introduction: Market outlook (2011 -2020 - 2030)

2011:

Total installed capacity of 4,000 MW
- **Meeting 0.4% of total EU electricity demand**
- Annual installations of 1,000 MW

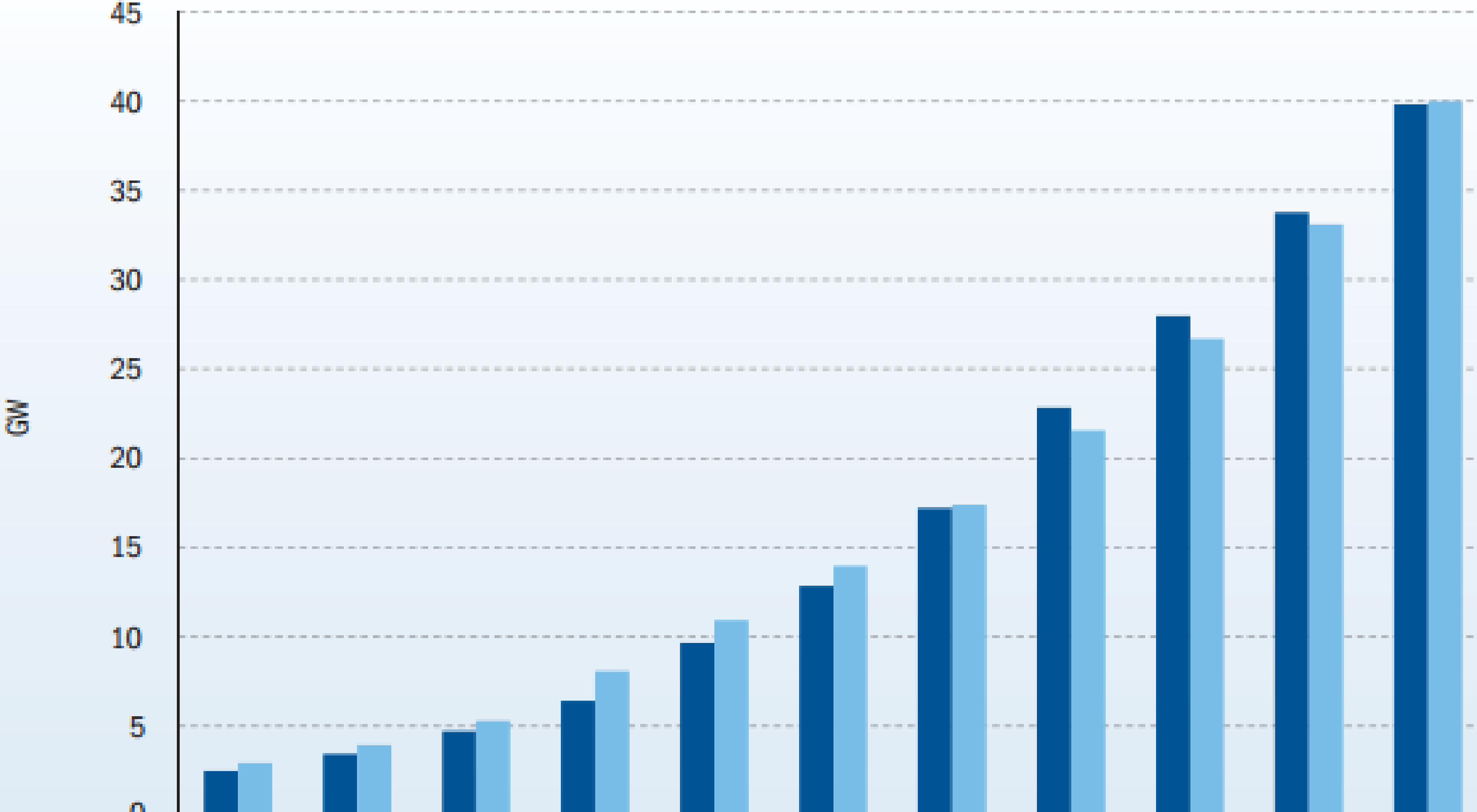
2020:

- Total installed capacity of 40,000 MW
- **Meeting 4% and 4.2% of total EU electricity demand**
- Annual installations of 6,900 MW

• 2030:

- Total installed capacity of 150,000 MW
- Annual installations of 13,700 MW
- **Meeting 13.9% of total EU electricity demand**

FIGURE 1.8 HISTORICAL ONSHORE GROWTH (1995-2005) COMPARED TO EWEA'S OFFSHORE PROJECTION (2010-2020)



	1995 / 2010	1996 / 2011	1997 / 2012	1998 / 2013	1999 / 2014	2000 / 2015	2001 / 2016	2002 / 2017	2003 / 2018	2004 / 2019	2005 / 2020
Onshore	2.5	3.4	4.7	6.4	9.6	12.9	17.2	22.8	28.0	33.8	39.8
Offshore	2.9	3.9	5.3	8.1	10.9	14.0	17.4	21.6	26.7	33.1	40.0

Source: EWEA

FACTS (Offwind Project)

- **Type:** Research project;
- **Project Owner:** IRIS; International Research Institute of Stavanger, Norway;
- **Project Manager:** Jafar Mahmoudi,
- **Financing**: NER (Nordic Energy research); VattenFall (Research and Development) and Own Financing;
- **Period:** 2012-2014;
- **Partners:** 10 partners:
  - *Norway:* IRIS; SINTEF; Norskvind,
  - *Sweden:* Lund University,
  - *Denmark:* Aalborg Univ; Vattenfall (Research and Development),
  - *Portugal:* Megajoule,
  - *Germany:* FuE-Zentrum FH Kiel GmbH ,
  - *US:* NREL, National Renewable Energy Laboratory (associated member)
  - *Russia:* NRG Soft Ltd.

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FACTS (**Offwind Code**)

- **Outcome:** Software for power prediction from a wind farm
- **Application:** Offshore (as well as on Shore)
- **Utilility:** Design and Operation
- **Open Source code** for Offwind Association
- **Code Validation** based on IEA- Task 31, VattenFall & NorskVind Measurements /Results
- **Software Architecture:**
  - **Engineering Level**: User manual friendly for engineer (not researchers), Web based (as well as local installation)
  - **Advanced Level**: CFD, Computational Fluid dynamic (Cloud based as well as local installation), including:
    - *Coupling between meso- and microscale (CFD) models*
    - Wind- wave interaction
    - *MetOcean-CFD modelling approach*
    - *Wind data based on Google Earth Map and WF-AEP world wide wind map estimate*

Offwind Objectives

- The primary objective of the project is to develop tools for design and operation assessment and forecasting for offshore wind farms.
- The tools will lead to **optimal localization** of a wind farm and more importantly how to locate future wind farms with respect to each other within the same wind energy cluster.
- The tools will also lead to a **more safer wind farm operation** as the operation parameters can be more accurately predicted and thus reduce the probability of wind turbine failure under severe weather conditions.

Offwind Work packages

- **WP 1:** Numerical modeling for wind turbine and wind farm performance predictions
- **WP 2** Experiments and model validation and calibration
- **WP 3** Fully coupled wind-wave interaction model
- **WP 4** Now-casting of available farm power based on data driven modelling
- **WP 5** Database

Offwind Project Partners

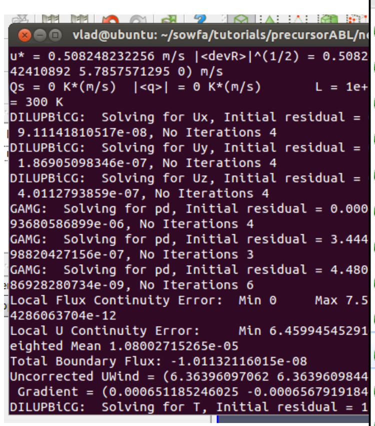
Organization	Country	Main partners	Participate
IRIS (Research center)	Norway	Wp1, Wp2,	Wp3, Wp5
SINTEF (Research center)	Norway	Wp1, Wp3	Wp4, Wp5
Norsk Vind Energi AS (Industry)	Norway	Wp2	Wp5
Aalborg (University)	Denmark	Wp4	Wp5
Vattenfall (Industry)	Denmark	Wp3, wp5	Wp1, Wp2
Megajoule	Portugal	Wp3	Wp1
Lund university (LTH)	Sweden	Wp1, Wp3	Wp5
FuE-Zentrum FH Kiel GmbH	Germany	Wp5	Wp2
National Renewable Energy Laboratory-NREL	USA	Wp1	Wp3
NRG Software	Russian	Software Development	Associated Call

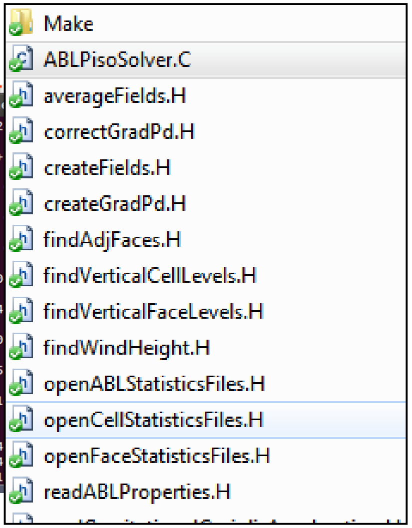
Scientist: creates model

Hey, I’ve got a great idea and designed math model for that simulation process. I’ve also made up these algorithms in code. Go ahead, use them!

Momentum transport

$$\underbrace{\frac{\partial \overline{u}_i}{\partial t}}_{\mathrm{I}} + \underbrace{\frac{\partial}{\partial x_j}\left(\overline{u}_j \overline{u}_i\right)}_{\mathrm{II}} = \underbrace{-2\varepsilon_{i3k}\Omega_3 \overline{u}_k}_{\mathrm{III}} - \underbrace{\frac{\partial \tilde{p}}{\partial x_i}}_{\mathrm{IV}} - \underbrace{\frac{1}{\rho_0}\frac{\partial}{\partial x_i}\overline{p}_0(x,y)}_{\mathrm{V}} - \underbrace{\frac{\partial}{\partial x_j}\left(\tau_{ij}^D\right)}_{\mathrm{VI}} - \underbrace{g\left(\frac{\overline{\theta}-\theta_0}{\theta_0}\right)\delta_{i3}}_{\mathrm{VII}} + \underbrace{\frac{1}{\rho_0} f_i^T}_{\mathrm{VIII}}$$





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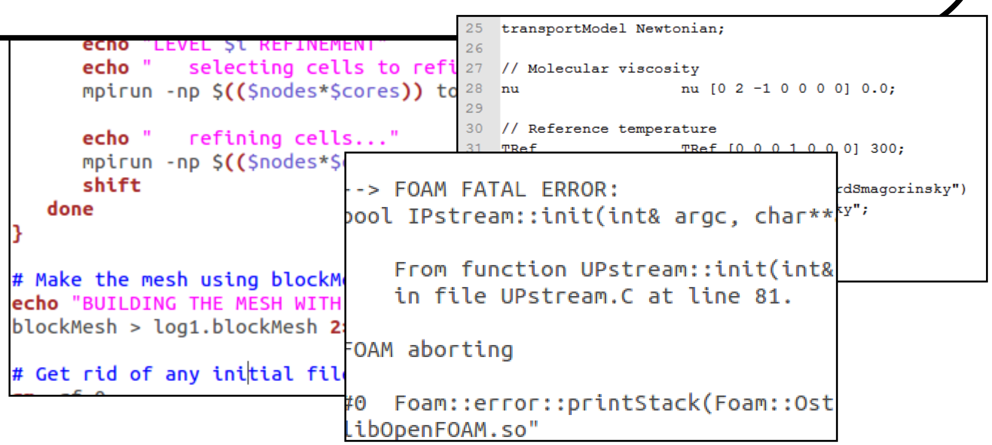
Engineer: uses the solver

Please, tell me how to use that function that you've created? It doesn't even compile on my machine. How am I supposed to feed it with input data filling these txt-files? I don't understand why it is failing at line 81. Oh, god… why do I need that weird library XYZ? I'm wasting my time dealing with that…



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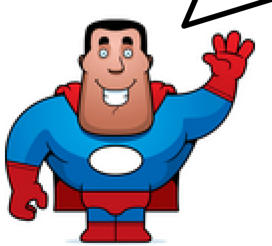
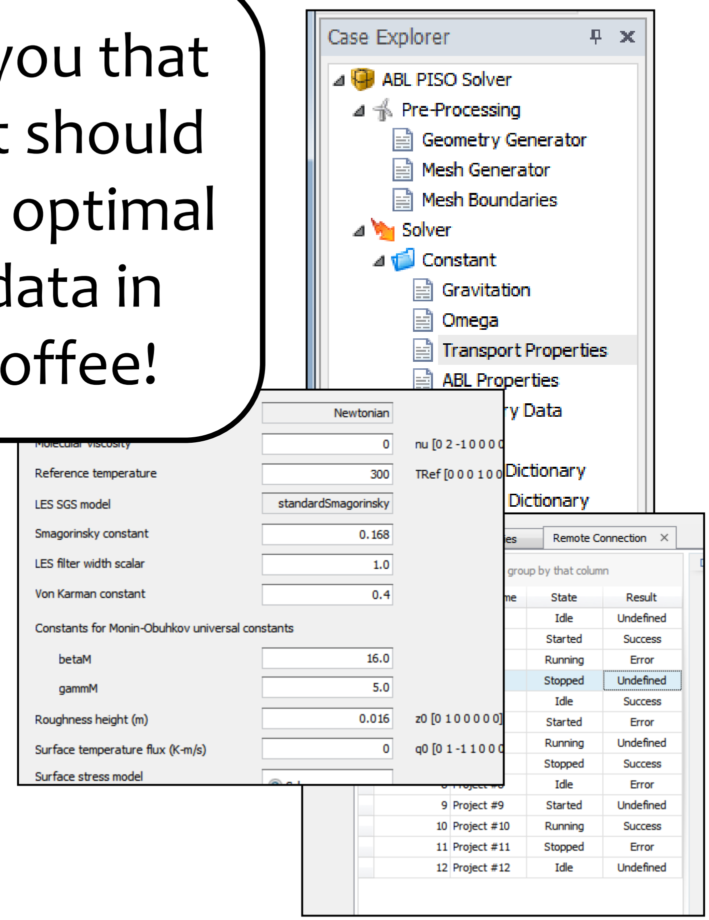
Offwind: merge two worlds

Hello, Engineer! I'm going to ease you that part! I will ask Scientist about what should be done and provide it to you in an optimal way. Just click here, input some data in these forms and go drink some coffee!





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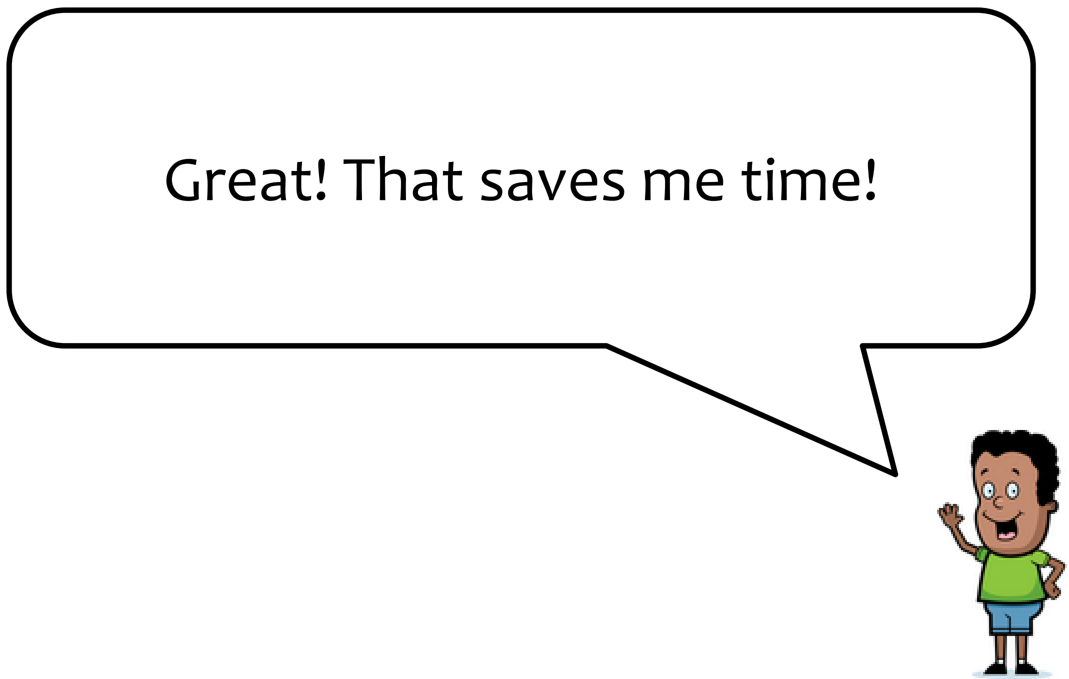
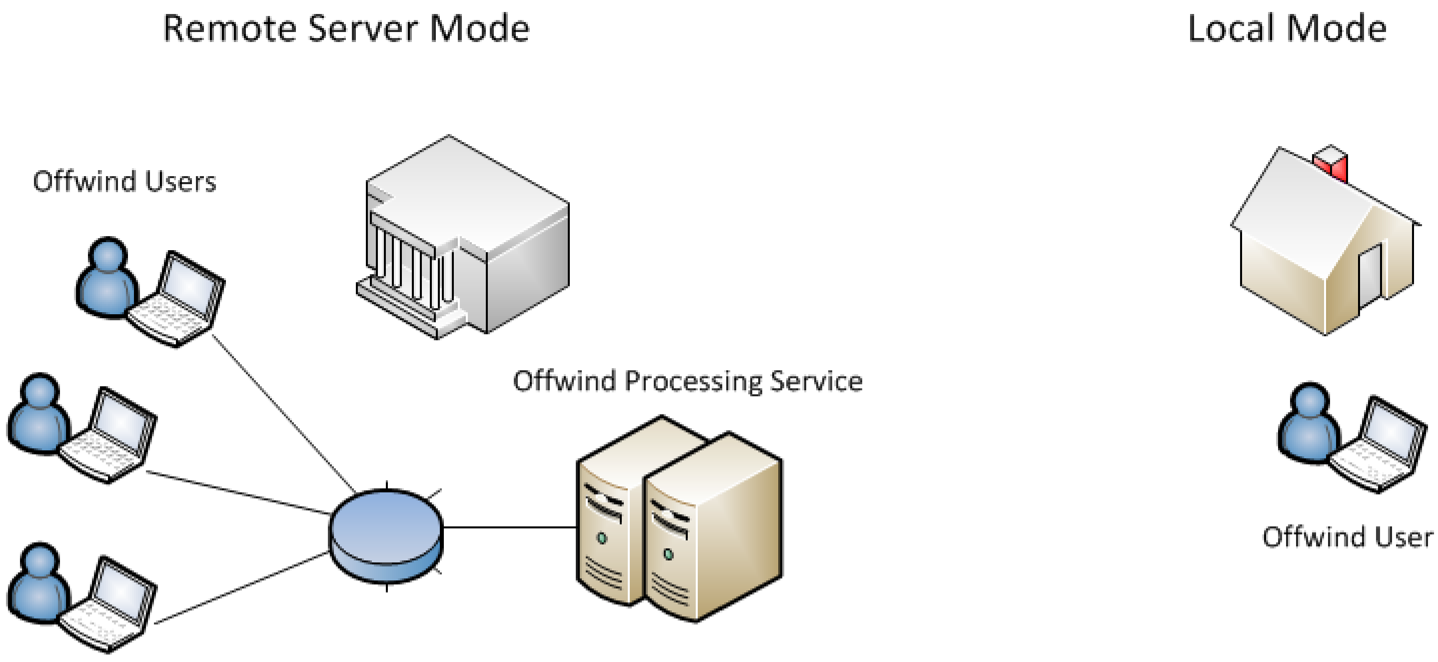
Engineer: focuses on his tasks



Offwind Code Specification



Offwind Code specification

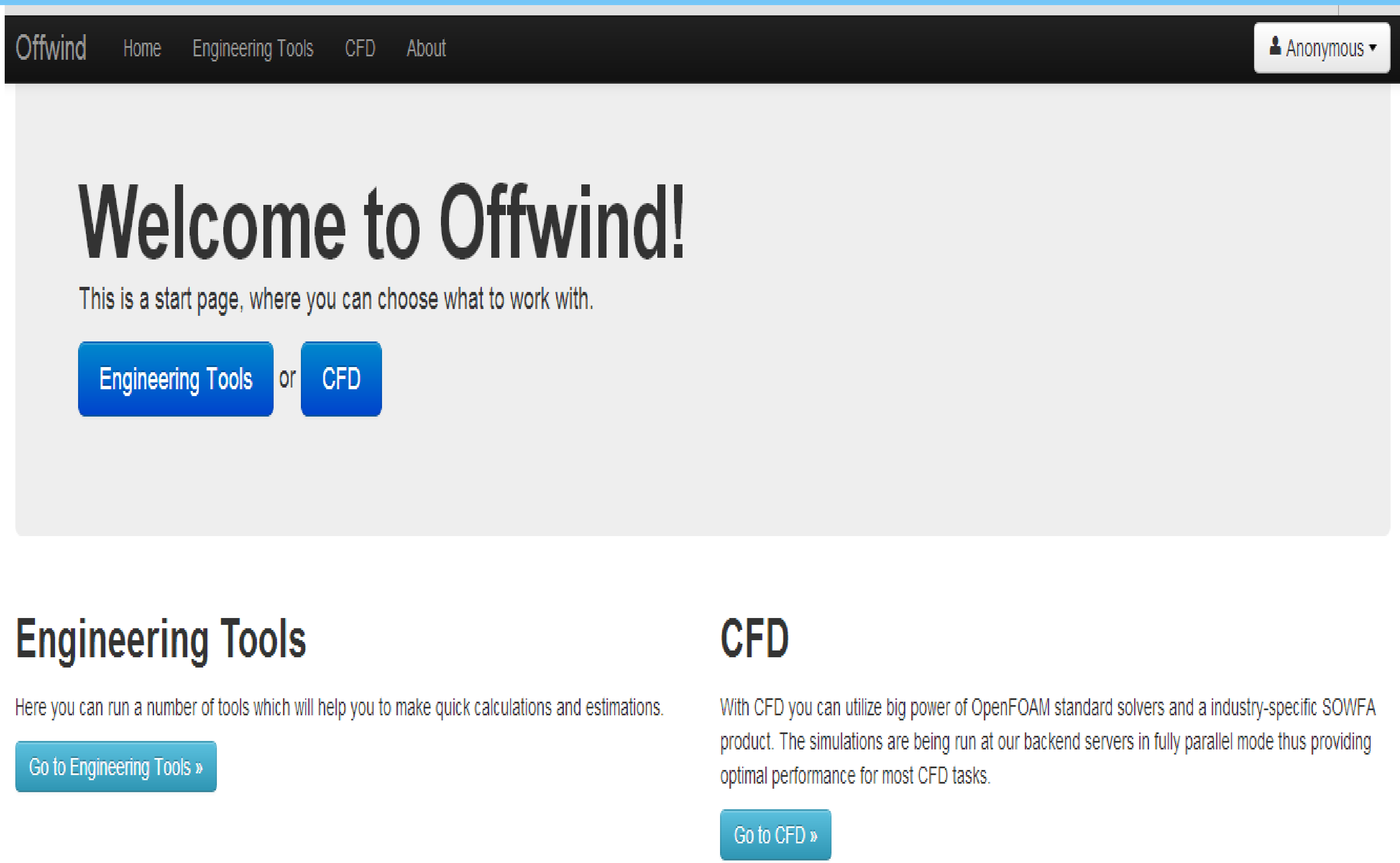
•The code has been developed for industrial purpose and engineers (not necessarily researcher). Looking to this, we have put lots of time and effort on very user friendly interface (Using Baltic call & IRIS) in two different levels.

•**Engineering tool (based on empirical equations):** While engineers can easily get the results in accurate level and very fast (minutes). This will be mainly Web based design

•**Advanced Level (CFD):** Again, using Google Earth, wind data and based on our solver (Offwind solver) based on OpenFoam. His part will be combined based on web- Cloud-based and local installation.

•The Offwind code has been developed to be "**Open Code**" to get the most impact

Offwind- WEB- GUI



Offwind Web: Architecture

Web Application
- Web Interface
- Queue Manager

•URL: http://tools.offwind.eu
•OS: Windows 7
•CPU: Intel i7 3770 (4 cores)
•RAM: 32 Gb
•HDD: 1 TB (no redundancy)
•Location: IRIS, Norway

Server Application (Processing Service)
- CFD Processor
- Storage

•URL: http://proc.offwind.eu
•OS: Ubuntu Linux
•CPU: Intel i7 2700 (4 cores)
•RAM: 32 Gb
•HDD: 750 GB (no redundancy)
•Location: IRIS, Norway

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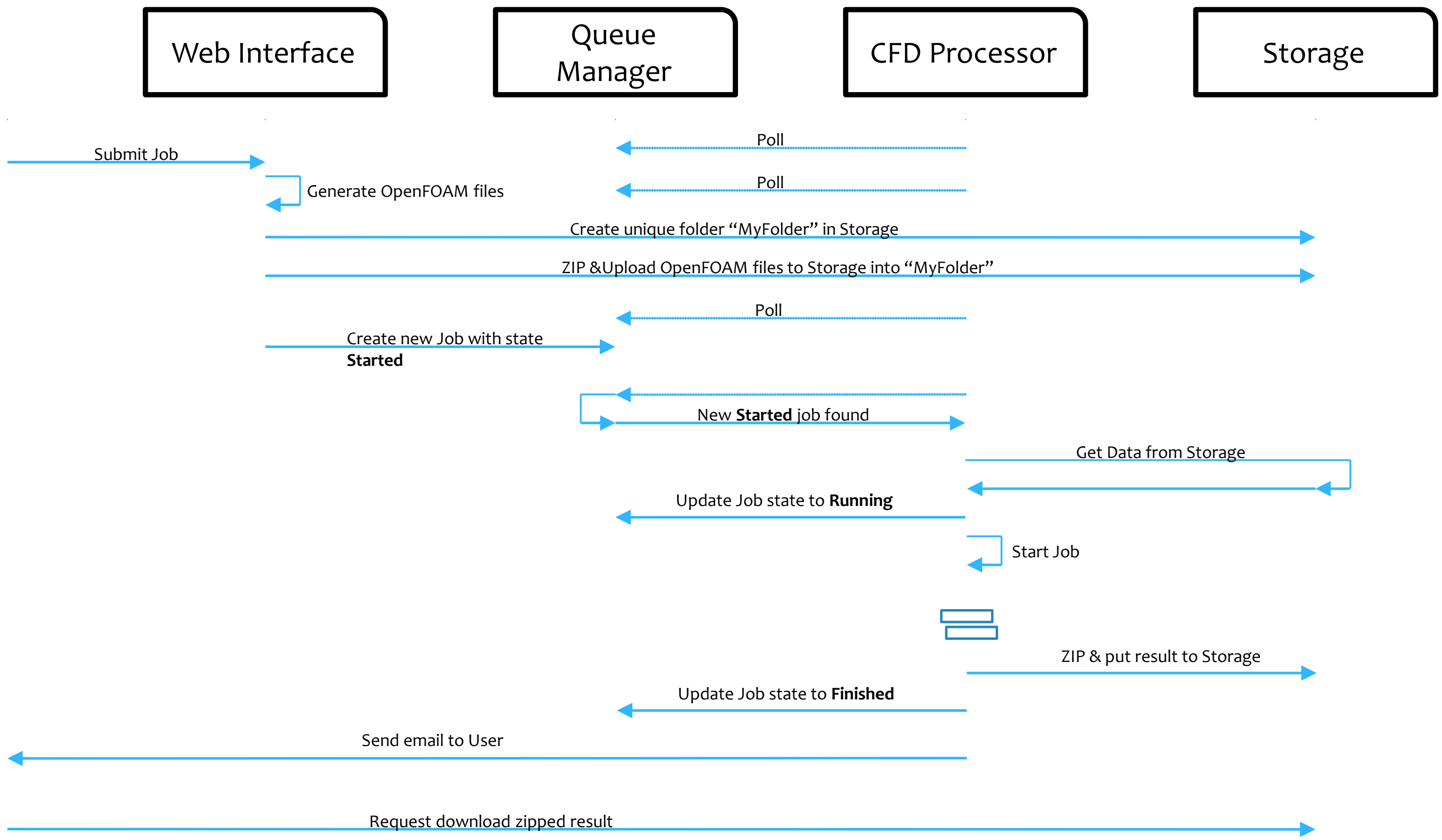
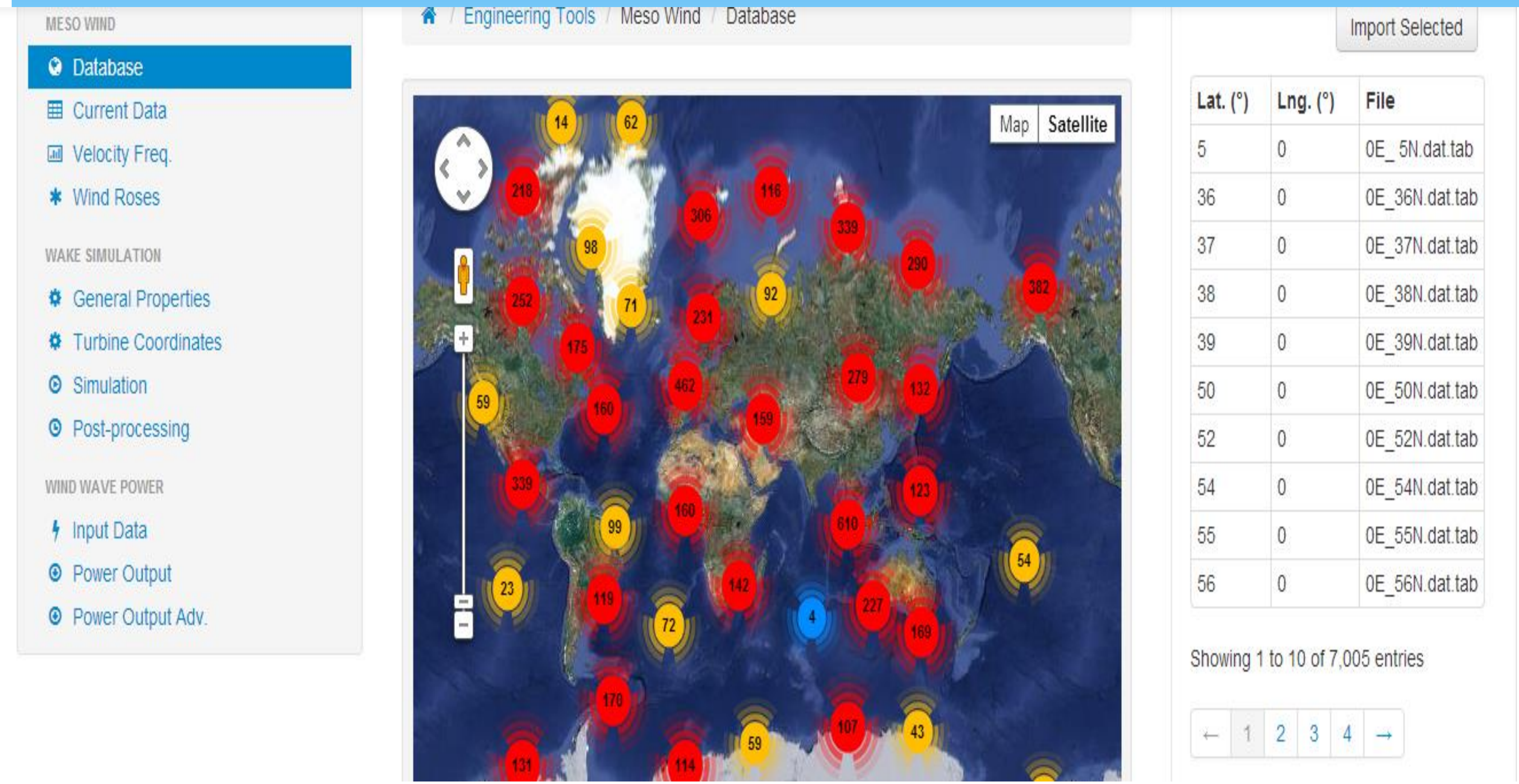
Offwind Web: Sequence Diagram



Meso Scale Wind- Web



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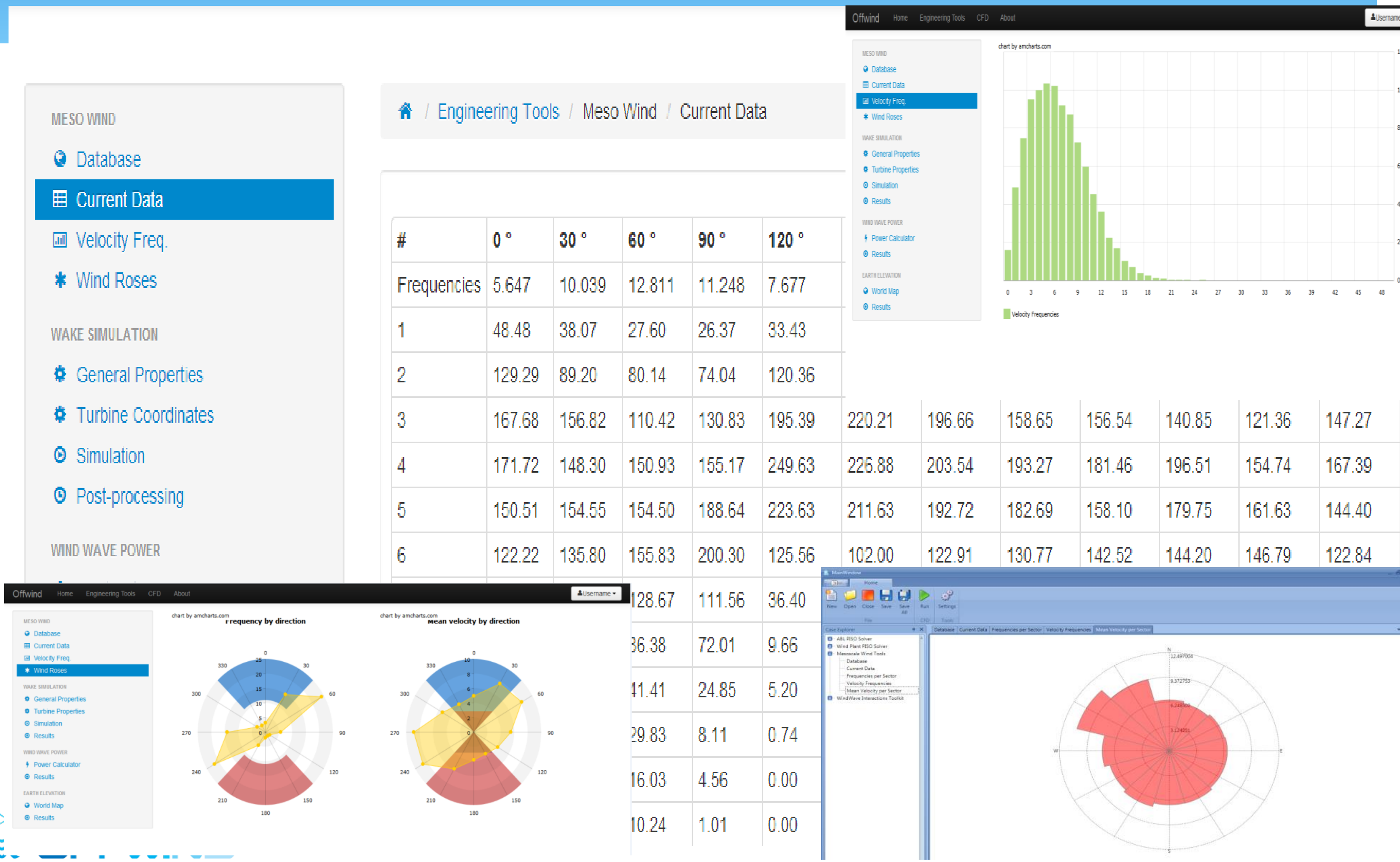
The OpenFOAM database rapidly supplies the user with a general view of the local winds, based on global data information

Meso Scale Wind



Meso Scale Wind

OFFWIND Goal regarding Mesoscale ::

to supply mesoscale results to provide data to configure microscale simulations at set-up or through coupling between models

Operational set-up not yet ready to be able to run mesoscale simulations upon request from user

=> information is collected from global analysis and reanalysis databases and made available on the OFFWIND web-platform

=> user may set-up microscale simulations using his own measured data or mesoscale results

The OpenFOAM database rapidly supplies the user with a general view of the local winds, based on global data information

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Mesoscale wind Model

Procedure:

Identify typical meteorological year at any site by analysing one or more analysis/ Reanalysis datasets (eg. FNL and MERRA, as used in OFFWIND). Once year is identified, simulate it on 3x3km meshes

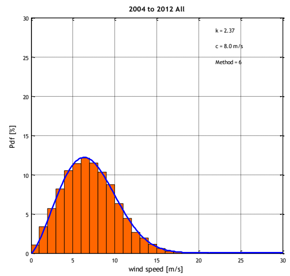
Two possibilities are then available:

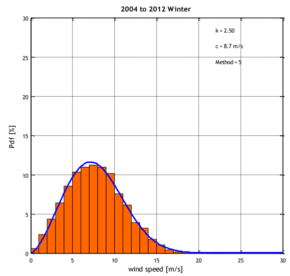
Engineering version: use mesoscale data series at the site to identify relevant sectors and dominant wind speeds per sector. Configure CFD simulations accordingly.

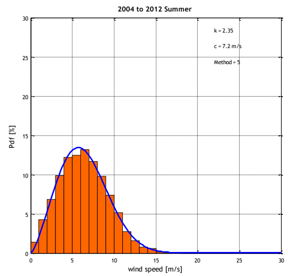
Advanced version: extract boundary conditions for OpenFOAM from mesoscale 3D fields
. either in time-dependent mode (costly), or
. averaging bc's per sector to produce steady-state simulations.

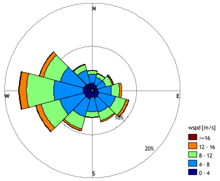
Lillgrund Test Case :: Mesoscale

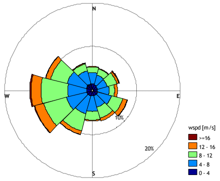
The FNL Analysis database was analysed at a location near Lillgrund (at point 13E, 56N).
The Long-Term Climate was defined using the period 2003-2012 for FNL, in terms of annual, winter and summer velocity and direction distributions.

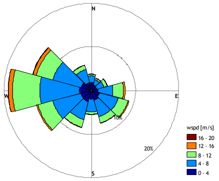












The mesoscale modelling of the Lillgrund test site had two goals:

1. To compare results between the mesoscale model and local data
2. To use mesoscale results to configure or force the CFD simulations

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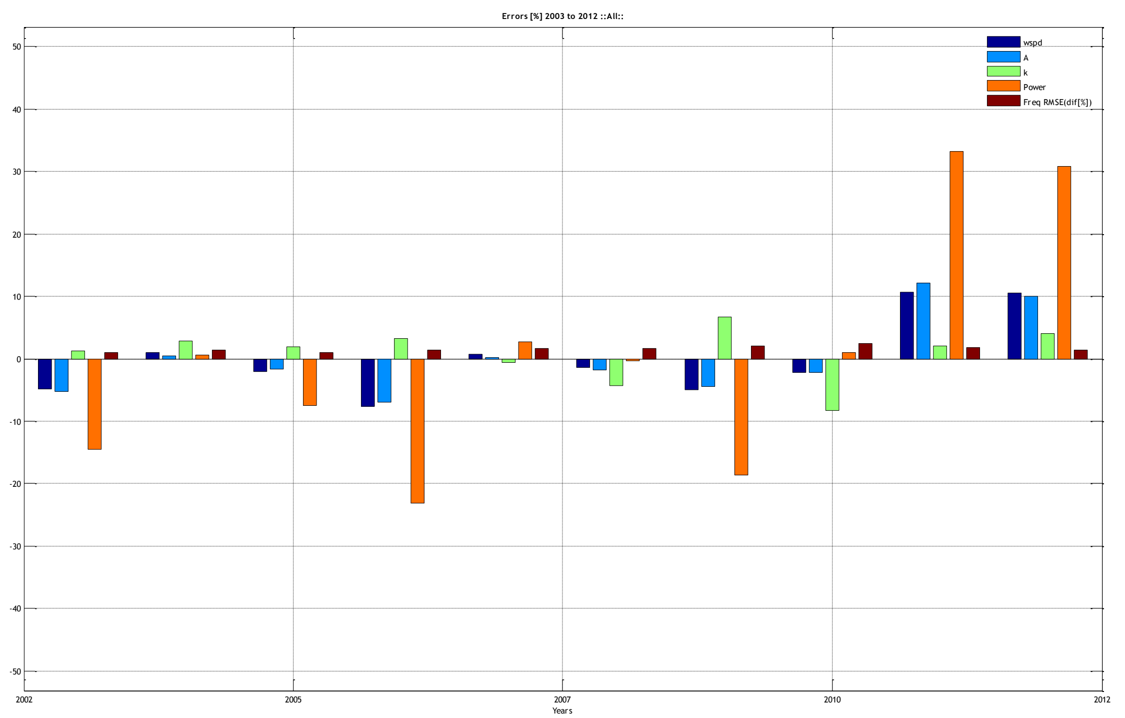
Lillgrund Test Case :: Mesoscale

A similar analysis was performed then for each individual year, and a statistical procedure carried out to identify the year that most resembled long-term behaviour, both annually and seasonally. From this, the year 2008 emerged as the most representative of the long-term climatology, followed by year 2004.



Lillgrund Test Case : Mesoscale

The mesoscale simulation was performed using the WRF mesoscale model, on 3km meshes, using FNL Analysis forcing and the following parametrisations:

PBL model:
Surface Layer model:
Etc.

The following wind distribution and statistics were obtained at point (55.50°N, 12.76°E)

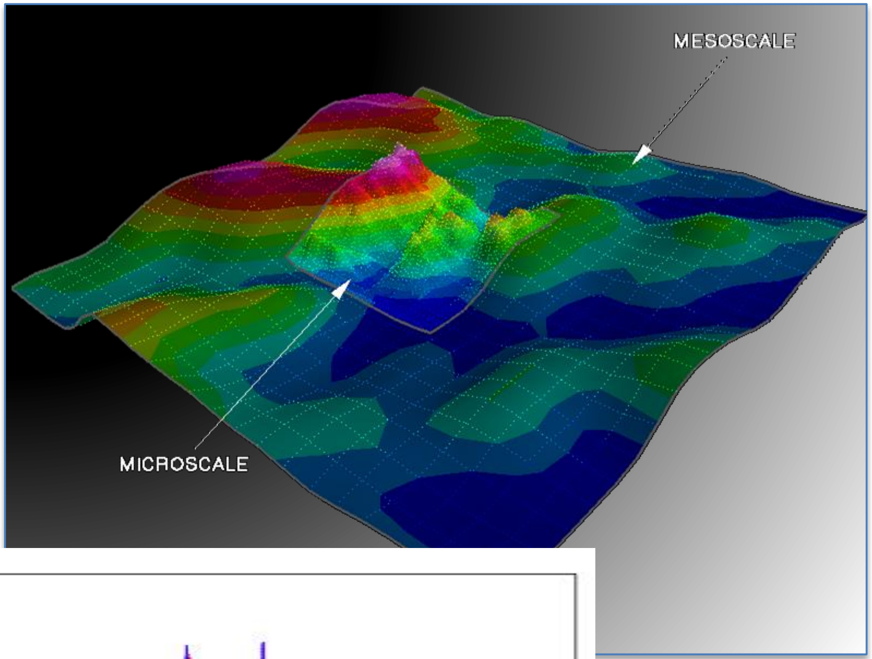
Summary Tables

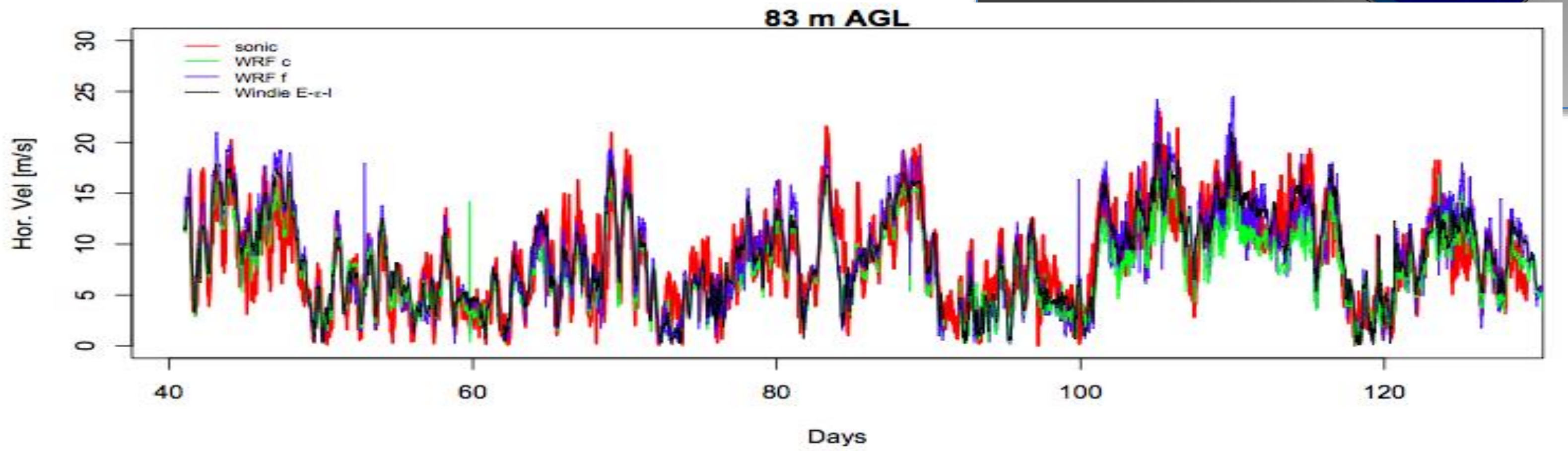
Height [m]	Mean Wind Spd [m/s]	Weibull A [m/s]	Weibull k	Max. Wind Spd [m/s]	Power Density [W/m2]
65	**9.2**	10.5	2.26	25.8	842
80	**9.4**	10.8	2.29	26.3	908
100	**9.8**	11.2	2.31	26.8	1003
65_no	**8.2**	9.3	2.14	24.0	612
80_no	**9.5**	10.9	2.35	26.3	912
100_no	**9.5**	10.9	2.35	26.3	912

Lillgrund Test Case :: Mesoscale (ongoing)

Next steps:

- Extract boundary conditions from mesoscale model to couple with CFD simulations
- Test steady-state (average bc's per wind direction) or time-dependent coupling
- Compare results with measurements, and traditional CFD simulations, by season, hour of day, stratification class, etc.





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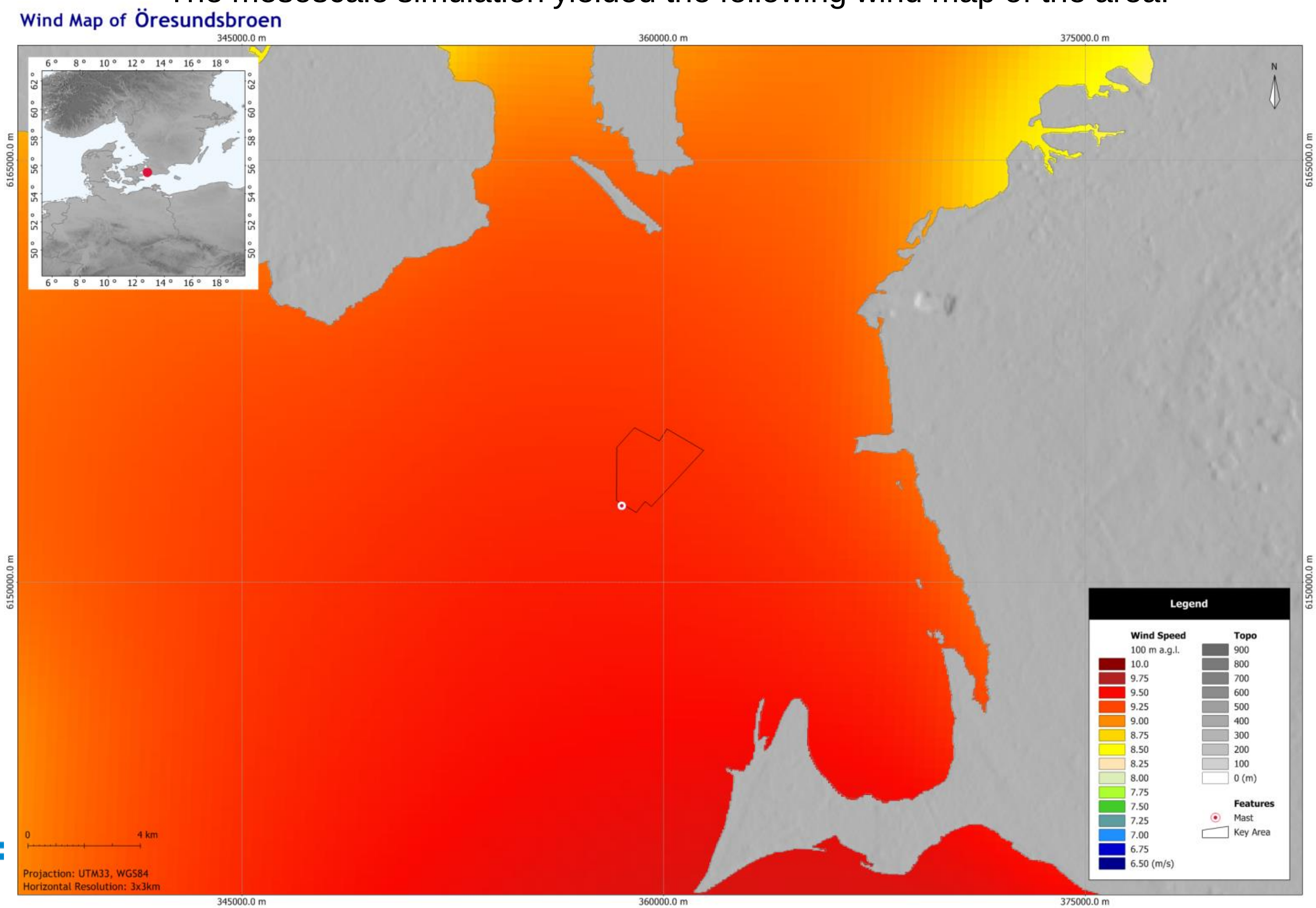
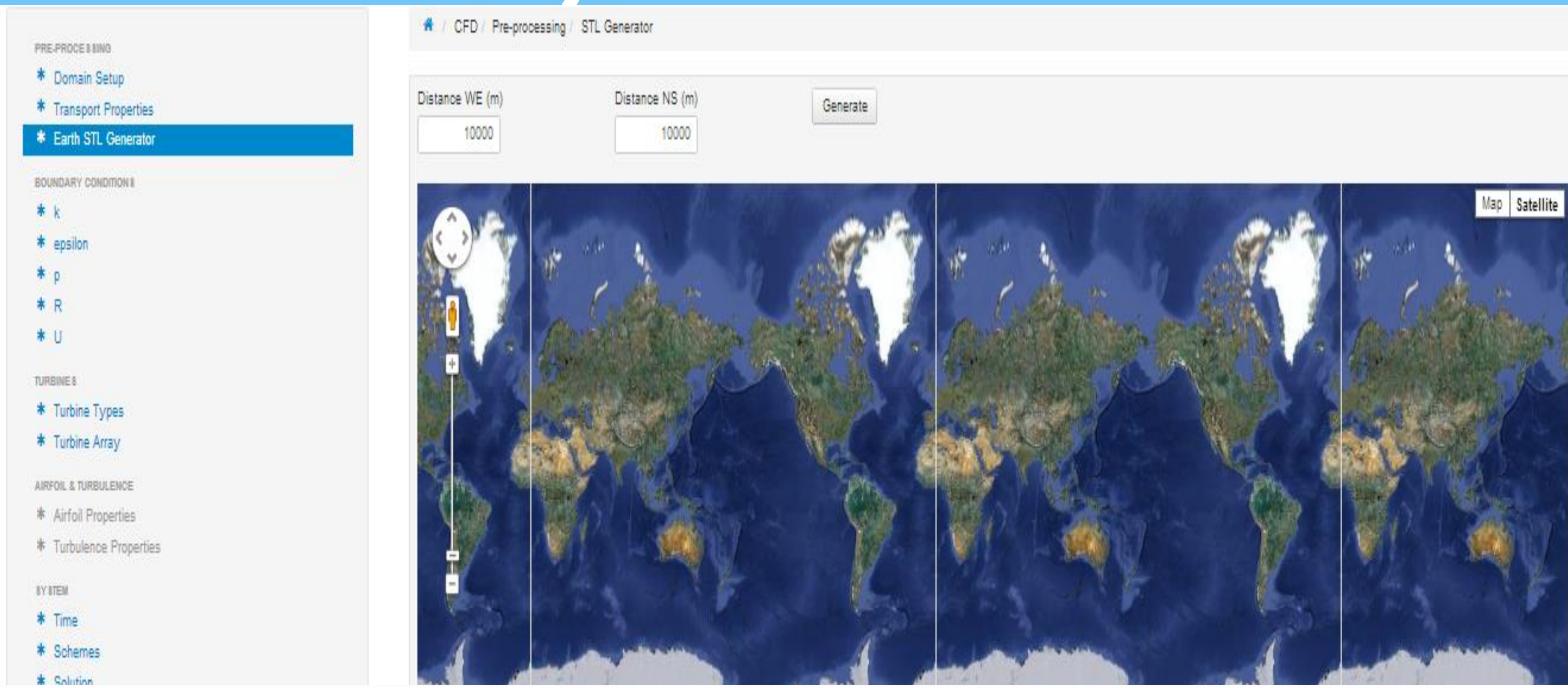
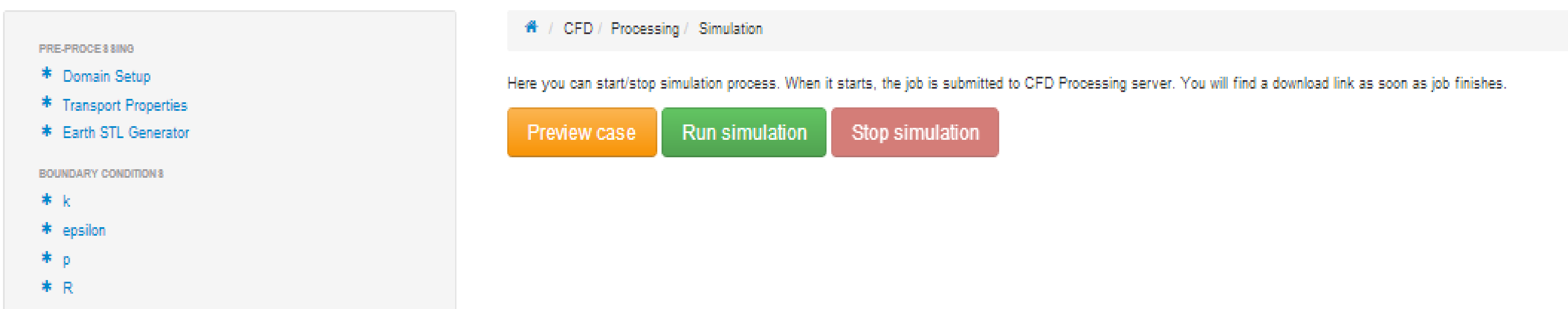
Lillgrund Test Case :: Mesoscale

The mesoscale simulation yielded the following wind map of the area:



Advanced CFD tool- Web Model Submit the job on the cloud Server

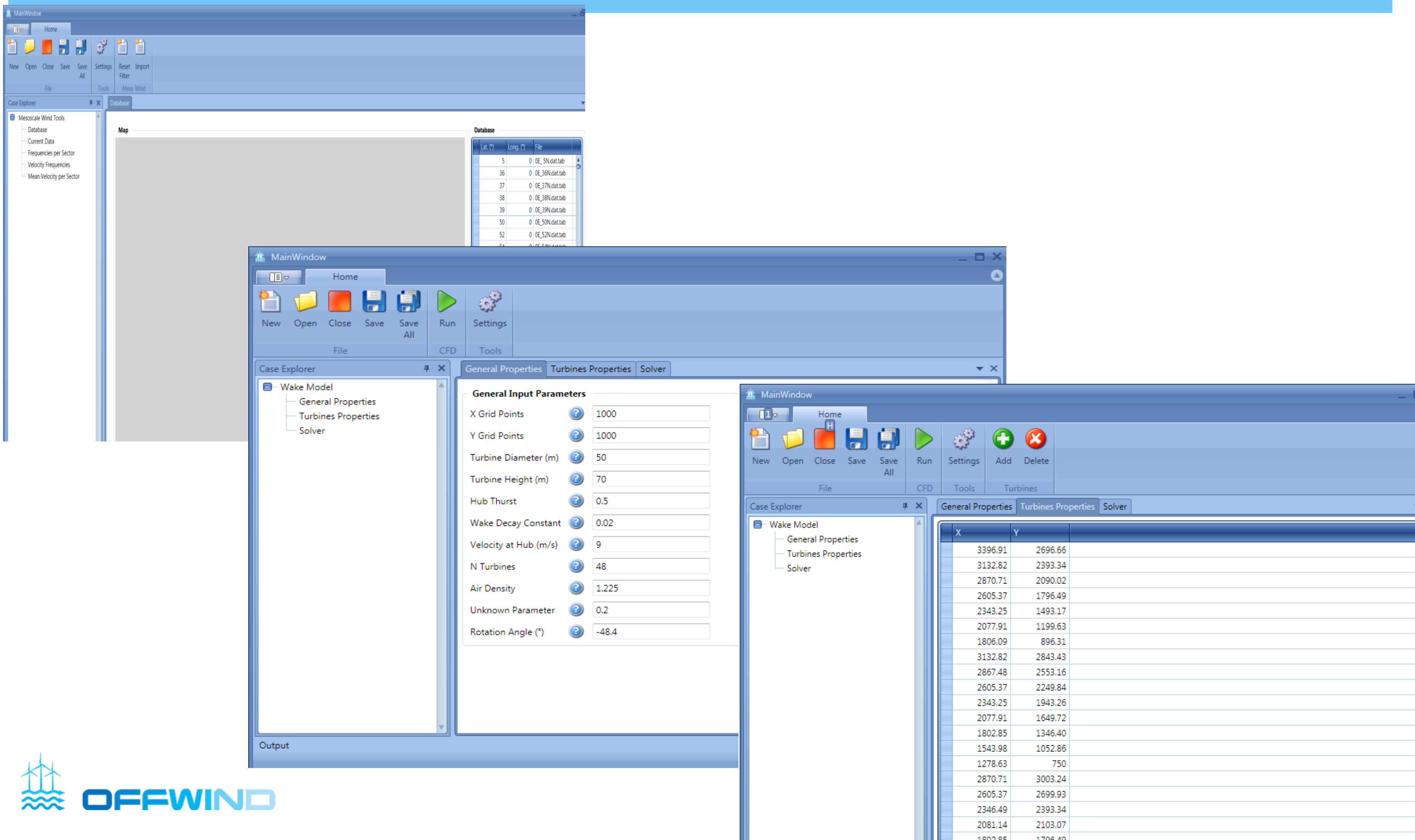




Wind- Wake Model

OffWindEng: Base on Jensen Model

Advanced: OffWindSolver : (PisoFoam+ Actuator Line/Actuator Disk)



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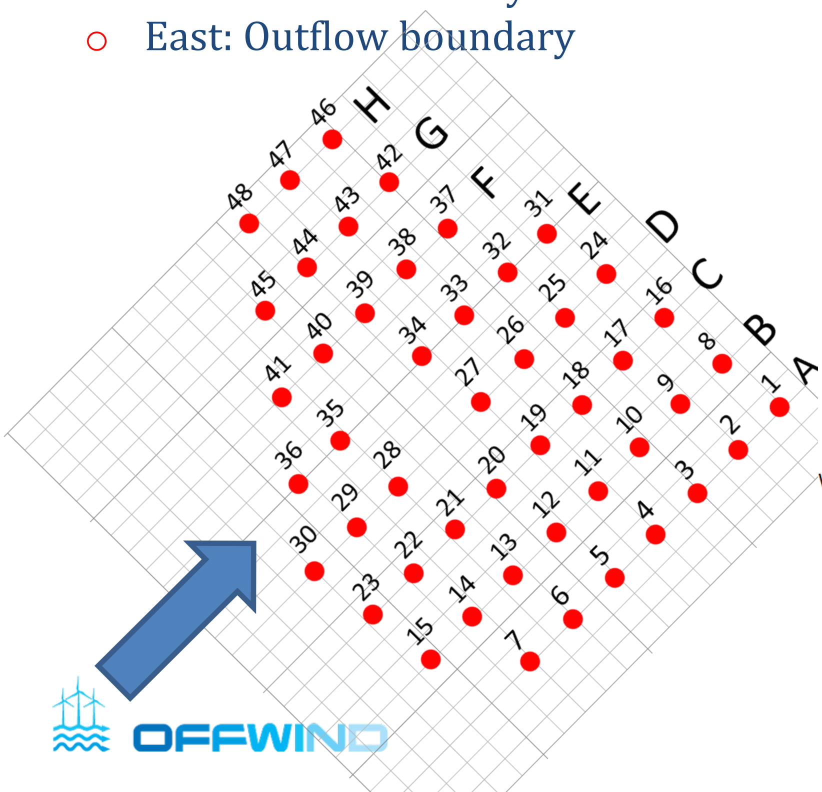
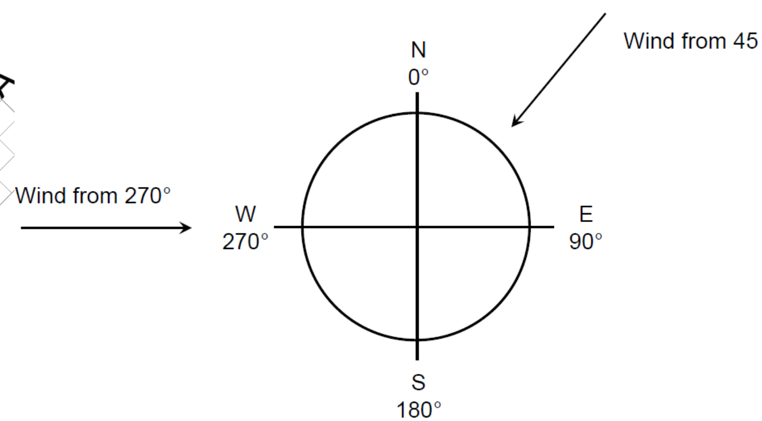
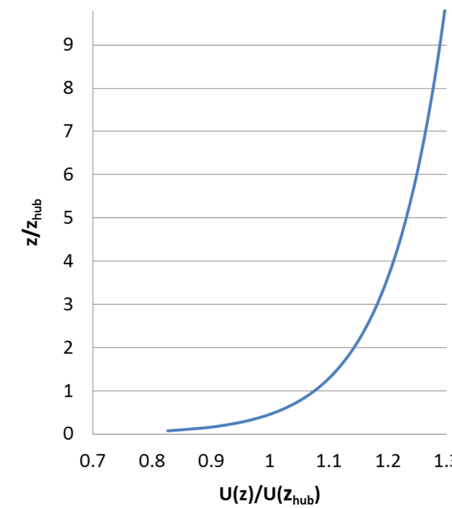
Validation - Lillgrund Computational set up

- Lillgrund offshore facility operated by Vattenfall Vindkraft AB:
  - Wind farm with 48 wind turbine
  - Rotor diameter = 93 m & Height 115 m
- Boundary condition:
  - North, south and top: Free slip boundary condition
  - West: Inlet boundary condition – atmospheric boundary layer
  - East: Outflow boundary



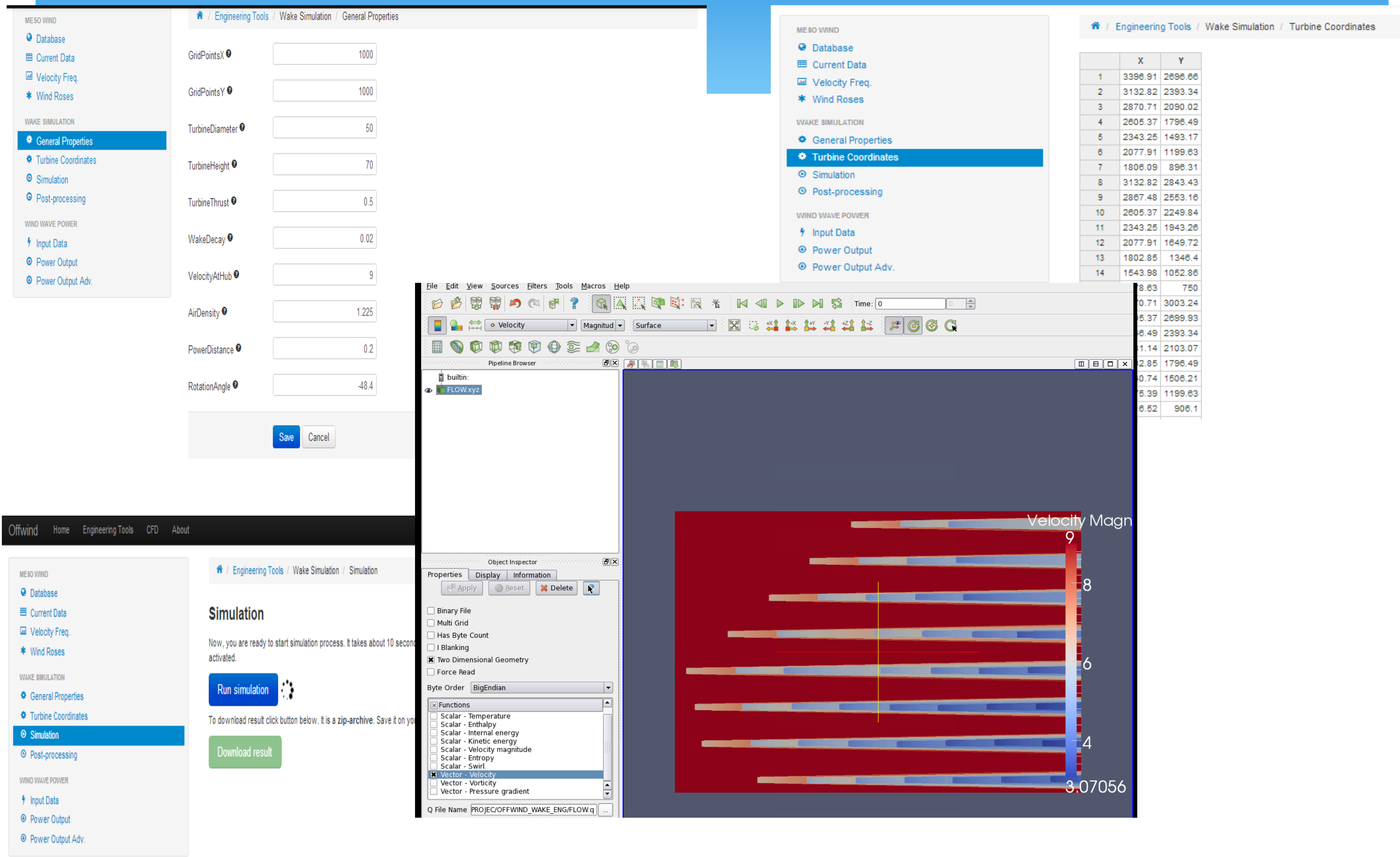




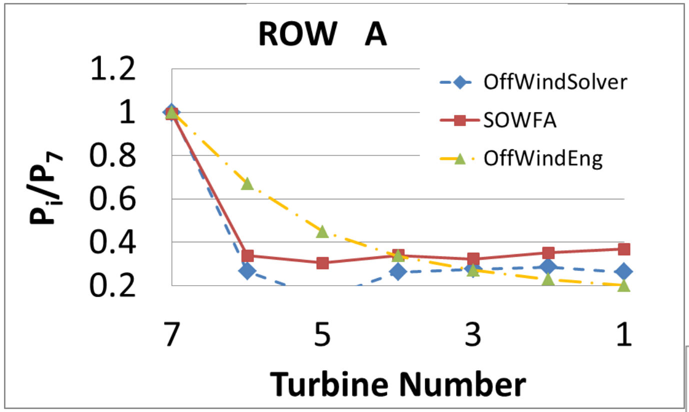
Boundary layer profile

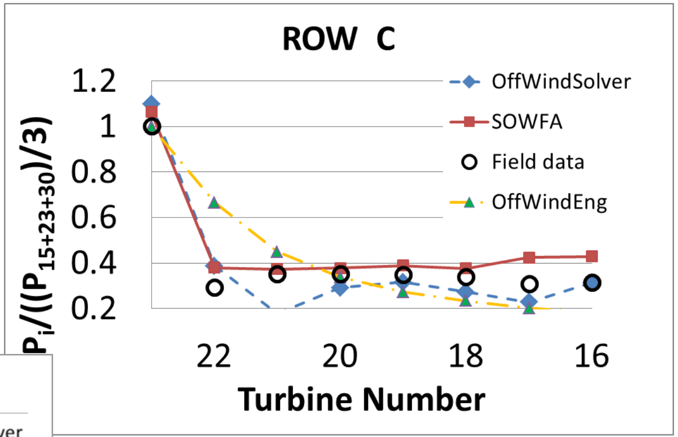
$$\frac{U(z)}{u_*} = \frac{1}{\kappa}\ln\left(\frac{z}{z_0}\right)$$

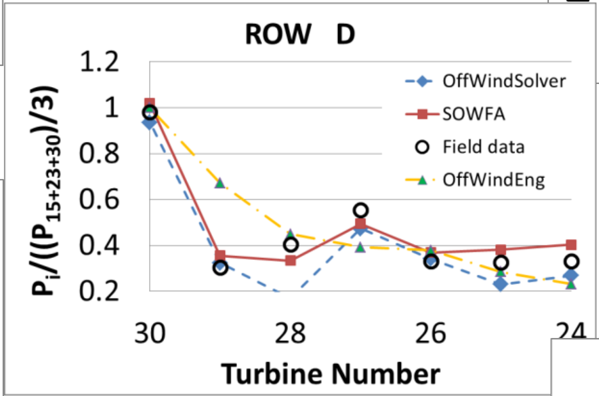
Wind- Wake Model- Web Model

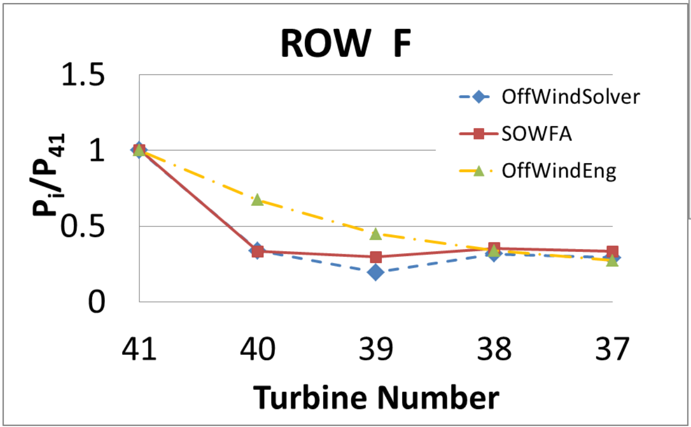


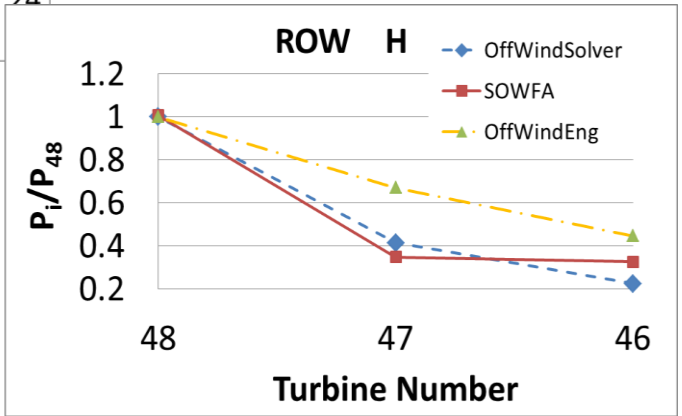
Time-averaged power of turbine normalized by the first turbine power in the row











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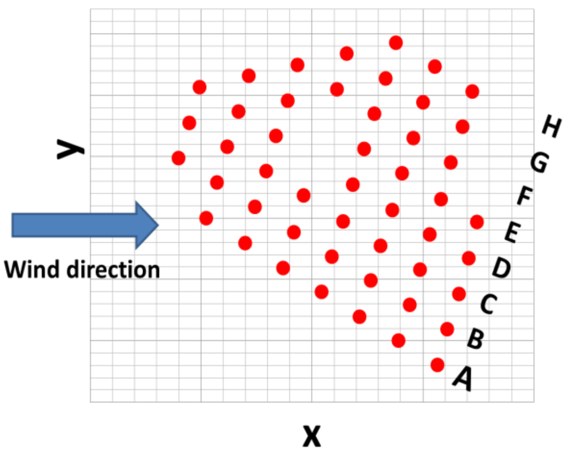
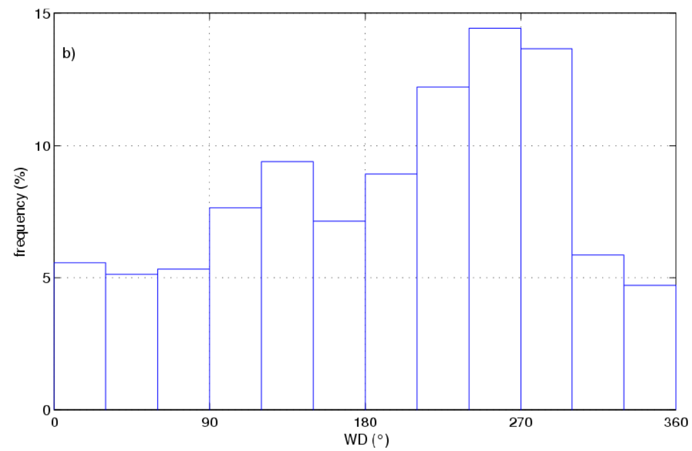
Computational Domains for Dominant Wind Directions (WD)

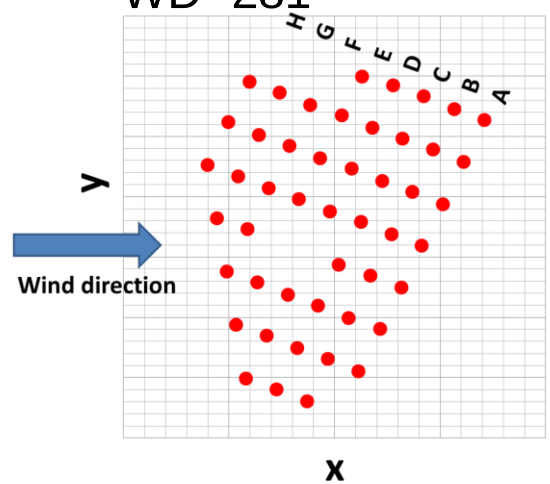
WD -191^0



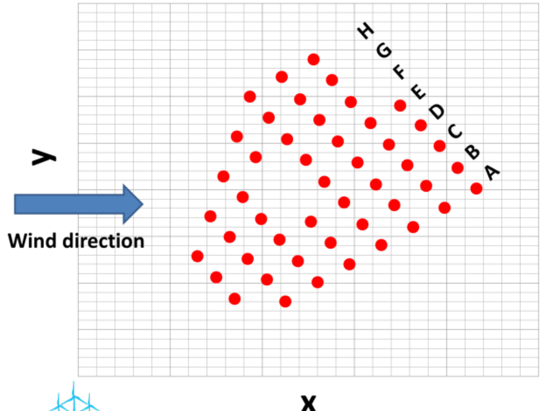


Distribution of the wind at Lillgrung side

WD -281^0

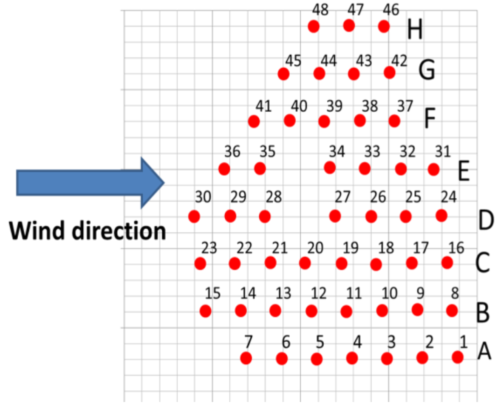


WD -251^0



http://en.wikipedia.org/wiki/File:Turbiny_wiatrowe_w_Szwecji,_2011_ubt.JPG

WD -221^0



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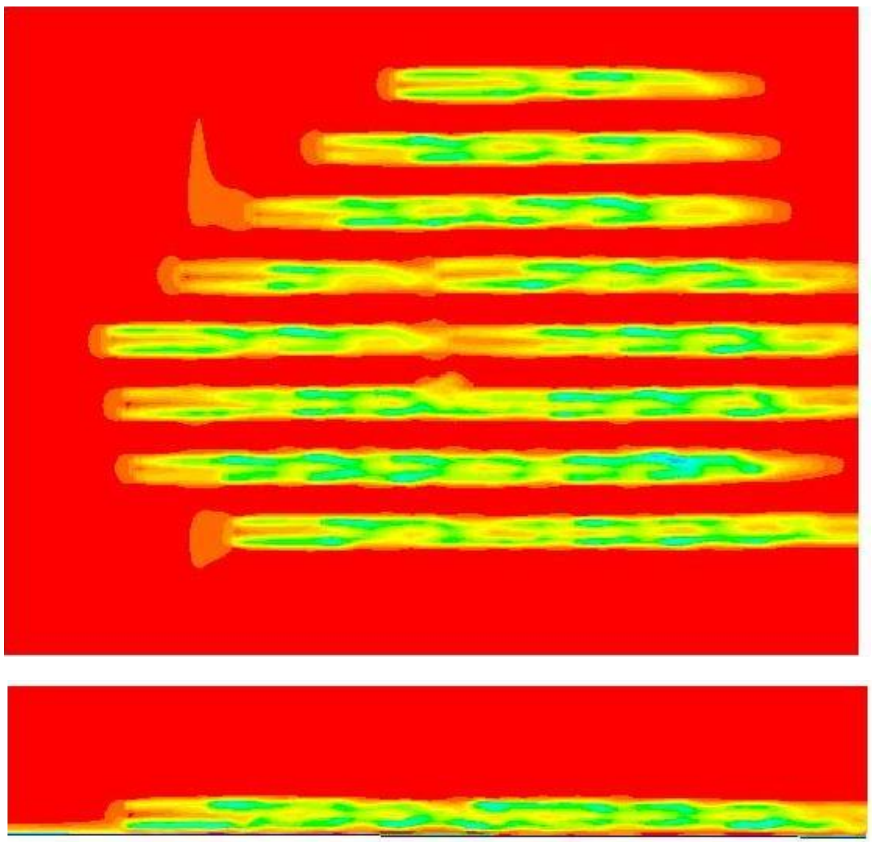
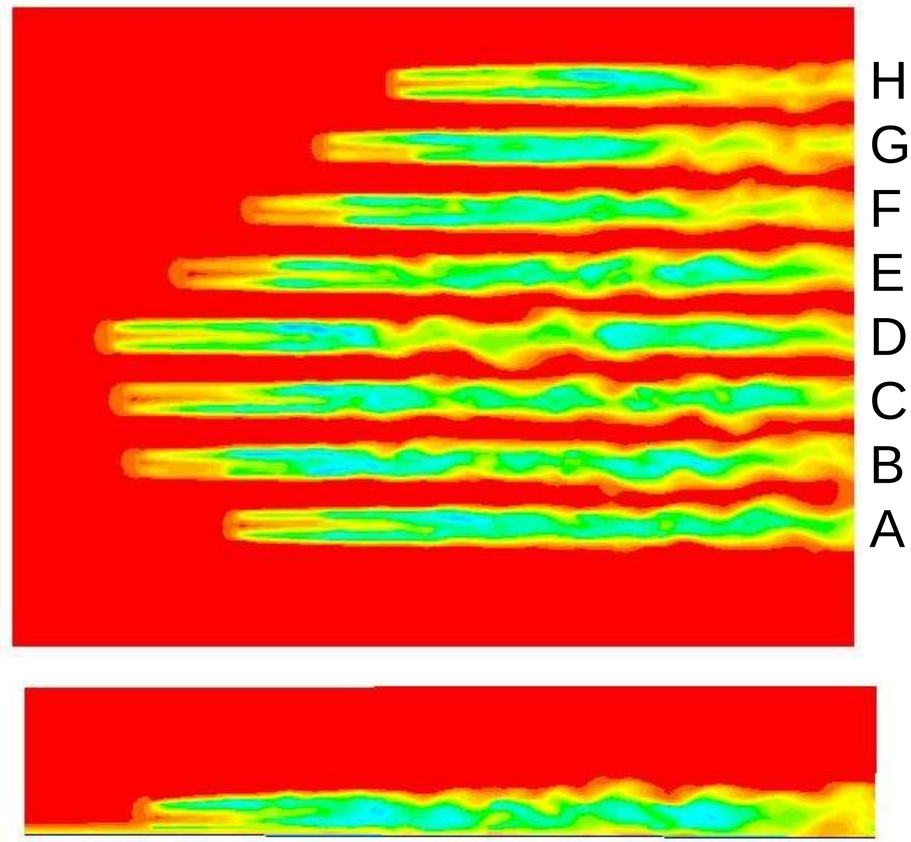
Instantaneous Velocity Contour at the Rotor Hub Height

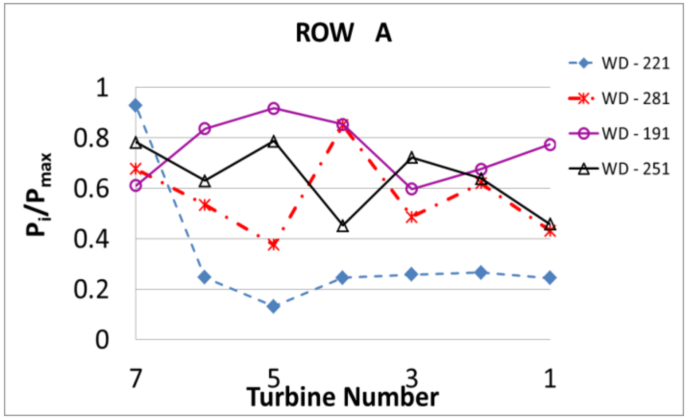
t = 100 s not fully developed

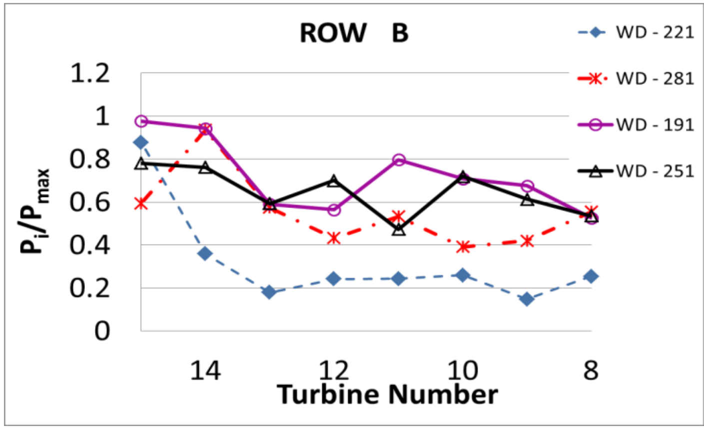


t = 300 s – fully developed

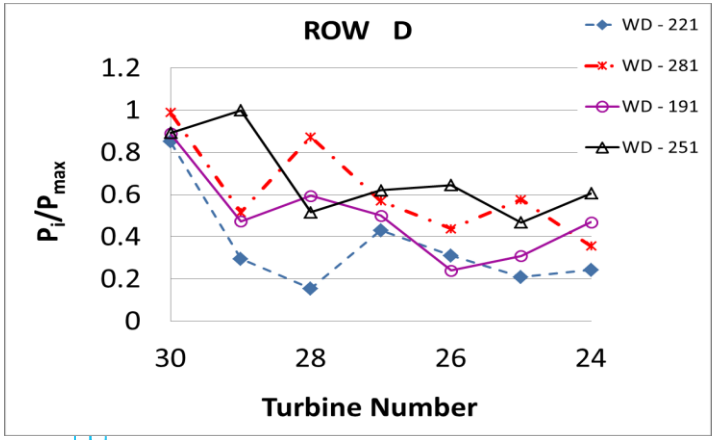


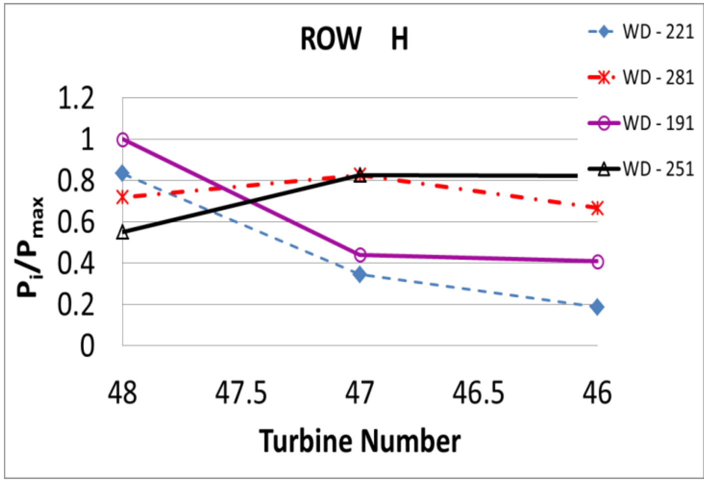
Time-Averaged Power Normalized by the Farm Average Power





- WD – 221 determines the loss in power to the largest number of the turbine of the wind farm





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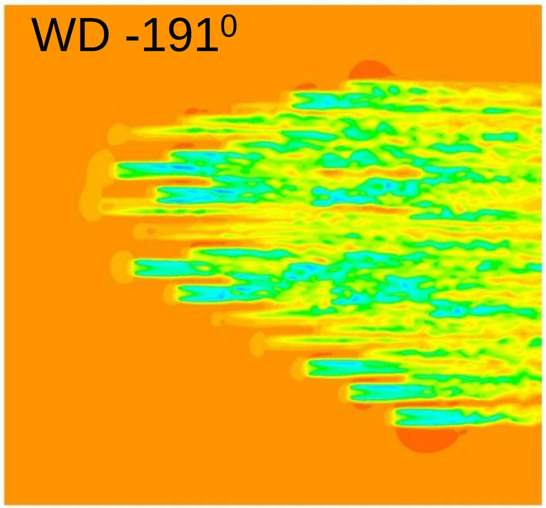
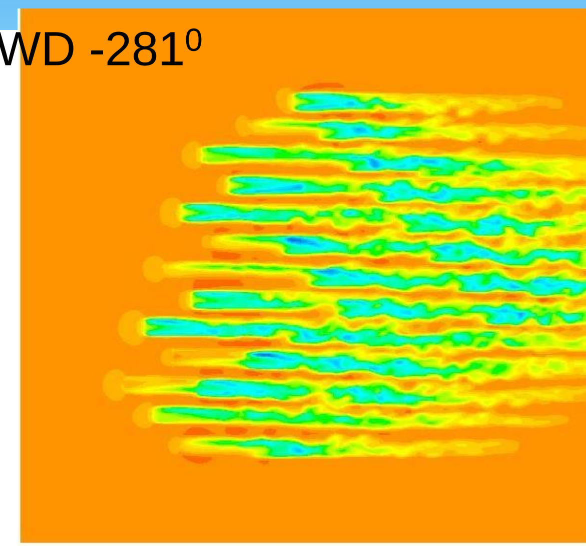
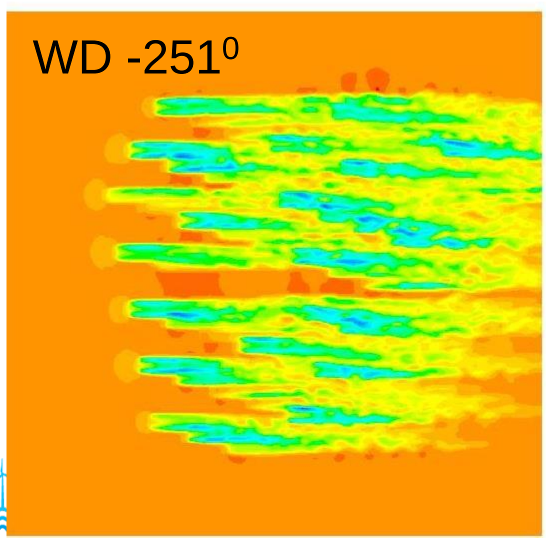
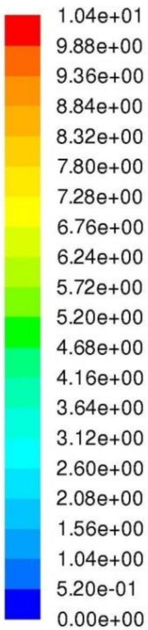
Instantaneous Velocity Contours: horizontal plane at the rotor hub height

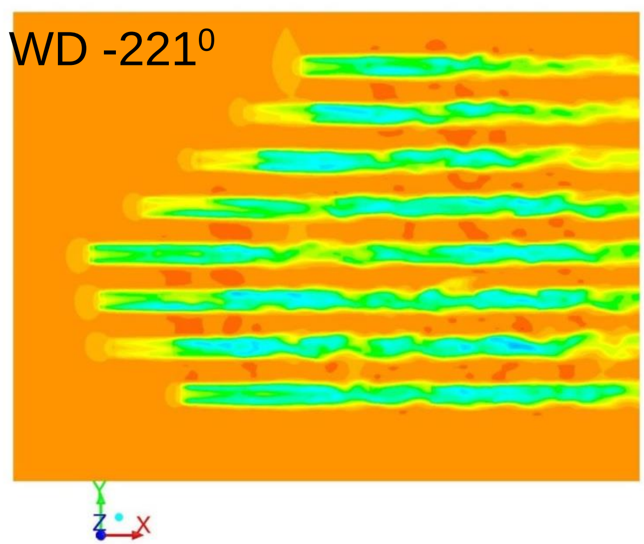


A high wind turbine interaction, to a larger number of turbine is noticed for WD = 221^{0}









Wind-Wave Model- **Web Model**
LES Based Model

MESO WIND
- Database
- Current Data
- Velocity Freq.
- Wind Roses

WAKE SIMULATION
- General Properties
- Turbine Coordinates
- Simulation
- Post-processing

WIND WAVE POWER
- Input Data
- Power Output
- Power Output Adv.

Engineering Tools / Wind Wave / Input Data

WindSpeed: 7
ReferenceHeight
TurbineHubHeight
TurbineDiameter
TurbineEfficiency
WaveSpeed

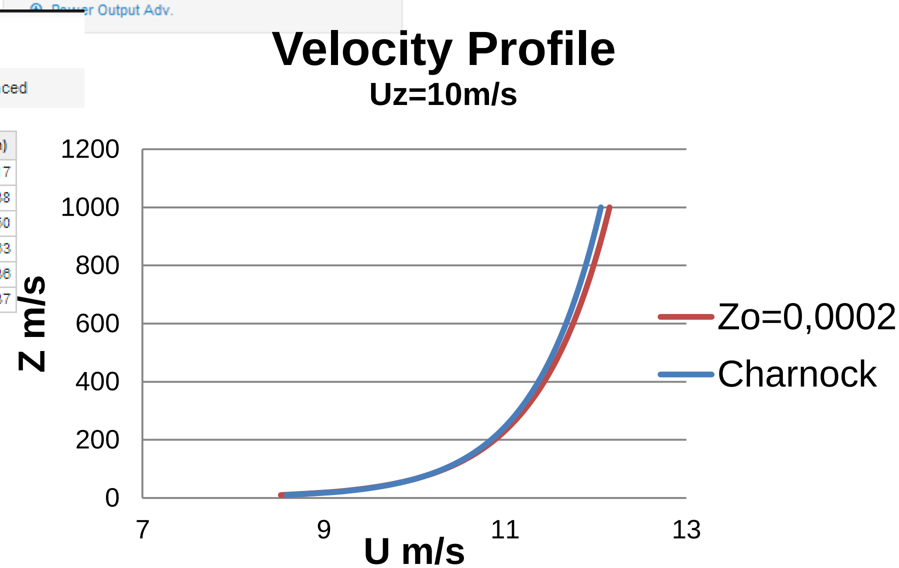
Save Canc

Engineering Tools / Wind Wave / Power Output

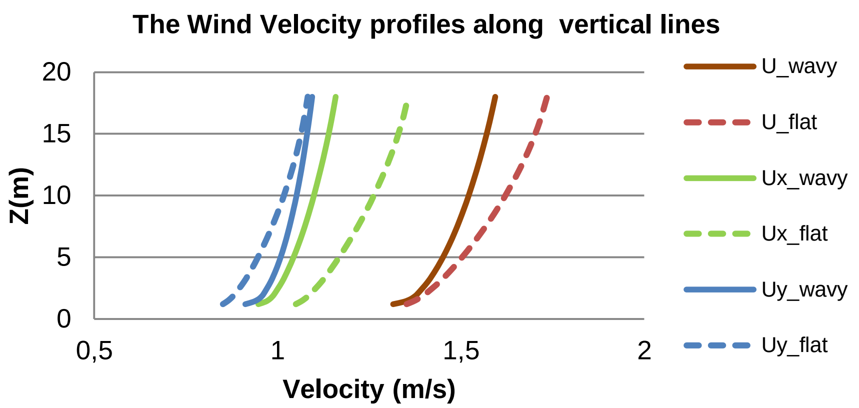
	Method	Velocity (m/s)	Power Output (MW)	Diff. (%)
1	Charnok	7.88494622	1.57649861	0.00000000
2	Toba	8.03542382	1.66849055	5.83520581
3	Sugimori	8.08187310	1.69759258	7.68119718
4	Smith	8.04907427	1.67700822	6.37549600
5	Johnson	8.07455071	1.69298257	7.38877622
6	Drennan	8.02566668	1.66241995	5.45013755

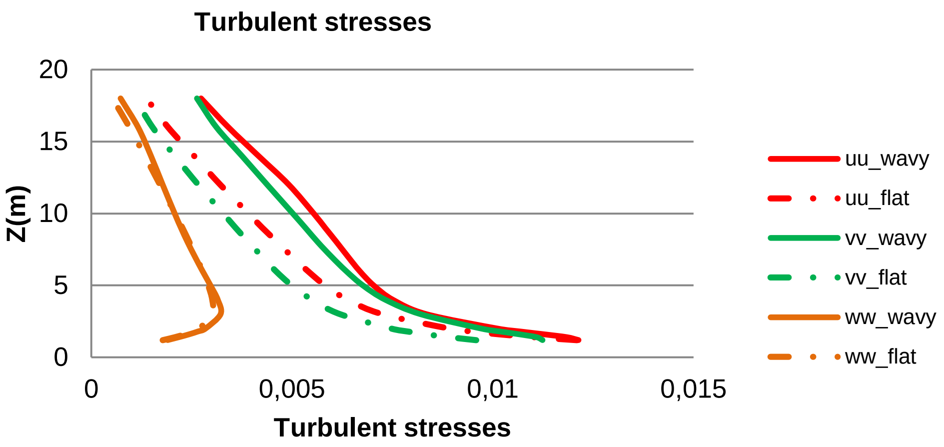
Engineering Tools / Wind Wave / Power Output Advanced

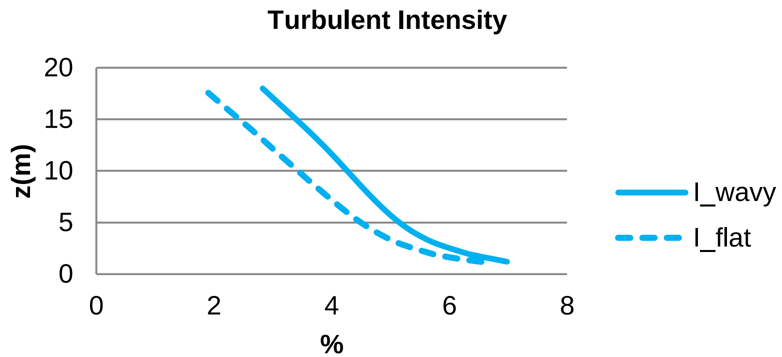
	Method	Friction Velocity (m/s)	Roughness Height (m)
1	Charnok	0.21993920	0.00005917
2	Toba	0.25733800	0.00037638
3	Sugimori	0.26888222	0.00060050
4	Smith	0.26073060	0.00043363
5	Johnson	0.26706236	0.00055936
6	Drennan	0.25491302	0.00033937



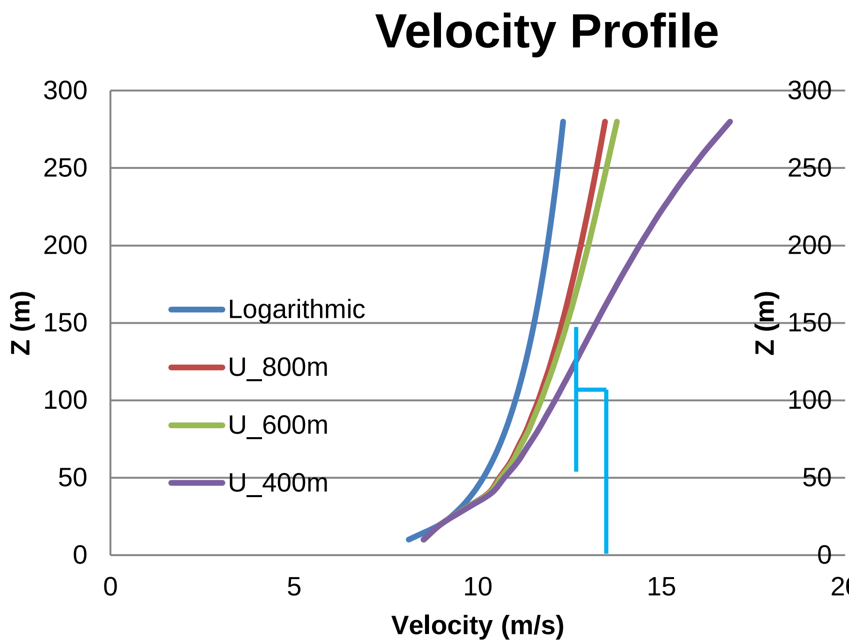
Wind-Wave- **Advanced Model**

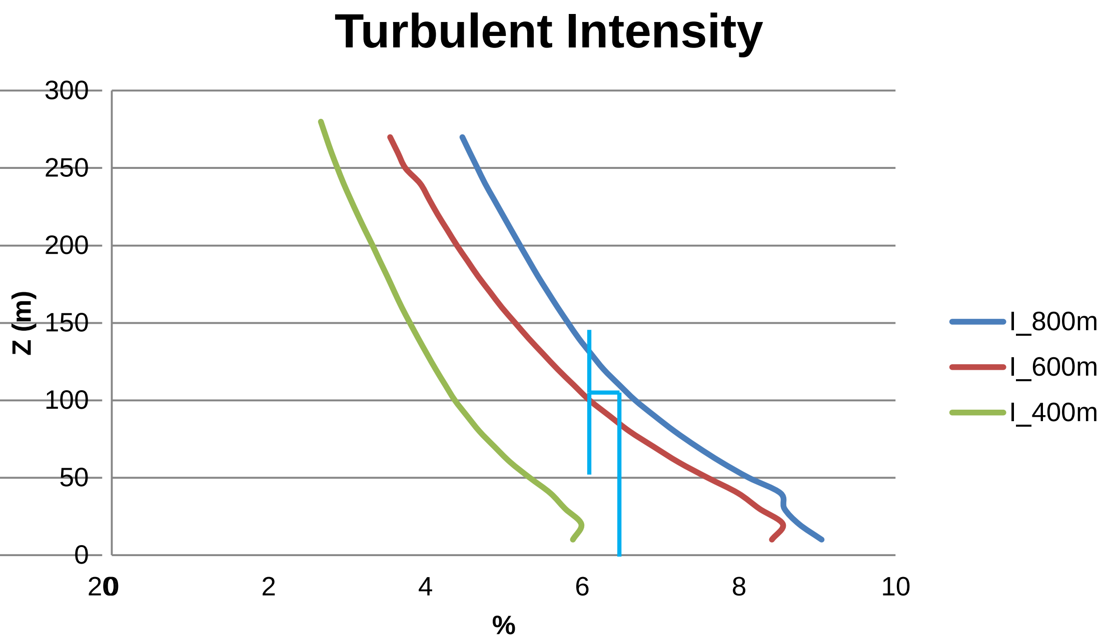






Wind-Wave Model- **Advanced Model**





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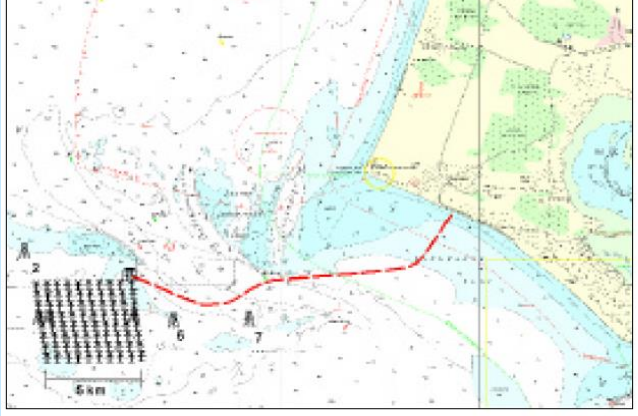
Nowcasting



Short-term forecasting up to 60 minutes (Nowcasting)

Controller dynamics affect the wind flow

- Realistic farm and turbine control algorithms
- Using fast statistical models for wind prediction
- Estimation of power production within the next short time period

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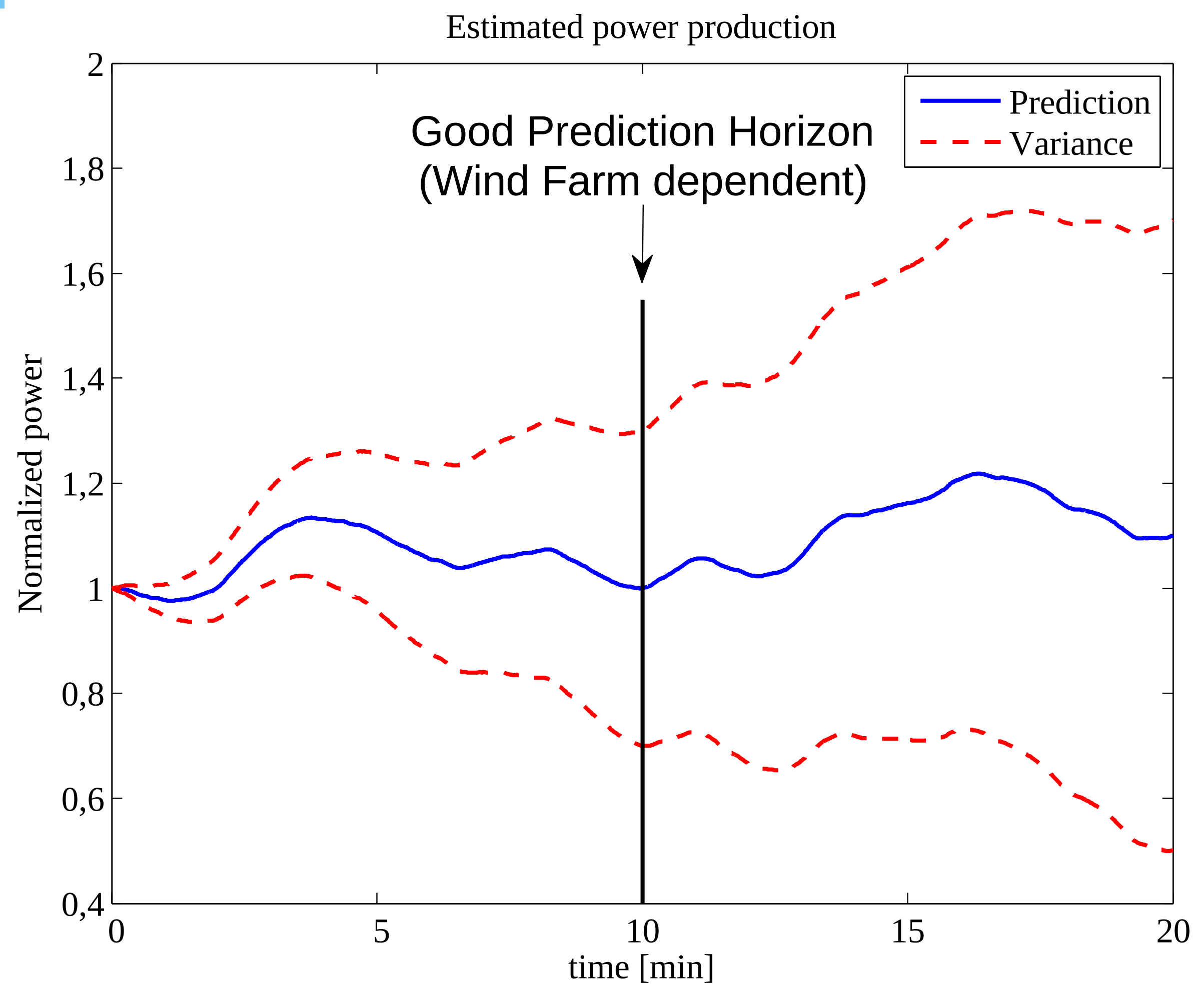
Nowcasting

Simple wind/wake model

Current front row wind speed propagates to next rows

Wind farm dependent time scale



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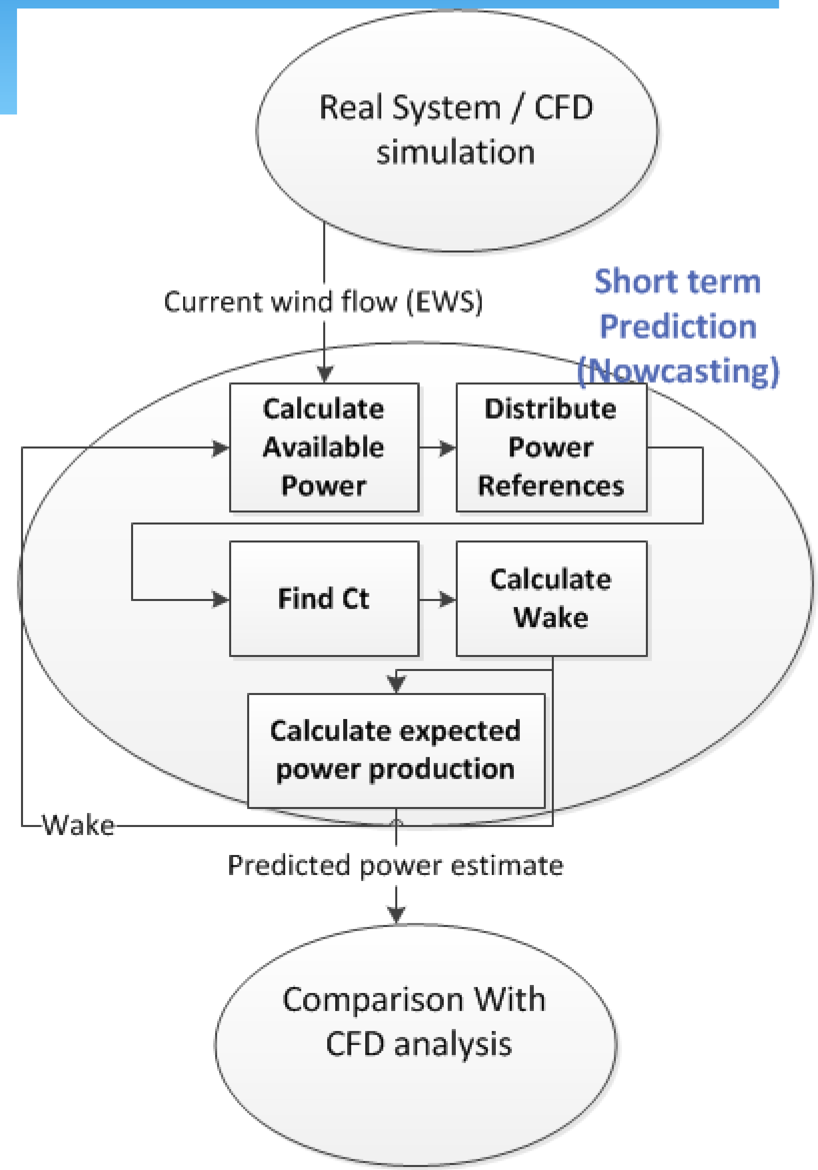
Nowcasting

Fast online power production estimates.

Continuous input from real wind farm/CFD simulator



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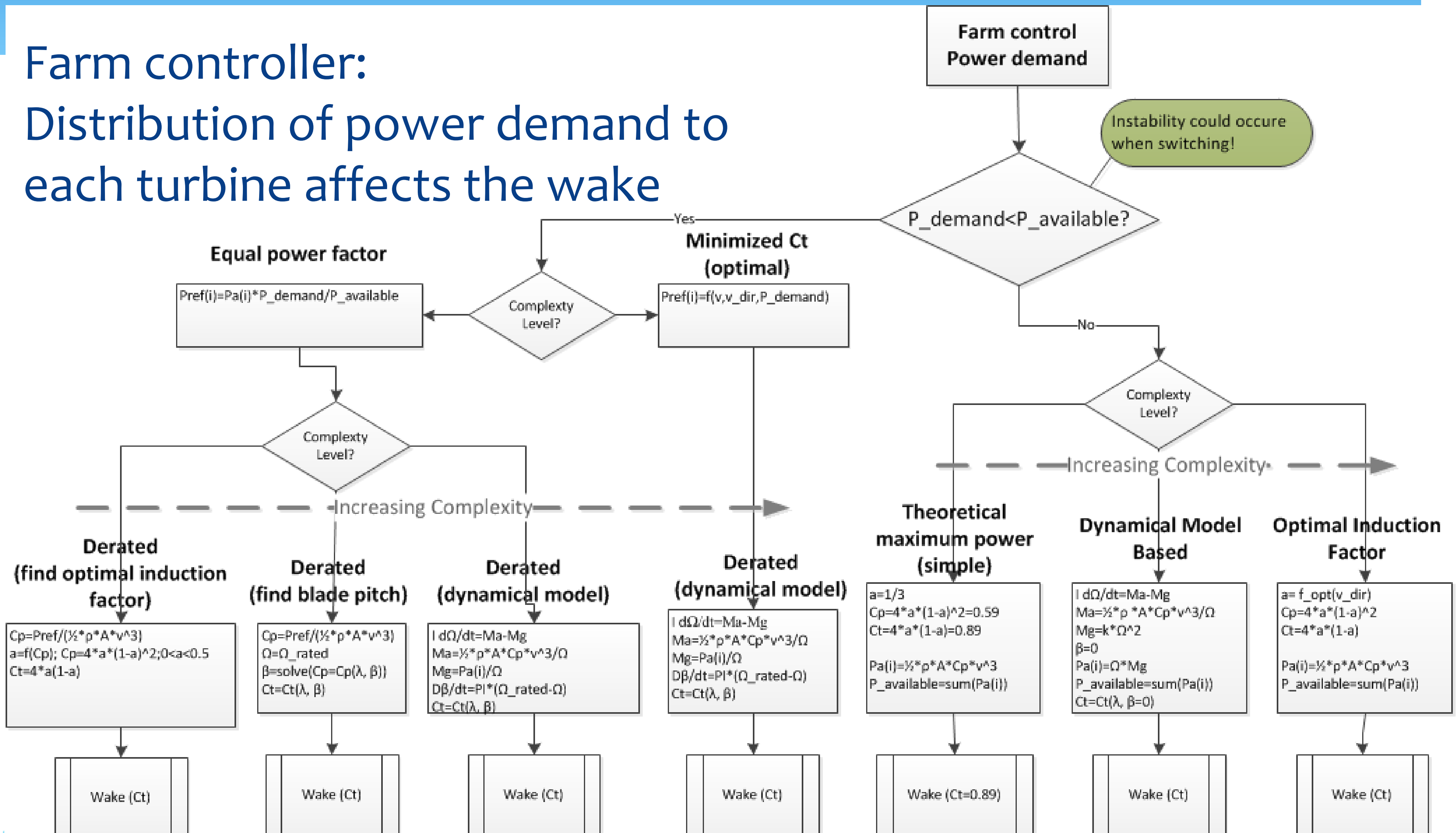
Wind farm controller modes

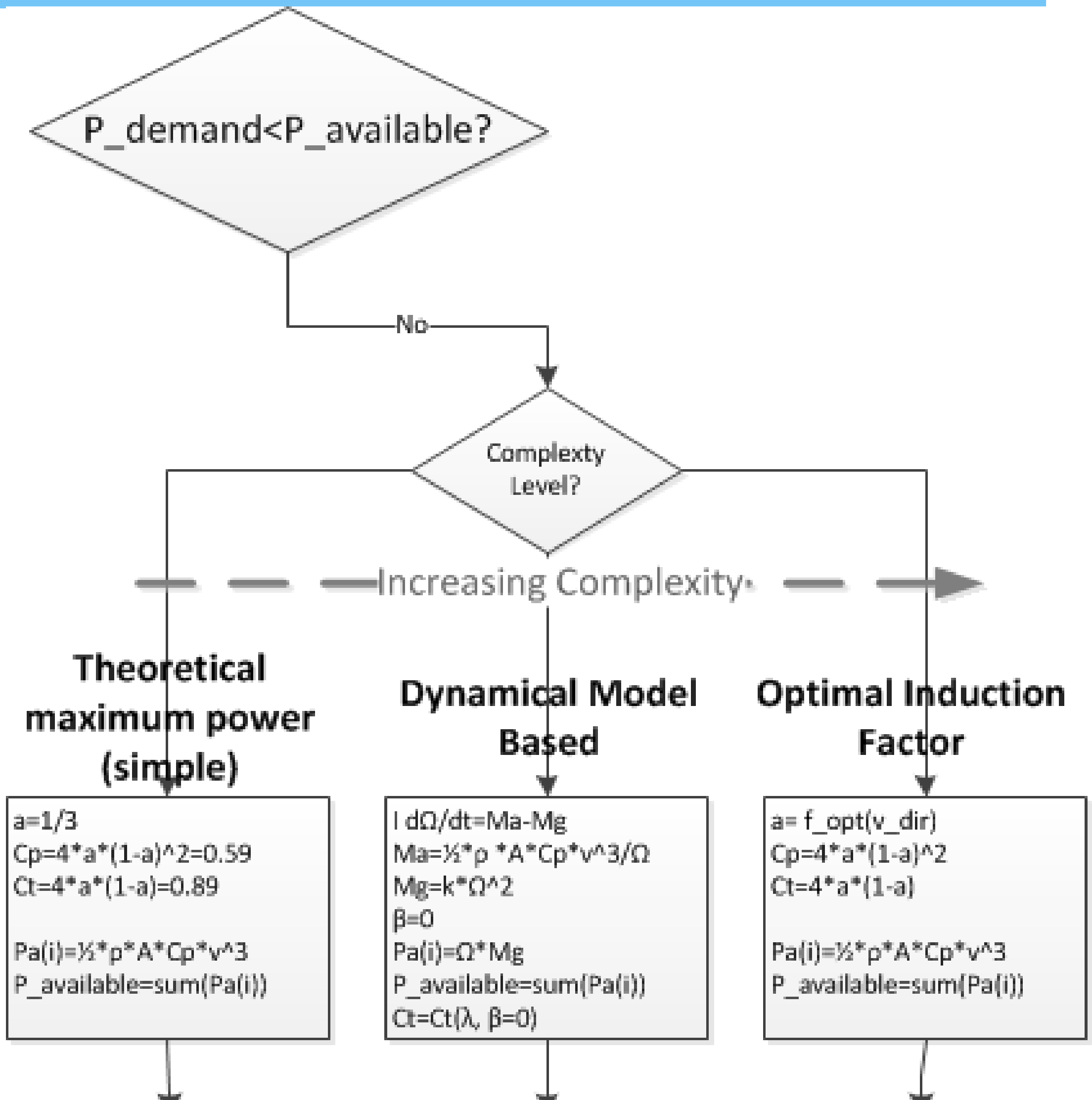
Farm controller:
Distribution of power demand to each turbine affects the wake



Wind farm controller modes

Only looking at full power production
(Not partial load demand from grid)

Single turbine controller and dynamics has a large effect on wake.



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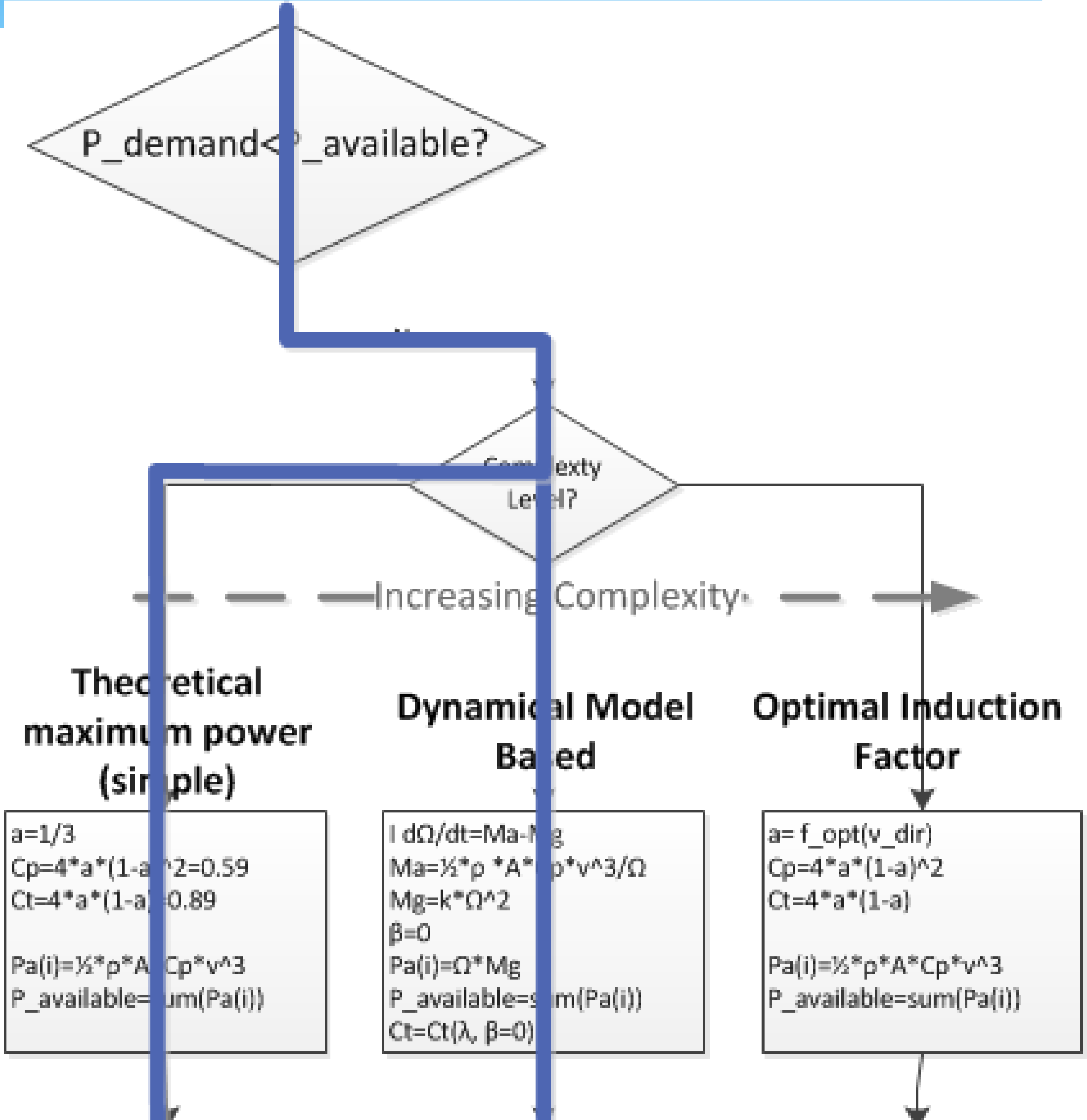

OFFWIND Workshop

22-23, Oct, 2013

Stavanger

Free registration

Jafar.Mahmoudi@iris.no

OFFWIND

Thank you for your attention